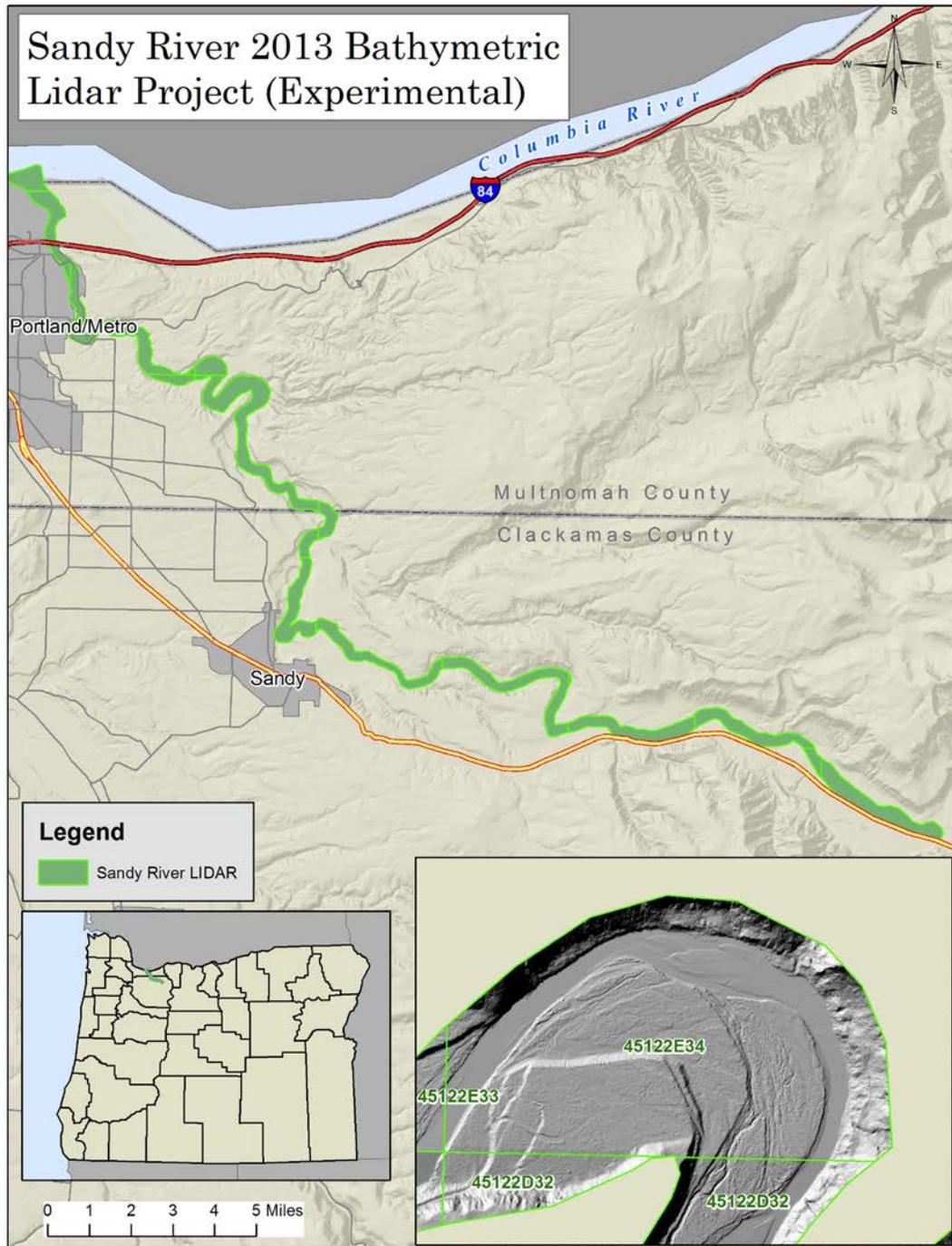




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Sandy River, OR Bathymetric Lidar Project, 2012 – Delivery QC Analysis
Lidar QC Report – March 26th, 2013



Map featuring Sandy River, OR Bathymetric Lidar Project Delivery data extent.

The Oregon Department of Geology & Mineral Industries has contracted with Watershed Sciences 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 2007-2009 Lidar Data Acquisition Price Agreement (pgs 14-23). Data submitted under this price agreement is 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 Sandy River, OR Bathymetric Lidar Project Lidar Project – Delivery products furnished by the lidar vendor as documentation that all data meets project specific standards.

Upon receipt from vendor (Watershed Sciences), all lidar data for Delivery was independently reviewed by staff from the Oregon Department of Geology and Mineral Industries (DOGAMI) 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 within lidar elevation points, 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 resubmitted.
- 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 collected independent GPS ground elevations, which were then compared against delivered lidar elevation models.

Data Completeness

Data for the Sandy River, OR Bathymetric Lidar Project Bathymetric area were collected September 22nd, 2012. Total area of delivered data totals 10.81 square miles. Two lasers were implemented in this study. A green lidar system (Green) was used to map elevations of the river bed and a near infrared laser (NIR) was used to map elevations outside the channel. Delivery (Figure 1) includes data in the format of grids, trajectory files, intensity images, RGB GeoTiffs, Lidar ASCII Standard (LAS) point files, RTK survey data, a shapefile of the delivery area, and

the lidar delivery report (Table 1). Bare earth (NIR and Green) and highest hit (NIR) grids were delivered in ArcInfo Grid format with 1 meter cell size. Lidar point data is delivered in LAS binary format for ground classified returns as well as the entire lidar point cloud. Georeferenced intensity images and orthophotography are supplied in TIF format. 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 Sandy River, OR Bathymetric Lidar Project collection area (Figure 1):

Delivery Quadrangles: 45121c8, 45122c1, 45122c2, 45122d1, 45122d2, 45122d3, 45122e3, 45122e4

FINAL Delivery	Resolution	Format	Tiling	
<i>Bare Earth DEMs</i>	1 meter	grid	quad	x
<i>Highest Hit DEMs</i>	1 meter	grid	quad	x
<i>Trajectory files</i>	1 sec	ascii (TXYZRPH)	project	x
<i>Intensity Images</i>	0.5 meter	tif	100th quad	x
<i>NIR LAS</i>	8pts/m ²	las	100th quad	x
<i>Green LAS</i>	4-5pts/m ²	las	100th quad	x
<i>Orthophotography</i>	0.5 meter	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 Oregon Lambert, NAD83 (HARN), Intl Feet with exception of trajectory files).

- Bare Earth Grids: Tin interpolated grids created from lidar ground returns.
- Bare Earth Bathymetric Grids: Tin interpolated grids created from merged green laser returns of the channel bed and NIR lidar ground classified returns.
- Highest Hit Grids: Tin interpolated grids created from the highest lidar elevation for a given 1 meter cell.
- Intensity TIF: TIF raster built using returned lidar pulse intensity values gathered from highest hit returns.

- Orthophotography: Orthorectified aerial imagery collected from aircraft mounted camera. Photos contain red, green, and blue bands (RBG).
- 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).
- NIR 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).
- Green 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).
- 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.

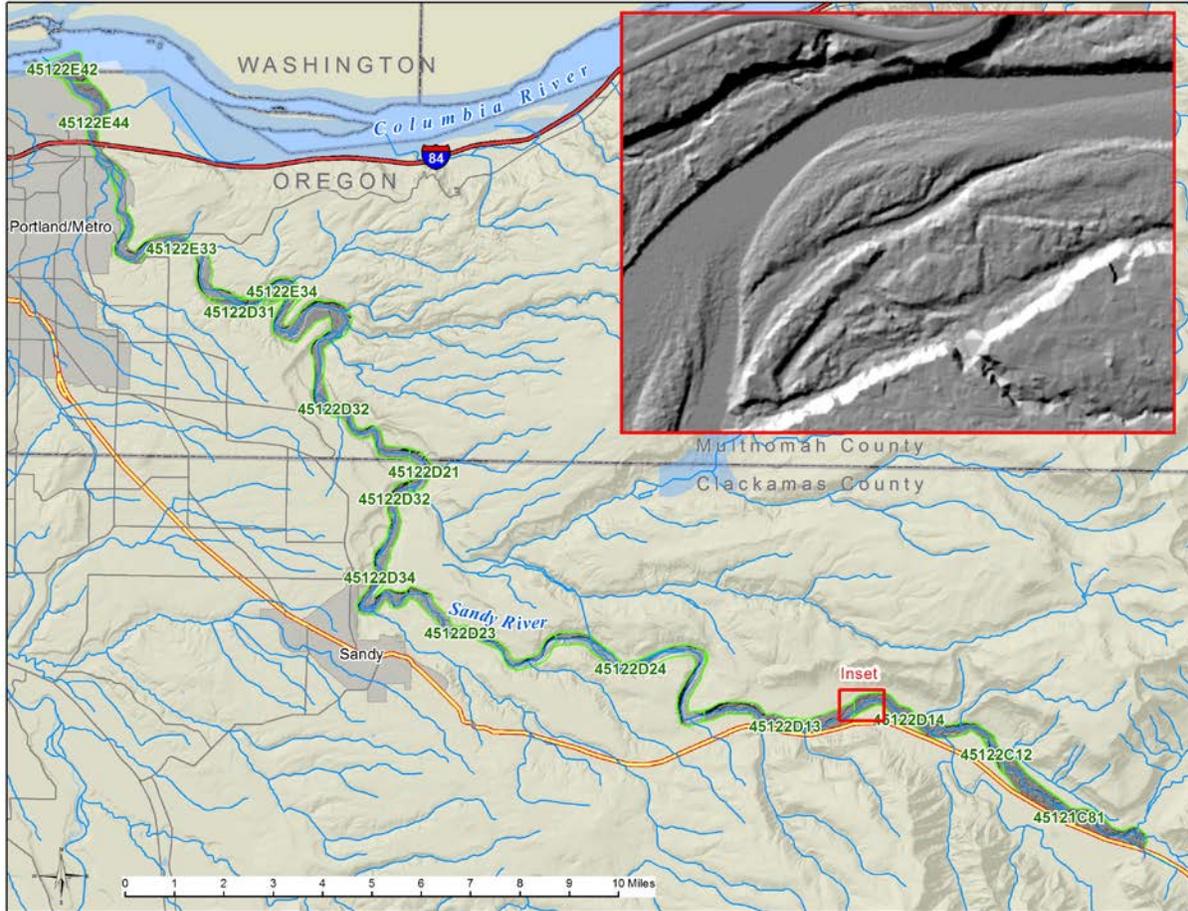


Figure 1. Sandy River, OR Bathymetric Lidar Project area. Data is referenced to USGS 7.5 minute quadrangles within the extents of the Sandy River, OR Bathymetric Lidar Project Survey collection area.

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 88 delivered data tiles for both green and NIR laser data 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. The average number of points used

for flight line comparison was 2,517,637 per flight line for the NIR and 1,007,094 per line for the green lidar (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 68 flight lines for NIR lidar and 63 flight lines for green lidar were sampled and compared for consistency.

Summary Statistics	NIR Lidar	Green Lidar
# of Tiles	88	88
# of Flight Line Sections	68	63
Avg # of Points	2,517,537	1,007,094
Avg. Magnitude Z error (m)	0.025	0.037

Table 2a. Summary Results of Consistency Analysis

	NIR (m)	NIR(ft)	Green(m)	Green(ft)
Mean	0.025	0.082	0.037	0.123
Standard Error	0.001	0.002	0.001	0.003
Standard Deviation	0.004	0.015	0.006	0.020
Sample Variance	0.000	0.000	0.000	0.000
Range	0.025	0.083	0.028	0.093
Minimum	0.019	0.061	0.027	0.087
Maximum	0.044	0.144	0.055	0.180

Table 2b. Descriptive Statistics for Magnitude Z Error.

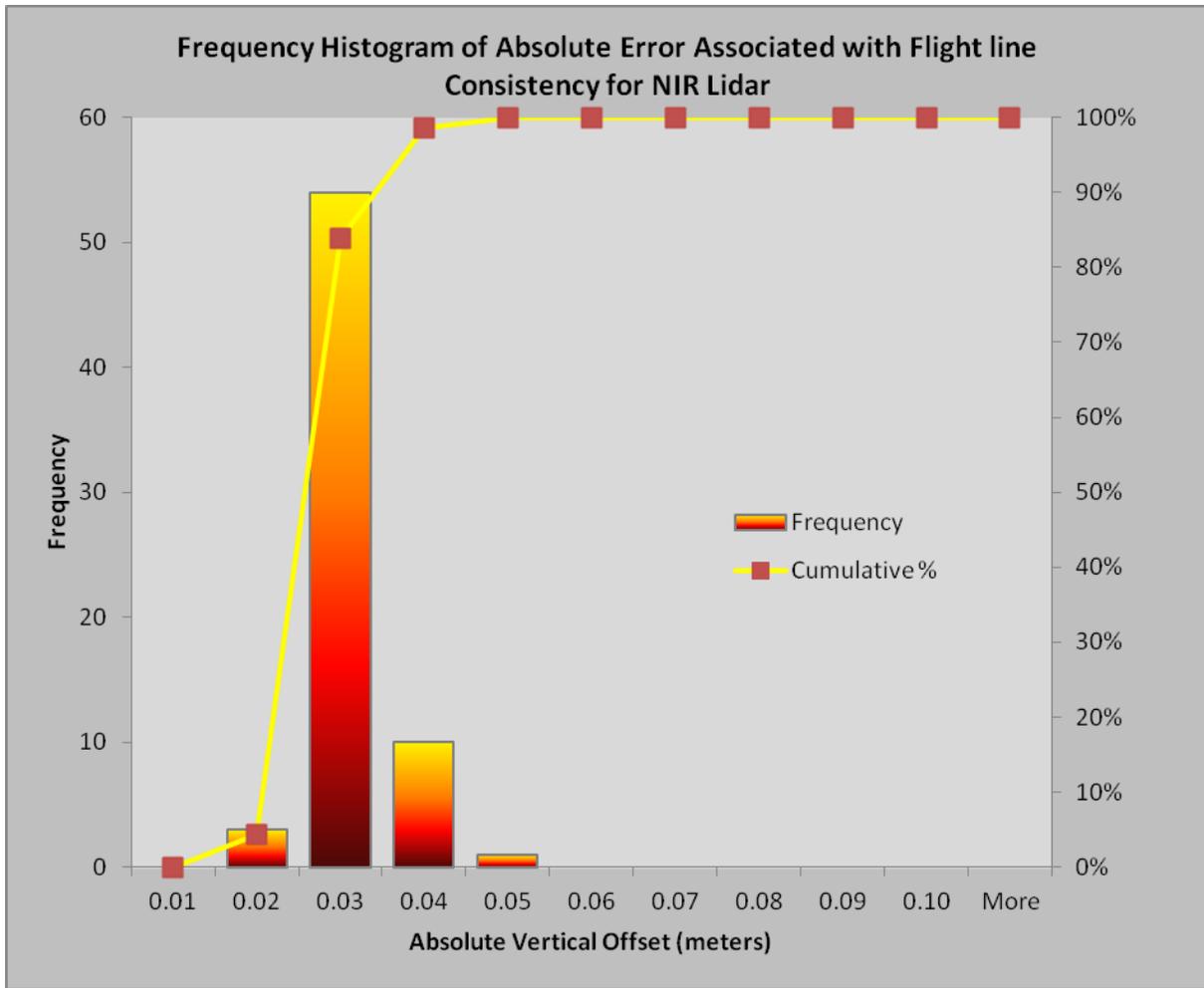


Figure 2a. Flight line Consistency histogram for NIR Lidar.

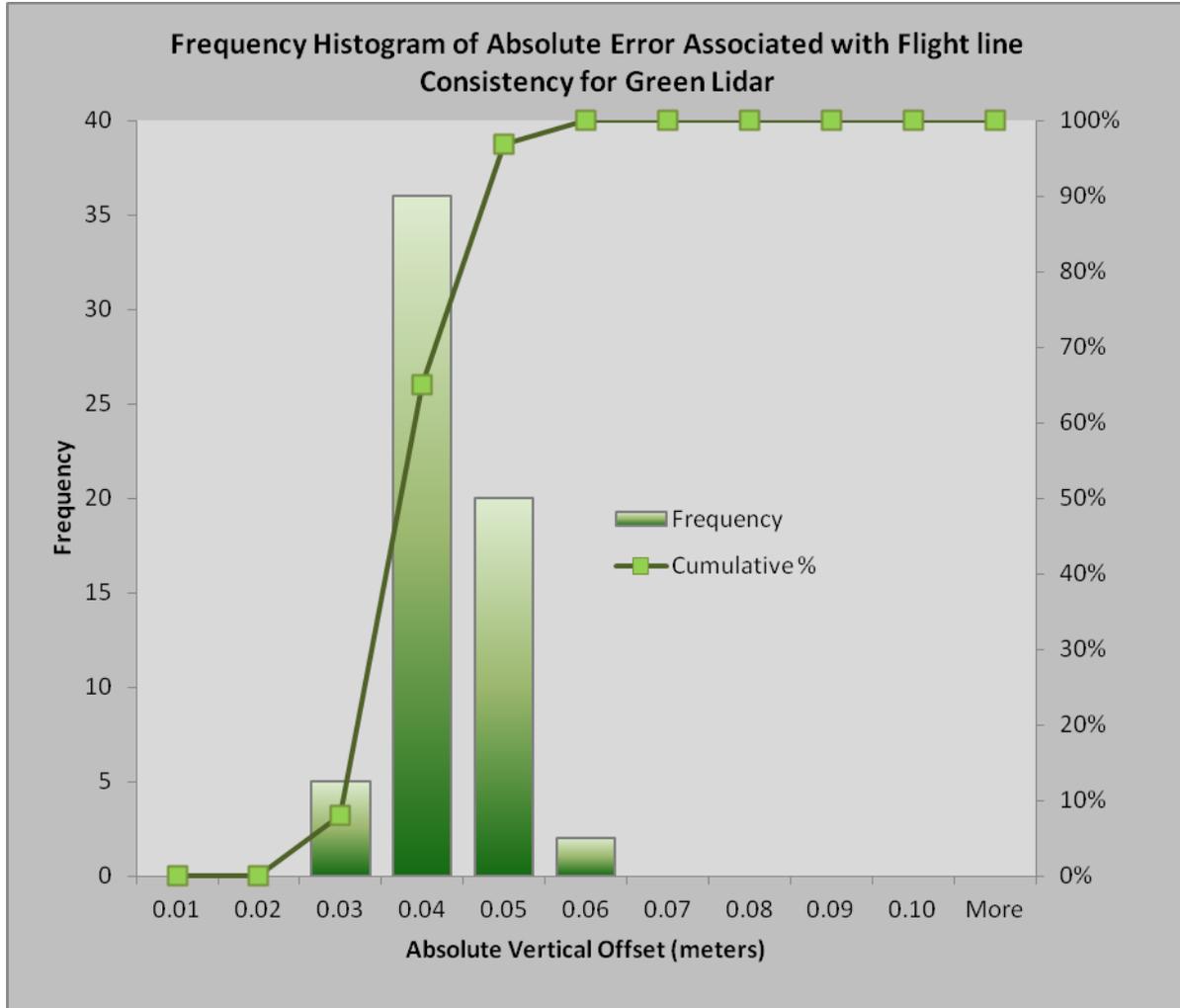


Figure 2b. Flight line Consistency histogram for Green Lidar.

Results of the consistency analysis found the average flight line offset to be 0.025 (NIR) 0.037 (Green) meters with a maximum error of 0.055m (Green) (Table 2b). Distribution of error showed over 96% of all error in both Green and NIR was less than 0.05m (Figure 2a and 2b). 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.

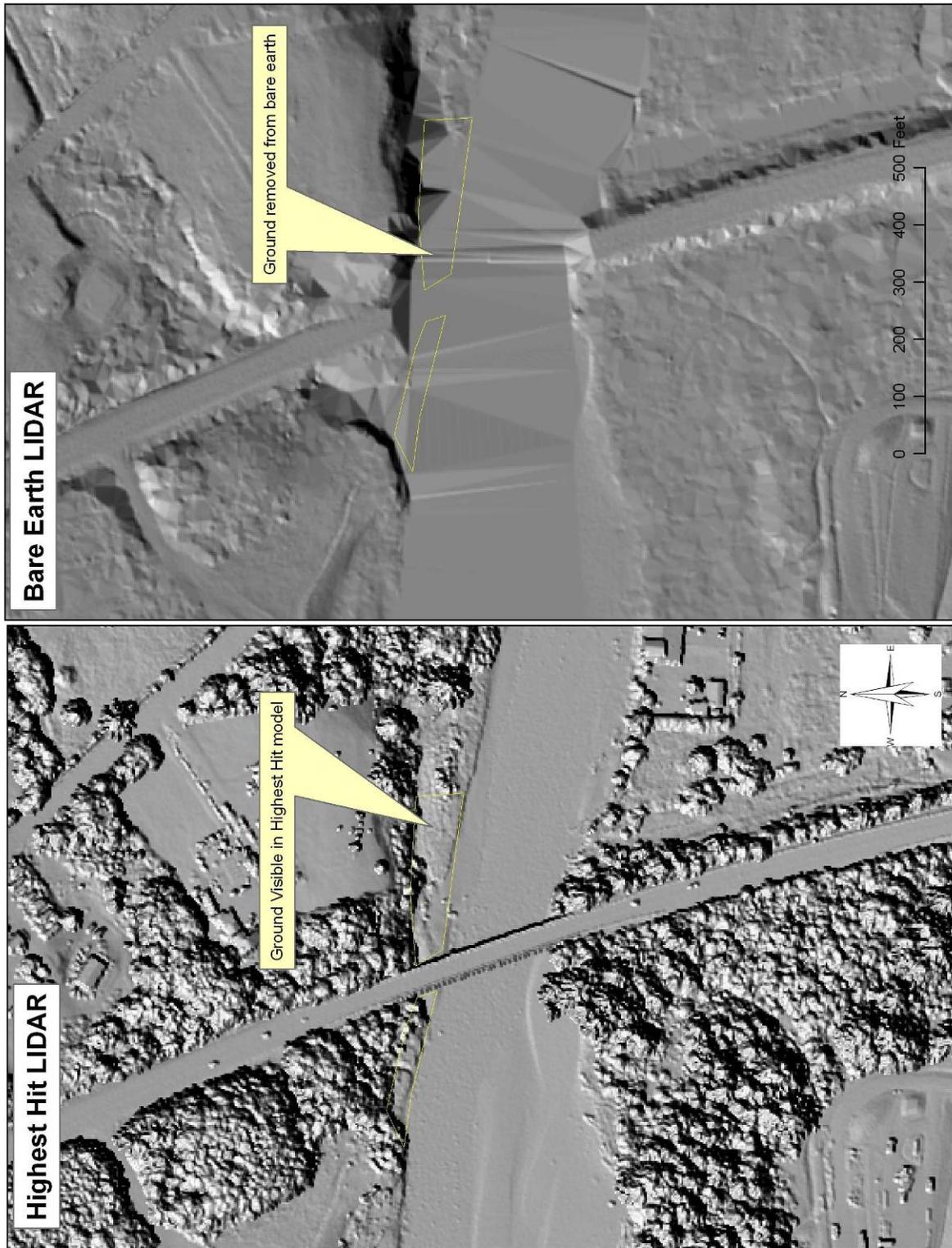


Figure 3. General example of missing ground in lidar bare earth data. Ground is clearly visible in highest hit model, but has been removed from the bare earth model. This type of classification error is common near water body features.

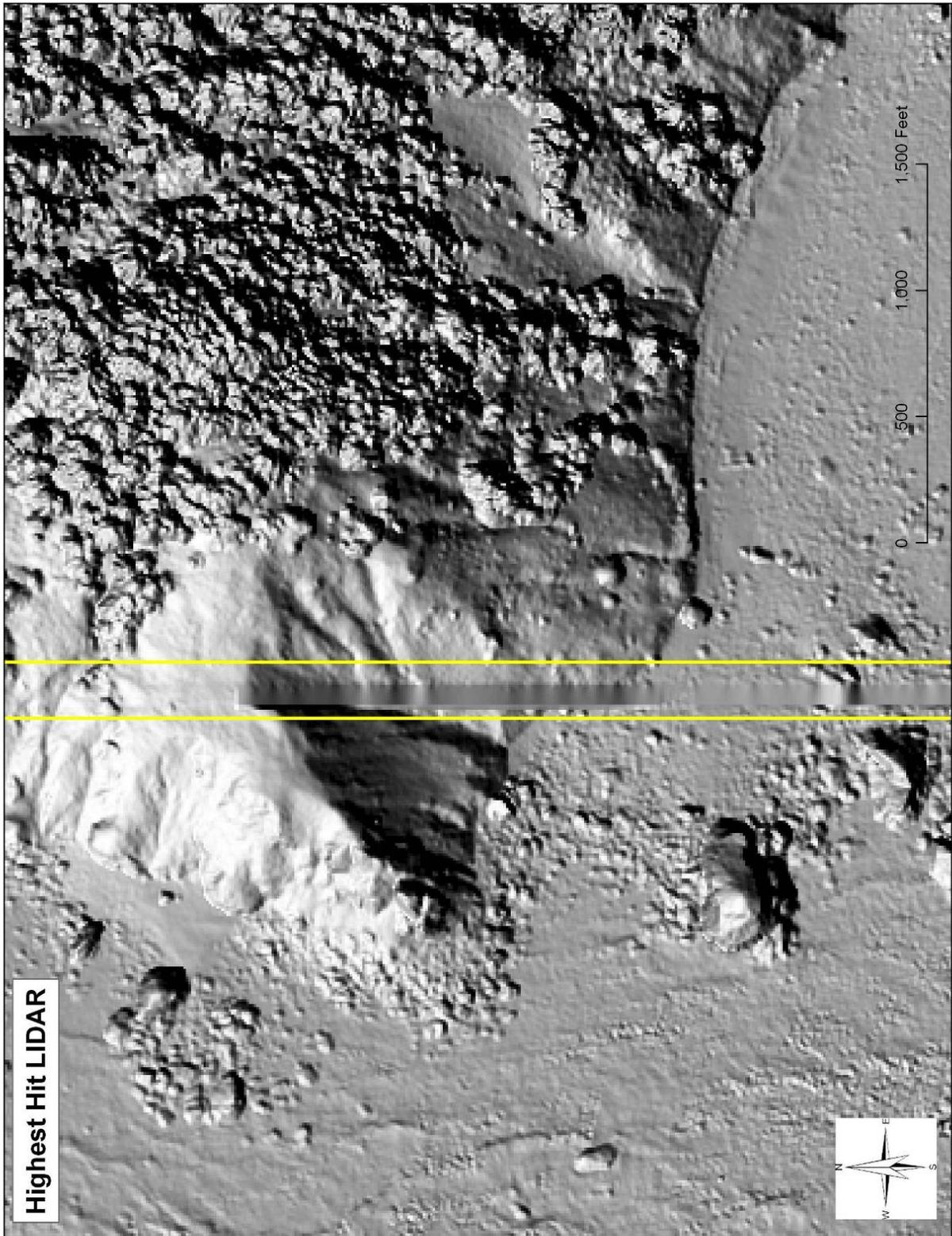


Figure 4. General example of tile artifact found in highest hit lidar data. Artifact is a seam line error created due to misclassification of ground at edge of lidar processing tiles.



Figure 5. General 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.

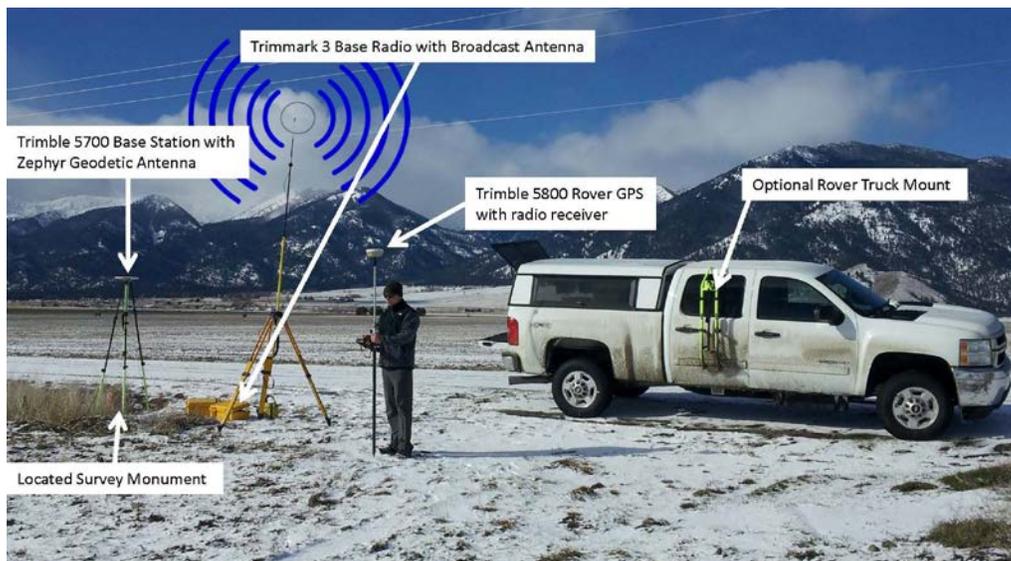


Figure 5. The Trimble 5700 base station antenna located over a known reference point near Cove, OR. Corrected GPS position and elevation information is then transmitted by a Trimmark III base radio to the 5800 GPS rover unit.

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 epics).

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).

In addition to collecting GCP data, DOGAMI acquired survey cross section data collected by FEMA for comparison to green laser data within the channel. OLC does not have an accuracy specification for green lidar in channels.

A total of 42 measured GCP's were obtained in the delivery region and compared with the bare earth lidar elevation grids. The data delivered to DOGAMI was found to have a mean vertical offset of -0.042 meters (-0.136 feet) and an RMSE value of 0.054 meters (0.178 ft). Offset values ranged from -0.150 to 0.040 meters (Table 3 and Figure 7).

A total of 663 measured in-stream survey elevations were obtained in the delivery region and compared with the green lidar elevation grids within the wetted perimeter. The data delivered to DOGAMI was found to have a mean vertical offset of 0.000 meters (0.001 feet) and an RMSE value of 0.314 meters (1.030 ft). Offset values ranged from -2.761 to 1.312 meters (Table 3 and Figure 8).

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

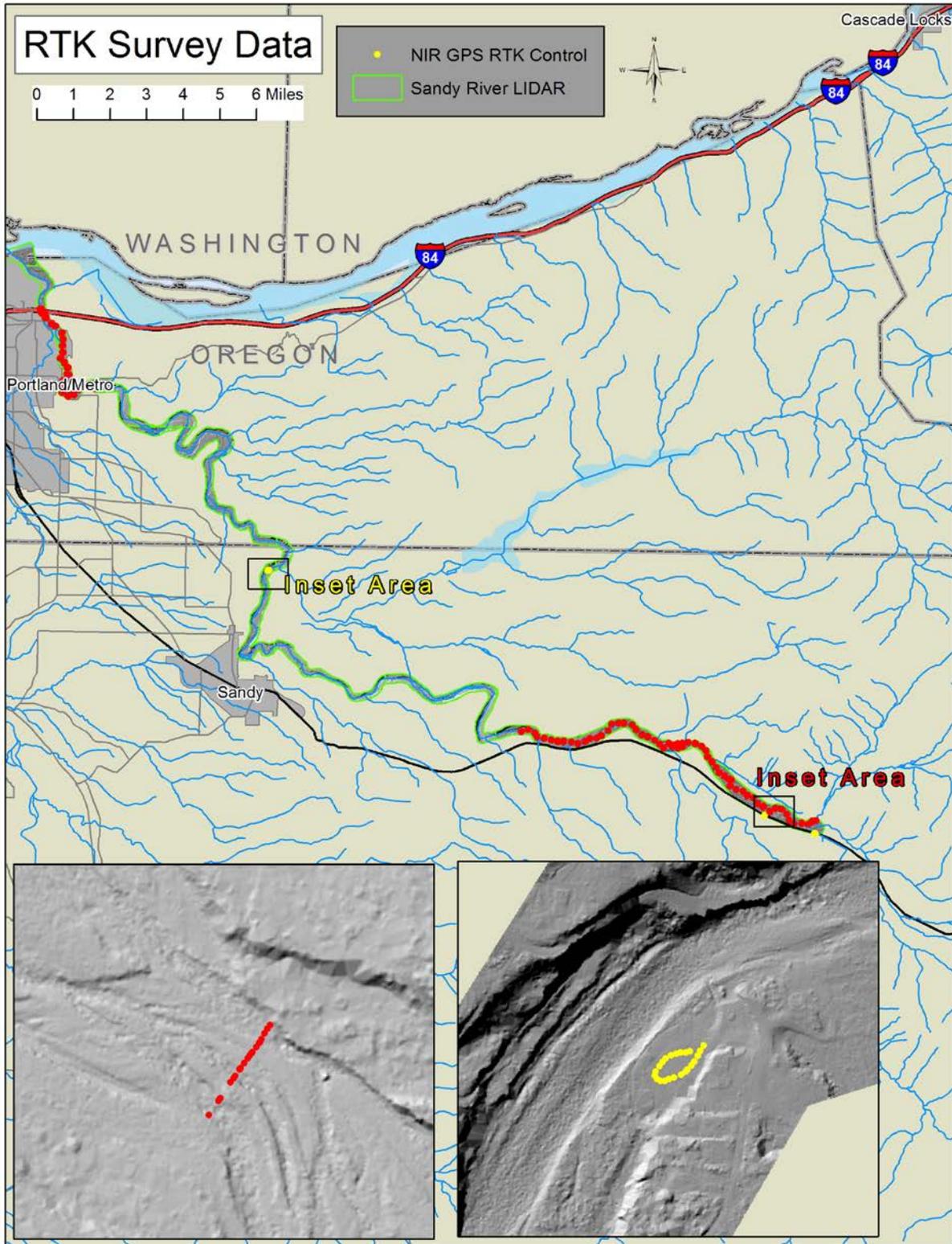


Figure 6. Locations of RTK control surveyed by DOGAMI. Data was used to test absolute accuracy for the Sandy River, OR Bathymetric Lidar Project lidar survey within the Delivery extent.

	<i>NIR (m)</i>	<i>NIR (ft)</i>	<i>Green (m)</i>	<i>Green (ft)</i>
Mean	-0.042	-0.136	0.000	0.001
Standard Error	0.005	0.018	0.012	0.040
Standard Deviation	0.035	0.116	0.314	1.030
Range	0.190	0.623	4.073	13.363
Minimum	-0.150	-0.492	-2.761	-9.057
Maximum	0.040	0.131	1.312	4.305
RMSE	0.054	0.178	0.314	1.030

Table 3. Descriptive Statistics for absolute value vertical offsets.

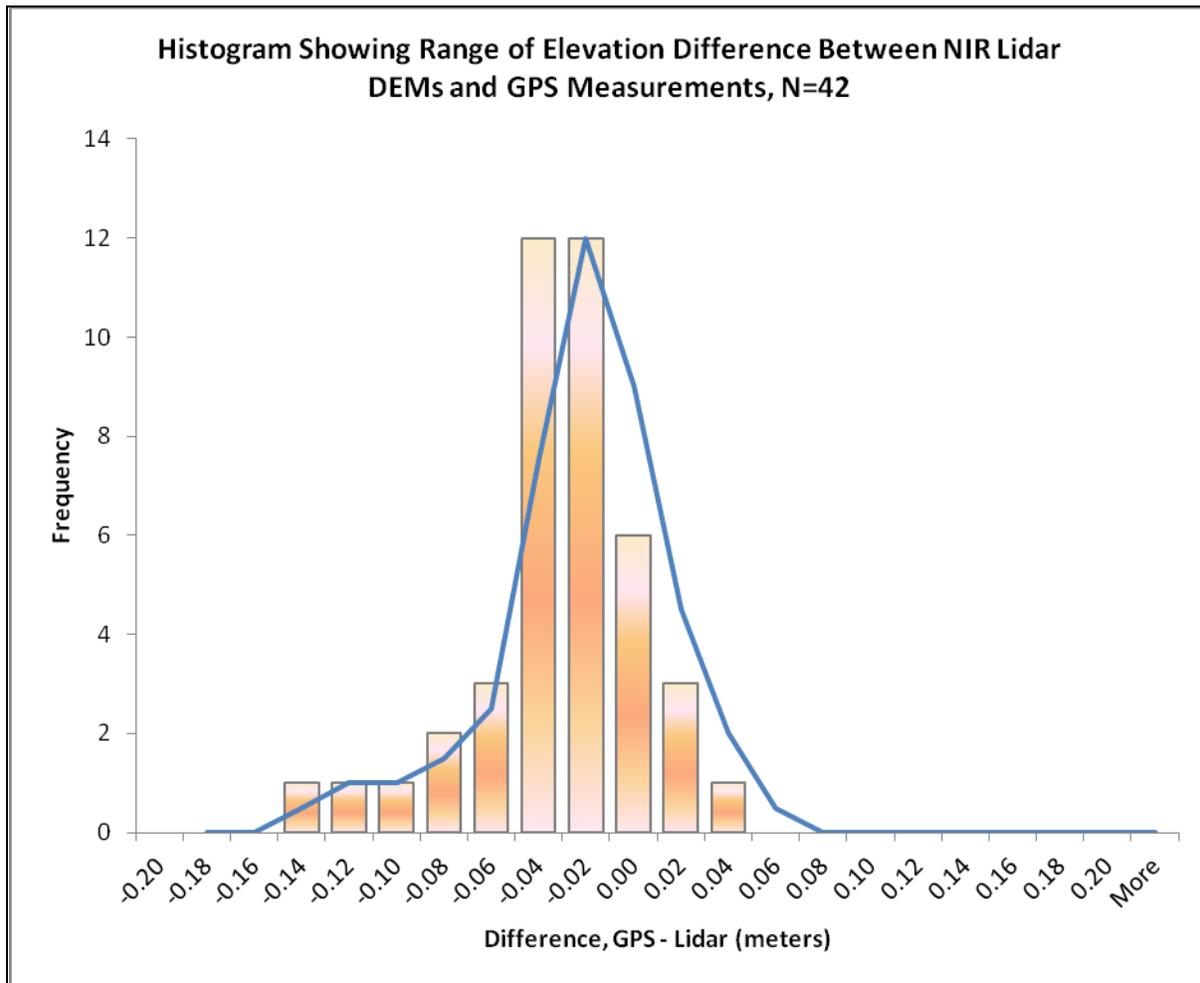


Figure 7. _NIR lidar accuracy comparing GPS points to bare earth DEMs

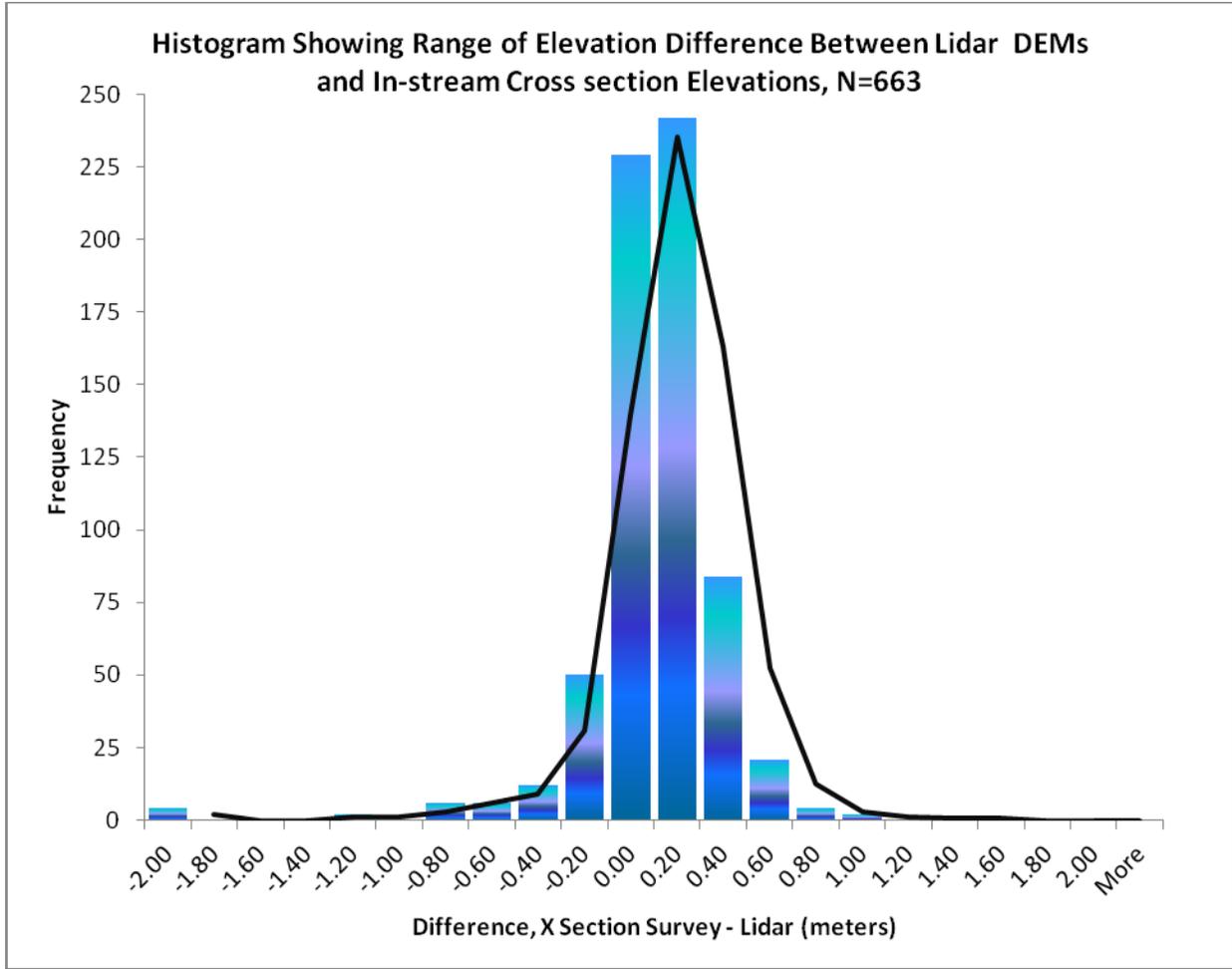
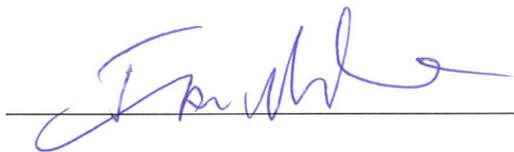


Figure 8. Green lidar accuracy comparing cross section survey data to in-stream lidar elevations.

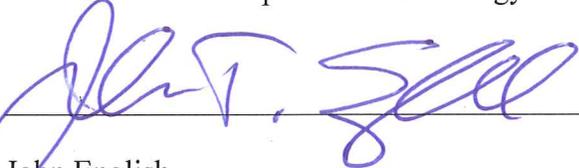
Acceptance

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 March 18th, 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: 4/2/2013

Ian Madin
Chief Scientist – Department of Geology & Mineral Industries


_____ Date: 4/2/2013

John English
Lidar Database Coordinator – Department of Geology & Mineral Industries