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# California FEMA R9 Lidar

## Report Produced for U.S. Geological Survey

USGS Contract: G16PC00022

Task Order: G17PD00044

Report Date: 03/5/2018

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# Executive Summary

The primary purpose of this project was to develop a consistent and accurate surface elevation dataset derived from high-accuracy Light Detection and Ranging (lidar) technology for the California FEMA R9 Project Area.

The lidar data were processed and classified according to project specifications. Detailed breaklines and bare-earth Digital Elevation Models (DEMs) were produced for the project area. Data was formatted according to tiles with each tile covering an area of 5000 ft by 5000 ft. A total of 1,511 tiles were produced for the QL1 Mendocino County AOI encompassing an area of approximately 1,228 sq. miles. A total of 2,780 tiles were produced for the QL2 FEMA Region IX AOIs encompassing an area of approximately 2,201 sq. miles. 4,291 tiles were delivered for the entire project equating to approximately 3,429 sq. miles.

## THE PROJECT TEAM

Dewberry served as the prime contractor for the project. In addition to project management, Dewberry was responsible for LAS classification, all lidar products, breakline production, Digital Elevation Model (DEM) production, and quality assurance.

Dewberry's Gary D. Simpson completed ground surveying for the project and delivered surveyed checkpoints. His task was to acquire surveyed checkpoints for the project to use in independent testing of the vertical accuracy of the lidar-derived surface model. He also verified the GPS base station coordinates used during lidar data acquisition to ensure that the base station coordinates were accurate. Please see Survey_Data folder included in the final deliverables to view the separate Survey Reports for each AOI that were created for this project.

Quantum Spatial, Inc. and Eagle Mapping, Inc completed lidar data acquisition and data calibration for the project area.

Kinetics completed some breakline production in the Mendocino QL1 AOI and completed classification for Upper Pit AOI and E-Terra completed classification for Russian Mendocino AOI and Mendocino QL1 AOI. Dewberry was responsible for all QA/QC of the final deliverables.

## SURVEY AREA

The project area addressed by this report falls within the California counties of Mendocino, Shasta, Alpine, Butte, Modoc, and Lassen.

## DATE OF SURVEY

The lidar aerial acquisition was conducted from March 3, 2017 to August 24, 2017.

## COORDINATE REFERENCE SYSTEM

Data produced for the project were delivered in the following reference system.

**Horizontal Datum:** The horizontal datum for the project is North American Datum of 1983 with the 2011 Adjustment (NAD 83 (2011))
**Vertical Datum:** The Vertical datum for the project is North American Vertical Datum of 1988 (NAVD88)
**Coordinate System:** California State Plane Zone 1 and Zone 2
**Units:** Horizontal units are in U.S. Survey Feet, Vertical units are in U.S. Survey Feet.
**Geiod Model:** Geoid12B (Geoid 12B was used to convert ellipsoid heights to orthometric heights).

## LIDAR VERTICAL ACCURACY

For the California FEMA R9 Lidar Project, the tested $RMSE_z$ of the classified lidar data for checkpoints in non-vegetated terrain equaled **0.24 ft (7.3 cm)** compared with the 10 cm specification; and the NVA of the classified lidar data computed using $RMSE_z$ x 1.9600 was equal to **0.46 ft (14 cm),** compared with the 19.6 cm specification.

For the California FEMA R9 Lidar Project, the tested VVA of the classified lidar data computed using the $95^{th}$ percentile was equal to **0.77 ft (23.5 cm),** compared with the 29.4 cm specification.

Additional accuracy information and statistics for the classified lidar data, raw swath data, and bare earth DEM data are found in the following sections of this report.

## PROJECT DELIVERABLES

The deliverables for the project are listed below.

1. Classified Point Cloud Data (Tiled)
2. Bare Earth Surface (Raster DEM – IMG Format)
3. Digital Surface Model (Raster DEM – IMG Format)—Mendocino AOI only
4. Intensity Images (8-bit gray scale, tiled, GeoTIFF format)
5. Breakline Data (File GDB)
6. Independent Survey Checkpoint Data (Report, Photos, & Points)
7. Calibration Points
8. Metadata
9. Project Report (Acquisition, Processing, QC)
10. Project Extents, Including a shapefile derived from the lidar deliverable

## PROJECT TILING FOOTPRINT

Four thousand two hundred ninety-one (4291) tiles were delivered for the project. Each tile's extent is 5,000 feet by 5,000 feet (see Appendix A for a complete listing of delivered tiles).

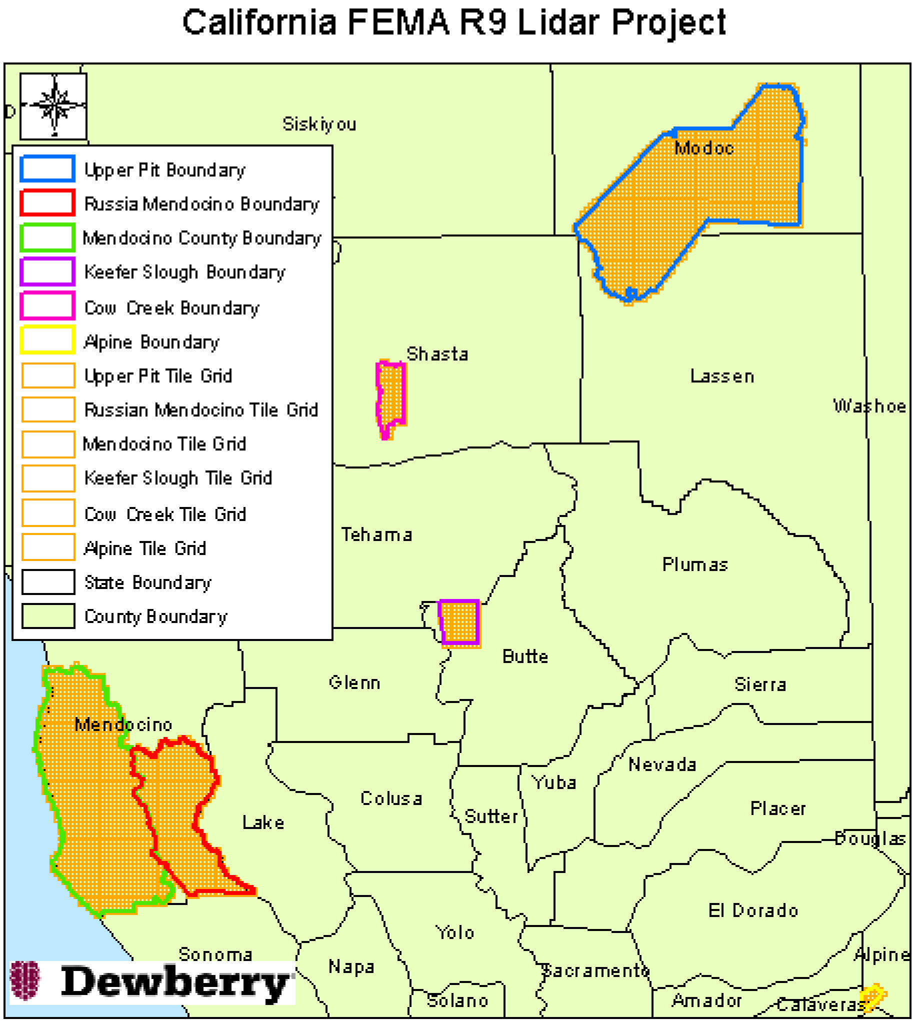


Figure 1 - Project Map

# Lidar Acquisition Report

Dewberry elected to subcontract the lidar acquisition and calibration activities for Mendocino QL1 AOI to Quantum Spatial, Inc. Quantum Spatial, Inc was responsible for providing lidar acquisition, calibration and delivery of lidar data files to Dewberry.

Dewberry received calibrated swath data from Quantum Spatial, Inc on June 6, 2017.

## LIDAR ACQUISITION DETAILS

Quantum Spatial, Inc planned 506 passes for the project area as a series of parallel flight lines with cross flightlines for the purposes of quality control. The flight plan included zigzag flight line collection as a result of the inherent IMU drift associated with all IMU systems. In order to reduce any margin for error in the flight plan, Quantum Spatial, Inc followed FEMA's Appendix A "guidelines" for flight planning and, at a minimum, includes the following criteria:

- A digital flight line layout using LEICA MISSION PRO flight design software for direct integration into the aircraft flight navigation system.
- Planned flight lines; flight line numbers; and coverage area.
- Lidar coverage extended by a predetermined margin beyond all project borders to ensure necessary over-edge coverage appropriate for specific task order deliverables.
    - Local restrictions related to air space and any controlled areas have been investigated so that required permissions can be obtained in a timely manner with respect to schedule. Additionally, Quantum Spatial, Inc will file our flight plans as required by local Air Traffic Control (ATC) prior to each mission.

Quantum Spatial, Inc monitored weather and atmospheric conditions and conducted lidar missions only when no conditions exist below the sensor that will affect the collection of data. These conditions include leaf-off for hardwoods, no snow, rain, fog, smoke, mist and low clouds. Lidar systems are active sensors, not requiring light, thus missions may be conducted during night hours when weather restrictions do not prevent collection. Quantum Spatial, Inc accesses reliable weather sites and indicators (webcams) to establish the highest probability for successful collection in order to position our sensor to maximize successful data acquisition.

Within 72-hours prior to the planned day(s) of acquisition, Quantum Spatial, Inc closely monitored the weather, checking all sources for forecasts at least twice daily. As soon as weather conditions were conducive to acquisition, our aircraft mobilized to the project site to begin data collection. Once on site, the acquisition team took responsibility for weather analysis.

Quantum Spatial, Inc lidar sensors are calibrated at a designated site located at the Lawrence County Airport in Courtland, Alabama and are periodically checked and adjusted to minimize corrections at project sites.

## LIDAR SYSTEM PARAMETERS

Quantum Spatial operated two Cessna Caravan (single-turboprop) aircraft (Tail # N704MD and N208NR) outfitted with a LEICA ALS80-HP LiDAR system during the collection of the study area. Table 1 illustrates Quantum Spatial, Inc system parameters for lidar acquisition on this project.

| Item | Parameter |
|---|---|
| System | Leica ALS-70 HP |
| Altitude (AGL meters) | 1650 |
| Approx. Flight Speed (knots) | 130 |
| Scanner Pulse Rate (kHz) | 340.4 |
| Scan Frequency (hz) | 56 |
| Pulse Duration of the Scanner (nanoseconds) | 2.5 |
| Pulse Width of the Scanner (m) | 0.75 |
| Swath width (m) | 884.2 |
| Central Wavelength of the Sensor Laser (nanometers) | 1064 |
| Did the Sensor Operate with Multiple Pulses in The Air? (yes/no) | Yes |
| Beam Divergence (milliradians) | 25 |
| Nominal Swath Width on the Ground (m) | 884.2 |
| Swath Overlap (%) | 63 |
| Total Sensor Scan Angle (degree) | 30 |
| Computed Down Track spacing (m) per beam | 1.19 |
| Computed Cross Track Spacing (m) per beam | 0.84 |
| Nominal Pulse Spacing (single swath), (m) | 0.5 |
| Nominal Pulse Density (single swath) (ppsm), (m) | 4 |
| Aggregate NPS (m) (if ANPS was designed to be met through single coverage, ANPS and NPS will be equal) | 0.35 |
| Aggregate NPD (m) (if ANPD was designed to be met through single coverage, ANPD and NPD will be equal) | 8 |
| Maximum Number of Returns per Pulse | 8 |

**Table 1: Quantum Spatial, Inc lidar system parameters**

## ACQUISITION STATUS REPORT AND FLIGHTLINES

Upon notification to proceed, the flight crew loaded the flight plans and validated the flight parameters. The Acquisition Manager contacted air traffic control and coordinated flight pattern requirements. Lidar acquisition began immediately upon notification that control base stations were in place. During flight operations, the flight crew monitored weather and atmospheric conditions. Lidar missions were flown only when no condition existed below the sensor that would affect the collection of data. The pilot constantly monitored the aircraft course, position, pitch, roll, and yaw of the aircraft. The sensor operator monitored the sensor, the status of PDOPs, and performed the first Q/C review during acquisition. The flight crew constantly reviewed weather and cloud locations. Any flight lines impacted by unfavorable conditions were marked as invalid and re-flown immediately or at an optimal time.

Figure 2 shows the combined trajectory of the flightlines.

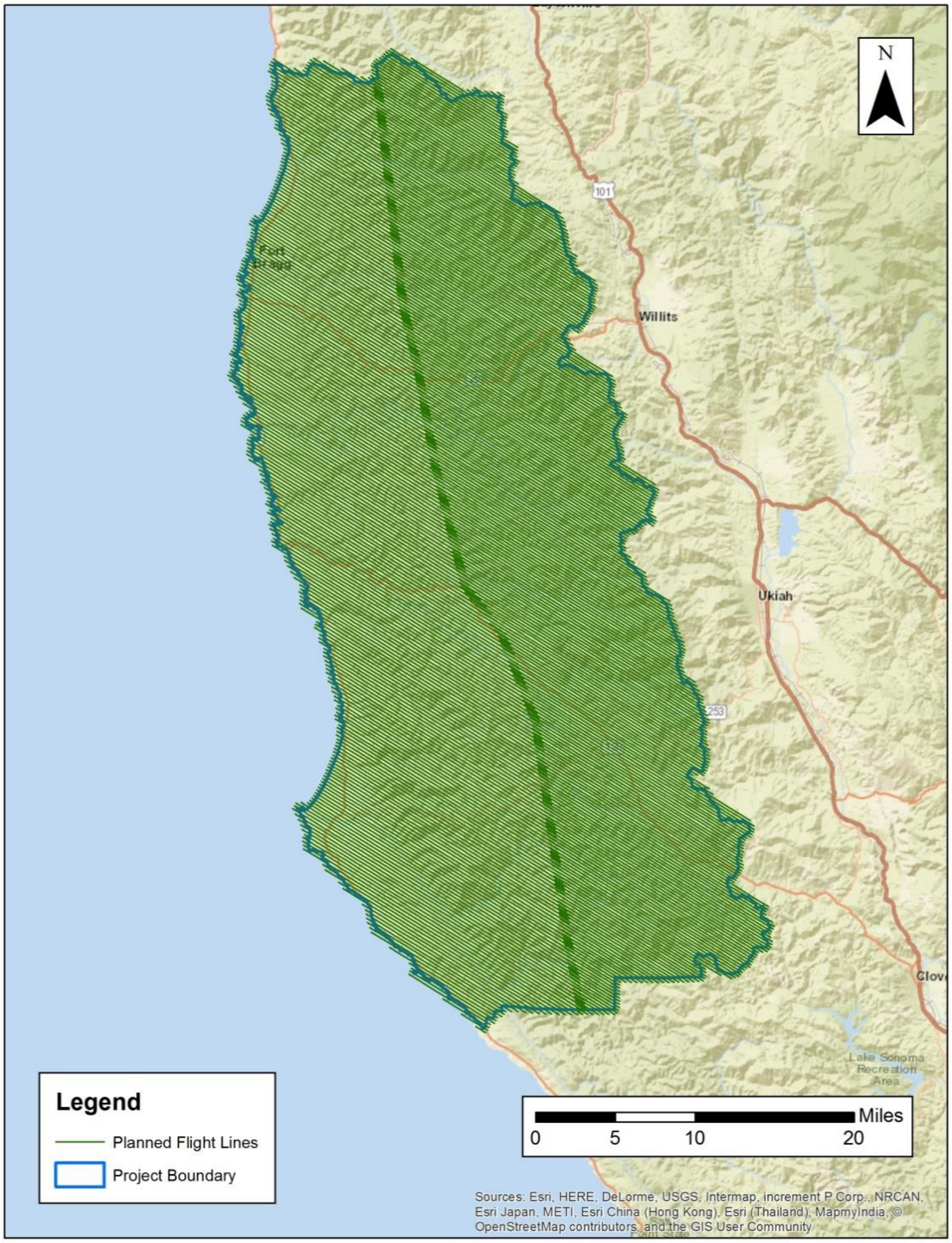


**Figure 2: Trajectories as flown by Quantum Spatial, Inc**

## LIDAR CONTROL

Nine existing NGS monuments base stations were used to control the lidar acquisition for the Mendocino, CA LiDAR project area. The coordinates of all used base stations are provided in the table below. All control and calibration points are also provided in shapefile format as part of the final deliverables.

| Name | NAD83 (2011) State Plane CA Zone II | | Ellipsoid Ht (NAD83(2011), m) | Orthometric Ht (NAVD88 Geoid12B, m) |
|---|---|---|---|---|
| | Easting X (m) | Northing Y (m) | | |
| DH6077 | 6050970.98140 | 2284870.40645 | 2.219 | 33.507 |
| DH6305 | 6124274.46355 | 2182504.12490 | 59.356 | 90.282 |
| HOPB | 6256237.95360 | 2126054.15465 | 353.835 | 383.768 |
| Mendo | 6110248.86751 | 2226585.75889 | 25.581 | 56.424 |
| MENDO_3 | 6118028.60156 | 2052025.79253 | -1.510 | 30.627 |
| P059 | 6070649.07926 | 2104569.64046 | -10.822 | 21.497 |
| P185 | 6066402.14191 | 2225935.57997 | 146.834 | 178.183 |
| P190 | 6220678.65698 | 2216380.78358 | 203.300 | 233.207 |
| P312 | 6082651.61636 | 2323211.03056 | 255.389 | 286.016 |

**Table 2 – Base stations used to control lidar acquisition**

## AIRBORN GPS KINEMATIC

Airborne GPS data was processed using the PosPac kinematic On-The-Fly (OTF) software suite. Flights were flown with a minimum of 6 satellites in view (13° above the horizon) and with a PDOP of better than 4. Distances from base station to aircraft were kept to a maximum of 40km.

For all flights, the GPS data can be classified as excellent, with GPS residuals of 3cm average or better but no larger than 10cm being recorded.

GPS processing reports for each mission are included in Appendix B.

## GENERATION AND CALIBRATION OF LASER POINTS (RAW DATA)

The initial step of calibration is to verify availability and status of all needed GPS and Laser data against field notes and compile any data if not complete.

Subsequently the mission points are output, initially with default values from Leica or the last mission calibrated for the system. The initial point generation for each mission calibration is verified within Microstation/Terrascan for calibration errors. If a calibration error greater than specification is observed within the mission, the roll, pitch and scanner scale corrections that need to be applied are calculated. The missions with the new calibration values are regenerated and validated internally once again to ensure quality.

Data collected by the lidar unit is reviewed for completeness, acceptable density and to make sure all data is captured without errors or corrupted values. In addition, all GPS, aircraft trajectory, mission information, and ground control files are reviewed and logged into a database.

On a project level, a supplementary coverage check is carried out to ensure no data voids unreported by Field Operations are present.

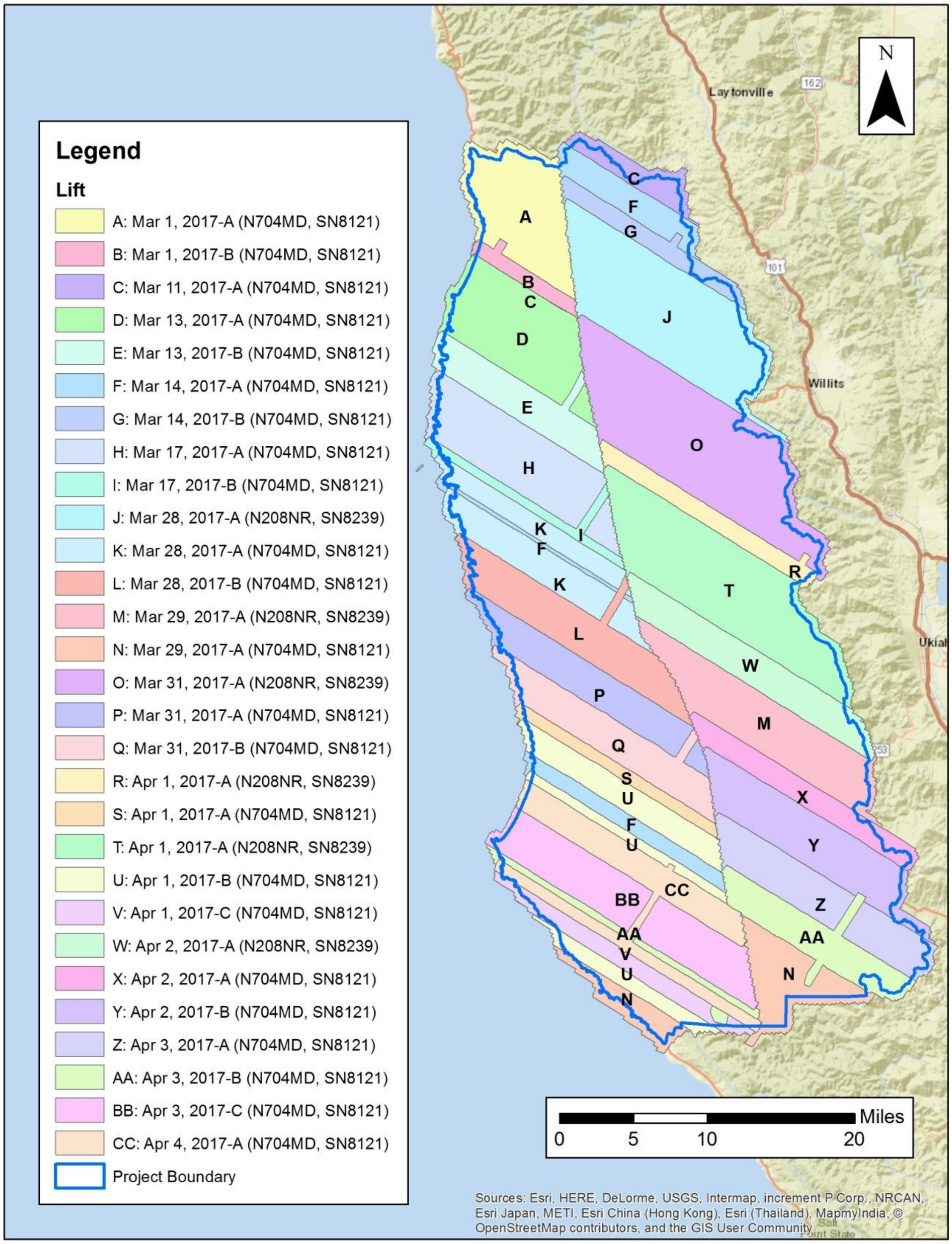


**Figure 3 – Lidar swath output showing complete coverage.**

## BORESIGHT AND RELATIVE ACCURACY

The initial points for each mission calibration are inspected for flight line errors, flight line overlap, slivers or gaps in the data, point data minimums, or issues with the lidar unit or GPS. Roll, pitch and scanner scale are optimized during the calibration process until the relative accuracy is met.

Relative accuracy and internal quality are checked using at least 3 regularly spaced QC blocks in which points from all lines are loaded and inspected. Vertical differences between ground surfaces of each line are displayed. Color scale is adjusted so that errors greater than the specifications are flagged. Cross sections are visually inspected across each block to validate point to point, flight line to flight line and mission to mission agreement.

For this project the specifications used are as follow:

Relative accuracy <= 6 cm maximum difference within individual swaths and <=8 cm RMSDz between adjacent and overlapping swaths.

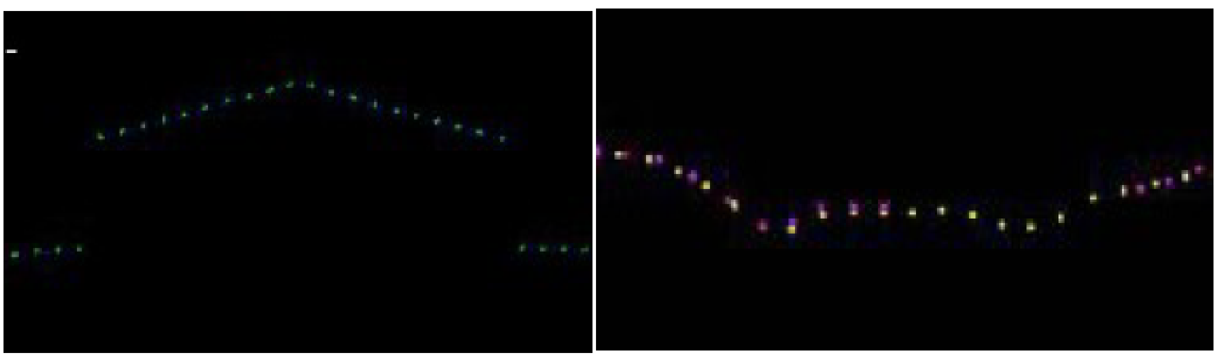

**Figure 4 – Profile views showing correct roll and pitch adjustments.**

## PRELIMINARY VERTICAL ACCURACY ASSESSMENT

A preliminary $RMSE_z$ error check is performed by Quantum Spatial, Inc at this stage of the project life cycle in the raw lidar dataset against GPS static and kinematic data and compared to $RMSE_z$ project specifications. The lidar data is examined in non-vegetated, flat areas away from breaks. Lidar ground points for each flight line generated by an automatic classification routine are used.

Prior to delivery to Dewberry, the elevation data was verified internally to ensure it met Non-vegetated Vertical Accuracy (NVA) requirements ($RMSE_z \leq 10$ cm and $Accuracy_z$ at the 95% confidence level ≤ 19.6 cm) when compared to static and kinematic GPS checkpoints. Below is a summary for the test:

The calibrated Mendocino QL1 LiDAR dataset was tested to 0.080 m vertical accuracy at 95% confidence level based on $RMSE_z$ (0.041 m x 1.9600) when compared to 11 of 16 GPS static check points.

The following are the final statistics for the GPS static checkpoints used by Quantum Spatial, Inc to internally verify vertical accuracy.

| Number | NAD83 (2011) State Plane CA Zone II | | NAVD88 (Geoid 12B) | Laser Z (ft) | Delta Z |
|---|---|---|---|---|---|
| | Easting X (ft) | Northing Y (ft) | Known Z (ft) | | |
| DH6077 | 6050971 | 2284870 | 109.931 | removed | * |
| KT2304 | 6105206 | 2259134 | 326.43 | 326.43 | 0 |
| KT2305_RESET | 6152533 | 2272428 | 1911.138 | 1911.09 | -0.048 |
| MENDO_01 | 6157655 | 2082329 | 1470.299 | 1470.22 | -0.079 |
| MENDO_05 | 6062115 | 2338759 | 102.155 | 102.09 | -0.065 |
| MENDO_06 | 6137025 | 2331853 | 2710.352 | 2710.41 | 0.058 |
| P184 | 6076851 | 2173231 | 462.558 | slope | * |
| P190 | 6220679 | 2216381 | 765.113 | outside | * |
| P312 | 6082652 | 2323211 | 938.371 | slope | * |
| PGE_VEG15_70.1 | 6145209 | 2158216 | 195.485 | 195.77 | 0.285 |
| MENDO_02 | 6091516 | 2077261 | 99.317 | 99.18 | -0.137 |
| MENDO_03 | 6118029 | 2052026 | 100.482 | 100.42 | -0.062 |
| MENDO_04 | 6110249 | 2226586 | 185.118 | 185.28 | 0.162 |
| DH6303 | 6196472 | 2138202 | 1648.196 | 1648.26 | 0.064 |
| DH6305 | 6124274 | 2182504 | 296.2 | slope | * |
| JT9640 | 6211492 | 2094123 | 1097.26 | 1097.03 | -0.23 |

Table 3 - Static GPS Points

| 100 % of Totals | # of Points | RMSEz (m) NVA Spec=0.1 m | NVA at 95% Spec=0.196 m | Mean (m) | Std Dev (m) | Min (m) | Max (m) |
|---|---|---|---|---|---|---|---|
| Non-Vegetated Terrain | 11 | 0.041 | 0.080 | -0.001 | 0.043 | -0.070 | 0.087 |

Table 4 - Static GPS Vertical Accuracy Results

Overall the calibrated lidar data products collected by Quantum Spatial, Inc meet or exceed the requirements set out in the Statement of Work. The quality control requirements of Quantum Spatial, Inc quality management program were adhered to throughout the acquisition stage for this project to ensure product quality.

## Lidar Acquisition Report

Dewberry elected to subcontract the lidar acquisition and calibration activities for FEMA Region IX QL2 AOIs to Eagle Mapping, Inc. Eagle Mapping was responsible for providing lidar acquisition, calibration and delivery of lidar data files to Dewberry.

Dewberry received calibrated swath data from Eagle Mapping between April and September 2017.

## LIDAR ACQUISITION DETAILS

Eagle Mapping, Inc planned 137 passes for the project area as a series of parallel flight lines with cross flightlines for the purposes of quality control. The flight plan included zigzag flight line collection as a result of the inherent IMU drift associated with all IMU systems. In order to reduce any margin for error in the flight plan, Eagle Mapping, Inc followed FEMA's Appendix A "guidelines" for flight planning and, at a minimum, includes the following criteria:

- A digital flight line layout using Track Air Flight Management software for direct integration into the aircraft flight navigation system.
- Planned flight lines; flight line numbers; and coverage area.
- Lidar coverage extended by a predetermined margin beyond all project borders to ensure necessary over-edge coverage appropriate for specific task order deliverables.
- Local restrictions related to air space and any controlled areas have been investigated so that required permissions can be obtained in a timely manner with respect to schedule. Additionally, Eagle Mapping, Inc will file our flight plans as required by local Air Traffic Control (ATC) prior to each mission.

Eagle Mapping, Inc monitored weather and atmospheric conditions and conducted lidar missions only when no conditions exist below the sensor that will affect the collection of data. These conditions include leaf-off for hardwoods, no snow, rain, fog, smoke, mist and low clouds. Lidar systems are active sensors, not requiring light, thus missions may be conducted during night hours when weather restrictions do not prevent collection. Eagle Mapping, Inc accesses reliable weather sites and indicators (webcams) to establish the highest probability for successful collection in order to position our sensor to maximize successful data acquisition.

Within 72-hours prior to the planned day(s) of acquisition, Eagle Mapping, Inc closely monitored the weather, checking all sources for forecasts at least twice daily. As soon as weather conditions were conducive to acquisition, our aircraft mobilized to the project site to begin data collection. Once on site, the acquisition team took responsibility for weather analysis.

Eagle Mapping LiDAR sensors are calibrated at a designated site located at the Chilliwack Regional Airport in Chilliwack BC, Canada and are periodically checked and adjusted to minimize corrections at project sites.

## LIDAR SYSTEM PARAMETERS

A Riegl LMS-Q1560 dual-channel LiDAR system was used for acquisition of the LiDAR data. This system was installed in a Piper Navajo aircraft operated by Peregrine Aerial Surveys out of Abbotsford, BC. Table 5 illustrates Eagle Mapping's system parameters for LiDAR acquisition on this project.

| Item | Parameter |
|---|---|
| System | Riegl Q1560 |
| Altitude (AGL meters) | 2000 |
| Approx. Flight Speed (knots) | 150 |
| Scanner Pulse Rate (kHz) | 800 |
| Scan Frequency (hz) | 183 |

| Item | Parameter |
|---|---|
| Pulse Duration of the Scanner (nanoseconds) | 3 |
| Pulse Width of the Scanner (m) | 0.9 |
| Swath width (m) | 2217 |
| Central Wavelength of the Sensor Laser (nanometers) | 1064 |
| Did the Sensor Operate with Multiple Pulses in The Air? (yes/no) | Yes |
| Beam Divergence (milliradians) | <0.25 |
| Nominal Swath Width on the Ground (m) | 2217 |
| Swath Overlap (%) | 25 |
| Total Sensor Scan Angle (degree) | 58 |
| Computed Down Track spacing (m) per beam | 0.77 |
| Computed Cross Track Spacing (m) per beam | 0.77 |
| Nominal Pulse Spacing (single swath), (m) | 0.7 |
| Nominal Pulse Density (single swath) (ppsm), (m) | 2.0 |
| Aggregate NPS (m) (if ANPS was designed to be met through single coverage, ANPS and NPS will be equal) | 0.7 |
| Aggregate NPD (m) (if ANPD was designed to be met through single coverage, ANPD and NPD will be equal) | 2.0 |
| Maximum Number of Returns per Pulse | 7 |

Table 5: Eagle Mapping, Inc lidar system parameters

## ACQUISITION STATUS REPORT AND FLIGHTLINES

Upon notification to proceed, the flight crew loaded the flight plans and validated the flight parameters. The Acquisition Manager contacted air traffic control and coordinated flight pattern requirements. Lidar acquisition began immediately upon notification that control base stations were in place. During flight operations, the flight crew monitored weather and atmospheric conditions. Lidar missions were flown only when no condition existed below the sensor that would affect the collection of data. The pilot constantly monitored the aircraft course, position, pitch, roll, and yaw of the aircraft. The sensor operator monitored the sensor, the status of PDOPs, and performed the first Q/C review during acquisition. The flight crew constantly reviewed weather and cloud locations. Any flight lines impacted by unfavorable conditions were marked as invalid and re-flown immediately or at an optimal time.

Figure 5 shows the combined trajectory of the flightlines.

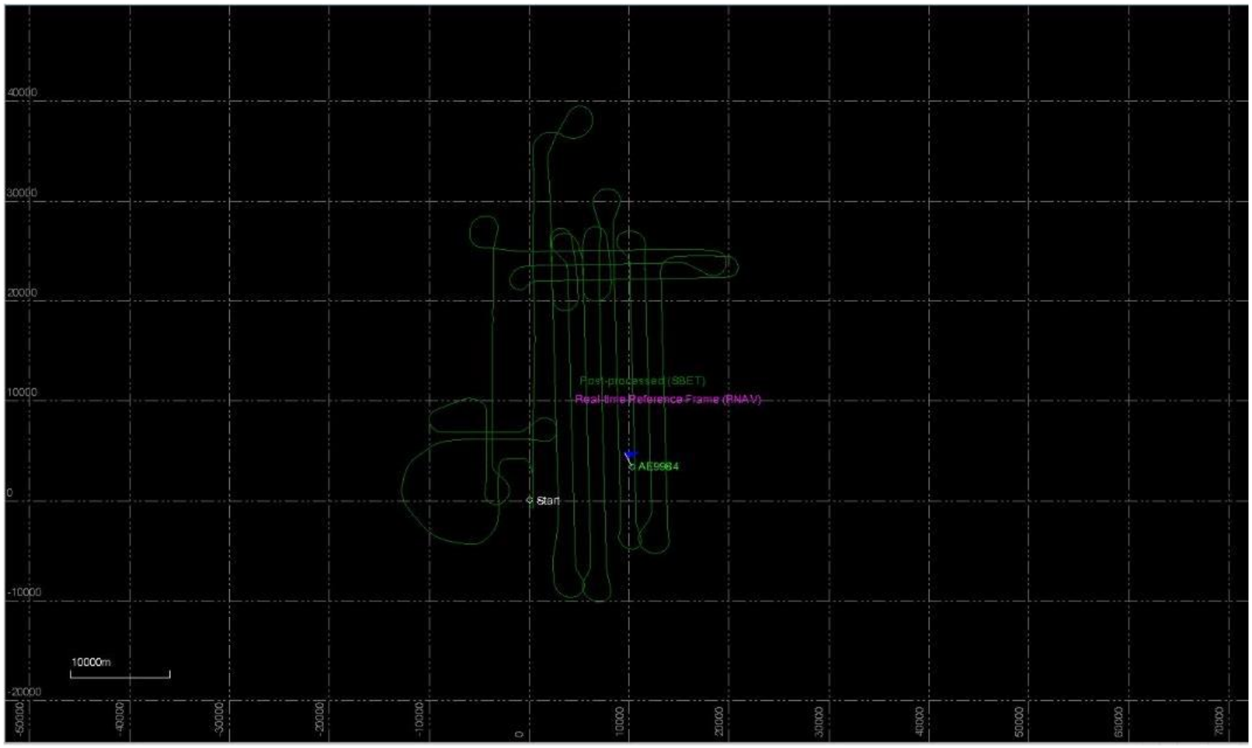


**Figure 5: Trajectories as flown by Eagle Mapping, Inc**

## LIDAR CONTROL

Eagle Mapping deployed static GPS base stations during the acquisition of the Mendocino project. Considerations were made for location access and clear visibility of the horizon. Static sessions were recorded at 1 Hz samples for the highest quality post processed solution. These static base sessions were then incorporated during the kinematic post-processing of aircraft position. Stations established by Eagle Mapping were set on existing NGS monuments. Additionally CORS stations at 5 Hz or better were used if accessibility was limited or no NGS monuments were available. The coordinates of these base stations are provided in the table below. All control and calibration points are also provided in shapefile format as part of the final deliverables.

| Name | NAD83 (2011) State Plane CA Zone I and II | | Ellipsoid Ht (NAD83(2011), ft) |
|---|---|---|---|
| | Easting X (ft) | Northing Y (ft) | |
| Cow Creek-AE9984 | 6512130.883 | 2079832.415 | 135.280 |
| Russian Mendocino-KT2012 | 6220128.944 | 2176565.778 | 159.590 |
| Keefer Slough-DL9239 | 6553826.010 | 1857466.210 | 50.250 |
| Upper Pit- AC8620 | 6850625.600 | 2316557.624 | 1268.714 |
| Upper Pit-DH6407 | 2396529.554 | 6963111.923 | 1312.578 |

| | | | |
|---|---|---|---|
| Alpine- CMBB | 6594492.621 | 2199049.677 | 696.285 |
| Alpine- DECH | 6967481.829 | 2208395.180 | 1965.439 |
| Alpine-P133 | 2659793.745 | 14570298.304 | 1782.415 |
| Alpine- P141 | 7020130.474 | 2147058.852 | 2170.371 |
| Alpine- P143 | 7198950.094 | 2046494.923 | 1734.155 |
| Alpine- 310 | 7036761.878 | 2034067.320 | 1791.884 |
| Alpine- P649 | 7070526.666 | 2156224.956 | 2154.551 |

**Table 6 – Base stations used to control lidar acquisition**

## AIRBORN GPS KINEMATIC

Airborne GPS data was processed using the Applanix PosPAC v8.1 software suite. Flights were flown with a minimum of 7 satellites in view (12° above the horizon) and with a PDOP of better than 3. Distances from base station to aircraft were kept to a maximum of 30 miles.

For all flights the GPS data can be classified as excellent with GPS residuals of 3 cm average or better but no larger than 10 cm being recorded.

GPS processing reports for each mission are included in Appendix C.

## GENERATION AND CALIBRATION OF LASER POINTS (RAW DATA)

The initial step of calibration is to verify availability and status of all needed GPS and Laser data against field notes and compile any data if not complete.

Subsequently the mission points are output using Riegl's RiProcess software initially with default values from Riegl or the last mission calibrated for the system. The initial point generation for each mission calibration is verified within Microstation/Terrascan for calibration errors. If a calibration error greater than specification is observed within the mission the roll pitch and scanner scale corrections that need to be applied are calculated. The missions with the new calibration values are regenerated and validated internally once again to ensure quality.

Data collected by the lidar unit is reviewed for completeness acceptable density and to make sure all data is captured without errors or corrupted values. In addition all GPS aircraft trajectory mission information and ground control files are reviewed and logged into a database.

On a project level a supplementary coverage check is carried out to ensure no data voids unreported by Field Operations are present.

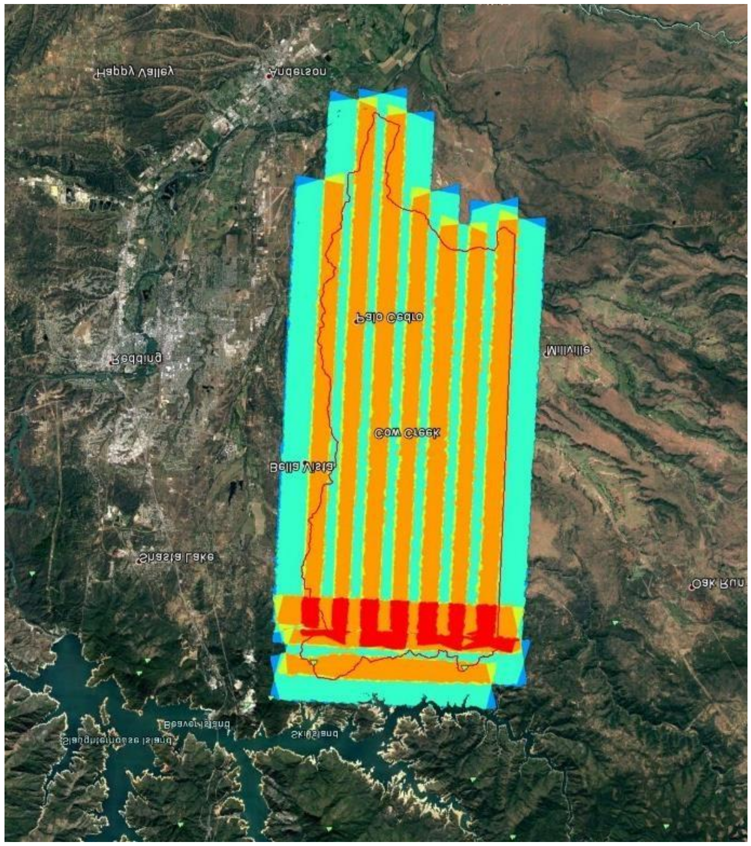


**Figure 6 – Lidar swath output showing complete coverage for Cow Creek**

## BORESIGHT AND RELATIVE ACCURACY

The initial points for each mission calibration are inspected for flight line errors flight line overlap slivers or gaps in the data point data minimums or issues with the lidar unit or GPS. Roll pitch and scanner scale are optimized during the calibration process until the relative accuracy is met.

Relative accuracy and internal quality are checked using at least 3 regularly spaced QC blocks in which points from all lines are loaded and inspected. Vertical differences between ground surfaces of each line are displayed. Color scale is adjusted so that errors greater than the specifications are flagged. Cross sections are visually inspected across each block to validate point to point flight line to flight line and mission to mission agreement.

For this project the specifications used are as follow:
Relative accuracy <= 6 cm maximum difference within individual swaths and <=8 cm RMSDz between adjacent and overlapping swaths.

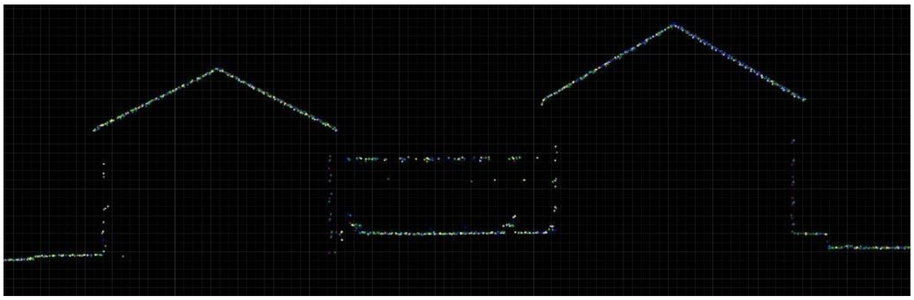

Figure 7 – Profile views showing correct roll and pitch adjustments.

## PRELIMINARY VERTICAL ACCURACY ASSESSMENT

Dewberry conducted the survey for ground control points (GCPs) which were used to test the accuracy of the calibrated swath data. These GCPs were available to use as control in case the swath data exhibited any biases which would need to be adjusted or removed. The coordinates of all GCPs, accuracy results from testing the calibrated swath data against the GCPs, and vertical bias adjustments per project area are provided in tables below.

The following are the final statistics for the GPS static checkpoints used by Eagle Mapping Inc to internally verify vertical accuracy.

| Number | NAD83 (2011) State Plane CA Zone I | | NAVD88 (GEOID 12B) | | |
|---|---|---|---|---|---|
| | Easting X (US ft) | Northing Y (US ft) | Known Z (US ft) | Laser Z (US ft) | Dz (US ft) |
| C01 | 6512192.2 | 2080188.6 | 531.26 | 531.48 | 0.22 |
| C01A | 6512185.15 | 2080135.54 | 531.84 | 532.04 | 0.2 |
| C02 | 6495476.91 | 2066355.05 | 422.74 | 422.56 | -0.18 |
| C03 | 6495517.16 | 2099326.99 | 533.76 | 533.46 | -0.3 |
| C04 | 6518923.03 | 2104468.48 | 568.23 | 568.28 | 0.05 |
| C05 | 6504834.81 | 2124353.53 | 618.9 | 619.08 | 0.18 |
| C05A | 6504874.08 | 2124348.11 | 618.27 | 618.33 | 0.06 |
| C06 | 6493688.2 | 2135662.02 | 774.22 | 774.12 | -0.1 |
| C06A | 6493684.29 | 2135644.68 | 773.62 | 773.51 | -0.11 |

Table 7 - Static GPS Points for Cow Creek AOI

| 100 % of Totals | # of Points | RMSEz NVA Spec=0.33 (US ft) | NVA at 95% Spec=0.64 (US ft) | Mean (US ft) | Std Dev (US ft) | Min (US ft) | Max (US ft) |
|---|---|---|---|---|---|---|---|
| Non-Vegetated Terrain | 9 | 0.17 | 0.33 | 0.00 | 0.18 | -0.30 | +0.22 |

Table 8 - Static GPS Vertical Accuracy Results for Cow Creek AOI

| Number | NAD83 (2011) State Plane CA Zone II | | NAVD88 (GEOID 12B) | | |
|---|---|---|---|---|---|
| | Easting X (US ft) | Northing Y (US ft) | Known Z (US ft) | Laser Z (US ft) | Dz (US ft) |
| K01 | 6615199.48 | 2399094.85 | 246.4 | 246.2 | -0.2 |
| K02 | 6594783.25 | 2409129.6 | 173.28 | 173.51 | 0.23 |
| K02A | 6594794.48 | 2409114.95 | 173.16 | 173.29 | 0.13 |
| K03 | 6573872.1 | 2439165.45 | 201.01 | 200.99 | -0.02 |
| K03A | 6573887.57 | 2439130.01 | 200.63 | 200.54 | -0.09 |
| K04 | 6596160.07 | 2424217.46 | 229.9 | 229.73 | -0.17 |
| K05 | 6573783.27 | 2400406.86 | 142.67 | 142.68 | 0.01 |
| K05A | 6573769.12 | 2400418.36 | 142.01 | 142.04 | 0.03 |
| K06 | 6584739.89 | 2422345.75 | 181.74 | 181.8 | 0.06 |
| K06A | 6584734.01 | 2422357.29 | 181.73 | 181.73 | 0 |

Table 9 - Static GPS Points for Keefer Slough AOI

| 100 % of Totals | # of Points | RMSEz NVA Spec=0.33 (US ft) | NVA at 95% Spec=0.64 (US ft) | Mean (US ft) | Std Dev (US ft) | Min (US ft) | Max (US ft) |
|---|---|---|---|---|---|---|---|
| Non-Vegetated Terrain | 10 | 0.12 | 0.24 | 0.00 | 0.13 | -0.20 | +0.23 |

Table 10 - Static GPS Vertical Accuracy Results for Keefer Slough AOI

| Number | NAD83 (2011) State Plane CA Zone II | | NAVD88 (GEOID 12B) | | |
|---|---|---|---|---|---|
| | Easting X (US ft) | Northing Y (US ft) | Known Z (US ft) | Laser Z (US ft) | Dz (US ft) |
| R01 | 6265976.75 | 2076036.44 | 374.24 | 374.34 | 0.1 |
| R02 | 6244309.61 | 2118125.02 | 500.69 | 500.85 | 0.16 |
| R02A | 6244253.14 | 2118141.5 | 503.17 | 503.56 | 0.39 |
| R03 | 6262626.82 | 2119295.51 | 776.07 | 776.12 | 0.05 |
| R04 | 6221824.73 | 2166554.99 | 582.01 | 581.82 | -0.19 |
| R04A | 6221835.76 | 2166558.99 | 582.05 | 582.01 | -0.04 |

| | | | | | |
|---|---|---|---|---|---|
| R05 | 6200862.17 | 2141203.51 | 2104.6 | 2104.52 | -0.08 |
| R06 | 6234961.9 | 2144297.72 | 564.74 | 564.89 | 0.15 |
| R06A | 6234920.5 | 2144208.5 | 563.85 | 563.71 | -0.14 |
| R07 | 6220800.28 | 2213409.98 | 676.77 | 676.64 | -0.13 |
| R07A | 6220778.55 | 2213417.26 | 677.32 | 677.16 | -0.16 |
| R08 | 6193546.98 | 2246662.57 | 1630.74 | 1630.91 | 0.17 |
| R08A | 6193545.14 | 2246635.73 | 1629.06 | 1629.27 | 0.21 |
| R09 | 6265754.93 | 2199302.02 | 1319.83 | 1319.69 | -0.14 |
| R09A | 6265751.85 | 2199336.38 | 1318.2 | 1317.97 | -0.23 |
| R10 | 6246831.85 | 2245149.68 | 949.4 | 949.23 | -0.17 |
| R10A | 6246811.32 | 2245149.95 | 950.08 | 950.06 | -0.02 |
| R11 | 6217610.83 | 2190498.78 | 653.9 | 654.05 | 0.15 |

Table 11 - Static GPS Points for Russian Mendocino AOI

| 100 % of Totals | # of Points | RMSEz NVA Spec=0.33 (US ft) | NVA at 95% Spec=0.64 (US ft) | Mean (US ft) | Std Dev (US ft) | Min (US ft) | Max (US ft) |
|---|---|---|---|---|---|---|---|
| Non-Vegetated Terrain | 18 | 0.17 | 0.33 | 0.00 | 0.17 | -0.23 | +0.39 |

Table 12 - Static GPS Vertical Accuracy Results for Russian Mendocino AOI

| Number | NAD83 (2011) State Plane CA Zone I | | NAVD88 (GEOID 12B) | | |
|---|---|---|---|---|---|
| | Easting X (US ft) | Northing Y (US ft) | Known Z (US ft) | Laser Z (US ft) | Dz (US ft) |
| U01 | 6789627.45 | 2286138.920 | 4122.22 | 4122.26 | +0.04 |
| U02 | 6797444.07 | 2370327.56 | 4284.74 | 4284.62 | -0.12 |
| U03 | 6868675.49 | 2275548.67 | 4588.31 | 4588.41 | +0.1 |
| U04 | 6852221.99 | 2321054.67 | 4204.56 | 4204.73 | +0.17 |
| U05 | 6869040.80 | 2409147.98 | 4304.76 | 4304.77 | +0.01 |
| U06 | 6962111.94 | 2430171.75 | 4372.09 | 4372.13 | +0.04 |
| U07 | 6973121.21 | 2335152.50 | 4449.82 | 4449.60 | -0.22 |
| U08 | 6929218.90 | 2405316.03 | 4412.24 | 4412.32 | +0.08 |
| U09 | 7005409.54 | 2503849.33 | 4821.98 | 4821.87 | -0.11 |

| | | | | | |
|---|---|---|---|---|---|
| **U10** | 7034008.19 | 2457046.70 | 6252.32 | 6252.30 | -0.02 |
| **U11** | 6823974.41 | 2297041.66 | 4168.46 | 4168.68 | +0.22 |
| **U12** | 6913510.63 | 2425958.28 | 4498.73 | 4498.69 | -0.04 |
| **U13** | 6963238.13 | 2384862.99 | 4416.23 | 4416.08 | -0.15 |
| **U14** | 6989344.22 | 2458617.77 | 4522.91 | 4523.16 | +0.25 |
| **U15** | 6796032.30 | 2326125.43 | 4158.45 | 4158.64 | +0.19 |
| **U16** | 6848454.50 | 2423233.77 | 4592.24 | 4591.82 | -0.42 |

**Table 13 - Static GPS Points for Upper Pitt AOI**

| 100 % of Totals | # of Points | RMSEz NVA Spec=0.33 (US ft) | NVA at 95% Spec=0.64 (US ft) | Mean (US ft) | Std Dev (US ft) | Min (US ft) | Max (US ft) |
|---|---|---|---|---|---|---|---|
| Non-Vegetated Terrain | 16 | 0.17 | 0.34 | 0.00 | 0.18 | -0.42 | 0.25 |

**Table 14 - Static GPS Vertical Accuracy Results for Upper Pitt AOI**

| Number | NAD83 (2011) State Plane CA Zone II | | NAVD88 (GEOID 12B) | | |
|---|---|---|---|---|---|
| | Easting X (US ft) | Northing Y (US ft) | Known Z (US ft) | Laser Z (US ft) | Dz (US ft) |
| **A01** | 7124184.130 | 1947138.58 | 7954.69 | 7954.620 | -0.070 |
| **A02** | 7128484.790 | 1944571.90 | 7573.36 | 7573.520 | +0.160 |
| **A03** | 7133315.630 | 1942263.90 | 7339.72 | 7339.710 | -0.010 |
| **A04** | 7114640.030 | 1929765.75 | 6941.77 | 6941.910 | +0.140 |
| **A05** | 7122595.330 | 1937166.20 | 7093.84 | 7093.800 | -0.040 |
| **A06** | 7126786.960 | 1940314.37 | 7283.30 | 7283.090 | -0.210 |

**Table 15 - Static GPS Points for Alpine AOI**

| 100 % of Totals | # of Points | RMSEz NVA Spec=0.33 (US ft) | NVA at 95% Spec=0.64 (US ft) | Mean (US ft) | Std Dev (US ft) | Min (US ft) | Max (US ft) |
|---|---|---|---|---|---|---|---|
| Non-Vegetated Terrain | 6 | 0.13 | 0.25 | -0.05 | 0.14 | -0.21 | +0.16 |

**Table 16 - Static GPS Vertical Accuracy Results for Alpine AOI**

Overall the calibrated lidar data products collected by Eagle Mapping Inc meet or exceed the requirements set out in the Statement of Work. The quality control requirements of Eagle Mapping Inc quality management program were adhered to throughout the acquisition stage for this project to ensure product quality.

# Lidar Processing & Qualitative Assessment

## INITIAL PROCESSING

Once Dewberry receives the calibrated swath data from the acquisition provider Dewberry performs several validations on the dataset prior to starting full-scale production on the project. These validations include vertical accuracy of the swath data inter-swath (between swath) relative accuracy validation intra-swath (within a single swath) relative accuracy validation verification of horizontal alignment between swaths and confirmation of point density and spatial distribution. This initial assessment allows Dewberry to determine if the data are suitable for full-scale production. Addressing issues at this stage allows the data to be corrected while imposing the least disruption possible on the overall production workflow and overall schedule.

### Final Swath Vertical Accuracy Assessment

Once Dewberry received the calibrated swath data from Quantum Spatial and Eagle Mapping Dewberry tested the vertical accuracy of the non-vegetated terrain swath data prior to additional processing. Dewberry tested the vertical accuracy of the swath data using the one hundred non-vegetated (open terrain and urban) independent survey check points. The vertical accuracy is tested by comparing survey checkpoints in non-vegetated terrain to a triangulated irregular network (TIN) that is created from the raw swath points. Only checkpoints in non-vegetated terrain can be tested against raw swath data because the data has not undergone classification techniques to remove vegetation buildings and other artifacts from the ground surface. Checkpoints are always compared to interpolated surfaces from the lidar point cloud because it is unlikely that a survey checkpoint will be located at the location of a discrete lidar point. Dewberry typically uses LP360 software to test the swath lidar vertical accuracy Terrascan software to test the classified lidar vertical accuracy and Esri ArcMap to test the DEM vertical accuracy so that three different software programs are used to validate the vertical accuracy for each project. Project specifications require a NVA of 19.6 (0.64 ft) cm based on the $RMSE_z$ (10 cm/0.33 ft) x 1.96. The dataset for the California FEMA R9 Lidar Project satisfies this criteria. This raw lidar swath data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 (0.33 ft) cm $RMSE_z$ Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ = 7 cm (0.23 ft) equating to +/- 14 cm (0.46 ft) at 95% confidence level. The table below shows all calculated statistics for the raw swath data.

| 100 % of Totals | # of Points | RMSEz (ft) NVA Spec=0.33 ft | NVA- Non-vegetated Vertical Accuracy ((RMSEz x 1.9600) Spec=0.64 ft | Mean (ft) | Median (ft) | Skew | Std Dev (ft) | Min (ft) | Max (ft) | Kurtosis |
|---|---|---|---|---|---|---|---|---|---|---|
| NVA | 100 | 0.23 | 0.46 | -0.05 | -0.08 | 0.25 | 0.23 | -0.69 | 0.68 | 0.36 |

Table 17: NVA at 95% Confidence Level for Raw Swaths

Two checkpoints were removed from the raw swath vertical accuracy testing. One checkpoint (NVA-69) was removed from the raw swath vertical accuracy testing due to its location underneath a tree. Only non-vegetated terrain checkpoints are used to test the raw swath data because the raw swath data has not been classified to remove vegetation structures and other above ground features from the ground classification. While NVA-69 is located on asphalt, there is an overhanging tree modeled by the lidar point cloud. The high points from the tree canopy caused erroneous high values during the swath vertical accuracy testing so this point was removed from the final calculations. Once the data underwent the classification process the trees were removed from the final ground classification and this point could be used in the final vertical accuracy testing for the fully classified lidar data. Table 18 below provides the coordinates for this checkpoint and the vertical accuracy results from the raw swath data. Table 19 below provides the usable vertical accuracy results of this checkpoint from the fully classified lidar. The differences in the tables show how above ground features can cause erroneous vertical accuracy results in the raw swath data. Figure 8 below shows a 3D model of the lidar point cloud and the location of the checkpoint beneath a tree.

| Point ID | NAD83(2011) State Plane CA Zone 1 and 2 | | NAVD88 (Geoid 12B) | Lidar Z (ft) | Delta Z | AbsDeltaZ |
|---|---|---|---|---|---|---|
| | Easting X (ft) | Northing Y (ft) | Survey Z (ft) | | | |
| NVA-69 | 6051018.92 | 2285265.58 | 111.69 | 119.74 | 8.05 | 8.05 |

Table 18-Checkpoint removed from raw swath vertical accuracy testing

| Point ID | NAD83(2011) State Plane CA Zone 1 and 2 | | NAVD88 (Geoid 12B) | Lidar Z (ft) | Delta Z | AbsDeltaZ |
|---|---|---|---|---|---|---|
| | Easting X (ft) | Northing Y (ft) | Survey Z (ft) | | | |
| NVA-69 | 6051018.92 | 2285265.58 | 111.69 | 111.67 | -0.02 | 0.02 |

Table 19: Final tested vertical accuracy for NVA-69 post ground classification

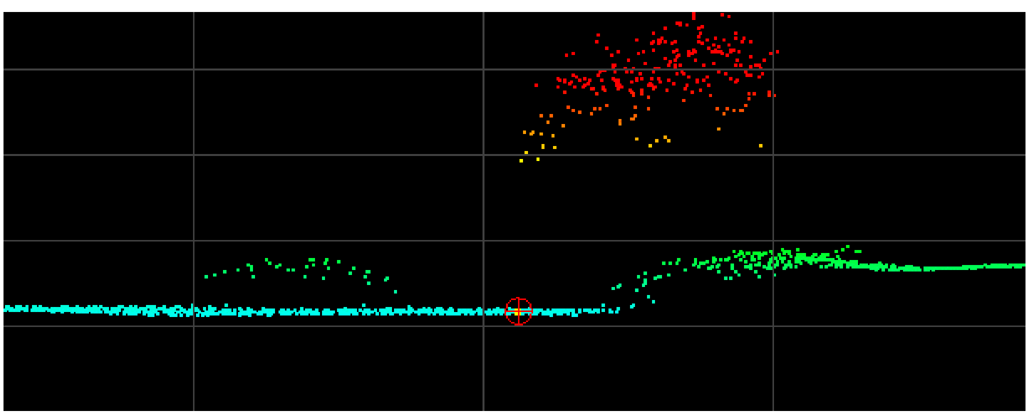

Figure 8 – Non-vegetated checkpoint NVA-69 shown as the large red marker is located underneath a tree. This point was removed from raw swath vertical accuracy testing because above ground features including trees have not been separated from the ground classification yet.

Another checkpoint (NVA-73) was removed from the raw swath vertical accuracy testing due to its location outside of the project boundary.

## Inter-Swath (Between Swath) Relative Accuracy

Dewberry verified inter-swath or between swath relative accuracy of the dataset by creating Delta-Z (DZ) orthos. According to the SOW USGS Lidar Base Specifications v1.2 and ASPRS Positional Accuracy Standards for Digital Geospatial Data 10 cm Vertical Accuracy Class or QL2 data must meet inter-swath relative accuracy of 8 cm RMSDz or less with maximum differences less than 16 cm. These measurements are to be taken in non-vegetated and flat open terrain using single or only returns from all classes. Measurements are calculated in the DZ orthos on 1-meter pixels or cell sizes. Areas in the dataset where overlapping flight lines are within 8 cm of each other within each pixel are colored green areas in the dataset where overlapping flight lines have elevation differences in each pixel between 8 cm to 16 cm are colored yellow and areas in the dataset where overlapping flight lines have elevation differences in each pixel greater than 16 cm are colored red. Pixels that do not contain points from overlapping flight lines are colored according to their intensity values. Areas of vegetation and steep slopes (slopes with 16 cm or more of valid elevation change across 1 linear meter) are expected to appear yellow or red in the DZ orthos. If the project area is heavily vegetated Dewberry may also create DZ Orthos from the initial ground classification only while keeping all other parameters consistent. This allows Dewberry to review the ground classification relative accuracy beneath vegetation and to ensure flight line ridges or other issues do not exist in the final classified data.

Flat open areas are expected to be green in the DZ orthos. Large or continuous sections of yellow or red pixels can indicate the data was not calibrated correctly or that there were issues during acquisition that could affect the usability of the data especially when these yellow/red sections follow the flight lines and not the terrain or areas of vegetation. The DZ orthos for California FEMA R9 Lidar are shown in the figure below; this project meets inter-swath relative accuracy specifications.

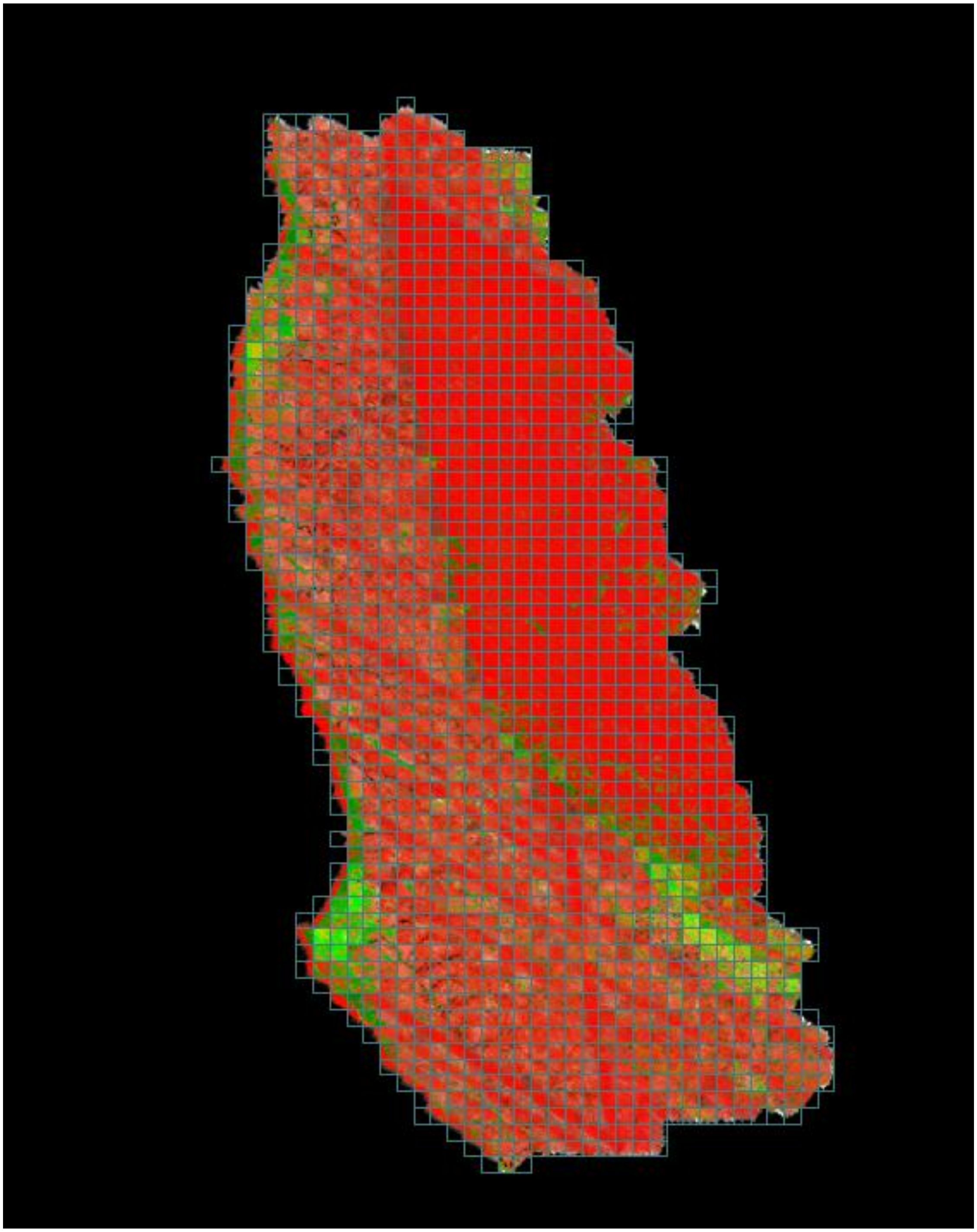

**Figure 9-Single return DZ Orthos for the Mendocino QL1 AOI. Heavy vegetation obscured much of this AOI so additional verifications were performed. Open, flat areas are shown in green as they meet specifications. Inter-swath relative accuracy passes specifications.**

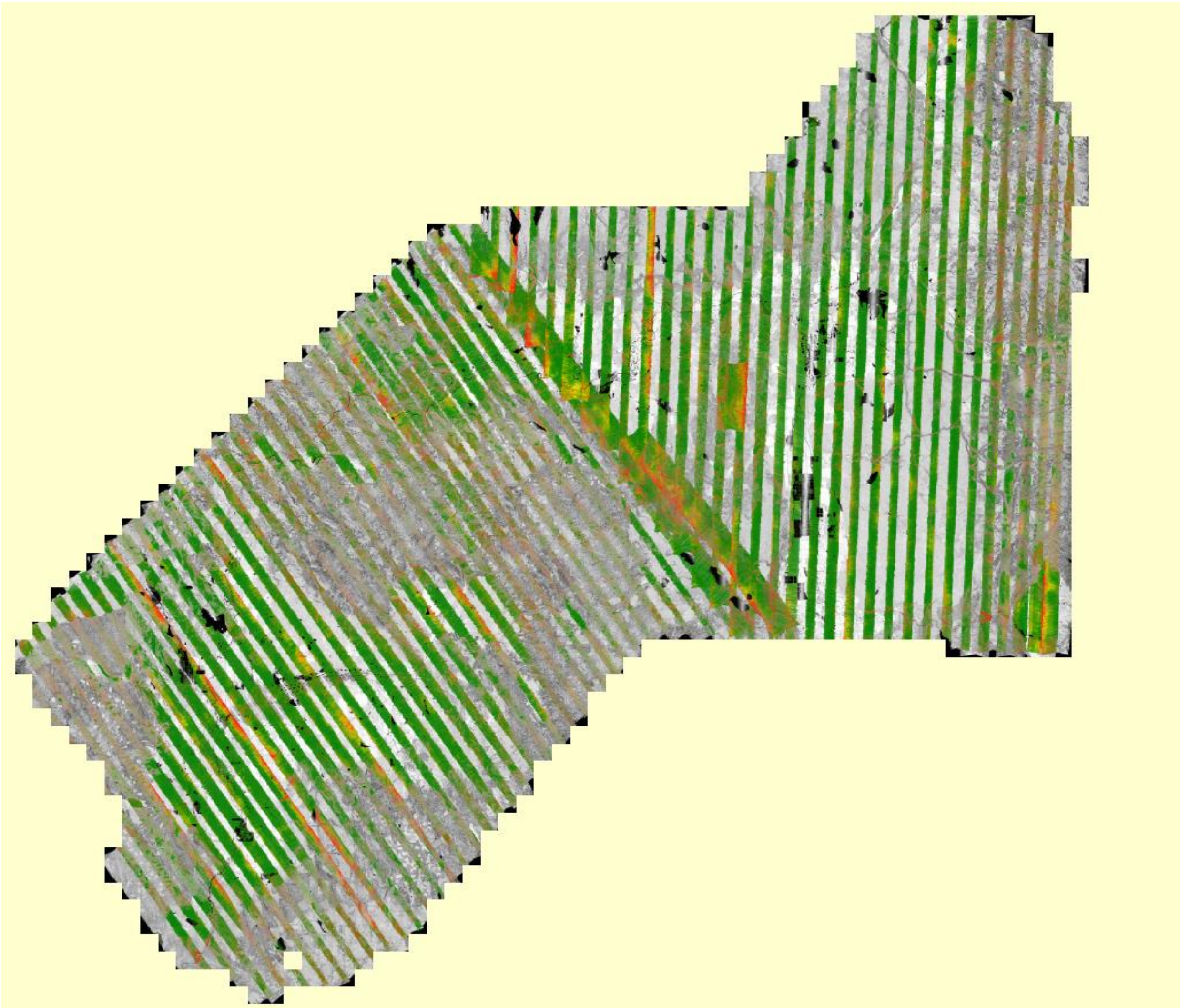

**Figure 10- Single return DZ Orthos for the Upper Pit AOI. Inter-swath relative accuracy passes specifications.**

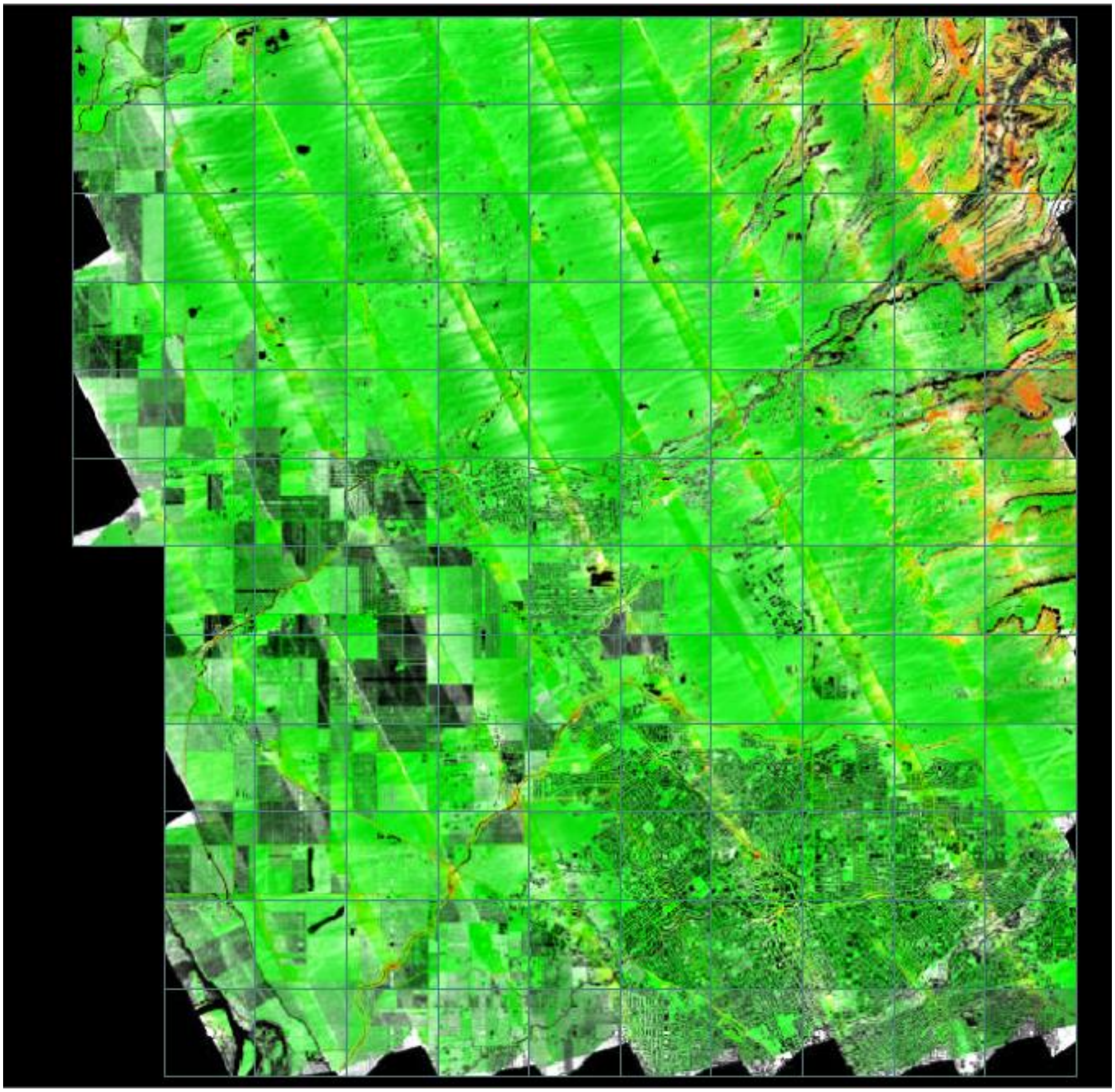

**Figure 11- Single return DZ Orthos for the Keefer Slough AOI. Inter-swath relative accuracy passes specifications.**

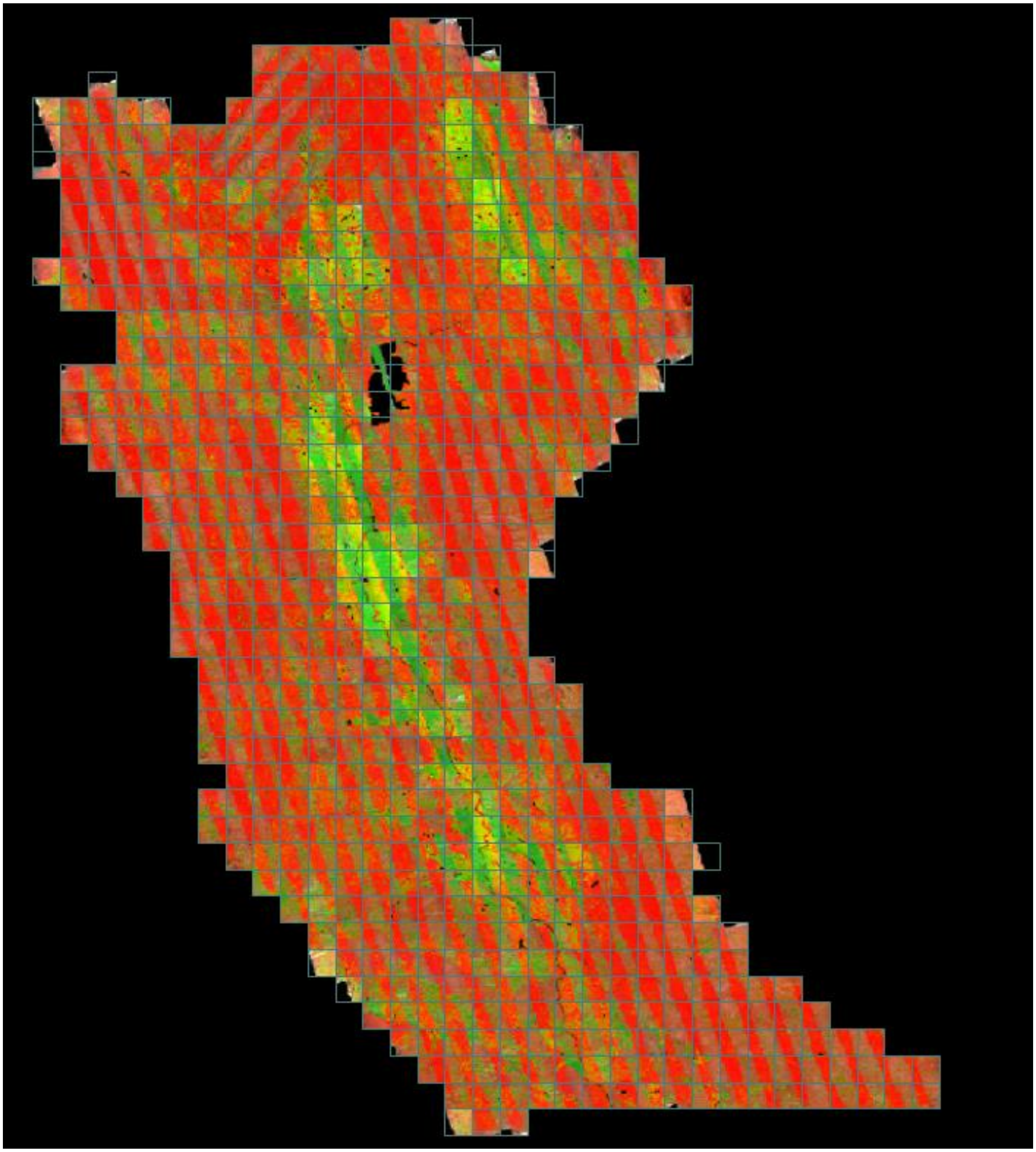

**Figure 12-- Single return DZ Orthos for the Russian Mendocino AOI. Heavy vegetation obscured much of this AOI so additional verifications were performed. Open, flat areas are shown in green as they meet specifications. Inter-swath relative accuracy passes specifications.**

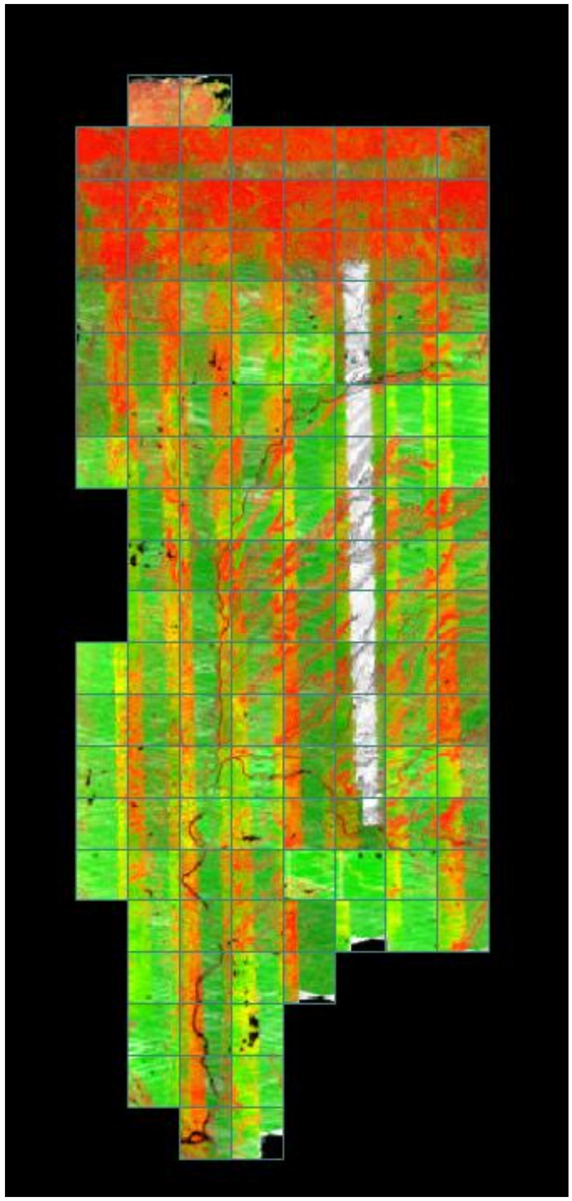

**Figure 13-- Single return DZ Orthos for the Cow Creek AOI. Inter-swath relative accuracy passes specifications.**

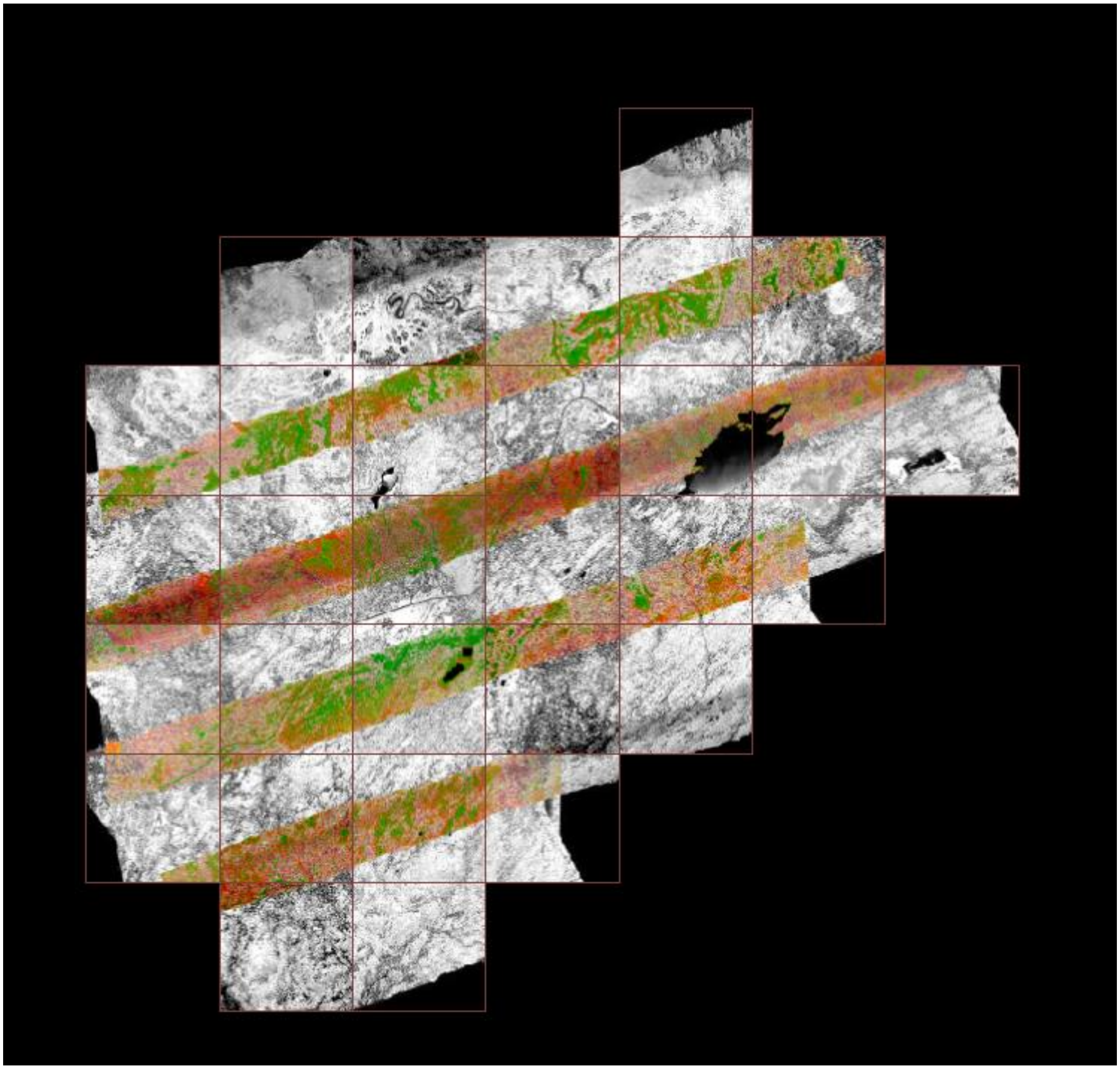

**Figure 14-- Single return DZ Orthos for the Alpine AOI. Inter-swath relative accuracy passes specifications.**

## Intra-Swath (Within a Single Swath) Relative Accuracy

Dewberry verifies the intra-swath or within swath relative accuracy by using Quick Terrain Modeler (QTM) scripting and visual reviews. QTM scripting is used to calculate the maximum difference of all points within each 1-meter pixel/cell size of each swath. Dewberry analysts then identify planar surfaces acceptable for repeatability testing and analysts review the QTM results in those areas. According to the SOW USGS Lidar Base Specifications v1.2 and ASPRS Positional Accuracy Standards for Digital Geospatial Data 10 cm Vertical Accuracy Class or QL2 data must meet intra-swath relative accuracy of 6 cm maximum difference or less. The image below shows two examples of the intra-swath relative accuracy of California FEMA R9; this project meets intra-swath relative accuracy specifications.

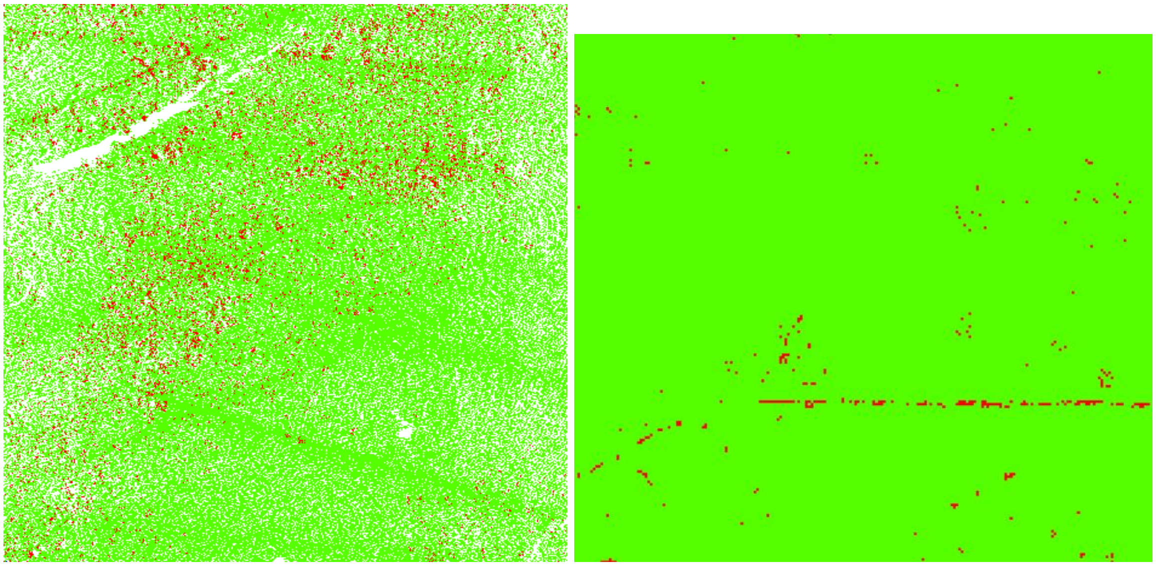

**Figure 15–Intra-swath relative accuracy. Each AOI's Intra-swath relative accuracy was tested and meets spec. The left image shows a large portion of the dataset; flat open areas are colored green as they are within 6 cm whereas sloped terrain is colored red because it exceeds 6 cm maximum difference as expected due to actual slope/terrain change. The right image is a close-up of a flat area. With the exception of few trees (shown in red as the elevation/height difference in vegetated areas will exceed 6 cm) this open flat area is acceptable for repeatability testing. Intra-swath relative accuracy passes specifications.**

## Horizontal Alignment

To ensure horizontal alignment between adjacent or overlapping flight lines Dewberry uses QTM scripting and visual reviews. QTM scripting is used to create files similar to DZ orthos for each swath but this process highlights planar surfaces such as roof tops. In particular horizontal shifts or misalignments between swaths on roof tops and other elevated planar surfaces are highlighted. Visual reviews of these features including additional profile verifications are used to confirm the results of this process. The image below shows an example of the horizontal alignment between swaths for California FEMA R9; no horizontal alignment issues were identified.

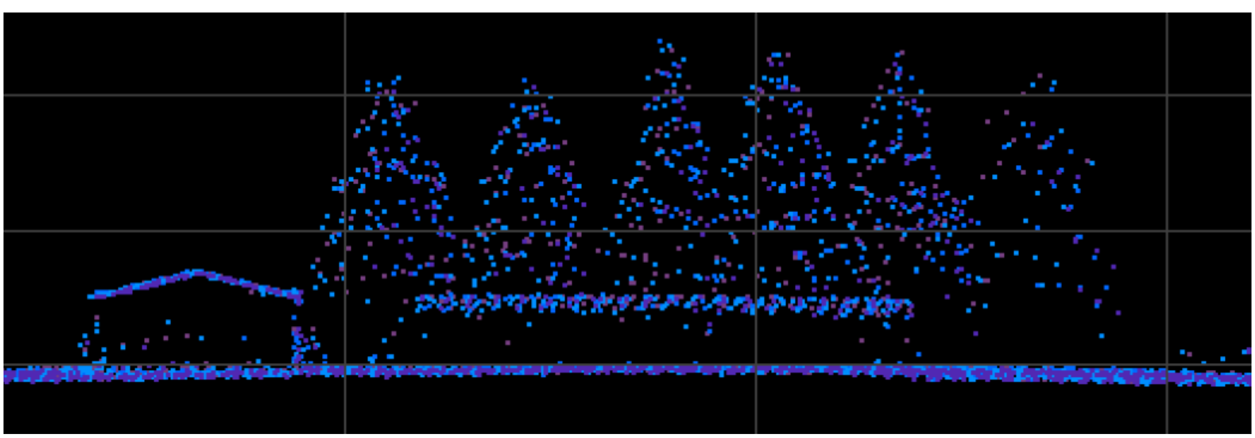

**Figure 16– Horizontal Alignment. Two separate flight lines differentiated by color (Teal/Purple) are shown in this profile. There is no visible offset between these two flight lines. No horizontal alignment issues were identified.**

## Point Density and Spatial Distribution

The required Aggregate Nominal Point Spacing (ANPS) for the Mendocino QL1 AOI is no greater than 0.35 meters which equates to an Aggregate Nominal Point Density (ANPD) of 8 points per square meter or greater. The required Aggregate Nominal Point Spacing (ANPS) for the FEMA Region IX AOIs is no greater than 0.71 meters which equates to an Aggregate Nominal Point Density (ANPD) of 2 points per square meter or greater. Density calculations were performed using first return data only located in the geometrically usable center portion (typically ~90%) of each swath. By utilizing statistics the Mendocino QL1 AOI was determined to have an ANPS of 0.30 meters or an ANPD of 10.79 points per square meter which satisfies the project requirements. A visual review of a 1-square meter density grid (figure below) shows that there are some 1-meter cells that do not contain 8 points per square meter (red areas) due to the irregular spacing of lidar point cloud data. Most 1-square meter cells contain at least 8 points per square meter (green areas) and when density is viewed/analyzed by representative 1-square kilometer areas (to account for the irregular spacing of lidar point clouds) density passes with no issues.

**Figure 17– 1-square meter density grid. There are some 1-meter cells that do not contain 8 points per square meter (red areas) due to the irregular spacing of lidar point cloud data. Most 1-sqaure meter cells contain at least 8 points per square meter (green areas) showing there are no systematic density issues. When density is viewed/analyzed by representative 1-square kilometer areas density passes with no issues.**

By utilizing statistics the five FEMA AOIs were determined to have an ANPS of 0.56 meters or an ANPD of 3.15 points per square meter which satisfies the project requirements. A visual review of a 1-square meter density grid (figure below) shows that there are some 1-meter cells that do not contain 2 points per square meter (red areas) due to the irregular spacing of lidar point cloud data.  Most 1-sqaure meter cells contain at least 2 points per square meter (green areas) and when density is viewed/analyzed by representative 1-square kilometer areas (to account for the irregular spacing of lidar point clouds) density passes with no issues.

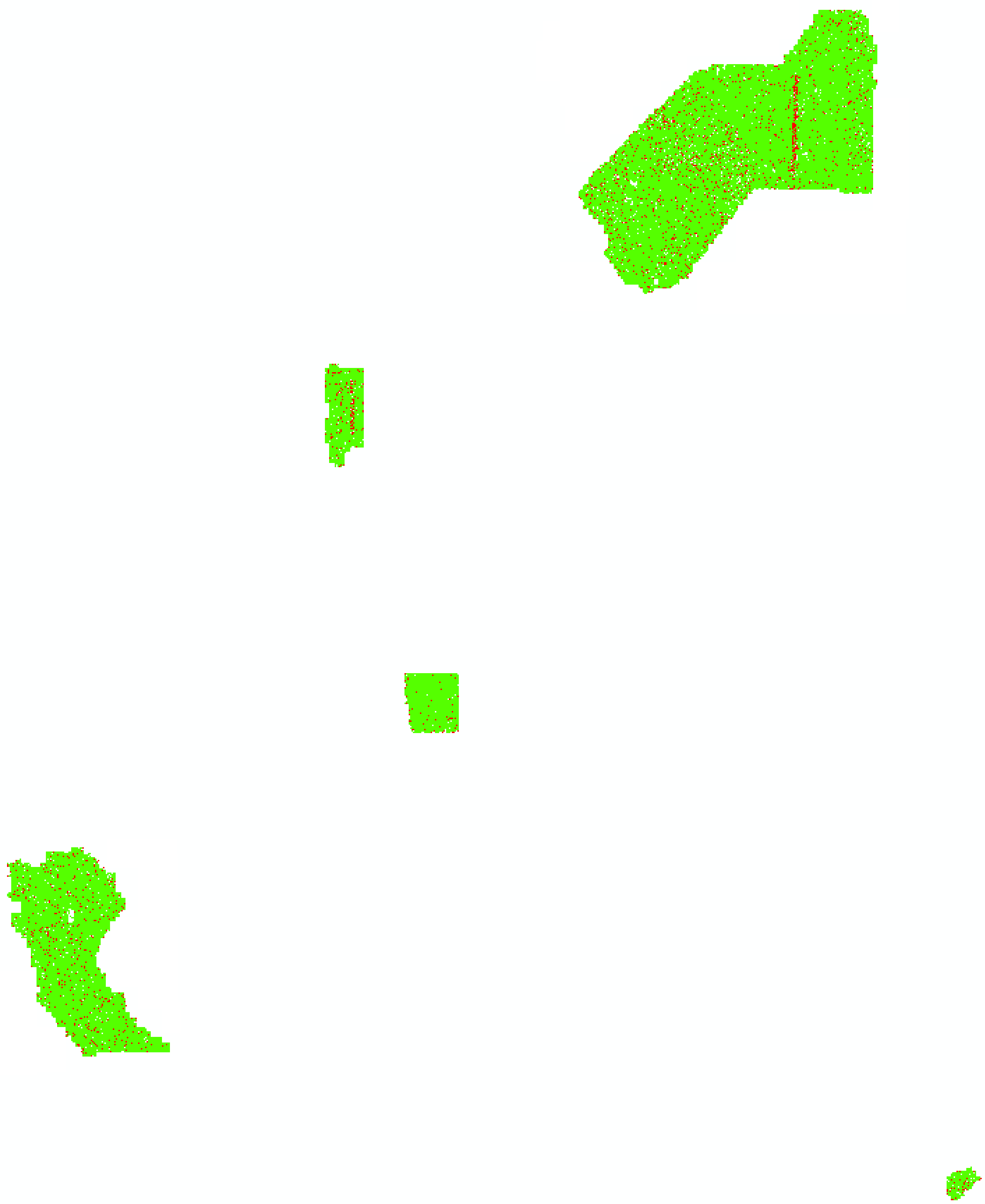

**Figure 18– 1-square meter density grid. There are some 1-meter cells that do not contain 2 points per square meter (red areas) due to the irregular spacing of lidar point cloud data. Most 1-sqaure meter cells contain at least 2 points per square meter (green areas) showing there are no systematic density issues. When density is viewed/analyzed by representative 1-square kilometer areas density passes with no issues.**

The spatial distribution of points must be uniform and free of clustering. This specification is tested by creating a grid with cell sizes equal to the design NPS*2. ArcGIS tools are then used to calculate the number of first return points of each swath within each grid cell. At least 90% of the cells must contain 1 lidar point excluding acceptable void areas such as water or low NIR reflectivity features i.e. some asphalt and roof composition materials. This project passes spatial distribution requirements as shown in the image below.

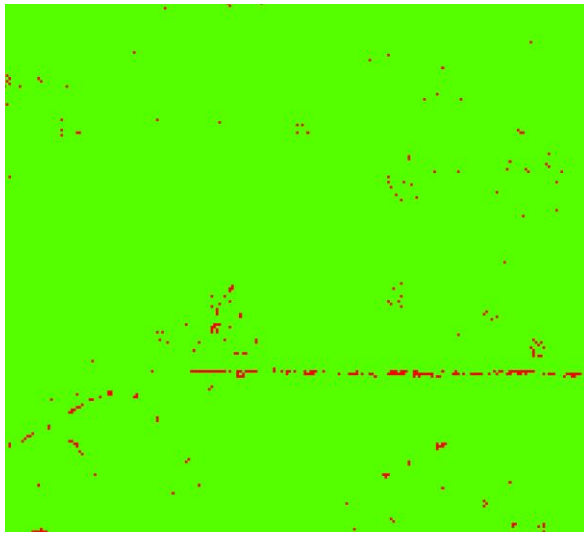

**Figure 19– Spatial Distribution. All cells (2*NPS cellsize) containing at least one lidar point are colored green. Cells that do not contain a lidar point including water bodies which are acceptable NoData area are colored red. Without removing acceptable NoData areas due to water 98% of cells contain at least one lidar point.**

## DATA CLASSIFICATION AND EDITING

Once the calibration absolute swath vertical accuracy and relative accuracy of the data was confirmed Dewberry utilized a variety of software suites for data processing. The data was processed using GeoCue and TerraScan software. The initial step is the setup of the GeoCue project which is done by importing a project defined tile boundary index encompassing the entire project area. The acquired 3D laser point clouds in LAS binary format were imported into the GeoCue project and tiled according to the project tile grid. Once tiled the laser points were classified using a proprietary routine in TerraScan. This routine classifies any obvious low outliers in the dataset to class 7 and high outliers in the dataset to class 18. Points along flight line edges that are geometrically unusable are identified as withheld and classified to a separate class so that they will not be used in the initial ground algorithm. After points that could negatively affect the ground are removed from class 1 the ground layer is extracted from this remaining point cloud. The ground extraction process encompassed in this routine takes place by building an iterative surface model. Additional classification routines were applied to the QL1 Mendocino AOI. QL1 Mendocino required buildings to be assigned to class 6 and Low vegetation, medium vegetation, and high vegetation were classed to class 3, 4, 5 respectively based on height parameters provided by the client.

This surface model is generated using three main parameters: building size iteration angle and iteration distance. The initial model is based on low points being selected by a "roaming window" with the assumption that these are the ground points. The size of this roaming window is determined by the building size parameter. The low points are triangulated and the remaining points are evaluated and subsequently added to the model if they meet the iteration angle and distance constraints. This process is repeated until no additional points are added within iterations. A second critical parameter is the maximum terrain angle constraint which determines the maximum terrain angle allowed within the classification model.

Each tile was then imported into Terrascan and a surface model was created to examine the ground classification. Dewberry analysts visually reviewed the ground surface model and corrected errors in the ground classification such as vegetation buildings and bridges that were present following the initial processing conducted by Dewberry. Dewberry analysts employ 3D visualization techniques to view the point cloud at multiple angles and in profile to ensure that non-ground points are removed from the ground classification. Bridge decks are classified to class 17 using Bridge saddle breaklines compiled by Dewberry. After the ground classification corrections were completed the dataset was processed through a water classification routine that utilizes breaklines compiled by Dewberry to automatically classify hydro features. The water classification routine selects ground points within the breakline polygons and automatically classifies them as class 9 water. During this water classification routine points that are within 1x NPS or less of the hydrographic features are moved to class 10 an ignored ground due to breakline proximity. Overage points are then identified in Terrascan and GeoCue is used to set the overlap bit for the overage points and the withheld bit is set on the withheld points previously identified in Terrascan before the ground classification routine was performed.

The lidar tiles were classified to the following classification schema:

- Class 1 = Unclassified used for all other features that do not fit into the Classes 2, 7, 9, 10, 17 or 18 including vegetation buildings etc.
- Class 2 = Bare-Earth Ground
- Class 7 = Low Noise
- Class 9 = Water points located within collected breaklines
- Class 10 = Ignored Ground due to breakline proximity
- Class 17 = Bridge Decks
- Class 18 = High Noise

Mendocino QL1 AOI additional classes:

- Class 3 = Low Noise
- Class 4 = Medium Noise
- Class 5 = High Noise
- Class 6 = Buildings

After manual classification the LAS tiles were peer reviewed and then underwent a final QA/QC. After the final QA/QC and corrections all headers appropriate point data records and variable length records including spatial reference information are updated in GeoCue software and then verified using proprietary Dewberry tools.

## Lidar Qualitative Assessment

Dewberry's qualitative assessment utilizes a combination of statistical analysis and interpretative methodology or visualization to assess the quality of the data for a bare-earth digital terrain model

(DTM). This includes creating pseudo image products such as lidar orthos produced from the intensity returns Triangular Irregular Network (TIN)'s Digital Elevation Models (DEM) and 3-dimensional models as well as reviewing the actual point cloud data. This process looks for anomalies in the data areas where man-made structures or vegetation points may not have been classified properly to produce a bare-earth model and other classification errors. This report will present representative examples where the lidar and post processing had issues as well as examples of where the lidar performed well.

## VISUAL REVIEW

The following sections describe common types of issues identified in lidar data and the results of the visual review for California FEMA R9.

### Data Voids

The LAS files are used to produce density grids using the commercial software package QT Modeler (QTM) which creates a 3-dimensional data model derived from Class 2 (ground) points in the LAS files. Grid spacing is based on the project density deliverable requirement for un-obscured areas. Acceptable voids (areas with no lidar returns in the LAS files) that are present in the majority of lidar projects include voids caused by bodies of water. No unacceptable voids are present in the California FEMA R9 lidar project.

### Artifacts

Artifacts are caused by the misclassification of ground points and usually represent vegetation and/or man-made structures. The artifacts identified are usually low lying structures such as porches or low vegetation used as landscaping in neighborhoods and other developed areas. These low lying features are extremely difficult for the automated algorithms to detect as non-ground and must be removed manually. The vast majority of these features have been removed but a small number of these features are still in the ground classification. The limited numbers of features remaining in the ground are usually 0.3 meters or less above the actual ground surface and should not negatively impact the usability of the dataset.

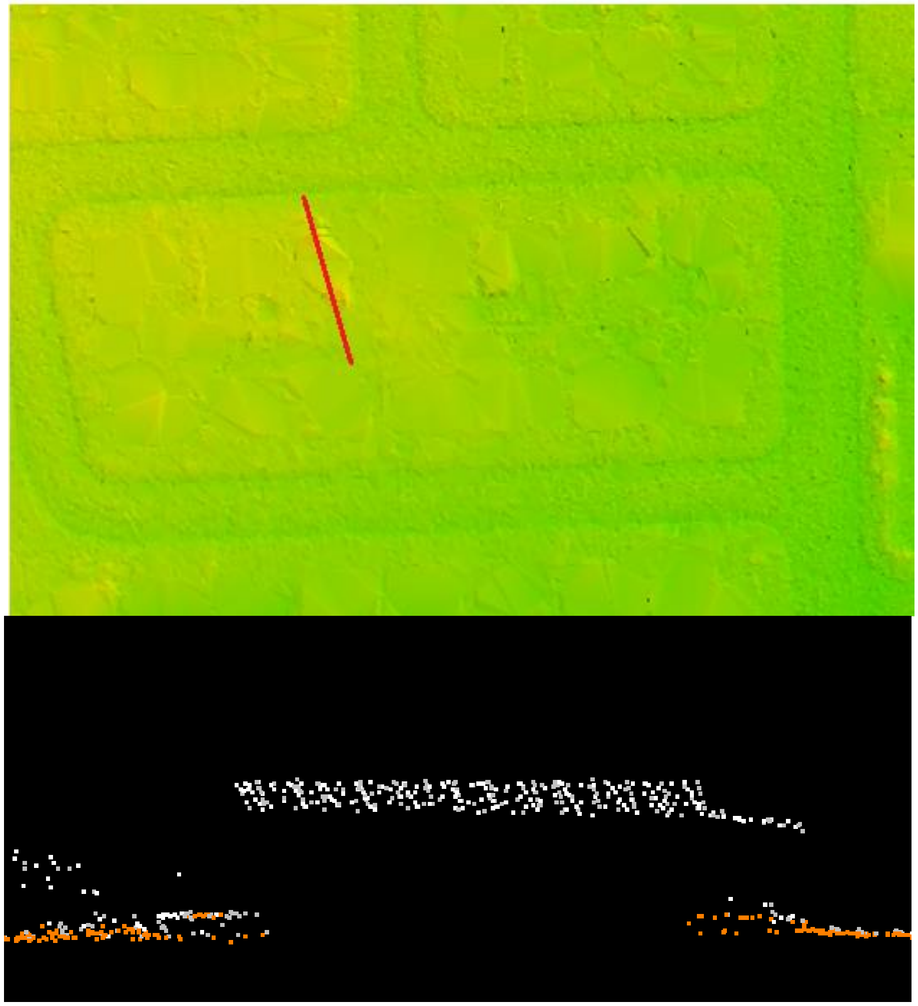

**Figure 20 – Tile number 10SDJ823325. Profile with points colored by class (class 1=white class 2=orange) is shown in the bottom view and a TIN of the surface is shown in the top view. The cross section identifies a low porch. A limited number of these small features are still classified as ground but do not impact the usability of the dataset.**

## Bridge Removal Artifacts

The DEM surface models are created from TINs or Terrains. TIN and Terrain models create continuous surfaces from the inputs. Because a continuous surface is being created the TIN or Terrain will use interpolation to continue the surface beneath the bridge where no lidar data was acquired. Locations where bridges were removed will generally contain less detail in the bare-earth surface because these areas are interpolated.

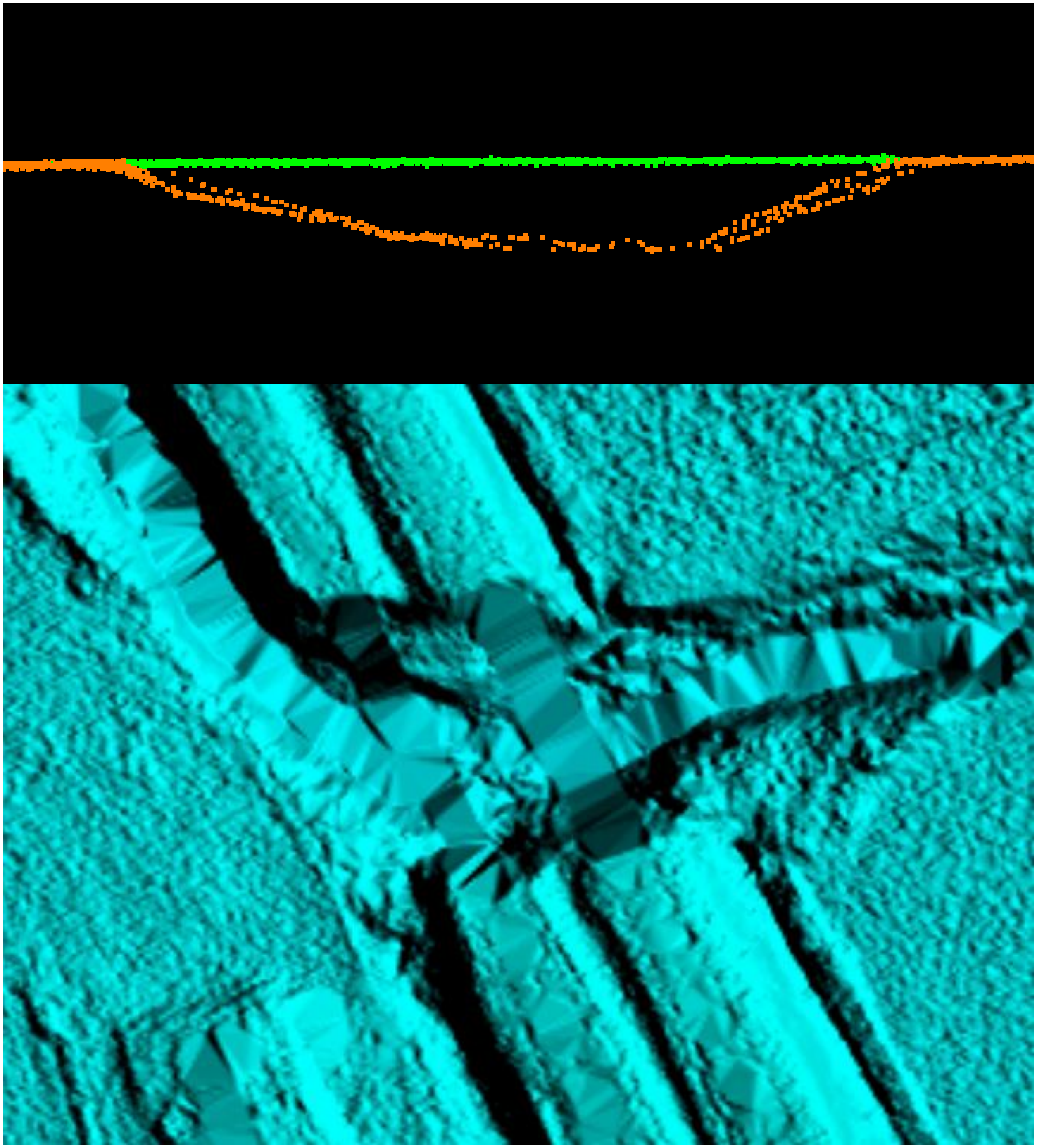

**Figure 21 – Tile number 10SDJ823264. The DEM in the bottom view shows an area where a bridge has been removed from ground. The surface model must make a continuous model and in order to do so points are connected through interpolation. This results in less detail where the surface must be interpolated. The profile in the top view shows the lidar points of this particular feature colored by class. All bridge points have been removed from ground (orange) and are bridge deck (green).**

## Culverts and Bridges

Bridges have been removed from the bare earth surface while culverts remain in the bare earth surface. In instances where it is difficult to determine if the feature is a culvert or bridge such as with some small bridges Dewberry erred on assuming they would be culverts especially if they are on secondary or tertiary roads. Below is an example of a culvert that has been left in the ground surface.

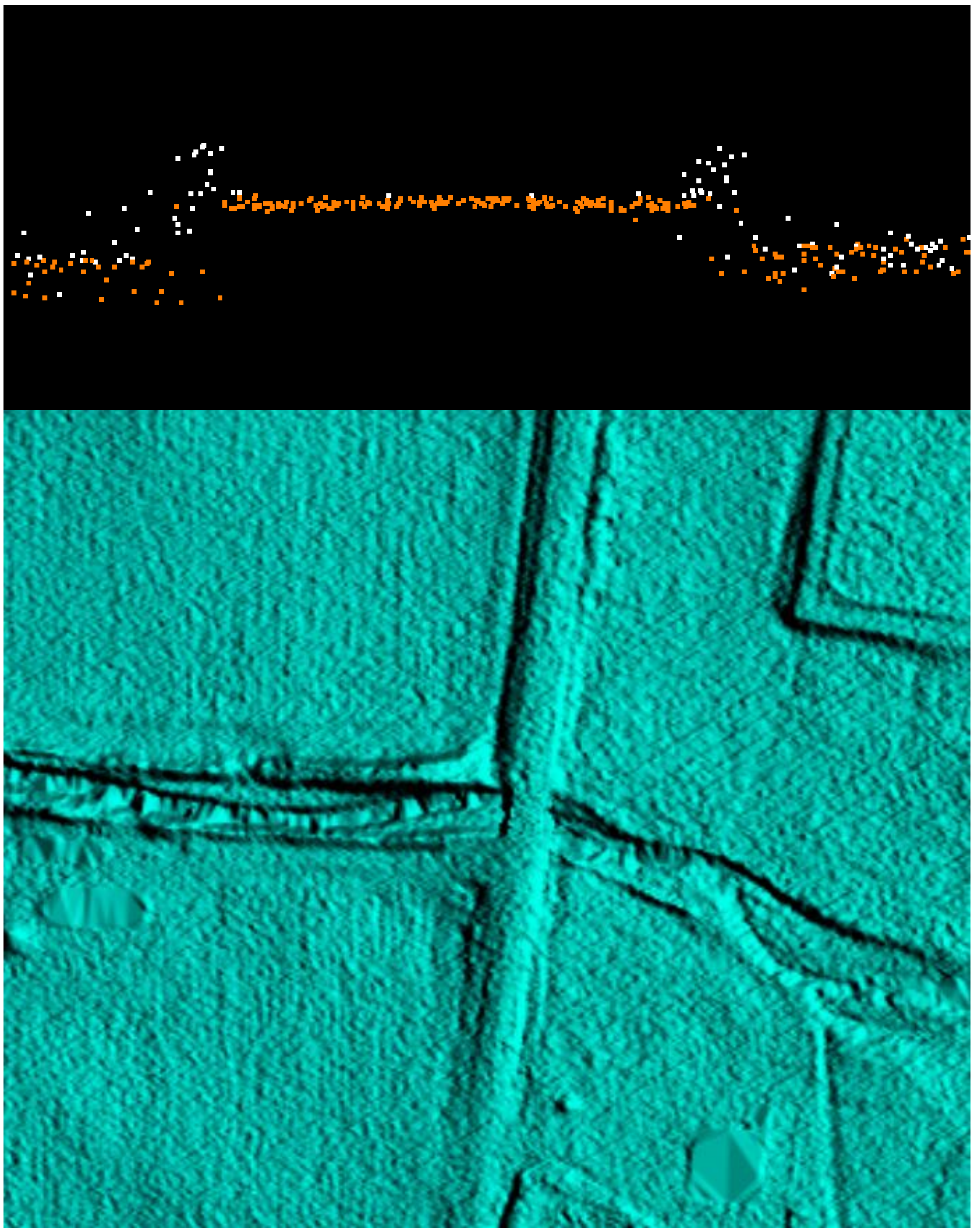

**Figure 22– Tile number 10SDJ854280. Profile with points colored by class (class 1=white class 2=orange) is shown in the top view and the DEM is shown in the bottom view. This culvert remains in the bare earth surface. Bridges have been removed from the bare earth surface and classified to class 17**

## Elevation Change Within Breaklines

While water bodies are flattened in the final DEMs other features such as linear hydrographic features can have significant changes in elevation within a small distance. In linear hydrographic features this is often due to the presence of a structure that affects flow such as a dam or spillway. Dewberry has reviewed the DEMs to ensure that changes in elevation are shown from bank to bank. These changes are often shown as steps to reduce the presence of artifacts while ensuring consistent downhill flow. An example is shown below.

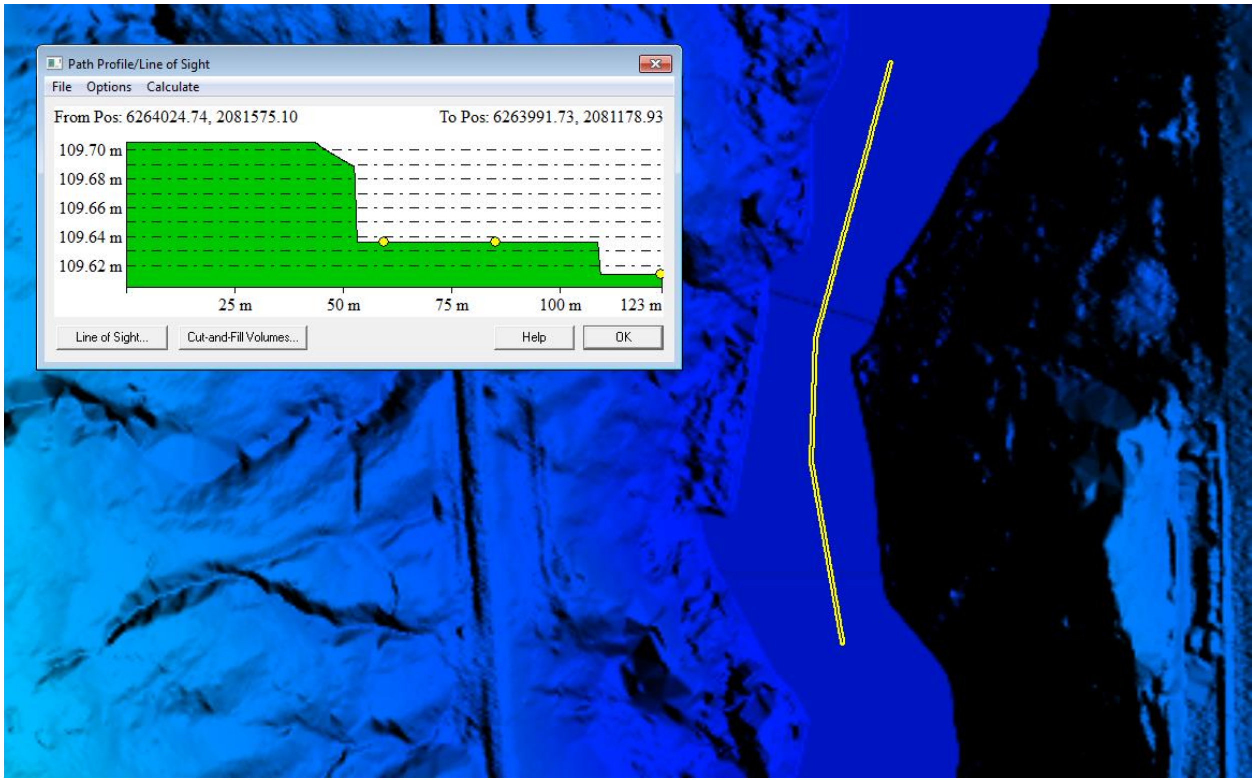


**Figure 23 – Tile number 10SDJ948022. Elevation change has been stair stepped. The steps are flat from bank to bank and flow consistently downhill.**

## FORMATTING

After the final QA/QC is performed and all corrections have been applied to the dataset all lidar files are updated to the final format requirements and the final formatting header information point data records and variable length records are verified using Dewberry proprietary tools. The table below lists some of the main lidar header fields that are updated and verified.

| Classified Lidar Formatting | | |
|---|---|---|
| **Parameter** | **Requirement** | **Pass/Fail** |
| LAS Version | 1.4 | Pass |
| Point Data Format | Format 6 | Pass |

| | | |
|---|---|---|
| Coordinate Reference System | NAD83 (2011) State Plane California Zone 1 and Zone 2 US Survey Feet and NAVD88 (Geoid 12B) US Survey Feet in WKT Format | Pass |
| Global Encoder Bit | Should be set to 17 for Adjusted GPS Time | Pass |
| Time Stamp | Adjusted GPS Time (unique timestamps) | Pass |
| System ID | Should be set to the processing system/software and is set to NIIRS10 for GeoCue software | Pass |
| Multiple Returns | The sensor shall be able to collect multiple returns per pulse and the return numbers are recorded | Pass |
| Intensity | 16 bit intensity values are recorded for each pulse | Pass |
| Classification | Required Classes include:<br>Class 1: Unclassified<br>Class 2: Ground<br>Class 7: Low Noise<br>Class 9: Water<br>Class 10: Ignored Ground<br>Class 17: Bridge Decks<br>Class 18: High Noise<br><br>Mendocino QL1 Additional Classes:<br>Class 3: Low Vegetation<br>Class 4 : Medium Vegetation<br>Class 5 : High Vegetation<br>Class 6: Buildings | Pass |
| Overlap and Withheld Points | Overlap (Overage) and Withheld points are set to the Overlap and Withheld bits | Pass |
| Scan Angle | Recorded for each pulse | Pass |
| XYZ Coordinates | Unique Easting Northing and Elevation coordinates are recorded for each pulse | Pass |

# Derivative Lidar Products

USGS required several derivative lidar products to be created. Each type of derived product is described below.

## DIGITAL SURFACE MODEL

Mendocino QL1 AOI required individually tiled 1 foot Digital Surface Models (DSM) be delivered. The DSM files were created from the first return point cloud excluding the noise classes: Class 7-Low Noise and Class 18- High Noise. The DSM files were delivered in 32-bit floating .IMG format.

# Lidar Positional Accuracy

## BACKGROUND

Dewberry quantitatively tested the dataset by testing the vertical accuracy of the lidar. The vertical accuracy is tested by comparing the discreet measurement of the survey checkpoints to that of the interpolated value within the three closest lidar points that constitute the vertices of a three-dimensional triangular face of the TIN. Therefore the end result is that only a small sample of the lidar data is actually tested. However there is an increased level of confidence with lidar data due to the relative accuracy. This relative accuracy in turn is based on how well one lidar point "fits" in comparison to the next contiguous lidar measurement and is verified as part of the initial processing. If the relative accuracy of a dataset is within specifications and the dataset passes vertical accuracy requirements at the location of survey checkpoints the vertical accuracy results can be applied to the whole dataset with high confidence due to the passing relative accuracy. Dewberry typically uses LP360 software to test the swath lidar vertical accuracy Terrascan software to test the classified lidar vertical accuracy and Esri ArcMap to test the DEM vertical accuracy so that three different software programs are used to validate the vertical accuracy for each project.

Dewberry also tests the horizontal accuracy of lidar datasets when checkpoints are photo-identifiable in the intensity imagery. Photo-identifiable checkpoints in intensity imagery typically include checkpoints located at the ends of paint stripes on concrete or asphalt surfaces or checkpoints located at 90 degree corners of different reflectivity e.g. a sidewalk corner adjoining a grass surface. The XY coordinates of checkpoints as defined in the intensity imagery are compared to surveyed XY coordinates for each photo-identifiable checkpoint. These differences are used to compute the tested horizontal accuracy of the lidar. As not all projects contain photo-identifiable checkpoints the horizontal accuracy of the lidar cannot always be tested.

## SURVEY VERTICAL ACCURACY CHECKPOINTS

For the vertical accuracy assessment one hundred seventy nine (179) check points were surveyed for the project and are located within bare earth/open terrain grass/weeds/crops and forested/fully grown land cover categories. Please see the survey deliverables to view the survey report which details and validates how the survey was completed for this project.

Checkpoints were evenly distributed throughout the project area so as to cover as many flight lines as possible using the “dispersed method” of placement.

All checkpoints surveyed for vertical accuracy testing purposes are listed in the following table.

| Point ID | NAD83(2011) State Plane CA Zone 1 and 2 | | NAVD88 (Geoid 12B) |
|---|---|---|---|
| | Easting X (ft) | Northing Y (ft) | Elevation (ft) |
| NVA-43 | 7128464.86 | 1943734.96 | 7525.56 |
| NVA-95 | 7115034.68 | 1930134.05 | 6930.33 |
| NVA-47 | 6571039.54 | 2442723.31 | 207.13 |
| NVA-48 | 6605370.80 | 2429850.04 | 430.06 |
| NVA-49 | 6597363.51 | 2407519.83 | 174.89 |
| NVA-101 | 6595370.52 | 2395641.43 | 171.18 |

| | | | |
|---|---|---|---|
| NVA-50 | 6192300.37 | 2241785.06 | 1243.19 |
| NVA-51 | 6250799.99 | 2244952.04 | 966.92 |
| NVA-52 | 6249503.36 | 2226477.56 | 890.52 |
| NVA-53 | 6220173.20 | 2217276.33 | 767.72 |
| NVA-54 | 6204820.98 | 2222378.91 | 1119.69 |
| NVA-55 | 6218421.63 | 2198021.98 | 641.33 |
| NVA-56 | 6262759.63 | 2201962.34 | 1095.64 |
| NVA-57 | 6235798.64 | 2178873.05 | 817.10 |
| NVA-58 | 6219919.61 | 2172956.74 | 639.31 |
| NVA-59 | 6202643.65 | 2146667.32 | 2121.68 |
| NVA-60 | 6236239.91 | 2144973.34 | 577.11 |
| NVA-61 | 6280631.92 | 2123271.12 | 2341.18 |
| NVA-62 | 6226861.37 | 2126115.55 | 607.33 |
| NVA-63 | 6235484.54 | 2086286.63 | 783.52 |
| NVA-64 | 6266443.08 | 2075809.63 | 377.37 |
| NVA-96 | 6243475.69 | 2129281.29 | 517.44 |
| NVA-97 | 6248351.78 | 2258955.76 | 1283.33 |
| NVA-65 | 6058833.18 | 2349111.46 | 112.61 |
| NVA-66 | 6132740.06 | 2334910.12 | 2775.29 |
| NVA-67 | 6152576.03 | 2272565.46 | 1901.08 |
| NVA-68 | 6058395.73 | 2310068.07 | 86.97 |
| NVA-69 | 6051018.92 | 2285265.58 | 111.69 |
| NVA-70 | 6051829.52 | 2242884.24 | 131.00 |
| NVA-71 | 6105210.57 | 2259004.26 | 323.32 |
| NVA-72 | 6121452.24 | 2258300.94 | 342.28 |
| NVA-73 | 6171270.47 | 2262965.93 | 1628.71 |
| NVA-74 | 6180210.14 | 2212764.07 | 1734.78 |
| NVA-75 | 6111152.70 | 2226285.66 | 192.96 |
| NVA-76 | 6054815.30 | 2230888.48 | 14.68 |
| NVA-77 | 6063363.05 | 2200661.48 | 10.88 |
| NVA-78 | 6112951.10 | 2188616.20 | 90.11 |
| NVA-79 | 6154134.20 | 2201137.03 | 1369.31 |
| NVA-80 | 6194462.50 | 2137732.39 | 1575.01 |
| NVA-81 | 6142043.34 | 2162344.19 | 238.23 |
| NVA-82 | 6082201.99 | 2153556.93 | 294.50 |
| NVA-83 | 6082149.31 | 2123334.28 | 108.87 |
| NVA-84 | 6143913.76 | 2123011.88 | 1608.67 |
| NVA-85 | 6173176.97 | 2132200.25 | 395.78 |
| NVA-86 | 6186190.11 | 2108417.74 | 691.21 |
| NVA-87 | 6122750.70 | 2091874.73 | 2340.67 |
| NVA-88 | 6091480.92 | 2078092.80 | 124.18 |
| NVA-89 | 6112069.59 | 2058208.19 | 113.87 |
| NVA-90 | 6157688.48 | 2082261.97 | 1467.26 |
| NVA-91 | 6152837.29 | 2075565.54 | 1683.99 |
| NVA-92 | 6125837.86 | 2044612.68 | 65.92 |
| NVA-93 | 6075466.13 | 2105401.19 | 170.16 |
| NVA-94 | 6076409.90 | 2177650.39 | 186.43 |

| | | | |
|---|---|---|---|
| NVA-98 | 6167969.55 | 2139953.45 | 346.23 |
| NVA-99 | 6139176.36 | 2282057.70 | 432.70 |
| NVA-100 | 6162496.55 | 2087996.65 | 1828.56 |
| NVA-44 | 6496457.45 | 2100404.39 | 493.44 |
| NVA-45 | 6519656.93 | 2078115.84 | 580.60 |
| NVA-46 | 6507518.74 | 2124112.44 | 584.99 |
| NVA-102 | 6508173.04 | 2090316.47 | 485.41 |
| NVA-01 | 6999171.21 | 2493594.38 | 4747.35 |
| NVA-02 | 7005399.83 | 2503237.99 | 4818.27 |
| NVA-03 | 7011293.69 | 2475237.66 | 5157.80 |
| NVA-04 | 7009668.68 | 2454748.60 | 5254.13 |
| NVA-05 | 6961747.65 | 2461122.79 | 4903.37 |
| NVA-06 | 6983289.15 | 2448085.38 | 4467.98 |
| NVA-07 | 6917622.71 | 2429095.32 | 4360.35 |
| NVA-08 | 6849778.08 | 2433574.34 | 4971.52 |
| NVA-09 | 6844049.16 | 2427798.02 | 4777.15 |
| NVA-10 | 6892351.77 | 2415868.32 | 4325.68 |
| NVA-11 | 6931791.84 | 2411957.02 | 4438.87 |
| NVA-12 | 6961229.13 | 2427913.61 | 4370.28 |
| NVA-13 | 7016089.85 | 2414960.23 | 5337.06 |
| NVA-14 | 7026225.69 | 2398829.79 | 6454.67 |
| NVA-15 | 6985006.70 | 2409837.84 | 4512.06 |
| NVA-16 | 6961815.81 | 2394190.65 | 4414.60 |
| NVA-17 | 6924137.54 | 2400086.69 | 4407.86 |
| NVA-18 | 6893633.10 | 2400813.39 | 4322.18 |
| NVA-19 | 6854943.31 | 2395982.18 | 4296.70 |
| NVA-20 | 6822066.59 | 2383759.61 | 4264.94 |
| NVA-21 | 6798007.96 | 2369621.84 | 4281.52 |
| NVA-22 | 6849995.12 | 2380876.72 | 4711.28 |
| NVA-23 | 6871784.43 | 2411590.43 | 4314.82 |
| NVA-24 | 6926867.00 | 2384062.95 | 4410.88 |
| NVA-25 | 6971689.65 | 2366651.18 | 4421.24 |
| NVA-26 | 6967627.24 | 2380187.27 | 4397.26 |
| NVA-27 | 7027467.42 | 2349273.97 | 5236.81 |
| NVA-28 | 7002904.77 | 2337060.76 | 4751.68 |
| NVA-29 | 6973190.96 | 2334989.11 | 4452.27 |
| NVA-30 | 6905471.24 | 2352710.75 | 5640.00 |
| NVA-31 | 6864779.03 | 2344531.84 | 4372.05 |
| NVA-32 | 6822193.30 | 2326205.70 | 4177.72 |
| NVA-33 | 6798381.75 | 2324026.30 | 4149.68 |
| NVA-34 | 6772763.96 | 2341813.64 | 4241.60 |
| NVA-35 | 6755150.89 | 2323095.44 | 4416.41 |
| NVA-36 | 6774348.30 | 2321028.33 | 4418.36 |
| NVA-37 | 6799514.70 | 2292923.59 | 4132.03 |
| NVA-38 | 6852174.31 | 2318408.14 | 4210.50 |
| NVA-39 | 6858831.54 | 2290723.47 | 4449.68 |
| NVA-40 | 6844451.60 | 2259698.25 | 5251.93 |

| | | | |
|---|---|---|---|
| NVA-41 | 6808580.09 | 2260196.08 | 4157.65 |
| NVA-42 | 6786999.57 | 2283544.49 | 4120.97 |
| VVA-37 | 7136700.24 | 1943935.32 | 7331.10 |
| VVA-38 | 7121400.10 | 1941422.04 | 7284.62 |
| VVA-41 | 6614406.35 | 2435032.06 | 660.63 |
| VVA-42 | 6580355.72 | 2408288.43 | 152.27 |
| VVA-79 | 6609248.87 | 2408759.61 | 216.90 |
| VVA-81 | 6586371.79 | 2416312.16 | 173.35 |
| VVA-25 | 6232714.34 | 2258619.51 | 1061.85 |
| VVA-26 | 6215709.62 | 2244783.58 | 812.02 |
| VVA-27 | 6183842.55 | 2248625.88 | 2102.20 |
| VVA-28 | 6210827.54 | 2221711.01 | 741.29 |
| VVA-29 | 6256037.49 | 2206332.31 | 1005.47 |
| VVA-30 | 6262132.59 | 2236770.06 | 1108.93 |
| VVA-31 | 6227353.21 | 2186539.87 | 672.93 |
| VVA-32 | 6203744.05 | 2198479.57 | 1737.54 |
| VVA-33 | 6200016.56 | 2180049.26 | 1819.93 |
| VVA-34 | 6232399.53 | 2156594.55 | 558.05 |
| VVA-35 | 6217591.69 | 2138194.84 | 2456.27 |
| VVA-36 | 6261221.77 | 2096678.75 | 480.53 |
| VVA-75 | 6252143.82 | 2097015.45 | 930.44 |
| VVA-76 | 6203520.24 | 2230460.09 | 896.01 |
| VVA-01 | 6075049.23 | 2313231.49 | 171.29 |
| VVA-02 | 6141866.37 | 2323839.89 | 2262.59 |
| VVA-03 | 6077053.89 | 2276254.32 | 475.21 |
| VVA-04 | 6143131.02 | 2268293.57 | 1417.88 |
| VVA-05 | 6094736.85 | 2236756.77 | 410.12 |
| VVA-06 | 6146414.23 | 2212801.89 | 533.29 |
| VVA-07 | 6085004.31 | 2212484.40 | 775.91 |
| VVA-08 | 6101158.15 | 2178373.62 | 919.09 |
| VVA-09 | 6154240.74 | 2154986.87 | 316.54 |
| VVA-10 | 6086242.98 | 2140647.29 | 824.35 |
| VVA-11 | 6168408.76 | 2139557.87 | 348.10 |
| VVA-12 | 6129608.05 | 2116590.05 | 1451.90 |
| VVA-13 | 6178038.40 | 2121200.67 | 632.32 |
| VVA-14 | 6094442.09 | 2100424.82 | 831.19 |
| VVA-15 | 6102386.05 | 2087859.40 | 1085.80 |
| VVA-16 | 6178874.31 | 2092663.14 | 1092.94 |
| VVA-17 | 6114998.96 | 2071145.72 | 1335.29 |
| VVA-18 | 6129446.64 | 2050752.02 | 688.66 |
| VVA-19 | 6212295.48 | 2093746.70 | 1102.12 |
| VVA-20 | 6093752.93 | 2261467.10 | 468.70 |
| VVA-21 | 6125708.37 | 2282585.17 | 377.55 |
| VVA-22 | 6076025.16 | 2337479.97 | 46.79 |
| VVA-23 | 6203975.31 | 2097133.24 | 863.36 |
| VVA-77 | 6071111.96 | 2331384.33 | 15.98 |
| VVA-78 | 6093373.93 | 2114120.42 | 448.72 |

| | | | |
|---|---|---|---|
| VVA-39 | 6494041.23 | 2141896.79 | 880.83 |
| VVA-80 | 6497710.87 | 2117678.56 | 580.39 |
| VVA-43 | 7005726.55 | 2492086.32 | 4792.49 |
| VVA-44 | 6992911.07 | 2467658.12 | 4568.75 |
| VVA-45 | 6965824.60 | 2451353.24 | 4516.85 |
| VVA-47 | 6997100.72 | 2425996.57 | 4657.71 |
| VVA-48 | 6935047.32 | 2437526.11 | 4932.60 |
| VVA-49 | 6853615.86 | 2438548.85 | 5113.55 |
| VVA-50 | 6860642.05 | 2416669.77 | 4352.98 |
| VVA-51 | 6913977.37 | 2414006.51 | 4326.22 |
| VVA-52 | 6955495.90 | 2414631.02 | 4422.59 |
| VVA-53 | 7023548.55 | 2408259.20 | 5848.72 |
| VVA-55 | 6970691.87 | 2371870.48 | 4423.28 |
| VVA-56 | 6945333.98 | 2381840.33 | 4539.54 |
| VVA-57 | 6912309.17 | 2384427.42 | 4406.56 |
| VVA-58 | 6850891.78 | 2388838.62 | 4623.88 |
| VVA-59 | 6820112.67 | 2403254.58 | 4771.67 |
| VVA-60 | 6792570.76 | 2374806.80 | 4418.19 |
| VVA-61 | 6863820.32 | 2363918.40 | 4743.96 |
| VVA-62 | 6903078.16 | 2367351.89 | 5463.57 |
| VVA-63 | 6956268.44 | 2355979.36 | 4406.98 |
| VVA-64 | 7014526.10 | 2366049.91 | 5751.86 |
| VVA-65 | 7018642.92 | 2337461.99 | 5039.41 |
| VVA-66 | 6967223.66 | 2349563.72 | 4414.62 |
| VVA-67 | 6894646.25 | 2324019.06 | 6413.72 |
| VVA-68 | 6858179.76 | 2331859.81 | 4230.96 |
| VVA-69 | 6799330.30 | 2351839.91 | 4209.73 |
| VVA-70 | 6772419.00 | 2326500.62 | 4270.18 |
| VVA-71 | 6824634.11 | 2302366.75 | 4160.71 |
| VVA-72 | 6867625.77 | 2277039.33 | 4509.69 |
| VVA-73 | 6827800.21 | 2262521.85 | 4731.08 |
| VVA-74 | 6776889.91 | 2295430.39 | 4237.13 |

**Table 20: California FEMA R9 surveyed accuracy checkpoints**

One hundred seventy nine checkpoints were surveyed for vertical accuracy testing. Three points had to be removed from the results. Two checkpoints NVA-73 and VVA-02 were outside the project boundary and VVA-35 had an incorrect survey resulting in the lidar being lower than the checkpoint. With these three points removed the amount of checkpoints used still exceeded the amount of checkpoints required for vertical accuracy testing.

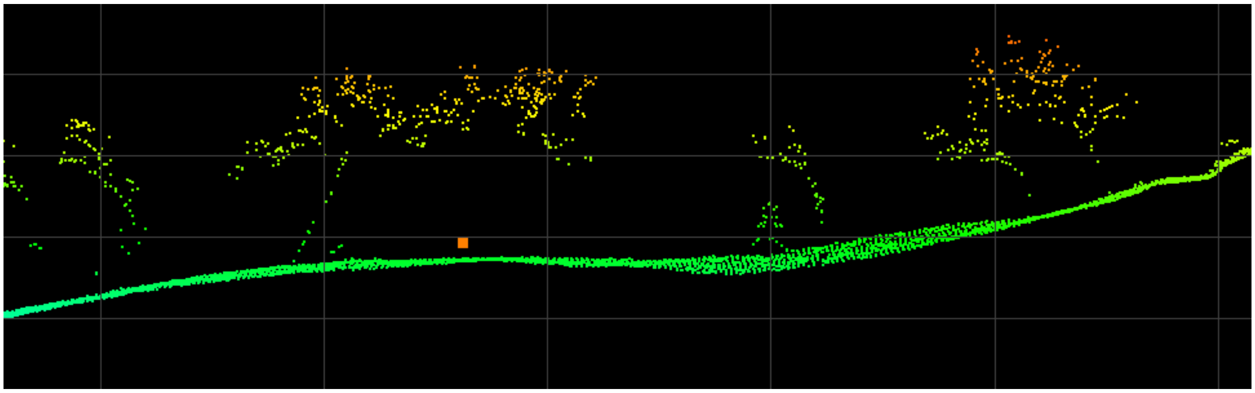

**Figure 24 – VVA-35 shown as the orange square in the profile is located 6+ feet above the actual ground surface. This checkpoint was removed from all vertical accuracy calculations due to incorrect survey.**

The figure below shows the location of the QA/QC checkpoints used to test the positional accuracy of the dataset.

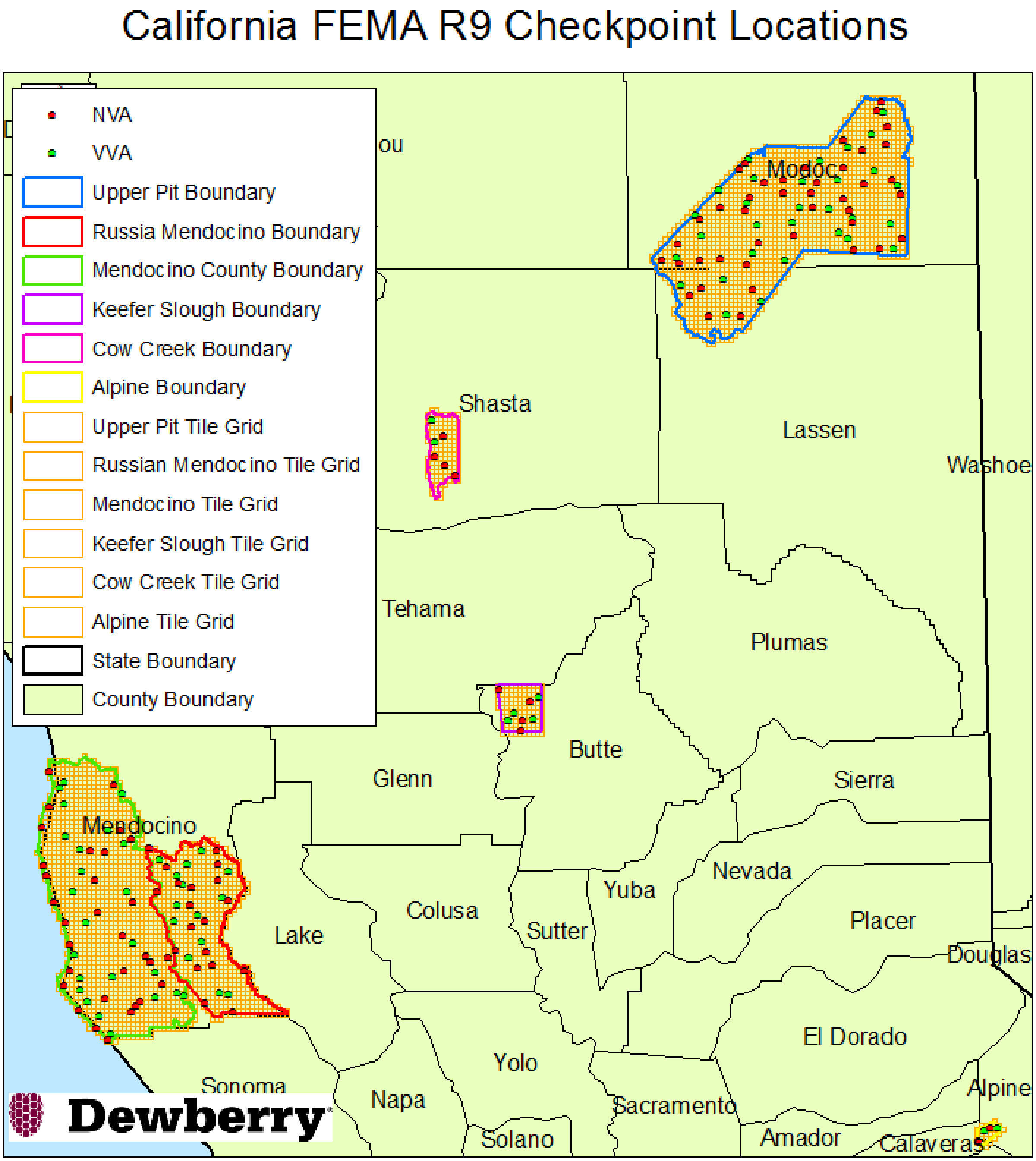


**Figure 25 – Location of QA/QC Checkpoints**

## VERTICAL ACCURACY TEST PROCEDURES

NVA (Non-vegetated Vertical Accuracy) is determined with check points located only in non-vegetated terrain including open terrain (grass dirt sand and/or rocks) and urban areas where there is a very high probability that the lidar sensor will have detected the bare-earth ground surface and where random errors are expected to follow a normal error distribution. The NVA determines how well the calibrated lidar sensor performed. With a normal error distribution the vertical accuracy at the 95% confidence level is computed as the vertical root mean square error ($RMSE_z$) of the checkpoints x 1.9600. For the California FEMA R9 Lidar project vertical accuracy must be 0.64 ft (19.6 cm) or less based on an $RMSE_z$ of 0.33 ft (10 cm) x 1.9600.

**VVA** (Vegetated Vertical Accuracy) is determined with all checkpoints in vegetated land cover categories including tall grass weeds crops brush and low trees and fully forested areas where there is a possibility that the lidar sensor and post-processing may yield elevation errors that do not follow a normal error distribution. VVA at the 95% confidence level equals the $95^{th}$ percentile error for all checkpoints in all vegetated land cover categories combined. The California FEMA R9 Lidar Project VVA standard is 0.96 ft (29.4 cm) based on the $95^{th}$ percentile. The VVA is accompanied by a listing of the 5% outliers that are larger than the $95^{th}$ percentile used to compute the VVA; these are always the largest outliers that may depart from a normal error distribution. Here $Accuracy_z$ differs from VVA because $Accuracy_z$ assumes elevation errors follow a normal error distribution where RMSE procedures are valid whereas VVA assumes lidar errors may not follow a normal error distribution in vegetated categories making the RMSE process invalid.

The relevant testing criteria are summarized in Table 21.

| Quantitative Criteria | Measure of Acceptability |
|---|---|
| Non-Vegetated Vertical Accuracy (NVA) in open terrain and urban land cover categories using $RMSE_z$ *1.9600 | 0.64 ft (based on $RMSE_z$ (0.33 ft) * 1.9600) |
| Vegetated Vertical Accuracy (VVA) in all vegetated land cover categories combined at the 95% confidence level | 0.96 ft (based on combined $95^{th}$ percentile) |

**Table 21 — Acceptance Criteria**

The primary QA/QC vertical accuracy testing steps used by Dewberry are summarized as follows:

1. Dewberry's team surveyed QA/QC vertical checkpoints in accordance with the project's specifications.
2. Next Dewberry interpolated the bare-earth lidar DTM to provide the z-value for every checkpoint.
3. Dewberry then computed the associated z-value differences between the interpolated z-value from the lidar data and the ground truth survey checkpoints and computed NVA VVA and other statistics.
4. The data were analyzed by Dewberry to assess the accuracy of the data. The review process examined the various accuracy parameters as defined by the scope of work. The overall descriptive statistics of each dataset were computed to assess any trends or anomalies. This report provides tables graphs and figures to summarize and illustrate data quality.

## VERTICAL ACCURACY RESULTS

The table below summarizes the tested vertical accuracy resulting from a comparison of the surveyed checkpoints to the elevation values present within the fully classified lidar LAS files.

| Land Cover Category | # of Points | NVA — Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=0.64 ft | VVA — Vegetated Vertical Accuracy (95th Percentile) Spec=0.96 ft |
|---|---|---|---|
| NVA | 101 | 0.46 | |

| | | | |
|---|---|---|---|
| VVA | 75 | | 0.77 |

Table 22 — Tested NVA and VVA

This lidar dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 0.33 ft (10 cm) RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ = 0.24 ft (7.3 cm) equating to +/- 0.46 ft (14 cm) at 95% confidence level. Actual VVA accuracy was found to be +/- 0.77 ft (23.5 cm) at the 95th percentile.

The figure below illustrates the magnitude of the differences between the QA/QC checkpoints and lidar data. This shows that the majority of lidar elevations were within +/- 0.25 ft of the checkpoints elevations but there were some outliers where lidar and checkpoint elevations differed by up to +2 feet.

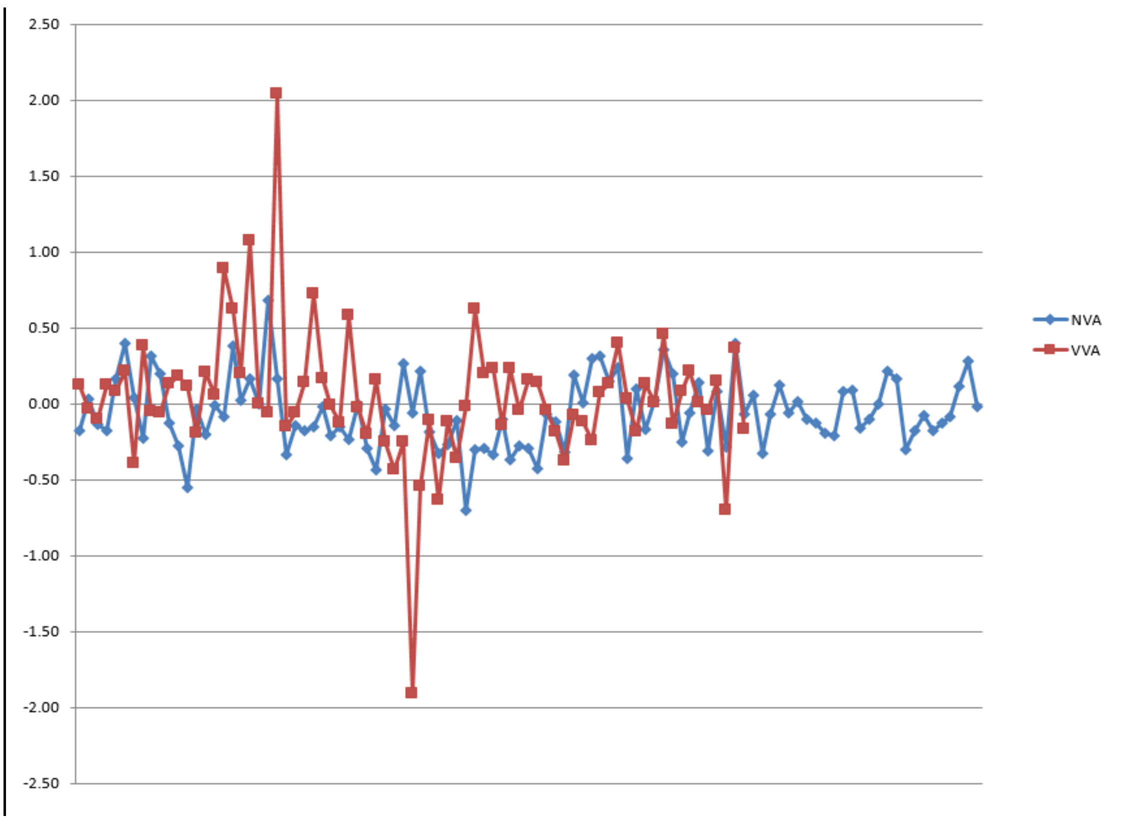


Figure 26 – Magnitude of elevation discrepancies per land cover category

Table 23 lists the 5% outliers that are larger than the VVA 95th percentile.

| Point ID | NAD83(2011) State Plane CA Zone 1 and 2 | | NAVD88 (Geoid 12B) | Lidar Z (ft) | Delta Z | AbsDeltaZ |
|---|---|---|---|---|---|---|
| | Easting X (ft) | Northing Y (ft) | Survey Z (ft) | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| VVA-36 | 6261221.77 | 2096678.75 | 480.53 | 481.42 | 0.89 | 0.886 |
| VVA-01 | 6075049.23 | 2313231.49 | 171.29 | 172.36 | 1.07 | 1.071 |
| VVA-05 | 6094736.85 | 2236756.77 | 410.12 | 412.16 | 2.04 | 2.04 |
| VVA-20 | 6093752.93 | 2261467.10 | 468.70 | 466.79 | -1.91 | 1.91 |

**Table 23 — 5% Outliers**

Table 24 provides overall descriptive statistics.

| 100 % of Totals | # of Points | RMSEz (ft) Spec=0.33 ft NVA | Mean (ft) | Median (ft) | Skew | Std Dev (ft) | Kurtosis | Min (ft) | Max (ft) |
|---|---|---|---|---|---|---|---|---|---|
| NVA | 101.00 | 0.24 | -0.06 | -0.08 | 0.33 | 0.23 | 0.48 | -0.70 | 0.68 |
| VVA | 75.00 | N/A | 0.04 | 0.00 | 0.29 | 0.45 | 9.11 | -1.91 | 2.04 |

**Table 24 — Overall Descriptive Statistics**

The figure below illustrates a histogram of the associated elevation discrepancies between the QA/QC checkpoints and elevations interpolated from the lidar triangulated irregular network (TIN). The frequency shows the number of discrepancies within each band of elevation differences. Although the discrepancies vary between a low of -1.91 feet and a high of +2.04 feet the histogram shows that the majority of the discrepancies are skewed on the positive side. The vast majority of points are within the ranges of -0.25 feet to +0.25 feet.

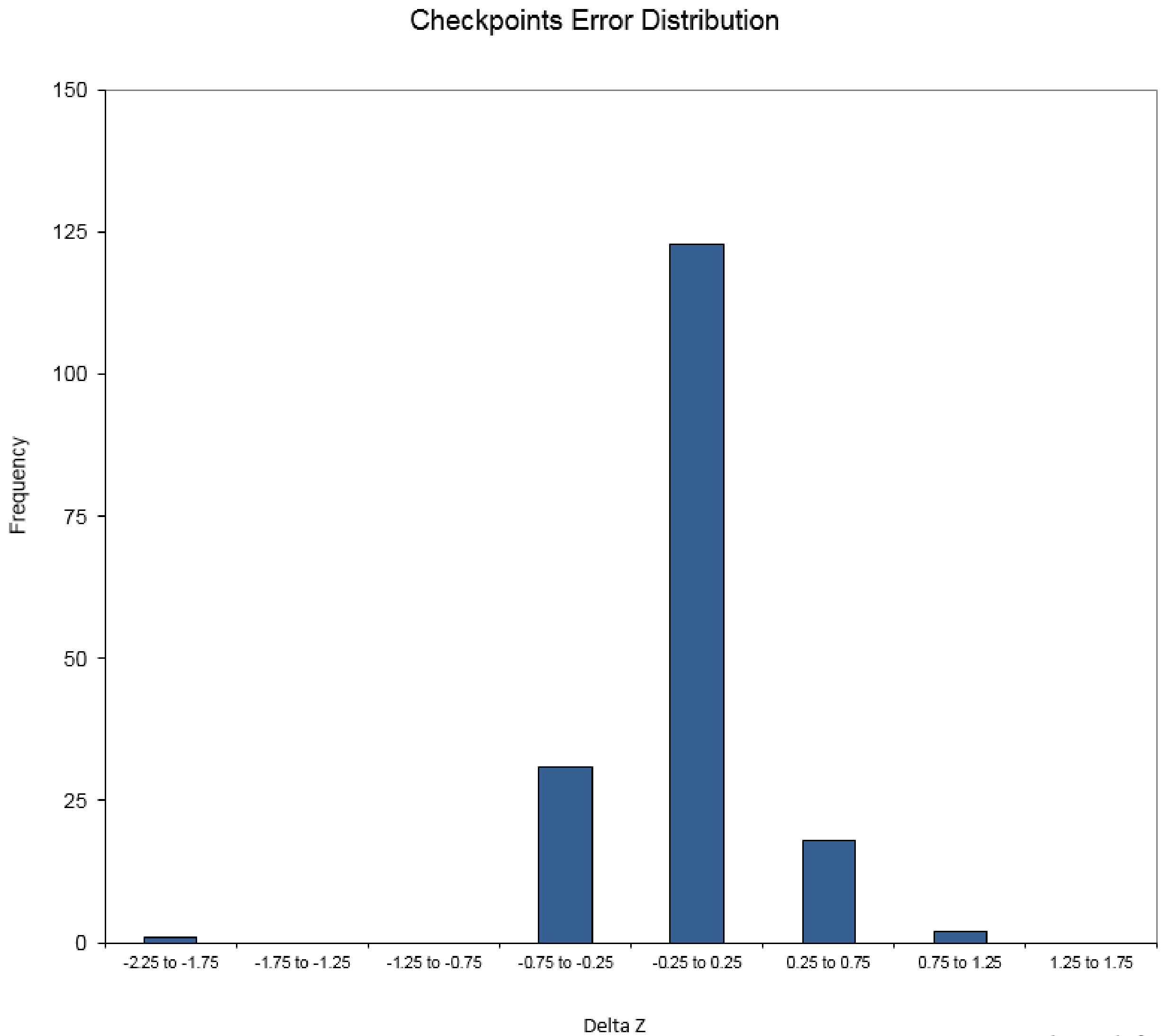


Figure 27 – Histogram of Elevation Discrepancies with errors in meters

**Based on the vertical accuracy testing conducted by Dewberry the lidar dataset for the California FEMA R9 Lidar Project satisfies the project's pre-defined vertical accuracy criteria.**

## HORIZONTAL ACCURACY TEST PROCEDURES

Horizontal accuracy testing requires well-defined checkpoints that can be identified in the dataset. Elevation datasets including lidar datasets do not always contain well-defined checkpoints suitable for horizontal accuracy assessment. However the ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) recommends at least half of the NVA vertical check points should be located at the ends of paint stripes or other point features visible on the lidar intensity image allowing them to double as horizontal check points.

Dewberry reviews all NVA checkpoints to determine which if any of these checkpoints are located on photo-identifiable features in the intensity imagery. This subset of checkpoints are then used for horizontal accuracy testing.

The primary QA/QC horizontal accuracy testing steps used by Dewberry are summarized as follows:

1. Dewberry's team surveyed QA/QC vertical checkpoints in accordance with the project's specifications and tried to locate half of the NVA checkpoints on features photo-identifiable in the intensity imagery.
2. Next Dewberry identified the well-defined features in the intensity imagery.
3. Dewberry then computed the associated xy-value differences between the coordinates of the well-defined feature in the lidar intensity imagery and the ground truth survey checkpoints.
4. The data were analyzed by Dewberry to assess the accuracy of the data. Horizontal accuracy was assessed using NSSDA methodology where horizontal accuracy is calculated at the 95% confidence level. This report provides the results of the horizontal accuracy testing.

## HORIZONTAL ACCURACY RESULTS

Five checkpoints were determined to be photo-identifiable in the intensity imagery and were used to test the horizontal accuracy of the lidar dataset. As only five (5) checkpoints were photo-identifiable the results are not statistically significant enough to report as a final tested value but the results of the testing are still shown in the Table below.

Using NSSDA methodology (endorsed by the ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014)) horizontal accuracy at the 95% confidence level (called ACCURACYr) is computed by the formula RMSEr * 1.7308 or RMSExy * 2.448.

No horizontal accuracy requirements or thresholds were provided for this project. However lidar datasets are generally calibrated by methods designed to ensure a horizontal accuracy of 1 meter (3.28 ft) or less at the 95% confidence level.

| # of Points | $RMSE_x$ (Target=1.34 ft) | $RMSE_y$ (Target=1.34 ft) | $RMSE_r$ (Target=1.9 ft) | $ACCURACY_r$ ($RMSE_r$ x 1.7308) Target=3.28 ft |
|---|---|---|---|---|
| 5 | 0.66 | 0.70 | 0.96 | 1.66 |

Table 25-Tested horizontal accuracy at the 95% confidence level

This data set was produced to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 1.35 ft (41 cm) RMSEx/RMSEy Horizontal Accuracy Class which equates to Positional Horizontal Accuracy = +/- 3.28 ft (1 meter) at a 95% confidence level. Five (5) checkpoints were photo-identifiable but do not produce a statistically significant tested horizontal accuracy value. Using this small sample set of photo-identifiable checkpoints positional accuracy of this dataset was found to be RMSEx = 0.66 ft (20.1 cm) and RMSEy = 0.70 ft (21.3 cm) which equates to +/- 1.66 ft (50.6 cm) at 95% confidence level. While not statistically significant the results of the small sample set of checkpoints are within the produced to meet horizontal accuracy.

# Breakline Production & Qualitative Assessment Report

## BREAKLINE PRODUCTION METHODOLOGY

Dewberry used GeoCue software to develop lidar stereo models of the project area so the lidar derived data could be viewed in 3-D stereo using Socet Set softcopy photogrammetric software. Using lidargrammetry procedures with lidar intensity imagery Dewberry used the stereo models to stereo-compile the Lakes and Ponds and Rivers and Streams in accordance with the project's Data Dictionary. Kinetics used LP360 and intensity imagery to collect the Lakes and Ponds, Rivers and Streams, and Tidal in accordance with the project's Data Dictionary.

All drainage breaklines are monotonically enforced to show downhill flow. Water bodies are at a constant elevation where the lowest elevation of the water body has been applied to the entire water body.

## BREAKLINE QUALITATIVE ASSESSMENT

Dewberry completed breakline qualitative assessments according to a defined workflow. The following workflow diagram represents the steps taken by Dewberry to provide a thorough qualitative assessment of the breakline data.

Completeness and horizontal placement is verified through visual reviews against lidar intensity imagery. Automated checks are applied on all breakline features to validate topology including the 3D connectivity of features enforced monotonicity on linear hydrographic breaklines and flatness on water bodies.

The next step is to compare the elevation of the breakline vertices against the ground elevation extracted from the ESRI Terrain built from the lidar ground points keeping in mind that a discrepancy is expected because of the hydro-enforcement applied to the breaklines and because of the interpolated imagery used to acquire the breaklines. A given tolerance is used to validate if the elevations differ too much from the lidar.

After all corrections and edits to the breakline features the breaklines are imported into the final GDB and verified for correct formatting.

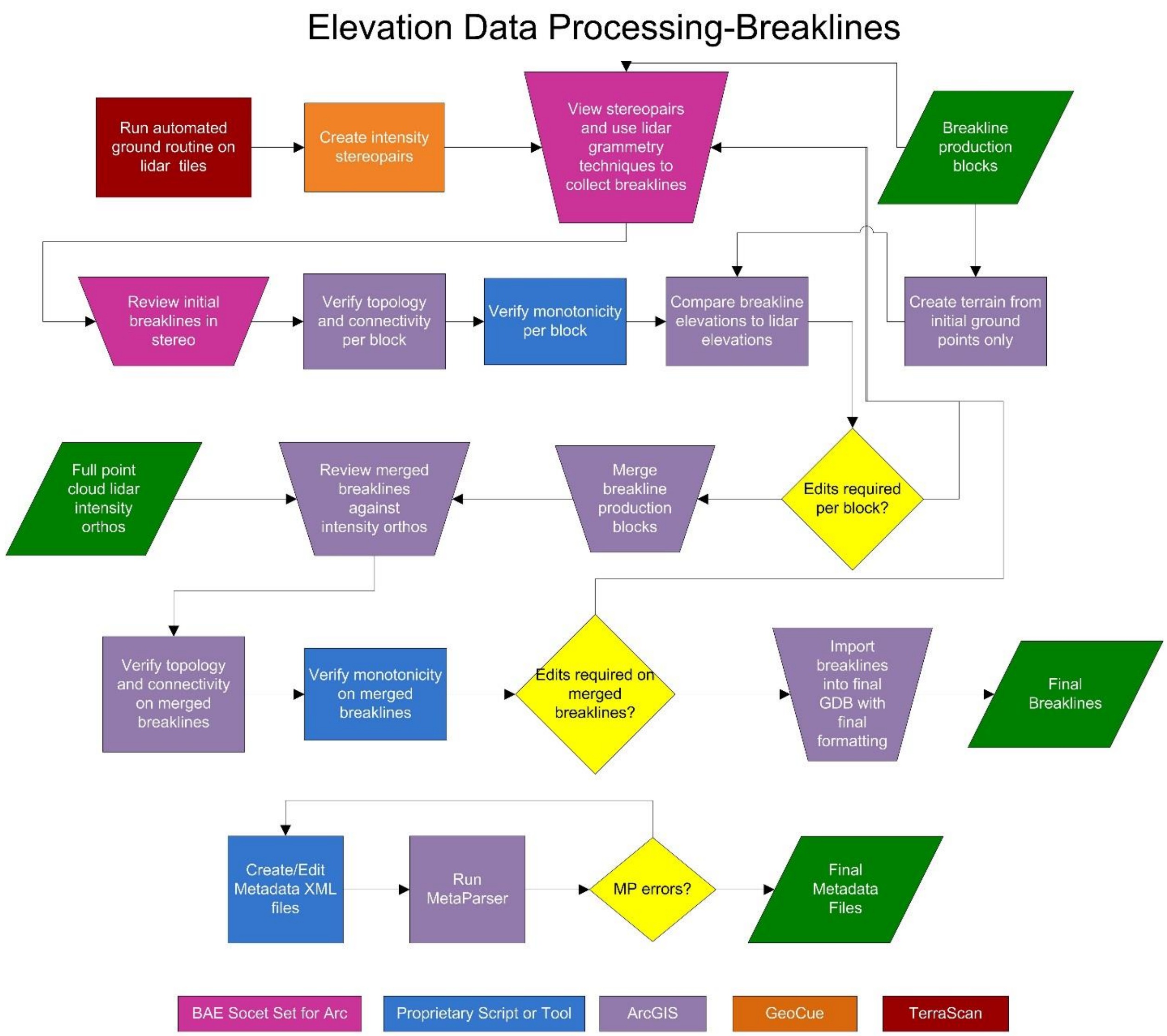


**Figure 28-Breakline QA/QC workflow**

## BREAKLINE CHECKLIST

The following table represents a portion of the high-level steps in Dewberry's Production and QA/QC checklist that were performed for this project.

| Pass/Fail | Validation Step |
|---|---|
| Pass | Use lidar-derived data which may include intensity imagery stereo pairs bare earth ground models density models slope models and terrains to collect breaklines according to project specifications. |
| Pass | In areas of heavy vegetation or where the exact shoreline is hard to delineate it is better to err on placing the breakline *slightly* inside or seaward of the shoreline (breakline can be inside shoreline by 1x-2x NPS). |

| | |
|---|---|
| Pass | After each producer finishes breakline collection for a block each producer must perform a completeness check breakline variance check and all automated checks on their block before calling that block complete and ready for the final merge and QC |
| Pass | After breaklines are completed for production blocks all production blocks should be merged together and completeness and automated checks should be performed on the final merged GDB. Ensure correct snapping-horizontal (xy) and vertical (z)-between all production blocks. |
| Pass | Check entire dataset for missing features that were not captured but should be to meet baseline specifications or for consistency. Features should be collected consistently across tile bounds. Check that the horizontal placement of breaklines is correct. Breaklines should be compared to full point cloud intensity imagery and terrains |
| Pass | Breaklines are correctly edge-matched to adjoining datasets in completion coding and horizontal placement. |
| Pass | Using a terrain created from lidar ground (all ground including 2 8 and 10) and water points (class 9) compare breakline Z values to interpolated lidar elevations. |
| Pass | Perform all Topology and Data Integrity Checks |
| Pass | Perform hydro-flattening and hydro-enforcement checks including monotonicity and flatness from bank to bank on linear hydrographic features and flatness of water bodies. Tidal waters should preserve as much ground as possible and can include variations or be non-monotonic. |

**Table 26-A subset of the high-level steps from Dewberry's Production and QA/QC checklist performed for this project.**

# DATA DICTIONARY

The following data dictionary was used for this project.

## Horizontal and Vertical Datum

The horizontal datum shall be North American Datum of 1983(2011) Units in US Survey Feet. The vertical datum shall be referenced to the North American Vertical Datum of 1988 (NAVD 88) Units in US Survey Feet. Geoid12B shall be used to convert ellipsoidal heights to orthometric heights.

## Coordinate System and Projection

All data shall be projected to California State Plane Zone 1 or Zone 2 Horizontal Units in US Survey Feet and Vertical Units in US Survey Feet.

## Inland Streams and Rivers

**Feature Dataset:** BREAKLINES
**Feature Type:** Polygon
**Contains Z Values:** Yes
**XY Resolution:** Accept Default Setting
**XY Tolerance:** 0.003

**Feature Class:** STREAMS_AND_RIVERS
**Contains M Values:** No
**Annotation Subclass:** None
**Z Resolution:** Accept Default Setting
**Z Tolerance:** 0.001

### Description

This polygon feature class will depict linear hydrographic features with a width greater than 100 feet.

### Table Definition

| Field Name | Data Type | Allow Null Values | Default Value | Domain | Precision | Scale | Length | Responsibility |
|---|---|---|---|---|---|---|---|---|
| OBJECTID | Object ID | | | | | | | Assigned by Software |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| SHAPE | Geometry | | | | | | | Assigned by Software |
| SHAPE_LENGTH | Double | Yes | | | 0 | 0 | | Calculated by Software |
| SHAPE_AREA | Double | Yes | | | 0 | 0 | | Calculated by Software |

### Feature Definition

| Description | Definition | Capture Rules |
|---|---|---|
| Streams and Rivers | Linear hydrographic features such as streams rivers canals etc. with an average width greater than 100 feet for FEMA Region IX AOIs and 20 feet for Mendocino QL1 AOI. In the case of embankments if the feature forms a natural dual line channel then capture it consistent with the capture rules. Other natural or manmade embankments will not qualify for this project. | Capture features showing dual line (one on each side of the feature). Each vertex placed should maintain vertical integrity. Generally both banks shall be collected to show consistent downhill flow. There are exceptions to this rule where a small branch or offshoot of the stream or river is present.<br><br>The banks of the stream must be captured at the same elevation to ensure flatness of the water feature. If the elevation of the banks appears to be different see the task manager or PM for further guidance.<br><br>Breaklines must be captured at or just below the elevations of the immediately surrounding terrain. Under no circumstances should a feature be elevated above the surrounding lidar points. Acceptable variance in the negative direction will be defined for each project individually.<br><br>These instructions are only for docks or piers that follow the coastline or water's edge not for docks or piers that extend perpendicular from the land into the water. If it can be reasonably determined where the edge of water most probably falls beneath the dock or pier then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water at the measured elevation of the water.<br><br>Every effort should be made to avoid breaking a stream or river into segments.<br><br>Dual line features shall break at road crossings (culverts) for FEMA Region IX AOIs and continue through road crossings (culverts) for Mendocino QL1 AOI. In areas where a bridge is present the dual line feature shall continue through the bridge.<br><br>Islands: The double line stream shall be captured around an island if the island is greater than 1 acre for FEMA Region IX AOIs and 1/4 acre for Mendocino QL1 AOI. In this case a segmented polygon shall be used around the island in order to allow for the island feature to remain as a "hole" in the feature. |

## Inland Ponds and Lakes

**Feature Dataset:** BREAKLINES
**Feature Type:** Polygon
**Contains Z Values:** Yes
**XY Resolution:** Accept Default Setting
**XY Tolerance:** 0.003

**Feature Class:** PONDS_AND_LAKES
**Contains M Values:** No
**Annotation Subclass:** None
**Z Resolution:** Accept Default Setting
**Z Tolerance:** 0.001

### Description

This polygon feature class will depict closed water body features that are at a constant elevation.

### Table Definition

| Field Name | Data Type | Allow Null Values | Default Value | Domain | Precision | Scale | Length | Responsibility |
|---|---|---|---|---|---|---|---|---|
| OBJECTID | Object ID | | | | | | | Assigned by Software |
| SHAPE | Geometry | | | | | | | Assigned by Software |
| SHAPE_LENGTH | Double | Yes | | | 0 | 0 | | Calculated by Software |
| SHAPE_AREA | Double | Yes | | | 0 | 0 | | Calculated by Software |

### Feature Definition

| Description | Definition | Capture Rules |
|---|---|---|
| Ponds and Lakes | Land/Water boundaries of constant elevation water bodies such as lakes reservoirs ponds etc. Features shall be defined as closed polygons and contain an elevation value that reflects the best estimate of the water elevation at the time of data capture. Water body features will be captured for features 2 acres in size or greater for FEMA Region IX AOIs and ½ acres in size or greater for Mendocino QL1 AOI.<br><br>“Donuts” will exist where there are islands within a closed water body feature. | Water bodies shall be captured as closed polygons with the water feature to the right. The compiler shall take care to ensure that the z-value remains consistent for all vertices placed on the water body.<br><br>Breaklines must be captured at or just below the elevations of the immediately surrounding terrain. Under no circumstances should a feature be elevated above the surrounding lidar points. Acceptable variance in the negative direction will be defined for each project individually.<br><br>An Island within a Closed Water Body Feature that is 1 acre in size or greater for FEMA Region IX AOIs and ¼ acre in size or greater for Mendocino QL1 will also have a “donut polygon” compiled.<br><br>These instructions are only for docks or piers that follow the coastline or water’s edge not for docks or piers that extend perpendicular from the land into the water. If it can be reasonably determined where the edge of water most probably falls beneath the dock or pier then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no |

| | | |
|---|---|---|
| | | clear indication of the location of the water's edge beneath the dock or pier then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water at the measured elevation of the water. |

## Tidal Waters

**Feature Dataset**: BREAKLINES
**Feature Type**: Polygon
**Contains Z Values**: Yes
**XY Resolution**: Accept Default Setting
**XY Tolerance**: 0.003

**Feature Class**: TIDAL_WATERS
**Contains M Values**: No
**Annotation Subclass**: None
**Z Resolution**: Accept Default Setting
**Z Tolerance**: 0.001

### Description

This polygon feature class will outline the land / water interface at the time of lidar acquisition.

### Table Definition

| Field Name | Data Type | Allow Null Values | Default Value | Domain | Precision | Scale | Length | Responsibility |
|---|---|---|---|---|---|---|---|---|
| OBJECTID | Object ID | | | | | | | Assigned by Software |
| SHAPE | Geometry | | | | | | | Assigned by Software |
| SHAPE_LENGTH | Double | Yes | | | 0 | 0 | | Calculated by Software |
| SHAPE_AREA | Double | Yes | | | 0 | 0 | | Calculated by Software |

### Feature Definition

| Description | Definition | Capture Rules |
|---|---|---|
| TIDAL_WATERS | The coastal breakline will delineate the land water interface using lidar data as reference. In flight line boundary areas with tidal variation the coastal shoreline may show stair stepping as no feathering is allowed. Stair stepping is allowed to show as much ground as the collected data permits. | The feature shall be extracted at the apparent land/water interface as determined by the lidar intensity data to the extent of the tile boundaries. Differences caused by tidal variation are acceptable and breaklines delineated should reflect that change with no feathering.<br><br>Breaklines must be captured at or just below the elevations of the immediately surrounding terrain. Under no circumstances should a feature be elevated above the surrounding lidar points. Acceptable variance in the negative direction will be defined for each project individually.<br><br>If it can be reasonably determined where the edge of water most probably falls beneath the dock or pier then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier then the edge of water will follow the outer edge of the dock |

| | | |
|---|---|---|
| | | or pier as it is adjacent to the water at the measured elevation of the water.<br><br>Breaklines shall snap and merge seamlessly with linear hydrographic features. |

## Beneath Bridge saddle breaklines

**Feature Dataset:** BREAKLINES
**Feature Type:** Polyline
**Contains Z Values:** Yes
**XY Resolution:** Accept Default Setting
**XY Tolerance:** 0.003

**Feature Class:** Bridge_Breaklines
**Contains M Values:** No
**Annotation Subclass:** None
**Z Resolution:** Accept Default Setting
**Z Tolerance:** 0.001

### Description

This polyline feature class is used to enforce terrain beneath bridge decks where ground data may not have been acquired. Enforcing the terrain beneath bridge decks prevents bridge saddles.

### Table Definition

| Field Name | Data Type | Allow Null Values | Default Value | Domain | Precision | Scale | Length | Responsibility |
|---|---|---|---|---|---|---|---|---|
| OBJECTID | Object ID | | | | | | | Assigned by Software |
| SHAPE | Geometry | | | | | | | Assigned by Software |
| SHAPE_LENGTH | Double | Yes | | | 0 | 0 | | Calculated by Software |

### Feature Definition

| Description | Definition | Capture Rules |
|---|---|---|
| Bridge saddle breaklines | Bridge saddle breaklines should be used where necessary to enforce terrain beneath bridge decks and to prevent bridge saddles in the bare earth DEMs. | Bridge saddle breaklines should be collected beneath bridges where bridge saddles exist or are likely to exist in the bare earth DEMs.<br><br>Bridge saddle breaklines should be collected perpendicular to the bridge deck so that the endpoints are on either side of the bridge deck. Typically two bridge saddle breaklines are collected per bridge deck one at either end of the bridge deck to enforce the terrain under the full bridge deck.<br><br>The endpoints of the bridge saddle breaklines will match the elevation of the ground at their xy position to enforce the ground/bare earth elevations beneath the bridge deck and prevent bridge saddles from forming. |

# DEM Production & Qualitative Assessment

## DEM PRODUCTION METHODOLOGY

Dewberry utilized ESRI software and Global Mapper for the DEM production and QC process. ArcGIS software is used to generate the products and the QC is performed in both ArcGIS and Global Mapper. The figure below shows the entire process necessary for bare earth DEM production starting from the lidar swath processing.

The final bare-earth lidar points are used to create a terrain. The final 3D breaklines collected for the project are also enforced in the terrain. The terrain is then converted to raster format using linear interpolation. For most projects a single terrain/DEM can be created for the whole project. For very large projects multiple terrains/DEMs may be created. The DEM(s) is reviewed for any issues requiring corrections including remaining lidar mis-classifications erroneous breakline elevations poor hydro-flattening or hydro-enforcement and processing artifacts. After corrections are applied the DEM(s) is then split into individual tiles following the project tiling scheme. The tiles are verified for final formatting and then loaded into Global Mapper to ensure no missing or corrupt tiles and to ensure seamlessness across tile boundaries.

The creation of first return DSMs follows a similar workflow as required for bare earth DEMs except that breaklines are not used to enforce the first return terrain. Additionally rather than ground only data the first return of all point classes except for noise-classes 7 and 18 are used to create the multipoint file and subsequent terrain. Review of the DSMs including looking for spikes divots or noise points not properly classified to the noise classes (classes 7 and 18) other lidar mis-classifications and processing artifacts. As breaklines are not used in DSMs, DSMs are not hydro-flattened or hydro-enforced. After corrections are applied the DSM is then split into individual tiles following the project tiling scheme. The tiles are verified for final formatting and then loaded into Global Mapper to ensure no missing or corrupt tiles and to ensure seamlessness across tile boundaries.


Figure 29-DEM Production Workflow

## DEM QUALITATIVE ASSESSMENT

Dewberry performed a comprehensive qualitative assessment of the bare earth DEM deliverables to ensure that all tiled DEM products were delivered with the proper extents were free of processing artifacts and contained the proper referencing information. This process was performed in ArcGIS software with the use of a tool set Dewberry has developed to verify that the raster extents match those of the tile grid and contain the correct projection information. The DEM data was reviewed at a scale of 1:5000 to review for artifacts caused by the DEM generation process and to review the hydro-flattened features. To perform this review Dewberry creates HillShade models and overlays a partially transparent colorized elevation model to review for these issues. All corrections are completed using Dewberry's proprietary correction workflow. Upon completion of the corrections the DEM data is loaded into Global Mapper for its second review and to verify corrections. Once the DEMs are tiled out the final tiles are again loaded into Global Mapper to ensure coverage extents and that the final tiles are seamless.

The images below show an example of a bare earth DEM.

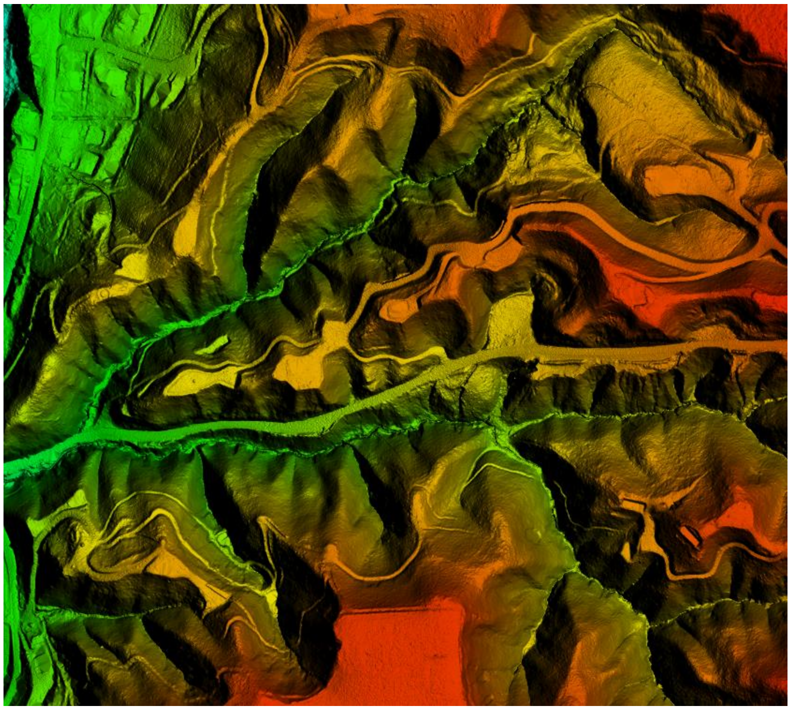

**Figure 30-Tile 10SDJ822417. The bare earth DEM is shown in the image above.**

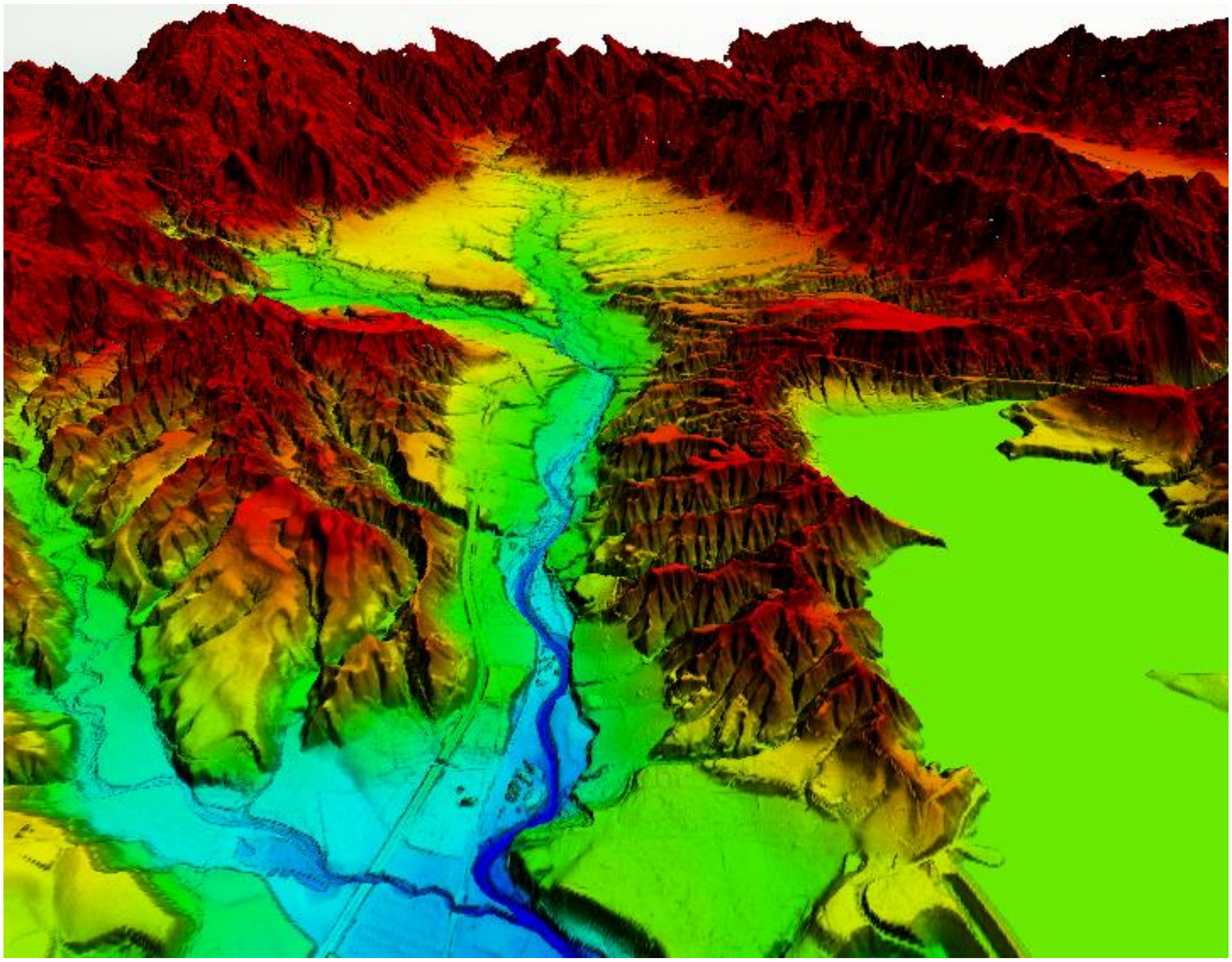

**Figure 31-Tile 10SDJ822417. 3D Profile view of the bare earth DEM**

When some bridges are removed from the ground surface the distance from bridge abutment to bridge abutment is small enough that the DEM interpolates across the entire bridge opening forming 'bridge saddles.' Dewberry collected 3D Bridge saddle breaklines in locations where bridge saddles were present and enforced these breaklines in the final DEM creation to help mitigate the bridge saddle artifacts. The image below on the left shows a bridge saddle while the image below on the right shows the same bridge after Bridge saddle breaklines have been enforced.

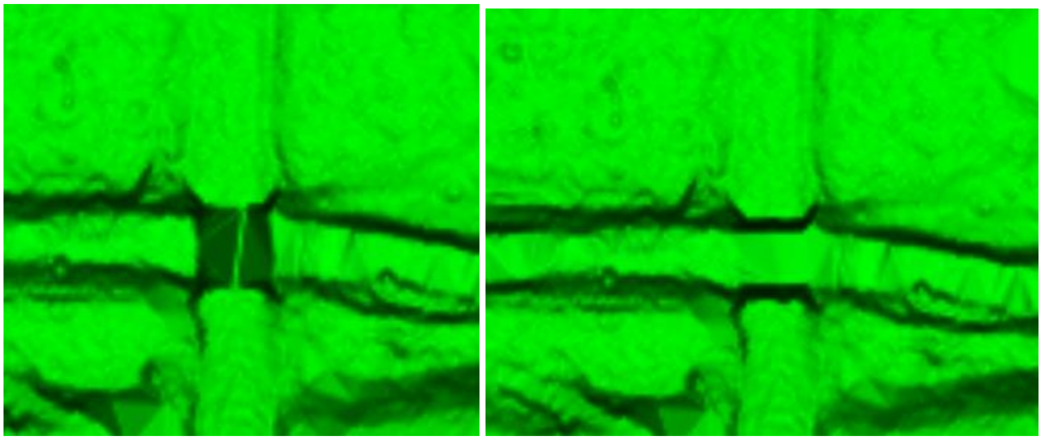

**Figure 32- DEM on the left shows a bridge saddle artifact while the DEM on the right shows the same location after Bridge saddle breaklines have been enforced.**

## DEM VERTICAL ACCURACY RESULTS

The same 176 checkpoints that were used to test the vertical accuracy of the lidar were used to validate the vertical accuracy of the final DEM products as well. Accuracy results may vary between the source lidar and final DEM deliverable. DEMs are created by averaging several lidar points within each pixel which may result in slightly different elevation values at each survey checkpoint when compared to the source LAS which does not average several lidar points together but may interpolate (linearly) between two or three points to derive an elevation value. The vertical accuracy of the DEM is tested by extracting the elevation of the pixel that contains the x/y coordinates of the checkpoint and comparing these DEM elevations to the surveyed elevations. Dewberry typically uses LP360 software to test the swath lidar vertical accuracy Terrascan software to test the classified lidar vertical accuracy and Esri ArcMap to test the DEM vertical accuracy so that three different software programs are used to validate the vertical accuracy for each project.

Table 27 summarizes the tested vertical accuracy results from a comparison of the surveyed checkpoints to the elevation values present within the final DEM dataset.

| Land Cover Category | # of Points | NVA – Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=0.64 ft | VVA – Vegetated Vertical Accuracy (95th Percentile) Spec=0.96 ft |
|---|---|---|---|
| NVA | 101 | 0.46 | |
| VVA | 75 | | 0.89 |

**Table 27 – DEM tested NVA and VVA**

This DEM dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a (0.33 ft) 10 cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ = 0.23 ft (7 cm) equating to +/- 0.46 (14 cm) at 95% confidence level. Actual VVA accuracy was found to be +/- 0.89 ft (27.1 cm) at the 95th percentile.

Table 28 lists the 5% outliers that are larger than the VVA 95$^{th}$ percentile.

| Point ID | NAD83(2011) State Plane CA Zone 1 and 2 | | NAVD88 (Geoid 12B) | DEM Z (ft) | Delta Z | AbsDeltaZ |
|---|---|---|---|---|---|---|
| | Easting X (ft) | Northing Y (ft) | Survey Z (ft) | | | |
| VVA-05 | 6094736.85 | 2236756.77 | 410.12 | 412.16 | 2.04 | 2.038081 |
| VVA-09 | 6154240.74 | 2154986.87 | 316.54 | 317.44 | 0.90 | 0.902778 |
| VVA-20 | 6093752.93 | 2261467.10 | 468.70 | 466.79 | -1.91 | 1.911849 |
| VVA-01 | 6075049.23 | 2313231.49 | 171.29 | 172.39 | 1.10 | 1.100151 |

Table 28 — 5% Outliers

Table 29 provides overall descriptive statistics.

| 100 % of Totals | # of Points | RMSEz (ft) Spec=0.33 ft | Mean (ft) | Median (ft) | Skew | Std Dev (ft) | Kurtosis | Min (ft) | Max (ft) |
|---|---|---|---|---|---|---|---|---|---|
| NVA | 101.00 | 0.23 | -0.06 | -0.10 | 0.38 | 0.23 | 0.44 | -0.69 | 0.68 |
| VVA | 75.00 | N/A | 0.04 | 0.01 | 0.31 | 0.45 | 8.87 | -1.91 | 2.04 |

Table 29 — Overall Descriptive Statistics

**Based on the vertical accuracy testing conducted by Dewberry the DEM dataset for the California FEMA R9 satisfies the project's pre-defined vertical accuracy criteria.**

## DEM CHECKLIST

The following table represents a portion of the high-level steps in Dewberry's bare earth DEM Production and QA/QC checklist that were performed for this project.

| Pass/Fail | Validation Step |
|---|---|
| Pass | Masspoints (LAS to multipoint) are created from ground points only (class 2 and class 8 if model key points created but no class 10 ignored ground points or class 9 water points |
| Pass | Create a terrain for each production block using the final bare earth lidar points and final breaklines. |
| Pass | Convert terrains to rasters using project specifications for grid type formatting and cell size |
| Pass | Create hillshades for all DEMs |
| Pass | Manually review bare-earth DEMs in ArcMap with hillshades to check for issues |
| Pass | DEMs should be hydro-flattened or hydro-enforced as required by project specifications |
| Pass | DEMs should be seamless across tile boundaries |
| Pass | Water should be flowing downhill without excessive water artifacts present |
| Pass | Water features should NOT be floating above surrounding |
| Pass | Bridges should NOT be present in bare-earth DEMs. |
| Pass | Any remaining bridge saddles where below Bridge saddle breaklines were not used need to be fixed by adding below Bridge saddle breaklines and re-processing. |

| | |
|---|---|
| Pass | All qualitative issues present in the DEMs as a result of lidar processing and editing issues must be marked for corrections in the lidar These DEMs will need to be recreated after the lidar has been corrected. |
| Pass | Calculate DEM Vertical Accuracy including NVA VVA and other statistics |
| Pass | Split the DEMs into tiles according to the project tiling scheme |
| Pass | Verify all properties of the tiled DEMs including coordinate reference system information cell size cell extents and that compression has not been applied to the tiled DEMs |
| Pass | Load all tiled DEMs into Global Mapper to verify complete coverage to the (buffered) project boundary and that no tiles are corrupt. |

**Table 30-A subset of the high-level steps from Dewberry's bare earth DEM Production and QA/QC checklist performed for this project.**

## Appendix A: Complete List of Delivered Tiles

| | | | | |
|---|---|---|---|---|
| 10SGH559562 | 10TFL989778 | 10TFL597423 | 10SDJ528779 | 10SDJ702232 |
| 10SGH574563 | 10TGL004778 | 10TFL612423 | 10SDJ543779 | 10SDJ717233 |
| 10SGH543577 | 10TGL020779 | 10TFL628424 | 10SDJ559779 | 10SDJ732233 |
| 10SGH559578 | 10TGL035779 | 10TFL643424 | 10SDJ330792 | 10SDJ747233 |
| 10SGH574578 | 10TGL050779 | 10TFL658424 | 10SDJ345792 | 10SDJ382244 |
| 10SGH589578 | 10TGL065779 | 10TFL673424 | 10SDJ360792 | 10SDJ397244 |
| 10SGH543593 | 10TGL081779 | 10TFL688424 | 10SDJ376793 | 10SDJ412244 |
| 10SGH558593 | 10TGL096780 | 10TFL704424 | 10SDJ391793 | 10SDJ427245 |
| 10SGH574593 | 10TGL111780 | 10TFL719425 | 10SDJ406793 | 10SDJ443245 |
| 10SGH589593 | 10TGL126780 | 10TFL734425 | 10SDJ421793 | 10SDJ458245 |
| 10SGH604593 | 10TGL142780 | 10TFL460437 | 10SDJ437793 | 10SDJ473245 |
| 10SGH543608 | 10TGL157780 | 10TFL475437 | 10SDJ452793 | 10SDJ488245 |
| 10SGH558608 | 10TGL172780 | 10TFL490437 | 10SDJ467794 | 10SDJ503245 |
| 10SGH574608 | 10TGL187781 | 10TFL505437 | 10SDJ482794 | 10SDJ519246 |
| 10SGH589608 | 10TGL203781 | 10TFL521438 | 10SDJ497794 | 10SDJ534246 |
| 10SGH604609 | 10TGL218781 | 10TFL536438 | 10SDJ513794 | 10SDJ549246 |
| 11SGH619609 | 10TGL233781 | 10TFL551438 | 10SDJ528794 | 10SDJ564246 |
| 10SGH543623 | 10TGL248781 | 10TFL566438 | 10SDJ543794 | 10SDJ580246 |
| 10SGH558623 | 10TGL264782 | 10TFL582438 | 10SDJ558795 | 10SDJ595246 |
| 10SGH573624 | 10TFL517788 | 10TFL597438 | 10SDJ314807 | 10SDJ610247 |
| 10SGH589624 | 10TFL532788 | 10TFL612439 | 10SDJ330807 | 10SDJ625247 |
| 10SGH604624 | 10TFL547788 | 10TFL627439 | 10SDJ345807 | 10SDJ641247 |
| 11SGH619624 | 10TFL562789 | 10TFL643439 | 10SDJ360808 | 10SDJ656247 |
| 11SGH634624 | 10TFL578789 | 10TFL658439 | 10SDJ375808 | 10SDJ671247 |
| 10SGH558639 | 10TFL593789 | 10TFL673439 | 10SDJ391808 | 10SDJ686247 |
| 10SGH573639 | 10TFL608789 | 10TFL688439 | 10SDJ406808 | 10SDJ702248 |
| 10SGH588639 | 10TFL623789 | 10TFL704440 | 10SDJ421808 | 10SDJ717248 |
| 10SGH604639 | 10TFL639789 | 10TFL719440 | 10SDJ436808 | 10SDJ732248 |
| 11SGH619639 | 10TFL654790 | 10TFL734440 | 10SDJ452809 | 10SDJ747248 |
| 10SGH604654 | 10TFL669790 | 10TFL749440 | 10SDJ467809 | 10SDJ381259 |
| 10TEK644788 | 10TFL684790 | 10TFL460452 | 10SDJ482809 | 10SDJ397259 |
| 10TEK659788 | 10TFL699790 | 10TFL475452 | 10SDJ497809 | 10SDJ412260 |
| 10TEK629803 | 10TFL715790 | 10TFL490452 | 10SDJ513809 | 10SDJ427260 |
| 10TEK644803 | 10TFL730791 | 10TFL505453 | 10SDJ528809 | 10SDJ442260 |
| 10TEK659803 | 10TFL745791 | 10TFL521453 | 10SDJ543810 | 10SDJ458260 |
| 10TEK629818 | 10TFL760791 | 10TFL536453 | 10SDJ314822 | 10SDJ473260 |
| 10TEK644818 | 10TFL776791 | 10TFL551453 | 10SDJ330822 | 10SDJ488260 |
| 10TEK659818 | 10TFL791791 | 10TFL566453 | 10SDJ345823 | 10SDJ503261 |
| 10TEK628833 | 10TFL806791 | 10TFL581453 | 10SDJ360823 | 10SDJ519261 |

| | | | | |
|---|---|---|---|---|
| 10TEK644833 | 10TFL821792 | 10TFL597454 | 10SDJ375823 | 10SDJ534261 |
| 10TEK659833 | 10TFL837792 | 10TFL612454 | 10SDJ391823 | 10SDJ549261 |
| 10TEK674834 | 10TFL852792 | 10TFL627454 | 10SDJ406823 | 10SDJ564261 |
| 10TEK628848 | 10TFL867792 | 10TFL642454 | 10SDJ421823 | 10SDJ579261 |
| 10TEK644848 | 10TFL882792 | 10TFL658454 | 10SDJ436824 | 10SDJ595262 |
| 10TEK659849 | 10TFL898792 | 10TFL673455 | 10SDJ451824 | 10SDJ610262 |
| 10TEK674849 | 10TFL913793 | 10TFL688455 | 10SDJ467824 | 10SDJ625262 |
| 10TEK689849 | 10TFL928793 | 10TFL703455 | 10SDJ482824 | 10SDJ640262 |
| 10TEK704849 | 10TFL943793 | 10TFL719455 | 10SDJ497824 | 10SDJ656262 |
| 10TEK720849 | 10TFL959793 | 10TFL734455 | 10SDJ512824 | 10SDJ671262 |
| 10TEK613863 | 10TFL974793 | 10TFL749455 | 10SDJ528825 | 10SDJ686263 |
| 10TEK628864 | 10TFL989794 | 10TFL764456 | 10SDJ543825 | 10SDJ701263 |
| 10TEK643864 | 10TGL004794 | 10TFL475468 | 10SDJ314838 | 10SDJ717263 |
| 10TEK659864 | 10TGL020794 | 10TFL490468 | 10SDJ329838 | 10SDJ732263 |
| 10TEK674864 | 10TGL035794 | 10TFL505468 | 10SDJ345838 | 10SDJ366274 |
| 10TEK689864 | 10TGL050794 | 10TFL520468 | 10SDJ360838 | 10SDJ381275 |
| 10TEK704864 | 10TGL065794 | 10TFL536468 | 10SDJ375838 | 10SDJ397275 |
| 10TEK720865 | 10TGL081795 | 10TFL551468 | 10SDJ390838 | 10SDJ412275 |
| 10TEK613879 | 10TGL096795 | 10TFL566469 | 10SDJ406839 | 10SDJ427275 |
| 10TEK628879 | 10TGL111795 | 10TFL581469 | 10SDJ421839 | 10SDJ442275 |
| 10TEK643879 | 10TGL126795 | 10TFL597469 | 10SDJ436839 | 10SDJ457275 |
| 10TEK658879 | 10TGL141795 | 10TFL612469 | 10SDJ451839 | 10SDJ473276 |
| 10TEK674879 | 10TGL157796 | 10TFL627469 | 10SDJ467839 | 10SDJ488276 |
| 10TEK689879 | 10TGL172796 | 10TFL642469 | 10SDJ482839 | 10SDJ503276 |
| 10TEK704880 | 10TGL187796 | 10TFL657470 | 10SDJ497840 | 10SDJ518276 |
| 10TEK719880 | 10TGL202796 | 10TFL673470 | 10SDJ512840 | 10SDJ534276 |
| 10TEK613894 | 10TGL218796 | 10TFL688470 | 10SDJ527840 | 10SDJ549276 |
| 10TEK628894 | 10TGL233796 | 10TFL703470 | 10SDJ543840 | 10SDJ564277 |
| 10TEK643894 | 10TGL248797 | 10TFL718470 | 10SDJ314853 | 10SDJ579277 |
| 10TEK658894 | 10TGL263797 | 10TFL734470 | 10SDJ329853 | 10SDJ595277 |
| 10TEK674895 | 10TFL532803 | 10TFL749471 | 10SDJ344853 | 10SDJ610277 |
| 10TEK689895 | 10TFL547804 | 10TFL764471 | 10SDJ360853 | 10SDJ625277 |
| 10TEK704895 | 10TFL562804 | 10TFL474483 | 10SDJ375853 | 10SDJ640277 |
| 10TEK719895 | 10TFL577804 | 10TFL490483 | 10SDJ390854 | 10SDJ656278 |
| 10TEK612909 | 10TFL593804 | 10TFL505483 | 10SDJ405854 | 10SDJ671278 |
| 10TEK628909 | 10TFL608804 | 10TFL520483 | 10SDJ421854 | 10SDJ686278 |
| 10TEK643909 | 10TFL623805 | 10TFL535483 | 10SDJ436854 | 10SDJ701278 |
| 10TEK658910 | 10TFL638805 | 10TFL551484 | 10SDJ451854 | 10SDJ716278 |
| 10TEK673910 | 10TFL654805 | 10TFL566484 | 10SDJ466854 | 10SDJ732278 |
| 10TEK689910 | 10TFL669805 | 10TFL581484 | 10SDJ482855 | 10SDJ366290 |
| 10TEK704910 | 10TFL684805 | 10TFL596484 | 10SDJ314868 | 10SDJ381290 |
| 10TEK719910 | 10TFL699805 | 10TFL612484 | 10SDJ329868 | 10SDJ396290 |

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|---|---|---|---|---|
| 10TEK612924 | 10TFL715806 | 10TFL627485 | 10SDJ344868 | 10SDJ412290 |
| 10TEK627924 | 10TFL730806 | 10TFL642485 | 10SDJ360869 | 10SDJ427290 |
| 10TEK643925 | 10TFL745806 | 10TFL657485 | 10SDJ375869 | 10SDJ442290 |
| 10TEK658925 | 10TFL760806 | 10TFL673485 | 10SDJ420869 | 10SDJ457291 |
| 10TEK673925 | 10TFL776806 | 10TFL688485 | 10SDJ436869 | 10SDJ473291 |
| 10TEK688925 | 10TFL791806 | 10TFL703485 | 10SDJ451870 | 10SDJ488291 |
| 10TEK704925 | 10TFL806807 | 10TFL718486 | 10SDJ466870 | 10SDJ503291 |
| 10TEK719926 | 10TFL821807 | 10TFL734486 | 10SDJ436885 | 10SDJ518291 |
| 10TEK627940 | 10TFL836807 | 10TFL749486 | 10SDH887975 | 10SDJ533291 |
| 10TEK643940 | 10TFL852807 | 10TFL764486 | 10SDH903976 | 10SDJ549292 |
| 10TEK658940 | 10TFL867807 | 10TFL779486 | 10SDH918976 | 10SDJ564292 |
| 10TEK673940 | 10TFL882808 | 10TFL474498 | 10SDH887991 | 10SDJ579292 |
| 10TEK688940 | 10TFL897808 | 10TFL490498 | 10SDH902991 | 10SDJ594292 |
| 10TEK703941 | 10TFL913808 | 10TFL505498 | 10SDH918991 | 10SDJ610292 |
| 10TEK719941 | 10TFL928808 | 10TFL520499 | 10SDH933991 | 10SDJ625292 |
| 10TEK627955 | 10TFL943808 | 10TFL535499 | 10SDH948991 | 10SDJ640293 |
| 10TEK642955 | 10TFL958808 | 10TFL550499 | 10SDH963991 | 10SDJ655293 |
| 10TEK658955 | 10TFL974809 | 10TFL566499 | 10SDH979992 | 10SDJ671293 |
| 10TEK673955 | 10TFL989809 | 10TFL581499 | 10SDH994992 | 10SDJ686293 |
| 10TEK688956 | 10TGL004809 | 10TFL596499 | 10SEH009992 | 10SDJ701293 |
| 10TEK703956 | 10TGL019809 | 10TFL611500 | 10SEH024992 | 10SDJ716293 |
| 10TEK719956 | 10TGL035809 | 10TFL627500 | 10SEH040992 | 10SDJ732294 |
| 10TEK627970 | 10TGL050810 | 10TFL642500 | 10SEH055992 | 10SDJ366305 |
| 10TEK642970 | 10TGL065810 | 10TFL657500 | 10SEH070993 | 10SDJ381305 |
| 10TEK657971 | 10TGL080810 | 10TFL672500 | 10SEH085993 | 10SDJ396305 |
| 10TEK673971 | 10TGL096810 | 10TFL688500 | 10SEH100993 | 10SDJ411305 |
| 10TEK688971 | 10TGL111810 | 10TFL703501 | 10SEH116993 | 10SDJ427306 |
| 10TEK703971 | 10TGL126810 | 10TFL718501 | 10SEH131993 | 10SDJ442306 |
| 10TEK718971 | 10TGL141811 | 10TFL733501 | 10SEH146993 | 10SDJ457306 |
| 10TEK612985 | 10TGL157811 | 10TFL749501 | 10SDJ872006 | 10SDJ472306 |
| 10TEK627985 | 10TGL172811 | 10TFL764501 | 10SDJ887006 | 10SDJ488306 |
| 10TEK642986 | 10TGL187811 | 10TFL779501 | 10SDJ902006 | 10SDJ503306 |
| 10TEK657986 | 10TGL202811 | 10TFL794502 | 10SDJ918006 | 10SDJ518307 |
| 10TEK672986 | 10TGL218811 | 10TFL459513 | 10SDJ933006 | 10SDJ533307 |
| 10TEK688986 | 10TGL233812 | 10TFL474513 | 10SDJ948007 | 10SDJ549307 |
| 10TEK703986 | 10TGL248812 | 10TFL489513 | 10SDJ963007 | 10SDJ564307 |
| 10TEK718986 | 10TGL263812 | 10TFL505514 | 10SDJ978007 | 10SDJ579307 |
| 10TEL611000 | 10TFL547819 | 10TFL520514 | 10SDJ994007 | 10SDJ594307 |
| 10TEL627001 | 10TFL562819 | 10TFL535514 | 10SEJ009007 | 10SDJ609308 |
| 10TEL642001 | 10TFL577819 | 10TFL550514 | 10SEJ024007 | 10SDJ625308 |
| 10TEL657001 | 10TFL592819 | 10TFL566514 | 10SEJ039008 | 10SDJ640308 |
| 10TEL672001 | 10TFL608820 | 10TFL581514 | 10SEJ055008 | 10SDJ655308 |

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|---|---|---|---|---|
| 10TEL688001 | 10TFL623820 | 10TFL596515 | 10SEJ070008 | 10SDJ670308 |
| 10TEL703002 | 10TFL638820 | 10TFL611515 | 10SEJ085008 | 10SDJ686308 |
| 10TEL718002 | 10TFL653820 | 10TFL626515 | 10SEJ100008 | 10SDJ701309 |
| 10TEL611016 | 10TFL669820 | 10TFL642515 | 10SEJ116008 | 10SDJ716309 |
| 10TEL626016 | 10TFL684820 | 10TFL657515 | 10SEJ131009 | 10SDJ731309 |
| 10TEL642016 | 10TFL699821 | 10TFL672516 | 10SEJ146009 | 10SDJ350320 |
| 10TEL657016 | 10TFL714821 | 10TFL687516 | 10SDJ856021 | 10SDJ366320 |
| 10TEL672016 | 10TFL730821 | 10TFL703516 | 10SDJ872021 | 10SDJ381320 |
| 10TEL687017 | 10TFL745821 | 10TFL718516 | 10SDJ887021 | 10SDJ396320 |
| 10TEL703017 | 10TFL760821 | 10TFL733516 | 10SDJ902021 | 10SDJ411321 |
| 10TEL718017 | 10TFL775822 | 10TFL748516 | 10SDJ917021 | 10SDJ426321 |
| 10TEL611031 | 10TFL791822 | 10TFL764517 | 10SDJ933022 | 10SDJ442321 |
| 10TEL626031 | 10TFL806822 | 10TFL779517 | 10SDJ948022 | 10SDJ457321 |
| 10TEL641031 | 10TFL821822 | 10TFL794517 | 10SDJ963022 | 10SDJ472321 |
| 10TEL657031 | 10TFL836822 | 10TFL809517 | 10SDJ978022 | 10SDJ487321 |
| 10TEL672032 | 10TFL852822 | 10TFL459528 | 10SDJ994022 | 10SDJ503322 |
| 10TEL687032 | 10TFL867823 | 10TFL474528 | 10SEJ009022 | 10SDJ518322 |
| 10TEL702032 | 10TFL882823 | 10TFL489529 | 10SEJ024023 | 10SDJ533322 |
| 10TEL718032 | 10TFL897823 | 10TFL504529 | 10SEJ039023 | 10SDJ548322 |
| 10TEL611046 | 10TFL912823 | 10TFL520529 | 10SEJ054023 | 10SDJ564322 |
| 10TEL626046 | 10TFL928823 | 10TFL535529 | 10SEJ070023 | 10SDJ579322 |
| 10TEL641047 | 10TFL943824 | 10TFL550529 | 10SEJ085023 | 10SDJ594323 |
| 10TEL657047 | 10TFL958824 | 10TFL565530 | 10SEJ100023 | 10SDJ609323 |
| 10TEL672047 | 10TFL973824 | 10TFL581530 | 10SEJ115024 | 10SDJ625323 |
| 10TEL687047 | 10TFL989824 | 10TFL596530 | 10SDJ841036 | 10SDJ640323 |
| 10TEL702047 | 10TGL004824 | 10TFL611530 | 10SDJ856036 | 10SDJ655323 |
| 10TEL717047 | 10TGL019824 | 10TFL626530 | 10SDJ871036 | 10SDJ670323 |
| 10TEL611061 | 10TGL034825 | 10TFL642530 | 10SDJ887036 | 10SDJ685324 |
| 10TEL626062 | 10TGL050825 | 10TFL657531 | 10SDJ902036 | 10SDJ701324 |
| 10TEL641062 | 10TGL065825 | 10TFL672531 | 10SDJ917037 | 10SDJ716324 |
| 10TEL656062 | 10TGL080825 | 10TFL687531 | 10SDJ932037 | 10SDJ350335 |
| 10TEL672062 | 10TGL095825 | 10TFL702531 | 10SDJ948037 | 10SDJ365335 |
| 10TEL687062 | 10TGL111825 | 10TFL718531 | 10SDJ963037 | 10SDJ381335 |
| 10TEL702062 | 10TGL126826 | 10TFL733531 | 10SDJ978037 | 10SDJ396336 |
| 10TEL717063 | 10TGL141826 | 10TFL748532 | 10SDJ993037 | 10SDJ411336 |
| 10TEL610077 | 10TGL156826 | 10TFL763532 | 10SEJ009038 | 10SDJ426336 |
| 10TEL626077 | 10TGL172826 | 10TFL779532 | 10SEJ024038 | 10SDJ442336 |
| 10TEL641077 | 10TGL187826 | 10TFL794532 | 10SEJ039038 | 10SDJ457336 |
| 10TEL656077 | 10TGL202827 | 10TFL809532 | 10SEJ054038 | 10SDJ472336 |
| 10TEL671077 | 10TGL217827 | 10TFL443543 | 10SEJ070038 | 10SDJ487337 |
| 10TEL687078 | 10TGL233827 | 10TFL458544 | 10SEJ085038 | 10SDJ502337 |
| 10TEL702078 | 10TGL248827 | 10TFL474544 | 10SDJ826051 | 10SDJ518337 |

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|---|---|---|---|---|
| 10TEL717078 | 10TGL263827 | 10TFL489544 | 10SDJ841051 | 10SDJ533337 |
| 10TEL626092 | 10TFL562834 | 10TFL504544 | 10SDJ856051 | 10SDJ548337 |
| 10TEL641092 | 10TFL577834 | 10TFL519544 | 10SDJ871051 | 10SDJ563337 |
| 10SEJ882977 | 10TFL592835 | 10TFL535544 | 10SDJ887052 | 10SDJ579338 |
| 10SEJ897977 | 10TFL608835 | 10TFL550545 | 10SDJ902052 | 10SDJ594338 |
| 10SEJ912977 | 10TFL623835 | 10TFL565545 | 10SDJ917052 | 10SDJ609338 |
| 10SEJ928977 | 10TFL638835 | 10TFL580545 | 10SDJ932052 | 10SDJ624338 |
| 10SEJ943977 | 10TFL653835 | 10TFL596545 | 10SDJ947052 | 10SDJ640338 |
| 10SEJ958978 | 10TFL668836 | 10TFL611545 | 10SDJ963052 | 10SDJ655338 |
| 10SEJ973978 | 10TFL684836 | 10TFL626545 | 10SDJ978053 | 10SDJ670339 |
| 10SEJ989978 | 10TFL699836 | 10TFL641546 | 10SDJ993053 | 10SDJ685339 |
| 10SFJ004978 | 10TFL714836 | 10TFL657546 | 10SEJ008053 | 10SDJ701339 |
| 10SFJ019978 | 10TFL729836 | 10TFL672546 | 10SEJ024053 | 10SDJ716339 |
| 10SEJ882992 | 10TFL745836 | 10TFL687546 | 10SEJ039053 | 10SDJ335350 |
| 10SEJ897992 | 10TFL760837 | 10TFL702546 | 10SEJ054053 | 10SDJ350350 |
| 10SEJ912992 | 10TFL775837 | 10TFL718547 | 10SEJ069054 | 10SDJ365351 |
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| 10SDJ504230 | 10TGM213177 | 10TFL791776 | 10TFL673409 | 10SDJ361777 |
| 10SDJ519230 | 10TGM228177 | 10TFL806776 | 10TFL689409 | 10SDJ376777 |
| 10SDJ534231 | 10TGM244178 | 10TFL822776 | 10TFL704409 | 10SDJ391777 |
| 10SDJ549231 | 10TGM106191 | 10TFL837777 | 10TFL719409 | 10SDJ406778 |
| 10SDJ565231 | 10TGM122191 | 10TFL852777 | 10TFL475422 | 10SDJ421778 |
| 10SDJ580231 | 10TGM137192 | 10TFL867777 | 10TFL490422 | 10SDJ437778 |
| 10SDJ595231 | 10TGM152192 | 10TFL883777 | 10TFL506422 | 10SDJ452778 |
| 10SDJ610231 | 10TGM167192 | 10TFL898777 | 10TFL521422 | 10SDJ467778 |
| 10SDJ626232 | 10TGM183192 | 10TFL913777 | 10TFL536422 | 10SDJ482778 |
| 10SDJ641232 | 10TGM198192 | 10TFL928778 | 10TFL551423 | 10SDJ498779 |
| 10SDJ656232 | 10TGM213193 | 10TFL944778 | 10TFL567423 | 10SDJ513779 |
| 10SDJ671232 | 10TGM228193 | 10TFL959778 | 10TFL582423 | 10TFL974778 |
| 10SDJ686232 | | | | |

## Appendix B: Quantum Spatial GPS Processing

Appendix B is a separate document located in the Reports folder of the deliverables.

## Appendix C: Eagle Mapping GPS Processing

Appendix C is a separate document located in the Reports folder of the deliverables.