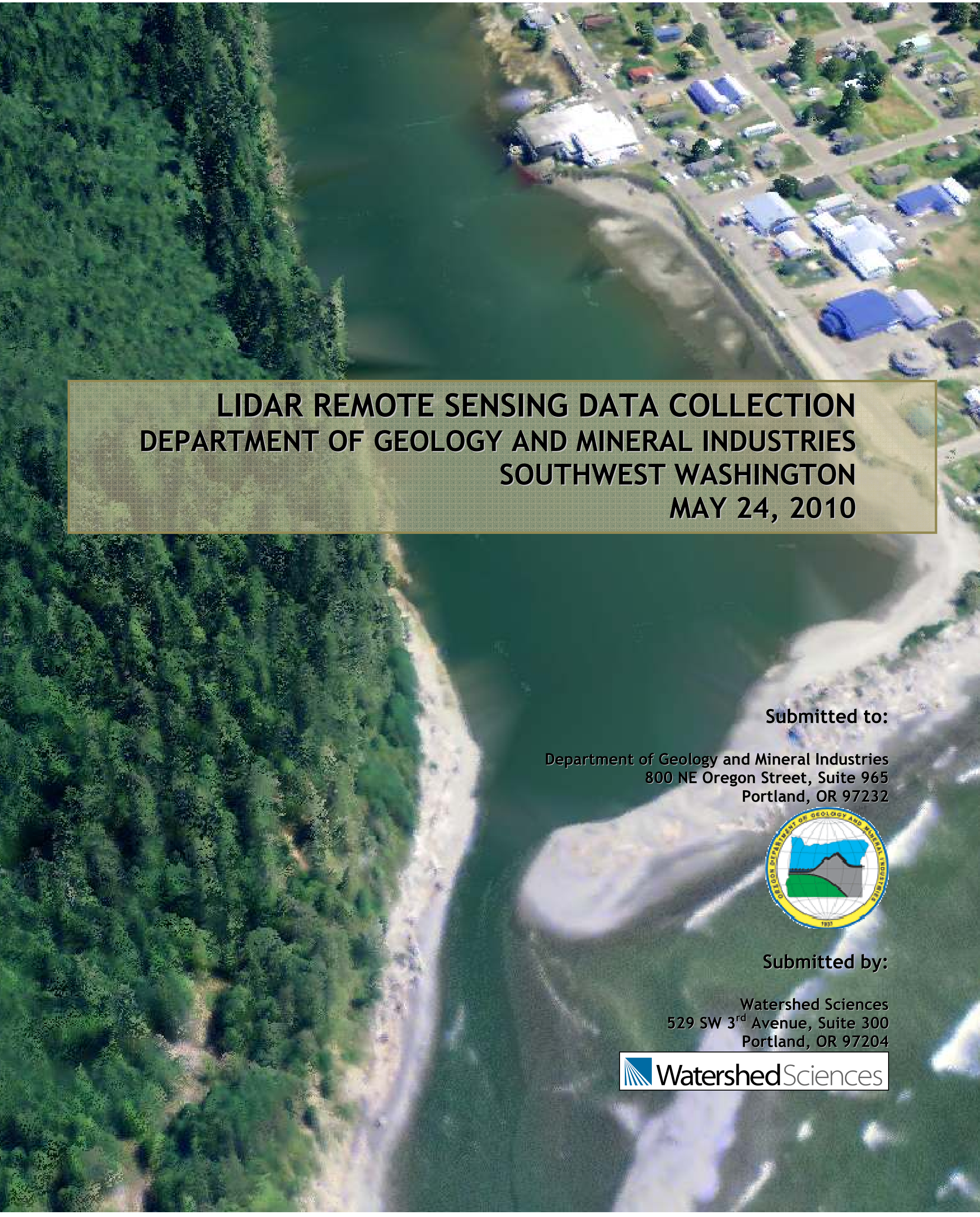

LIDAR REMOTE SENSING DATA COLLECTION
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
SOUTHWEST WASHINGTON
MAY 24, 2010

Submitted to:

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LiDAR Remote Sensing Data Collection:
DOGAMI, Southwest Washington Study Area

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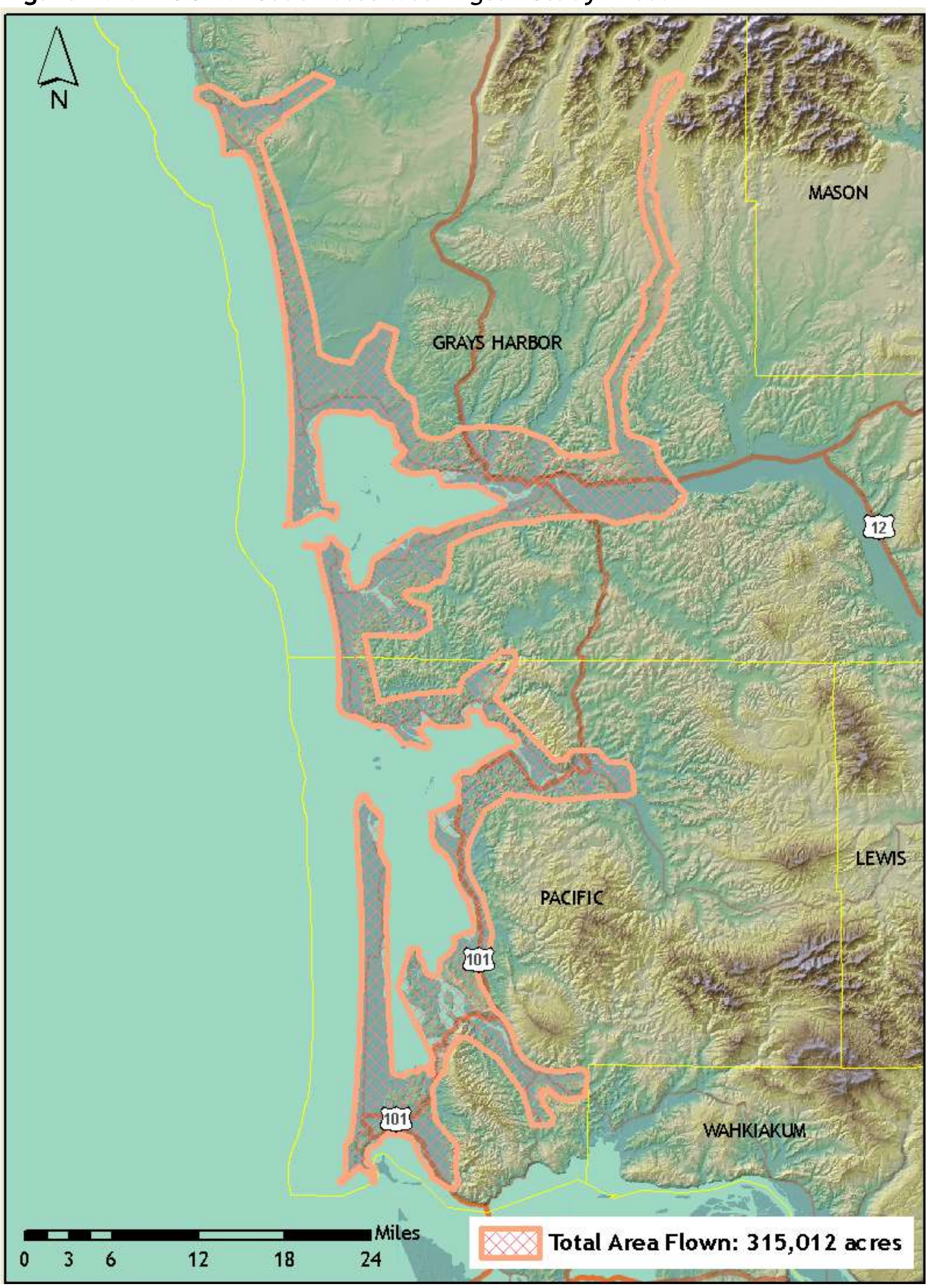
1. Overview

1.1 Study Area

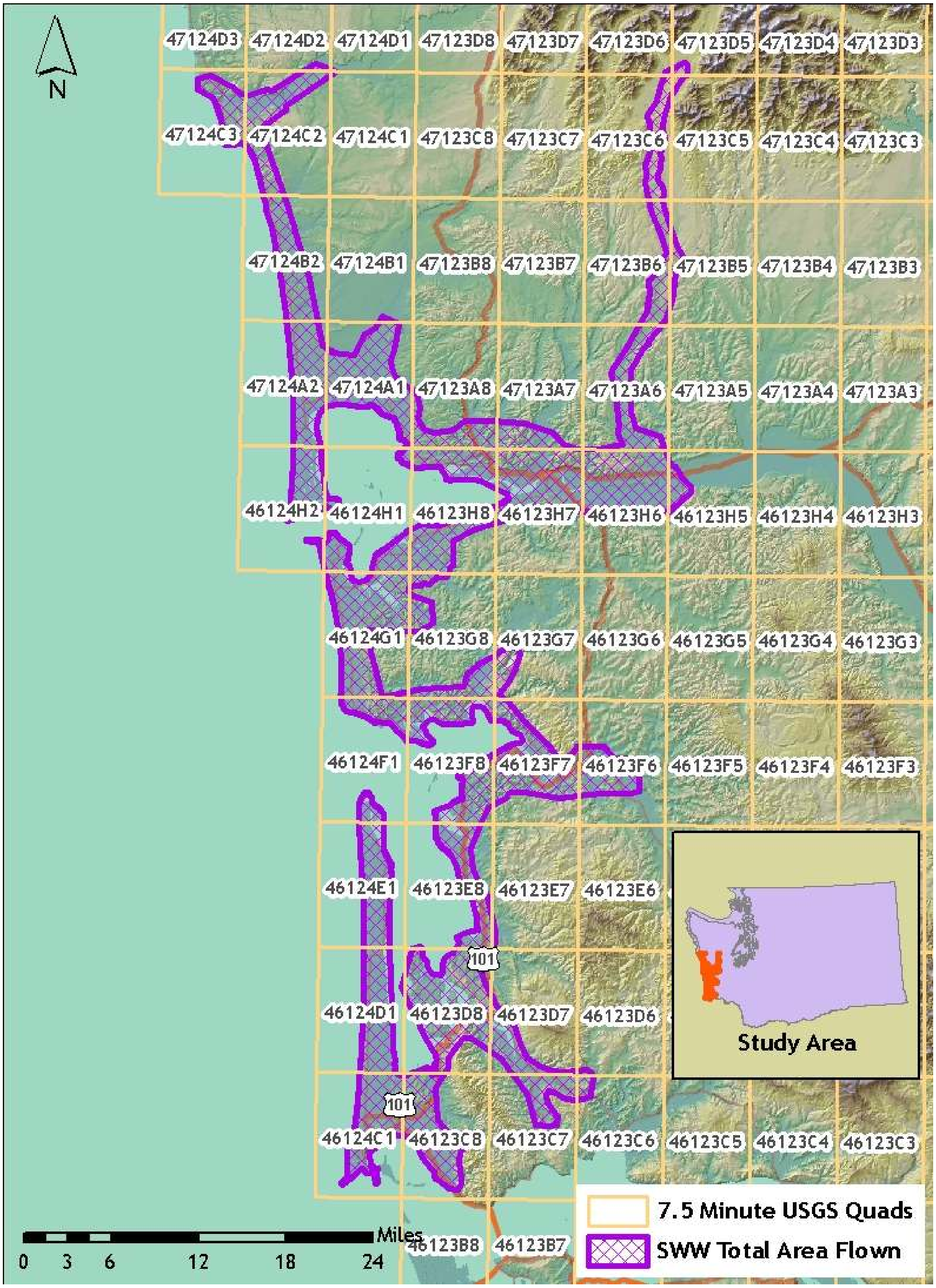
Watershed Sciences, Inc. has collected Light Detection and Ranging (LiDAR) data of the Southwest Washington Study Area for the Oregon Department of Geology and Mineral Industries (DOGAMI). The area of interest (AOI) covers 463 square miles (296,307 acres) and the total area flown (TAF) covers 492 square miles (315,012 acres). The TAF acreage is greater than the original AOI acreage due to buffering and flight planning optimization (**Figure 1.1** below). The native projection for this LiDAR collection is UTM Zone 10; horizontal and vertical datum: NAD83 (CORS96)/NAVD88 (Geoid03); units: meters.

***Figure 1.1**. DOGAMI Southwest Washington Study Area.*



1.2 Area Delivered

***Figure 1.2**. Southwest Washington Study Area, illustrating the delivered 7.5 minute USGS quads.*



2. Acquisition

2.1 Airborne Survey Overview – Instrumentation and Methods

The LiDAR survey utilized a Leica ALS50 Phase II and an ALS60 Phase II mounted in Cessna Caravan 208B. The dual laser acquisition was set to acquire ≥105,000 laser pulses per second (i.e. 105 kHz pulse rate) and flown at 2000 meters above ground level (AGL), capturing a scan angle of ±24° 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*

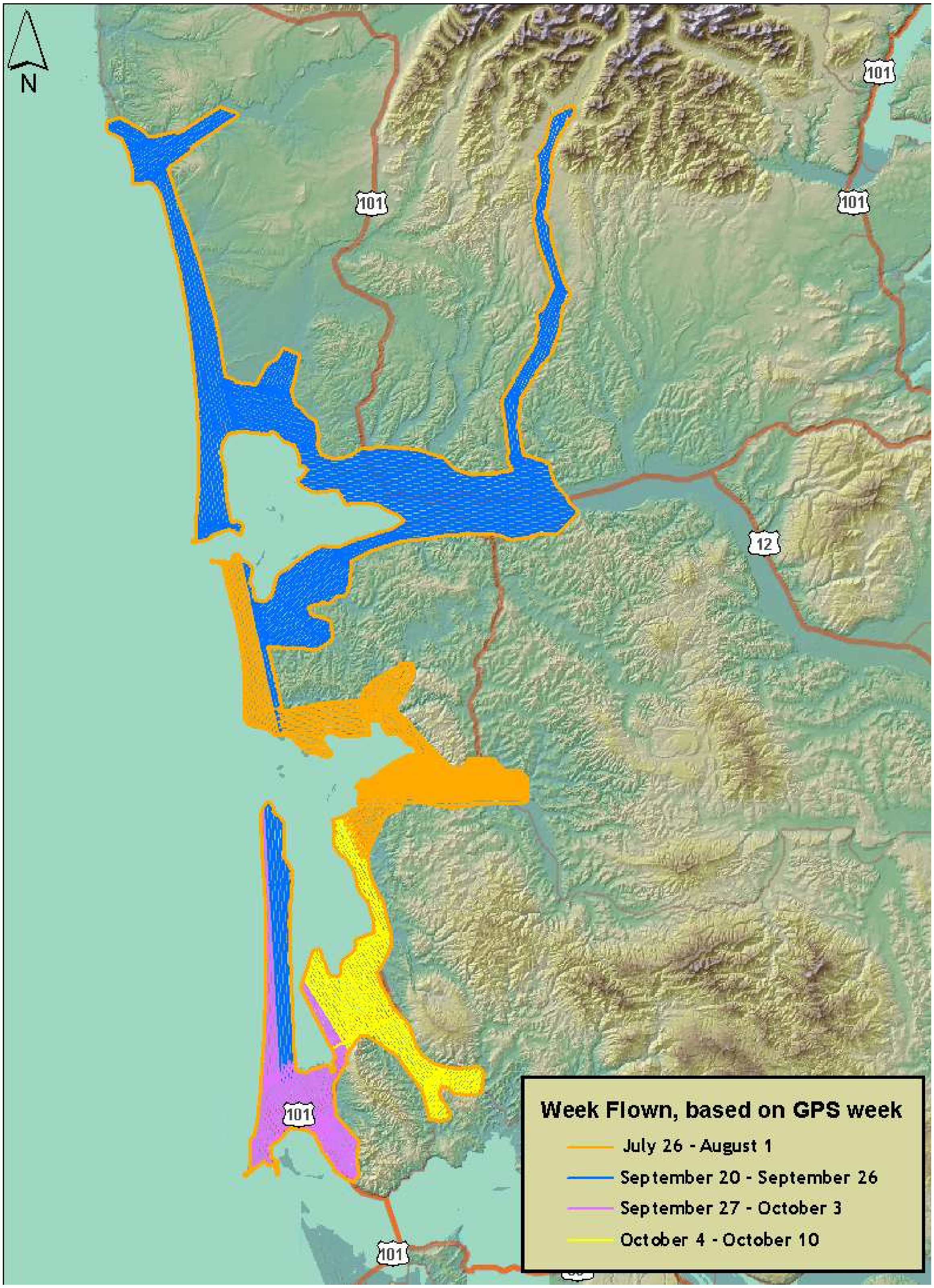
Sensor	Leica ALS50 Phase II and ALS60
Survey Altitude (AGL)	2000 m
Pulse Rate	>105 kHz
Pulse Mode	Single
Mirror Scan Rate	77 Hz, 58 Hz
Field of View	48° (±24° from nadir)
Overlap	100% (50% Side-lap)

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 study area.

[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 as "degrees from nadir".

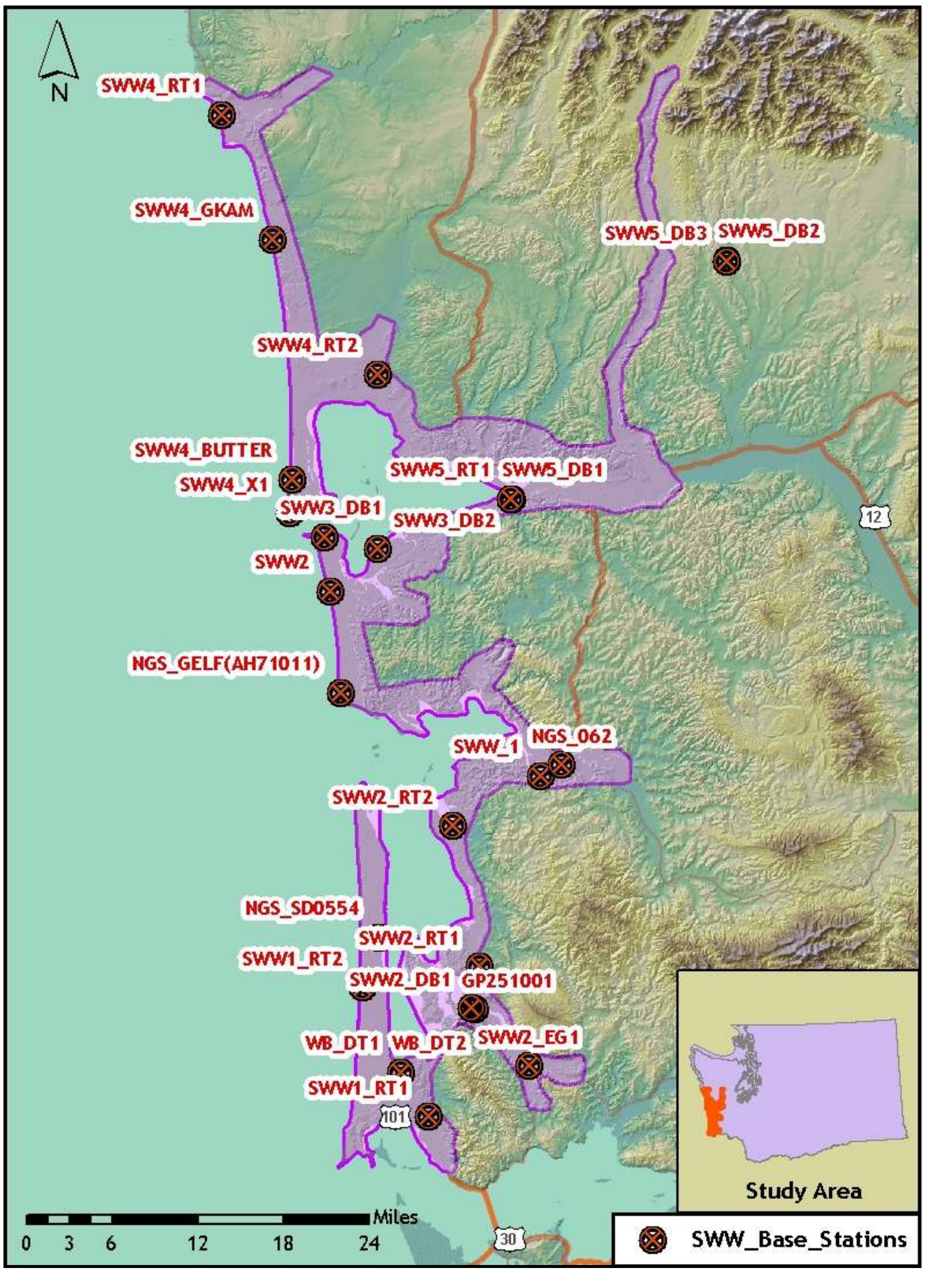
Figure 2.1. Actual flightlines for the Southwest Washington Study Area illustrating the dates flown, based on GPS week.



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.

Figure 2.2. *Base stations for the Southwest Washington Study Area.*



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

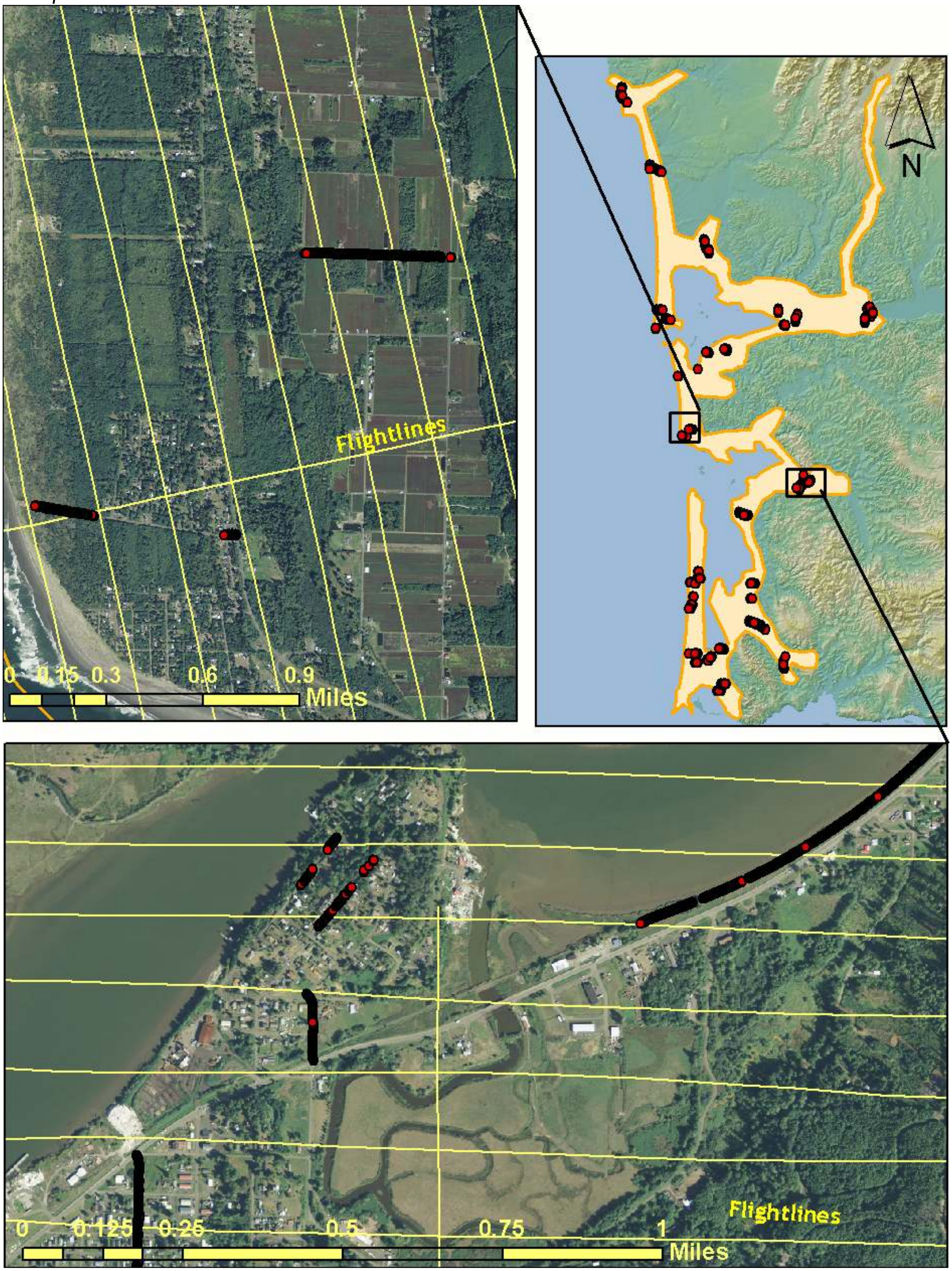
Table 2.2. *Base Station Surveyed Coordinates, (NAD83/NAVD88, OPUS corrected) used for kinematic post-processing of the aircraft GPS data for the Southwest Washington Study Area.*

	Datum NAD83 (HARN)		**GRS80**
Base Station ID	**Latitude (North)**	**Longitude (West)**	**Ellipsoid Height (m)**
GP251001	46 25 32.13262	123 53 23.79688	-19.634
NGS_062	46 40 31.98082	123 45 54.48440	-19.157
NGS_GELF (AH71011)	46 44 47.29974	124 5 36.96750	-18.653
NGS_SD0554	46 29 53.91673	124 1 54.72243	-21.390
SWW_1	46 39 50.85259	123 47 46.59394	-18.349
SWW1_RT1	46 18 58.15076	123 57 22.66717	-20.834
SWW1_RT2	46 26 47.32202	124 03 19.69617	-17.188
SWW2	46 50 58.19753	124 06 35.99974	-19.214
SWW2_DB1	46 25 36.56363	123 53 40.74200	-19.708
SWW2_EG1	46 22 8.55479	123 48 30.84533	-18.535
SWW2_RT1	46 28 9.93462	123 52 58.81018	25.227
SWW2_RT2	46 36 44.01789	123 55 32.99722	-19.636
SWW3_DB1	46 54 16.98327	124 07 14.75646	-17.101
SWW3_DB2	46 53 35.83553	124 02 27.65372	-21.864
SWW4_BUTTER	46 57 45.83370	124 10 13.59654	-19.33
SWW4_GKAM	47 12 25.57322	124 12 13.44405	-17.316
SWW4_RT1	47 19 57.86193	124 16 59.85920	19.892
SWW4_RT2	47 04 15.77032	124 02 39.77192	-19.547
SWW4_X1	46 55 41.93028	124 10 21.17129	-17.755
SWW5_DB1	46 56 45.39353	123 50 35.82693	-18.401
SWW5_DB2	47 11 26.93824	123 31 35.29492	127.134
SWW5_DB3	47 11 21.80335	123 31 36.17668	123.471
SWW5_RT1	46 56 45.40554	123 50 40.32889	-17.744
WB_DT1	46 21 38.37277	123 59 50.86247	-20.977
WB_DT2	46 21 38.29486	123 59 50.95002	-20.935

In the Southwest Washington Study Area, a total of 9,187 RTK (Real-time kinematic) points were collected.

Figure 2.3. *Selected RTK point locations in Southwest Washington study area; images are NAIP orthophotos.*

Figure 2.4. *Selected RTK point locations in Southwest Washington study area; 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 818 flightlines and over 11 billion points.

- Project Average = 0.05 m (0.15 ft)
- Median Relative Accuracy = 0.05 m (0.14 ft)
- 1σ Relative Accuracy = 0.05m (0.16 ft)
- 2σ Relative Accuracy = 0.07 m (0.22 ft)

Figure 3.1. *Statistical relative accuracies, non slope-adjusted.*

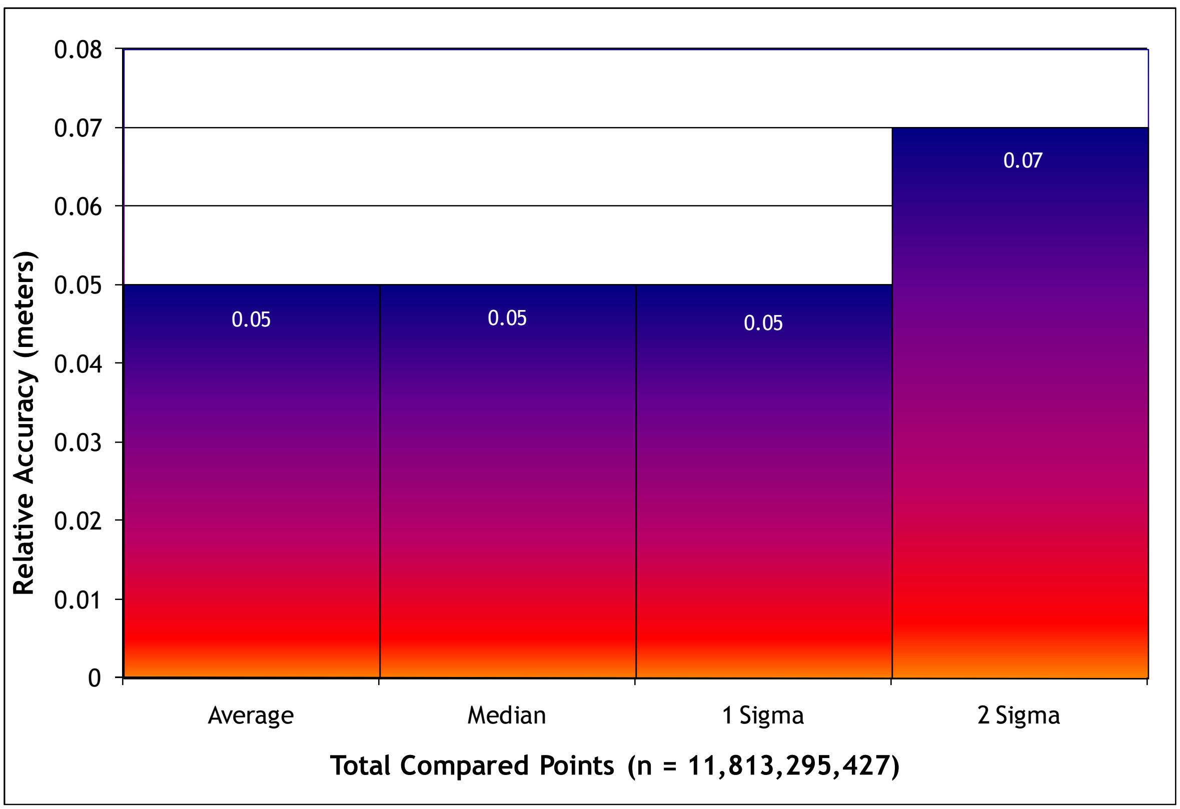
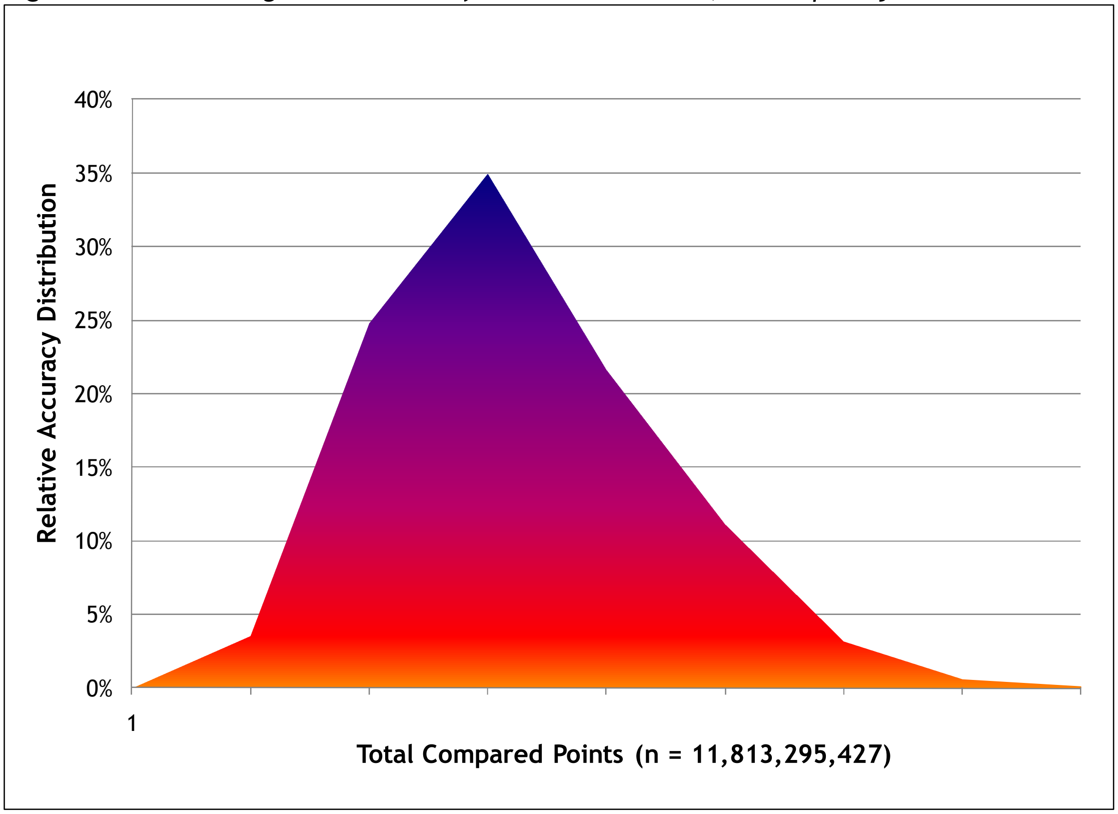


***Figure 3.2**. Percentage distribution of relative accuracies, non slope-adjusted.*



3.2 Absolute Accuracy

Absolute accuracy compares known RTK ground survey points to the closest laser point. For the Southwest Washington Study Area, a total of 9,187 RTK points were collected. Absolute accuracy is reported for the entire study area. Histogram and absolute deviation statistics are reported in **Figures 3.3 and 3.4**.

***Table 3.1**. Absolute Accuracy: deviation between laser points and RTK survey points.*

Sample Size (n): 9,187	
Root Mean Square Error (RMSE): 0.05m (0.15 ft)	
Standard Deviations	**Deviations**
sigma (σ): 0.05 m (0.15 ft)	**Minimum Δz:** -0.24 m (-0.79 ft)
2 sigma (σ): 0.09 m (0.30 ft)	**Maximum Δz:** 0.19 m (0.61 ft)
	Average Δz: 0.04 m (0.12 ft)

***Figure 3.3**. Southwest Washington Study Area histogram statistics*

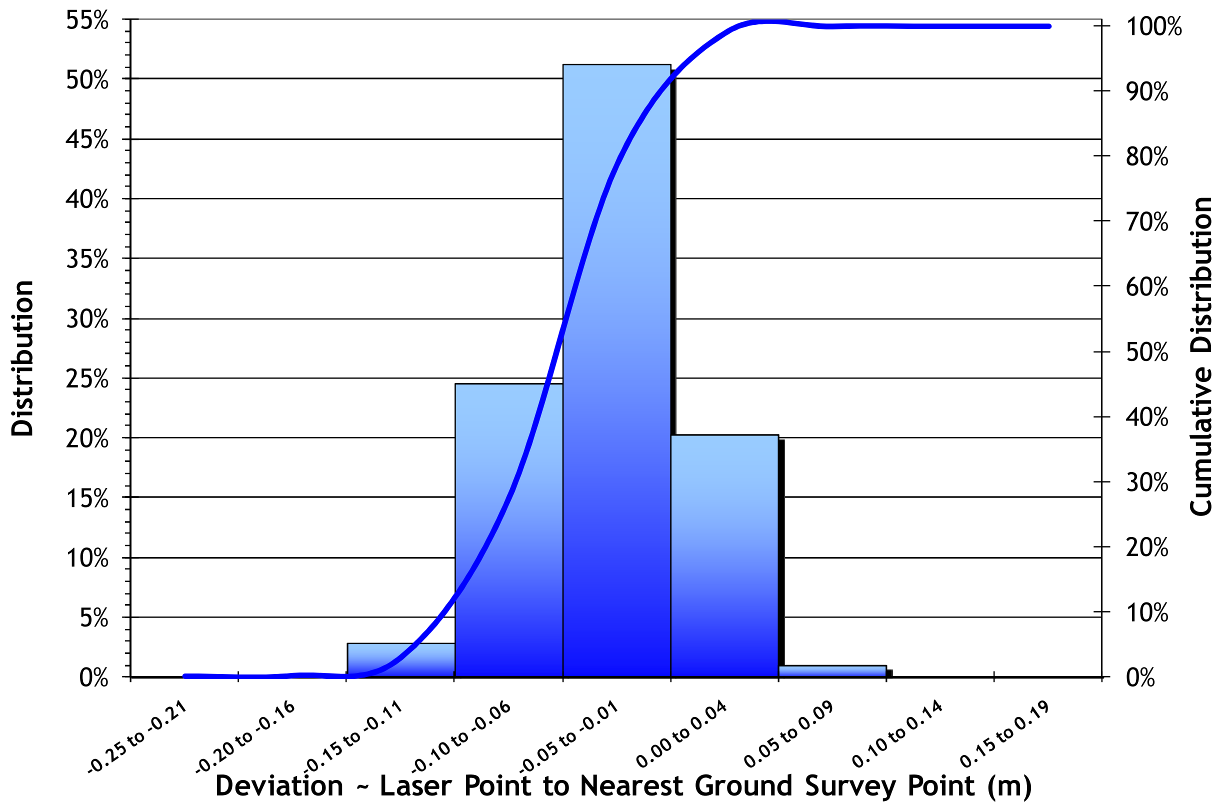
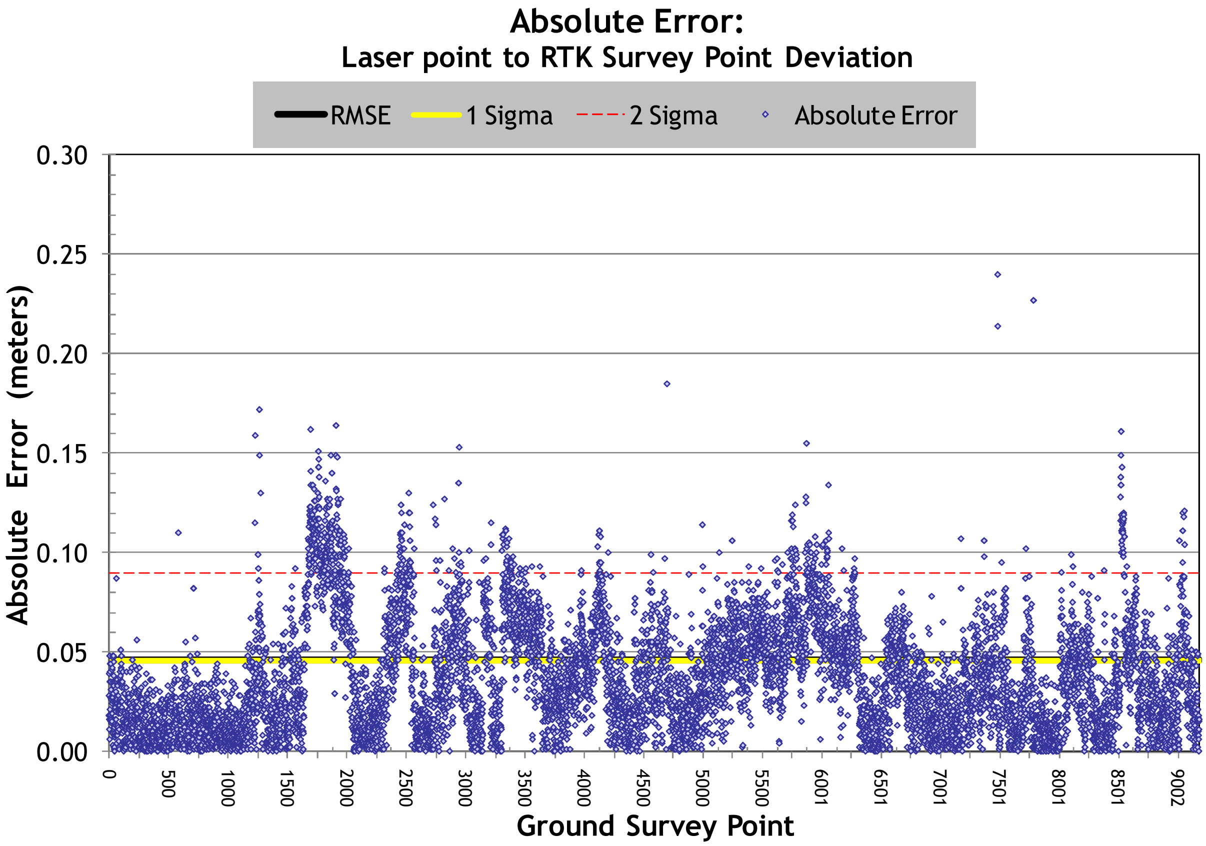


Figure 3.4. Southwest Washington Study Area point absolute deviation statistics.



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 Southwest Washington Study Area data.*

Average Pulse Density (per square ft)	Average Pulse Density (per square m)	Average Ground Density (per square ft)	Average Ground Density (per square m)
0.90	9.7	.08	.85

Figure 4.1. *Histogram of first return laser point density.*

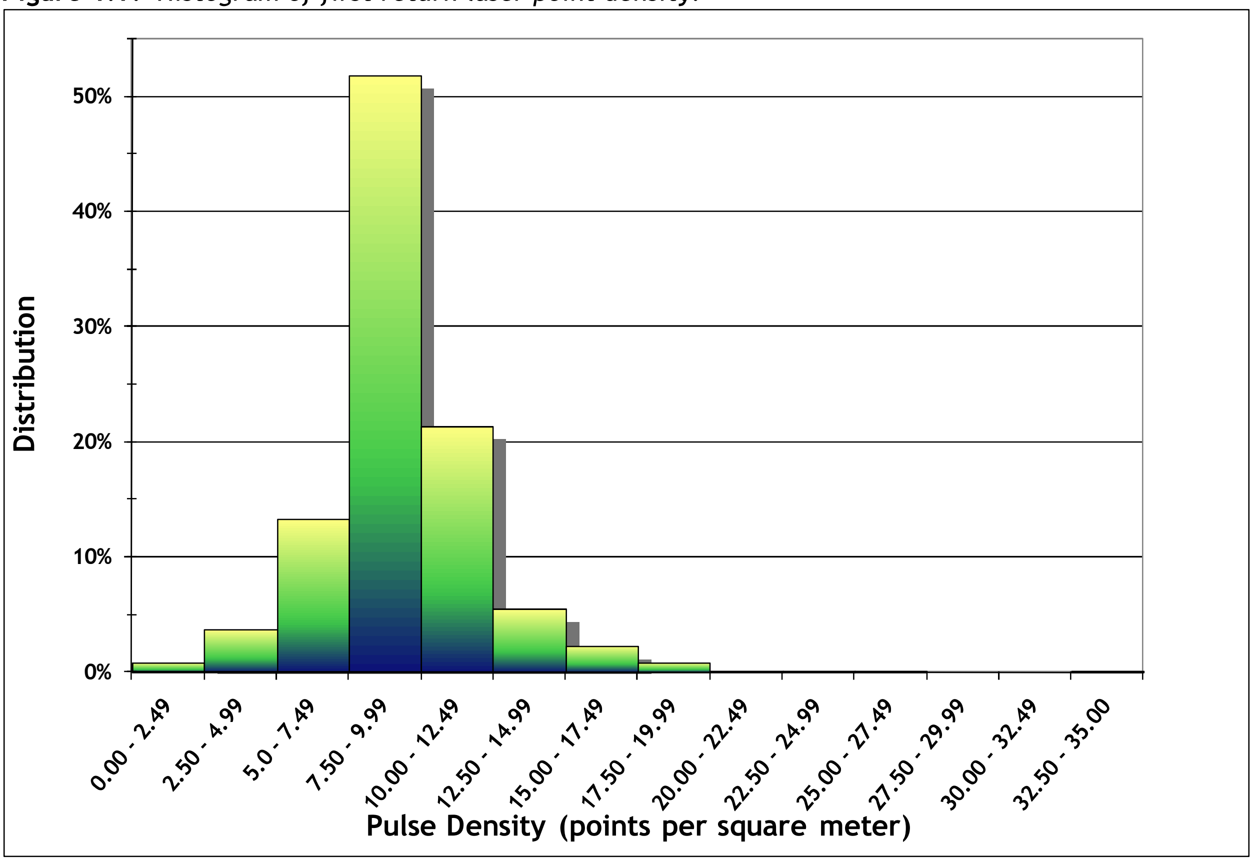
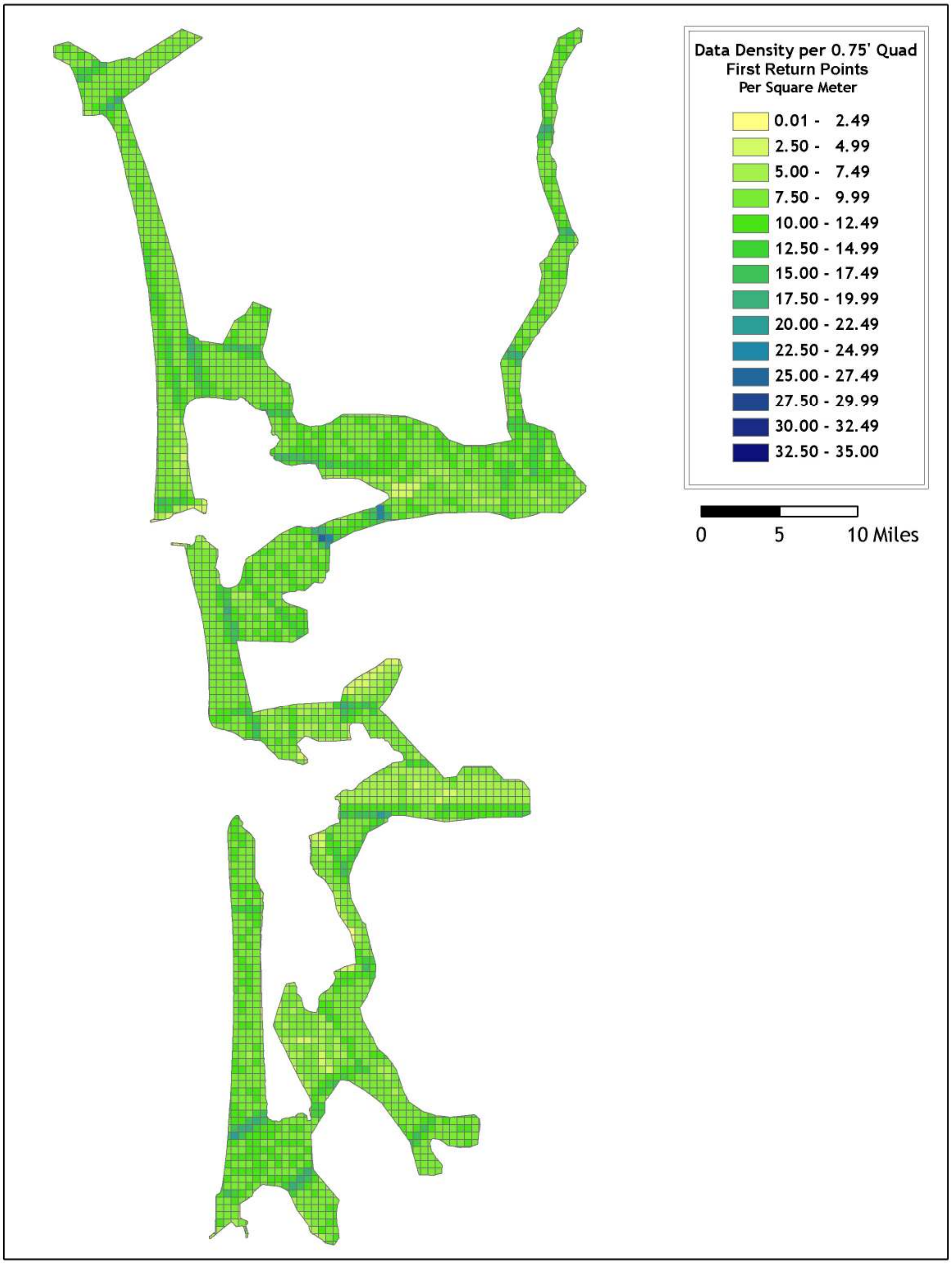


Figure 4.2. F*irst return laser point densities per processing bin.*

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



Ground classifications were derived from ground surface modeling. Classifications were performed by reseeding of the ground model where it was determined that the ground model failed, 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.*

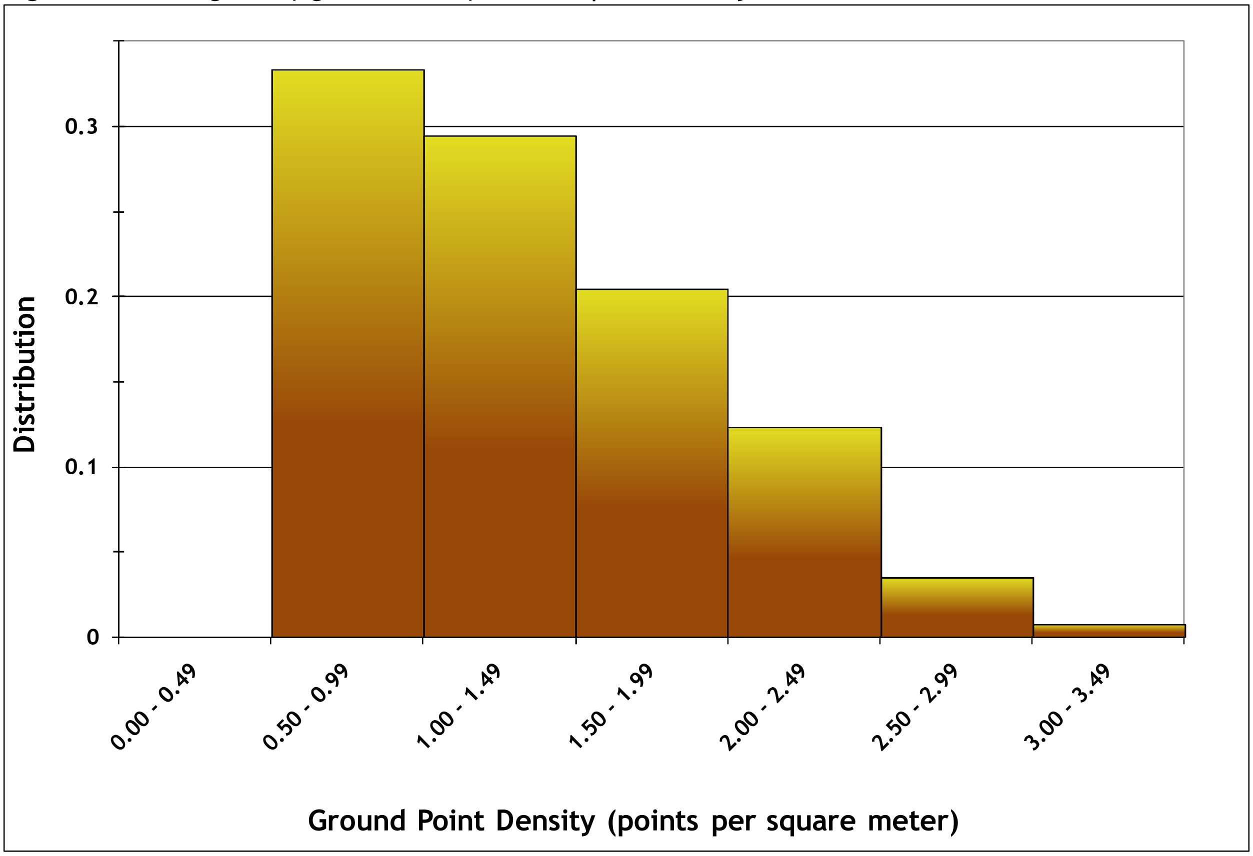
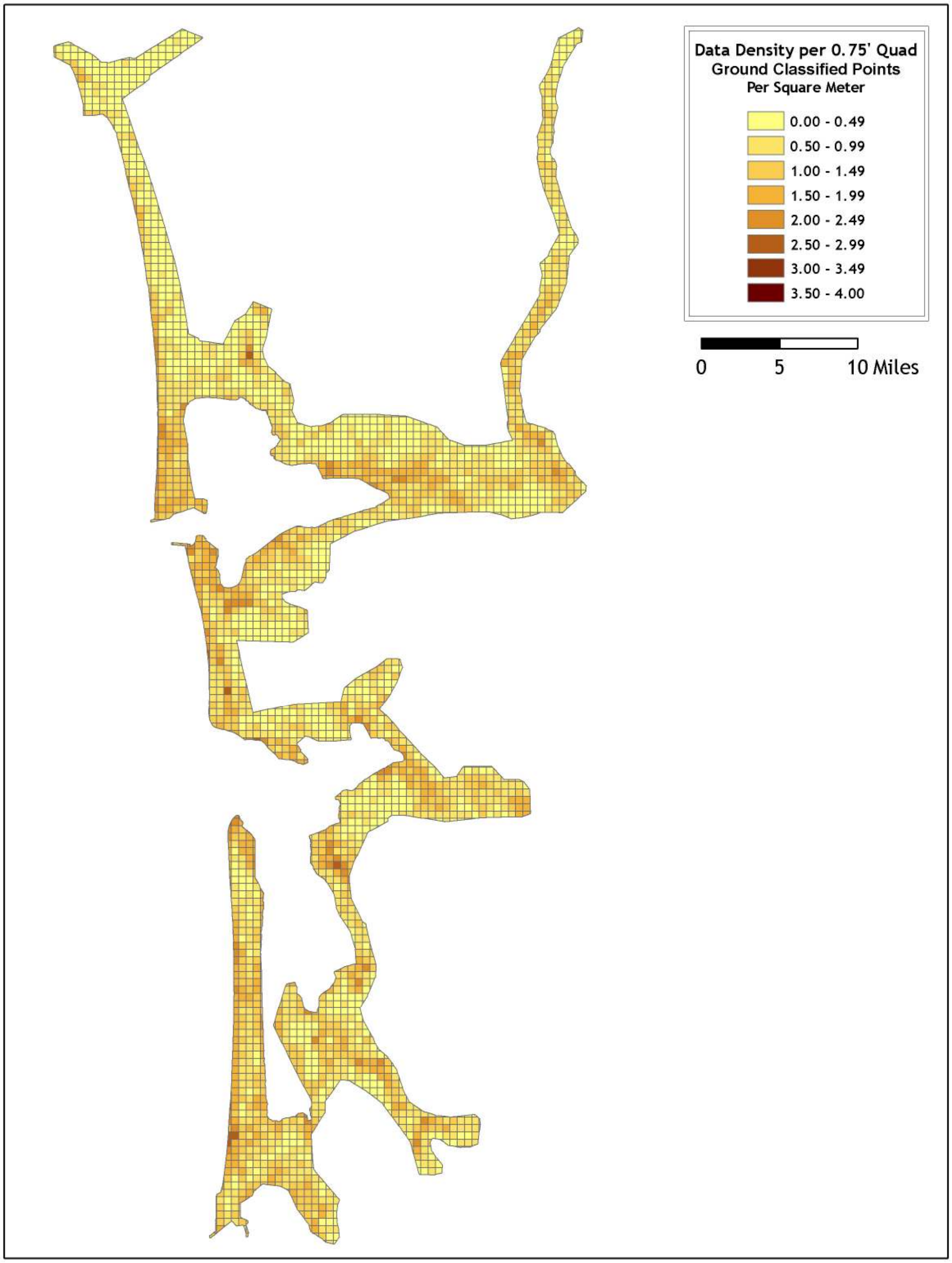


Figure 4.4. *Ground-classified laser point density.*



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

5. Selected Imagery

Figure 5.1. *Image of Curry River, near Wynoochee Dam, Washington. RGB values are extracted onto a 3-dimensional LiDAR point cloud.*

Figure 5.2. Dendritic patterns in a tidal delta in Gray's Harbor, Washington. RGB values extracted onto a 3-dimensional LiDAR point cloud.

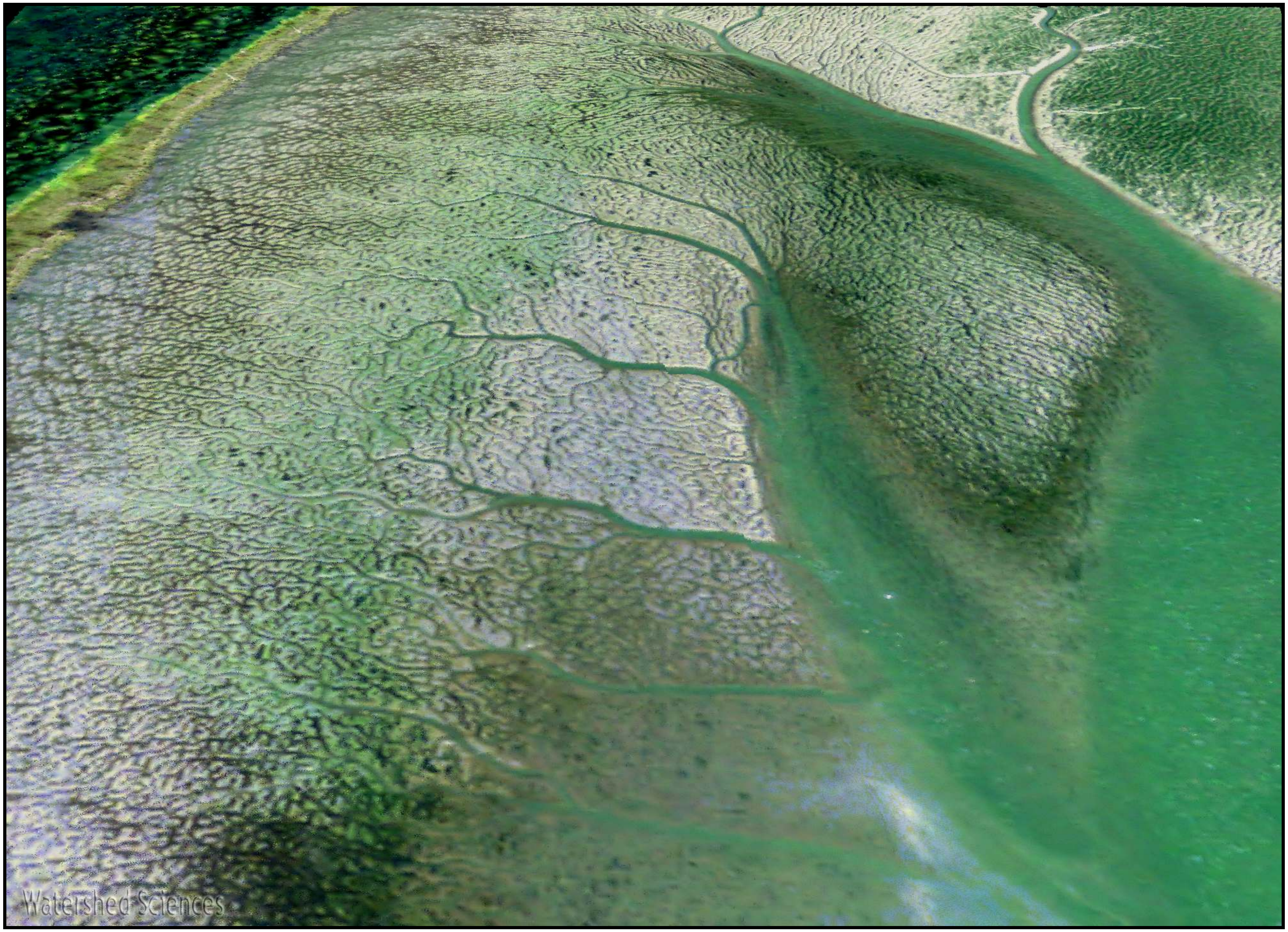


Figure 5.3. Wreck Creek's convergence with the Pacific Ocean, north of Moclips, Washington. RGB values extracted onto a 3-dimensional LiDAR point cloud.

Figure 5.4. Point Grenville, Taholah, WA. RGB values extracted onto a 3-dimensional LiDAR point cloud.