SKY RESEARCH

Orthophotography and LiDAR Terrain Data Collection
Rogue River, Oregon
Final Report

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Prepared for
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1.0 INTRODUCTION

LiDAR (Light Detection and Ranging) data were acquired and used for the creation of a bare earth digital elevation model (DEM) and 2 foot contours along the Rogue River Greenway and Recreation Corridor, between Touville State Park and Downtown Grants Pass (Figure 1). High resolution color orthophotgraphs were collected simultaneously with the LiDAR data and processed to further enhance the delineation of topographical features. Both data sets were integrated into a Geographic Information System (GIS) to allow rapid access and analysis of geospatial data. This document summarizes the data collection, image processing, and analysis activities associated with the orthophotography and LiDAR data collected over the Rogue River. This report and final data delivery are the final deliverables associated with this project.

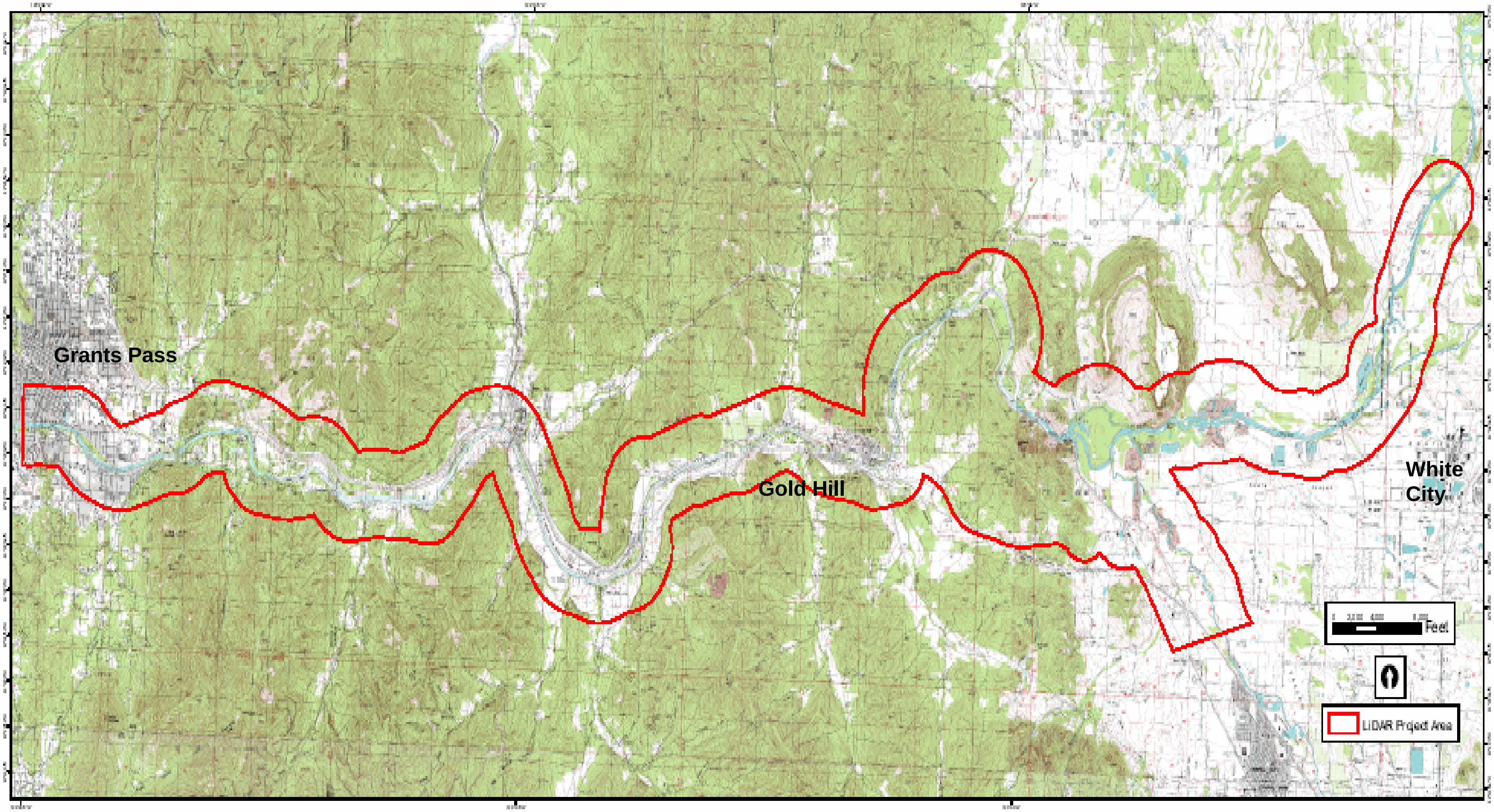

Figure 1. LiDAR and orthophotgraphy data acquisition area along the Rogue River

2.0 TECHNOLOGIES AND WORKFLOW

2.1 Airborne Platform

The ALTM 3100 LiDAR system, ALTM 4K02 Digital Metric Camera, and the Position and Orientation System (POS) were mounted in the Sky Research Pilatus PC-12 (Figure 2). The Pilatus PC-12 is a pressurized, large, single-engine turbo prop utility aircraft, designed to perform a wide range of missions. The LiDAR sensor and camera system are co-mounted inside the aircraft near the tail; modifications have been made to the aircraft to allow the sensors to collect data through a hole in the floor of the plane's fuselage.

Figure 2. Sky Research Pilatus PC-12 Aircraft

2.2 LiDAR System

LiDAR is a scanning and ranging laser system that is capable of producing precise high-resolution topographic data. The technology has been in existence for twenty years, although the commercial application for topographic maps has developed only within the last five years.

The basic components of the LiDAR data collection system are as follows: Laser scanner, global positioning system (GPS), and Inertial Measurement Unit (IMU). The laser scanner is mounted in the aircraft and emits high-frequency infrared laser beams. The scanner records the time difference between the emission of the laser pulses and the reception of the reflected signal. A mirror mounted in front of the laser rotates, directing the laser pulses to sweep back and forth perpendicular to the flight direction, which allows the laser scanner to collect swaths of topographic data as the aircraft moves forward. The position of the aircraft is determined by processing differential, dual-frequency, kinematic GPS observations. The GPS located in the aircraft is supported by several ground stations that are located within the vicinity of the acquisition area. The IMU determines the orientation of the aircraft (pitch, roll, and yaw) during data collection. By combining the IMU data with the post-processed GPS data, the exact trajectory of each laser pulse is determined during data processing.

2.2.1 LiDAR Sensor Specifications

The LiDAR sensor specifications are summarized in Table 1 below.

Table 1. LiDAR Specifications

Detector type:	Optech® LiDAR ALTM 3100.
Spacing:	30 centimeters (cm) to 5 meters (m) spot spacing.
Contour Interval:	Dependent on spot spacing with an approximate 1 m (spacing) to 30.5 cm (contour interval) ratio.
Operating Altitude:	80-3,500 m above ground level (AGL) nominal
Elevation Accuracy:	<15 cm at 1200 m; 1 sigma <25 cm at 2000 m; 1 sigma <35 cm at 3000 m; 1 sigma
Horizontal Accuracy:	Better than 1/3,000 x altitude; 1 sigma
Range Accuracy:	2-3 cm, single shot.
Range Resolution:	1 cm
Measurement Rate:	33,000 to 100,000 measurements per second.
Scan Angle:	0 to ± 25°
Swath Width:	Variable from 0 to 0.93 x altitude.
Scan Frequency:	0-70 Hertz (Hz), depending on scan angle
Laser Classification:	Class IV (FDA Code of Federal Regulations (CFR) 21)
Laser Repetition Rate:	33 kilohertz (kHz) (max. altitude above ground level (AGL) 3500 m) 50 kHz (max. altitude (AGL) 2500 m) 70 kHz (max. altitude (AGL) 1700 m) 100 kHz (max. altitude (AGL) 1100 m)
Operating Temperature:	10-35° Celsius (C)
Humidity:	0-95% non-condensing

2.2.2 LiDAR Data Quality Assessment

During data acquisition over the Rogue River area, the sensor operator observed real-time LiDAR swath coverage to assure full coverage of the survey area. The operator also monitored in-flight Position Dilution of Precision (PDOP) and GPS satellite coverage. If tolerance thresholds of either were exceeded, data acquisition activities were put on hold until acceptable conditions resumed. After the data acquisition flight, data from GPS base stations were checked against in-flight GPS data for concurrence. Once data quality assessments were completed, all data (image and ancillary) were transferred to a centralized location for pre-processing and quality control analysis.

2.3 Orthophotography System

High-resolution digital color aerial photography is collected by mounting a digital camera with high-resolution Charged Couple Device (CCD) backing into the aircraft. The camera is linked to either a computer or a manual trigger device which controls the frequency and length of exposures, resulting in overlapping high-quality aerial photographs of the earth. Information collected from the GPS and IMU are used to rectify the aerial photographs. This is accomplished by assigning a geographic coordinate to each image derived from the processing of the GPS data. In addition, distortions created by camera tilt, lens distortion, and terrain displacement are removed to produce an orthophotograph. This ortho-rectification is accomplished by employing the following techniques: 1) using the IMU data to remove the distortion due to camera tilt; 2) calibrating lens distortion based on camera lens parameters; and 3) removing terrain displacement by using a Digital Terrain Model (DTM). Once rectified, the orthophotographs are mosaiced together to create a seamless and accurate representation of the entire site area.

2.3.1 Digital Camera Specifications

The specifications for the camera used to generate the Rogue River aerial photographs are provided in Table 2 below.

Table 2. Camera Specifications

Detector Type:	OPTECH ALTM 4K02 Digital Metric Camera DSS 301 SN0046- 55 millimeters (mm) lens
Lens Type:	Zeiss Distagon
Focal length:	55.073 mm
Field of View:	36°
CCD Specifications:	4,092 (along flight) x 4,079 (cross flight) Pixel size of 0.000138 inches (in)
Shutter Speed:	1/125 to 1/4000 second
Principal Point	Xppac (mm) -0.390, Accuracy 0.0036 Yppac 0.222, Accuracy 0.0036 Measured from image center (pixel size = 9 microns)
Pixel Non-Squareness	1.0, Accuracy 0.0000001
VIS Calibrated Gain Value	0.98
VIS Calibrated ISO	300
VIS Calibrated Exposure Compensation	-0.70

2.3.2 Orthophotography Data Quality Assessment

During the data acquisition flight over the Rogue River, the sensor operator observed the real-time photograph footprint coverage to assure required percentage of overlap for the survey area. The operator observed real-time photo display for verification of image quality. The operator also monitored in-flight PDOP and GPS satellite coverage. If tolerance thresholds of either were exceeded, data acquisition activities were put on hold until acceptable conditions resumed. After the data acquisition flight, data from GPS base stations were checked against in-flight GPS data for concurrence. Once data quality assessments were completed, all data (image and ancillary) were transferred to a centralized location for pre-processing and quality control.

3.0 DATA ACQUISITION

This project began in May 2007 and ended in August 2007 (Table 3). Following project planning, mobilization to the Rogue River area commenced and included the following:

- Deploying ground support personnel to establish ground fiducials, establish and operate GPS base stations, and provide logistical support;
- Mobilizing the Pilatus PC-12 aircraft (with co-mounted orthophotography/LiDAR sensors), pilots, and operators for aerial data acquisition

The airborne surveys required two days of data acquisition (see Table 3). The flight lines were established during project planning and achieved the objective of covering the data collection area in minimal flight time, while achieving the required spatial resolution, overlap, etc.

After acquisition, the data were processed and analyzed, and the draft data was uploaded to the RVCOG interactive mapping site (IMS). Final data delivery and reporting concluded in August 2007.

Table 3. Project Schedule

ACTIVITY	DATE
Project Planning and Data Acquisition	
Project planning	May 13-29, 2007
Data acquisition	May 30 - 31, 2007
Data Processing and Analysis	
LiDAR	June 01 – July 30, 2007
Orthophotos	June 01 – July 30, 2007
Deliverables	
Draft Orthophotography/LiDAR Datasets Delivered via Web Services	June 30, 2007
Final Data and Report Delivery	August 06, 2007

Table 4 provides the flight survey parameters, which are the same for both the LiDAR and orthophotography data acquisition, since the two sensors were collecting data simultaneously during the survey flights. The data collection parameters achieved during the survey met the survey requirements and expectations.

Table 4. Flight Survey Parameters

Altitude:	1,000 meters AGL
Airspeed:	105 knots

3.1 Data Collection

3.1.1 LiDAR

Sky Research acquired elevation data using an ALTM 3100 airborne LiDAR system over approximately 28,000 acres over the Rogue River, at an average altitude of 1,000 meters and a laser repetition rate of 71 kHz (71,000 measurements per second). The vertical and horizontal accuracies of these data are less than 10 cm and 33 cm RMSE, respectively. The average spot spacing was 37 cm. The LiDAR data collection parameters are provided in Table 5. Figure 1 illustrates the LiDAR data collection area in the Rogue River area.

Table 5. LiDAR Data Acquisition Parameters

Measurements per second:	71,000
Scan Width:	317 m
Scan Overlap:	50%
Scan Frequency:	50 Hz
Scan Angle:	+/- 13°
Average Spot Spacing:	0.54 m
Vertical Accuracy:	10 cm
Horizontal Accuracy:	33 cm

3.1.2 Orthophotography

In conjunction with the LiDAR data collection, high-resolution color orthophotography were collected with the co-mounted OPTECH ALTM 4K02 Digital Metric camera. Aerial imagery was obtained simultaneously with GPS ground control, insuring a horizontal precision of less than 33 cm RMSE. The orthophotography collection parameters are provided in Table 6.

Table 6. Color Orthophotography Data Acquisition Parameters

Field of View:	36°
Imaging Swath/Photo Coverage:	45% forward lap, 75% side lap
Ortho-rectified Pixel Size, Re-sampled:	0.16 meters/pixel

3.2 PDOP During Data Acquisition

PDOP is a mathematical function expressing the relative quality of solutions, based on the geometry of the satellites. A PDOP value of "one" indicates optimal geometry of available satellites, while higher values are scaled to the dilution of precision related to in-optimal geometry. The best PDOP would occur with one satellite directly overhead and three others evenly spaced about the horizon. PDOP could theoretically be infinite, if all of the satellites were in the same plane.

PDOP has a multiplicative effect on the User Range Error (URE) value. For example, a URE of 10 ft., with a PDOP of “one”, would give an assumed best accuracy of 10 ft. A PDOP of “two”, however, would result in an assumed accuracy of 20 ft. Due to this multiplicative effect of PDOP on the URE, Sky Research performs LiDAR data collection only when the PDOP is below a value of 3.0. The PDOP values experienced during Rogue River survey are illustrated in Figure 3. The PDOP values shown in Figure 3 limited the URE and allowed the LiDAR data collected to meet the required accuracies.

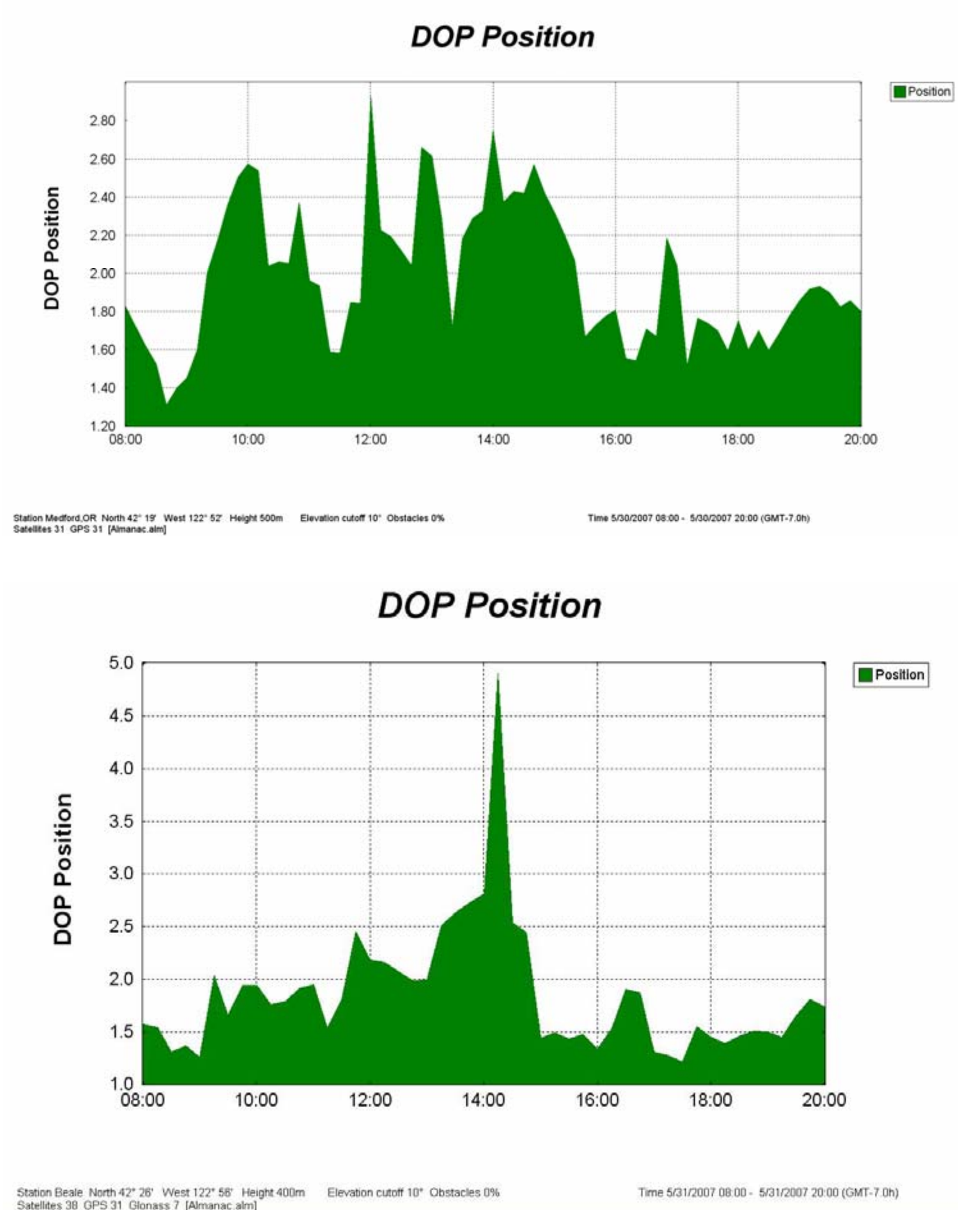

Figure 3. PDOP Between 8am and 8pm Pacific Time on May 30 and May 31, 2007.

4.0 ACCURACY ASSESSMENT

4.1 Ground Control

In order to provide differential kinematic GPS solutions for the aircraft positioning system, rectify digital orthophotography, and obtain quality control data, horizontal and vertical ground survey control was established across the Rogue River target area. The horizontal positions of the survey control are referenced to the North American Datum of 1983, CORS96 adjustment (NAD83/CORS96). The horizontal survey control stations were established using fast-static GPS observations referencing National Geodetic Survey (NGS) Continuously Operating Reference Stations (CORS).

Elevations of the survey control are referenced to the North American Vertical Datum of 1988 (NAVD88), established by static GPS measurements and a high-resolution geoid model with observational checks to local NGS vertical control monuments when available. The NGS Geoid model, Geoid03, was utilized to reach the NAVD88 from the adjusted ellipsoid heights.

4.1.1 Description

During the data acquisition flight, the sensor operator observed the real-time LiDAR swath coverage to assure full coverage of the survey area. The operator also monitored for adequate in-flight PDOP and GPS satellite coverage. If tolerance thresholds of either were exceeded, data acquisition activities were put on hold until acceptable conditions resumed. After the data acquisition flight, data from GPS base stations were checked against in-flight GPS data for concurrence. Once data quality assessments were completed, all data (image and ancillary) were transferred to a centralized location for pre-processing and quality control. Table 7 includes the CORS control stations that were used to establish the Sky Research survey network.

Dual-frequency GPS data were collected simultaneously onboard the aircraft and at strategically-located ground stations. The ground stations were located so that the longest baseline (distance between aircraft and ground station) was no more then 30 kilometers. Two ground stations were operated during airborne LiDAR data acquisition over the Rogue River.

Table 7. CORS Control Stations Utilized

Mark Designation	***Geodetic Station Number***	***Network Constraint***
Dodson Butte CORS ARP	AJ7211	Horizontal Ellipsoid Height
Klamath Falls 1 CORS ARP	DH7225	Horizontal Ellipsoid Height
Yreka CORS ARP	AF9640	Horizontal Ellipsoid Height

Photograph panel control points were geometrically dispersed at eight locations throughout the Rogue River site to control the digital orthophotography. The panel point locations consisted of a 1.2 m x 1.2 m plastic white “cross” with either a 60 cm long, 1 cm diameter steel pin or a 25 cm galvanized metal spike.

4.1.2 Quality Control/Quality Assurance

Quality control and assurance (QA/QC) data were obtained using post-process kinematic GPS observations from a minimum of two survey control base stations. No radial GPS vectors were used in the computation of the QA/QC survey positions. QA/QC data was taken throughout the project site for horizontal and vertical checks of the airborne-acquired data.

All GPS survey data used for the establishment of ground control were analyzed and adjusted using least squares methods. Final coordinates and positional uncertainties were computed from a properly-weighted, full-constraint, least-squares adjustment, fixing the aforementioned NGS control stations. The primary site control was utilized for the LiDAR base stations, as reference for the establishment of orthophotography control points, and for the LiDAR QA/QC. The final adjustment yielded the positional uncertainties for the Primary Survey Control relative to true datum, as shown in Table 8. Tables 9 and 10 show the accuracies of the orthophotography panel points and the LiDAR QA/QC data, respectively.

Table 8. Primary Survey Control

Maximum Horizontal RMSE:	0.001 m
Maximum Vertical RMSE:	0.006 m
Minimum Horizontal RMSE:	0.001 m
Minimum Vertical RMSE:	0.005 m
Average Horizontal RMSE:	0.005 m
Average Vertical RMSE:	0.001 m

Table 9. Orthophotography Panel Points

Maximum Horizontal RMSE:	0.014 m
Maximum Vertical RMSE:	0.017 m
Minimum Horizontal RMSE:	0.003 m
Minimum Vertical RMSE:	0.007 m
Average Horizontal RMSE:	0.006 m
Average Vertical RMSE:	0.010 m

Table 10. LiDAR QA/QC Positions

Maximum Horizontal RMSE:	0.025 m
Maximum Vertical RMSE:	0.038 m
Minimum Horizontal RMSE:	0.008 m
Minimum Vertical RMSE:	0.015 m
Average Horizontal RMSE:	0.015 m
Average Vertical RMSE:	0.026 m

4.2 LiDAR Control

The accuracy of LiDAR elevation data at Yekau Lake was evaluated by comparison with the QA/QC data and is summarized in Table 11. A total of 75 QA/QC control points were collected at different locations across the project site.

Table 11. RMSE for LiDAR data

Average Dz (meters)	+0.005
Minimum Dz (meters)	-0.127
Maximum Dz (meters)	0.086
Average Magnitude (meters)	0.038
Root Mean Square (meters	0.047
Standard Deviation (meters)	0.047

4.3 Orthophotography Control

The horizontal accuracy of orthophotography was evaluated by comparison of locations of the aforementioned orthophotography panel points with the same targets visible in the photographs (see Figure 4 for panel locations). The RMSE was calculated, and average horizontal errors are listed in Table 12. Auto triangulation results represent cumulative RMSE calculations for tie points used in ortho-rectification as well as RMSE values for photograph position (See Table 13). A total of 3,308 photos and 109,917 image points were used in the Auto-Triangulation RMSE analysis. Seven GPS surveyed control panels were used to measure map accuracy.

Table 12. RMSE for Orthophotography

	X Coordinate Deviation	Y Coordinate Deviation
Linear RMSE (meter)	0.101 (0.333ft)	0.507 (1.666ft)
Horizontal Radial RMSE (meter)	0.3048 (1.000004971 ft)	

Table 13. Auto Triangulation Results

Parameters (meters)	**X/Omega**	**Y/Phi**	**Z/Kappa**	**XY**
RMS Control	0.083	0.095	0.087	0.089
RMS Limits	0.1	0.1	0.1	n/a
Max Ground Residual	0.136	0.198	0.119	n/a
Residual Limits	0.2	0.2	0.2	n/a
Mean Std Dev Object	0.080	0.092	0.390	n/a
RMS Photo Position	0.007	0.007	0.012	n/a
RMS Photo Attitude	0.009	0.006	0.016	n/a
Mean Std Dev Photo Position	0.025	0.022	0.030	n/a
Mean Std Dev Photo Attitude	0.003	0.002	0.007	n/a

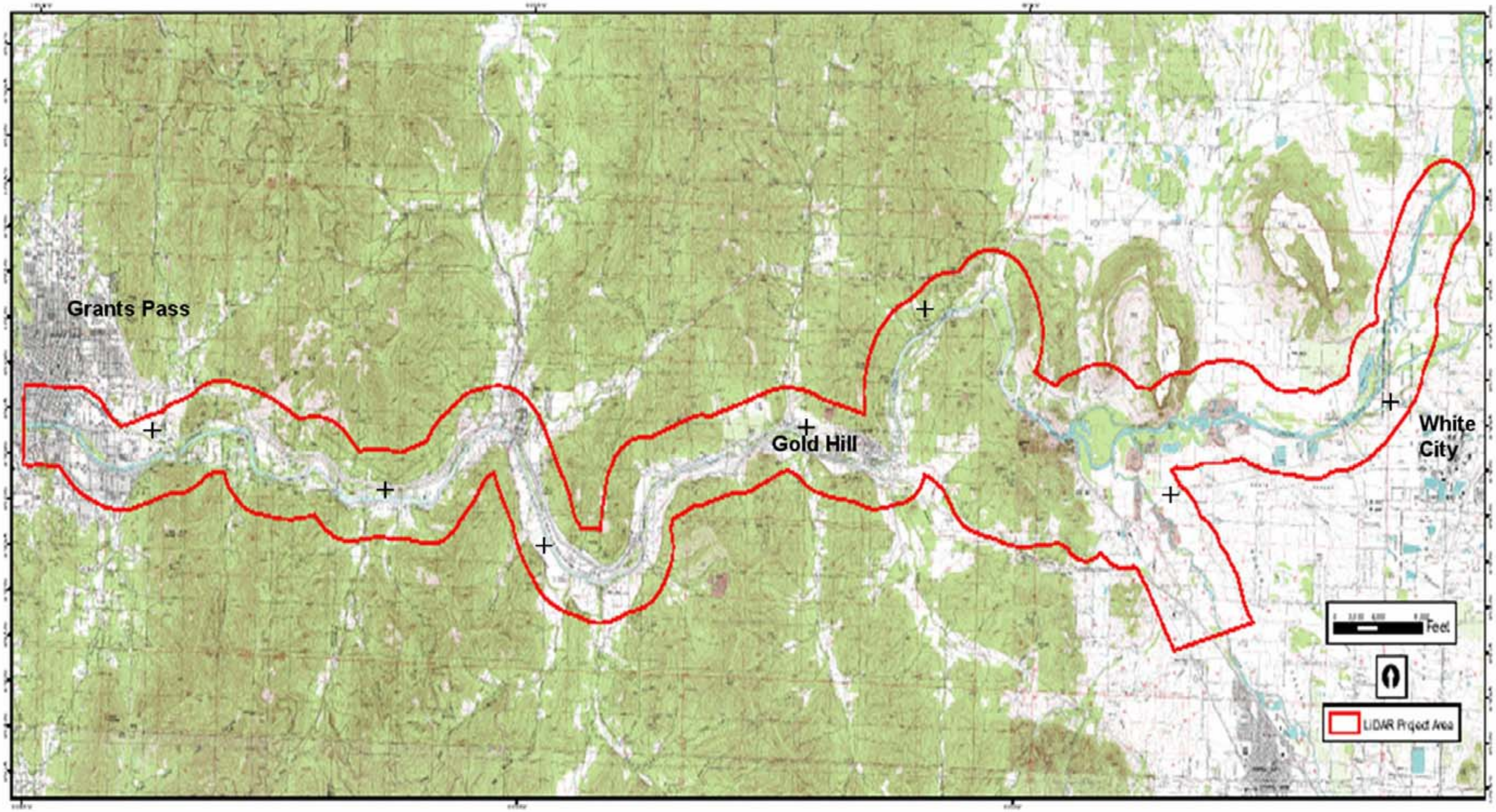

Figure 4. Panel Points for Orthophotography Control (+)