OLC Lane County Delivery 4-10 Acceptance Report.pdf

Lane_County_Delivery_1-3_Acceptance_Report.pdf

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OLC Lane County Lidar Project, 2013-2015
Delivery 4 – 10 Lidar QC Report – November 10th, 2016

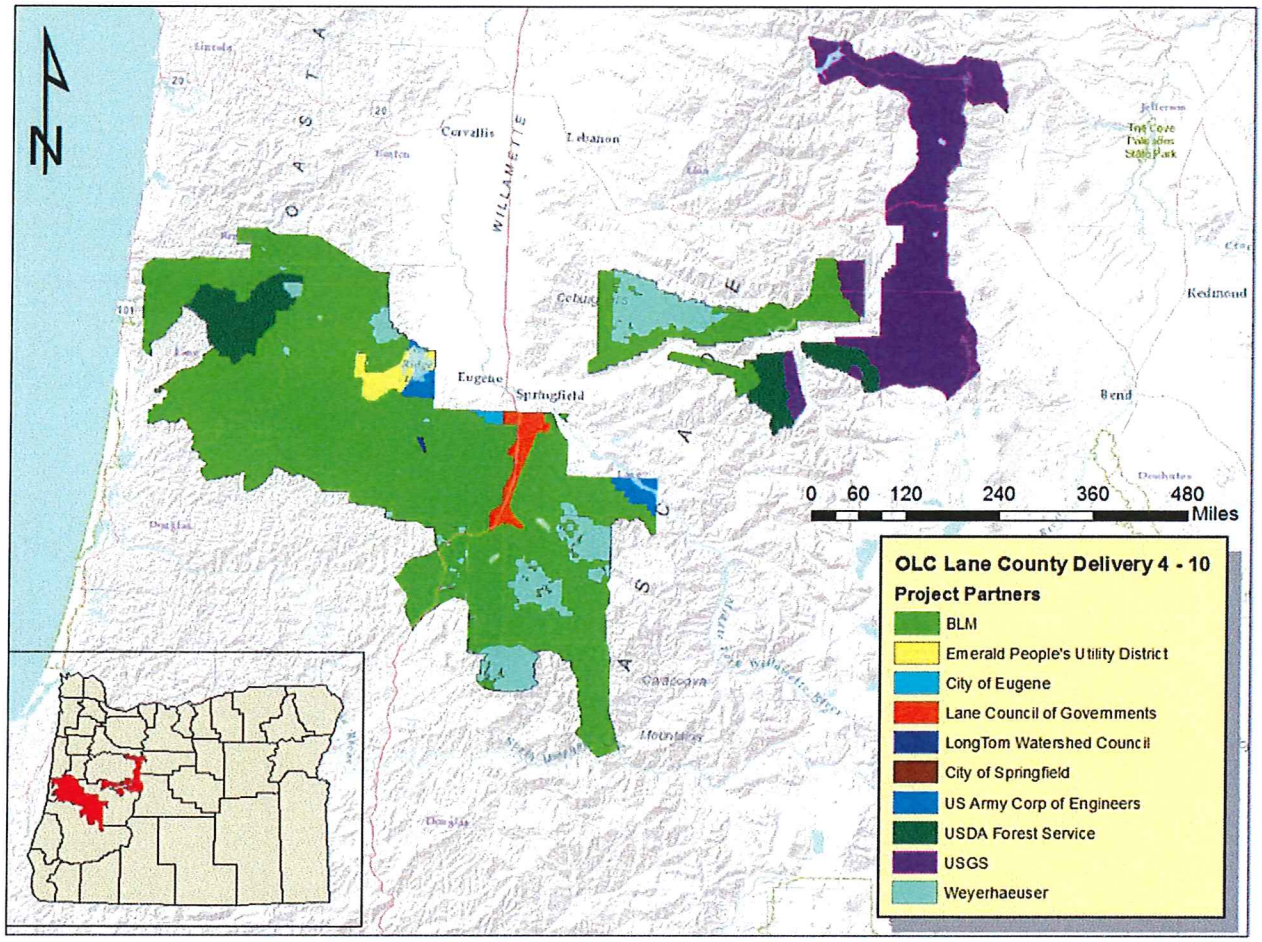

Figure 1: Map showing the extent of OLC Lane County Deliveries 4 through 10 and the project partners.

The Oregon Department of Geology & Mineral Industries (DOGAMI) has contracted with Watershed Sciences (WSI) to collect high resolution lidar topographic data for multiple areas within the Pacific Northwest. Areas for lidar and ortho-imagery data collection have been designed as part of a collaborative effort of State, Federal, and Local agencies in order to meet a wide range of project goals. The vendor has agreed to certain conditions of data quality and standards for all lidar data deliverables listed in sections A through C of the 2007-2014 Lidar Data Acquisition Price Agreement (OPA #8865, pages 14-23). Data submitted under this price agreement are to be collected at a

resolution of at least 8 pulses per square meter and processed to meet or exceed the agreed upon data quality standards. This document itemizes and reports upon the Lane County Delivery 4 -10 Lidar Project (Figure 1) products furnished by the lidar vendor as documentation that all data meets project specific standards.

Upon receipt from vendor WSI, all lidar data for Lane County Delivery 4 -10 were independently reviewed by DOGAMI staff to ensure project specifications were met. All data was inventoried for completeness and checked for quality, which included examining lidar data for errors associated with internal data consistency, model quality, and accuracy. The specific quality control checks are:

- Data Completeness examines all data associated with this delivery to ensure that all required data products are present and function correctly. Quality control review is conducted on every data file delivered to DOGAMI. Lidar ASCII Standard (LAS) point files have been loaded into TerraSolid and ArcGIS to ensure complete and correct lidar data coverage and file integrity. Raster and vector files have been viewed in ArcMap and cross referenced with the delivery area to ensure proper coverage, extent and integrity.
- Spot Diameter Analysis determines the area of ground that is intersected by a laser pulse from the lidar sensor. The spot diameter is a product of the flying height of the aircraft and the beam divergence of the sensor used during acquisition of the data
- Swath Overlap is independently verified by analyzing flight line extents in TerraSolid and making direct measurements of flight line overlap in multiple lidar tiles.
- Swath-to-Swath Consistency Analysis involves examining flight line offsets to quantify the accuracy of data calibration. Calibration influences elevation data quality. Poor calibration leads to small but systematic errors within lidar elevation points, which then create inaccuracies within derived lidar elevation models.
- Visual Analysis is carried out in order to identify potential data artifacts and misclassifications of lidar point data. Lidar point data is classified as either ground, above ground, or error points. Sophisticated processing scripts are used to classify point data and remove error points. The vendor reviews the automated classification to fix misclassifications of point data. The delivered bare earth digital elevation model (DEM) is then reviewed by DOGAMI to ensure that the data classification is correct and there are no topographic processing artifacts. If valid errors are found, data must be corrected and resubmitted.
- Absolute Accuracy Analysis compares the delivered bare-earth DEMs with independent Ground Check Points (GCPs) to quantify vertical and horizontal accuracy. For each lidar collection project DOGAMI staff collects independent GCPs with survey-grade GPS, which are then compared against delivered lidar elevation models.
- Metadata Analysis compares the structure of the metadata file against FGDC standards. Metadata content is reviewed by using a visual check as well as analysis by the USGS Geospatial Metadata validation service.

Data Completeness

Deliveries 4 through 10 of the OLC Lane County project were collected between September 7th 2013 and July 8th 2015. Total area of delivered data for deliveries 4 -10 equals 2,887 square miles (1,847,680 acres). These deliveries contain data for 111 USGS 7.5 minute quads within the boundary of the Lane County Delivery 4 -10 survey collection area (Figure 2):

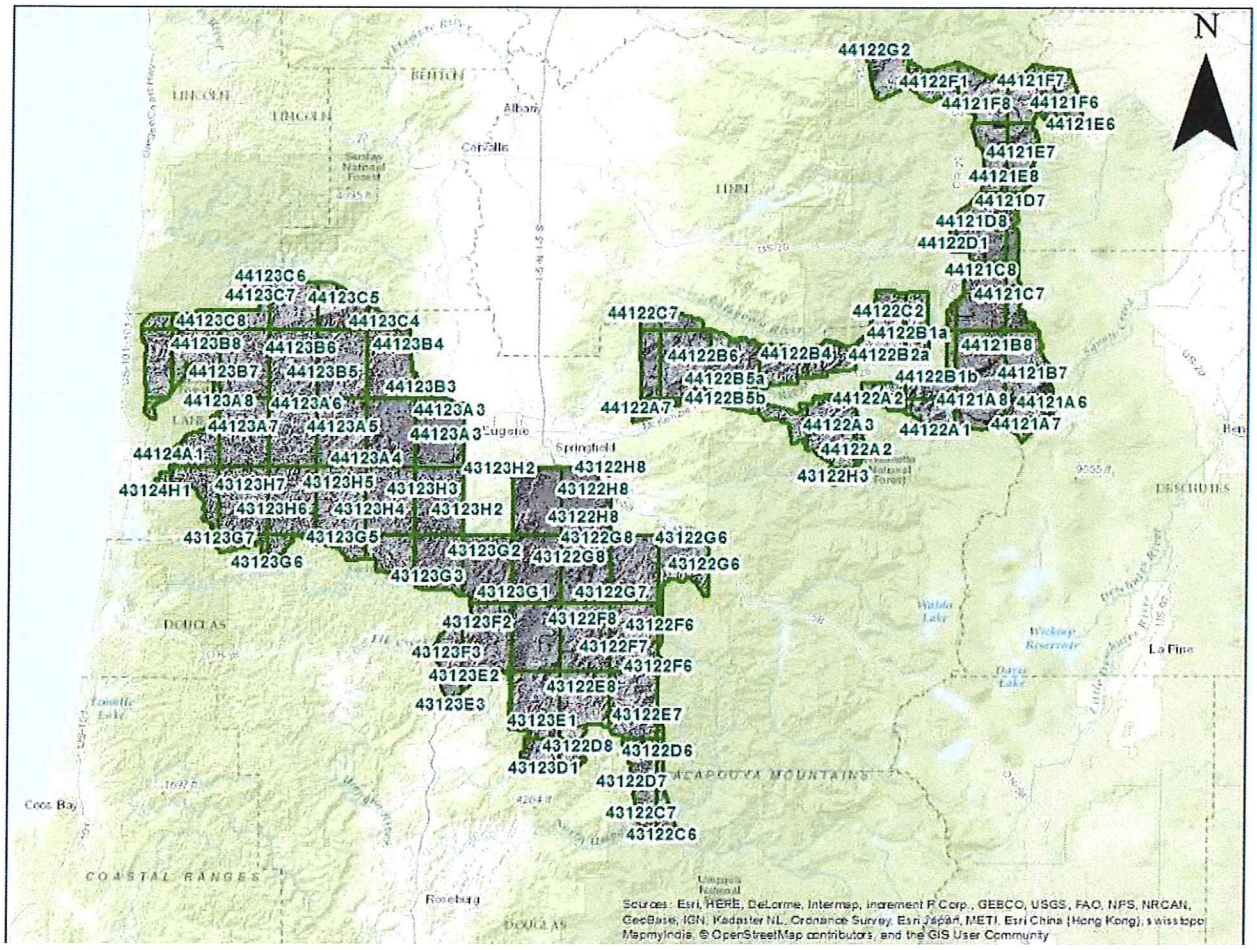

Figure 2: Lane County Delivery 4 -10 delivery area. Data is referenced to USGS 7.5 minute quadrangles within the extents of the Lane County Delivery 4 -10 collection area.

We review data acquisition parameters to ensure that the vendor has met all data collection requirements outlined in the Lidar Data Acquisition Price Agreement (OPA #8865). DOGAMI staff verifies acquisition specifications by analyzing LAS point data records. Every LAS file (version 1.2 or higher) contains binary data consisting of a header block, variable length record and point data. The header block contains information such as point numbers, coordinate bounds, and GPS time. The variable length record includes information on who created the data and the recorded length of information. The point data records include information on return number, intensity value and scan angle rank. Using the "Create LAS Dataset" tool in the ArcGIS™ Data Management toolbox, we analyze

multiple LAS headers and create statistical information about the collection method for the entire project. Analyzing the LAS files and the information stored within them allows DOGAMI to verify acquisition requirements were met during data collection (Table 1).

Quality Control for Aerial Acquisition Specifications			
Specifications	**Description**	**Checked on this delivery**	**Comments**
Survey Conditions	Lidar data collection shall be conducted in snow-free conditions with the contractor make best effort to acquire data in leaf-off and low stream conditions	Yes	None
Pulse Returns	Lidar sensor used must be capable of recording a minimum of 4 returns per laser pulse, including first and last returns.	Yes	5 return classes
Spot Diameter	Produce an on-ground laser spot diameter no less than 15cm and no greater than 40cm	Yes	None
Horizontal Datum	North American Datum (NAD) 83 (2011) or the most current horizontal datum at the beginning of the survey	Yes	None
Vertical Datum	North American Vertical Datum (NAVD) 88 (Geoid 12A) or the most current Geoid model at the beginning of the survey	Yes	None
Scan Angle	Laser scan angle must not exceed 30 degrees overall (+15 to -15 degrees)	Yes	None
Swath Overlap	Contractor shall plan surveys with 50% sidelap of adjacent swaths. Survey must be designed for 100% double coverage at planned aircraft height above ground.	Yes	None
Design Pulse Density	Aggregate design multi-swath pulse density must be 8.0 pulses per square meter or higher.	Yes	None
Intensity Range	Record intensity range of at least 8 bits	Yes	None
GPS Procedures	At least two dual frequency L1-L2 GPS reference receivers operating during missions at 1 Hz or higher. All GPS measurements must be made with Positional Dilution of Precision (PDOP) less than or equal to 3.0 with at least 6 satellites in view.	Yes	None

Table 1: Acquisition Specifications Checklist

We review each product deliverable's format, resolution and tiling scheme in order to verify content completeness. Deliveries 4 - 10 of the OLC Lane County lidar project includes data in the format of LAS point files, bare earth grids, highest hit grids, intensity images, trajectory files, ground point density rasters, RTK survey data, vector files of the delivery area and the report of survey. The OLC Lane County project also collected 3 inch ortho imagery for 149 sq. miles of the project area. Lidar all-return point cloud data is delivered as LAS binary format with all required attribute fields populated (Table 2). Bare earth surface models are created from identified ground points and interpolated via triangulated irregular network into an ArcGIS™ Grid format with 3ft cell size (Table 3). Highest hit digital surface models (DSM) are created from a raster of first-return points that are

delivered in ArcGIS™ Grid format with 3ft cell size (Table 4). Georeferenced intensity images created from first-return points and are supplied in TIFF format (Table 5). Supplementary data including trajectory files, ground density rasters, real time kinematic ground survey data (used for absolute vertical adjustment) and delivery area shapefiles are provided in various formats (Table 6). The report of survey is a digital text report, supplied by the vendor, that describes lidar data collection methods and processing. The report also provides accuracies associated with calibration, consistency, absolute error and point classification (Table 7). Optional Ortho-imagery collected during the same time as the lidar are delivered in TIFF format and at a resolution of 3 inch pixels (Table 8).

Quality Control for Delivered All-Return LAS Files			
Specifications	**Description**	**Checked on this delivery**	**Comments**
LAS File Description	Binary file of all Lidar points collected in survey (Class, flight line #, GPS Time, Echo, Easting, Northing, Elevation, Intensity, Scan Angle, Echo Number, and Scanner).	Yes	None
Format	LAS version 1.2 or most commonly distributed LAS format files, as specified in a Purchase Order	Yes	None
Projection	Oregon Statewide Lambert Conformal Conic	Yes	None
Horizontal Datum	NAD 1983 (2011)	Yes	None
Horizontal Units	International Feet	Yes	None
Vertical Datum	NAVD 88 (Geoid 12A)	Yes	None
Vertical Units	International Feet	Yes	None
Classification	Class 1 - Unclassified; Class2 – Ground Classification of ground returns must be as complete as is feasible and without avoidable return misclassification	Yes	None
Return Number	Must list all valid returns – Lidar sensor used must be capable of recording a minimum **of 4 returns per laser pulse**, including first and last returns.	Yes	Up to 5 returns were recorded
Time	GPS Seconds per week Use header information – time should be between 0 and 604800	Yes	None
Attributes	No duplicate entries	Yes	None
Location	Each return contain easting, northing, elevation information reported to nearest 0.01 meter (0.01 feet)	Yes	None
RGB values	All LAS files have RGB values attributed to them where applicable.	Yes	None
Delivery	LAS data must be delivered in 1/100th USGS 7.5 minute quadrangle tiles or specified in Purchase Order	Yes	None

Gaps	Check for Gaps in LAS coverage. (Already part of QC process)	Yes	None

Table 2: Quality Control for LAS Deliverables

Quality Control for Delivered Bare Earth DEMs			
Specifications	**Description**	**Checked on this delivery**	**Comments**
Bare Earth DEM Description	Raster of ground surface, interpolated via triangulated irregular network from identified ground points.	Yes	None
Projection	Oregon Statewide Lambert Conformal Conic	Yes	None
Horizontal Datum	NAD 83 (2011)	Yes	None
Horizontal Units	International Feet	Yes	None
Vertical Datum	NAVD 88 (Geoid 12A)	Yes	None
Vertical Units	International Feet	Yes	None
Format	Esri™ 32 bit pixel depth floating point grid	Yes	None
Cell Size / Resolution	3 foot (1m if UTM projection specified)	Yes	None
Tiling	Full USGS 7.5-minute quadrangle (7.5 minute by 7.5 minute) tiles, unless otherwise specified in a purchase order	Yes	None
Attributes	No duplicate entries	Yes	None
Gaps	Surface Models must not have tiling artifacts or gaps at tile boundaries or artifacts such as pits, birds, striping or aliasing	Yes	None

Table 3: Quality Control for Bare Earth DEMs

Quality Control for Delivered Highest-Hit DSMs			
Specifications	**Description**	**Checked on this delivery**	**Comments**
Highest Hit Description	Tin interpolated grids created from the highest Lidar elevation for a given 3ft cell.	Yes	None
Projection	Oregon Statewide Lambert Conformal Conic	Yes	None
Horizontal Datum	NAD 83 (2011)	Yes	None
Horizontal Units	International Feet	Yes	None
Vertical Datum	NAVD 88 (Geoid 12A)	Yes	None
Vertical Units	International Feet	Yes	None
Format	Esri™ 32 bit pixel depth floating point grid	Yes	None

Cell Size / Resolution	3 foot (1m if UTM projection specified)	Yes	None
Tiling	Full USGS 7.5-minute quadrangle (7.5 minute by 7.5 minute) tiles, unless otherwise specified in a purchase order	Yes	None
Attributes	No duplicate entries	Yes	None
Gaps	Surface Models must not have tiling artifacts or gaps at tile boundaries or artifacts such as pits, birds, striping or aliasing	Yes	None

Table 4: Quality Control for Highest-Hit DSMs

Quality Control for Delivered Intensity Images			
Specifications	**Description**	**Checked on this delivery**	**Comments**
Intensity Description	TIFF Raster built using returned lidar pulse intensity values gathered from highest hit returns	Yes	None
Horizontal Datum	NAD83 2011	Yes	None
Projection	Oregon Statewide Lambert Conformal Conic	Yes	None
Horizontal Units	International Feet	Yes	None
Format	GEOTIFF	Yes	None
Pixel Depth	8 bit pixel depth gray scale	Yes	16 bit pixel depth – better than required
Cell Size (X, Y)	1.5 foot (1m if UTM projection specified)	Yes	none
Normalized	Intensity shall have been normalized if the sensor or combination of sensors used on the project allow.	Yes	None
Attributes	Intensity file structure conforms to full USGS 7.5 minute quadrangle (7.5 minute by 7.5 minute) tiles	Yes	None
Gaps	Deliverable tiles checked for significant gaps not covered by aerial acquisition checks and/or caused by processing	Yes	None

Table 5: Quality Control of Intensity Images

Quality Control for Supplementary Data					
Specifications	**Description**	**Format**	**Tiling**	**Projection**	**Checked on this delivery**
Ground Survey Point Shapefile	Ground Control Points used for survey calibration and assessment of absolute vertical accuracy	Esri™ Shapefile		NAD 1983 UTM Zone 11N (2011), meter	Yes
Trajectory Files	Point location measurements of the aircraft used to collect lidar data. Data is collected using an Inertial Measurement Unit (IMU), and collects measurements of: Easting (meters), Northing (meters), Ellipsoid Height (meters) of aircraft, aircraft roll (degrees), aircraft pitch (degrees), aircraft heading (degrees). Measurements are collected at one second intervals.	ascii point file - (TXYZRPH)	Date and time of acquisition	NAD 1983 UTM Zone 11N (2011), meter	Yes
Trajectory Shapefile	Trajectory data in Esri™ shapefile format attributed with project name and date of acquisition for each flight line	Esri™ Shapefile		NAD 1983 UTM Zone 11N (2011), meter	Yes
7.5 minute Quadrangle	Geometry file depicting the geospatial area associated with deliverables.	Esri™ Shapefile	Full USGS 7.5 minute quadrangle	NAD 1983 Oregon Statewide Lambert Conformal Conic (2011), Intl. Feet	Yes
0.75 minute 1/100th quadrangle	Geometry file depicting the geospatial area associated with deliverables.	Esri™ Shapefile	1/100th USGS 7.5 minute quadrangle	NAD 1983 Oregon Statewide Lambert Conformal Conic (2011), Intl. Feet	Yes
TerraSolid Processing Bins	DGN file that contains processing bins for all LAS files	DXF or DGN file	1/100th USGS 7.5 minute quadrangle	NAD 1983 Oregon Statewide Lambert Conformal Conic (2011), Intl. Feet	Yes
Delivery Area Shapefile	Geometry file depicting the geospatial area associated with deliverables.	Esri™ Shapefile	Alaska State Plane NAD 83	NAD 1983 Oregon Statewide Lambert Conformal Conic (2011), Intl. Feet	Yes

Table 6: Quality Control for Supplementary Data

Quality Control of the Report of Survey			
Specifications	**Description**	**Checked on this delivery**	**Comment**
Project Overview	Acquisition information that includes location map, project area, total area flown, acquisition dates and specified coordinate system and datum	Yes	Yes
Aerial Acquisition	Acquisition parameters including information about the aircraft, sensor, flight elevation and a map of flight line trajectories showing dates of collection	Yes	Yes
Report of Ground Survey	A detailed description of GPS procedures used in establishing the reference network and control points for the project. Includes a reference map and table showing monuments used and the location of all GCPs collected.	Yes	Yes
Calibration Report	A report for the systems used in the data acquisition	Yes	More information needed
Relative Accuracy Assessment	Relative accuracy refers to the internal consistency of the data set and is measured as the differential between lidar points collected from different flight lines. Data should be presented as summary statistics and histogram form based on the entire study area.	Yes	Yes
Vertical Accuracy Assessment	Vertical accuracy shall be reported to meet the guidelines of the National Standard for Spatial Data Accuracy (Federal Geographic Data Committee (FGDC), 1998) and ASPRS Guidelines for Vertical Accuracy Reporting for Lidar Data V1.0 (American Society for Photogrammetry and Remote Sensing (ASPRS), 2004). Data shall be presented as both summary statistics and in histogram form.	Yes	Yes
Pulse Density Assessment	Contractor's assessment of pulse density over the project area, including maps showing design pulse density and ground return densities by quarter-quadrangle and histograms of both density parameters.	Yes	Yes
Summary Table	Table of deliverables, listing file formats and total number and data volume of each deliverable.	Yes	Table of deliverables not listed

Table 7: Quality Control of the Report of Survey

Quality Control of Ortho Imagery			
Specifications	**Description**	**Checked on this delivery**	**Comments**
Ortho-Imagery Description	The photography or Four-Band Radio Metric Image Enhanced Survey (FRIES) utilized an UltraCam Eagle 260 megapixel camera mounted in a Cessna 208B Caravan. The UltraCam Eagle is an 80 mm, 260 megapixel large format digital aerial camera manufactured by the Microsoft Corporation. The system is gyro-stabilized and contains a fully integrated UltraNav flight management system with a POS-AV 510 IMU embedded within the body of the camera unit.	Yes	Ortho imagery product exceeds expectation
Projection	Oregon Statewide Lambert Conformal Conic	Yes	None
Horizontal Datum	NAD 83 (2011)	Yes	None
Horizontal Units	International Feet	Yes	None
Resolution	3 inch pixel resolution	Yes	TIFF resolution is 0.25. Equates to roughly 3 inch resolution if the horizontal units are in feet.
Format	8 bit Geo-TIFF	Yes	None
Spectral Bands	Four band imagery is multispectral, which means that it is collected from several parts of the electromagnetic spectrum. Four band imager typically contains red, green, blue, and near infrared bands.	Yes	Each imagery TIFF contains 4 bands and the option to change band combinations.

Table 8: Quality Control of Ortho Imagery

Spot Diameter Analysis

Horizontal accuracy is not specified in the price agreement since true horizontal accuracy is regarded as a product of the lidar spot diameter (SD). The lidar spot diameter is the area of ground that is intersected by a single pulse from the lidar sensor. SD is a function of range and beam divergence. The range is calculated as the distance between the laser aperture and the detected surface. The reported range value is given as above ground level flying height (AGL) of the sensor during collection. Beam divergence (γ) is the degree by which the light pulse emitted from the sensor fans out from a straight line. Beam divergence is measured in radians, with 1 radian = 57.3 degrees. The lidar SD is calculated by multiplying AGL and beam divergence, SD = AGL * γ

Lane County Delivery 4 – 10 data was collected using a Leica ALS50 at 900 meters AGL and an ALS70 lidar sensors flown at 1400 meters. Lane County Delivery 10 was collected with an ALS80 sensor flown at 1500m AGL. The specification sheet for ALS 50 and ALS70 reports a beam divergence value of 0.22 milliradians @ $1/e^2$, meaning that ~85% of the laser energy falls within this divergence. The specification sheet for ASL80 reports a beam divergence value of 0.20-0.26 mr @ 1/e^2, meaning that ~85% of the laser energy falls within that divergence.

The spot diameters for the Lane County project is 0.198 meters for ALS50, 0.308 meters for ALS70 and 0.345 meters for ALS80. The average spot diameter for the lidar collected for Lane County Delivery 4 -10 is 0.284 meters, which is within the project specification tolerance of 0.15 meter to 0.40 meter for spot diameter.

Swath-to-Swath Consistency Analysis

DOGAMI has specified that lidar consistency must average less than 0.15m (0.49 feet) in vertical offsets between flight lines. DOGAMI measures consistency offsets throughout delivered datasets to ensure that project specifications are met.

Consistency refers to lidar elevation differences between overlapping flight lines. Consistency errors are created by poor lidar system calibration settings associated with sensor platform mounting. Errors in consistency manifest as vertical offsets between individual flight lines. Consistency offsets were measured using the "Find Match" tool within the TerraMatch© software toolset. This tool uses aircraft trajectory information linked to the lidar point cloud to quantify flight line-to-flight line offsets.

To quantify the magnitude of this error 9502 delivered data tiles were examined for vertical offset between flight lines. Data tiles with less than 1000 points were not used in analysis. Selection of tiles aimed to evenly sample the delivered spatial extent of data. Each tile measured 750 x 750 meters in size (Figure 4). Within each tile, we selected all ground classified points from each flight line, and compared the elevations of the points in each set of overlapping lines. The average number of points used for flight line comparison was 4,678,954 per tile (Table 9a). Error measurements were

calculated by differencing the nearest point from an adjacent flight line within 1 meter in the horizontal plane and 0.2 meters in the vertical plane. Each flight line was compared to adjacent flight lines, and the average magnitude of vertical error was calculated. A total of 3,750 flight lines were sampled and compared for consistency.

Results of the consistency analysis found the average flight line offset to be 0.04 meters with a maximum error of 0.10 meters (Table 9b). Distribution of error showed 96% of all error was less than 0.06 meters. These results show that all data are within tolerances of data consistency according to contract agreement.

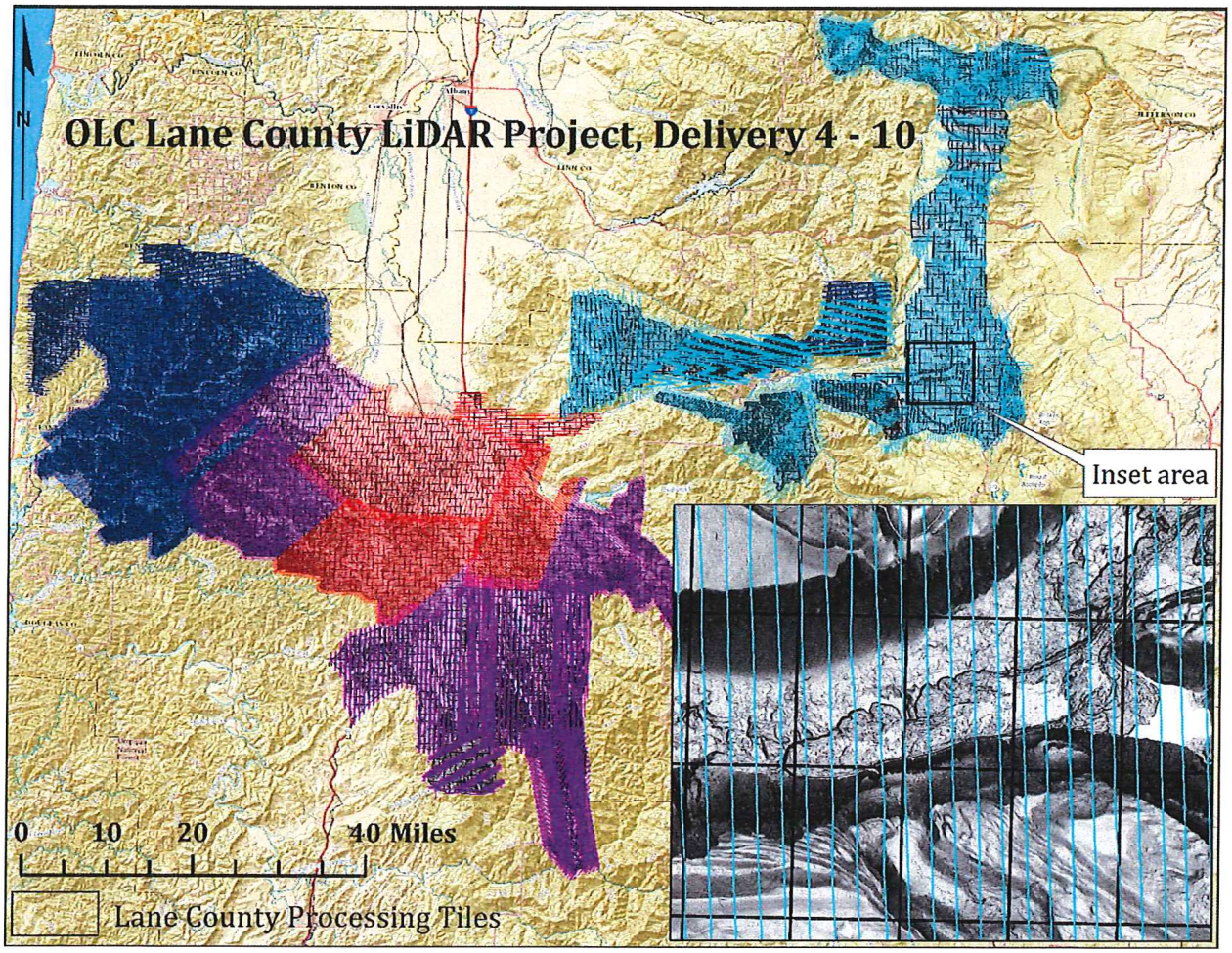

Figure 3: Spatial distribution of flight lines and processing tiles used in the consistency analysis.

Table 9a: Summary Results of Consistency Analysis

Summary Statistics	
# of Tiles	9502
# of Flight Line Sections	3750
Avg. # of Points	4,678,954
Avg. Magnitude Z error	0.04 meters

Table 9b: Descriptive Statistics for Magnitude Z Error.

Descriptive Statistics	Meters	Feet
Mean	0.04	0.13
Standard Error	0.00	0.00
Standard Deviation	0.010	0.03
Sample Variance	0.00	0.00
Range	0.10	0.33
Minimum	0.00	0.00
Maximum	0.10	0.33

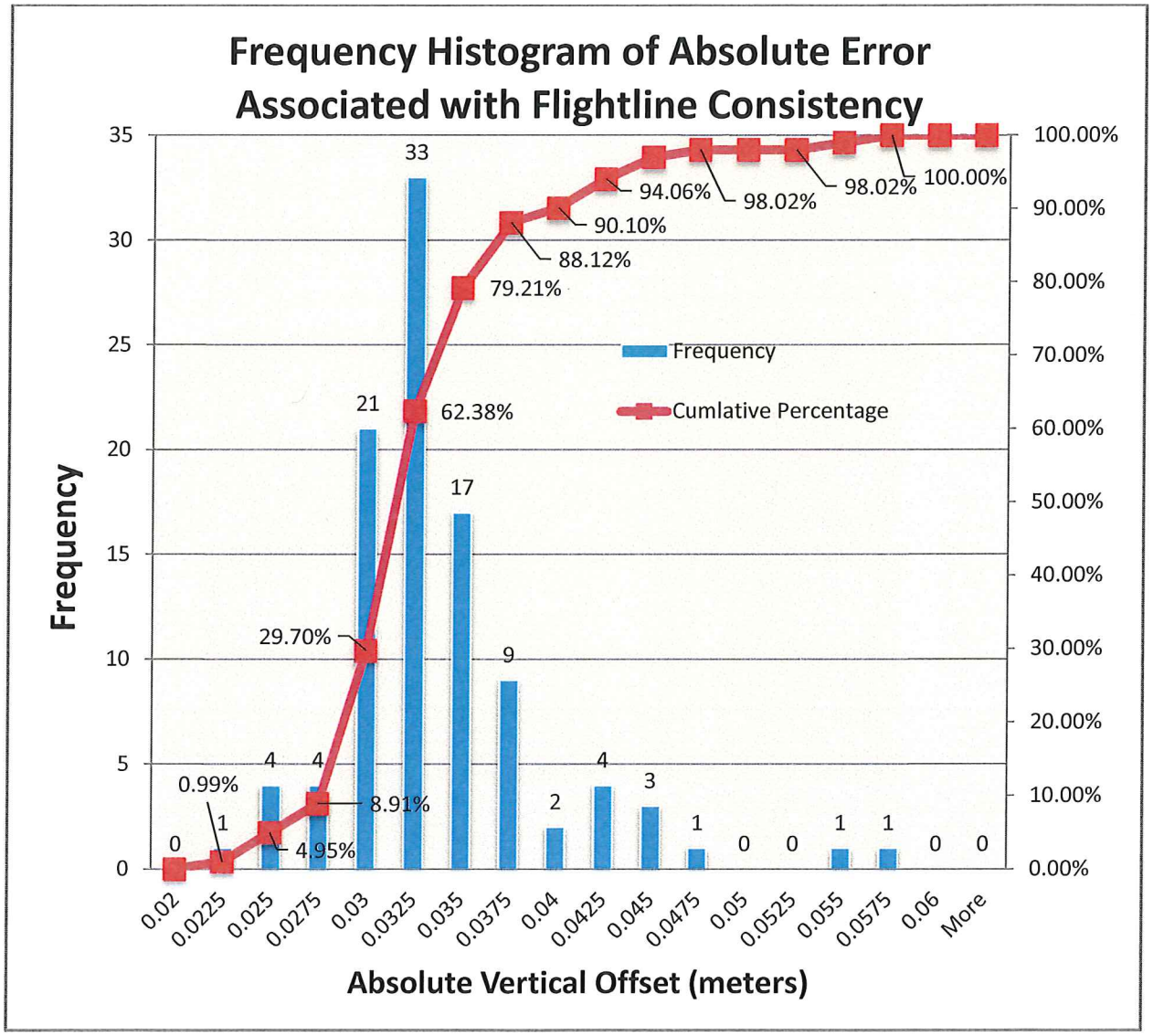

Figure 4: Flight line Consistency Histogram in meters

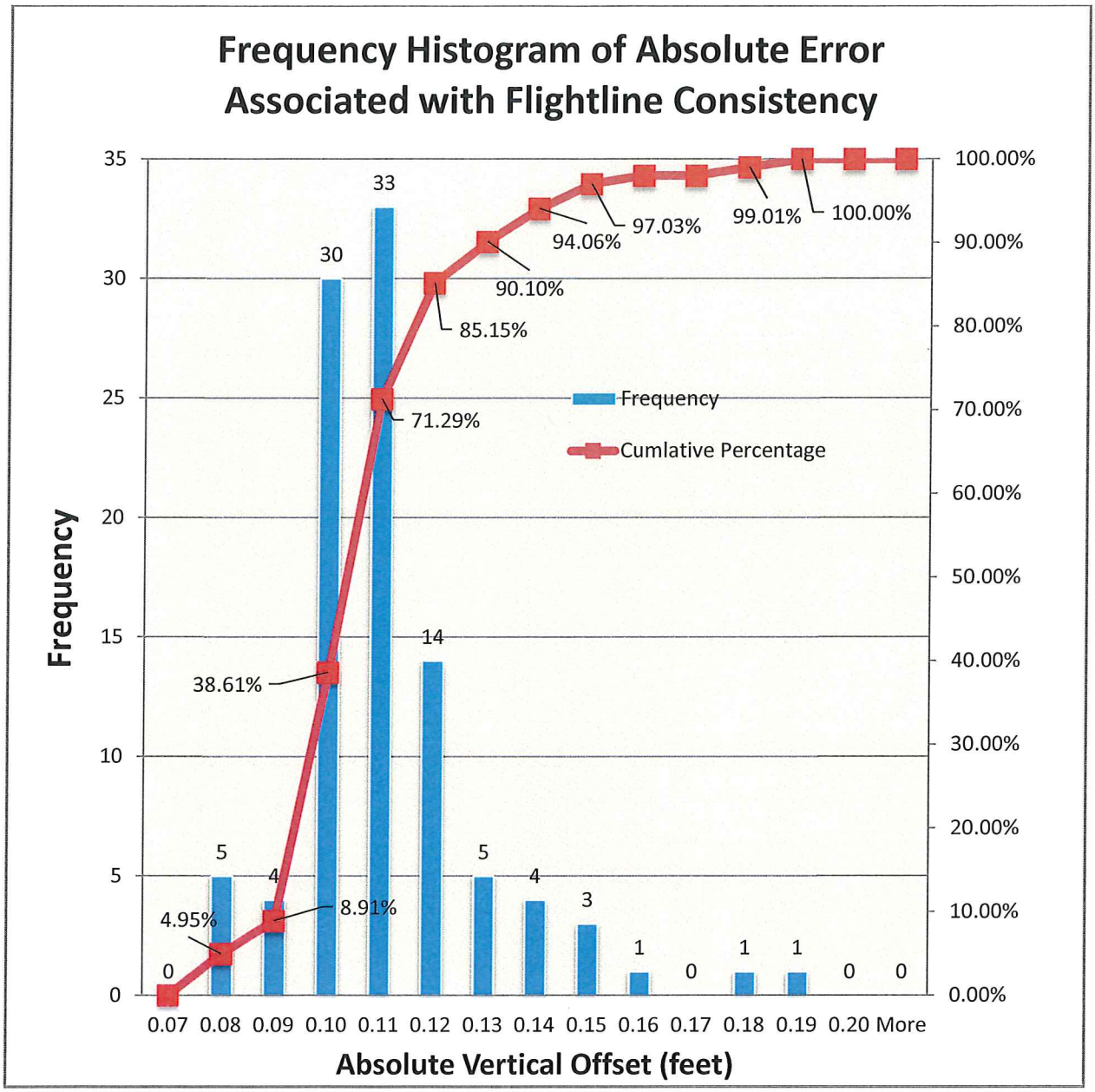

Figure 5: Flight line Consistency Histogram in feet

Visual Analysis

Lidar 3ft grids were loaded into ArcGIS™ software for visual analysis. Data were examined through slope and hillshade models of bare-earth returns. Hillshades of the DSMs were used to identify areas of missing ground (Figure 6). Both DEM and DSM rasters were examined for calibration offsets, tiling artifacts (Figure 7), seam line offsets, pits (Figure 8), and birds.

Calibration offsets typically are visualized as a corduroy-like pattern within a hillshaded lidar model. These offsets present themselves along steep slopes and typically stand out more in DSM rasters than

DEM rasters. Tiling artifacts are a result of missing or misclassified data along the edge of lidar processing tiles. These artifacts present themselves as linear features typically 1-2 grid cells in width, and are present in both DSM and DEM models (Figure 7). Seam line offsets occur where two distinct days of lidar data overlap. Errors occur as a result of improper absolute vertical error adjustments. These errors are typically visualized as a linear stair step running along the edge of connecting flight lines. Pits and birds refer to uncommonly high or low points that are the result of atmospheric and sensor noise. Pits (low points) typically occur where the laser comes in contact with water on the ground (Figure 8). Birds (high points) typically occur where the laser comes into contact with atmospherics[1].

During visual analysis of OLC Lane County Delivery 4-10 raster data, 3310 observed errors were digitized for spatial reference and stored in Esri™ shapefile format. Each feature was assigned an ID value and included a brief description of the observed error. The shapefile was then delivered to the vendor for locating and fixing errors. Upon receiving the observed error locations, the vendor performed an analysis to conclude whether the error was valid and provided comments on how the data was adjusted. 3087 out of the 3310 observed errors (93.3 %) were adjusted and the data was reprocessed to accommodate fixes. Some of the reported errors by DOGAMI staff were not fixed by the vendor because either there was not enough data to improve the digital elevation model or the QC call was not valid (call to remove bridge points from ground when the feature was actually a culvert). Errors that were not fixed by the vendor were reviewed by DOGAMI staff to ensure justification was valid. Final sets of lidar 3ft grids were loaded into ArcGIS™ software and examined to ensure edits were made and visually inspected an additional time for completeness (Figure 9).

[1]Atmospherics include clouds, rain, fog, or virga

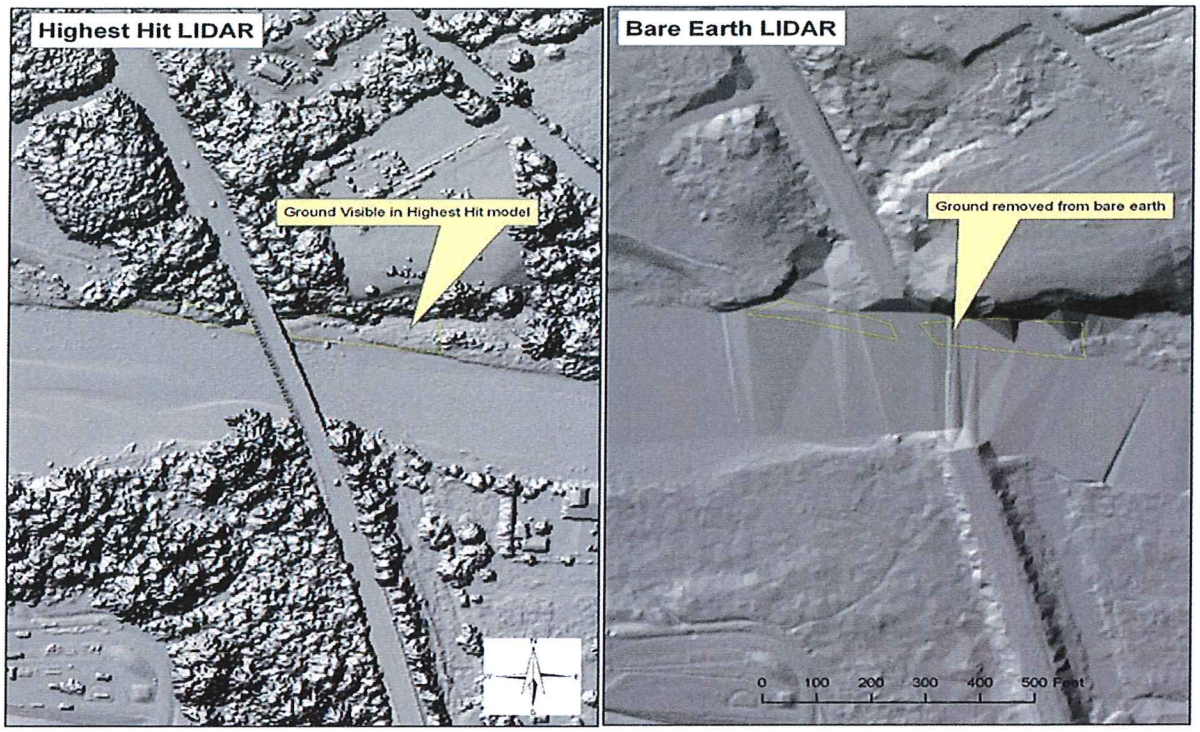

Figure 6: Example of missing ground in lidar DEM hillshaded raster. Ground is clearly visible in highest hit model, but has been removed from the bare earth model. This type of classification error is common near water body features

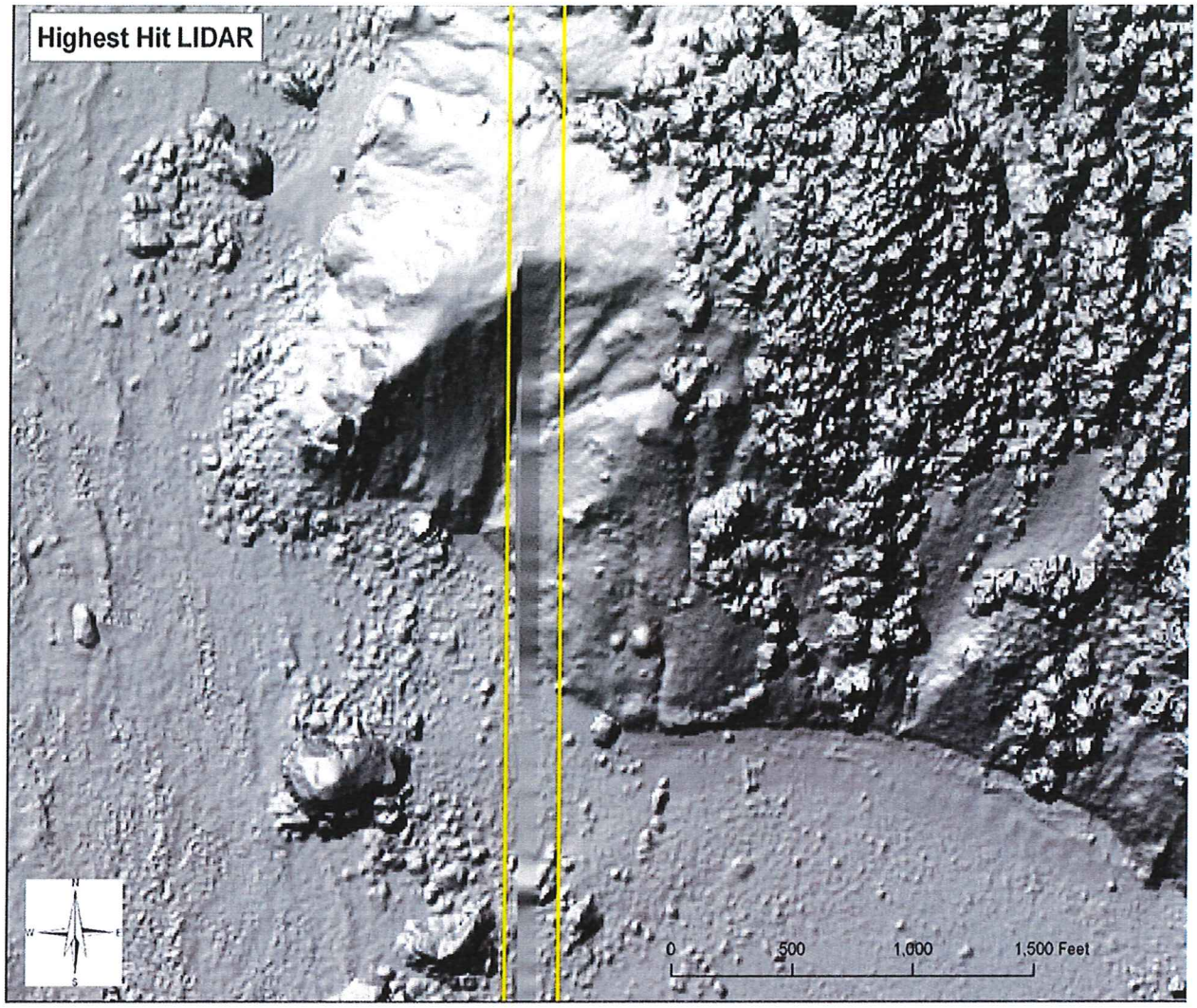

Figure 7: Example of tile artifact found in highest hit lidar data. Artifact is a seam line error created due to misclassification of ground at edge of lidar processing tiles.

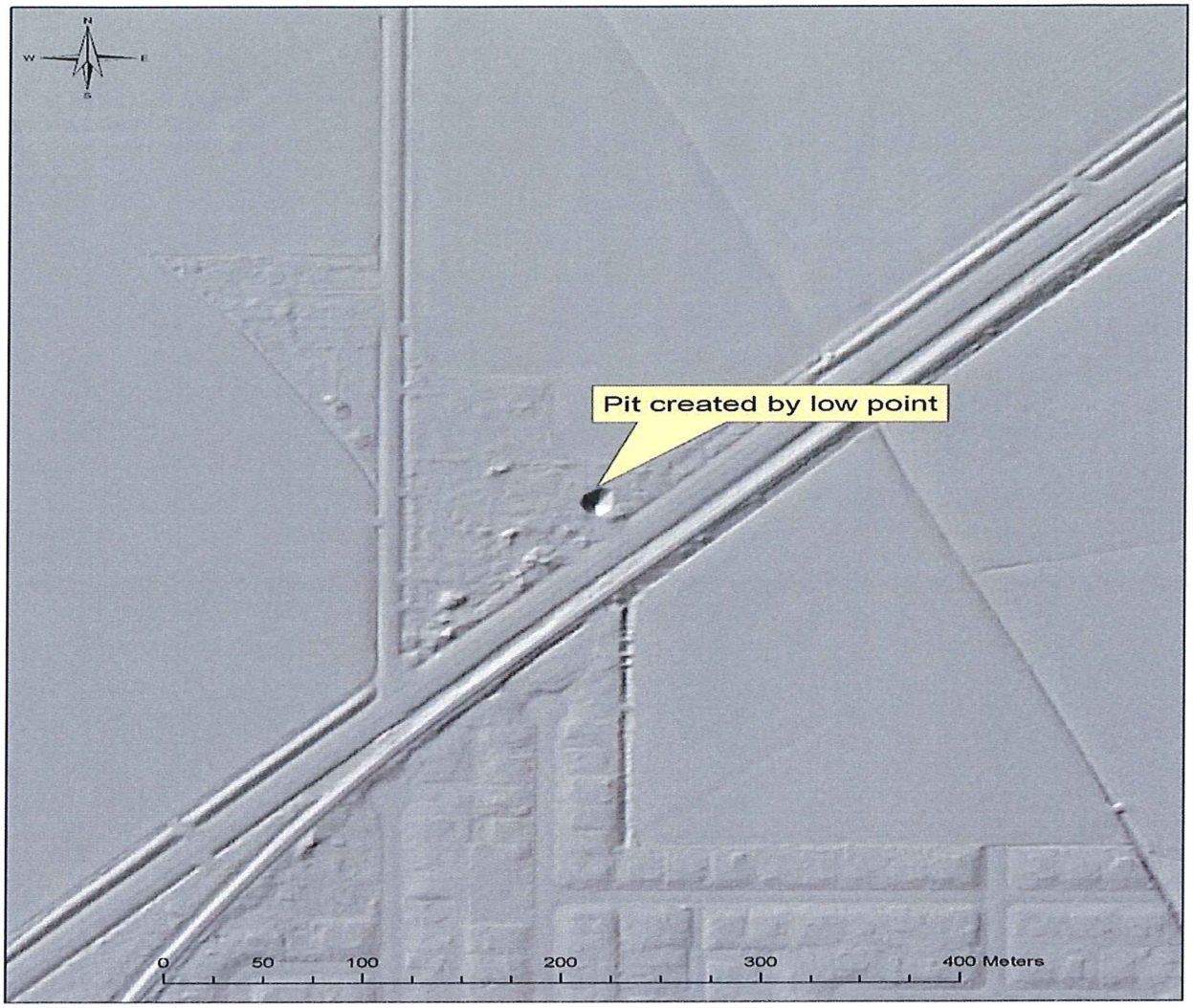

Figure 8: Example of "Pit" caused by low point in ground model. Pits are caused when standing water absorbs the lidar pulse. Pits are evident in ground model as the lowest point elevation is assigned to the grid cell value. Inversely the pit is not observable in the highest hit model as the highest point elevation is assigned to the grid value.

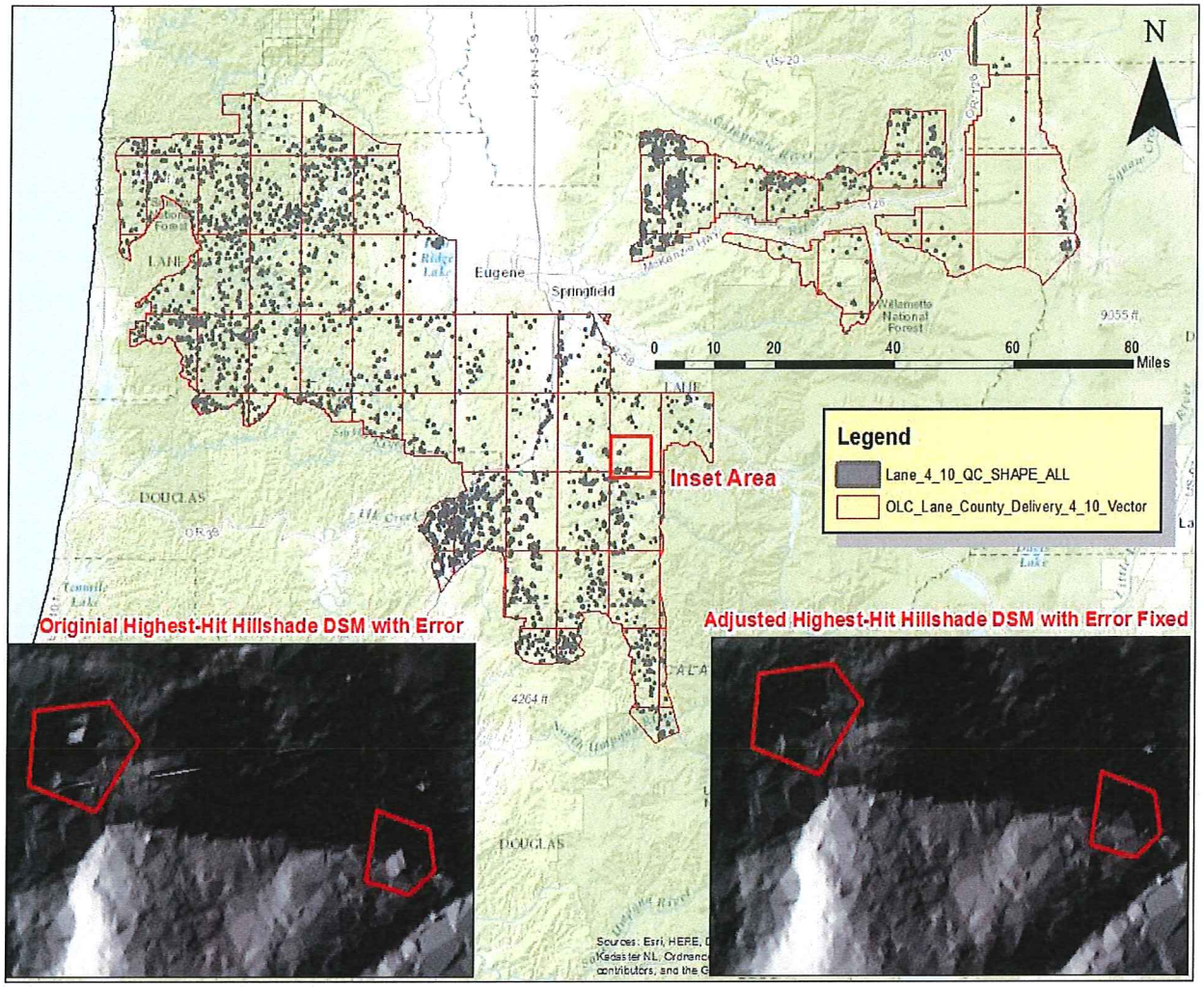

Figure 9: Spatial distribution of visual QC errors located by DOGAMI staff.

Absolute Accuracy Analysis

Absolute accuracy refers to the mean vertical offset of lidar data relative to measured ground-control points (GCP) obtained throughout the lidar sampling area. DOGAMI used a Trimble™ 5700/5800 Total Station GPS surveying system (Figure 11) to measure GCP's. This system consisted of a GPS base station (5700 unit), Zephyr Geodetic antenna, Trimmark 3 radio, and 5800 "rover". The 5700 base station was mounted on a fixed height (typically 1.8 m) tripod and located over a known geodetic survey monument followed by a site calibration on several adjacent benchmarks to precisely establish a local coordinate system. This step is critical in order to eliminate various survey errors. For example, Trimble reports that the 5700/5800 GPS system have horizontal errors of approximately ±1-cm + 1ppm (parts per million * the baseline length) and ±2-cm in the vertical (TrimbleNavigationSystem, 2005). These errors may be compounded by other factors such as poor satellite geometry, multipath, and poor atmospheric conditions, combining to increase the total error

to several centimeters. Thus, the site calibration process is critical in order to minimize these uncertainties.

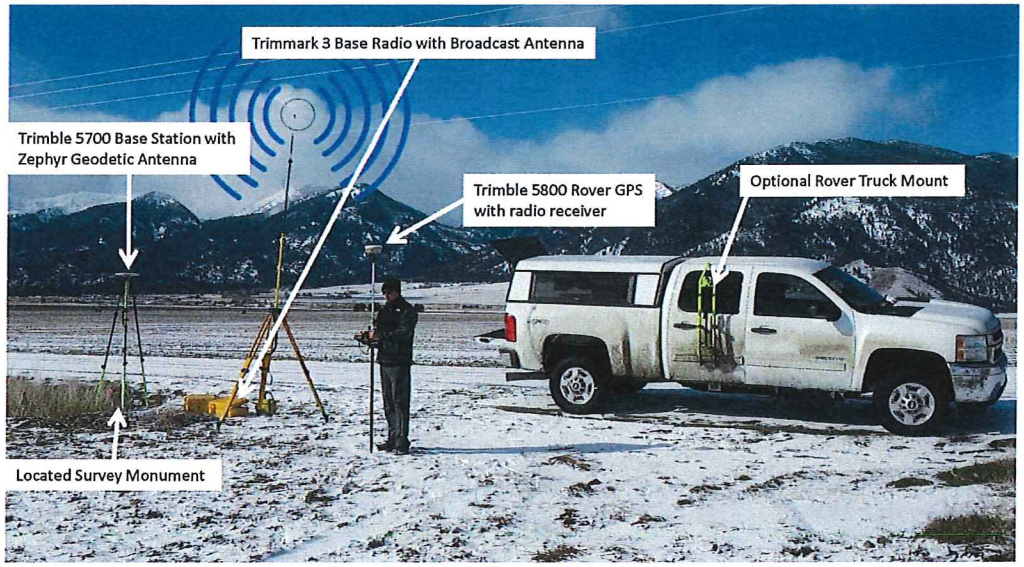

Figure 11: The Trimble 5700 base station antenna located over a known reference point outside Baker City. Corrected GPS position and elevation information is then transmitted by a Trimmark III base radio to the 5800 GPS rover unit.

The approach adopted for DOGAMI lidar surveys was comprised of two components:

1) Verify the horizontal and vertical coordinates established by Watershed Sciences for a select number of survey monuments used to calibrate the lidar survey. These surveys typically involved a minimum of two hours of GPS occupation over a known point. The collected data were then submitted to the National Geodetic Survey (NGS) Online Positioning User Service (OPUS) for post-processing against several Continuously Operating Reference Stations (CORS) operated by the NGS.
2) Collect GCP's along relatively flat surfaces (roads, paths, parking lots etc.). This step involved the collection of both continuous measurements (from a vehicle as well as from a backpack) as well as static measurements (typically 5 epochs).

Having collected the GCP data, the GPS data was post-processed using Trimble's Business Center software. Data post-processing typically involved calibrations against at least three CORS stations as well as from local site calibrations performed in the field using those benchmarks that had been independently verified. Data is post processed to refine measurements so that horizontal and vertical errors are less than 0.02 meters (0.065 feet). Horizontal accuracy of data is tested by reoccupying a sample subset of survey monuments used for processing of lidar data. Each occupation's x and y coordinates are compared with the vendor coordinates for offsets (Figure 9).

DOGAMI collected GCP points on June 17th and 18th, 2014; June 3rd and 10th 2015; August 18th and 19th 2015; and September 1st 2nd and 3rd 2016. Ground conditions were good every day of collection with no snow and no inclement weather on any collection dates. DOGAMI staff occupied 16 different base stations throughout the Lane County Delivery 4 -10 project areas in order to complete elevation comparisons in multiple terrain, vegetation coverage and elevations. All monuments DOGAMI occupied were established by WSI (See Report of Survey). Accuracy assessments of survey monuments are provided in the form of an OPUS solution from NGS, below is the OPUS solution for monument Lane 07.

NGS OPUS SOLUTION REPORT
==========

All computed coordinate accuracies are listed as peak-to-peak values.
For additional information: http://www.ngs.noaa.gov/OPUS/about.jsp#accuracy

USER: jacob.edwards@dogami.state.or.us DATE: June 27, 2014
RINEX FILE: 5957066s.14o TIME: 20:02:52 UTC

SOFTWARE: page5 1209.04 master53.pl 022814 START: 2014/03/07 18:28:00
EPHEMERIS: igs17825.eph [precise] STOP: 2014/03/07 20:37:00
NAV FILE: brdc0660.14n OBS USED: 4460 / 4650 : 96%
ANT NAME: TRM41249.00 SCIT # FIXED AMB: 22 / 23 : 96%
ARP HEIGHT: 1.800 OVERALL RMS: 0.009(m)

REF FRAME: NAD_83(2011)(EPOCH:2010.0000) IGS08 (EPOCH:2014.1803)

X:	-2528073.736(m)	0.029(m)	-2528074.587(m)	0.029(m)
Y:	-3837931.647(m)	0.029(m)	-3837930.426(m)	0.029(m)
Z:	4408019.300(m)	0.023(m)	4408019.327(m)	0.023(m)

LAT:	43 59 52.25865	0.015(m)	43 59 52.27169	0.015(m)
E LON:	236 37 36.51793	0.008(m)	236 37 36.45588	0.008(m)
W LON:	123 22 23.48207	0.008(m)	123 22 23.54412	0.008(m)
EL HGT:	143.335(m)	0.045(m)	142.957(m)	0.045(m)
ORTHO HGT:	166.288(m)	0.077(m) [NAVD88 (Computed using GEOID12A)]		

	UTM COORDINATES UTM (Zone 10)	STATE PLANE COORDINATES SPC (3602 OR S)
Northing (Y) [meters]	4871701.692	262917.564
Easting (X) [meters]	470078.778	1269589.419
Convergence [degrees]	-0.25923103	-1.96568499
Point Scale	0.99961101	0.99999945
Combined Factor	0.99958854	0.99997697

US NATIONAL GRID DESIGNATOR: 10TDP7007871701(NAD 83)

BASE STATIONS USED

PID	DESIGNATION	LATITUDE	LONGITUDE	DISTANCE(m)
DE6236	LPSB LANE CNTY COOP CORS ARP	N440304.409	W1230524.248	23461.1
DO8790	RSBG ROSEBURG CORS ARP	N431406.050	W1232133.727	84763.3
DI0946	LFLO FLORENCE COOP CORS ARP	N435900.967	W1240627.690	58942.5

DOGAMI was able to test the horizontal accuracy of survey monuments used to reference the lidar data while conducting vertical control measurements. For internal purposes only, the XY coordinates of survey monuments surveyed by DOGAMI were compared to the survey monuments provided by the vendor. The average horizontal accuracy for all monument locations occupied by DOGAMI during GCP data collection is 0.01 meters Northing and 0.02 meters Easting (Table 10). The average root mean square error (RMSE) for positional accuracy for all monument locations occupied by DOGAMI during GCP data collection is 0.02 meters.

Table 10: Average accuracy values for occupied monuments

Occupied Monuments	***meters***	feet
Avg. Northing accuracy	0.01	0.03
Avg. Easting accuracy	0.02	0.07
Avg. RMSE for positional accuracy	0.02	0.07

Vertical accuracy analysis of delivered lidar data consisted of differencing collected GCP data and the lidar DEMs to expose elevation offsets. These offsets were used to produce a mean vertical error and vertical RMSE value for the entire delivered data set. Project specifications list the maximum acceptable mean vertical offset to be 0.20 meters (0.65 feet) and the maximum vertical RSME to not exceed 0.0925 meters (0.303 feet).

A total of 2125 measured GCP's were obtained in the Lane County Delivery 4 -10 project area and were compared with the lidar elevation grids (Figure 12). The data delivered to DOGAMI was found to have a mean vertical offset of -0.01 meters (-0.03 feet) and an RMSE value of 0.03 meters (0.10 feet). Offset values ranged from -0.08 meters (-0.26 feet) to 0.07 meters (0.23 feet) (Table 11 and Figure 13 and 14).

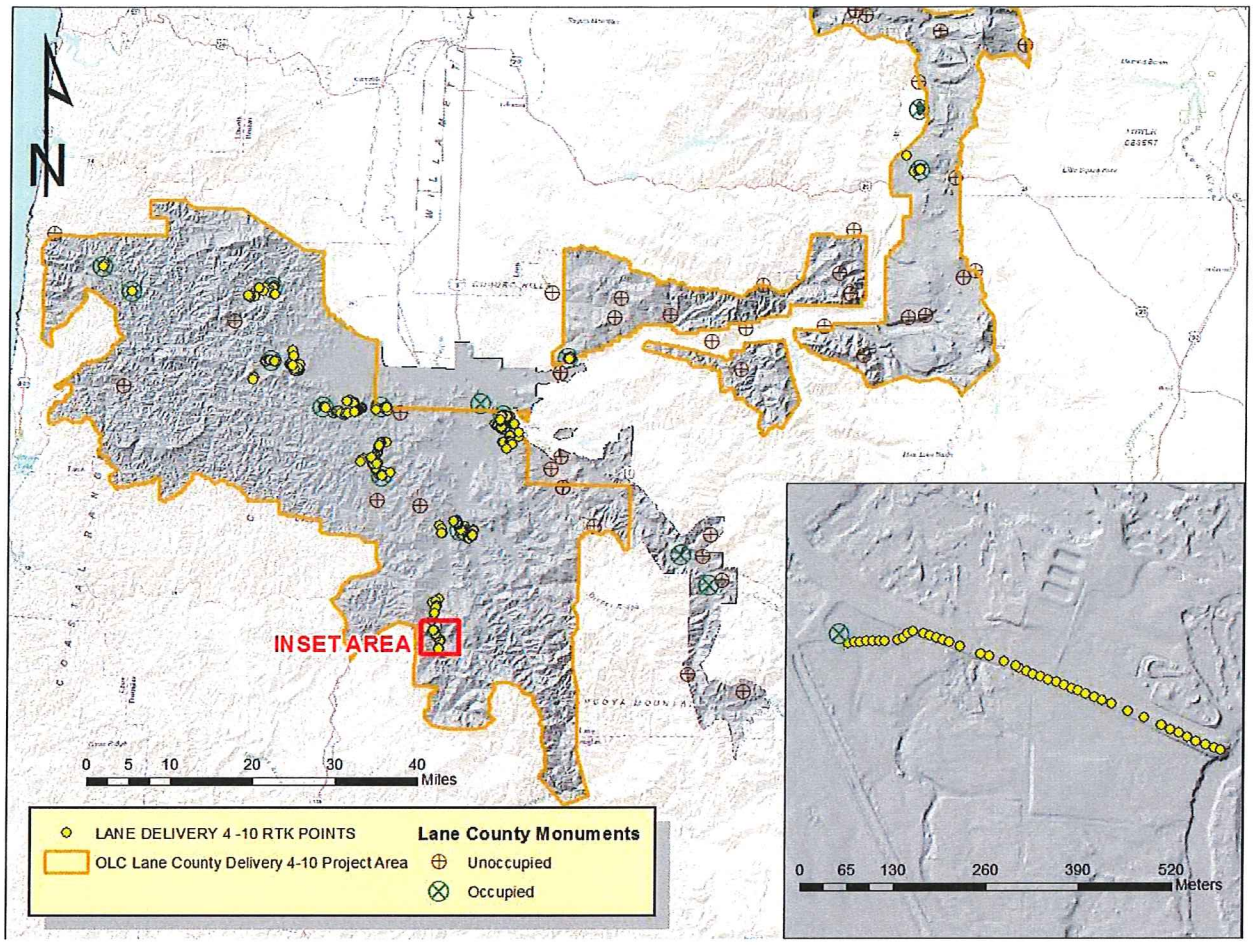

Figure 12: Locations of GCPs surveyed by DOGAMI staff. Data was used to test absolute accuracy for the Lane County Delivery 4 -10 project areas.

Table 11: Descriptive Statistics for absolute value vertical offsets.

Descriptive Statistics	Meters	Feet
Mean	-0.01	-0.03
Standard Error	0.00	0.00
Standard Deviation	0.03	0.11
Range	0.15	0.49
Minimum	-0.08	-0.26
Maximum	0.07	0.23
RMSE	0.03	0.10

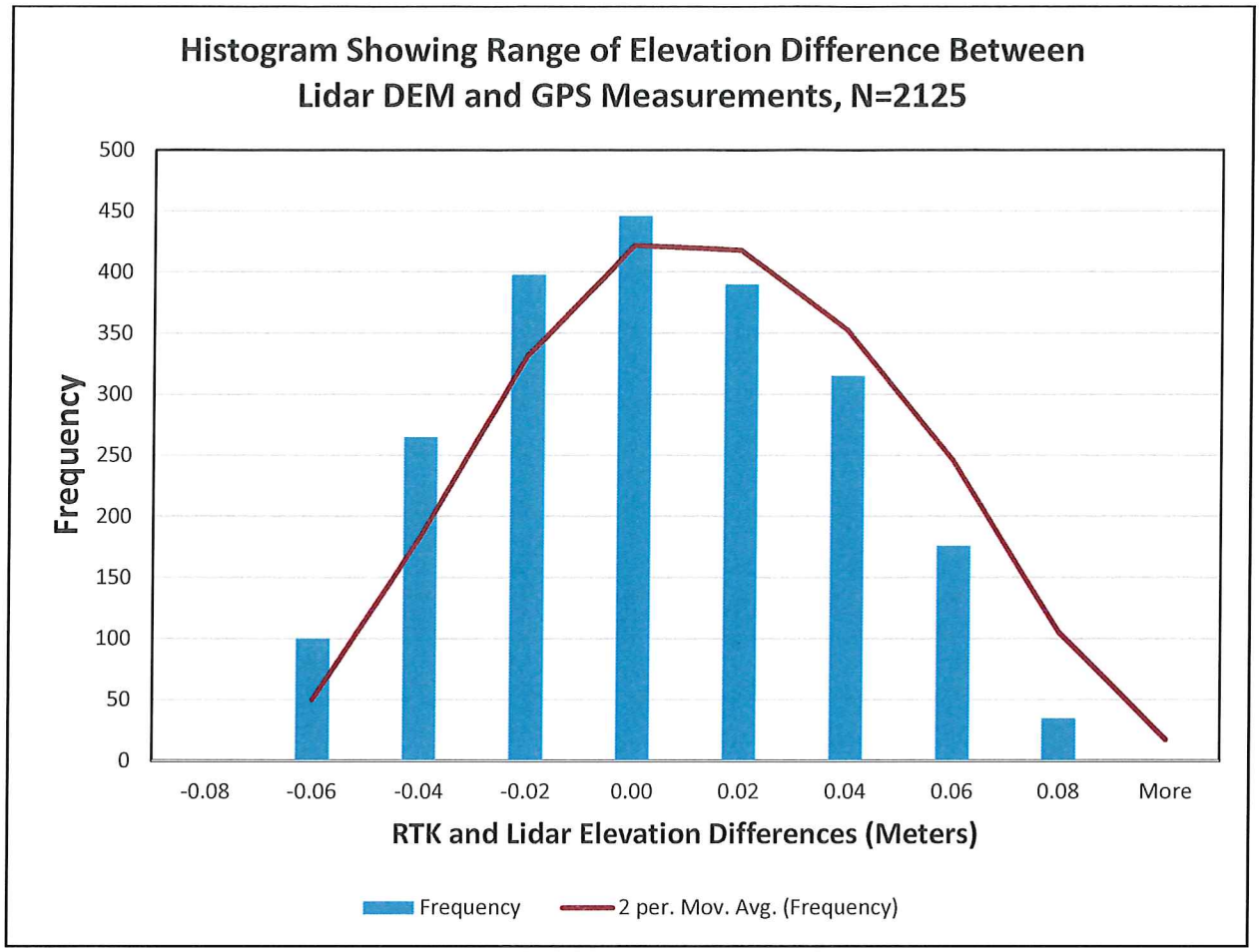

Figure 13: Histogram of absolute vertical accuracy in meters.

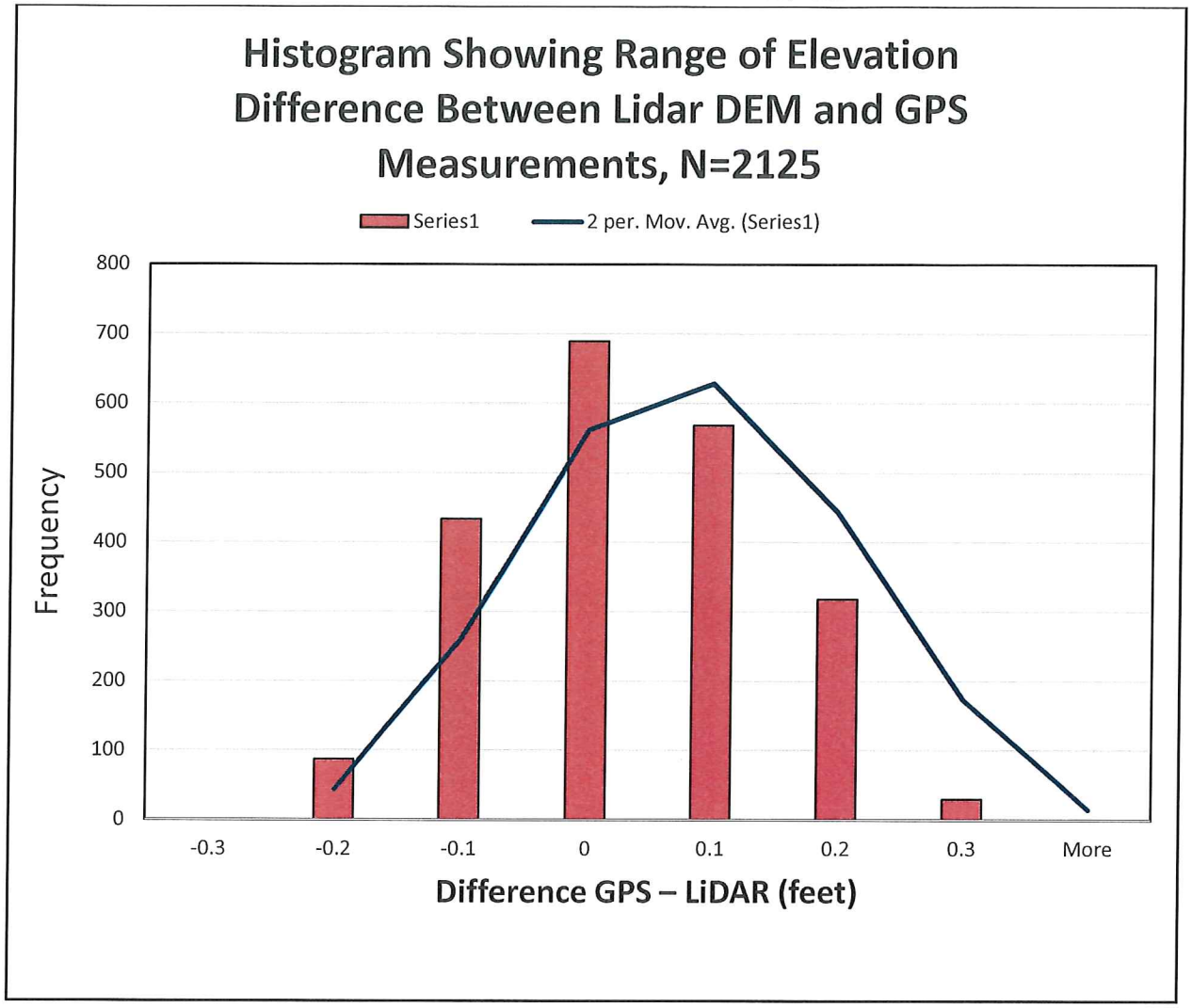

Figure 14: Histogram of absolute vertical accuracy in feet.

Pulse Density

DOGAMI has specified that the aggregate design multi-swath pulse density for the Lane County Delivery 4-10 project areas must be 8.0 pulses per square meter (m^2) or higher. Pulse density is calculated as the number of pulses per unit area, commonly measured as pulses per m^2. This calculation is based on the number of first return pulses divided by the area of the tile.

The all-return LAS points are comprised of multiple returns from each laser pulse. These multiple returns are created when a laser pulse encounters multiple reflection surfaces as it travels toward the ground. Pulse density was measured by parsing out first-return points from the all-return LAS files. First-return points are used to assess pulse density because multiple returns from a single pulse would introduce bias into the statistics. DOGAMI staff used Bentley© Microstation software to filter the LAS point files and output new LAS files that only contain first-return points. Statistics were calculated on the newly created files using the ArcGIS 3D analyst tool called "Point File Information." This tool calculated the total number of first return points for each LAS file. Each Las file's first return point count was then compared to the size of each LAS file to determine the overall pulse per square

meter. Using the 1/100th USGS 7.5 minute quadrangle extents, DOGAMI staff created polygons that graphically depict the pulse density of the project area (Figure 15).

To quantify pulse density of Lane County Delivery 4-10, 5,943 all-return LAS files (100%) were parsed into first-return point files and compared to their data extents. Results of the pulse density analysis found the average pulse density to be 12.91 pulses per m^2 (Table 12). Certain types of surfaces (dense vegetation, water) may return fewer pulses than the laser originally emitted; therefore density values can vary according to terrain and land cover. Pulse densities for Lane County delivery 4-10 LAS tiles ranged from 0 pulses per m^2 to 61.55 pulses per m^2 (Figure 15). 5,174 LAS tiles out of 5,943 (87%) have a pulse density of ≥ 8.00 pulses per m^2 (Figure 16). These results show that all data are within tolerances of pulse density according to the contract agreement.

Summary Statistics	*Pulses per m^2*
Mean	12.91
Standard Error	0.08
Standard Deviation	6.45
Sample Variance	41.65
Range	61.55
Minimum	0.00
Maximum	61.55

Table 12: Summary Results of Pulse Density Analysis

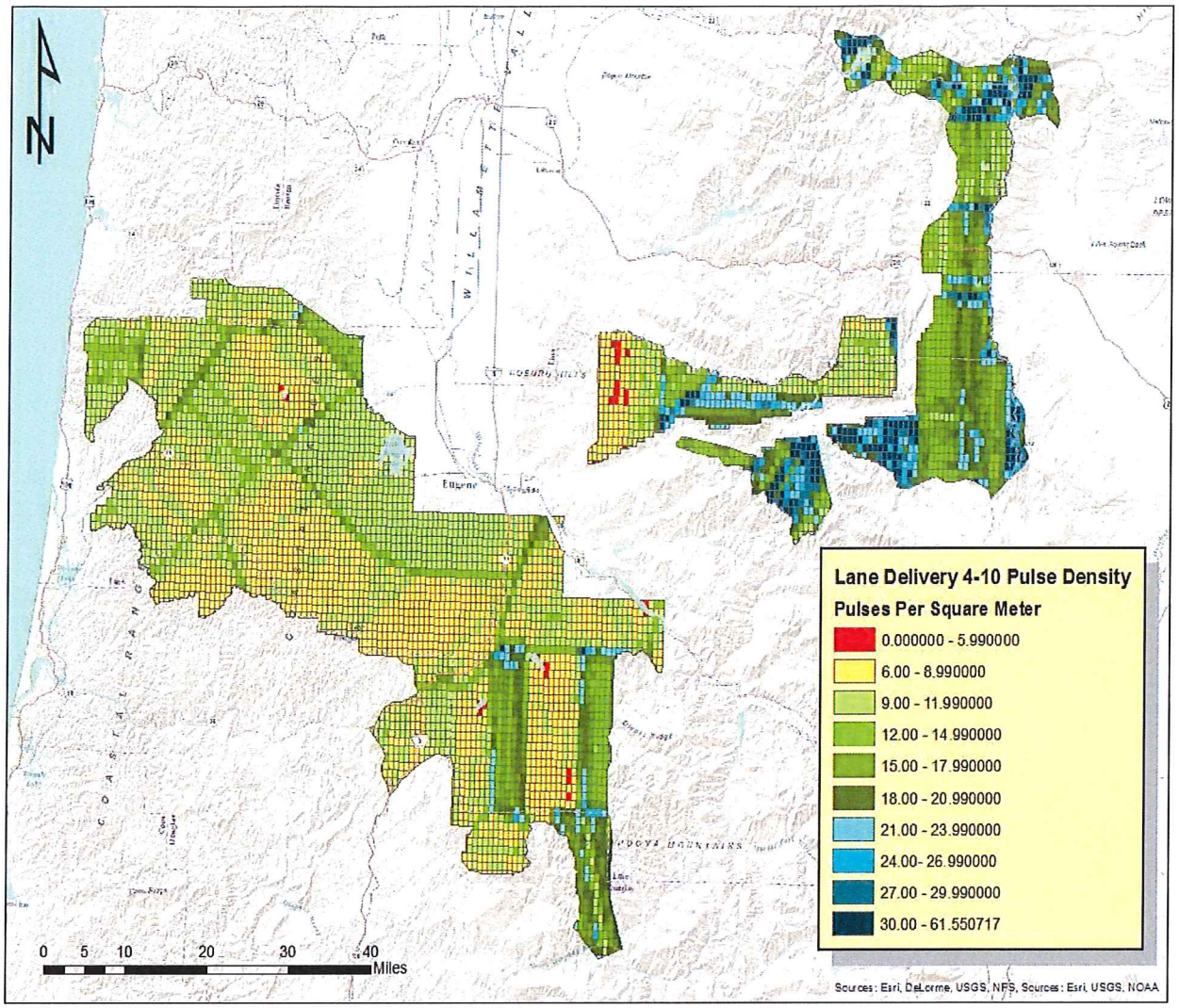

Figure 15: Pulse Density of 1/100th USGS 7.5 minute quadrangle LAS tiles.

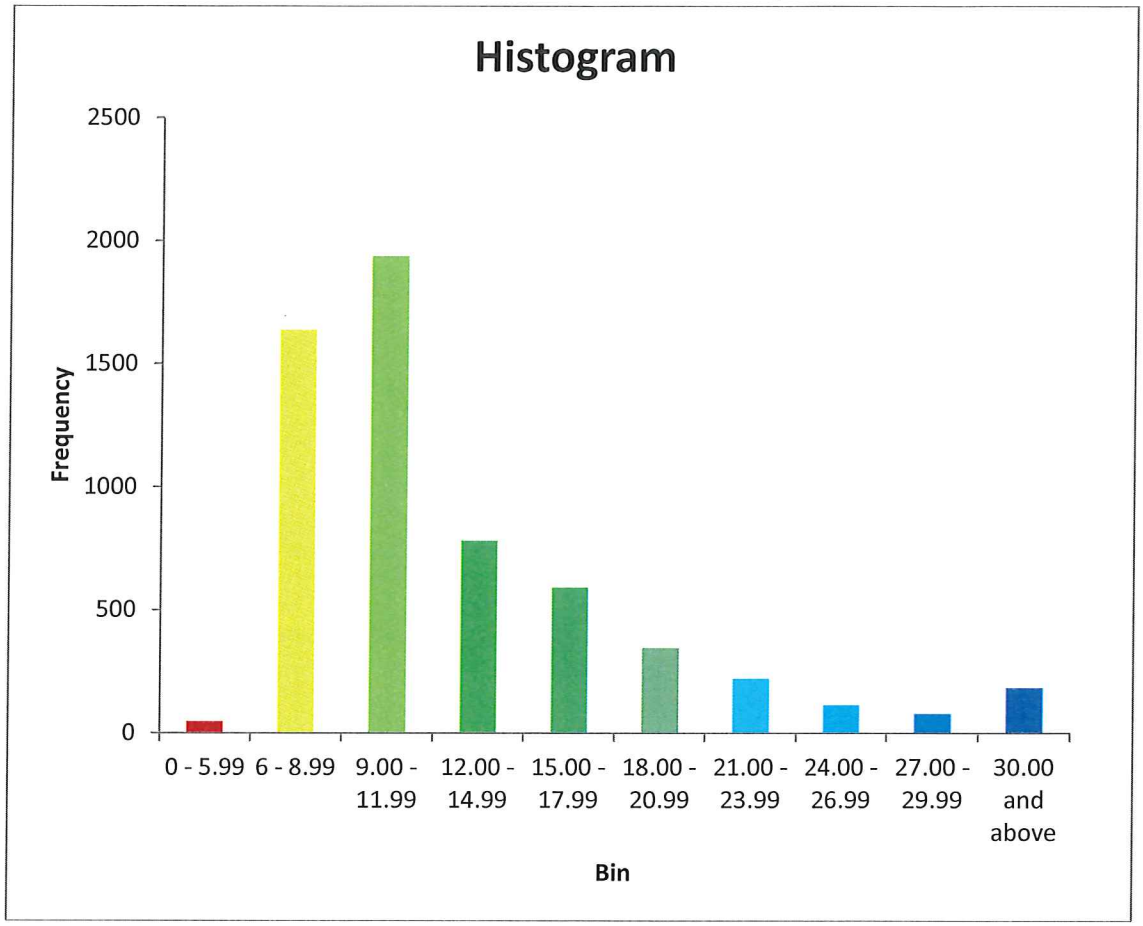

Figure 16: Histogram of Average Pulse Densities for Lane County Delivery 4-10.

Orthophotography Image Inventory

Aerial imagery was collected and processed to produce georeferenced and ortho-corrected raster imagery. These orthophotos were then used to attribute the LAS point cloud with RGB and Infrared values. The delivered raster data were checked for their completeness and locations of ortho calibration targets were checked for consistency (Figure 17). Imagery was also checked for gross seam lines and raster errors. DOGAMI requires a horizontal accuracy of ≤0.61 meters for delivered ortho photography. The horizontal accuracy of the delivered orthophotography has a reported RMSE of 0.12 meters (0.39 meters). Ground features were used as control for accuracy assessment (Figure 18). All imagery has been loaded and reviewed for completeness and readability.

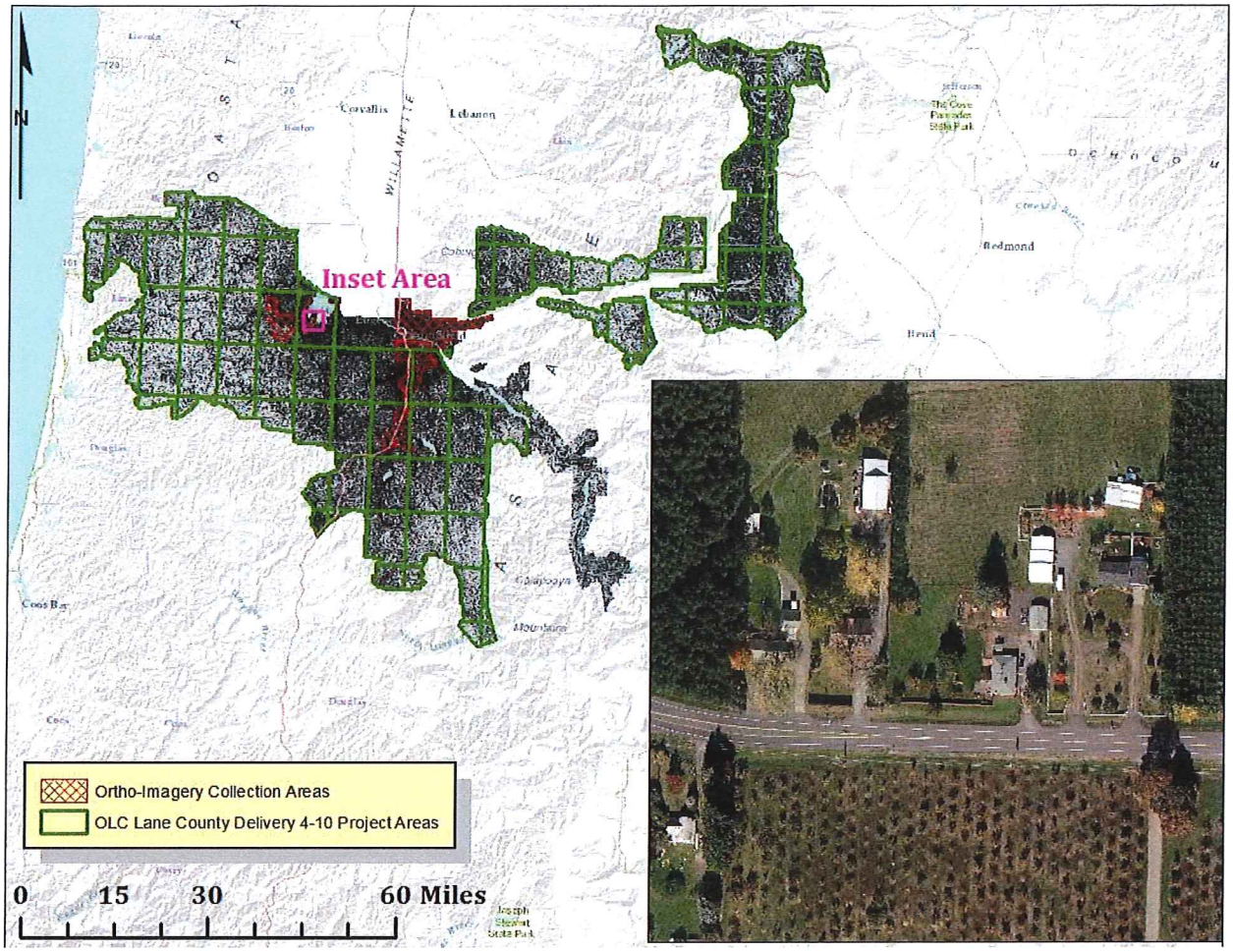

Figure 17: Location of aerial imagery collection for Lane delivery 4-10 project areas.

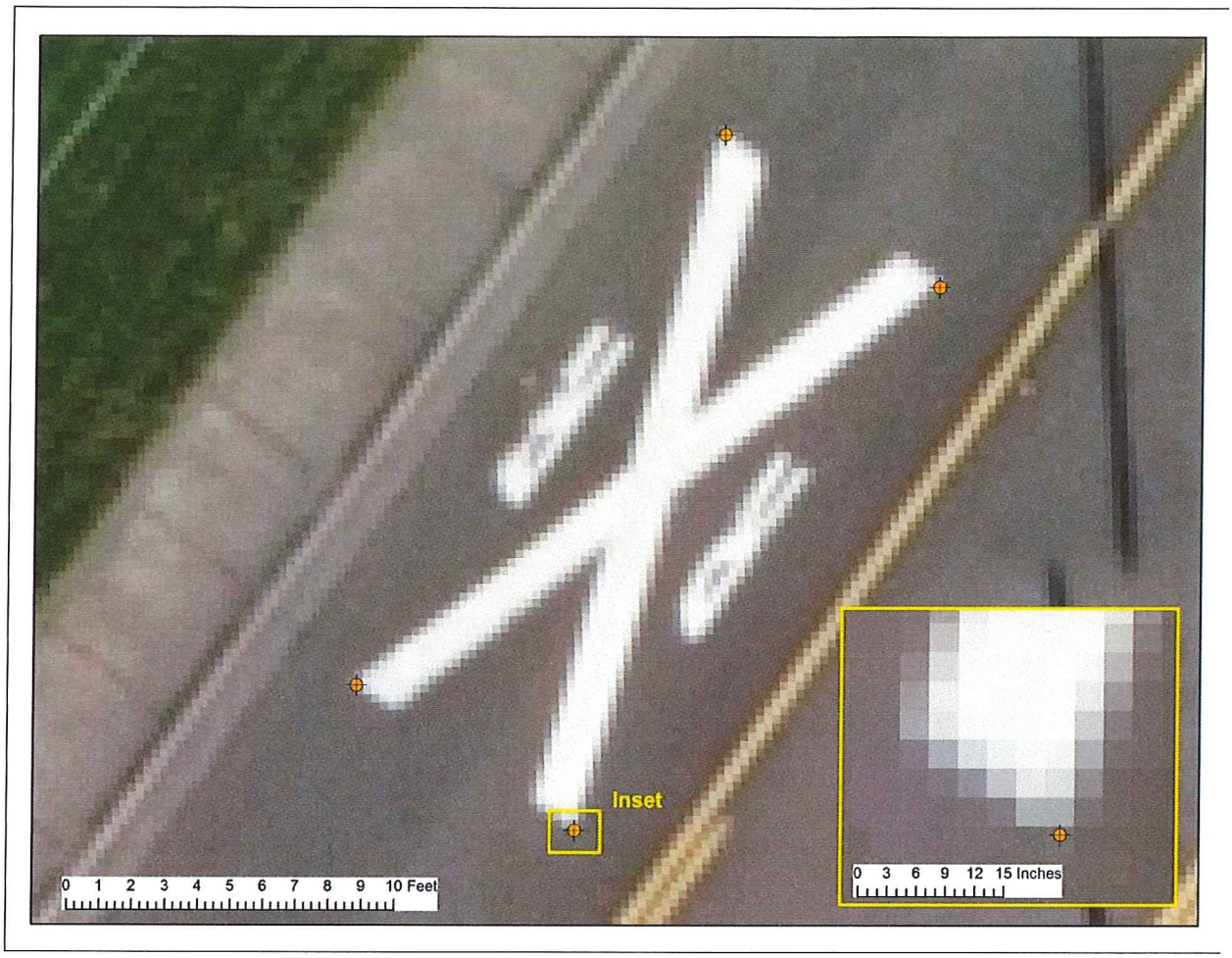

Figure 18. Aerial Target feature used to ortho-rectify imagery.

Metadata Analysis

Metadata analysis compared the structure of the metadata file against FGDC standards. Metadata content was reviewed by using a visual check in Esri ArcCatalog as well as analysis by the USGS Geospatial Metadata validation service: http://geo-nsdi.er.usgs.gov/validation/. 5 metadata files, representing 25% of all metadata associated with this delivery were viewed by DOGAMI staff. No structure issues were found when validating the compliance of metadata to FGDC standards.

Acceptance

The data described in this report meet and exceed project specifications laid out in the contracted data standards agreement. All components of data to be delivered have been received as of December 28th, 2015. Quality control has confirmed that all delivered data is within specification and function correctly. Quality Assurance has evaluated acquisition parameters to confirm that data was collected within project design scope. Consistency analysis has concluded that all data contains flight line to flight line vertical offset less than the threshold of 0.15 meters as specified in the agreement. The vendor has adequately responded to all fixable errors identified as part of the visual analysis. Perceived grid errors identified by DOGAMI that were found to be false have been documented by the vendor and explained to the satisfaction of DOGAMI reviewers. Absolute accuracy analysis of the data has concluded that absolute vertical error of lidar data is less than the specified tolerance of 0.20 meters as specified in the data standards agreement.

Approval Signatures

_____ Date: 12/20/16

Jacob Edwards
Lidar Database Coordinator – Department of Geology & Mineral Industries

Department of Geology & Mineral Industries
800 NE Oregon St, Suite 965
Portland, OR 97232

Lane County LIDAR Project, 2013-2014 – Delivery 1-3 QC Analysis

LIDAR QC Report – October 8, 2014

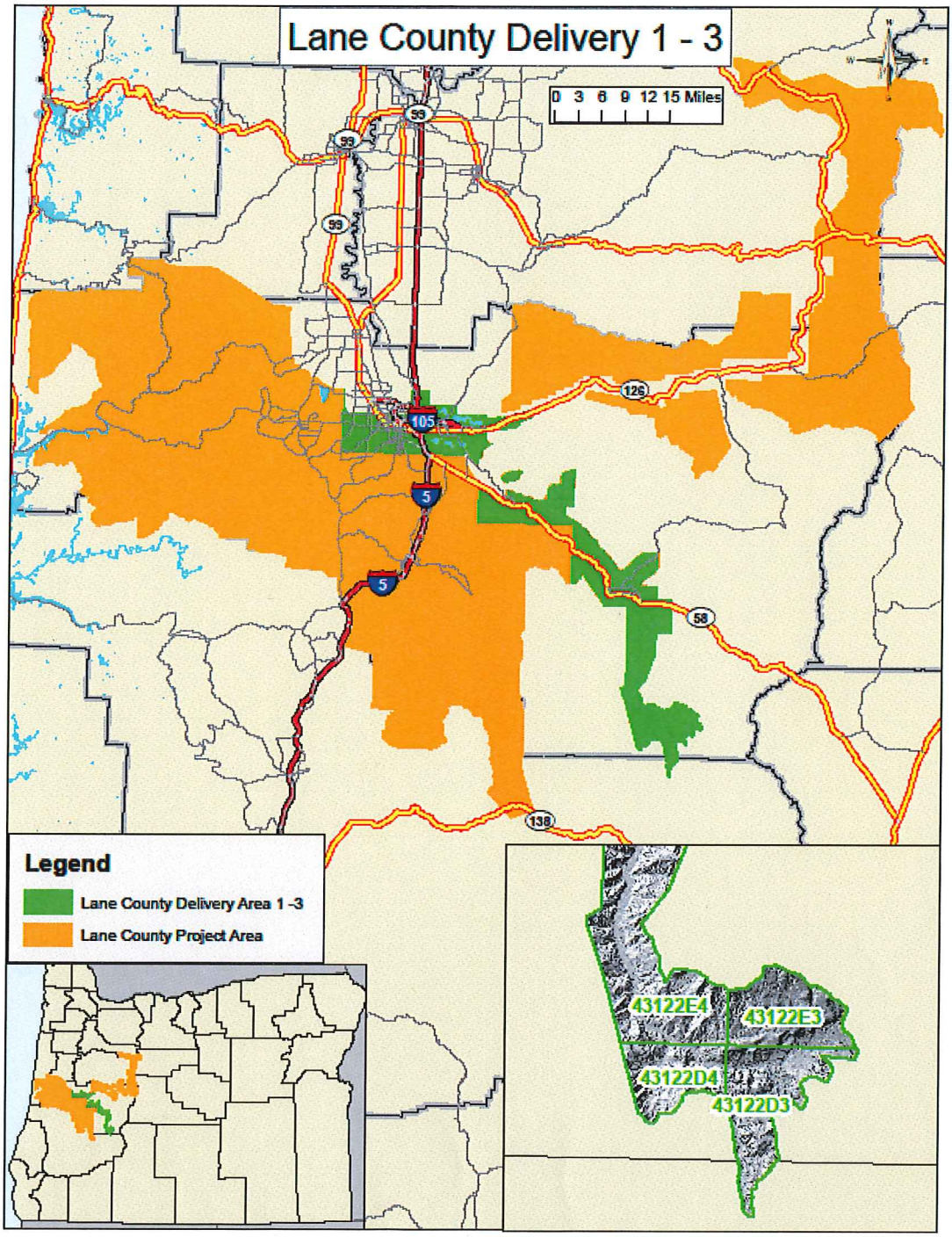

Figure 1. Map featuring Lane County Delivery 1- 3 data extent.

The Oregon Department of Geology & Mineral Industries (DOGAMI) has contracted with Watershed Sciences Inc. (WSI) to collect high resolution lidar topographic data for multiple areas within the State of Oregon. Areas for lidar data collection have been designed as part of a collaborative effort of State, Federal, and Local agencies in order to meet a wide range of project goals. The vendor has agreed to certain conditions of data quality and standards for all lidar data deliverables listed in sections A through C (OPA #8865) of the 2007-2014 Lidar Data Acquisition Price Agreement (pages 14-23). Data submitted under this price agreement are to be collected at a resolution of at least 8 points per square meter and processed to meet or exceed the agreed upon data quality standards. This document itemizes and reports upon Lane County Lidar Project – Delivery 1 - 3 (Figure 1) products furnished by the lidar vendor as documentation that all data meets project specific standards.

Upon receipt from vendor WSI, all lidar data for Delivery 1 - 3 were independently reviewed by DOGAMI staff to ensure project specifications were met. All data was inventoried for completeness and checked for quality, which included examining lidar data for errors associated with internal data consistency, model quality, and accuracy.

- Data Completeness examines all data associated with this delivery to ensure that all required data products are present and function correctly. Quality assurance and quality control is conducted on every data file delivered to DOGAMI. Lidar ASCII Standard (LAS) point files have been loaded into TerraSolid and ArcGIS to ensure complete and correct lidar data coverage and file integrity. Raster and vector files have been viewed in ArcMap and cross referenced with the delivery area to ensure proper coverage, extent and integrity.
- Swath Overlap was independently verified by analyzing flight line extents in TerraSolid and making direct measurements of flight line overlap in multiple lidar tiles.
- Consistency Analysis involves examining flight line offsets to quantify the accuracy of data calibration. Calibration influences elevation data quality. Poor calibration leads to small but systematic errors within lidar elevation points, which then create inaccuracies within derived lidar elevation models.
- Visual Check is carried out in order to identify potential data artifacts and misclassifications of lidar point data. Lidar point data is classified as either ground, above ground, or error points. Sophisticated processing scripts are used to classify point data and remove error points. The vendor performs quality control analysis to fix misclassifications of point data. The delivered bare earth DEM is then reviewed by DOGAMI to ensure that the data classification is correct and there are no topographic processing artifacts. If valid errors are found, data must be corrected and resubmitted.
- Absolute Accuracy compares the delivered bare-earth DEMs with independent GCPs to quantify vertical and horizontal accuracy. For each lidar collection project DOGAMI staff collects independent GPS ground control points, which are then compared against delivered lidar elevation models.
- Ortho Imagery Analysis involves a visual check of data quality and positional accuracy. A visual check is carried out in order to identify potential artifacts within or between orthoimagery tiles. Horizontal accuracy is determined by comparing the location of static features visible in both the orthoimagery and the lidar intensity image. If errors are found then the data must be resubmitted.

- Spot Diameter Analysis determines the area of ground that is intersected by a laser pulse from the lidar sensor. The spot diameter is a product of the flying height of the aircraft and the beam divergence of the sensor used during acquisition of the data
- Metadata Analysis compares the structure of the metadata file against FGDC standards. Metadata content was reviewed by using a visual check as well as analysis by the USGS Geospatial Metadata validation service.

Data Completeness

Data for Lane County Delivery 1 - 3 areas were collected between September 7th 2014 through January 25th 2014 (see WSI report for dates). Total area of delivered data equals 405.94 square miles. This delivery contains data for the following USGS 7.5 minute quads (listed by Ohio Code #) within the boundary of the Lane County survey collection area (Figure 2):

Delivery 1: 44122a6, 44122a7, 44122a8, 44123a1, 441223a2

Delivery 2: 43122d3, 43122d4, 43122e3, 43122e4

Delivery 3: 43122f3, 43122f4, 43122f5, 43122g4, 43122g5, 43122h5, 43122h6, 43122h7, 43122h8

We conduct quality control of data deliverables to ensure that project specifications (Table 1) have been met. Lane County Delivery 1 - 3 includes data in the format of grids, trajectory files, intensity images, LAS point files, ground point density rasters, RTK survey data, a shapefile of the delivery area, and the lidar delivery report. Bare earth and highest hit grids were delivered in Esri Grid format with 3ft cell size. Lidar point data is delivered in LAS binary format for ground classified returns as well as the entire lidar point cloud. The lidar point cloud is infused with RGB (red-green-blue) attributes per project specifications. Georeferenced intensity images are supplied in TIF format. Supplementary data includes ground density rasters displaying locations where ground returns are low, and time-stamped flightline shapefiles. Real time kinematic ground survey data (used for absolute vertical adjustment) is supplied in shapefile format.

We conduct quality assurance on data deliverables in order to determine if the data achieved project specifications outlined in sections A through C (OPA #8865) of the 2007-2014 Lidar Data Acquisition Price Agreement (pages 14-23). Specifically we test:

- Data completeness and consistency
- Spot Diameter
- Swath Overlap
- Swath to Swath Consistency
- DEM Quality
- Orthoimagery

First, each project deliverable's format, resolution and tiling scheme are reviewed in order to verify content completeness (Table 2.) DOGAMI staff verifies acquisition specifications by creating an LAS dataset from the all-return LAS points. The "Create LAS Dataset" tool in the ArcGIS Data Management toolbox is used to complete this task. Statistical information is then calculated for the LAS dataset using the "LAS Dataset Statistics" tool in ArcGIS. Statistical

information was created for both the LAS dataset as well as the individual LAS files provided by the vendor. The tool exports a report that contains information pertaining to point classifications, number of pulse returns and the scan angle of the lidar sensor.

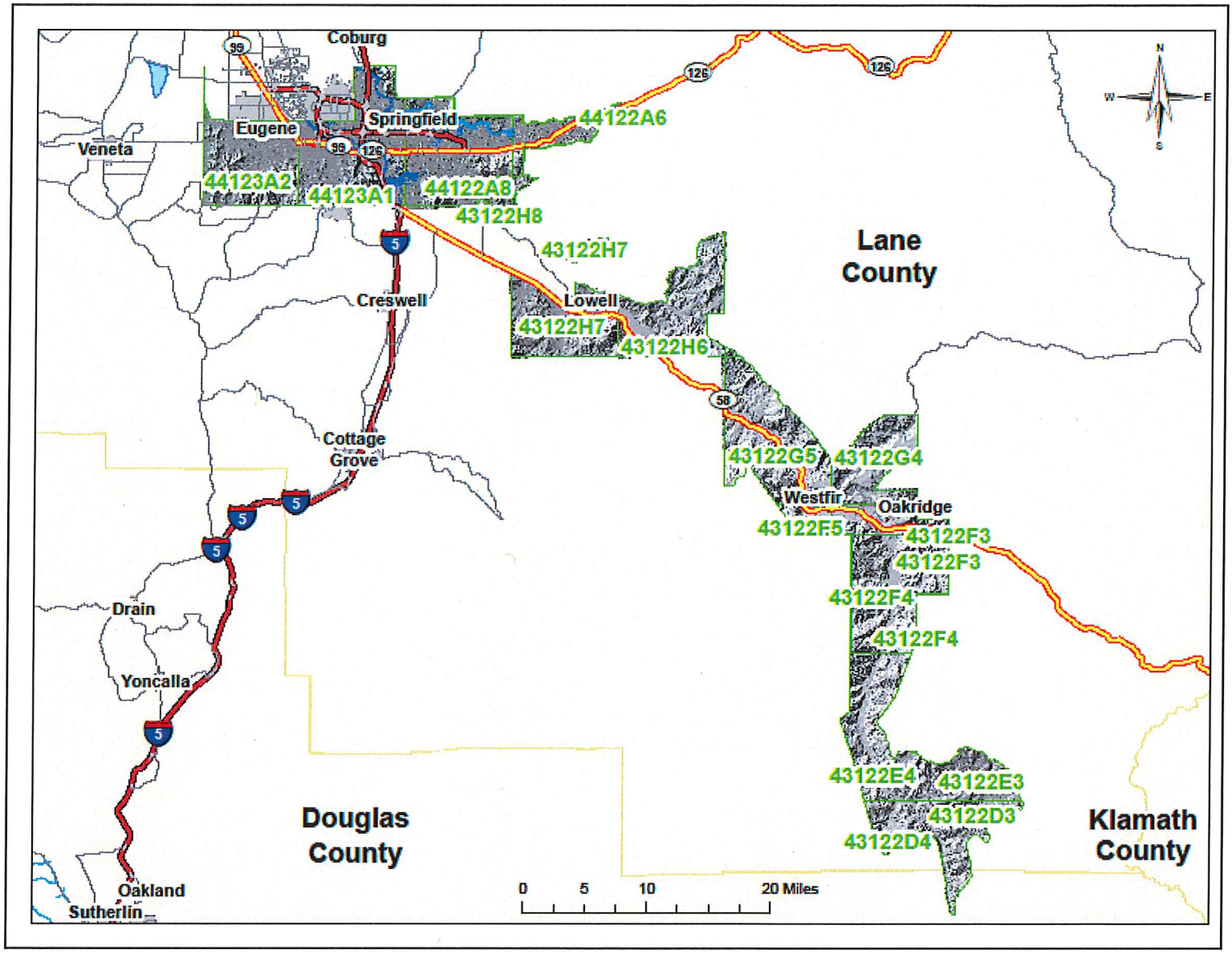

Figure 2: Lane County Delivery 1-3 area. Data is referenced to USGS 7.5 minute quadrangles within the extents of the Lane County Project Collection area.

Quality Control of Deliverables Achieving Delivery Specifications					
FINAL Delivery		**Format**	**Tiling**	**Description**	**Verified**
Bare Earth DEMs	3ft	32 bit pixel depth floating point GRID	Full USGS 7.5 minute quadrangle	Raster of ground surface, interpolated via triangulated irregular network from identified ground points.	X
Highest Hit DEMs	3ft	32 bit pixel depth floating point GRID	Full USGS 7.5 minute quadrangle	Rasters of first-return surface, cell heights are highest first return within that cell.	X
Ground Density Raster	3 ft	32 bit pixel depth floating point GRID	Full USGS 7.5 minute quadrangle	Raster showing the number of ground-classified returns per square meter over the project area.	X
Intensity Images	1.5ft	TIFF	Full USGS 7.5 minute quadrangle	Normalized geo-referenced 8-bit pixel depth grayscale	X
All-Return LAS	8pts/m^2	LAS version 1.2	1/100th USGS 7.5 minute quadrangle	LAS point could delivered in tiled LAS files. **RGB attributes infused into point cloud.**	X
Ground LAS	**Not specified**	LAS version 1.2	1/100th USGS 7.5 minute quadrangle	LAS point could delivered in tiled LAS files. **RGB attributes infused into point cloud.**	X
4 Band Ortho Imagery	3 inch pixel	4 Band (RGBI) 8-bit TIFF	1/100th USGS 7.5 minute quadrangle	Four-band (color infrared, i.e. red-green-blue-near infrared) orthophotographic imagery	X
Trajectory files	1 sec	ascii point file - (TXYZRPH) and ESRI shapefile	Date and time of acquisition	Recorded aircraft trajectory data compiled into (Smoothed Best Estimate of Trajectory (SBET)	X
GCP Shapefile		ESRI Shapefile		Ground Control Points used for survey calibration and assessment of absolute vertical accuracy	X
7.5 minute Quadrangle		ESRI Shapefile	Full USGS 7.5 minute quadrangle	Geometry file depicting the geospatial area associated with deliverables.	X
0.75 minute 1/100th quadrangle		ESRI Shapefile	1/100th USGS 7.5 minute quadrangle	Geometry file depicting the geospatial area associated with deliverables.	X
Ortho Imagery Shapefile		ESRI Shapefile	1/100th USGS 7.5 minute quadrangle	Geometry file depicting the geospatial area associated with imagery collection.	X
TerraSolid Processing Bins		DXF or DGN file	1/100th USGS 7.5 minute quadrangle	DGN file that contains processing bins for all LAS files	X

Project AOI Shapefile		ESRI Shapefile	OGIC, NAD83 (2011), Intl feet projection	Geometry file depicting the project area of interest.	***X***
Report		PDF		Digital text report that describes lidar **and photo** acquisition methods and results.	***X***

Table 1. Deliverable Checklist

Quality Assurance of Deliverables Achieving Acquisition Specifications			
Specification	**Description**	**Checked on this delivery**	**Independent Verification**
Data Collection Season	Target collection window is July 10, 2013 until July 10th 2014.	yes	September 7th 2013 through January 25th 2014
Survey Conditions	Lidar data collection shall be conducted in snow-free conditions with the contractor make best effort to acquire data in leaf-off and low stream conditions	yes	Within spec
Coverage	No voids between swaths. No voids due to cloud coverage or instrument failure.	yes	Within spec
Pulse Returns	Lidar sensor used must be capable of recording a minimum of 4 returns per laser pulse, including first and last returns.	yes	5 return classes
Projection	Oregon Lambert	yes	Within spec
Vertical Datum (units)	NAVD88 Geoid 12A (International feet)	yes	Within spec
Horizontal Datum (units)	NAD83 2011 (International feet)	yes	Within spec
Swath Overlap	Contractor shall plan surveys with 50% sidelap of adjacent swaths. Survey must be designed for 100% double coverage at planned aircraft height above ground.	yes	Within spec
Pulse Density	Aggregate design multi-swath pulse density must be 8.0 pulses per square meter or higher.	yes	8.7 per m^2
Scan Angle	Laser scan angle will not exceed 30 degrees overall (+15 to -15 degrees).	yes	Within spec

Table 2. Acquisition Specifications Checklist

Deliverable Descriptions:

- Bare Earth Grids: Tin interpolated grids created from lidar ground returns.
- Highest Hit Grids: Tin interpolated grids created from the highest lidar elevation for a given 3ft cell.
- Intensity TIF: TIF raster built using returned lidar pulse intensity values gathered from highest hit returns.
- Trajectory File: File contains point location measurement of the aircraft used to collect lidar data. Data is collected using an Inertial Measurement Unit (IMU), and collects measurements of: Easting (meters), Northing (meters), Ellipsoid Height (meters) of aircraft, aircraft roll (degrees), aircraft pitch (degrees), aircraft heading (degrees). Measurements are collected at one second intervals. Data is projected in UTM zone 10, NAD83 (2011) HARN.
- LAS: Binary file of all lidar points collected in survey (Class, flight line #, GPS Time, Echo, Easting, Northing, Elevation, Intensity, Scan Angle, Echo Number, and Scanner).
- Ground LAS: Binary file of lidar points classified as ground (Class, flight line #, GPS Time, Echo, Easting, Northing, Elevation, Intensity, Scan Angle, Echo Number, and Scanner).
- RTK Point Data: Ground GPS Survey data used to correct raw lidar point cloud for vertical offsets.
- Delivery Area Shapefile: Geometry file depicting the geospatial area associated with deliverables.
- Report: Report provides detailed description of data collection methods and processing. The vendor also reports accuracies associated with calibration, consistency, absolute error, and point classifications.
- All data projected in Oregon Lambert, NAD83 (2011), Intl Feet with exception of trajectory files.

Spot Diameter Analysis

Horizontal accuracy is not specified in the price agreement since true horizontal accuracy is regarded as a product of the lidar spot diameter(SD). The lidar spot diameter is the area of ground that is intersected by a single pulse from the lidar sensor. SD is a function of range and beam divergence. The range is calculated as the distance between the laser aperture and the detected surface. The reported range value is given as above ground level flying height (AGL) of the sensor during collection. Beam divergence (γ) is the degree by which the light pulse emitted from the sensor fans out from a straight line. Beam divergence is measured in radians, with 1 radian = 57.3 degrees. The lidar SD is calculated by multiplying AGL and beam divergence, SD = AGL * γ

Lane County delivery 1 data was collected using Leica ALS70 and ALS50 lidar sensors flown at 1400 meters AGL. The Leica ALS70 specification sheet reports a beam divergence value of 0.22 milliradians @ $1/e^2$, meaning that ~85% of the laser energy falls within this divergence. The Leica ALS50 specification sheet reports a beam divergence value of 0.33 milliradians @ $1/e^2$, meaning that ~85% of the laser energy falls within this divergence.

Lane county delivery 2 and delivery 3 data were collected using a Leica ALS70 and ALS50 lidar sensor flown at 900 meters AGL. Leica ALS70 specification sheet reports a beam

divergence value of 0.22 milliradians @ $1/e^2$, meaning that ~85% of the laser energy falls within this divergence. Leica ALS50 specification sheet reports a beam divergence value of 0.33 milliradians @ $1/e^2$, meaning that ~85% of the laser energy falls within this divergence.

The range of spot diameters for the Lane county deliveries 1-3 is between 0.308 meters and 0.462 meters. This equals an average spot diameter of 0.385 meters for these deliveries, which is within the project specification tolerance of 0.15 meter to 0.40 meter for SD.

Swath Overlap

Swath overlap is independently verified by measuring the amount of flight line overlap in multiple lidar tiles. This is accomplished by importing the all-return LAS files into a CAD software called TerraSolid™. Each LAS file contains header information that includes the trajectory number or flight line that was flown during its acquisition. The LAS files are assigned a color value based on the flight line number so that multiple swaths can be displayed and percent overlap can be measured (Figure 3). 100 all-return LAS files (10%) were loaded into TerraSolid and direct measurements were made in multiple locations. All 100 all-return LAS files contained ≥ 50% sidelap of adjacent swaths. These results show that all data are within specification.

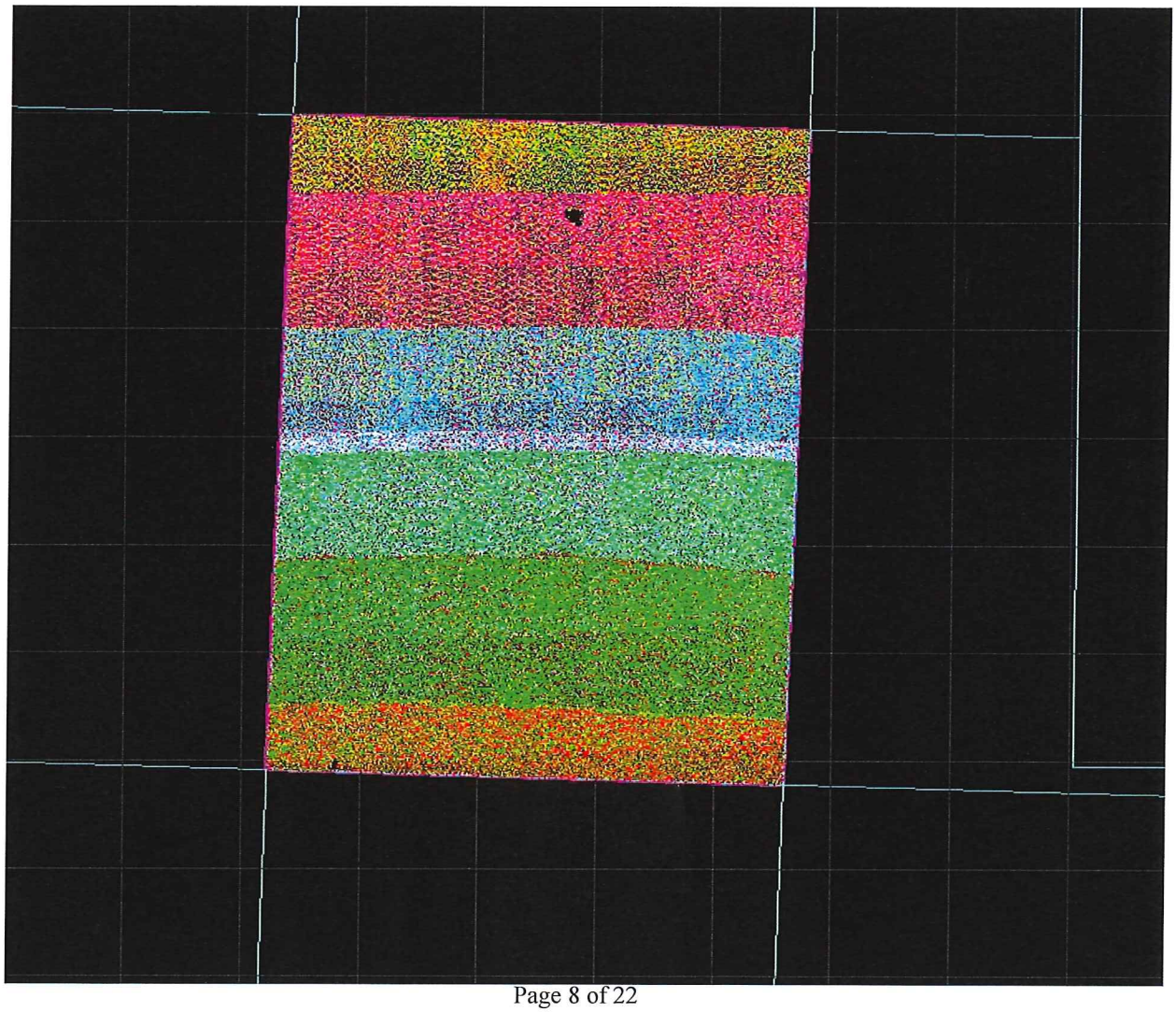

Figure 3. Lidar points colored by flight line in the 0.75 minute 1/100th quadrangle 44122A8119.

Swath-to-Swath Consistency Analysis:

DOGAMI has specified that lidar consistency must average less than 0.15m (0.49 feet) in vertical offsets between flight lines. DOGAMI measures consistency offsets throughout delivered datasets to ensure that project specifications are met.

Consistency refers to lidar elevation differences between overlapping flight lines. Consistency errors are created by poor lidar system calibration settings associated with sensor platform mounting. Errors in consistency manifest as vertical offsets between individual flight lines. Consistency offsets were measured using the "Find Match" tool within the TerraMatch© software toolset. This tool uses aircraft trajectory information linked to the lidar point cloud to quantify flight line-to-flight line offsets.

To quantify the magnitude of this error 19,867 of 19,937 delivered data tiles (99.6%) were examined for vertical offset between flight lines. Data tiles with less than 1000 points were not used in analysis. Each tile measured 750 x 750 meters in size (Figure 4). The average number of points used for flight line comparison was 1,439,310 per tile (Table 2a). Error measurements were calculated by differencing the nearest point from an adjacent flight line within 1 meter in the horizontal plane and 0.2 meters in the vertical plane. Each flight line was compared to adjacent flight lines, and the average magnitude of vertical error was calculated. 905 flight lines out of 1,014 total flightlines (89%) were sampled and compared for consistency.

Results of the consistency analysis found the average flight line offset to be 0.029 meters with a maximum error of 0.047m (Table 2b). Distribution of error showed 96% of all error was less than 0.11m and 100% less than 0.15m (Figure 5). These results show that all data are within specification.

Summary Statistics

# of Tiles	19867
# of Flight Line Sections	905
Avg # of Points	1,439,310
Avg. Magnitude Z error (m)	0.072

Table 2a. Summary Results of Consistency Analysis

	meters	*feet*
Mean	0.072	0.237
Standard Error	0.001	0.002
Standard Deviation	0.022	0.073
Sample Variance	0.000	0.002
Range	0.141	0.464
Minimum	0.015	0.049
Maximum	0.156	0.513

Table 2b. Descriptive Statistics for Magnitude Z Error.

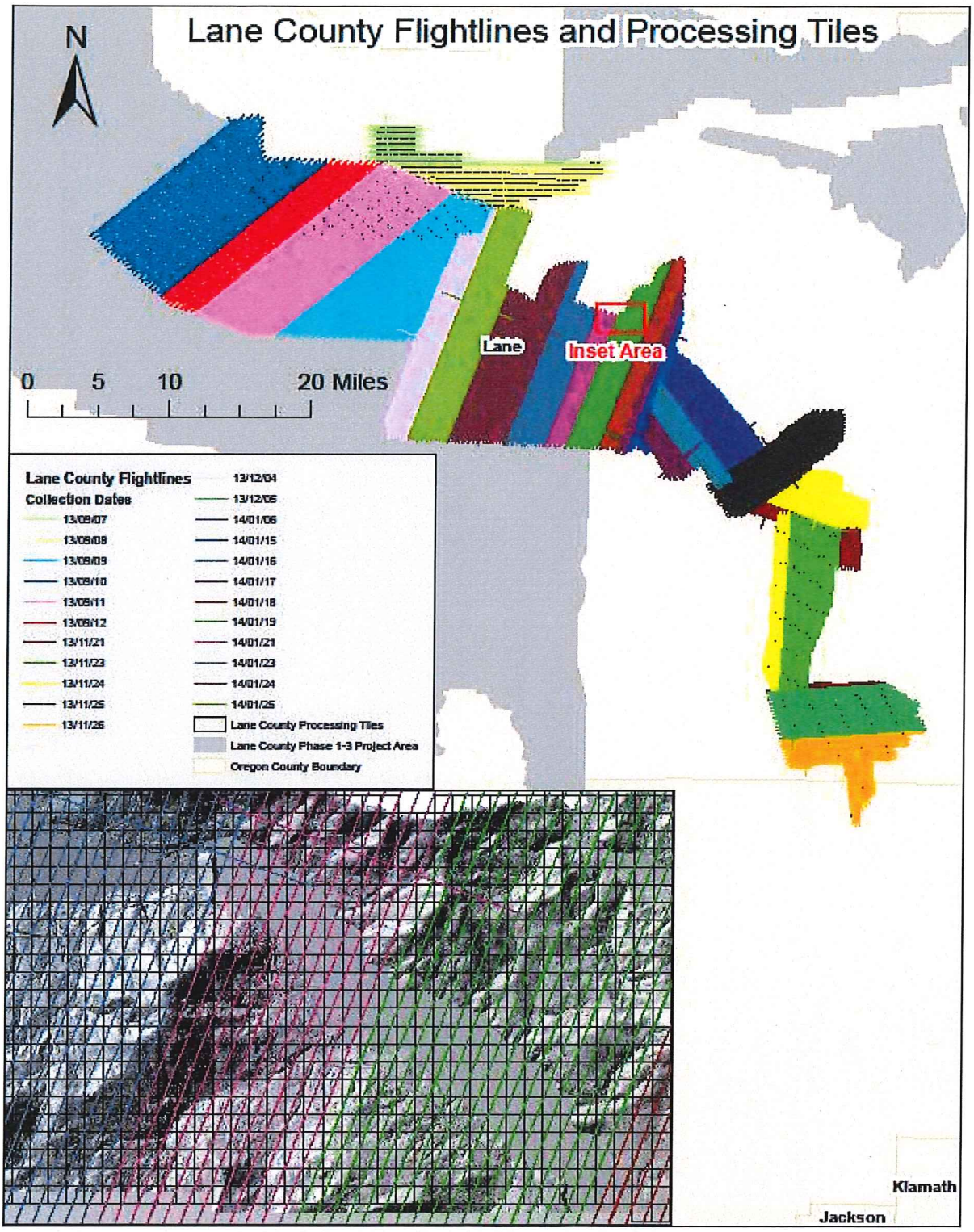

Figure 4. Spatial distribution of flight lines and an example of the processing tiles used in the consistency analysis

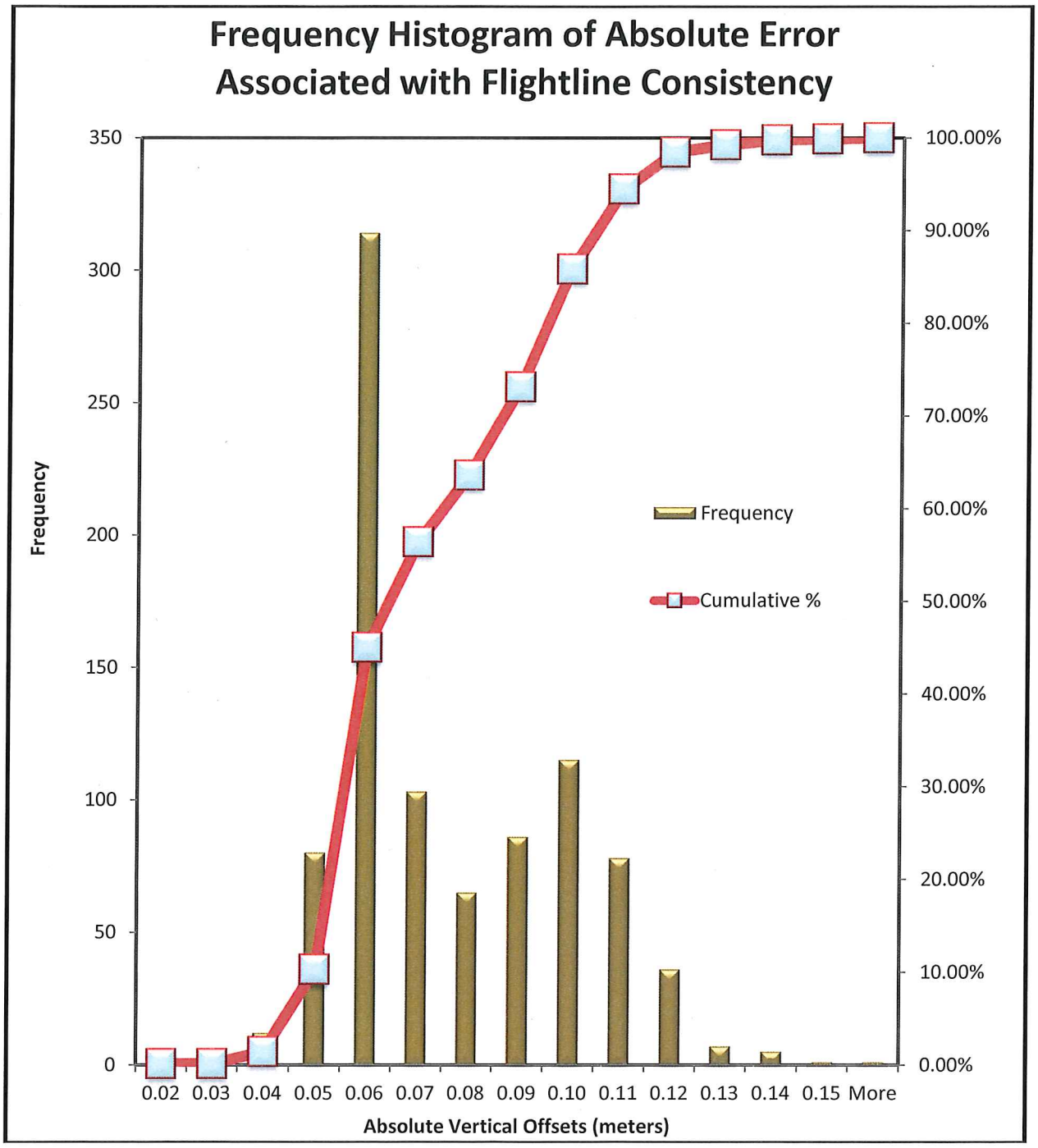

Figure 5. Flight line Consistency Histogram

DEM Quality Visual Inspection

Lidar 3ft grids were loaded into ArcGIS software for visual analysis. Data were examined through slope and hillshade models of bare-earth returns. Hillshades of the highest hit models were used to identify areas of missing ground (Figure 6). Both bare-earth and highest hit models were examined for calibration offsets, tiling artifacts (Figure 7), seam line offsets, pits (Figure 8), and birds.

Calibration offsets typically are visualized as a corduroy-like pattern within a hillshaded lidar model. These offsets present themselves along steep slopes and typically stand out more in highest hit models than bare earth. Tiling artifacts are a result of missing or misclassified data along the edge of lidar processing tiles. These artifacts present themselves as linear features typically 1-2 grid cells in width, and are present in both the highest hit and bare earth models (e.g. Figure 7). Seam line offsets occur where two distinct days of lidar data overlap. Errors occur as a result of improper absolute vertical error adjustments. These errors are typically visualized as a linear stair step running along the edge of connecting flight lines. Pits and birds refer to uncommonly high or low points that are the result of atmospheric and sensor noise. Pits (low points) typically occur where the laser comes in contact with water on the ground (Figure 8). Birds (high points) typically occur where the laser comes into contact with atmospherics (atmospherics include clouds, rain, fog or virga).

Errors located during visual analysis were digitized for spatial reference and stored in ESRI shapefile format. Each feature was assigned an ID value and commented to describe the nature of the observed error. The shapefile was delivered to the vendor for locating and fixing errors. Upon receiving the observed error locations, the vendor performed an analysis to conclude whether the error was valid. For all valid errors found, the vendor has reprocessed the data to accommodate fixes. For all observed errors that are found to be false, the vendor has produced an image documenting the nature of the feature in grid and point data format. A readme file was created explaining all edits performed. Corrected data was delivered to DOGAMI. This data were examined to ensure edits were made, and visually inspected for completeness, then combined into the original delivery.

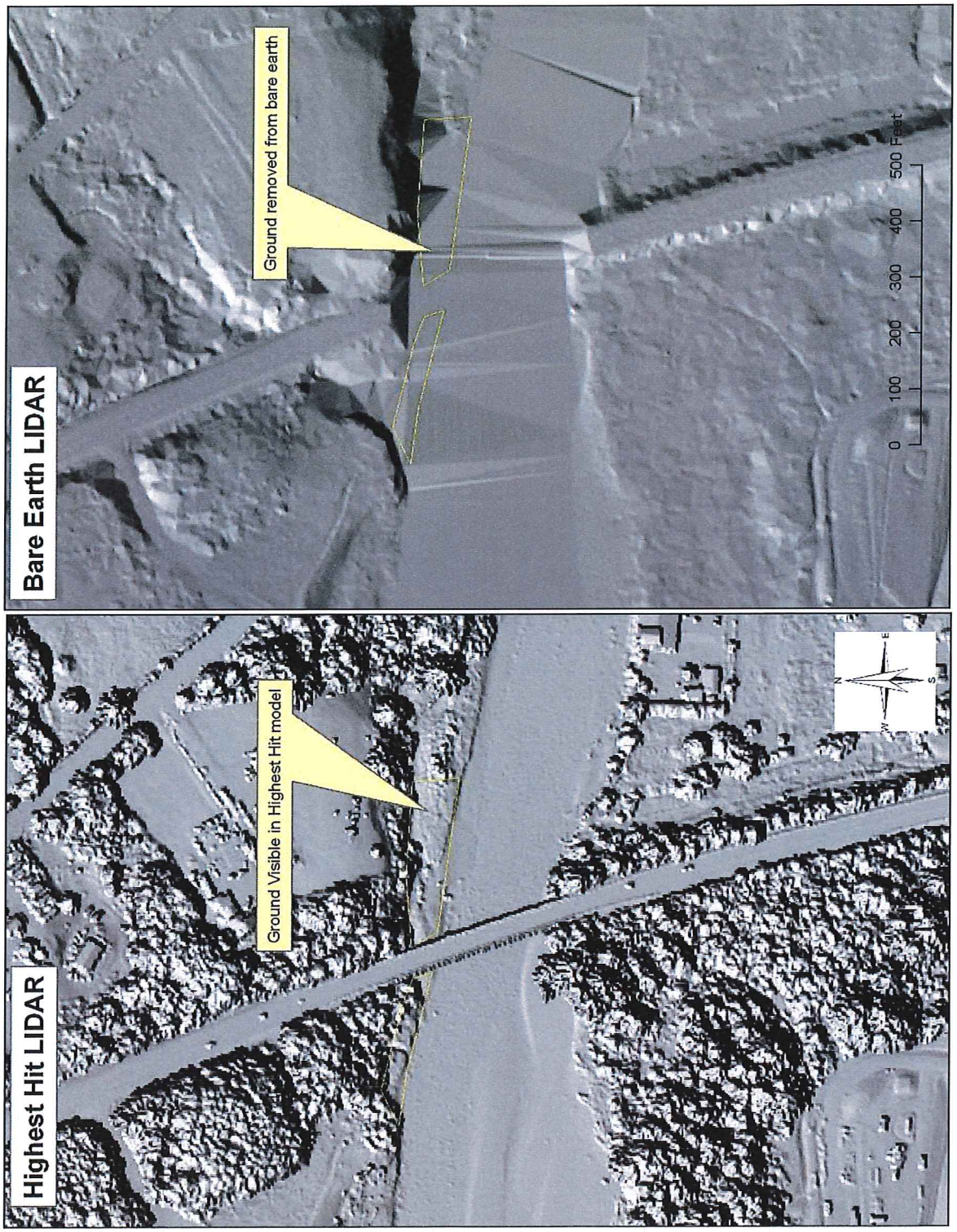

Figure 6. Example of missing ground in lidar bare earth data. Ground is clearly visible in highest hit model, but has been removed from the bare earth model. This type of classification error is common near water body features.

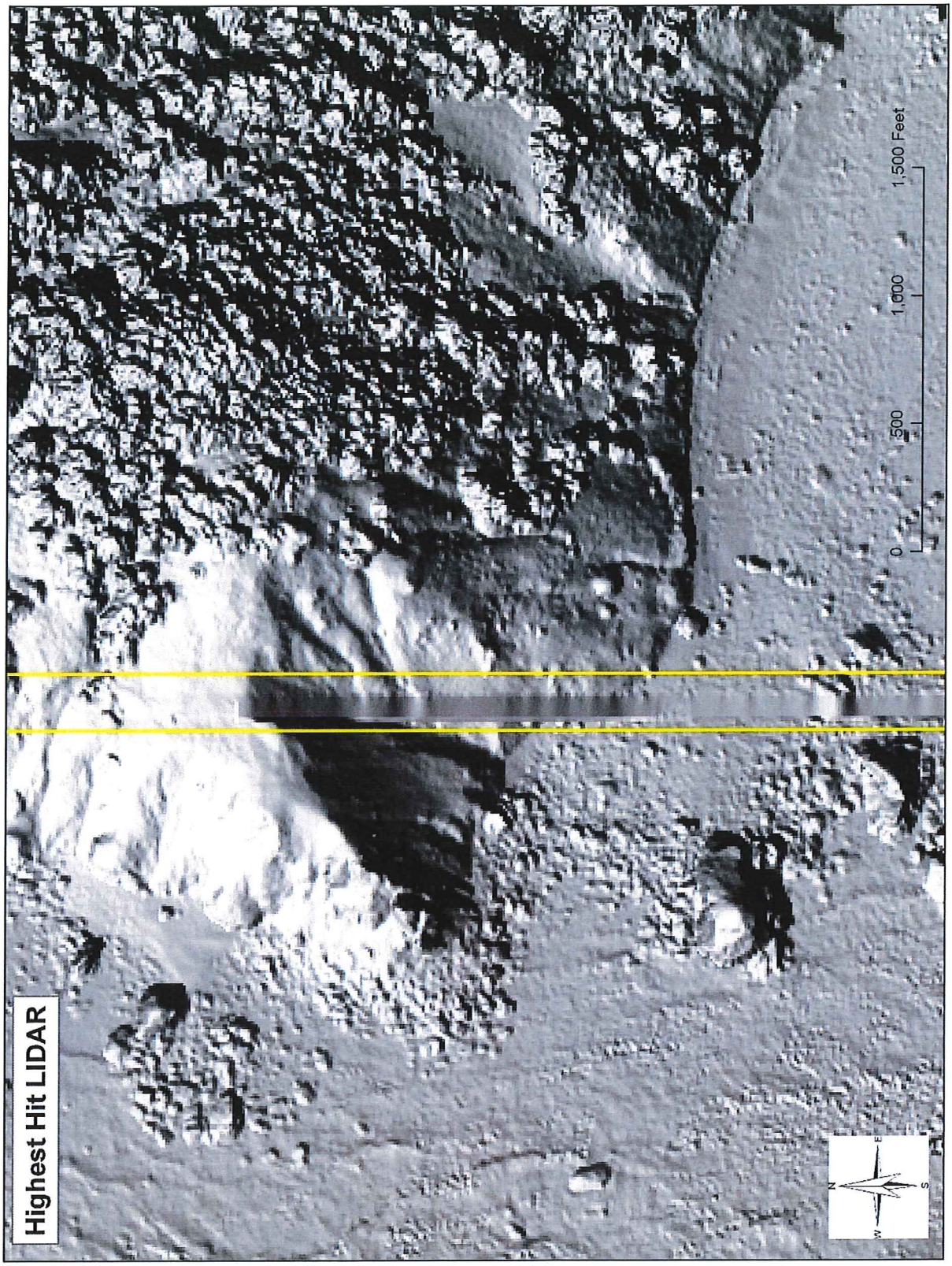

Figure 7. Example of tile artifact found in highest hit lidar data. Artifact is a seam line error created due to misclassification of ground at edge of lidar processing tiles.

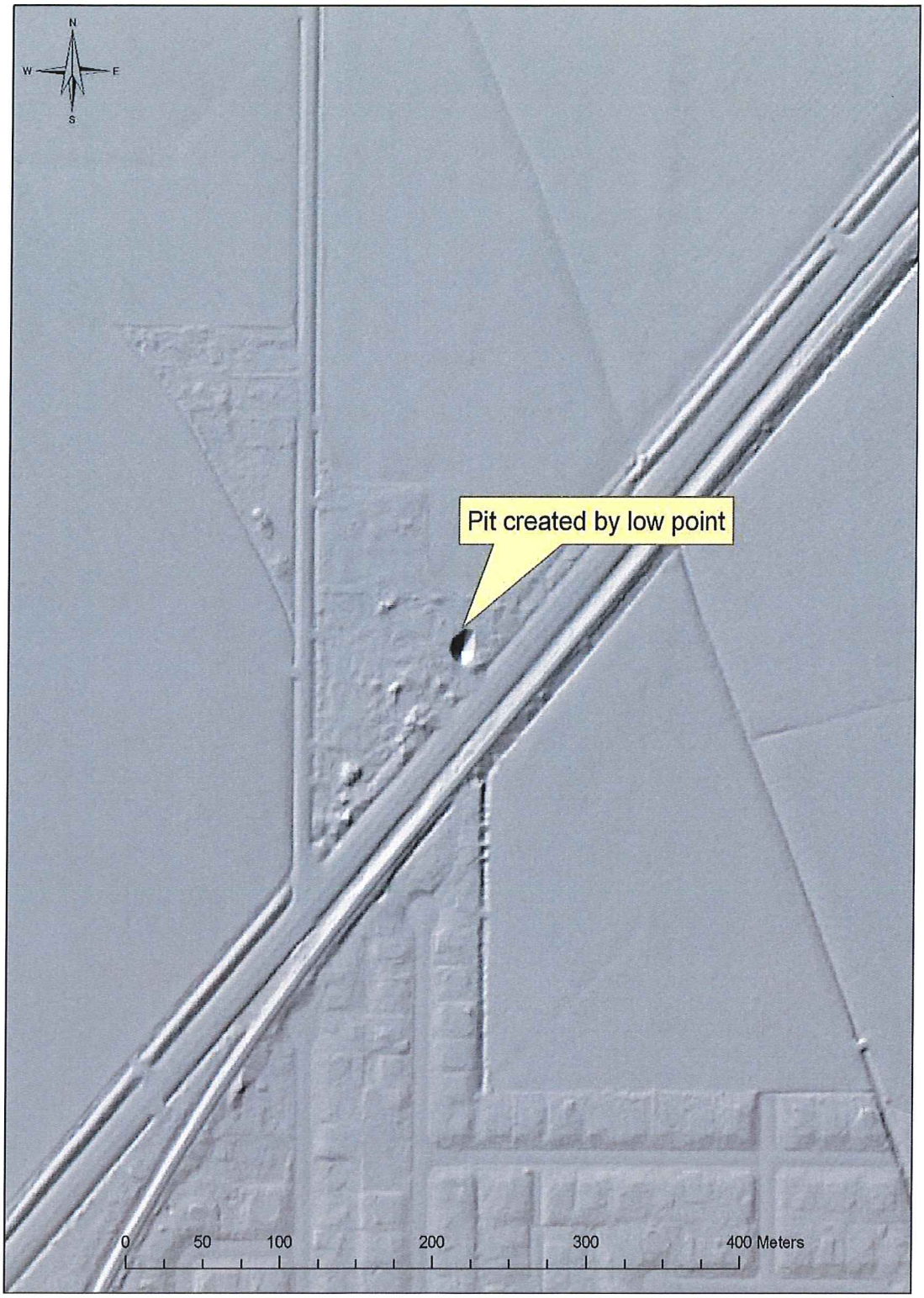

Figure 8. Example of "Pit" caused by low point in ground model. Pits are caused when standing water absorbs the lidar pulse. Pits are evident in ground model as the lowest point elevation is assigned to the grid cell value. Inversely the pit is not observable in the highest hit model as the highest point elevation is assigned to the grid value

Absolute Accuracy Analysis:

Absolute accuracy refers to the mean vertical offset of lidar data relative to measured ground-control points (GCP) obtained throughout the lidar sampling area. DOGAMI used a Trimble™ 5700/5800 Total Station GPS surveying system (Figure 9) to measure GCP's. This system consisted of a GPS base station (5700 unit), Zephyr Geodetic antenna, Trimmark 3 radio, and 5800 "rover". The 5700 base station was mounted on a fixed height (typically 2.0 m) tripod and located over a known geodetic survey monument followed by a site calibration on several adjacent benchmarks to precisely establish a local coordinate system. This step is critical in order to eliminate various survey errors. For example, Trimble reports that the 5700/5800 GPS system have horizontal errors of approximately ±1-cm + 1ppm (parts per million * the baseline length) and ±2-cm in the vertical (TrimbleNavigationSystem, 2005). These errors may be compounded by other factors such as poor satellite geometry, multipath, and poor atmospheric conditions, combining to increase the total error to several centimeters. Thus, the site calibration process is critical in order to minimize these uncertainties.

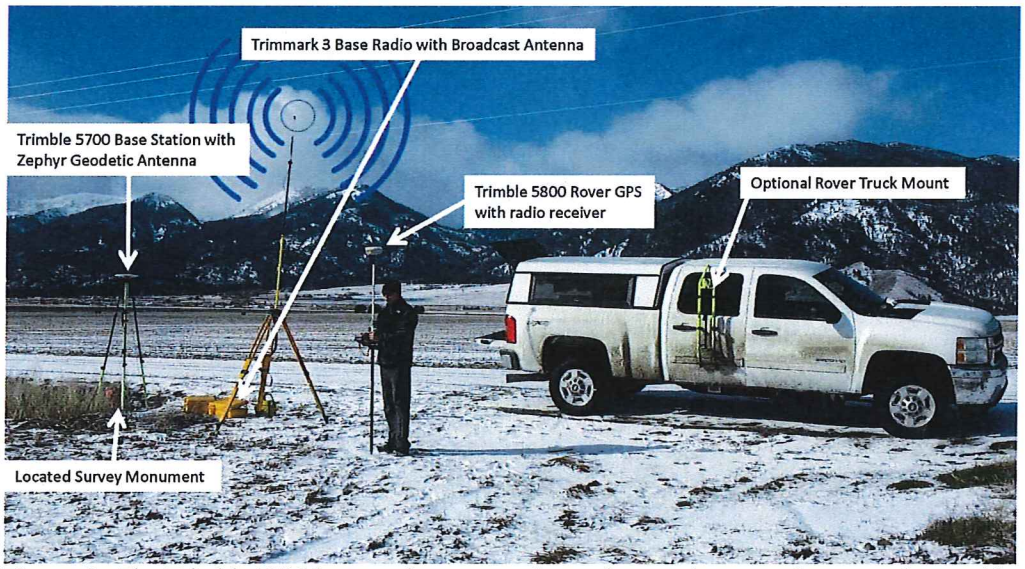

Figure 9. The Trimble 5700 base station antenna located over a known reference point outside Baker City. Corrected GPS position and elevation information is then transmitted by a Trimmark III base radio to the 5800 GPS rover unit.

The approach adopted for DOGAMI lidar surveys was comprised of two components:

1) Verify the horizontal and vertical coordinates established by WSI for a select number of survey monuments used to calibrate the lidar survey. These surveys typically involved a minimum of two hours of GPS occupation over a known point. The collected data were then submitted to the National Geodetic Survey (NGS) Online Positioning User Service (OPUS) for post-processing against several Continuously Operating Reference Stations (CORS) operated by the NGS.
2) Collect GCP's along relatively flat surfaces (roads, paths, parking lots etc.). This step involved the collection of both continuous measurements (from a vehicle as well as from a backpack) as well as static measurements (typically 5 epochs).

Having collected the GCP data, the GPS data was post-processed using Trimble's Geomatic Office software. Data post-processing typically involved calibrations against at least three CORS stations as well as from local site calibrations performed in the field using those benchmarks that had been independently verified. Data is post processed to refine measurements so that horizontal and vertical errors are less than 0.02 meters (0.065 feet). Horizontal accuracy of data is tested by reoccupying a sample subset of survey monuments used for processing of lidar data. Each occupation's x and y coordinates are compared with the vendor coordinates for offsets.

DOGAMI collected GCP points on March 4th through March 7th 2014 and June 19th and 20th 2014. Ground conditions were good every day of collection with no snow and only minimal inclement weather on March 6th. The base stations used in the GCP data collection for Lane County Delivery 1 – 3 were located on monuments 13, 19, 24 and 34 which were established by WSI (See Report of Survey). Accuracy assessments of survey monuments are provided in the form of an OPUS solution from NGS, below is the OPUS solution for monument 13.

NAV FILE: brdc0620.14n	OBS USED: 5951 / 6211 : 96%
ANT NAME: TRM41249.00 SCIT # FIXED	AMB: 36 / 44 : 82%
ARP HEIGHT: 1.800	OVERALL RMS: 0.017(m)

REF FRAME: NAD_83(2011) (EPOCH:2010.0000)		IGS08 (EPOCH:2014.1697)	
X: -2501835.167(m)	0.017(m)	-2501836.022(m)	0.017(m)
Y: -3853818.142(m)	0.016(m)	-3853816.920(m)	0.016(m)
Z: 4409086.400(m)	0.013(m)	4409086.422(m)	0.013(m)
LAT: 44 0 41.08496	0.010(m)	44 0 41.09806	0.010(m)
E LON: 237 0 32.51415	0.006(m)	237 0 32.45209	0.006(m)
W LON: 122 59 27.48585	0.006(m)	122 59 27.54791	0.006(m)
EL HGT: 119.032(m)	0.023(m)	118.644(m)	0.023(m)
ORTHO HGT: 142.473(m)	0.042(m)	[NAVD88 (Computed using GEOID12A)]	

	UTM COORDINATES UTM (Zone 10)	STATE PLANE COORDINATES SPC (3602 OR S)
Northing (Y) [meters]	4873140.441	263442.239
Easting (X) [meters]	500723.970	1300276.085
Convergence [degrees]	0.00627525	-1.70418938
Point Scale	0.99960001	1.00000292
Combined Factor	0.99958135	0.99998426

DOGAMI was able to test the horizontal accuracy of survey monuments used to reference the lidar data while conducting vertical control measurements. For internal purposes only, the XY coordinates of survey monuments surveyed by DOGAMI were compared to the survey monuments provided by the vendor. The average horizontal accuracy for all monument locations occupied by DOGAMI during GCP data collection is 0.008 meters Northing and 0.006

meters Easting (Table 3). The RMSE for positional accuracy for all monument locations occupied by DOGAMI during GCP data collection is 0.015 meters.

	meters	*feet*
Avg. Northing accuracy	0.008	0.026
Avg. Easting accuracy	0.006	0.019
Avg. RMSE for positional accuracy	0.015	0.059

Table 3. Average accuracy values for occupied monuments.

Vertical accuracy analysis of delivered lidar data consisted of differencing collected GCP data and the lidar Digital Elevation Models (DEM) to expose offsets. These offsets were used to produce a mean vertical error and vertical RMSE value for the entire delivered data set. Project specifications list the maximum acceptable mean vertical offset to be 0.20 meters (0.65 feet).

A total of 610 measured GCP's were obtained in the Lane County delivery areas 1 – 3 (Figure 10) were compared with the lidar elevation grids. The data delivered to DOGAMI was found to have a mean vertical offset of -0.019 meters (-0.063 feet) and an RMSE value of 0.058 meters (0.189 ft). Offset values ranged from -0.061 to 0.052 meters (Table 4 and Figure 11).

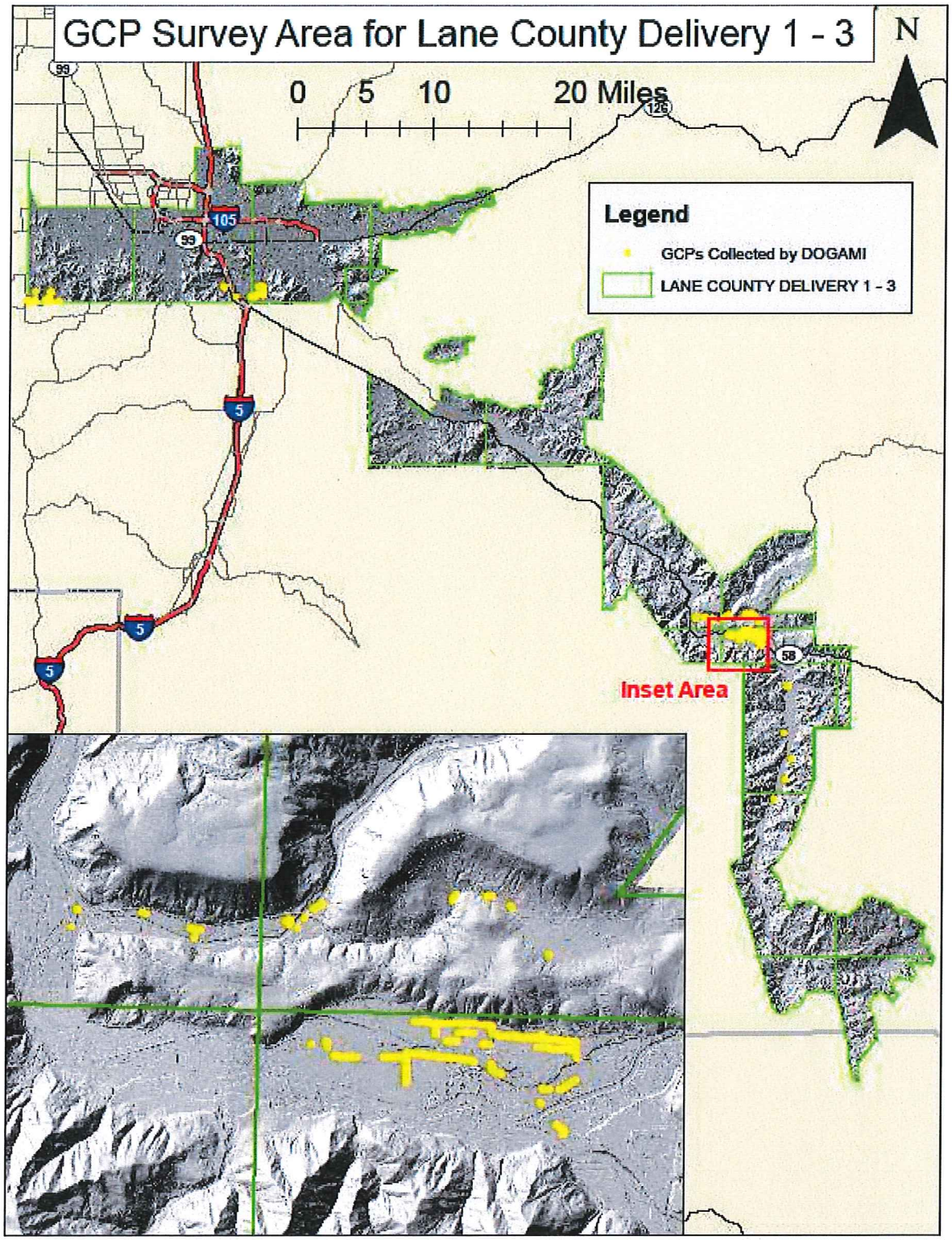

Figure 10. Locations of GCPs surveyed by DOGAMI staff. Data was used to test absolute accuracy for the Lane County lidar survey within the Delivery 1 - 3 project areas.

	Meters	*Feet*
Mean	-0.019	-0.063
Standard Error	0.001	0.003
Standard Deviation	0.025	0.083
Range	0.113	0.371
Minimum	-0.061	-0.199
Maximum	0.052	0.172
RMSE	0.058	0.189

Table 4. Descriptive Statistics for absolute value vertical offsets.

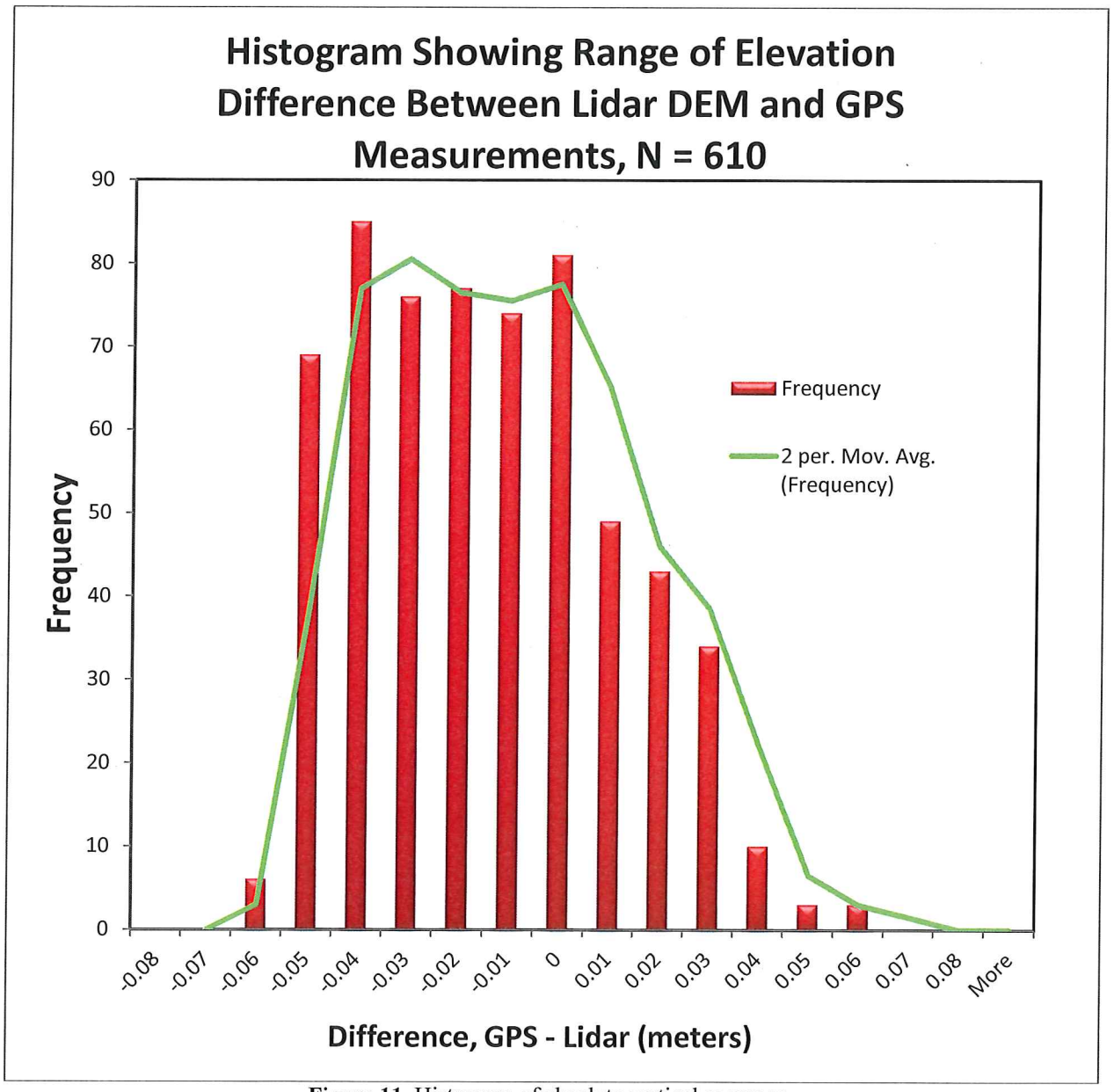

Figure 11. Histogram of absolute vertical accuracy

Ortho Imagery Quality by Visual Inspection

Aerial imagery was collected and processed by WSI to produce georeferenced and ortho-corrected 4 band, 8-bit imagery at 3 inch pixel size. The delivered raster data were checked for their completeness and positional accuracy. Positional accuracy was measured by comparing static features visible in both the orthoimagery and corresponding lidar intensity image (Figure 12). All orthoimagery files were reviewed by DOGAMI staff and imagery was found to have accuracy within 18 inches (one pixel), but since the intensity image has a 1.5ft pixel, that is the smallest error we can report. All ortho-imagery has been loaded and reviewed for completeness and reliability. Visual checks for gross seamline errors and warped pixels were performed by DOGAMI staff. All errors reported to WSI were corrected and resubmitted.

Figure 12. Comparison of orthoimagery to corresponding lidar intensity image

Metadata Analysis

Metadata analysis compared the structure of the metadata file against FGDC standards. Metadata content was reviewed by using a visual check as well as analysis by the USGS Geospatial Metadata validation service: http://geo-nsdi.er.usgs.gov/validation/ 76 metadata files, representing 10% of all metadata associated with this delivery were viewed by DOGAMI staff. No structure issues were found when validating the compliance of metadata to FGDC standards.

Acceptance

The data described in this report meets and exceeds project specifications laid out in the contracted data standards agreement. All components of data to be delivered have been received as of July 16th, 2013. Quality control has confirmed that all delivered data is within specification and function correctly. Quality Assurance has evaluated acquisition parameters to confirm that data was collected within project design scope. Consistency analysis has concluded that all data contains flight line to flight line vertical offset less than the threshold of 0.15 meters as specified in the agreement. The vendor has adequately responded to all fixable errors identified as part of the visual analysis. Perceived grid errors identified by DOGAMI that were found to be false have been documented by the vendor and explained to the satisfaction of DOGAMI reviewers. Absolute accuracy analysis of the data has concluded that absolute vertical error of lidar data is less than the specified tolerance of 0.20 meters as specified in the data standards agreement. Pulse density analysis has concluded that the multi-swath pulse density of the collection is higher than the 8.0 pulses per m² required by project specifications.

Approval Signatures

Date: 10/14/2014

Ian Madin
Chief Scientist – Department of Geology & Mineral Industries

Date: 10/14/2014

Jacob Edwards
Lidar Database Coordinator – Department of Geology & Mineral Industries