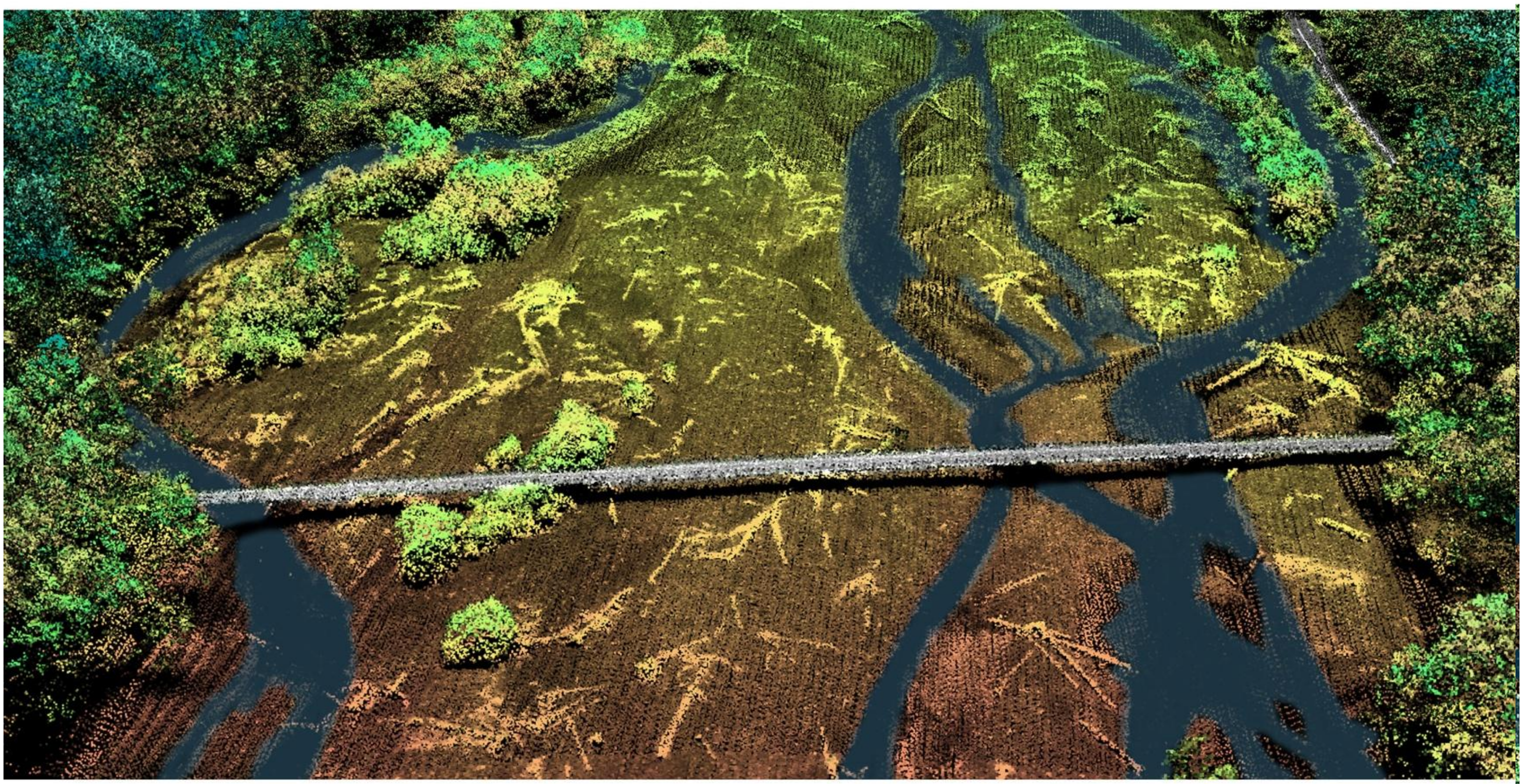
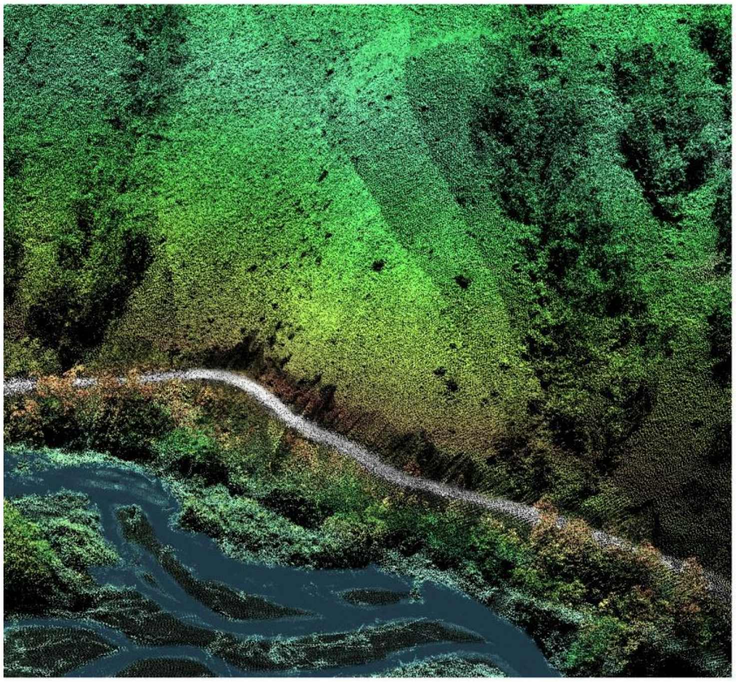
LiDAR REMOTE SENSING

PIERCE COUNTY • WASHINGTON

Delivery 21 – 12/13/2011





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PIERCE COUNTY

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1. Overview

Watershed Sciences, Inc. (WSI) collected Light Detection and Ranging (LiDAR) data of Pierce County for Delivery 21 on April 23rd, June 5th, July 23rd, 24th, and 28th, August 27th, and September 3rd and 6th, 2011. This report documents the data acquisition, processing methods, accuracy assessment, and deliverables of that data as well as the statistics and PLS oversight maintain throughout the entire project. The total area in Delivery 21 is 31,405 acres, making the final delivered area for Pierce County 932,850 acres.

Figure 1. *Pierce County Delivery Status Map*

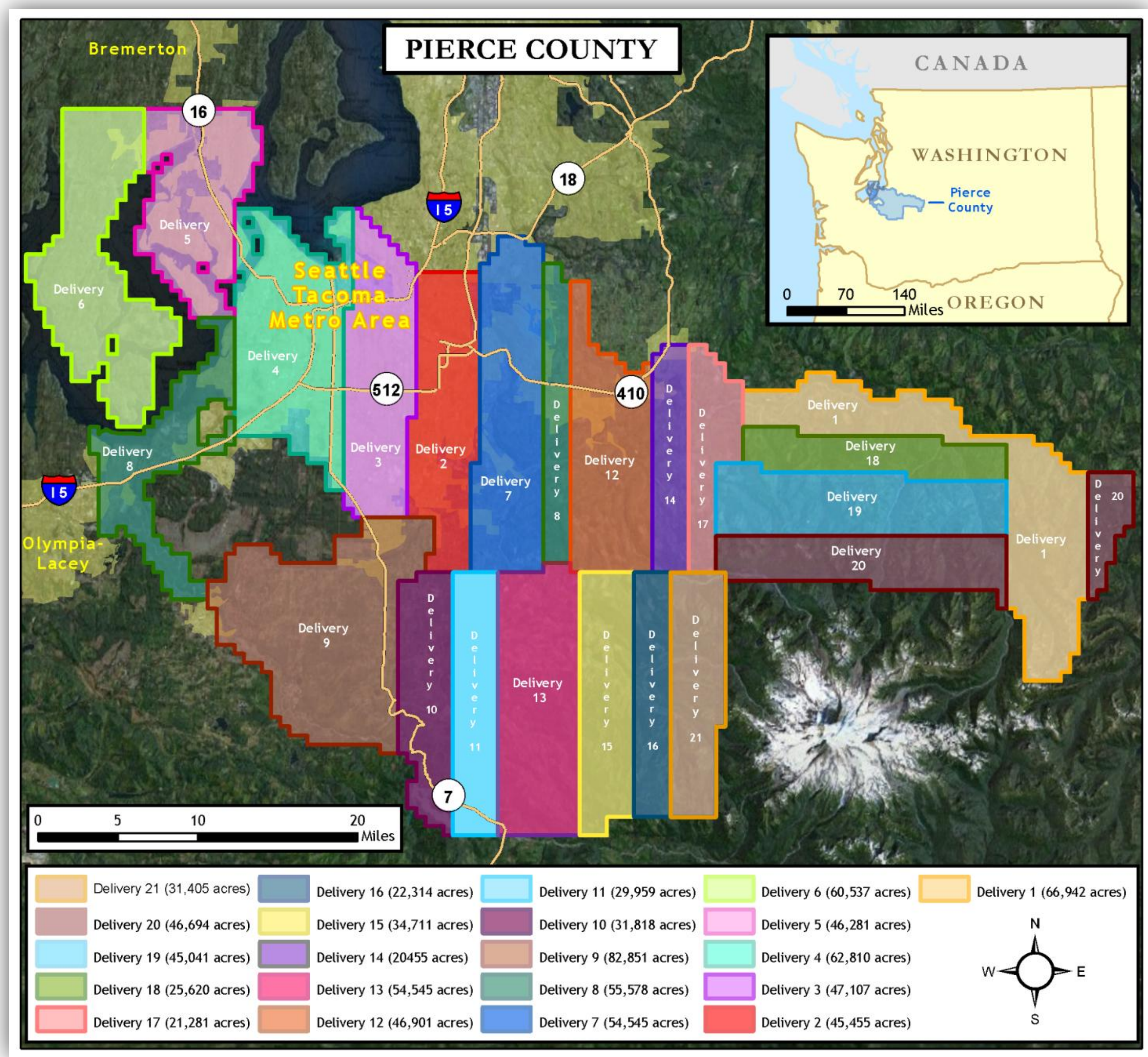


Table 1. Delivery schedule for Pierce County, Washington.

Delivery	Area	Flight Dates	Delivery Dates
Delivery 1	66,942 acres	10/19/10 – 10/21/10 11/03/10 – 11/04/10	02/14/11
Delivery 2	45,455 acres	12/03/10 – 12/06/10 12/08/10, 12/10/10	02/28/11
Delivery 3	47,107 acres	12/03/10 – 12/06/10 12/08/10, 12/10/10	03/07/11
Delivery 4	62,810 acres	12/08/10, 12/10/10 01/02/11, 01/04/11	03/25/11
Delivery 5	46,281 acres	01/02/11, 01/04/11 01/26/11, 01/30/11	04/05/11
Delivery 6	60,537 acres	01/26/11, 01/27/11 01/30/11, 02/05/11	04/26/11
Delivery 7	54,545 acres	12/03/10, 12/04/10 02/09/11	05/05/11
Delivery 8	55,578 acres	01/03/11 02/08/11 – 02/10/11 02/20/11	05/31/11
Delivery 9	82,851 acres	12/04/10 – 12/06/10 02/01/11, 02/02/11 02/07/11, 02/20/11	06/17/11
Delivery 10	31,818 acres	12/04/10 – 12/05/10 02/01/11, 04/20/11	06/27/11
Delivery 11	29,959 acres	12/03/10 - 12/04/10 02/09/11, 04/20/11 04/22/11 – 04/23/11	07/12/11
Delivery 12	46,901 acres	02/10/11 04/22/11 – 04/23/11 04/29/11	07/28/11
Delivery 13	54,545 acres	02/09/11 – 02/10/11 04/22/11 – 04/23/11 04/29/11, 06/03/11 06/04/11	08/15/11
Delivery 14	20,455 acres	04/22/11 – 04/23/11 06/05/11	08/29/11
Delivery 15	34,711 acres	02/10/11,04/22/11, 04/29/11, 06/04/11 07/02/11, 07/04/11	09/07/11
Delivery 16	22,314 acres	04/22/11, 04/23/11 06/05/11, 07/04/11 07/24/11	09/30/11
Delivery 17	21,281 acres	11/03/10, 11/04/10 06/05/11, 07/23/11 07/28/11, 07/30/11 08/27/11, 09/03/11 09/04/11 – 09/06/11	10/15/11
Delivery 18	25,620 acres	10/19/10, 07/23/11 07/28/11, 07/30/11 09/04/11 - 09/06/11	10/28/11
Delivery 19	45,041 acres	10/19/10, 07/23/11 07/28/11, 07/30/11 09/04/11, 09/05/11	11/11/11
Delivery 20	46,694 acres	10/19/10,10/21/10 07/23/11, 07/28/11 09/03/11, 09/04/11 09/06/11	12/01/11
Delivery 21	31,405 acres	04/23/11, 06/05/11 07/23/11, 07/24/11 07/28/11, 08/27/11 09/03/11, 09/06/11	12/13/11
Total Delivered Area	**932,850 acres**		

2. Acquisition

2.1 Airborne Survey – Instrumentation and Methods

The LiDAR survey used two Leica ALS50 Phase II and an ALS 60 laser systems mounted in a Cessna Caravan 208B. The Leica systems were set to acquire ≥83,000 – 105,900 laser pulses per second (i.e., 83 – 105.9 kHz pulse rate) and flown at 900 - 1300 meters above ground level (AGL) depending on weather and terrain, capturing a scan angle of ±14° from nadir. These settings were developed to yield points with an average native pulse density of ≥8 pulses per square meter over terrestrial surfaces. It is not uncommon for some types of surfaces (e.g. dense vegetation or water) to return fewer pulses than the laser originally emitted. These discrepancies between 'native' and 'delivered' density will vary depending on terrain, land cover, and the prevalence of water bodies.

The Cessna Caravan is a stable platform, ideal for flying slow and low for high density projects. The Leica ALS50 Phase II sensor head installed in the Caravan 208B is shown on the left.

All areas were surveyed with an opposing flight line side-lap of ≥50% (≥100% overlap) to reduce laser shadowing and increase surface laser painting. The Leica laser systems allow up to four range measurements (returns) per pulse, and all discernable laser returns were processed for the output dataset.

To accurately solve for laser point position (geographic coordinates x, y, z), the positional coordinates of the airborne sensor and the attitude of the aircraft were recorded continuously throughout the LiDAR data collection mission. Aircraft position was measured twice per second (2 Hz) by an onboard differential GPS unit. Aircraft attitude was measured 200 times per second (200 Hz) as pitch, roll and yaw (heading) from an onboard inertial measurement unit (IMU). To allow for post-processing correction and calibration, aircraft/sensor position and attitude data are indexed by GPS time.

2.2 Ground Survey – Instrumentation and Methods


Trimble GPS equipment used to survey Pierce County

WSI staff surveyor, Chris Yotter-Brown (WA PLS 46328), certified all monuments and provided PLS oversight for the Pierce County data collection. The survey control plan was designed to provide redundant control within 13 nautical miles of the mission areas for LiDAR flights. The controls were set prior to the airborne missions. Monument coordinates are provided in **Table 2** and shown in **Figure 2**. In addition, cover classes have been collected and a full statistical analysis was performed **(Table 5)**.

Simultaneous with the airborne data collection mission, Watershed Sciences conducted multiple static (1 Hz recording frequency) ground surveys over the survey monuments. Indexed by time, these GPS data are used to correct the continuous onboard measurements of aircraft position recorded throughout the mission. After the airborne survey, the static GPS data are processed using triangulation with Continuously Operating Reference Stations (CORS) and checked using the Online Positioning User Service (OPUS[1]) to quantify daily variance. Multiple sessions are processed over the same monument to confirm antenna height measurements and reported position accuracy.

2.2.1 Instrumentation

For this project area, both Trimble GPS receiver model R7 with Zephyr Geodetic antenna with ground plane and Trimble GNSS receiver model R7 with Zephyr Geodetic Model 2 antenna where deployed for all static control. A Trimble model R8 GNSS unit was used for collecting check points using real time kinematic (RTK) survey techniques. For RTK data, the collector began recording after remaining stationary for 5 seconds then calculating the pseudo range position from at least three epochs with the relative error under 1.5 cm horizontal and 2 cm vertical. All GPS measurements are made with dual frequency L1-L2 receivers with carrier-phase correction.

2.2.2 Monumentation

Watershed Sciences incorporated control monuments that were located by Watershed Sciences field staff and certified by our staff surveyor, Chris Yotter-Brown (WA PLS 46328). Monuments selected were found to have good visibility and optimal location to support a LiDAR Acquisition flight (**Table 2**). Published PLS monuments can be found in **Appendix B.**

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

Table 2. Base Station control coordinates for Pierce County, Washington.

Base Station ID	Datum: NAD83 (CORS96)		GRS80
	Latitude	Longitude	Ellipsoid Z (meters)
PIERCE5_DT1	47°04'42.75983"N	121°32'12.57157"W	1479.911
PIERCE5_DT2	47°03'28.67722"N	121°31'33.99588"W	1614.859
PRC5_JM1*	47°03'37.90999"N	121°39'02.36162"W	1399.087
PRC5_JM2*	47°02'45.45128"N	121°39'03.28117"W	1323.192
CANYON_FALL	47°07'35.87273"N	122°13'31.45962"W	17.654
THUN_FIELD_RES	47°06'08.99191"N	122°17'23.21542"W	140.792
PRC_05	47°09'00.95667"N	122°20'09.48913"W	102.405
PRC_06	47°14'03.96855"N	122°29'48.51236"W	84.086
PRC_07	47°16'34.94795"N	122°34'26.89973"W	62.339
PRC_08	47°14'04.14993"N	122°29'48.91289"W	84.186
PRC_09	47°04'02.57741"N	122°42'53.17806"W	-15.941
PRC_10	47°05'39.36891"N	122°37'22.60117"W	57.472
PRC_11	47°09'20.13636"N	122°05'59.66019"W	182.229
PRC_12	47°10'12.88897"N	122°05'13.30278"W	182.531
PRC_13	47°09'48.75262"N	122°00'03.48110"W	207.153
PRC_13B*	47°09'49.20703"N	122°00'03.47643"W	207.094
FS2762*	47°05'39.36896"N	122°27'48.38614"W	80.642
TOWHEAD*	47°16'24.98888"N	122°39'04.73026"W	-17.754
PRC_JM1	46°56'15.11896"N	122°27'49.81342"W	128.644
PRC_JM2*	46°56'15.76860"N	122°30'28.44968"W	113.205
PRC_14	46°51'48.18146N	122°15'28.94994"W	237.698
PRC_15	46°51'52.87082"N	122°16'07.64355"W	268.068
PRC_16	47°05'41.55215"N	121°58'49.22075"W	508.384
PRC_16B*	47°05'41.41029"N	121°58'49.14234"W	508.409
PIERCE_17	46°58'02.68909"N	122°00'31.20599"W	871.040
PIERCE_18*	46°56'49.56910"N	122°12'26.79502"W	423.250
PRC_19*	46°57'39.02310"N	122°00'13.41752"W	900.955
PRC_20*	47°00'55.82779"N	121°38'44.38894"W	1416.250

* Basestations that have not been published by the PLS to date.

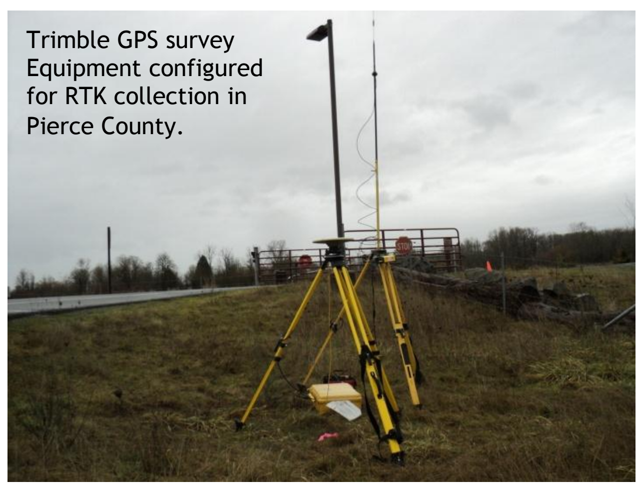
2.2.3 Methodology


Trimble GPS equipment during Pierce County LiDAR acquisition.

Each aircraft is assigned a ground crew member with two Trimble R7 receivers and an R8 receiver. The ground crew vehicles are equipped with standard field survey supplies and equipment including safety materials. All control monuments are observed for a minimum of one survey session lasting no fewer than 4 hours and another session lasting no fewer than 2 hours. At the beginning of every session the tripod and antenna are reset, resulting in two independent instrument heights and data files. Data is collected at a rate of 1Hz using a 10 degree mask on the antenna.

The ground crew uploads the static GPS data collected during the flight to our online Dropbox site on a daily basis to be returned to the office for Professional Land Surveyor (PLS) oversight, QA/QC review and processing. OPUS processing triangulates the monument position using 3 CORS stations resulting in a fully adjusted position. After multiple days of data have been collected at each monument, accuracy and error ellipses are calculated from the OPUS reports. This information leads to a rating of the monument based on FGDC-STD-007.2-1998[2] Part 2 table 2.1 at the 95% confidence level. When a statistically stable position is found, CORPSCON[3] 6.0.1 software is used to convert the UTM positions to geodetic positions.

RTK and aircraft mounted GPS measurements are made during periods with PDOP[4] 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. Static GPS data collected in a continuous session average the high PDOP into the final solution in the method used by CORS stations. RTK positions are collected 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). RTK measurements are not taken on highly reflective surfaces such as center line stripes or lane markings on roads. RTK points were taken no closer than one meter to any nearby terrain breaks such as road edges or drop offs.


Trimble GPS survey Equipment configured for RTK collection in Pierce County.

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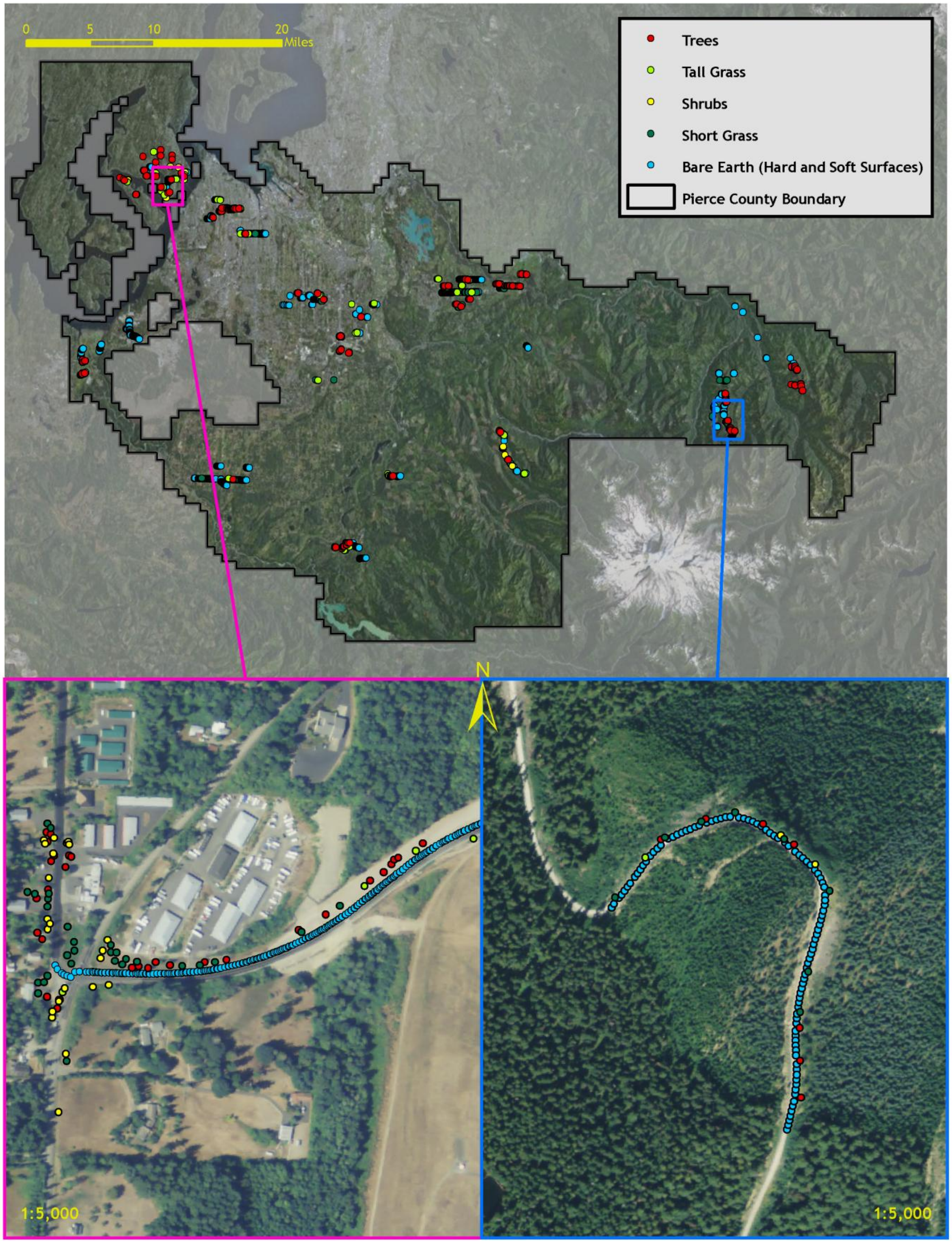
[2] Federal Geographic Data Committee Draft Geospatial Positioning Accuracy Standards
[3] U.S. Army Corps of Engineers , Engineer Research and Development Center Topographic Engineering Center software
[4]PDOP: Point Dilution of Precision is a measure of satellite geometry, the smaller the number the better the geometry between the point and the satellites.

***Figure 2**. Landcover locations including RTK used for the Pierce County data acquisition, processing, and accuracy checks.*



3. LiDAR Data Processing

3.1 Applications and Work Flow Overview

1. Resolved kinematic corrections for aircraft position data using kinematic aircraft GPS and static ground GPS data.

   Software: Waypoint GPS v.8.10, Trimble Geomatics Office v.1.62

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

   Software: IPAS v.1.35

3. Calculated laser point position by associating SBET position to each laser point return time, scan angle, intensity, etc. Created raw laser point cloud data for the entire survey in *.las (ASPRS v. 1.2) format. Data were converted to orthometric elevations (NAVD88) by applying a Geoid09 correction.

   Software: ALS Post Processing Software v.2.70, Corpscon 6.0.1

4. Imported raw laser points into manageable blocks (less than 500 MB) to perform manual relative accuracy calibration and filter for pits/birds. Ground points were then classified for individual flight lines (to be used for relative accuracy testing and calibration).

   Software: TerraScan v.10.009 and v. 11.007

5. Using ground classified points per each flight line, the relative accuracy was tested. Automated line-to-line calibrations were then performed for system attitude parameters (pitch, roll, heading), mirror flex (scale) and GPS/IMU drift. Calibrations were performed on ground classified points from paired flight lines. Every flight line was used for relative accuracy calibration.

   Software: TerraMatch v.10.006 and v. 11.005

6. Position and attitude data were imported. Resulting data were classified as ground and non-ground points. Statistical absolute accuracy was assessed via direct comparisons of ground classified points to ground RTK survey data.

   Software: TerraScan v.10.009 and v. 11.007, TerraModeler v.10.004 and v. 11.002

7. Bare Earth models were created as a triangulated surface and exported as ERDAS Imagine grids at a 3–foot pixel resolution.

   Software: TerraScan v.10.009, ArcMap v. 9.3.1, TerraModeler v.10.004 and v. 11.002

3.2 Aircraft Kinematic GPS and IMU Data

LiDAR survey datasets were referenced to the 1 Hz static ground GPS data collected over pre-surveyed monuments with known coordinates. While surveying, the aircraft collected 2 Hz kinematic GPS data, and the onboard inertial measurement unit (IMU) collected 200 Hz aircraft attitude data. Waypoint GPS v.8.10 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.1.35 was used to develop a trajectory file that includes corrected aircraft position and attitude information. The trajectory data for the entire flight survey session were incorporated into a final smoothed best estimated trajectory (SBET) file that contains accurate and continuous aircraft positions and attitudes.

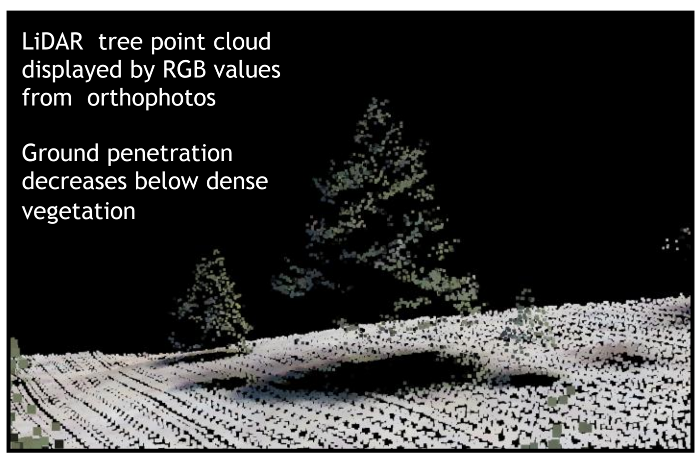
3.3 Laser Point Processing

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 with each point maintaining 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 for subsequent processing. 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 survey area and positional accuracy of the laser points.

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

LiDAR points were then filtered for noise, pits (artificial low points), and birds (true birds as well as erroneously high points) by screening for absolute elevation limits, isolated points and height above ground. Each bin was then manually inspected for remaining pits and birds and spurious points were removed. In 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. Common sources of non-terrestrial returns are clouds, birds, vapor, haze, decks, brush piles, etc.



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 scale). Automated sensor attitude and scale corrections yielded 3-5 cm improvements in the relative accuracy. Once system misalignments were corrected, vertical GPS drift was then resolved and removed per flight line, yielding a slight improvement (<1 cm) in relative accuracy.

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 to improve ground detail. This manual editing of ground often occurs in areas with known ground modeling deficiencies, such as: bedrock outcrops, cliffs, deeply incised stream banks, and dense vegetation. In some cases, automated ground point classification erroneously included known vegetation (i.e., understory, low/dense shrubs, etc.). These points were manually reclassified as default. Ground surface rasters were then developed from triangulated irregular networks (TINs) of ground points.

4. LiDAR Accuracy Assessment

4.1 Laser Noise and Relative Accuracy

Laser point absolute accuracy is largely a function of laser noise and relative accuracy. To minimize these contributions to absolute error, a number of noise filtering and calibration procedures were performed prior to evaluating absolute accuracy.

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 survey was approximately 0.02 meters.

Relative Accuracy
Relative accuracy refers to the internal consistency of the data set - the ability to place a laser point in the same location over multiple flight lines, GPS conditions, and aircraft attitudes. Affected by system attitude offsets, scale, and GPS/IMU drift, internal consistency 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). See Appendix A for further information on sources of error and operational measures that can be taken to improve relative accuracy.

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 survey 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. System misalignment offsets (pitch, roll and heading) and scale were solved for each individual mission and applied to respective mission datasets. The data from each mission were then blended when imported together to form the entire area of interest.
3. Automated Z Calibration: Ground points per line were used to calculate the vertical divergence between lines caused by vertical GPS drift. Automated Z calibration was the final step employed for relative accuracy calibration.

4.2 Absolute Accuracy

To minimize the contributions of laser noise and relative accuracy to absolute error, a number of noise filtering and calibration procedures were performed prior to evaluating absolute accuracy. The LiDAR quality assurance process uses the data from the real-time kinematic (RTK) ground survey conducted in Pierce County. For the area delivered area in Pierce County thus far, a total of 11,148 RTK GPS measurements were collected by Watershed Sciences, Inc. on hard surfaces distributed among multiple flight swaths.

The vertical accuracy of the LiDAR data is described as the mean and standard deviation (sigma ~σ) of divergence of LiDAR point coordinates from RTK ground survey point coordinates. To provide a sense of the model predictive power of the dataset, the root mean square error (RMSE) for vertical accuracy is also provided. These statistics assume the error distributions for x, y, and z are normally distributed, thus we also consider the skew and kurtosis of distributions when evaluating error statistics.

Statements of statistical accuracy apply to fixed terrestrial surfaces only and may not be applied to areas of dense vegetation or steep terrain (See Appendix A).

5. Study Area Results

Summary statistics for point resolution and accuracy (relative and absolute) of the LiDAR data collected in Pierce County are presented below in terms of central tendency, variation around the mean, and the spatial distribution of the data (for point resolution by tile). Overall statistics have been updated with each delivery.

5.1 Data Summary

***Table 3**. LiDAR Resolution and Accuracy - Specifications and Achieved Values*

	Targeted	Achieved
Resolution:	≥ 8 points/m^2	0.837 points/ft^2 (9.01 points/m^2)
Vertical Accuracy (1 σ):	<15 cm	0.103 ft (3.15 cm)

5.2 Data Density/Resolution

The average first-return density of delivered dataset is 0.837 points per square foot (9.01 points/m^2) (**Table 3**). The initial dataset, acquired to be ≥8 points per square meter, was filtered as described previously to remove spurious or inaccurate points. Additionally, some types of surfaces (i.e., dense vegetation, breaks in terrain, water, steep slopes) may return fewer pulses (delivered density) than the laser originally emitted (native density).

Ground classifications were derived from automated ground surface modeling and manual, supervised classifications where it was determined that the automated model had failed. Ground return densities will be lower in areas of dense vegetation, water, or buildings. **Figures 5-48** show the distribution of average native and ground point densities for each tile.

Cumulative LiDAR data resolution for Pierce County:

- Average Point (First Return) Density = 0.837 points/ft^2 (9.01 points/m^2)
- Average Ground Point Density = 0.165 points/ft^2 (1.77 points/m^2)

Figure 3. Cumulative density distribution for first return laser points

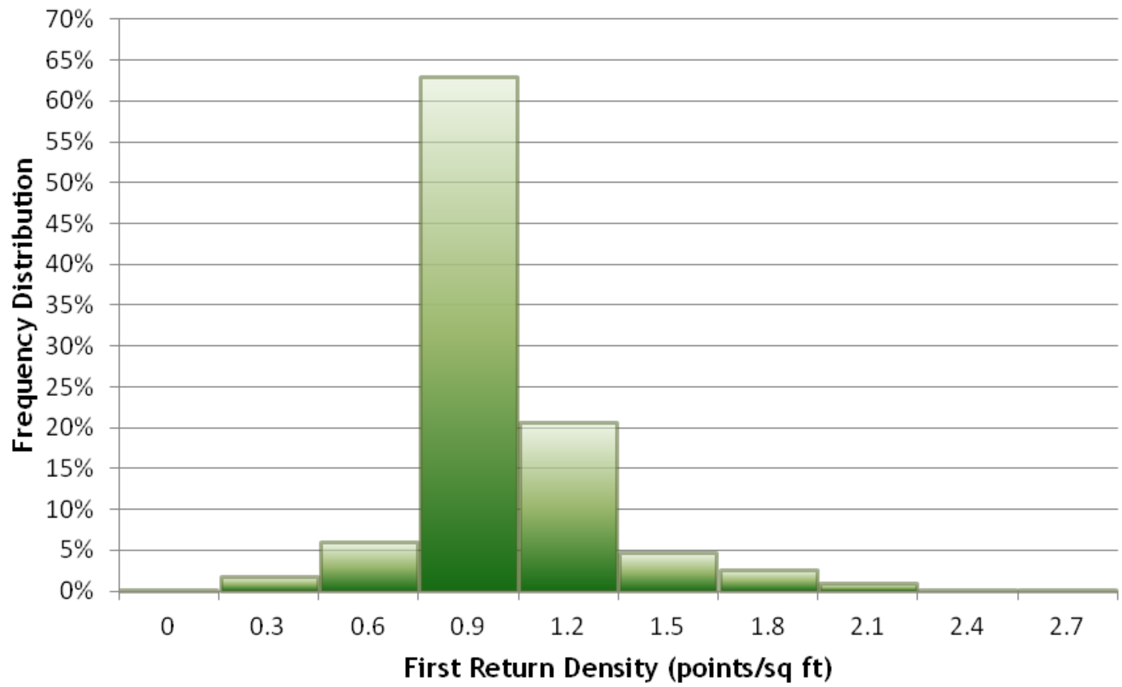


Figure 4. Cumulative density distribution for ground classified laser points

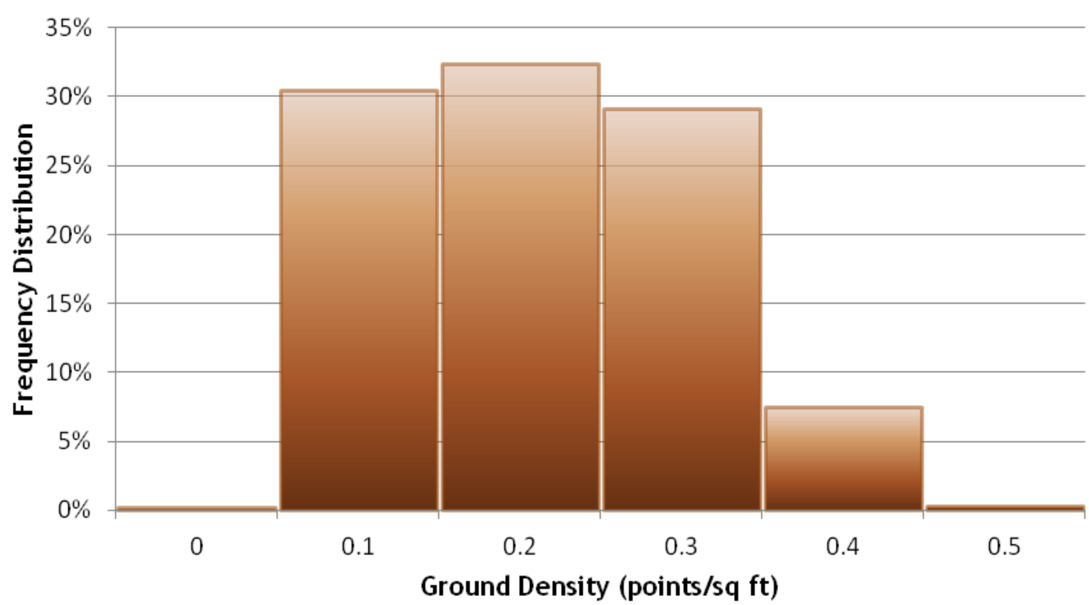


Figure 5. *Density distribution map for first return points by tile for Delivery 1.*

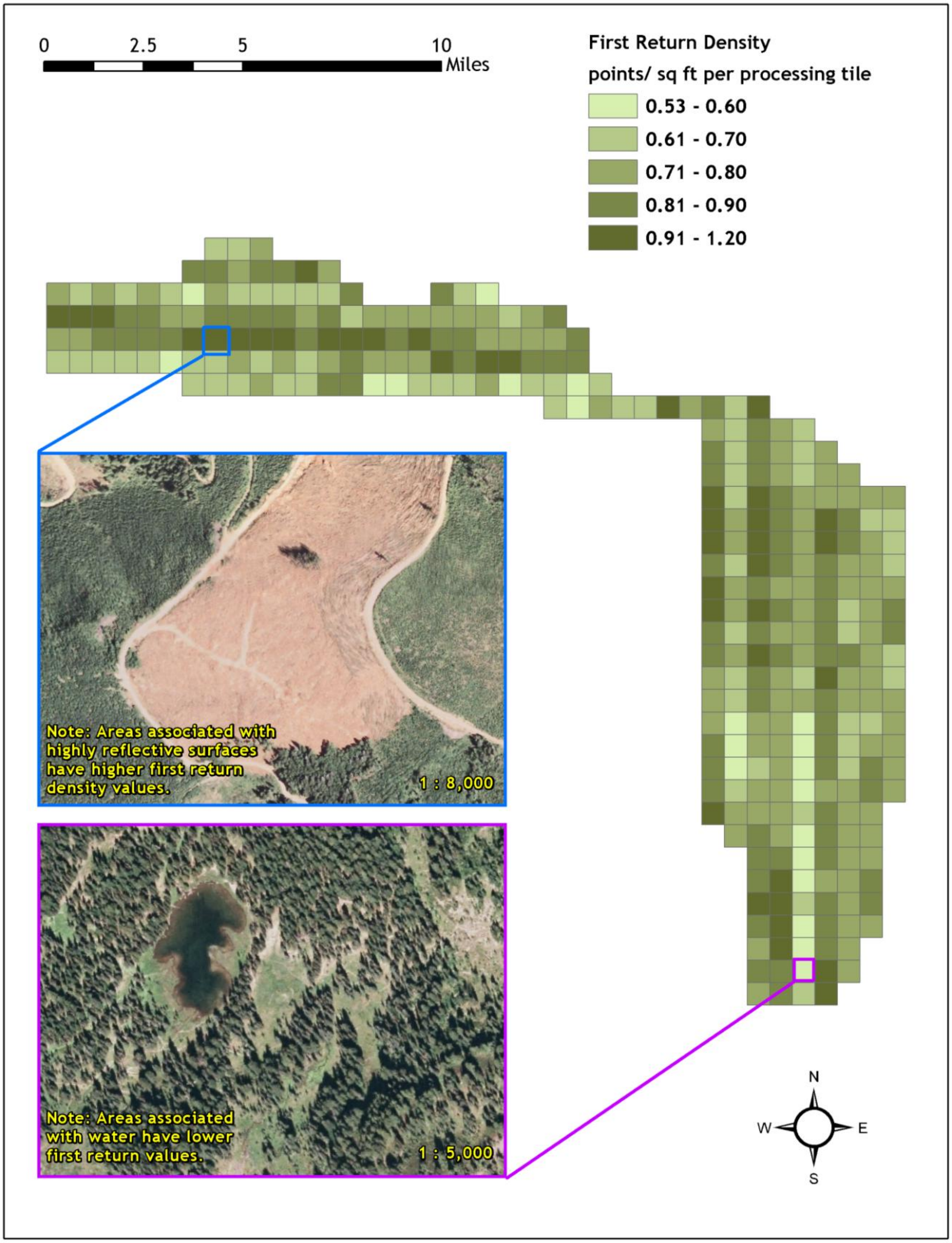


Figure 6. *Density distribution map for ground classified points by tile for Delivery 1.*

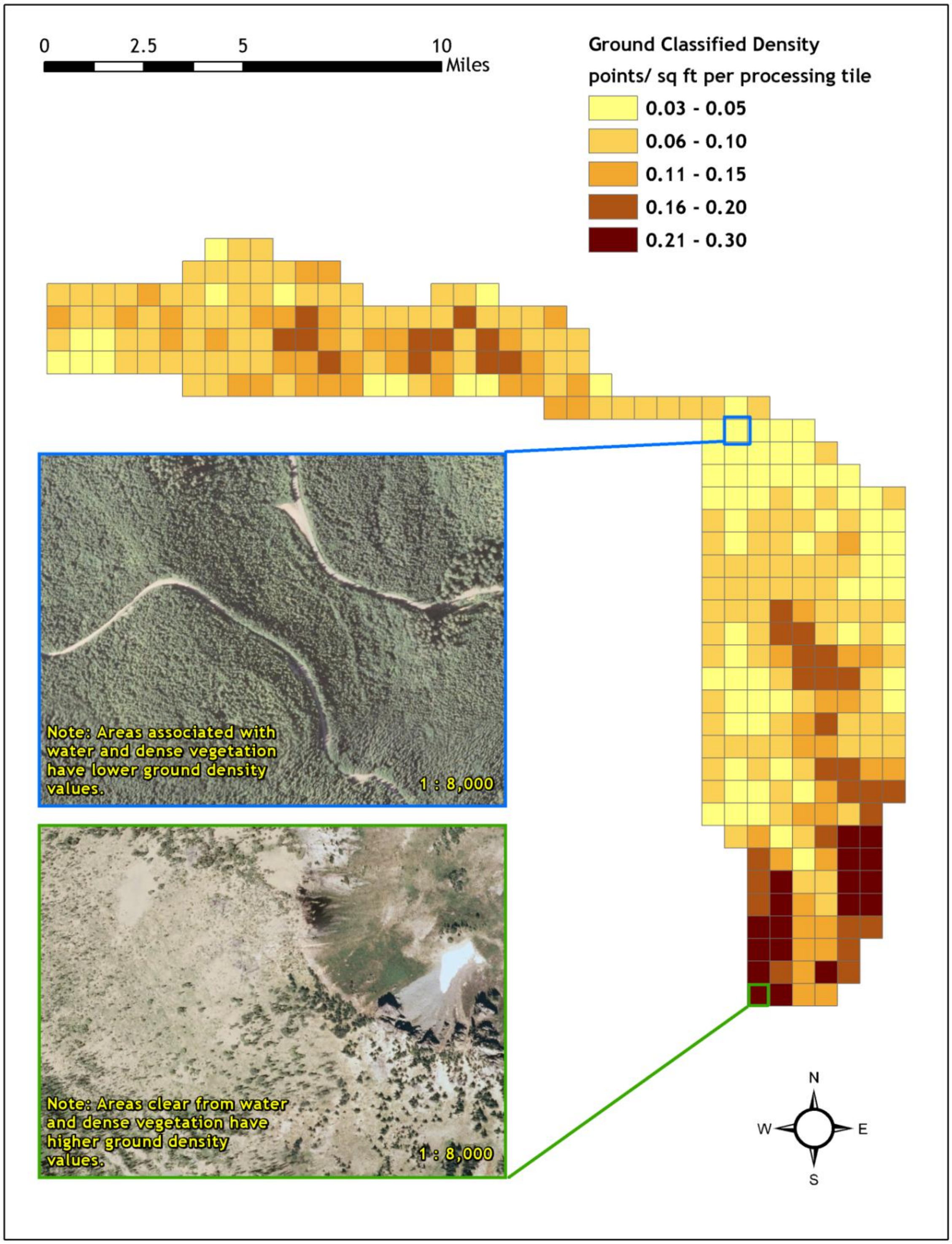


Figure 7. Density distribution map for first return points by tile for Delivery 2.

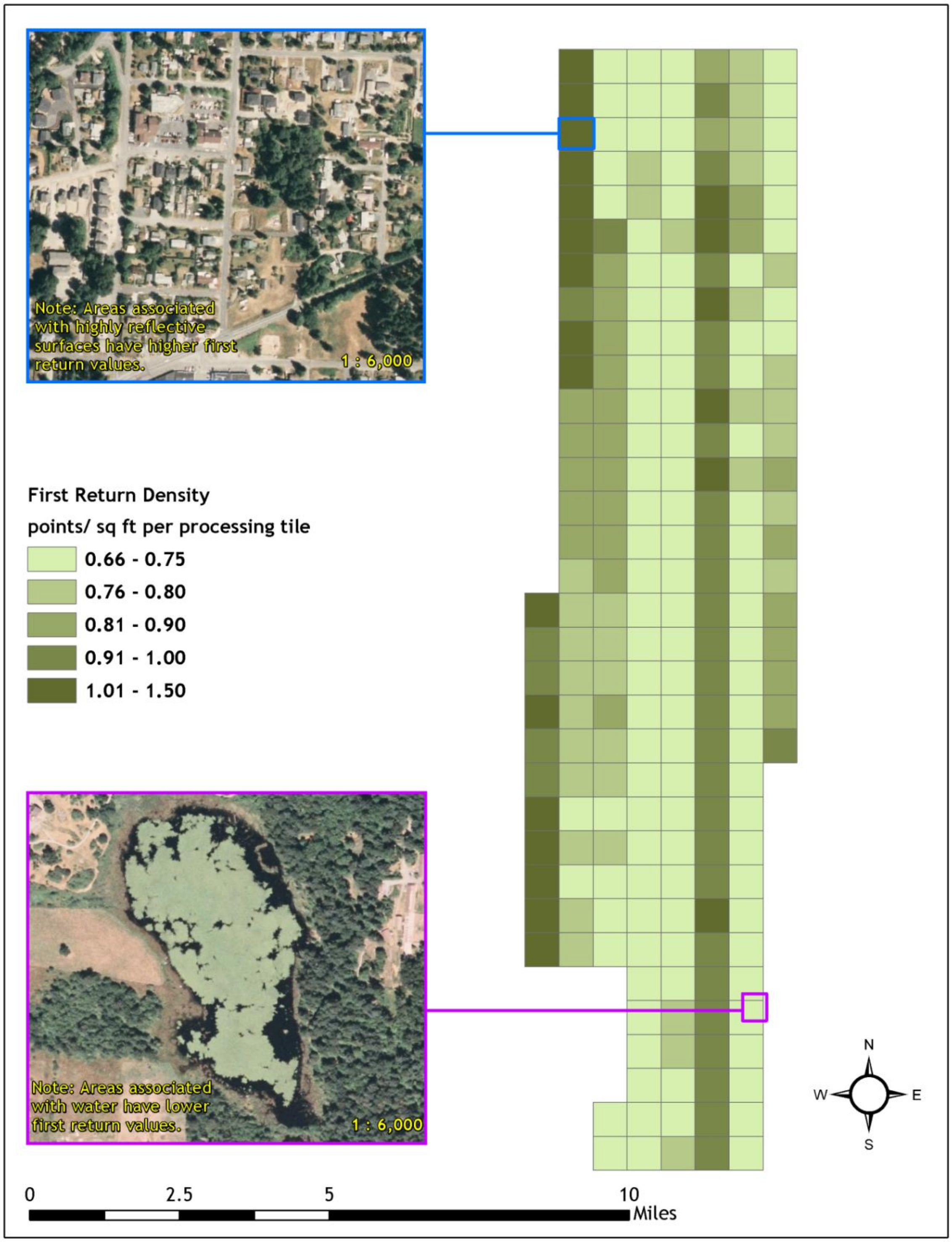


Figure 8. *Density distribution map for ground classified points by tile for Delivery 2.*

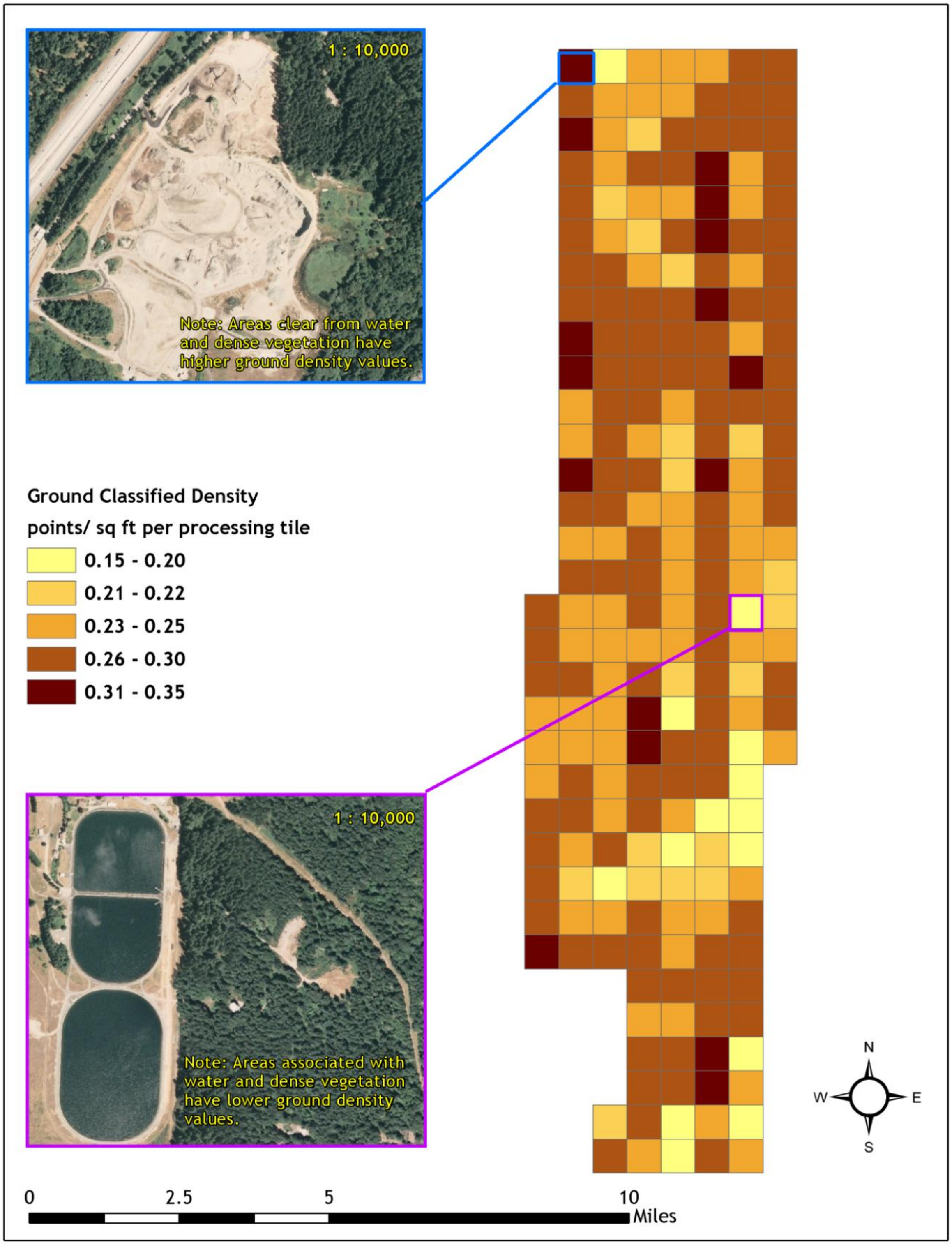


Figure 9. Density distribution map for first return points by tile for Delivery 3.

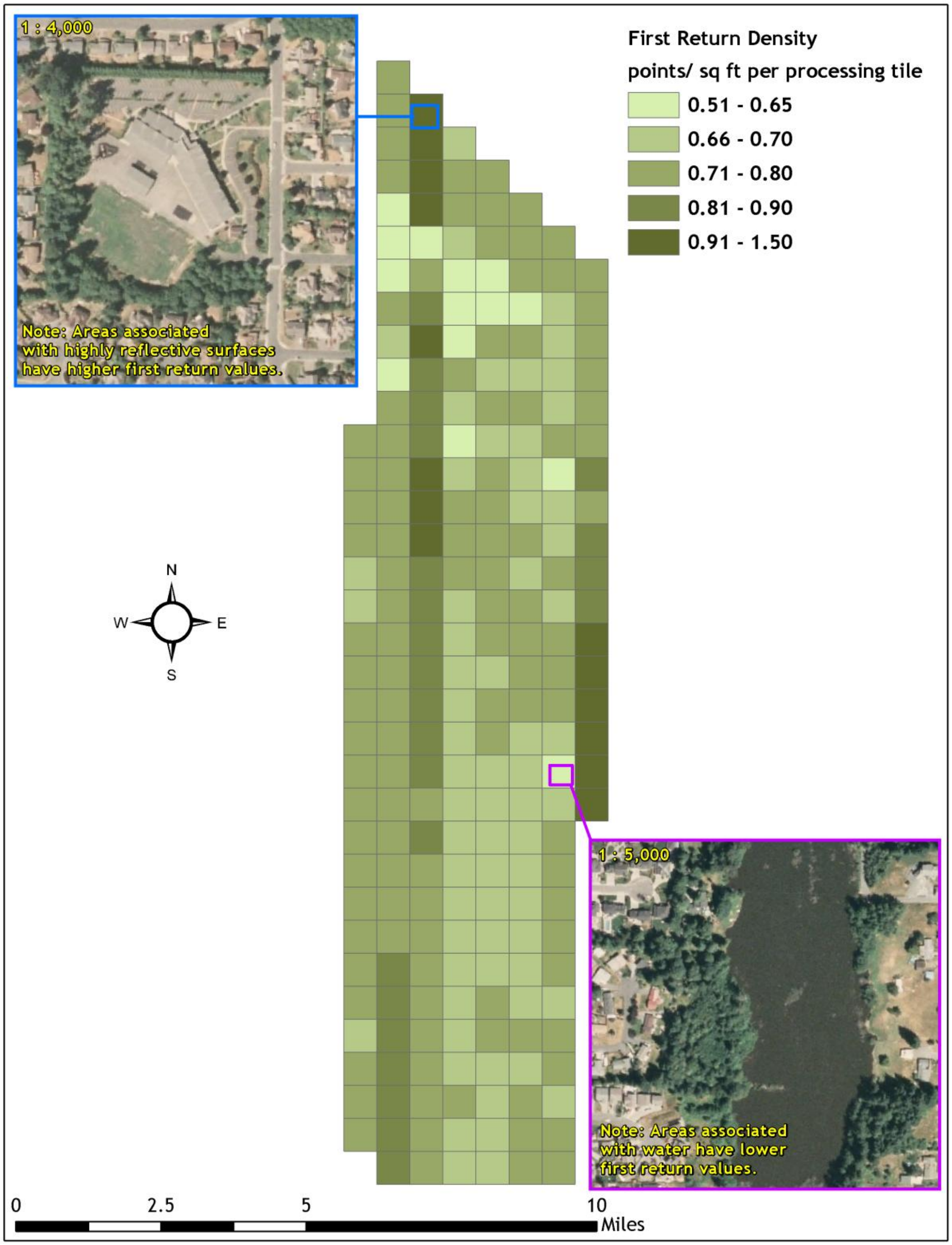


Figure 10. *Density distribution map for ground classified points by tile for Delivery 3.*

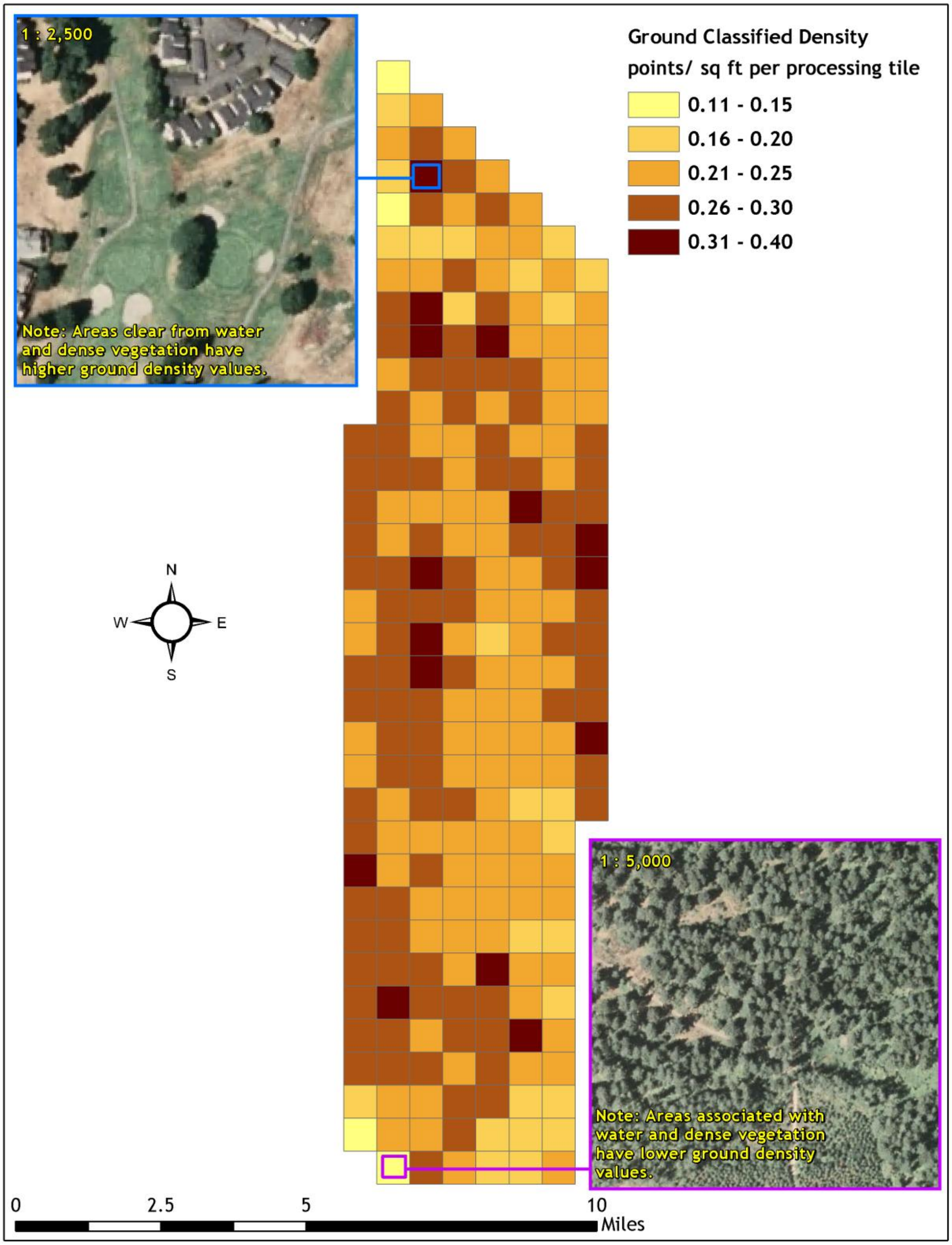


Figure 11. *Density distribution map for first return points by tile for Delivery 4.*

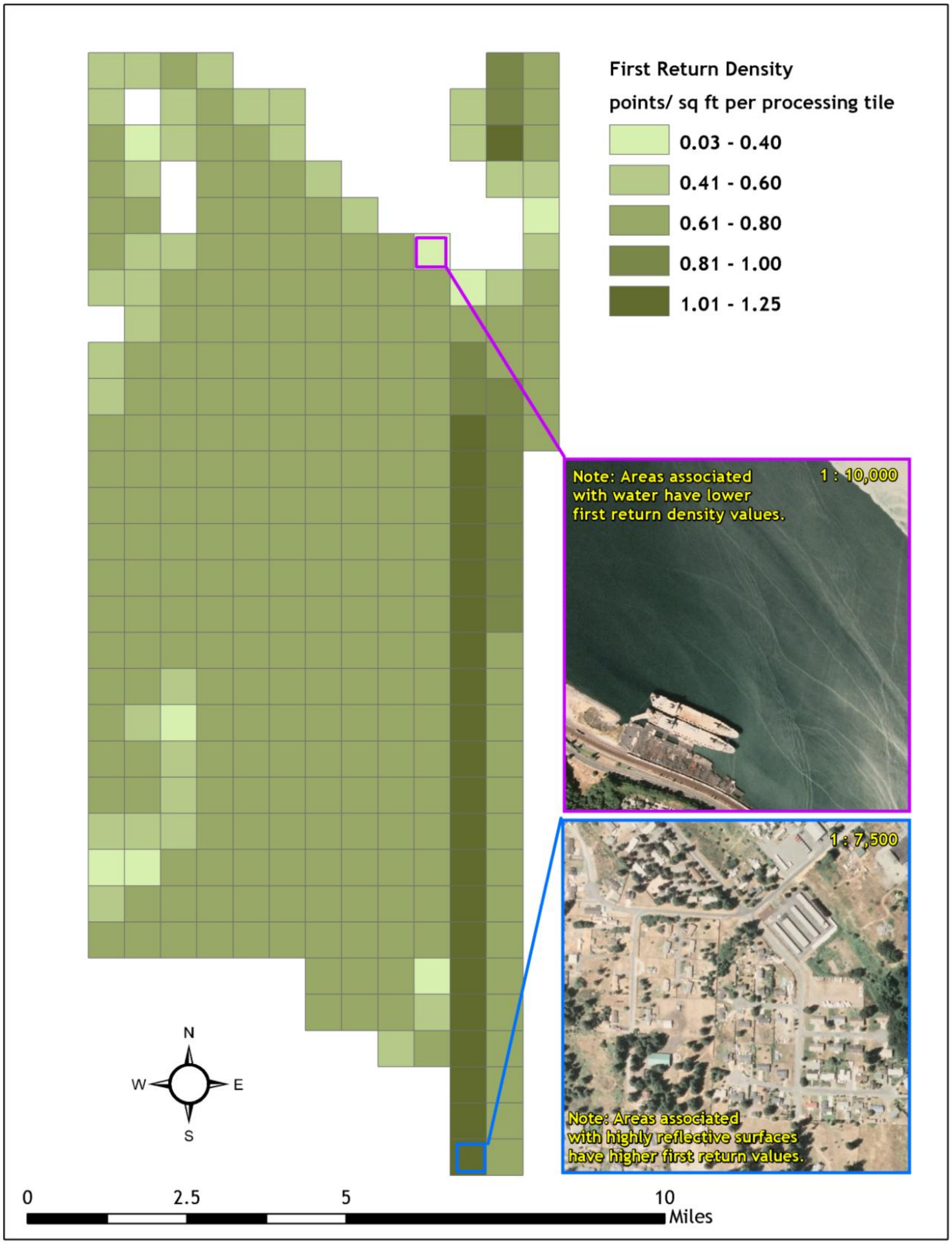


***Figure 12**. Density distribution map for ground classified points by tile for Delivery 4.*

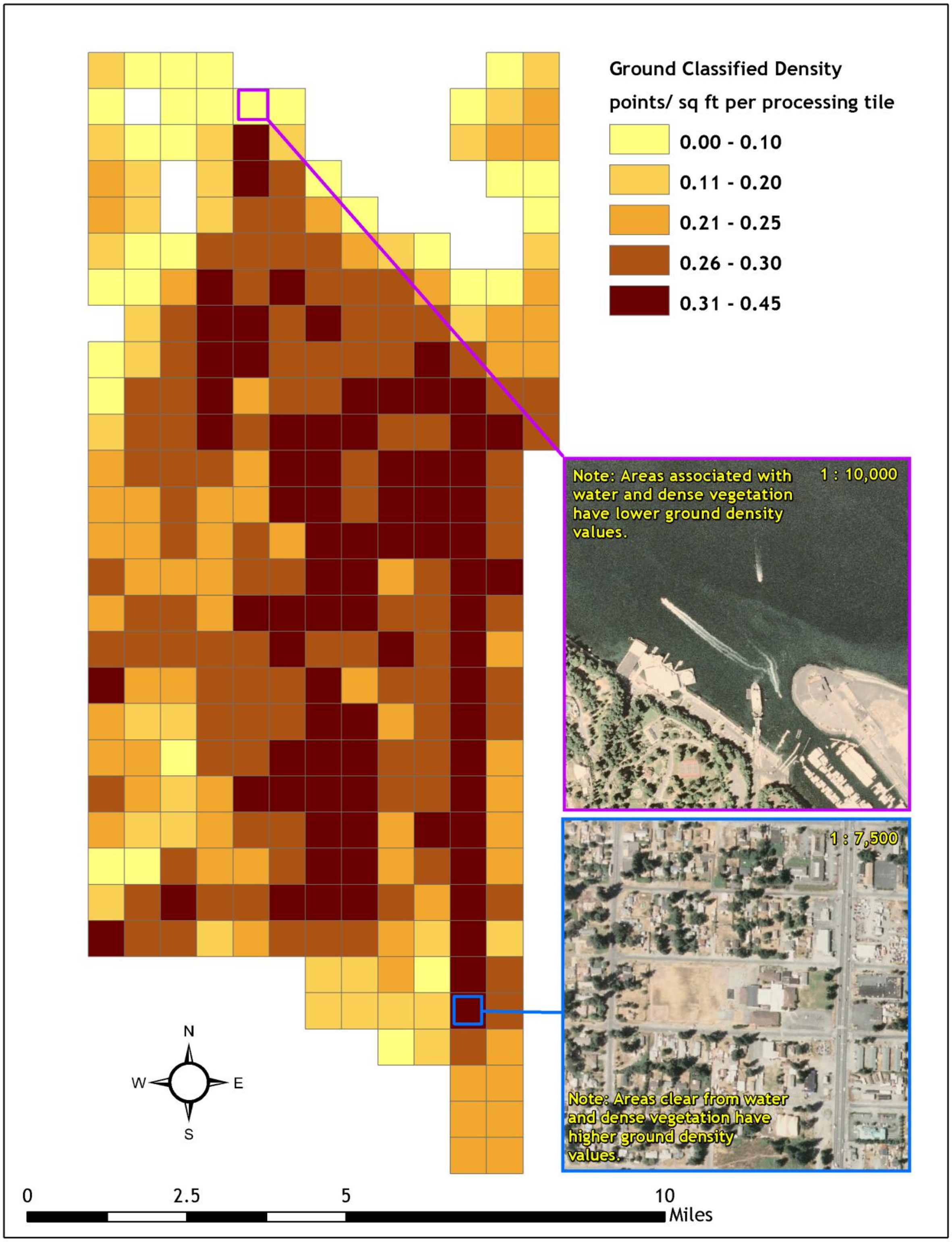


Figure 13. *Density distribution map for first return points by tile for Delivery 5.*

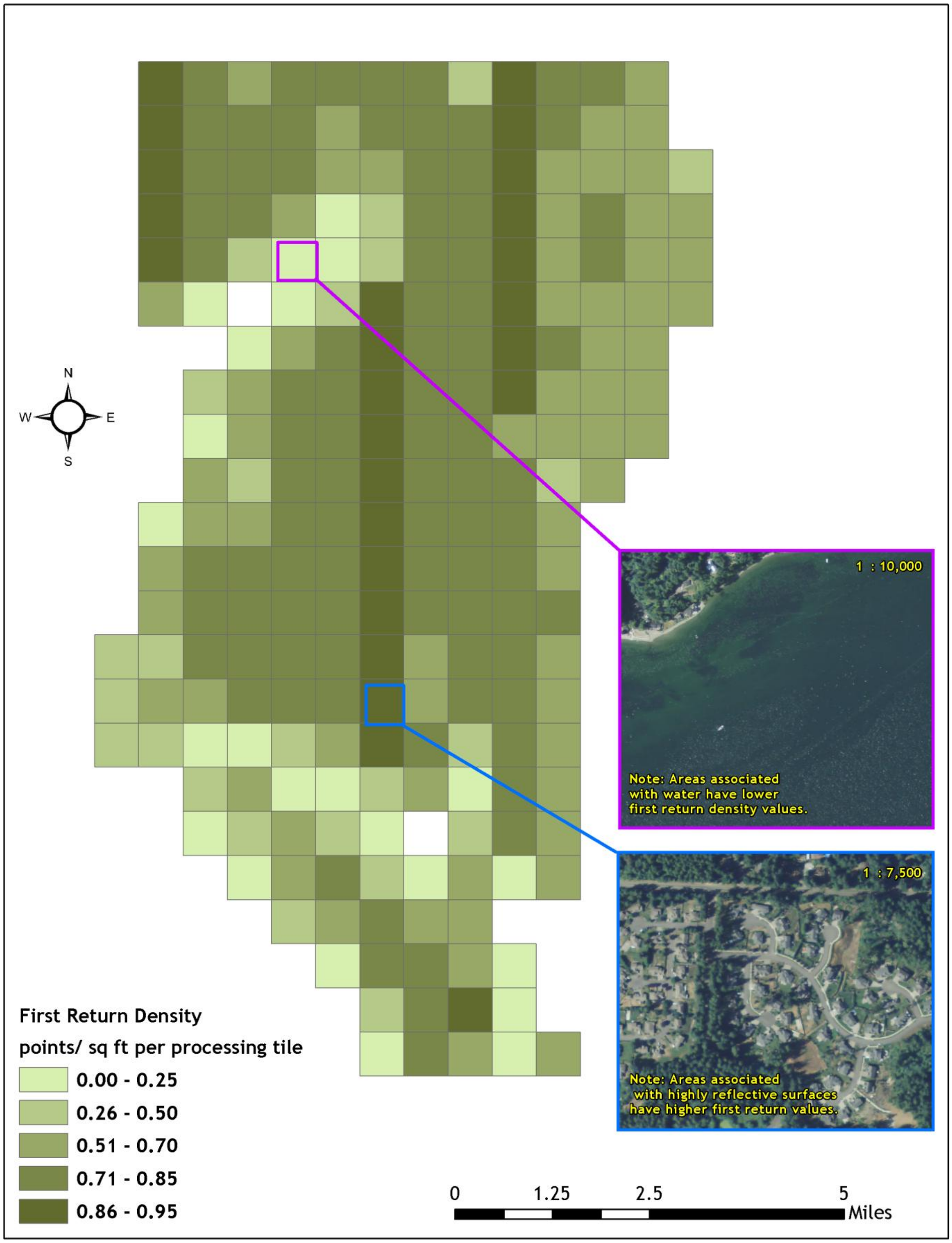


Figure 14. *Density distribution map for ground classified points by tile for Delivery 5.*

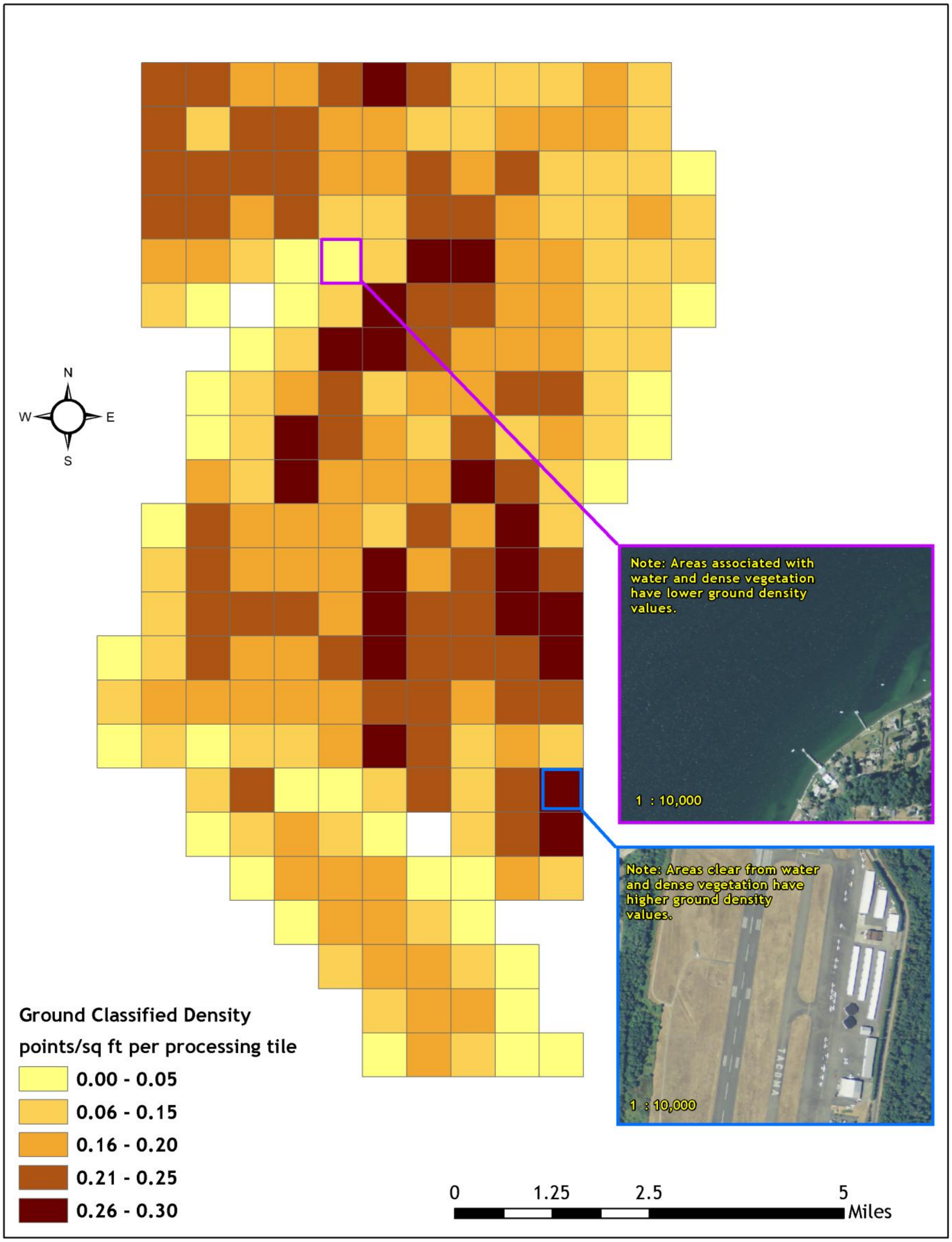


Figure 15. *Density distribution map for first return points by tile for Delivery 6.*

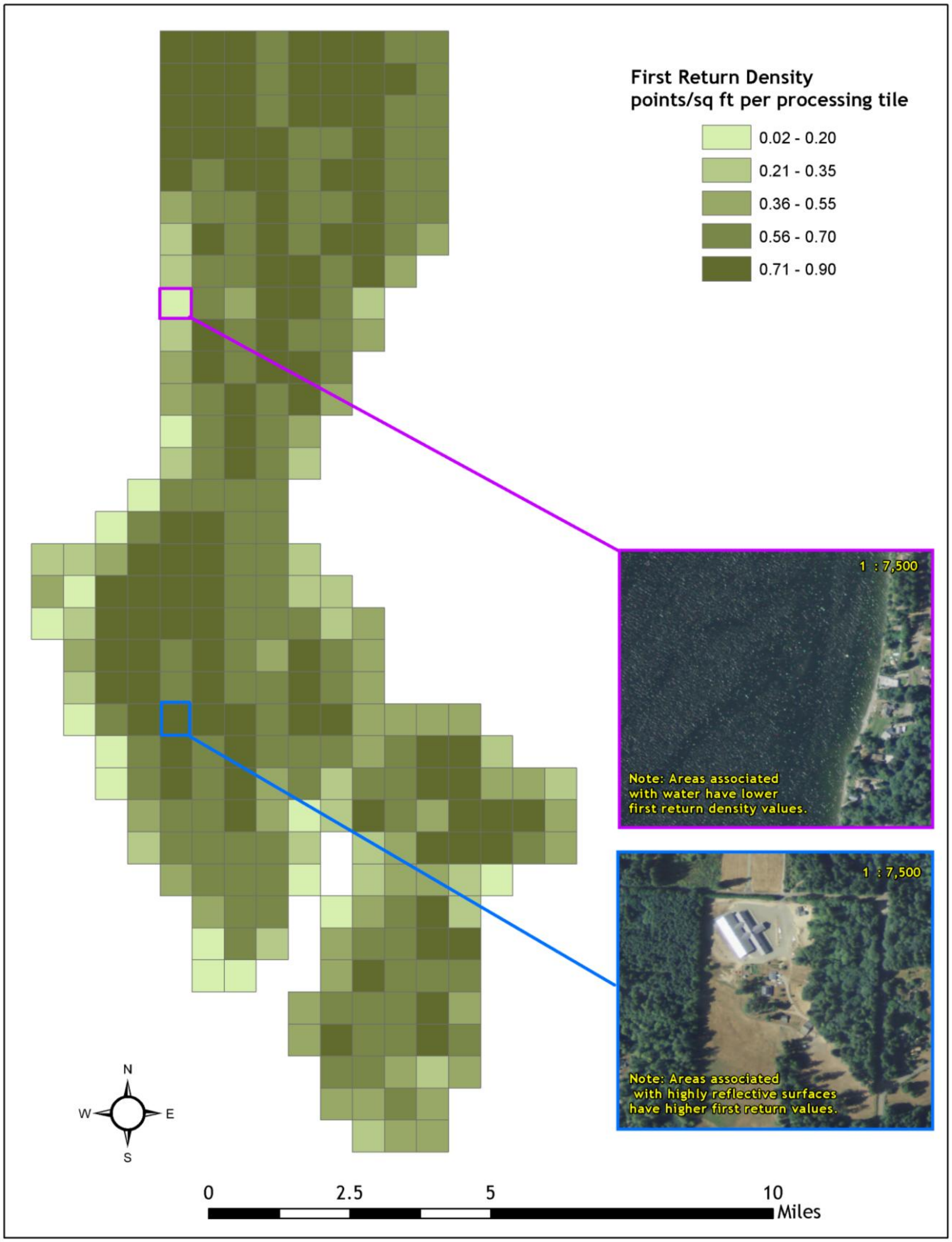


Figure 16. *Density distribution map for ground classified points by tile for Delivery 6.*

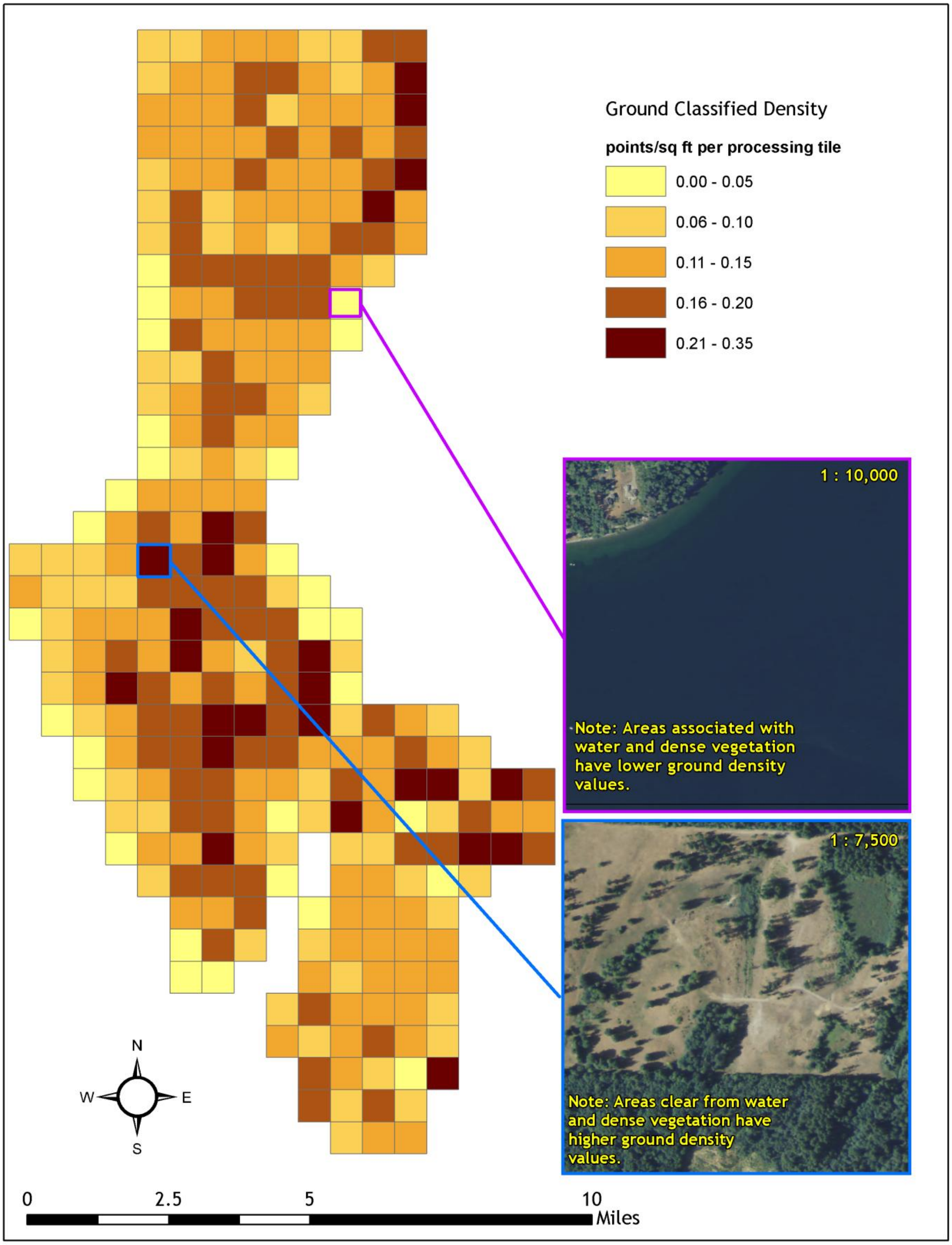


***Figure 17**. Density distribution map for first return points by tile for Delivery 7.*

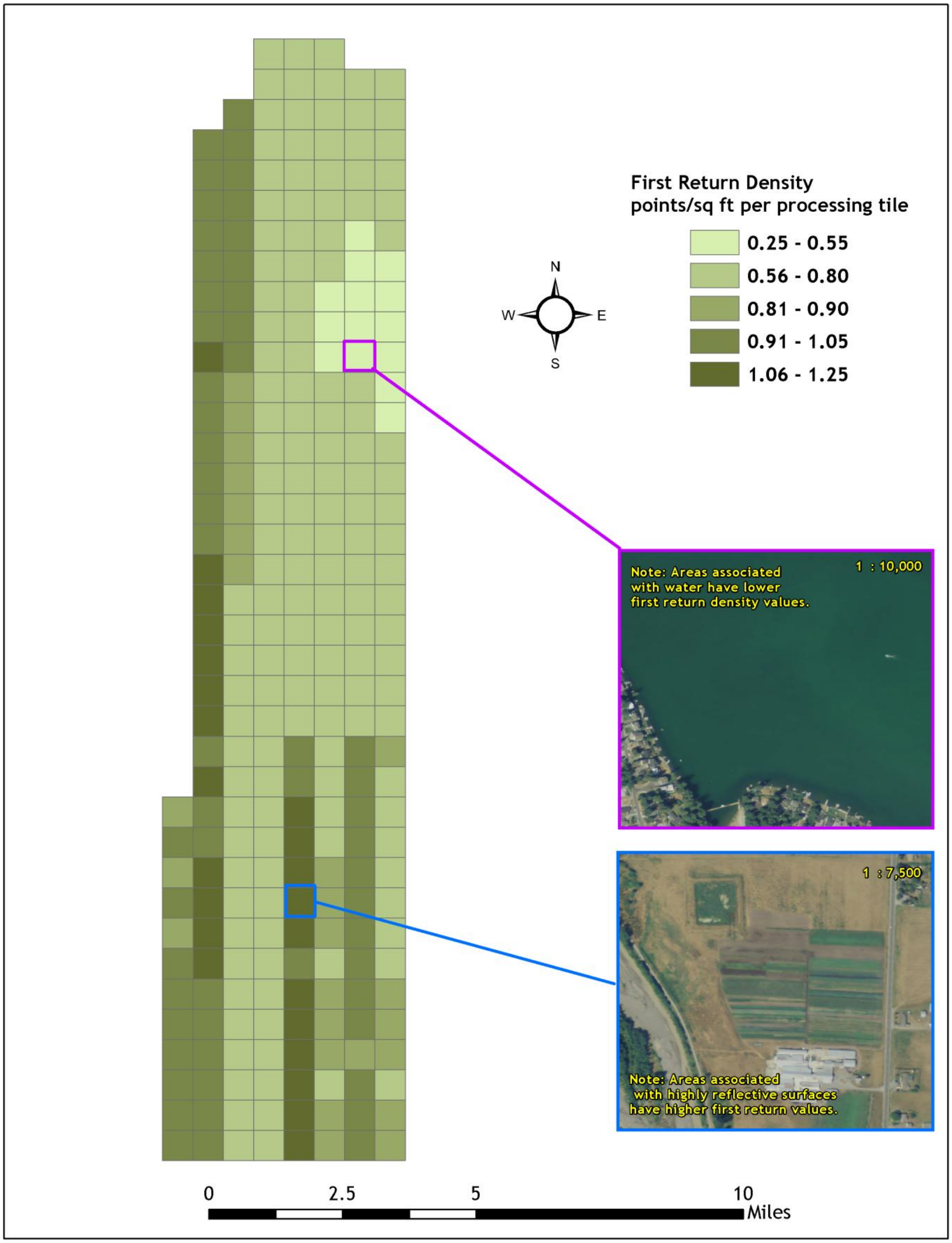


Figure 18. *Density distribution map for ground classified points by tile for Delivery 7.*

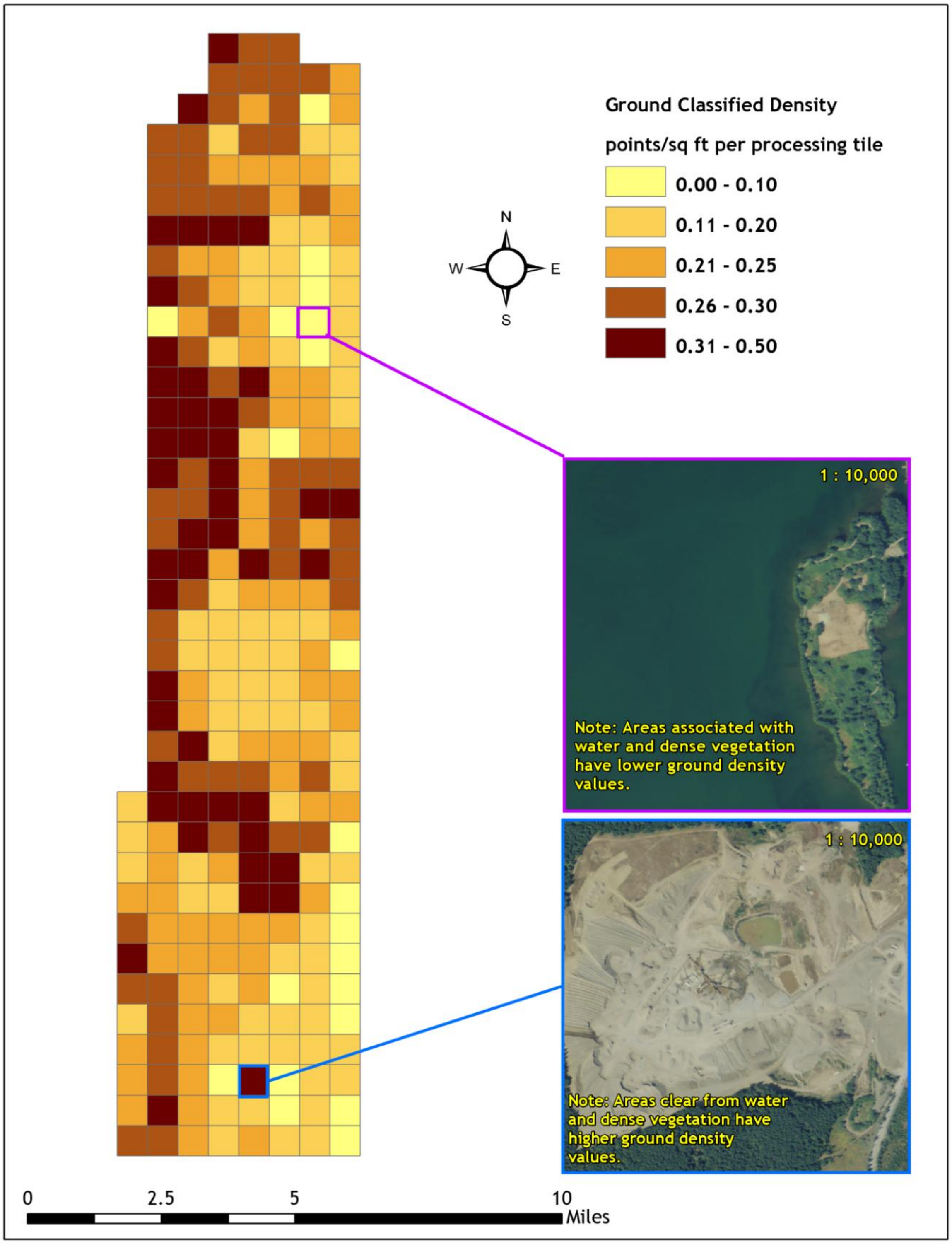


Figure 19. Density distribution map for first return points by tile for Delivery 8.

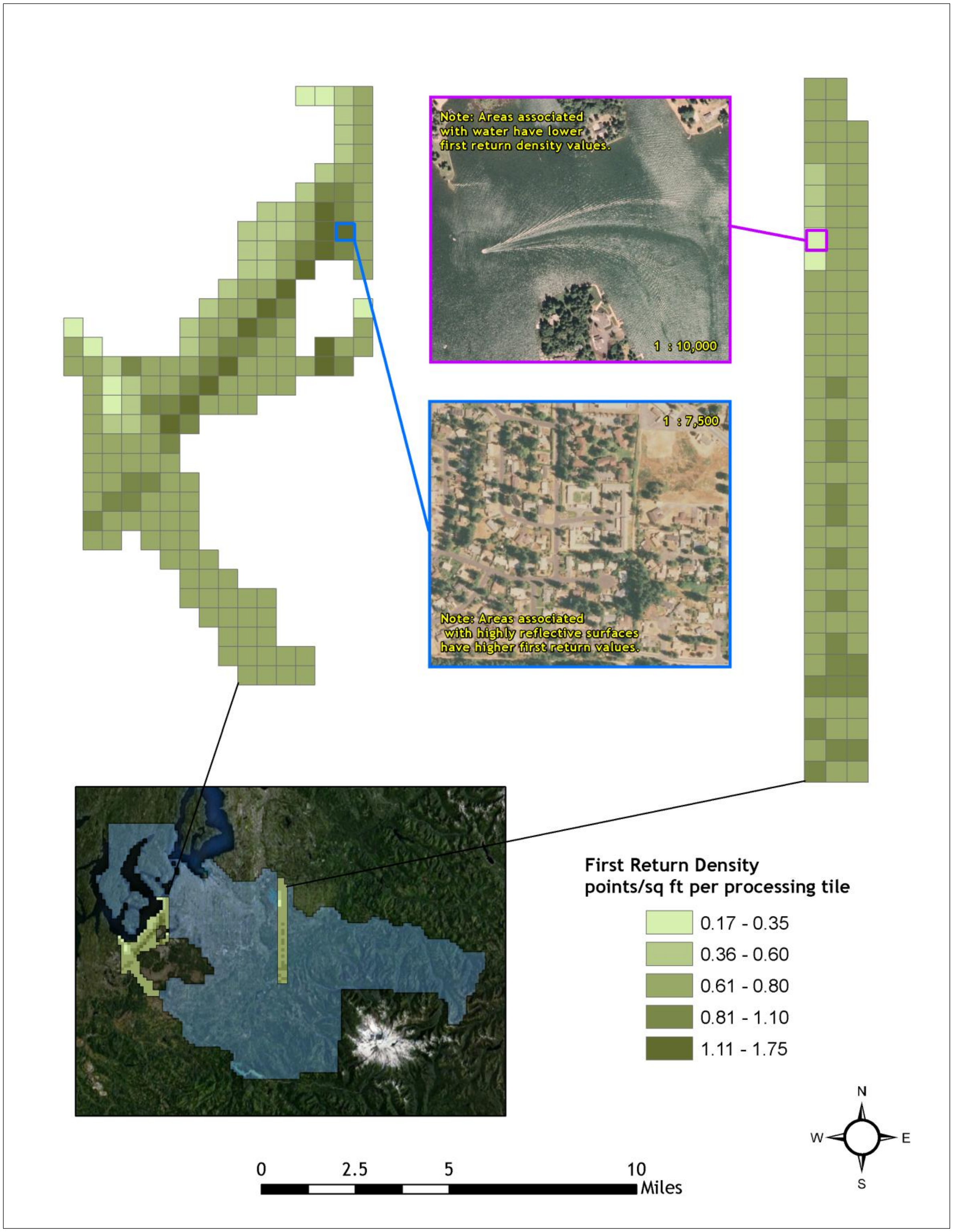


Figure 20. *Density distribution map for ground classified points by tile for Delivery 8.*

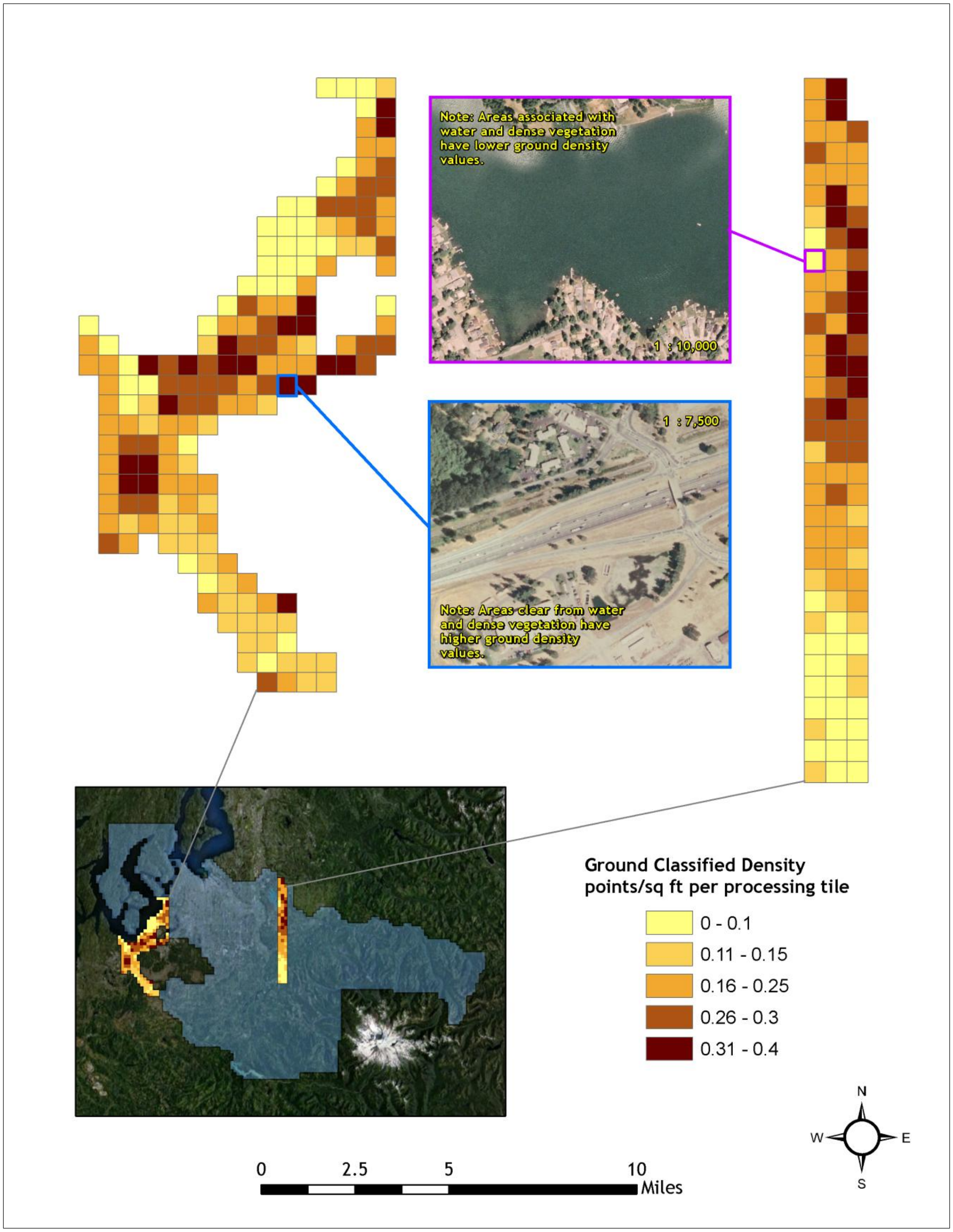


***Figure 21**. Density distribution map for first return points by tile for Delivery 9.*

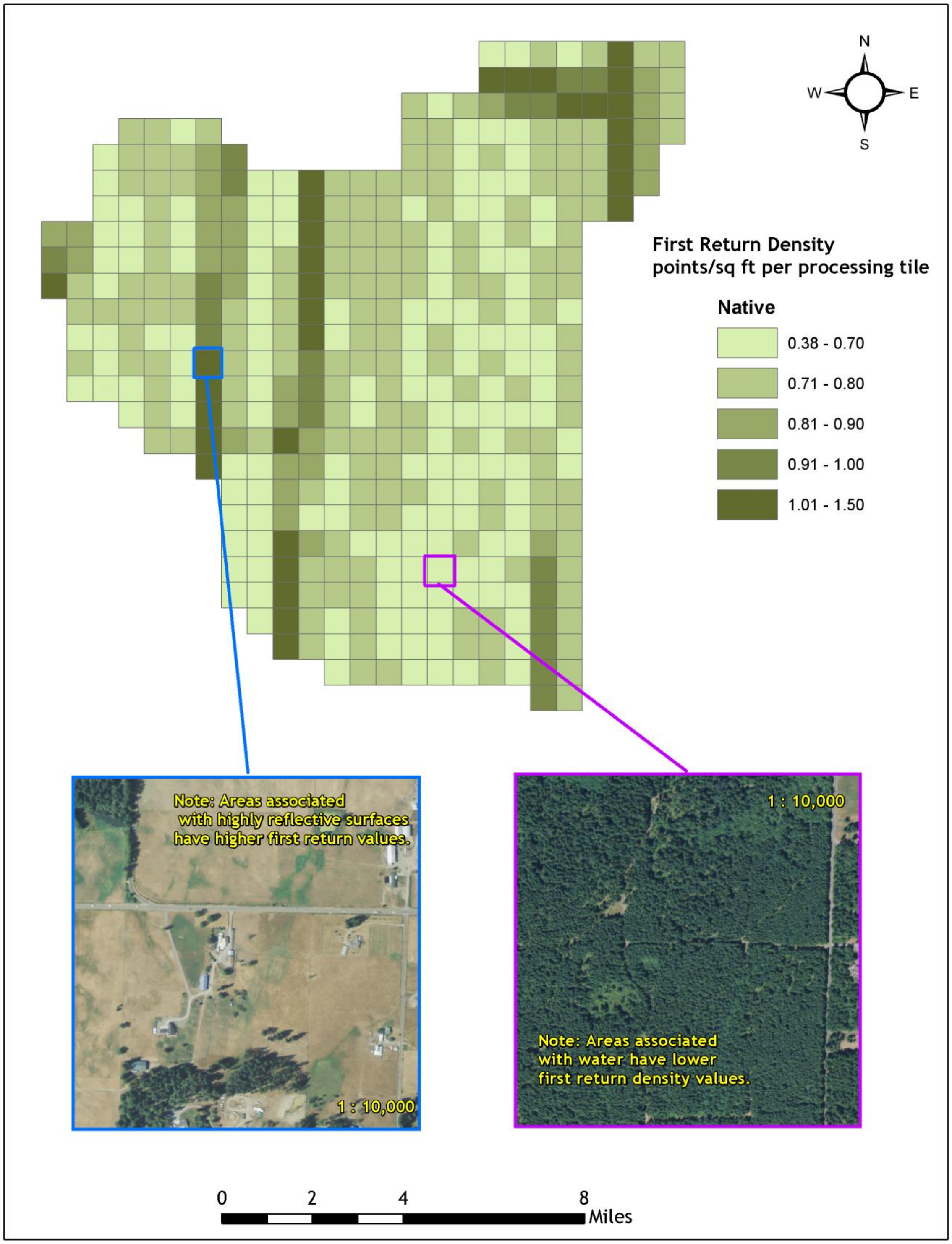


Figure 22. Density distribution map for ground classified points by tile for Delivery 9.

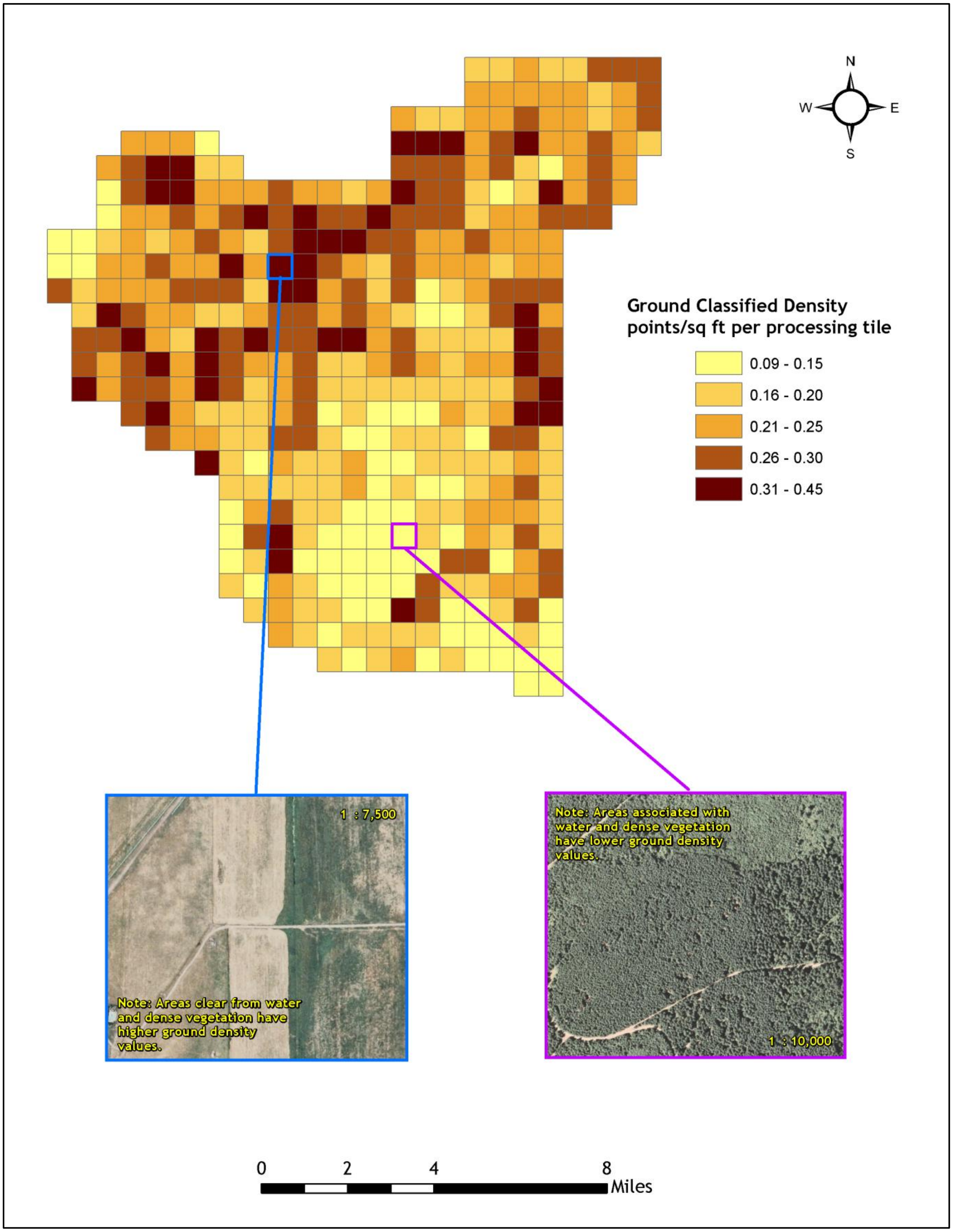


Figure 23. *Density distribution map for first return points by tile for Delivery 10.*

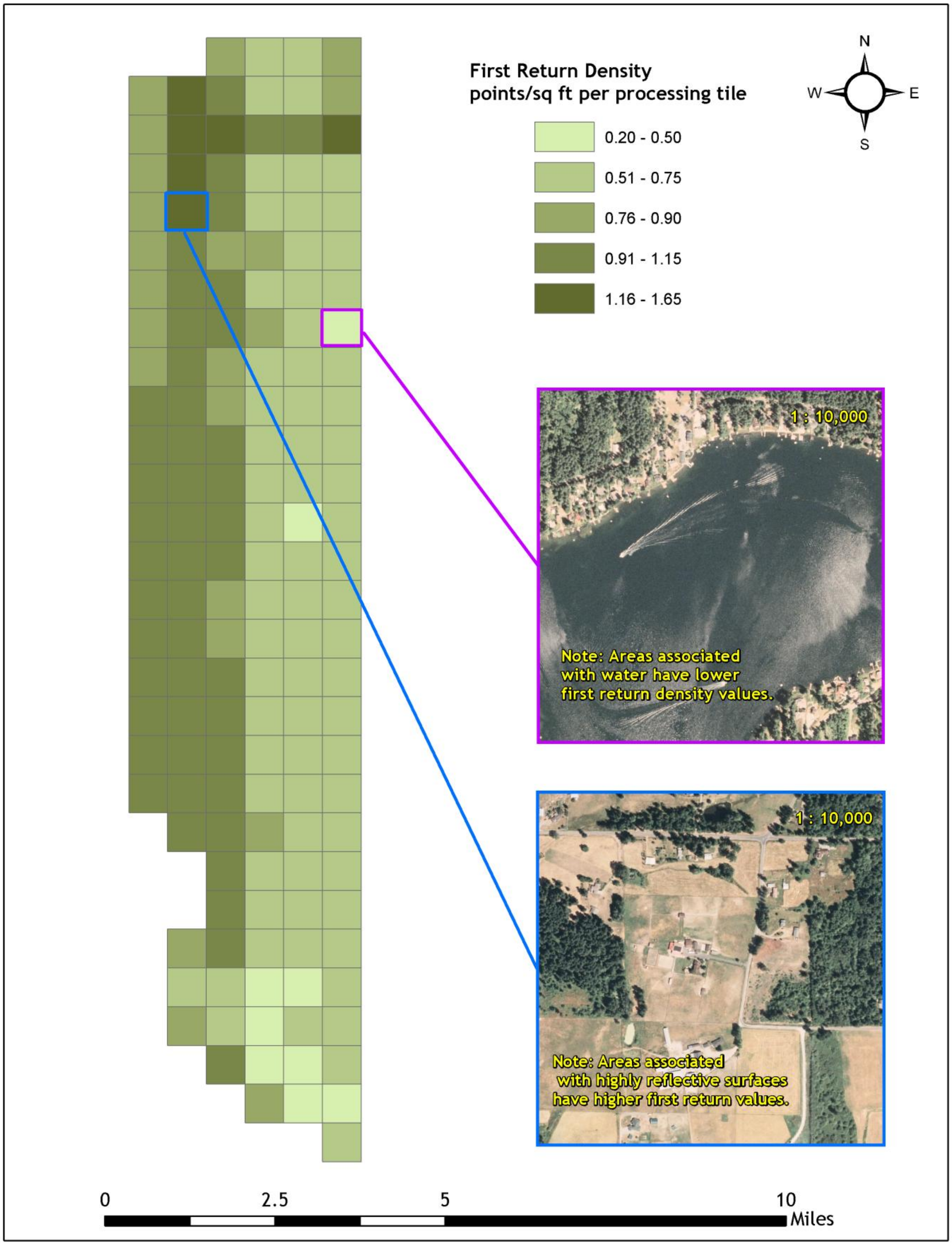


Figure 24. Density distribution map for ground classified points by tile for Delivery 10.

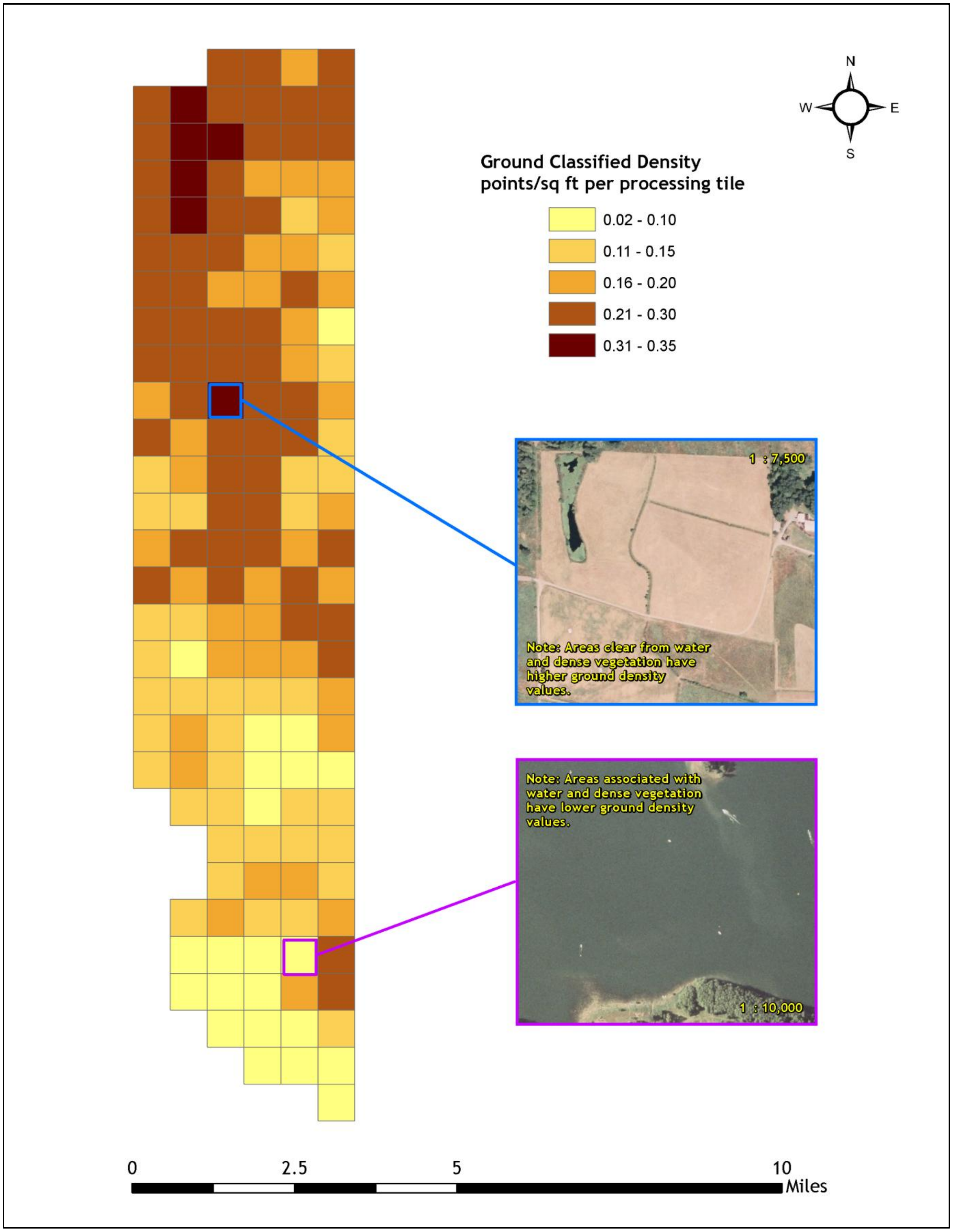


***Figure 25**. Density distribution map for first return points by tile for Delivery 11.*

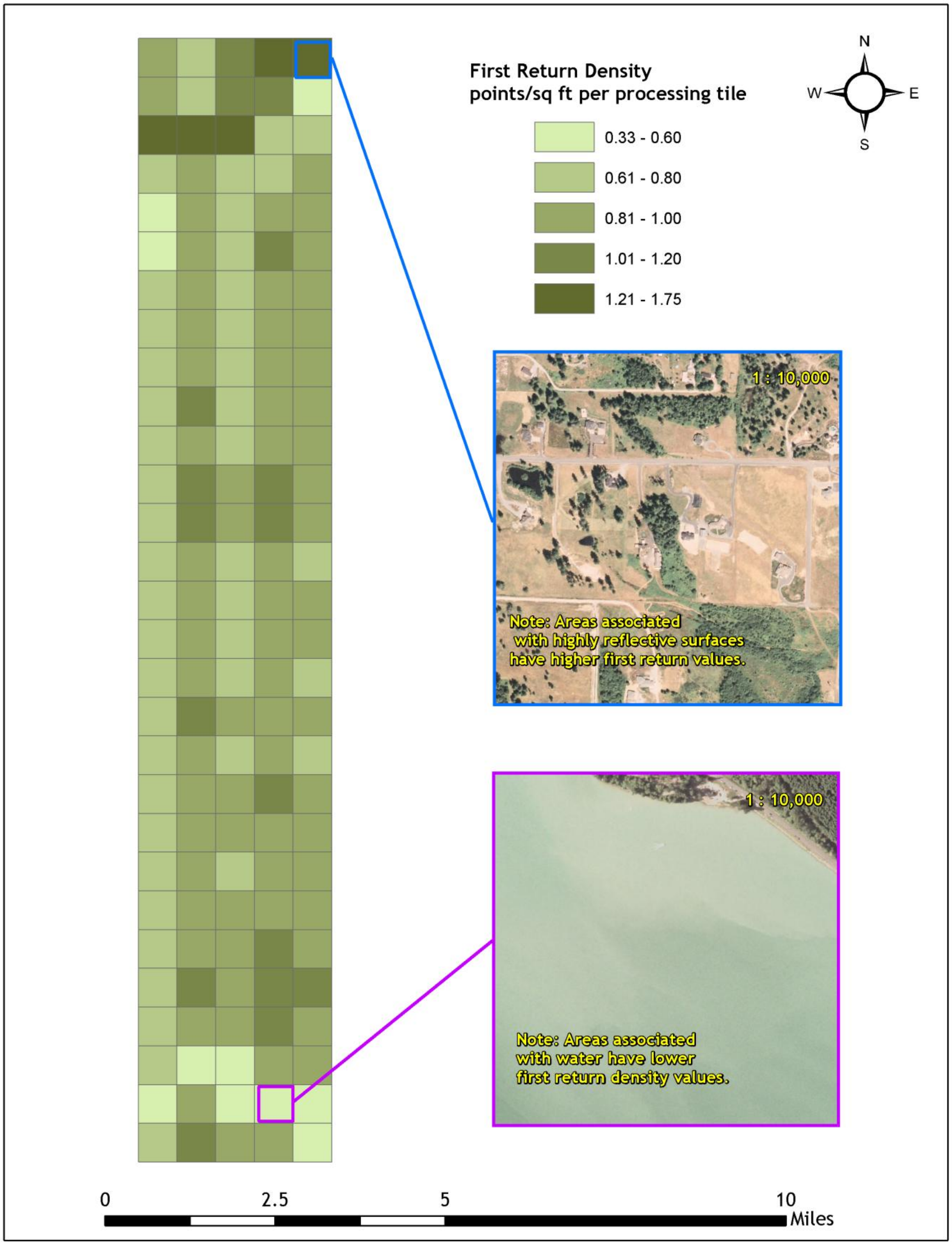


***Figure 26**. Density distribution map for ground classified points by tile for Delivery 11.*

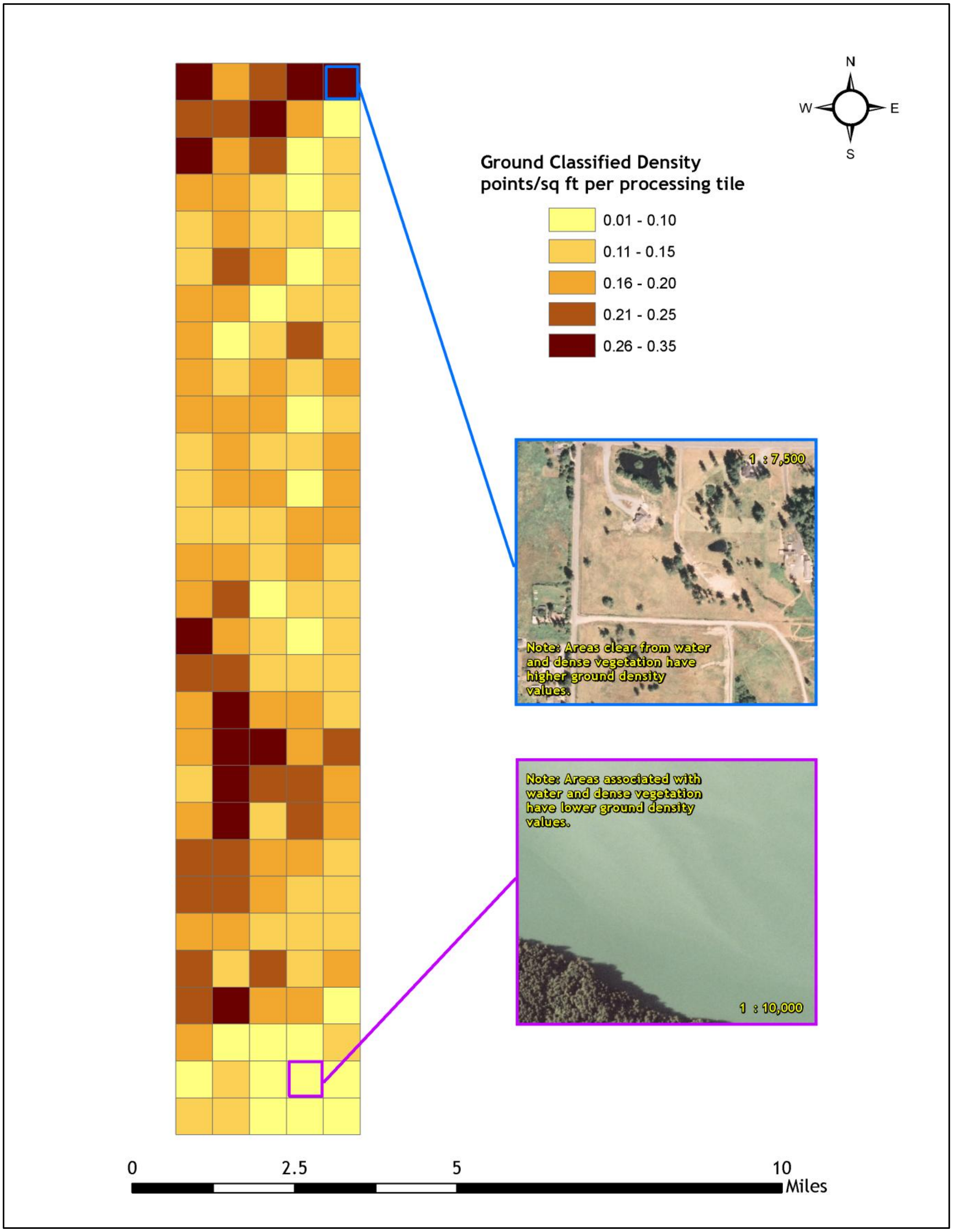


***Figure 27**. Density distribution map for first return points by tile for Delivery 12.*

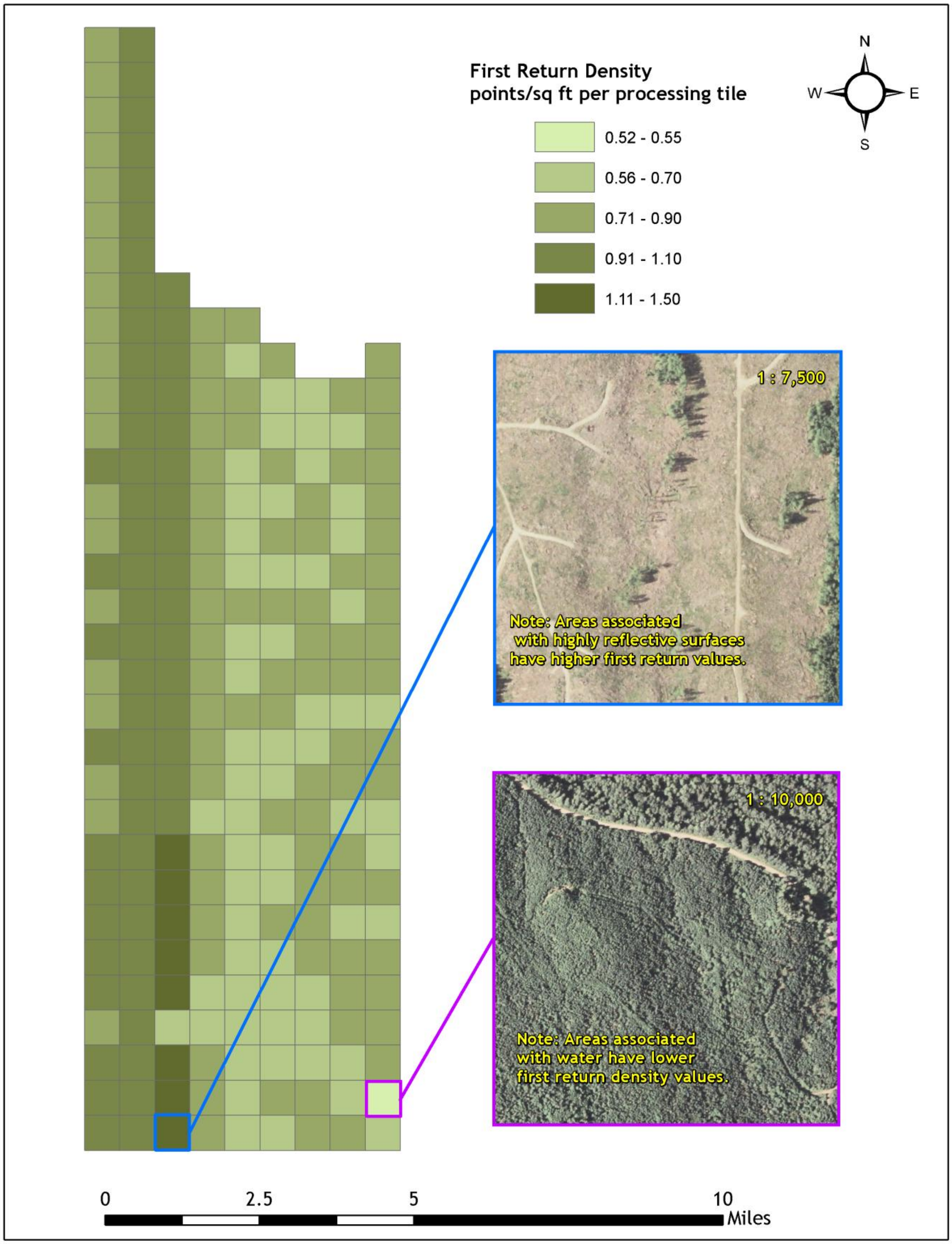


Figure 28. *Density distribution map for ground classified points by tile for Delivery 12.*

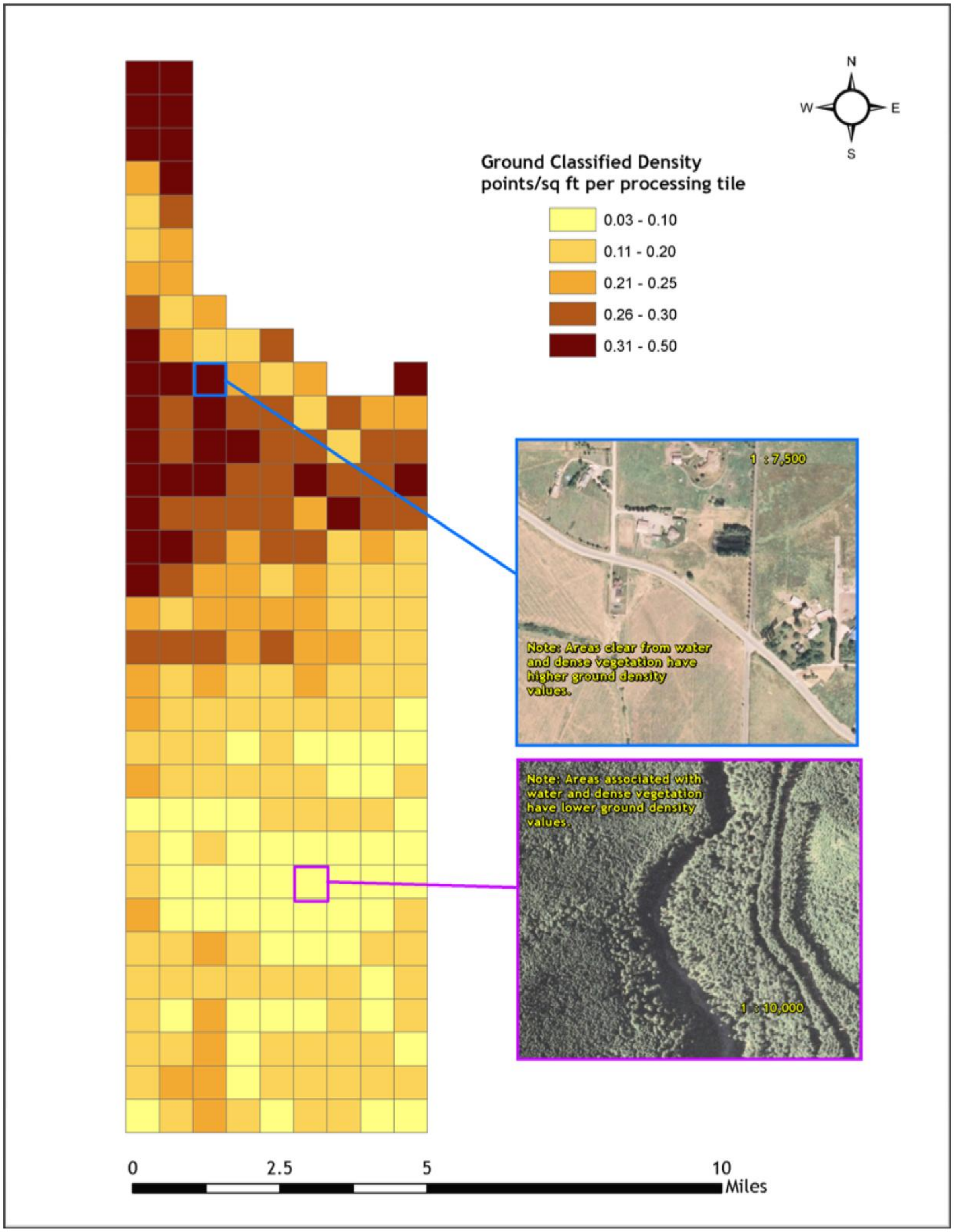


Figure 29. Density distribution map for first return points by tile for Delivery 13.

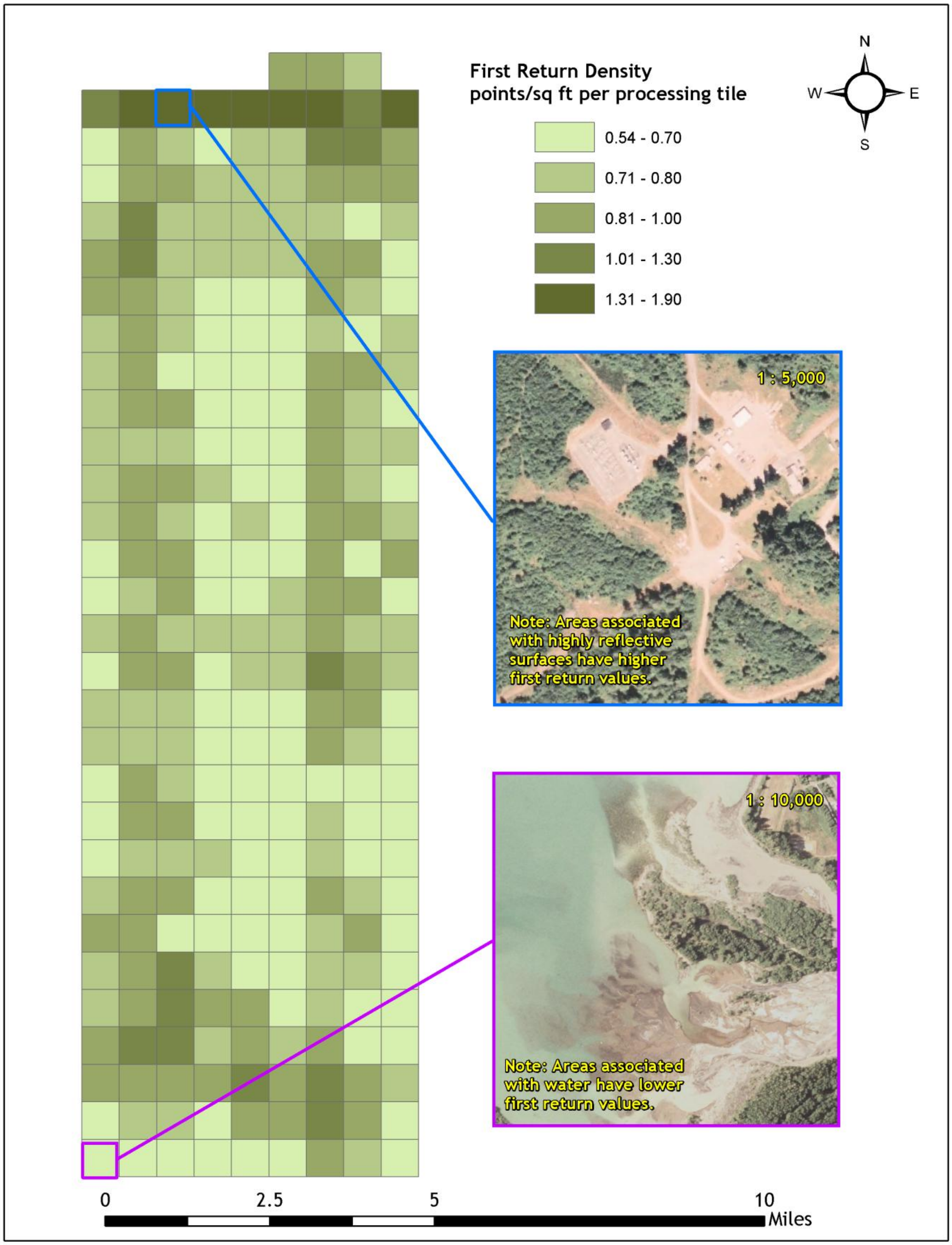


***Figure 30**. Density distribution map for ground classified points by tile for Delivery 13.*

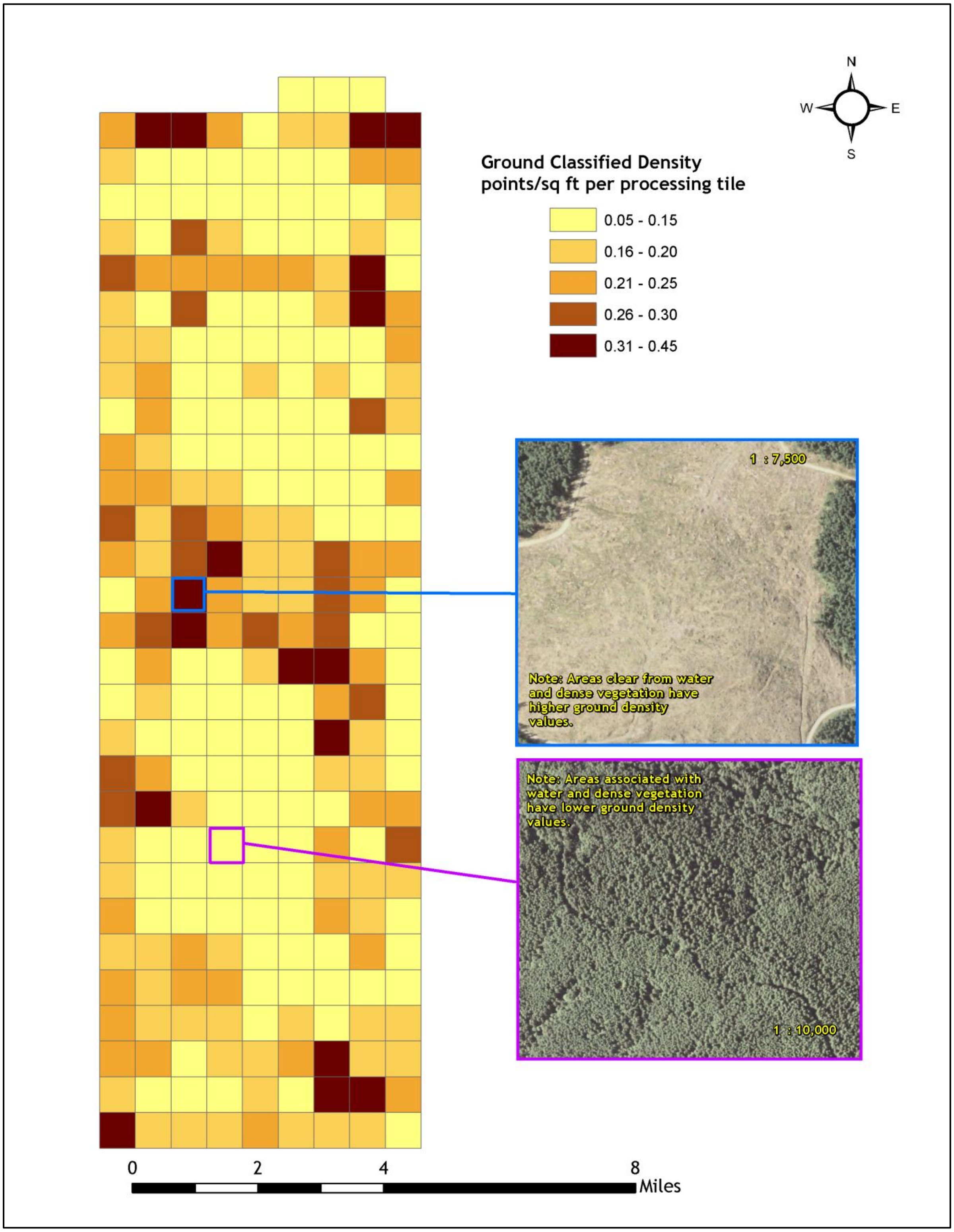


***Figure 31**. Density distribution map for first return points by tile for Delivery 14.*

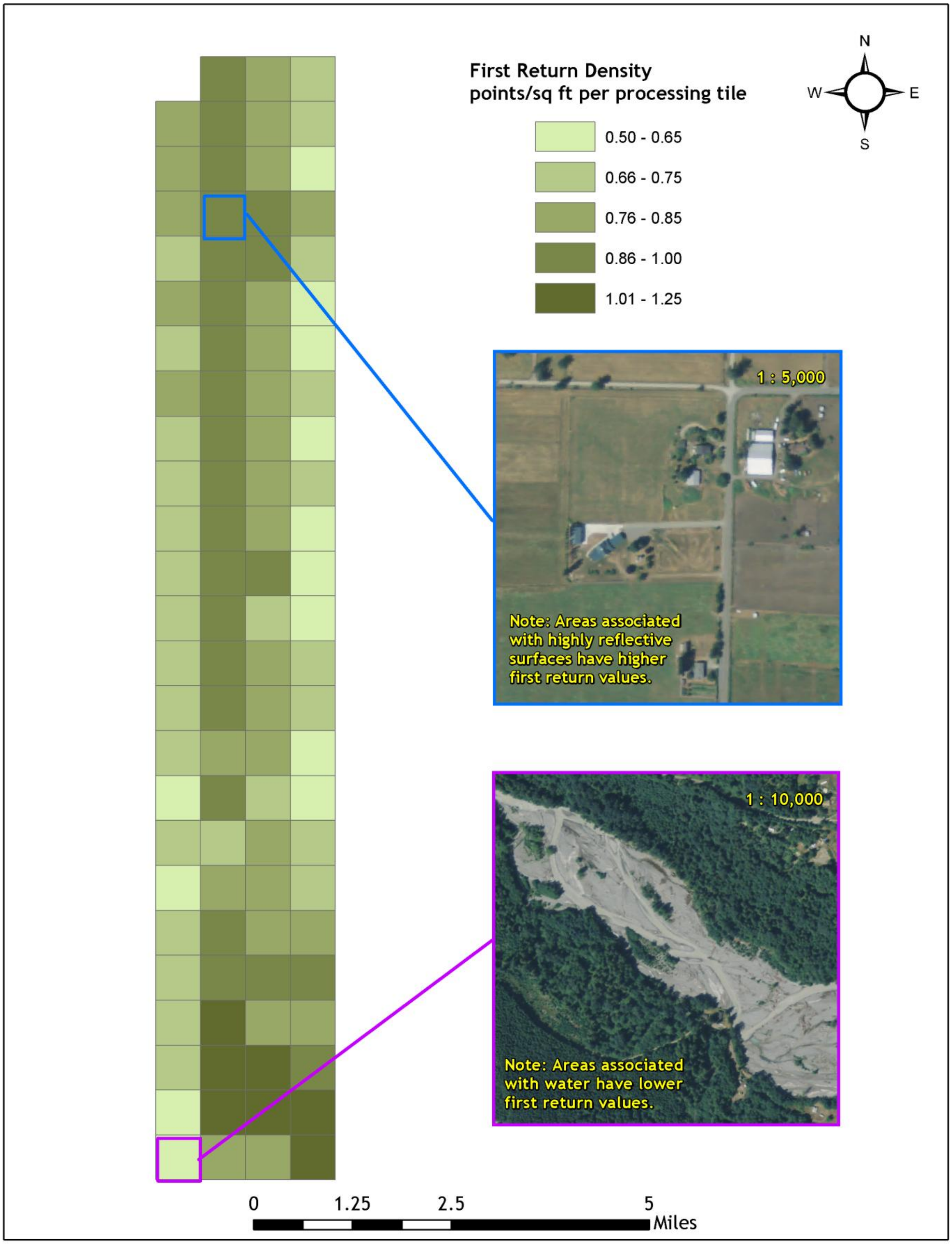


__Figure 32__. Density distribution map for ground classified points by tile for Delivery 14.

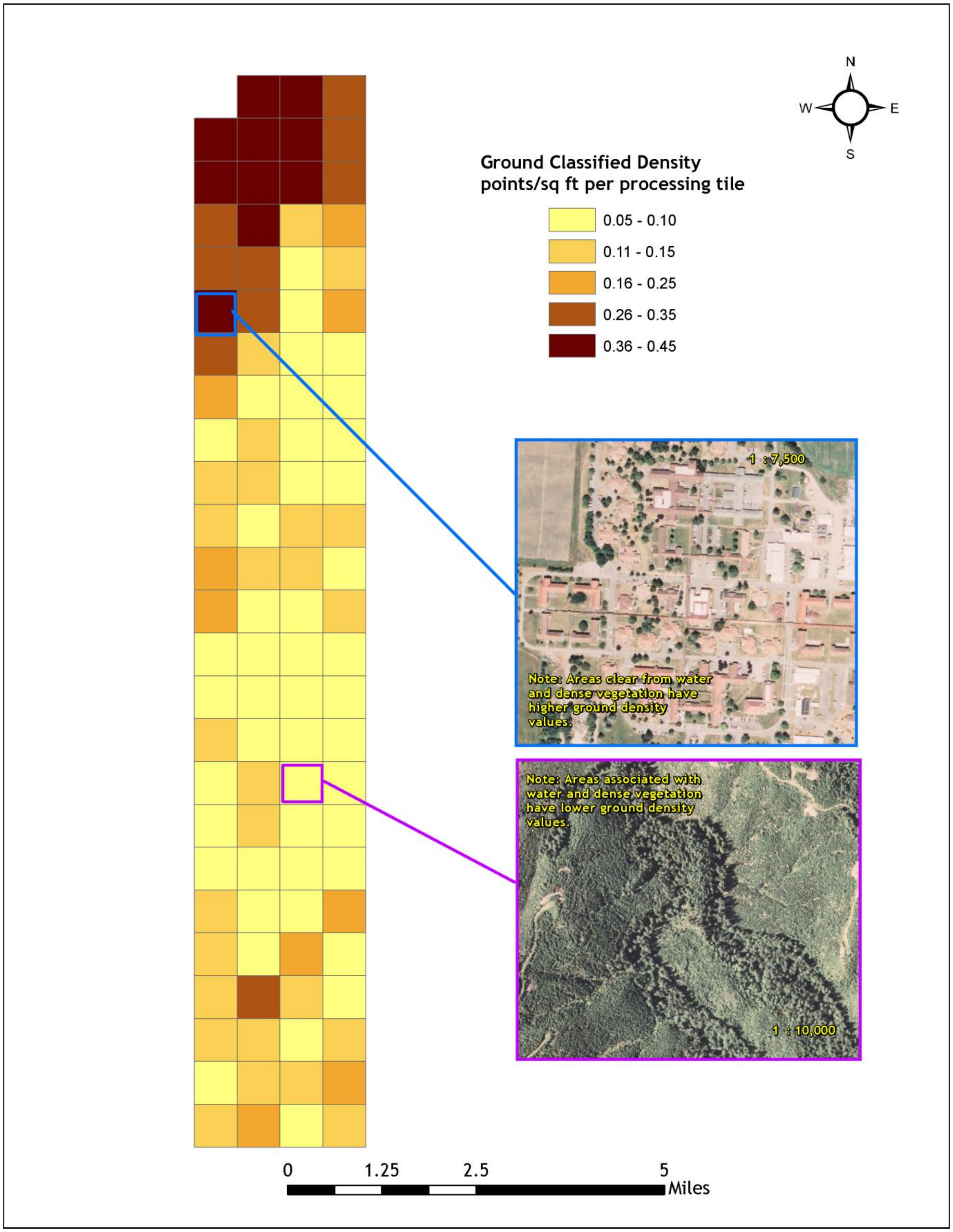


***Figure 33**. Density distribution map for first return points by tile for Delivery 15.*

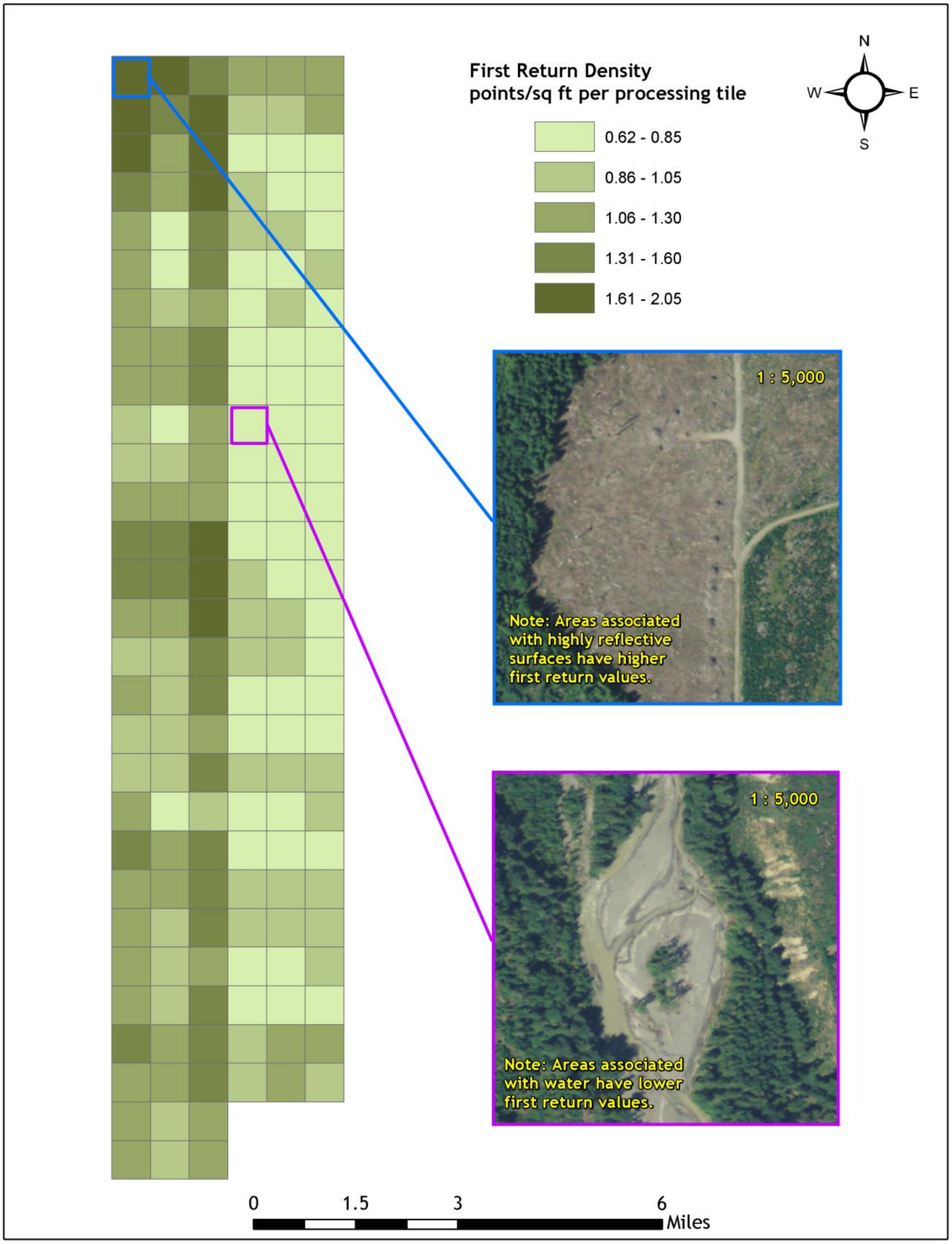


***Figure 34**. Density distribution map for ground classified points by tile for Delivery 15.*

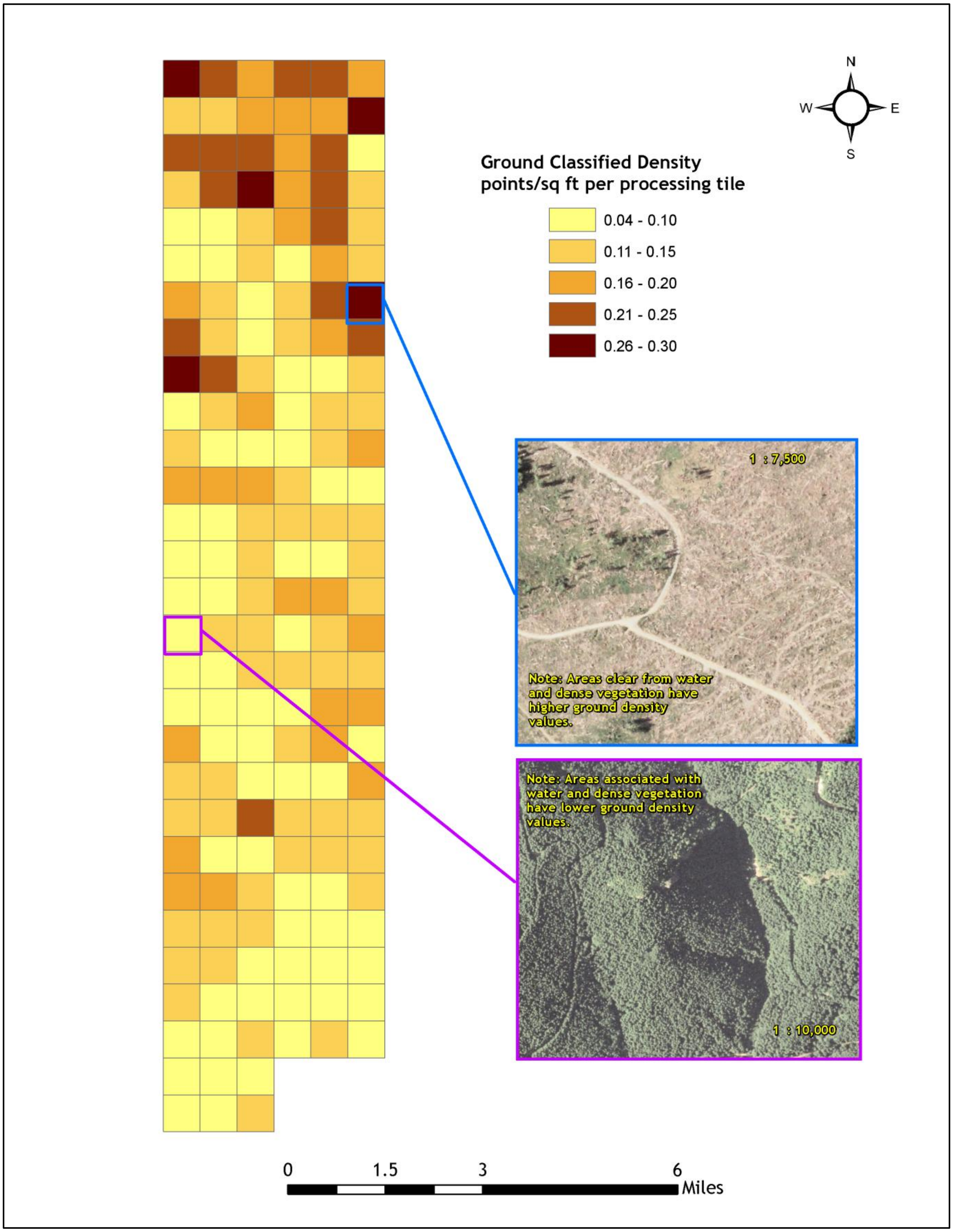


Figure 35. *Density distribution map for first return points by tile for Delivery 16.*

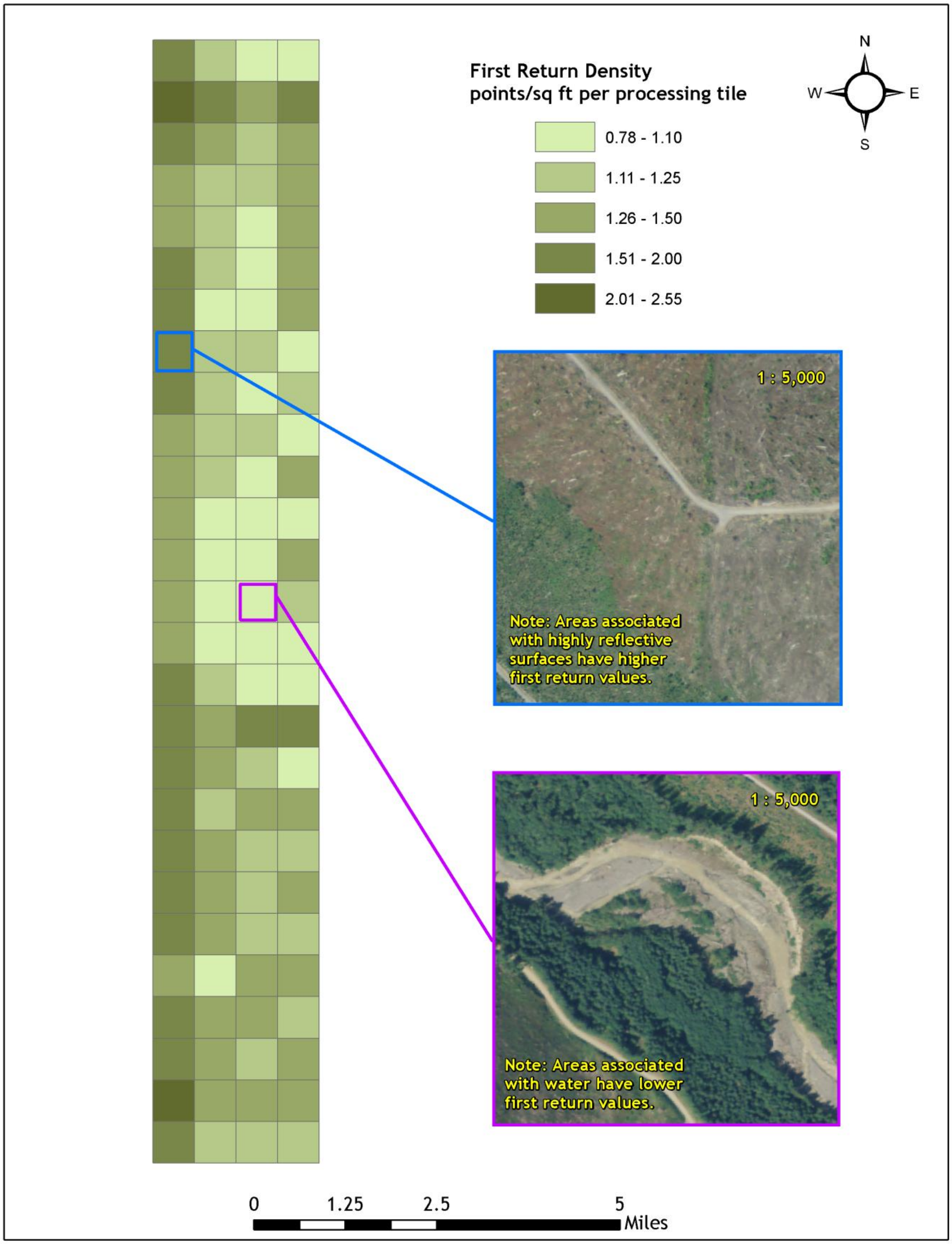


Figure 36. *Density distribution map for ground classified points by tile for Delivery 16.*

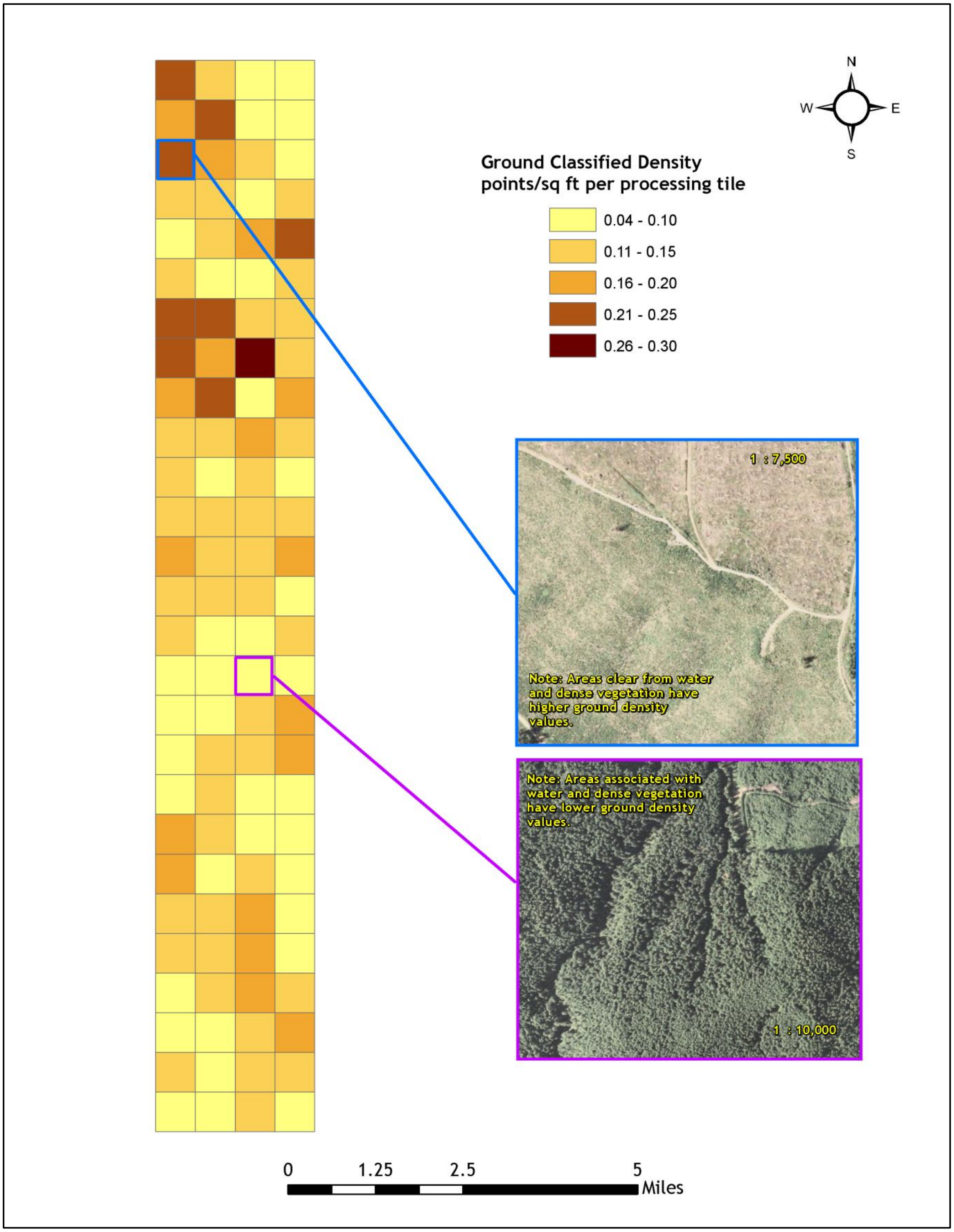


Figure 37. Density distribution map for first return points by tile for Delivery 17.

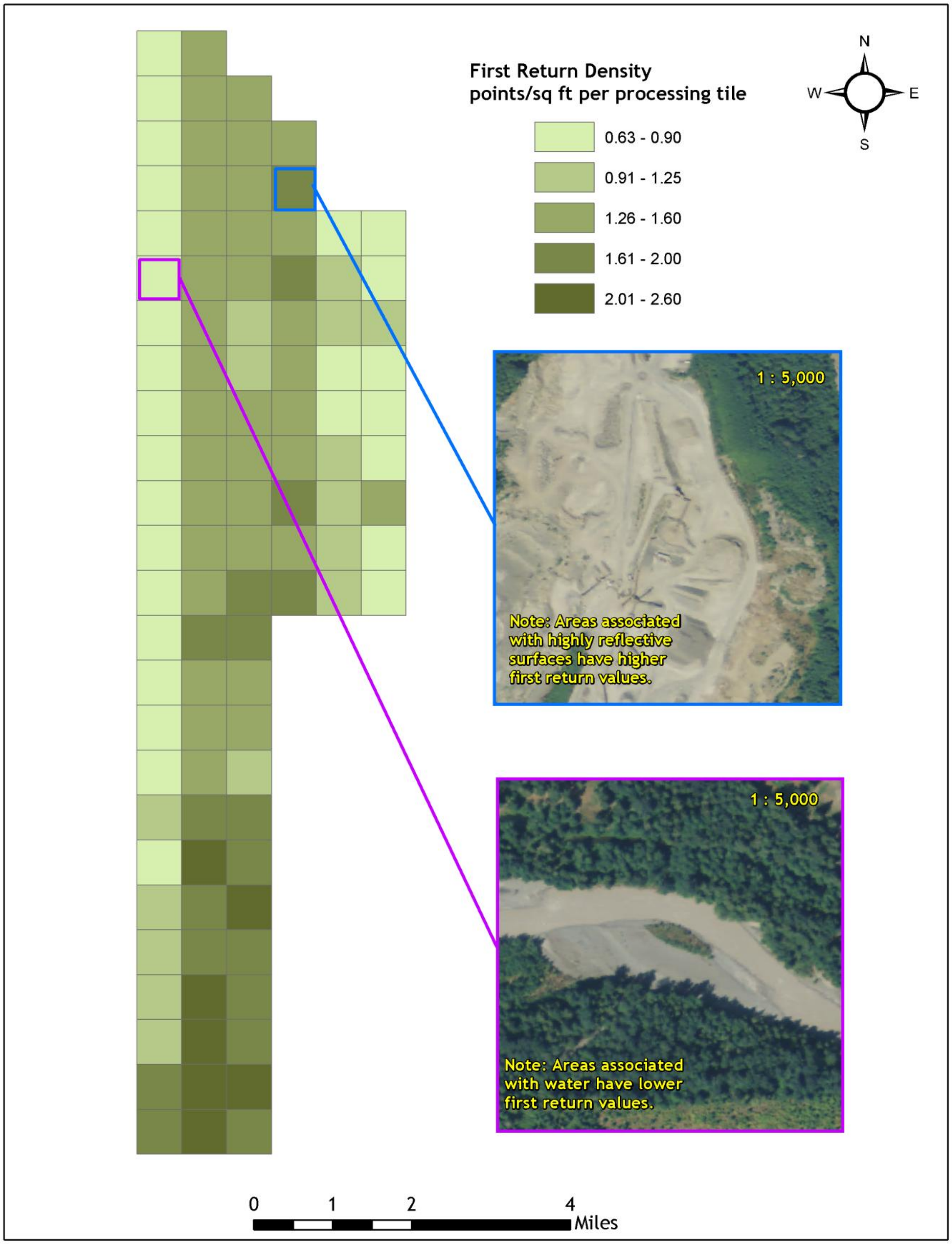


Figure 38. *Density distribution map for ground classified points by tile for Delivery 17.*

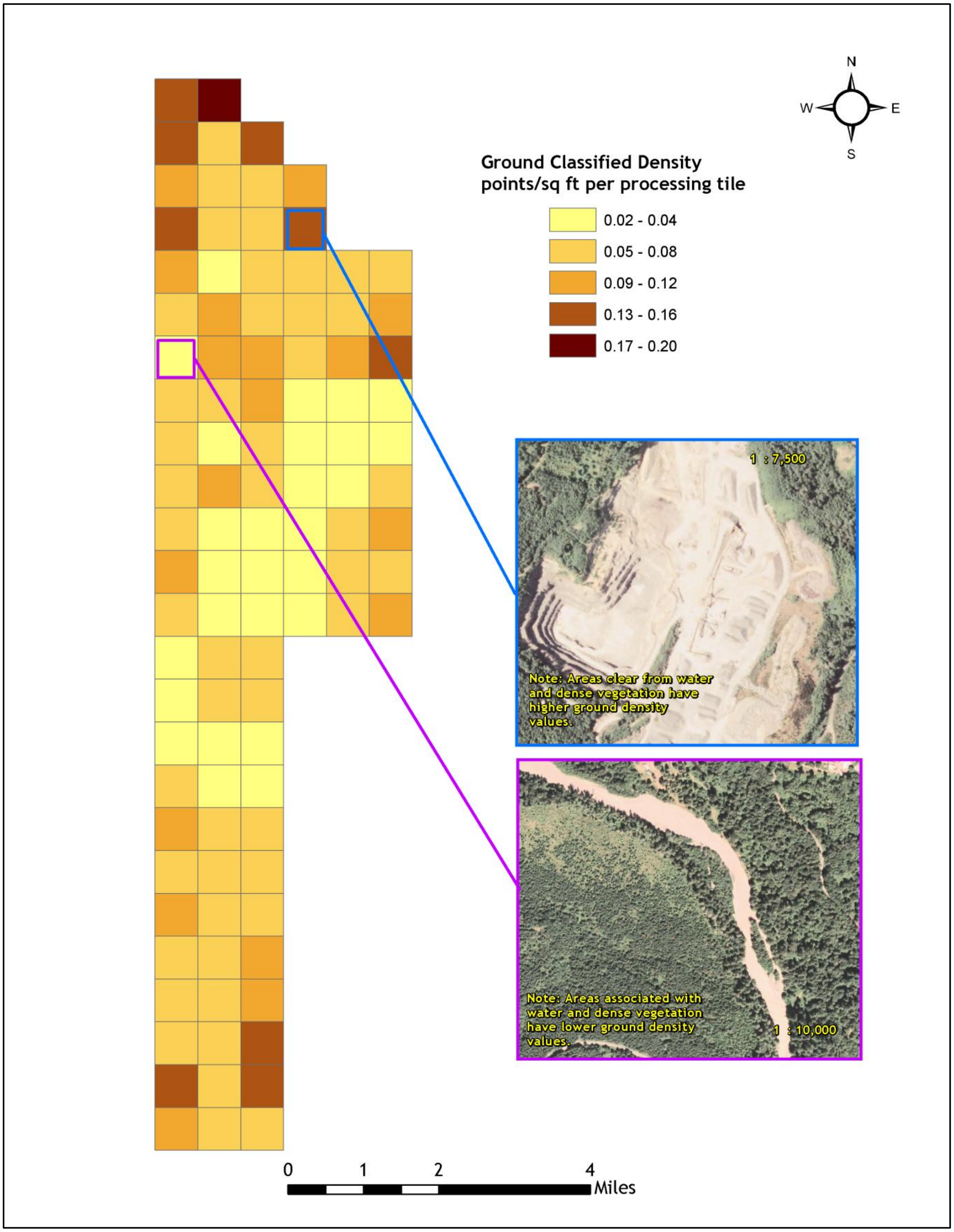


Figure 39*. Density distribution map for first return points by tile for Delivery 18.*

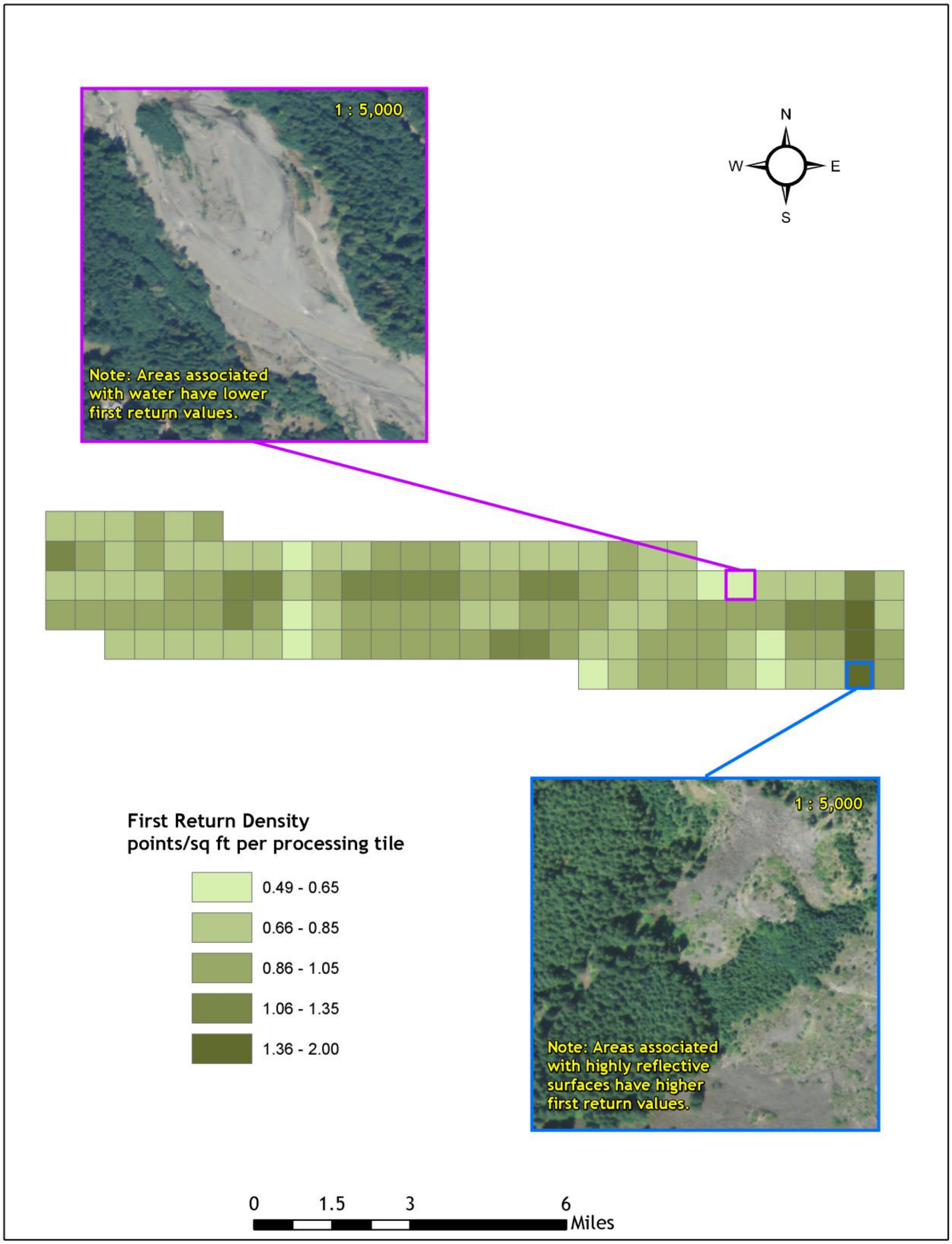


Figure 40. *Density distribution map for ground classified points by tile for Delivery 18.*

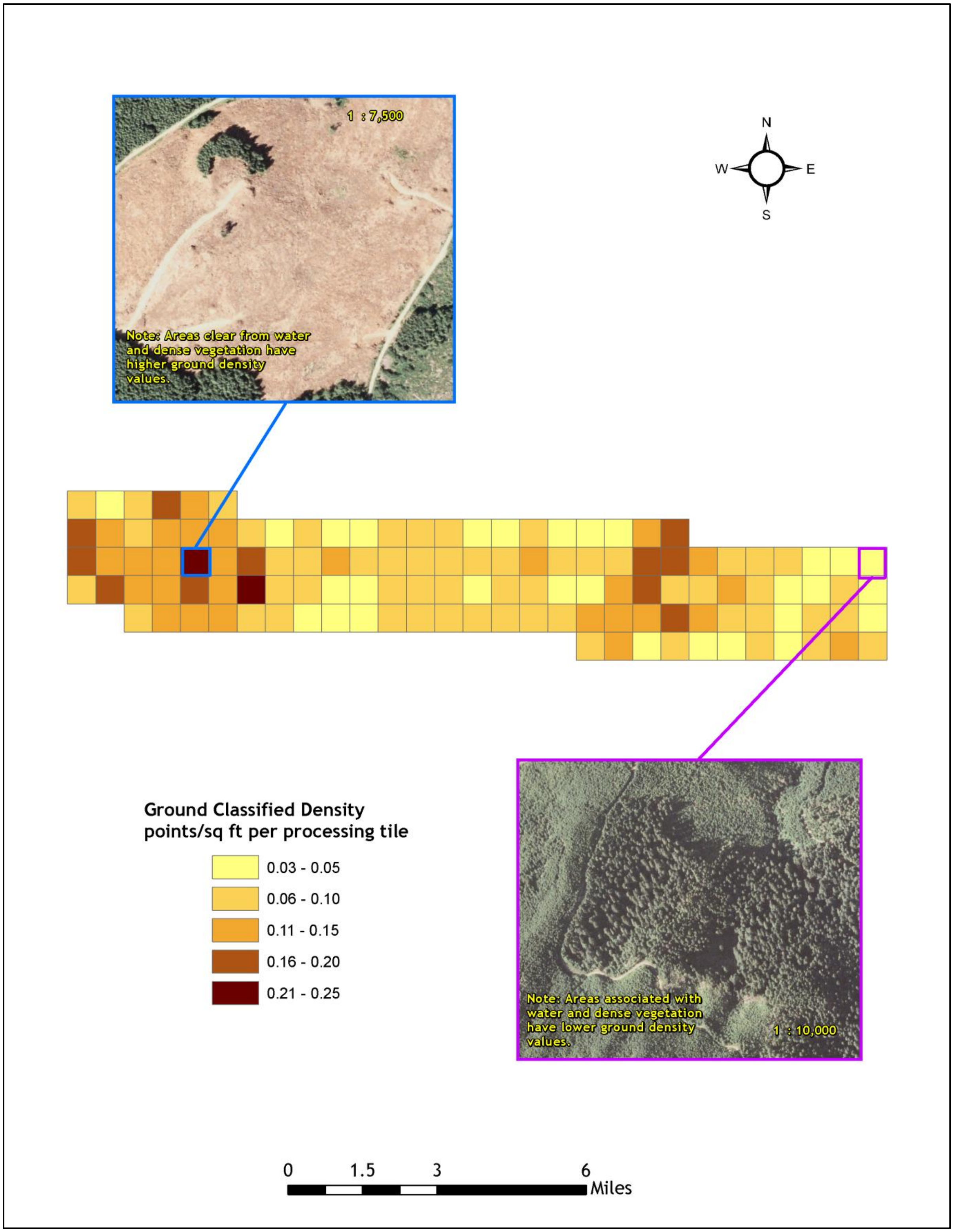


Figure 41. Density distribution map for first return points by tile for Delivery 19.

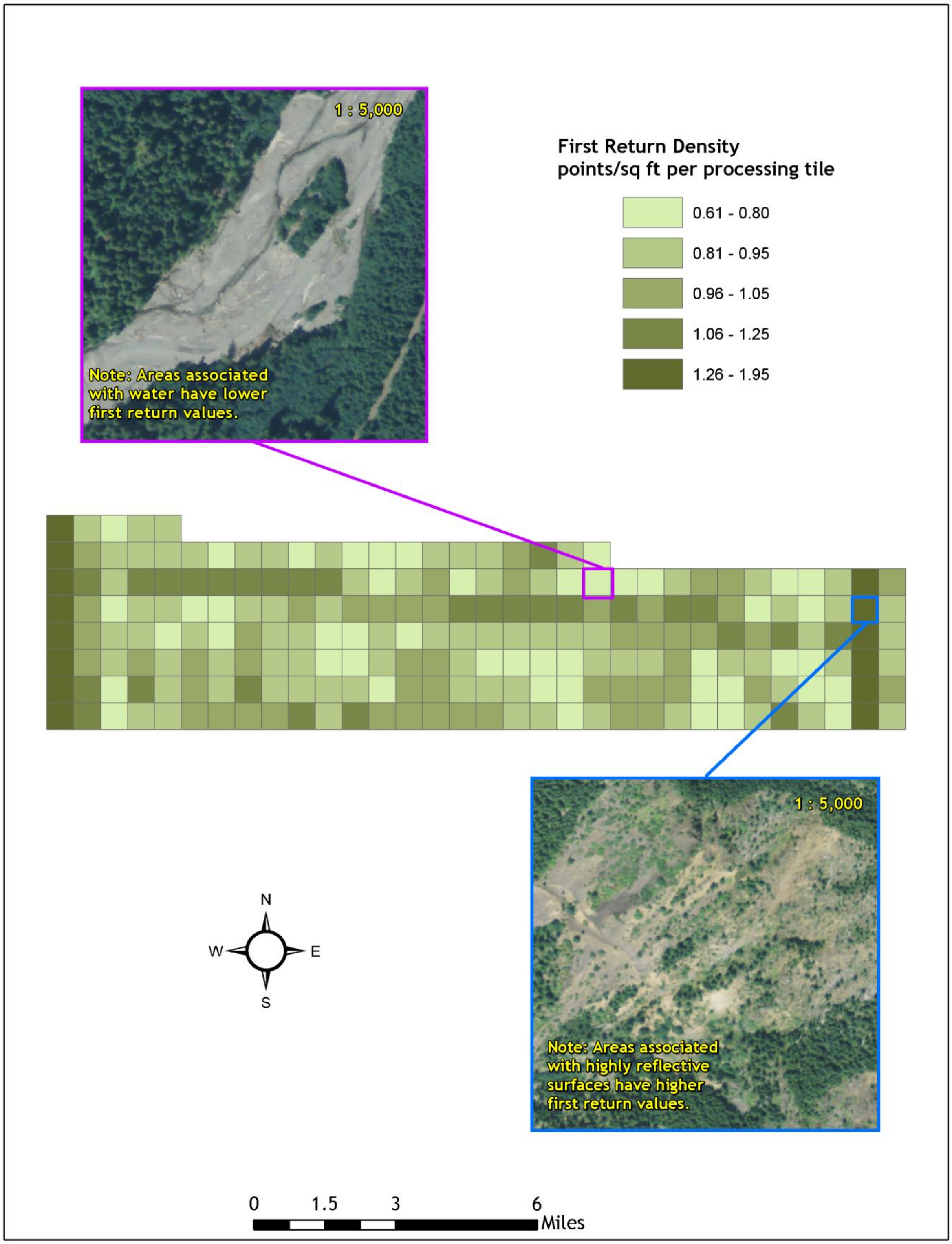


Figure 42. Density distribution map for ground classified points by tile for Delivery 18.

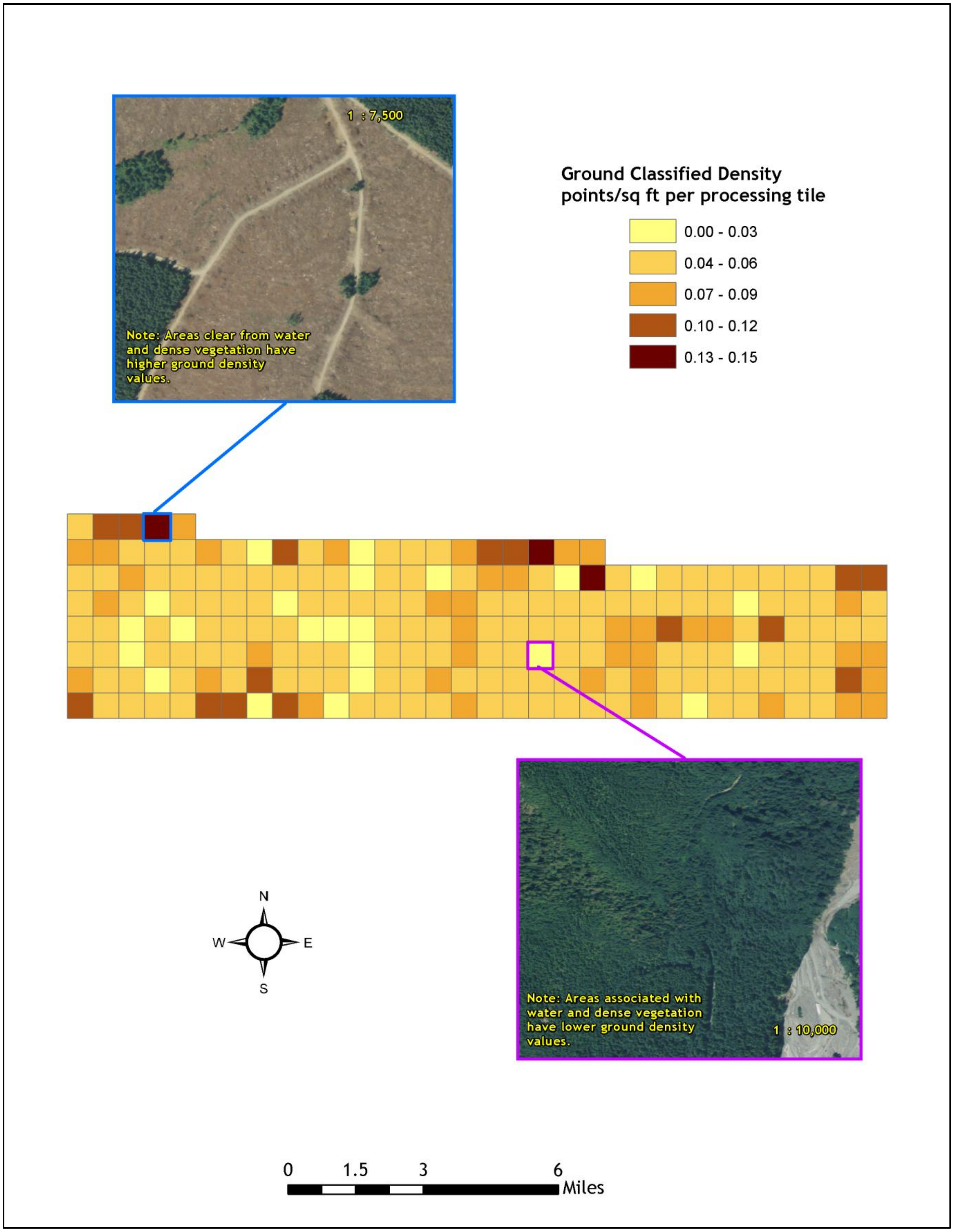


Figure 43. *Density distribution map for first return points by tile for Delivery 20.*

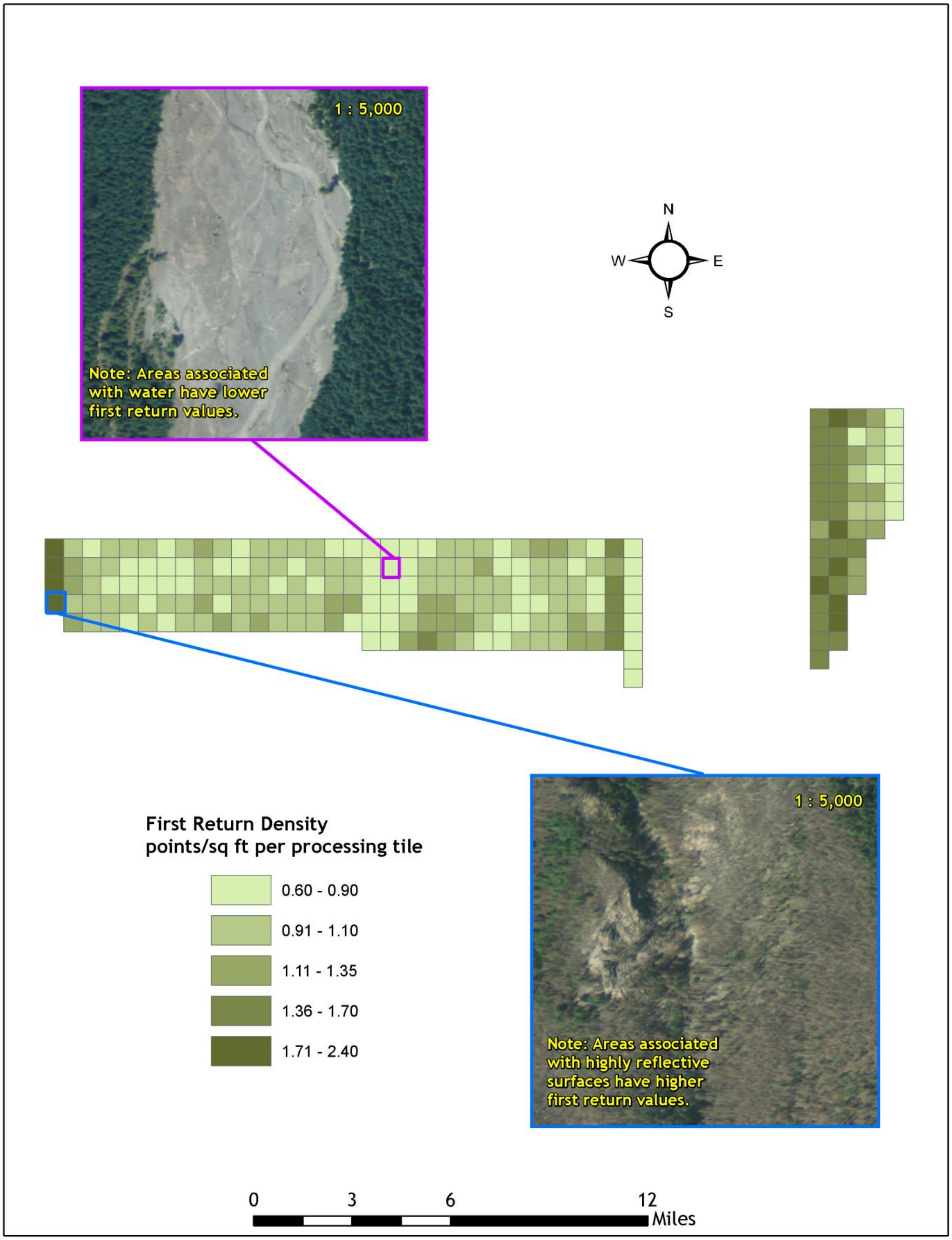


***Figure 44**. Density distribution map for ground classified points by tile for Delivery 20.*

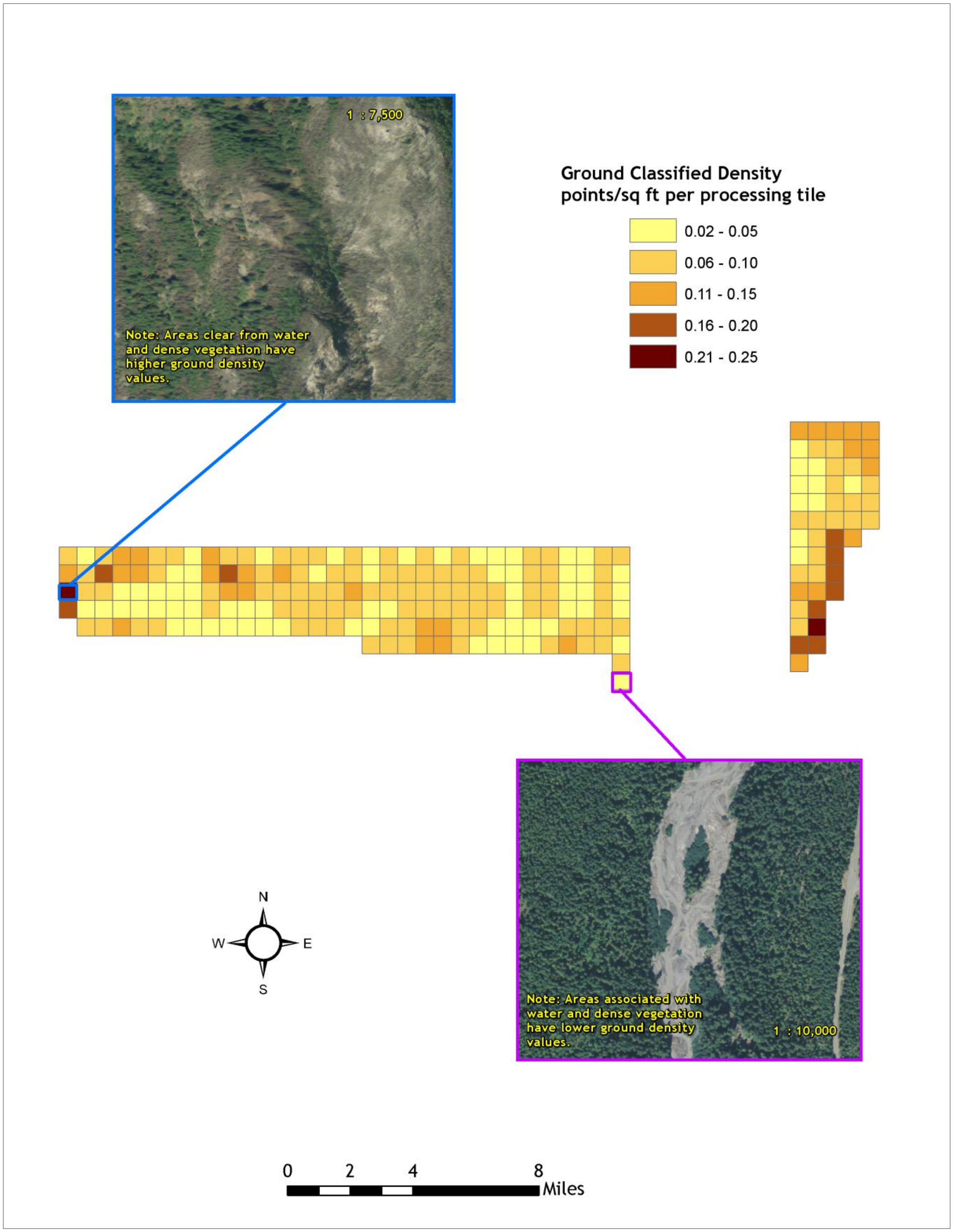


Figure 45. *Density distribution map for first return points by tile for Delivery 21.*

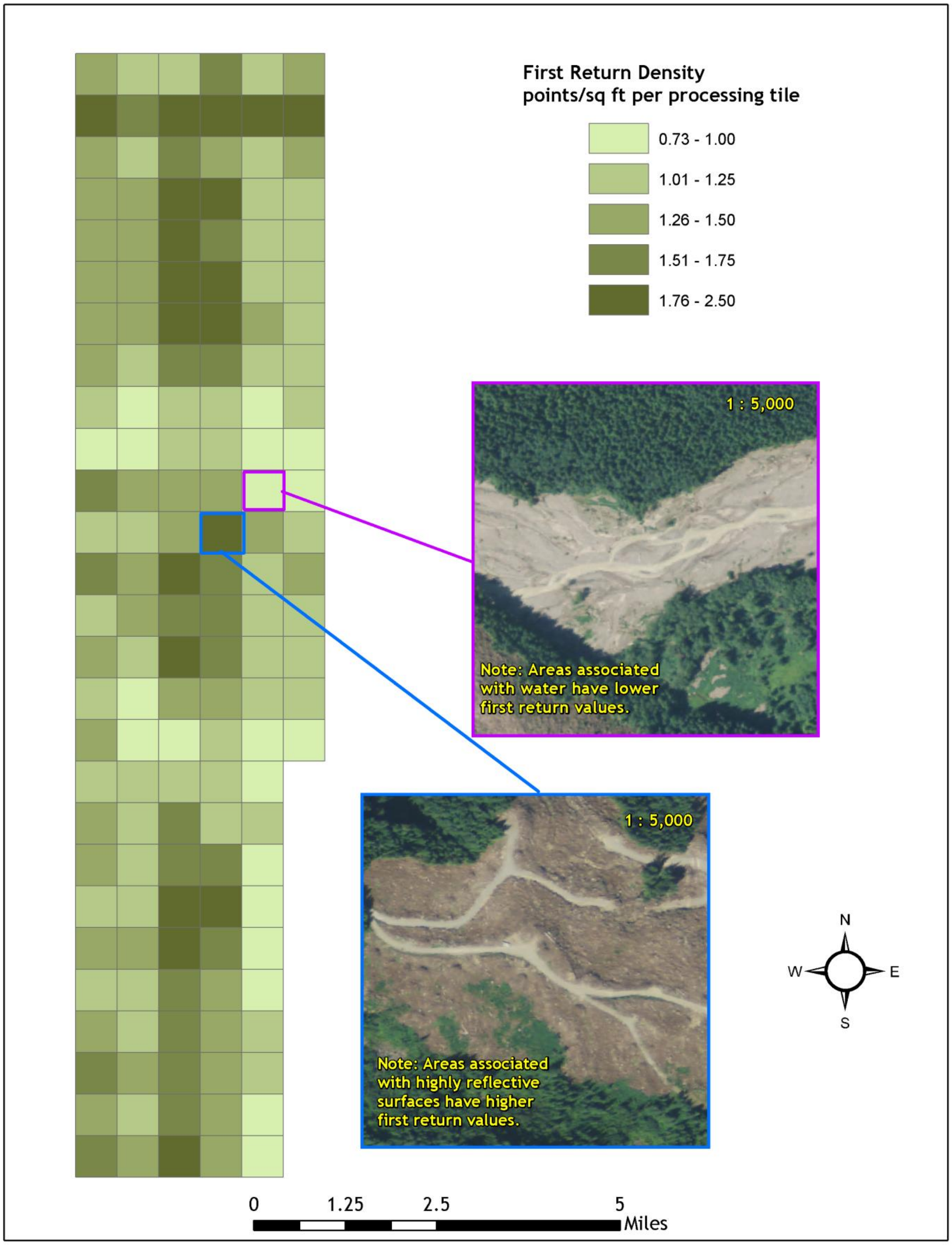


Figure 46. Density distribution map for ground classified points by tile for Delivery 21.

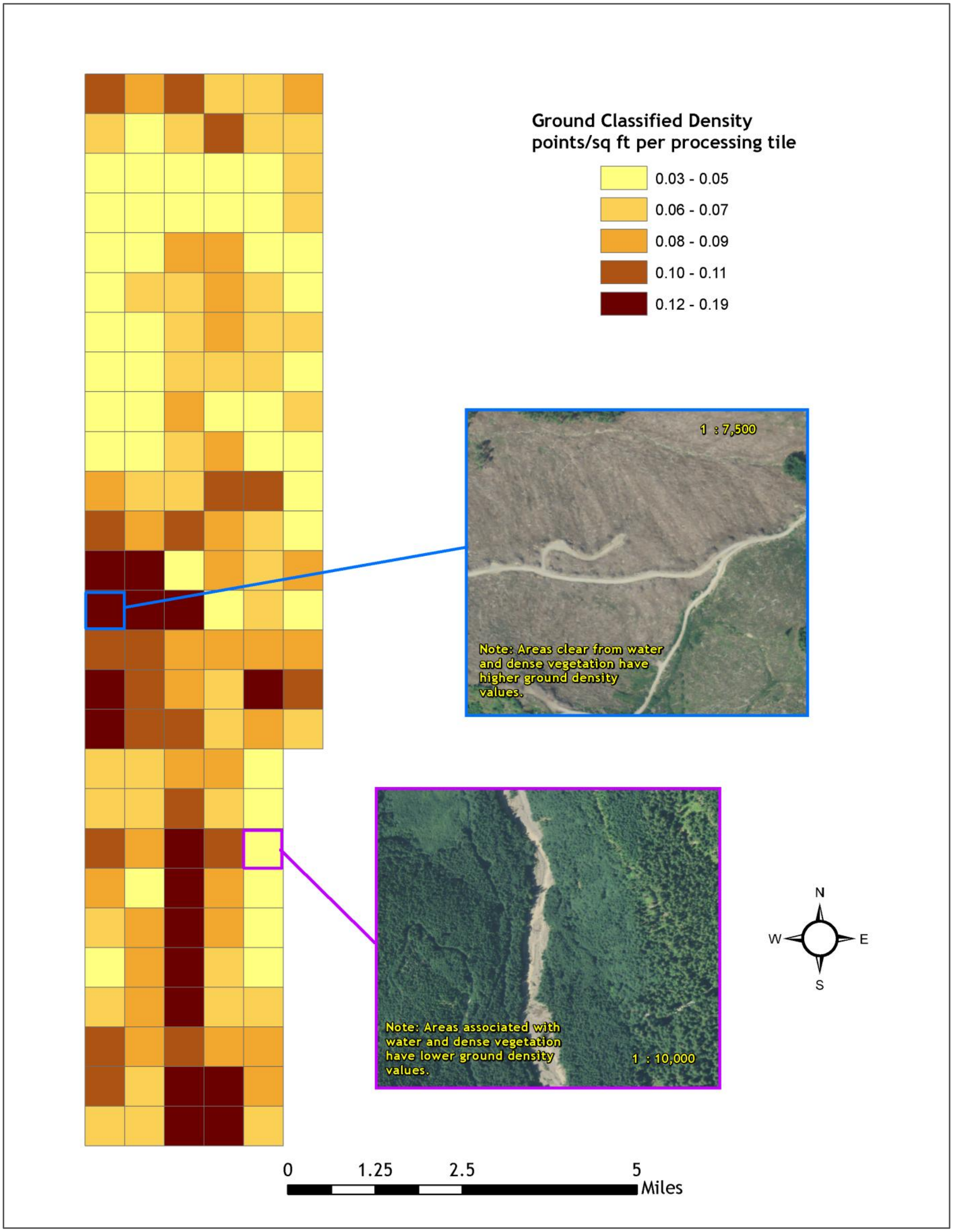


***Figure 47*. *Final d*ensity distribution map for first return points by tile for Pierce County.**

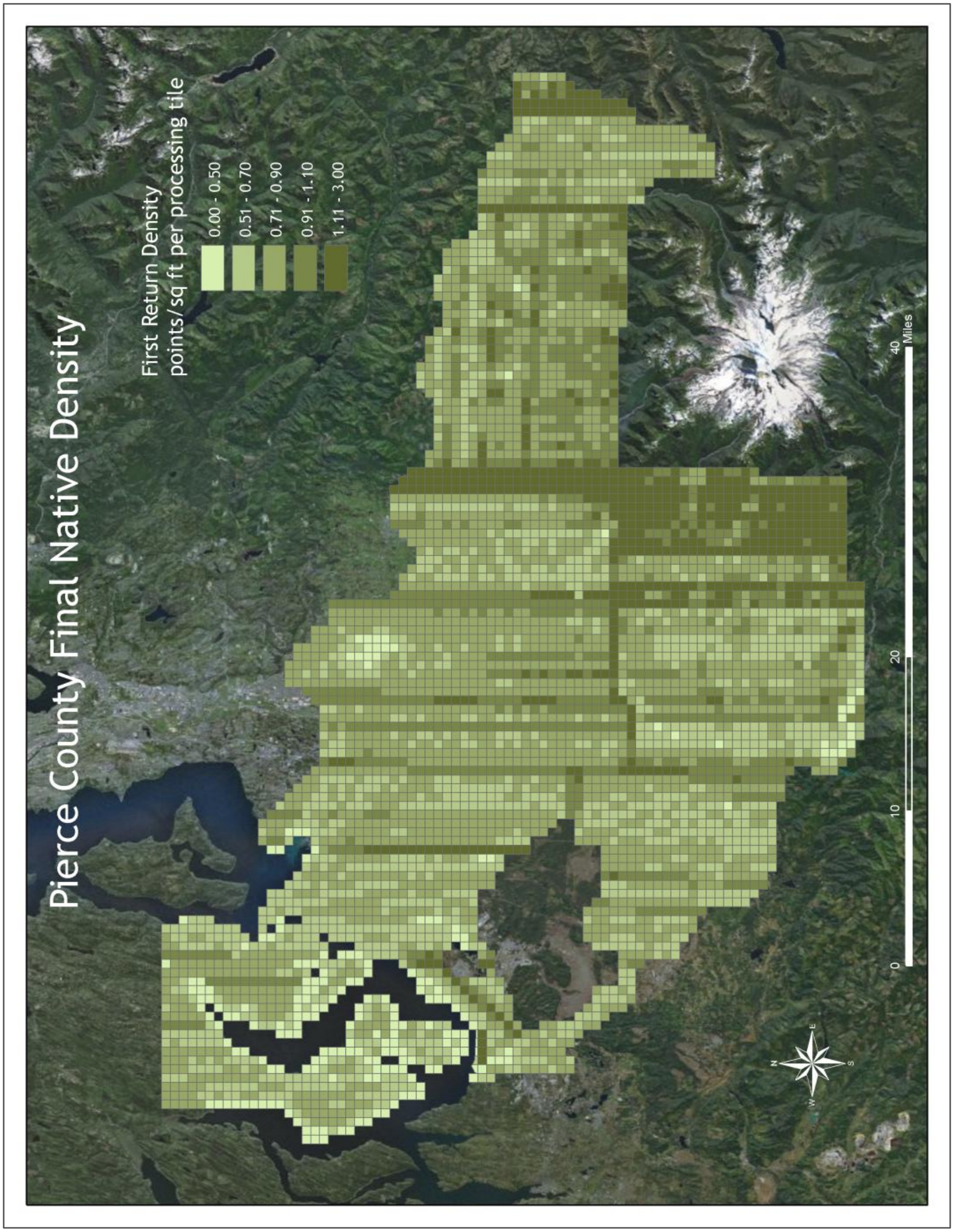
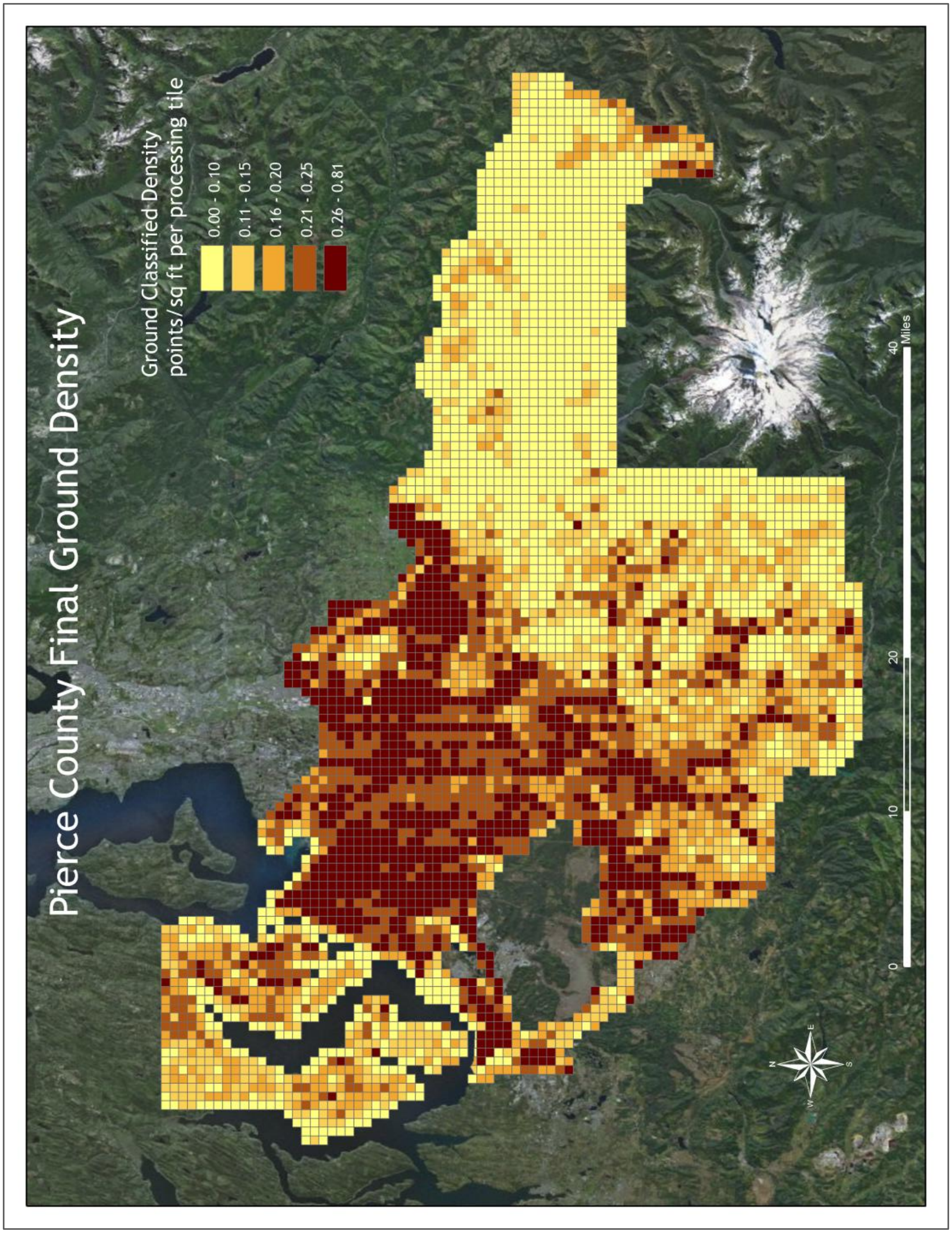


***Figure 48**. **Final d**ensity distribution map for ground classified points by tile for Pierce County.*

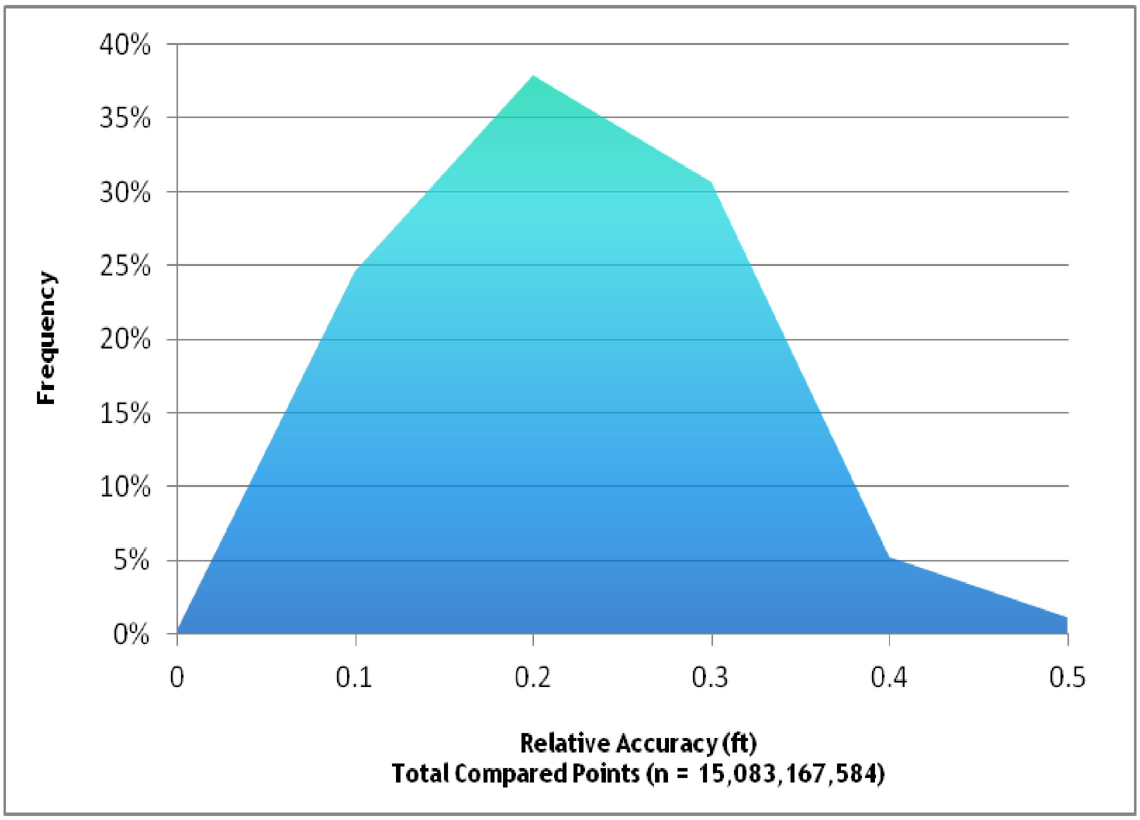


5.3 Relative Accuracy Calibration Results

Cumulative relative accuracy statistics for the Pierce County dataset measure the full survey calibration including areas outside the delivered boundary. These statistics will be updated with each delivery.

- Project Average = 0.174 ft (0.047m)
- Median Relative Accuracy = 0.169 ft (0.052m)
- 1σ Relative Accuracy = 0.081 ft (0.025m)
- 1.96σ Relative Accuracy = 0.159 ft (0.048m)

***Figure 49**. Distribution of relative accuracies per flight line, non slope-adjusted.*



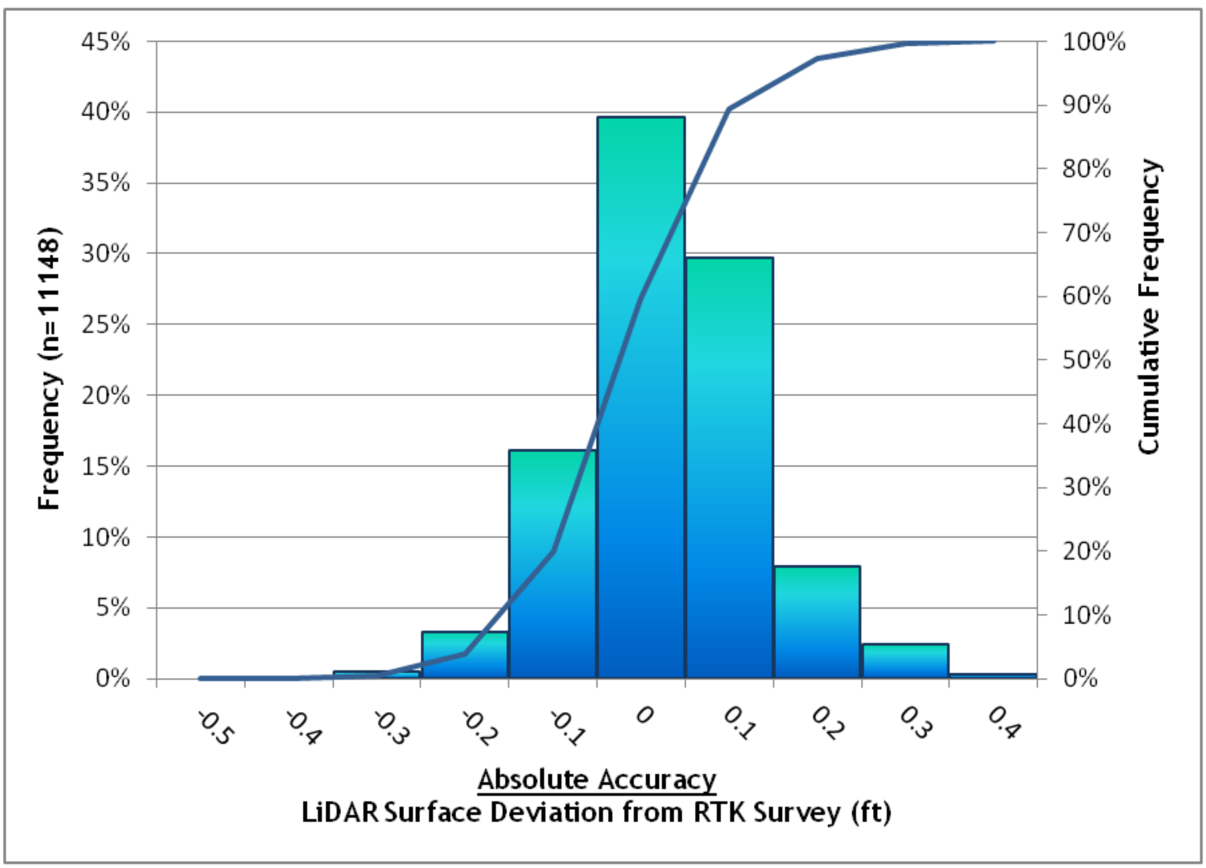
5.4 Absolute Accuracy

Cumulative absolute accuracies for Pierce County delivered data:

Table 4. *Absolute Accuracy – Cumulative deviation between laser points and RTK hard surface survey points*

Absolute Accuracy Assessment	
RTK Survey Sample Size (n): 11,148	
Root Mean Square Error (RMSE) = 0.105 ft (0.157m)	Minimum Δz = -0.486 ft (-0.148m)
Standard Deviations 1 sigma (σ): 0.103 ft (0.032m) 1.96 sigma (σ): 0.202 ft (0.062m)	Maximum Δz = 0.384 ft (0.117m)
	Average Δz = -0.020 ft (-0.006m)

Figure 50. *Absolute Accuracy - Histogram Statistics*



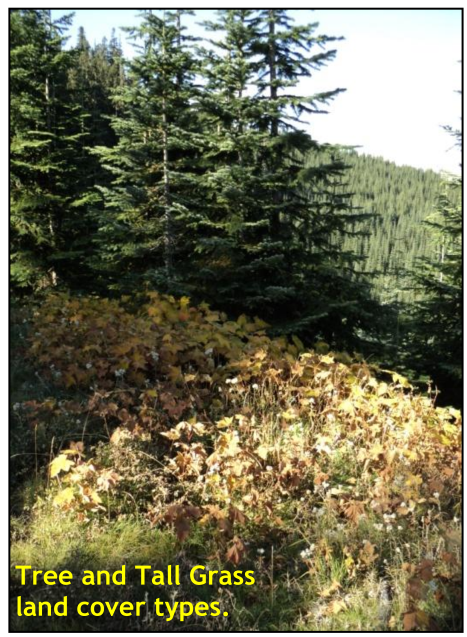
5.5 Land Cover Accuracy

Cumulative accuracies for different land cover classes collected for the Pierce County dataset:

Table 5. *Land Cover Accuracy – Cumulative deviation between laser points and cover class point locations.*

Landcover Type	Count	Average (ft)	RMSE (ft)	1 Sigma ft(m)	1.96 Sigma ft(m)
Bare Earth (Hard and Soft Surfaces)	11166	-0.020 ft (-0.006m)	0.105 ft (0.034m)	0.103 ft (0.031m)	0.202 ft (0.062m)
Trees	281	0.077 ft (0.023m)	0.275 ft (0.089m)	0.264 ft (0.081m)	0.518 ft (0.158m)
Tall Grass	162	0.184 ft (0.056m)	0.336 ft (0.109m)	0.283 ft (0.086m)	0.554 ft (0.169m)
Shrubs	307	0.138 ft (0.042m)	0.440 ft (0.143m)	0.418 ft (0.127m)	0.819 ft (0.250m)
Short Grass	397	0.031 ft (0.009m)	0.160 ft (0.052m)	0.157 ft (0.048m)	0.308 ft (0.094m)

Figure 51. *Examples of land cover types in Pierce County.*



6. Model Development

6.1 Hydro Flattened & Breakline Enforced Terrain Models

David C. Smith and Associates (DSA), Portland, OR created breaklines for Pierce County using LiDAR-grammetry techniques. **Table 6** describes the type and definition of each breakline collected. The breaklines were used to supplement the LiDAR data in creation of a hydro-flattened ground model. A breakline was created around lakes and ponds with areas larger than ~2 acres. Rivers with widths greater than ~10ft were represented as a double line feature and flatten from side-to-side. A single line feature was used to represent streams less than ~10ft to ensure downstream flow. Road crossings (i.e. culverts) were retained in the ground model, but bridges were removed.

- Water boundaries were enforced using hard breaklines and water surfaces were flattened based on the elevation from the breaklines. The breakline boundaries were also used to reassign any ground classified points within the water delineated areas to a water class.
- Hard breaklines (lake edges, islands, etc.) were incorporated into the TIN by enforcing triangle edges (adjacent to the breakline) to the elevation values derived from the LiDAR-grammetric breakline. This implementation corrected interpolation along the hard edge.
- LiDAR data points within three feet of a breakline were ignored from the ground classification, giving precedence to breakline Z values.

***Table 6**. Breaklines collected for Pierce County.*

Feature	Implementation	Description
Water Lake	Hard Breakline	Lake Bodies
Water Stream	Hard Breakline	Streams smaller than ~10 feet were digitized as single stream centerlines.
Water Island	Hard Breakline	Islands
Water River	Hard Breakline	Rivers wider than 10 ft were digitized as double line features outlining the edge of bank.
Breakline	Hard Breakline	Breakline to supplement LiDAR data

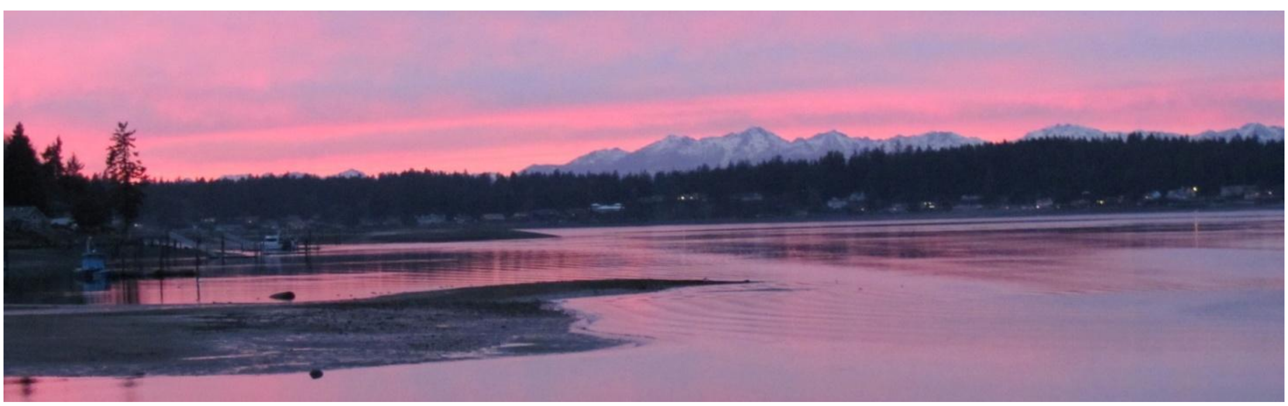
7. Projection/Datum and Units

	Projection:	Washington State Plane South (FIPS 4602)
Datum	**Vertical:**	NAVD88 Geoid09
	Horizontal:	NAD83 (1991 HARN)
	Units:	U.S. Survey Feet

8. Deliverables

Point Data:	LAS 1.2 format • All Returns (default, ground, noise, ignored ground, and water classes) • RAW Data (1 swath/file)
Vector Data:	• Tile Index of LiDAR Points (ESRI file geodatabase format) • Tile Index of DEMs (ESRI file geodatabase format) • Bridge Layer (ESRI file geodatabase format) • Hydrologic Breaklines (ESRI file geodatabase format)
Raster Data:	• Elevation Models (3 ft. resolution) • Bare Earth Model (IMG format) • Hydro-flattened Bare Earth Model (IMG format) • Intensity Images (1.5 ft. resolution, TIFF format)
Data Report:	• Full report containing introduction, methodology, and accuracy

* A final DEM set will be tiled and delivered after all edits have been accepted by Pierce County.



9. Certifications

Watershed Sciences provided LiDAR services for the Pierce County study area as described in this report.

I, Russ Faux, have reviewed the attached report for completeness and hereby state that it is a complete and accurate report of this project.

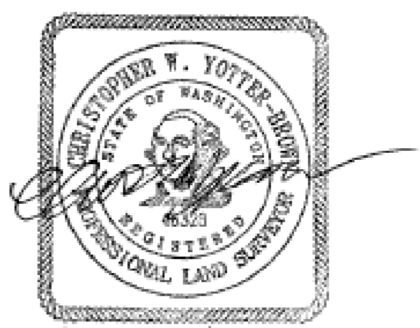
Russell Faux

Russ Faux
Principal
Watershed Sciences, Inc.

I, Christopher W. Yotter-Brown, being first dully sworn, say that as described in the Ground Survey subsection of the Acquisition section of this report was completed by me or under my direct supervision and was completed using commonly accepted standard practices. Accuracy statistics shown in the Accuracy Section have been reviewed by me to meet National Standard for Spatial Data Accuracy.

12/13/2011

Christopher W. Yotter-Brown, PLS Oregon & Washington
Watershed Sciences, Inc
Portland, OR 97204



Renews: 12/21/2012

10. Selected Images

Figure 52. *The top image is a 3D point cloud looking northeast at where the National Forest Develop Road 7810 crosses the Carbon River in Pierce County, WA, colored by height. The bottom image is a 3D point cloud looking west at the Mowich River just to the west of Mt. Rainier, colored by height.*

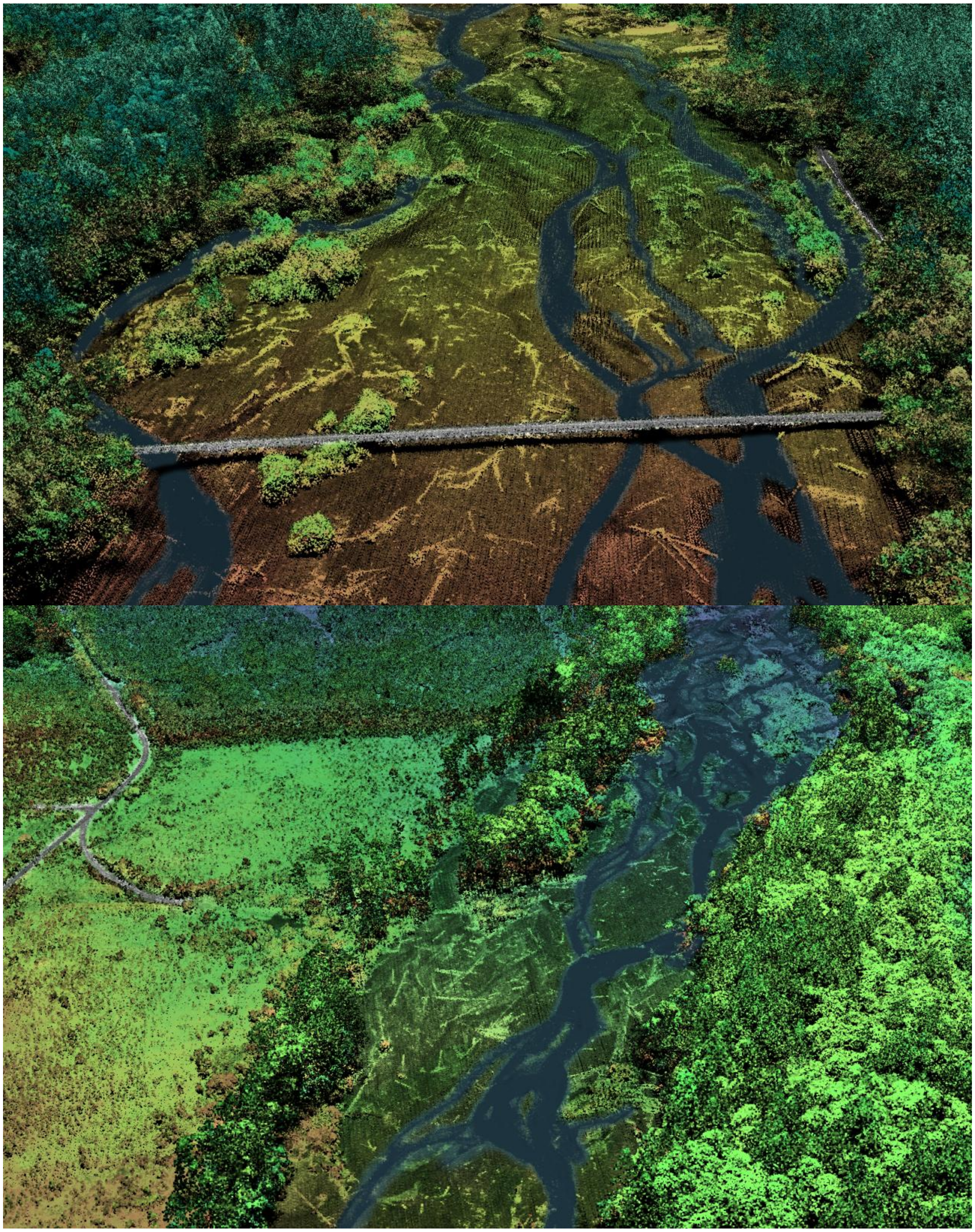


Figure 53. *The top image is a 3D point cloud looking northeast at the Carbon River and National Forest Develop Road, colored by height. The bottom image is a 3D point cloud looking east at a field and dirt roads to the south of the Mowich River in Pierce County, WA, colored by height.*

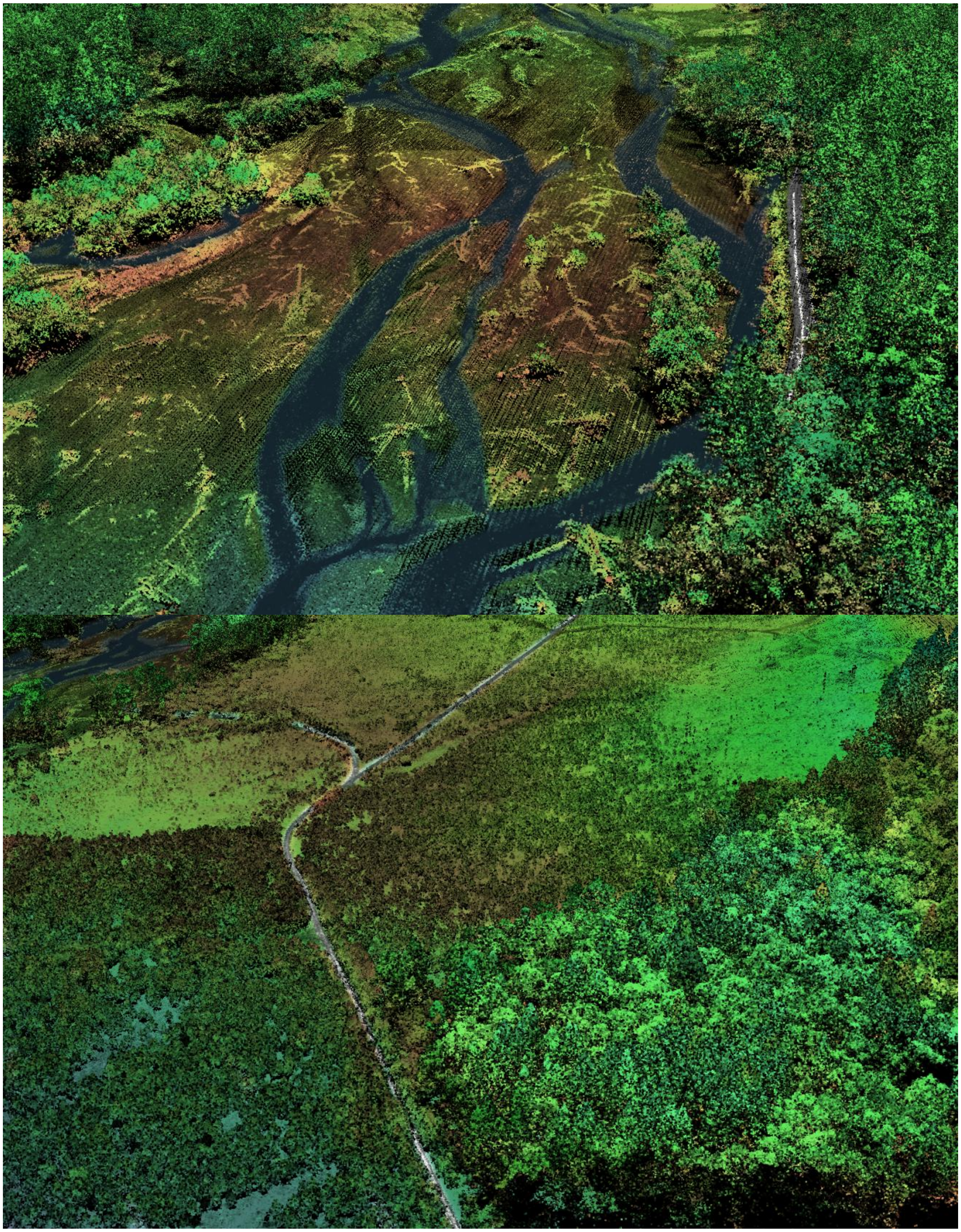
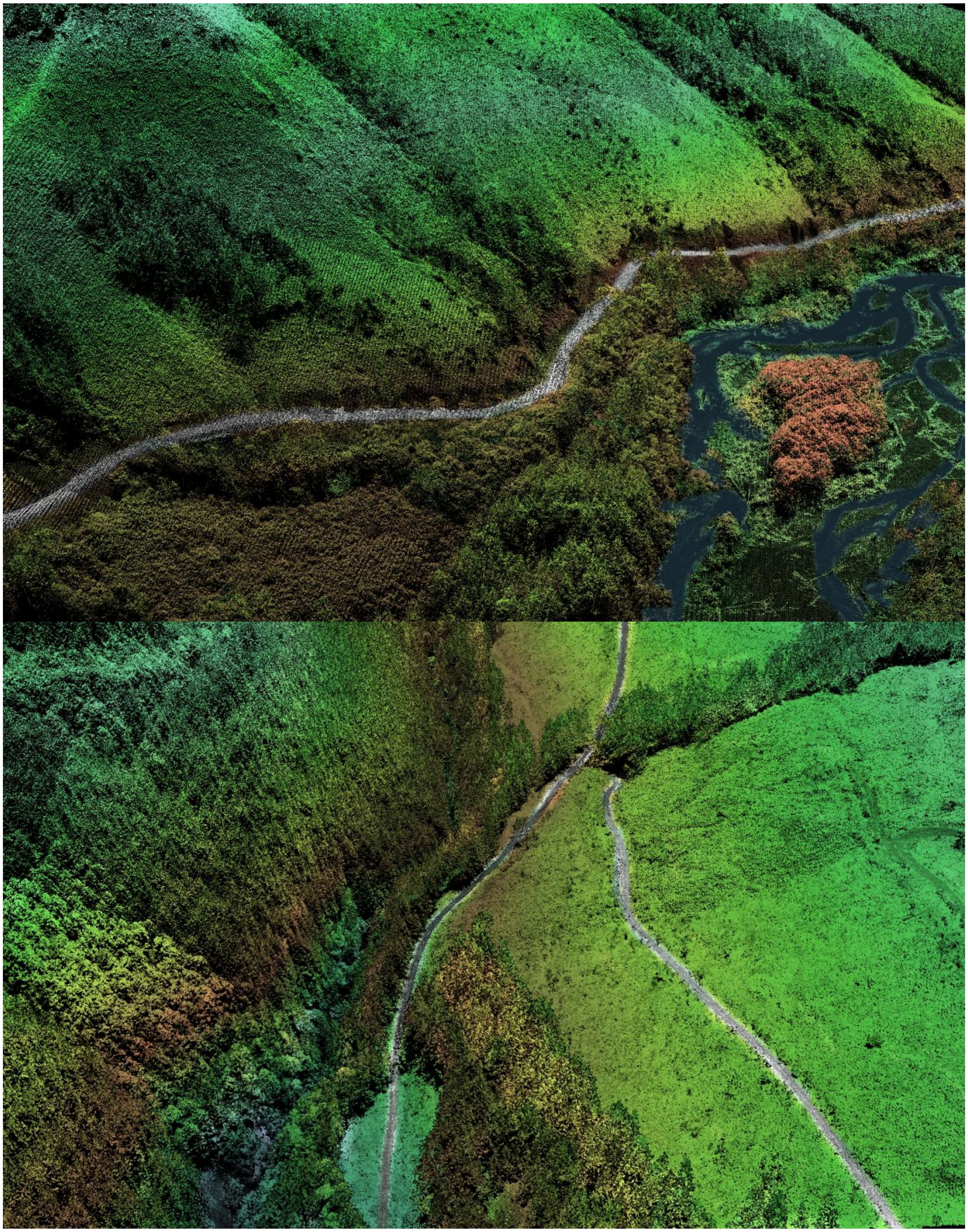


***Figure 54**. The top image is a 3D point cloud looking southwest at the Puyallup River and National Forest Develop Road in Pierce County, WA, colored by height. The bottom image is a 3D point cloud looking south at National Forest Develop Road 5942 and National Forest Develop Road 59, colored by height.*



11. 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.

1.96-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.

12. Citations

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

Appendix A

LiDAR accuracy error sources and solutions:

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

Operational measures taken to improve relative accuracy:

1. Low Flight Altitude: Terrain following is employed to maintain a constant above ground level (AGL). Laser horizontal errors are a function of flight altitude above ground (i.e., ~ 1/3000th AGL flight altitude).
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 $\pm 15^{o}$ 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. Ground survey RTK points are distributed to the extent possible throughout multiple flight lines and across the survey 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.

Appendix B

PLS Survey attachments:

SURVEY DATASHEET (Version 1.0)

PID: BBCK63
Designation: PIERCE5_DT1
Stamping: PIERCE5_DT1
Stability: Monument will probably hold position well
Setting: Object driven into ground
Description: Drive approximately 23.7 miles SE of Enumclaw on Hwy 410 to NF 72 on the east side of the Hwy. Turn left onto NF 72, stay to the right at the Y in the road off the Hwy. Continue 1.4 miles then turn left to stay on NF 72. Continue 2.5 miles then turn sharply right to stay on NF 72. Drive .9 miles stay to the right, continue .4 miles stay to the left. Continue another 2.1 miles turn sharply right onto NF 7250. Drive .2 miles and monument is on the right side of the road to the north.
Observed: 2010-10-20T16:29:00Z
Source: OPUS - page5 1106.16

Close-up View

REF_FRAME:	EPOCH:	SOURCE:	UNITS:	SET PROFILE	DETAILS
NAD_83(CORS96)	2002.0000	NAVD88 (Computed using GEOID09)	m		

LAT:	47° 4' 42.75983"	± 0.010 m
LON:	-121° 32' 12.57157"	± 0.007 m
ELL HT:	1479.911	± 0.018 m
X:	-2276457.939	± 0.012 m
Y:	-3709487.961	± 0.015 m
Z:	4648799.277	± 0.007 m
ORTHO HT:	1499.627	± 0.034 m

	UTM 10	SPC 4602(WA S)
NORTHING:	5214931.215m	194502.094m
EASTING:	611074.707m	421264.916m
CONVERGENCE:	1.07157412°	-0.75314563°
POINT SCALE:	0.99975163	0.99995168
COMBINED FACTOR:	0.99951977	0.99971977

CONTRIBUTED BY

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Watershed Sciences

Horizon View

The numerical values for this position solution have satisfied the quality control criteria of the National Geodetic Survey. The contributor has verified that the information submitted is accurate and complete.

SURVEY DATASHEET (Version 1.0)

PID: BBCK64
Designation: PIERCE5_DT2
Stamping: PIERCE5_DT2
Stability: Monument will probably hold position well
Setting: Object driven into ground
Description: Drive approximately 23.7 miles SE of Enumclaw on Hwy 410 to NF 72 on the east side of the Hwy. Stay on 72 for 7.3 miles and turn sharply right onto NF 7250. Drive .2 miles and stay to the left at the Y in the road past PIERCE5_DT1 and continue for .8 miles on NF 7250 stay to the right at the Y in the road. Drive 1.1 miles then take a sharp left and continue .1 mile uphill to the second clearing where the road dead-ends with a fire pit. Monument is on the north side of the clearing.
Observed: 2010-10-21T15:42:00Z
Source: OPUS - page5 1106.16

Close-up View

REF_FRAME: NAD_83(CORS96)	EPOCH: 2002.0000	SOURCE: NAVD88 (Computed using GEOID09)	UNITS: m	SET PROFILE	DETAILS

LAT:	47° 3' 28.67722"	± 0.003 m
LON:	-121° 31' 33.99588"	± 0.006 m
ELL HT:	1614.859	± 0.027 m
X:	-2276688.269	± 0.009 m
Y:	-3711420.124	± 0.019 m
Z:	4647339.450	± 0.018 m
ORTHO HT:	1634.448	± 0.049 m

	UTM 10	SPC 4602(WA S)
NORTHING:	5212659.698m	192204.004m
EASTING:	611931.224m	422048.828m
CONVERGENCE:	1.07906283°	-0.74536195°
POINT SCALE:	0.99975398	0.99994865
COMBINED FACTOR:	0.99950098	0.99969560

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Horizon View

The numerical values for this position solution have satisfied the quality control criteria of the National Geodetic Survey. The contributor has verified that the information submitted is accurate and complete.

SURVEY DATASHEET (Version 1.0)

PID:	BBCK73
Designation:	CANYON_FALLS
Stamping:	CANYON_FALLS
Stability:	Monument will probably hold position well
Setting:	Object driven into ground
Description:	From the intersection of 128th St E and MC Cutcheon Rd E, turn right (heading south) and drive 0.9 miles to mark on your right side (E). The monument is located 4.8 meters @ 280 degrees from the approximate center-line of the road. For added reference the monument is 1.5 meters @ 75 degrees from the witness post (marker)
Observed:	2010-12-05T15:27:00Z
Source:	OPUS - page5 1106.16

Close-up View

REF_FRAME: NAD_83(CORS96)	EPOCH: 2002.0000	SOURCE: NAVD88 (Computed using GEOID09)	UNITS: m	SET PROFILE	DETAILS

LAT:	47° 7' 35.87273"	± 0.004 m
LON:	-122° 13' 31.45962"	± 0.013 m
ELL HT:	17.654	± 0.020 m
X:	-2318253.665	± 0.011 m
Y:	-3677706.861	± 0.018 m
Z:	4651367.423	± 0.012 m
ORTHO HT:	39.823	± 0.038 m

	UTM 10	SPC 4602(WA S)
NORTHING:	5219527.390m	200762.096m
EASTING:	558749.586m	369098.708m
CONVERGENCE:	0.56768492°	-1.25332724°
POINT SCALE:	0.99964242	0.99995927
COMBINED FACTOR:	0.99963965	0.99995651

CONTRIBUTED BY

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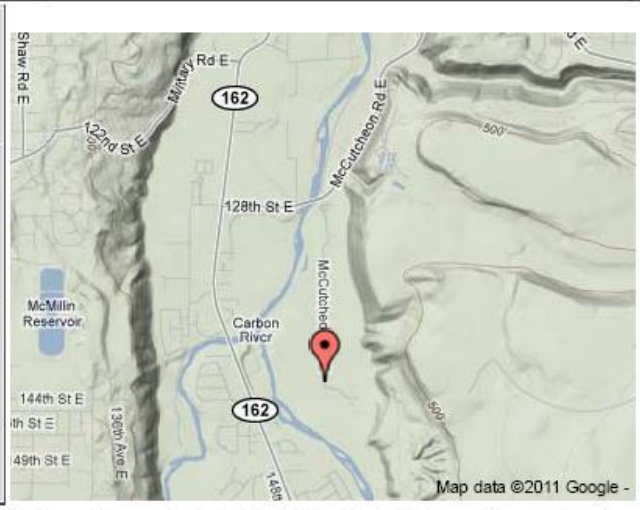
Horizon View



The numerical values for this position solution have satisfied the quality control criteria of the National Geodetic Survey. The contributor has verified that the information submitted is accurate and complete.

SURVEY DATASHEET (Version 1.0)

PID: AH8377
Designation: THUN FIELD RESET
Stamping: THUN FIELD RESET
Stability: May hold commonly subject to ground movement
Setting: Set in top of concrete monument
Mark Condition: G
Description:
Observed: 2010-12-04T15:29:00Z See Also 1994
Source: OPUS - page5 1106.16

Close-up View

REF_FRAME: NAD_83(CORS96)	EPOCH: 2002.0000	SOURCE: NAVD88 (Computed using GEOID09)	UNITS: m	SET PROFILE	DETAILS

LAT:	47° 6' 8.99191"	± 0.014 m
LON:	-122° 17' 23.21542"	± 0.020 m
ELL HT:	140.792	± 0.014 m
X:	-2323479.367	± 0.020 m
Y:	-3676832.518	± 0.017 m
Z:	4649631.749	± 0.006 m
ORTHO HT:	162.990	± 0.029 m

	UTM 10	SPC 4602(WA S)
NORTHING:	5216799.107m	198188.729m
EASTING:	553891.282m	364154.600m
CONVERGENCE:	0.52029865°	-1.30009014°
POINT SCALE:	0.99963569	0.99995537
COMBINED FACTOR:	0.99961363	0.99993331

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Watershed Sciences

Horizon View

The numerical values for this position solution have satisfied the quality control criteria of the National Geodetic Survey. The contributor has verified that the information submitted is accurate and complete.

SURVEY DATASHEET (Version 1.0)

PID: BBCK75
Designation: PRC_05
Stamping: PRC_05
Stability: Monument will probably hold position well
Setting: Object driven into ground
Description: Traveling on 112th St E turn left at stop light onto Woodland Ave E. Follow Woodland Ave E for apprx 0.3 miles. Monument will be on the left hand side of the road at a pullout for a recreational area. Monument is located 1 meter SE of the Northern Corner of fence and 5 paces (roughly 4-5 meters) East of the Eastern edge of the road.
Observed: 2010-12-06T15:48:00Z
Source: OPUS - page5 1106.16

Close-up View

REF_FRAME: NAD_83(CORS96)	EPOCH: 2002.0000	SOURCE: NAVD88 (Computed using GEOID09)	UNITS: m	SET PROFILE	DETAILS

LAT:	47° 9' 0.95667"	± 0.010 m
LON:	-122° 20' 9.48913"	± 0.005 m
ELL HT:	102.405	± 0.005 m
X:	-2324346.877	± 0.006 m
Y:	-3671647.868	± 0.009 m
Z:	4653216.880	± 0.005 m
ORTHO HT:	124.816	± 0.019 m

	UTM 10	SPC 4602(WA S)
NORTHING:	5222076.691m	203578.171m
EASTING:	550341.529m	360773.191m
CONVERGENCE:	0.48683759°	-1.33364029°
POINT SCALE:	0.99963115	0.99996326
COMBINED FACTOR:	0.99961510	0.99994721

CONTRIBUTED BY

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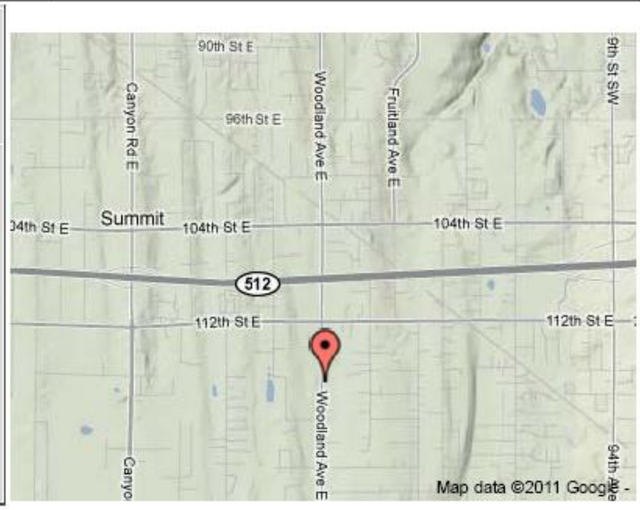
Horizon View



The numerical values for this position solution have satisfied the quality control criteria of the National Geodetic Survey. The contributor has verified that the information submitted is accurate and complete.

SURVEY DATASHEET (Version 1.0)

PID: BBCK74
Designation: PRC_06
Stamping: PRC_06
Stability: Monument will probably hold position well
Setting: Object driven into ground
Description: From intersection of Union Ave and Center St, follow Center street west for 0.9 miles. Take ramp right (N), after the timed light for traffic control, immediately turn right to the roads shoulder. Drive on the grass "road" for 0.2 miles, driving towards the dark brown/black fence (of the park & ride parking lot). Monument is marked by a stake and orange flagging. It is 2 feet from the fringe of the fence.
Observed: 2010-12-11T14:54:00Z
Source: OPUS - page5 1106.16

Close-up View

REF_FRAME: NAD_83(CORS96)	EPOCH: 2002.0000	SOURCE: NAVD88 (Computed using GEOID09)	UNITS: m	SET PROFILE	DETAILS

LAT:	47° 14' 3.96855"	± 0.022 m
LON:	-122° 29' 48.51236"	± 0.022 m
ELL HT:	84.086	± 0.006 m
X:	-2330949.675	± 0.020 m
Y:	-3659307.807	± 0.019 m
Z:	4659562.363	± 0.014 m
ORTHO HT:	106.691	± 0.020 m

	UTM 10	SPC 4602(WA S)
NORTHING:	5231339.422m	213228.797m
EASTING:	538087.695m	348815.609m
CONVERGENCE:	0.36941611°	-1.45047363°
POINT SCALE:	0.99961783	0.99997887
COMBINED FACTOR:	0.99960465	0.99996570

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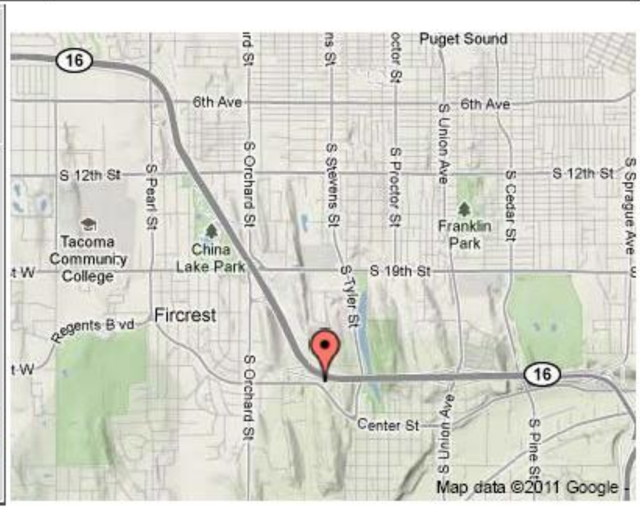
Horizon View



The numerical values for this position solution have satisfied the quality control criteria of the National Geodetic Survey. The contributor has verified that the information submitted is accurate and complete.

SURVEY DATASHEET (Version 1.0)

PID: BBCK77
Designation: PRC_07
Stamping: PRC_07
Stability: Monument will probably hold position well
Setting: Object driven into ground
Description: Drive to the end of 24th St SW where you will turn left (follow the signs for Tacoma Narrows Airport). Follow this side road for 0.2 miles to the end of the road and turn right onto Stone Dr NW. Drive 0.4 miles along Stone Dr. NW until a gravel road pullout appears on your right. Take the gravel road until you reach the end (0.1 miles) of it. Monument is 5 meters up a small hill to the South.
Observed: 2010-12-11T15:44:00Z
Source: OPUS - page5 1106.16

Close-up View

REF_FRAME: NAD_83(CORS96)	EPOCH: 2002.0000	SOURCE: NAVD88 (Computed using GEOID09)	UNITS: m	SET PROFILE	DETAILS

LAT:	47° 16' 34.94795"	± 0.008 m
LON:	-122° 34' 26.89973"	± 0.014 m
ELL HT:	62.339	± 0.001 m
X:	-2334034.885	± 0.012 m
Y:	-3653260.515	± 0.008 m
Z:	4662711.063	± 0.006 m
ORTHO HT:	85.000	± 0.017 m

	UTM 10	SPC 4602(WA S)
NORTHING:	5235965.279m	218040.767m
EASTING:	532208.989m	343084.651m
CONVERGENCE:	0.31285517°	-1.50664569°
POINT SCALE:	0.99961275	0.99998747
COMBINED FACTOR:	0.99960298	0.99997769

CONTRIBUTED BY

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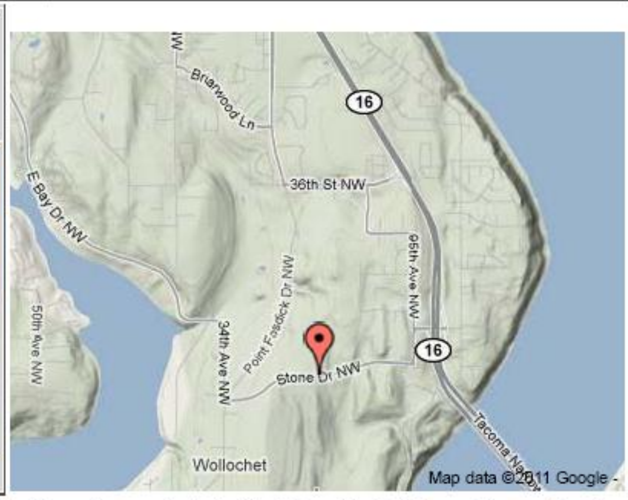
Horizon View



The numerical values for this position solution have satisfied the quality control criteria of the National Geodetic Survey. The contributor has verified that the information submitted is accurate and complete.

SURVEY DATASHEET (Version 1.0)

PID: BBCK82
Designation: PRC_08
Stamping: PRC_08
Stability: Monument will probably hold position well
Setting: Object driven into ground
Description: From Center St (west) take WA-16E ramp on your left (east), continue on WA-16E. After the timed light for traffic control immediately turn to the roads shoulder. There you will head east on the grass service road for approximately 0.2 miles towards a dark brown/black fence (located near a park and ride parking lot). The monument is located 37 feet NxNW of the Western end of the fence.
Observed: 2011-01-02T16:00:00Z
Source: OPUS - page5 1106.16

Close-up View

REF_FRAME: NAD_83(CORS96)	EPOCH: 2002.0000	SOURCE: NAVD88 (Computed using GEOID09)	UNITS: m	SET PROFILE	DETAILS

LAT:	47° 14' 4.14993"	± 0.005 m
LON:	-122° 29' 48.91289"	± 0.018 m
ELL HT:	84.186	± 0.010 m
X:	-2330954.608	± 0.013 m
Y:	-3659299.870	± 0.013 m
Z:	4659566.240	± 0.009 m
ORTHO HT:	106.791	± 0.024 m

	UTM 10	SPC 4602(WA S)
NORTHING:	5231344.966m	213234.609m
EASTING:	538079.237m	348807.329m
CONVERGENCE:	0.36933472°	-1.45055445°
POINT SCALE:	0.99961782	0.99997888
COMBINED FACTOR:	0.99960463	0.99996569

CONTRIBUTED BY

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Watershed Sciences

Horizon View

The numerical values for this position solution have satisfied the quality control criteria of the National Geodetic Survey. The contributor has verified that the information submitted is accurate and complete.

SURVEY DATASHEET (Version 1.0)

PID: BBCK83
Designation: PRC_09
Stamping: PRC_09
Stability: Monument will probably hold position well
Setting: Object driven into ground
Description: Traveling on I-5 South take exit 114 toward Nisqually. Turn left at Nisqually Cut Off Rd and continue for apprx. 0.2 miles. Monument is located on the right side apprx. 18 feet from the white line on the edge of the road.
Observed: 2011-02-06T16:26:00Z
Source: OPUS - page5 1106.16

Close-up View

REF_FRAME: NAD_83(CORS96)	EPOCH: 2002.0000	SOURCE: NAVD88 (Computed using GEOID09)	UNITS: m	SET PROFILE	DETAILS

LAT:	47° 4' 2.57741"	± 0.013 m
LON:	-122° 42' 53.17806"	± 0.017 m
ELL HT:	-15.941	± 0.018 m
X:	-2352175.508	± 0.023 m
Y:	-3661812.932	± 0.013 m
Z:	4646858.762	± 0.011 m
ORTHO HT:	6.228	± 0.035 m

	UTM 10	SPC 4602(WA S)
NORTHING:	5212691.608m	195105.434m
EASTING:	521657.363m	331795.733m
CONVERGENCE:	0.20883222°	-1.60880081°
POINT SCALE:	0.99960576	0.99995002
COMBINED FACTOR:	0.99960826	0.99995252

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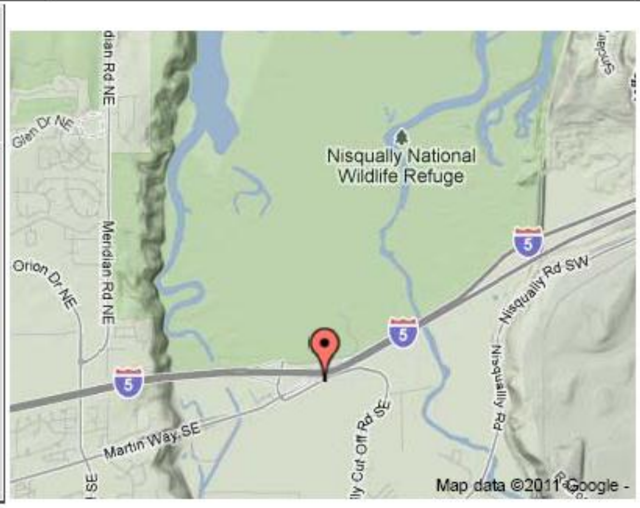
Horizon View



The numerical values for this position solution have satisfied the quality control criteria of the National Geodetic Survey. The contributor has verified that the information submitted is accurate and complete.

SURVEY DATASHEET (Version 1.0)

PID:	BBCK84
Designation:	PRC_10
Stamping:	PRC_10
Stability:	Monument will probably hold position well
Setting:	Object driven into ground
Description:	From I-5 Southbound take exit 119 towards Steilacoom/Dupont Rd. Turn right on Steilcoom road and follow for 0.1 miles and turn into gravel parking lot. Monument is on the south end of the undeveloped lot closest to the freeway slightly into the vegetation.
Observed:	2011-02-06T16:00:00Z
Source:	OPUS - page5 1106.16

Close-up View

REF_FRAME:	EPOCH:	SOURCE:	UNITS:	SET PROFILE	DETAILS
NAD_83(CORS96)	2002.0000	NAVD88 (Computed using GEOID09)	m		

LAT:	47° 5' 39.36891"	± 0.009 m
LON:	-122° 37' 22.60117"	± 0.012 m
ELL HT:	57.472	± 0.013 m
X:	-2345150.651	± 0.016 m
Y:	-3663776.528	± 0.004 m
Z:	4648947.965	± 0.013 m
ORTHO HT:	79.842	± 0.028 m

	UTM 10	SPC 4602(WA S)
NORTHING:	5215708.952m	197901.487m
EASTING:	528615.368m	338848.385m
CONVERGENCE:	0.27618532°	-1.54209813°
POINT SCALE:	0.99961006	0.99995408
COMBINED FACTOR:	0.99960106	0.99994508

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Horizon View

The numerical values for this position solution have satisfied the quality control criteria of the National Geodetic Survey. The contributor has verified that the information submitted is accurate and complete.

SURVEY DATASHEET (Version 1.0)

PID: BBCL04
Designation: PRC_11
Stamping: PRC_11
Stability: Monument will probably hold position well
Setting: Object driven into ground
Description: The monument is located on the South side of 112th St E. Apprx. 170 ft West of 248th Ave and 360 ft East of 246th Ave Ct E. The monument lies 4 feet South of the edge of the pavement (112th St) within the gravel shoulder, very close to where grass and gravel meet.
Observed: 2011-02-10T15:35:00Z
Source: OPUS - page5 1106.16

Close-up View

REF_FRAME: NAD_83(CORS96)	EPOCH: 2002.0000	SOURCE: NAVD88 (Computed using GEOID09)	UNITS: m	SET PROFILE	DETAILS

LAT:	47° 9' 20.13636"	± 0.014 m
LON:	-122° 5' 59.66019"	± 0.015 m
ELL HT:	182.229	± 0.009 m
X:	-2308997.761	± 0.020 m
Y:	-3680871.296	± 0.010 m
Z:	4653678.203	± 0.007 m
ORTHO HT:	204.316	± 0.023 m

	UTM 10	SPC 4602(WA S)
NORTHING:	5222847.850m	203780.432m
EASTING:	568231.078m	378683.947m
CONVERGENCE:	0.65997729°	-1.16216469°
POINT SCALE:	0.99965722	0.99996419
COMBINED FACTOR:	0.99962866	0.99993563

CONTRIBUTED BY

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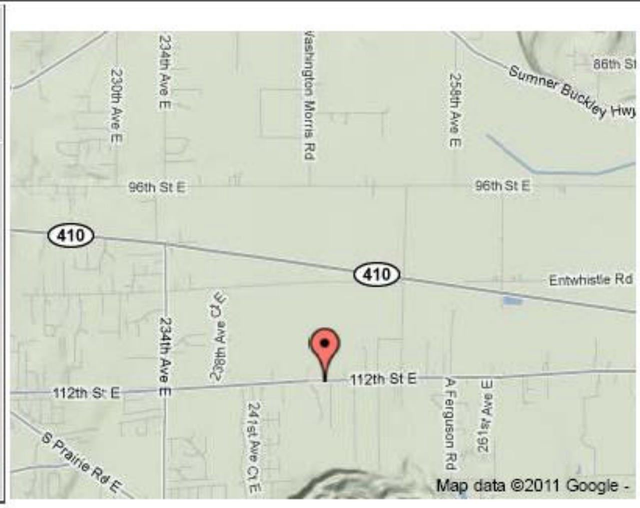
Watershed Sciences

Horizon View



The numerical values for this position solution have satisfied the quality control criteria of the National Geodetic Survey. The contributor has verified that the information submitted is accurate and complete.

SURVEY DATASHEET (Version 1.0)

PID: BBCK85
Designation: PRC_12
Stamping: PRC_12
Stability: Monument will probably hold position well
Setting: Object driven into ground
Description: From 254th Ave turn right (E) on 96th St and continue 0.2 miles. Site is on N shoulder of road ~0.04 miles E of two red sheds that are located in the corners of two adjacent pastures. Monument is 15ft 6in N of the centerline of 96th St, 6ft 10in SE of a wooden fence post on which there is a ~8 inch square wooden sign board that no longer contains a sign, 4ft S of a fence made of wire mesh with barbed wire strands, and 98ft WNW of a power pole numbered "567380" and "160566".
Observed: 2011-04-12T14:55:00Z
Source: OPUS - page5 1106.16

Close-up View

REF_FRAME: NAD_83(CORS96)	EPOCH: 2002.0000	SOURCE: NAVD88 (Computed using GEOID09)	UNITS: m	SET PROFILE	DETAILS

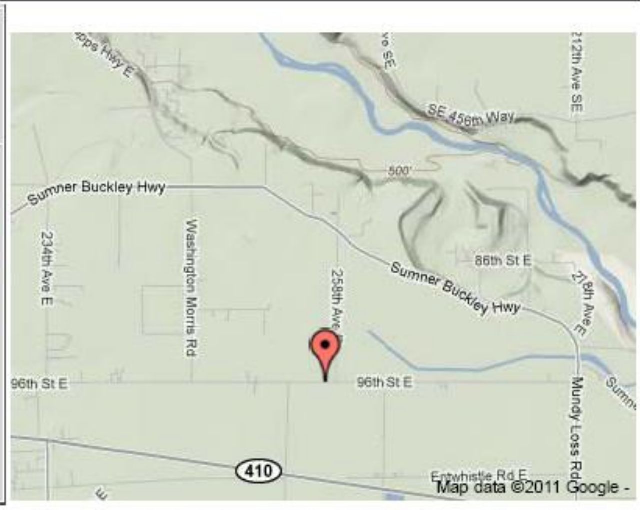
LAT:	47° 10' 12.88897"	± 0.010 m
LON:	-122° 5' 13.30278"	± 0.031 m
ELL HT:	182.531	± 0.013 m
X:	-2307535.952	± 0.028 m
Y:	-3680378.178	± 0.017 m
Z:	4654786.100	± 0.003 m
ORTHO HT:	204.657	± 0.028 m

	UTM 10	SPC 4602(WA S)
NORTHING:	5224487.596m	205389.409m
EASTING:	569188.180m	379693.018m
CONVERGENCE:	0.66957864°	-1.15281085°
POINT SCALE:	0.99965883	0.99996677
COMBINED FACTOR:	0.99963023	0.99993816

CONTRIBUTED BY

wsiopus
Watershed Sciences


Horizon View



The numerical values for this position solution have satisfied the quality control criteria of the National Geodetic Survey. The contributor has verified that the information submitted is accurate and complete.

SURVEY DATASHEET (Version 1.0)

PID: BBCK86
Designation: PRC_13
Stamping: PRC_13
Stability: Monument will probably hold position well
Setting: Object driven into ground
Description: After entering the town of Buckley, WA travel east on Main St and continue 1.4 miles (follow road as it jogs sharply left and immediately sharply right, at which point it becomes Collins Rd) to site on S shoulder of road. Monument is 21ft 4in S of center-line of Collins Rd, 8ft 3in N of a tall wire strand fence, and 157ft E of a yellow fire hydrant.
Observed: 2011-04-08T16:24:00Z
Source: OPUS - page5 1106.16

Close-up View

REF_FRAME:	EPOCH:	SOURCE:	UNITS:	SET PROFILE	DETAILS
NAD_83(CORS96)	2002.0000	NAVD88 (Computed using GEOID09)	m		

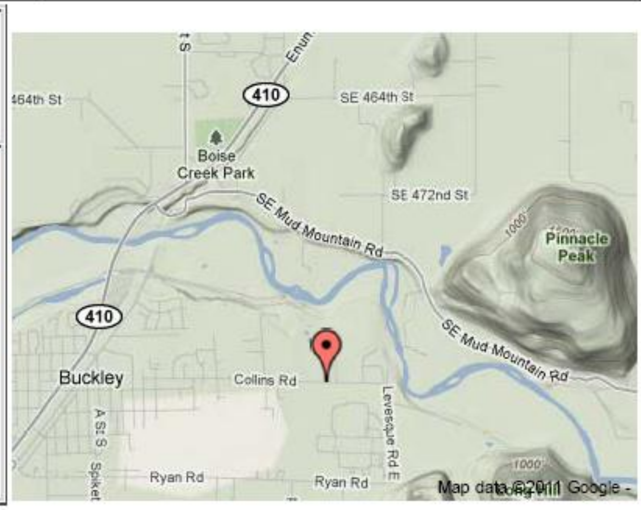
LAT:	47° 9' 48.75262"	± 0.010 m
LON:	-122° 0' 3.48110"	± 0.020 m
ELL HT:	207.153	± 0.011 m
X:	-2302303.756	± 0.020 m
Y:	-3684317.833	± 0.005 m
Z:	4654297.389	± 0.011 m
ORTHO HT:	228.962	± 0.025 m

	UTM 10	SPC 4602(WA S)
NORTHING:	5223822.347m	204516.491m
EASTING:	575719.709m	386202.047m
CONVERGENCE:	0.73262295°	-1.09029608°
POINT SCALE:	0.99967046	0.99996558
COMBINED FACTOR:	0.99963800	0.99993311

CONTRIBUTED BY

wsiopus
Watershed Sciences


Horizon View



The numerical values for this position solution have satisfied the quality control criteria of the National Geodetic Survey. The contributor has verified that the information submitted is accurate and complete.

SURVEY DATASHEET (Version 1.0)

PID: BBCL03
Designation: PRC_JM1
Stamping: PRC_JM1
Stability: Monument will probably hold position well
Setting: Object driven into ground
Description: From Gig Harbor, WA. Take WA-16 E toward Tacoma. Then merge to I-5 southbound and follow for 4.7 miles. Take exit 127 for WA-512 E toward Puyallup and continue for 2.0 miles. Take WA-7 toward Spanaway and continue for 5.1 miles. Slight right onto WA-507 for 12.5 miles. Turn left at WA-702 South and continue 4.3 miles. Monument is on right of the road at the intersection with an unmarked roadway.
Observed: 2011-02-05T16:26:00Z
Source: OPUS - page5 1106.16

Close-up View

REF_FRAME: NAD_83(CORS96)	EPOCH: 2002.0000	SOURCE: NAVD88 (Computed using GEOID09)	UNITS: m	SET PROFILE	DETAILS

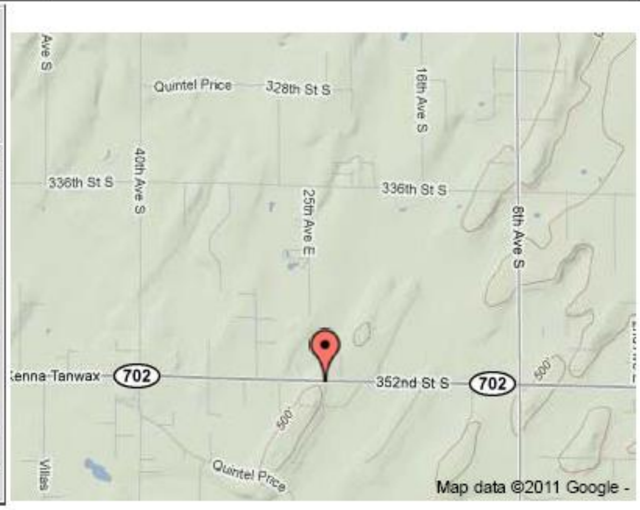
LAT:	46° 56' 15.11896"	± 0.008 m
LON:	-122° 27' 49.81342"	± 0.013 m
ELL HT:	128.644	± 0.008 m
X:	-2341835.690	± 0.008 m
Y:	-3681070.720	± 0.012 m
Z:	4637119.895	± 0.009 m
ORTHO HT:	150.646	± 0.022 m

	UTM 10	SPC 4602(WA S)
NORTHING:	5198361.929m	180170.454m
EASTING:	540809.541m	350489.812m
CONVERGENCE:	0.39173123°	-1.42652296°
POINT SCALE:	0.99962047	0.99993350
COMBINED FACTOR:	0.99960031	0.99991333

CONTRIBUTED BY

WSIOPUS
Watershed Sciences

Horizon View



The numerical values for this position solution have satisfied the quality control criteria of the National Geodetic Survey. The contributor has verified that the information submitted is accurate and complete.

SURVEY DATASHEET (Version 1.0)

PID:	BBCK87
Designation:	PRC_14
Stamping:	PRC_14
Stability:	Monument will probably hold position well
Setting:	Object driven into ground
Description:	Heading West on Center St W from Eatonville take a left (SW) on Larson St W, which will then make a sharp 90 degree turn to your right and become Orchard Ave (S). Drive apprx. 75 meters, there will be a pull out to your left (E). The monument resides in this area and is approximately 5 feet away from the edge of the road. Noticeable markings near the monument are a long pile of rocks as well as concrete dividers that run perpendicular to the road.
Observed:	2011-04-19T16:39:00Z
Source:	OPUS - page5 1106.16

Close-up View

REF_FRAME: NAD_83(CORS96)	EPOCH: 2002.0000	SOURCE: NAVD88 (Computed using GEOID09)	UNITS: m	SET PROFILE	DETAILS

LAT:	46° 51' 48.18146"	± 0.008	m
LON:	-122° 15' 28.94994"	± 0.003	m
ELL HT:	237.698	± 0.012	m
X:	-2331851.234	± 0.007	m
Y:	-3694611.391	± 0.006	m
Z:	4631567.118	± 0.010	m
ORTHO HT:	258.996	± 0.026	m

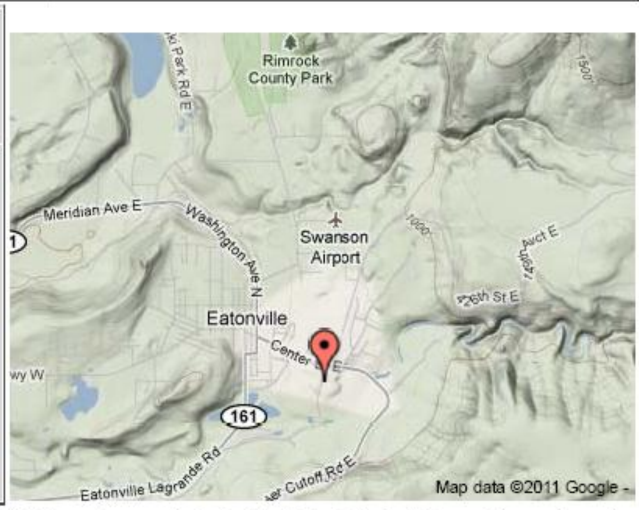
	UTM 10	SPC 4602(WA S)
NORTHING:	5190249.825m	171560.335m
EASTING:	556551.330m	365970.916m
CONVERGENCE:	0.54144018°	-1.27703404°
POINT SCALE:	0.99963931	0.99992638
COMBINED FACTOR:	0.99960206	0.99988912

CONTRIBUTED BY

wsiopus

Watershed Sciences

Horizon View



The numerical values for this position solution have satisfied the quality control criteria of the National Geodetic Survey. The contributor has verified that the information submitted is accurate and complete.

SURVEY DATASHEET (Version 1.0)

PID: BBCM31
Designation: PRC_15
Stamping: PIERCE 15
Stability: Monument will probably hold position well
Setting: Object driven into ground
Description: From Eatonville HWY take a right (E) on Larson St W for 0.21 miles where it will then make a sharp right turn and become Orchard Ave S. Travel approximately 250 feet and pull off to the left shoulder(E). The monument is located 80 feet East of the edge of the road's pavement. It is apprx. 15 feet away from where the pullout (with a ground cover of 5-8 inch grass) meets a shrub fence line.
Observed: 2011-04-19T16:28:00Z
Source: OPUS - page5 1106.16

Close-up View

REF_FRAME: NAD_83(CORS96)	EPOCH: 2002.0000	SOURCE: NAVD88 (Computed using GEOID09)	UNITS: m	SET PROFILE	DETAILS

LAT:	46° 51' 52.87082"	± 0.006 m
LON:	-122° 16' 7.64355"	± 0.015 m
ELL HT:	268.068	± 0.009 m
X:	-2332498.939	± 0.013 m
Y:	-3694102.093	± 0.008 m
Z:	4631688.293	± 0.007 m
ORTHO HT:	289.405	± 0.023 m

	UTM 10	SPC 4602(WA S)
NORTHING:	5190386.889m	171723.415m
EASTING:	555730.766m	365154.879m
CONVERGENCE:	0.53360769°	-1.28484151°
POINT SCALE:	0.99963817	0.99992649
COMBINED FACTOR:	0.99959617	0.99988447

CONTRIBUTED BY

wsiopus
Watershed Sciences

Horizon View

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SURVEY DATASHEET (Version 1.0)

PID:	BBCK88
Designation:	PRC_16
Stamping:	PRC_16
Stability:	Monument will probably hold position well
Setting:	Object driven into ground
Description:	The monument is located within a clear cut next to the gravel road you drive in on. Its apprx. location is 30 meters past the beginning of the clear cut. And is 7 feet from the left side (S) of the edge of the gravel road.
Observed:	2011-04-28T16:39:00Z
Source:	OPUS - page5 1106.16

Close-up View

REF_FRAME: NAD_83(CORS96)	EPOCH: 2002.0000	SOURCE: NAVD88 (Computed using GEOID09)	UNITS: m	SET PROFILE	DETAILS

LAT:	47° 5' 41.55215"	± 0.012 m
LON:	-121° 58' 49.22075"	± 0.013 m
ELL HT:	508.384	± 0.016 m
X:	-2304049.047	± 0.015 m
Y:	-3690066.278	± 0.005 m
Z:	4649324.150	± 0.018 m
ORTHO HT:	529.646	± 0.032 m

	UTM 10	SPC 4602(WA S)
NORTHING:	5216211.768m	196854.667m
EASTING:	577382.683m	387622.537m
CONVERGENCE:	0.74692016°	-1.07531208°
POINT SCALE:	0.99967359	0.99995418
COMBINED FACTOR:	0.99959394	0.99987450

CONTRIBUTED BY

wsiopus
Watershed Sciences

Horizon View

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SURVEY DATASHEET (Version 1.0)

PID: BBCM30
Designation: PRC_17
Stamping: PIERCE 17
Stability: Monument will probably hold position well
Setting: Object driven into ground
Description: MONUMENT IS LOCATED OFF WA 165 APPROX. 5 MI. E. OF MT. RAINIER NAT'L PARK. MONUMENT IS LOCATED APPROX. 6 MI. E. FROM FORK OF WA 165 AND CARBON CRK. RD. ON WA 165. MONUMENT IS LOCATED ON N. SIDE OF WA 165 APPROX 150 YDS. FROM RD. ON A SMALL HILLTOP.
Observed: 2011-07-06T18:16:00Z
Source: OPUS - page5 1106.16

Close-up View

REF_FRAME: NAD_83(CORS96)	EPOCH: 2002.0000	SOURCE: NAVD88 (Computed using GEOID09)	UNITS: m	SET PROFILE	DETAILS

LAT:	46° 58' 2.68909"	± 0.023 m
LON:	-122° 0' 31.20599"	± 0.015 m
ELL HT:	871.040	± 0.012 m
X:	-2311500.757	± 0.018 m
Y:	-3697929.438	± 0.020 m
Z:	4639930.099	± 0.012 m
ORTHO HT:	891.736	± 0.027 m

	UTM 10	SPC 4602(WA S)
NORTHING:	5202019.814m	182728.654m
EASTING:	575412.118m	385201.231m
CONVERGENCE:	0.72466344°	-1.09589032°
POINT SCALE:	0.99966990	0.99993684
COMBINED FACTOR:	0.99953342	0.99980033

CONTRIBUTED BY

wsiopus
Watershed Sciences

Horizon View

The numerical values for this position solution have satisfied the quality control criteria of the National Geodetic Survey. The contributor has verified that the information submitted is accurate and complete.