LiDAR Remote Sensing Data Collection
Department of Geology and Mineral Industries
Yambo Study Area

September 30, 2010

Submitted to:

Department of Geology and Mineral Industries
800 NE Oregon Street, Suite 965
Portland, OR 97232

Submitted by:

Watershed Sciences
529 SW 3rd Avenue, Suite 300
Portland, OR 97204

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DOGAMI, Yambo Study Area

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1. Overview

1.1 Study Area

Watershed Sciences, Inc. has collected Light Detection and Ranging (LiDAR) data of the Yambo Study Area for the Oregon Department of Geology and Mineral Industries (DOGAMI). The area of interest (AOI) totals 1,063 square miles (680,432 acres) and the total area flown (TAF) covers 1,083 square miles (692,852 acres). The TAF acreage is greater than the original AOI acreage due to buffering and flight planning optimization (**Figure 1.1** below). This report will be amended to reflect new data and cumulative statistics for the overall LiDAR survey with every delivery. DOGAMI data are delivered in OGIC (HARN): Projection: Oregon Statewide Lambert Conformal Conic; horizontal and vertical datum: NAD83 (HARN)/NAVD88 (Geoid03); units: International Feet.

***Figure 1.1**. DOGAMI Yambo Study Area.*

1.2 Area Delivered to Date

Total delivered acreage to date is detailed below.

DOGAMI Yambo Study Area				
	Delivery Date	**Acquisition Dates**	**AOI Acres**	**TAF Acres**
Delivery Area 2	September 30, 2010	March 1, 2010 – June 5, 2010	**60,810**	**62,451**
Delivery Area 3	September 30, 2010	May 7, 2010 – July 14, 2010	**120,812**	**122,938**

Figure 1.2. *Yambo Study Area, illustrating the delivered portions of the TAF.*

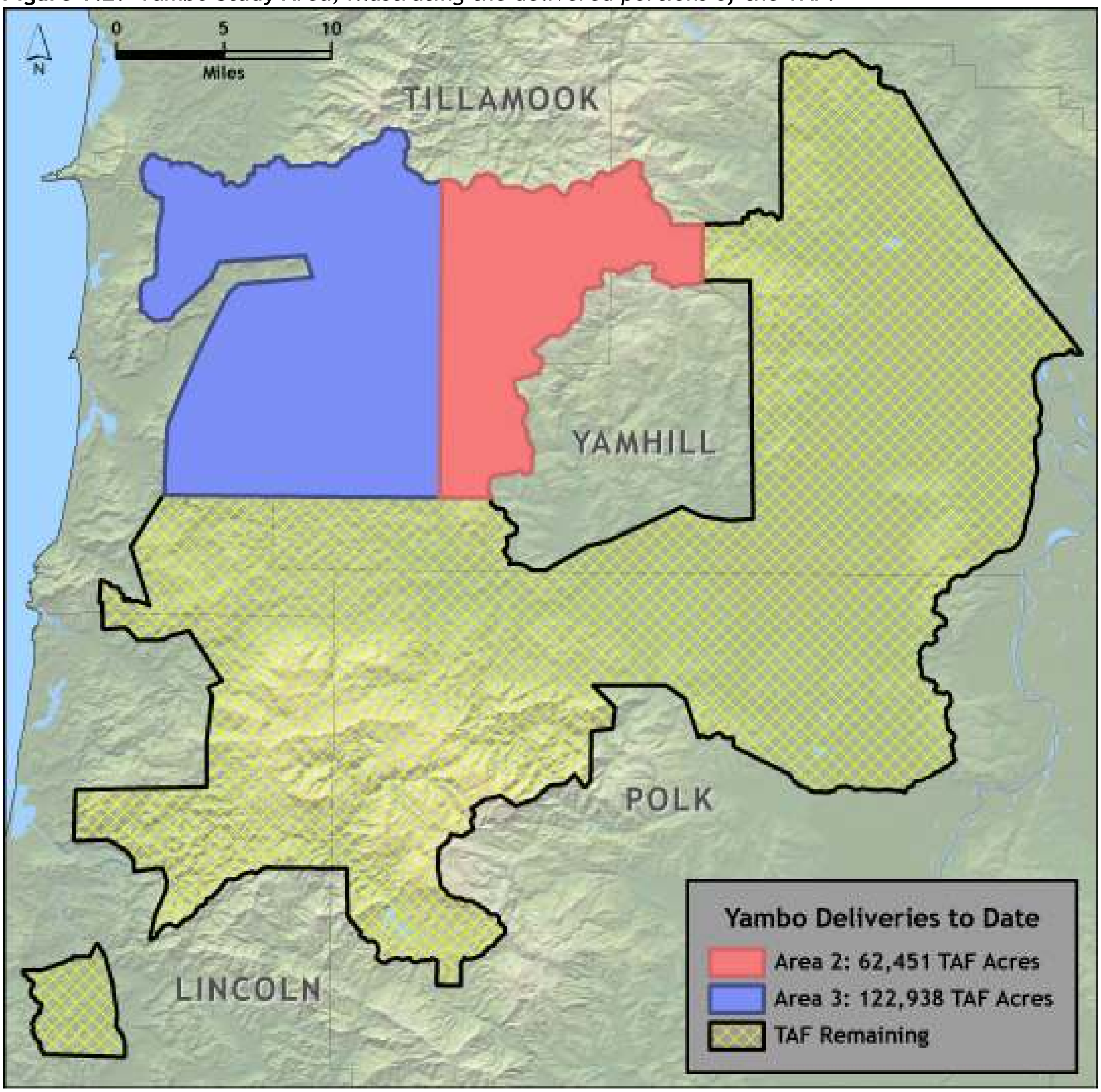
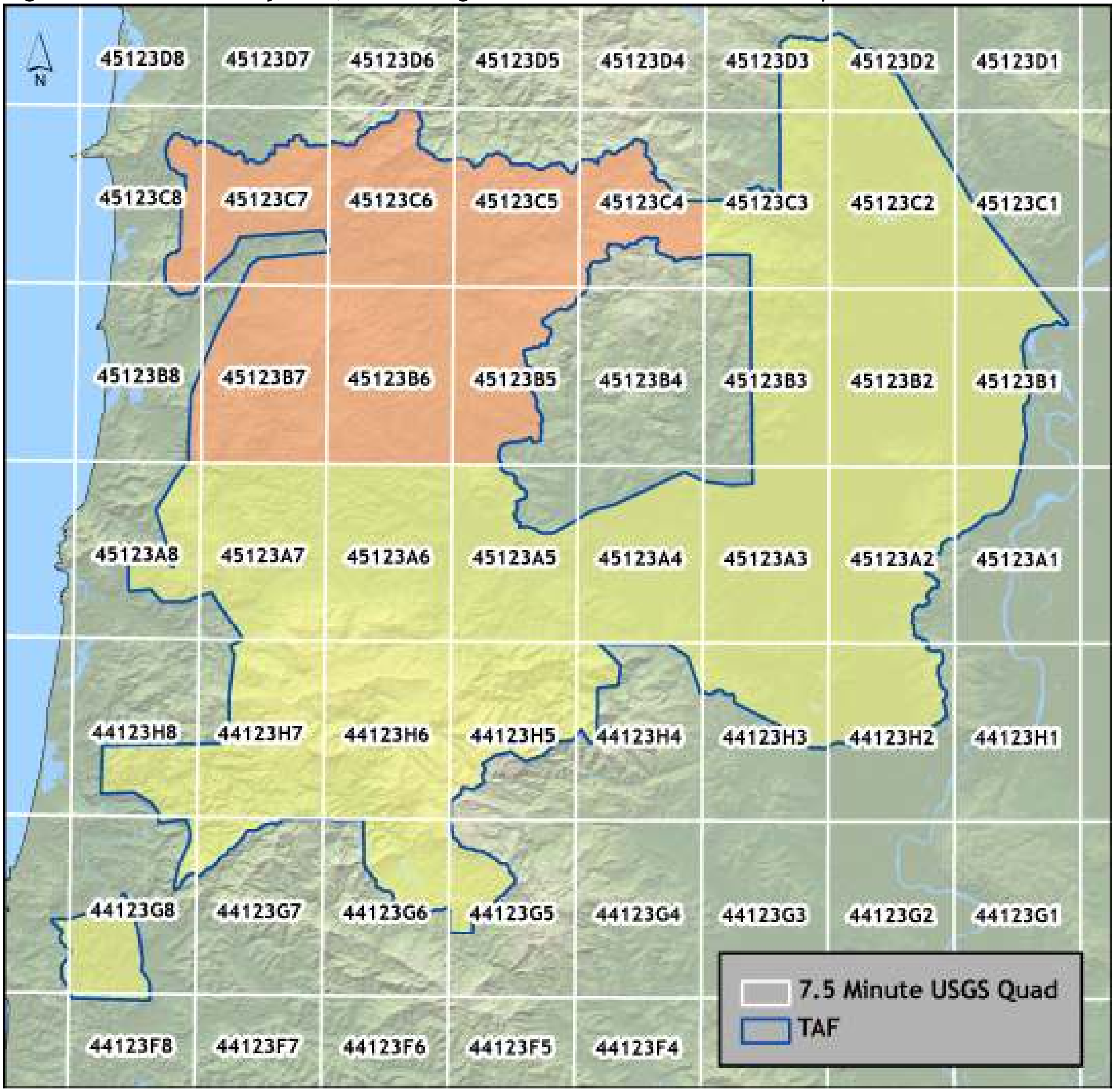


Figure 1.3. *Yambo Study Area, illustrating the delivered 7.5 minute USGS quads.*



2. Acquisition

2.1 Airborne Survey Overview – Instrumentation and Methods

The LiDAR survey utilized Leica ALS60 and Leica ALS50 sensors mounted in multiple Cessna Caravans 208B. The Leica systems were set to acquire ≥105,000 laser pulses per second (i.e. 105 kHz pulse rate) and flown at 900 and 1300 meters above ground level (AGL), capturing a scan angle of ±14^{o} 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 ALS60 sensor head installed in the Caravan is shown on the right.

Table 2.1 *LiDAR Survey Specifications*

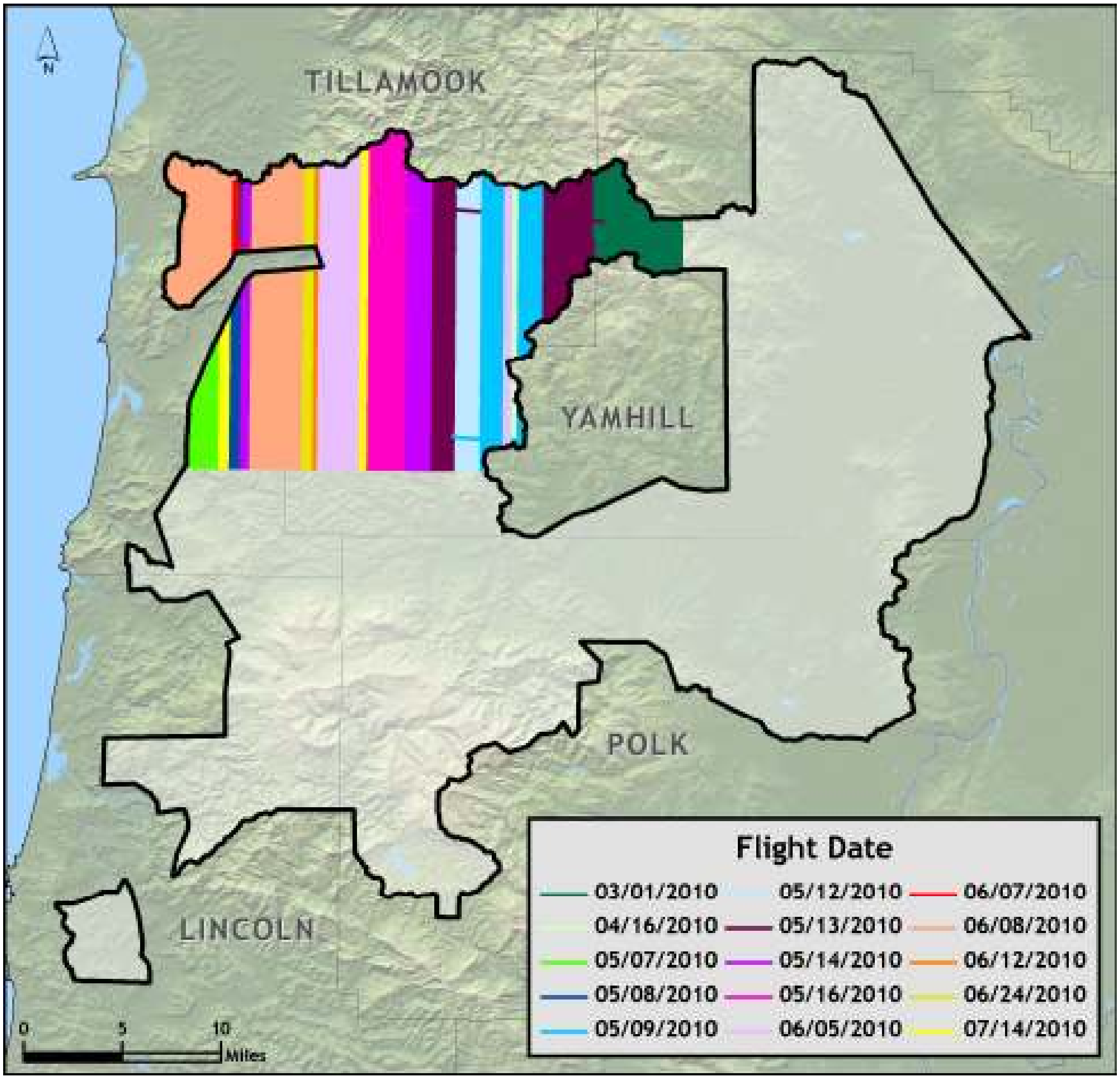
Sensor	Leica ALS60, Leica ALS50
Survey Altitude (AGL)	900 m and 1300 m
Pulse Rate	>105 kHz
Pulse Mode	Single
Mirror Scan Rate	52 Hz
Field of View	28^{o} (±14^{o} from nadir)
Roll Compensated	Up to 15^{o}
Overlap	100% (50% Side-lap)

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 deliveries 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*. Actual flightlines for the Yambo Study Area illustrating the dates flown for deliveries to date.*



2.2 Ground Survey – Instrumentation and Methods

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

Base Station in the Yambo Study Area

2.2.1 Instrumentation

For this study area all Global Navigation Satellite System (GNSS[3]) survey work used a Trimble GPS receiver model R7 with a Zephyr Geodetic antenna and ground plane for static control points. A Trimble GPS R8 unit is used primarily for RTK work but when needed, it can be used as a static receiver as well. For RTK data, the collector begins recording after remaining stationary for 5 seconds then calculating the pseudo range position from at least three epochs with the relative error under 1.5cm horizontal and 2cm vertical. All GPS measurements are made with dual frequency L1-L2 receivers with carrier-phase correction.

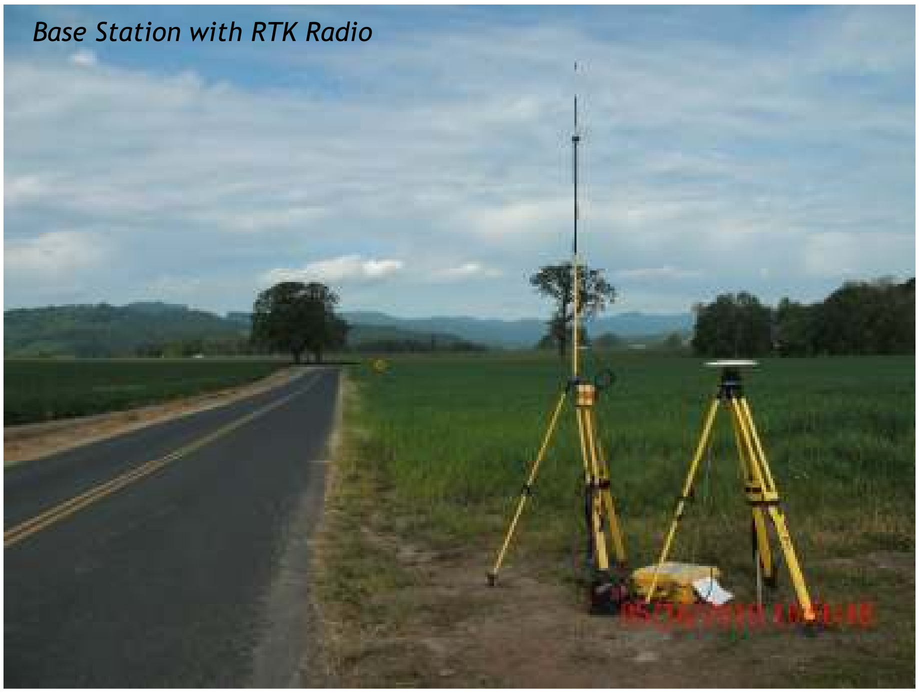
2.2.2 Monumentation

Whenever possible, existing and established survey benchmarks shall serve as control points during LiDAR acquisition including those previously set by Watershed Sciences. In addition to NGS, the county surveyor's offices and ODOT often establish their own benchmarks. NGS benchmarks are preferred for control points. In the absence of NGS benchmarks, county surveys, or ODOT monumentation, Watershed Sciences produces our own monuments. These monuments are spaced at a minimum of one mile and every effort is made to keep these monuments within the public right of way. If monuments are required on private property, consent from the owner is required. All monumentation is done with 5/8" x 24" or 30" rebar topped with an aluminum cap.

[2] Online Positioning User Service (OPUS) is run by the National Geodetic Survey to process corrected monument positions.
[3] GNSS: Global Navigation Satellite System consisting of the U.S. GPS constellation and Soviet GLONASS constellation

2.2.3 Methodology

Each aircraft is assigned a ground crew member with two R7 receivers and an R8 receiver. The ground crew vehicles are equipped with standard field survey supplies and equipment including safety materials. All data points are observed for a minimum of two survey sessions lasting no fewer than 6 hours. At the beginning of every session the tripod and antenna are reset, resulting in two independent instrument heights and data files. Data are collected at a rate of 1Hz using a 10 degree mask on the antenna.



Base Station with RTK Radio

The ground crew uploads the GPS data to our FTP site on a daily basis to be collected by the office for PLS oversight, QA/QC review and post-processing. OPUS processing triangulates the monument position using 3 CORS stations resulting in a fully adjusted position. CORPSCON[4] 6.0.1 software is used to convert the geodetic positions from the OPUS reports. After multiple days of data have been collected at each monument, accuracy and error ellipses are calculated. This information leads to a rating of the monument based on FGDC-STD-007.2-1998[5] Part 2 table 2.1 at the 95% confidence level.

All GPS measurements are made during periods with PDOP less than or equal to 3.0 and with at least 6 satellites in view of both a stationary reference receiver and the roving receiver. RTK positions are collected on 20% of the flight lines and on bare earth locations such as paved, gravel or stable dirt roads, and other locations where the ground is clearly visible (and is likely to remain visible) from the sky during the data acquisition and RTK measurement period(s). In order to facilitate comparisons with LiDAR measurements, RTK measurements are not taken on highly reflective surfaces such as center line stripes or lane markings on roads. In addition, it is desirable to include locations that can be readily identified and occupied during subsequent field visits in support of other quality control procedures described later. Examples of identifiable locations would include manhole and other flat utility structures that have clearly indicated center points or other measurement locations. In the absence of utility structures, a PK nail can be driven into asphalt or concrete and marked with paint.

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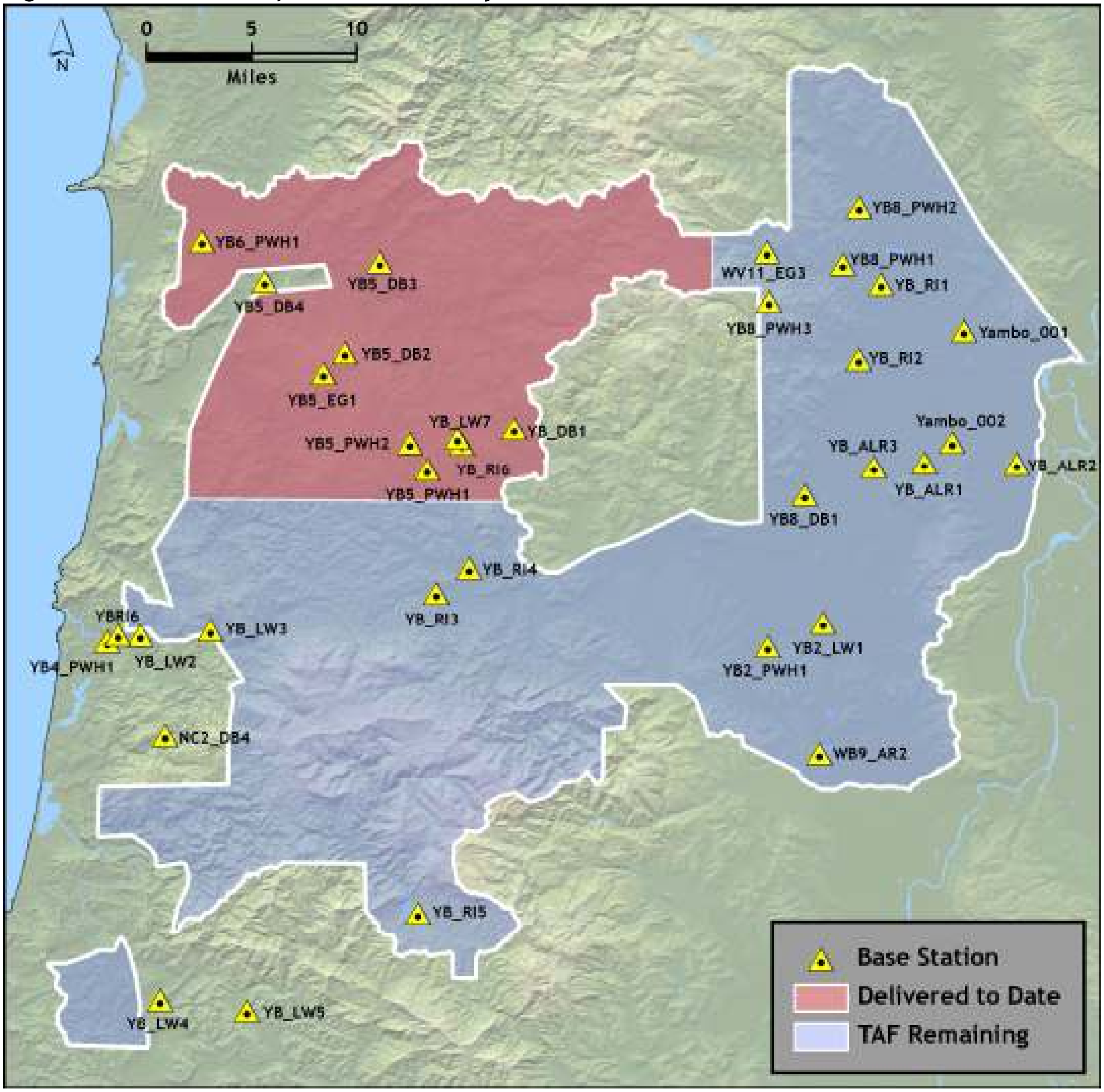
[4] U.S. Army Corps of Engineers , Engineer Research and Development Center Topographic Engineering Center software

[5] Federal Geographic Data Committee Draft Geospatial Positioning Accuracy Standards

Table 2.2. *Base Station Surveyed Coordinates, (NAD83/NAVD88, OPUS corrected) used for kinematic post-processing of the aircraft GPS data for the Yambo Study Area.*

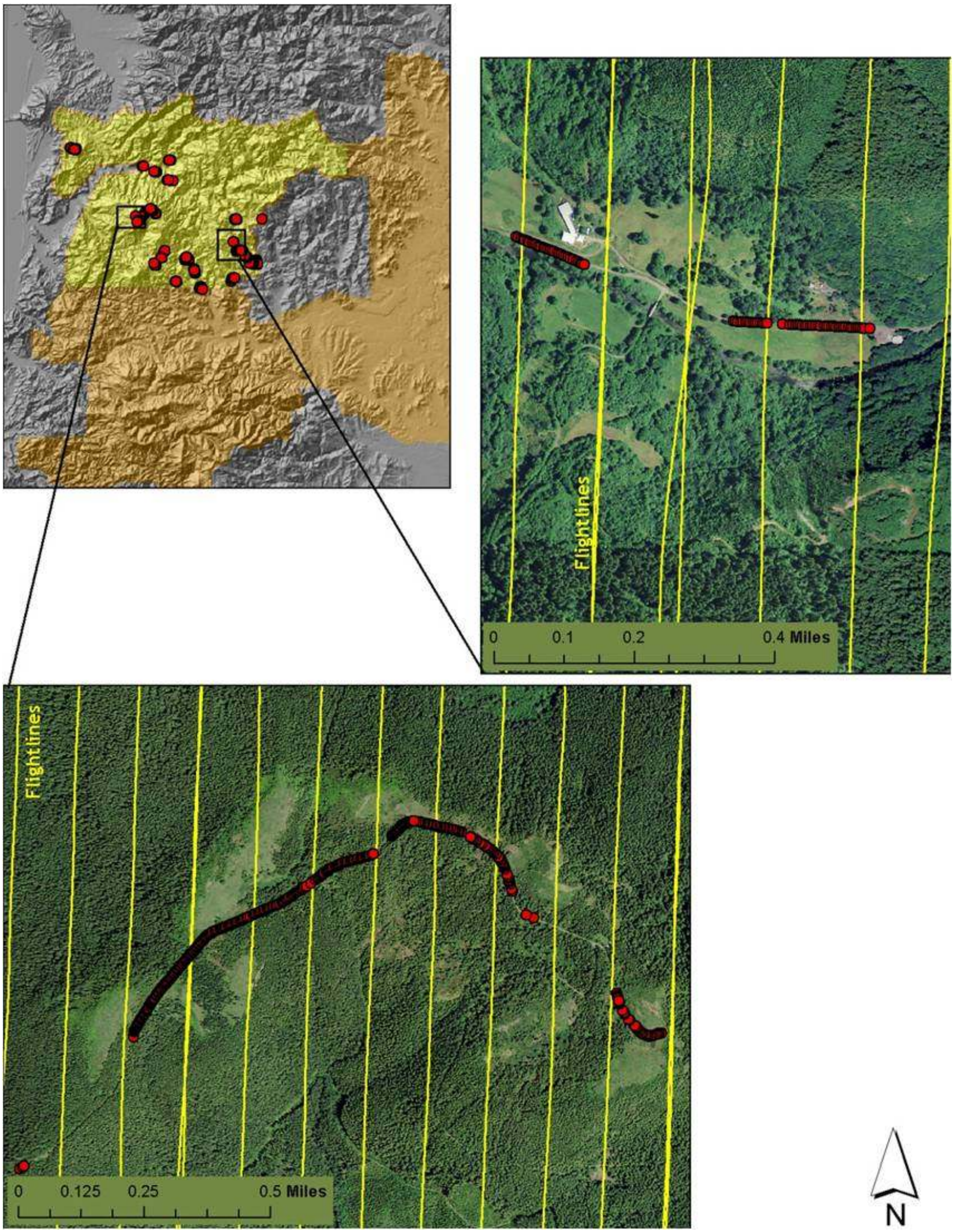
	Datum NAD83 (HARN)		GRS80 (Geoid 03)
PID	**Lat**	**Long**	**Ellips**
Yambo_002	45 10 04.02192	123 08 27.18124	27.979
Yambo_001	45 14 40.80509	123 07 47.39043	26.920
YB_ALR1	45 09 11.87802	123 10 04.42373	27.153
YB_ALR2	45 09 10.55025	123 04 40.87143	26.931
YB_ALR3	45 09 01.18776	123 13 02.50809	27.021
YB_RI1	45 16 38.07885	123 12 39.76092	32.605
YB_RI2	45 13 29.37686	123 13 57.64191	27.662
WB9_AR2	44 57 08.25321	123 16 10.74392	47.350
YB2_PWH1	45 01 32.88251	123 19 12.71976	32.621
YB2_LW1	45 02 32.67450	123 16 00.10390	35.623
WV11_EG3	45 17 56.90315	123 19 22.02617	117.408
YB_RI3	45 03 41.76302	123 38 38.51435	107.284
YB_RI4	45 04 44.78105	123 36 43.31042	92.539
YB_RI5	44 50 24.05343	123 39 33.66278	319.384
YB_LW3	45 02 03.52089	123 51 50.38801	109.729
YB_LW5	44 46 16.73625	123 49 29.32957	57.052
YB_LW4	44 46 40.77293	123 54 32.04912	-1.573
YB_RI6	45 09 52.41733	123 37 13.50468	421.961
YBRI6	45 01 32.04708	123 57 52.15663	-18.835
YB_LW7	45 10 08.66426	123 37 28.28248	453.991
YB5_PWH2	45 09 55.09298	123 40 15.05132	421.849
YB5_PWH1	45 08 49.66036	123 39 13.72549	273.112
YB5_DB2	45 13 37.49404	123 44 06.71446	908.309
YB_DB1	45 10 34.38212	123 34 08.69834	384.902
YB5_DB4	45 16 34.05079	123 48 52.74602	12.002
YB5_DB3	45 17 25.47599	123 42 07.33694	83.695
YB8_PWH1	45 17 27.89020	123 14 54.07926	45.501
YB8_PWH2	45 19 48.06449	123 13 57.11501	46.432
YB8_PWH3	45 15 53.64665	123 19 13.85714	419.795
YB5_EG1	45 12 46.32075	123 45 21.85479	936.554
YB8_DB1	45 07 51.72000	123 17 05.03728	25.910
YB6_PWH1	45 18 13.25004	123 52 35.04928	246.589
YB_LW2	45 01 49.45785	123 55 56.01333	9.440
NC2_DB4	44 57 41.05701	123 54 25.27865	224.796
YB4_PWH1	45 01 49.74323	123 57 14.76443	-17.033

Figure 2.2. Base stations for the Yambo Study Area.



For data delivered to date, 2,015 RTK (Real-time kinematic) points were collected in the study area. **Figures 2.3** shows detailed views of selected RTK locations for the area delivered to date.

Figure 2.3. *Selected RTK point locations in the study area for delivery areas 2 and 3; images are NAIP orthophotos.*



3. Accuracy

3.1 Relative Accuracy

Relative Accuracy Calibration Results

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 cm). 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 320 flightlines and over one billion points. Relative accuracy is reported for the portion of the study area shown in **Figure 3.1** below.

- Project Average = 0.29 ft (0.09 m)
- Median Relative Accuracy = 0.28 ft (0.09 m)
- 1σ Relative Accuracy = 0.30 ft (0.09 m)
- 2σ Relative Accuracy = 0.38 ft (0.12 m)

***Figure 3.1**. Relative Accuracy Covered Area.*

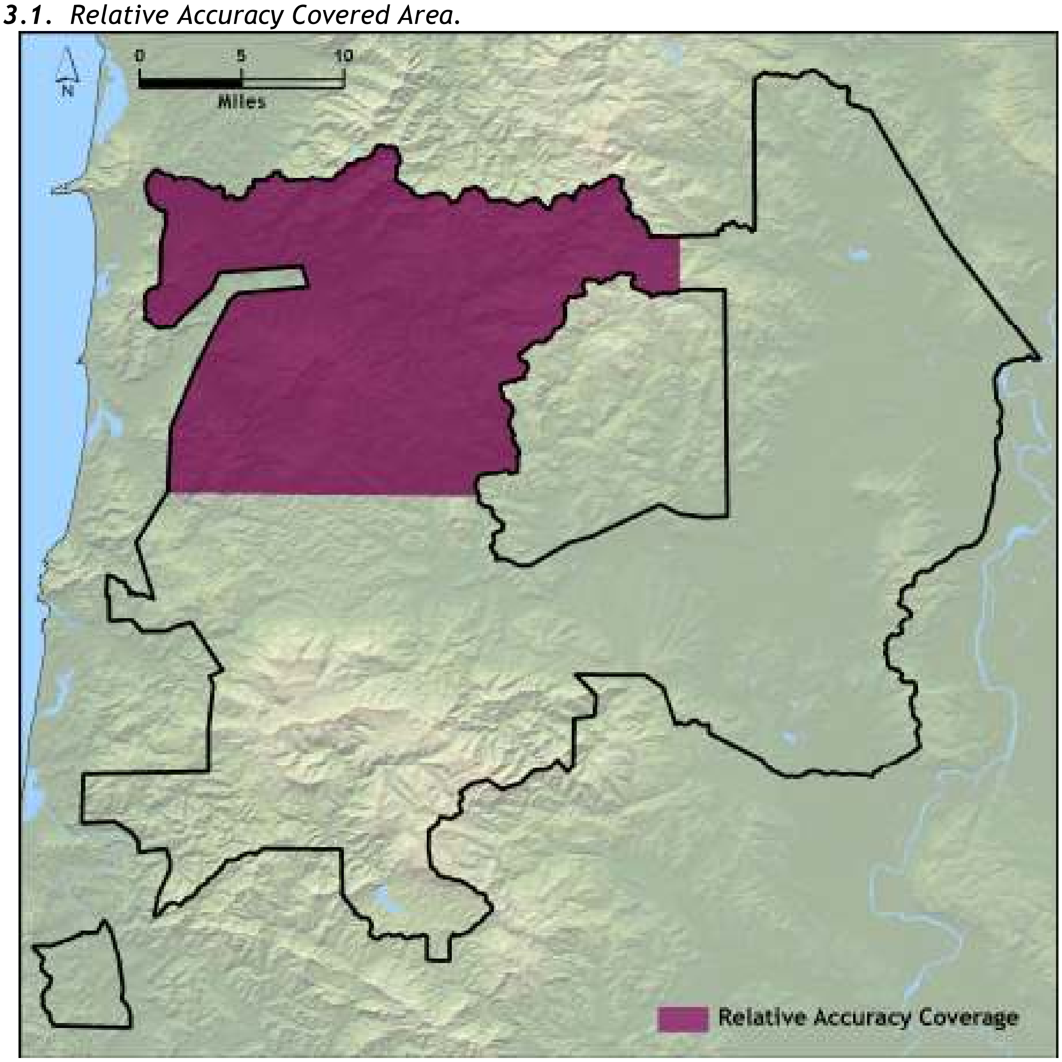


Figure 3.2. Statistical relative accuracies, non slope-adjusted.

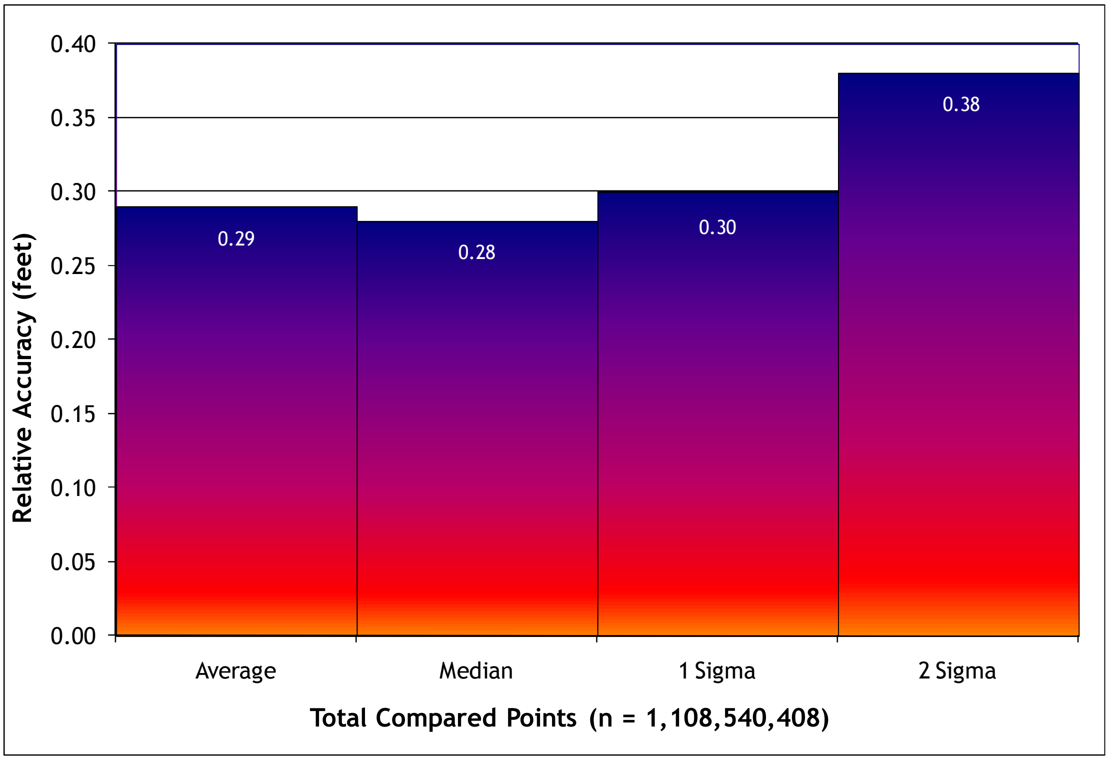
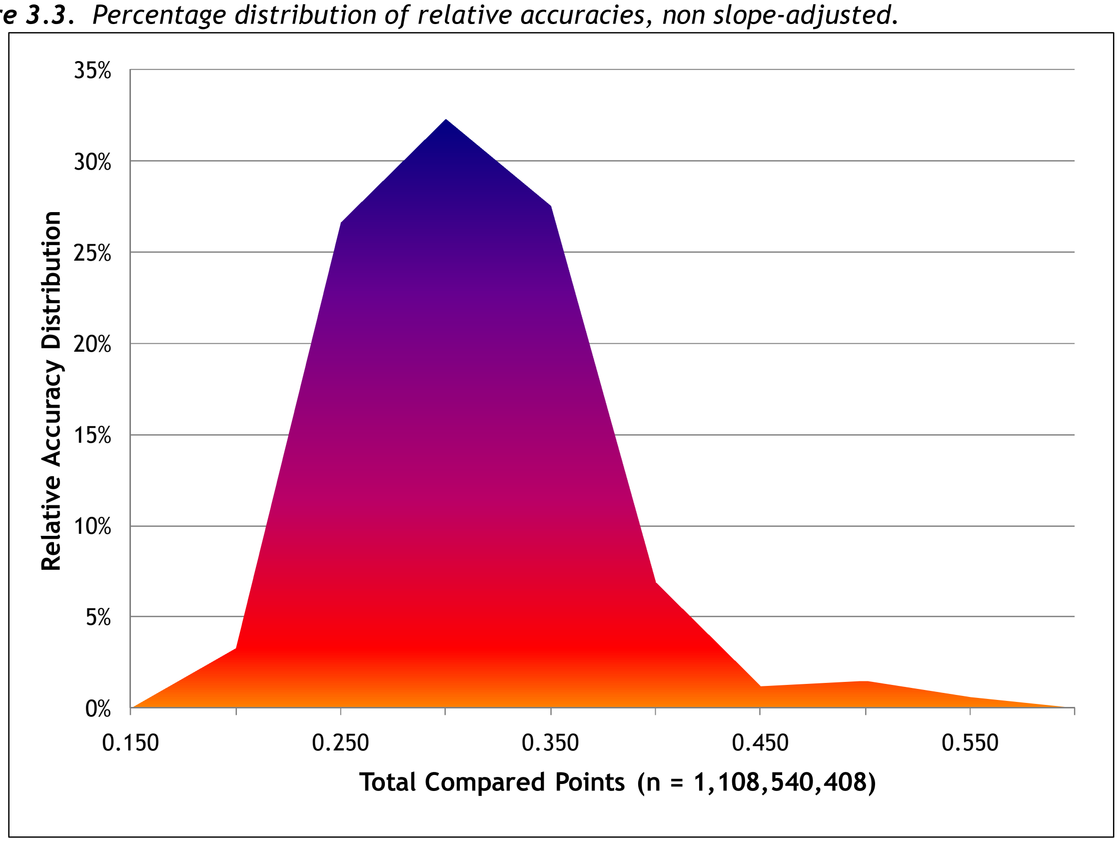


Figure 3.3. Percentage distribution of relative accuracies, non slope-adjusted.



3.2 Absolute Accuracy

Absolute accuracy compares known RTK ground survey points to the closest laser point. For the Yambo Study Area, 2,015 RTK points were collected for data delivered to date. Absolute accuracy is reported for the portion of the study area shown in **Figure 3.4** and reported in **Table 3.1** below. Histogram and absolute deviation statistics are reported in **Figures 3.5 and 3.6**.

Table 3.1. *Absolute Accuracy – Deviation between laser points and RTK survey points.*

Sample Size (n): 2,015	
Root Mean Square Error (RMSE): 0.13 ft (0.04m)	
Standard Deviations	**Deviations**
1 sigma (σ): 0.12 ft (0.04 m)	**Minimum Δz:** -0.56 ft (-0.17 m)
2 sigma (σ): 0.27 ft (0.08 m)	**Maximum Δz:** 0.38 ft (0.12 m)
	Average Δz: 0.10 ft (0.03 m)

Figure 3.4. *Absolute Accuracy Covered Area.*

Figure 3.5. *Yambo Study Area histogram statistics*

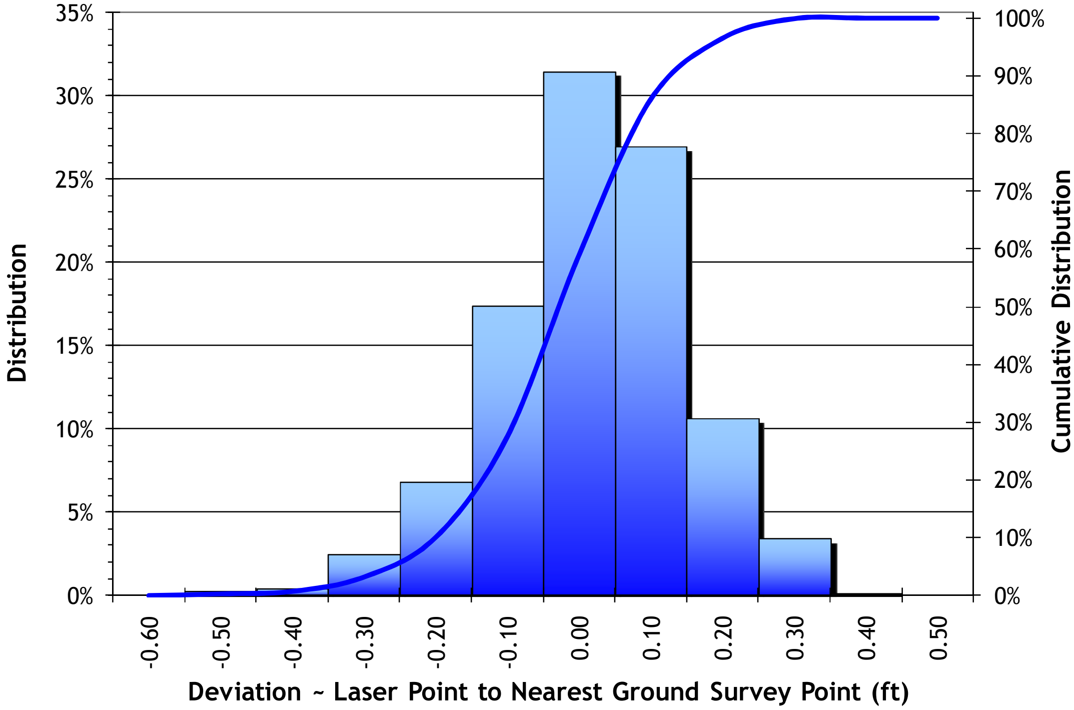
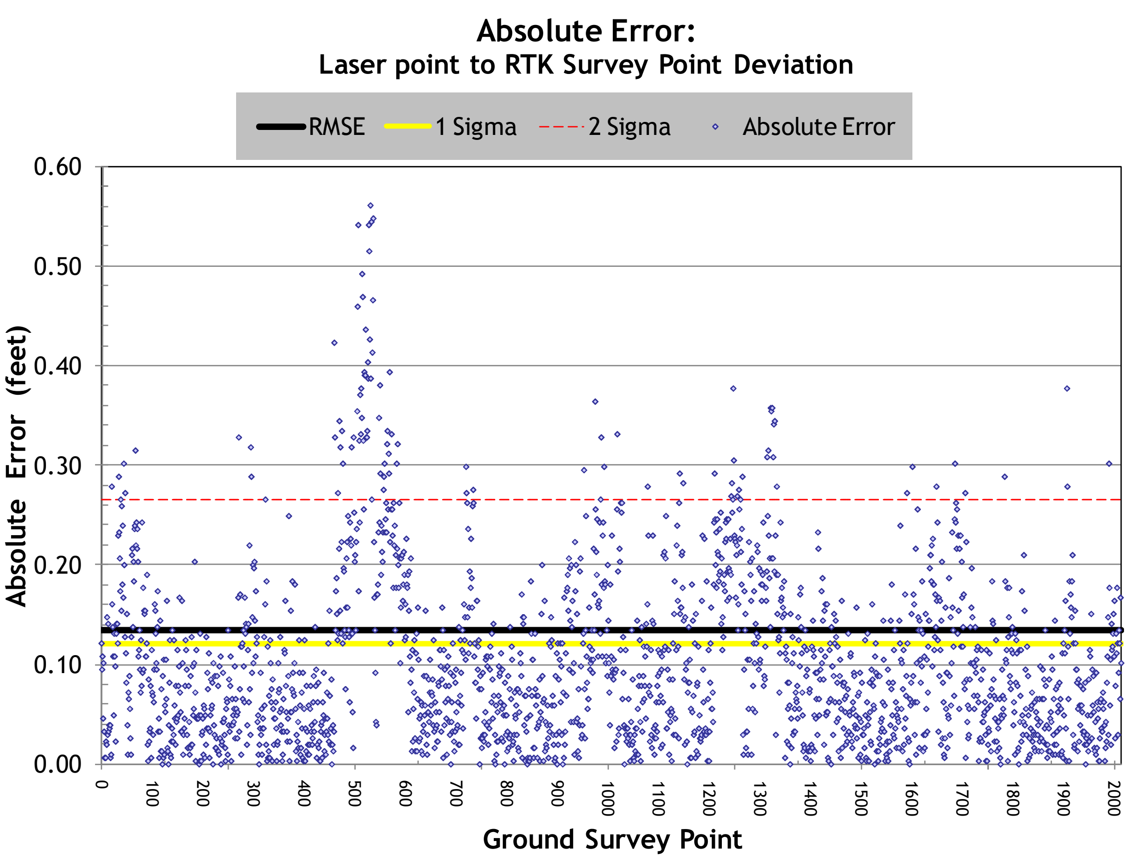


Figure 3.6. *Yambo Study Area point absolute deviation statistics.*



4. Data Density/Resolution

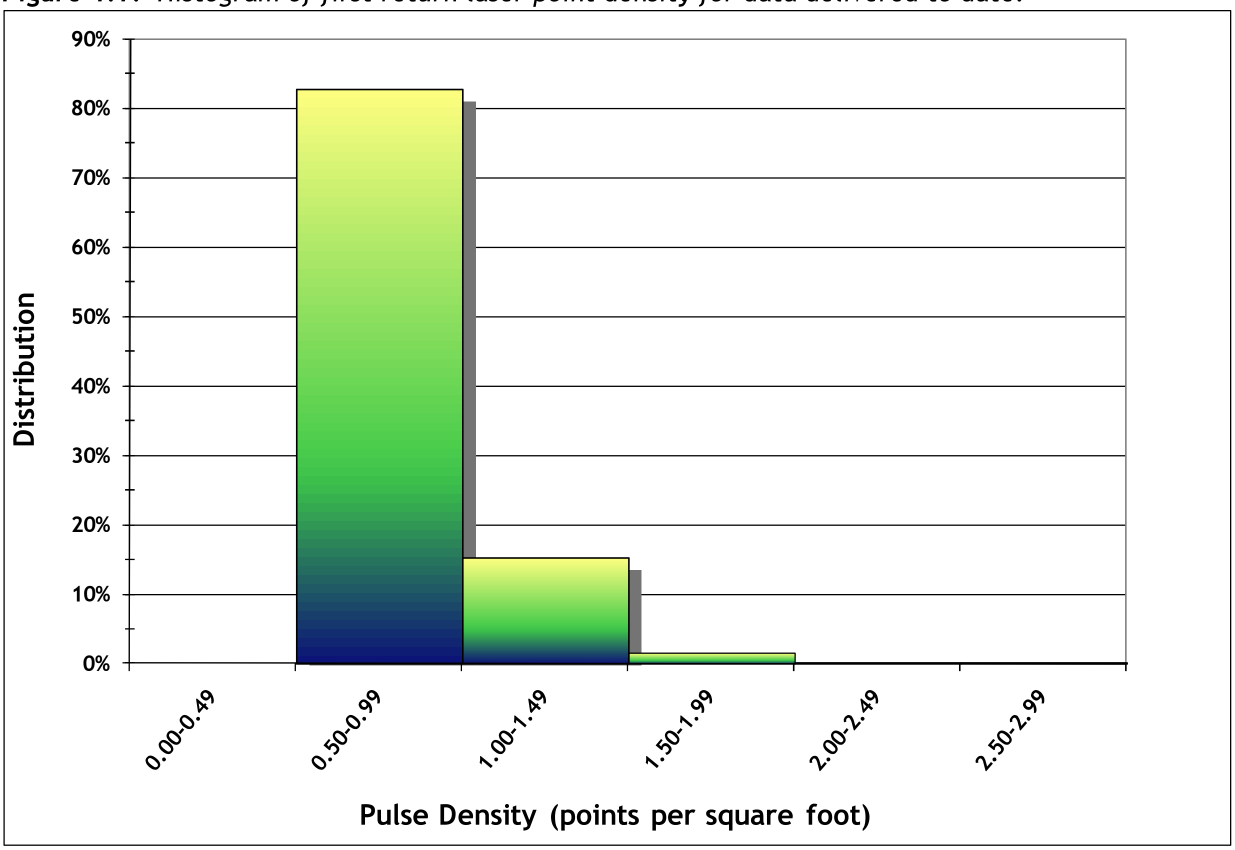
4.1 Density Statistics

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 vary according to terrain, land cover and water bodies. Density histograms and maps (**Figures 4.1 – 4.4)** have been calculated based on first return laser point density and ground-classified laser point density.

Table 4.1. *Average density statistics for Yambo Study Area data delivered to date.*

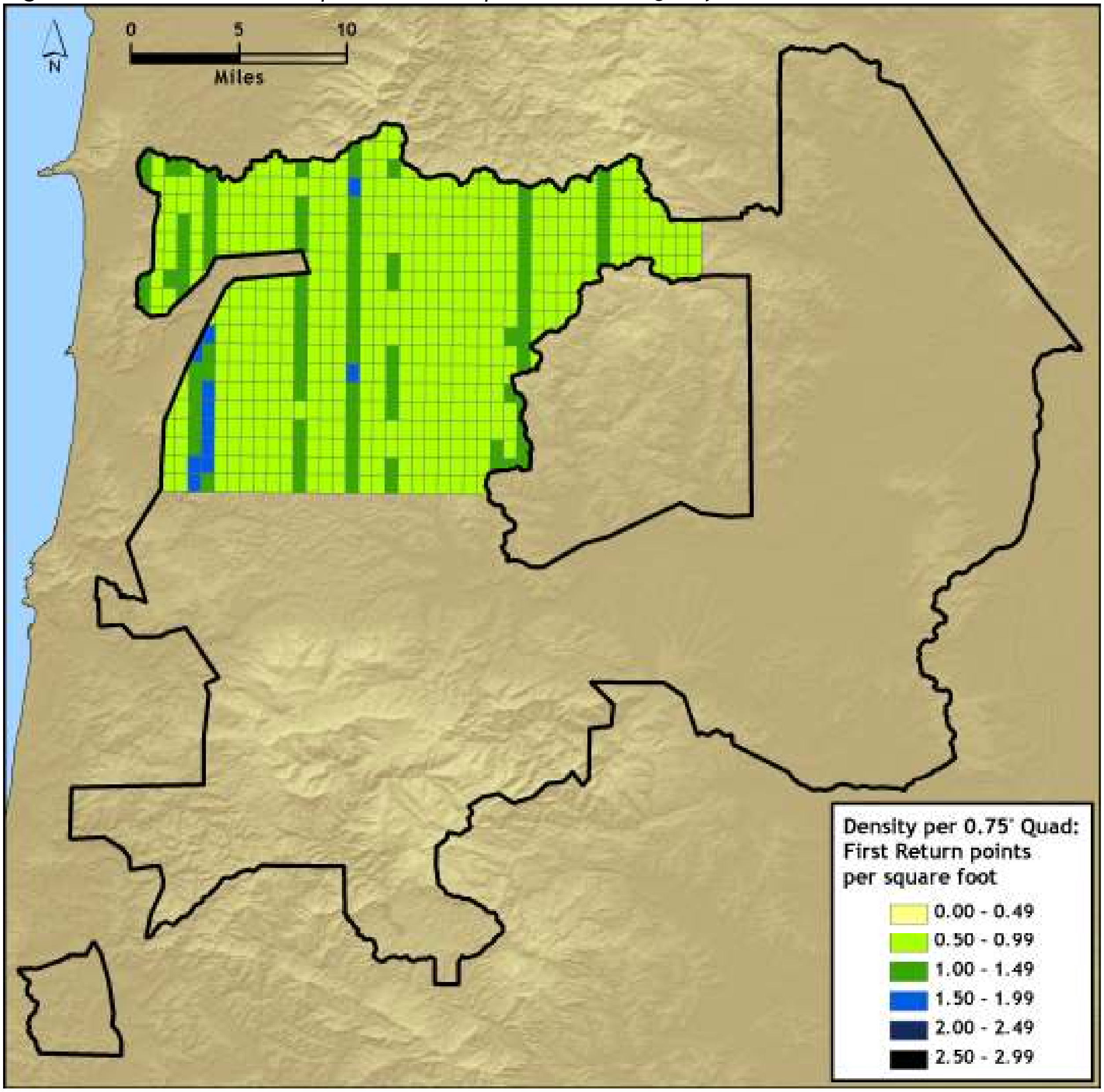
Average Pulse Density (per square ft)	Average Pulse Density (per square m)	Average Ground Density (per square ft)	Average Ground Density (per square m)
0.87	9.4	.045	.48

Figure 4.1. *Histogram of first return laser point density for data delivered to date.*



Pts ft^2	Pts m^2
0.00	0.00
0.10	1.08
0.20	2.15
0.30	3.23
0.40	4.31
0.50	5.38
0.60	6.46
0.70	7.53
0.80	8.61
0.90	9.69
1.00	10.76
1.10	11.84
1.20	12.92
1.30	13.99
1.40	15.07
1.50	16.15
1.60	17.22
1.70	18.30
1.80	19.37
1.90	20.45
2.00	21.53
2.10	22.60
2.20	23.68
2.30	24.76
2.40	25.83
2.50	26.91
2.60	27.99
2.70	29.06
2.80	30.14
2.90	31.22
3.00	32.29

Figure 4.2. *First return laser point densities per 0.75' USGS Quad for data delivered to date.*



Pts ft²	Pts m²
0.00	0.00
0.10	1.08
0.20	2.15
0.30	3.23
0.40	4.31
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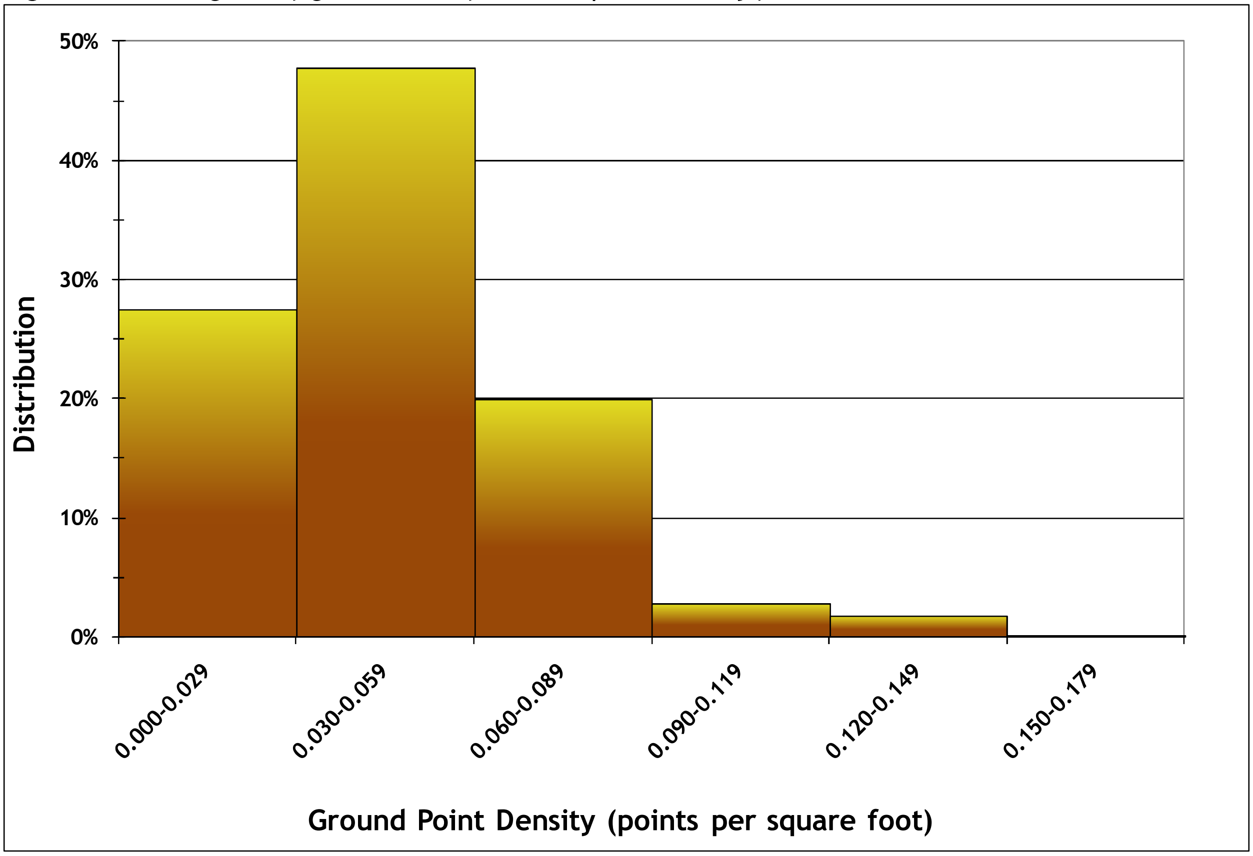
1.70	18.30
1.80	19.37
1.90	20.45
2.00	21.53
2.10	22.60
2.20	23.68
2.30	24.76
2.40	25.83
2.50	26.91
2.60	27.99
2.70	29.06
2.80	30.14
2.90	31.22
3.00	32.29

Ground classifications were derived from ground surface modeling. In areas where the ground model failed, classifications were manually performed by reseeding the ground model, usually under dense vegetation and/or at breaks in terrain, steep slopes and at bin boundaries.

Figure 4.3. *Histogram of ground-classified laser point density for data delivered to date.*



Pts ft²	Pts m²
0.00	0.00
0.10	1.08
0.20	2.15
0.30	3.23
0.40	4.31
0.50	5.38
0.60	6.46
0.70	7.53
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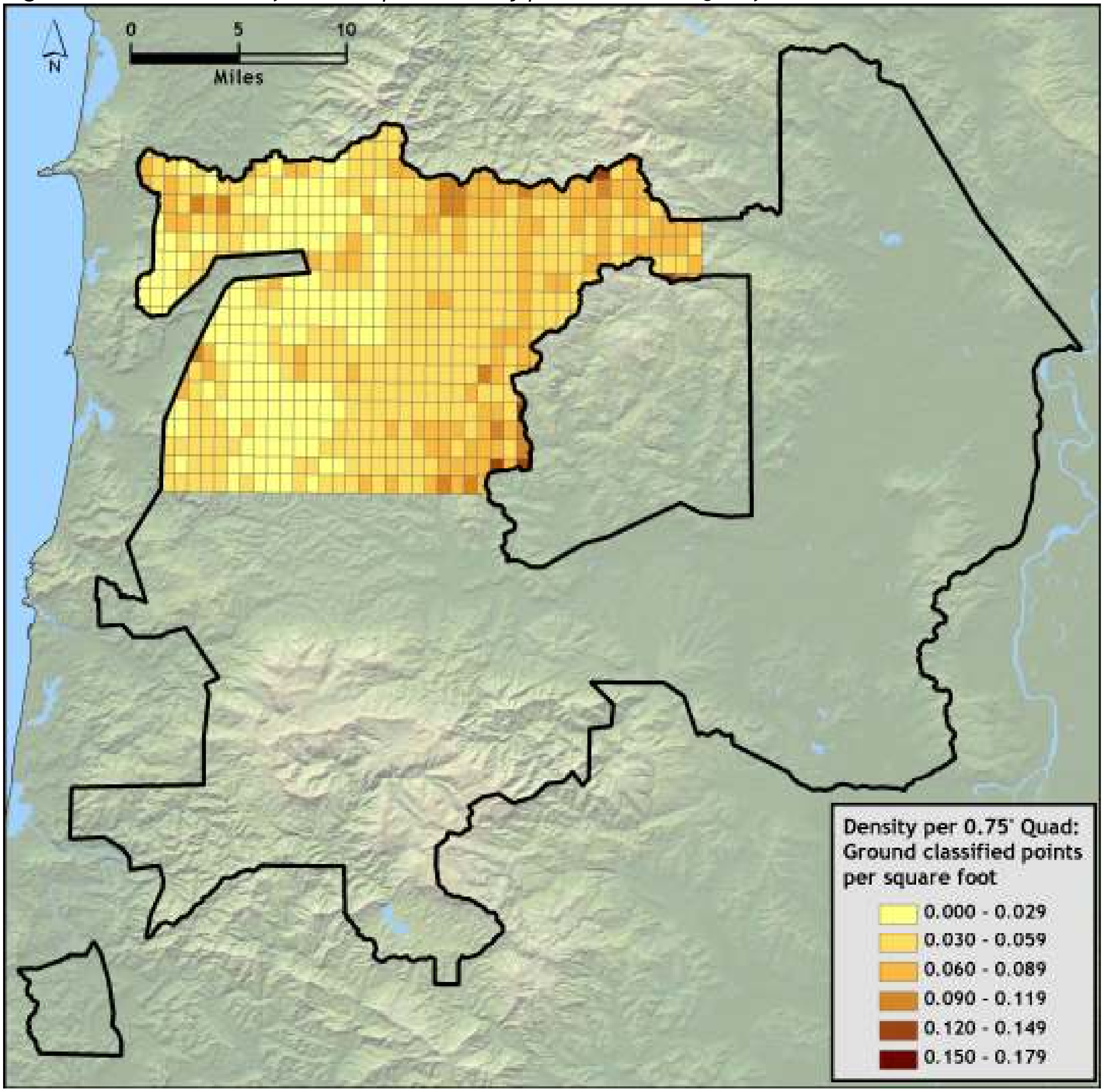
2.50	26.91
2.60	27.99
2.70	29.06
2.80	30.14
2.90	31.22
3.00	32.29

Figure 4.4. *Ground-classified laser point density per 0.75' USGS Quad for data delivered to date.*



Pts ft²	Pts m²
0.00	0.00
0.10	1.08
0.20	2.15
0.30	3.23
0.40	4.31
0.50	5.38
0.60	6.46
0.70	7.53
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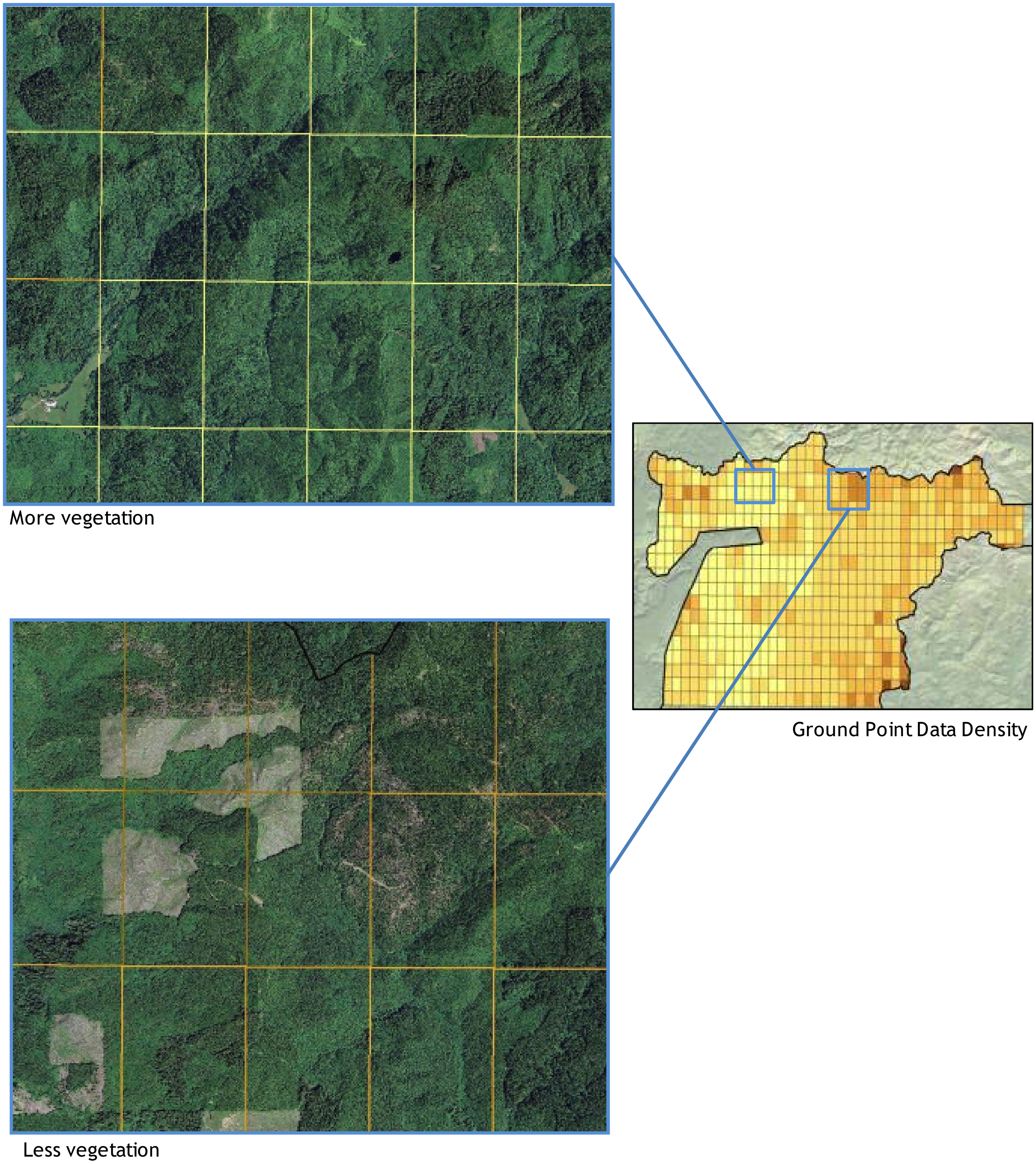
2.60	27.99
2.70	29.06
2.80	30.14
2.90	31.22
3.00	32.29

Figure 4.5. *Ground point density data tends to be lower in heavily forested areas, and higher in areas with less dense vegetation.*



5. Selected Imagery

Figure 5.1. *View of Nestucca River, one mile north east of McGuire Reservoir. First image derived from highest hit LiDAR, second image derived from bare earth LiDAR, third image derived from NAIP orthophoto draped over highest hit LiDAR.*

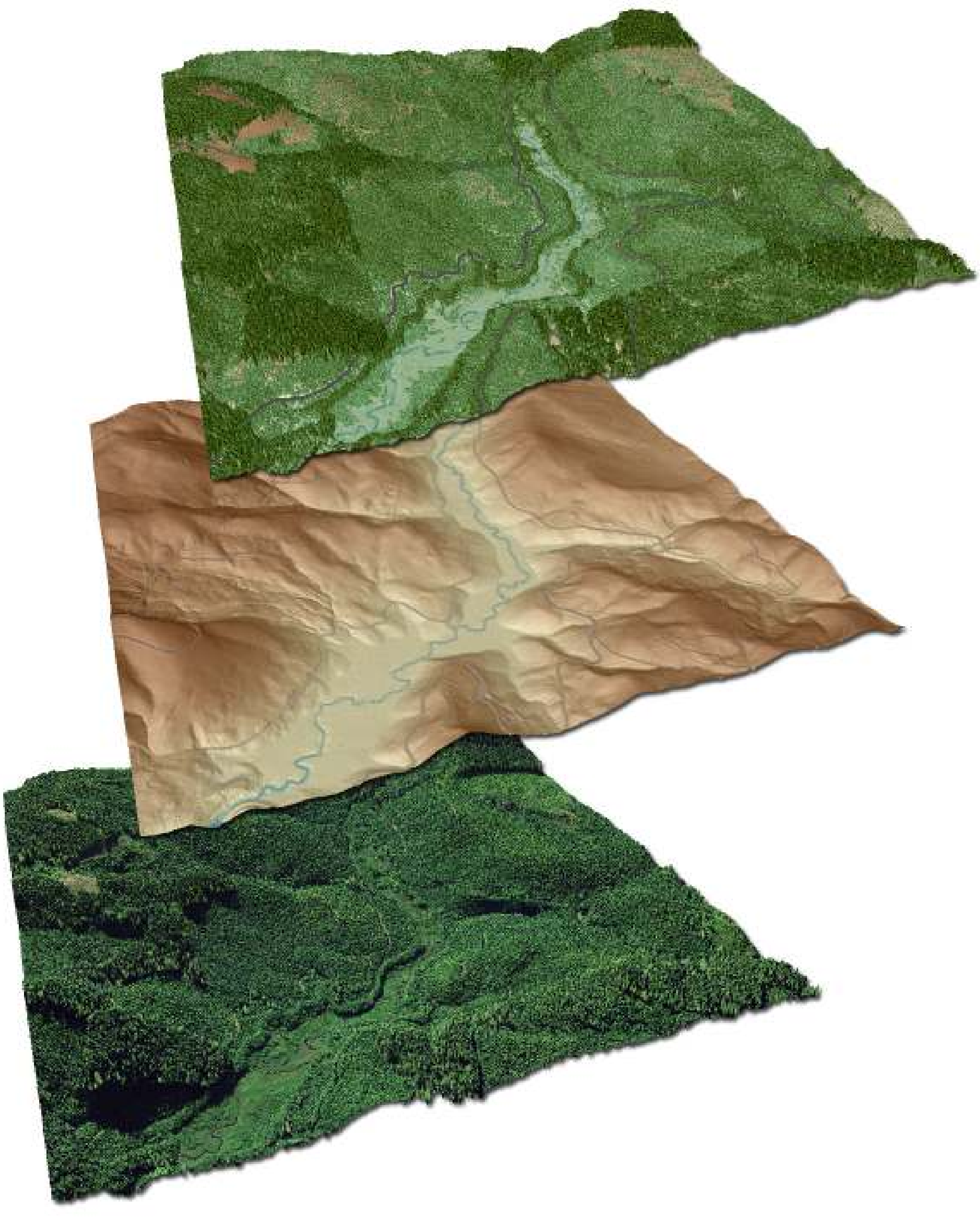


Figure 5.2. *Section of Upper Nestucca River in Siuslaw National Forest, viewed from the south. Top image derived from highest hit LiDAR, bottom image derived from bare earth LiDAR.*

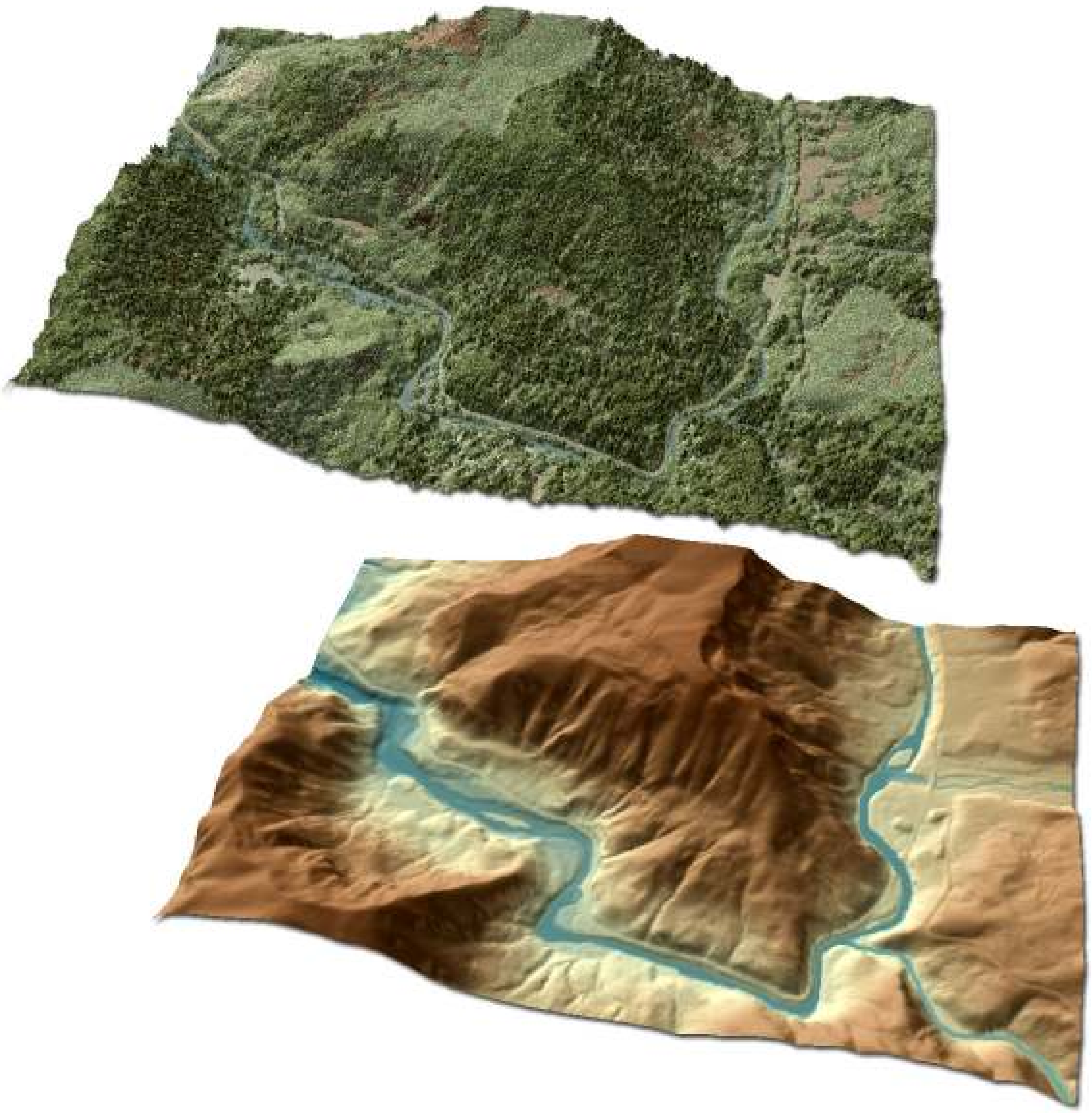


Figure 5.3. *Siuslaw National Forest near Blaine Road, East of Beaver, Oregon. Image is a three dimensional LiDAR point cloud with RGB values extracted from a NAIP orthophoto.*

Figure 5.4. *Summit of Mount Hebo. Image is a three dimensional LiDAR point cloud with RGB values extracted from a NAIP orthophoto.*