NOVEMBER 22, 2013

Sonoma County Vegetation Mapping and LiDAR Program:

Delivery Area 1

Technical Data Report

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INTRODUCTION

WSI is pleased to report that data collection, processing, and reporting are complete for the NASA ROSES Sonoma County LiDAR and Imagery survey of Delivery Area One. Data specifications, processessing, methodology, resolution and accuracy statistics are presented within.

Overview

The Sonoma County LiDAR and Vegetation Mapping Consortium along with NASA, have contracted WSI to collect Light Detection and Ranging (LiDAR) data to be used for vegetation mapping and the creation of high quality data for use in planning, conservation and Resource Management.

Data is in the process of being collected for all of Sonoma County, Lake Mendocino, and the Lake Sonoma watershed boundary, to the north of Sonoma County, as indicated on the overview map on the following page. The Sonoma area of interest (AOI) for Delivery Area One encompasses approximately 146,200 of the total 1,080,768 AOI acres.

LiDAR data and orthophotography began acquisition on September 28, 2013 and is still in progress. Deliverables include LiDAR point data, digital orthophotos, intensity, forest metric and hydroflattened rasters, one-foot contours, and 2D building planemetric vectors of the study area.

PROJECTION:
State Plane, California Zone II,
FIPS Zone 0402

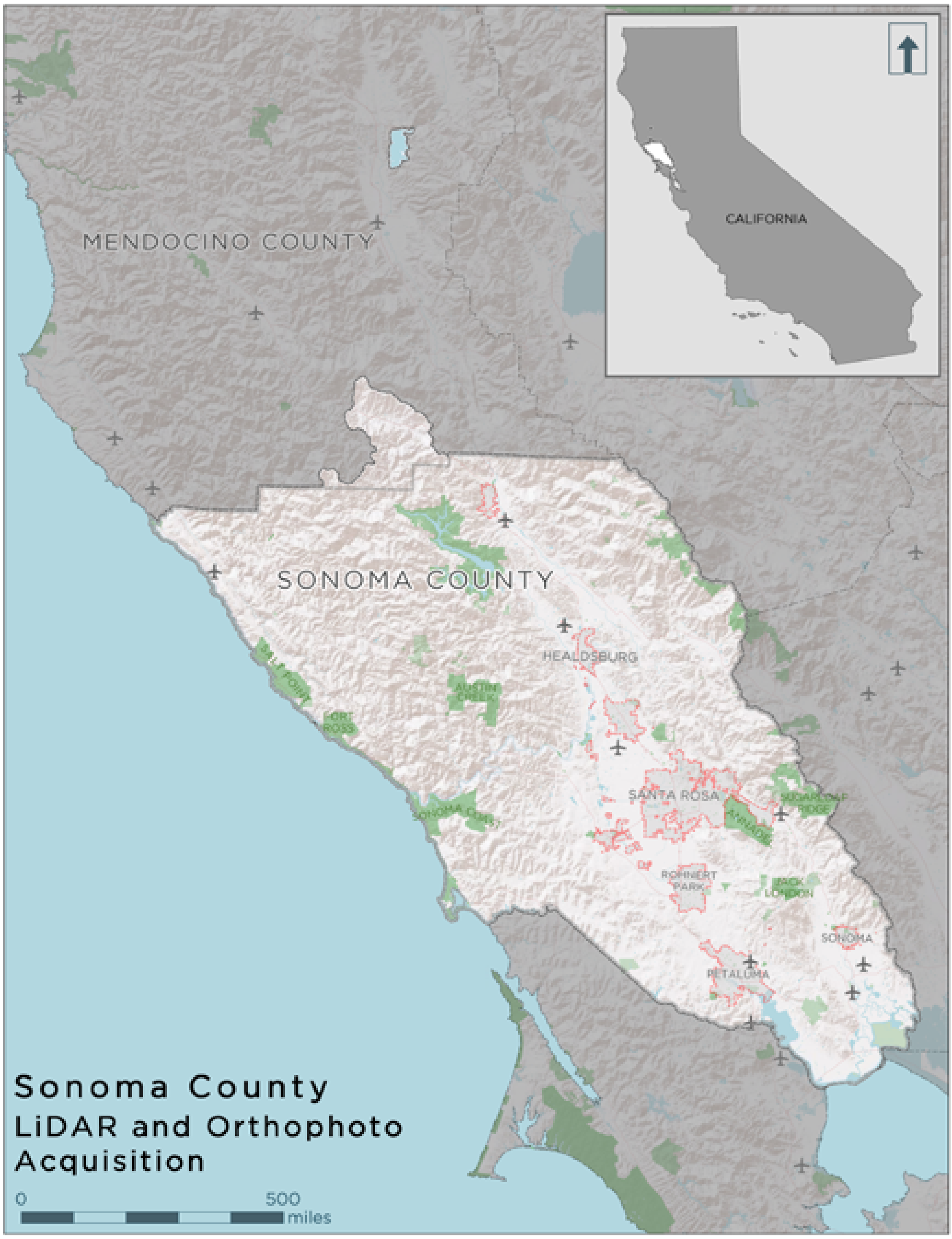
DATUM:
Horizontal: North American
Datum of 1983 (NAD83) 2011

North American Vertical Datum
1988 (NAVD88), GEOID 12a

UNITS:
US Survey Feet

- Sonoma County Agricultural Preservation and Open Space District (SCAPOSD)
- Sonoma County Water Agency (SCWA)
- California Department of Fish and Wildlife (CDFW)
- United States Geologic Survey (USGS)
- County of Sonoma Information Systems Department (ISD)
- Sonoma County Department of Transportation of Public Works (TPW)
- Nature Conservancy

INTRODUCTION



NASA Roses Sonoma County LiDAR & Imagery Survey			
	Acquisition Dates		Delivery Date
	Lidar	Orthophotos	
Delivery Area 1	9/28/2013 - 10/7/2013	10/11/2013- 10/12/2013	11/22/2013

Delivery Area Map. Delivery Area One highlighted in orange

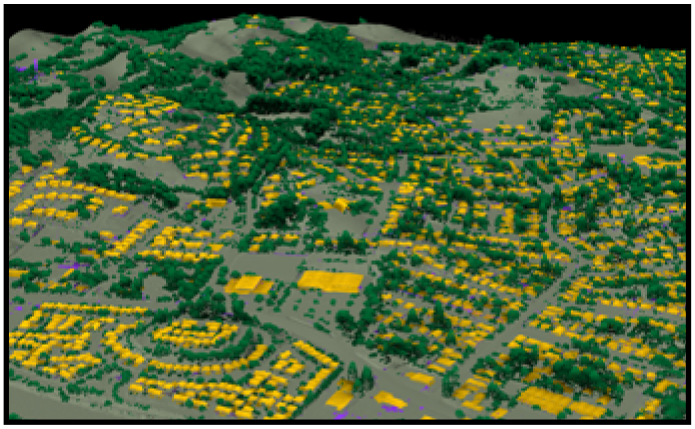
Orthophoto of neighborhood in Petaluma, California

Planning

Flightlines were developed using ALTM-NAV Planner (v.3.0) software. Careful planning of the pulse rate, flight altitude, and ground speed ensured that data quality and coverage conditions (8 pulses per square meter) were met while optimizing flight paths for minimal flight times.

The mission planning conducted at WSI was designed to optimize flight efficiency while meeting or exceeding project accuracy and resolution specifications. In this process, known factors were prepared for, such as GPS constellation availability, photography and acquisition windows, and resource allocation. In addition, a variety of logistical barriers were anticipated, namely required permitting, air space restrictions, and acquisition personnel logistics.

While in the field, weather hazards and conditions affecting flight were continuously monitored due to their impact on the daily success of airborne and ground operations. For a more robust description of the planning that occurred for the NASA ROSES Sonoma County Vegetation Mapping Project please refer to the Ground Survey Plan and GPS Procedure Plan that was created and distributed prior to data acquisition (Appendix A).



Petaluma, California. Feature extracted LiDAR

Ground Survey

Monumentation

Ground data has been collected for all missions thus far, which included establishing and occupying survey control, collecting static positional data, collecting ground check points (GCPs) using GPS real-time kinematic (RTK), and Post-Processed Kinematic (PPK) survey with a roving radio relayed unit, and installing air targets.

Using the High Accuracy Reference Network (HARN) and the Continuous Operation Reference System (CORS), WSI tied to a network of points with orthometric heights determined by differential leveling. Where available, First Order National Geodetic Survey (NGS) published monuments with NAVD88 are used. In the absence of NGS benchmarks, WSI established new monuments. For the Sonoma County Delivery Area One, one NGS monument and one previously established WSI monument, as well as three new monuments, have been established and occupied (see table on the following page). Every effort is made to keep monuments established by WSI within the public right of way or on public lands. If monuments are required on private property, consent from the owner is required. All monumentation is done with five-eigths-inch by 30-inch rebar topped with a two inch diameter aluminum cap stamped “Watershed Sciences, Inc.”

WSI owns and operates multiple sets of Trimble GPS and Global Navigation Satellite System (GNSS) dual-frequency L1-L2 receivers, which were used in both static and GCP surveys (listed in the table below).

During each LiDAR mission, a ground-based technician was deployed, outfitted with two Trimble Base Stations (R7) and one RTK Rover (R8).

Above: Sonoma_12 survey cap and accompanying R7 Base Station.

GPS Specifications	Survey Control Monuments	Ground Check Points (GCPs)
Accuracy	RMSExy ≤ 1.5 cm (0.6 in.)	RMSExyz ≤ 2 cm (0.8 in.)
	RMSEz ≤ 2.0 cm (0.8 in.)	Deviation from monument coordinates
Resolution	Minimum of one per 13 nautical mi. spacing	≥ 25 per surveyed monument
	Minimum independent occupation of 4 hrs. & 2 hrs.	969 Total
Equipment	Trimble R7	Trimble R7
	R8 GNSS	R8 GNSS
	GLONASS	GLONASS

Final Monument Positions

All static control points were observed for a minimum of one two-hour session and one four-hour session. At the beginning of every session the tripod and antenna were reset, resulting in two independent instrument heights and data files. Fixed height tripods were used when available. Data were collected at a recording frequency of one hertz using a 10-degree mask on the antenna.

GPS data was uploaded to WSI servers for WSI PLS QA/QC and oversight. OPUS processing triangulated the monument position using three CORS stations resulting in a fully adjusted position. After multiple sessions of data collection at each monument, accuracy was calculated. Blue Marble Geographics Desktop v. 2.5.0 software was used to convert the geodetic positions from the OPUS reports. A total of five control monuments were surveyed for Delivery Area One of this project. Upon completion of the project, a total network adjustment will be performed. All established monuments will be certified by a CA PLS upon final delivery. The final monument positions are presented in the table above.

Subset of Monuments within Sonoma County Delivery Area 1

PID	Latitude	Longitude	Ellipsoid (m)
PGE_CO_01	38 °15' 03.05878"	-122°35' 20.51059"	-3.623
L21_01	38°15' 40.02375"	-122° 36' 53.31200"	-5.660
SONOMA_07	38°15' 09.10626"	-122°29' 19.95490"	-11.258
SONOMA_12	38°18' 08.45064"	-122°49' 57.93663"	-13.052
SONOMA_13	38°15' 24.14708"	-122°21' 39.79471"	2.876

Ground Check Points

A Trimble R7 base unit was set up over an appropriate monument to broadcast a real-time correction to a roving R8 unit. This RTK rover survey allows for precise location measurement (2.0 centimeters). The GCP survey was conducted during periods with a Position Dilution of Precision (PDOP) of 3.0 and in view of at least six satellites by the stationary reference and roving receiver. For the RTK survey, the collector recorded at least a five-second stationary observation, and then calculated the pseudorange position from three one-second epochs with the relative error less than 1.5 centimeters horizontal and 2.0 centimeters vertical.

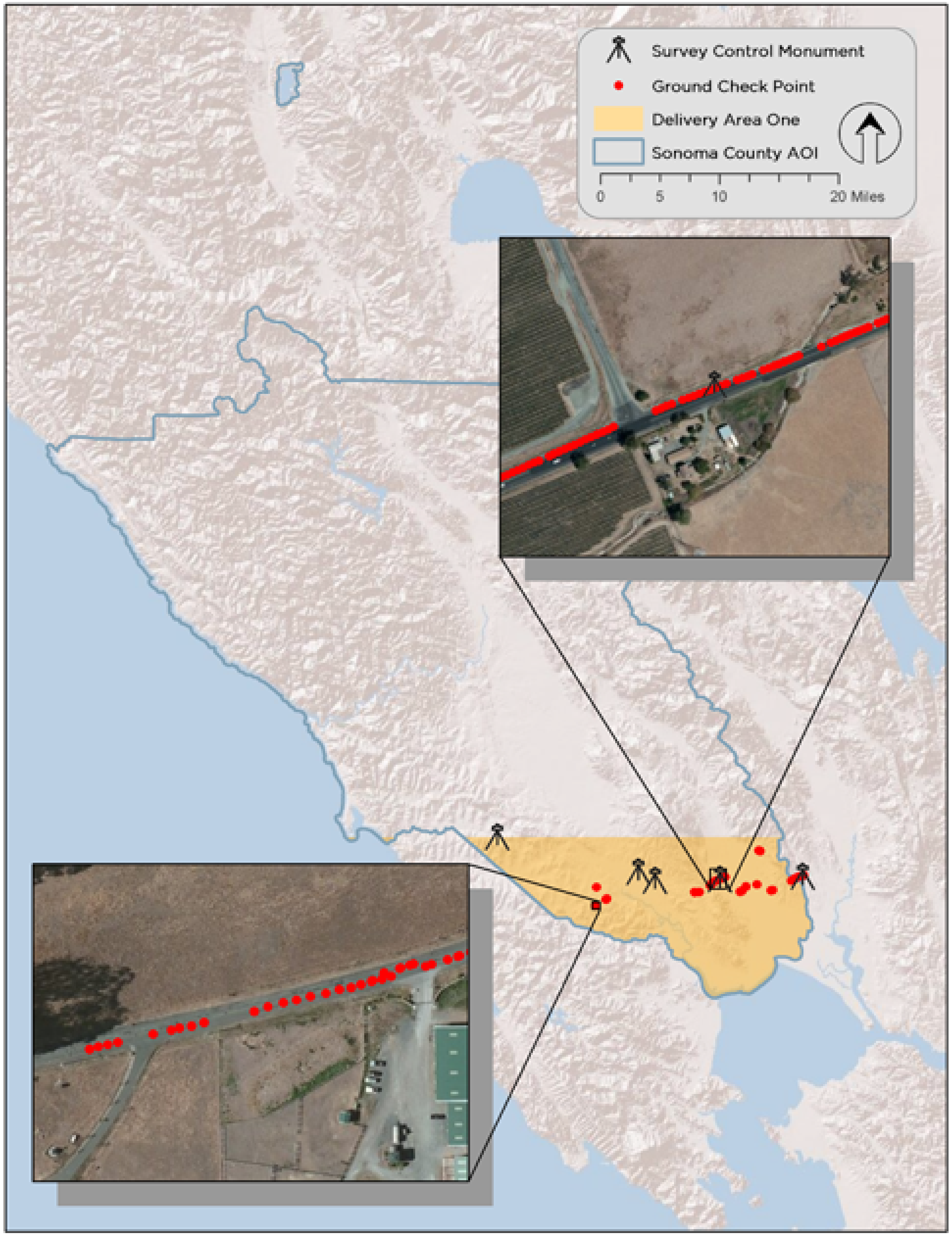
Monument Accuracy:

FGDC-STD-007.2-1998 Rating	
Standard Deviation Northing, Easting	0.02 m
Standard Deviation Z	0.05 m

The PPK Survey is similar to an RTK survey, where a roving GPS unit is paired with a static GPS base station and deployed to collect true ground points, however, a radio connection to the base need not be established. This potentially allows for greater dispersion of ground data beyond the limit of radio communication, though no real-time correction is available. All geometry is identical to that of a real-time survey, but baselines are post-processes and point values are determined afterward using applicable software. Precision thresholds are equal to RTK thresholds and out-of-tolerance points are discarded.

Ground check point (GCP) positions were collected (through means of RTK and PPK Survey) on bare earth locations such as paved, gravel, or stable dirt roads, and other locations where the ground was clearly visible (and was likely to remain visible) from the sky during the data acquisition and GCP measurement periods. In order to facilitate comparisons with LiDAR data, GCP measurements were not taken on highly reflective surfaces such as center line stripes or lane markings on roads.

For each control monument, at least 25 GCPs were taken within five nautical miles of the base. The planned locations for these control points were determined prior to field deployment, and the suitability of these locations was verified on site. The distribution of ground check points depended on ground access constraints, and may not be equitably distributed throughout the study area. A total of 1,834 GCPs were used to calibrate Delivery Area One.



Right: Ground Control and GCP positions for Delivery Area One.

Receiver Equipment Specifications:

Receiver Model	Antenna	OPUS Antenna ID	Use
Trimble R7 GNSS	Zephyr GNSS Geodetic Model 2	TRM55972.00	Static
Trimble R8	Integrated Antenna R8 Model 2	TRM_R8_Model 2	Static & RTK

Land Class cover Checkpoints

In addition to the hard-surface GCP data collection, check points were also collected across the delivery area on three different land class cover types to provide Supplemental Vertical Accuracy (SVA) statistics in accordance with National Standard for Spatial Data Accuracy (NSSDA) guidelines and used the U.S. Geological Survey's Land Cover Institute's land cover class definitions as a guideline (USGS LCI).

The dominant land cover classes within the delivery area are listed below. The descriptions provide further detail regarding the actual vegetation. In order to further refine the USGS class standard for Grassland/Herbaceous, "above the knee" and "below the knee" were used as the defining line between tall grass and short grass. This analysis demonstrates that the vertical accuracy of the interpolated ground surface, across all land cover classes, meets or exceeds vertical accuracy specifications.

A total of 71 Individual land class checkpoints in three different land cover classes were collected. Additional land cover classes will be added as they are encountered throughout the project.

Land Cover Classification	
Shrub (25)	Areas characterized by natural or semi-natural woody vegetation with aerial stems, generally less than six meters tall, with individuals or clumps not touching to interlocking. Both evergreen and deciduous species of true shrubs, young trees, and trees or shrubs that are small or stunted because of environmental conditions are included.
Grasslands/Herbaceous Short Grass (40)	Areas dominated by upland grasses and forbs. In rare cases, herbaceous cover is less than 25 percent, but exceeds the combined cover of the woody species present. These areas are not subject to intensive management, but they are often utilized for grazing. Distinguished as below the knee in length.
Grasslands/Herbaceous Tall Grass (25)	Areas dominated by upland grasses and forbs. In rare cases, herbaceous cover is less than 25 percent, but exceeds the combined cover of the woody species present. These areas are not subject to intensive management, but they are often utilized for grazing. Distinguished as above the knee in length.

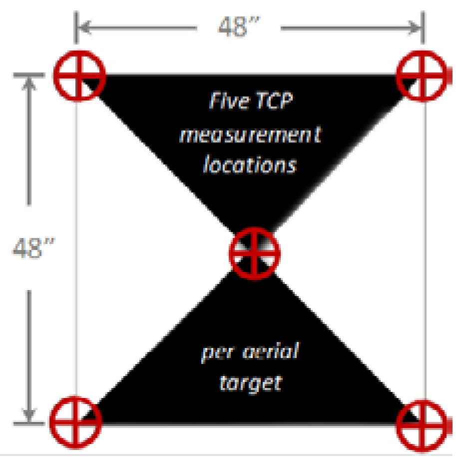
Aerial Targets

Prior to photo acquisition, permanent and temporary aerial photo targets were installed throughout the study area. The air targets were set within two miles of a GPS base location and target control points (TCPs) were collected at each corner of the target, as well as the center point, for utilization in the processing and quality control of the orthophoto deliverables.

Because temporary air targets are subject to possible outside influences (e.g., weather, curious public, wildlife), WSI identifies locations adequate for collection of TCPs that are on permanent features. Selected locations include existing aerial targets, turn-arrows, STOP bars, etc. that are visible from the aircraft. WSI also paints permanent targets in appropriate locations when necessary. Additional permanent air targets were identified in the field and used for processing orthophotos.

All TCPs were acquired using one of two methods. For every transmission line, the air targets that were set within two miles of a GPS base location had TCPs collected at each corner of the target as well as the center point. In order to increase TCP sample size for data quality, WSI also used a Fast-Static (FS) survey technique by baseline post-processing. For the air targets that were set this way, WSI collected a single static session with the R8 rover set over the center point of the target. The FS sessions lasted 15-30 minutes, depending on the distance from the air target to the base station. The static sessions and the concurrent R7 base session data were later processed in Trimble Business Center software. The use of post processing eliminates the need to deal with radio link issues, and fast static methodology generally results in precision equal to or better than full RTK collection on each target.

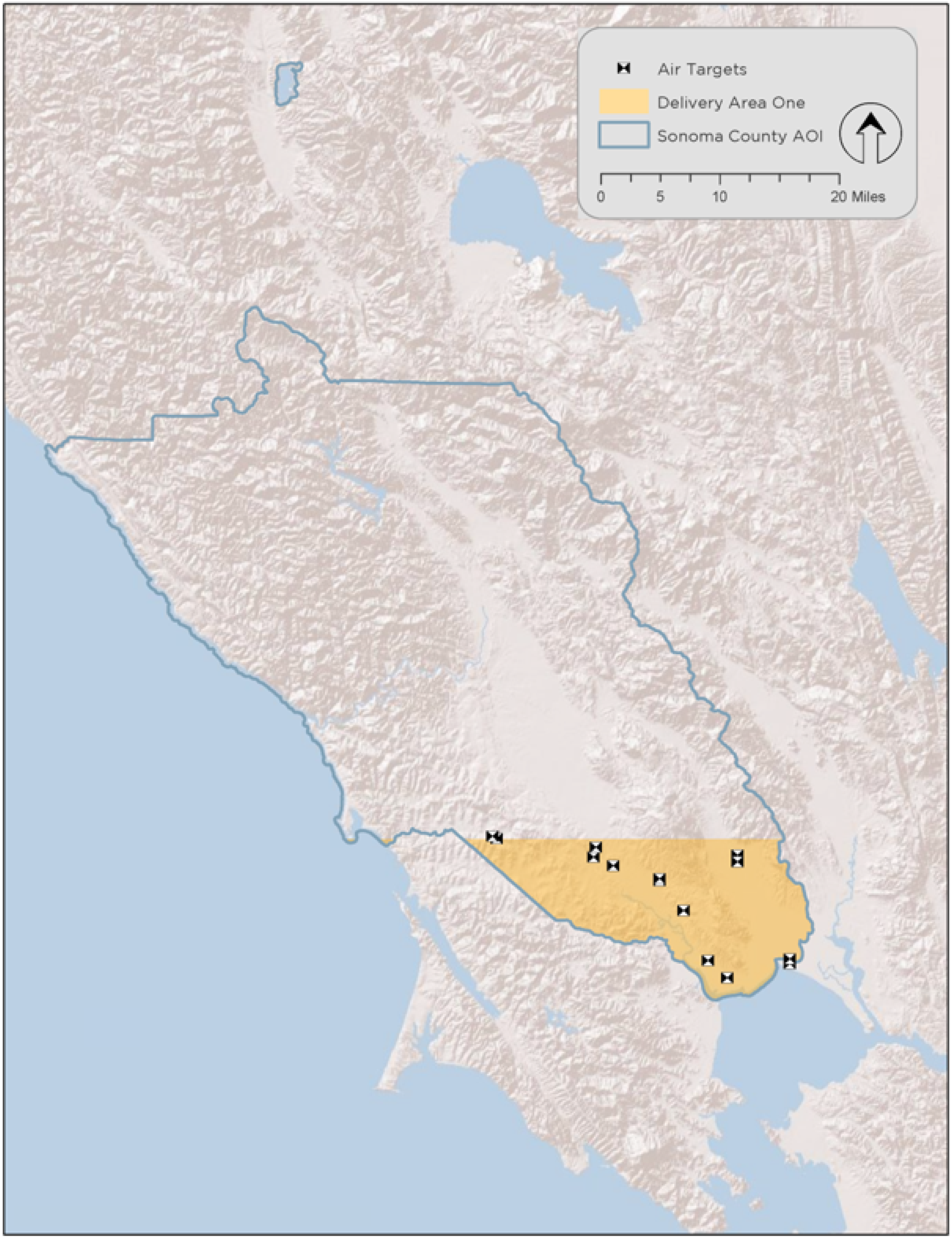
GPS Specifications	
GPS Satellite Constellation	≥ 6
GPS PDOP	≤ 3.0
GPS Baselines	≤ 13 nm



Temporary air target

Examples of permanent air targets

Placement of air targets, permanant and temporary, within Delivery Area One.



Airborne Survey

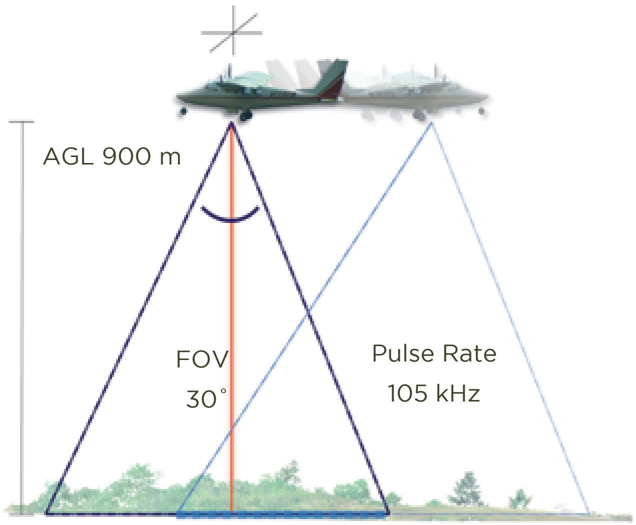
LiDAR Survey

The LiDAR survey began on September 28, 2013, and is scheduled to be completed by November 2013. Two airplanes have been deployed using an ALS50 and an ALS70 mounted in a Cessna 208-B Grand Caravan and a Navajo respectively. The systems was set to acquire ≥105,000 laser pulses per second and flown at 900 meters above ground level (AGL), capturing a scan angle of 15 degrees from nadir (30 degree field of view). The LiDAR system settings and flight parameters were designed to yield high-resolution data of >8 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 (e.g., 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 variable according to distribution of terrain, land cover, and water bodies.

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

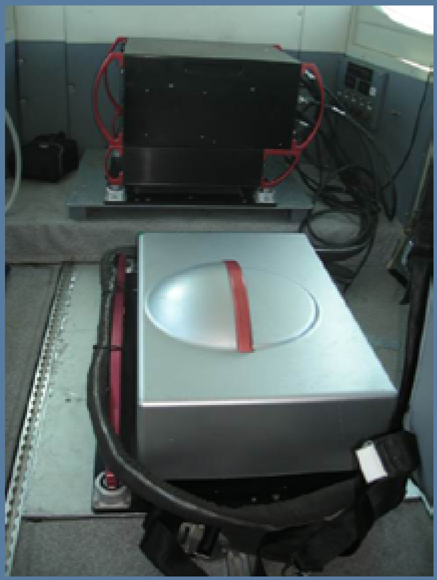
Piper PA-31 Navajo

Cessna 208 Caravan



The LiDAR sensor operators constantly monitored the data collection settings during acquisition of the data, including pulse rate, power setting, scan rate, gain, field of view, and pulse mode. For each flight, the crew performed airborne calibration maneuvers designed to improve the calibration results during the data processing stage. They were also in constant communication with the ground crew to ensure proper ground GPS coverage for data quality. The LiDAR coverage was completed with no data gaps or voids, barring non-reflective surfaces (e.g., open water, wet asphalt). All necessary measures were taken to acquire data under conditions (e.g., minimum cloud decks) and in a manner (e.g., adherence to flight plans) that prevented the possibility of data gaps. All WSI LIDAR systems are calibrated per the manufacturer and our own specifications, and tested by WSI for internal consistency for every mission using proprietary methods.

The acquisition occurred at maximum solar zenith angles given latitude and time of year, under clear conditions with no cloud cover, and less than 10 percent cloud shadow. Weather conditions were constantly assessed in-flight, as adverse conditions not only affect data quality, but can prove unsafe for flying. The study area was surveyed with opposing flight line side-lap of ≥60 percent (≥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.



ALS50 system mounted in the Cessna Grand Caravan

LiDAR Survey Specifications	
Aircraft	Cessna Grand Caravan & Piper PA-31 Navajo
Sensors	ALS50 & ALS70
Altitude	900 meter AGL
Targeted Aircraft Speed	150 knots
Coverage	60% Sidelap, 100% Overlap
Targeted Pulse Density	≥ 8 pulses/m^2
Pulse Mode	Single
Laser Pulse Rate	105,000 Hz
Field of View	30˚

Photography

Orthophoto acquisition was conducted between 10:00 AM and 12:00 PM on October 11 and 12, 2013.

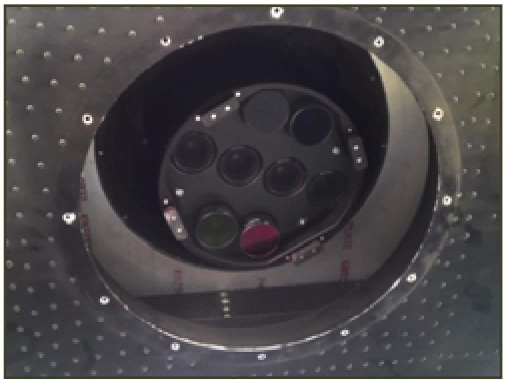
The photography survey utilized an UltraCam Eagle 260 megapixel camera mounted in a Cessna 208-B Grand Caravan. The UltraCam Eagle is an 80 mm, 260 megapixel large format digital aerial camera manufactured by the Microsoft Corporation. The system is gyro-stabilized and contains a fully integrated UltraNav flight management system with a POS-AV 510 IMU embedded within the body of the camera unit.

The Eagle was designed with high efficiency, high resolution, and high accuracy in mind. With a physical pixel size of 5.2 microns, the Eagle captures a 6.5 centimeter ground sample distance (GSD) at a flying height of 1000 meters AGL. This sensor size of the camera is 20,010 x 13,080 pixels in size, which allows for total ground coverage of 1300 x 850 meters within a single captured image frame at 1000 meters AGL. This large footprint coupled with a fast frame rate (1.8 seconds per frame) allows for highly efficient acquisition. The precise integrated UltraNav system is accurate enough for direct georeferencing in many applications.

UltraCam Eagle Manufacture Specifications	
Focal length	80mm
Data format	RGBNIR
Pixel size	5.2 µm
Image size	20,010 X 13,080 pixels
Frame rate	>1.8 s
FOV	66° X 46°
GSD at 1000 m	6.5 cm
Image width at 800 m	1,040 m

Above: A Cessna Grand Caravan 208B was employed in the collection of all orthoimagery.

Below: UltraCam Eagle installed in the aircraft.



Left: UltraCam Eagle lens configuration as viewed from the Cessna Caravan.

The UltraCam Eagle simultaneously collects panchromatic and multispectral (RGB, NIR) imagery in 14 bit format. The spectral sensitivity of the panchromatic charged coupled device (CCD) array ranges from 400-720 nm, with 16,000 grey values per pixel. 4 separate 27 mm lenses collect red (590-720 nm), green (490-660 nm), blue (410-590 nm) and near infrared (690-990 nm) light. Panchromatic lenses collect high resolution imagery by illuminating 9 CCD arrays, writing 9 raw image files. RGB and NIR lenses collect lower resolution imagery, written as 4 individual raw image files. Level 2 images are created by stitching together raw image data from the 9 panchromatic CCDs, and ultimately combined with the multispectral image data to yield Level 3 pan-sharpened TIFFs in 8 bit format.

Above: WSI painted permanant air target
Below: WSI temporary air target

Digital Orthophotography Survey Specifications	
Aircraft	Cessna 208-B Grand Caravan
Sensor	UltraCam Eagle
GPS Satellite Constellation	6
GPS PDOP	3.0
GPS Baselines	≤ 13nm
Image	8-bit GeoTIFF
Along Track Overlap	30%
Spectral Bands	Red, Green, Blue, NIR
Resolution	6 in. pixel size

In the WSI office, quality checks are built in throughout processing steps, and automated methodology allows for rapid data processing. There is no offshoring, which allows for in-house data collection and processing.

This section describes the processing methodologies for all data acquired by WSI for the NASA Roses Sonoma County Vegetation Mapping project, including LiDAR and orthophotography. All of our methodologies and deliverables are compliant with federal and industry specifications and guidelines (USGS v.13, FGDC NSSDA, and ASPRS).

LiDAR Data Processing

Calibration

Once the LiDAR data arrived to the Portland office, WSI employed a suite of techniques to calibrate it. 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.	IPAS TC v. 3.2, Trimble Business Center v. 3.01,
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.	IPAS TC v. 3.2
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. 1.2) 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 ALSPP 2.75 Build #9
Import raw laser points into subset bins (less than 500 megabites, to accommodate file size constraints in processing software). Filter for noise and perform manual relative accuracy calibration.	TerraScan v. 13, Custom WSI 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. 13, TerraScan v. 13, Custom WSI software
Assess fundamental vertical accuracy via direct comparisons of ground classified points to ground RTK survey data.	TerraScan v. 13
Assign headers (e.g., projection information, variable length record, project name, GEOTIFF tags) to *.las files.	Las Monkey v. 1.4.6

LiDAR Point Classification

This section outlines the methodology WSI employed in the classification of the point cloud and the classifications (see table).

Laser Point Processing Methodology

Laser point coordinates are computed using the independent data from the LiDAR system (pulse time, scan angle), and aircraft trajectory data (SBET). Laser point returns (first through fourth) are assigned associated coordinates (x, y, z), along with unique intensity values (0-255). The data are output into LAS v. 1.2 files. Each point maintains the corresponding scan angle, return number (echo), intensity, and x, y, z (easting, northing, and elevation) information.

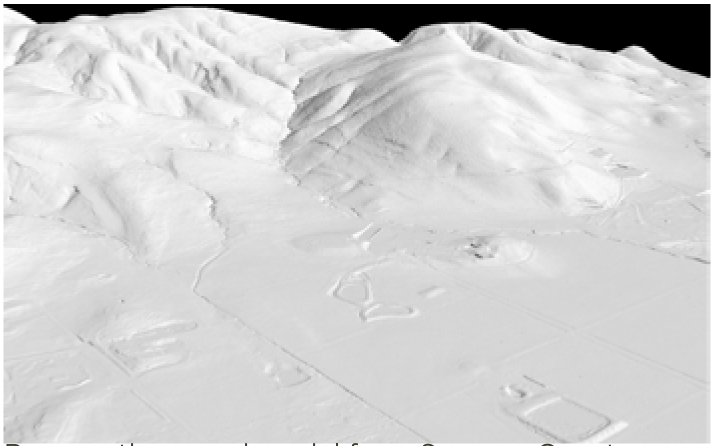
To facilitate laser point processing, tiles (polygons) are created to divide large, initial laser point files into manageable sizes (<500 MB). Point data calibration is performed to correct system offsets for pitch, roll, heading, and mirror scale (structural flex in the mirror mount material). Points from overlapping lines are tested for internal consistency and final adjustments are made for system misalignments. Automated sensor attitude and scale corrections yield three to five centimeter improvements in the relative accuracy. Once the system misalignments are corrected, vertical GPS drift is then resolved and removed per flight line, yielding a slight improvement (<1 centimeter) in relative accuracy. At this point in the workflow, data have passed a robust calibration that reduces inconsistencies from sensor attitude offsets, mirror scale, and GPS drift using a comprehensive procedure that uses overlapping survey data.

The LiDAR points are then filtered for noise, pits, and birds by automated screening and manual inspection. Spurious points are removed. For a tile containing approximately 7.5 to 9.0 million points, common sources of non-terrestrial returns are clouds, birds, vapor, and haze.

The TerraSolid software suite is designed specifically for classifying near-ground points. The processing sequence begins by removing all points that are not near the ground surface. The ground surface is refined through a statistical surface algorithm with constraints based on geometric relationships between points as well as point attribute filters. The resulting bare earth model is visually inspected using both triangulated irregular network (TIN) surface models and point cloud data. Additional ground point modeling is performed in site-specific areas to improve ground detail. Where ground point classification includes known vegetation (e.g., understory, low/dense shrubs, etc.) these points are manually reclassified as non-grounds.

Sonoma County Point Cloud Classification

Point Classification Description	Point Classification Number
Ground	1
Default	2
Vegetation	3
Building	6
Noise (manually classed)	7
Water	9
Ignored Ground	10
Noise (automatically classed)	11



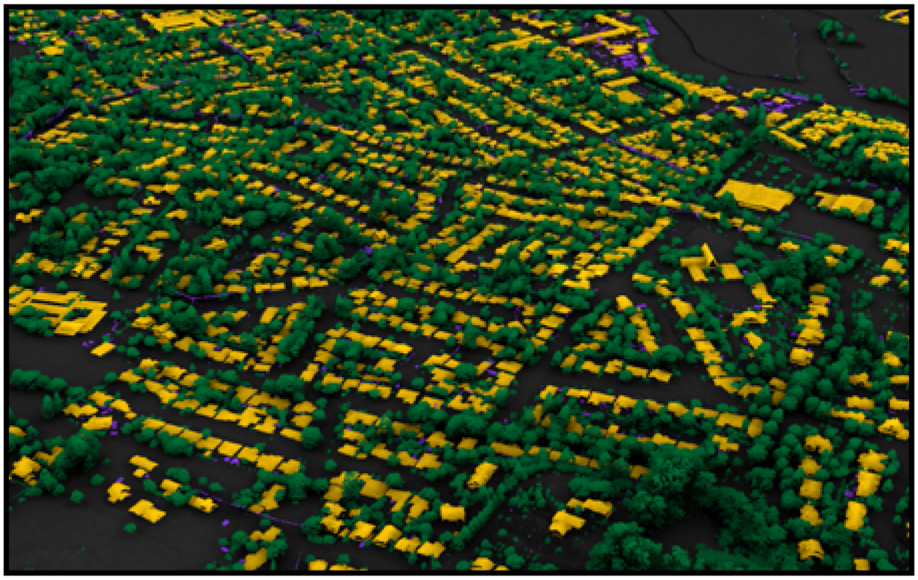
Bare-earth ground model from Sonoma County

Feature Extraction

WSI employs in-house methods for LiDAR feature extraction focusing on vegetation, water, and human-made structures. Accurate feature coding of the point cloud is essential for the extraction of vector layers, such as building footprints. Visual verification of correctness is conducted through a random sampling method that compares classifications to known areas identified in orthophotography. The general workflow for feature extraction is as follows:

Feature Extraction Workflow
All points seven feet or higher above the ground surface are given an initial classification of vegetation.
An initial building point classification is developed utilizing characteristics of the LiDAR points that are indicative of anthropogenic structures (e.g., height above ground, texture, planarity).
The vegetation classification is further refined using characteristics of the LiDAR points that are indicative of vegetation (e.g., multiple pulse returns, texture).
Classified points are manually inspected to complete the vegetation and building classification. Points above seven feet that do not represent vegetation or buildings (e.g., lamp post, street lights) are returned to the default class (1).
Ground classified points (2) within rivers and lakes that meet the size specifications outlined in the USGS LiDAR Base Specification (v1.0) are classified as water (9).
Classification accuracy is given a final review.

Petaluma, California. Feature extracted LiDAR



Building Classification and Vectorization

The objective of the building point classification and polygon generation is to provide accurate building representations in a timely fashion (considering the point density, complexity, and scale of the project). Three datasets have been generated that meet the objective:

1. Point cloud with building classified points
2. Building polygons showing the location of building classified points
   - Purpose: To provide bounding polygons delineating all building classified points in the LiDAR dataset without modification.
3. Building polygons with right angles and correct orientations enforced
   - Purpose: To provide a cartographic representation of building footprints.

Heavy vegetation can obscure portions of buildings from the LiDAR pulse. The extracted polygon layers are a direct representation of areas where the LiDAR pulse came into contact with a building surface. No inferences were made to account for obscured building surfaces.

All LiDAR points ascertained as building roof tops were classified as “Building” (ASPRSS code = class 6) by employing an automatic primary classification process followed by a detailed secondary analysis to ensure completeness and correctness.

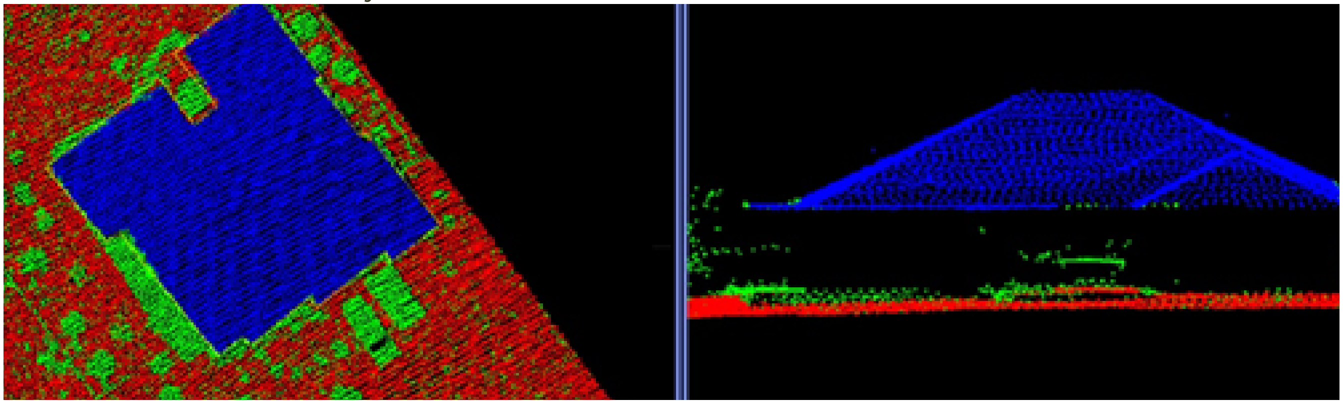
Building Point Classification Methodology

1. Preprocessing
   a. Ground point classification was completed.
   b. Points greater than 2.13m (7ft) above the triangulated ground surface were initially considered to be building candidates.

2. Primary Classification
   a. Groups of candidate points that formed planes were classified as building points.

3. Secondary Verification
   a. LAS files were inspected using TerraSolid products and significant remaining errors were corrected.
      i. Errors of Omission: Buildings with significant number of points not classified as building or missed entirely
      ii. Errors of Commission: Things other than buildings classified as such (RVs, trees, bridges, etc.)

Aerial (left) and cross-sectional (right) views of building-classified LiDAR points after primary classification and secondary verification

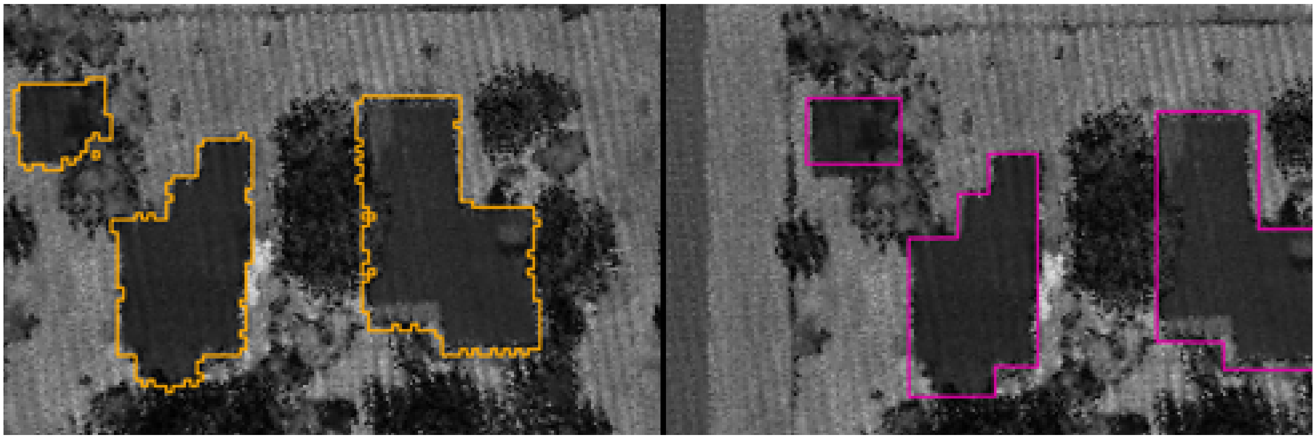


Building Vectorization Methodology

1. Vector Deliverable 1- “Building Point Extent”
   a. A bounding polygon showing the presence or absence of building classified points was generated from the point cloud.
   b. Interior gaps, if present, were removed from each bounding polygon.

2. Vector Deliverable 2- “Cartographic Buildings”
   a. The polygons from Deliverable 1 were generalized to extract probable build ing edges and dominant orientation angles.
   b. The polygons were redrawn with enforcement of right angles between all edge segments.
   c. Resulting polygons were rotated to fit dominant orientations.
   d. A supervised analysis corrected for edges that did not intersect at right angles.
   e. Only buildings greater than 9.29 meter (100 feet) were retained in the final data set.

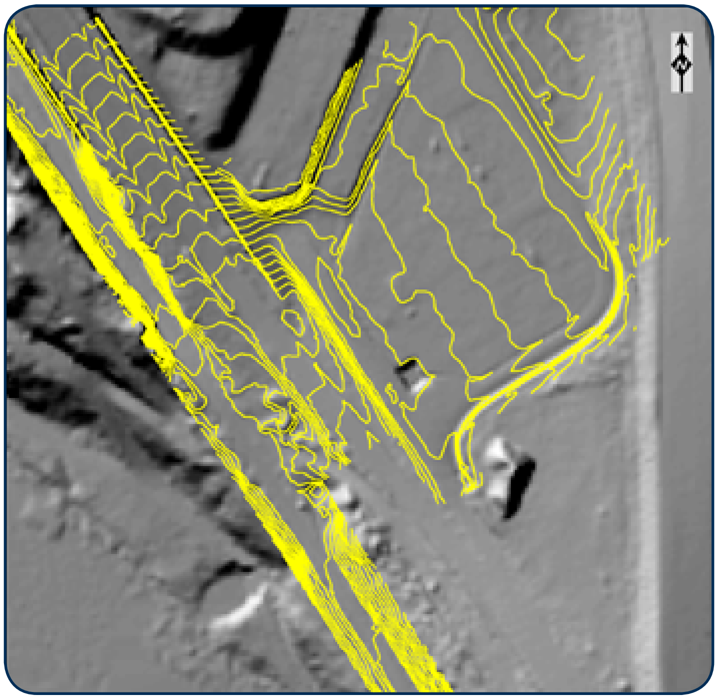
Building Point Extent (left) and Cartographic Buildings (right) vector deliverables, overlaid on 0.25 meter intensity imagery



Contours

Using automated processes, one-foot (30.48 cm) contours were created for the Sonoma County Delivery Area One study area. The workflow for contour generation is as follows:

Contour Generation Workflow
Contour sinuosity was minimized through a smoothing operation based on elevation bounds and a thinning operation constrained by elevation bounds within a sampling window.
Contour lines (one-foot intervals) were derived from ground-classified LiDAR point data using MicroStation v.8.01 and TerraModelor contour derivation tools.
Ground point density rasters were created within Bentley MicroStation v8i. Areas with less than 0.02 ground-classified points per square foot were considered "sparse" and areas with higher densities were considered “covered.” Building vectors were generated and areas of intersect between point density rasters and building vectors were identified; building vector rasters were used instead of point density rasters for sparse contour generation.
Contour lines were intersected with ground point density rasters and a confidence field was added to the contour shapefile. Contour lines over sparse areas are assigned a low confidence, while contour lines over covered areas are designated as high confidence. Areas with low ground point density are commonly beneath buildings and bridges, in locations with extraordinarily dense vegetation, over water, and in other areas where the LiDAR laser is unable to sufficiently penetrate the ground surface.



Left: Bare earth hillshade overlaid with one-foot contours and planimetric vectors. Contour lines in areas with sparse ground-classified LiDAR points, such as beneath buildings, are given a low confidence value, while contour lines in areas with high ground-classified LiDAR point density are given a high confidence value.

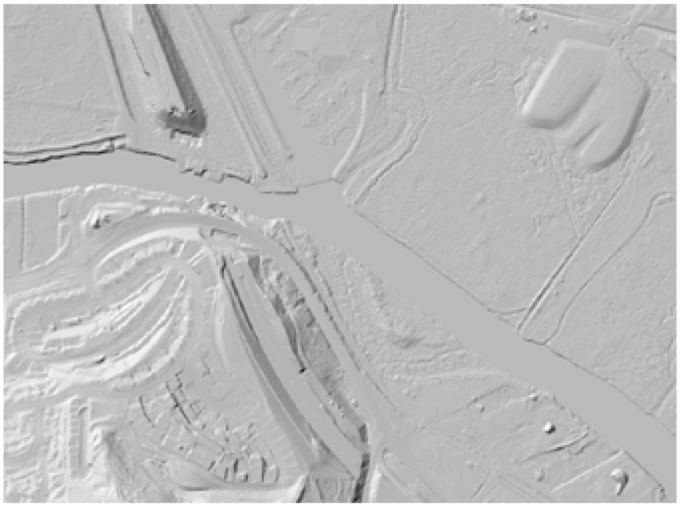
Hydro-Flattening

The bare-earth hydro-flattened digital DEM has been hydro-flattened according to the U.S. Geological Survey's National Geospatial Program's "LiDAR Guidelines and Base Specification" Version 13 (USGS NGP). For all water bodies perceived to be "flat," LiDAR points were sampled to arrive at an elevation threshold defining the water surface at a uniform elevation where the water edge meets the surrounding terrain. Intensity rasters, hillshades, and orthophotos were used to determine the edges of hydrological features. Breaklines were then created to encompass all areas considered to be water and were assigned the water surface elevation value determined previously. All "flat" water bodies greater than two acres were considered for hydro-flattening. All "islands" one acre or greater were retained in the DEMs.

Centerlines were digitized for all water surfaces not perceived as "flat." Thousands of points were sampled along the stream and channel centerlines to generate three-dimensional z values. A smoothing algorithm was then applied to ensure the centerlines consistently run downstream. LiDAR points were classified as water using the z threshold values of the appropriate centerlines. A breakline polygon was created around the water points with all discontinuities such as bridges and overhanging vegetation removed. Z values were applied to the breakline polygon based on the elevation values of the closest, associated centerline vertex. Again, "islands" were retained in the bare-earth DEMs if greater than one acre in size.

The bare-earth DEMs were created by triangulating all ground classified points and inserting 3-D breaklines utilizing TerraSolid's TerraScan and TerraModeler software. For non-flat features any ground points within one meter of the breaklines were reclassified to "ignored-ground" (ASPRS code: 10) before triangulation. The highest-hit DEMs were generated from "ground" and "default" classified points. In instances where "water" classified points had the highest elevation value, the water surface elevation from the bare-earth raster was used.

Examples of bare-earth hydroflattend DEMs along the Petaluma River in Delivery Area One of the Sonoma County Project Area

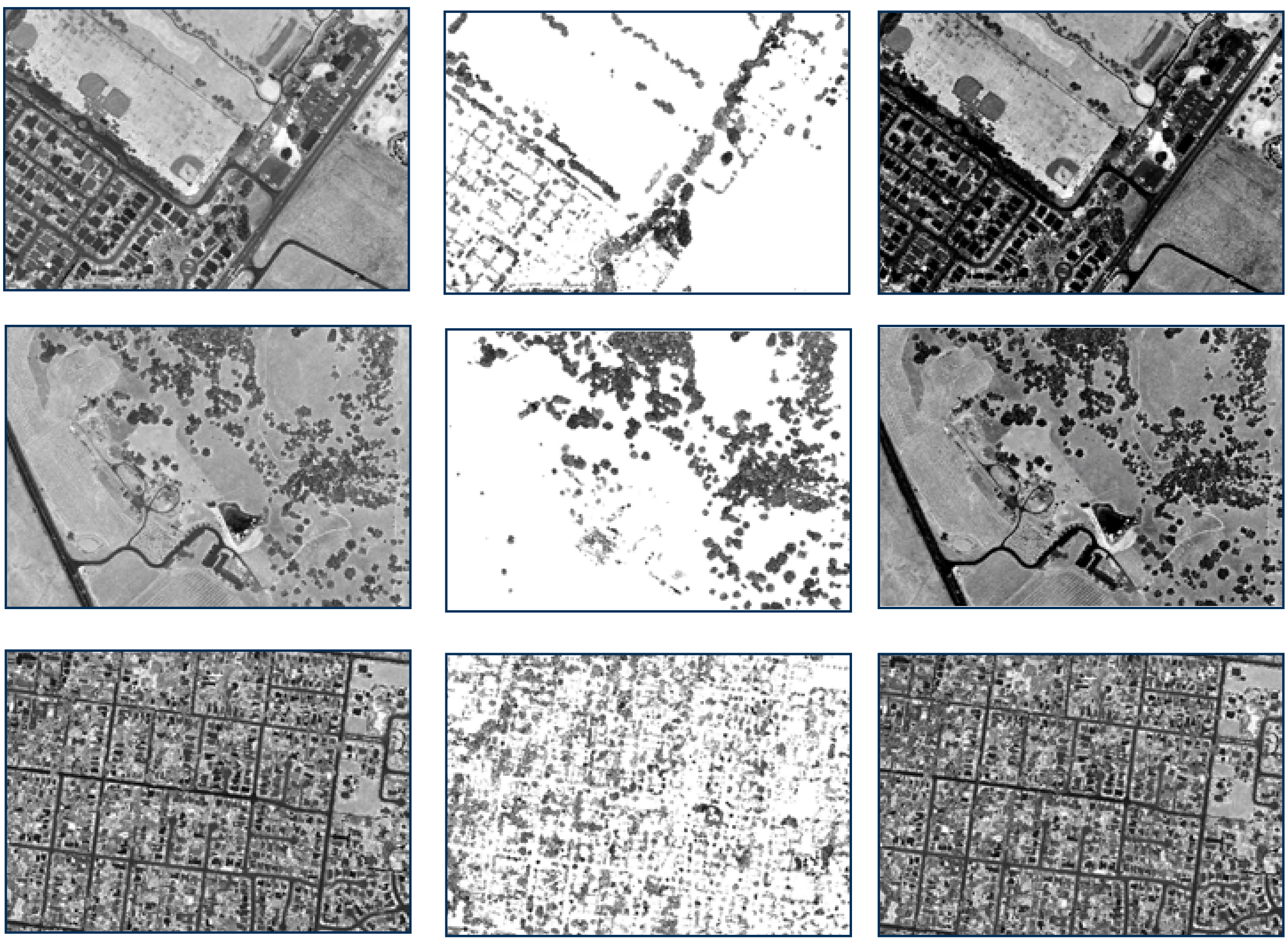


Intensity Rasters

Point data for this LiDAR survey are attributed with intensity values. Intensity is a unitless index of the voltage received from a discrete LiDAR return. It is largely a measure of reflectivity and composition of the object that reflected the laser radiation. During the flight, the receiver collected photons per LiDAR return and translated these to volts per return. These voltage returns were then scaled from a theoretical maximum. Intensity values were derived and stored as 8-bit unitless values (0-255).

Three different intensity rasters were created for Sonoma County, all are one-meter resolution rasters: the first is an interpolation of based on average of first returns, the second is the interpoloation based on average of vegetation returns and the third is the interpolation based on average of all returns. (see images below)

Intensity images: First column: interpolation based on average of vegetation returns. Second column: interpolation based on average of first returns. Third column: interpolation based on average of all returns.



Orthophoto Processing

Within the UltraMap software suite, raw acquired images are radiometrically and geometrically corrected using the camera's calibrations files and output as Level Two images. The resulting radiometry is then manually edited to ensure each image has the appropriate tone, no pixels are clipped, and each image is blended with its neighbors. Once radiometry has been edited, separate RGB and Panchromatic images are blended together to form single level Three pan-sharpened Four-band TIFF images.

The kinematic GPS positional data is post-processed in office using static monument coordinates from base stations. Base stations were occupied for a minimum of 6 hours, and were running during the time of acquisition. Photo position and orientation are calculated by linking the time of image capture, the corresponding aircraft position and attitude, and the smoothed best estimate of trajectory (SBET) data in POSPacMMS, and outputting an initial Exterior Orientations (EO) file.

The EO file is combined with level Three TIFFs within the Inpho software suite to place the images frames spatially. Aerial triangulation is performed to tie the image frames to each other, and to align them with surveyed ground control coordinates. A point cloud ground model is generated from the image frames by finding matching pixels between images and calculating the coordinates of each extracted point. Triangulated image frames are then draped onto a DEM derived from the extracted point cloud and orthorectified. Individual orthorectified tiffs are blended together to remove seams and corrected for any remaining radiometric differences between images using Inpho's OrthoVista. The 4-Band image mosaic is tiled to create a usable GeoTIFF raster product.

The 4-band GeoTIFF format allows for flexibility in image analysis and display. By adjusting the image band setup to display the near infrared spectral band as red (this display is known as color-infrared), vegetation stands out extremely vividly in the orthophoto mosaic.

The processing workflow for orthophotos is as follows:

Orthophoto 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.	Pos Pac MMS v. 6.1
Develop a smoothed best estimate of trajectory (SBET) file that blends post-processed aircraft position with attitude data. Sensor heading, position, and attitude will be calculated throughout the survey.	Pos Pac MMS v. 6.1
Create exterior orientation (EO) files for each photo image with omega, phi, and kappa.	POS-EO and Pos Pac MMS v. 6.1
Convert "Level 00" raw imagery into geometrically corrected "Level 02" image files.	UltraMap Raw Data Center v. 3.0
Apply radiometric adjustments to "Level 02" image files to create "Level 03" Pan-sharpened tiffs.	UltraMap Radiometry v. 3.0
Apply EO to photos, measure ground control points, and perform aerial triangulation.	Inpho Match-AT v. 5.5
Import DEM, orthorectify, and clip triangulated photos to specified area of interest.	Inpho OrthoMaster v. 5.5
Mosaic orthorectified imagery, blending seams between individual photos and correcting for radiometric differences between photos.	Inpho Orthovista v. 5.5

Final Tiling Scheme

The final tiling scheme for Sonoma County is in Califonia State Plane, FIPS Zone Two projection. It is made up of 55 non-overlapping Raster Extents (R.E.) and 11,052 LiDAR tiles within the project area. The R.E. is 37,800 feet by 37,800 feet. Within each R.E. are individually named tiles that are aligned to an 18 by 18 grid measuring 2,100 feet by 2,100 feet. The R.E. and tiling schemes will be clipped to a 350 meter buffer of the county line, referred to as the total area flown (TAF).

Raster Extent.: SOCO_0002

The naming convention for the R.E.s begins with a four-character abbreviation of the project name: Sonoma County (SOCO) and is followed by a four-digit numbering scheme that increases as the tiles move from west to east and south to north. In the example above, the R.E. is for Sonoma County, and is the second R.E. in the project area.

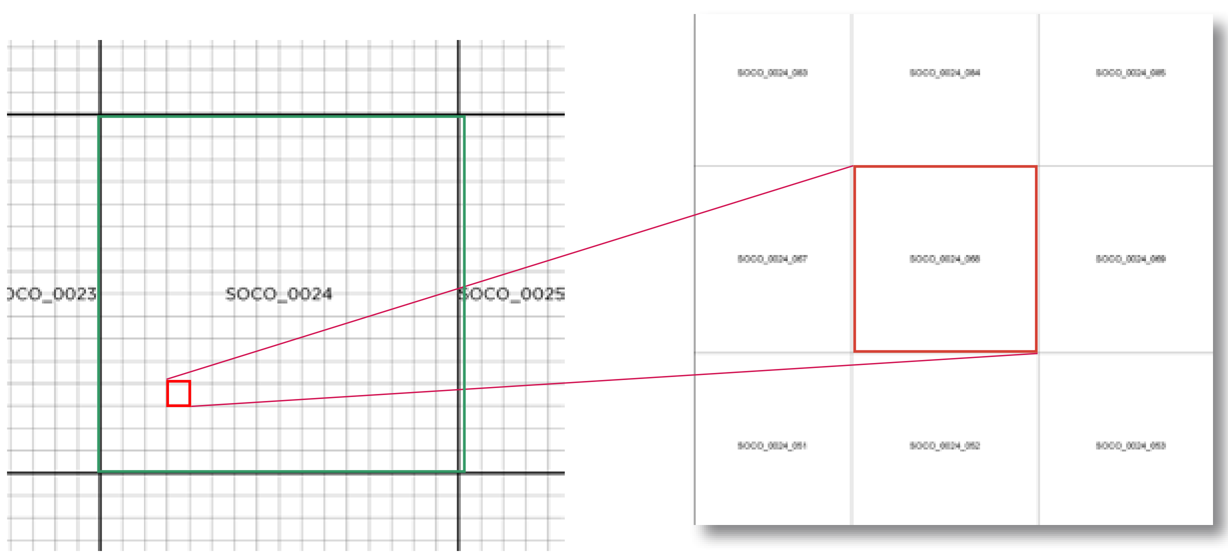
TILE: SOCO_0002_001

The tiling naming scheme is preceded by the corresponding R.E. name and followed by a four digit number that starts at 001 in the southwest corner of the R.E. and ends at 324 in the northeast corner of the R.E. In the example above, the tile is within the Sonoma County R.E.number 0002, in the southwest corner.

The R.E. and tiles will be clipped to the TAF. This process may exclude tiles that fall outside of the delivery area, so tile names may not be contiguous.

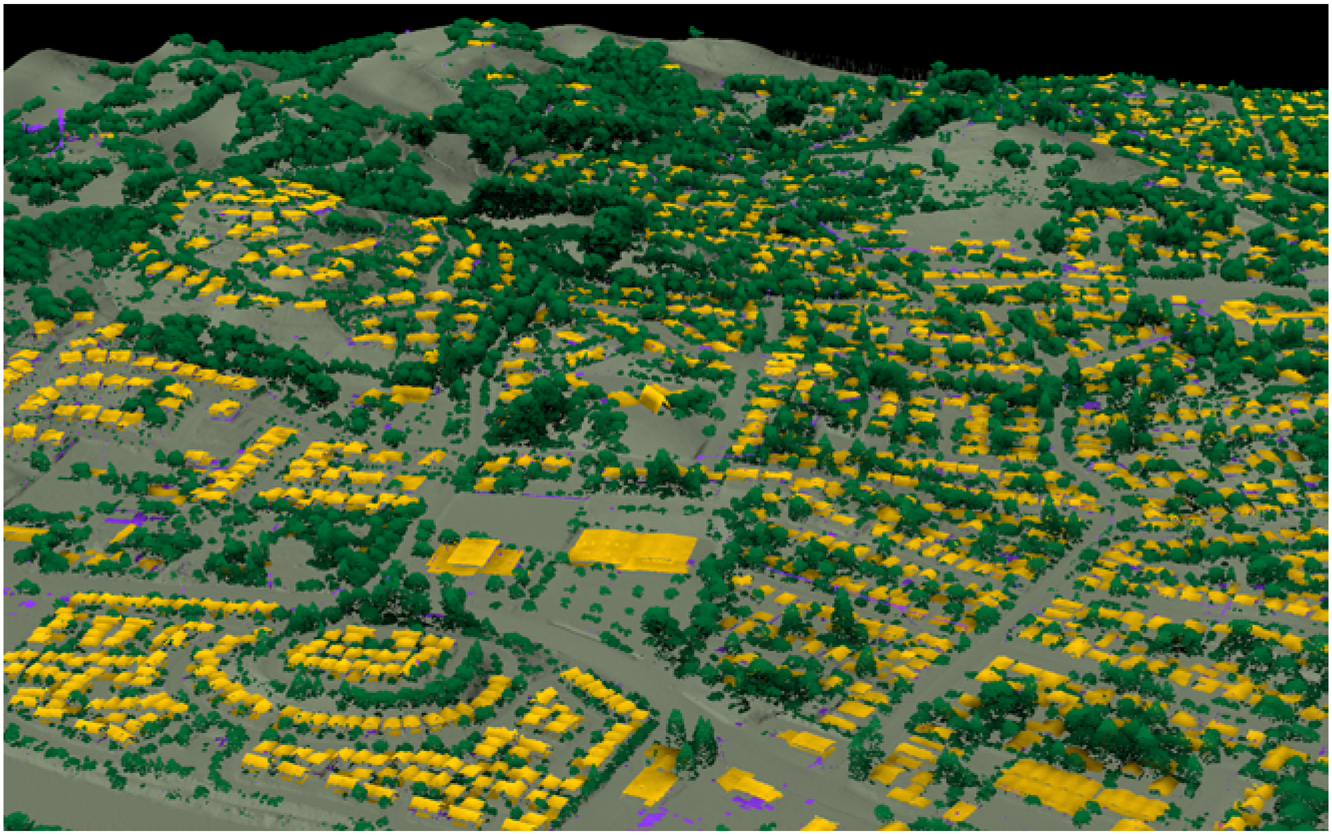
The R.E. and tiling scheme will produce raster images that do not overlap and do not have data gaps between R.E.s or tiles, as per Sonoma County LiDAR Consortium specifications.

Left: Raster Extent and Right: LiDAR Tile



WSI strives to provide the most comprehensive and user-friendly deliverable products possible. Deliverables for this project can be categorized according to LiDAR, rasters, vectors, and orthophotography.

Feature extracted LiDAR of Petaluma, California



Sonoma County Deliverables			
Deliverable			Format
Enhanced Classified LiDAR Point Cloud		classified: Ground, Default, Vegetation, Water, and Building	*.las 1.2 format
		Eight points per square meter	
LiDAR Derived Rasters	Ground Surface Models	Bare Earth Digital Elevation Model	ESRI 32-bit floating point grid
		Three-Foot First Return Highest Hit digital Elevation Model	
		Three-Foot Hydro-Flattened Digital Elevation Model	
	Forest Metrics	Three-Foot Canopy Density Raster	
		Three-Foot Vegetation Height Raster	
	Intensity Images	interpolation based on average of first returns, native radiometric resolution	
		interpolation based on average of vegetation returns, native radiometric resolution	
		interpolation based on average of all returns native radiometric resolution	
Vectors	Extent Shapes	Area of Interest (AOI)	GeoDatabase Featureclass
		Total Area Flown (TAF)	
	Planimetrics	Hydro- Flattened Ground Surface Model Breaklines	
		One-foot Contours,	
		2D Building Planimetrics, "Building Point Extents" and "Cartographic Buildings"	
Orthophotos	Six-inch full county		*.tiff
Metadata			*.xml
Data Report			*.pdf

Results

Accuracy Assessment

In some cases statistics were generated for larger areas than the extent represented by delivered areas. Accuracy statistics are a product of calibration and data QA/QC methodology that are spatially coincident with production workflow, which at times exceeds the areal extent of delivery workflow.

Vertical Accuracy Statistics	WSI Results (meters)	WSI Results (feet)
Sample Size (n)	1,834 Ground Control Points	
Root Mean Square Error	0.03	0.09
1 Sigma	0.03	0.08
2 Sigma	0.06	0.06
Minimum Δz	-0.10	-0.31
Maximum Δz	0.10	0.32
95% Confidence Level	0.05	0.17

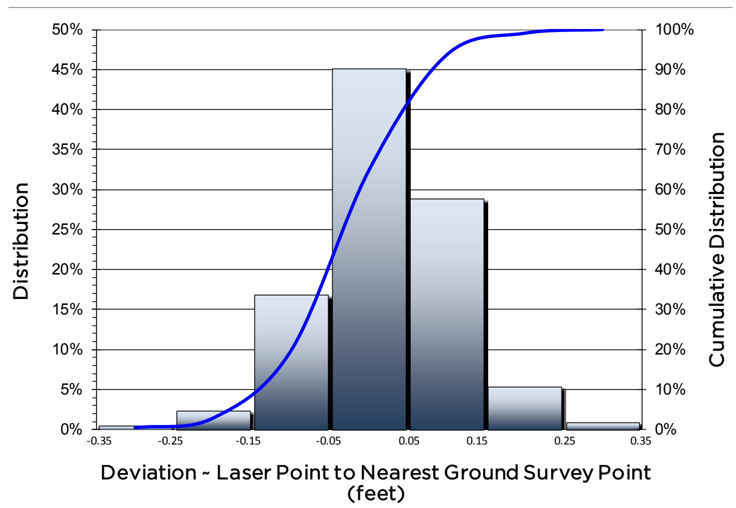
Vertical Accuracy

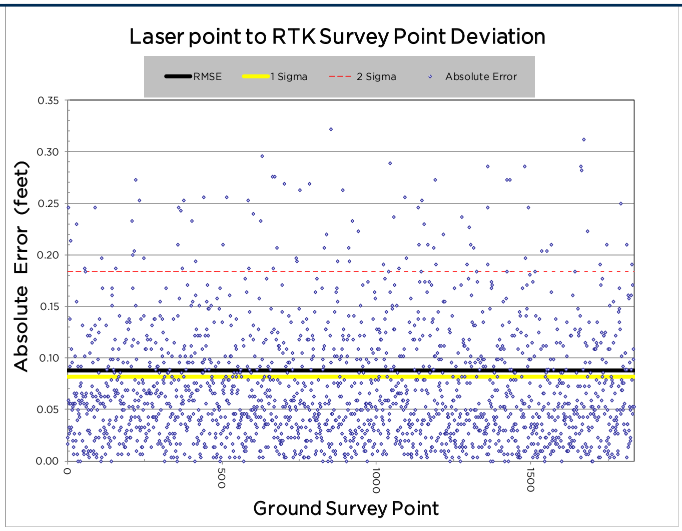
Vertical Accuracy reporting is designed to meet guidelines presented in the National Digital Elevation Program (NDEP), National Standard for Spatial Data Accuracy (NSSDA) (FGDC, 1998), and the ASPRS Guidelines for Vertical Accuracy Reporting for LiDAR Data V1.0 (ASPRS, 2004). The statistical model compares known ground survey points (GCPs) to the closest laser point. Vertical accuracy statistical analysis uses GCPs 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 Sonoma study area, 1,834 GCPs were used to calibrate Delivery Area One.

Vertical accuracy statistics are reported as both "Compiled to Meet" and "Tested to Meet" for delivery area one. Land class accuracies are reported as "Compiled to Meet," as no independent survey data was gathered and withheld specifically for land classes.

Ground survey data to be delivered with this report includes all GCPs, reserved checkpoints, and land class checkpoints.

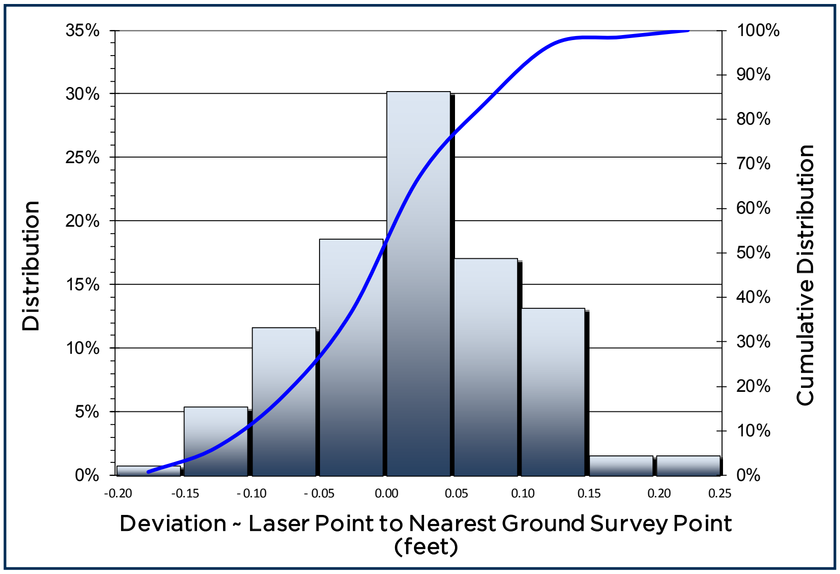
"Compiled to Meet" Histogram and Deviation Statistics





"Tested to Meet" accuracy results were peformed on 129 independently surveyed checkpoints that were withheld from the GCP data set prior to calibration for Delivery Area One.

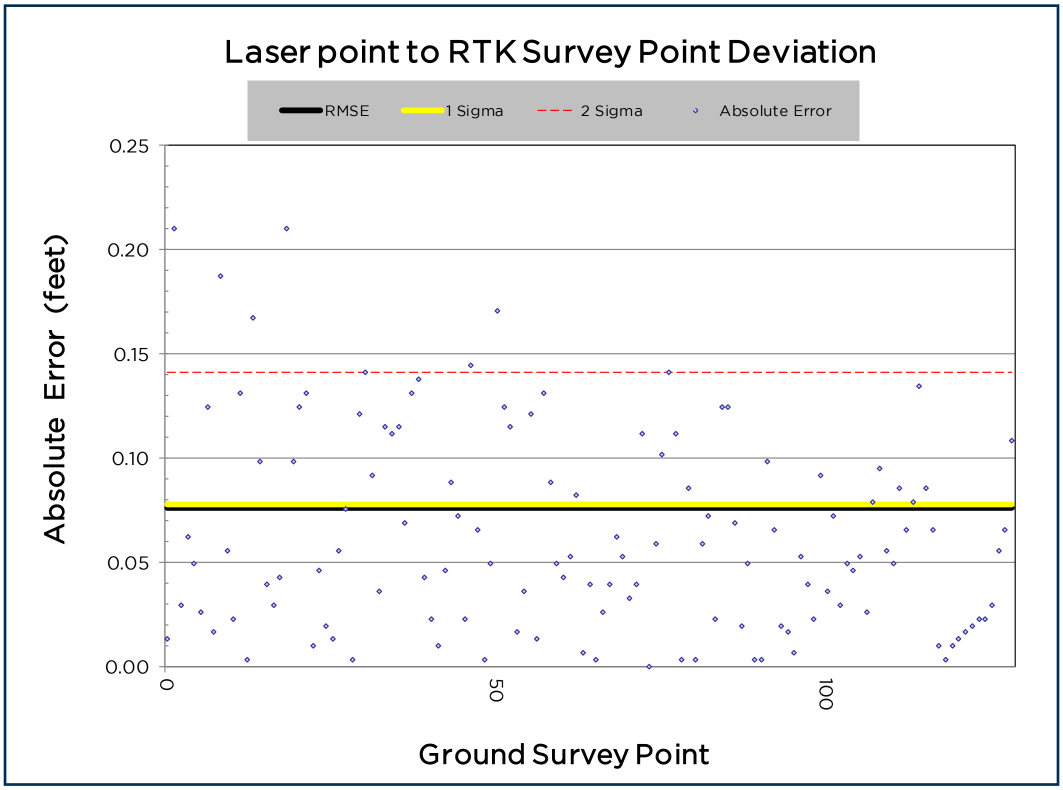
"Tested to Meet" Histogram



"Tested to Meet" Accuracy Results

Vertical Accuracy Results	
Sample Size (n)	129
Root Mean Square Error	0.02 m (0.08 ft.)
1 Standard Deviation	0.02 m (0.08 ft.)
2 Standard Deviation	0.04 m (0.14 ft.)
Minimum Deviation	-0.05 m (-0.17 ft.)
Maximum Deviation	0.06m (0.21 ft.)
95% Confidence Level	0.05 m (0.15 ft.)

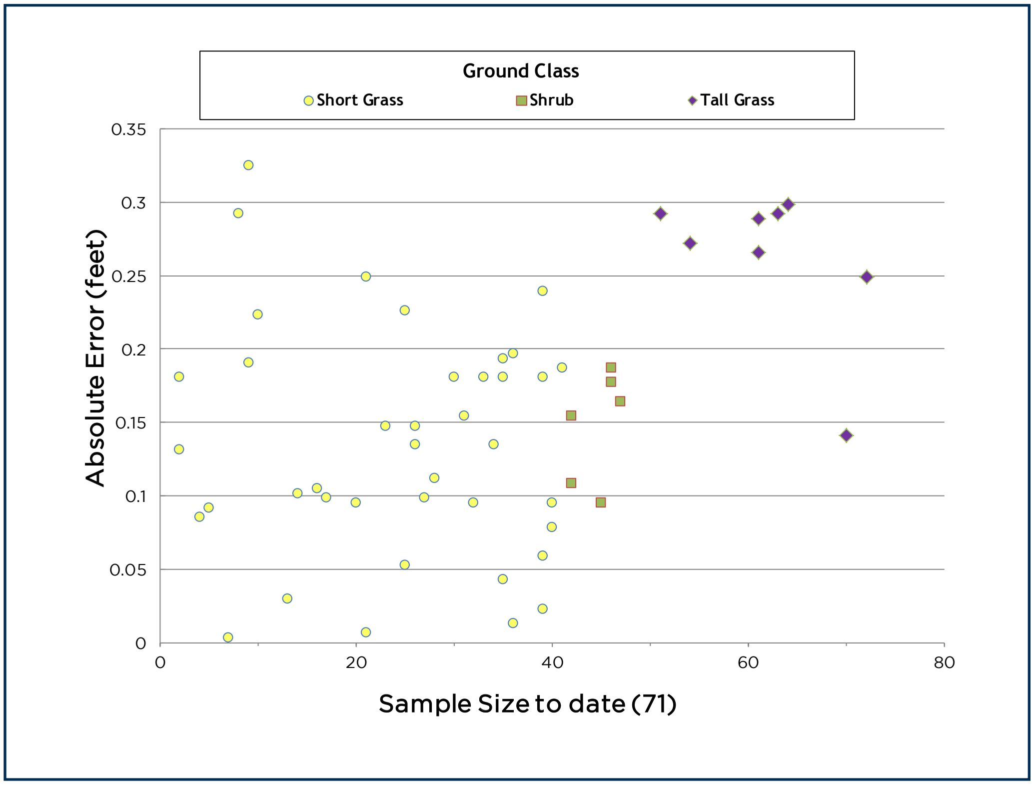
"Tested to Meet" Deviation Statistics



Land Class Vertical Accuracy

A total of 71 Individual land class checkpoints in three different land cover classes were collected.

Land Cover Vertical Accuracy						
	Shrub N= 6		Short Grass N =40		Tall Grass N= 25	
	meters	feet	meters	feet	meters	feet
Bias (Average Dz)	0.05	0.15	0.03	0.09	0.12	0.40
95th Percentile	0.06	0.18	0.08	0.25	0.21	0.18
Minimum	0.03	0.10	-0.07	-0.22	0.00	-0.01
Maximum	0.06	0.19	0.10	0.32	0.23	0.74
Average Magnitude	0.05	0.15	0.04	0.13	0.12	0.40
1 Sigma	0.05	0.17	0.06	0.18	0.13	0.53



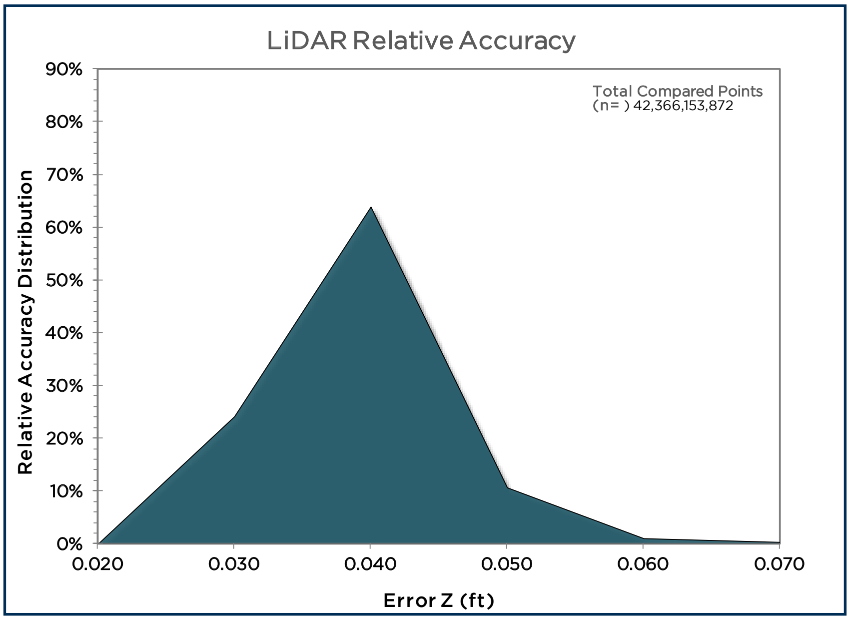
Relative Accuracy

Swath-to-Swath

Relative 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 are based on the comparison of 405 flightlines and over 42 billion points. Relative accuracy is reported for the entire Delivery Area One portion of the study area.

Relative Accuracy Calibration Results	
Project Average	0.03 m (0.11 ft.)
Median Relative Accuracy	0.03 m (0.11 ft.)
1σ Relative Accuracy	0.04 m (0.12 ft.)
2σ Relative Accuracy	0.05 m (0.15 ft.)



Within Swath

WSI defines "within swath relative accuracy" as a measure of the point-to-point consistency across the width of a LiDAR swath. The statistic is derived through a GCP survey of flat pavement (typically airport tarmac) measured orthogonal to the direction of flight. The measure evaluates tilting or warping of the raw data, as well as "smiles" and "frowns" at the edge of scan. This test is performed with each system calibration upon installation of the sensor in the aircraft, as well as periodically during a sensor's residence within a specific aircraft.

Within Swath RMSE	
0.02 meters	**0.07 feet**

Density Results

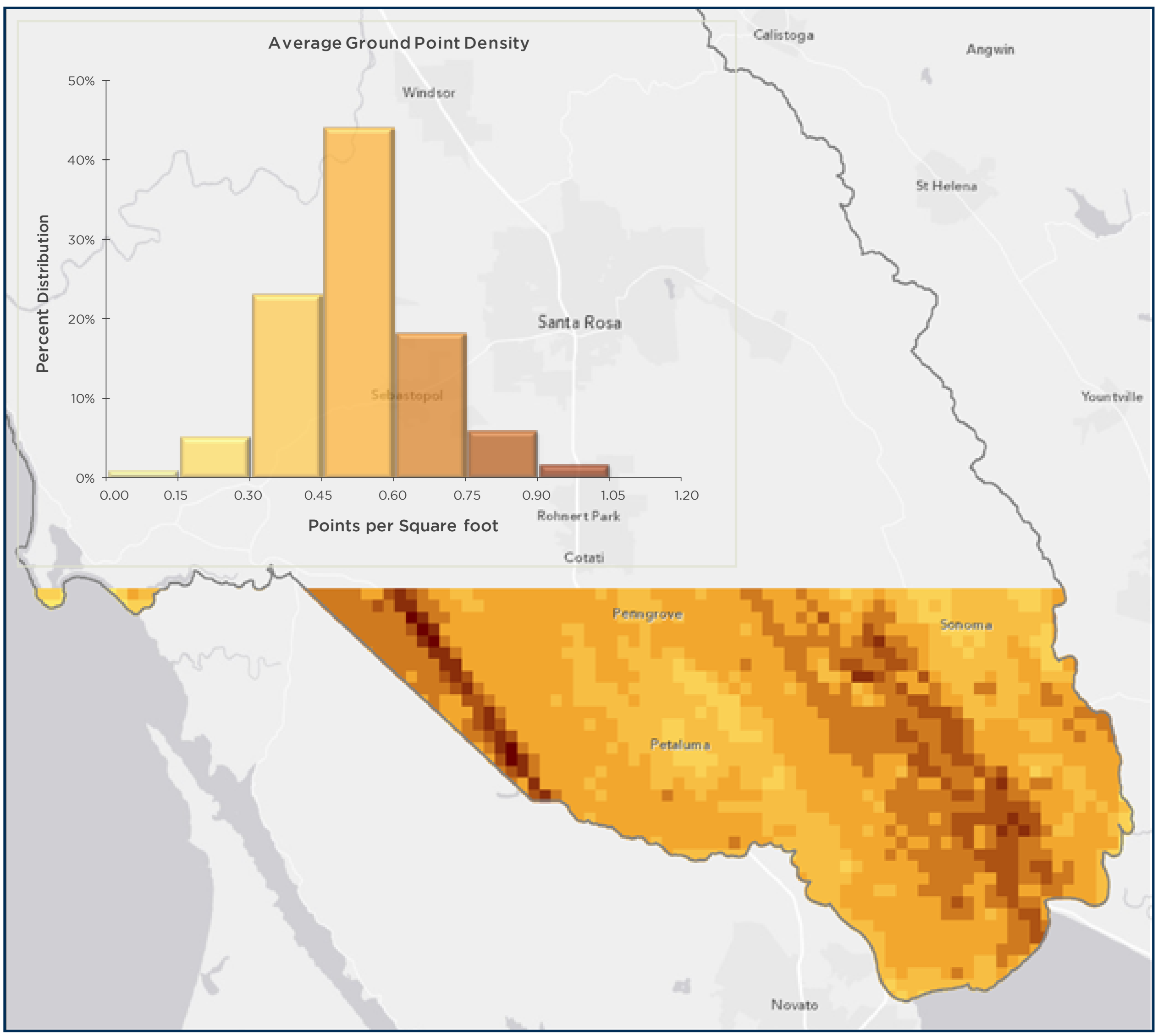
The native pulse density is the number of pulses emitted by the LiDAR system. The pulse density resolution specification for the NASA ROSES Sonoma County study area is a minimum mean of 8 pulses per square meter (ppsm); WSI achieved 11.08 ppsm. Some types of surfaces (e.g., dense vegetation, water) may 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 have been calculated based on first return laser point density and ground-classified laser point density.

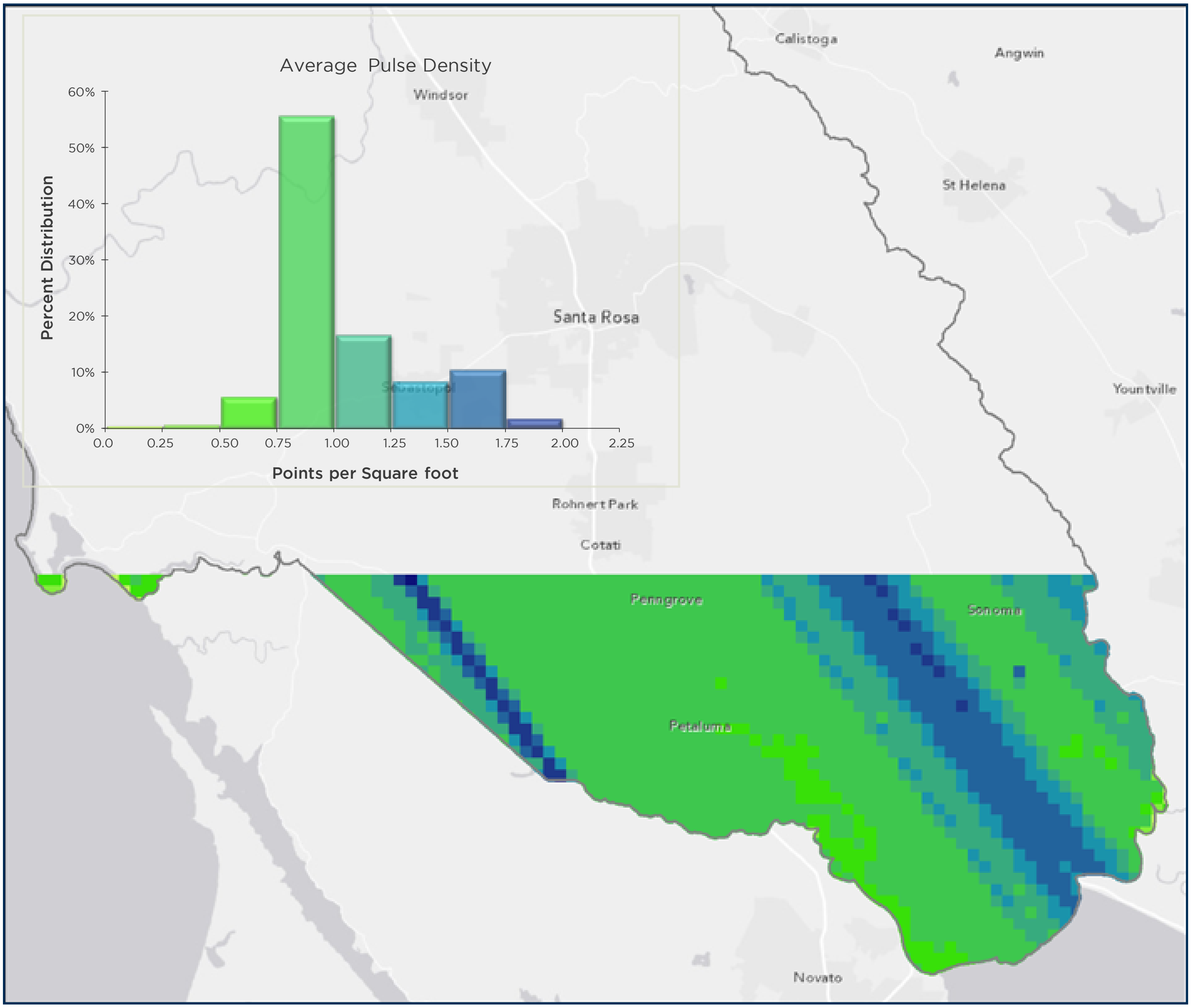
Density results

Ground Density	points per square meter	points per square foot
	5.73	0.53
Pulse Density	pulses per square meter	pulses per square foot
	11.08	1.03

Delivery Area 1 Ground Point Density



Delivery Area 1 Pulse Density Map



Orthophoto Accuracy Assessment

To assess the spatial accuracy of the orthophotographs, artificial check points were established. Thirty check points, distributed evenly across the total acquired area, were generated on surface features such as painted road lines and fixed high-contrast objects on the ground surface. They were then compared against check points identified from the LiDAR intensity images. The accuracy of the final mosaic was calculated in relation to the LiDAR-derived check points and is listed above.

Orthophoto Horizontal Accuracy (n=10)	WSI Achieved (m)	WSI Achieved (ft.)
RMSE	0.248	0.814
1 Sigma	0.273	0.897
2 Sigma	0.407	1.335

Above: Example of co-registration of color images with LiDAR intensity images.

Best Practices

WSI Standards

WSI has high standards and adheres to best practices in all efforts. In the field, rigorous quality control methods include deployment of base stations at pre-surveyed level one monuments and collecting GCPs, and efficient planning to reduce flight times and mobilizations.

In the laboratory, quality checks are built in throughout processing steps, and automated methodology allows for rapid data processing. There is no offshoring, which allows for in-house data collection and processing.

WSI's innovation and adaptive culture rises to technical challenges and the needs of clients. Reporting and communication to our clients are prioritized through regular updates and meetings.

APPENDIX A

September 19, 2013

Ground Survey & GPS Plan

Sonoma County Vegetation Mapping and LiDAR Program, 2013

Sonoma County Agricultural Preservation and Open Space District, representing the Sonoma County LiDAR and Vegetation Mapping Consortium

WSI Applied Remote Sensing and Analysis

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WSI Applied Remote Sensing and Analysis

Ground Survey

Monumentation

Where available, National Geodetic Survey (NGS) published monuments or other government control will be utilized by WSI. In the absence of NGS benchmarks, we will establish new survey monuments within public right of way or on public lands. All static control points will be observed for a minimum of two independent sessions (4+ hours, 2+ hours) at varying instrument heights. These independent occupations help to minimize error in baseline measurements. GPS data will be collected at a recording frequency of 1Hz using a ten degree antenna mask. Data files will be uploaded to WSI servers daily for staff PLS QA/QC and oversight. Using the NGS Continuously Operating Reference Station (CORS) network, WSI will triangulate three nearby stations to each of its static control sessions in order to adjust their positions. After enough static data has been collected to finalize each monument position, overall accuracy will be assessed. Upon completion of the project, a total network adjustment may be performed if necessary. All ground survey work will be certified by a California PLS.

LiDAR Acquisition Support

During each LiDAR mission, a ground-based technician will deploy two Trimble base stations within 13 nautical miles of the area to be flown. (Both absolute and relative accuracy degrade abruptly when baseline lengths exceed 13 nm, or 24 km.) This redundancy is important for risk mitigation and verification of baseline measurements. WSI aims to gather ample ground truthing data in every independent LiDAR mission.

Applied Remote Sensing and Analysis

GPS

Ground Survey Checkpoints

Using a Trimble TDL450H radio, real-time kinematic (RTK) corrections will be broadcast from a base station to a roving GPS unit in order to collect ground truthing data. (If beyond radio range, a post-processed kinematic [PPK] method will be employed.) WSI typically observes over 500 calibration ground survey points for every 150 square miles. For the Sonoma County project, a minimum of 10,500 well dispersed points will be collected on hard surfaces throughout the county, as well as a minimum of 100 points per dominant land cover class. Within this point dataset, approximately 1000 will be extracted as checkpoints. For RTK & PPK survey points, WSI achieves $RMSE_{XY}$ of $\leq$ 1.5 cm and $RMSE_{Z}$ of $\leq$ 2.0 cm (deviation from base positions).

All measurements are made during periods with a Position Dilution of Precision (PDOP) of $<$ 3.0 while tracking at least eight satellites. Daily forecasts from Trimble Planning software along with point collection thresholds ensure that these conditions are met. Each survey point will be derived from five individual measurements, of which the three closest one-second epochs will be averaged to calculate the pseudo-range position. Any point which exceeds WSI's relative error threshold will be discarded. RTK positions are observed on bare earth locations such as paved, gravel or hardpacked dirt roads, while avoiding grade breaks and highly reflective surfaces such as center-line stripes or lane markings.

Our goal is to have an abundance of high quality widely distributed RTK observations under our tight tolerances in order to minimize the possibility and subsequent effect of random errors (due to multipath, electromagnetic interference, etc.). GPS quality (due to dense foliage and abrupt terrain) as well as access constraints may limit ground truthing ability in certain parts of the study area.

GPS Equipment

WSI owns and operates a fleet of Trimble Global Navigation Satellite System (GNSS) dual-frequency L1-L2 receivers to be used for both static and roving RTK surveys.

Receiver Model	Antenna	OPUS Antenna ID	Use
Trimble R7 GNSS	Zephyr GNSS Geodetic Model 2	TRM55972.00	Static
Trimble R8	Integrated Antenna R8 Model 2	TRM_R8_Model2	Static & RTK
Trimble R10	Integrated R10	TRMR10	Static & RTK
Trimble R6	Integrated Antenna R6 Model 2	TRMR6-2	Static & RTK

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