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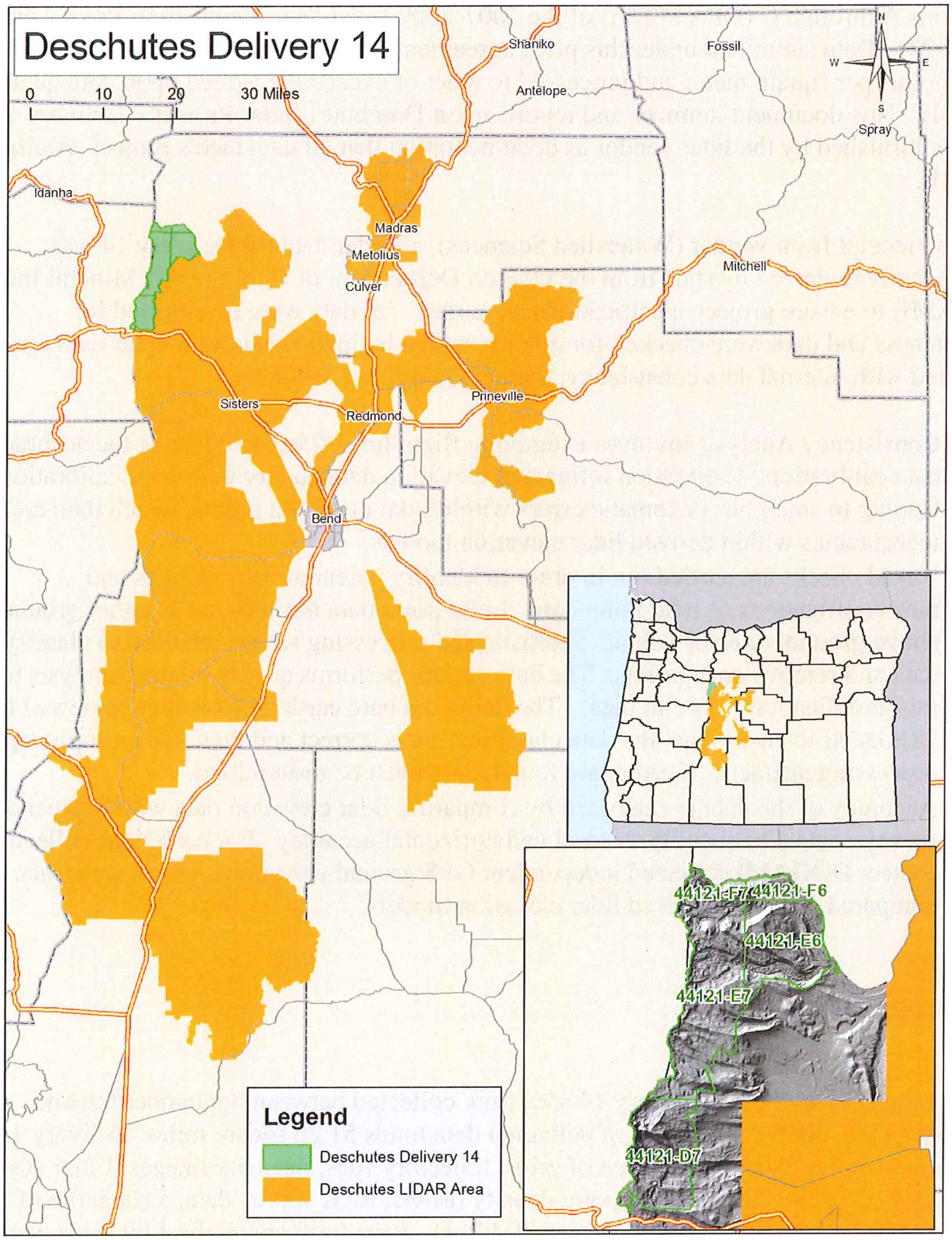
Deschutes LIDAR Project, 2010 – Delivery 14 QC Analysis

LIDAR QC Report – February 10th, 2011



Map featuring Deschutes Delivery 14 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 Deschutes Lidar Project – Delivery 14 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 14 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.

<u>Data Completeness</u>

Data for Deschutes Delivery 14 area were collected between September 5th and September 11th, 2010 . Total area of delivered data totals 51.26 square miles. Delivery 14 (Figure 1) includes data in the format of grids, trajectory files, intensity images, Lidar ASCII Standard (LAS) point files, 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 is delivered in LAS binary format for ground classified returns as well as the entire lidar point cloud. 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 Deschutes Survey collection area (Figure 1):

Delivery 14: 44121d7, 44121e6, 44121e7, 44121f6, 44121f7

FINAL Delivery	Resolution	Format	Tiling	
Bare Earth DEMs	3ft	grid	quad	x
Highest Hit DEMs	3ft	grid	quad	x
Trajectory files	1 sec	ascii (TXYZRPH)	flight	x
Intensity Images	1.5ft	tif	100th quad	x
LAS	8pts/m^2	las	100th quad	x
Ground Returns	N/A	las	100th quad	x
Ground Density Raster	3ft	grid	quad	x
RTK point data		shape		x
Delivery Area shapefile		shape	quad	x
Report		pdf		x

Miscellaneous		Format	Tiling	
Processing bins		dxf 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.
- 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.

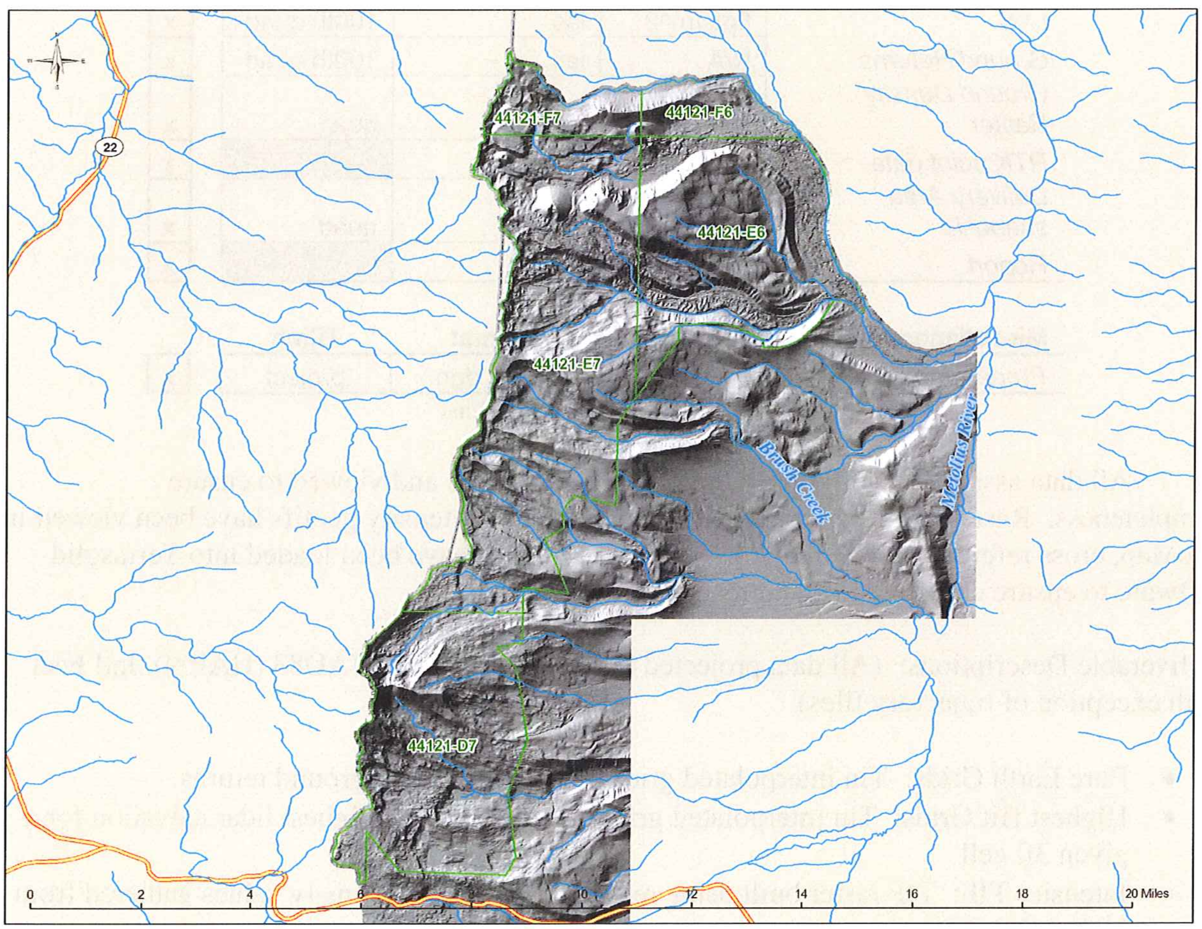


Figure 1. Delivery 14 location area. Data is referenced to USGS 7.5 minute quadrangles within the extents of the Deschutes Survey collection area.

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 308 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. The average number of points used for flight line comparison was 867,073 per tile (Table 2a). Error measurements were calculated by differencing the nearest point from an adjacent flight line within 1 meters 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 378 flight lines were sampled and compared for consistency.

Summary Statistics

# of Tiles	308
# of Flight Line Sections	378
Avg # of Points	867,073
Avg. Magnitude Z error (m)	0.035

Table 2a. Summary Results of Consistency Analysis

	meters	***feet***
Mean	0.050	0.163
Standard Error	0.001	0.002
Standard Deviation	0.010	0.034
Sample Variance	0.000	0.000
Range	0.065	0.214
Minimum	0.024	0.077
Maximum	0.089	0.291

Table 2b. Descriptive Statistics for Magnitude Z Error.

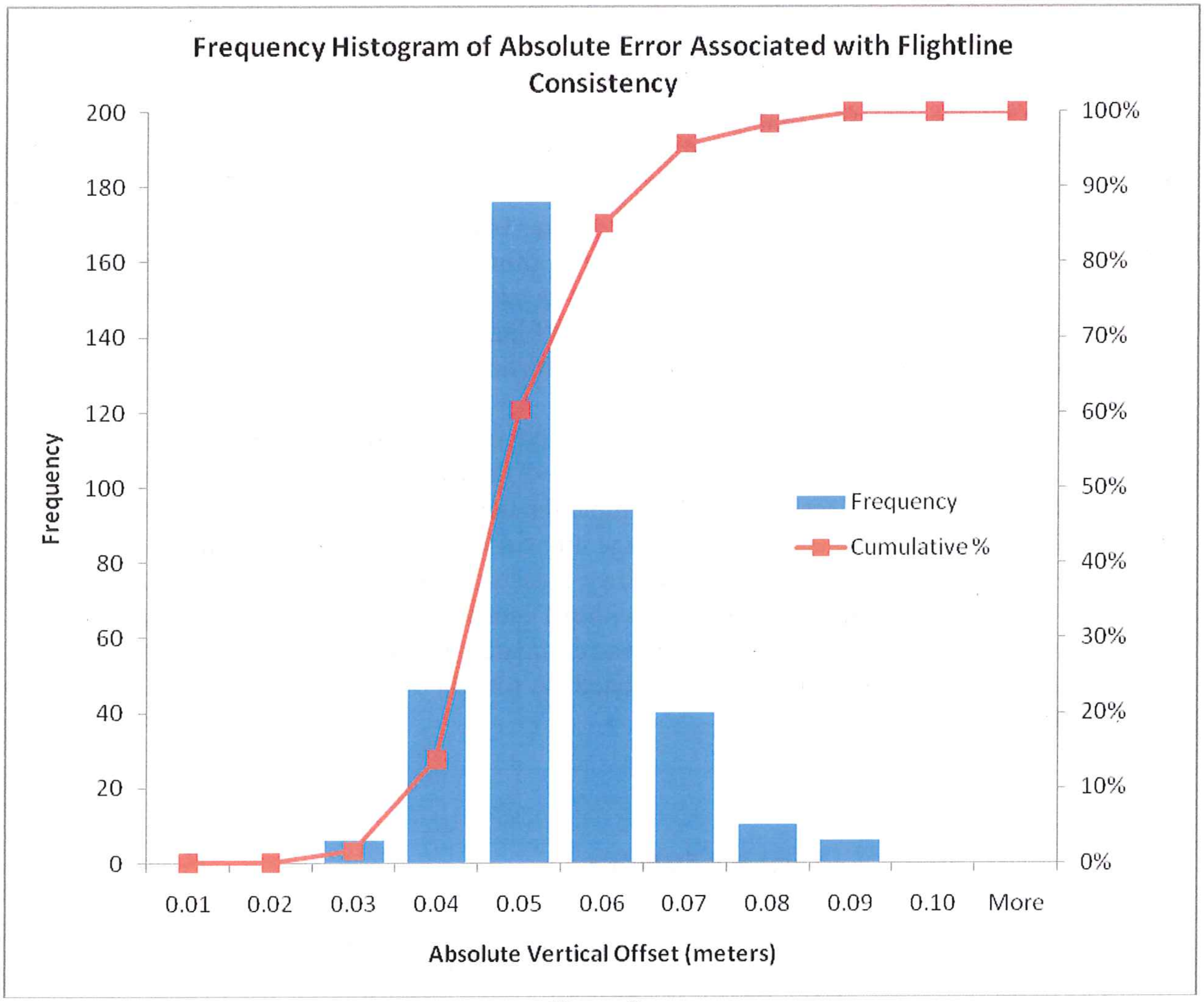


Figure 2.

Results of the consistency analysis found the average flight line offset to be 0.050 meters with a maximum error of 0.089m (Table 2b). Distribution of error showed over 95% of all error was less than 0.07m and 98% was less than 0.08m (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 atmospherics[1].

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.

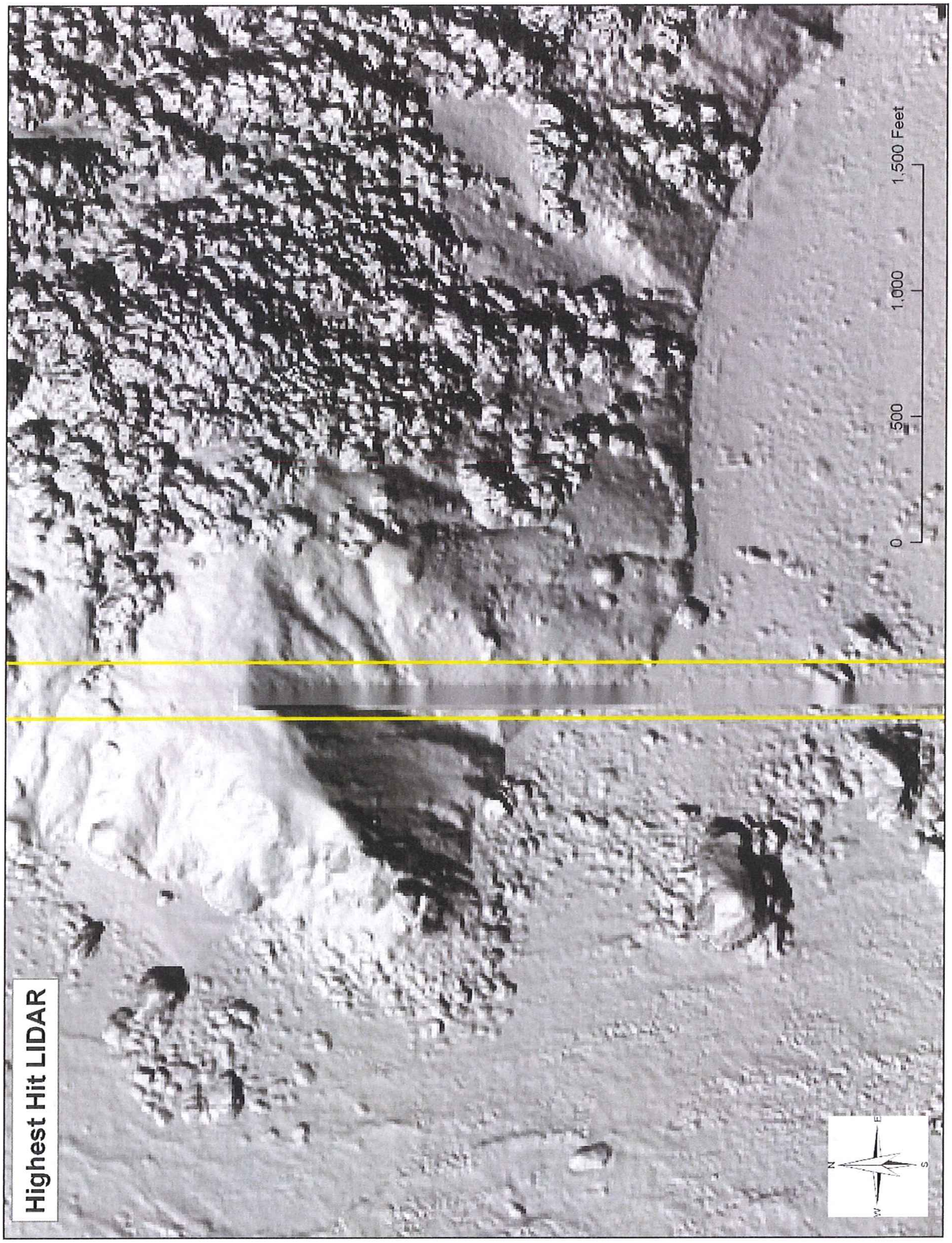


Figure 4. Example of tile artifact found in highest hit lidar data. Artifact is a seam line error created due to misclassification of ground at edge of lidar processing tiles.

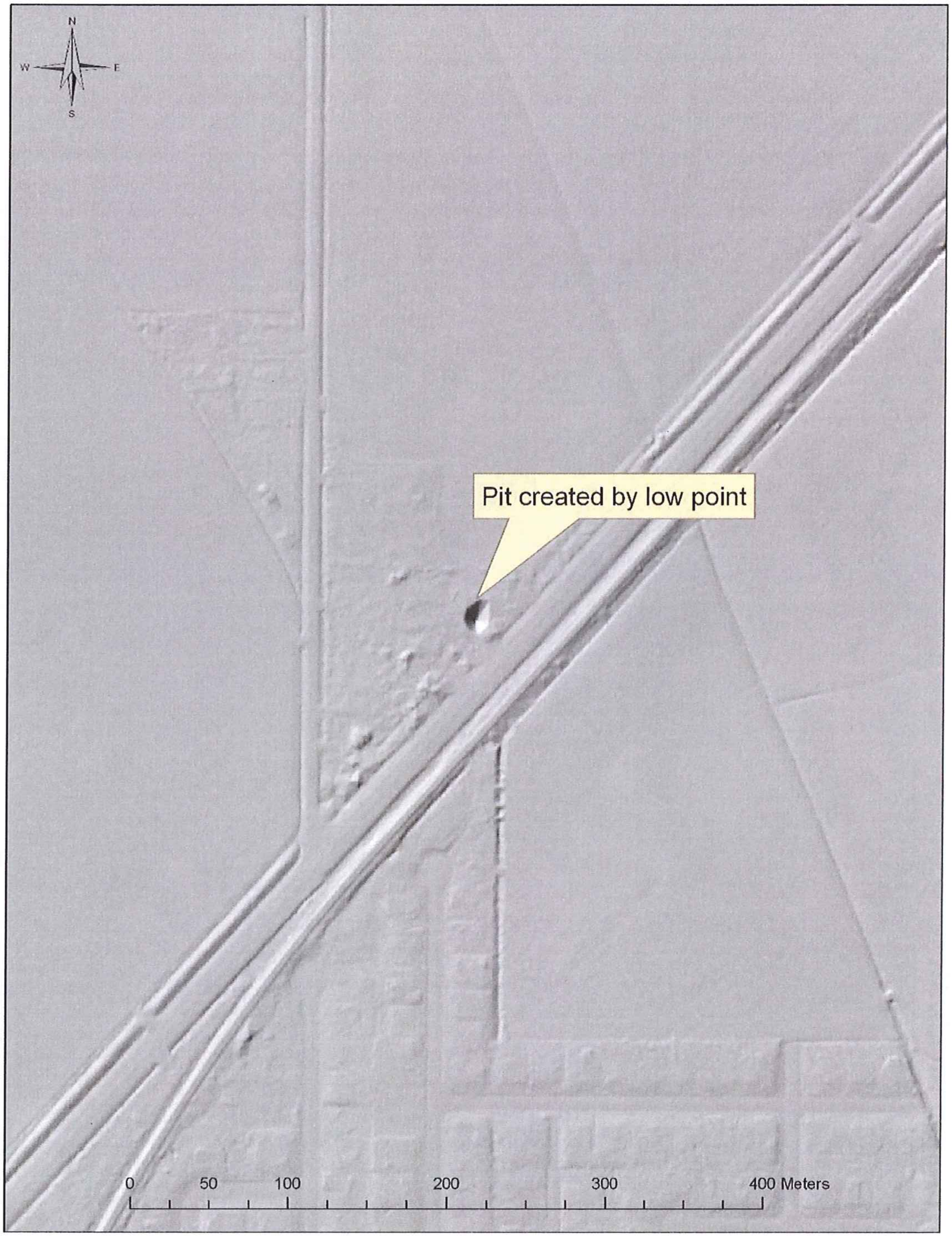


Figure 5. Example of "Pit" caused by low point in ground model. Pits are caused when standing water absorbs the lidar pulse. Pits are evident in ground model as the lowest point elevation is assigned to the grid cell value. Inversely the pit is not observable in the highest hit model as the highest point elevation is assigned to the grid value

Absolute Accuracy and Data Match Analyses:

Delivery 14 was added to the Deschutes survey late in the overall project time line. Collection of GCP points was not possible due to snowpack and road conditions. For this reason, Delivery 14 was treated as a special case where by absolute accuracy was determined using the lidar contractor's GPS RTK ground control points (GCP) as well as a comparative analysis to adjacent data already finalized and approved. GPS RTK data collected by the lidar contractor (Watershed Sciences) was collected and processed under supervision of a licensed Oregon surveyor. For an additional check data overlap between Delivery 14 and previous Deschutes deliveries Delivery 2 and Delivery 4 were compared for elevation consistency. USGS quadrangles 44121 e6, 44121e7, and 44121d7 contain approximately 63 square miles of overlap between Delivery 14 and Deliveries 2 and 4. Bare Earth rasters were differenced to quantify and located areas of discrepancy. It is expected that the comparison statistics reveal RMS values less than 0.1 meters and RMS 95% values less than 0.15 meters.

To calculate raster differences, overlapping rasters were differenced by subtracting the previous delivery bare earth rasters (i.e. Delviery 2 or 4) from Delivery 14 rasters. The difference raster values were then squared. Raster statistics yielded mean squared values for each of the three compared rasters. The square root of the mean for each raster was then calculated to produce an RMS value.

The analysis will also look to identify systematic differences where the previous data lines up with Delivery 14. This would manifest itself as a seam or step between data stemming from a systematic mismatch between data.

Absolute Accuracy

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 1601 measured GCP's were obtained in the Delivery 14 region and compared with the lidar elevation grids. The data delivered to DOGAMI was found to have a mean vertical offset of -0.011 meters (-0.037 feet) and an RMSE value of 0.036 meters (0.117 ft). Offset values ranged from -0.186 to 0.095 meters (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 1/3333rd 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 vender and in almost every case, the reported results were consistent with those obtained by DOGAMI staff.

	Meters	Feet
Mean	-0.011	-0.037
Standard Error	0.001	0.003
Standard Deviation	0.034	0.111
Range	0.281	0.922
Minimum	-0.186	-0.610
Maximum	0.095	0.312
RMSE	0.036	0.117

Table 3. Descriptive Statistics for absolute value vertical offsets.

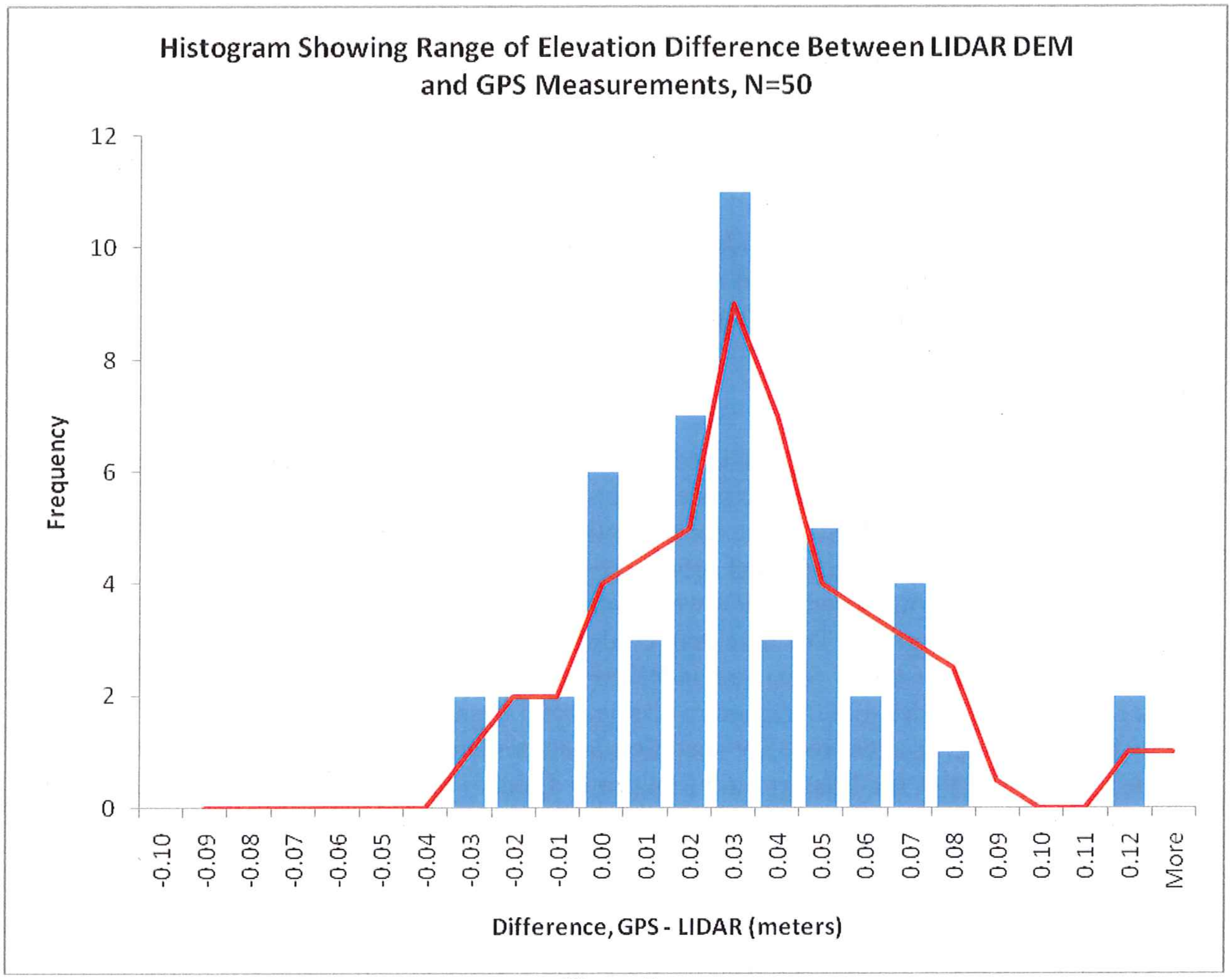


Figure 7.

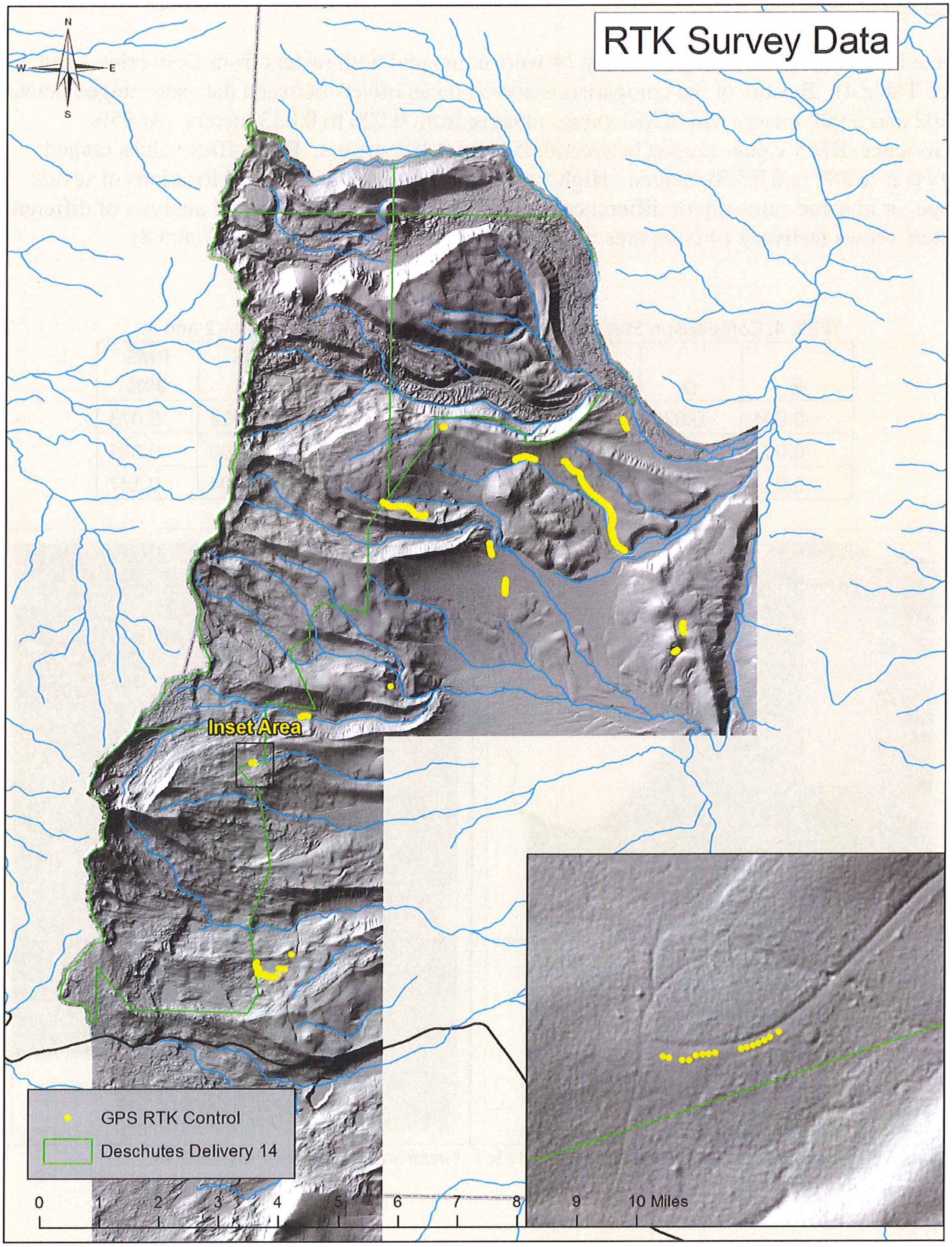


Figure 6. Locations of RTK control surveyed by DOGAMI. Data was used to test absolute accuracy for the Deschutes lidar survey within the Delivery 14 extent.

Data Match Analysis

Three bare earth rasters from Delivery 14 were compared with rasters from Deliveries 2 and 4 (See Table 4). Results of the comparison showed mean offsets between data sets ranged between 0.002 and 0.009 meters with RMS values ranging from 0.026 to 0.053 meters. At 95% confidence, RMS values ranged between0.052 and 0.104 meters. Raw offset values ranged between -4.383 and 5.566 meters. High values were found to be isolated locations of severe slope, or in some cases minor differences in ground classifications. Visual analysis of difference rasters shows Delivery 14 compares well with Deliveries 2 and 4 (Figures 7 and 8).

Table 4. Comparison Statistics between Delivery 14 and Deliveries 2 and 4.

$\bar{x}$	σ	min	max	RMS	RMS 95%	RMS 99%
-0.004	0.026	-4.383	4.181	0.026	0.052	0.073
-0.002	0.030	-4.197	5.566	0.030	0.060	0.085
-0.012	0.051	-2.106	3.087	0.053	0.104	0.147

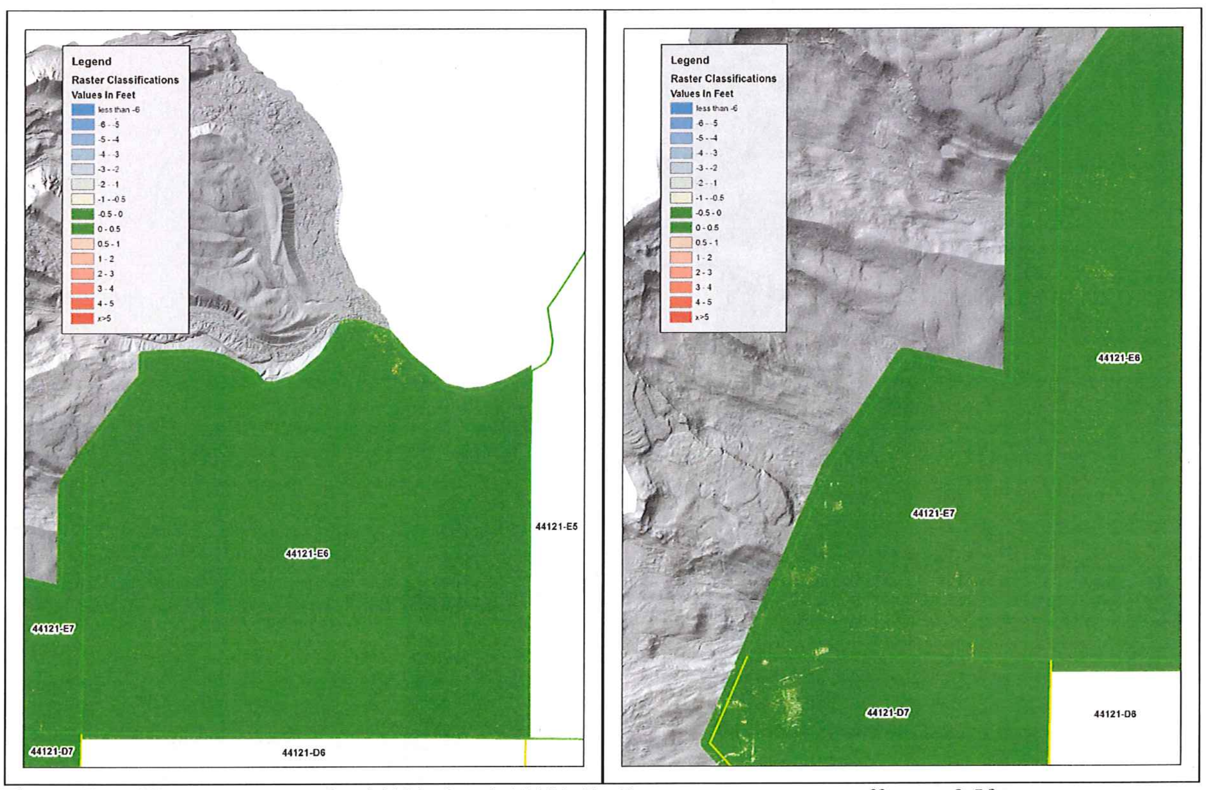


Figure 7. Difference Rasters for 44121e6 and 44121e7. Green area represents offsets ± 0.5ft.

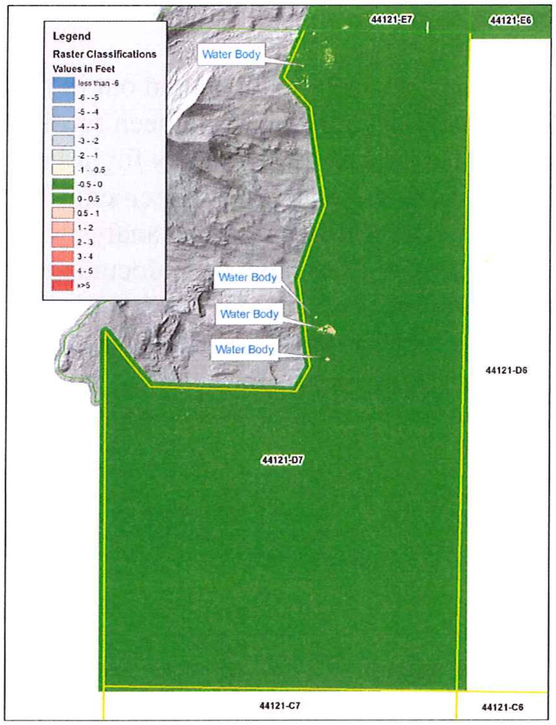


Figure 8. Difference Raster for 44121d7.

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 February 10th, 2011. 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: 2/11/2011

Ian Madin
Chief Scientist – Department of Geology & Mineral Industries

_______________________________ Date: 2/15/2011

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