LiDAR Acquisition and Processing Report: Lake County, California DR-4240

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

June 1, 2016

Prepared for:

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APPROVALS

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DHS/FEMA (Federal Emergency Management Agency)
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Subject: 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 LiDAR collection and processing deliverables 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 this deliverable have been developed to meet or exceed the government's requirements for this task order.

Respectfully submitted,

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Project Director
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01 Lake County LiDAR Collection Overview

Compass has provided FEMA with planning, acquisition, processing, and derivative product generation from LiDAR data over the area of interest (AOI) defined as Lake County, CA. The collection design required LiDAR be acquired to an aggregate nominal pulse spacing (ANPS) of 0.7 meters (2ppsm), including overlap, and processed according to the United States Geological Survey (USGS) National Geospatial Program (NGP) LiDAR Base Specification Version 1.2, to which FEMA Standards for Flood Risk Analysis and Mapping defer. The total area of the AOI is approximately 1,329 square miles. LiDAR were collected to the extent of the buffered project area (1,340 square miles with a 100-meter buffer of the AOI) and derivative products produced in compliance with this task order and the USGS NGP specifications.

The purpose of the Lake County LiDAR collection is to support various risk analyses including hydrologic analysis, hydraulic analysis, post-fire debris flow analysis, and non-regulatory product development (e.g. depth grids and risk probability grids).

LiDAR data were processed immediately after acquisition to ensure coverage, density, relative accuracy and nonvegetated vertical accuracy (NVA) met project specifications. LiDAR data were then classified using TerraSolid processing and modeling software into ground and non-ground points. Classifications include 1) Processed, but unclassified; 2) Bare Earth; 7) Low Noise; 9) Water; 10) Ignored Ground (near a breakline); 17) Bridge Decks; 18) High Noise. An independent QA/QC was performed on all data acquisition, processing, and final deliverables. The LiDAR point cloud and derivative DEMs are assured to meet vertical accuracy requirements.

02 Ground Control

2.1 BASE STATION AND GROUND CONTROL LOCATIONS

During LiDAR data collection the airborne GPS receiver was collecting data and the Dilution of Precision (PDOP) was monitored. The airborne GPS data were post-processed in DGPS mode, together with base station data, to provide high accuracy aircraft positions. The GPS trajectory was then combined with the IMU data using loosely coupled approach to yield high accuracy aircraft positions and attitude angles. The LiDAR data were then processed using the aircraft trajectory and raw LiDAR data.

Static GPS observations were performed at all ground control locations storing data at 1 second frequency for a minimum of 1hour 45minutes. The equipment used during the static survey consisted of Trimble Navigation's dual frequency R8 GNSS Model 3 GPS receiver. A two meter fixed height tripod was used for each setup to eliminate human error which could be introduced by mismeasurement of the GPS antenna heights. The static data collected at the RTK base station was downloaded and submitted to the office to be post processed utilizing the NGS Online Positioning User Service (OPUS). The deliverables have been processed using horizontal datum, North American Datum of 1983 (2011) meters and the vertical datum was the North American Vertical Datum of 1988 (NAVD 1988), Geoid 12B.

A total of 144 check points were collected to support the independent review component of the Lake County LiDAR task order. The locations are shown within the figures below.

- Figure 1 shows the layout of the 18 Ground Control Points (GCP) stations
- Figure 2 shows the locations of the 143 check points; 81 in open areas, 41 in tall grass, and 21 in wooded areas.

The field survey report can be referenced in Appendix A.

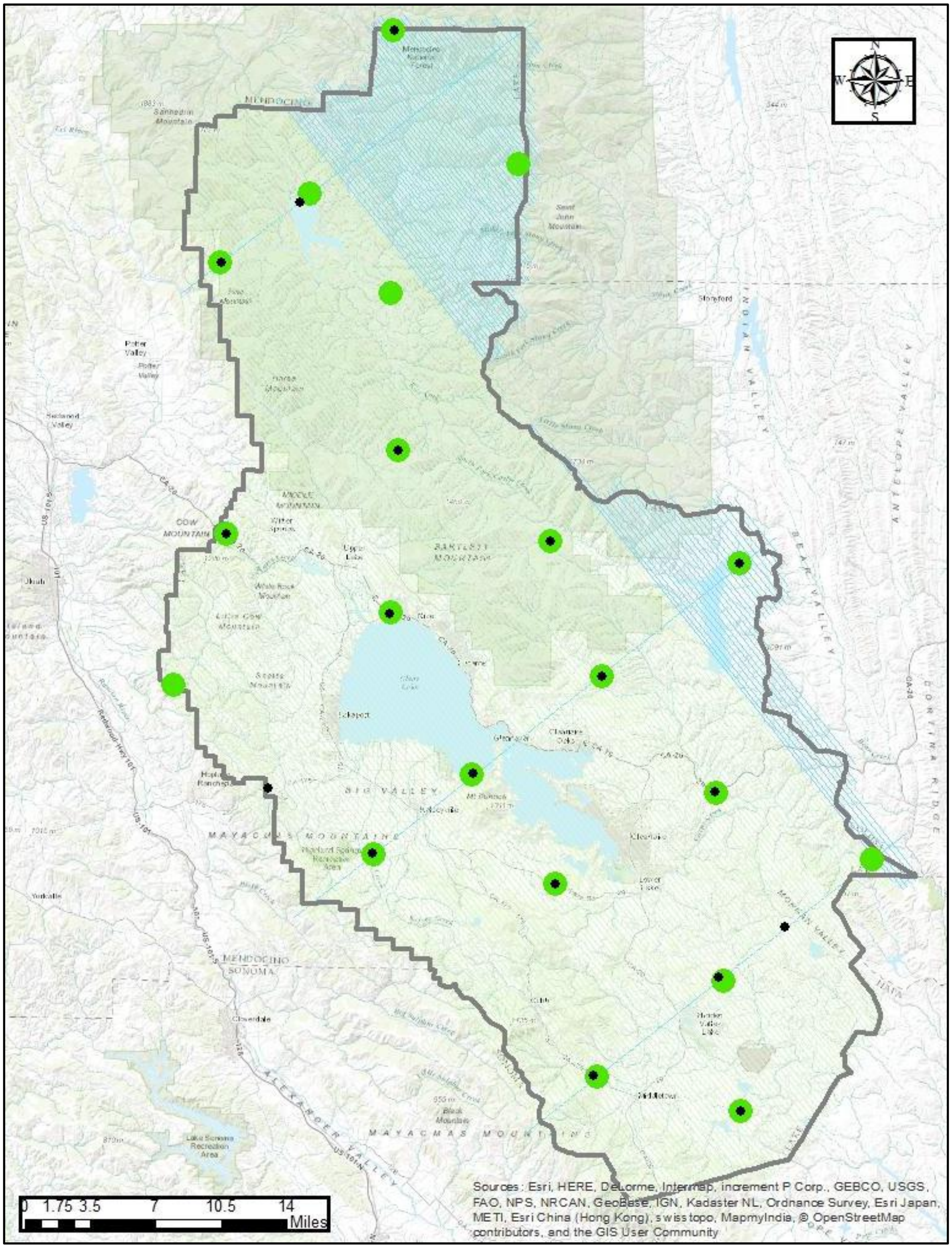

Figure 1: Ground Control Points

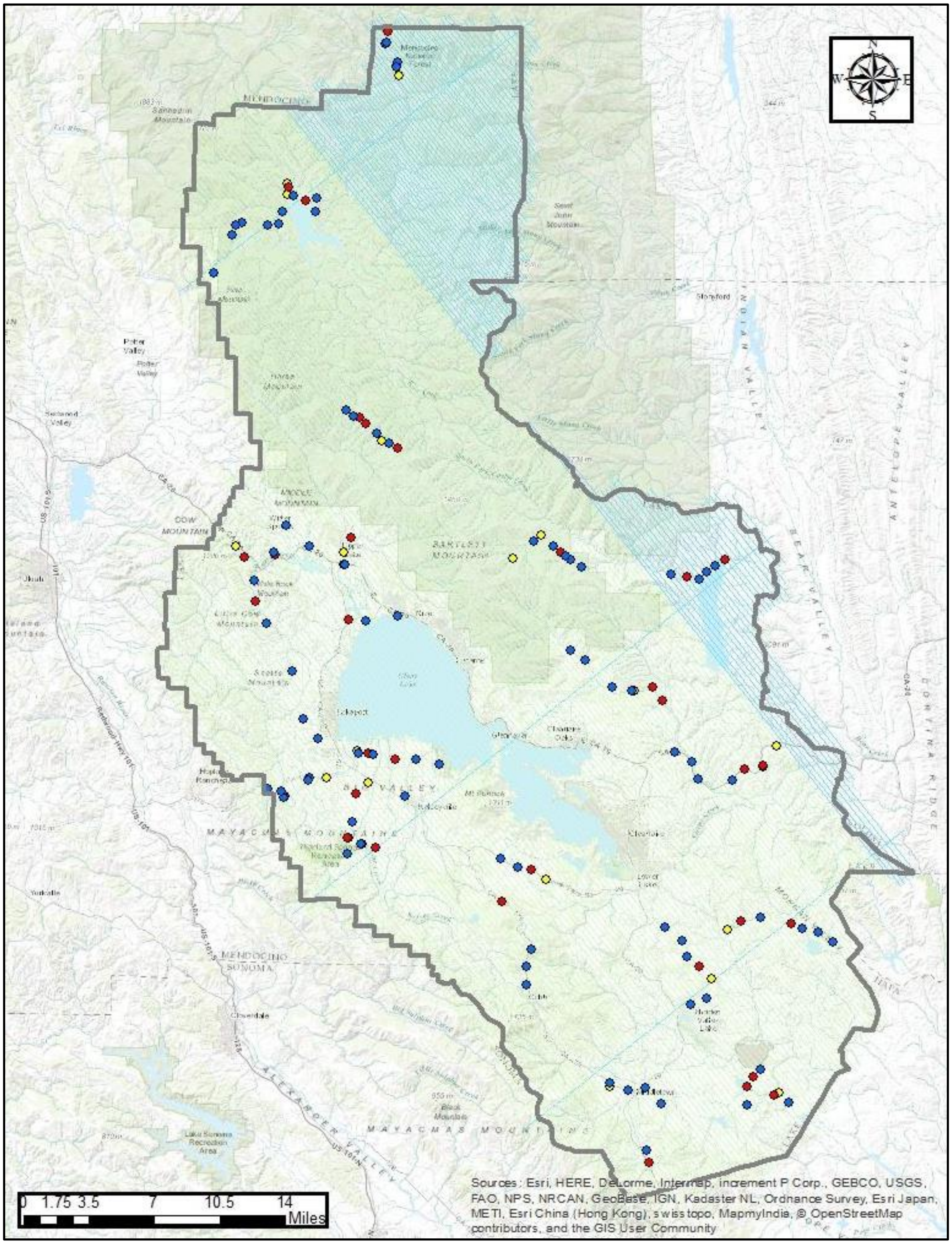

Figure 2: QC Checkpoints

03 DATA ACQUISITION / COLLECTION

3.1 Collection Area

Figure 3 displays the buffered project area with planned flight lines.

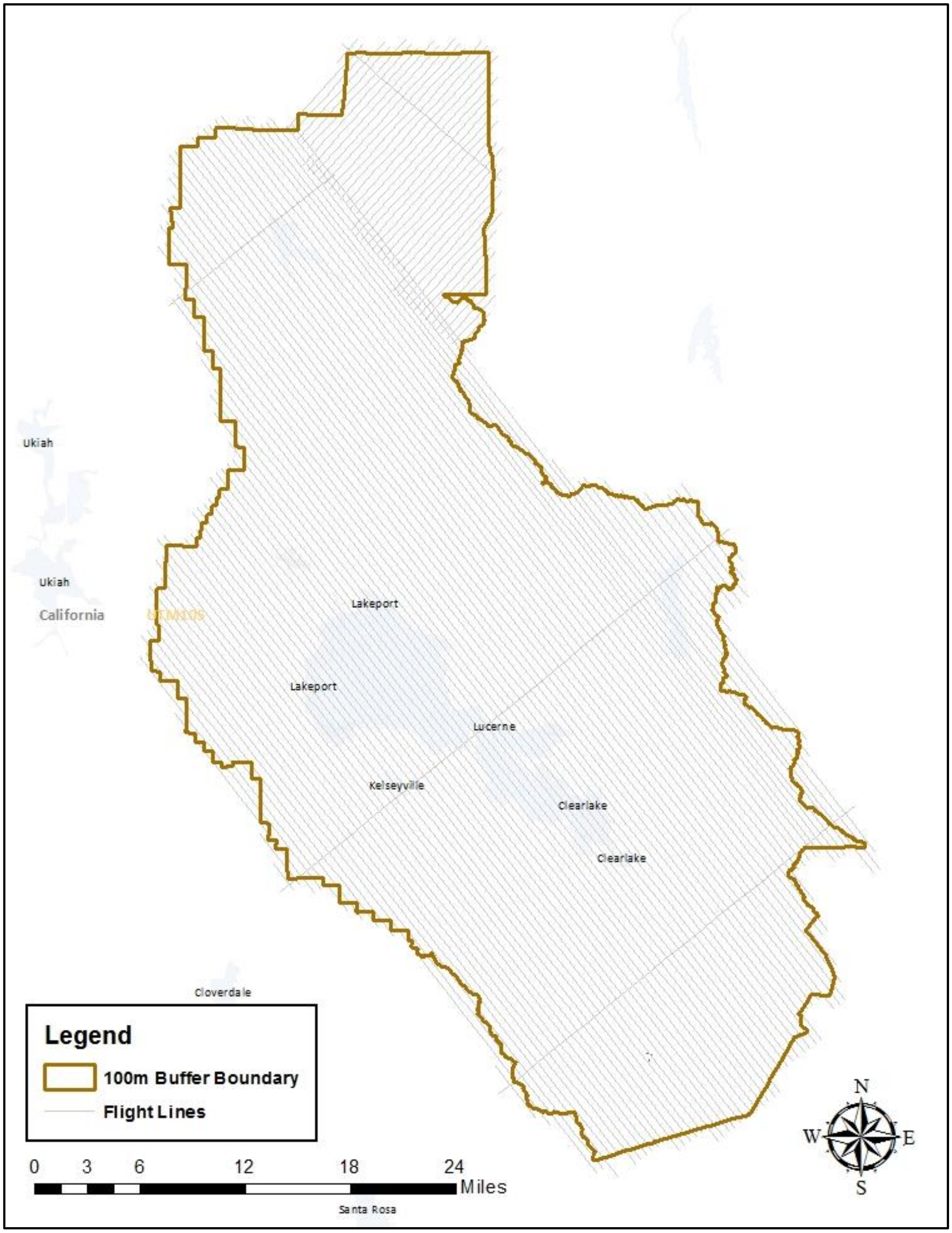

Figure 3: Planned Flight Lines

Figure 4 displays the flight line footprints.

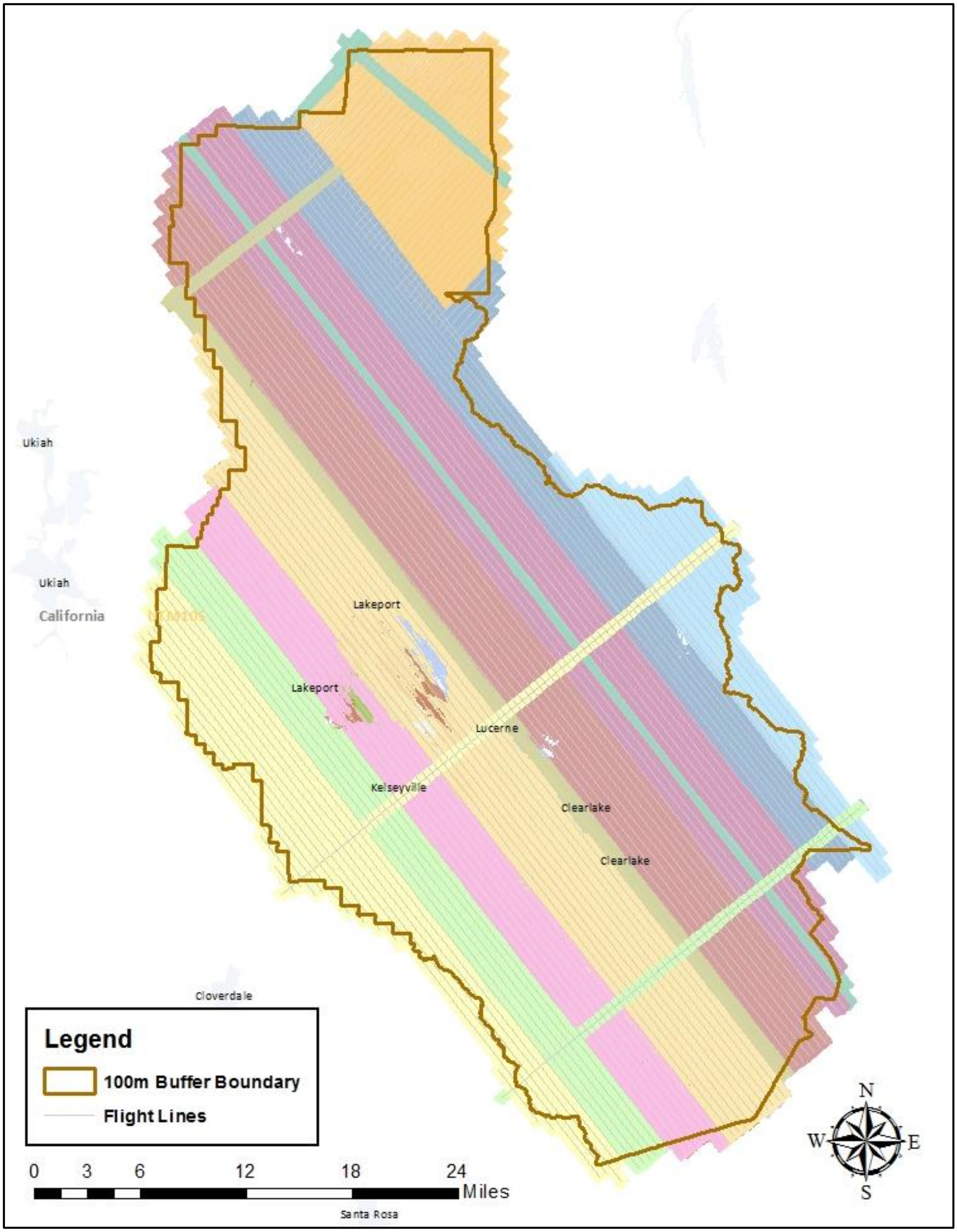

Figure 4: Flight Line Footprints

3.2 LiDAR Data Acquisition Considerations

LiDAR data were acquired using a twin engine aircraft equipped with an antenna and receiver for airborne GPS collection. Flight status was communicated during data collection.

Data were collected when the following environmental conditions allowed:

- Cloud and fog-free between the aircraft and ground
- Snow free (with the exception of some northern areas in the mountains that was approved by client)
- Leaf off

3.3 Project Design

The following present collection information and sensor parameters used to acquire a QL2 collection:

Collections (Lifts):	14
Collection Dates:	December 29th, 2015 – February 14th, 2016
Field of View (FOV):	27 degrees
Average Point Density (planned):	2 pts/m^2
Flight Level(s) AMT:	2,500 meters
Sensor Type:	Leica ALS-70
Sensor Serial Number(s):	7108

Detailed flight logs can be referenced in Appendix B.

04 LIDAR PRODUCTION

4.1 Verification of Data Usability

All acquired LiDAR data went through an initial review to assure that complete coverage had been obtained and that there were no gaps between flight lines before the flight crew left the project site. Once back in the office, the data were run through a complete iteration of processing to ensure that it was complete, uncorrupted, and that the entire project area has been covered without gaps between flight lines.

4.1.1 GPS/IMU Processing

Airborne GPS and IMU data were immediately processed using the airport GPS base station data, which was available to the flight crew upon landing the plane. This ensures the integrity of all the mission data. These results were also used to perform the initial LiDAR system calibration test.

4.1.2 Raw LiDAR Data Processing

Technicians processed the raw data to LAS format flight lines with full resolution output before performing internal QC. A starting configuration file was used in this process, which contains the latest calibration parameters for the sensor. The technicians also generated flight line trajectories for each of the flight lines during this process.

The following internal quality control checks were performed to verify complete coverage and ensure data quality:

- Trajectory files were checked to ensure completeness of acquisition for the flight lines, calibration lines, and cross flight lines.
- Thorough reviews of the data were performed to identify any data gaps in project area.
- A sample TIN surface was generated to ensure no anomalies are present in the data.
- Turbulence was inspected for each flight line. If any adverse quality issues were discovered, the flight line was rejected and re-flown.
- The achieved post spacing was evaluated against the project specified 0.7m NPS and also checked to make sure there is no clustering in point distribution.

4.1.3 LiDAR Data Processing

Data processing includes the following four (4) production steps for generating the final deliverables:

1. Raw data processing and boresight
2. Pre-processing
3. Post-processing
4. Product development

Quality control steps were incorporated throughout each step and are described in the following sections.

4.1.3.1 Raw Data Processing and Boresight

Raw data processing is the reduction of raw LiDAR, IMU, and GPS data into XYZ points. This is a hardware-specific, vendor-proprietary process. The raw LiDAR data processing algorithms use the sensor's complex set of electronic timing signals to compute ranges or distances to a reflective surface. The ranges were combined with positional information from the GPS/IMU system to orient those ranges in 3D space and to produce XYZ points.

The boresight for each lift was done individually as the solution may change slightly from lift to lift. The following steps describe the Raw Data Processing and Boresight process:

- Technicians processed the raw data to LAS format flight lines using the final GPS/IMU solution. This LAS data set was used as source data for boresight.
- Technicians first used proprietary and commercial software to calculate initial boresight adjustment angles based on sample areas selected in the lift. These areas cover calibration flight lines collected in the lift, cross tie and production flight lines. These areas are well distributed in the lift coverage and cover multiple terrain types that are necessary for boresight angle calculation. The technician then analyzed the results and made any necessary additional adjustment until it is acceptable for the selected areas. The boresight angle adjustment process ensures proper alignment between different look angles and between flight line overlap.
- Once the boresight angle calculation was completed for the selected areas, the adjusted settings were applied to all of the flight lines of the lift and checked for consistency. Technicians utilized commercial and proprietary software packages to analyze how well flight line overlaps match for the entire lift and adjusted as necessary until the results met the project specifications.

Once all lifts were completed with individual boresight adjustment, the technicians checked and corrected the vertical misalignment of all flight lines and also the matching between data and ground truth. The following criteria were used:

- Swath overlap difference, RMSDZ, ≤ 8 cm between adjacent swaths
- Swath overlap maximum difference ± 16 cm

A final vertical accuracy check of the boresighted flight lines was performed against the surveyed nonvegetated vertical accuracy (NVA) open terrain check points after the z correction to ensure meeting the requirement of $RMSE_Z$ (non-vegetated) ≤ 10 cm, NVA ≤ 19.6 cm 95% confidence level.

4.1.3.2 Pre-processing

Once boresighting was complete for the project and all lifts were tied to the ground control, the project was set up for filtering. The LiDAR data were cut to production tiles and flight line overlap points were reclassified temporarily for editing purposes.

4.1.3.3 Post-processing

The automated classification routines were applied to the tiled data first. The flight line overlap points, low noise points, high noise points and ground points were classified automatically in this process. Compass utilized commercial and proprietary software for automatic filtering. The parameters used in the process were customized for each terrain type per project to obtain optimum results. The algorithm has the ability to process large amounts of elevation point data in batch mode.

Once the automated filtering had been completed, the files were inspected through a visual validation to ensure that the filtering was not too aggressive or not aggressive enough. In cases where the filtering was too aggressive and important terrain have been filtered out, the data were either run through a different filter within the local area or was corrected during the manual filtering process. Bridge deck points were classified as well during the interactive editing process. The interactive editing was completed in visualization software that provides manual and automatic point classification tools. All manually inspected tiles then went through a peer review to ensure proper editing and consistency.

After the manual editing and peer review, all tiles went through another final automated classification routine. This process ensures only the required classifications are used in the final product (all points classified into any temporary classes during manual editing were re-classified into the project specified classifications). During this process, the points originally classified as flight line overlap were tagged as withheld points.

05 Product Development

5.1 Datum, Projection, and Units Project Specifications

All products developed and delivered for the Lake County LiDAR collection task order were referenced to the following horizontal and vertical datums, projection and units:

- Horizontal Datum: North American Datum of 1983 (2011)
- Vertical Datum: North American Vertical Datum of 1988 (Geoid 12B)
- Projection: Universal Transvers Mercator, Zone 10 North
- Horizontal Units: Meters
- Vertical Units: Meters

5.2 Raw Point Cloud Data

All collected flight lines that met project acquisition criteria were included in generating the raw point cloud product after boresight was completed and the adjustment was made to match data to the ground control. The flight lines went through the following processes:

- Assigned flight line ID to each point and file source ID to each flight line based upon the flight line trajectory
- Flagged flight line overlap points
- Aligned the raw point cloud swath data to deliverable projection/datum and unit
- Normalized intensity values to 16-bit
- Packaged final LAS 1.4 format

The raw point cloud data were delivered in fully compliant LAS v1.4 Point Record Format 6 with Adjusted Standard GPS Time. The flight lines included all collected and accepted points, and were fully calibrated, georeferenced, and adjusted to ground. Correct and properly formatted georeference information as Open Geospatial Consortium (OGC) well known text (WKT) was assigned in all LAS file headers. Intensity values were included for each point, normalized to 16-bit. The raw point cloud is a swath-based (flight line) product with one file per swath and one swath per file.

5.3 Classified Point Cloud Data

Once manual inspection, QC and final auto-filter was completed for the LiDAR tiles, the LAS data were packaged to the project specified tiling scheme, clipped to project boundary including the 100 meter buffer, formatted to LAS v1.4, and aligned with project horizontal and vertical specifications. The file header was formatted to meet the project specification with File Source ID assigned. This Classified Point Cloud product was used for the generation of derived products.

The classified point cloud product was delivered in fully compliant LAS v1.4 format, Point Record Format 6, with Adjusted Standard GPS Time at a precision sufficient to allow unique timestamps for each pulse. Correct and properly formatted georeference information as Open Geospatial Consortium (OGC) well known text (WKT) was assigned in all LAS file headers. Each tile has unique File Source ID assigned. The Point Source ID matches to the flight line ID in flight trajectory files. Intensity values were included for each point, normalized to 16-bit. The following classifications were used:

Class 1	Processed, but Unclassified
Class 2	Bare Earth Ground
Class 7	Low Noise (low, manually identified, if necessary)
Class 9	Water
Class 10	Ignored Ground (Breakline Proximity)
Class 17	Bridge Decks
Class 18	High Noise (high, manually identified, if necessary)

The classified point cloud product was delivered in tiles, without overlap, using the project tiling scheme.

5.4 LiDAR Hydro Breakline Collection

LiDAR Hydro Flattened Breaklines were collected and produced based on USGS LiDAR Base Specification version 1.2. The following hydro features were included:

- Inland Ponds and Lakes
- Inland Streams and Rivers
- Non-tidal Boundary Water
- Tidal Water

LiDAR Hydro Enforced Breaklines were developed in order to support FEMA's need for various risk analyses, as defined within the project's scope, including hydrologic analysis, hydraulic analysis, post-fire debris flow, and non-regulatory product development. The following hydro enforced breaklines were collected and delivered in addition to the hydro flattened breakline products:

- Additional Inland Ponds and Lakes
- Additional Inland Perennial Streams and Rivers
- Single line streams and culverts for flooding sources that drained in excess of 40 square miles

5.5 Hydro Flattened DEM

The Hydro Flattened DEM was generated using the LiDAR bare earth points and 3D hydro flattening polygons to a resolution of 1.0 meter. Bare earth points within a proximity of 1*ANPS along the hydro breaklines (points in Class 10) were excluded from the DEM generation process.

Technicians used proprietary software for the production of LiDAR-derived hydro-flattened bare earth DEM surface using a source TIN model to develop the 1-meter grid format product. Water bodies (inland ponds and lakes), inland streams and rivers, and other non-tidal water bodies were hydro-flattened within the DEM. Hydro-flattening was applied to all water impoundments, natural or man-made, that are larger than ~2 acres in area, to all streams that are nominally wider than 100', and to all non-tidal boundary waters bordering the project area, regardless of size.

After the initial hydro-flattened bare earth DEM was generated, technicians checked the tiles to ensure that hydro flattening was correctly applied and grid spacing met deliverable specifications. Tiles were then converted to ERDAS Imagine format. Georeference information was included in raster files. Void areas (i.e., areas outside the project boundary but within the tiling scheme) were coded using a unique "NODATA" value.

5.6 Hydro Enforced DEM

The Hydro Enforced DEM was generated by applying the additional hydro enforcement breakline features and hydraulic culvert breakline features to the Hydro Flattened DEM product. Using the USGS-NGP definition of a hydro enforced product, the additional single line stream and culvert features that were acquired as part of this task order were applied to the hydro enforced DEM product using elevations values tagged to those features from the LiDAR ground points. Those single line stream and culvert elevations were enforced into the DEM where all cells in the DEM along the hydro enforcement line features were modified to match the z elevations at vertices and the interpolated z elevations along the line feature geometry in between vertices.

Once the initial hydro-enforced bare earth DEM was generated, technicians checked the tiles to ensure that the grid spacing met project specifications. The technicians also checked the surface to ensure proper hydro-enforcement. The entire data set was checked for completed project coverage. The tiles were then converted to ERDAS Imagine format. Georeference information was included in raster files. Void areas (i.e., areas outside the project boundary, but within the tiling scheme) were coded using a unique "NODATA" value.

06 Conclusions

The Lake County, California LiDAR collection, acquired in response to the California Valley Fire and Butte Fire (DR-4240), includes the following deliverable products that were collected and controlled to FEMA and USGS-NGP (QL2) standards and specifications:

- Raw LiDAR Point Cloud
- Classified LiDAR Point Cloud
- Hydro Breaklines
    - Hydro flattening breaklines
    - Hydro enforcement breaklines
- Hydro-flattened DEM
- Hydro-enforced DEM
- Metadata
- LiDAR Acquisition, Processing, and Product Development Report
- Independent QA/QC Report

All products were independently assessed and assured to meet task order standards and specifications.

07 Appendix A: Survey Report

08 Appendix B: Flight Logs