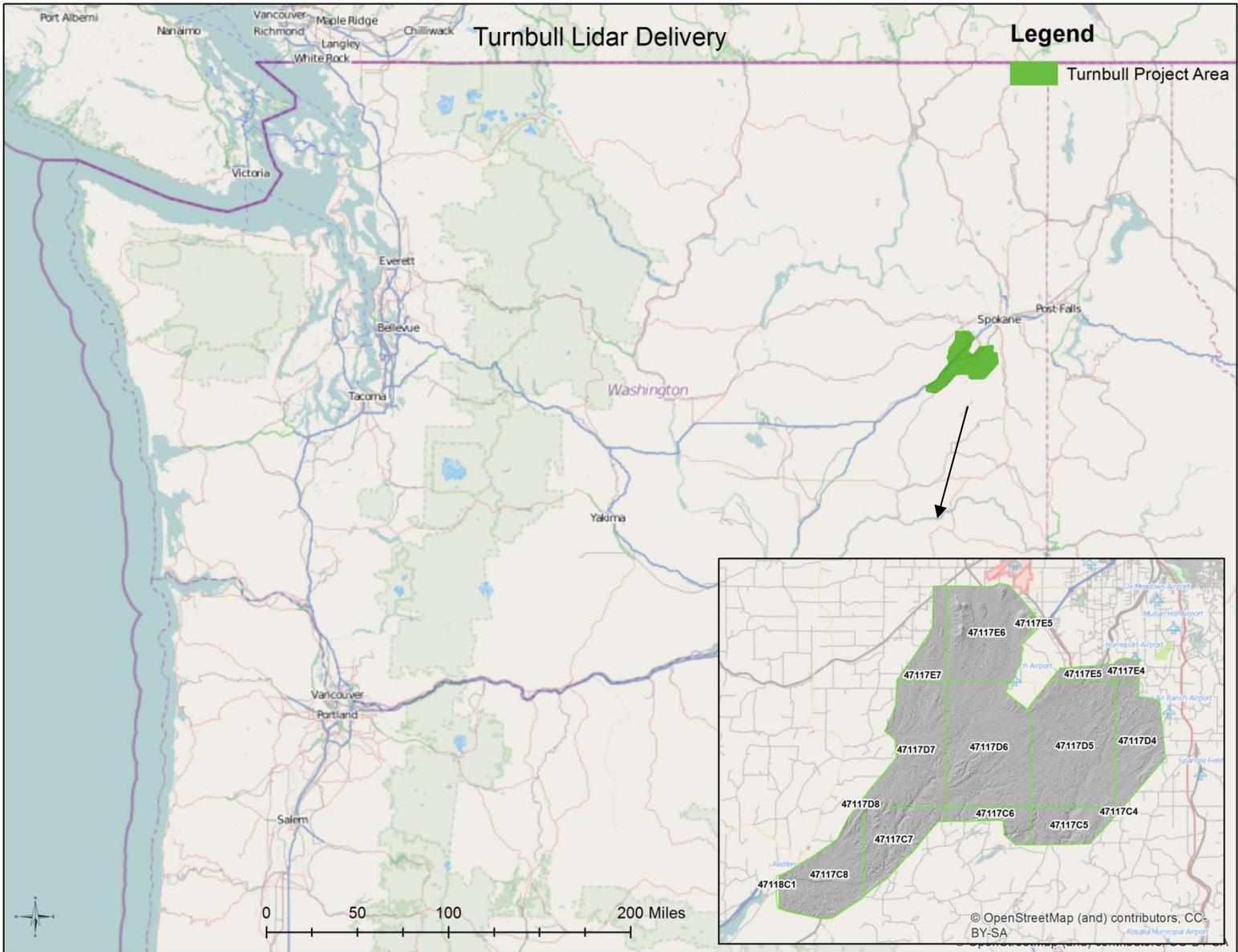




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Turnbull Lidar Project, 2013 –QC Analysis
LIDAR QC Report – September 20th, 2013



Map featuring Turnbull Delivery data extent.

The Oregon Department of Geology and Mineral Industries (DOGAMI) has contracted with a vendor (Watershed Sciences, Incorporated) 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 Exhibit A (OPA #8865) of the 2007-2009 Lidar Data Acquisition Price Agreement (pgs 14-23). Data purchased 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 Turnbull Lidar Project products furnished by the lidar vendor as documentation that all data meets project specific standards.

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

- Consistency Analysis involves examining flight line offsets to quantify the accuracy of data calibration. Calibration influences elevation data quality with poor calibration leading to small but systematic errors in lidar point elevations, which then create inaccuracies within derived lidar elevation models.
- Visual checks are 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 data 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 errors are found, data must be fixed and resubmitted, or the vendor must explain why there is no error.
- Accuracy of the data is examined by comparing lidar elevation data with independent survey control to quantify vertical and horizontal accuracy. For each lidar collection project DOGAMI independently collects accurate elevations for GPS ground control points, which are then compared against delivered lidar elevation models.

Data Completeness

Data for Turnbull area were collected between Oct. 10-11, 2012, Nov. 6-8, 2012 and July 21-23, 2013. Total area of delivered data totals 281.56 square miles. Turnbull (Figure 1) includes data in the form of bare earth and highest hit grids, trajectory files, intensity images, point clouds in ASPRS LASer (LAS) format, ground point density rasters, RTK survey data, a shapefile of the delivery area, and the lidar delivery report (Table 1). Bare earth and highest hit grids were delivered in ArcInfo Grid format with 3ft cell size. Lidar point data are delivered in separate files for all returns and for ground classified returns only. Georeferenced intensity images are supplied in TIF format. Supplementary data includes ground density rasters displaying locations where ground returns are low. Real time kinematic ground survey data (used for absolute vertical adjustment) is supplied in shapefile format. This delivery contains data for the following

USGS 7.5 minute quads (listed by Ohio Code #) within the boundary of the Rogue River Survey collection area (Figure 1):

Delivery: 47117C4, 47117C5, 47117C6, 47117C7, 47117C8, 47117D4, 47117D5, 47117D6, 47117D7, 47117D8, 47117E4, 47117E5, 47117E6, 47117E7, 47118C1

FINAL Delivery	Resolution	Format	Tiling	
<i>Bare Earth DEMs</i>	3ft	Grid	quad	x
<i>Highest Hit DEMs</i>	3ft	Grid	quad	x
<i>Trajectory files</i>	1 sec	ascii (TXYZRPH)	flight	x
<i>Intensity Images</i>	1.5ft	Tif	100th quad	x
<i>LAS</i>	8pts/m ²	Las	100th quad	x
<i>Ground Returns</i>	N/A	Las	100th quad	x
<i>Ground Density Raster</i>	3ft	Grid	quad	x
<i>RTK point data</i>		Shape		x
<i>Delivery Area shapefile</i>		Shape	quad	x
<i>Report</i>		Pdf		x
Miscellaneous				
<i>Processing bins</i>		dxr or dgn	project	x

Table 1. Deliverable Checklist

All data associated with this delivery has been loaded and viewed to ensure completeness. Raster imagery such as elevation grids and intensity geotifs have been viewed in ArcMap, cross referenced with the delivery area. Las files have been loaded into Terrasolid software to ensure completeness and readability.

Deliverable Descriptions: (All data projected in NAD_1983_UTM_Zone_11N_2011 with exception of trajectory files).

- 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 (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.

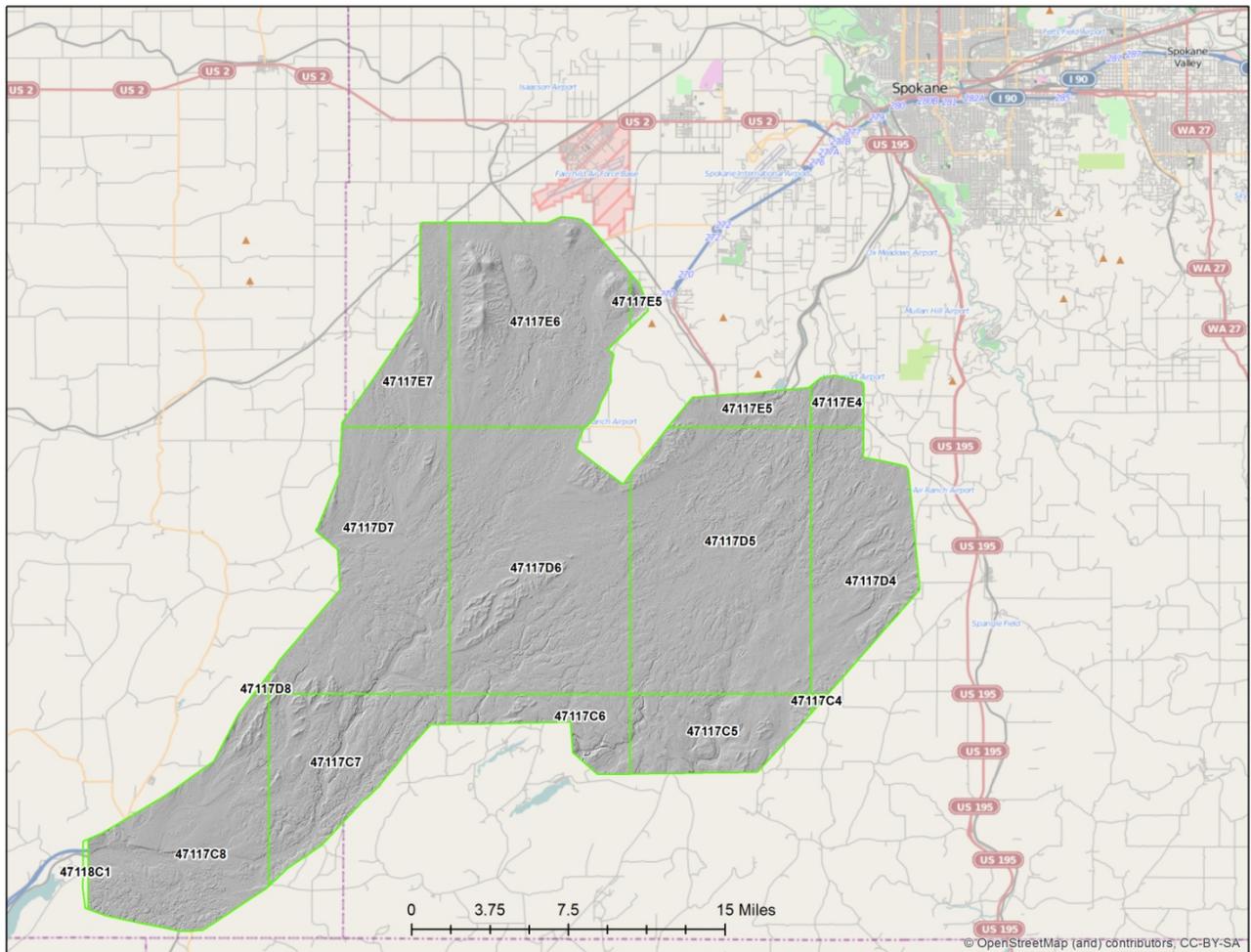


Figure 1. Turnbull Lidar Project area. Data is referenced to USGS 7.5 minute quadrangles within the extents of the Turnbull Lidar Project collection area.

Consistency Analysis:

DOGAMI has specified that lidar consistency, as measured by vertical offsets between flight lines, must average less than 0.15m (0.49 feet).. 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 639 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. 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 14,668,832.63 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. A total of 117 flight lines were sampled and compared for consistency.

Summary Statistics

# of Tiles	639
# of Flight Line Sections	221
Avg # of Points	14,668,832.63
Avg. Magnitude Z error (m)	0.02

Table 2a. Summary Results of Consistency Analysis

	<i>meters</i>	<i>feet</i>
Mean	0.027	0.088
Standard Error	0.000	0.001
Standard Deviation	0.002	0.007
Sample Variance	0.000	0.000
Range	0.012	0.038
Minimum	0.025	0.083
Maximum	0.037	0.121

Table 2b. Descriptive Statistics for Magnitude Z Error.

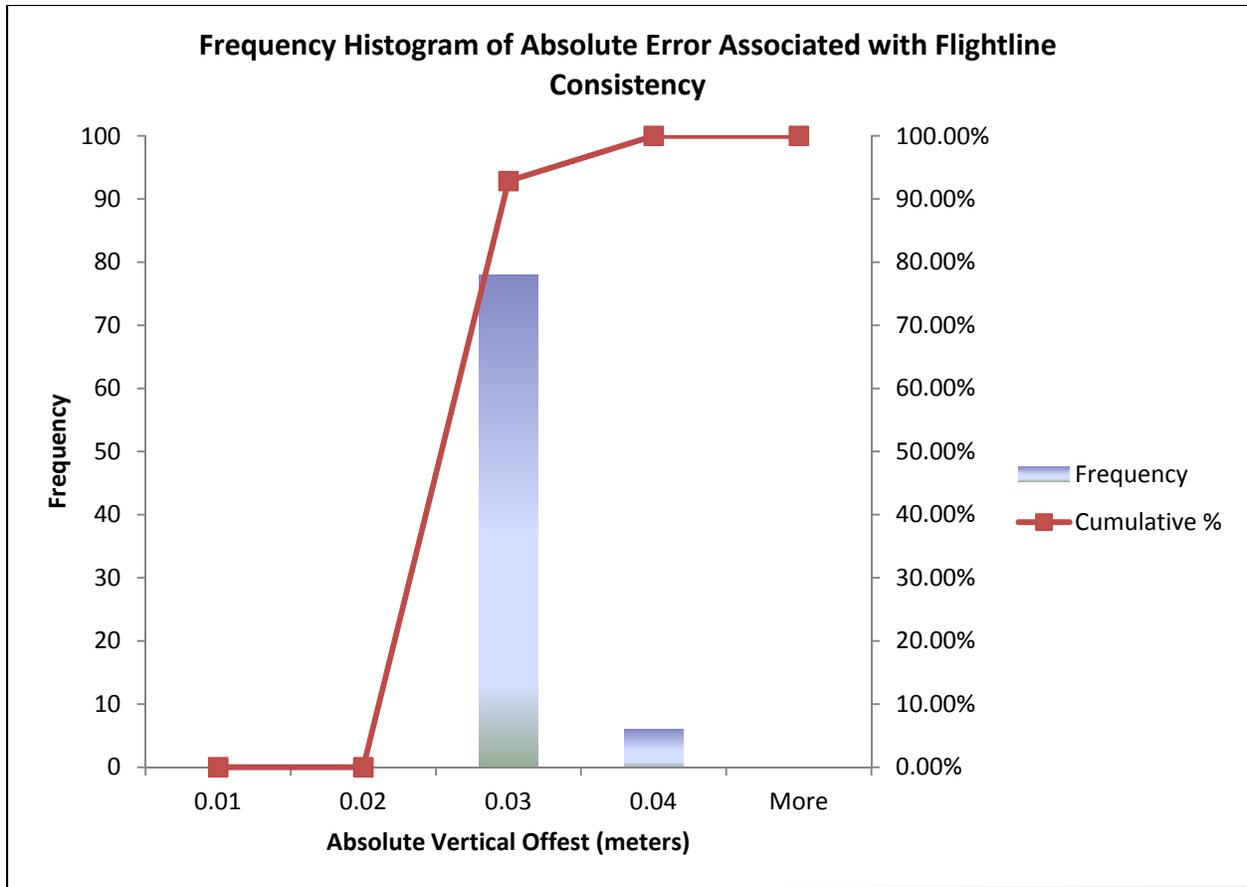


Figure 2. Flight line Consistency Histogram

Results of the consistency analysis found the average flight line offset to be 0.02 meters with a maximum error of 0.037 (Table 2b). Distribution of error showed 93% of all error was less than 0.03m and 99% was less than 0.04m (Figure 2). These results show that all data are within tolerances of data consistency according to contract agreement.

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 highest hit models were used to identify areas of missing ground (Figure 3). Both bare earth and highest hit models were examined for calibration offsets, tiling artifacts (Figure 4), seam line offsets, pits (Figure 5), and birds.

Calibration offsets typically are visualized as a corduroy-like patterning 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 3). 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 5). Birds (high points) typically occur where the laser comes into contact with atmospherics¹.

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.

¹ Atmospherics include clouds, rain, fog, or virga.

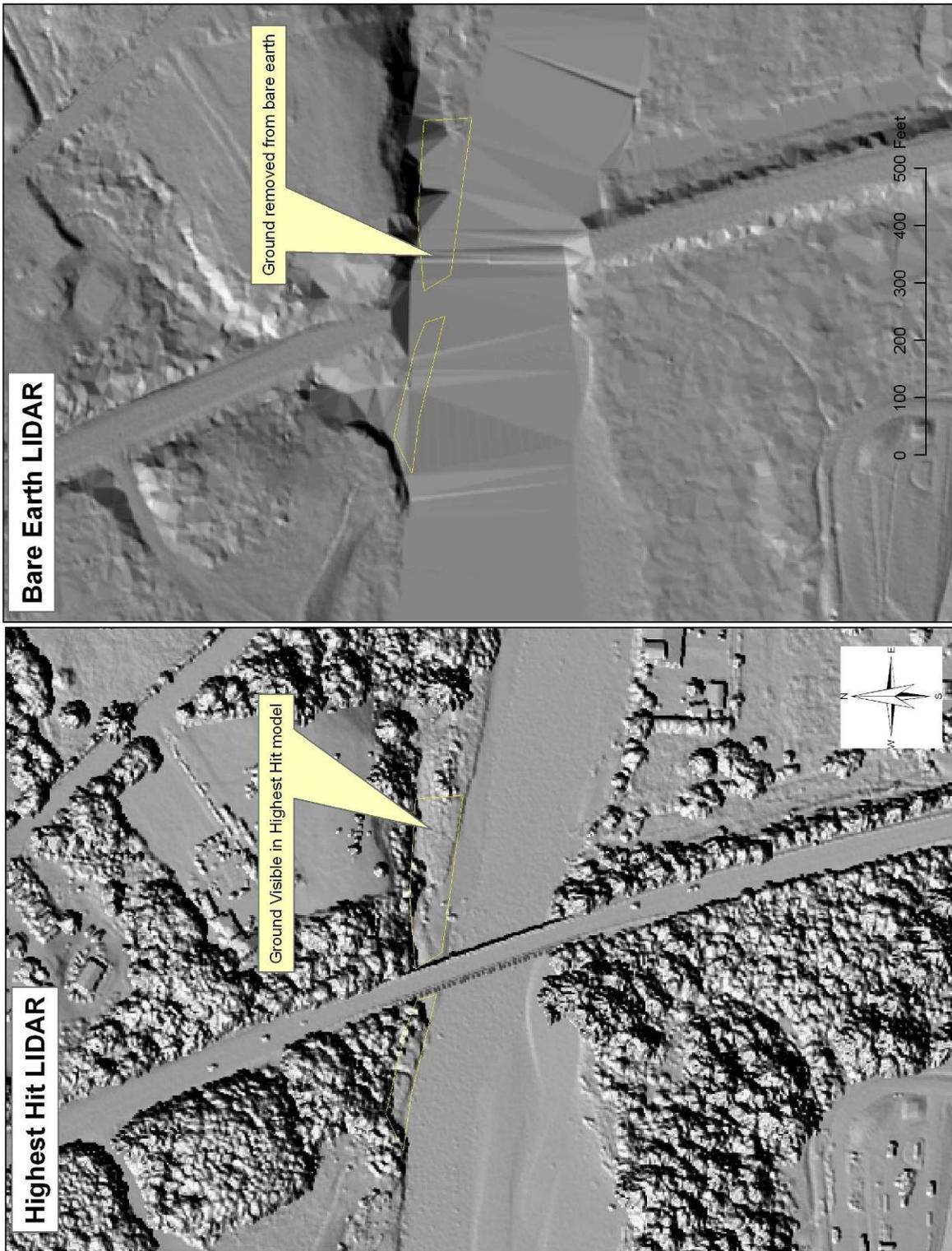


Figure 3. Example of missing ground in lidar bare earth data. Ground is clearly visible in highest hit model, but has been removed from the bare earth model. This type of classification error is common near water body features.

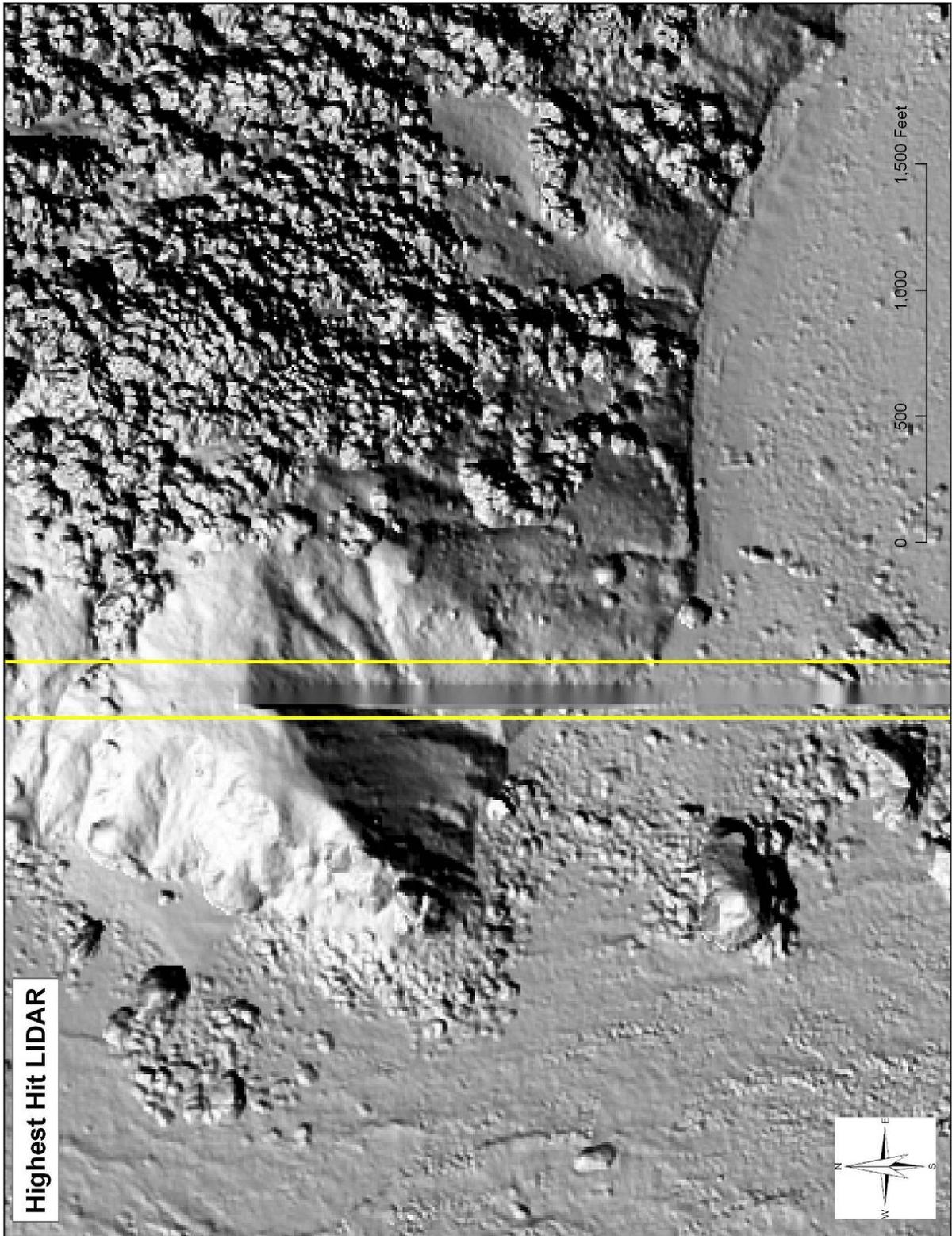


Figure 4. Example of tile artifact found in highest hit lidar data. Artifact is a seam line error created due to misclassification of ground at edge of lidar processing tiles.

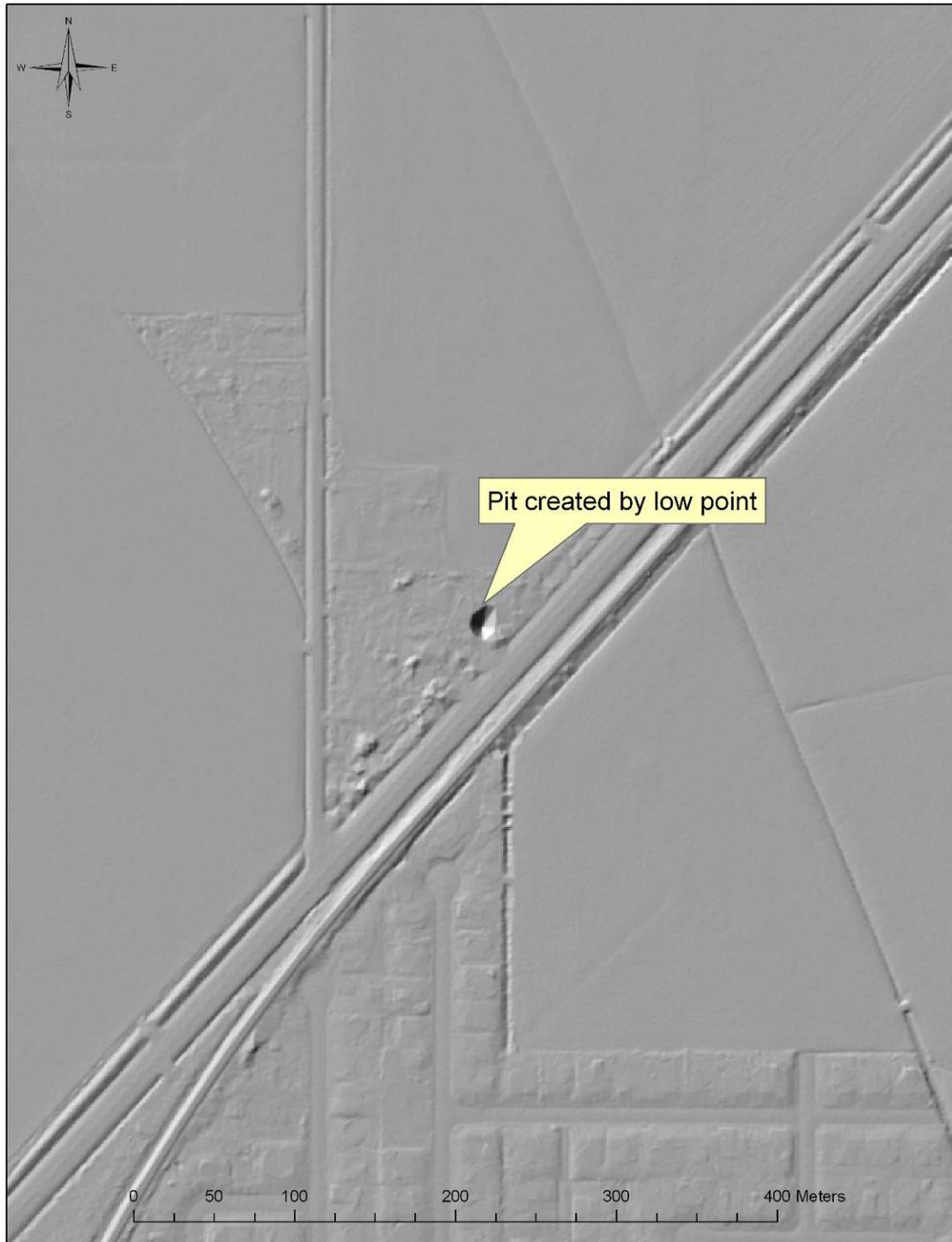


Figure 5. Example of “Pit” caused by low point in ground model. Pits are caused when standing water absorbs the lidar pulse. Pits are evident in ground model as the lowest point elevation is assigned to the grid cell value. Inversely the pit is not observable in the highest hit model as the highest point 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 5) 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 $\pm 1\text{-cm} + 1\text{ppm}$ (parts per million * the baseline length) and $\pm 2\text{-cm}$ 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.

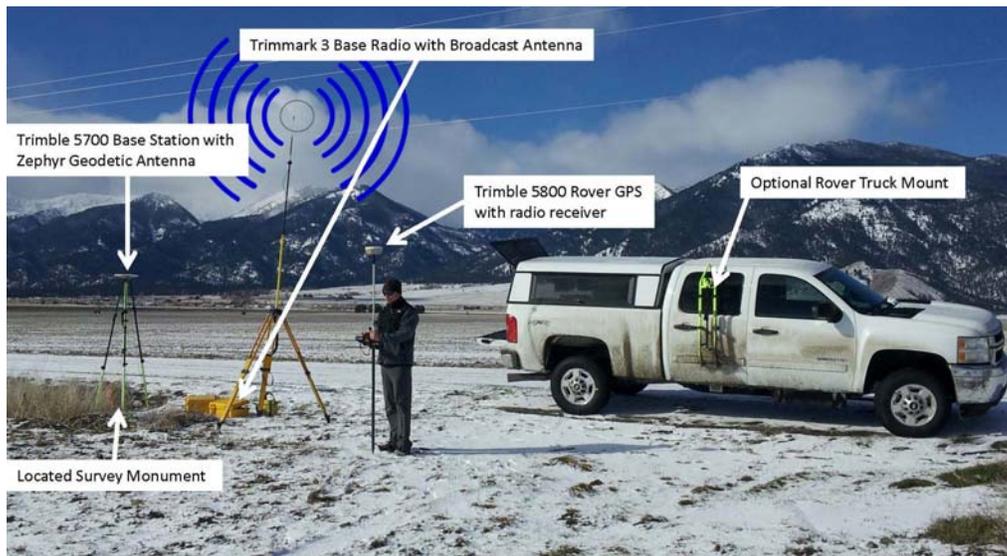


Figure 5. The Trimble 5700 base station antenna located over a known reference point at Cape Lookout State Park. Corrected GPS position and elevation information is then transmitted by a Trimmark III base radio to the 5800 GPS rover unit.

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 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.

Vertical accuracy analysis consisted of differencing control data and the delivered 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 3,412 measured GCP's were obtained in the region and compared with the lidar elevation grids. The data delivered to DOGAMI was found to have a mean vertical offset of 0.009 meters (0.029feet) and an RMSE value of 0.042 meters (0.138 ft). Offset values ranged from -0.162 meters (-0.531 feet) to 0.158 meters (0.518 feet) (Table 3 and Figure 7).

Horizontal accuracies were not specified in agreement since true horizontal accuracy is regarded as a product of the lidar ground foot print. Lidar is referenced to co-acquired GPS base station data that has accuracies far greater than the value of the lidar foot print. The ground footprint is equal to $1/3333^{\text{rd}}$ of above ground flying height. Survey altitude for this acquisition was targeted at 900 meters yielding a ground foot print of 0.27 meters. This value exceeds the typical accuracy value of ground control used to reference the lidar data (<0.01m). Project specifications require the lidar foot print to fall between 0.15 and 0.40 meters.

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 vender and in almost every case, the reported results were consistent with those obtained by DOGAMI staff.

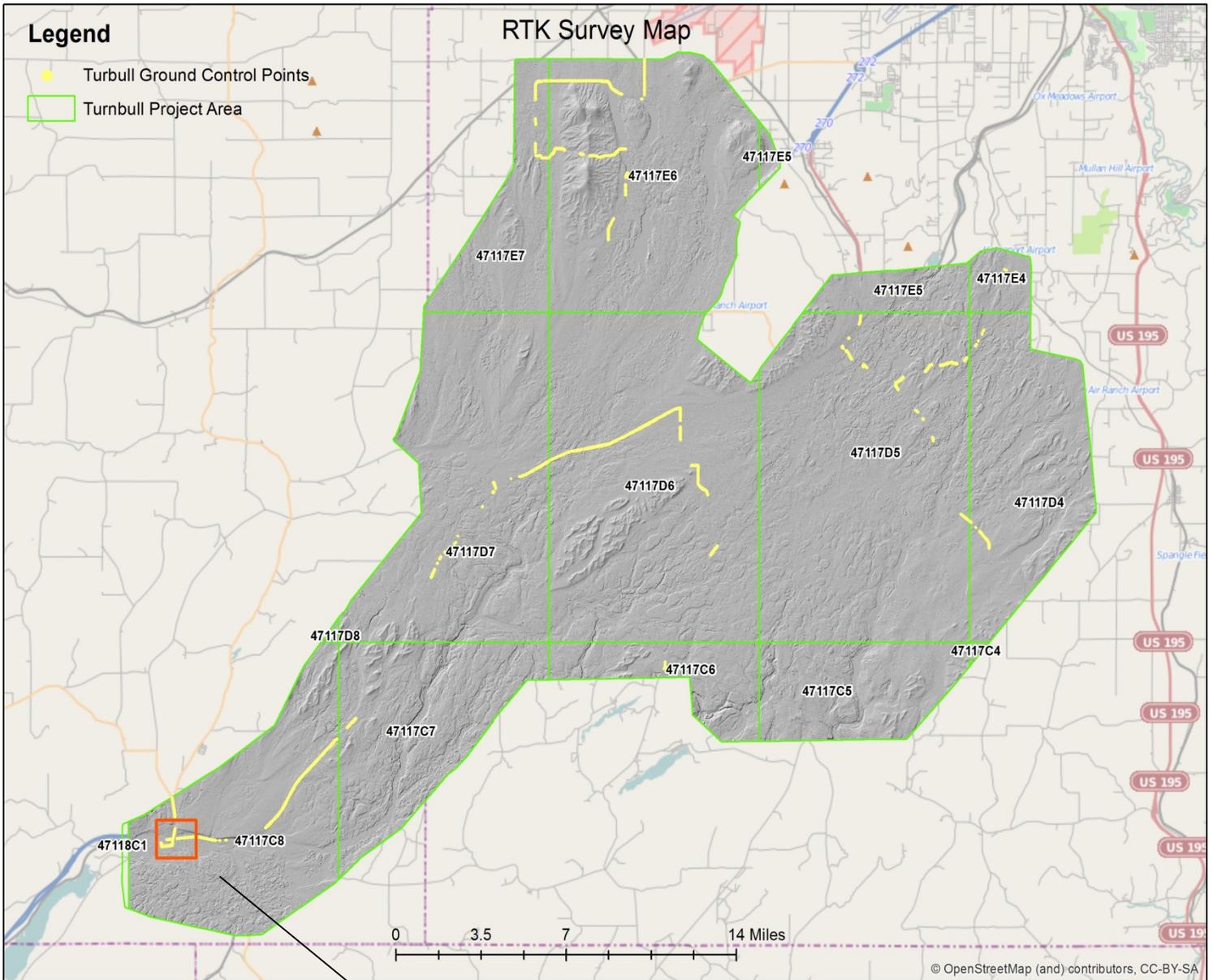


Figure 6. Locations of RTK control surveyed by DOGAMI. Data was used to test absolute accuracy for the Turnbull Project survey within the project extent.



	<i>Meters</i>	<i>Feet</i>
Mean	0.009	0.029
Standard Error	0.001	0.002
Standard Deviation	0.041	0.135
Range	0.320	1.050
Minimum	-0.162	-0.531
Maximum	0.158	0.518
RMSE	0.009	0.029

Table 3. Descriptive Statistics for absolute value vertical offsets.

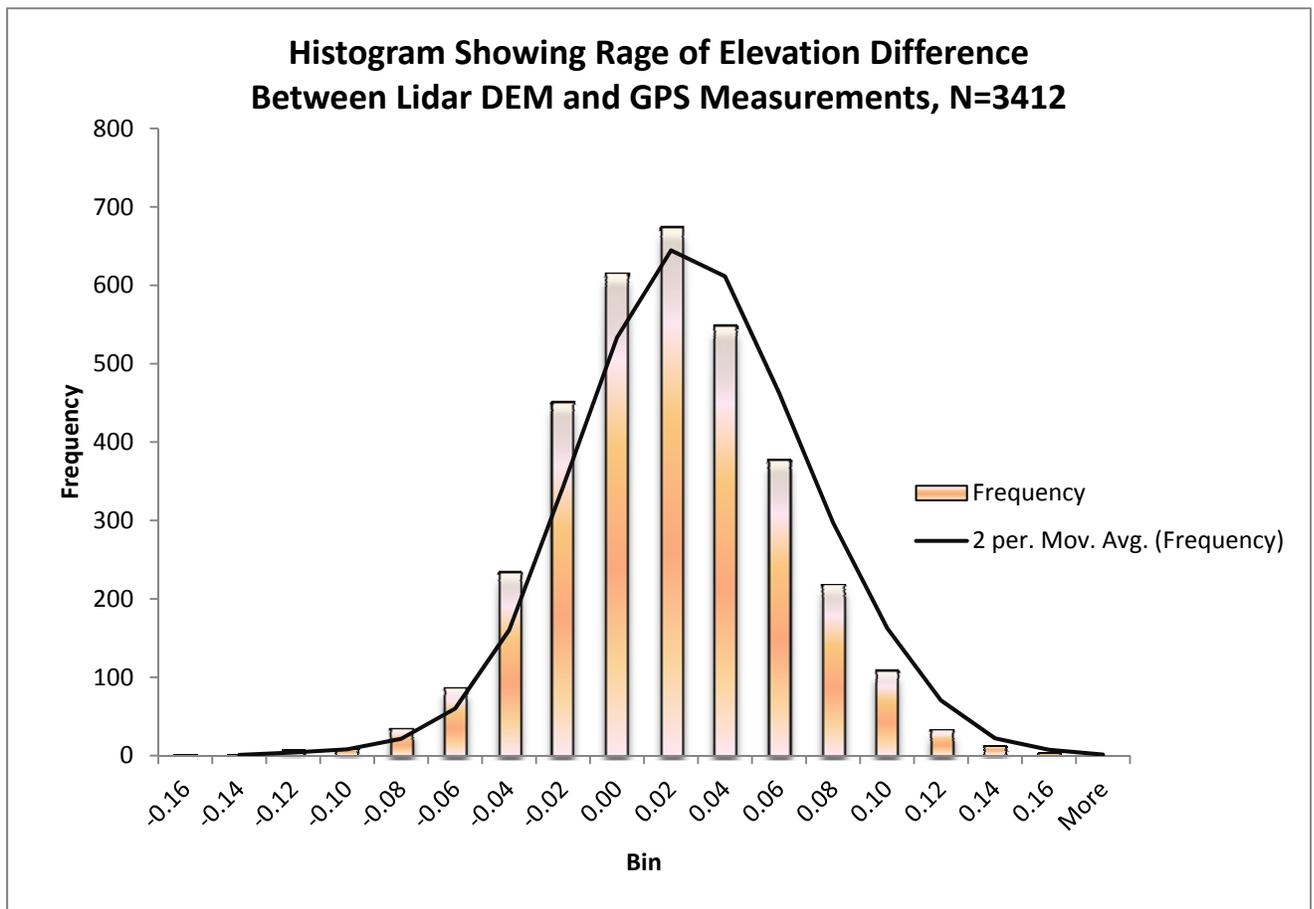


Figure 7. Histogram of absolute vertical accuracy

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 September 20th, 2013. 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 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: 9/20/13

Ian Madin
Chief Scientist – Department of Geology & Mineral Industries



_____ Date 9/20/13

Paul Ferro
Interim Lidar Database Coordinator – Department of Geology & Mineral Industries