# LiDAR Independent QA/QC Report: Lake County, California DR-4240

Contract #HSFE60-15-D-0003, Task Order #HSFE09-16-J-0001
June 1, 2016

**Prepared for:**

DHS/FEMA (Federal Emergency Management Agency)
Attn: Sherwin C. Turner, Contracting Officer/Team Leader
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**Submitted by:**

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# DOCUMENT HISTORY

## REVISION HISTORY

| Version Number | Version Date | Summary Changes | Team/Author |
|---|---|---|---|
| 1.0 | June 1, 2016 | Lake County, CA LiDAR Independent QA/QC Report | Brandon Banks |
| | | | |

## APPROVALS

This document requires the approval of the following persons:

| Role | Name | Phone Extension | Title (CLIN/RMC) | Review Date | Approved Date |
|---|---|---|---|---|---|
| Task Order Manager | Brandon Banks | 816.410.6373 | Task Order Manager | May 31, 2016 | May 31, 2016 |
| | | | | | |

## CLIENT DISTRIBUTION

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June 1, 2016

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**Subject: Independent QA/QC of Disaster Funded Lake County, California LiDAR Collection, Contract #HSFE60-15-D-0003, Task Order #HSFE09-16-J-0001**

Dear Mr. Turner,

The Compass PTS JV is pleased to provide the Lake County, California Independent QA/QC developed as part of this task order. The Lake County LiDAR collection, as specified in the scope of work and required by FEMA Standards for Flood Risk Analysis and Mapping, was designed, collected, and processed in accordance with the United States Geological Survey-National Geospatial Program's LiDAR Base Specification Version 1.2 (November 2014). The following table summarizes the key components to a Quality Level 2 (QL2) collection as required by the USGS specifications and the independently assessed actual results.

| Test | Design | Independent QA/QC Result | Pass/Fail |
|---|---|---|---|
| Nominal Pulse Spacing (m) | ≤0.71 | 0.6 | Pass |
| Nominal Pulse Density (pls/$m^2$) | ≥2.0 | 2.82 | Pass |
| Spatial Distribution and Regularity (%) | 90% | 96% | Pass |
| Overlap Consistency (cm) | ≤8.0 | 1.18 | Pass |
| NVA - Raw Point Cloud (cm) | ≤19.6 | 11 | Pass |
| NVA - Hydro-flattened DEM (cm) | ≤19.6 | 12.5 | Pass |
| NVA - Hydro-enforced DEM (cm) | ≤19.6 | 12.5 | Pass |
| VVA - Classified Point Cloud (cm) | ≤29.4 | 21.3 | Pass |
| VVA - Hydro-flattened DEM (cm) | ≤29.4 | 21.6 | Pass |
| VVA - Hydro-enforced DEM (cm) | ≤29.4 | 21.6 | Pass |

All products referenced herein and included with the Lake County, California LiDAR collection deliverable package have been developed to meet or exceed the government's requirements for this task order.

Respectfully submitted,

Lillian Pitts Robison
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# Table of Contents

# 01 Introduction

As part of the Lake County, California LiDAR collection and processing task order (#HSFE09-16-J-0001) executed in response to the California Valley Fire and Butte Fire disaster (DR-4240), Compass has performed independent QA/QC on the collected LiDAR and derivative products. The results of the independent QA/QC are presented in this report.

The following guidance and standards documents were considered as part of this independent QA/QC activity:

- FEMA Standards for Flood Risk Analysis and Mapping (Nov 2015)
- United States Geological Survey-National Geospatial Program (USGS-NGP) LiDAR Base Specification Version 1.2 (Nov 2014)
- FEMA Procedure Memorandum (PM) 61: Standards for Lidar and Other High Quality Digital Topography (Sept 2010)

## 1.1 Scope of Work

The Lake County, California LiDAR collection was designed in accordance with FEMA and USGS-NGP specifications for Quality Level 2 (QL2), which require the following fundamental criteria be met:

| | |
|---|---|
| Nominal Pulse Spacing | ≤0.71 meters |
| Nominal Pulse Density | ≥2.0 pulses per square meter |
| Nonvegetated Vertical Accuracy (95% confidence) | ≤19.6 centimeters |
| Vegetated Vertical Accuracy (95$^{th}$ percentile) | ≤29.4 centimeters |

## 1.2 Project Site

Lake County, California represents the collection's defined project area (DPA) of 1,329 square miles. With a 100-meter buffer, the buffered project area (BPA) is 1,340 square mile. All collected and developed data have been assured to extend to the BPA, with exception to data voids within the BPA as previously acknowledged and approved by the government as a result of snowpack in the higher elevations of the BPA at the time of collection.

Figure 1 depicts the Lake County California project site.

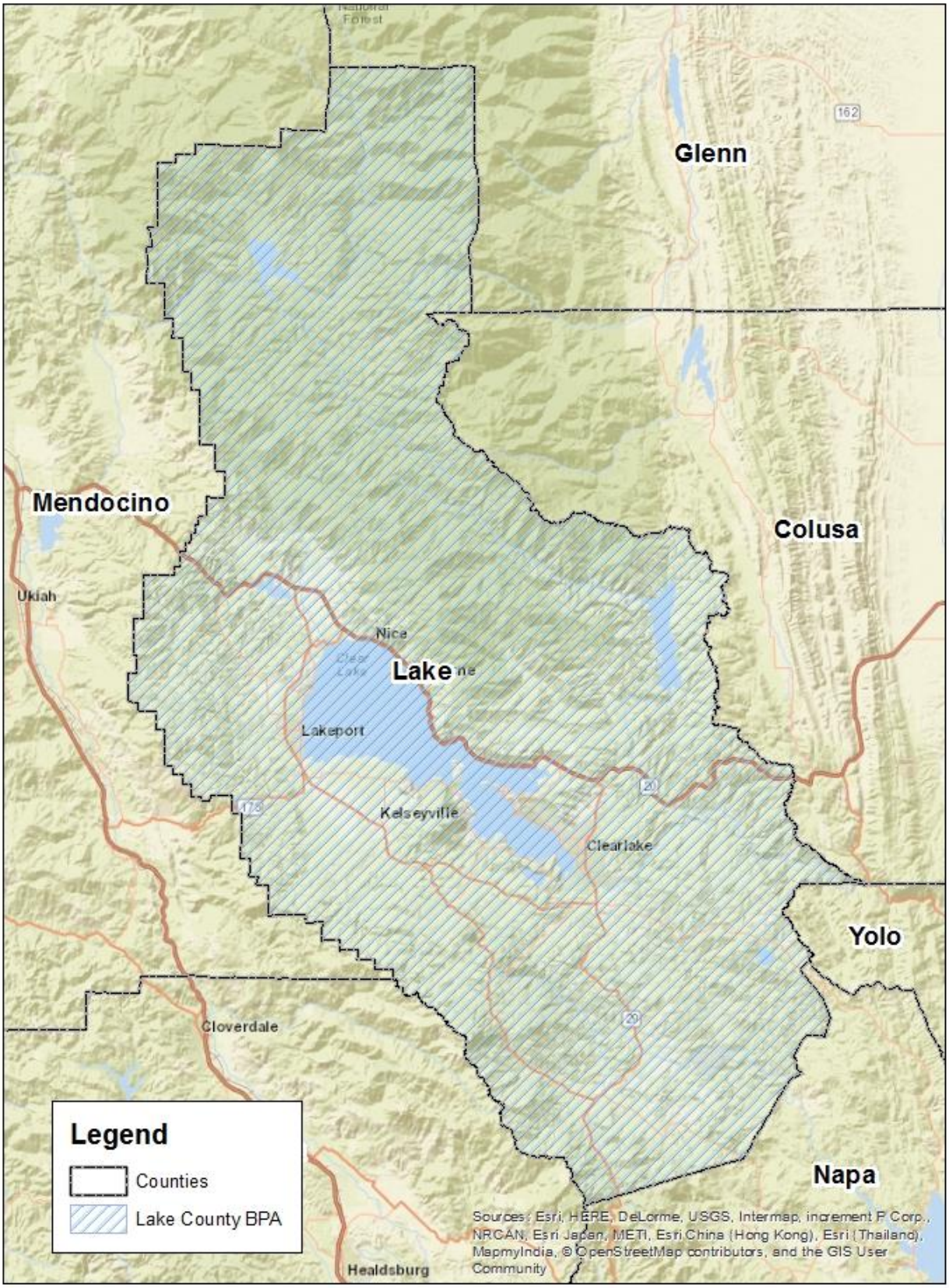


Figure 1: Lake County Buffered Project Area

## 1.3 Surveyed QC Checkpoints

161 checkpoints were surveyed in support of the Lake County, California LiDAR collection. 18 were control checkpoints used to boresight and control the raw point cloud. 81 QC checkpoints were surveyed in open terrain areas and were used to assess the nonvegetated vertical accuracy of the raw LiDAR point cloud, hydro-flattened digital elevation model (DEM) and hydro-enforced DEM. 62 QC checkpoints were surveyed in a combination of tall grass and woods and were used to assess the vegetated vertical accuracy of the classified LiDAR point cloud, hydro-flattened and hydro-enforced DEMs. Figure 2 depicts the ground control and QC checkpoints surveyed as part of the Lake County, California LiDAR collection task order.

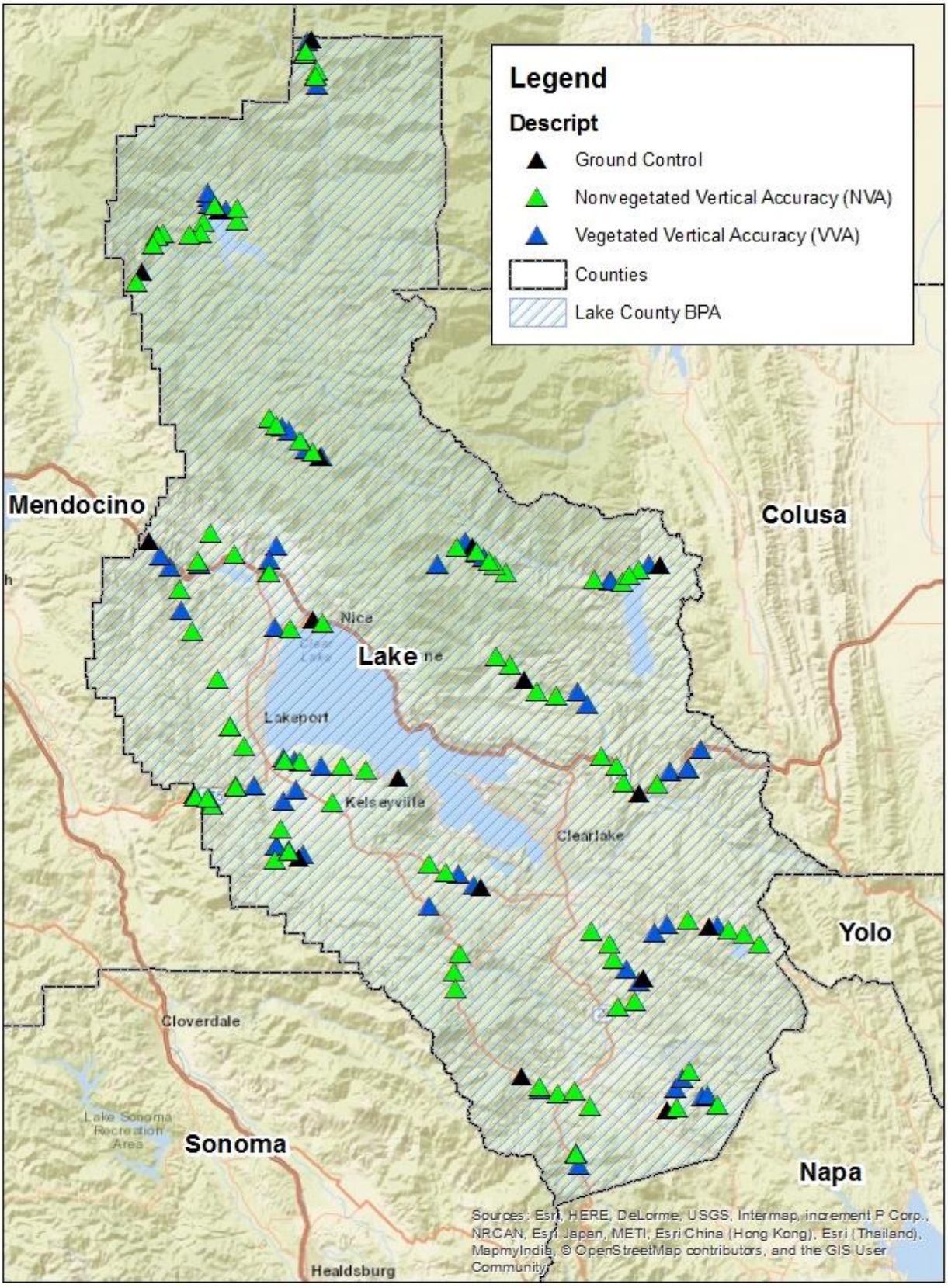


**Figure 2: Survey Points**

# 02 Independent QA/QC

Independent QA/QC activities were executed against the Lake County, California LiDAR collection using a macro and micro review methodology specified in FEMA's PM 61 guidance document. Macro reviews were automated processes and checks to establish overall data quality, completeness, and alignment with project standards and specifications such as horizontal and vertical reference systems and units. Micro reviews were more manual in nature and were used to check 10% of the project area to assure classification and elevation data are representative in the classified LiDAR and derivative products.

## 2.1 Raw LiDAR Point Cloud

The fully calibrated, georeferenced, and adjusted to ground raw LiDAR point cloud was assessed prior to classification and derivative product generation. The nominal pulse spacing (NPS), spatial distribution and regularity, nonvegetated vertical accuracy, and overlap consistency were reviewed.

### 2.1.1 Nonvegetated Vertical Accuracy

Nonvegetated vertical accuracy is a fundamental accuracy assessment of any LiDAR collection. The assessment is performed by comparing the elevation values from independently surveyed open terrain QC checkpoints to the TIN and/or DEM surface for the same coordinates. This assessment provides assurance the collection, boresight, and control have been appropriately calibrated to the ground. NVA for the Lake County, California LiDAR collection was assessed using the raw point cloud by building a Triangular Irregular Network (TIN) for all pulses around the 81 open terrain QC checkpoints. Since the checkpoints were surveyed in open terrain, the LiDAR pulses used to construct the TIN had a high probability of representing the ground without interference from structures or vegetation in these areas.

Two of the checkpoints proved to be anomalous and were removed from the assessment leaving 79 open terrain QC checkpoints. The Root Mean Square Error (RMSE) was calculated at 0.056 meters. The nonvegetated vertical accuracy (RMSE * 1.96) was calculated at 0.11 meters, which is well within the FEMA and USGS-NGP requirements of 0.196 meters.

### 2.1.2 Nominal Pulse Spacing and Density

Nominal pulse spacing was assessed using the USGS-NGP LiDAR Base Specification Version1.2 methodology where 1 square kilometer polygons were created along the centerlines for each swath. The polygons were used to count the total first return pulses for each polygonal area and sum the total points and assessed area to calculate Nominal Pulse Spacing (NPS) and Nominal Pulse Density (NPD). From the 120 swaths, a total of 321,901,209 million first return points were identified across 114,287,966 square meters of assessment area to calculate a 0.60 meters NPS and 2.82 points per square meter NPD, which are within tolerance of the USGS-NGP requirements of a NPS less than or equal to 0.71meters and a NPD greater than or equal to 2 points per square meter.

### 2.1.3 Spatial Distribution and Regularity

Spatial distribution and regularity of the raw LiDAR point cloud is assessed to ensure the geometrically usable points will approach a uniform and regular lattice rather than a collection of widely spaced, high-density profiles of the terrain. The assessment requires a density grid developed from the swath-based raw point cloud with grid cell sizes equal to twice the design ANPS, or 2 * 0.7 = 1.4 meter resolution grid. Spatial distribution and regularity grids were developed for each swath where the cell values were

calculated based on the number of first return pulses counted for each cell area. Across all 120 swaths, 3,162,554,539 pixels were assessed with 3,048,520,949 pixels containing at least one first return pulse resulting in a 96% passing rate, which exceeds the minimum requirement of 90% from the USGS-NGP specifications.

### 2.1.4 Smooth Surface Repeatability

Smooth surface repeatability is a measure of variations within LiDAR swaths where the surface would be expected to be flat and without variation. Smooth surface repeatability was not assessed for the Lake County, California LiDAR collection. After review of the project site and concurrence from the collection team, it was determined the lack of suitable flat, smooth, reflective surfaces with minimal slope variation were available to assess smooth surface repeatability.

### 2.1.5 Overlap Consistency

Overlap consistency is a measure of geometric alignment of two overlapping swaths and is the fundamental measure of quality of the calibration or boresight adjustment of the data from each lift and between swaths from a single lift. For this assessment, the overlap data were evaluated using 459 point locations within the swath overlap areas. The differences between swaths were compared and the RMSE was calculated to 0.0118 meters (1.18 cm) with a maximum difference of 7.42 centimeters. These results are within the USGS-NGP requirement of less than or equal to 8 cm RMSE and +/- 16 cm for maximum difference.

## 2.2 Classified LiDAR Point Cloud

A micro review of the classified LiDAR point cloud included an assessment of 167 tiles that were randomly selected but distributed across the 1,672 total tiles. This 10% review is twice the recommended micro review of 5% of the project area per FEMA PM 61. Figure 3 depicts the total project area with the micro review tiles.

Micro review assessment ensured the following classification was used in the LAS 1.4 files:

- Class 1 – Process, but Unclassified
- Class 2 – Bare Earth
- Class 7 – Low Noise
- Class 9 – Water
- Class 10 – Ignored Ground Points (near a breakline)
- Class 17 – Bridge Decks
- Class 18 – High Noise

### 2.2.1 LAS Classification Error

USGS-NGP has a requirement that no more than 1% of the nonwithheld points will have demonstrable errors. To assess the classification error, TINs were built using the ground points from the classified LAS files. A 1-meter DEM was sampled from the TIN and a hillshade was created. After visual inspections of the hillshades, the polygonal areas digitized around potential anomalies were used to sum all classified points within the anomalous area. The total number of classified points flagged as potential anomalies was divided by the total number of nonwithheld points represented in the micro review tiles resulting in

a 0.27% classification error, which is within the tolerance of less than 1% as required in the USGS-NGP specifications.

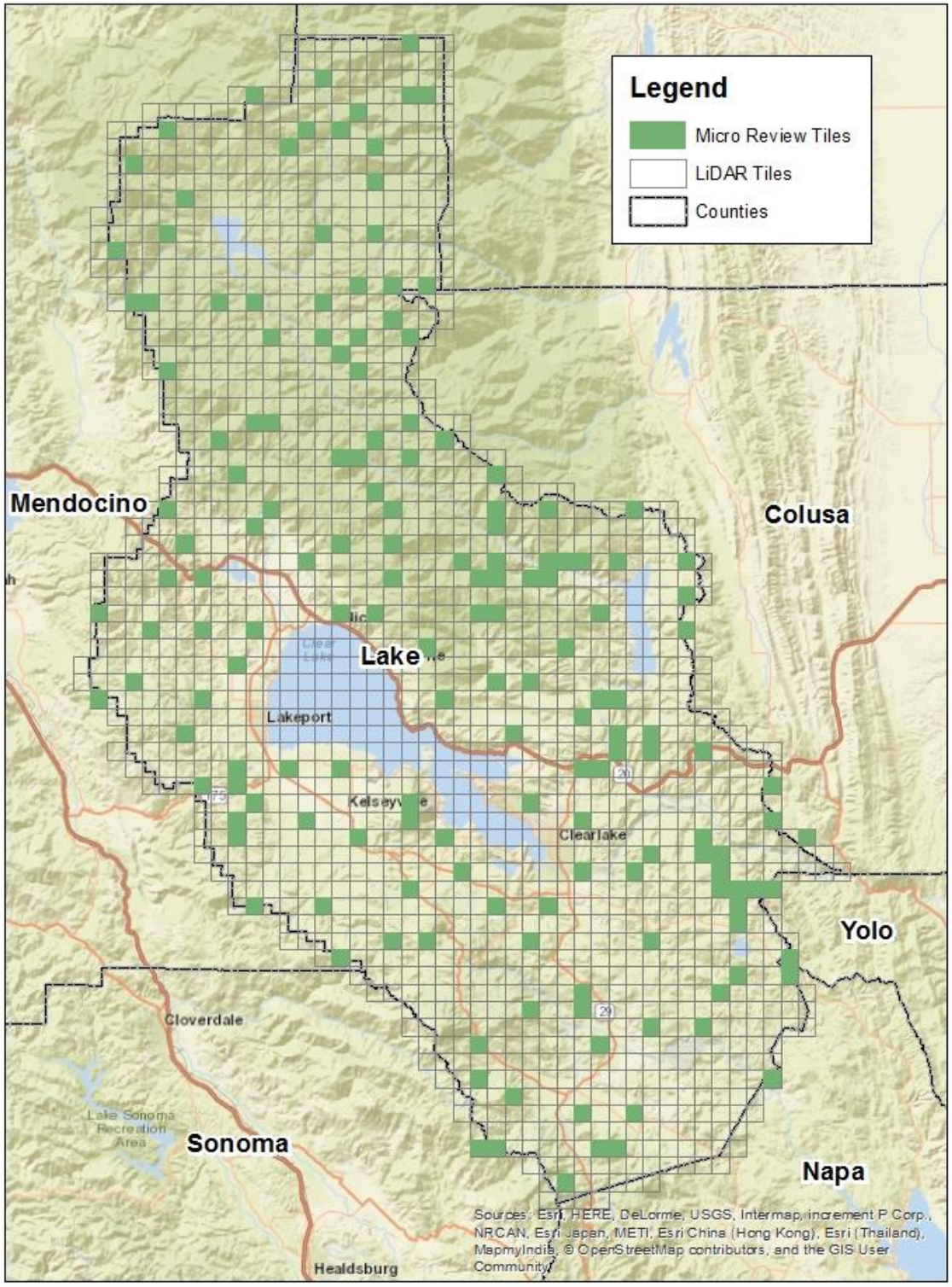


Figure 3: Micro Review Tiles

### 2.2.2 Vegetated Vertical Accuracy

Vegetated vertical accuracy of the classified LiDAR point cloud was calculated in a similar method as the nonvegetated vertical accuracy was calculated on the raw LiDAR point cloud. TINs were developed using the Class 2 – Bare Earth points for areas where vegetated QC checkpoints were surveyed. The TIN elevation value for the QC checkpoint locations was compared to the vegetated QC checkpoints' elevation value. An absolute value difference was applied and the 95$^{th}$ percentile value was calculated. The vegetated vertical accuracy of the classified LiDAR point cloud was calculated to be 21.3 cm, within the maximum threshold of 29.4 cm specified in the USGS-NGP specifications.

## 2.3 Hydro Breaklines

Hydro-flattening breaklines and hydro-enforcement breaklines were assessed as part of the Lake County, California LiDAR collection independent QA/QC activities. The following bullets were part of the breakline assessment with all features passing QC:

- Water bodies represented by a single elevation value
- Streams and Rivers with bank lines have been respectively flattened
- Breakline features have monotonicity enforced
- Breakline features at or below surrounding terrain
- FEMA standard topology rules have been enforced

## 2.4 Hydro-Flattened DEM

The hydro-flattened DEM micro review tiles were visually inspected to assure the hydro-flattening breaklines were appropriately applied.

- Water bodies were inspected to assure the single value elevation from the breakline flattened the waterbody with the corresponding elevation value.
- Larger stream and river features with bank lines were appropriately flattened with a decreasing gradient as the flow proceed downhill
- DEM flattened areas were lower than the surrounding terrain

### 2.4.1 Nonvegetated Vertical Accuracy

Nonvegetated vertical accuracy of the hydro-flattened DEM product was assessed using the open terrain QC checkpoints. The hydro-flattened DEM elevation values were compared to the surveyed open terrain QC checkpoint elevation values at the same coordinates. The RMSE was calculated at 0.064 meters. The nonvegetated vertical accuracy (RMSE * 1.96) was calculated at 0.125 meters, which is well within the FEMA and USGS-NGP requirements of 0.196 meters.

### 2.4.2 Vegetated Vertical Accuracy

Vegetated vertical accuracy of the hydro-flattened DEM product was assessed using the vegetated QC checkpoints. The hydro-flattened DEM elevation values were compared to the surveyed vegetated QC checkpoint elevation values at the same coordinates. An absolute value difference was applied and the 95$^{th}$ percentile value was calculated. The vegetated vertical accuracy of the hydro-flattened DEM was

calculated to be 21.6 cm, within the maximum threshold of 29.4 cm specified in the USGS-NGP specifications.

## 2.5 Hydro-Enforced DEM

Based on the USGS-NGP definition of a hydro-enforced product, the hydro-enforced DEM reviewed as part of the Lake County LiDAR collection independent QA/QC activity ensured mapped water bodies were level and that streams and rivers flow downhill. It is assumed that the mapped water bodies are represented in the hydro breaklines products, which includes additional water bodies, streams and rivers, and culvert features in excess of the standard hydro-flattening requirements. The single line streams and culverts were captured to represent flooding sources draining in excess of 40 square miles. Review of the hydro enforced DEM assures the cells in the hydro enforced DEM align with the hydro breaklines features where water bodies are flat and have monotonicity enforced. Culvert features were to breach fill represented by ground points in the classified LiDAR point cloud along the single line flooding source features.

### 2.5.1 Nonvegetated Vertical Accuracy

Nonvegetated vertical accuracy of the hydro-enforced DEM product was assessed using the open terrain QC checkpoints. The hydro-enforced DEM elevation values were compared to the surveyed open terrain QC checkpoint elevation values at the same coordinates. The RMSE was calculated at 0.064 meters. The nonvegetated vertical accuracy (RMSE * 1.96) was calculated at 0.125 meters, which is well within the FEMA and USGS-NGP requirements of 0.196 meters.

### 2.5.2 Vegetated Vertical Accuracy

Vegetated vertical accuracy of the hydro-enforced DEM product was assessed using the vegetated QC checkpoints. The hydro-enforced DEM elevation values were compared to the surveyed vegetated QC checkpoint elevation values at the same coordinates. An absolute value difference was applied and the $95^{th}$ percentile value was calculated. The vegetated vertical accuracy of the hydro-enforced DEM was calculated to be 21.6 cm, within the maximum threshold of 29.4 cm specified in the USGS-NGP specifications.

# 03 Conclusions

The independent QA/QC of the Lake County, California LiDAR collection, acquired in response to the California Valley Fire and Butte Fire (DR-4240), assures all deliverable products adhere to the collection's scope of work, FEMA's Standards for Flood Risk Analysis and Mapping, and the USGS-NGP LiDAR Base Specifications Version 1.2 for QL2 LiDAR.

The following summary table provides the fundamental QA/QC requirements and associated actual results.

| Test | Design | Independent QA/QC Result | Pass/Fail |
|---|---|---|---|
| Nominal Pulse Spacing (m) | ≤0.71 | 0.6 | Pass |
| Nominal Pulse Density (pls/$m^2$) | ≥2.0 | 2.82 | Pass |
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