San Diego County, CA

Pre-Flight Aerial Acquisition and Calibration Report

Federal Emergency Management Agency
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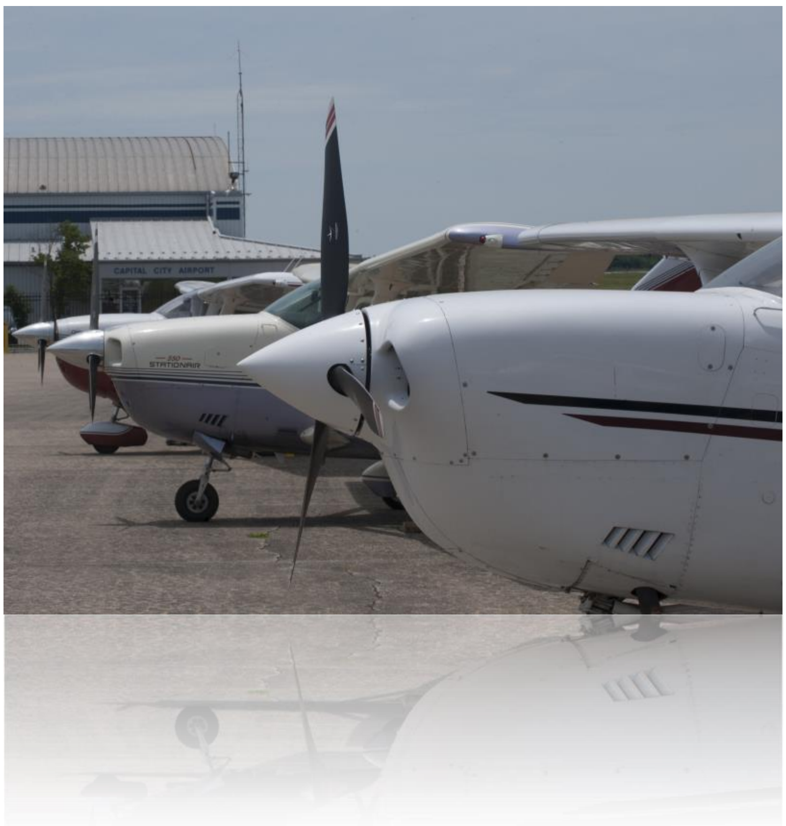

Completed by Quantum Spatial, Inc.

Submitted by: Joel Burroughs, Project Manager
523 Wellington Way, Suite 375
Lexington, KY 40503
Phone: (859) 277-8700 | Email: mshillenn@quantumspatial.com

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. SUMMARY / SCOPE

1.1. SUMMARY

This report contains a Work Plan and Pre-Op acquisition plan for the LiDAR for San Diego County, CA task order, issued by STARR on behalf of Federal Emergency Management Agency (FEMA). The intent of this document is to provide specific pre-flight information for the data acquisition/collection work completed for the project. Please see the Post-Flight report for details on the actual collection details.

1.2. SCOPE

The scope of the LiDAR for San Diego County, CA task order included the acquisition of aerial imagery using state of the art technology, along with necessary surveyed ground control points (GCPs) and airborne GPS and inertial navigation systems, for the study area. The aerial data collection was designed with the following specifications listed in Table 1 below.

Table 1. Planned LiDAR Specifications

LiDAR				
Average Point Density	**Flight Altitude (AGL)**	**Field of View**	**Side Overlap**	**RMSEz**
2 pts / m^2	5,577 ft	40.0 degrees	40%	10 cm or better

1.3. LOCATION / COVERAGE

The San Diego County, CA project boundary consists approximately 1640 square miles as shown in Figure 1.

Figure 1. San Diego County, CA Project Boundary

1.4. Acqiusition Conditions

The acquisition will be conducted when the majority of the ground is not obscured by snow, dense haze, fog, dust, floodwater, low cloud cover, or when there are other environmental conditions that could obscure the ground and negatively impact the project's positional accuracy. At the time of the acquisition, the GPS satellite configuration will consist of a minimum of six satellites with a geometry that supports a Positional Dilution of Precision (PDOP) of ≤ 3. The actual PDOP data will be collected and submitted as part of the Post-Flight Aerial Survey and Calibration Report. If a break in the data acquisition flight line should occur, a minimum of 500' overlap data will be collected when resuming the flight line to ensure the integrity of the collected data.

The data will meet or exceed FEMA specifications.

2. Planning / Equipment

The entire target area was broken into seven areas to account for airports and potential GPS Base Stations: Brown, Campo, Descano, Fallbrook, Palomar, Pauma, and Warner. Brown has 47 flight lines and approximately 888 flight line miles; Campo had 38 flight lines and approximately 686 flight line miles; Descanso has 133 flight lines and approximately 2,896 flight line miles; Fallbrook has 18 flight lines and approximately 171 flight line miles; Palomar has 32 flight lines and approximately 538 flight line miles; Pauma has 25 flight lines and approximately 267 flight line miles; and Warner has 106 flight lines and approximately 1674 flight line miles. As a whole, the project area is comprised of 399 planned flight lines and approximately 7120 flight line miles. Please refer to Figures 2 through 9.

Figure 2. Planned Flight Lines: Overview

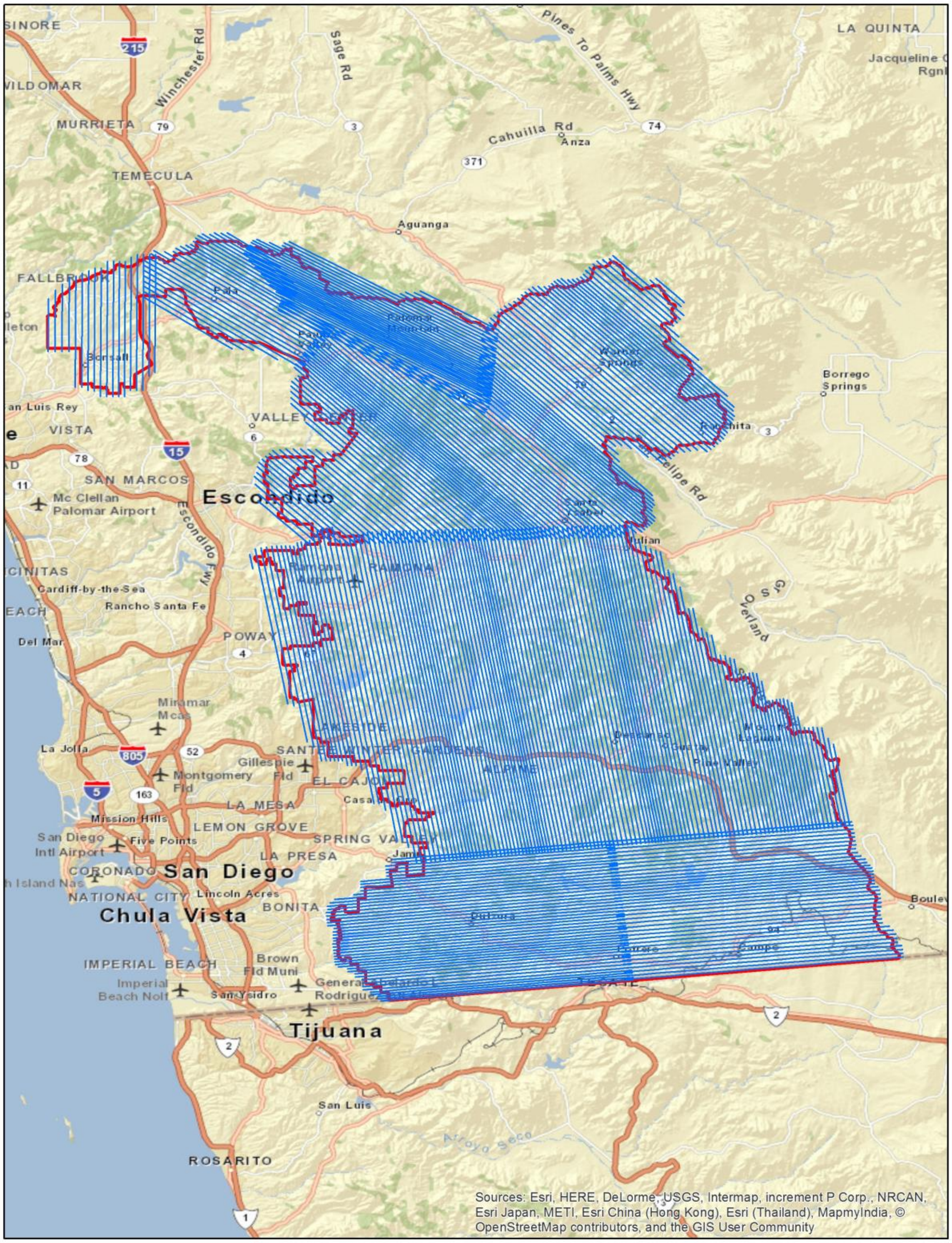

Figure 3. Planned Flight Lines: Brown

Figure 4. Planned Flight Lines: Campo

Figure 5. Planned Flight Lines: Descanso

Figure 6. Planned Flight Lines: Fallbrook

Figure 7. Planned Flight Lines: Palomar

Figure 8. Planned Flight Lines: Pauma

Figure 9. Planned Flight Lines: Warner

Detailed project flight planning calculations were performed for the San Diego County, CA project using Leica Mission planning software. Flight planning was based on the unique project requirements and characteristics of the project site. The basis of planning included: required accuracies, type of development, amount / type of vegetation within project area, required data posting, and potential altitude restrictions for flights in project vicinity. A brief summary of the aerial acquisition parameters for the project are shown in the LiDAR System Specification Table 2 below:

Table 2. LiDAR System Specifications

Area	Collection Blocks
Terrain and Aircraft	**Flying Height AGL:** • Brown: 1747 m; 5732 feet • Campo: 2167 m; 7110 feet • Descanso: 1767 m; 5797 feet • Palomar: 2074 m; 6804 feet • Pauma: 1757 m; 5764 feet • Warner: 1788 m; 5866 feet • Fallbrook: 1807 m; 5928 feet
	Recommended Ground Speed (GS): 115 kts
Scanner	**Field of View (FOV):** 40.0; degrees
	Scan Rate Setting used (SR): 41.8 Hz
Laser	**Laser Pulse Rate used:** 158 kHz
	Multi Pulse in Air Mode: Disabled
Coverage	**Full Swath Width:** 1237.5 m
Point Spacing and Density	**Maximum Point Spacing Across Track:** 1.42 m
	Maximum Point Spacing Along Track: 1.42 m
	Average Point Density: 2.16 pts / m^2

2.1. Planned GPS Stations

Normally existing high accuracy monuments at airports are utilized if possible. Typically a Primary Airport Control Monument (or Secondary) is available; otherwise any other high accuracy monument can be used. We typically prefer these on the airport grounds as they can be monitored for security by airport staff. If no monument is available or an existing monument is damaged, we will set a monument with re-bar and use OPUS to control the monument. These are then used for initial field processing of the data.

2.2. CALIBRATION PLANS

Periodic detailed boresighting of the LiDAR sensor is performed at a boresight facility established in Lexington, Kentucky for both our LiDAR and imagery platforms. Over 95 high-accuracy control points are located within this facility. The area also has numerous pitched roofs that are necessary in boresighting LiDAR instruments. Local boresights are also carried out at individual project sites. Typically these are established at local airports and consist of opposing and cross flights conducted at multiple flight elevations. The boresight data is processed by our Lead LiDAR Specialist with the results for all boresight parameters applied to the project acquisition.

2.2.1. CALIBRATION

All of our sensors are calibrated by flying lines at multiple altitudes and at varying directions over features on land, typically at the airport where the acquisition is staged. These lines are used to remove angular errors between the IMU and scanning mirror and to determine the precise positioning of the sensor in relationship with the phase center of the GPS antenna mounted on the fuselage of the aircraft.

2.2.2. CALIBRATION

The raw LiDAR surface is compared against ground points that are established for the calibration of the elevation surface. System biases are identified and removed during this calibration. An early statistical analysis takes place that provides an indication of the precision of the acquired data.

Additionally, each lift requires a cross flight over the lines collected during that flight. This also acts as a daily calibration and is used if any anomalies are discovered with processed data.

2.3. QUALITY CONTROL PROCEDURES FOR FLIGHT CREWS

2.3.1. ACQUISITION CREWS

An experienced and knowledgeable acquisition crew is also critical to a successful LiDAR project. We will bring one capable crew to the project site with four more in reserve should any unexpected health issues or similar complications arise.

Table 3

	Sensor Calibration Boresighting
✦	Photo Science routinely performs a Comprehensive Calibration process from our permanent boresighting location at the Capital City Airport in Frankfort, KY, as well as daily, local project specific boresighting locations.
✦	Photo Science established GPS survey points for LiDAR ground truthing and reflective survey analysis.
✦	Our calibration methodology adheres to the basic survey principle of *"working for the whole of the parts"* ensuring that residual values of the calibration are reduced, *not* multiplied.
✦	Photo Science calibration process validates roll, pitch, heading, pitch at swath edge, and torsion.

2.3.2. GENERAL FLIGHT MISSION PROCEDURES

On a lift by lift basis the flight crew will check cloud conditions, atmospheric conditions (fog or probability of fog) and winds and turbulence. If any of those factors would make acquisition difficult they will wait a few hours and review again.

LiDAR crews can fly at night or during the day. Night flights can be smoother in some cases, but extra care must be used as it is easy to lose orientation with the ground if in very rural areas or over large expanses of water. Additionally, if there are fog probabilities then flights will not take place as fog will block the laser. It must be clear below the aircraft at all times.

The initial item is to set the base station properly over the monument, verify it is secure and running. Prior to setting the crew will have ascertained that it has storage space on the hard drives and full battery life. They will also verify that it is running with proper collection parameters. PDOP is also reviewed as collection will not take place during times of high PDOP.

The LiDAR system (controller hard drives and Laser) is connected to the flight management system and once the project plan is loaded the parameters for collection will load as well. The sensor operator will verify that everything loaded correctly before flight.

Once the LiDAR has been started the crew will taxi to the run up area and wait for the IMU, GPS and the rest of the system level out. They will collect data in a stationary position for about 5-10 minutes until the POS (position and orientation system) provides good level characteristics (Green Lights!).

After this they crew will take off and start collection data, avoiding hard steep turns (banks typically <20 degrees). Collection requires that speeds be maintained, sometimes quite slow depending on the accuracy requirements. Additionally altitudes must be watched closely.

During flights the sensor operator must monitor the laser to sure that temperatures are consistent and within guidelines, that pulsing is taking place correctly and returns are consistent and within guidelines while watching atmospheric conditions, speeds and monitoring the pilot.

2.4. Procedure for tracking, executing and checking re-flights

All daily flights are tracked with specific logs for each area. These include general logs indicating the lines, date flown etc. as well as very specific mission logs concerning the lift, weather conditions, times, speeds and other criteria critical to the performance of the laser. The daily flight logs are faxed to the office on a daily basis and entered into an access database for tracking purposes. This helps determine where next to move crews and overall project status.

After flight each day, the GPS ground base station data is processed and verified and is then is run against the LiDAR POS data in both a forward and reverse sense. The two solutions are then compared against one another for all GPS epochs and the individual differences for the northing, easting, and elevation components are plotted for easy comparison. This data is then run against the LiDAR returns and a point cloud generated. Any anomalies in the data are quickly analyzed, and if required, re-flights take place for the portions of the flight missions that require remediation.

Once the data is checked it is archived, backed up and a set sent to the office via overnight delivery, while the backup copy remains with the crew.

The flight crews do not leave the area of collection until all data has been verified and shipped.

2.5. FLIGHT LOGS

Flight logs were completed by LIDAR sensor technicians for each mission during acquisition. These logs depict various information including:

- Job / Project #
- Flight Date / Lift Number
- FOV (Field of View)
- Scan Rate (HZ)
- Pulse Rate Frequency (Hz)
- Ground Speed
- Altitude
- Base Station
- PDOP avoidance times
- Flight Line #
- Flight Line Start and Stop Times
- Flight Line Altitude (AMSL)
- Heading
- Speed
- Returns
- Crab

Notes: (Visibility, winds, ride, weather, temperature, dew point, pressure, etc). Blank Flight Log example is included in Appendix A.

2.6. Equipment: Aircraft

The project flights are planned to utilize customized Cessna Caravan Tail Number N840JA.This aircraft provided an ideal, stable aerial base for LiDAR acquisition. This aerial platform has relatively fast cruise speeds which are beneficial for project mobilization / demobilization while maintaining relatively slow stall speeds which proved ideal for collection of the imagery captured by the LiDAR units.

Figure 10. Leica ALS80 LiDAR System.

2.7. LiDAR Sensor

Quantum Spatial will utilize a Leica ALS80, Serial Number 8146. This system is capable of collecting data at a maximum frequency of 1 MHz, which affords elevation data collection of up to 1,000,000 points per second. The system utilizes a Multi-Pulse in the Air option (MPIA). This sensor is also equipped with the ability to measure an unlimited number of returns per outgoing pulse from the laser. The intensity of the first four returns is also captured during aerial acquisition.

2.8. GROUND CONTROL COLLECTION

Compass Data will be responsible for collecting all control points needed to guarantee the accuracy of the LiDAR dataset. Quantum Spatial requires forty (40) calibration control points. These points will be used to check the dataset for any positional bias that needs to be corrected during the calibration process. These points are shown in figure 12.

In addition to the calibration points, we have selected NVA, VVA, and Horizontal control locations. These locations represent our recommendation in order to meet the proper project specifications. These points can be seen in figures 13-15. There are thirty four (34) recommended horizontal control points, (67) recommended non-vegetated vertical accuracy points (51 bare earth and 16 urban area), and fifty four (54) recommended vegetated vertical accuracy points (5 forested, 2 swamp, and 4 tall weeds). These points support vertical tests on the dataset. Each of these two functions shall remain independent of each other. Independent check or calibration points will need to be three times as accurate as the surface being checked. Therefore, in order to validate a LiDAR surface accurate to 10 cm, the collected elevation control data must be accurate to 3 cm.

The planned point locations are indicated in the graphics below.

Figure 11. Planned Ground Control Point Locations

Figure 12. Required Calibration Control Point Locations

Figure 13. Recommended NVA Ground Control Point Locations

Figure 14. Recommended VVA Ground Control Point Locations

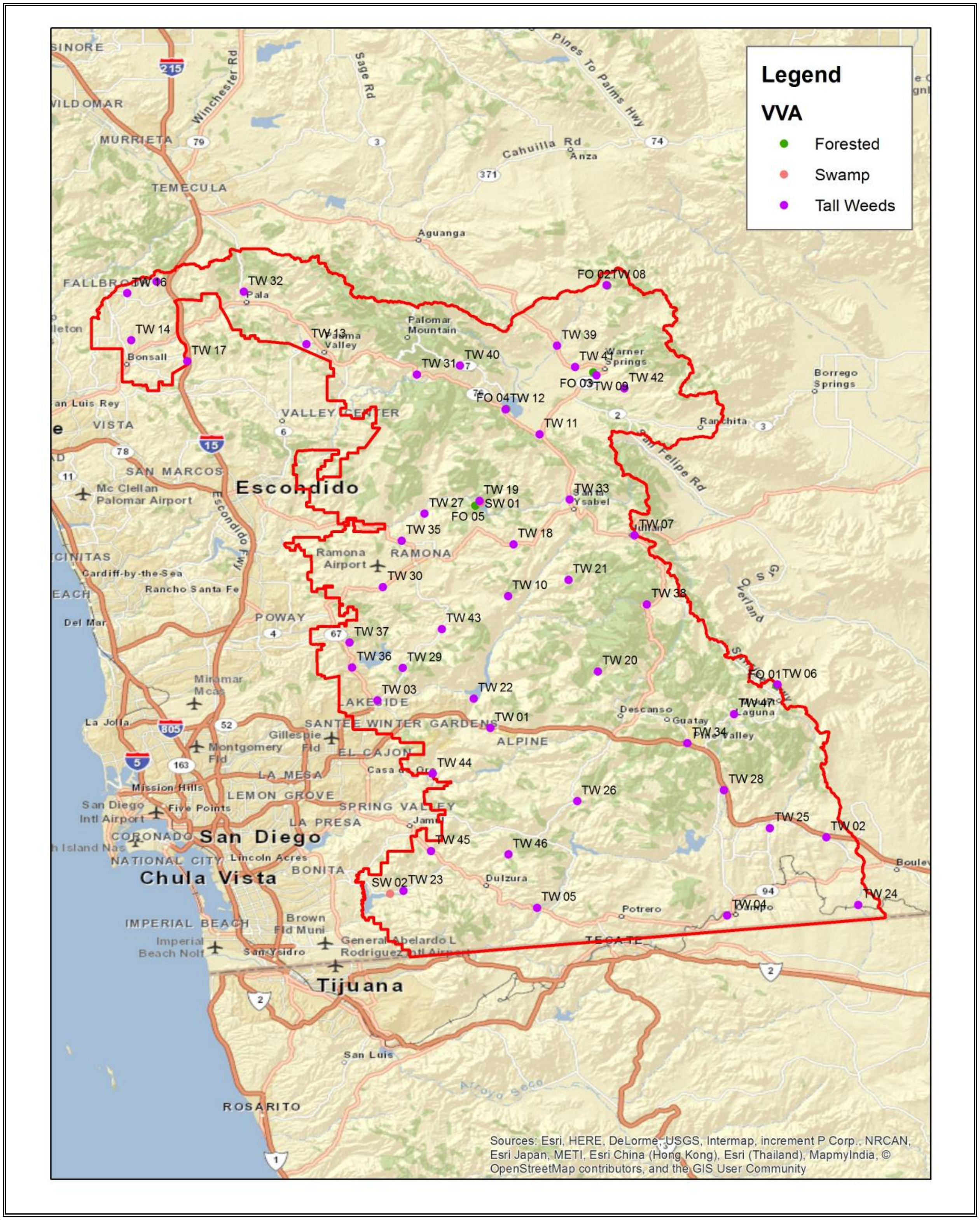

Figure 15.Recommended Horizontal Ground Control Point Locations