LiDAR Remote Sensing Data Collection: Lewis County Study Area, Washington

Submitted to:

Puget Sound Regional Council
1011 Western Avenue, Suite 500
Seattle, WA 98104-1035

Phillis A. Mann
Kitsap County
911 Carver Street
Bremerton, WA 98312

Matt Hyatt
GIS Manager
Lewis County Public Works
2025 NE Kresky Avenue
Chehalis, WA 98532

Washington State
Department of Natural Resources
1111 Washington Street SE
Olympia, WA 98504-7000

Submitted by:

Watershed Sciences, Inc.
215 SE Ninth Avenue, Suite 106
Portland, Oregon 97214

September 23, 2009

LiDAR Remote Sensing Data Collection:
Lewis County, Washington

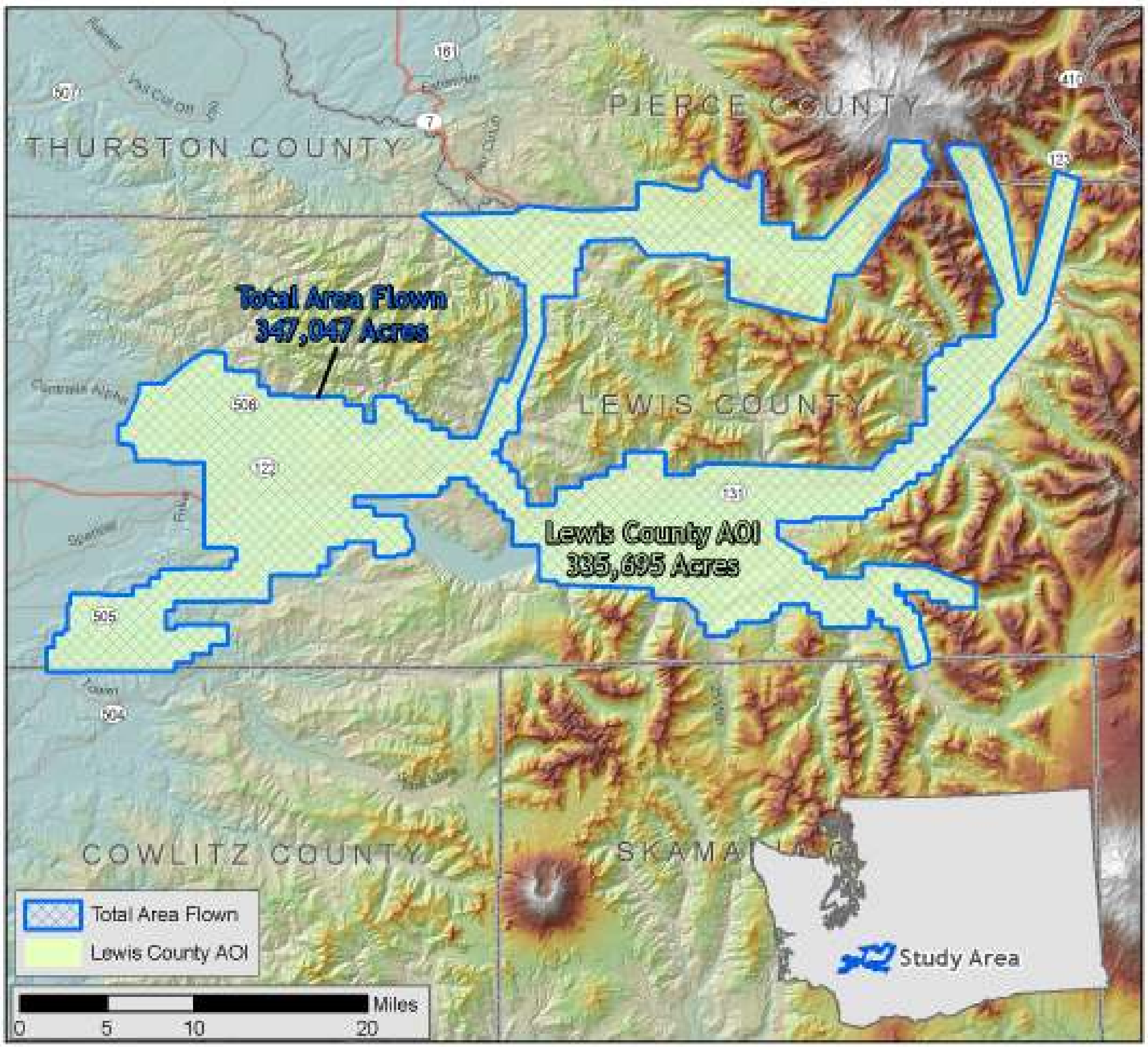
TABLE OF CONTENTS

1. Overview

1.1 Study Area

Watershed Sciences, Inc. (WS) collected Light Detection and Ranging (LiDAR) data in collaboration with the Puget Sound LiDAR Consortium (PSLC), Lewis County Department of Public Works, and Washington Department of Natural Resources (WA DNR). The extent of requested LiDAR area of interest (AOI) totals ~ 335,695 acres; the map below shows the AOI and the total area flown (TAF), covering ~347,047 acres. The area flown is greater than the original amount due to buffering of the original AOIs and flight planning optimization. The Lewis County study area consists of multiple areas for which the acquisition has been completed, but which will be processed as logistical constraints allow. This report will be amended to reflect new data and cumulative statistics for the overall LiDAR survey.

Figure1.1. *Lewis County, Washington study area, illustrating AOI and TAF.*



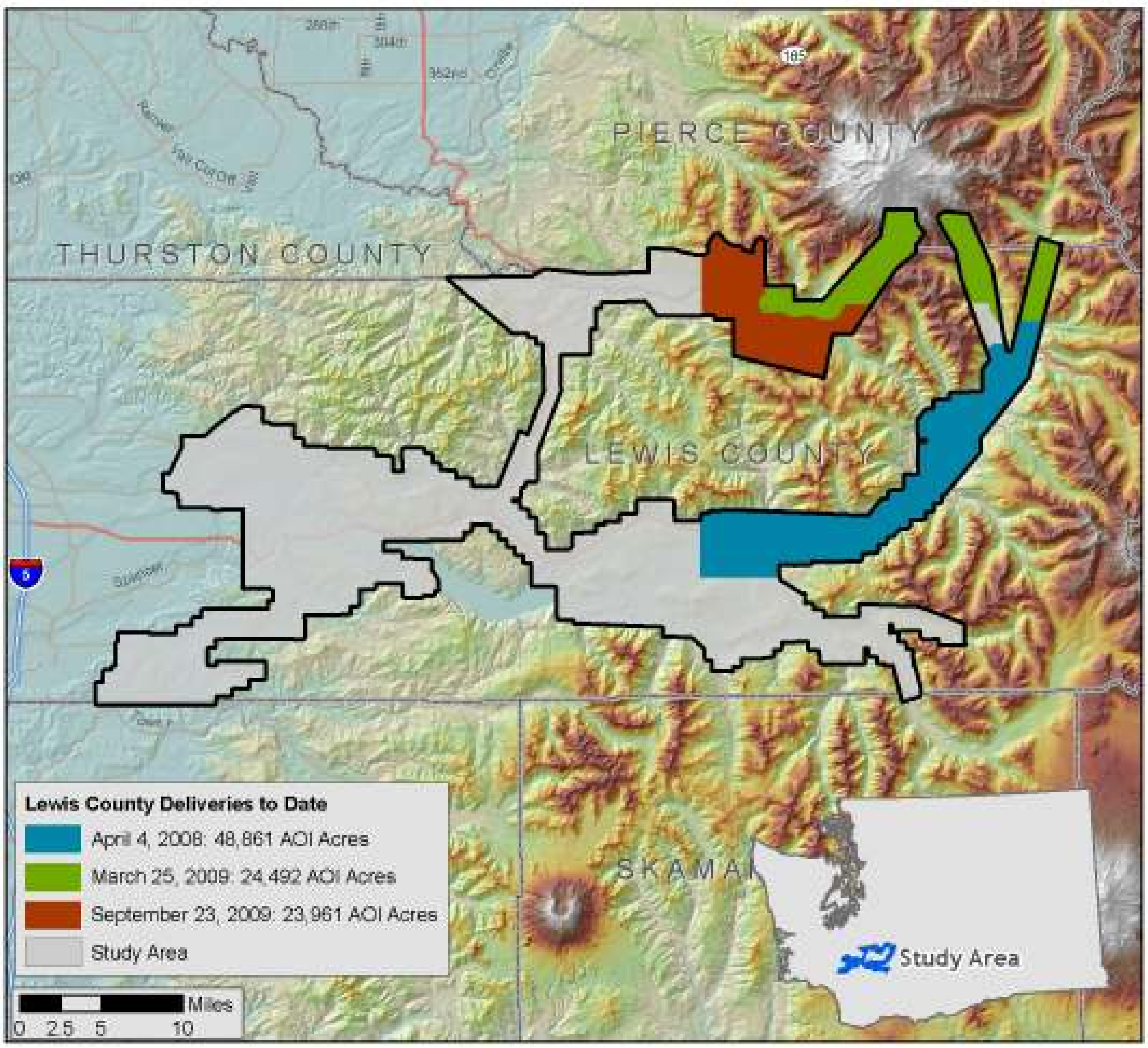
1.2 Area Delivered to Date

The total delivered acreage to date is detailed below.

Lewis County AOI		
Delivery Date	**AOI Acres**	**TAF Acres**
April 4, 2008	48,861	51,181
March 25, 2009*	24,492	26,170
September 23, 2009	23,961	24,312
Total	***97,314***	***101,663***

*Delivered as part of the National Park Service study area

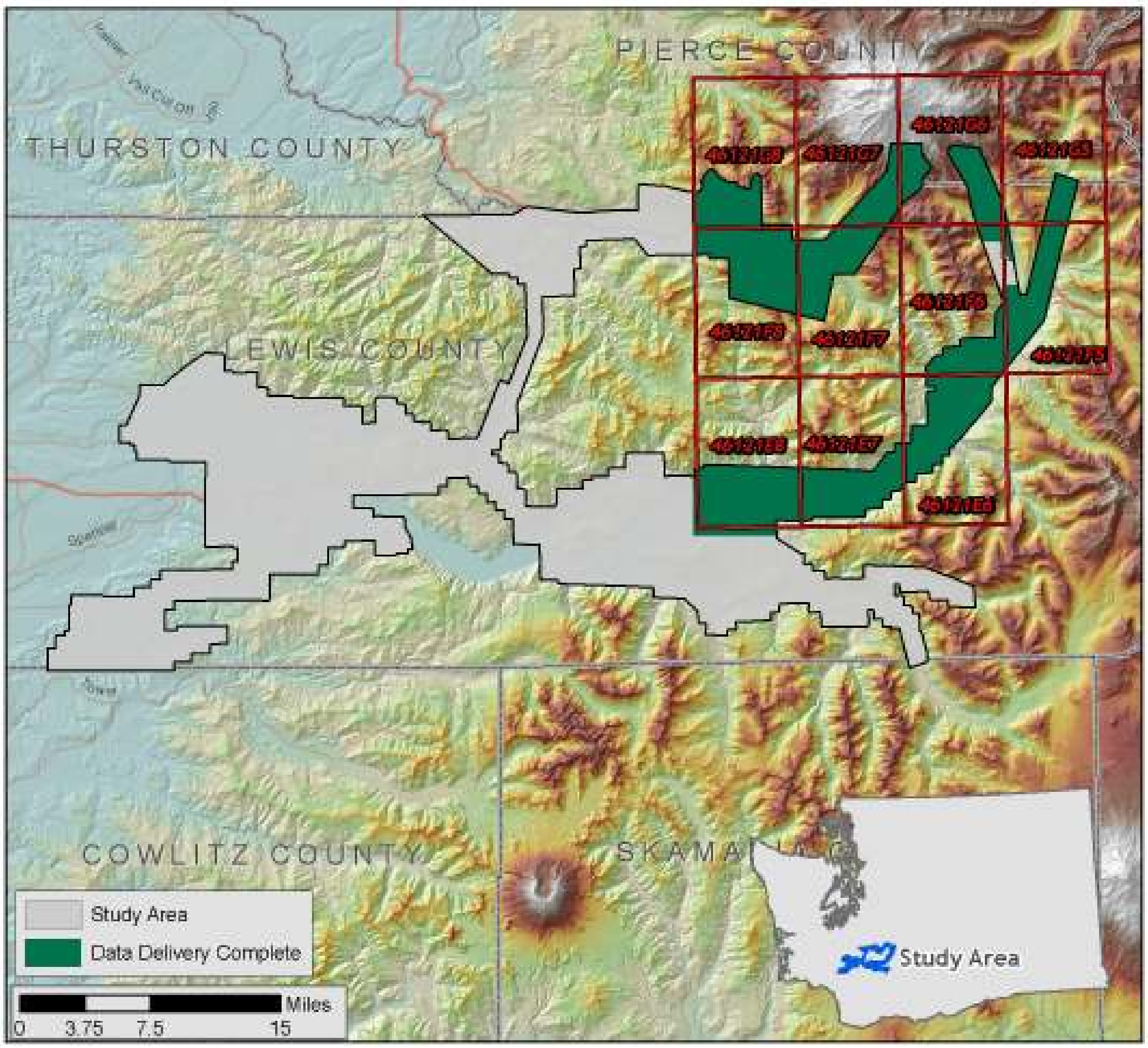
Figure 1.2. *Lewis County study area illustrating the delivered portion of the AOI.*



LiDAR data from the NPS Mt. Rainier data (delivered March 25, 2009, **Figure 1.2**) has been approved and is in public use. The inclusion of adjacent 2009 Lewis County LiDAR survey data (delivered September 23, 2009, **Figure 1.2**) revealed several ground model blemishes in the earlier dataset that were not discernable until viewed as a seamless surface. These misclassifications (primarily vegetation points misclassified as ground) have been corrected in the present delivery to improve overall data quality. A shapefile "LEWIS_RAINIER_SEAM.shp" is included in this delivery to describe the location of these corrections. In the case of stream channel bed and bank position changes that truly reflect changes in the physical landscape, the ground model was not altered. In these cases, a line at the boundary of the two study areas is occasionally discernible in the DEM datasets.

With respect to this boundary between the Mt. Rainier and the 2009 Lewis County data, all non-point data deliverables (elevation grids, intensity images, density rasters, and contours) are seamless and represented by complete tiles at this seam. Point data are delivered as two distinct datasets (folders are labeled "LEWIS_COUNTY_2009_ONLY" AND "NPS_RAINIER_ONLY"). This distinction eliminates complications arising from the presence of identical flightline numbers between datasets.

***Figure 1.3**. Lewis County, Washington study area, illustrating the delivered 7.5' USGS quads.*



1.3 Accuracy and Resolution

Ground-level real-time kinematic (RTK) surveys were conducted across multiple flightlines in the study area for quality assurance purposes. The accuracy of the LiDAR data is described as standard deviations of divergence (sigma ~ σ) from RTK ground survey points and root mean square error (RMSE) which considers bias (upward or downward). These statistics are calculated cumulatively. For the delivered portion of the study area, the data have the following accuracy statistics:

- RMSE of 0.10 feet
- 1-sigma absolute deviation of 0.11 feet
- 2-sigma absolute deviation of 0.21 feet

Data resolution specifications are for ≥8 pts per m^2. Section 4.2 demonstrates that total pulse density for the Lewis County AOIs delivered to date is 8.59 points per m^2 (0.80 points per square foot).

1.4 Data Format, Projection, and Units

Deliverables include point data in *.las v 1.2 and ascii format, 3- and 6-foot resolution bare ground model ESRI GRIDs, 3- and 6-foot resolution highest hit surface ESRI GRIDs, 3-foot resolution ground-classified point density ESRI GRIDs, 1.5-foot resolution intensity images in GeoTIFF format, Smoothed Best Estimate of Trajectory (200Hz frequency) information in ascii text format, 2-foor contour data, and a data report. **All AOIs are delivered in Washington State Plane South FIPS 4602, with horizontal units in and vertical units in US Survey Feet, in the NAD83 HARN/NAVD88 datum (Geoid 03).**

2. Acquisition

2.1 Airborne Survey Overview – Instrumentation and Methods

The LiDAR survey utilized a Leica ALS50 Phase II mounted in Cessna Caravan 208B. The Leica ALS50 Phase II system was set to acquire ≥105,000 laser pulses per second (i.e., 105 kHz pulse rate) and flown at 900 meters above ground level (AGL), capturing a scan angle of ±14° from nadir[1]. These settings are developed to yield points with an average native density of ≥8 points per square meter over terrestrial surfaces. The native pulse density is the number of pulses emitted by the LiDAR system. Some types of surfaces (i.e., 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 distributions of terrain, land cover and water bodies.

The Cessna Caravan is a powerful, stable platform, which is ideal for the often remote and mountainous terrain found in the Pacific Northwest. The Leica ALS50 sensor head installed in the Caravan is shown on the right.

Table 2.1 *LiDAR Survey Specifications*

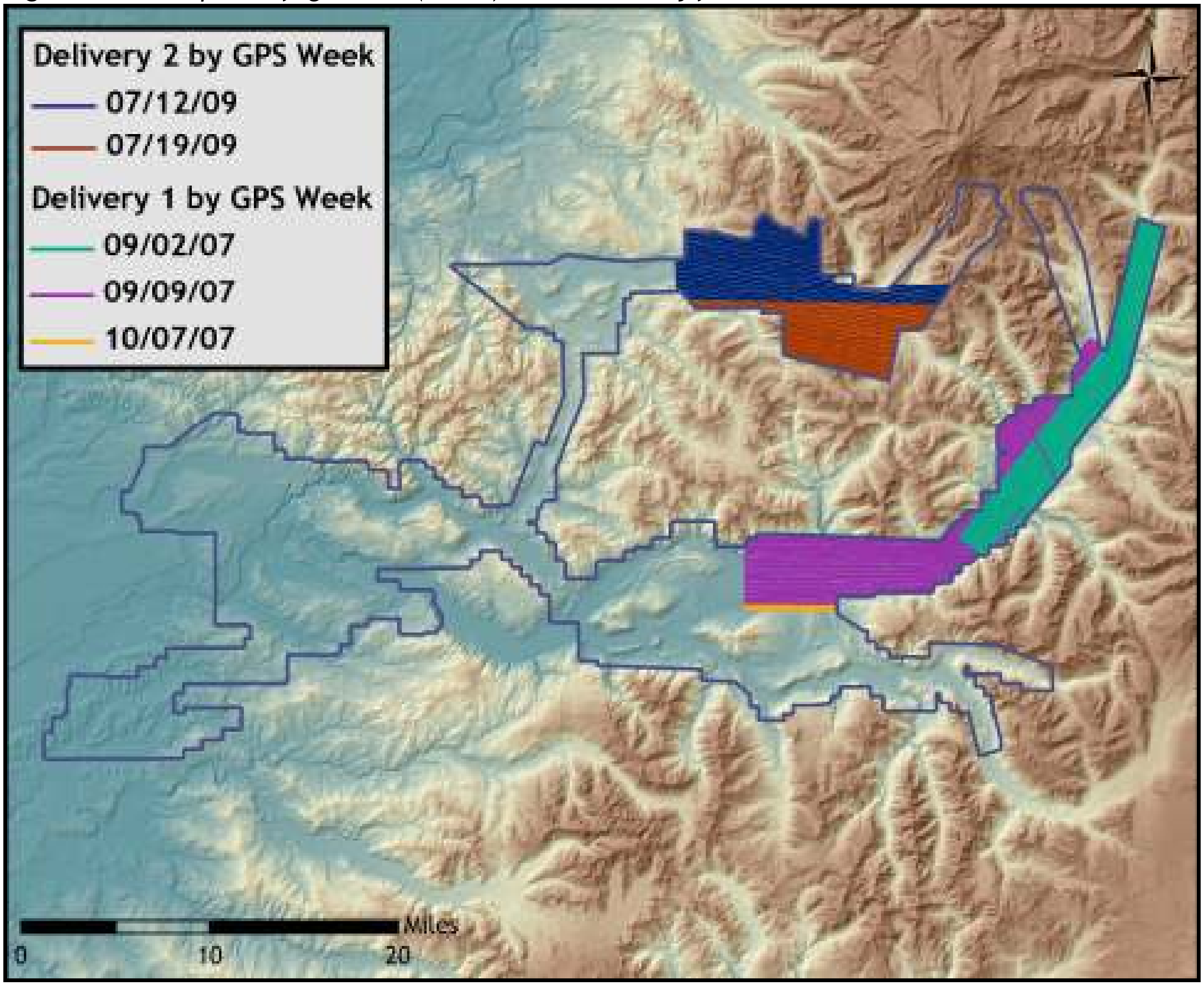
Sensor	Leica ALS50 Phase II and ALS60
Survey Altitude (AGL)	900 m and 1300 m
Pulse Rate	>105 kHz
Pulse Mode	Single
Mirror Scan Rate	52 Hz
Field of View	28° (±14° from nadir)
Roll Compensated	Up to 15°
Overlap	100% (50% Side-lap)

The study area was surveyed with opposing flight line side-lap of ≥50% (≥100% overlap) to reduce laser shadowing and increase surface laser painting. The system allows up to four range measurements per pulse, and all discernable laser returns were processed for the output dataset.

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 (2 Hz) by an onboard differential GPS unit. Aircraft attitude is measured 200 times per second (200 Hz) as pitch, roll and yaw (heading) from an onboard inertial measurement unit (IMU). **Figure 2.1** shows the flight lines completed for the area delivered to date.

[1] Nadir refers to the perpendicular vector to the ground directly below the aircraft. Nadir is commonly used to measure the angle from the vector and is referred to a "degrees from nadir".

Figure 2.1. *Completed flight lines (n=220) in Lewis County for area delivered to date.*



2.2 Ground Survey – Instrumentation and Methods

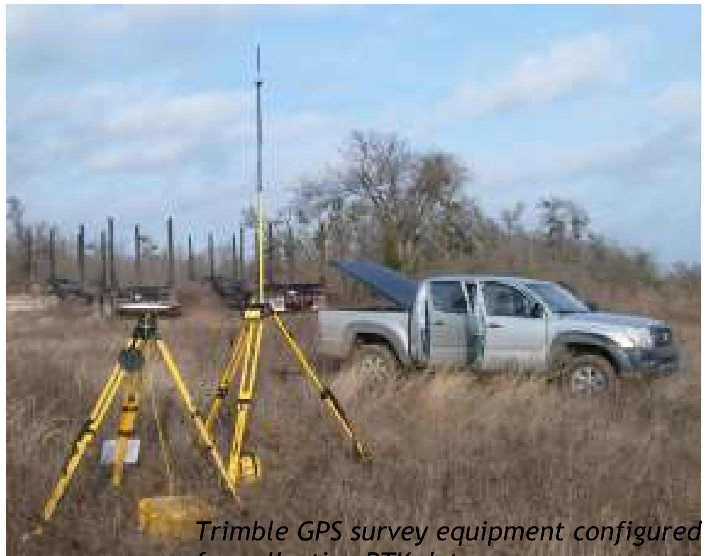
During the LiDAR survey, static (1 Hz recording frequency) ground surveys were conducted over monuments with known coordinates. Monument coordinates are provided in **Table 2.2** and shown in **Figure 2.2**. After the airborne survey, the static GPS data were processed using triangulation with CORS stations and checked against the Online Positioning User Service (OPUS[2]) to quantify daily variance. Multiple sessions were processed over the same monument to confirm antenna height measurements and reported position accuracy.

Table 2.2. *Base Station Surveyed Coordinates, (NAD83/NAVD88, OPUS corrected) used for kinematic post-processing of the aircraft GPS data for the Lewis County study area.*

	Datum NAD83(HARN)		GRS80
Base Station ID	Latitude (North)	Longitude (West)	Ellipsoid Height (m)
LC_PWH1	46 45 24.75493	122 0 38.77344	517.976
LC_PWH2	46 45 24.75544	122 0 38.68813	517.898
LC_RT1	46 31 04.23153	122 26 20.82304	248.853
LC_RT2	46 31 56.25820	122 32 07.87624	154.951
LC2	46 35 16.39962	121 40 58.89292	292.925
LCJR10	46 32 3.77809	121 47 22.62121	270.156
LCJR8	46 39 37.5557	121 37 0.31756	344.64
LCJR9	46 39 37.80458	121 37 0.35503	344.743
Lewis1_DB1	46 27 9.13376	122 33 14.09908	256.459
Lewis2_AXR1	46 32 09.85142	121 55 04.23385	268.483
Lewis2_DB1	46 30 08.66414	122 10 44.72734	219.023
Lewis3_AXR1	46 45 3.10674	122 10 54.91920	355.922
Lewis3_AXR2	46 43 14.16359	122 10 57.08130	414.223
NGS46155	46 33 1.98569	122 16 13.50983	265.802
WALEW01	46 34 32.00439	122 40 3.01110	154.991
WALEW02	46 23 54.48185	122 42 3.65623	68.025
Walew03	46 27 09.12336	122 33 13.95983	256.573

[2] Online Positioning User Service (OPUS) is run by the National Geodetic Survey to process corrected monument positions.

Multiple DGPS units were used for the ground real-time kinematic (RTK) portion of the survey. To collect accurate ground surveyed points, a GPS base unit was set up over monuments to broadcast a kinematic correction to a roving GPS unit. The ground crew used a roving unit to receive radio-relayed kinematic corrected positions from the base unit. This method is referred to as real-time kinematic (RTK) surveying and allows precise location measurement ($\sigma \leq 1.5$ cm ~ 0.6 in). 622 RTK ground points were collected throughout the portion of the study area completed to date and compared to LiDAR data for accuracy assessment. **Figures 2.2 and 2.3** show base station locations and detailed view of RTK point locations.



Trimble GPS survey equipment configured for collecting RTK data.

Figure 2.2*. Base station locations in the Lewis County study area.*

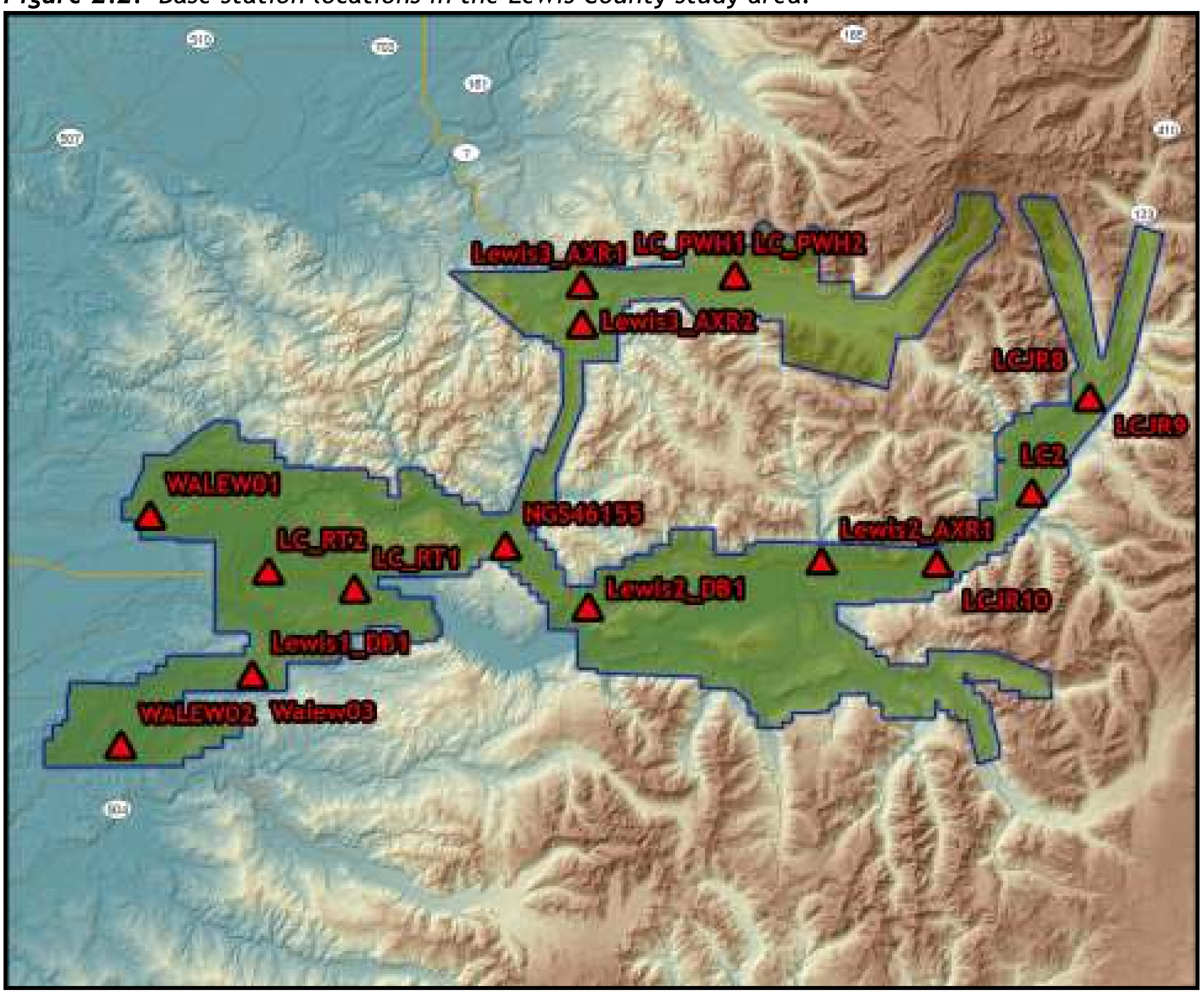
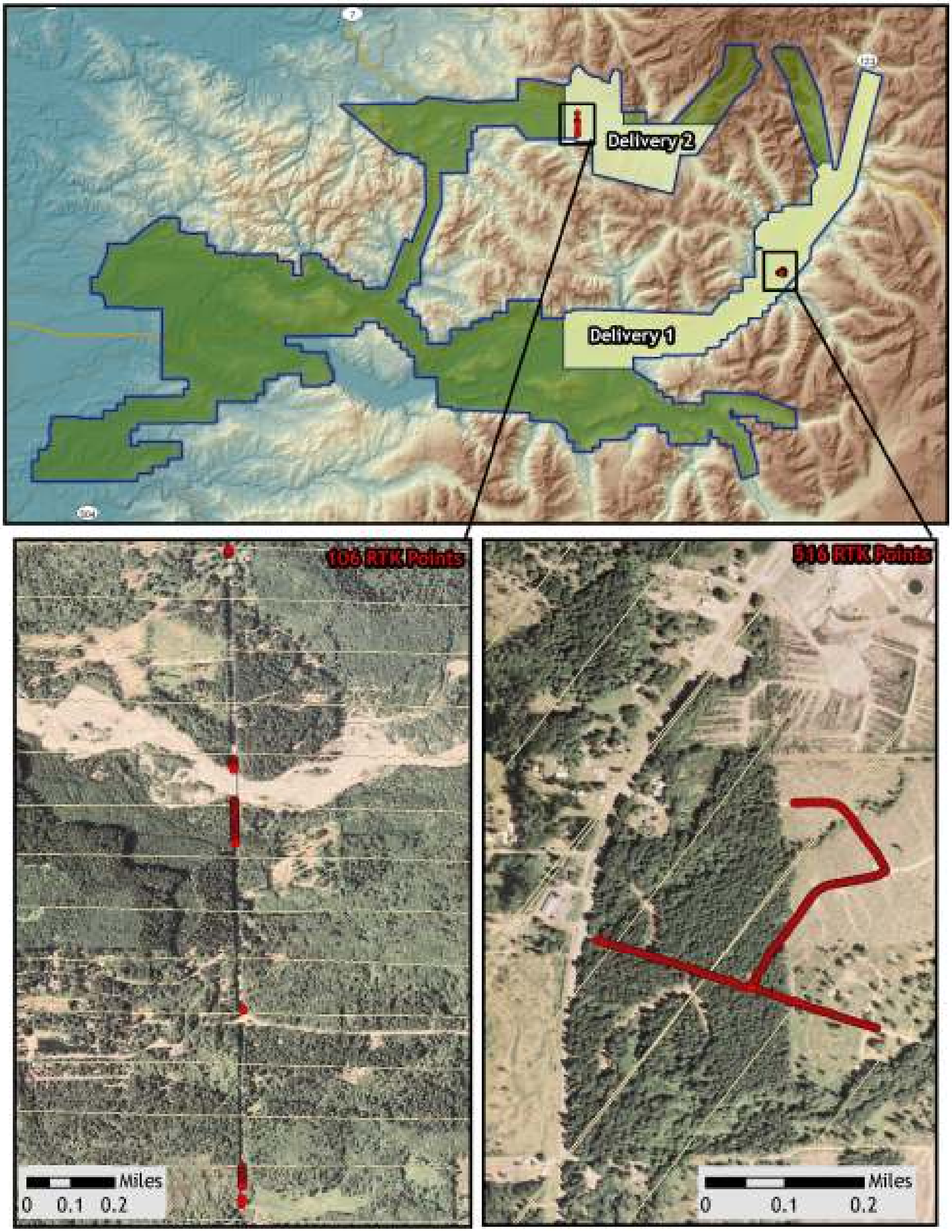


Figure 2.3. *RTK locations for deliveries 1 and 2 in the Lewis County study area.*



3. LiDAR Data Processing

3.1 Applications and Work Flow Overview

1. Resolve kinematic corrections for aircraft position data using kinematic aircraft GPS and static ground GPS data.
   Software: Waypoint GraphNav v.8.10, Trimble Geomatics Office v.1.63

2. Develop a smoothed best estimate of trajectory (SBET) file that blends the post-processed aircraft position with attitude data. Sensor head position and attitude are calculated throughout the survey. The SBET data are used extensively for laser point processing.
   Software: IPAS Pro 1.3

3. Calculate laser point position by associating the SBET position to each laser point return time, scan angle, intensity, etc. Creates raw laser point cloud data for the entire survey in *.las (ASPRS v1.2) format.
   Software: ALS Post Processing Software

4. Import raw laser points into manageable blocks (less than 500 MB) to perform manual relative accuracy calibration and filter for pits/birds. Ground points are then classified for individual flight lines (to be used for relative accuracy testing and calibration).
   Software: TerraScan v.9.001

5. Using ground classified points per each flight line, the relative accuracy is tested. Automated line-to-line calibrations are then performed 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.
   Software: TerraMatch v.9.001

6. Position and attitude data are imported. Resulting data are classified as ground and non-ground points. Statistical absolute accuracy is assessed via direct comparisons of ground classified points to ground RTK survey data. Data are then converted to orthometric elevations (NAVD88) by applying a Geoid03 correction. Ground models are created as a triangulated surface and exported as ArcInfo ASCII grids at a 3-foot pixel resolution.
   Software: TerraScan v.9.001, ArcMap v9.3, TerraModeler v.9.001

3.2 Aircraft Kinematic GPS and IMU Data

LiDAR survey datasets were referenced to 1 Hz static ground GPS data collected over pre-surveyed monuments with known coordinates. While surveying, the aircraft collected 2 Hz kinematic GPS data. The onboard inertial measurement unit (IMU) collected 200 Hz aircraft attitude data. Waypoint GPS v.7.80 was used to process the kinematic corrections for the aircraft. The static and kinematic GPS data were then post-processed after the survey to obtain an accurate GPS solution and aircraft positions. IPAS v.1.4 was used to develop a trajectory file that includes corrected aircraft position and attitude information. The trajectory data for the entire flight survey session was incorporated into a final smoothed best estimated trajectory (SBET) file that contains accurate and continuous aircraft positions and attitudes.

3.3 Laser Point Processing

Laser point coordinates were computed using the IPAS and ALS Post Processor software suites based on independent data from the LiDAR system (pulse time, scan angle), and aircraft trajectory data (SBET). Laser point returns (first through fourth) were assigned an associated (x, y, z) coordinate along with unique intensity values (0-255). The data were output into large 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.

These initial laser point files were too large to process. To facilitate laser point processing, bins (polygons) were created to divide the dataset into manageable sizes (< 500 MB). Flightlines and LiDAR data were then reviewed to ensure complete coverage of the study area and positional accuracy of the laser points.

Once the laser point data were imported into bins in TerraScan, a manual calibration was performed to assess the system offsets for pitch, roll, heading and mirror scale. Using a geometric relationship developed by Watershed Sciences, each of these offsets was resolved and corrected if necessary.

The LiDAR points were then filtered for noise, pits and birds by screening for absolute elevation limits, isolated points and height above ground. Each bin was then inspected for pits and birds manually; spurious points were removed. For a bin containing approximately 7.5-9.0 million points, an average of 50-100 points are typically found to be artificially low or high. These spurious non-terrestrial laser points must be removed from the dataset. Common sources of non-terrestrial returns are clouds, birds, vapor, and haze.

The internal calibration was refined using TerraMatch. Points from overlapping lines were tested for internal consistency and final adjustments were made for system misalignments (i.e., pitch, roll, heading offsets and mirror scale). Automated sensor attitude and scale corrections yielded 3-5 cm improvements in the relative accuracy. Once the system misalignments were corrected, vertical GPS drift was then resolved and removed per flight line, yielding a slight improvement (<1 cm) in relative accuracy. At this point in the workflow, data had passed a robust calibration designed to reduce inconsistencies from multiple sources (i.e., sensor attitude offsets, mirror scale, GPS drift) using a procedure that is comprehensive (i.e., uses all of the overlapping survey data).

The TerraScan software suite is designed specifically for classifying near-ground points (Soininen, 2004). The processing sequence began by 'removing' all points that were not 'near' the earth based on geometric constraints used to evaluate multi-return points. The resulting bare earth (ground) model was visually inspected and additional ground point modeling was performed in site-specific areas (over a 50-meter radius) to improve ground detail. This was only done in areas with known ground modeling deficiencies, such as: bedrock outcrops, cliffs, deeply incised stream banks, and dense vegetation. In some cases, ground point classification included known vegetation (i.e., understory, low/dense shrubs, etc.) and these points were reclassified as non-grounds. Ground surface rasters were developed from triangulated irregular networks (TINs) of ground points.

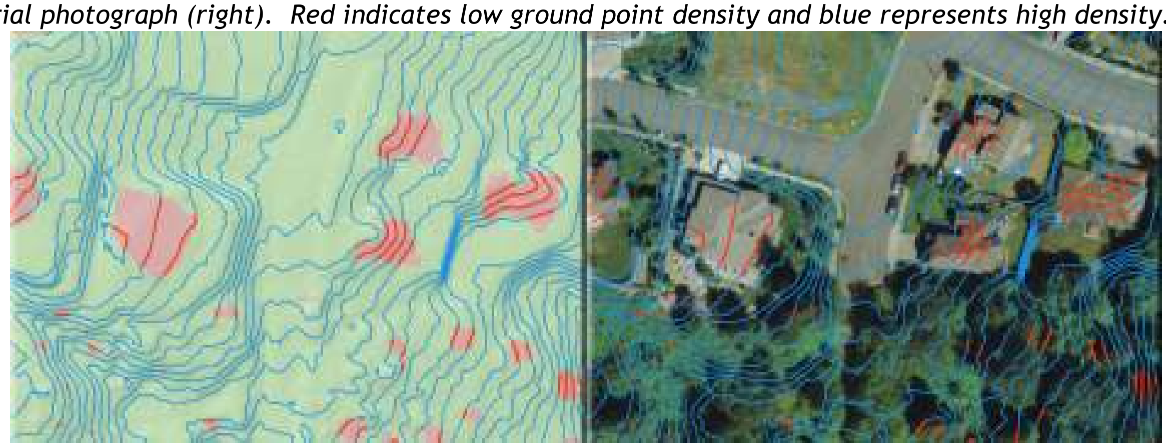
3.4 Contour Development

Contour lines were derived at a 2-foot interval from ground-classified LiDAR point data using MicroStation v. 8.01.

Ground point density rasters were created within MicroStation using a 3-foot step resolution and a 6-foot sampling radius. Areas with less than 0.02 ground-classified points per square foot (0.25 points per square meter) were considered as “sparse” and areas with higher densities were considered as “covered”. The ground point density rasters are in ESRI GRID format and have a 3-foot pixel resolution.

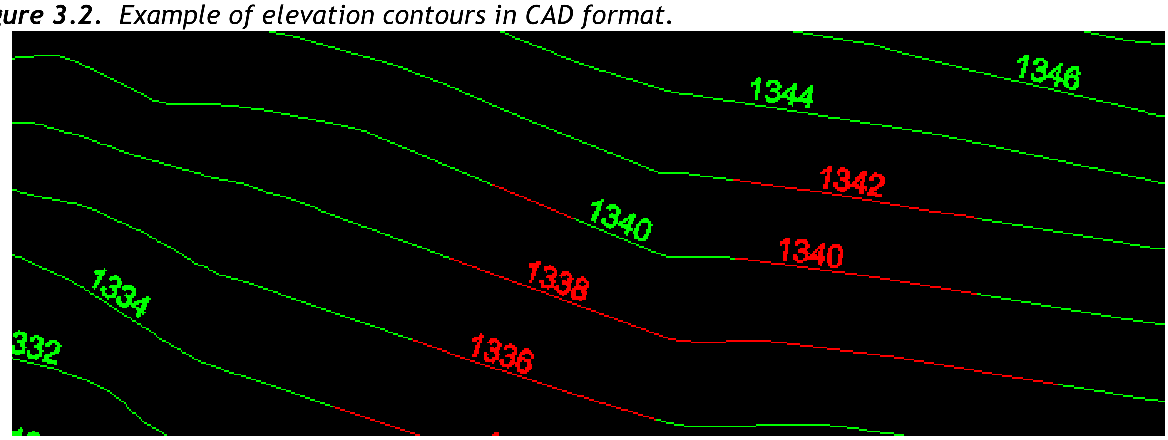
The elevation contour lines were intersected with the ground point density rasters and a confidence value was added to the contour lines. Contour lines over “sparse” areas have a low confidence, while contour lines over “covered” areas have a good confidence. Areas with low ground point density are commonly beneath buildings and bridges, in locations with dense vegetation, over water, and in other areas where laser pulses are unable to sufficiently penetrate to the ground surface. **Figure 3.1** is an example of a ground point density raster and contour lines.

Figure 3.1. *Elevation contours over LiDAR ground-classified point density raster (left) and true-color aerial photograph (right). Red indicates low ground point density and blue represents high density.*



The CAD files (*.DWG) are coded to display high and low confidence contours as green and red, respectively (**Figure 3.2**). The elevation label units are feet.

Figure 3.2. *Example of elevation contours in CAD format.*



4. LiDAR Accuracy and Resolution

4.1 Laser Point Accuracy

Laser point absolute accuracy is largely a function of internal consistency (measured as relative accuracy) and laser noise:

- **Laser Noise**: For any given target, laser noise is the breadth of the data cloud per laser return (i.e., last, first, etc.). Lower intensity surfaces (roads, rooftops, still/calm water) experience higher laser noise. The laser noise range for this mission was approximately 0.02 meters.

- **Relative Accuracy**: Internal consistency refers to the ability to place a laser point in the same location over multiple flight lines, GPS conditions, and aircraft attitudes.

- **Absolute Accuracy**: RTK GPS measurements taken in the study area compared to LiDAR point data.

Statements of statistical accuracy apply to fixed terrestrial surfaces only, not to free-flowing or standing water surfaces, moving automobiles, etc.

Table 4.1. *LiDAR accuracy is a combination of several sources of error. These sources of error are cumulative. Some error sources that are biased and act in a patterned displacement can be resolved in post processing.*

Type of Error	Source	Post Processing Solution
GPS (Static/Kinematic)	Long Base Lines	None
	Poor Satellite Constellation	None
	Poor Antenna Visibility	Reduce Visibility Mask
Relative Accuracy	Poor System Calibration	Recalibrate IMU and sensor offsets/settings
	Inaccurate System	None
Laser Noise	Poor Laser Timing	None
	Poor Laser Reception	None
	Poor Laser Power	None
	Irregular Laser Shape	None

4.1.1 Relative Accuracy

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

Operational measures taken to improve relative accuracy:

1. Low Flight Altitude: Terrain following was targeted at a flight altitude of 900 meters above ground level (AGL). Laser horizontal errors are a function of flight altitude above ground (i.e., ~ 1/3000th AGL flight altitude). Lower flight altitudes decrease laser noise on surfaces with even the slightest relief.
2. Focus Laser Power at narrow beam footprint: A laser return must be received by the system above a power threshold to accurately record a measurement. The strength of the laser return is a function of laser emission power, laser footprint, flight altitude and the reflectivity of the target. While surface reflectivity cannot be controlled, laser power can be increased and low flight altitudes can be maintained.
3. Reduced Scan Angle: Edge-of-scan data can become inaccurate. The scan angle was reduced to a maximum of ±14^{o} from nadir, creating a narrow swath width and greatly reducing laser shadows from trees and buildings.
4. Quality GPS: Flights took place during optimal GPS conditions (e.g., 6 or more satellites and PDOP [Position Dilution of Precision] less than 3.0). Before each flight, the PDOP was determined for the survey day. During all flight times, a dual frequency DGPS base station recording at 1-second epochs was utilized and a maximum baseline length between the aircraft and the control points was less than 19 km (11.5 miles) at all times.
5. Ground Survey: Ground survey point accuracy (i.e., <1.5 cm RMSE) occurs during optimal PDOP ranges and targets a minimal baseline distance of 4 miles between GPS rover and base. Robust statistics are, in part, a function of sample size (n) and distribution. The ground survey collected 622 RTK points that are distributed throughout multiple flight lines across the study area.
6. 50% Side-Lap (100% Overlap): Overlapping areas are optimized for relative accuracy testing. Laser shadowing is minimized to help increase target acquisition from multiple scan angles. Ideally, with a 50% side-lap, the most nadir portion of one flight line coincides with the edge (least nadir) portion of overlapping flight lines. A minimum of 50% side-lap with terrain-followed acquisition prevents data gaps.
7. Opposing Flight Lines: All overlapping flight lines are opposing. Pitch, roll and heading errors are amplified by a factor of two relative to the adjacent flight line(s), making misalignments easier to detect and resolve.

Relative Accuracy Calibration Methodology

1. Manual System Calibration: Calibration procedures for each mission require solving geometric relationships that relate measured swath-to-swath deviations to misalignments of system attitude parameters. Corrected scale, pitch, roll and heading offsets were calculated and applied to resolve misalignments. The raw divergence between lines was computed after the manual calibration was completed and reported for each study area.

2. Automated Attitude Calibration: All data were tested and calibrated using TerraMatch automated sampling routines. Ground points were classified for each individual flight line and used for line-to-line testing. ***The resulting overlapping ground points (per line) total 635,467,362 points from which to compute and refine relative accuracy***. System misalignment offsets (pitch, roll and heading) and mirror scale were solved for each individual mission. The application of attitude misalignment offsets (and mirror scale) occurs for each individual mission. The data from each mission was then blended when imported together to form the entire area of interest.

3. Automated Z Calibration: Ground points per line were utilized to calculate the vertical divergence between lines caused by vertical GPS drift. Automated Z calibration was the final step employed for relative accuracy calibration.

Relative Accuracy Calibration Results

Relative accuracies have been determined for all portions of the Lewis County study area delivered to date; the statistics are based on the comparison of 220 flightlines and 635,467,362 points. Relative accuracy statistics for the Lewis County study area are shown in **Figure 4.1** and graphically reported in **Figures 4.2 and 4.3**. For flightline coverage, see **Figure 2.1** in Section 2.1.

- Project Average = 0.33 ft
- Median Relative Accuracy = 0.27 ft
- 1σ Relative Accuracy = 0.32 ft
- 2σ Relative Accuracy = 0.66 ft

***Figure 4.1**. Portion of the study area for which relative accuracy statistics are reported.*

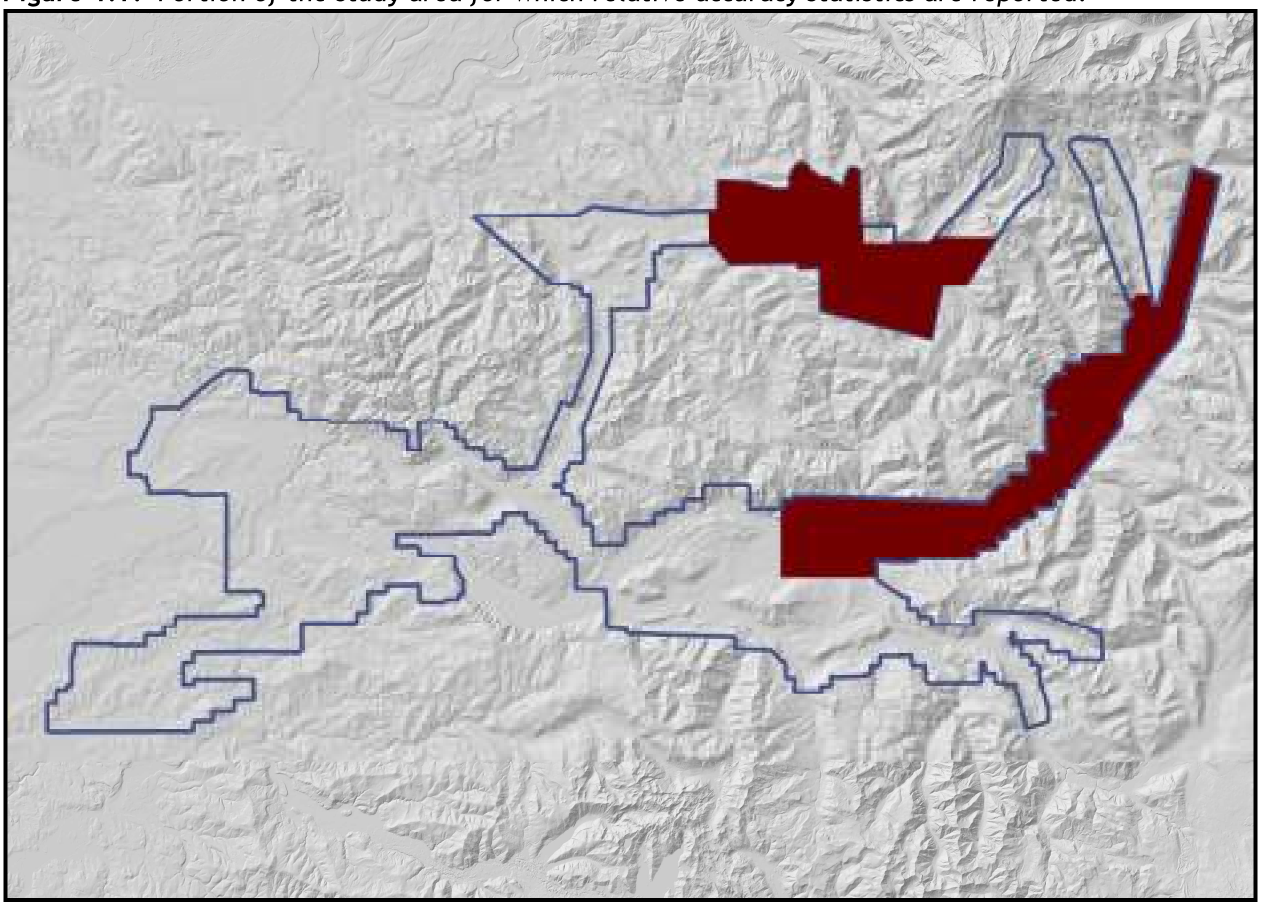


Figure 4.2. *Distribution of relative accuracies per flight line, non slope-adjusted.*

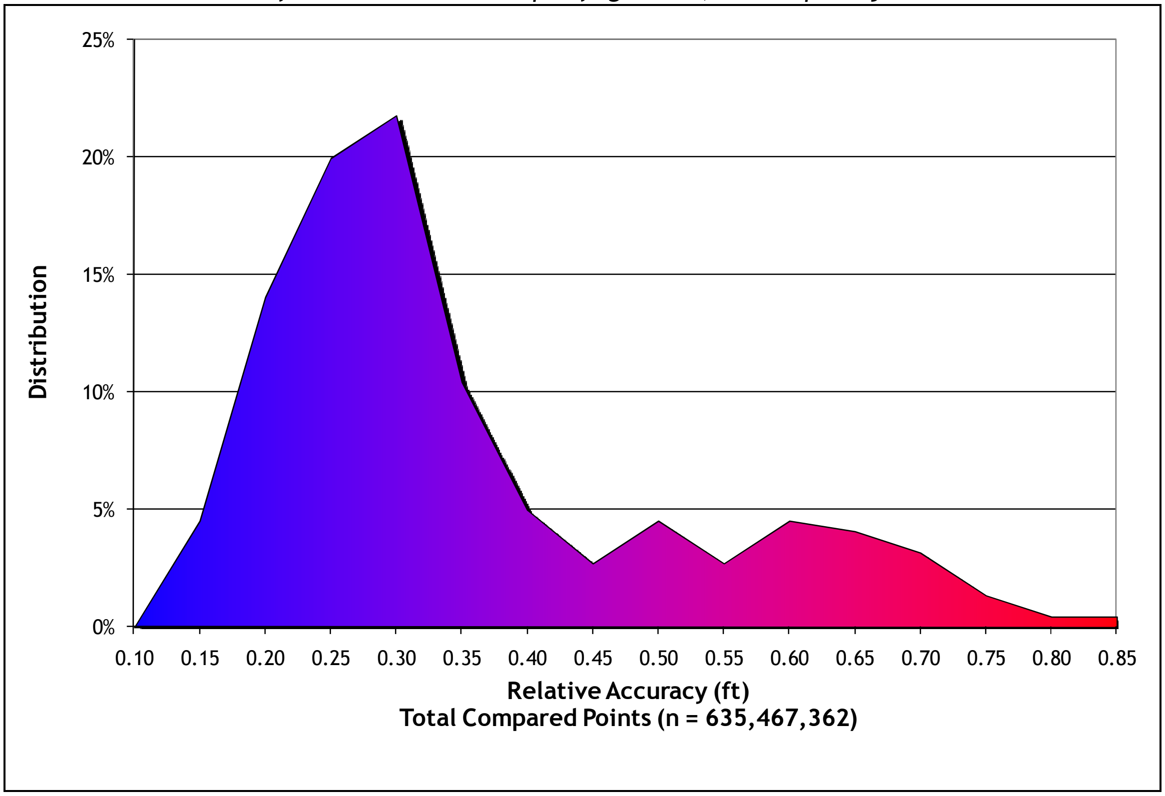
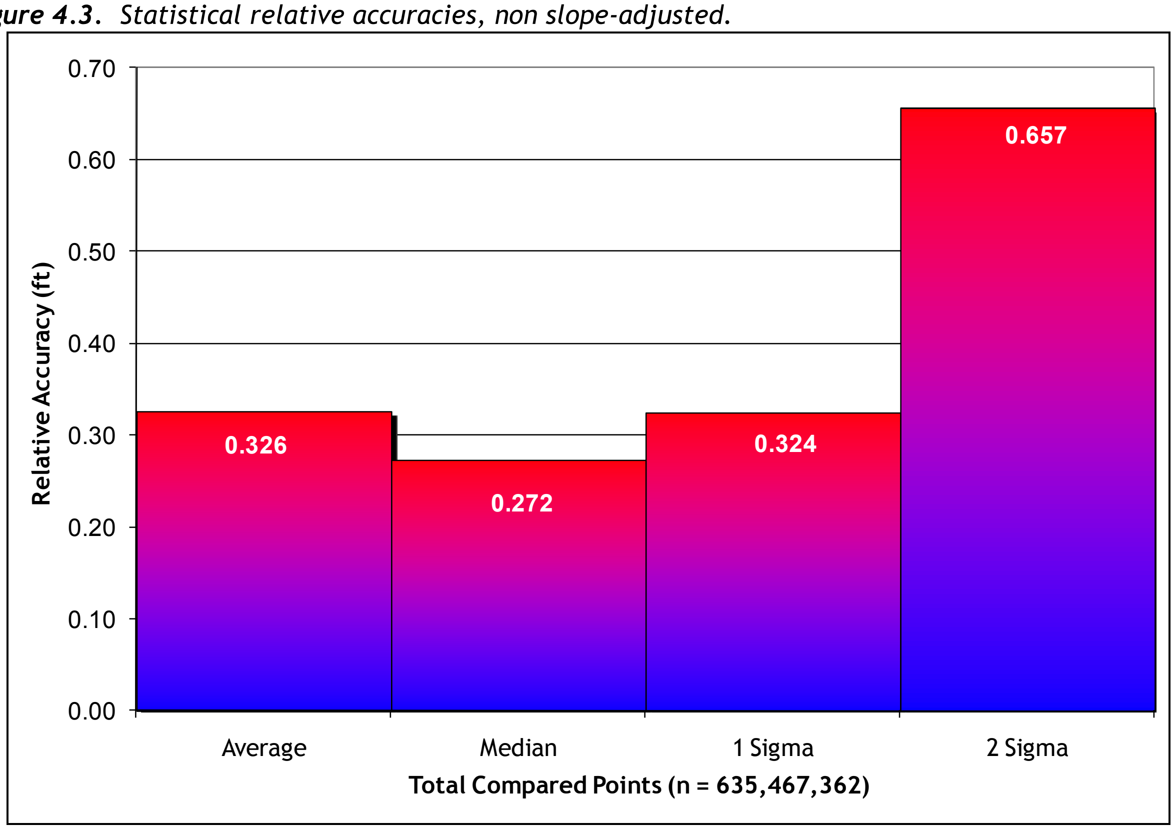


Figure 4.3. *Statistical relative accuracies, non slope-adjusted.*



4.1.2 Absolute Accuracy

The final quality control measure is a statistical accuracy assessment that compares known RTK ground survey points to the closest laser point. Absolute accuracy statistics have been developed for the area shown in **Figure 4.4** and graphically reported in **Figures 4.5** and **4.6.**

Table 4.2*. Absolute Accuracy – Deviation between laser points and RTK survey points.*

Sample Size (n): 622	
Root Mean Square Error (RMSE): 0.10 feet (0.03 m)	
Standard Deviations	**Deviations**
1 sigma (σ): 0.11 feet	**Minimum Δz:** -0.49 feet
2 sigma (σ): 0.21 feet	**Maximum Δz:** 0.21 feet
	Average Δz: -0.05 feet

Figure 4.4*. Portion of the study area for which absolute accuracy statistics are reported.*

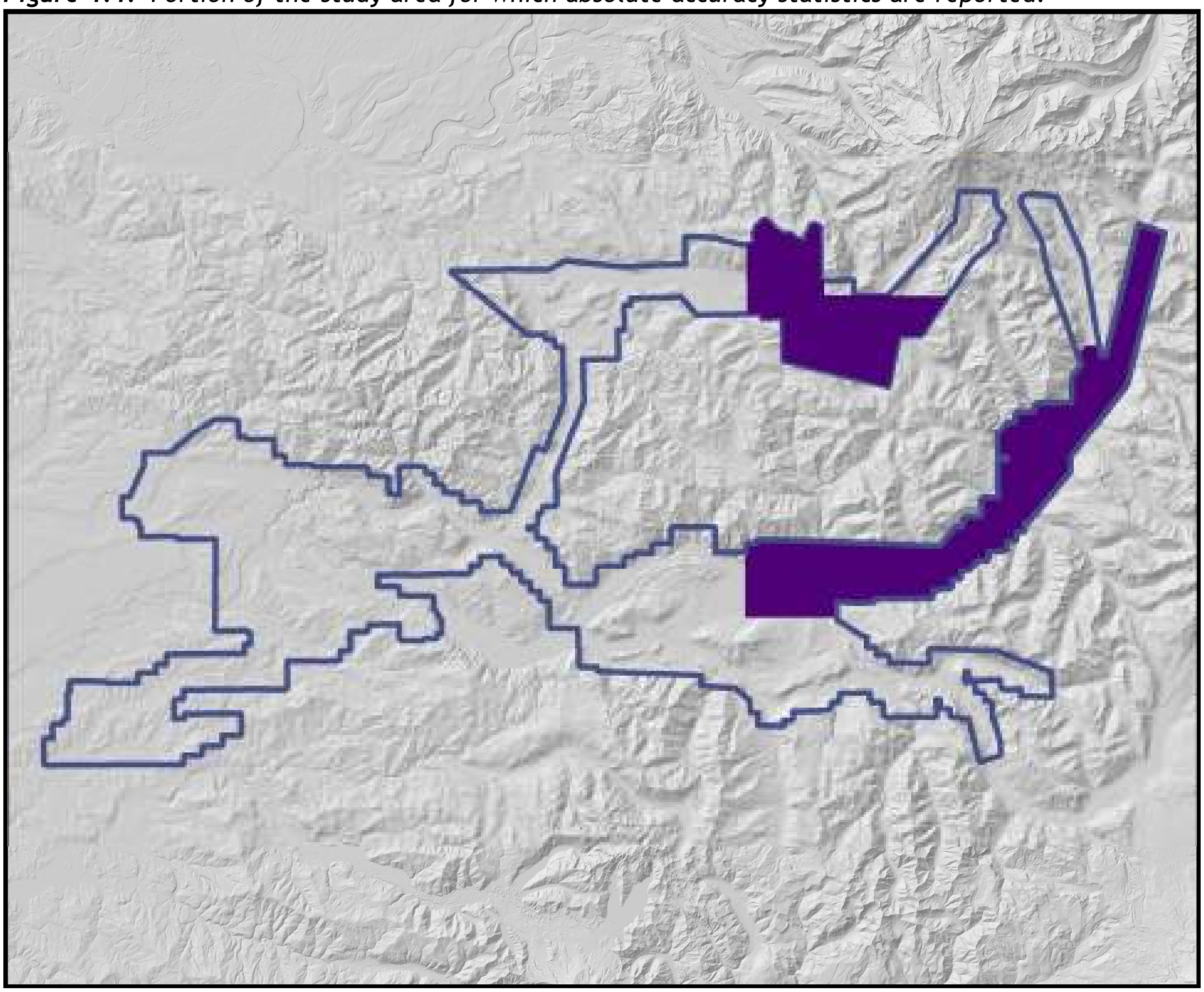


Figure 4.5. *Absolute accuracy histogram statistics*

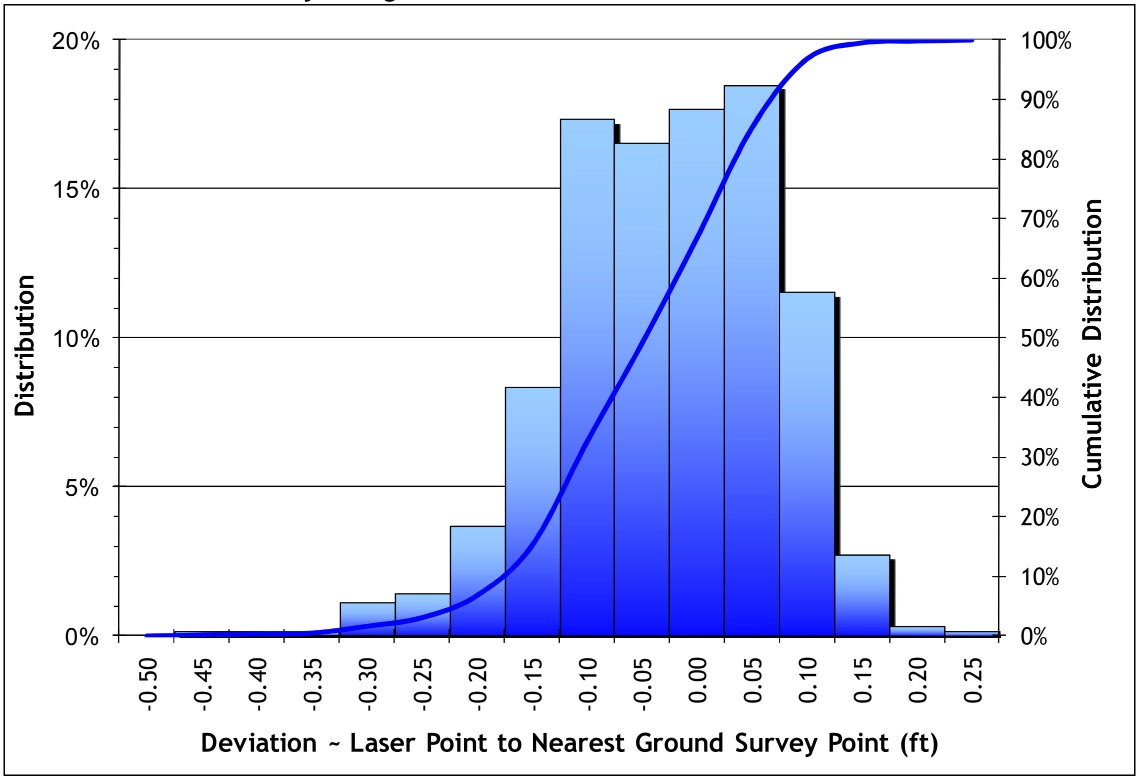
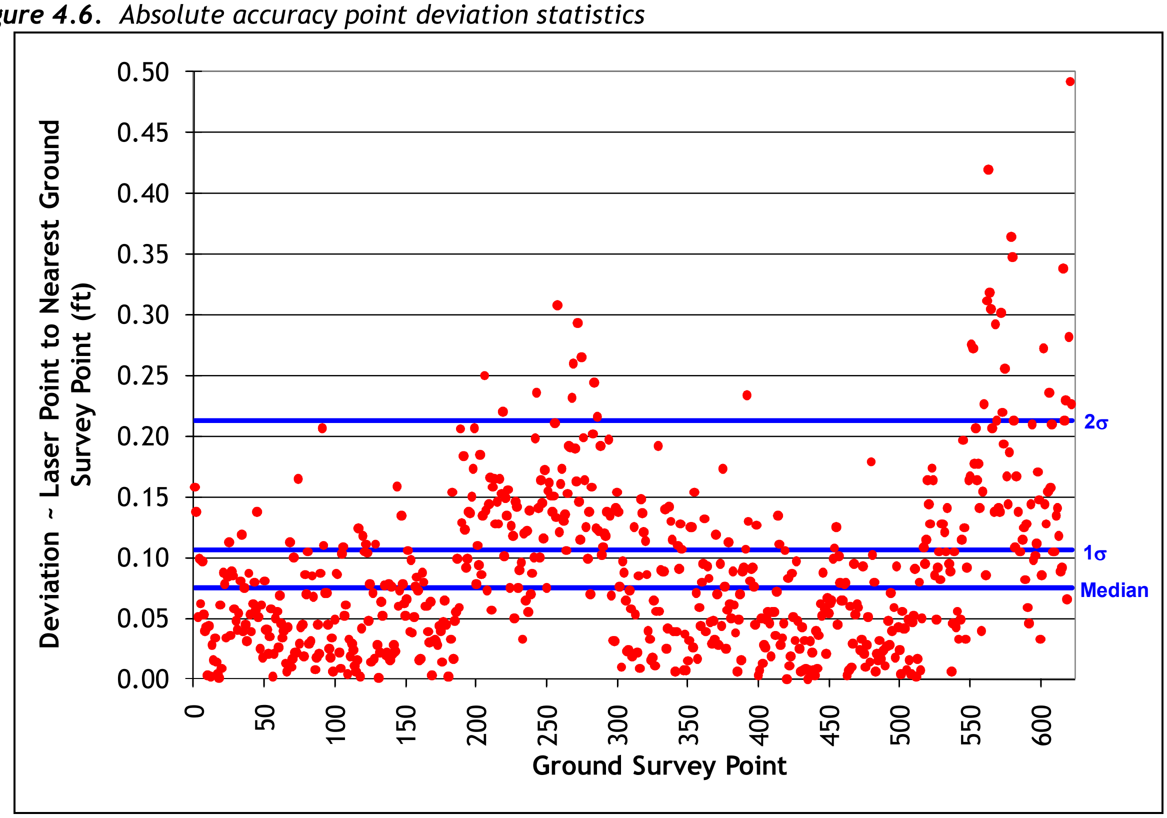


Figure 4.6. *Absolute accuracy point deviation statistics*



4.2 Data Density/Resolution

Some types of surfaces (i.e., 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 distributions of terrain, land cover and water bodies. Density histograms and maps (**Figures 4.7-4.10**) have been calculated based on first return laser point density and ground-classified laser point density.

- The total density for all delivered data for the Lewis County study area is **0.80 points per square foot** (**8.59 points per square meter**, based on first return pulses only).

4.2.1 First Return Laser Pulses per Square Foot

Figure 4.7. *Histogram of first return laser point density for data delivered to date in the Lewis County study area, per 0.75' USGS Quad.*

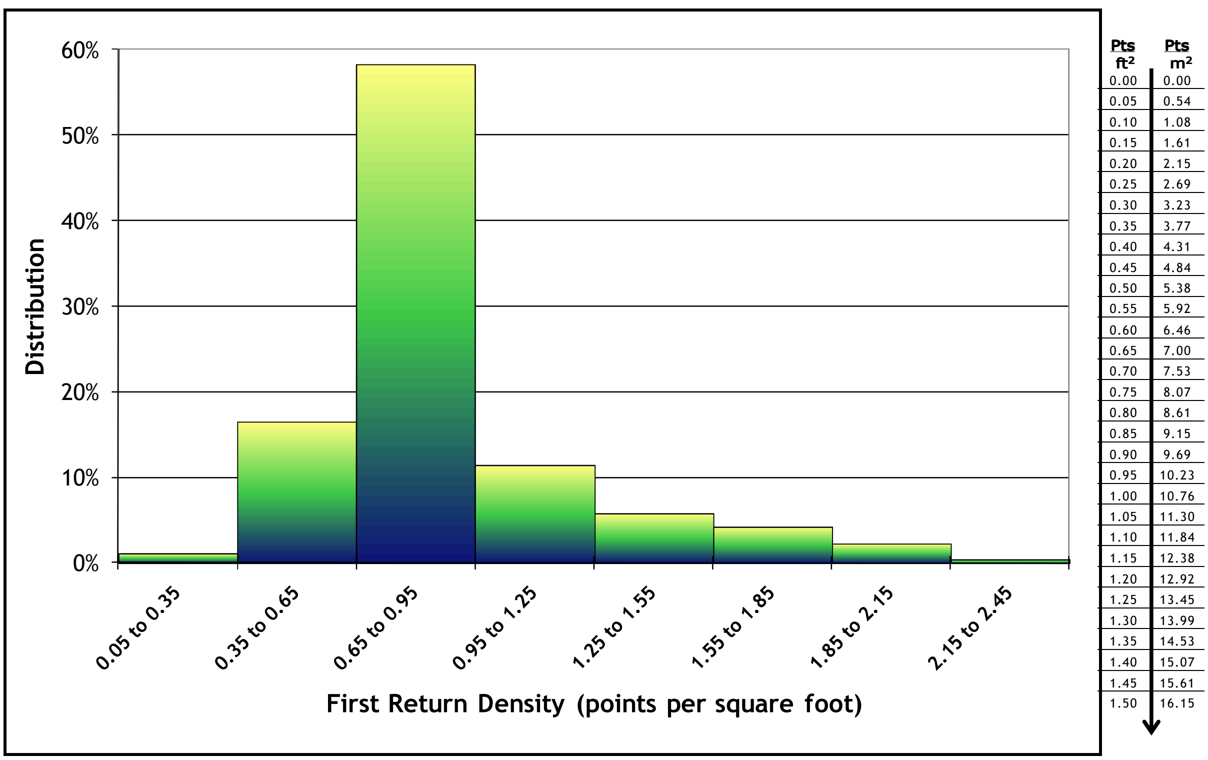
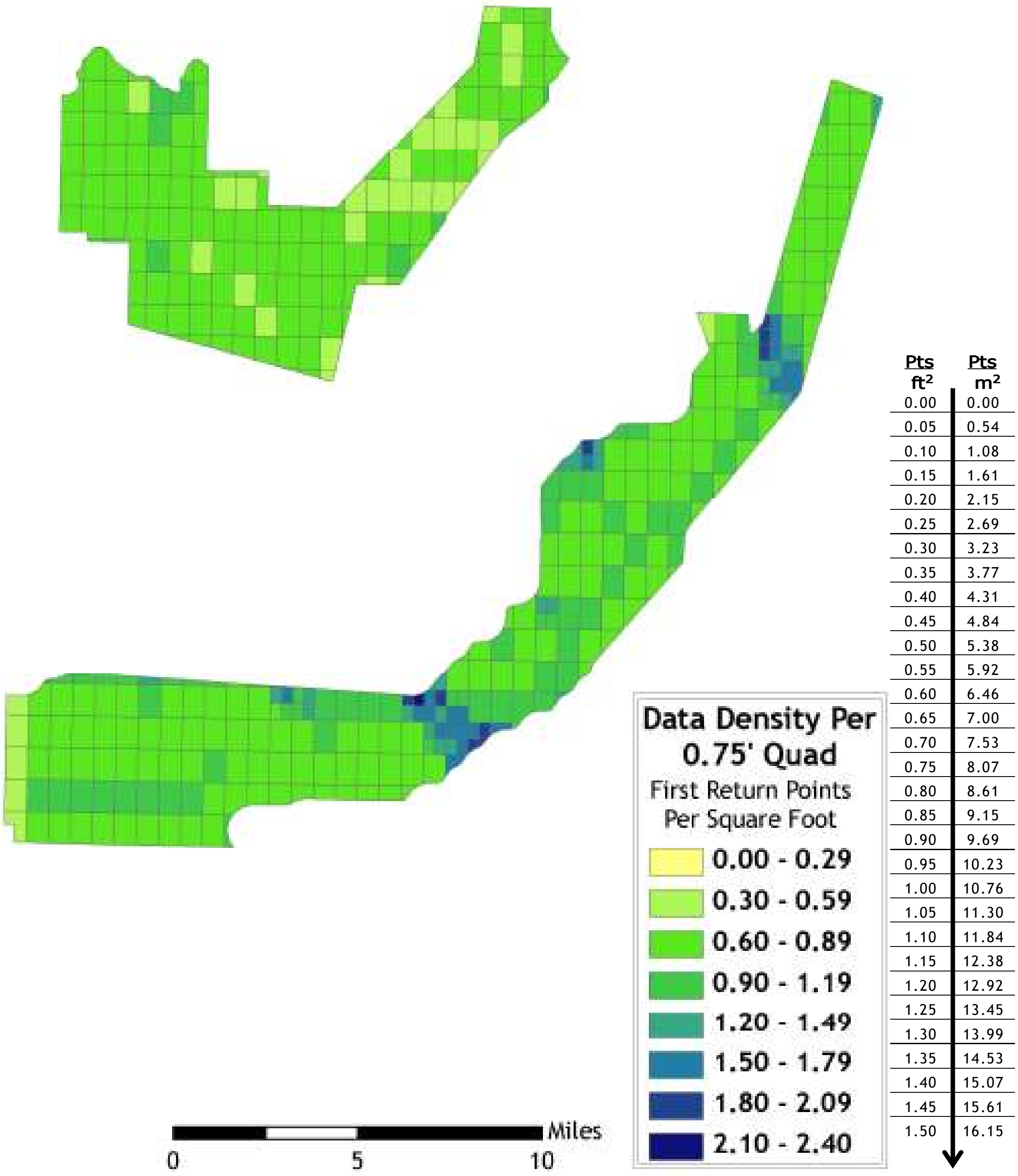


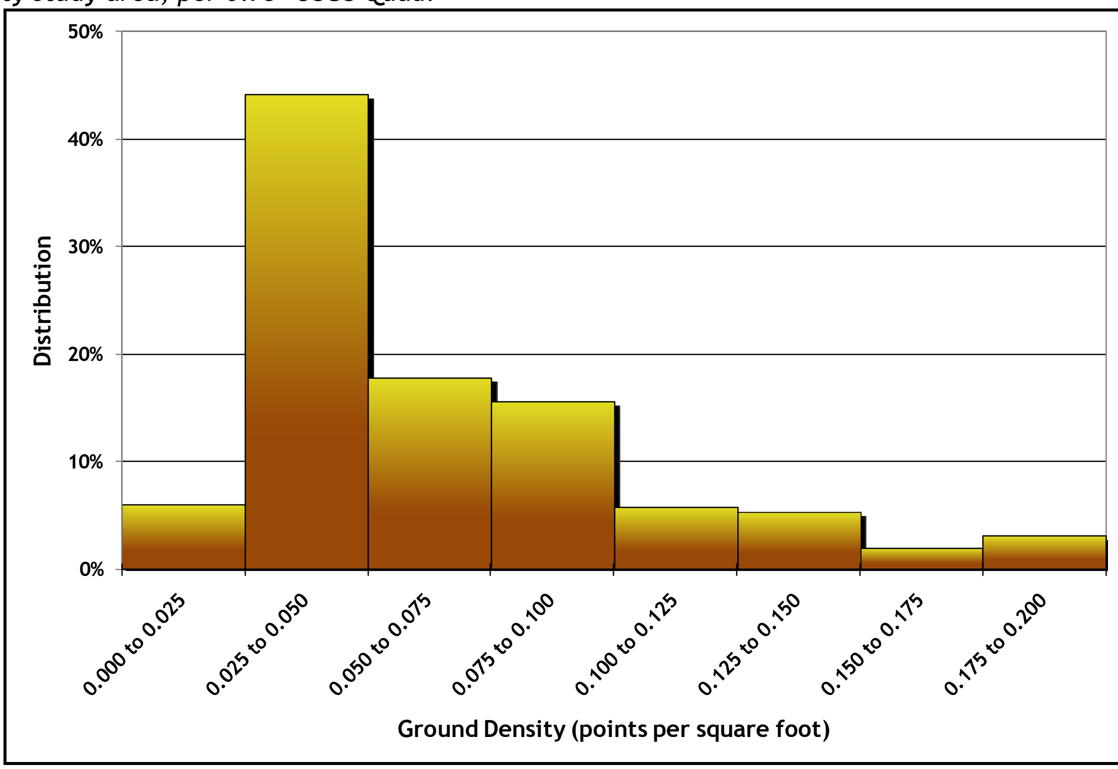
***Figure 4.8**. Image shows first return laser point density for data delivered to date in the Lewis County study area, per 0.75' USGS Quad.*



4.2.2 Classified Ground Points per Square Foot

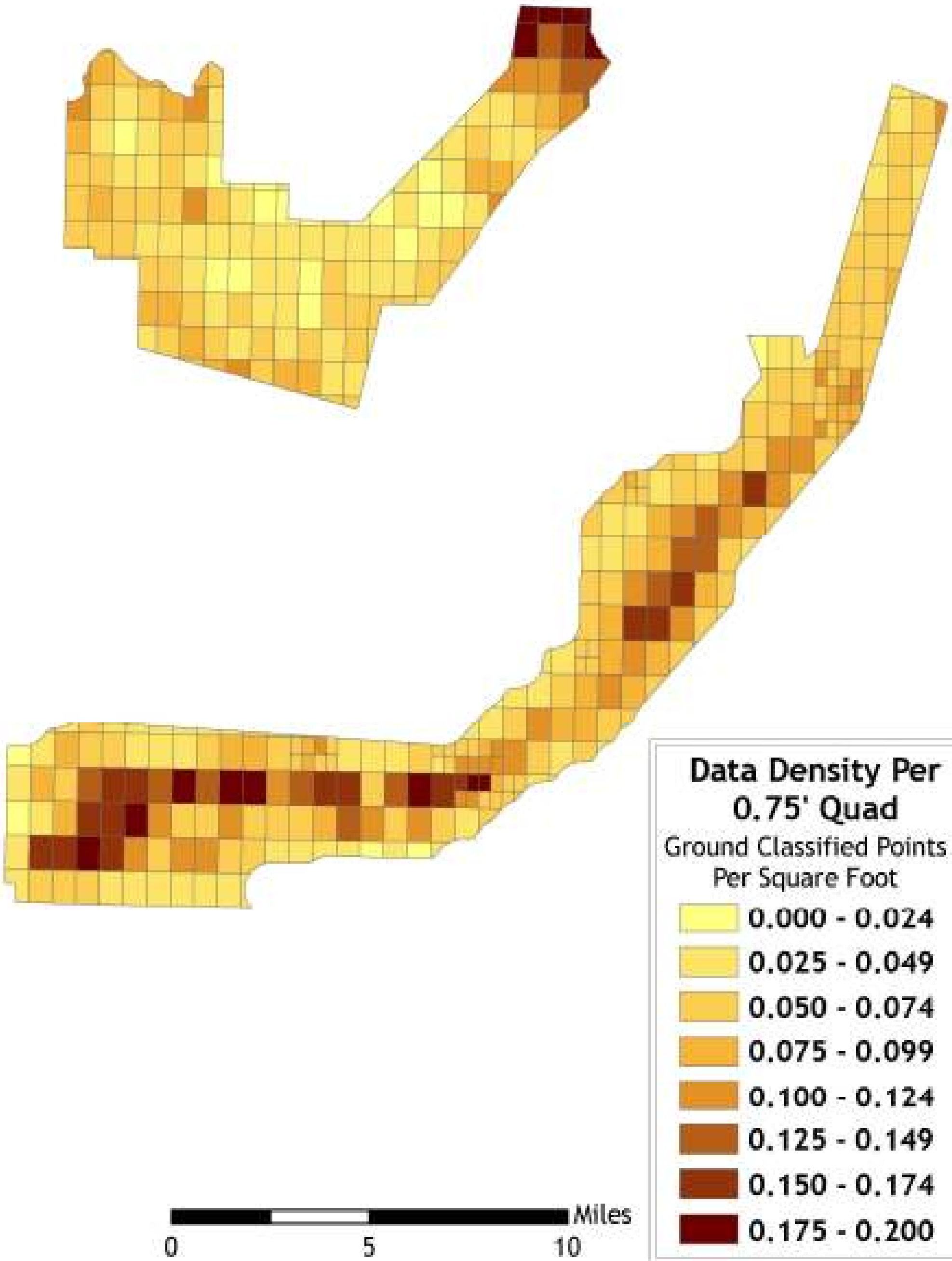
Ground classifications are derived from ground surface modeling. Supervised classifications were performed by reseeding of the ground model where it is determined that the ground model has failed, usually under dense vegetation and/or at breaks in terrain, steep slopes and at bin boundaries. Ground point density information is summarized below.

***Figure 4.9**. Histogram of ground-classified laser data density for data delivered to date in the Lewis County study area, per 0.75' USGS Quad.*



Pts ft²	Pts m²
0.00	0.00
0.05	0.54
0.10	1.08
0.15	1.61
0.20	2.15
0.25	2.69
0.30	3.23
0.35	3.77
0.40	4.31
0.45	4.84
0.50	5.38
0.55	5.92
0.60	6.46
0.65	7.00
0.70	7.53
0.75	8.07
0.80	8.61
0.85	9.15
0.90	9.69
0.95	10.23
1.00	10.76
1.05	11.30
1.10	11.84
1.15	12.38
1.20	12.92
1.25	13.45
1.30	13.99
1.35	14.53
1.40	15.07
1.45	15.61
1.50	16.15

Figure 4.10*. Image shows ground-classified laser point density for data delivered to date in the Lewis County study area, per 0.75' USGS Quad.*

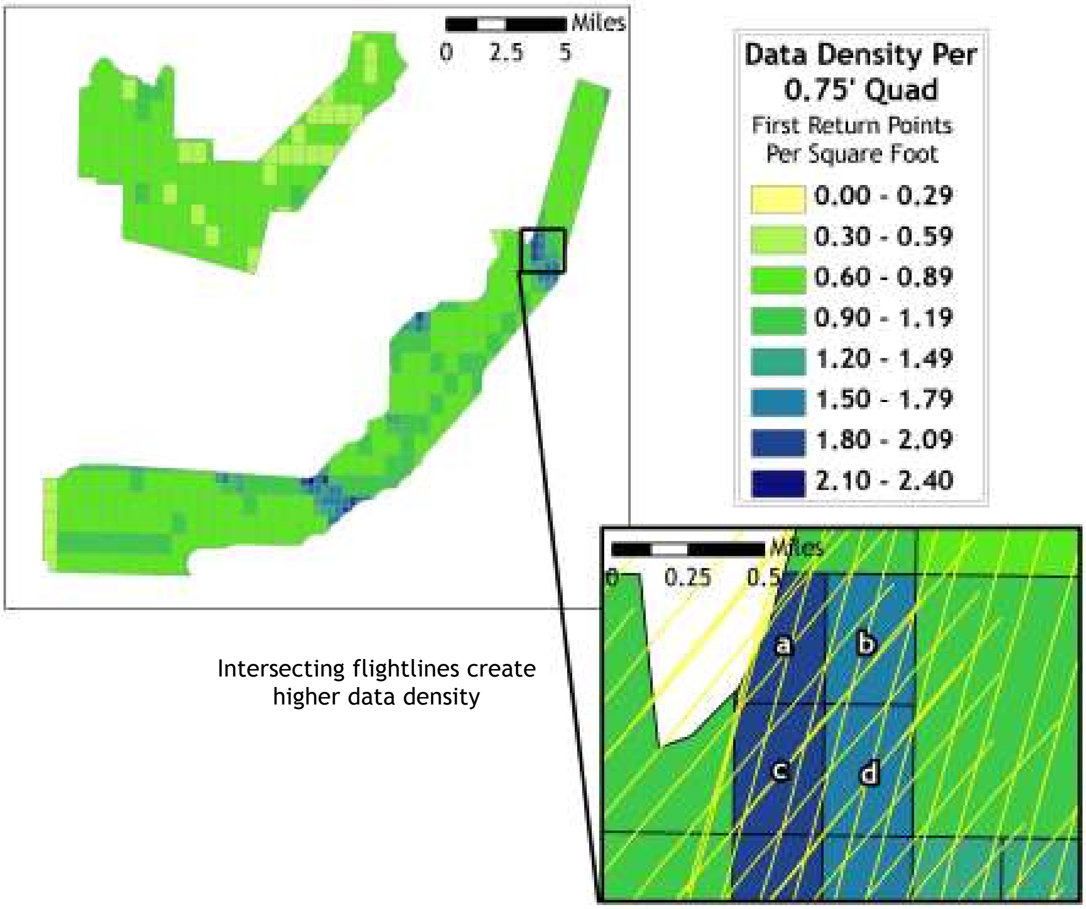


Pts ft²	Pts m²
0.00	0.00
0.05	0.54
0.10	1.08
0.15	1.61
0.20	2.15
0.25	2.69
0.30	3.23
0.35	3.77
0.40	4.31
0.45	4.84
0.50	5.38
0.55	5.92
0.60	6.46
0.65	7.00
0.70	7.53
0.75	8.07
0.80	8.61
0.85	9.15
0.90	9.69
0.95	10.23
1.00	10.76
1.05	11.30
1.10	11.84
1.15	12.38
1.20	12.92
1.25	13.45
1.30	13.99
1.35	14.53
1.40	15.07
1.45	15.61
1.50	16.15

4.2.3 Delivery 1 Density

Due to the shape of the area acquired in the Lewis County Delivery 1 data block, the overlapping flightlines cause higher densities between acquisition polygons (see **Figure 4.11** below); as a result, these data exceeded software processing capacity. In areas where this occurred, the 0.75' USGS Quad tiles were further sub-divided into quadrants labeled "a" through "d", clockwise starting with the upper left quadrant (see **Figure 4.11**). Conversely, the areas with incomplete coverage (southwest blocks) have a lower density. These data are included because Lewis County has expressed an interest in having as much coverage as possible.

Figure 4.11. *Illustration of high-density data blocks caused by overlapping flightlines.*



5. Data Specifications

	Targeted	Achieved
Resolution:	>8 points/m^2	8.59 points/m^2
Vertical Accuracy (1 σ):	<15 cm	3 cm

6. Projection/Datum and Units

The data were processed as ellipsoidal elevations and required a Geoid transformation to be converted into orthometric elevations (NAVD88). In TerraScan, the NGS published Geiod03 model was applied to each point. The data were processed using meters in the Universal Transverse Mercator (UTM) Zone 10 and NAD83 (CORS96)/NAVD88 datum and converted to the projection below.

	Projection:	Washington State Plane South (FIPS 4602)
Datum	**Vertical:**	NAVD88 Geoid03
	Horizontal:	NAD83 (HARN)
	Units:	U.S. Survey Feet

7. Deliverables For tiling convention, please see Figure 7.1.

7.1 Point Data (per 0.75' USGS Quads ~ 1/100th Quads)

- LAS v 1.2 Format
- ASCII Format (All points and ground classified points)

7.2 Vector Data

- Smoothed Best Estimate of Trajectory (SBET) Point Files in ASCII format
- 2-foot Contour Data (per 0.75' USGS Quads ~ 1/100th Quads)
  - AutoCAD Format (*.dwg)
  - Shapefile format
- Areas of Interest in shapefile format
  - 7.5' USGS Quad delineation in shapefile format (AOI and TAF)
  - 3.75' USGS Quad delineation in shapefile format (AOI and TAF)
  - 0.75' USGS Quad delineation in shapefile format (AOI and TAF)
  - NPS Mt. Rainier 2007/2008 study area delineation in shapefile format
  - Lewis County 2009 study area delineation in shapefile format
  - Mt. Rainier/Lewis County seam blemish edit polygons (see **Section 1.2**)

7.3 Raster Data

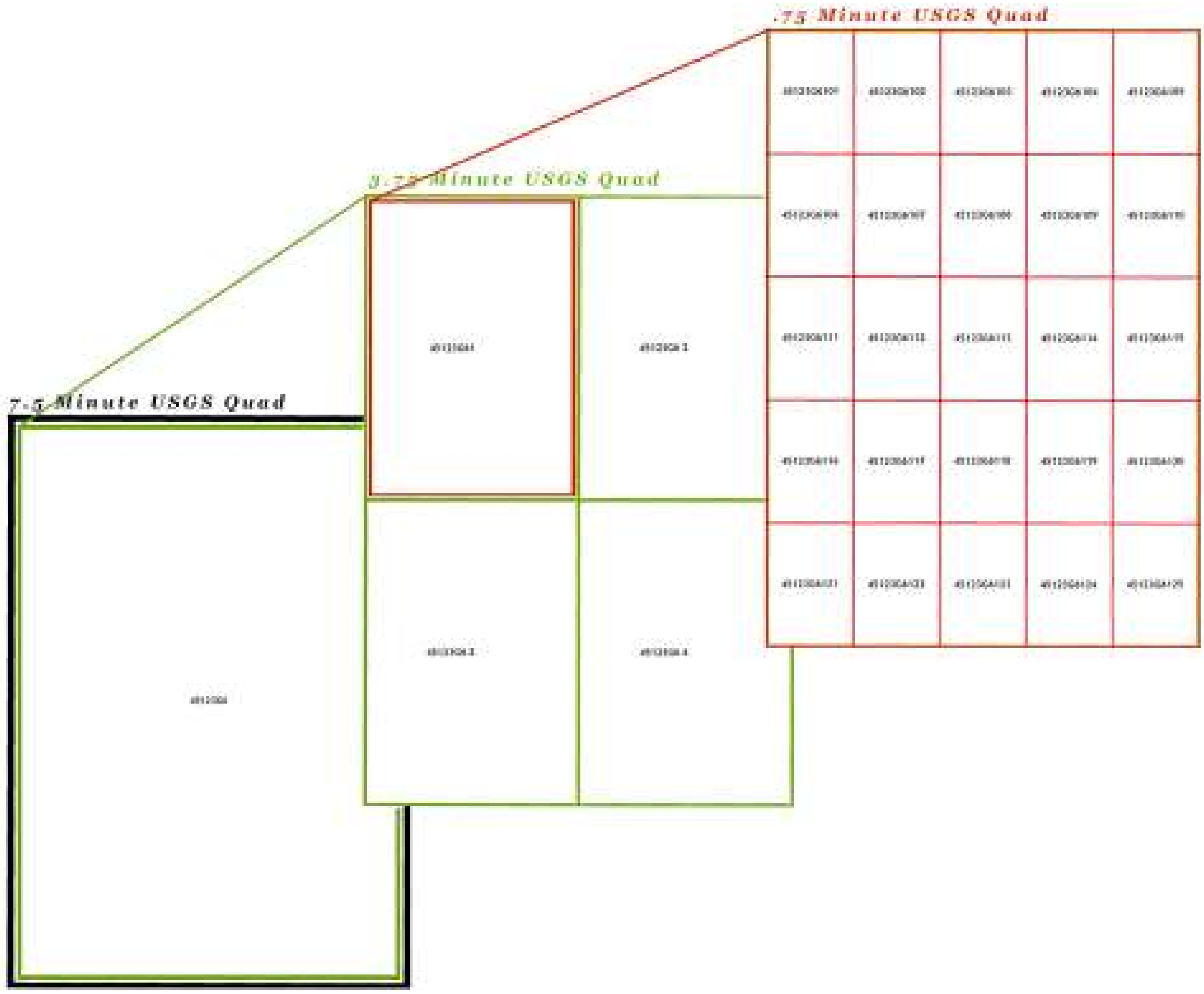
- ESRI GRIDs of LiDAR dataset, delivered per 3.75' USGS Quads ~ 1/4th Quads:
  - Bare Earth Modeled Points (3-foot and 6-foot resolution),
  - Vegetation Modeled Points- Highest Hit model (3-foot and 6-foot resolution),
- Surface intensity images in GEOTIFF format (1.5-foot resolution), delivered per 0.75' USGS Quads ~ 1/100th Quads
- ESRI GRIDs of Ground-classified point density (3.0-foot resolution), delivered per 0.75' USGS Quads ~ 1/100th Quads

7.4 Data Report

- Full Report containing introduction, methodology, accuracy, and example imagery
  - Word Format (*.doc), and PDF Format (*.pdf)

All Deliveries of Lewis County Data conform to the following tiling scheme:

***Figure 7.1**. 0.75' USGS Quad Delineation Naming Convention*



8. Selected Images

Example areas are presented to show paired, same-scene 3-D oblique and plan view imagery (**Figures 8.1-8.5**).

Figure 8.1*. Plan view showing the Cowlitz River, downstream of its confluence with Davis Creek (top image is derived from ground-classified LiDAR points, and bottom image is derived from highest hit classified LiDAR points).*

Figure 8.2. *3-d oblique view of the Cowlitz River, looking northward showing the confluences of Butter and Skate Creeks (top image is derived from ground-classified LiDAR points, and bottom image is NAIP Orthoimagery).*

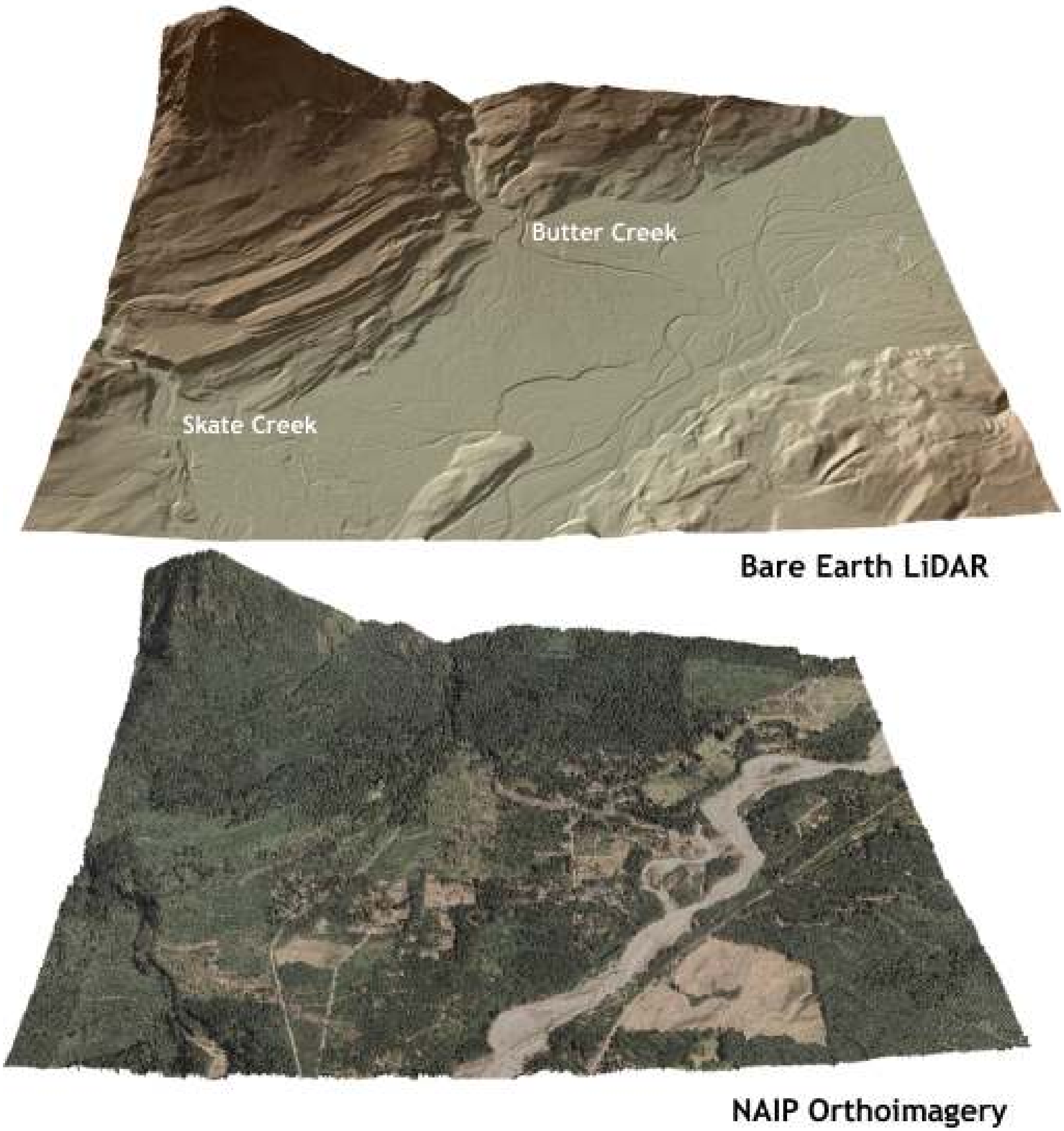


***Figure 8.3**. 3-d oblique view of the Cowlitz River, looking northward showing the confluences of Butter and Skate Creeks (top image is derived from highest-hit LiDAR points, and bottom image is NAIP Orthoimagery).*

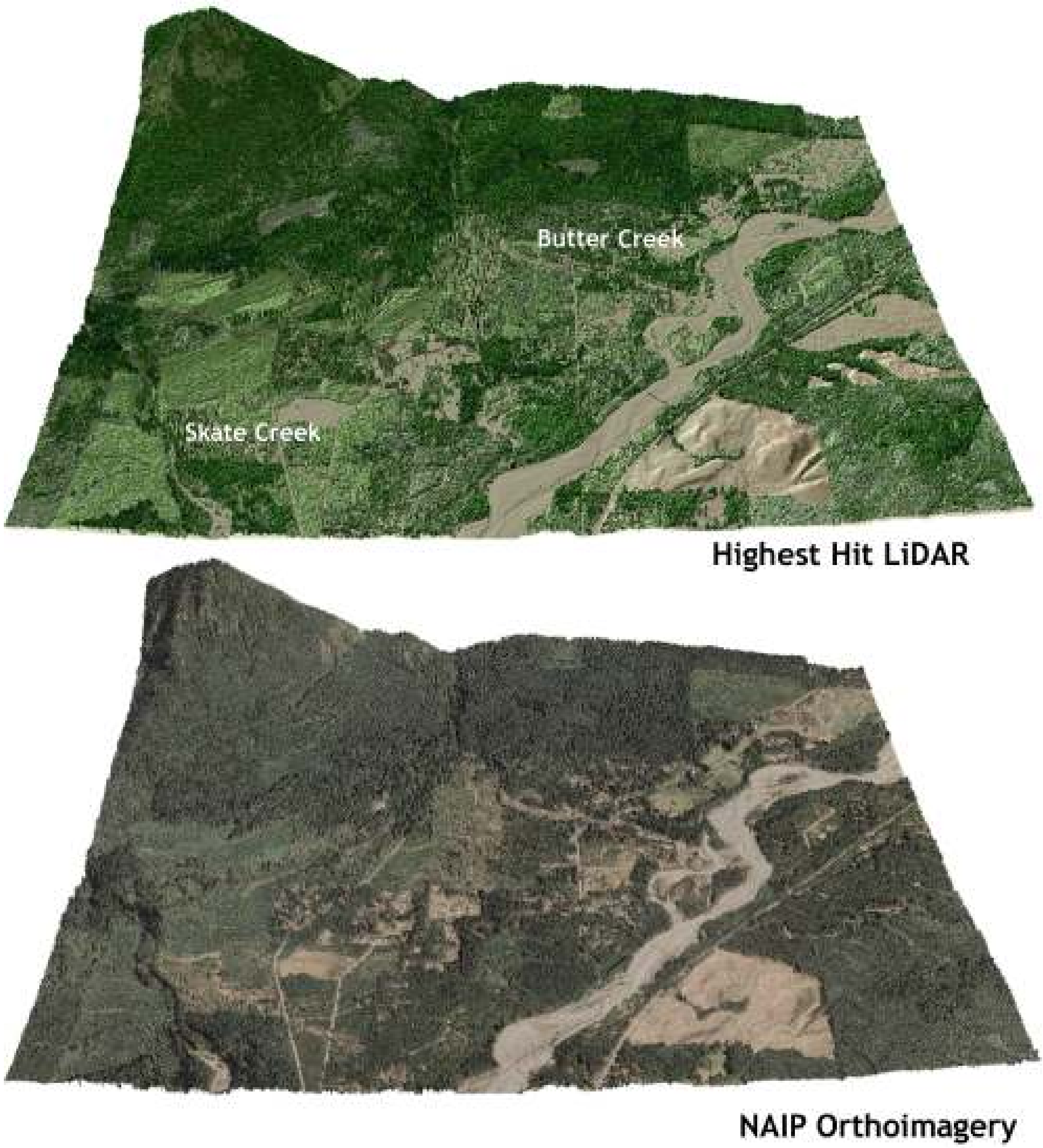
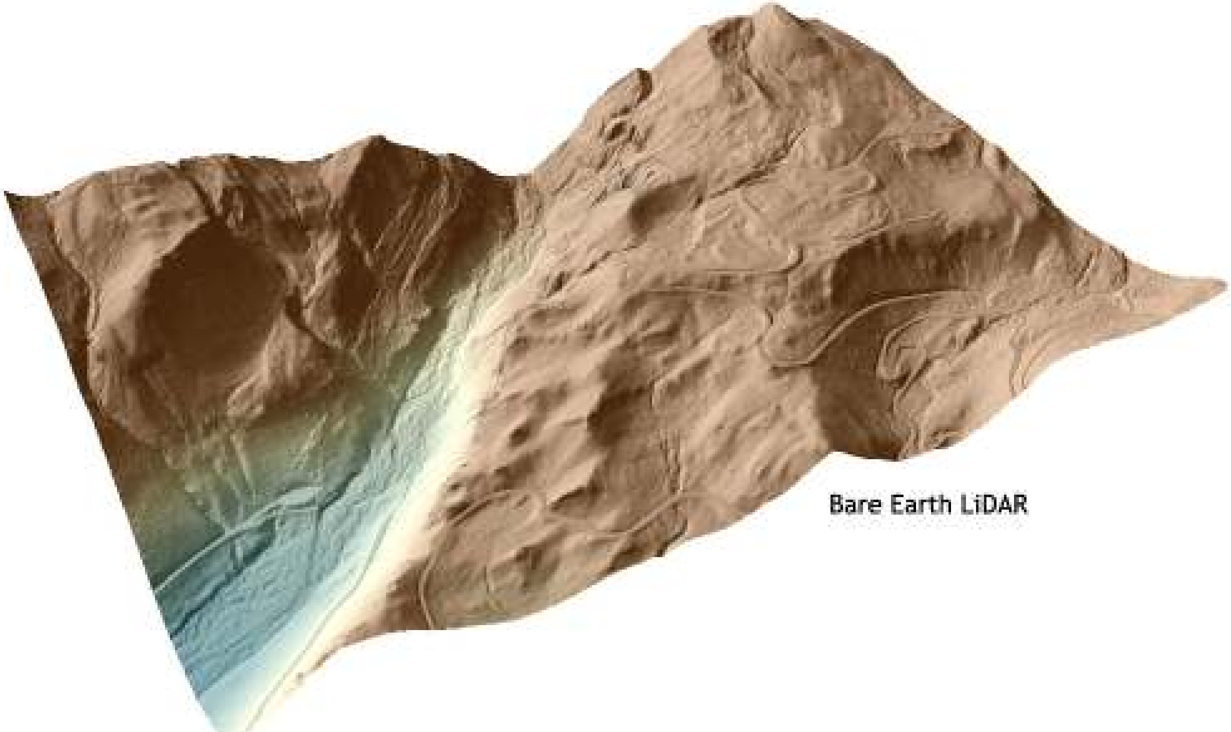


***Figure 8.4**. 3-d oblique view of the Paradise Park Visitor Center, looking northward (top image is derived from ground-classified LiDAR points, and bottom image is NAIP Orthoimagery).*



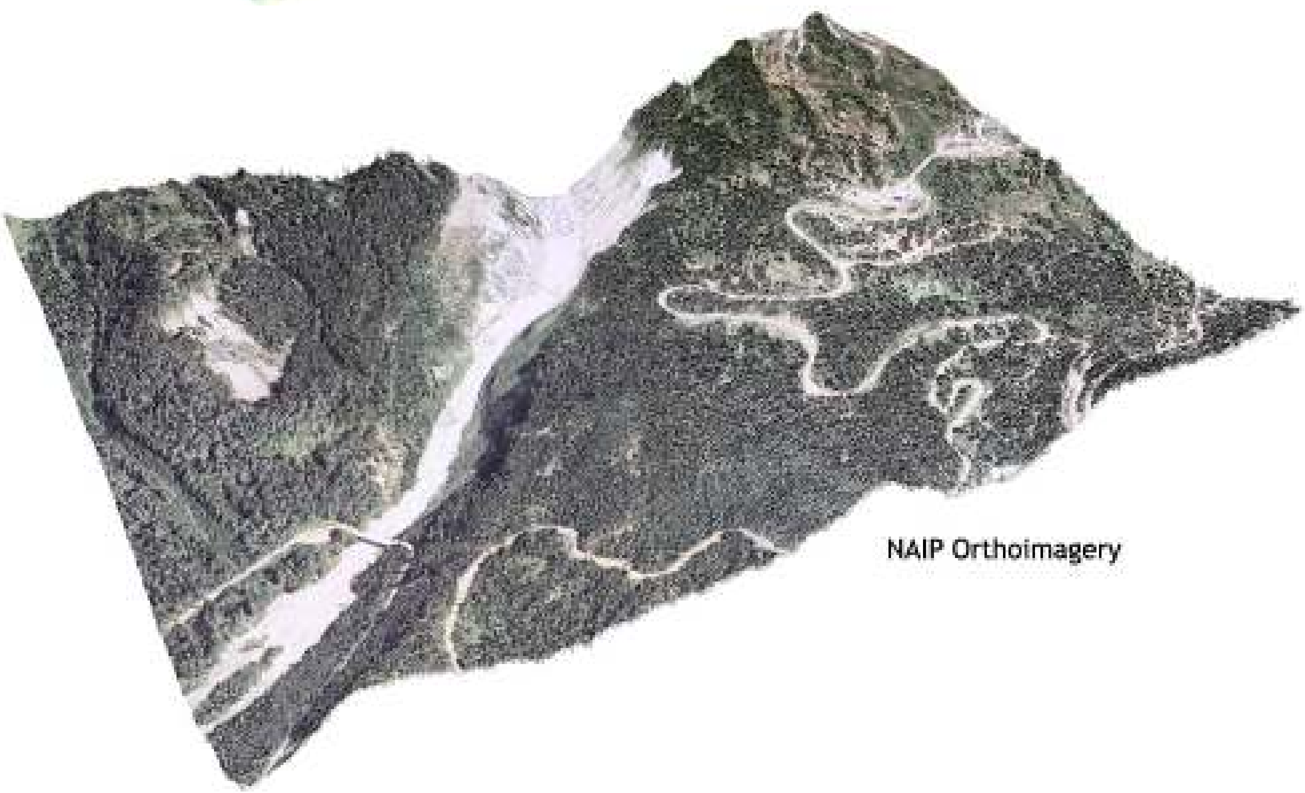
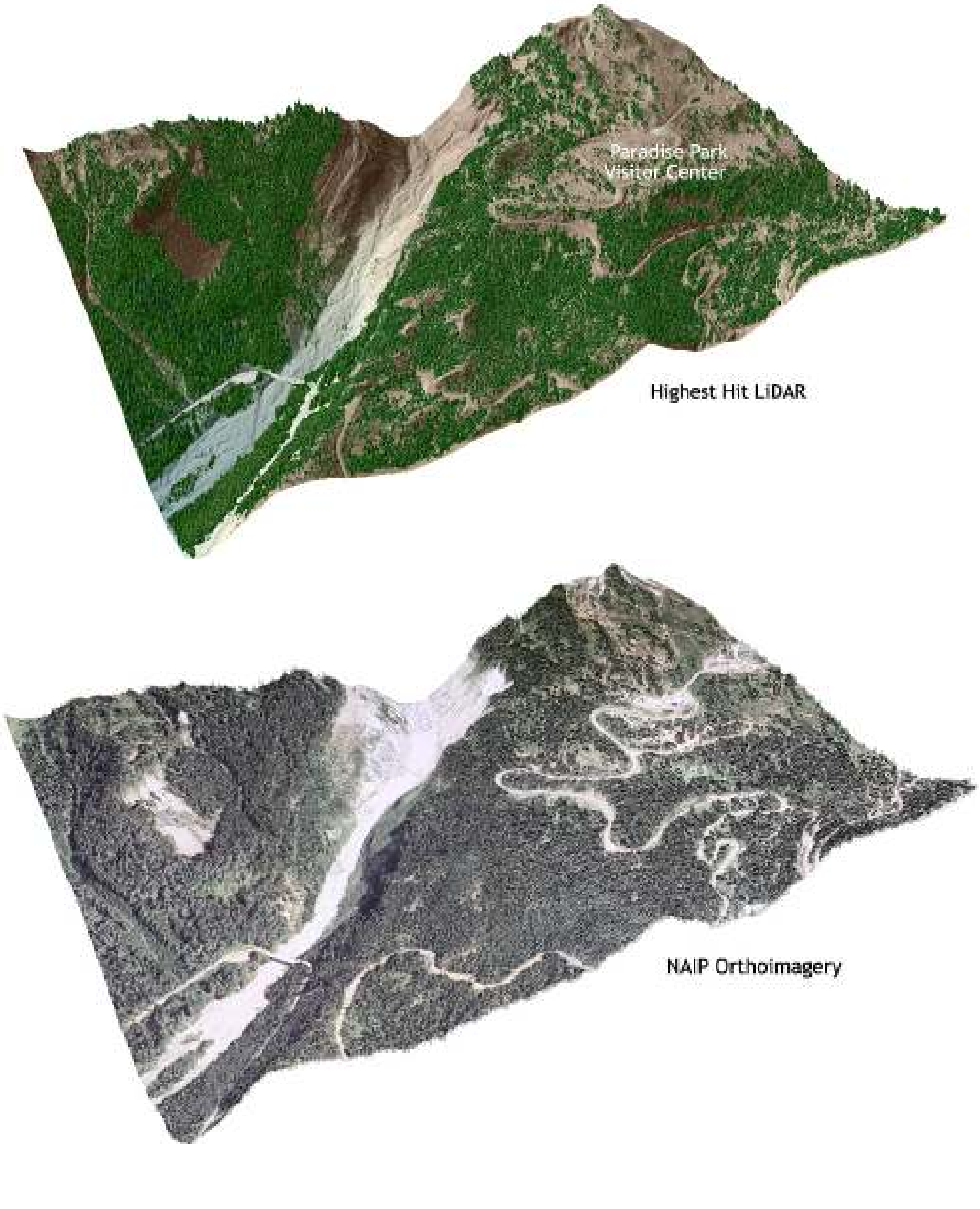


Figure 8.5. *3-d oblique view of Paradise Park Visitor Center, looking northward. (top image is derived from highest-hit LiDAR points, and bottom image is NAIP Orthoimagery).*



9. Glossary

1-sigma (σ) Absolute Deviation: Value for which the data are within one standard deviation (approximately 68th percentile) of a normally distributed data set.

2-sigma (σ) Absolute Deviation: Value for which the data are within two standard deviations (approximately 95th percentile) of a normally distributed data set.

Root Mean Square Error (RMSE): A statistic used to approximate the difference between real-world points and the LiDAR points. It is calculated by squaring all the values, then taking the average of the squares and taking the square root of the average.

Pulse Rate (PR): The rate at which laser pulses are emitted from the sensor; typically measured as thousands of pulses per second (kHz).

Pulse Returns: For every laser pulse emitted, the Leica ALS 50 Phase II system can record *up to four* wave forms reflected back to the sensor. Portions of the wave form that return earliest are the highest element in multi-tiered surfaces such as vegetation. Portions of the wave form that return last are the lowest element in multi-tiered surfaces.

Accuracy: The statistical comparison between known (surveyed) points and laser points. Typically measured as the standard deviation (sigma, σ) and root mean square error (RMSE).

Intensity Values: The peak power ratio of the laser return to the emitted laser. It is a function of surface reflectivity.

Data Density: A common measure of LiDAR resolution, measured as points per square meter.

Spot Spacing: Also a measure of LiDAR resolution, measured as the average distance between laser points.

Nadir: A single point or locus of points on the surface of the earth directly below a sensor as it progresses along its flight line.

Scan Angle: The angle from nadir to the edge of the scan, measured in degrees. Laser point accuracy typically decreases as scan angles increase.

Overlap: The area shared between flight lines, typically measured in percents; 100% overlap is essential to ensure complete coverage and reduce laser shadows.

DTM / DEM: These often-interchanged terms refer to models made from laser points. The digital elevation model (DEM) refers to all surfaces, including bare ground and vegetation, while the digital terrain model (DTM) refers only to those points classified as ground.

Real-Time Kinematic (RTK) Survey: GPS surveying is conducted with a GPS base station deployed over a known monument with a radio connection to a GPS rover. Both the base station and rover receive differential GPS data and the baseline correction is solved between the two. This type of ground survey is accurate to 1.5 cm or less.

10. Citations

Soininen, A. 2004. TerraScan User's Guide. TerraSolid.