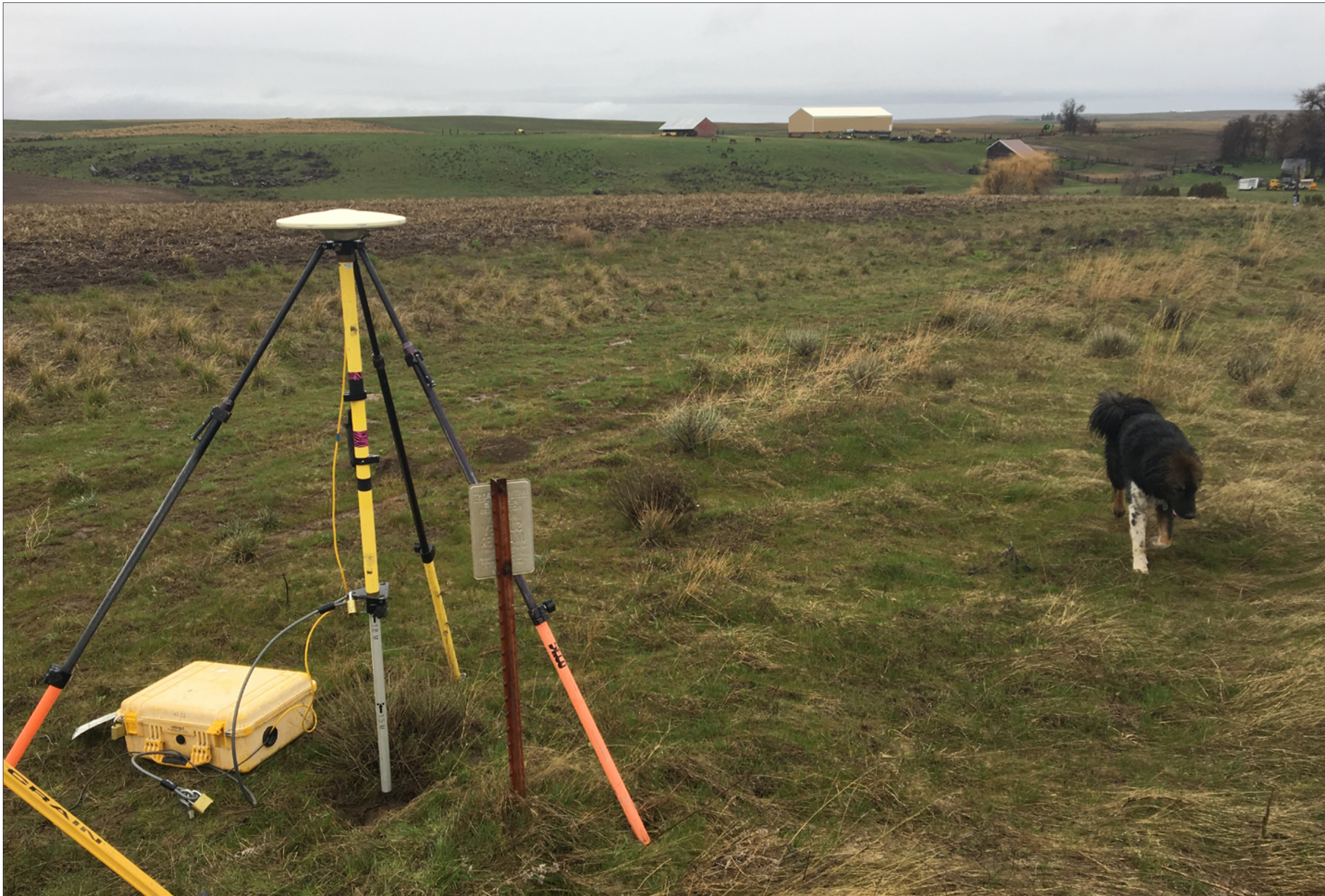
2017 OLC Grass Valley FEMA

August 8, 2017



Data collected for:
Oregon Department of Geology and Mineral Industries

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Contents

Project Overview

QSI has completed the acquisition and processing of Light Detection and Ranging (LiDAR) data describing the Oregon LiDAR Consortium's (OLC) Grass Valley FEMA Study Area. The OLC Grass Valley FEMA defined project area shown in Figure 1 encompasses 92,455 acres.

The collection of high resolution geographic data is part of an ongoing pursuit to amass a library of information accessible to government agencies as well as the general public.

LiDAR data acquisition occurred between April 28 and May 4, 2017. Settings for LiDAR data capture produced an average resolution of at least eight pulses per square meter. Final products are listed in page 3.

QSI acquires and processes data in the most current, NGS-approved datums and geoid. For OLC Grass Valley FEMA, all final deliverables are projected in Universal Transverse Mercator (UTM) Zone 10 N, using the NAD83 (2011) horizontal datum and the NAVD88 (Geoid 12B) vertical datum, with units in meters.

Table 1: Grass Valley delivery details

OLC Grass Valley	
Acquisition Dates	April 28 - May 4, 2017*
Defined Project Area	92,455 acres
Buffered Project Area	95,543 acres
Projection	UTM 10N
Datum: horizontal & vertical	NAD83 (2011) NAVD88 (Geoid 12B)
Units	meters

*See page four for specific acquisition dates.

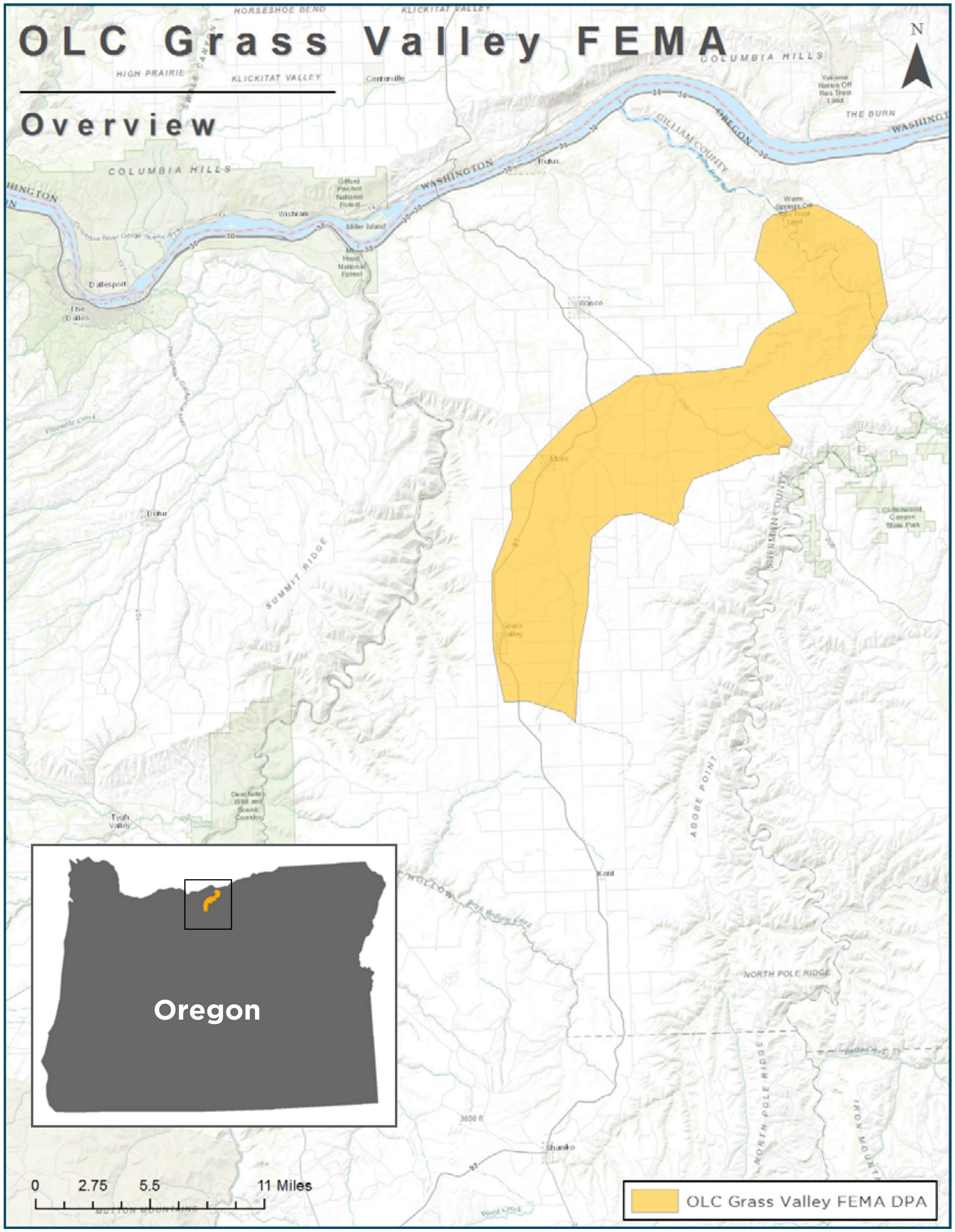

Figure 1: OLC Grass Valley FEMA study area location

Deliverable Products

Table 2: Products delivered for OLC Grass Valley FEMA study area.

OLC Grass Valley FEMA Projection: UTM 10N Horizontal Datum: NAD83 (2011) Vertical Datum: NAVD88 (GEOID12B) Units: meters	
Points	LAS v 1.4 tiled by 750 meter processing tiles • Default (1), ground (2), low noise (7), water (9), ignored ground (10), bridge decks (17), high noise (18) classified points LAS v 1.4 Swath files • Unclassified points
Rasters	1 meter ESRI GRID tiled to match 750 meter LAS processing tiles • Hydroflattened bare earth model
Vectors	Shapefiles (*.shp) • Defined project area (DPA) • Buffered project area (BPA) • 750 meter LAS tiling scheme, clipped to the DPA • Hydro breaklines • Check points used for testing non-vegetated vertical accuracy • Check points used for testing vegetated vertical accuracy • Ground control points used for LiDAR calibration • Project survey monuments
Metadata	• USGS-compliant metadata for all data products, as well as project-level metadata.

Aerial Acquisition

LiDAR Survey

The LiDAR survey utilized a Leica ALS 80 sensor mounted in a Cessna Grand Caravan. For system settings, please see Table 3. These settings are developed to yield points with an average native density of greater than eight pulses per square meter over terrestrial surfaces.

The native pulse density is the number of pulses emitted by the LiDAR system. Some types of surfaces such as dense vegetation or water may return fewer pulses than the laser originally emitted. Therefore, the delivered density can be less than the native density and lightly vary according to distributions of terrain, land cover, and water bodies. The study area was surveyed with opposing flight line side-lap of greater than 60 percent with at least 100 percent overlap to reduce laser shadowing and increase surface laser painting. The system allows up to four range measurements per pulse, and all discernible laser returns were processed for the output data set.

To solve for laser point position, it is vital to have an accurate description of aircraft position and attitude. Aircraft position is described as x, y, and z and measured twice per second (two hertz) by an onboard differential GPS unit. Aircraft attitude is measured 200 times per second (200 hertz) as pitch, roll, and yaw (heading) from an onboard inertial measurement unit (IMU).

Table 3: OLC Grass Valley FEMA acquisition specifications

OLC Grass Valley FEMA Acquisition	
Sensors Deployed	Leica ALS 80
Aircraft	Cessna Grand Caravan
Survey Altitude (AGL)	1,500 m
Pulse Rate	369.2 kHz
Pulse Mode	Multi (MPiA)
Field of View (FOV)	30°
Scan Rate	58.4 Hz
Overlap	100% overlap with 60% sidelap

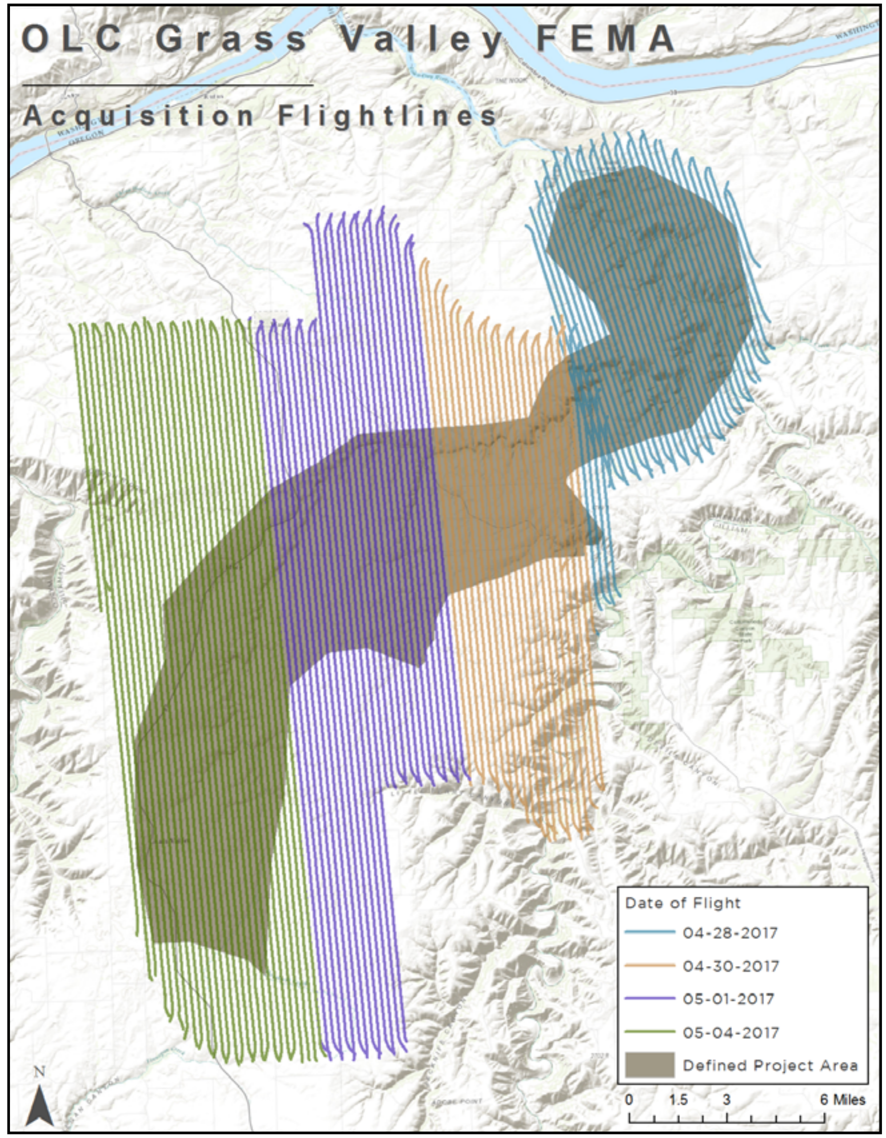

Figure 2: OLC Grass Valley FEMA acquisition specifications

Ground Survey

Ground control surveys were conducted to support the airborne acquisition. Ground survey data, including monumentation, ground control points (GCPs), and ground survey points (GSPs), are used to geospatially correct the aircraft positional coordinate data and to perform quality assurance checks on final LiDAR data.

Instrumentation

All Global Navigation Satellite System (GNSS) static surveys utilized Trimble R7 GNSS receivers with Zephyr Geodetic Model 2 RoHS antennas. Rover surveys for GCP and GSP collection were conducted with Trimble R8 and R10 GNSS receivers. Additionally, four permanent static GNSS stations from the Oregon Real-Time GNSS Network (ORGN; http://theorgn.net) were utilized for flight support and collection of GCPs and GSPs. See Table 5 for specifications of equipment used.

Monumentation

The spatial configuration of ground survey monuments and ORGN stations provided redundant control within 20 nautical miles of the mission areas for LiDAR flights. Monuments and ORGN stations were also used for collection of ground control points and ground survey points using real time kinematic (RTK), post processed kinematic (PPK), and fast static (FS) survey techniques. Monument and ORGN station locations were selected with consideration for satellite visibility, field crew safety, and optimal location for GCP/GSP coverage. New monumentation was set using 5/8" x 30" rebar topped with stamped 2-1/2" aluminum caps. QSI's professional land surveyor, Evon Silvia (OR PLS #81104) oversaw and certified the establishment of all monuments.

To correct the continuously recorded onboard measurements of the aircraft position, QSI concurrently conducted multiple static Global Navigation Satellite System (GNSS) ground surveys (1 Hz recording frequency) over each monument. During post-processing, the static GPS data were triangulated with nearby Continuously Operating Reference Stations (CORS) using the Online Positioning User Service (OPUS) for precise positioning. Multiple independent sessions over the same monument were processed to confirm antenna height measurements and to refine position accuracy. Table 4 provides the list of monuments used in the Grass Valley study area independent sessions over the same monument were processed to confirm antenna height measurements and to refine position accuracy.

Methodology

Ground control points and ground survey points were collected using real time kinematic (RTK), post-processed kinematic (PPK), and fast static (FS) survey techniques. For RTK surveys, a base receiver is positioned at a nearby monument to broadcast a kinematic correction to a roving receiver; for PPK and FS surveys, however, these corrections are post-processed. RTK and PPK surveys record observations for a minimum of five seconds, while FS surveys record observations for up to fifteen minutes on each GCP/GSP in order to support longer baselines for post-processing. All GCP and GSP measurements are made during periods with a Position Dilution of Precision (PDOP) no greater than 3.0 and in view of at least six satellites for both receivers. Relative errors for the position must be less than 1.5 centimeters horizontal and 2.0 centimeters vertical in order to be accepted.

In order to facilitate comparisons with high quality LiDAR data, GCP and GSP measurements are not taken on highly reflective surfaces such as center line stripes or lane markings on roads. GCPs and GSPs are taken no closer than one meter to any nearby terrain breaks such as road edges or drop offs. GCPs and GSPs were collected within as many flight lines as possible; however, the distribution depended on ground access constraints and may not be equitably distributed throughout the study area.

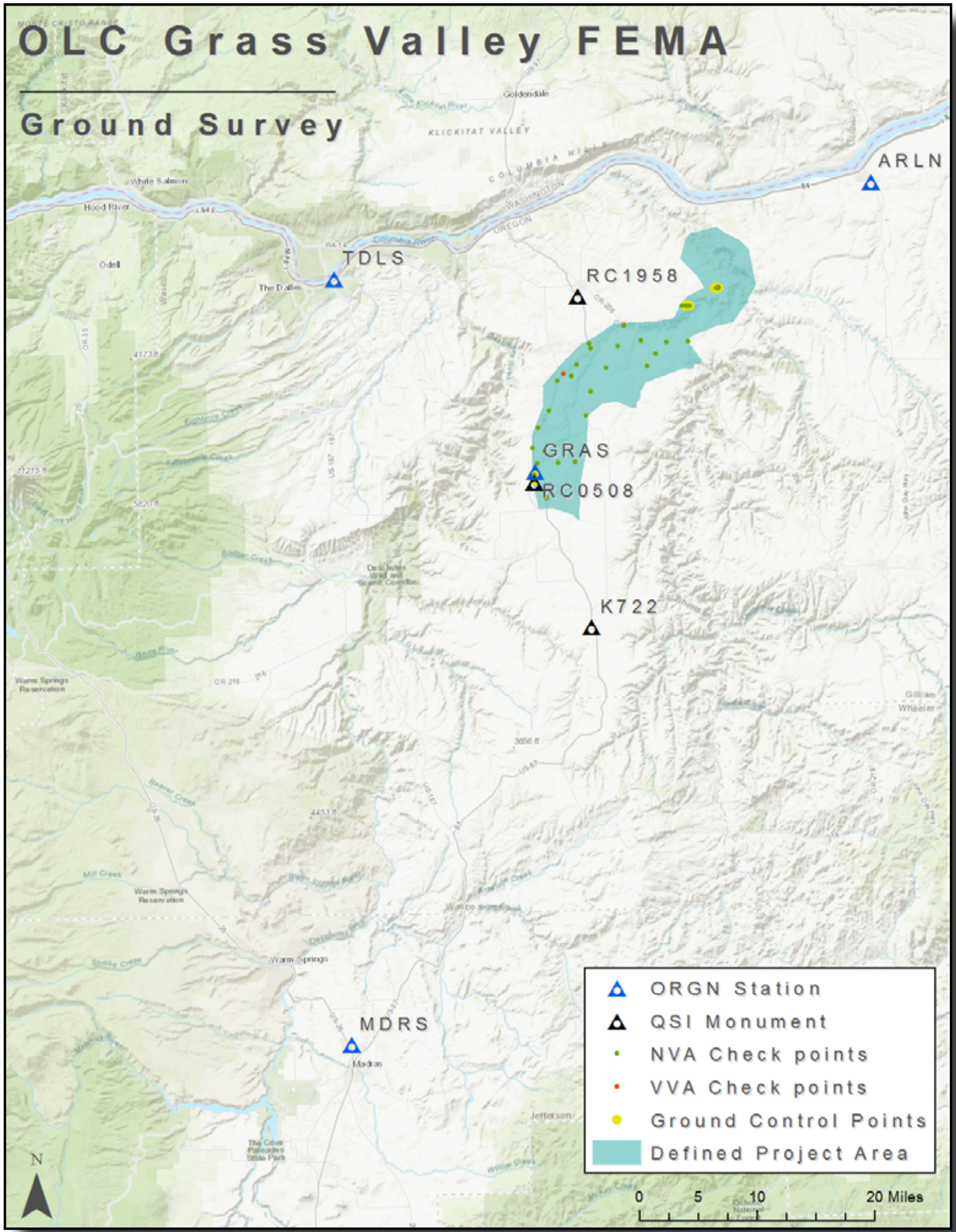

Figure 3: Grass Valley FEMA study area ground control

Figure 4: K722 monument

Figure 5: Zephyr GNSS Geodetic Model 2 antenna set up over K722 monument

Table 4: Grass Valley monuments. Coordinates are on the NAD83 (2011) datum, epoch 2010.00. NAVD88 height referenced to Geoid12B

	PID	Latitude	Longitude	Ellipsoid Height (m)	Orthometric Height (m)
QSI Monuments	K722	45° 10' 14.14714"	-120° 41' 44.33077"	796.320	817.142
	RC0508	45° 21' 02.35258"	-120° 47' 20.61736"	688.062	709.078
	RC1958	45° 34' 43.16298"	-120° 42' 12.38152"	408.617	429.946
ORGN Stations	TDLS	45° 36' 27.74446"	-121° 07' 46.16461"	26.928	48.410
	ARLN	45° 42' 29.52532"	-120° 10' 59.71154"	120.812	142.429
	GRAS	45° 21' 51.87542"	-120° 47' 14.62113"	677.871	698.904
	MDRS	44° 39' 50.49280"	-121° 07' 49.44945"	736.344	757.736

Table 5: Ground survey instrumentation

Instrumentation			
Receiver Model	Antenna	OPUS Antenna ID	Use
Trimble R7 GNSS	Zephyr GNSS Geodetic Model 2 RoHS	TRM57971.00	Static
Trimble R8 GNSS	Integrated Antenna	TRMR8_GNSS	Rover
Trimble R10 GNSS	Integrated Antenna	TRM_R10	Rover

Table 6: Monument accuracy

Monument Accuracy	
FGDC-STD-007.2-1998 Rating	
St Dev NE	2 cm
St Dev Z	2 cm

Processing

This section describes the processing methodologies for all data acquired by QSI for the 2017 OLC Grass Valley FEMA LiDAR project.

LiDAR Processing

Once the LiDAR data arrived in the laboratory, QSI employed a suite of automated and manual techniques for processing tasks. Processing tasks included: GPS, kinematic corrections, calculation of laser point position, relative accuracy testing and calibrations, classification of ground and non-ground points, and assessments of statistical absolute accuracy. The general workflow for calibration of the LiDAR data was as follows:

LiDAR Processing Step	Software Used
Resolve GPS kinematic corrections for aircraft position data using kinematic aircraft GPS (collected at two hertz) and static ground GPS (one hertz) data collected over geodetic controls.	POSGNSS v. 5.3, Trimble Business Center v. 3.61 PosPac MMS v.7.1
Develop a smoothed best estimate of trajectory (SBET) file that blends post-processed aircraft position with attitude data. Sensor heading, position, and attitude are calculated throughout the survey.	POSGNSS v. 5.3 POSPac MMS v 7.1
Calculate laser point position by associating SBET information to each laser point return time, with offsets relative to scan angle, intensity, etc. included. This process creates the raw laser point cloud data for the entire survey in *.las (ASPRS v. 1.4) format, in which each point maintains the corresponding scan angle, return number (echo), intensity, and x, y, z information. These data are converted to orthometric elevation (NAVD88) by applying a Geoid 12A correction.	Leica CloudPro 1.2.2
Import raw laser points into subset bins. Filter for noise and perform manual relative accuracy calibration.	GeoCue v 14.1.21.0, TerraScan v. 16.007, Custom QSI software
Classify ground points and test relative accuracy using ground classified points per each flight line. Perform automated line-to-line calibrations for system attitude parameters (pitch, roll, heading), mirror flex (scale), and GPS/IMU drift. Calibrations are performed on ground classified points from paired flight lines. Every flight line is used for relative accuracy calibration.	TerraMatch v. 16.008, TerraScan v. 16.007, Custom QSI software
Assess non-vegetated vertical accuracy and vegetated vertical accuracy via direct comparisons of ground classified points to reserved non-vegetated and vegetated checkpoint survey data.	TerraScan v. 16.007
Assign headers (e.g., projection information, variable length record, project name, GEOTIFF tags) to *.las files.	Las Monkey v. 2.2.1

LAS Classification Scheme

The classification classes are determined by the USGS Lidar Base Specification, version 1.2 specifications and are an industry standard for the classification of LIDAR point clouds. The classes used in the dataset are as follows and have the following descriptions:

- **Class 1 – Processed, but unclassified.** This class covers features such as vegetation, cars, utility poles, or any other point that does not fit into another deliverable class.
- **Class 2 – Bare earth ground**. Points used to create bare earth surfaces.
- **Class 7 – Low noise.** Erroneous points not meant for use below the identified ground surface.
- **Class 9 – Water.** Point returned off water surfaces.
- **Class 10 – Ignored ground.** Points found to be close to breakline features. Points are moved to this class from the Class 2 dataset. This class is ignored during the DEM creation process in order to provide smooth transition between the ground surface and hydro flattened surface.
- **Class 17 – Bridge decks.** Points falling on bridge decks.
- **Class 18 – High noise.** Erroneous points above ground surface not attributed to real features.

Hydro-Flattened Breaklines

Class 2 LiDAR was used to create a bare earth surface model. The surface model was then used to heads-up digitize 2D breaklines of inland streams and rivers with a 100 foot nominal width and inland ponds and lakes of two acres or greater surface area.

Elevation values were assigned to all inland ponds and lakes, inland pond and lake islands, inland streams and rivers and inland stream and river islands using Quantum Spatial proprietary software

All ground (ASPRS Class 2) LiDAR data inside of the collected inland breaklines were then classified to water (ASPRS Class 9) using TerraScan macro functionality. A buffer of three feet was also used around each hydro-flattened feature. These points were moved from ground (ASPRS Class 2) to ignored ground (ASPRS Class 10).

The breakline files were then translated to Esri file geodatabase format using Esri conversion tools.

Hydro-Flattened Raster DEM Creation

Hydro flattening breaklines are merged with Class 2 LAS and set to enforce elevations within closed areas identified as water while retaining near shore lidar elevations. This process is used to ensure a downstream gradient along streams and waterbodies are level.

LiDAR Accuracy Assessments

Relative Accuracy

Relative vertical accuracy refers to the internal consistency of the data set and is measured as the divergence between points from different flightlines within an overlapping area. Divergence is most apparent when flightlines are opposing. When the LiDAR system is well calibrated the line to line divergence is low (<10 centimeters). Internal consistency is affected by system attitude offsets (pitch, roll, and heading), mirror flex (scale), and GPS/IMU drift

Relative accuracy statistics, reported in Table 7 are based on the comparison of 124 full and partial flightlines and over 11 billion sample points.

Table 7: Relative accuracy

Relative Accuracy Calibration Results	
Project Average	0.031 m
Median Relative Accuracy	0.031 m
1σ Relative Accuracy	0.033 m
2σ Relative Accuracy	0.042 m
Flightlines	124
Sample points	11,120,271,608

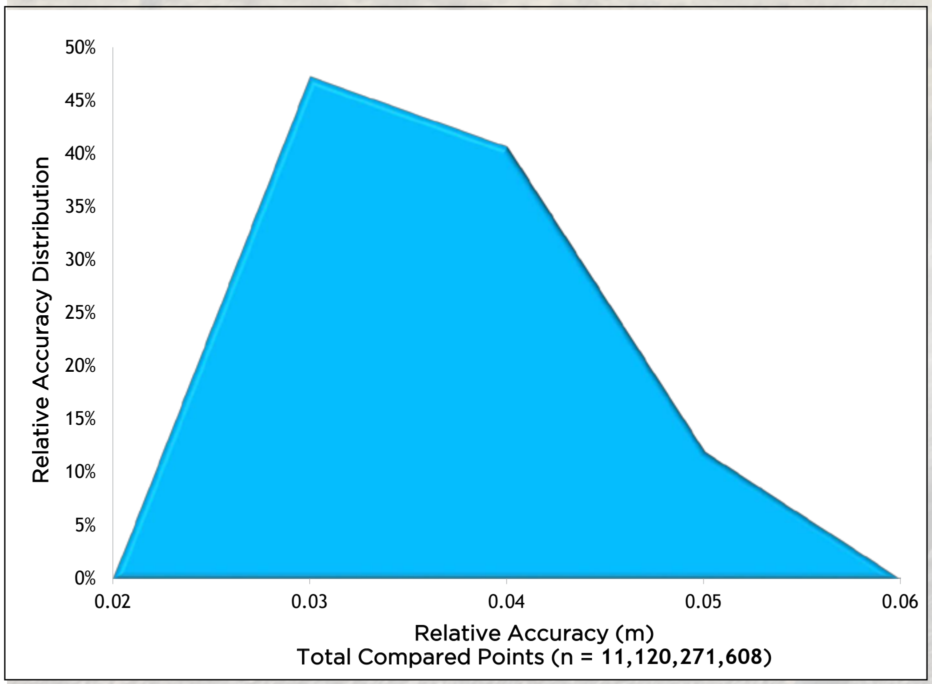

Figure 6: Relative accuracy based on 124 flightlines.

Vertical Accuracy

Vertical Accuracy reporting is designed to meet guidelines presented in the National Standard for Spatial Data Accuracy (NSSDA) (FGDC, 1998) and the ASPRS Positional Accuracy Standards for Digital Geospatial Data V1.0 (ASPRS, 2014). The statistical model compares known ground check points to the ground model, triangulated from the neighboring laser points. Vertical accuracy statistical analysis uses ground check points in open areas where the LiDAR system has a “very high probability” that the sensor will measure the ground surface and is evaluated at the 95th percentile.

For the OLC Grass Valley FEMA study area, a total of 295 ground control points (GCPs) were collected and used for calibration of the LiDAR data. An additional 43 check points were collected for independent verification. LAS data from the OLC Grass Valley FEMA project were compared to the independent check points to determine the NVA of the LAS Swath and of the Bare Earth DEM. A total of 21 check points were collected in areas of vegetated land cover; these points were used to verify the vegetated vertical accuracy of the bare earth DEM.

LAS Swath Non-vegetated Vertical Accuracy (NVA): 7.6 centimeters, meeting the required NVA of 18.1 centimeters per OLC requirement to achieve RMSEz of 9.25 centimeters. NVA was calculated at the 95 percent confidence level (1.96 x RMSEz), as defined by the NSSDA and in accordance with the National Digital Elevation Program (NDEP) and ASPRS Guidelines.

Bare Earth (BE) DEM Non-vegetated Vertical Accuracy (NVA): 8.5 centimeters, meeting the required NVA of 18.1 centimeters per OLC requirement to achieve RMSEz of 9.25 centimeters. NVA was calculated at the 95 percent confidence level (1.96 x RMSEz), as defined by the NSSDA and in accordance with the National Digital Elevation Program (NDEP) and ASPRS Guidelines.

Bare Earth (BE) surface Vegetated Vertical Accuracy (VVA): 10.7 centimeters, meeting the required VVA of 29.4 centimeters per USGS QL1 specifications. NVA was calculated at the 95 percent confidence level (1.96 x RMSEz), as defined by the NSSDA and in accordance with the National Digital Elevation Program (NDEP) and ASPRS Guidelines.

Table 8: Vertical accuracy results

Non-vegetated Vertical Accuracy	LAS Swath TIN Surface	Bare Earth DEM Surface
Sample Size (n)	43 Reserved Ground Check Points	43 Reserved Ground Check Points
Vertical Acccuracy at 95% Confidence Level (RMSE*1.96)	0.076 m	0.085 m
Root Mean Square Error (RMSEz)	0.039 m	0.043 m
Standard Deviation	0.035 m	0.048 m
Minimum Deviation	-0.092 m	-0.125 m
Maximum Deviation	0.105 m	0.093 m

Vegetated Vertical Accuracy	Bare Earth DEM Surface
Sample Size (n)	21 Reserved Ground Check Points
Vertical Acccuracy at 95th Percentile	0.107 m
Root Mean Square Error (RMSEz)	0.062 m
Standard Deviation	0.070 m
Minimum Deviation	-0.107 m
Maximum Deviation	0.108 m

Density

Pulse Density

Final pulse density is calculated after processing and is a measure of first returns per sampled area. Some types of surfaces (e.g., dense vegetation, water) may return fewer pulses than the laser originally emitted. Therefore, the delivered density can be less than the native density and vary according to terrain, land cover, and water bodies. Density histograms and maps have been calculated based on first return laser pulse density. Densities are reported for the entire study area.

Additionally, a density grid was generated with a cell size equal to twice the aggregate nominal pulse spacing; this grid was used to ensure that at least 90% of cells in the grid contained at least one LiDAR point.

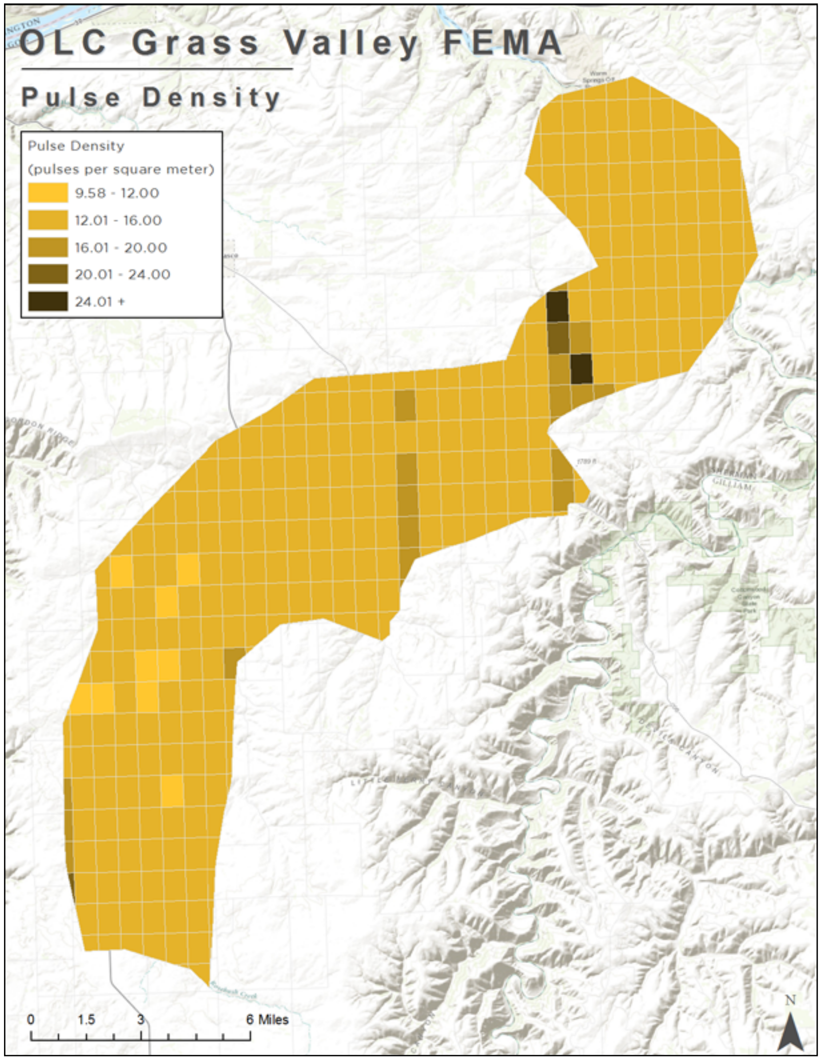

Table 9: Average pulse density

Average Pulse Density	pulses per square meter
	13.44

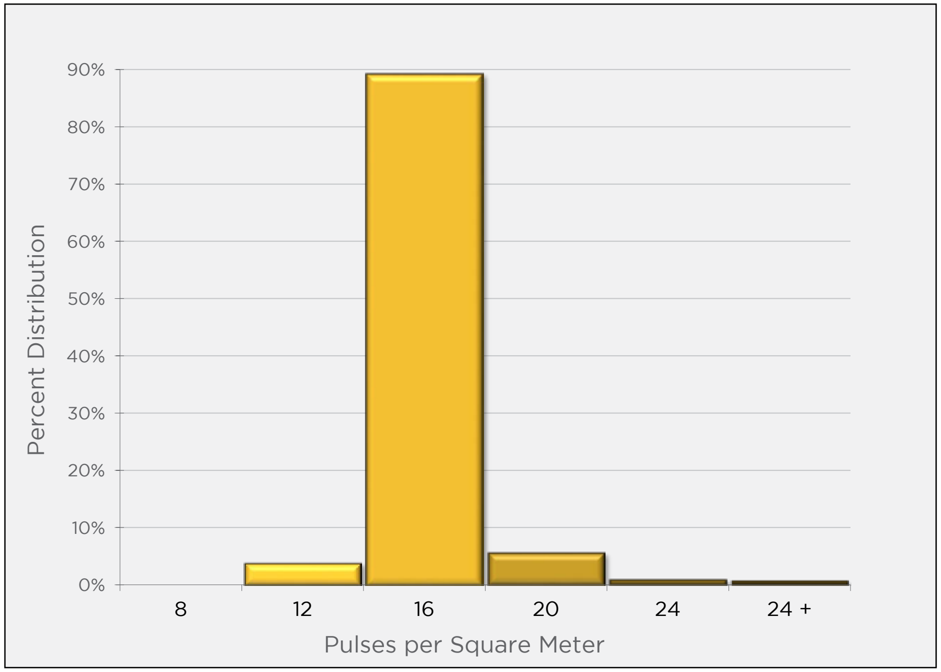

Figure 7: Average pulse density per 750 m tile (color scheme aligns with density chart).

Ground Density

Ground classifications were derived from ground surface modeling. Further classifications were performed by reseeding of the ground model where it was determined that the ground model failed, usually under dense vegetation and/or at breaks in terrain, steep slopes, and at tile

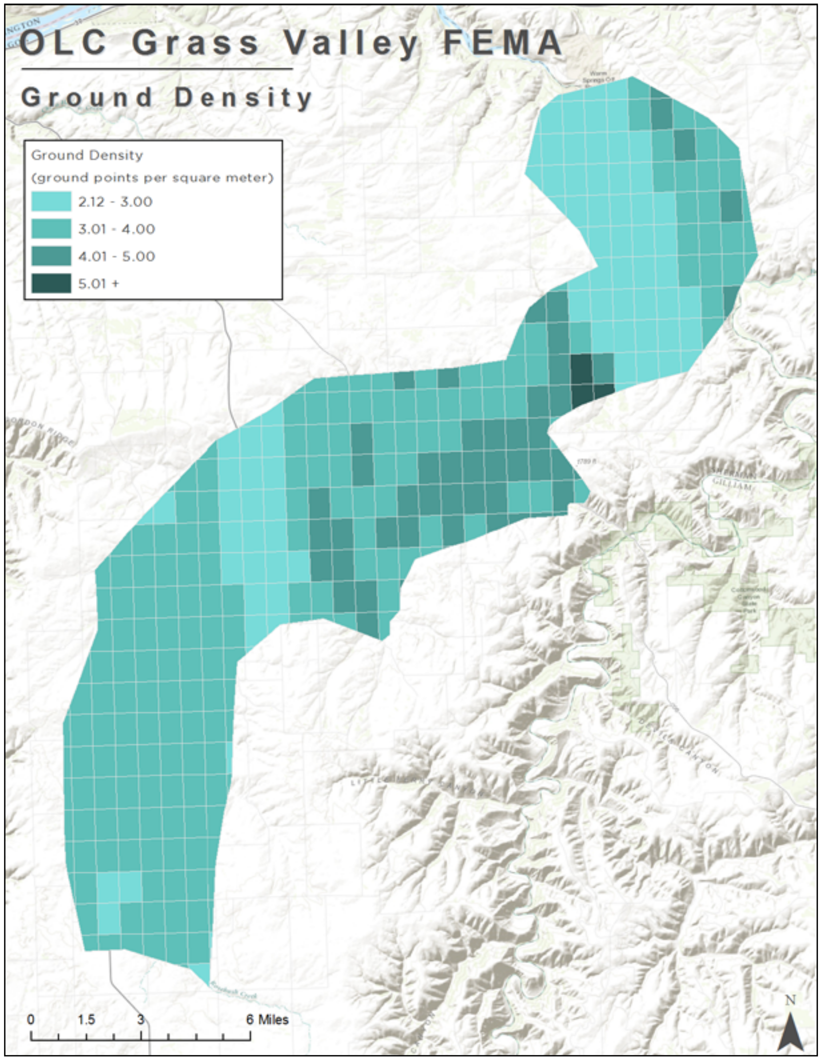

Table 10: Average ground density

Average Ground Density	points per square meter
	3.39

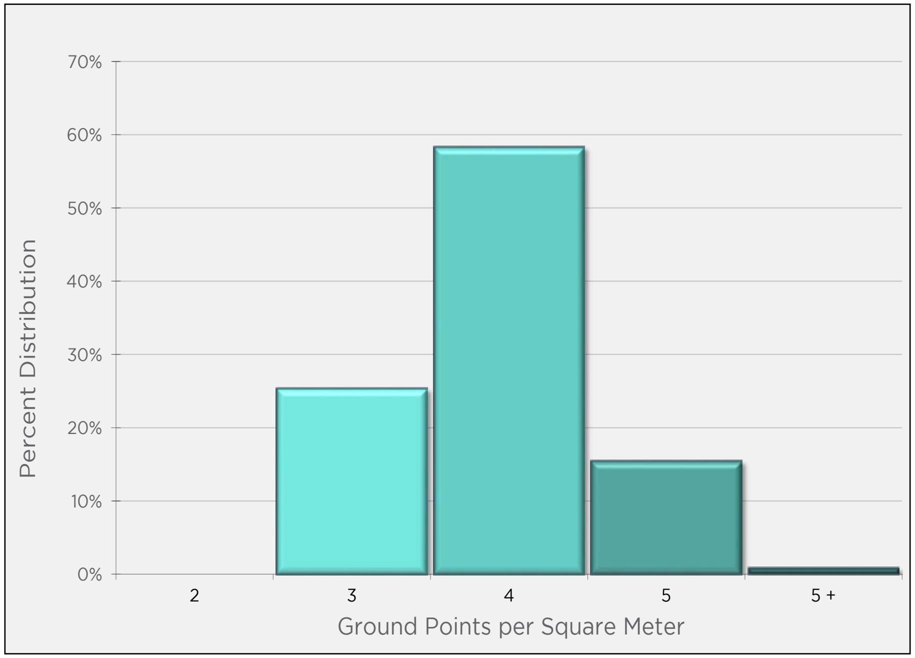

Figure 8: Average ground density per 750 m tile (color scheme aligns with density chart).

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Appendix A : PLS Certification

Quantum Spatial, Inc. provided LiDAR services for the OLC Grass Valley FEMA project as described in this report.

I, John English, have reviewed the attached report for completeness and hereby state that it is a complete and accurate report of this project.

August 8th, 2017

John English, GISP
Project Manager
Quantum Spatial, Inc.

I, Evon P. Silvia, PLS, being duly registered as a Professional Land Surveyor in and by the state of Oregon, hereby certify that the methodologies, static GNSS occupations used during airborne flights, and ground survey point collection were performed using commonly accepted Standard Practices. Field work conducted for this report was conducted between March 22 and May 1, 2017.

Accuracy statistics shown in the Accuracy Section of this Report have been reviewed by me and found to meet the "National Standard for Spatial Data Accuracy".

August 8, 2017

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