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

Alaska DNR LIDAR Project, 2010 – Delivery 1 QC Analysis

LIDAR QC Report – April 6th, 2011

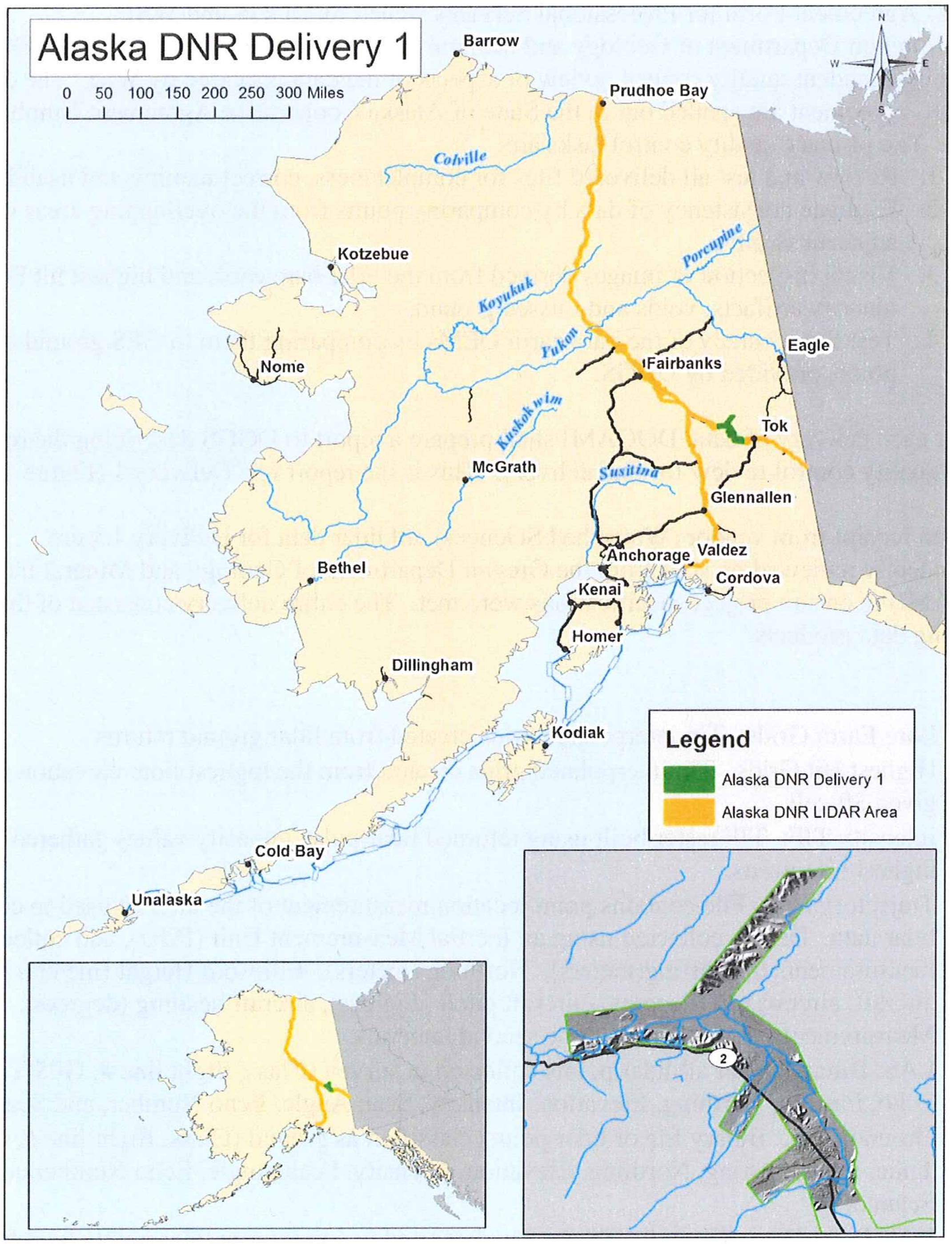

Figure 1. Map featuring Alaska DNR Delivery 1 data extent.

The Alaska Department of Natural Resources, Division of Geological and Geophysical Survey (DGGS) has contracted with Watershed Sciences, Inc (WSI) to collect high resolution lidar topographic data for a swath roughly parallel to proposed future pipeline rights of way. DGGS has specified the exact areas of data collection as well as a detailed description of data products to be delivered. The complete specifications are detailed in the September 14, 2010 Standard Agreement Form for Professional Services signed by DGGS and WSI.

The Oregon Department of Geology and Mineral Industries has contracted with DGGS to provide independent quality control review of aspects of the data provided by WSI. The details of the QC agreement are spelled out in the State of Alaska Cooperative Agreement Number MI-11-006. The primary quality control tasks are:

1. Review and test all delivered files for completeness, correct naming and usability.
2. Evaluate consistency of data by comparing points from the overlapping areas of adjacent swaths.
3. Visual inspection of images derived from the lidar bare earth and highest hit DEMs to identify artifacts, voids and missed ground.
4. Test the accuracy of the bare earth DEMs by comparing them to GPS ground control points provided by DGGS.

For each delivery of data, DOGAMI shall prepare a report to DGGS describing the results of the quality control review for that delivery. This is the report for Delivery 1 (Figure 1).

Upon receipt from vendor (Watershed Sciences), all lidar data for Delivery 1 were independently reviewed by staff from the Oregon Department of Geology and Mineral Industries (DOGAMI) to ensure project specifications were met. The entire delivery consisted of the following data products:

- 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.
- 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 Universal Transverse Mercator (Zones 6 and 7), NAD83 CORS96 meters.

Data Completeness

Data for Alaska DNR Delivery 1 area were collected between September 21st and October 1st, 2010. Total area of delivered data totals 187.85 square miles. Delivery 1 (Figure 2) includes data in the format of grids, trajectory files, intensity images, Lidar ASCII Standard (LAS) point files, 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 1 meter cell size. Lidar point data are delivered in LAS binary format for ground classified returns as well as the entire lidar point cloud. Georeferenced intensity images of 1 meter cell size are supplied in geoTIF format. Supplementary data include 1 meter cell size vegetation rasters displaying canopy and other vegetation metrics. Real time kinematic ground survey data (used for absolute vertical adjustment) are supplied in shapefile format. This delivery contains data for the following USGS 7.5 minute quads (listed by quadrangle tile name within the boundary of the Alaska DNR Survey collection area (Figure 2):

Delivery 1 Quadrangles: TNXB6, TNXC6, TNXD6, XMHB1, XMHC1, XMHD1.

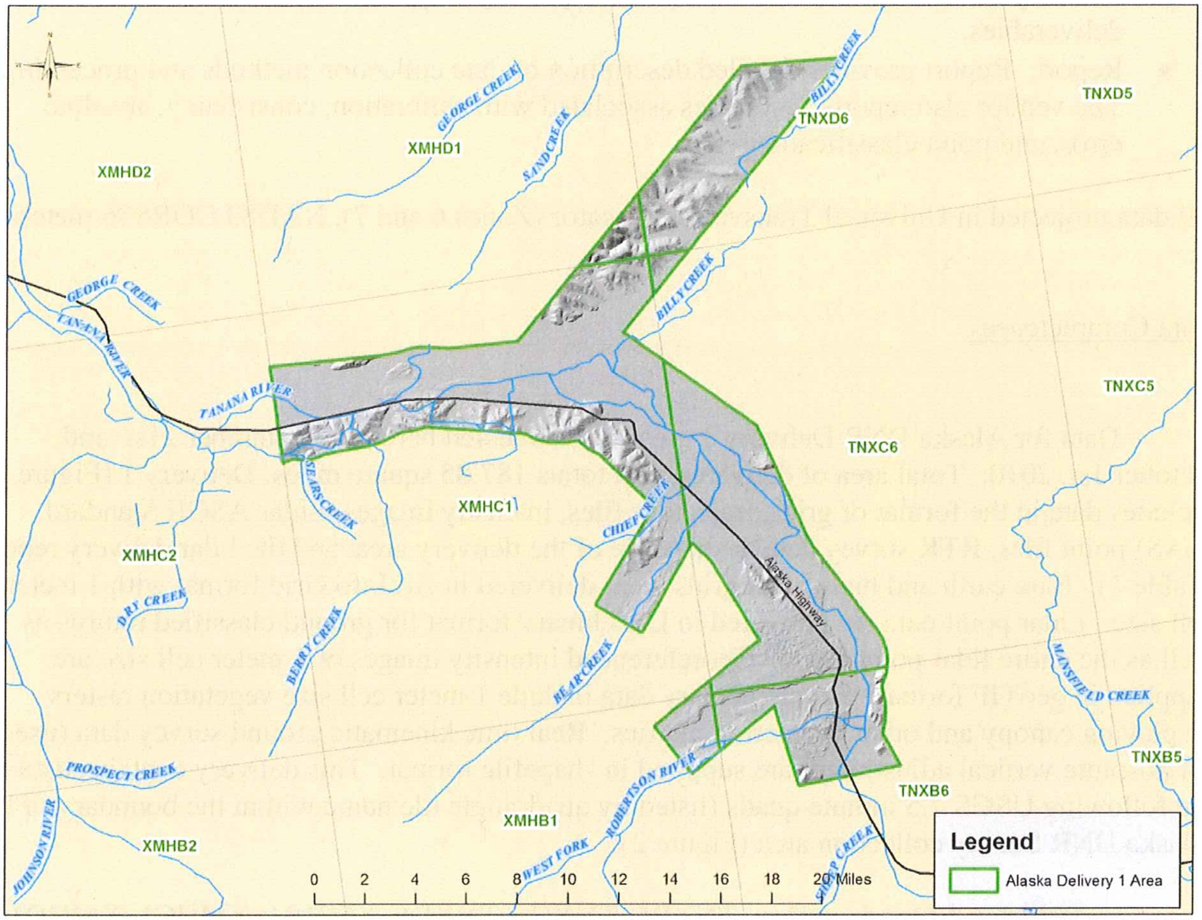

Figure 2. Delivery 1 location area. Data is referenced to USGS 7.5 minute quadrangles within the extents of the Alaska DNR Survey collection area

FINAL Delivery	Resolution	Format	Tiling	
Bare Earth DEMs	1 meter	grid	quad	x
Highest Hit DEMs	1 meter	grid	quad	x
Trajectory files	1 sec	sbet /shape	flight	x
Intensity Images	1 meter?	tif	quad	x
LAS	8pts/m^2	las	tiled	x
Ground Returns	N/A	las	tiled	x
First return Vegetation Raster	1 meter	grid	quad	x
RTK point data		shape		x
Delivery Area shapefile		shape	quad	x
Report		pdf		x

Miscellaneous		Format	Tiling	
Processing bins		Shape dxf/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 headers have been scanned to ensure completeness and readability (Figure 3).

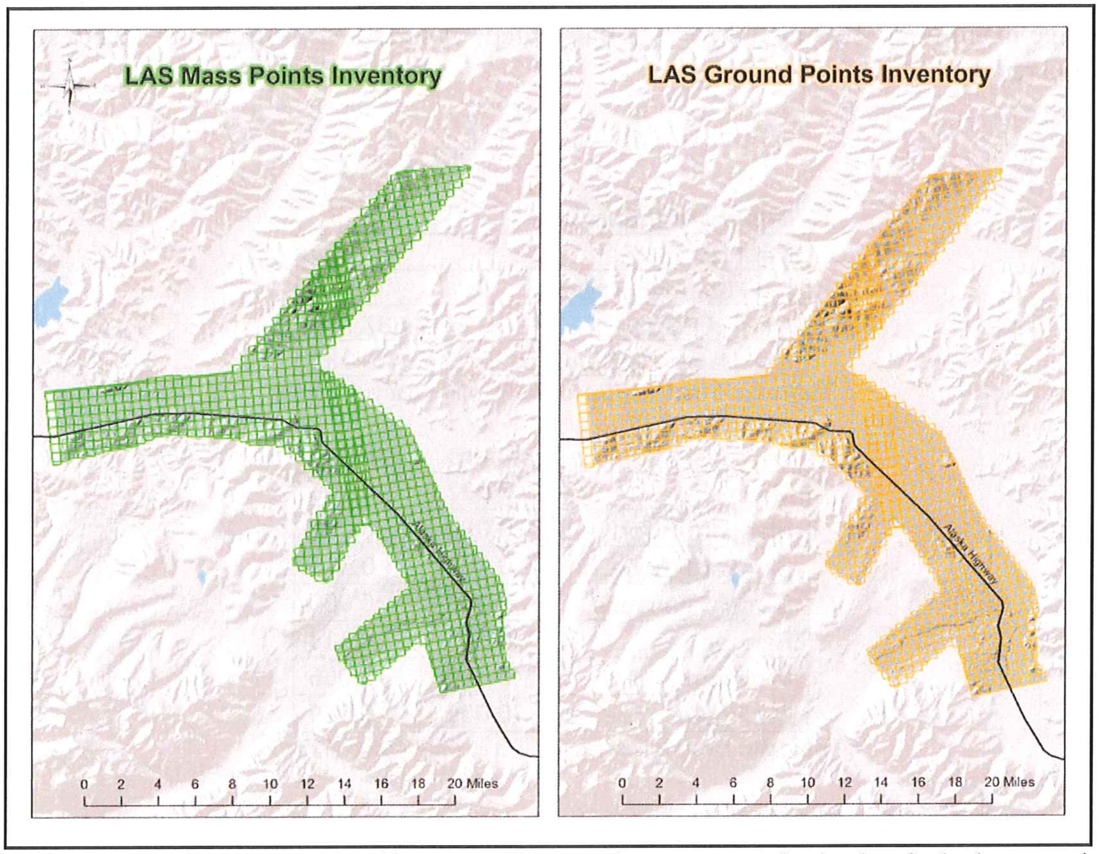

Figure 3. LIDAR Point Inventory graphic representing complete coverage of point data for both mass points and ground LAS files.

<u>Consistency Analysis:</u>

DGGS has specified that lidar consistency must average less than 0.15m (0.49 feet) in vertical offsets between adjacent 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 1100 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 7,687,706 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 245 flight lines were sampled and compared for consistency.

Summary Statistics

# of Tiles	1100
# of Flight Line Sections	245
Avg # of Points	7,687,706
Avg. Magnitude Z error (m)	0.032

Table 2a. Summary Results of Consistency Analysis

	meters	***feet***
Mean	0.032	0.106
Standard Error	0.000	0.001
Standard Deviation	0.005	0.018
Sample Variance	0.000	0.000
Range	0.035	0.113
Minimum	0.020	0.066
Maximum	0.055	0.179

Table 2b. Descriptive Statistics for Magnitude Z Error.

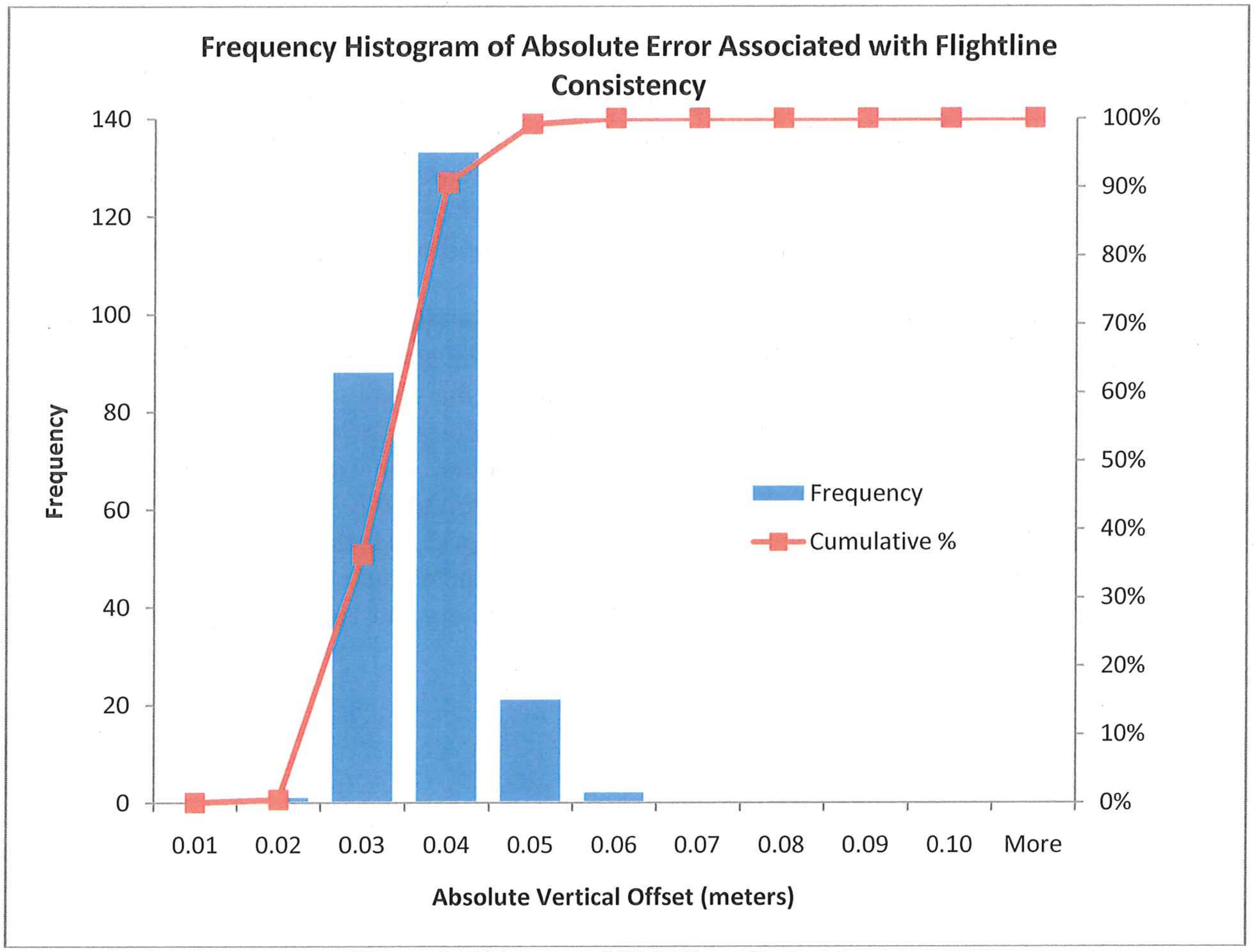

Figure 4. Histogram of flight line offsets values.

Results of the consistency analysis found the average flight line offset to be 0.032 meters with a maximum error of 0.055m (Table 2b). Distribution of error showed over 90% of all error was less than 0.04m and 99% was less than 0.05m (Figure 4). These results show that all data are within tolerances of data consistency according to contract agreement.

Visual Analysis

Lidar 1m 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 5). Both bare earth and highest hit models were examined for calibration offsets, tiling artifacts (Figure 6), seam line offsets, pits (Figure 6), 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 5). 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 7). 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 5. 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.

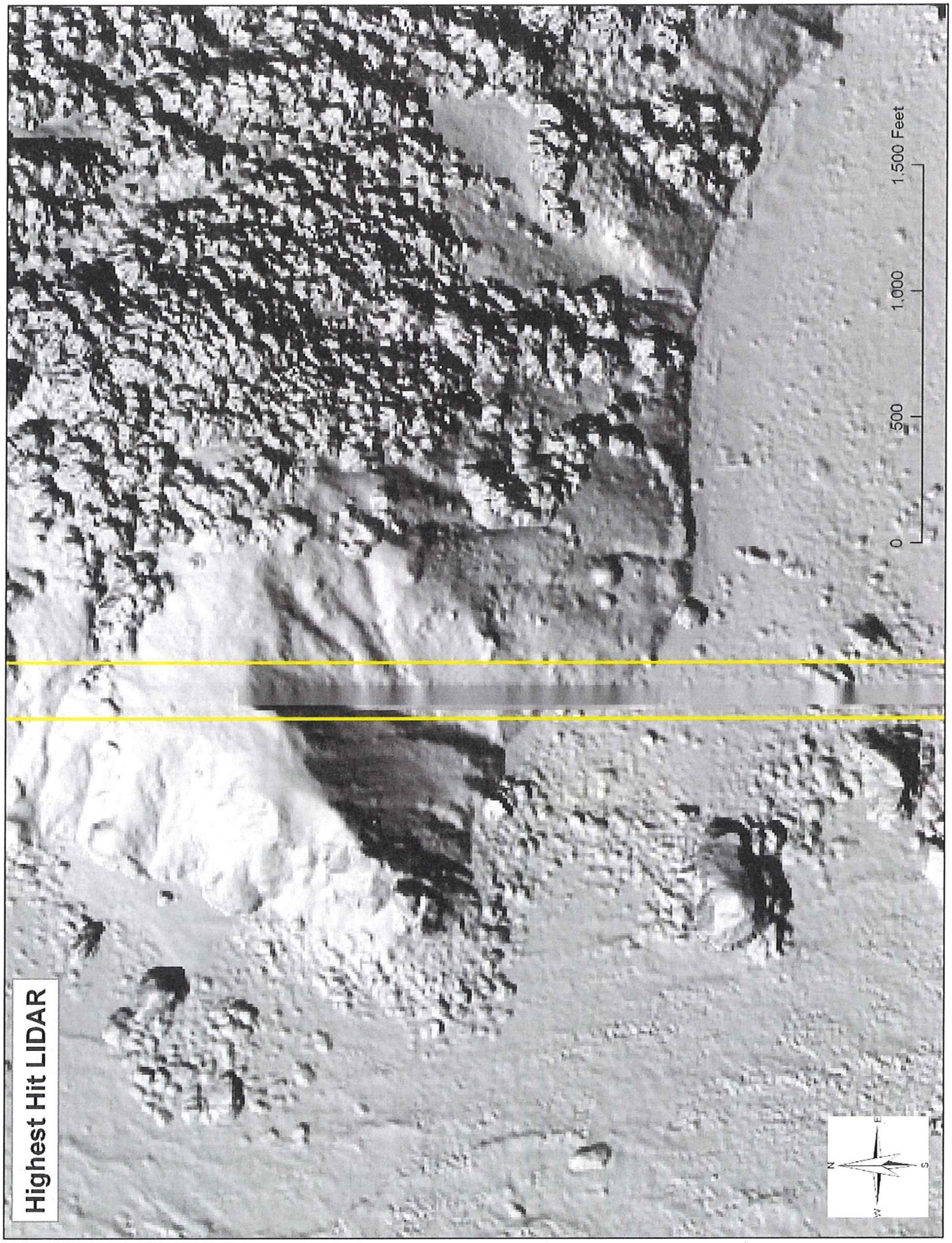

Figure 6. Example of tile artifact found in highest hit lidar data. Artifact is a seam line error created due to misclassification of ground at edge of lidar processing tiles.

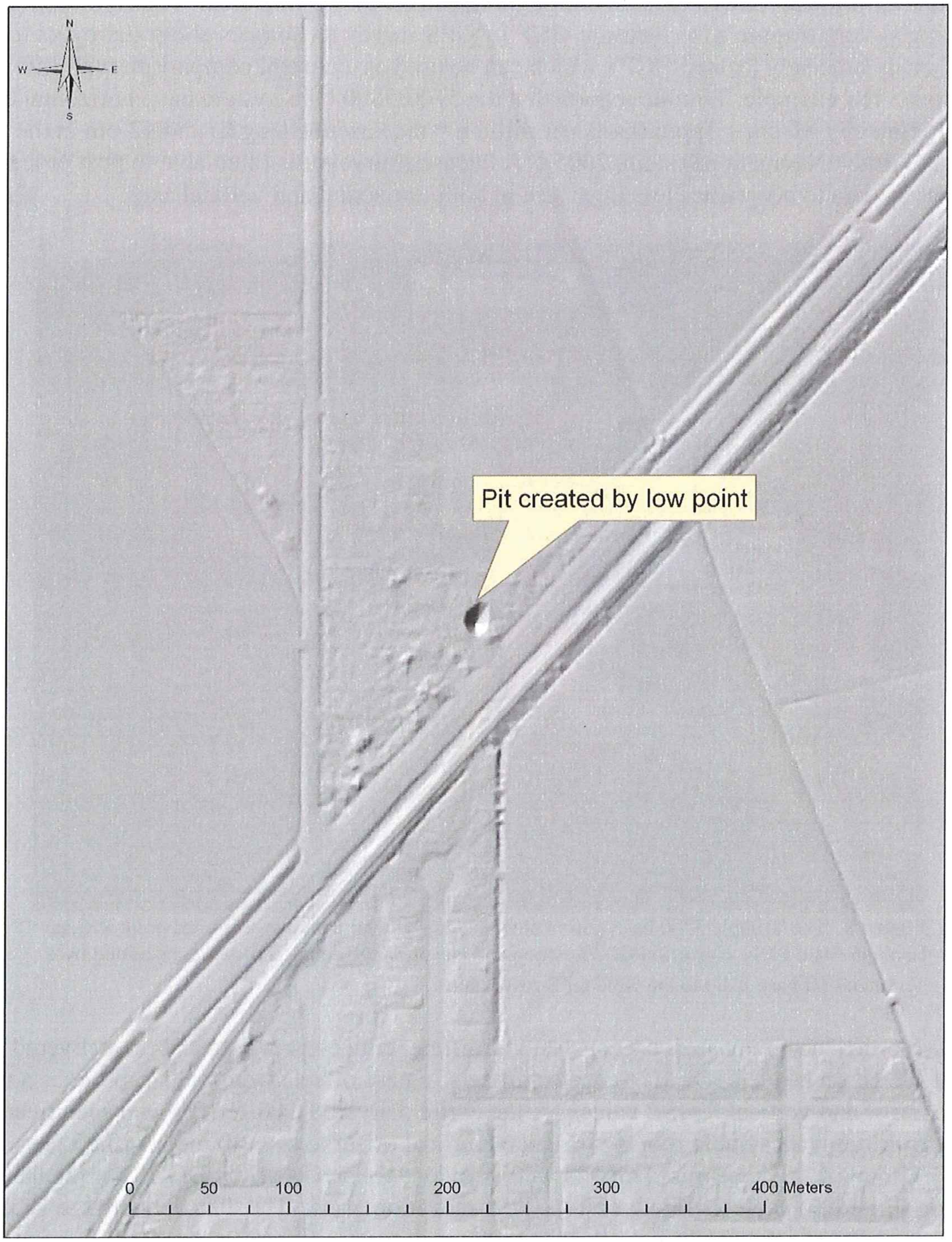

Figure 7. Example of "Pit" caused by low point in ground model. Pits are caused when standing water absorbs the lidar pulse. Pits are evident in ground model as the lowest point elevation is assigned to the grid cell value. Inversely the pit is not observable in the highest hit model as the highest point 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. The contractor used a surveying system (Figure 8) to measure GCP's. GPS survey techniques allow surveyors to collect many precisely located GCP's which can be used as a control comparison with LiDAR elevations. 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). A licensed surveyor is often able to post process GPS survey data to accuracies less than 1cm in both horizontal and vertical axes.

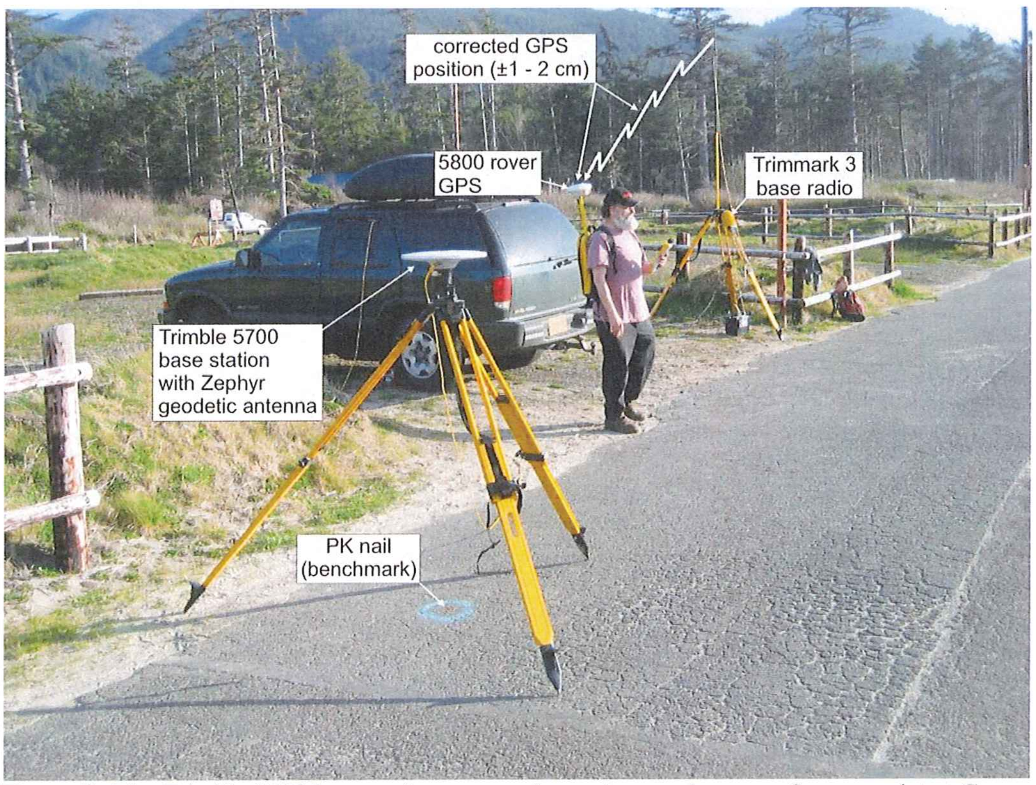

Figure 8. The Trimble 5700 base station antenna located over a known reference point at Cape Lookout State Park. Corrected GPS position and elevation information is then transmitted by a Trimmark III base radio to the 5800 GPS rover unit.

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 values for the entire delivered data set. Project specifications list the maximum acceptable root mean square vertical offset to be 0.20 meters (0.65 feet).

A total of 1535 measured GCP's were provided to DOGAMI by DGGS for the Delivery 1 region (Figure 9) and compared with the lidar elevation grids. The data delivered to DOGAMI was found to have a mean vertical offset of 0.000 meters (0.000 feet) and an RMSE value of 0.030 meters (0.098 ft). Offset values ranged from -0.092 to 0.083 meters (Table 3 and Figure 10).

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.

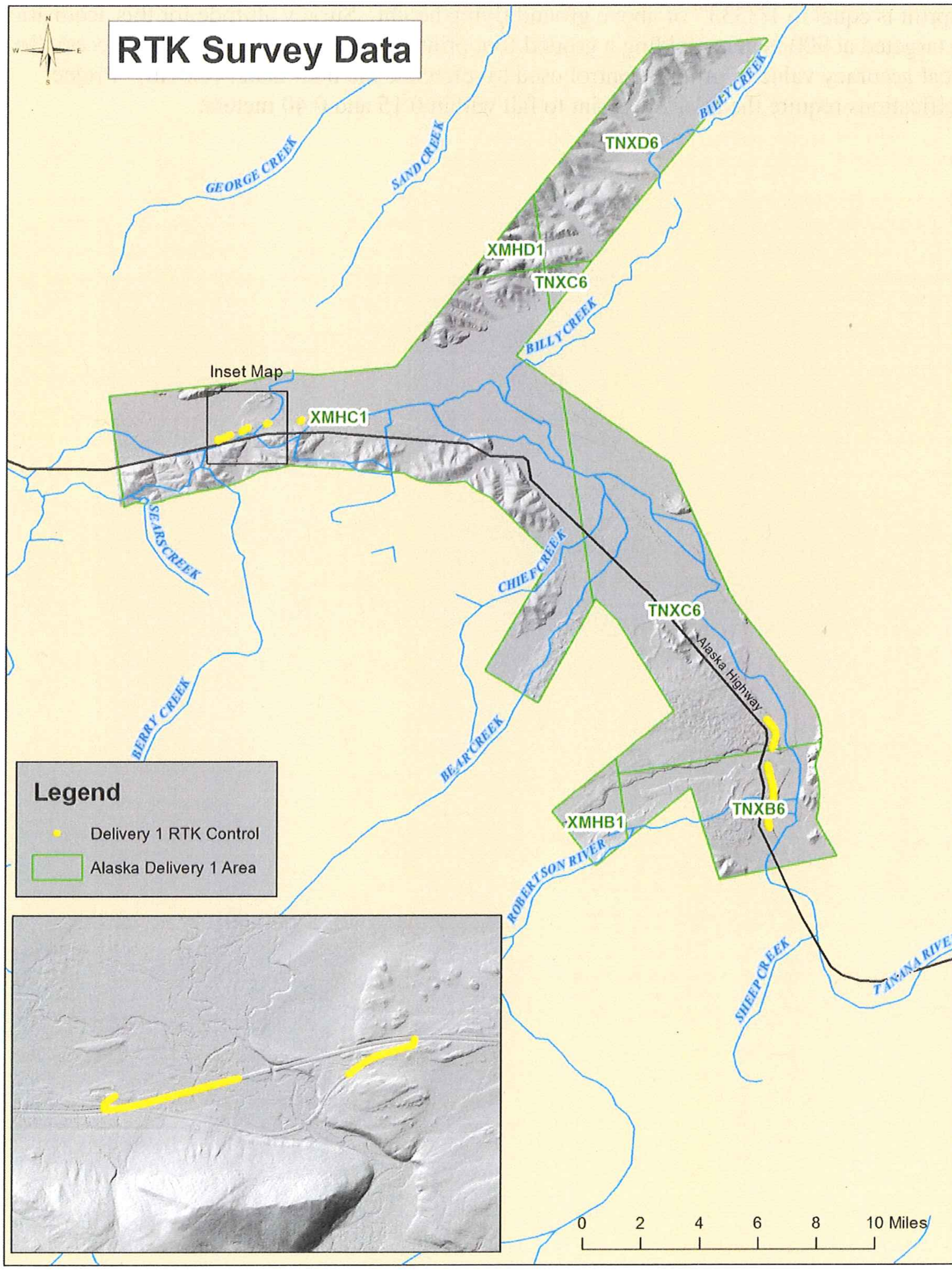

Figure 9. Locations of RTK control surveyed by Contractor. Data was used to test absolute accuracy for the Alaska DNR lidar survey within the Delivery 1 extent.

	Meters	*Feet*
Mean	0.000	0.000
Standard Error	0.001	0.003
Standard Deviation	0.030	0.098
Range	0.175	0.574
Minimum	-0.092	-0.302
Maximum	0.083	0.272
RMSE	0.030	0.098

Table 3. Descriptive Statistics for absolute value vertical offsets.

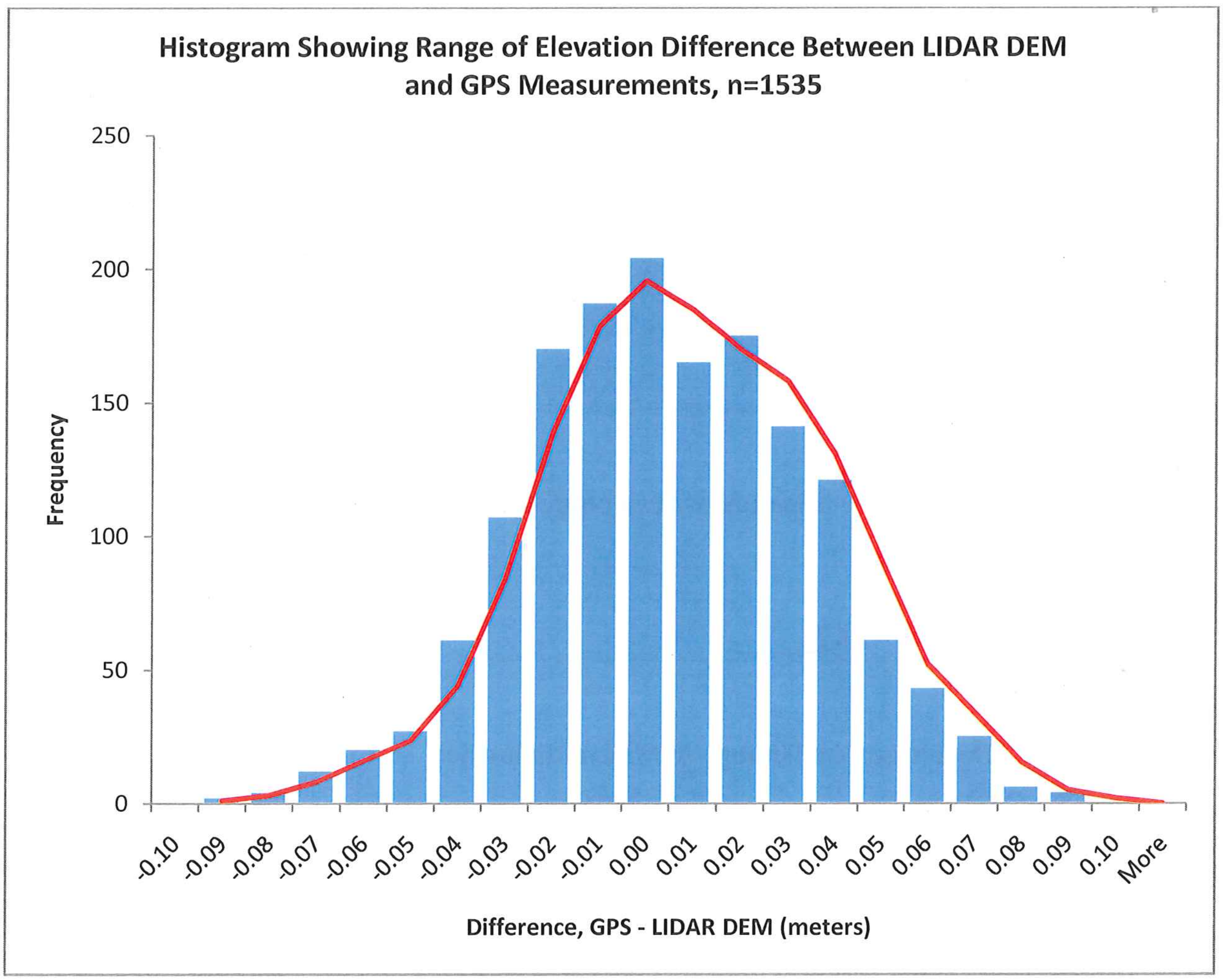

Figure 10. Histogram of elevation difference between Lidar DEM and GPS survey data.

Acceptance

The data described in this report meets or exceeds project specifications laid out in the contracted data standards agreement. All the required files for the delivery have been received as of April 6th, 2011, and are correctly named and useable. 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 quality control 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 Signature

______________________ Date: 4/18/11

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

______________________ Date: 4/18/11

Ian Madin
Chief Scientist – Department of Geology & Mineral Industries

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800 NE Oregon St, Suite 965
Portland, OR 97232

Alaska DNR LIDAR Project, 2010 – Delivery 2 QC Analysis

LIDAR QC Report – May 2nd, 2011

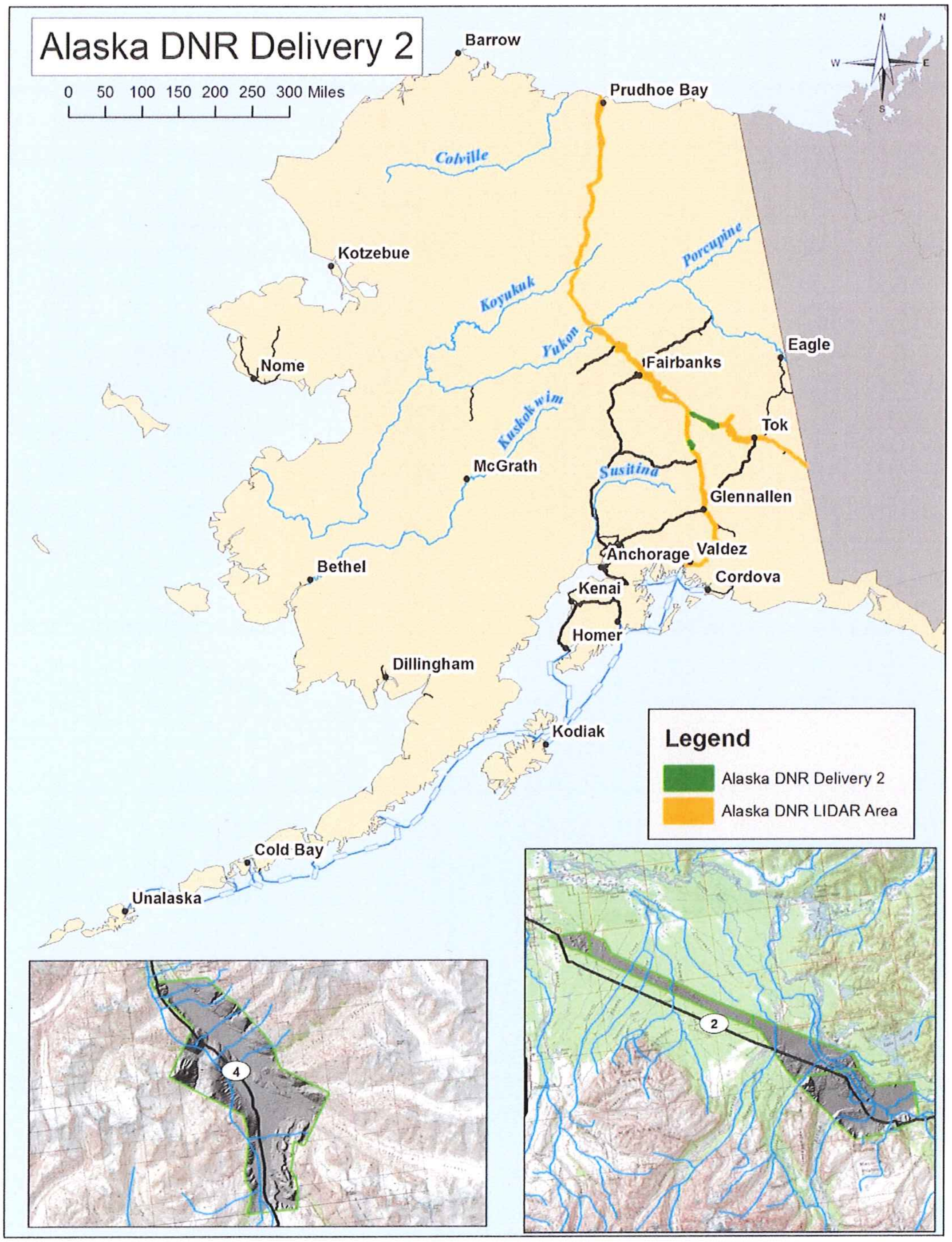

Figure 1. Map featuring Alaska DNR Delivery 2 data extent.

The Alaska Department of Natural Resources, Division of Geological and Geophysical Survey (DGGS) has contracted with Watershed Sciences, Inc (WSI) to collect high resolution lidar topographic data for a swath roughly parallel to proposed future pipeline rights of way. DGGS has specified the exact areas of data collection as well as a detailed description of data products to be delivered. The complete specifications are detailed in the September 14, 2010 Standard Agreement Form for Professional Services signed by DGGS and WSI.

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1. Review and test all delivered files for completeness, correct naming and usability.
2. Evaluate consistency of data by comparing points from the overlapping areas of adjacent swaths.
3. Visual inspection of images derived from the lidar bare earth and highest hit DEMs to identify artifacts, voids and missed ground.
4. Test the accuracy of the bare earth DEMs by comparing them to GPS ground control points provided by DGGS.

For each delivery of data, DOGAMI shall prepare a report to DGGS describing the results of the quality control review for that delivery. This is the report for Delivery 2 (Figure 1).

Upon receipt from vendor (Watershed Sciences), all lidar data for Delivery 2 were independently reviewed by staff from the Oregon Department of Geology and Mineral Industries (DOGAMI) to ensure project specifications were met. The entire delivery consisted of the following data products:

- 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.
- 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 Universal Transverse Mercator (Zones 6 and 7), NAD83 CORS96 meters.

Data Completeness

Data for Alaska DNR Delivery 2 area were collected between September 17th and September 27th, 2010. Total area of delivered data totals 149.09 square miles. Delivery 2 (Figure 2) includes data in the format of grids, trajectory files, intensity images, Lidar ASCII Standard (LAS) point files, 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 1 meter cell size. Lidar point data are delivered in LAS binary format for ground classified returns as well as the entire lidar point cloud. Georeferenced intensity images of 1 meter cell size are supplied in geoTIF format. Supplementary data include 1 meter cell size vegetation rasters displaying canopy and other vegetation metrics. Real time kinematic ground survey data (used for absolute vertical adjustment) are supplied in shapefile format. This delivery contains data for the following USGS 7.5 minute quads (listed by quadrangle tile name within the boundary of the Alaska DNR Survey collection area (Figure 2):

Delivery 2 Quadrangles: XMHb4, XMHc2, XMHd2, XMHd3, XMHd4.

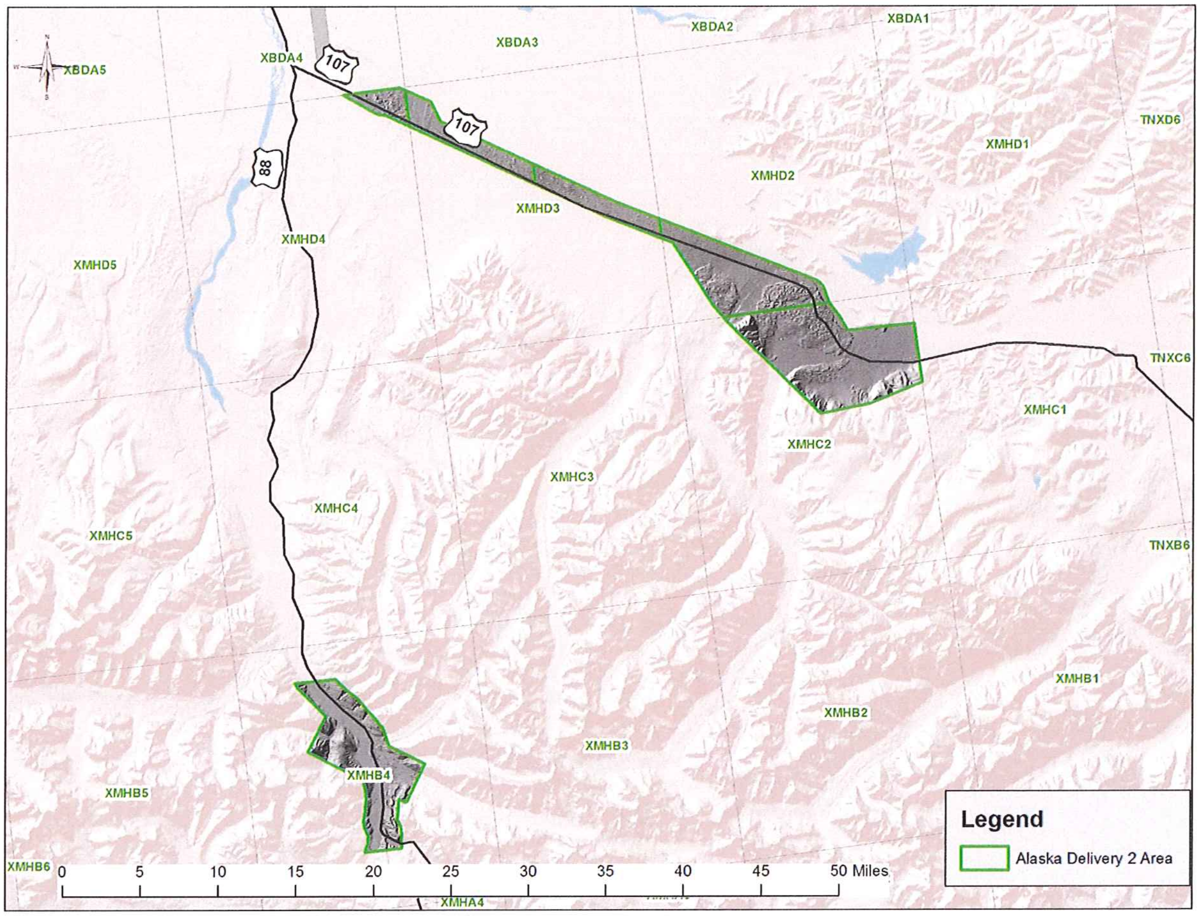

Figure 2. Delivery 2 location area. Data is referenced to USGS 7.5 minute quadrangles within the extents of the Alaska DNR Survey collection area

FINAL Delivery	Resolution	Format	Tiling	
Bare Earth DEMs	1 meter	grid	quad	x
Highest Hit DEMs	1 meter	grid	quad	x
Trajectory files	1 sec	sbet /shape	flight	x
Intensity Images	1 meter?	tif	quad	x
LAS	8pts/m^2	las	tiled	x
Ground Returns	N/A	las	tiled	x
First return Vegetation Raster	1 meter	grid	quad	x
RTK point data		shape		x
Delivery Area shapefile		shape	quad	x
Report		pdf		x

Miscellaneous		Format	Tiling	
Processing bins		Shape dxf/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 headers have been scanned to ensure completeness and readability (Figure 3).

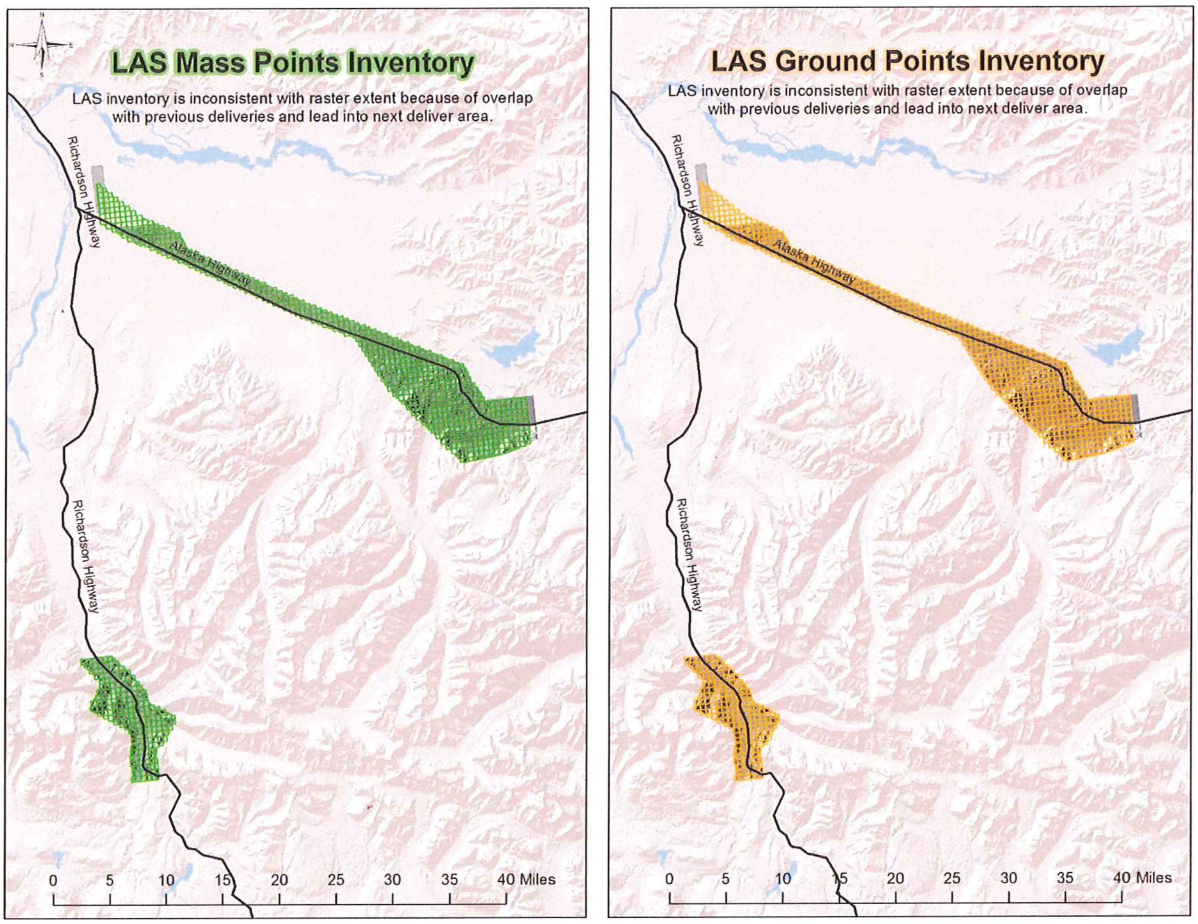

Figure 3. LIDAR Point Inventory graphic representing complete coverage of point data for both mass points and ground LAS files.

Consistency Analysis:

DGGS has specified that lidar consistency must average less than 0.15m (0.49 feet) in vertical offsets between adjacent 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 868 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 7,725,581 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 187 flight lines were sampled and compared for consistency.

Summary Statistics

# of Tiles	868
# of Flight Line Sections	187
Avg # of Points	7,725,581
Avg. Magnitude Z error (m)	0.034

Table 2a. Summary Results of Consistency Analysis

	meters	***feet***
Mean	0.034	0.112
Standard Error	0.001	0.002
Standard Deviation	0.010	0.033
Sample Variance	0.000	0.000
Range	0.065	0.213
Minimum	0.000	0.000
Maximum	0.065	0.213

Table 2b. Descriptive Statistics for Magnitude Z Error.

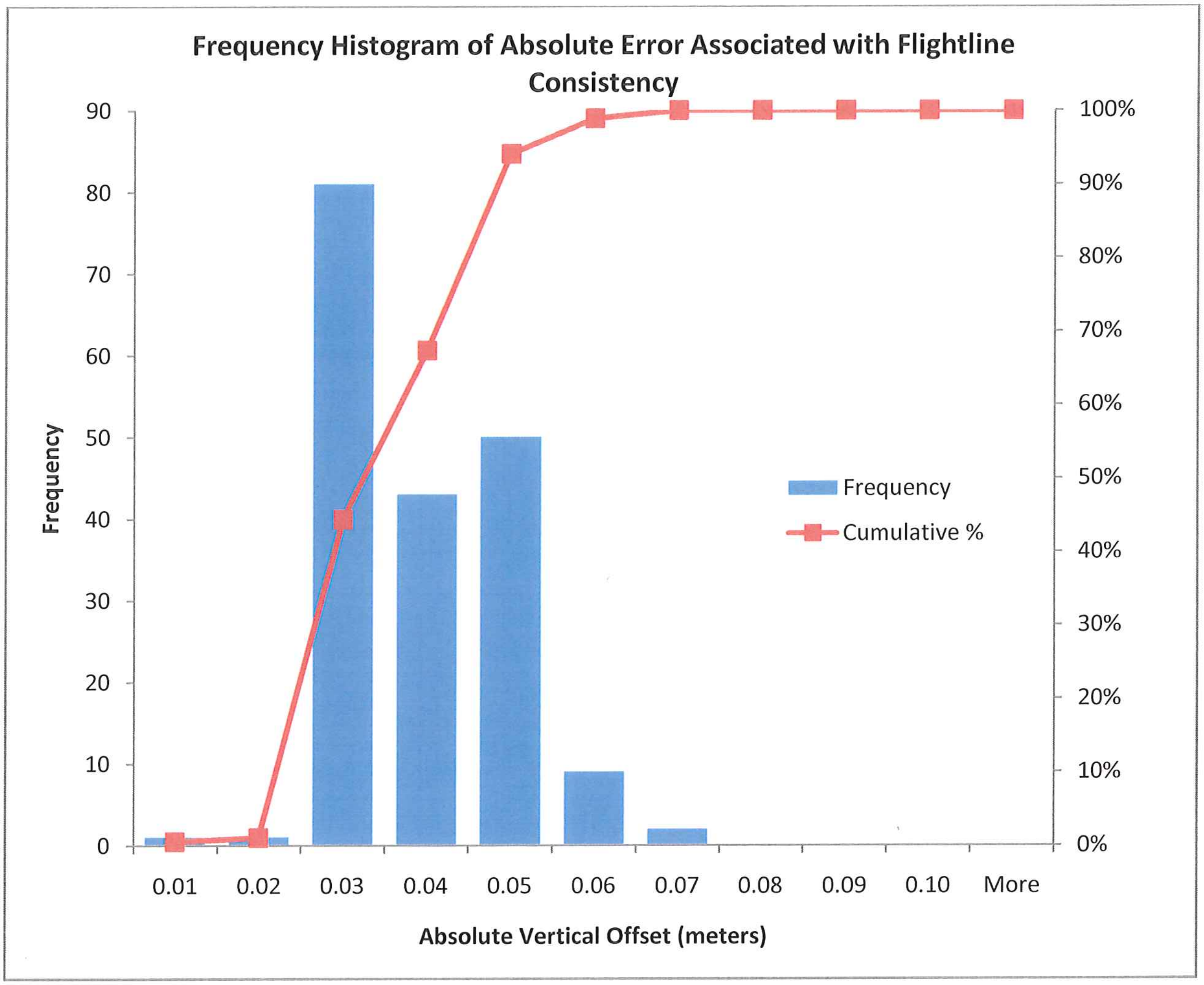

Figure 4. Histogram of flight line offsets values.

Results of the consistency analysis found the average flight line offset to be 0.034 meters with a maximum error of 0.065m (Table 2b). Distribution of error showed over 94% of all error was less than 0.05m and 99% was less than 0.07m (Figure 4). These results show that all data are within tolerances of data consistency according to contract agreement.

Visual Analysis

Lidar 1m 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 5). Both bare earth and highest hit models were examined for calibration offsets, tiling artifacts (Figure 6), seam line offsets, pits (Figure 6), 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 5). 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 7). 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.

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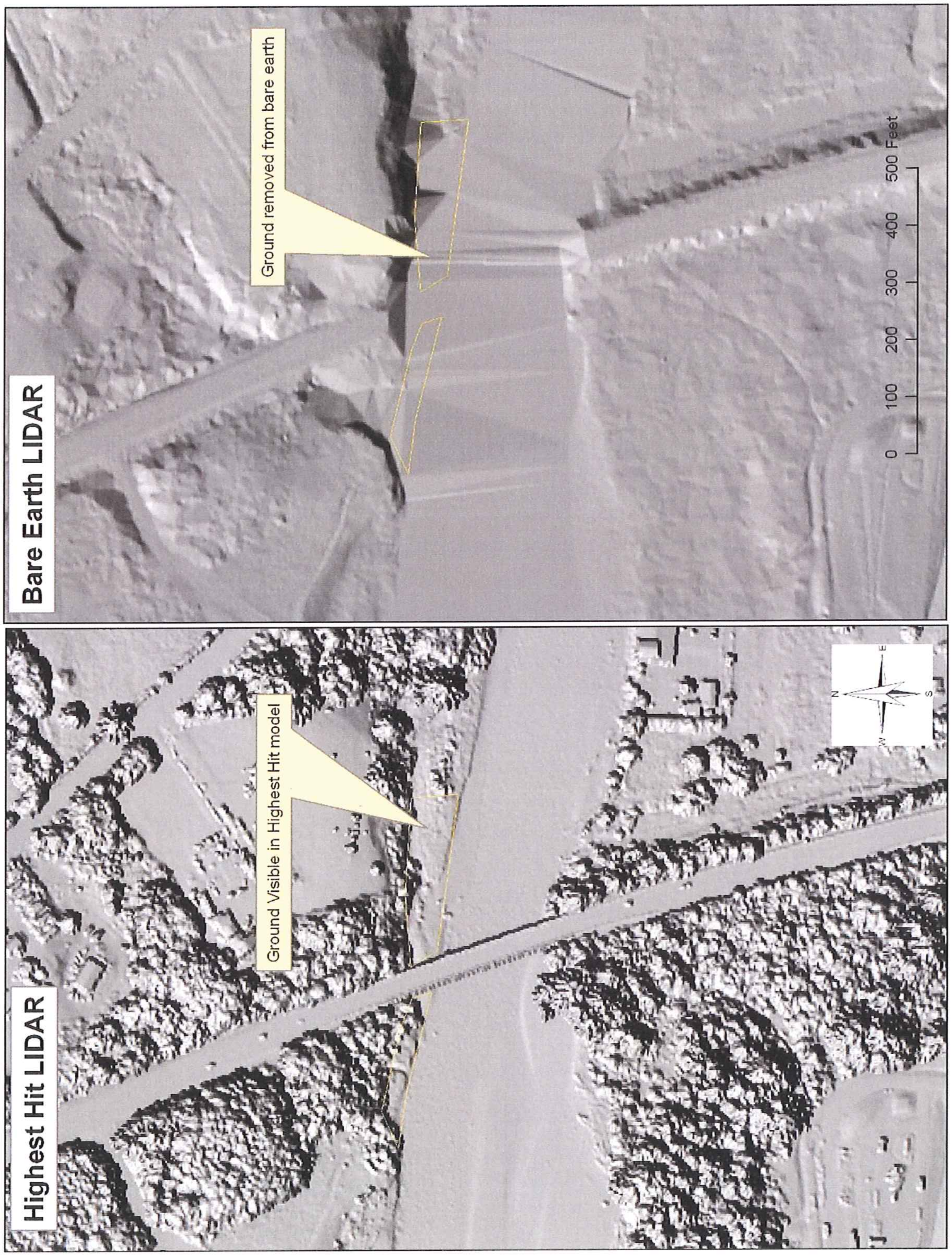

Figure 5. Example of missing ground in lidar bare earth data. Ground is clearly visible in highest hit model, but has been removed from the bare earth model. This type of classification error is common near water body features.

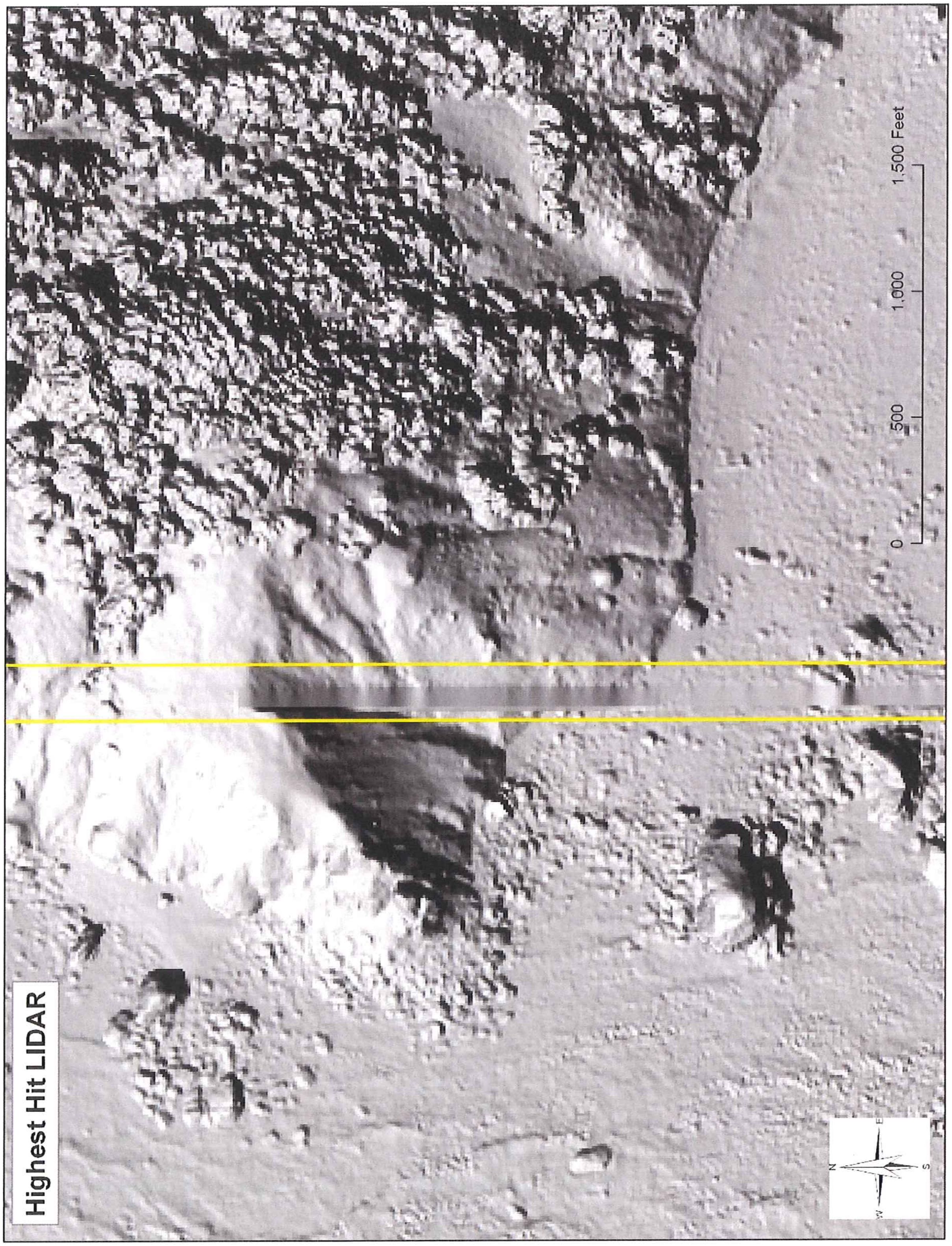

Figure 6. Example of tile artifact found in highest hit lidar data. Artifact is a seam line error created due to misclassification of ground at edge of lidar processing tiles.

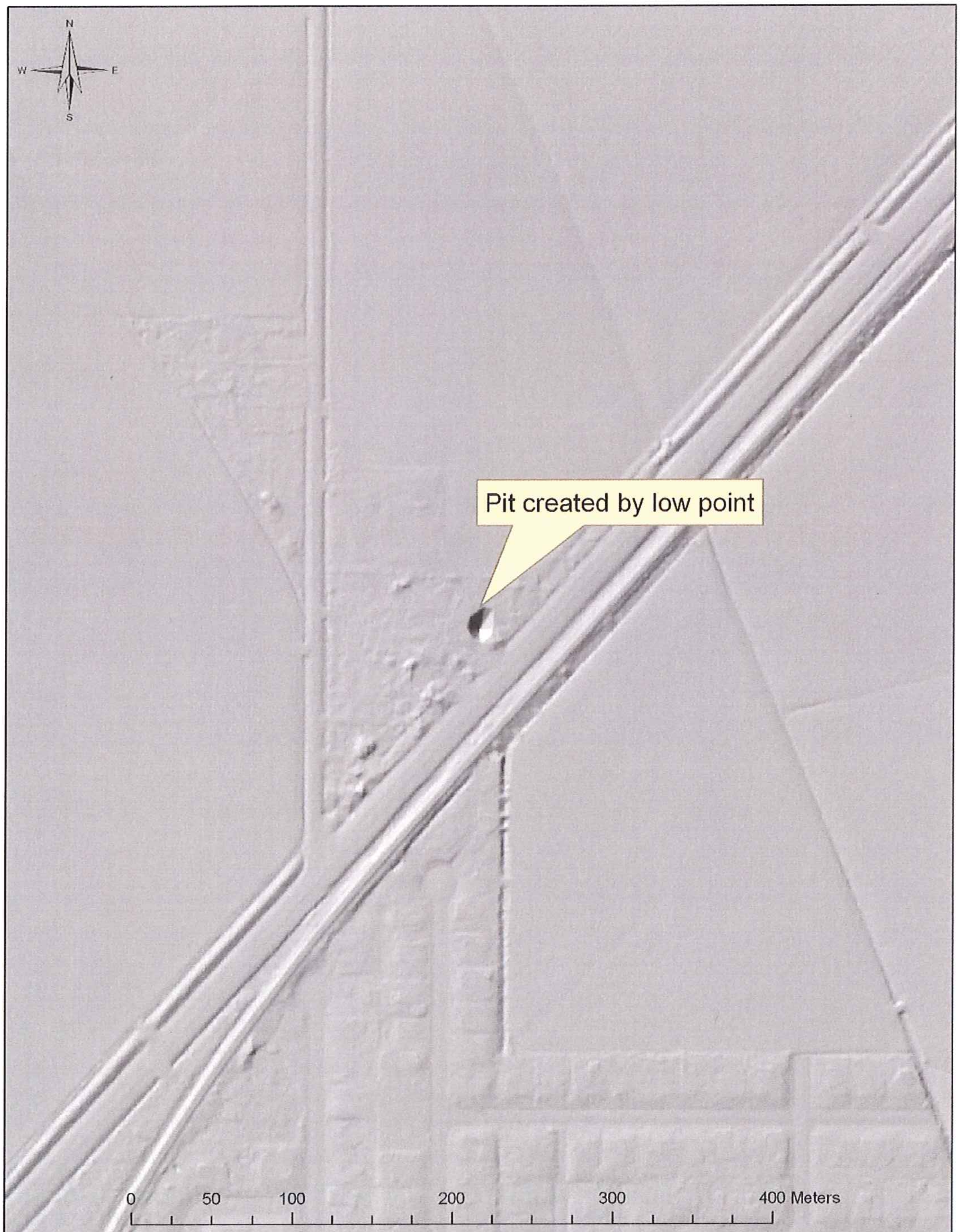

Figure 7. Example of "Pit" caused by low point in ground model. Pits are caused when standing water absorbs the lidar pulse. Pits are evident in ground model as the lowest point elevation is assigned to the grid cell value. Inversely the pit is not observable in the highest hit model as the highest point 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. The contractor used a surveying system (Figure 8) to measure GCP's. GPS survey techniques allow surveyors to collect many precisely located GCP's which can be used as a control comparison with LiDAR elevations. 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). A licensed surveyor is often able to post process GPS survey data to accuracies less than 1cm in both horizontal and vertical axes.

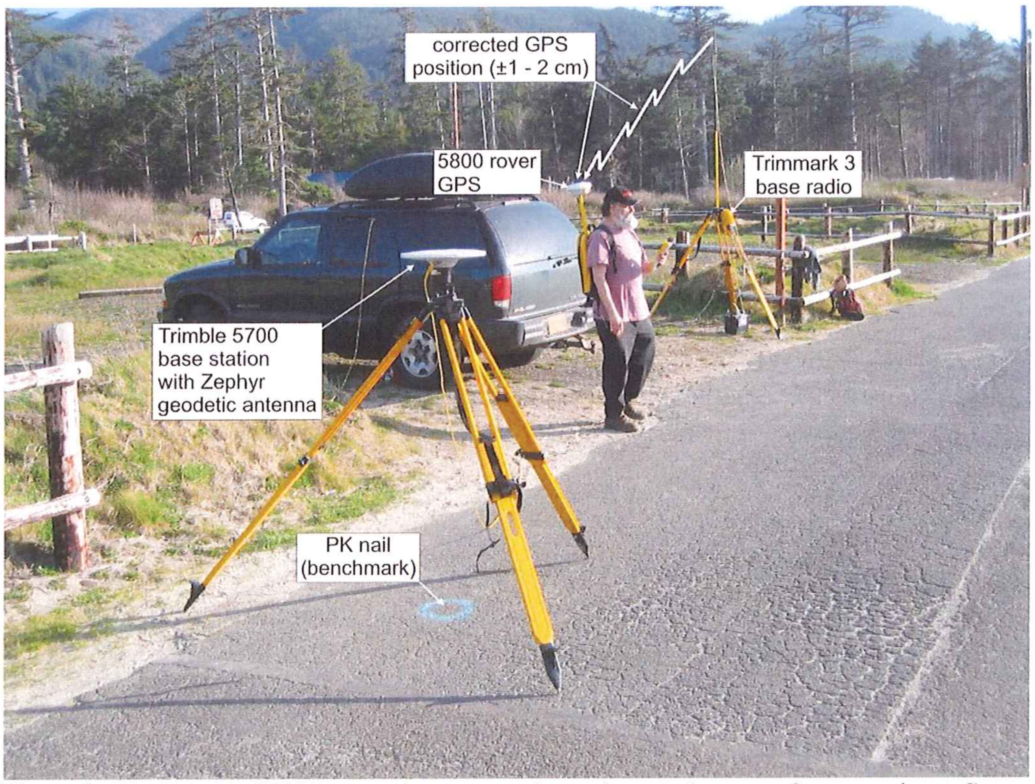

Figure 8. The Trimble 5700 base station antenna located over a known reference point at Cape Lookout State Park. Corrected GPS position and elevation information is then transmitted by a Trimmark III base radio to the 5800 GPS rover unit.

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 values for the entire delivered data set. Project specifications list the maximum acceptable root mean square vertical offset to be 0.20 meters (0.65 feet).

A total of 2511 measured GCP's were provided to DOGAMI by DGGS for the Delivery 2 region (Figure 9) and compared with the lidar elevation grids. The data delivered to DOGAMI was found to have a mean vertical offset of 0.026 meters (0.084 feet) and an RMSE value of 0.040 meters (0.130 ft). Offset values ranged from -0.092 to 0.203 meters (Table 3 and Figure 10).

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.

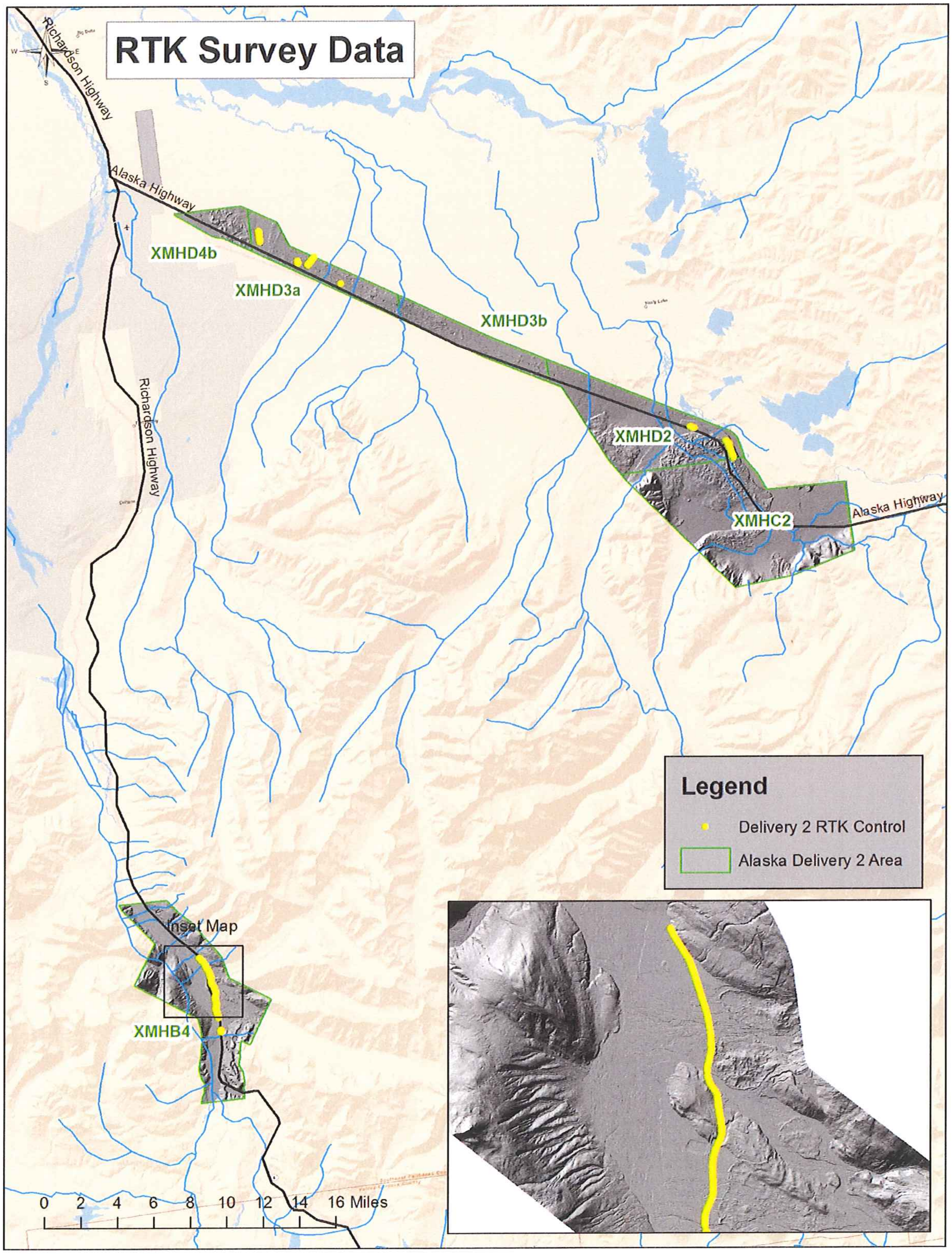

Figure 9. Locations of RTK control surveyed by Contractor. Data was used to test absolute accuracy for the Alaska DNR lidar survey within the Delivery 2 extent.

	Meters	*Feet*
Mean	0.026	0.084
Standard Error	0.001	0.002
Standard Deviation	0.030	0.100
Range	0.296	0.971
Minimum	-0.093	-0.305
Maximum	0.203	0.666
RMSE	0.040	0.130

Table 3. Descriptive Statistics for absolute value vertical offsets.

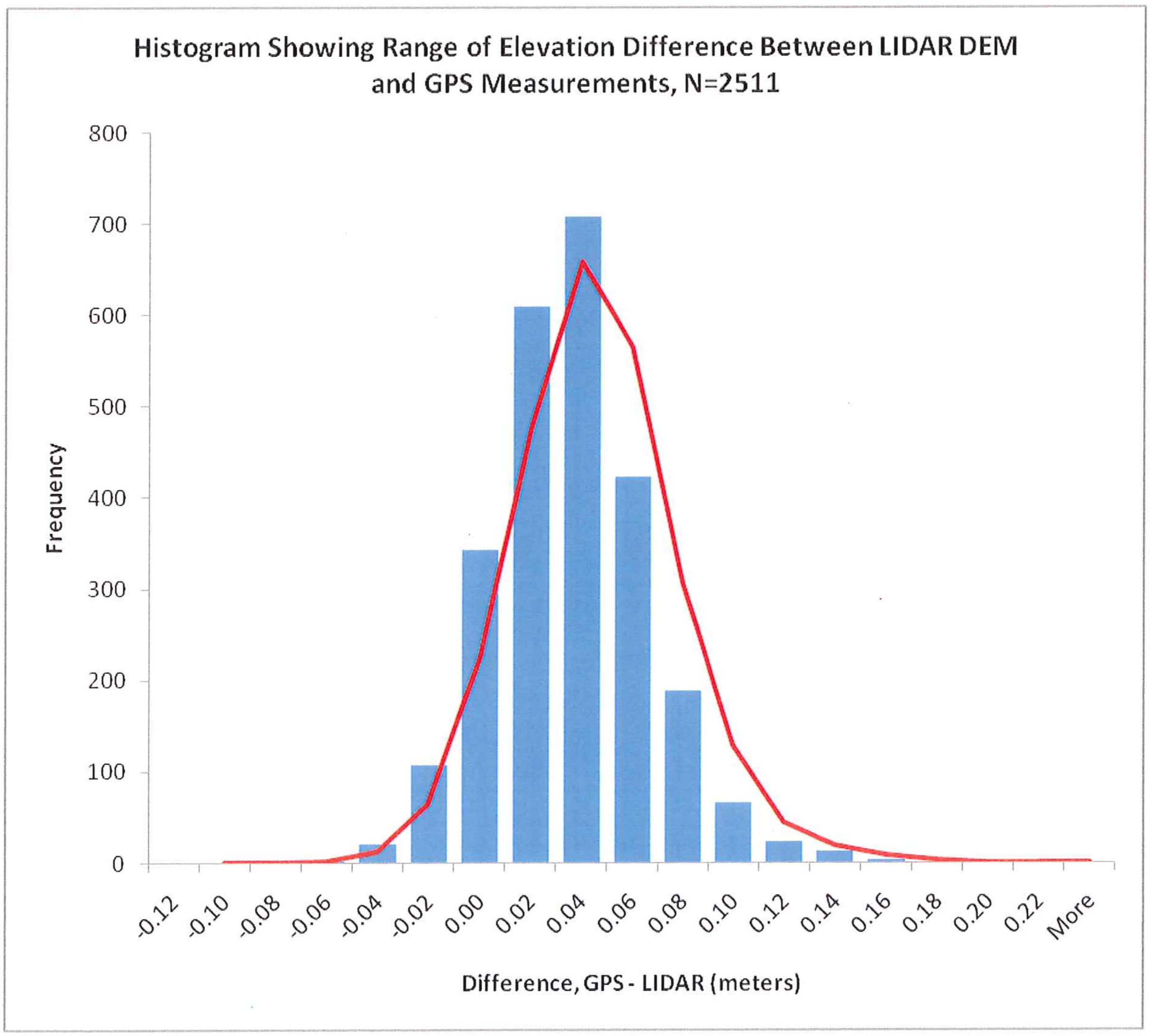

Figure 10. Histogram of elevation difference between Lidar DEM and GPS survey data.

Acceptance

The data described in this report meets or exceeds project specifications laid out in the contracted data standards agreement. All the required files for the delivery have been received as of May 2nd, 2011, and are correctly named and useable. 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 quality control 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 Signature

______________________________ Date: 5/4/2011

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

______________________________ Date: 5/4/2011

Ian Madin
Chief Scientist – Department of Geology & Mineral Industries

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

Alaska DNR LIDAR Project, 2010 – Delivery 3 QC Analysis

LIDAR QC Report – June 2nd, 2011

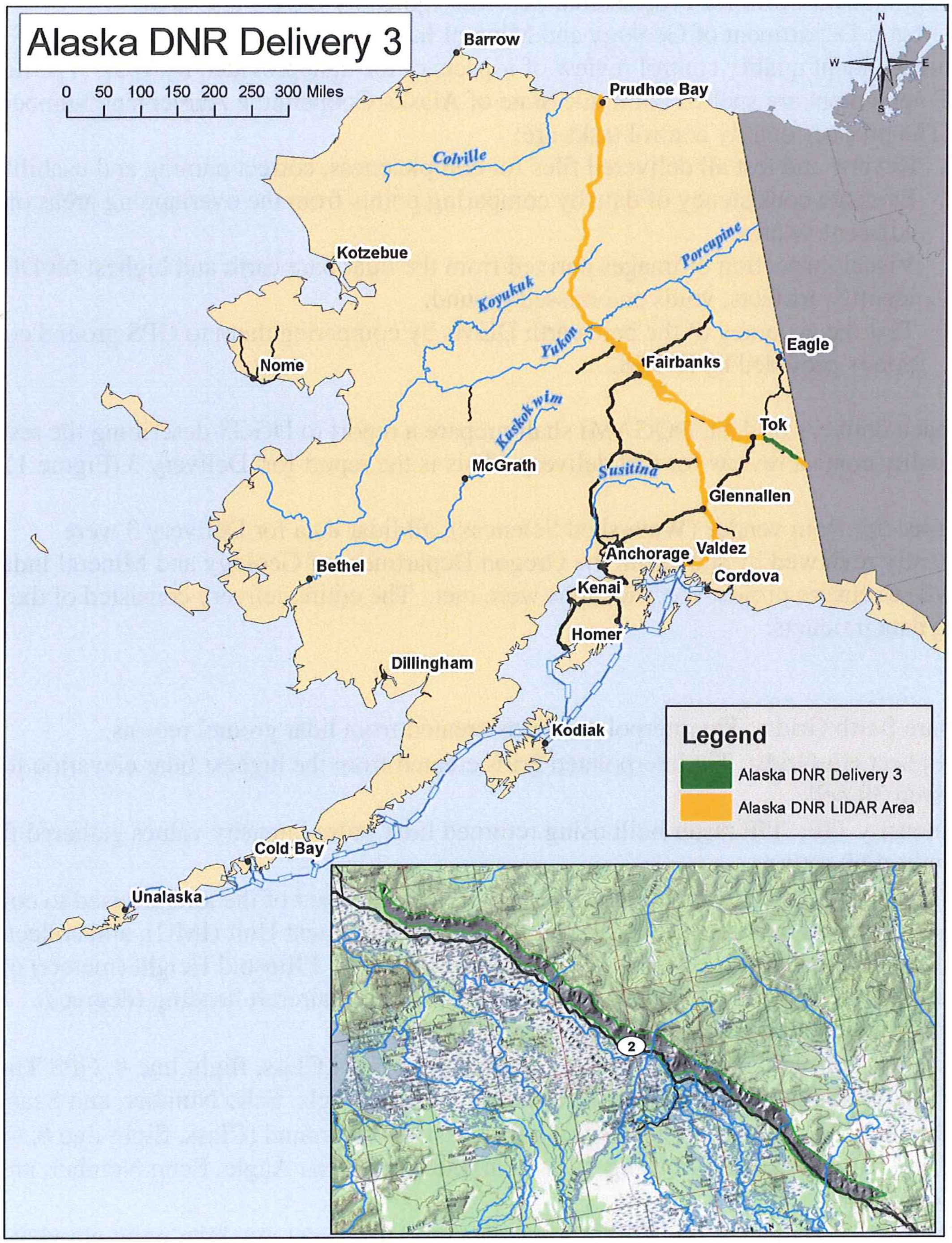

Figure 1. Map featuring Alaska DNR Delivery 3 data extent.

The Alaska Department of Natural Resources, Division of Geological and Geophysical Survey (DGGS) has contracted with Watershed Sciences, Inc (WSI) to collect high resolution lidar topographic data for a swath roughly parallel to proposed future pipeline rights of way. DGGS has specified the exact areas of data collection as well as a detailed description of data products to be delivered. The complete specifications are detailed in the September 14, 2010 Standard Agreement Form for Professional Services signed by DGGS and WSI.

The Oregon Department of Geology and Mineral Industries has contracted with DGGS to provide independent quality control review of aspects of the data provided by WSI. The details of the QC agreement are spelled out in the State of Alaska Cooperative Agreement Number MI-11-006. The primary quality control tasks are:

1. Review and test all delivered files for completeness, correct naming and usability.
2. Evaluate consistency of data by comparing points from the overlapping areas of adjacent swaths.
3. Visual inspection of images derived from the lidar bare earth and highest hit DEMs to identify artifacts, voids and missed ground.
4. Test the accuracy of the bare earth DEMs by comparing them to GPS ground control points provided by DGGS.

For each delivery of data, DOGAMI shall prepare a report to DGGS describing the results of the quality control review for that delivery. This is the report for Delivery 3 (Figure 1).

Upon receipt from vendor (Watershed Sciences), all lidar data for Delivery 3 were independently reviewed by staff from the Oregon Department of Geology and Mineral Industries (DOGAMI) to ensure project specifications were met. The entire delivery consisted of the following data products:

- 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.
- 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 Universal Transverse Mercator (Zones 6 and 7), NAD83 CORS96 meters.

Data Completeness

Data for Alaska DNR Delivery 3 area were collected between October 2nd and October 4thth, 2010. Total area of delivered data totals 61.91 square miles. Delivery 3 (Figure 2) includes data in the format of grids, trajectory files, intensity images, Lidar ASCII Standard (LAS) point files, 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 1 meter cell size. Lidar point data are delivered in LAS binary format for ground classified returns as well as the entire lidar point cloud. Georeferenced intensity images of 1 meter cell size are supplied in geoTIF format. Supplementary data include 1 meter cell size vegetation rasters displaying canopy and other vegetation metrics. Real time kinematic ground survey data (used for absolute vertical adjustment) are supplied in shapefile format. This delivery contains data for the following USGS 7.5 minute quads (listed by quadrangle tile name within the boundary of the Alaska DNR Survey collection area (Figure 2):

Delivery 3 Quadrangles: NABD1, NABD2, TNXA2, TNXB3.

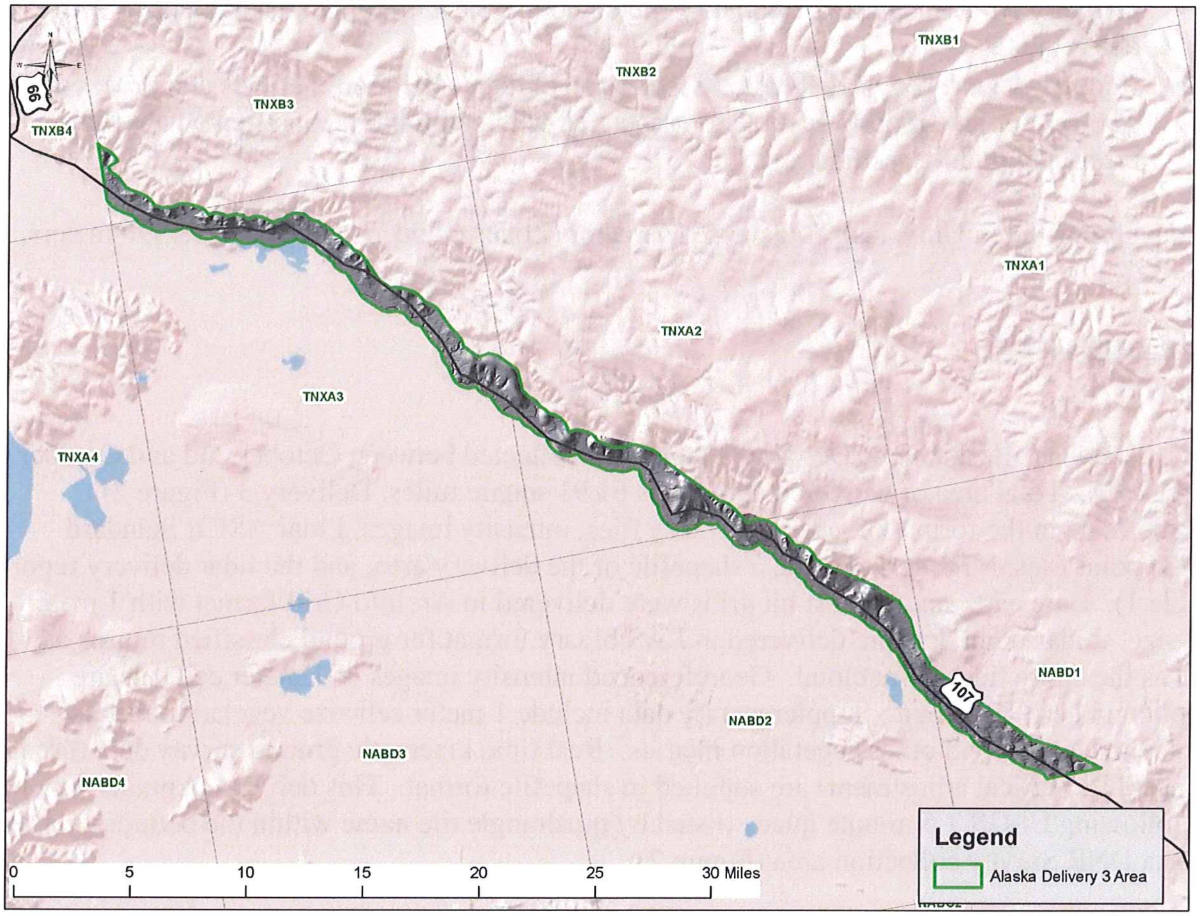

Figure 2. Delivery 3 location area. Data is referenced to USGS 7.5 minute quadrangles within the extents of the Alaska DNR Survey collection area

FINAL Delivery	Resolution	Format	Tiling	
Bare Earth DEMs	1 meter	grid	quad	x
Highest Hit DEMs	1 meter	grid	quad	x
Trajectory files	1 sec	sbet /shape	flight	x
Intensity Images	1 meter?	tif	quad	x
LAS	8pts/m^2	las	tiled	x
Ground Returns	N/A	las	tiled	x
First return Vegetation Raster	1 meter	grid	quad	x
RTK point data		shape		x
Delivery Area shapefile		shape	quad	x
Report		pdf		x

Miscellaneous		Format	Tiling	
Processing bins		Shape dxf/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 headers have been scanned to ensure completeness and readability (Figure 3).

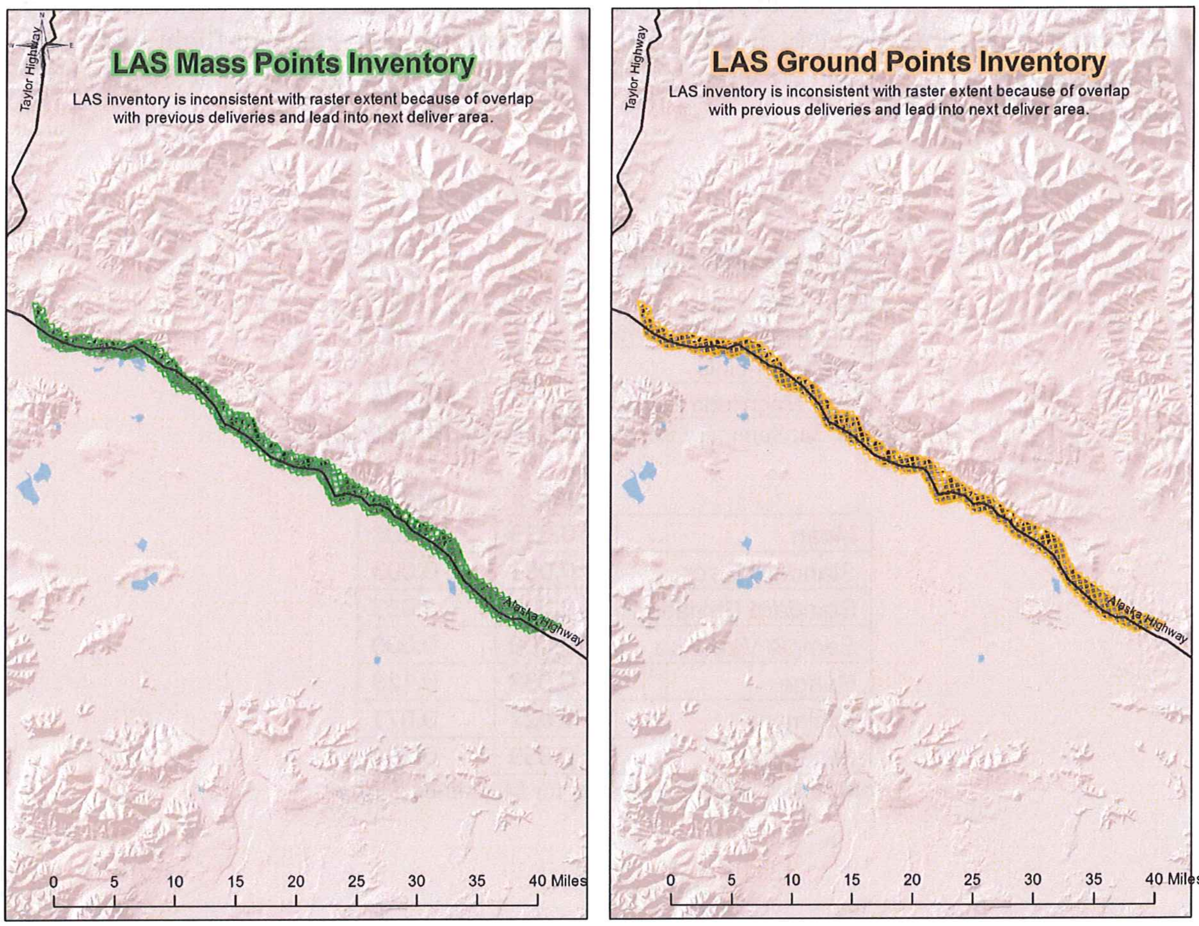

Figure 3. LIDAR Point Inventory graphic representing complete coverage of point data for both mass points and ground LAS files.

Consistency Analysis:

DGGS has specified that lidar consistency must average less than 0.15m (0.49 feet) in vertical offsets between adjacent 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 451 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 7,221,418 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 84 flight lines were sampled and compared for consistency.

Summary Statistics

# of Tiles	451
# of Flight Line Sections	84
Avg # of Points	7,221,418
Avg. Magnitude Z error (m)	0.033

Table 2a. Summary Results of Consistency Analysis

	meters	***feet***
Mean	0.033	0.108
Standard Error	0.001	0.003
Standard Deviation	0.007	0.023
Sample Variance	0.000	0.000
Range	0.038	0.123
Minimum	0.022	0.071
Maximum	0.059	0.194

Table 2b. Descriptive Statistics for Magnitude Z Error.

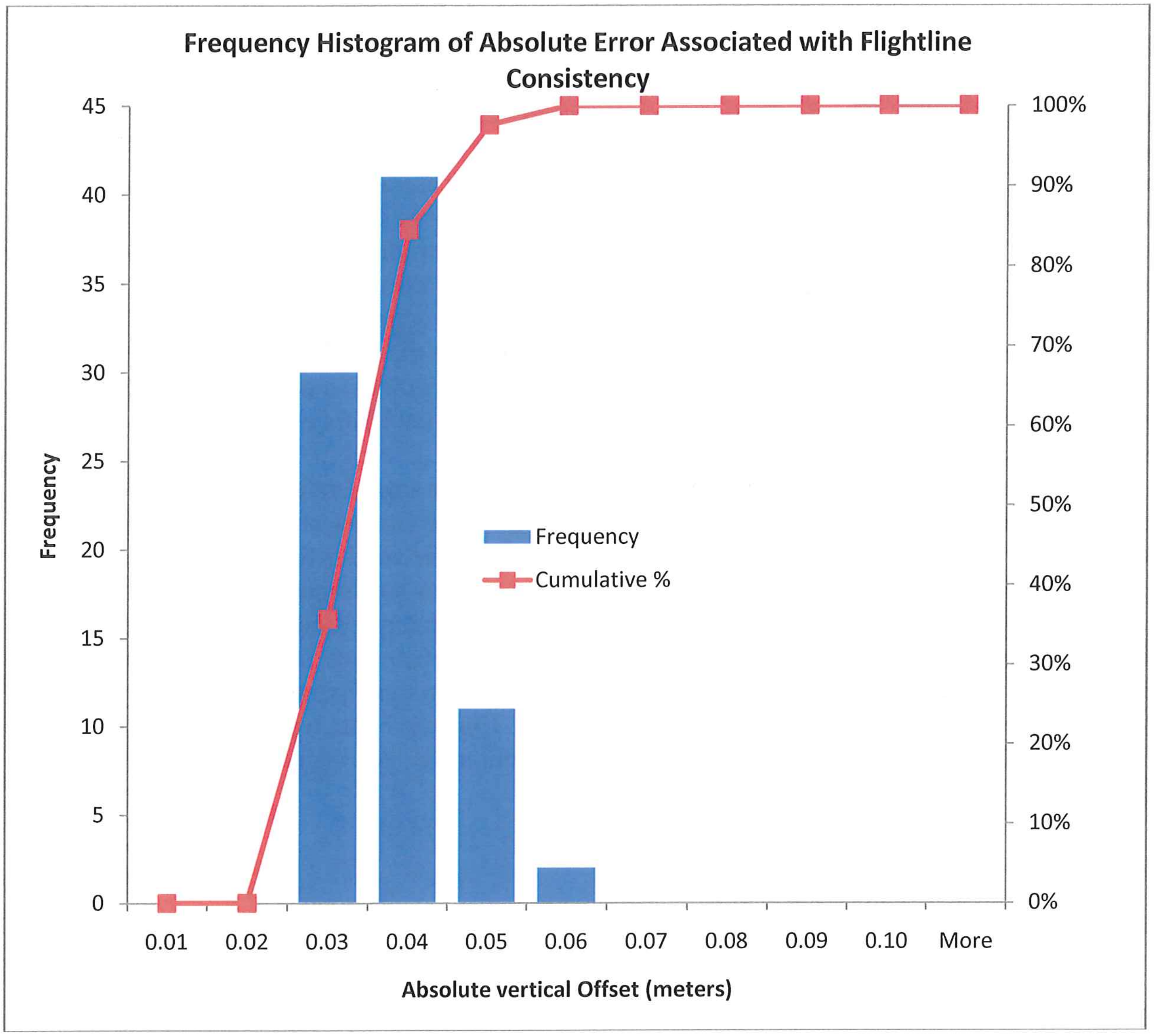

Figure 4. Histogram of flight line offsets values.

Results of the consistency analysis found the average flight line offset to be 0.033 meters with a maximum error of 0.059m (Table 2b). Distribution of error showed over 97% of all error was less than 0.05m and 99% was less than 0.06m (Figure 4). These results show that all data are within tolerances of data consistency according to contract agreement.

Visual Analysis

Lidar 1m 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 5). Both bare earth and highest hit

models were examined for calibration offsets, tiling artifacts (Figure 6), seam line offsets, pits (Figure 6), 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 5). 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 7). 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.

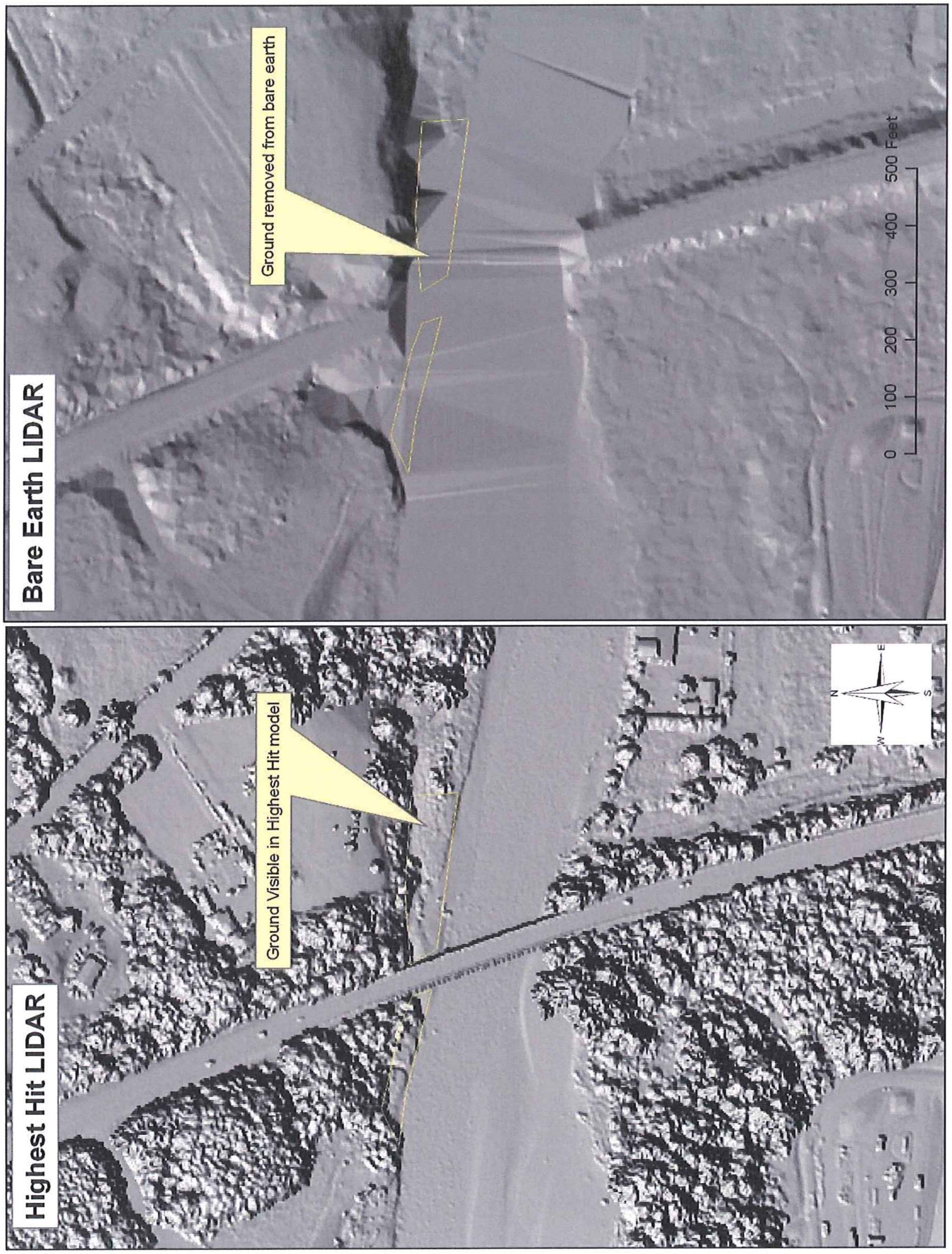

Figure 5. Example of missing ground in lidar bare earth data. Ground is clearly visible in highest hit model, but has been removed from the bare earth model. This type of classification error is common near water body features.

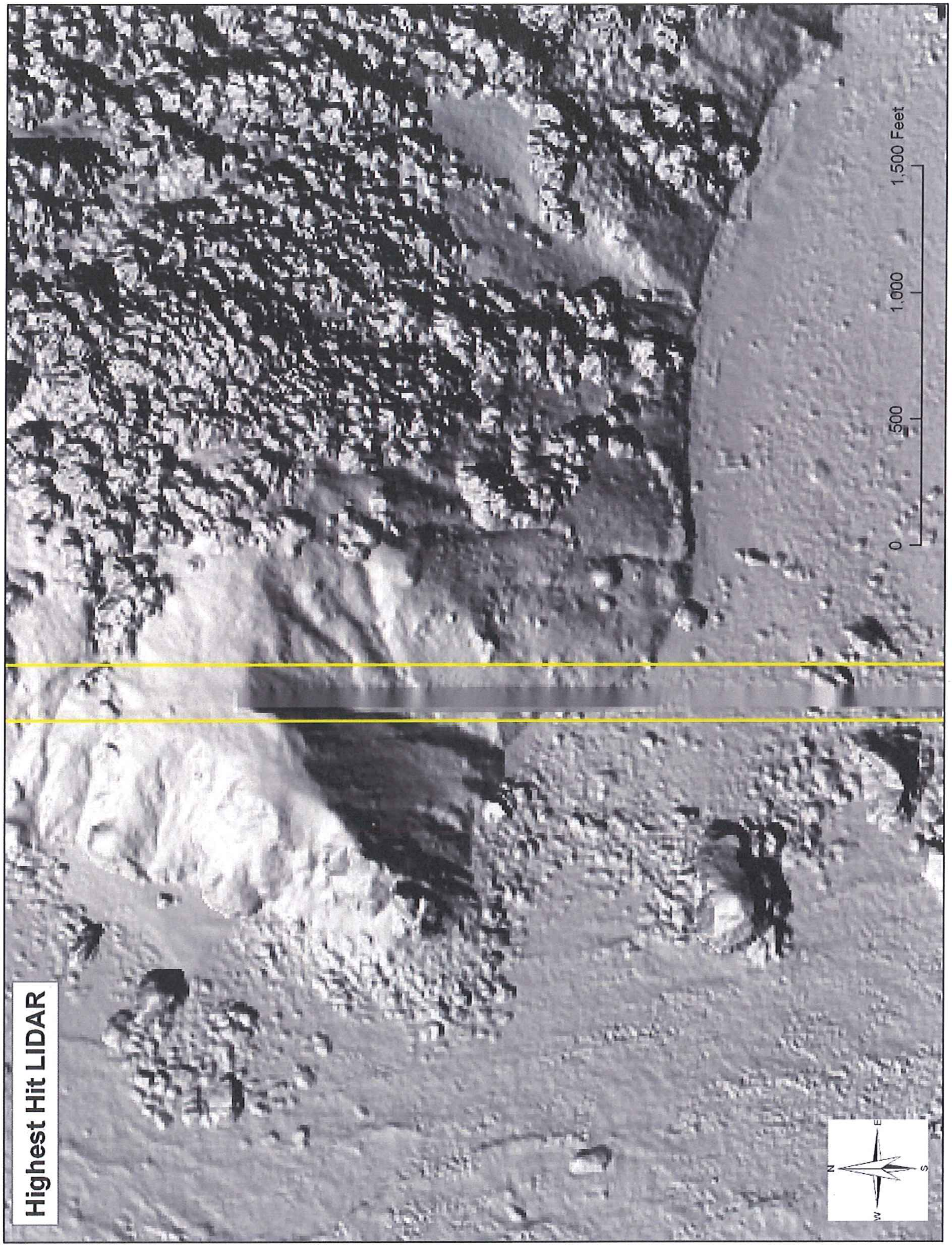

Figure 6. Example of tile artifact found in highest hit lidar data. Artifact is a seam line error created due to misclassification of ground at edge of lidar processing tiles.

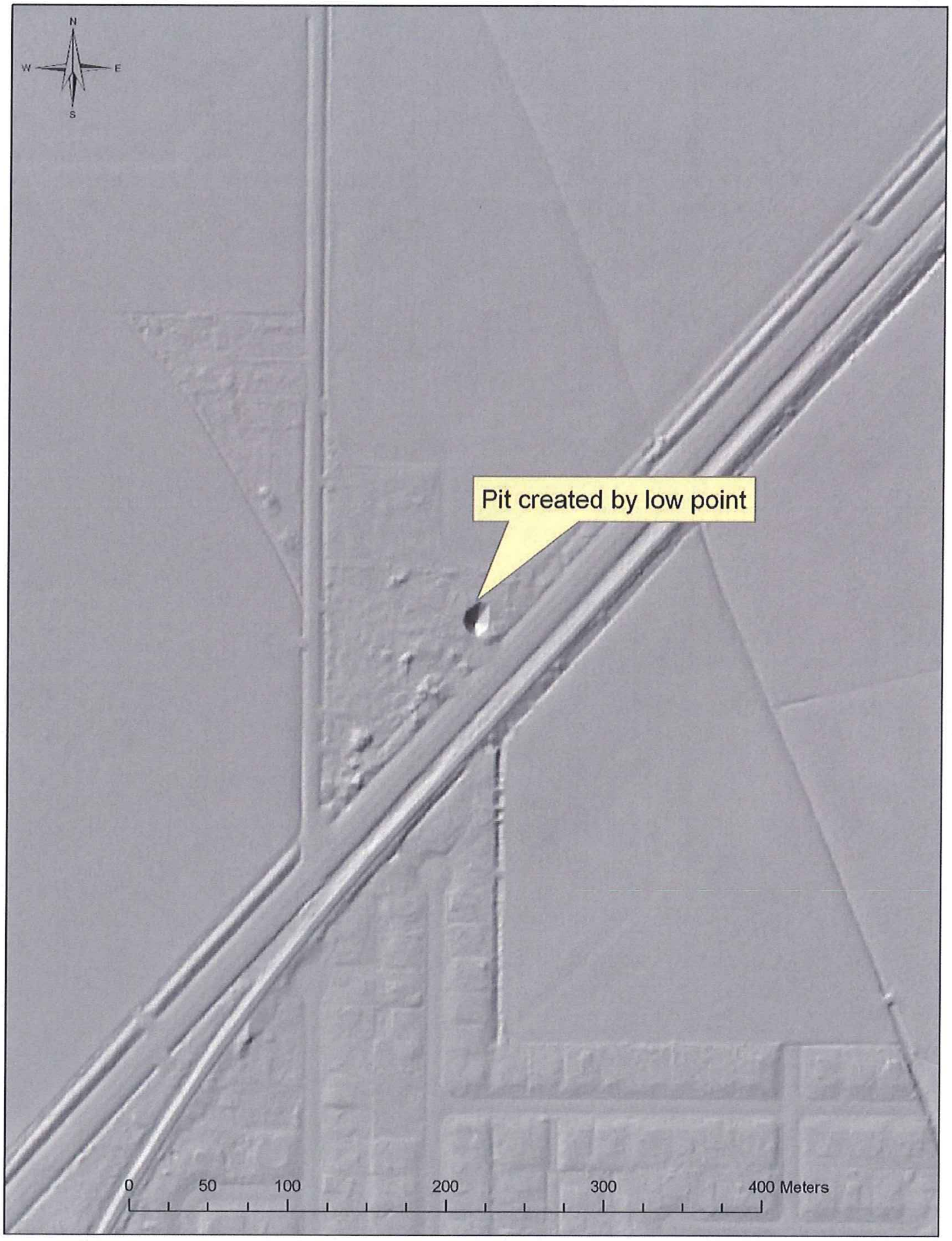

Figure 7. Example of "Pit" caused by low point in ground model. Pits are caused when standing water absorbs the lidar pulse. Pits are evident in ground model as the lowest point elevation is assigned to the grid cell value. Inversely the pit is not observable in the highest hit model as the highest point 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. The contractor used a surveying system (Figure 8) to measure GCP's. GPS survey techniques allow surveyors to collect many precisely located GCP's which can be used as a control comparison with LiDAR elevations. 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). A licensed surveyor is often able to post process GPS survey data to accuracies less than 1cm in both horizontal and vertical axes.

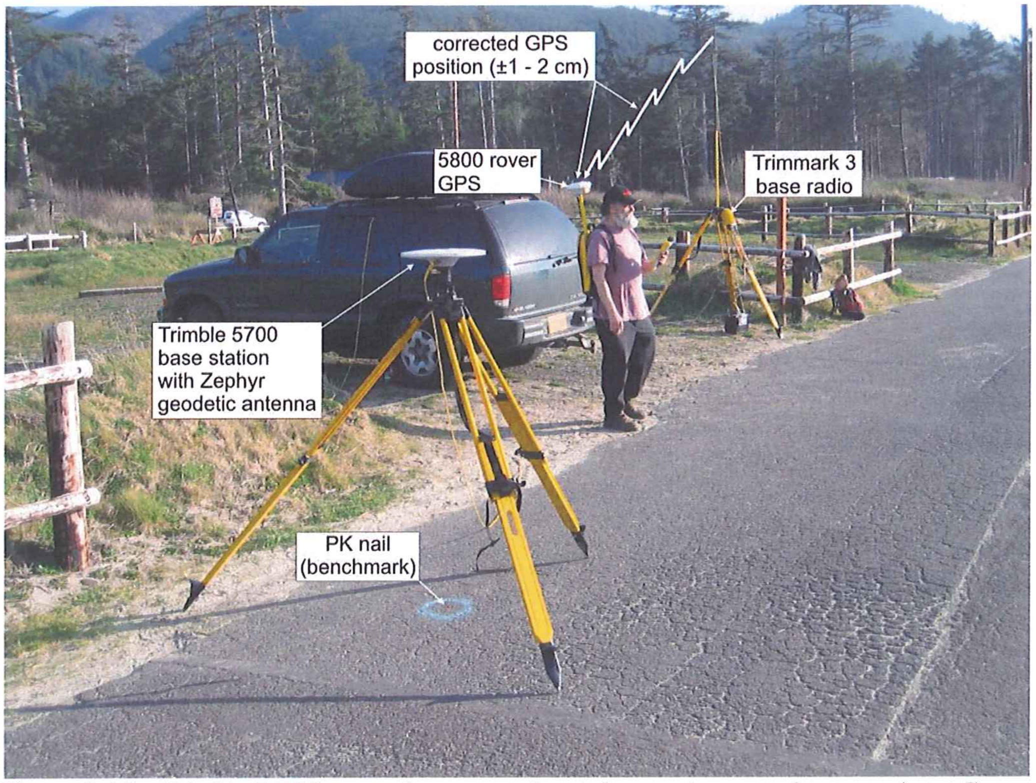

Figure 8. The Trimble 5700 base station antenna located over a known reference point at Cape Lookout State Park. Corrected GPS position and elevation information is then transmitted by a Trimmark III base radio to the 5800 GPS rover unit.

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 values for the entire delivered data set. Project specifications list the maximum acceptable root mean square vertical offset to be 0.20 meters (0.65 feet).

A total of 376 measured GCP's were provided to DOGAMI by DGGS for the Delivery 3 region (Figure 9) and compared with the lidar elevation grids. The data delivered to DOGAMI was found to have a mean vertical offset of -0.014 meters (-0.047 feet) and an RMSE value of 0.032 meters (0.092 ft). Offset values ranged from -0.096 to 0.065 meters (Table 3 and Figure 10).

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.

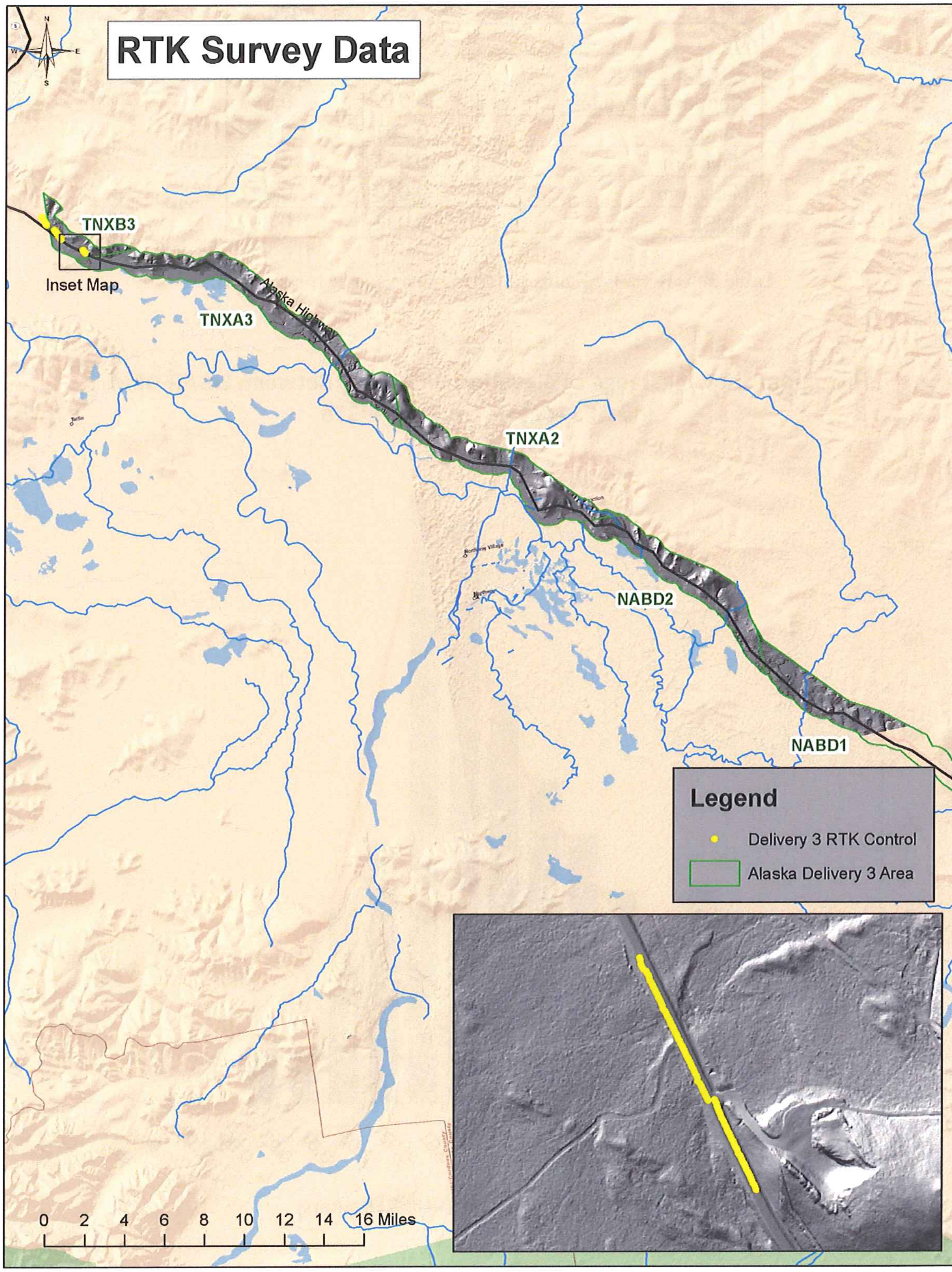

Figure 9. Locations of RTK control surveyed by Contractor. Data was used to test absolute accuracy for the Alaska DNR lidar survey within the Delivery 3 extent.

	Meters	Feet
Mean	-0.014	-0.047
Standard Error	0.001	0.005
Standard Deviation	0.029	0.094
Range	0.161	0.528
Minimum	-0.096	-0.315
Maximum	0.065	0.213
RMSE	0.032	0.092

Table 3. Descriptive Statistics for absolute value vertical offsets.

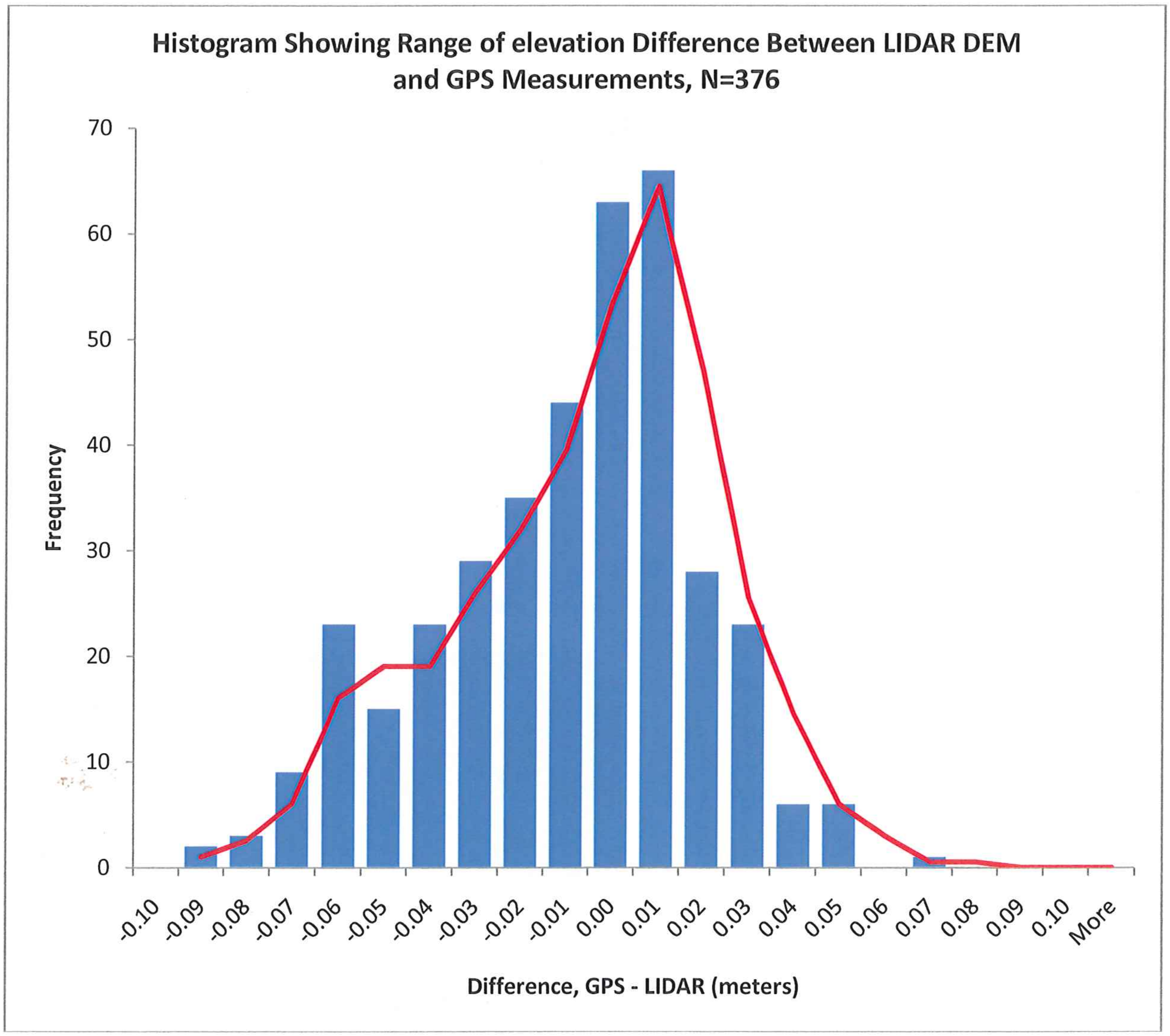

Figure 10. Histogram of elevation difference between Lidar DEM and GPS survey data.

Acceptance

The data described in this report meets or exceeds project specifications laid out in the contracted data standards agreement. All the required files for the delivery have been received as of June 2nd, 2011, and are correctly named and useable. 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 quality control 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 Signature

_______________________________ Date: 6/2/2011

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

_______________________________ Date: 6/2/2011

Ian Madin
Chief Scientist – Department of Geology & Mineral Industries

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

Alaska DNR LIDAR Project, 2011 – Delivery 4 QC Analysis

LIDAR QC Report – August 15th, 2011

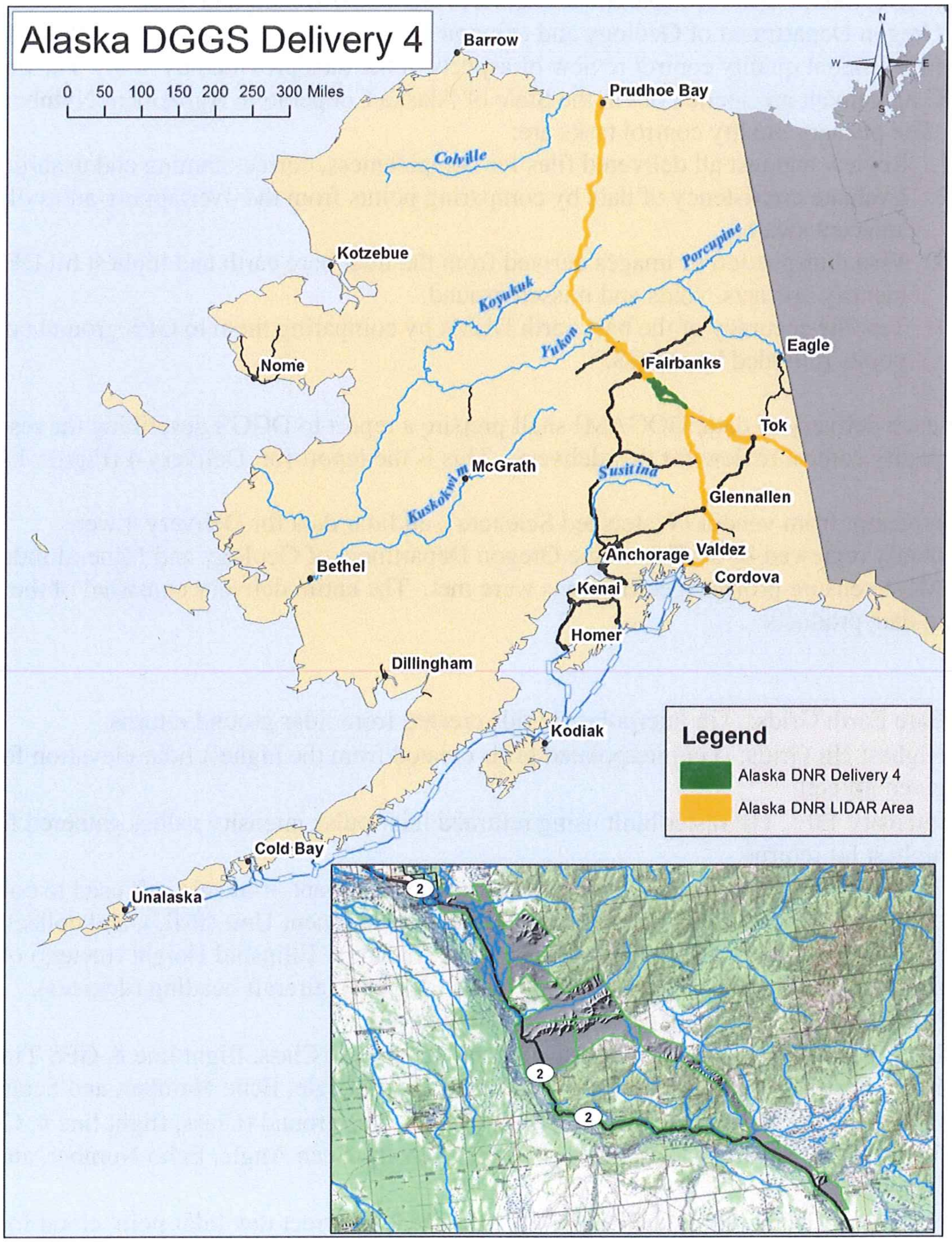

Figure 1. Map featuring Alaska DNR Delivery 4 data extent.

The Alaska Department of Natural Resources, Division of Geological and Geophysical Survey (DGGS) has contracted with Watershed Sciences, Inc (WSI) to collect high resolution lidar topographic data for a swath roughly parallel to proposed future pipeline rights of way. DGGS has specified the exact areas of data collection as well as a detailed description of data products to be delivered. The complete specifications are detailed in the September 14, 2010 Standard Agreement Form for Professional Services signed by DGGS and WSI.

The Oregon Department of Geology and Mineral Industries has contracted with DGGS to provide independent quality control review of aspects of the data provided by WSI. The details of the QC agreement are spelled out in the State of Alaska Cooperative Agreement Number MI-11-006. The primary quality control tasks are:

1. Review and test all delivered files for completeness, correct naming and usability.
2. Evaluate consistency of data by comparing points from the overlapping areas of adjacent swaths.
3. Visual inspection of images derived from the lidar bare earth and highest hit DEMs to identify artifacts, voids and missed ground.
4. Test the accuracy of the bare earth DEMs by comparing them to GPS ground control points provided by DGGS.

For each delivery of data, DOGAMI shall prepare a report to DGGS describing the results of the quality control review for that delivery. This is the report for Delivery 4 (Figure 1).

Upon receipt from vendor (Watershed Sciences), all lidar data for Delivery 4 were independently reviewed by staff from the Oregon Department of Geology and Mineral Industries (DOGAMI) to ensure project specifications were met. The entire delivery consisted of the following data products:

- 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.
- 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 Universal Transverse Mercator (Zones 6), NAD83 CORS96 meters.

Data Completeness

Data for Alaska DNR Delivery 4 area were collected between October 2nd and October 4thth, 2010. Total area of delivered data totals 263.78 square miles. Delivery 4 (Figure 2) includes data in the format of grids, trajectory files, intensity images, Lidar ASCII Standard (LAS) point files, 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 1 meter cell size. Lidar point data are delivered in LAS binary format for ground classified returns as well as the entire lidar point cloud. Georeferenced intensity images of 1 meter cell size are supplied in geoTIF format. Supplementary data include 1 meter cell size vegetation rasters displaying canopy and other vegetation metrics. Real time kinematic ground survey data (used for absolute vertical adjustment) are supplied in shapefile format. This delivery contains data for the following USGS 7.5 minute quads (listed by quadrangle tile name within the boundary of the Alaska DNR Survey collection area (Figure 2):

Delivery 4 Quadrangles: FAIC1, XBDA4, XBDA5, XBDB5, XBDB6, XBDC6.

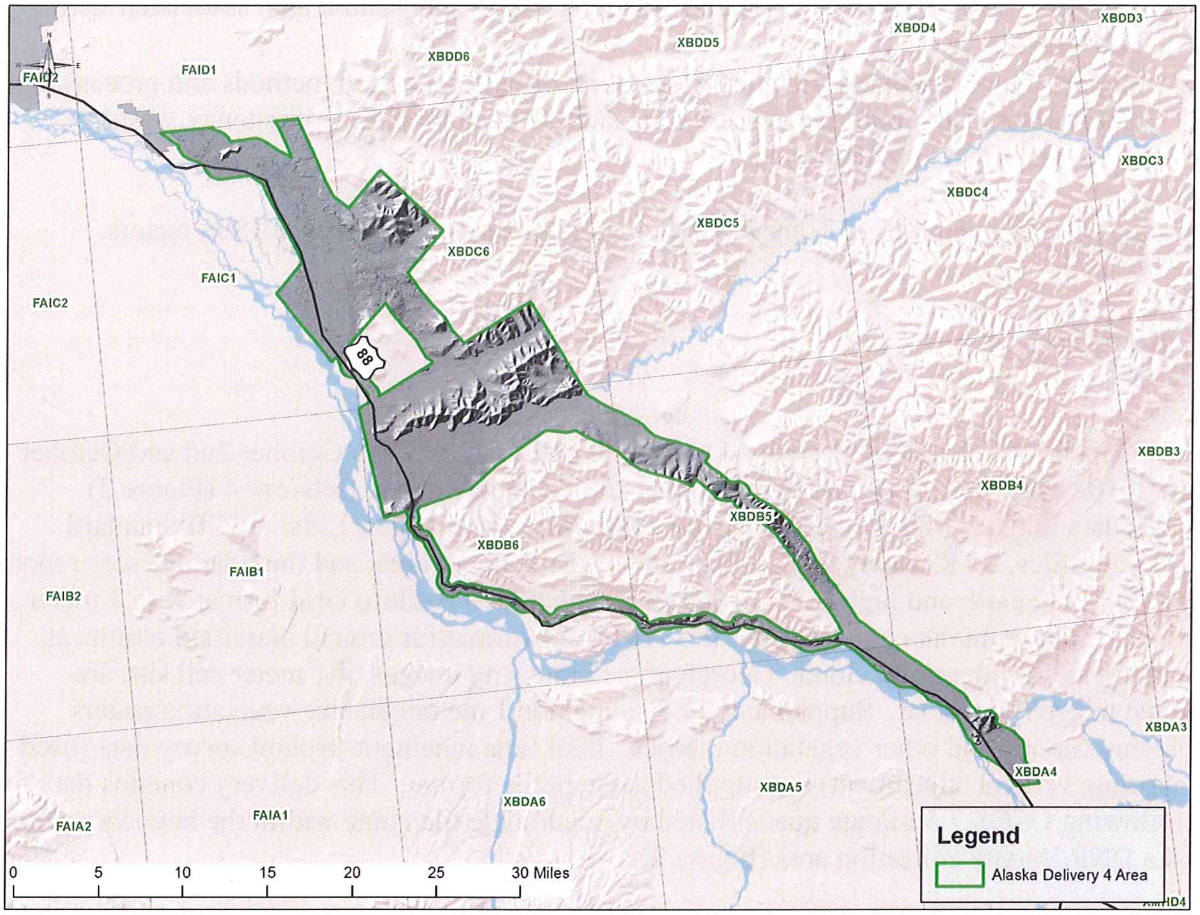

Figure 2. Delivery 4 location area. Data is referenced to USGS 7.5 minute quadrangles within the extents of the Alaska DNR Survey collection area

FINAL Delivery	Resolution	Format	Tiling	
Bare Earth DEMs	1 meter	grid	quad	x
Highest Hit DEMs	1 meter	grid	quad	x
Trajectory files	1 sec	sbet /shape	flight	x
Intensity Images	1 meter?	tif	quad	x
LAS	8pts/m^2	las	tiled	x
Ground Returns	N/A	las	tiled	x
First return Vegetation Raster	1 meter	grid	quad	x
RTK point data		shape		x
Delivery Area shapefile		shape	quad	x
Report		pdf		x

Miscellaneous		Format	Tiling	
Processing bins		Shape dxf/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 headers have been scanned to ensure completeness and readability (Figure 3).

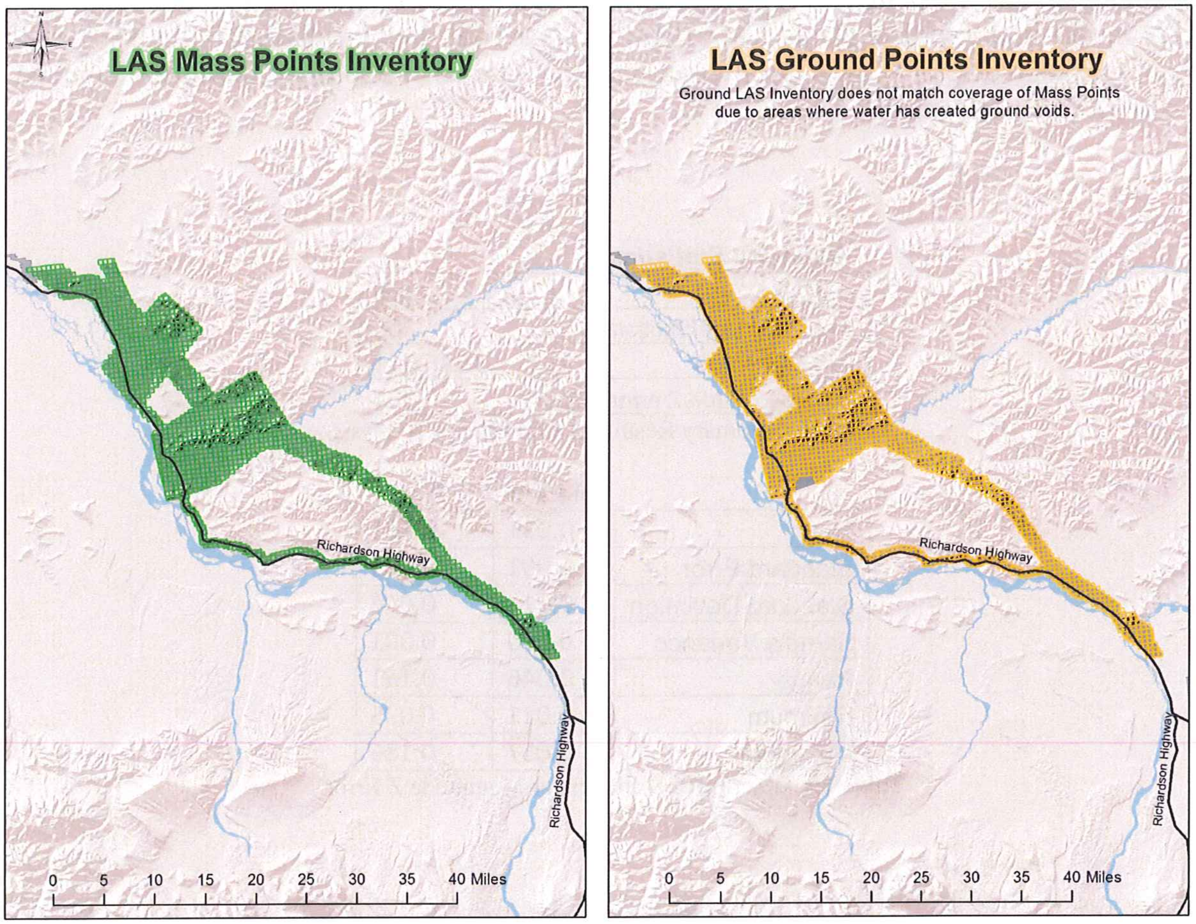

Figure 3. LIDAR Point Inventory graphic representing complete coverage of point data for both mass points and ground LAS files.

Consistency Analysis:

DGGS has specified that lidar consistency must average less than 0.15m (0.49 feet) in vertical offsets between adjacent 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 1505 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 3,745,911 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 306 flight lines were sampled and compared for consistency.

Summary Statistics

# of Tiles	1505
# of Flight Line Sections	306
Avg # of Points	3,745,911
Avg. Magnitude Z error (m)	0.031

Table 2a. Summary Results of Consistency Analysis

	meters	***feet***
Mean	0.031	0.101
Standard Error	0.001	0.003
Standard Deviation	0.013	0.044
Sample Variance	0.000	0.001
Range	0.046	0.151
Minimum	0.011	0.035
Maximum	0.057	0.186

Table 2b. Descriptive Statistics for Magnitude Z Error.

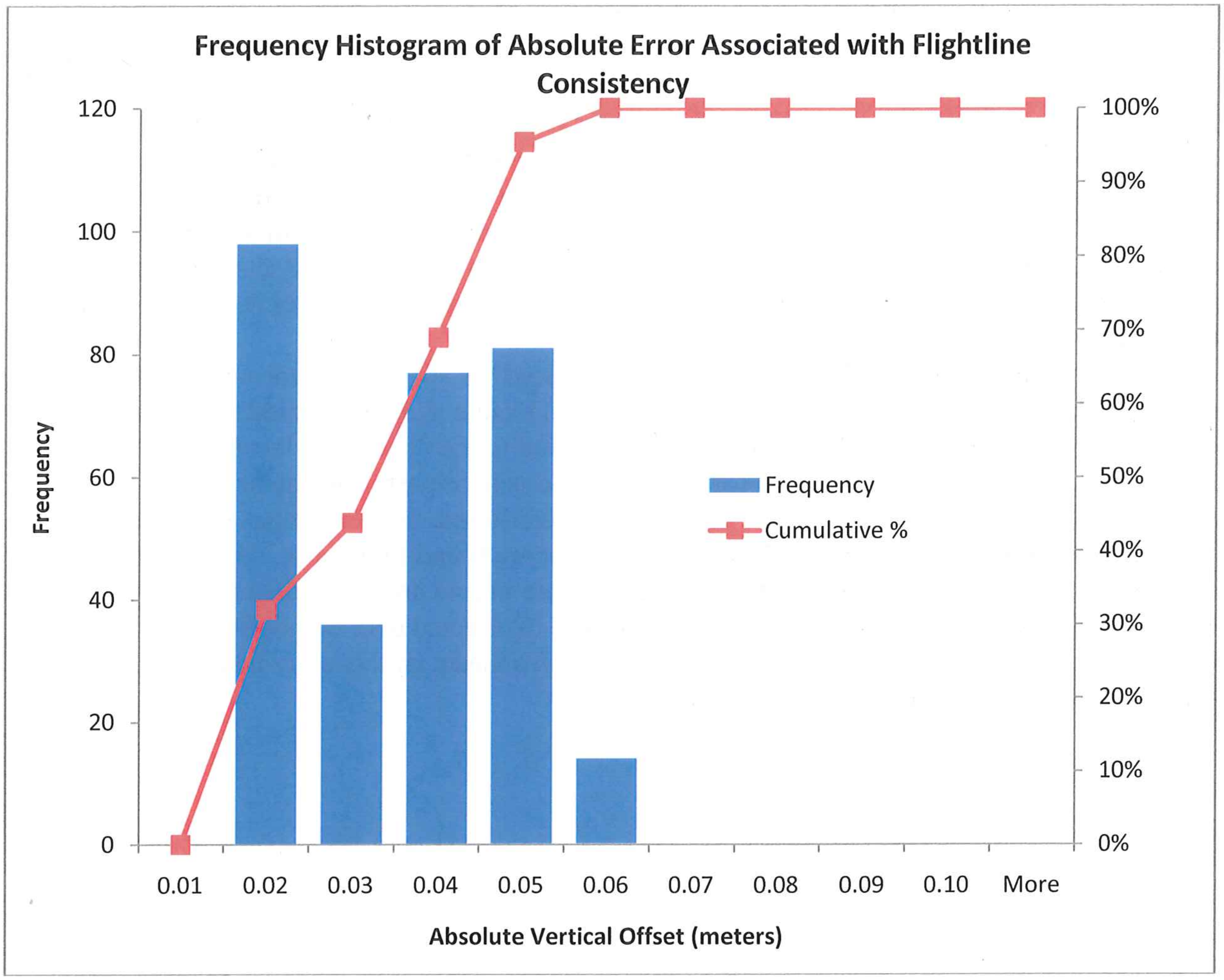

Figure 4. Histogram of flight line offsets values.

Results of the consistency analysis found the average flight line offset to be 0.031 meters with a maximum error of 0.057m (Table 2b). Distribution of error showed over 95% of all error was less than 0.05m and 99% was less than 0.06m (Figure 4). These results show that all data are within tolerances of data consistency according to contract agreement.

Visual Analysis

Lidar 1m 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 5). Both bare earth and highest hit models were examined for calibration offsets, tiling artifacts (Figure 6), seam line offsets, pits (Figure 6), 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 5). 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 7). 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.

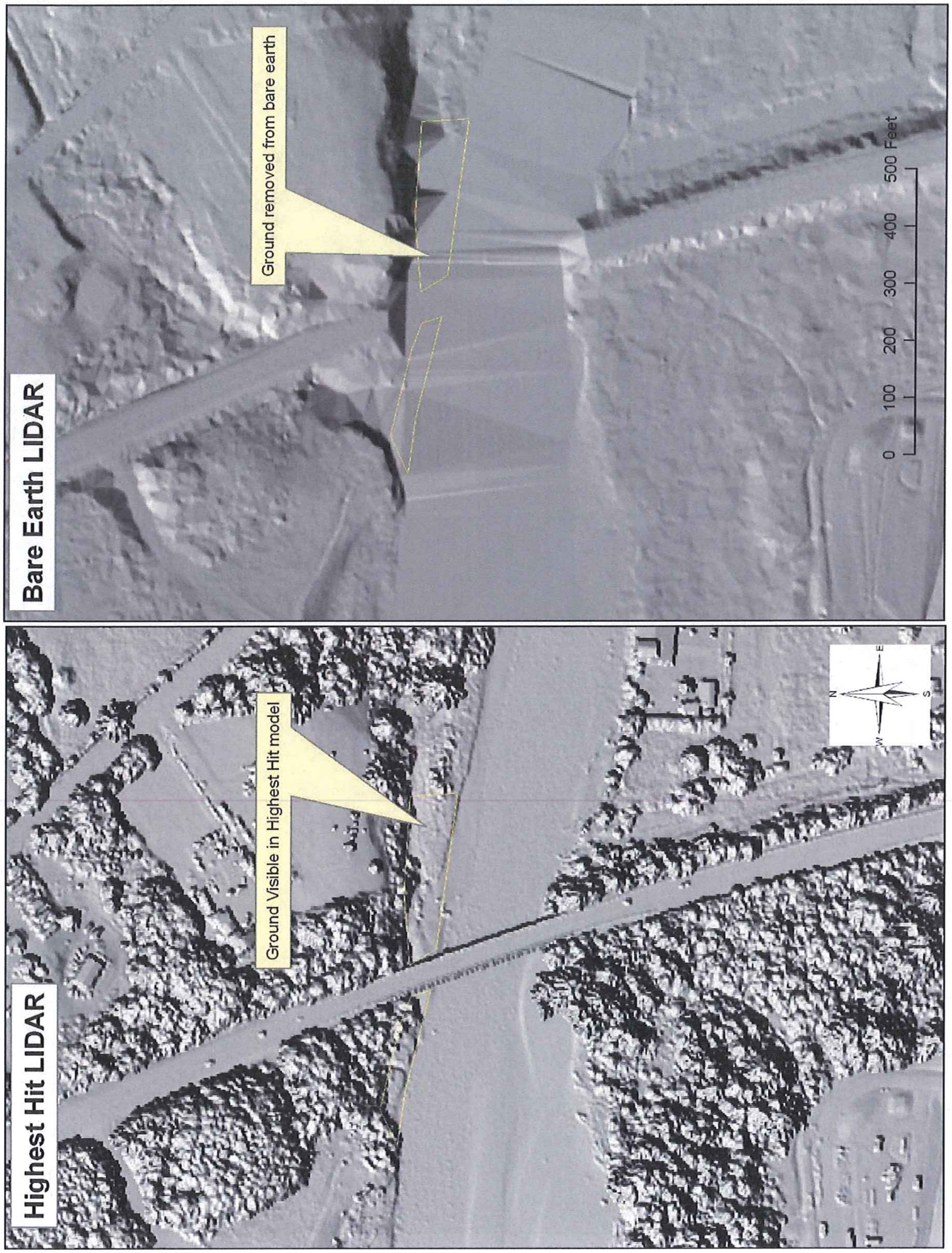

Figure 5. Example of missing ground in lidar bare earth data. Ground is clearly visible in highest hit model, but has been removed from the bare earth model. This type of classification error is common near water body features.

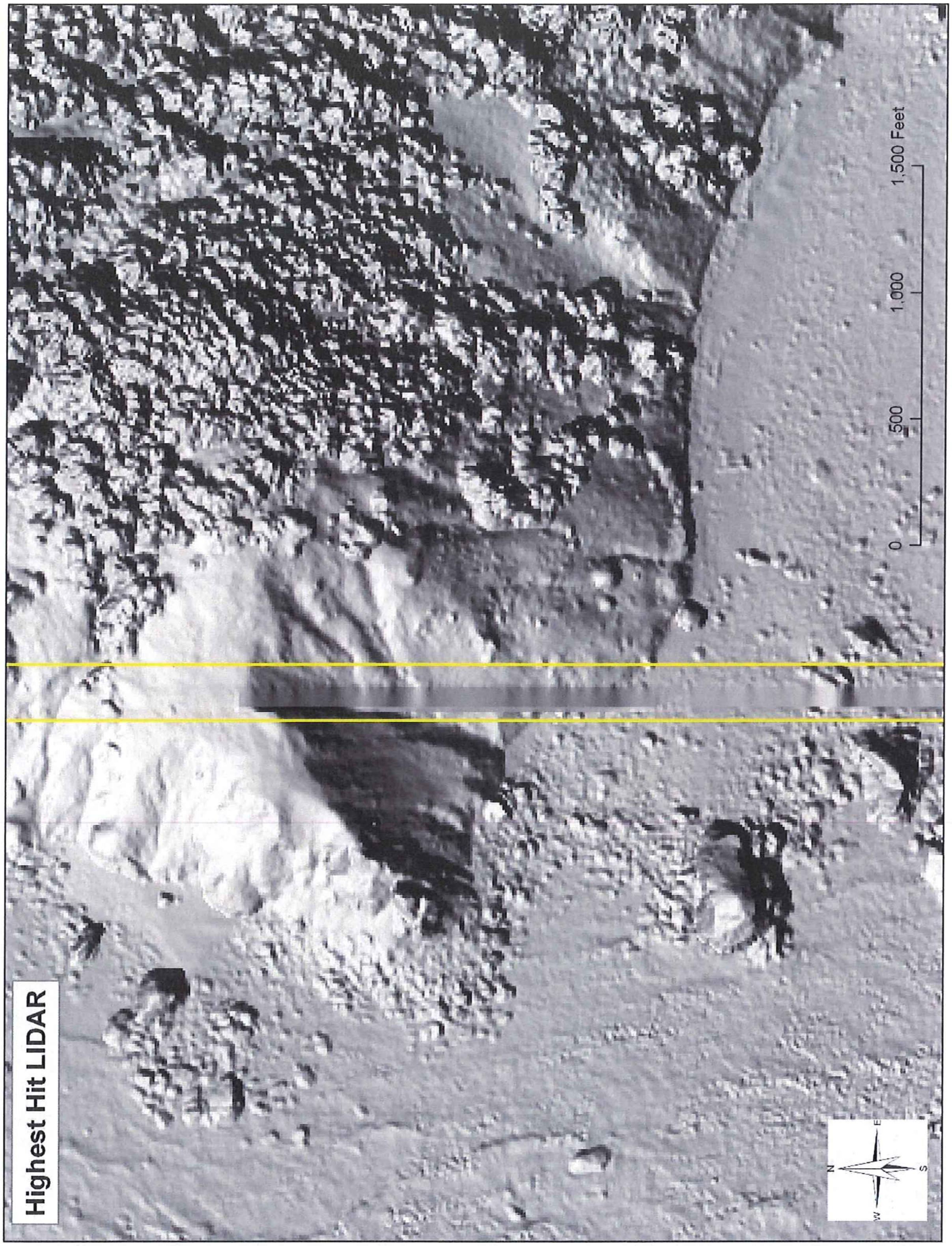

Figure 6. Example of tile artifact found in highest hit lidar data. Artifact is a seam line error created due to misclassification of ground at edge of lidar processing tiles.

Figure 7. 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. The contractor used a surveying system (Figure 8) to measure GCP's. GPS survey techniques allow surveyors to collect many precisely located GCP's which can be used as a control comparison with LiDAR elevations. 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). A licensed surveyor is often able to post process GPS survey data to accuracies less than 1cm in both horizontal and vertical axes.

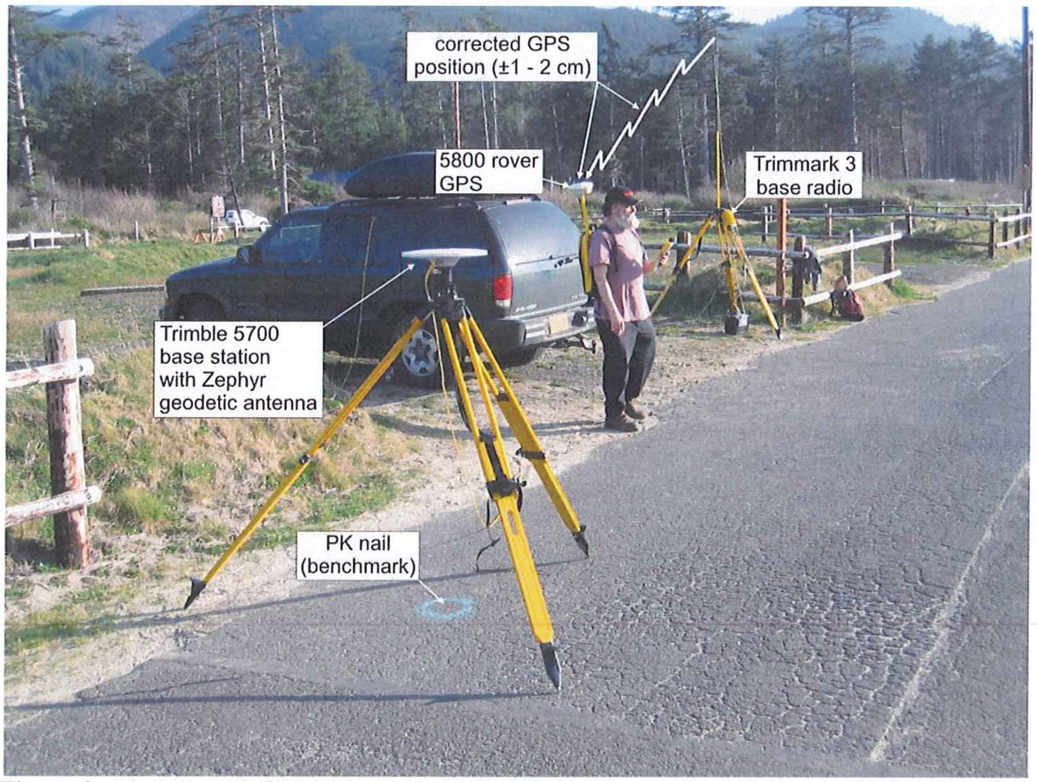

Figure 8. The Trimble 5700 base station antenna located over a known reference point at Cape Lookout State Park. Corrected GPS position and elevation information is then transmitted by a Trimmark III base radio to the 5800 GPS rover unit.

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 values for the entire delivered data set. Project specifications list the maximum acceptable root mean square vertical offset to be 0.20 meters (0.65 feet).

A total of 1663 measured GCP's were provided to DOGAMI by DGGS for the Delivery 4 region (Figure 9) and compared with the lidar elevation grids. The data delivered to DOGAMI was found to have a mean vertical offset of -0.014 meters (-0.047 feet) and an RMSE value of 0.041 meters (0.133 ft). Offset values ranged from -0.113 to 0.135 meters (Table 3 and Figure 10).

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.

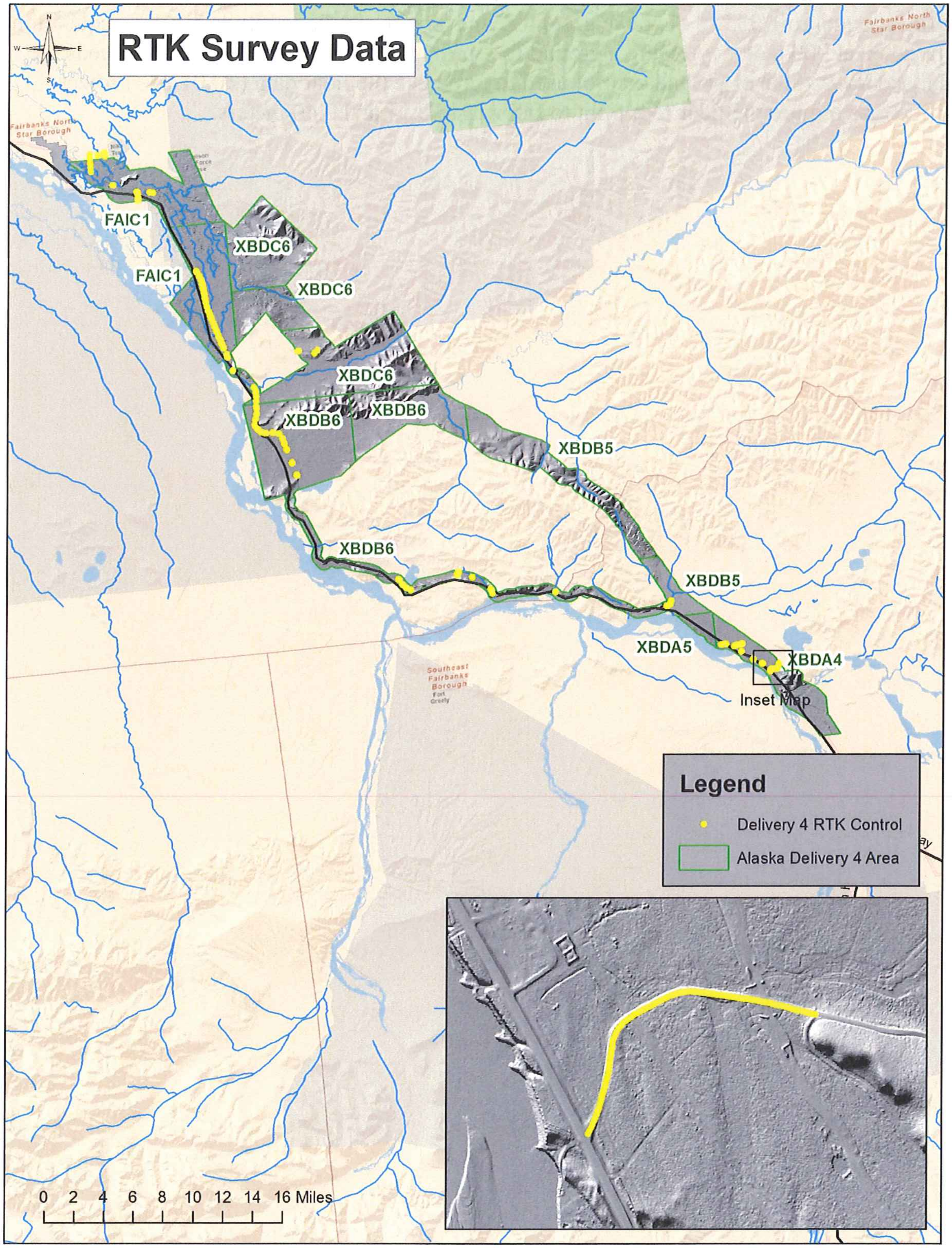

Figure 9. Locations of RTK control surveyed by Contractor. Data was used to test absolute accuracy for the Alaska DNR lidar survey within the Delivery 4 extent.

	Meters	*Feet*
Mean	-0.003	-0.011
Standard Error	0.001	0.003
Standard Deviation	0.040	0.133
Range	0.248	0.814
Minimum	-0.113	-0.371
Maximum	0.135	0.443
RMSE	0.041	0.133

Table 3. Descriptive Statistics for absolute value vertical offsets.

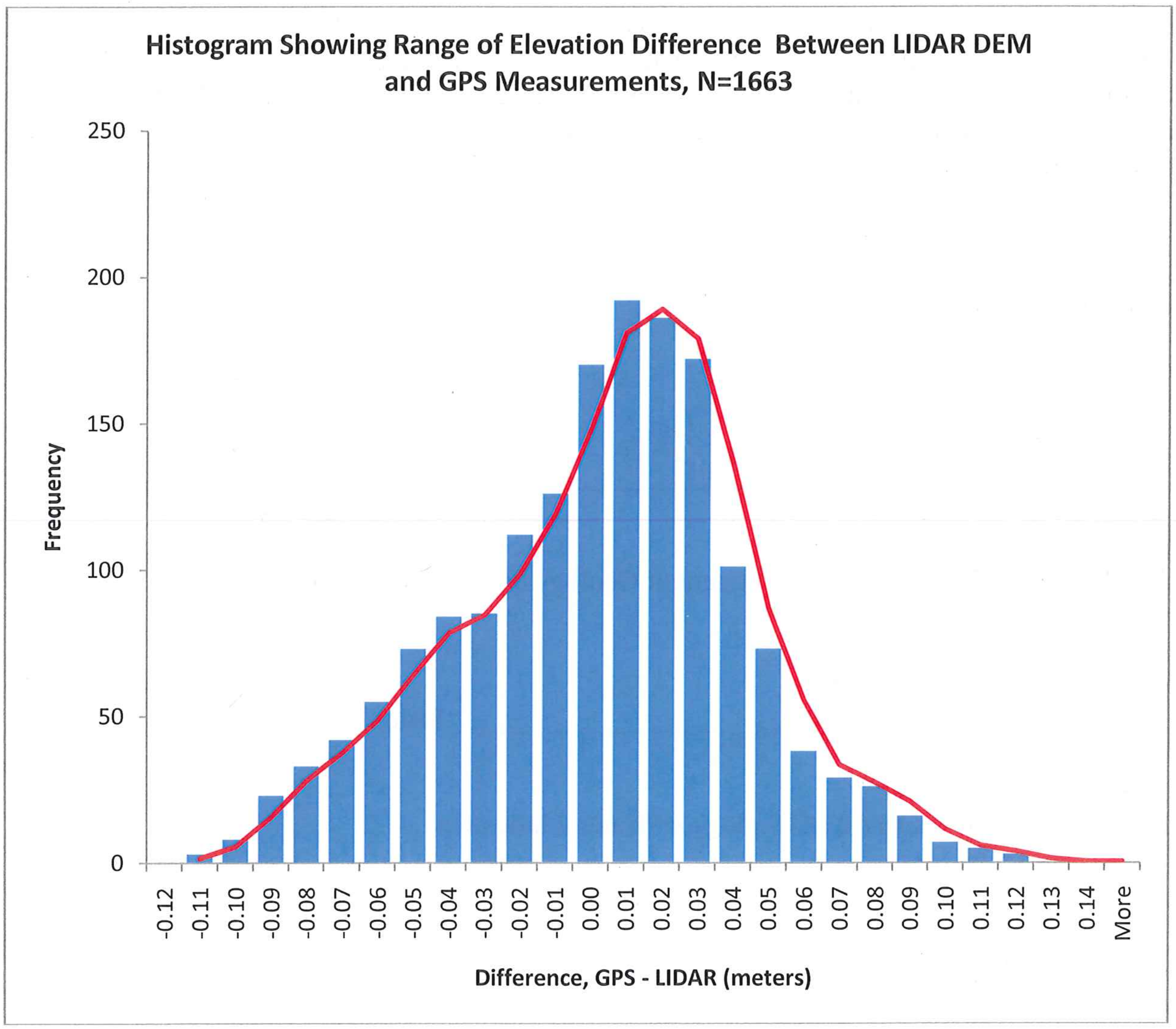

Figure 10. Histogram of elevation difference between Lidar DEM and GPS survey data.

Acceptance

The data described in this report meets or exceeds project specifications laid out in the contracted data standards agreement. All the required files for the delivery have been received as of August 15th, 2011, and are correctly named and useable. 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 quality control 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 Signature

____________________ Date: 8/15/2011

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

____________________ Date: 8/15/2011

Ian Madin
Chief Scientist – Department of Geology & Mineral Industries

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

Alaska DNR LIDAR Project, 2011 – Delivery 5 QC Analysis

LIDAR QC Report – September 26th, 2011

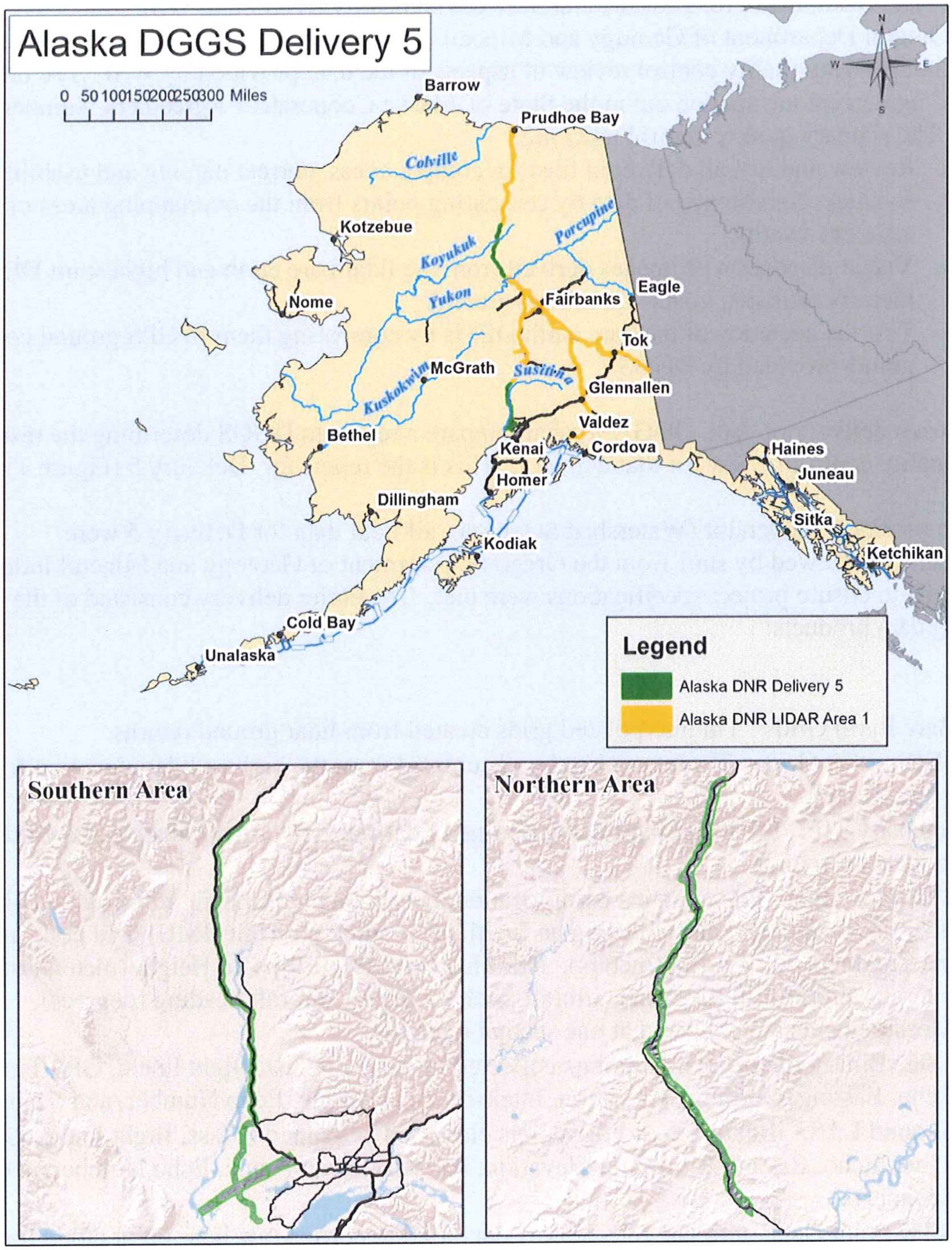

Figure 1. Map featuring Alaska DNR Delivery 5 data extent.

The Alaska Department of Natural Resources, Division of Geological and Geophysical Survey (DGGS) has contracted with Watershed Sciences, Inc (WSI) to collect high resolution lidar topographic data for a swath roughly parallel to proposed future pipeline rights of way. DGGS has specified the exact areas of data collection as well as a detailed description of data products to be delivered. The complete specifications are detailed in the September 14, 2010 Standard Agreement Form for Professional Services signed by DGGS and WSI.

The Oregon Department of Geology and Mineral Industries has contracted with DGGS to provide independent quality control review of aspects of the data provided by WSI. The details of the QC agreement are spelled out in the State of Alaska Cooperative Agreement Number MI-11-006. The primary quality control tasks are:

1. Review and test all delivered files for completeness, correct naming and usability.
2. Evaluate consistency of data by comparing points from the overlapping areas of adjacent swaths.
3. Visual inspection of images derived from the lidar bare earth and highest hit DEMs to identify artifacts, voids and missed ground.
4. Test the accuracy of the bare earth DEMs by comparing them to GPS ground control points provided by DGGS.

For each delivery of data, DOGAMI shall prepare a report to DGGS describing the results of the quality control review for that delivery. This is the report for Delivery 5 (Figure 1).

Upon receipt from vendor (Watershed Sciences), all lidar data for Delivery 5 were independently reviewed by staff from the Oregon Department of Geology and Mineral Industries (DOGAMI) to ensure project specifications were met. The entire delivery consisted of the following data products:

- 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.
- 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 Universal Transverse Mercator (Zones 6), NAD83 CORS96 meters.

Data Completeness

Data for Alaska DNR Delivery 5 area were collected between May 17th and June 16th, 2011. Total area of delivered data totals 386.25 square miles. Delivery 5 (Figure 2a and 2b) includes data in the format of grids, trajectory files, intensity images, Lidar ASCII Standard (LAS) point files, 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 1 meter cell size. Lidar point data are delivered in LAS binary format for ground classified returns as well as the entire lidar point cloud. Georeferenced intensity images of 1 meter cell size are supplied in geoTIF format. Supplementary data include 1 meter cell size vegetation rasters displaying canopy and other vegetation metrics. Real time kinematic ground survey data (used for absolute vertical adjustment) are supplied in shapefile format. This delivery contains data for the following USGS 7.5 minute quads (listed by quadrangle tile name within the boundary of the Alaska DNR Survey collection area (Figure 2):

Delivery 5 Quadrangles: ANCC8, BETA1, BETB1, BETB2, BETC2, BETD1, BETD2, TALA1, TALB1, TALC1, TALD1, TAND1, TYOB1, TYOB2, TYOC1, TYOC2, TYOD1, WISA1, WISB1.

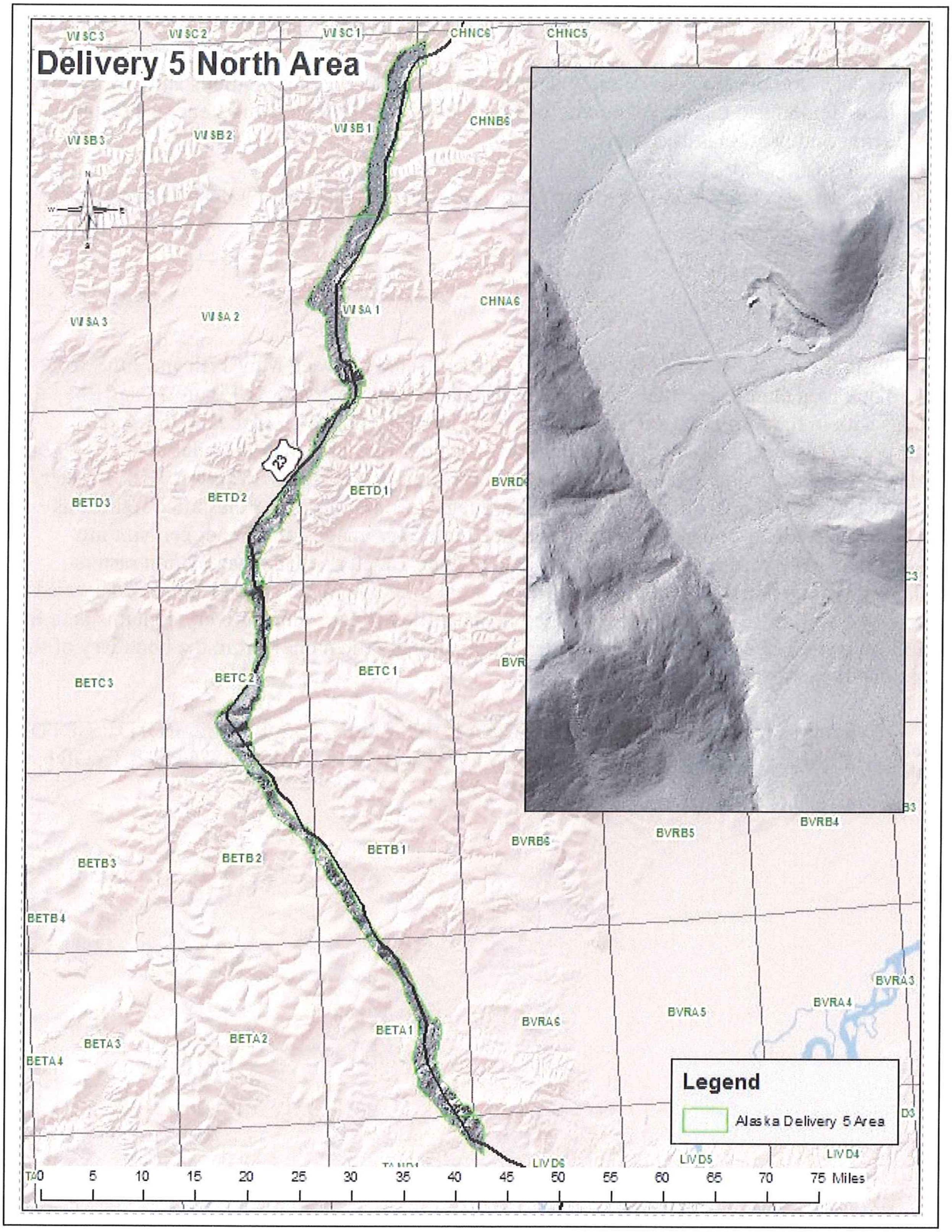

Figure 2a. Delivery 5 North Section location area. Data is referenced to USGS 7.5 minute quadrangles within the extents of the Alaska DNR Survey collection area.

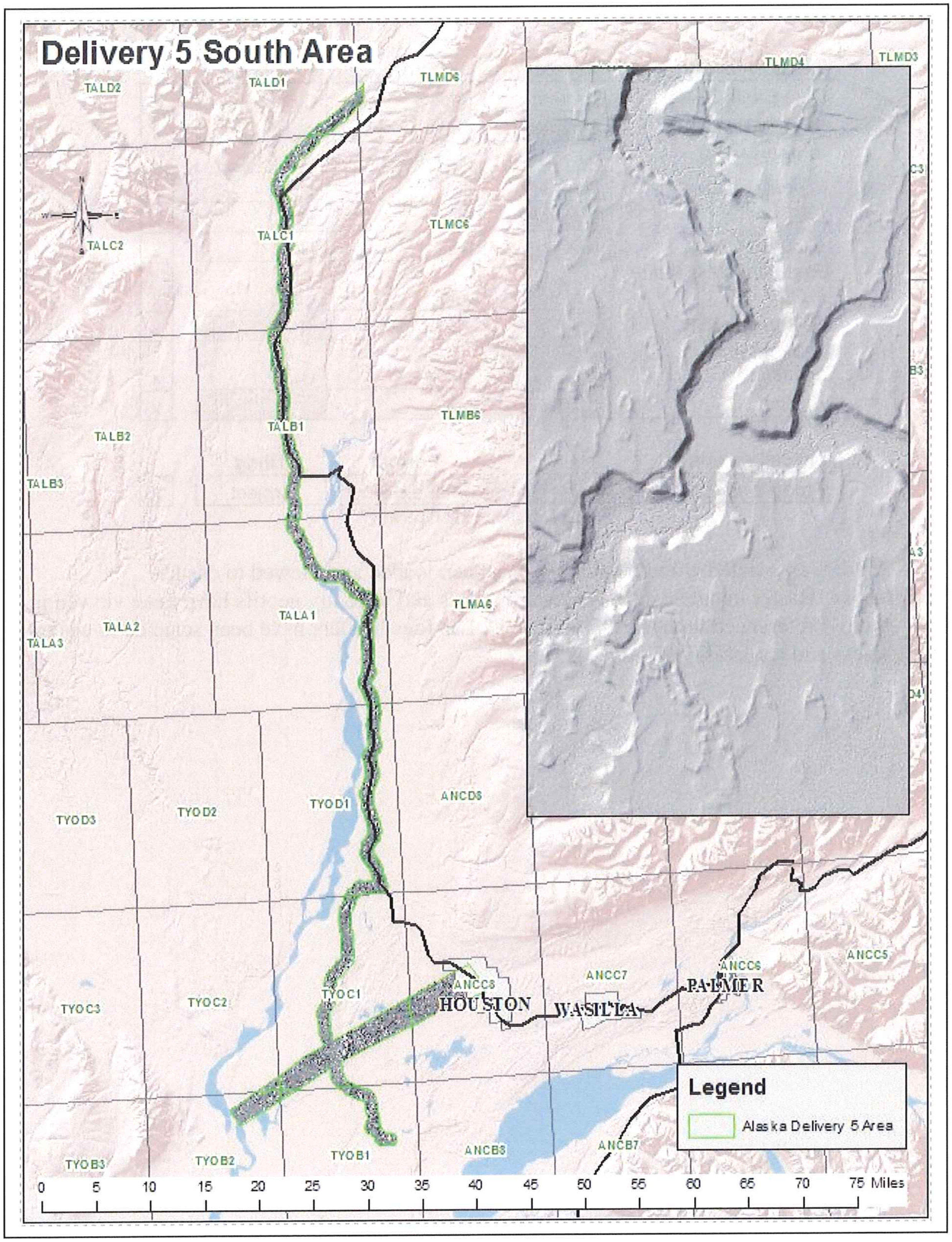

Figure 2b. Delivery 5 South Section location area. Data is referenced to USGS 7.5 minute quadrangles within the extents of the Alaska DNR Survey collection area.

FINAL Delivery	Resolution	Format	Tiling	
Bare Earth DEMs	1 meter	grid	quad	x
Highest Hit DEMs	1 meter	grid	quad	x
Trajectory files	1 sec	sbet /shape	flight	x
Intensity Images	1 meter?	tif	quad	x
LAS	8pts/m^2	las	tiled	x
Ground Returns	N/A	las	tiled	x
First return Vegetation Raster	1 meter	grid	quad	x
RTK point data		shape		x
Delivery Area shapefile		shape	quad	x
Report		pdf		x

Miscellaneous		Format	Tiling	
Processing bins		Shape dxf/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 headers have been scanned to ensure completeness and readability (Figure 3).

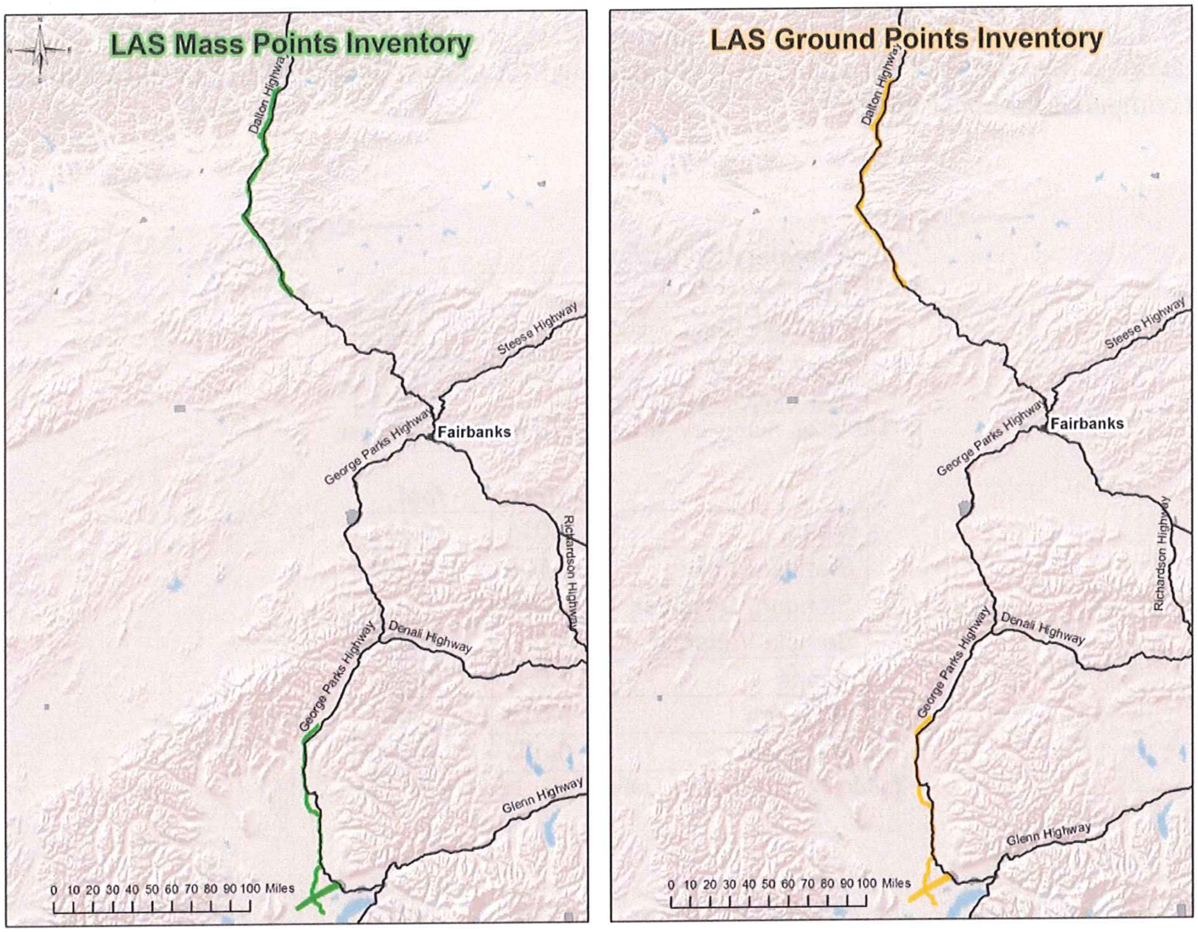

Figure 3. LIDAR Point Inventory graphic representing complete coverage of point data for both mass points and ground LAS files.

Consistency Analysis:

DGGS has specified that lidar consistency must average less than 0.15m (0.49 feet) in vertical offsets between adjacent 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 2430 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 6,598,466 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 494 flight lines were sampled and compared for consistency.

Summary Statistics

# of Tiles	2430
# of Flight Line Sections	494
Avg # of Points	6,598,466
Avg. Magnitude Z error (m)	0.034

Table 2a. Summary Results of Consistency Analysis

	meters	***feet***
Mean	0.034	0.111
Standard Error	0.000	0.001
Standard Deviation	0.008	0.025
Sample Variance	0.000	0.000
Range	0.058	0.189
Minimum	0.019	0.061
Maximum	0.076	0.250

Table 2b. Descriptive Statistics for Magnitude Z Error.

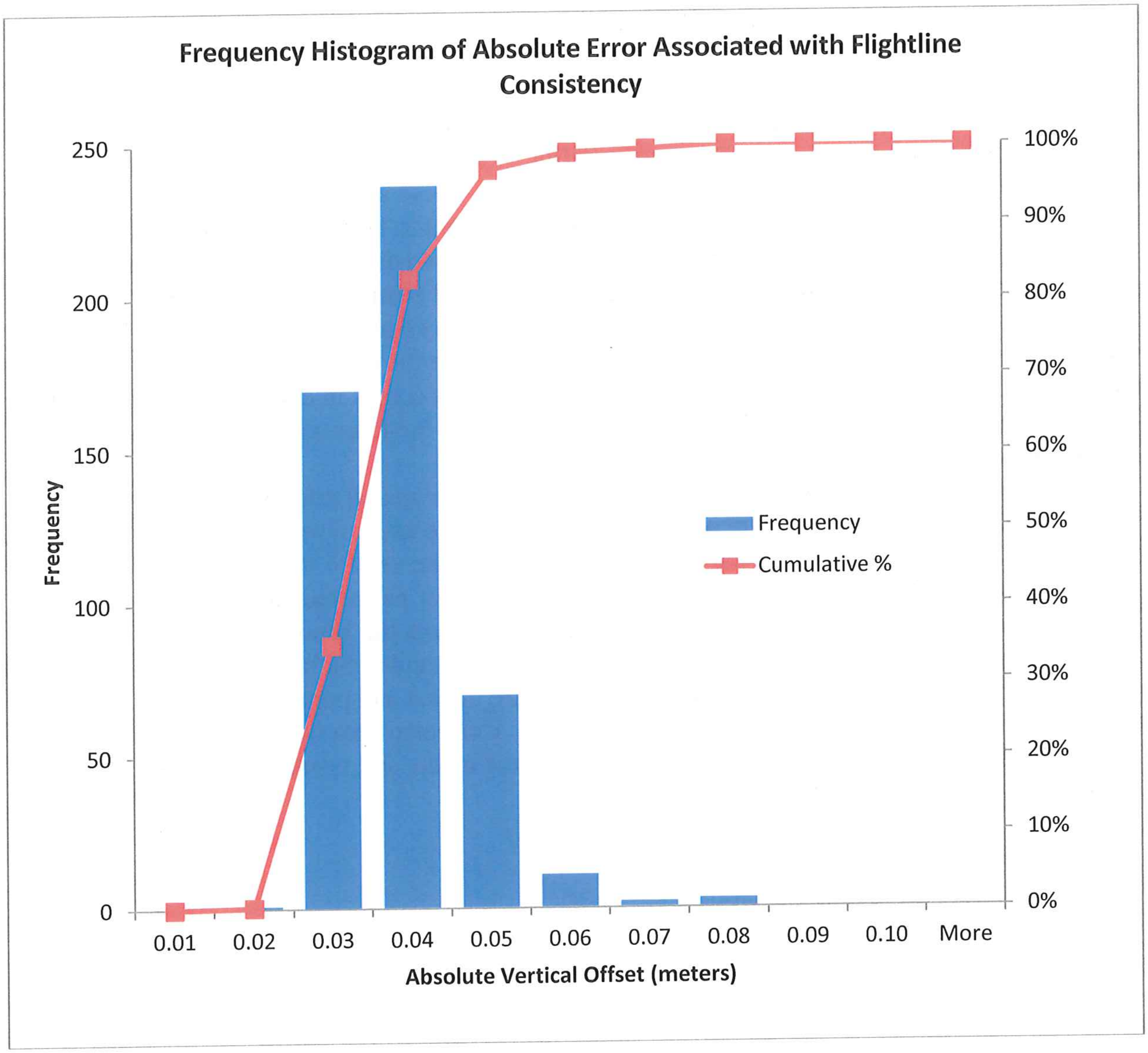

Figure 4. Histogram of flight line offsets values.

Results of the consistency analysis found the average flight line offset to be 0.031 meters with a maximum error of 0.057m (Table 2b). Distribution of error showed over 95% of all error was less than 0.05m and 99% was less than 0.06m (Figure 4). These results show that all data are within tolerances of data consistency according to contract agreement.

Visual Analysis

Lidar 1m 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 5). Both bare earth and highest hit

models were examined for calibration offsets, tiling artifacts (Figure 6), seam line offsets, pits (Figure 6), 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 5). 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 7). Birds (high points) typically occur where the laser comes into contact with atmospherics[1].

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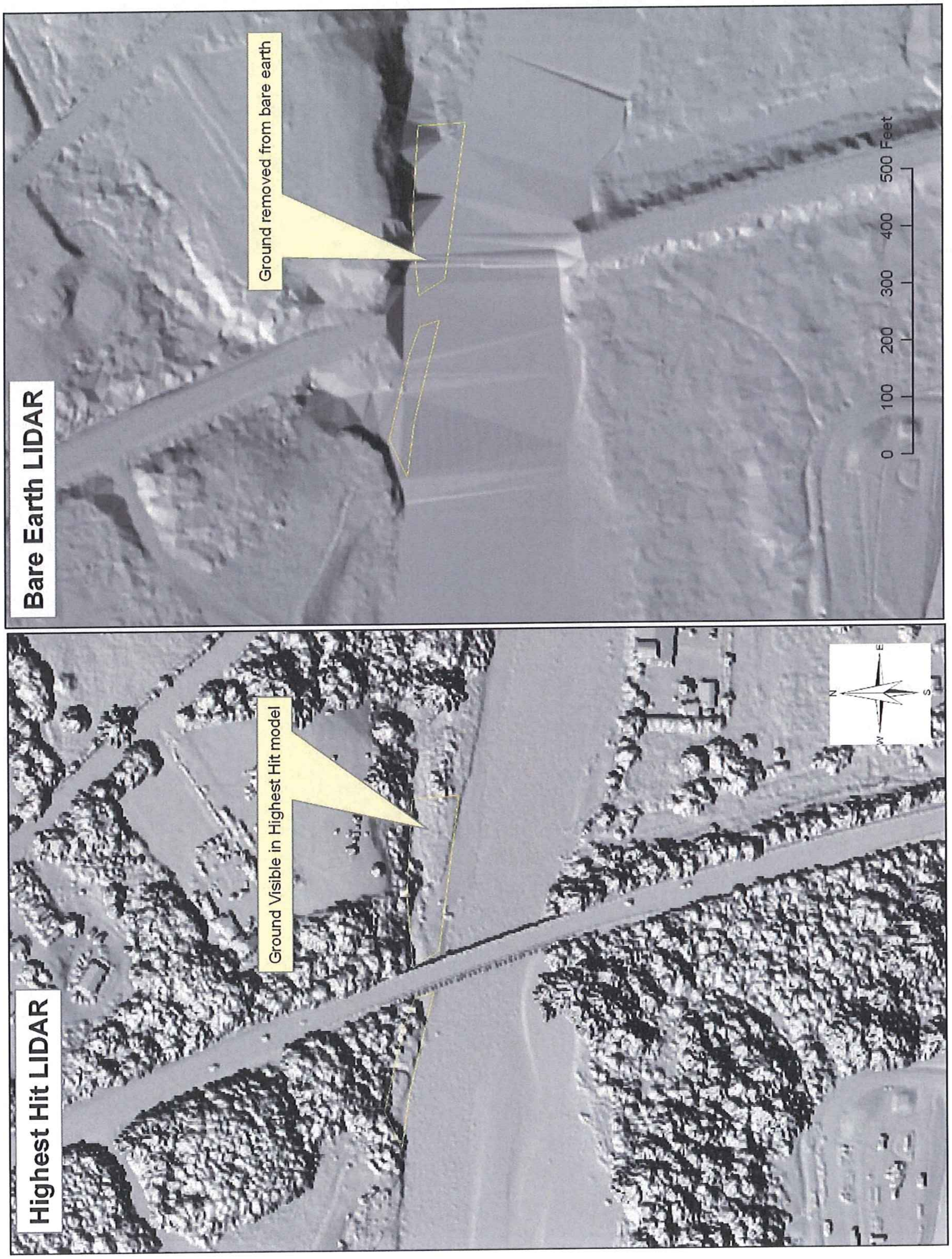

Figure 5. Example of missing ground in lidar bare earth data. Ground is clearly visible in highest hit model, but has been removed from the bare earth model. This type of classification error is common near water body features.

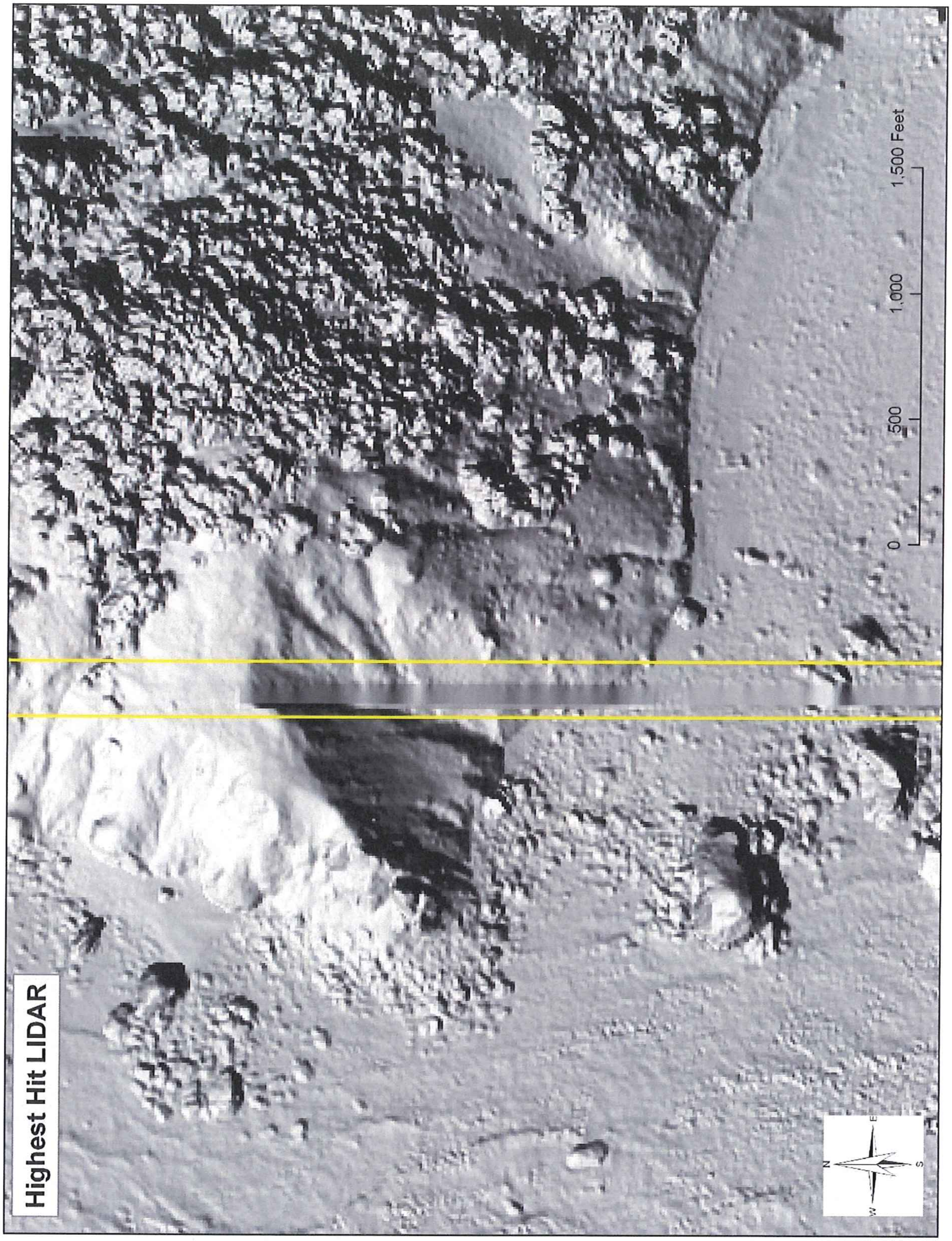

Figure 6. Example of tile artifact found in highest hit lidar data. Artifact is a seam line error created due to misclassification of ground at edge of lidar processing tiles.

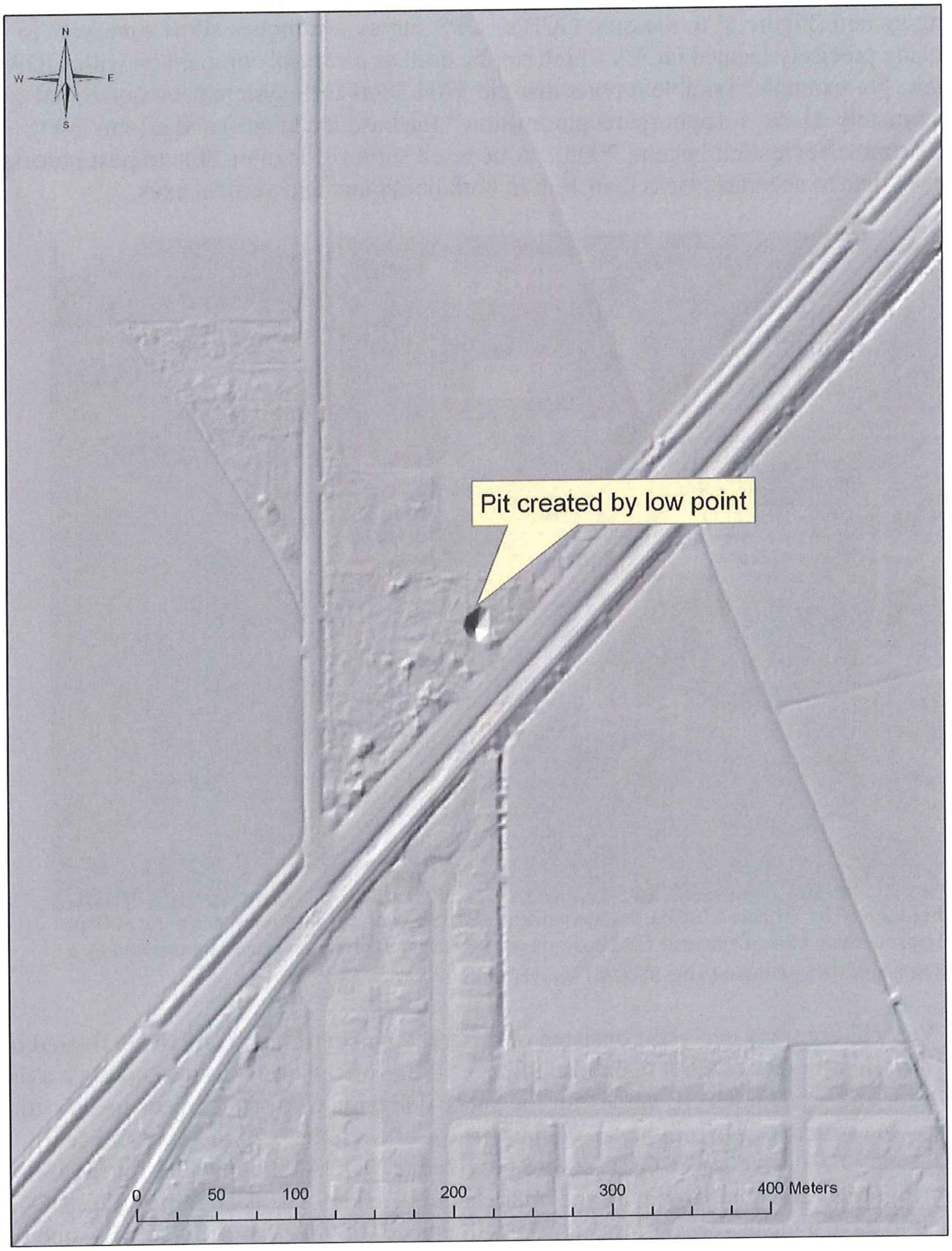

Figure 7. Example of "Pit" caused by low point in ground model. Pits are caused when standing water absorbs the lidar pulse. Pits are evident in ground model as the lowest point elevation is assigned to the grid cell value. Inversely the pit is not observable in the highest hit model as the highest point elevation is assigned to the grid value

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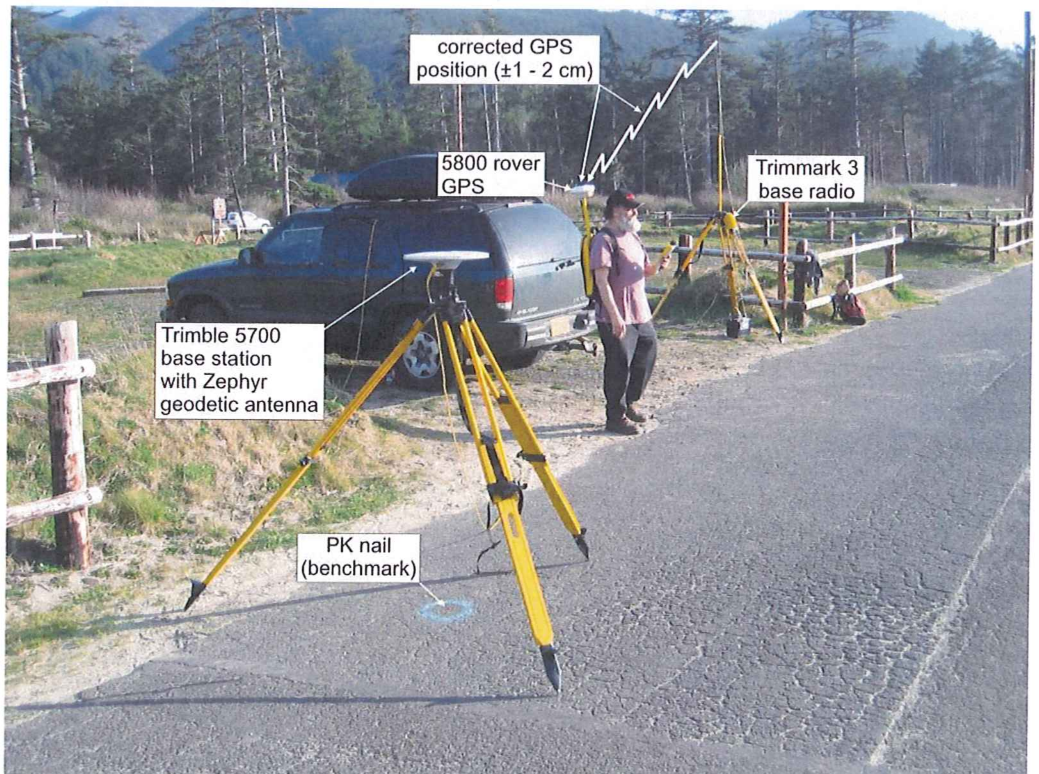

Figure 8. The Trimble 5700 base station antenna located over a known reference point at Cape Lookout State Park. Corrected GPS position and elevation information is then transmitted by a Trimmark III base radio to the 5800 GPS rover unit.

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 values for the entire delivered data set. Project specifications list the maximum acceptable root mean square vertical offset to be 0.20 meters (0.65 feet).

A total of 3815 measured GCP's were provided to DOGAMI by DGGS for the Delivery 5 region (Figure 9) and compared with the lidar elevation grids. The data delivered to DOGAMI was found to have a mean vertical offset of 0.018 meters (0.059 feet) and an RMSE value of 0.037 meters (0.122 ft). Offset values ranged from -0.103 to 0.167 meters (Table 3 and Figure 10).

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.

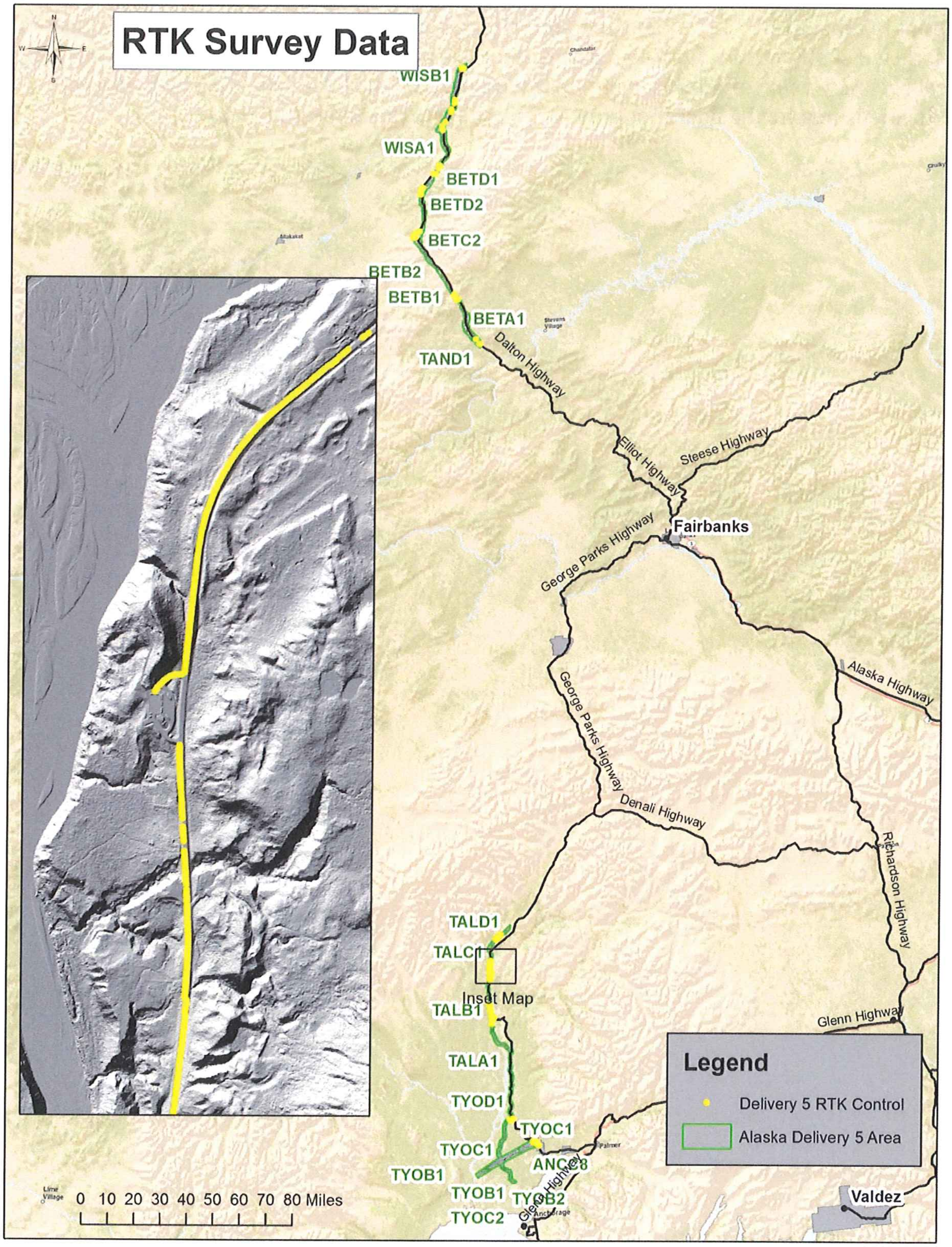

Figure 9. Locations of RTK control surveyed by Contractor. Data was used to test absolute accuracy for the Alaska DNR lidar survey within the Delivery 5 extent.

	Meters	*Feet*
Mean	0.018	0.059
Standard Error	0.001	0.002
Standard Deviation	0.033	0.107
Range	0.270	0.886
Minimum	-0.103	-0.338
Maximum	0.167	0.548
RMSE	0.037	0.122

Table 3. Descriptive Statistics for absolute value vertical offsets.

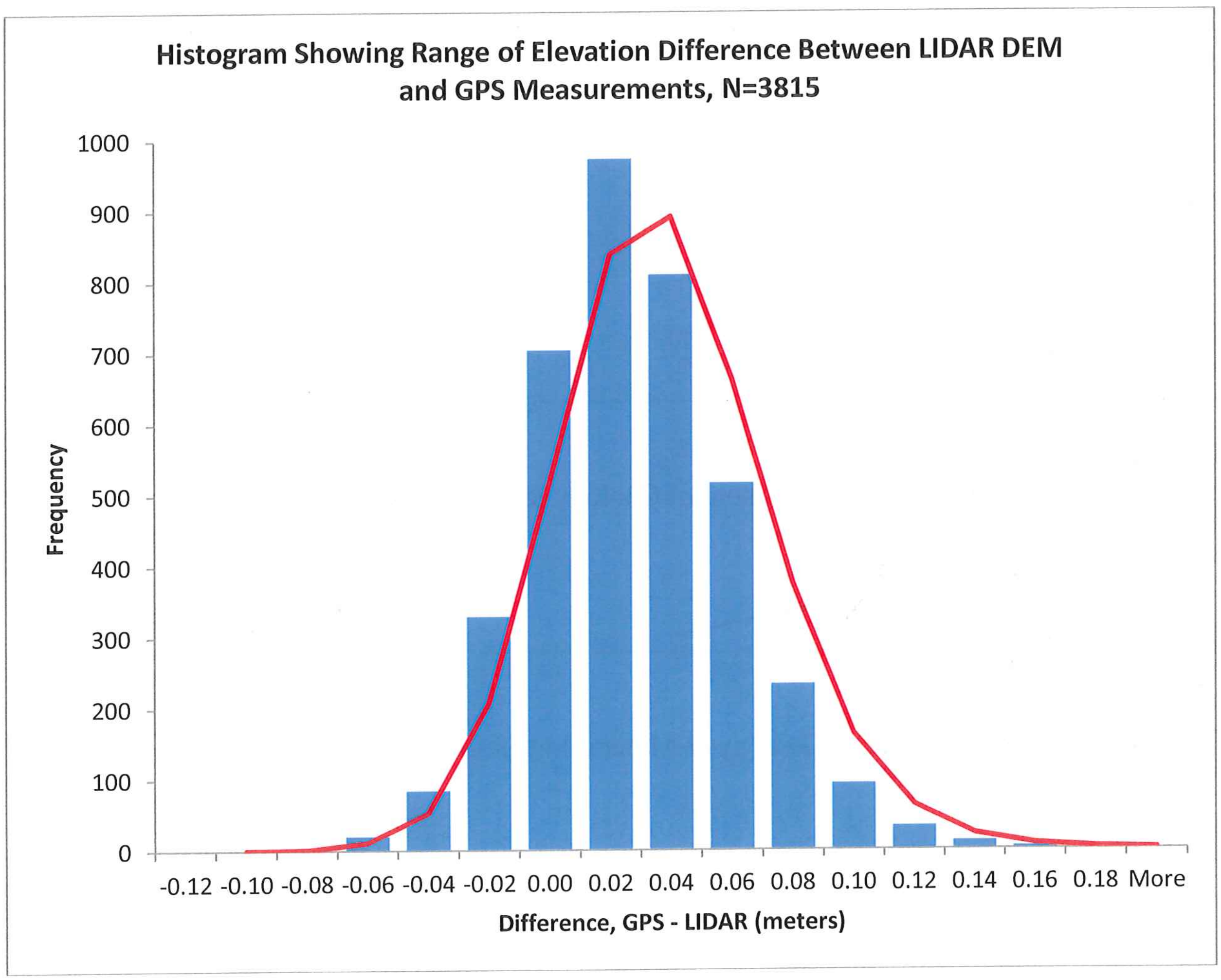

Figure 10. Histogram of elevation difference between Lidar DEM and GPS survey data.

Acceptance

The data described in this report meets or exceeds project specifications laid out in the contracted data standards agreement. All the required files for the delivery have been received as of September 26th, 2011, and are correctly named and useable. 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 quality control 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 Signature

____________________ Date: 9/26/2011

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

____________________ Date: 9/26/2011

Ian Madin
Chief Scientist – Department of Geology & Mineral Industries

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

Alaska DNR LIDAR Project, 2011 – Delivery 6 QC Analysis

LIDAR QC Report – October 21st, 2011

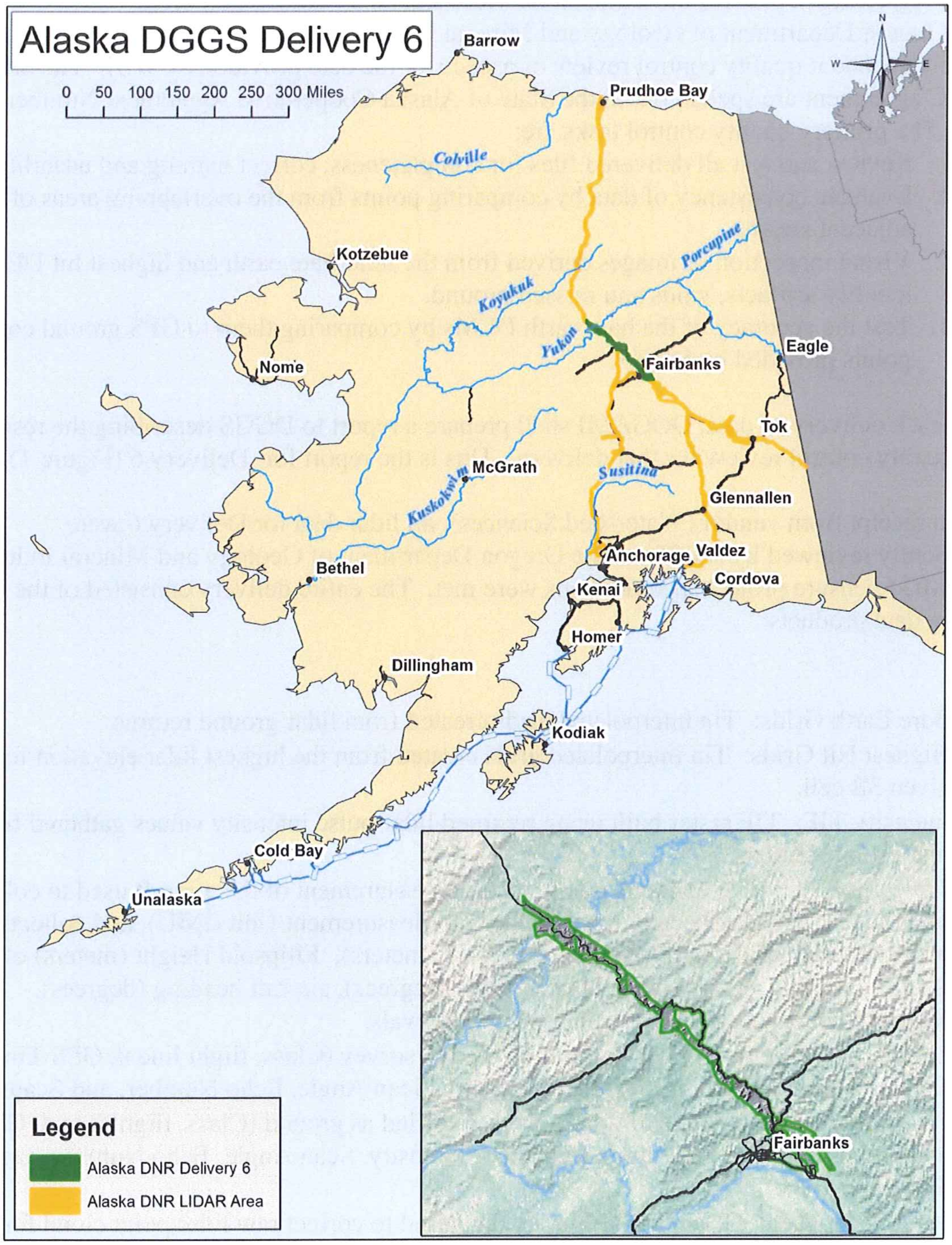

Figure 1. Map featuring Alaska DNR Delivery 6 data extent.

The Alaska Department of Natural Resources, Division of Geological and Geophysical Survey (DGGS) has contracted with Watershed Sciences, Inc (WSI) to collect high resolution lidar topographic data for a swath roughly parallel to proposed future pipeline rights of way. DGGS has specified the exact areas of data collection as well as a detailed description of data products to be delivered. The complete specifications are detailed in the September 14, 2010 Standard Agreement Form for Professional Services signed by DGGS and WSI.

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2. Evaluate consistency of data by comparing points from the overlapping areas of adjacent swaths.
3. Visual inspection of images derived from the lidar bare earth and highest hit DEMs to identify artifacts, voids and missed ground.
4. Test the accuracy of the bare earth DEMs by comparing them to GPS ground control points provided by DGGS.

For each delivery of data, DOGAMI shall prepare a report to DGGS describing the results of the quality control review for that delivery. This is the report for Delivery 6 (Figure 1).

Upon receipt from vendor (Watershed Sciences), all lidar data for Delivery 6 were independently reviewed by staff from the Oregon Department of Geology and Mineral Industries (DOGAMI) to ensure project specifications were met. The entire delivery consisted of the following data products:

- 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.
- 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 Universal Transverse Mercator (Zones 6), NAD83 CORS96 meters.

Data Completeness

Data for Alaska DNR Delivery 6 area were collected between May22nd and May 31st, 2011. Total area of delivered data totals 483.15 square miles. Delivery 6 (Figure 2) includes data in the format of grids, trajectory files, intensity images, Lidar ASCII Standard (LAS) point files, 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 1 meter cell size. Lidar point data are delivered in LAS binary format for ground classified returns as well as the entire lidar point cloud. Georeferenced intensity images of 1 meter cell size are supplied in geoTIF format. Supplementary data include 1 meter cell size vegetation rasters displaying canopy and other vegetation metrics. Real time kinematic ground survey data (used for absolute vertical adjustment) are supplied in shapefile format. This delivery contains data for the following USGS 7.5 minute quads (listed by quadrangle tile name within the boundary of the Alaska DNR Survey collection area (Figure 2):

Delivery 6 Quadrangles: FAID1, LIVA2, LIVA3, LIVB3, LIVB4, LIVC4, LIVC5, LIVD5, LIVD6.

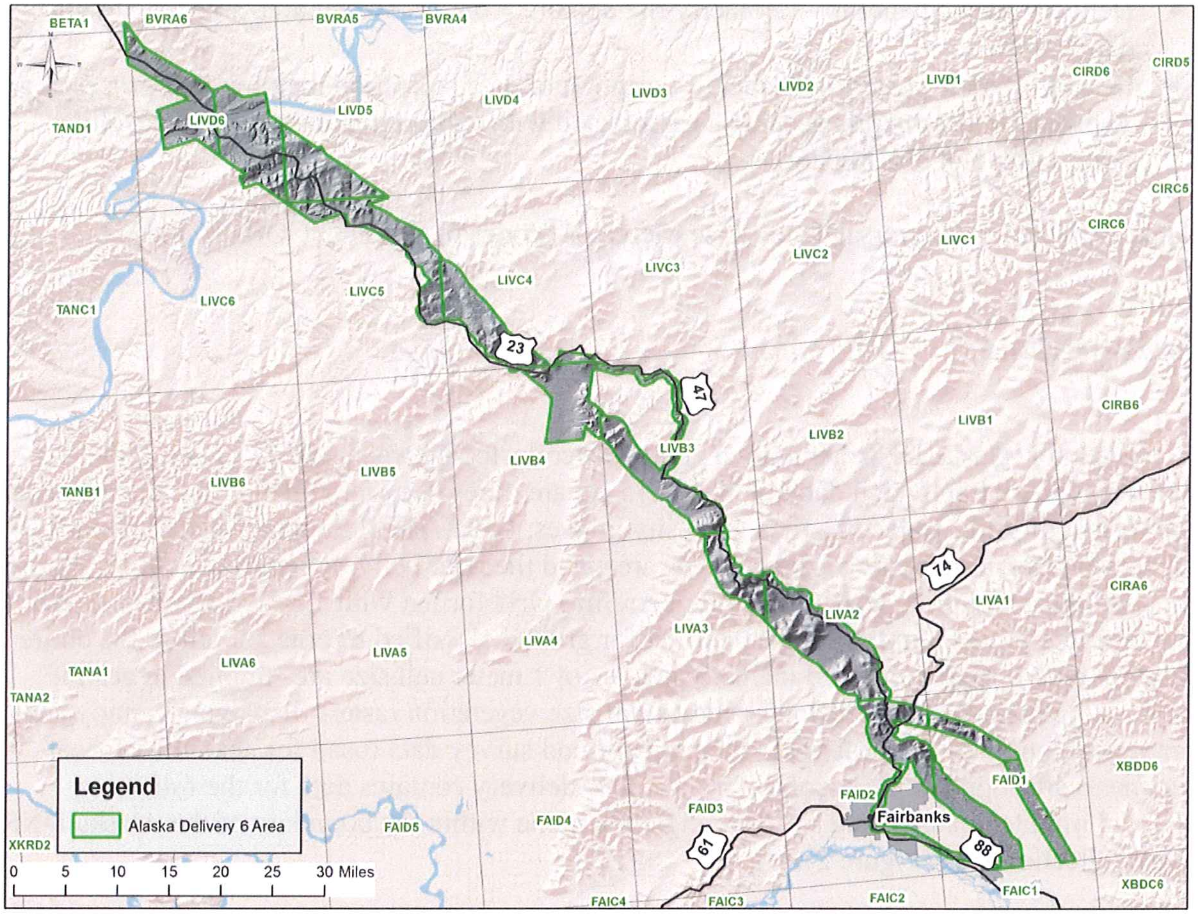


Figure 2. Delivery 6 location area. Data is referenced to USGS 7.5 minute quadrangles within the extents of the Alaska DNR Survey collection area

FINAL Delivery	Resolution	Format	Tiling	
Bare Earth DEMs	1 meter	grid	quad	x
Highest Hit DEMs	1 meter	grid	quad	x
Trajectory files	1 sec	sbet /shape	flight	x
Intensity Images	1 meter?	tif	quad	x
LAS	8pts/m^2	las	tiled	x
Ground Returns	N/A	las	tiled	x
First return Vegetation Raster	1 meter	grid	quad	x
RTK point data		shape		x
Delivery Area shapefile		shape	quad	x
Report		pdf		x

Miscellaneous		Format	Tiling	
Processing bins		Shape dxf/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 headers have been scanned to ensure completeness and readability (Figure 3).

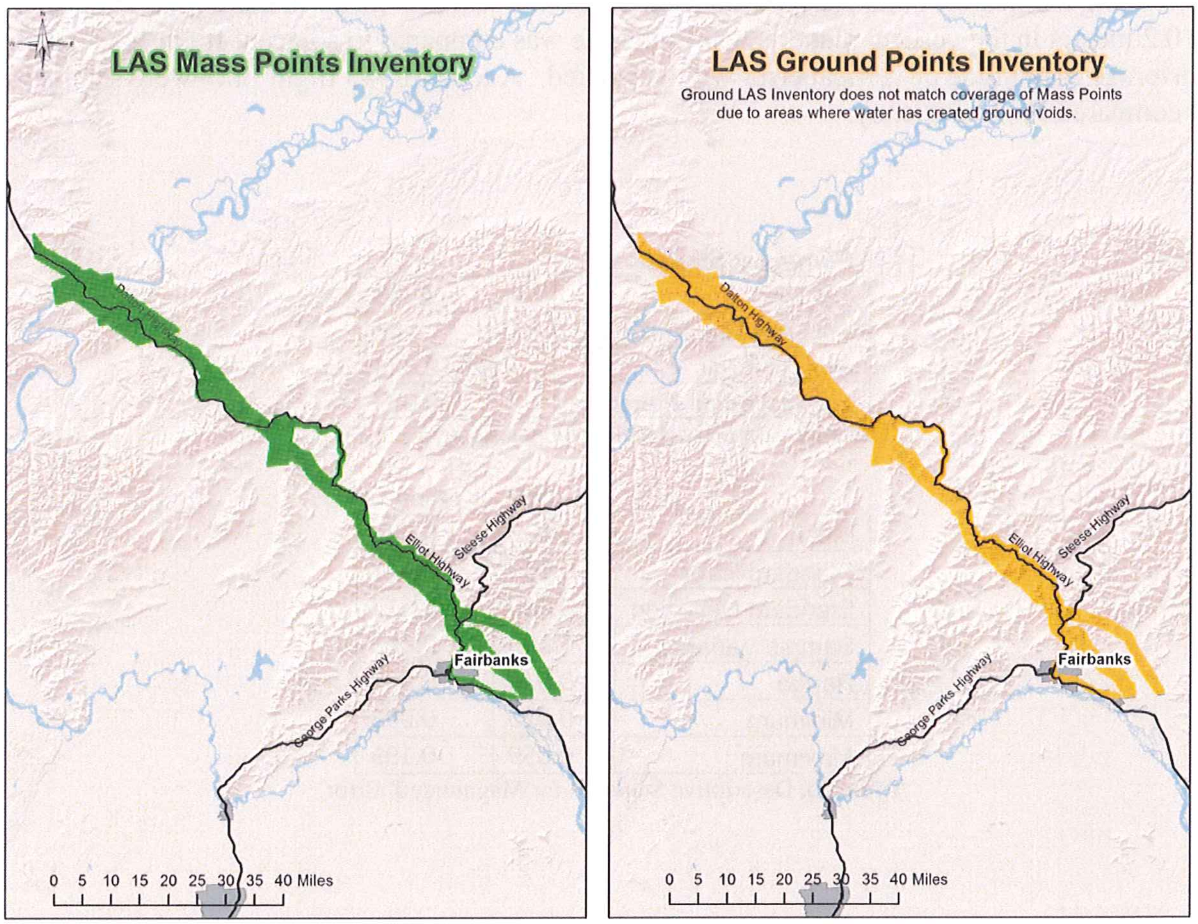


Figure 3. LIDAR Point Inventory graphic representing complete coverage of point data for both mass points and ground LAS files.

Consistency Analysis:

DGGS has specified that lidar consistency must average less than 0.15m (0.49 feet) in vertical offsets between adjacent 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 2698 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 14,972,324 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 445 flight lines were sampled and compared for consistency.

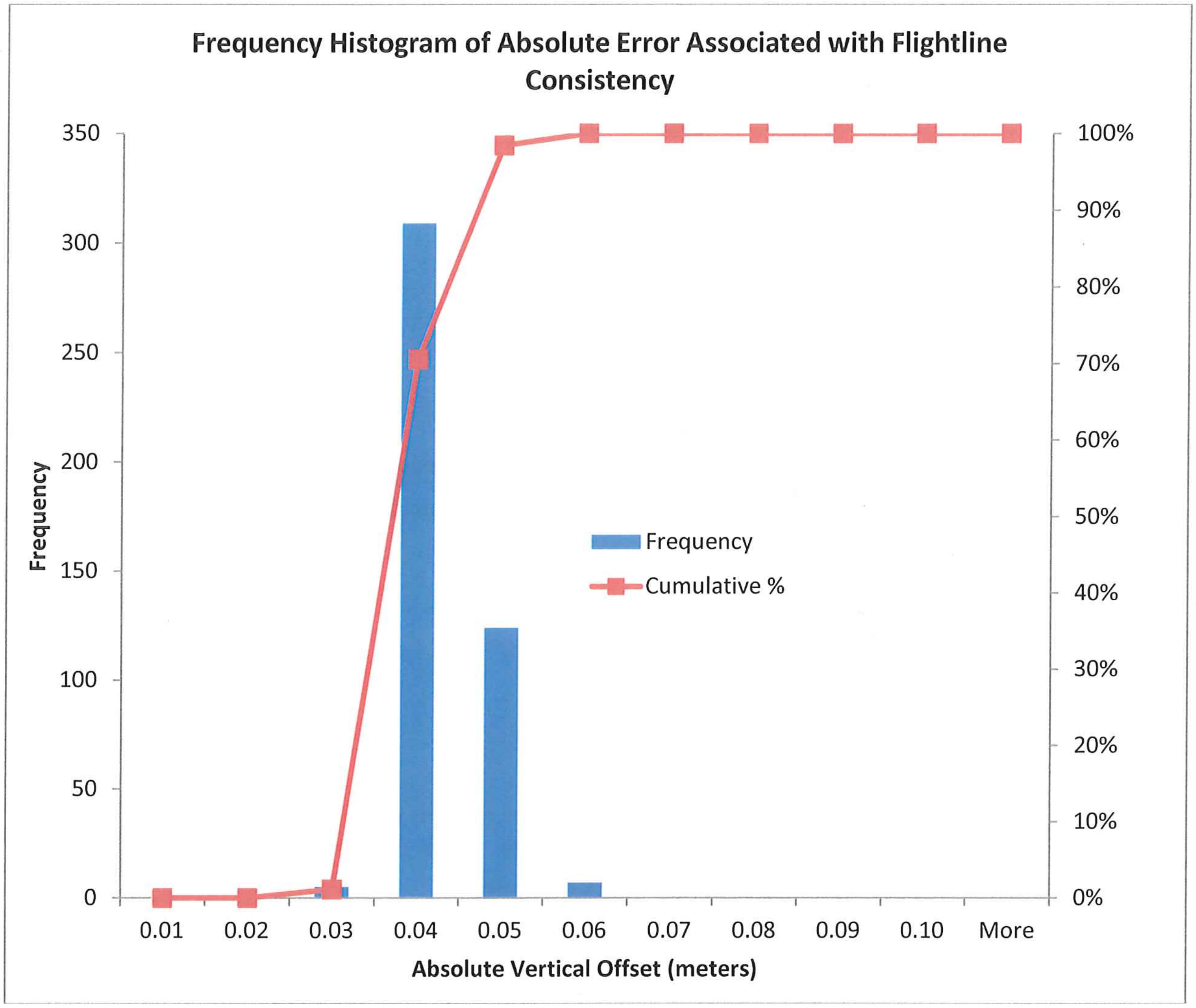
Summary Statistics

# of Tiles	2698
# of Flight Line Sections	445
Avg # of Points	14,972,324
Avg. Magnitude Z error (m)	0.037

Table 2a. Summary Results of Consistency Analysis

	meters	***feet***
Mean	0.037	0.122
Standard Error	0.000	0.001
Standard Deviation	0.005	0.017
Sample Variance	0.000	0.000
Range	0.030	0.099
Minimum	0.029	0.096
Maximum	0.059	0.195

Table 2b. Descriptive Statistics for Magnitude Z Error.


Frequency Histogram of Absolute Error Associated with Flightline Consistency
Frequency
Cumulative %
350
300
250
200
150
100
50
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
More
Absolute Vertical Offset (meters)

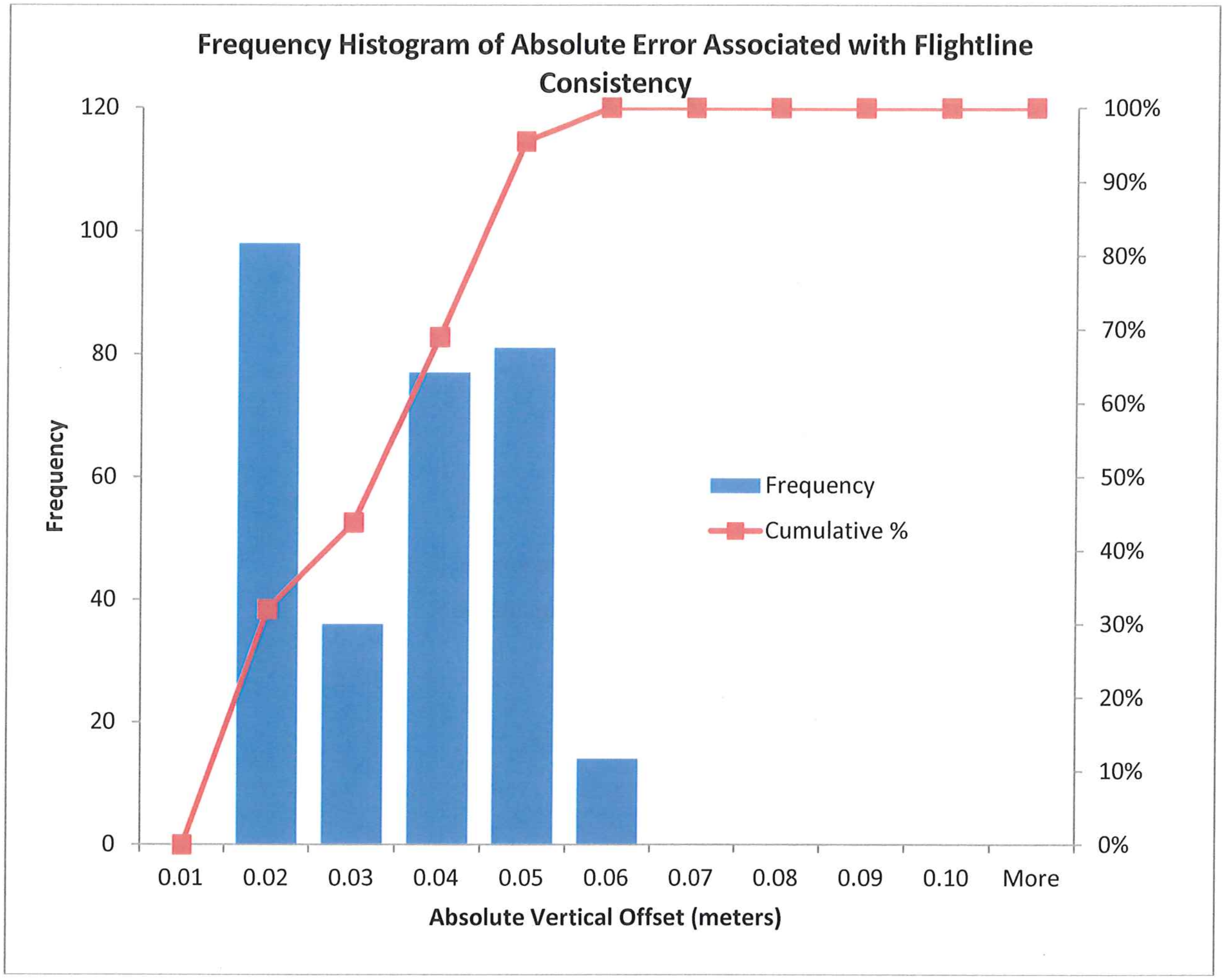


Figure 4. Histogram of flight line offsets values.

Results of the consistency analysis found the average flight line offset to be 0.037 meters with a maximum error of 0.059m (Table 2b). Distribution of error showed over 98% of all error was less than 0.05m and 99% was less than 0.06m (Figure 4). These results show that all data are within tolerances of data consistency according to contract agreement.

Visual Analysis

Lidar 1m 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 5). Both bare earth and highest hit models were examined for calibration offsets, tiling artifacts (Figure 6), seam line offsets, pits (Figure 6), 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 5). 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 7). 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.

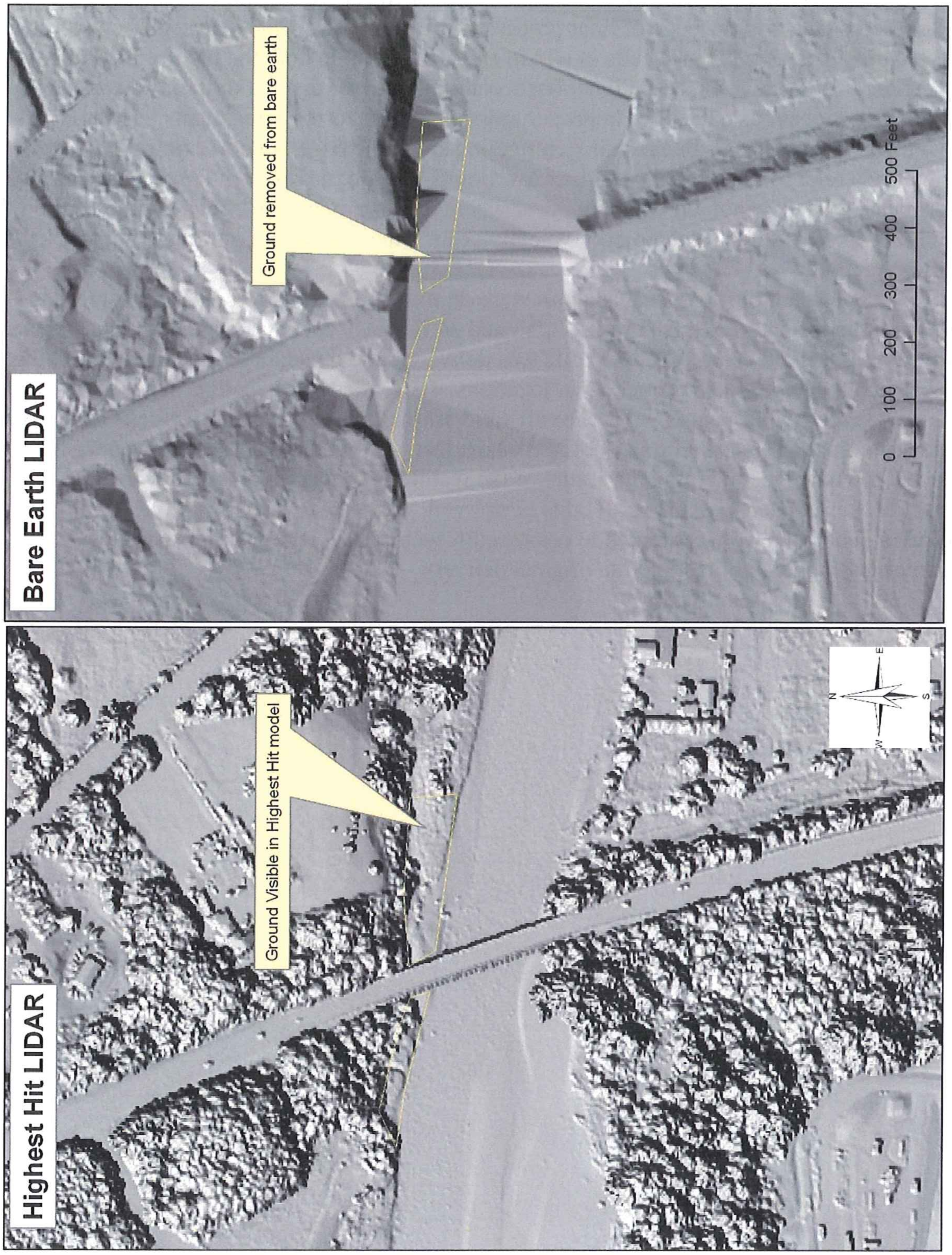


Figure 5. Example of missing ground in lidar bare earth data. Ground is clearly visible in highest hit model, but has been removed from the bare earth model. This type of classification error is common near water body features.

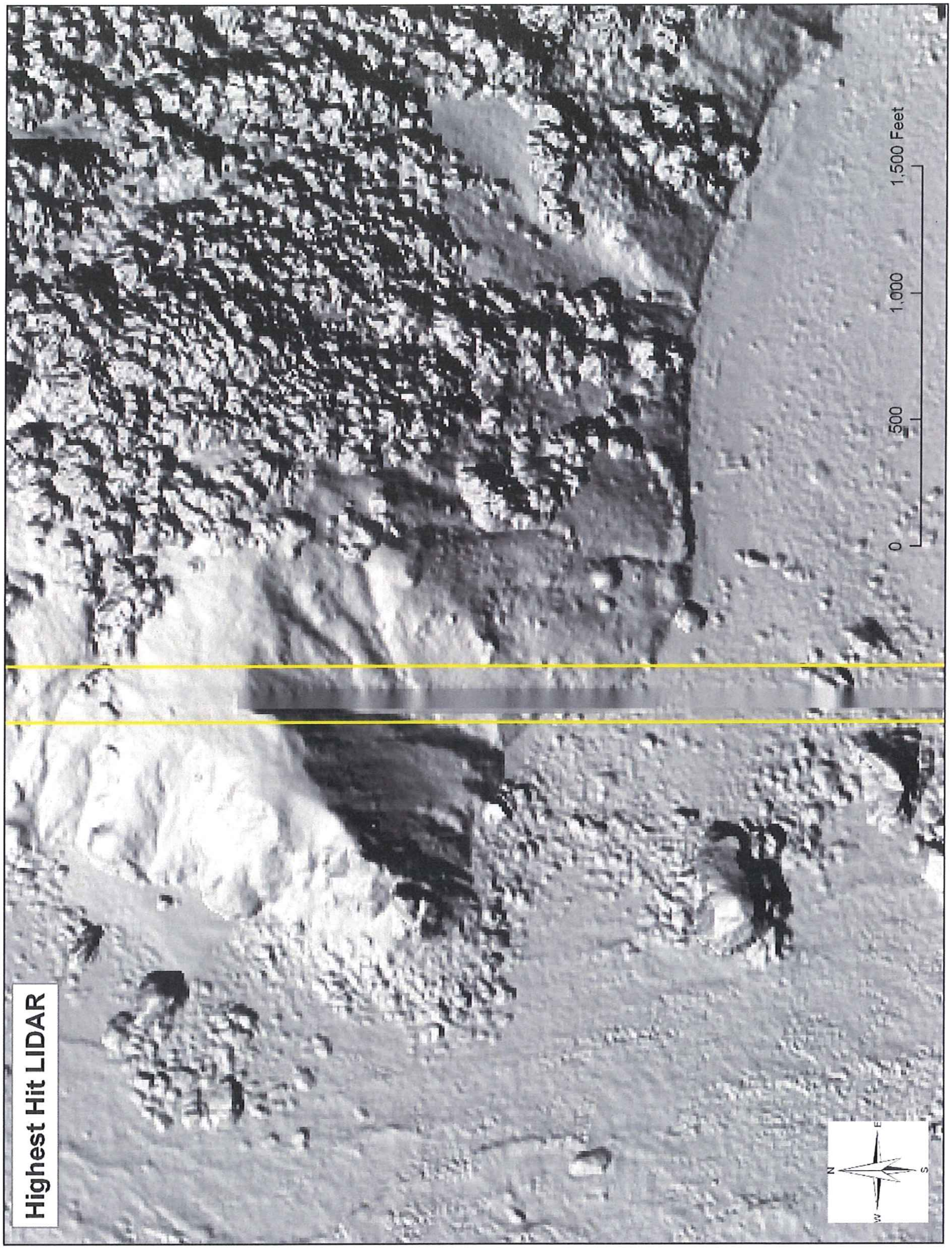


Figure 6. Example of tile artifact found in highest hit lidar data. Artifact is a seam line error created due to misclassification of ground at edge of lidar processing tiles.

Figure 7. 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. The contractor used a surveying system (Figure 8) to measure GCP's. GPS survey techniques allow surveyors to collect many precisely located GCP's which can be used as a control comparison with LiDAR elevations. 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). A licensed surveyor is often able to post process GPS survey data to accuracies less than 1cm in both horizontal and vertical axes.

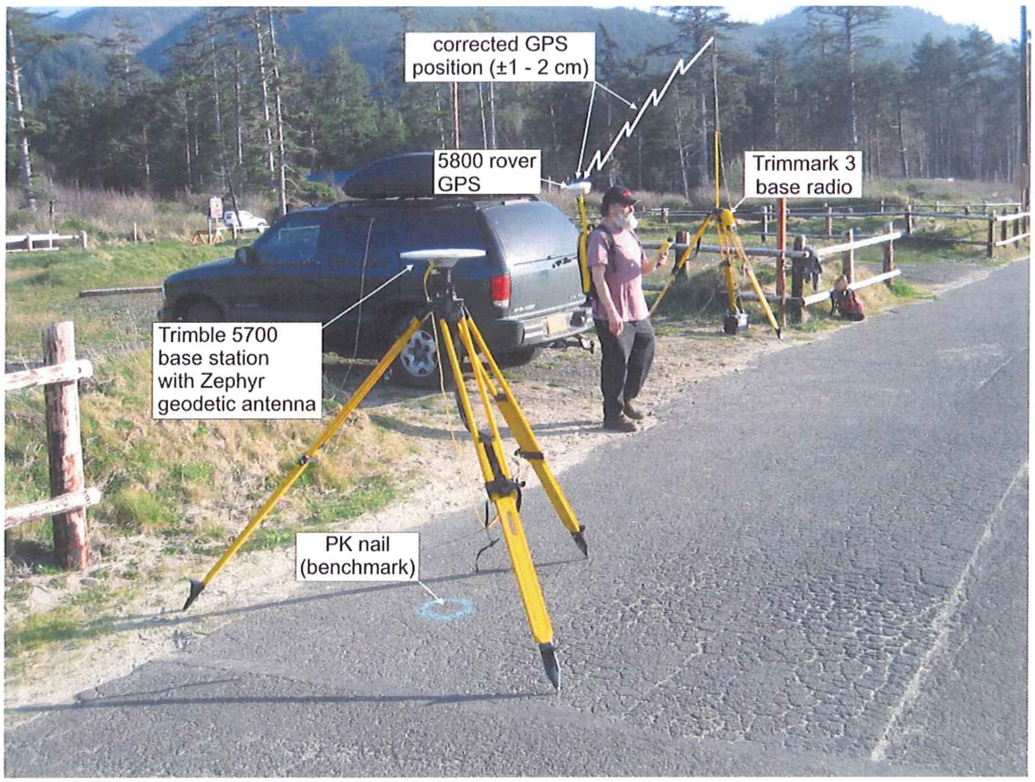


Figure 8. The Trimble 5700 base station antenna located over a known reference point at Cape Lookout State Park. Corrected GPS position and elevation information is then transmitted by a Trimmark III base radio to the 5800 GPS rover unit.

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 values for the entire delivered data set. Project specifications list the maximum acceptable root mean square vertical offset to be 0.20 meters (0.65 feet).

A total of 1663 measured GCP's were provided to DOGAMI by DGGS for the Delivery 6 region (Figure 9) and compared with the lidar elevation grids. The data delivered to DOGAMI was found to have a mean vertical offset of -0.014 meters (-0.047 feet) and an RMSE value of 0.041 meters (0.133 ft). Offset values ranged from -0.113 to 0.135 meters (Table 3 and Figure 10).

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.

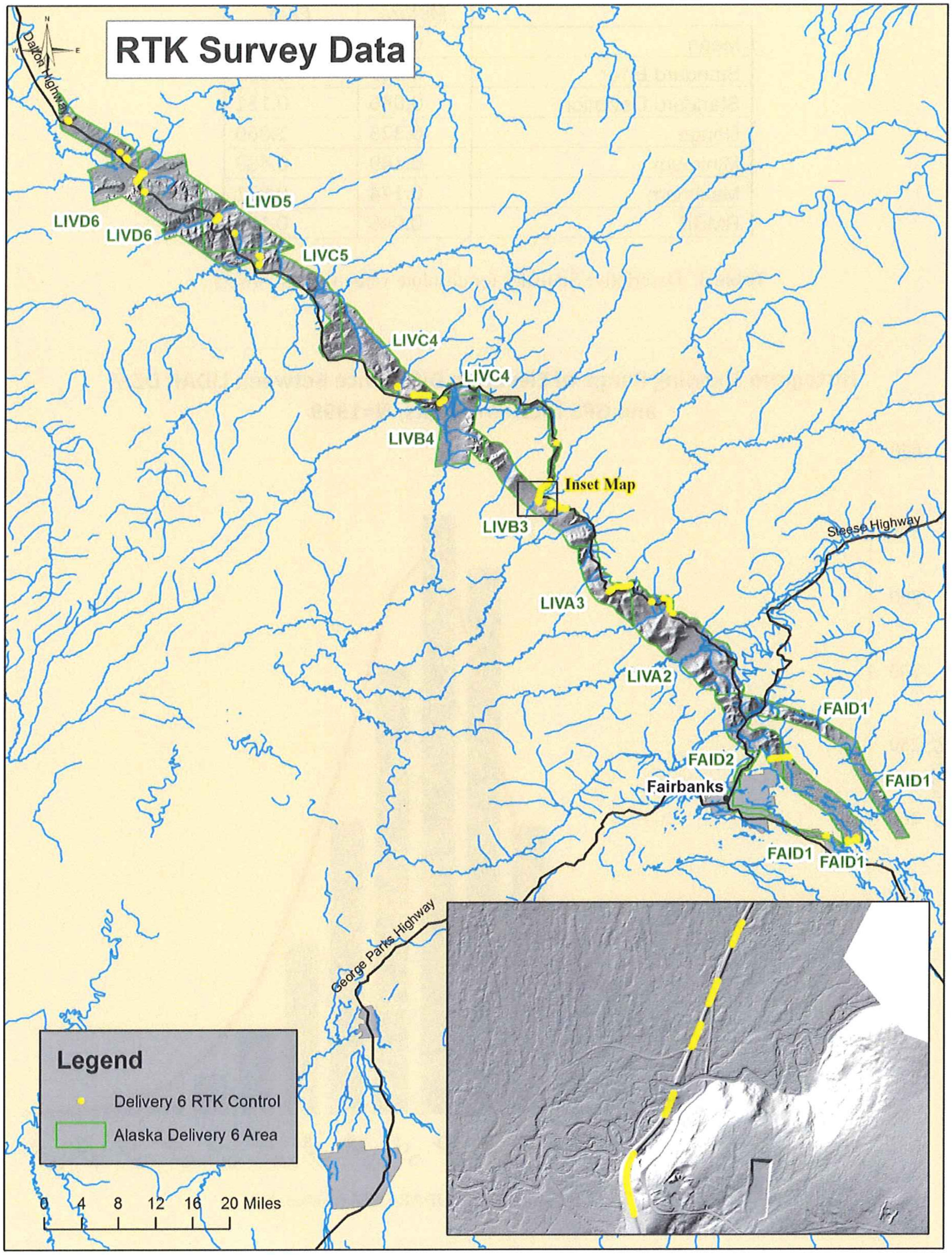


Figure 9. Locations of RTK control surveyed by Contractor. Data was used to test absolute accuracy for the Alaska DNR lidar survey within the Delivery 6 extent.

	Meters	Feet
Mean	0.005	0.018
Standard Error	0.001	0.003
Standard Deviation	0.046	0.151
Range	0.323	1.060
Minimum	-0.149	-0.489
Maximum	0.174	0.571
RMSE	0.046	0.153

Table 3. Descriptive Statistics for absolute value vertical offsets.

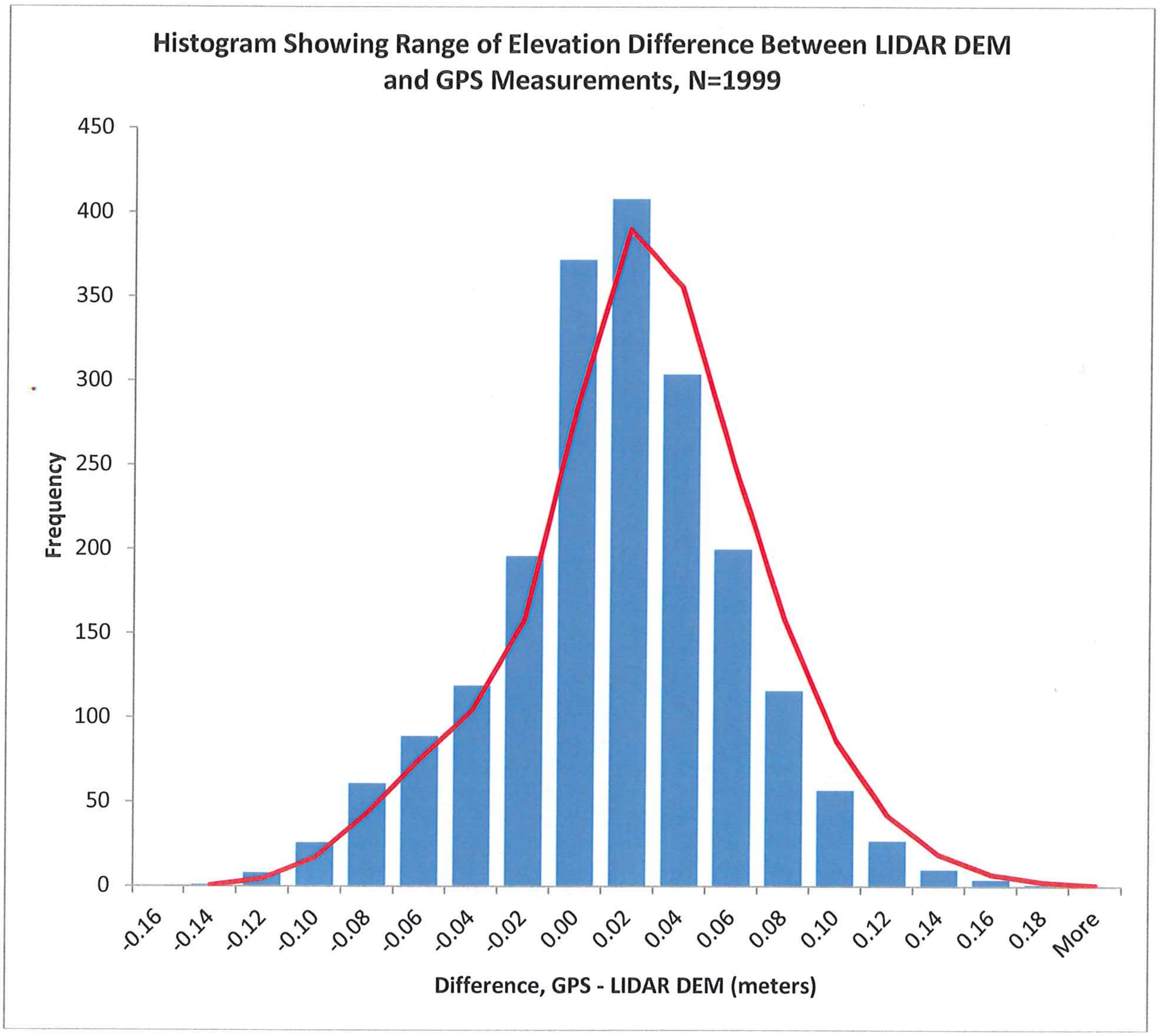


Figure 10. Histogram of elevation difference between Lidar DEM and GPS survey data.

Acceptance

The data described in this report meets or exceeds project specifications laid out in the contracted data standards agreement. All the required files for the delivery have been received as of October 21st, 2011, and are correctly named and useable. 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 quality control 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 Signature

____ Date: 10/26/2011

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

____ Date: 10/31/2011

Ian Madin
Chief Scientist – Department of Geology & Mineral Industries

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

Alaska DNR LIDAR Project, 2011 – Delivery7 QC Analysis

LIDAR QC Report – December 9th, 2011

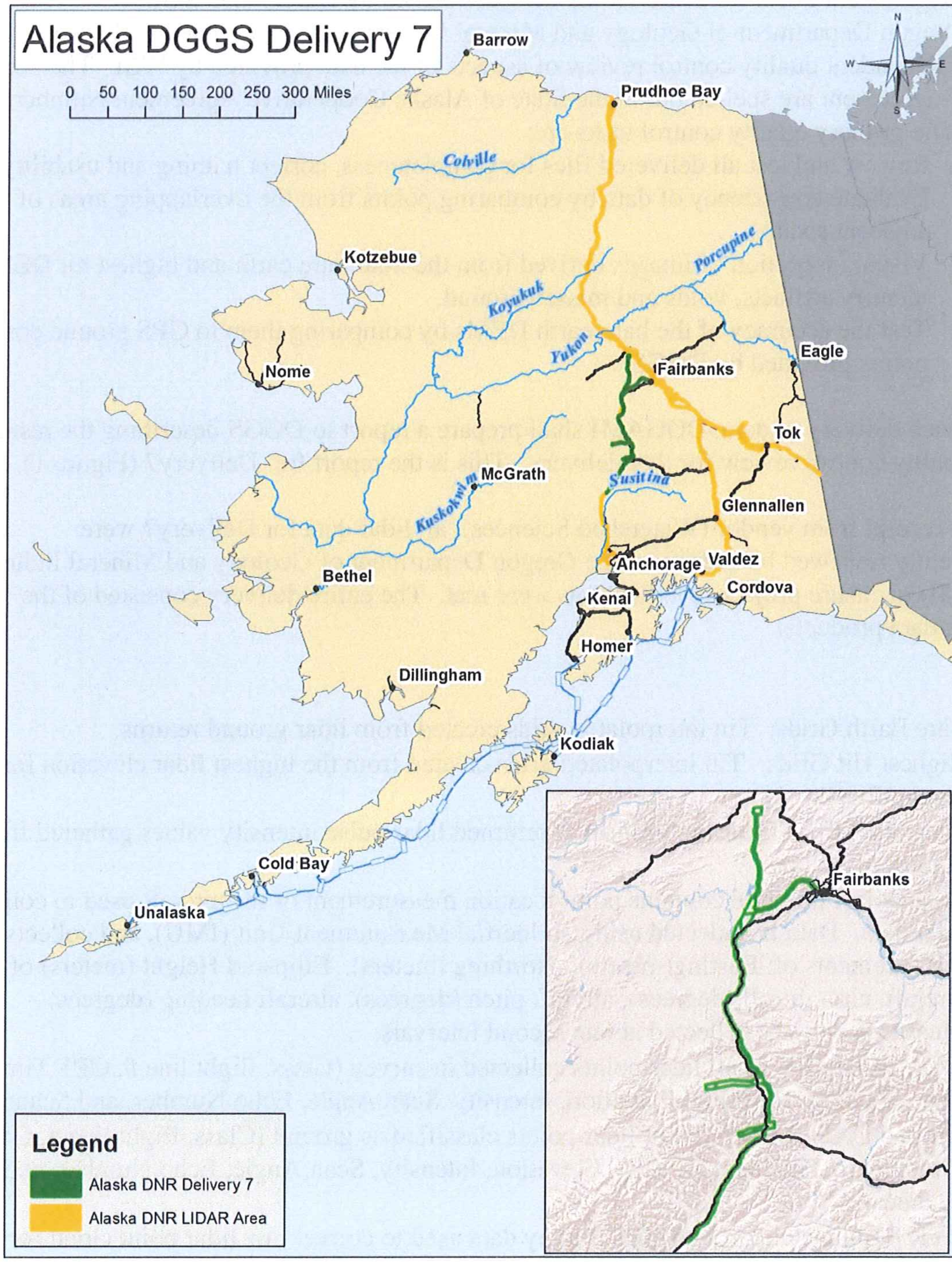


Figure 1. Map featuring Alaska DNR Delivery7 data extent.

The Alaska Department of Natural Resources, Division of Geological and Geophysical Survey (DGGS) has contracted with Watershed Sciences, Inc (WSI) to collect high resolution lidar topographic data for a swath roughly parallel to proposed future pipeline rights of way. DGGS has specified the exact areas of data collection as well as a detailed description of data products to be delivered. The complete specifications are detailed in the September 14, 2010 Standard Agreement Form for Professional Services signed by DGGS and WSI.

The Oregon Department of Geology and Mineral Industries has contracted with DGGS to provide independent quality control review of aspects of the data provided by WSI. The details of the QC agreement are spelled out in the State of Alaska Cooperative Agreement Number MI-11-006. The primary quality control tasks are:

1. Review and test all delivered files for completeness, correct naming and usability.
2. Evaluate consistency of data by comparing points from the overlapping areas of adjacent swaths.
3. Visual inspection of images derived from the lidar bare earth and highest hit DEMs to identify artifacts, voids and missed ground.
4. Test the accuracy of the bare earth DEMs by comparing them to GPS ground control points provided by DGGS.

For each delivery of data, DOGAMI shall prepare a report to DGGS describing the results of the quality control review for that delivery. This is the report for Delivery7 (Figure 1).

Upon receipt from vendor (Watershed Sciences), all lidar data for Delivery7 were independently reviewed by staff from the Oregon Department of Geology and Mineral Industries (DOGAMI) to ensure project specifications were met. The entire delivery consisted of the following data products:

- 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.
- 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 Universal Transverse Mercator (Zones 6), NAD83 CORS96 meters.

Data Completeness

Data for Alaska DNR Delivery7 area were collected between May20th and July 6th, 2011. Total area of delivered data totals 409.81 square miles. Delivery7 (Figure 2) includes data in the format of grids, trajectory files, intensity images, Lidar ASCII Standard (LAS) point files, 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 1 meter cell size. Lidar point data are delivered in LAS binary format for ground classified returns as well as the entire lidar point cloud. Georeferenced intensity images of 1 meter cell size are supplied in geoTIF format. Supplementary data include 1 meter cell size vegetation rasters displaying canopy and other vegetation metrics. Real time kinematic ground survey data (used for absolute vertical adjustment) are supplied in shapefile format. This delivery contains data for the following USGS 7.5 minute quads (listed by quadrangle tile name within the boundary of the Alaska DNR Survey collection area (Figure 2):

Delivery7 Quadrangles: FAIA5, FAIB4, FAIB5, FAIC4, FAIC5, FAID2, FAID3, FAID4, HEAA5, HEAA6, HEAB4, HEAB5, HEAC4, HEAC5, HEAC6, HEAD4, HEAD5, LIVA4, LIVAB, TLMD6.

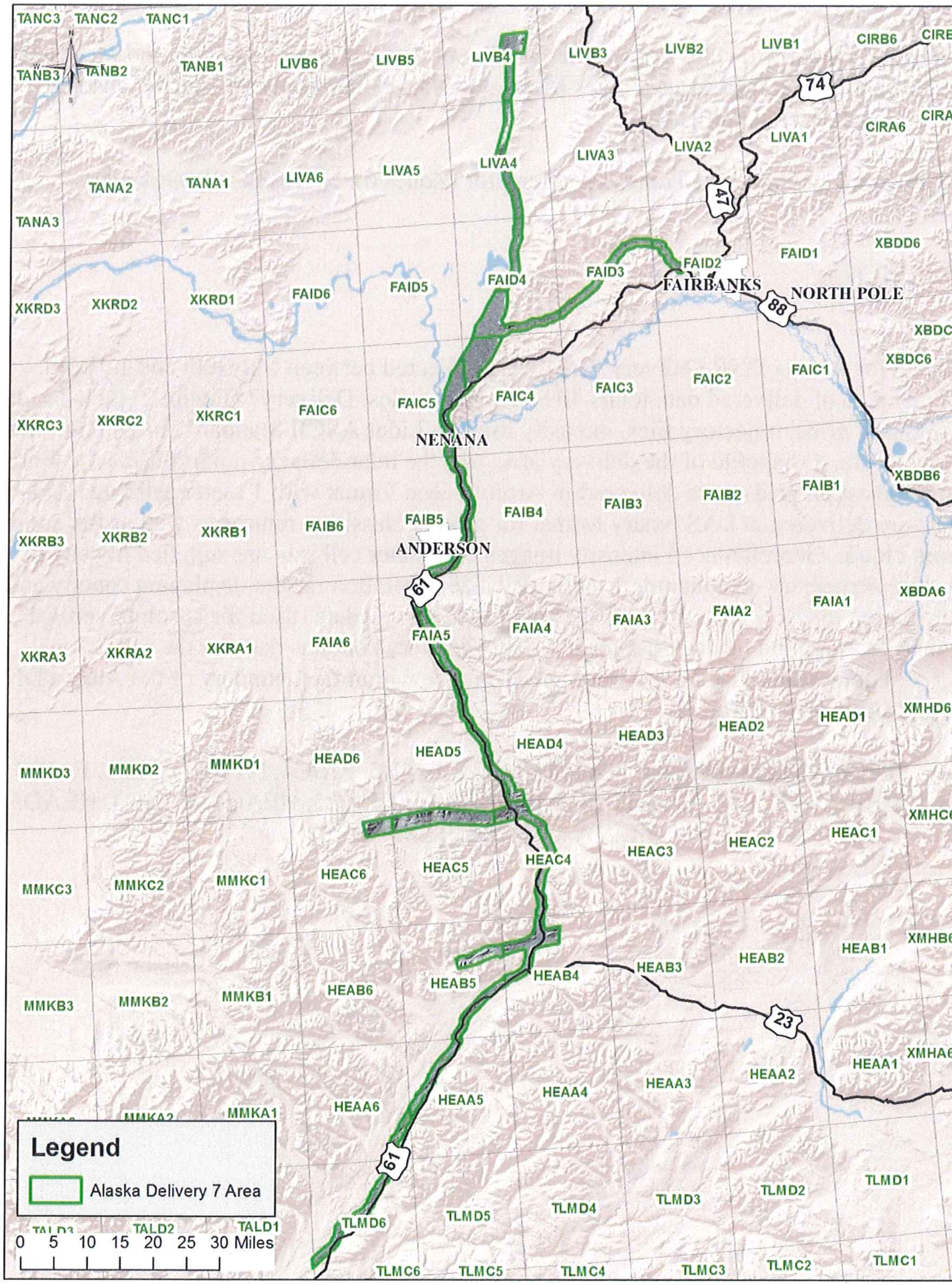


Figure 2. Delivery7 location area. Data is referenced to USGS 7.5 minute quadrangles within the extents of the Alaska DNR Survey collection area

FINAL Delivery	Resolution	Format	Tiling	
Bare Earth DEMs	1 meter	grid	quad	x
Highest Hit DEMs	1 meter	grid	quad	x
Trajectory files	1 sec	sbet /shape	flight	x
Intensity Images	1 meter?	tif	quad	x
LAS	8pts/m^2	las	tiled	x
Ground Returns	N/A	las	tiled	x
First return Vegetation Raster	1 meter	grid	quad	x
RTK point data		shape		x
Delivery Area shapefile		shape	quad	x
Report		pdf		x

Miscellaneous		Format	Tiling	
Processing bins		Shape dxf/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 headers have been scanned to ensure completeness and readability (Figure 3).

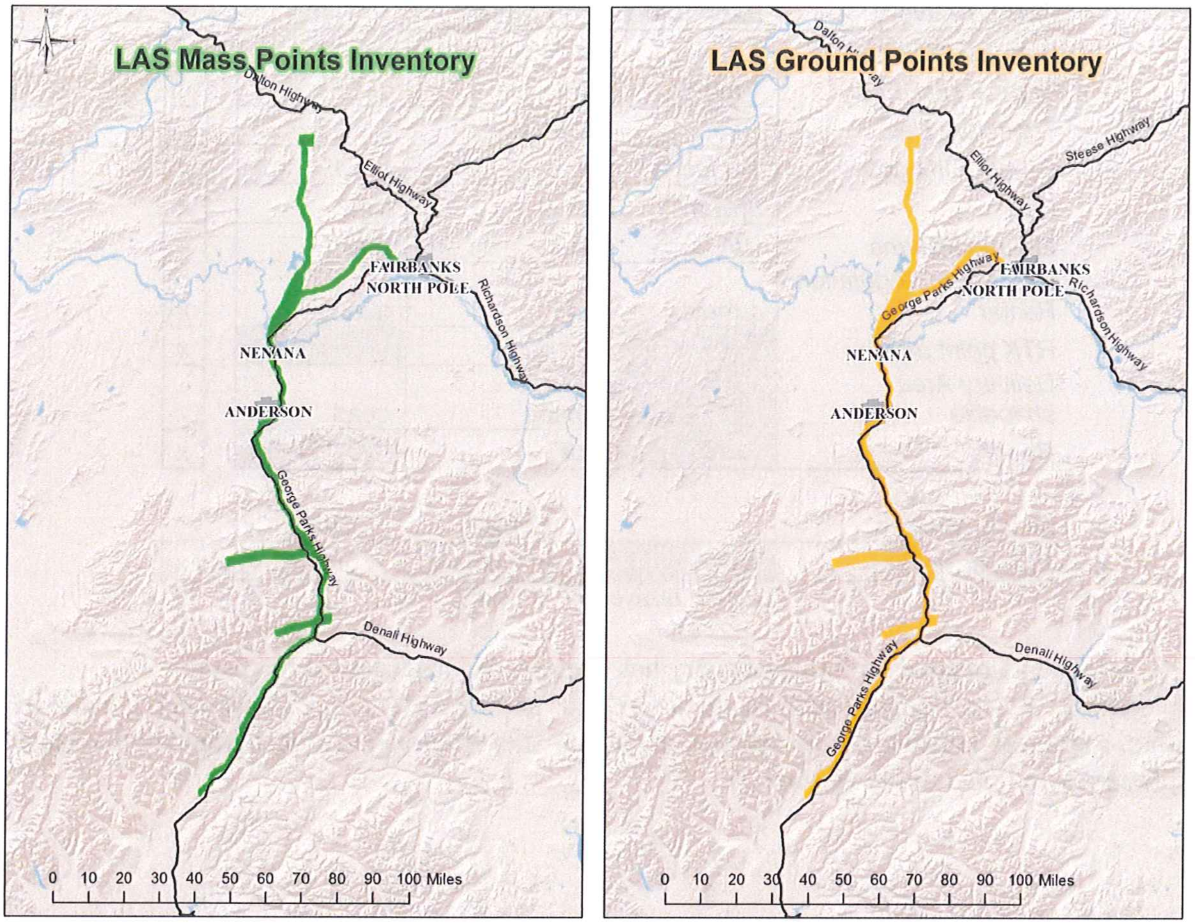


Figure 3. LIDAR Point Inventory graphic representing complete coverage of point data for both mass points and ground LAS files.

Consistency Analysis:

DGGS has specified that lidar consistency must average less than 0.15m (0.49 feet) in vertical offsets between adjacent 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 2595 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 5,109,867 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 579 flight lines were sampled and compared for consistency.

Summary Statistics

# of Tiles	2595
# of Flight Line Sections	445
Avg # of Points	5,109,867
Avg. Magnitude Z error (m)	0.038

Table 2a. Summary Results of Consistency Analysis

	meters	***feet***
Mean	0.038	0.124
Standard Error	0.000	0.001
Standard Deviation	0.009	0.029
Sample Variance	0.000	0.000
Range	0.050	0.165
Minimum	0.024	0.078
Maximum	0.074	0.244

Table 2b. Descriptive Statistics for Magnitude Z Error.

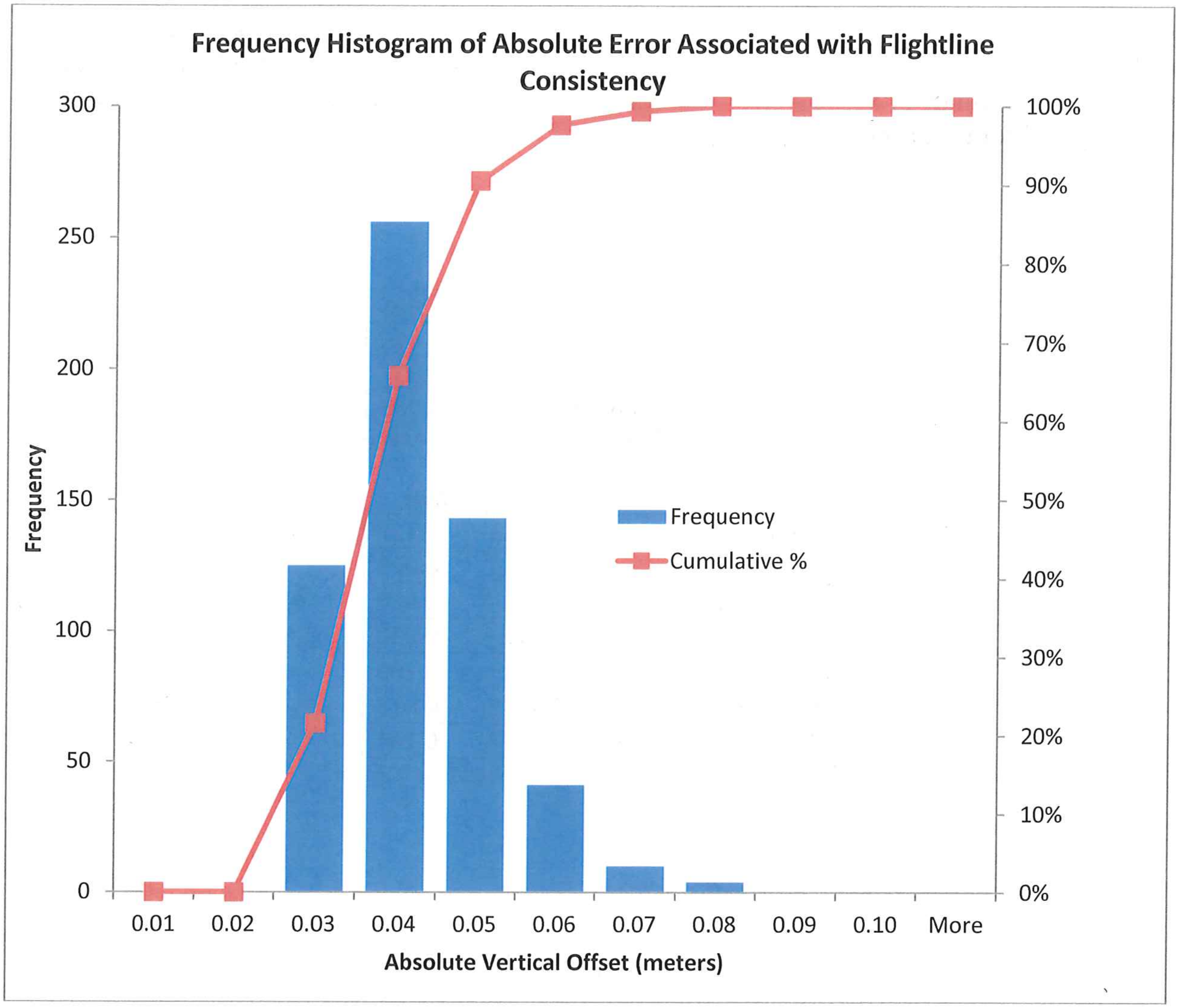


Figure 4. Histogram of flight line offsets values.

Results of the consistency analysis found the average flight line offset to be 0.038 meters with a maximum error of 0.074m (Table 2b). Distribution of error showed over 97% of all error was less than 0.06m and 99% was less than 0.07m (Figure 4). These results show that all data are within tolerances of data consistency according to contract agreement.

Visual Analysis

Lidar 1m 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 5). Both bare earth and highest hit models were examined for calibration offsets, tiling artifacts (Figure 6), seam line offsets, pits (Figure 6), 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 5). 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 7). Birds (high points) typically occur where the laser comes into contact with atmospherics[1].

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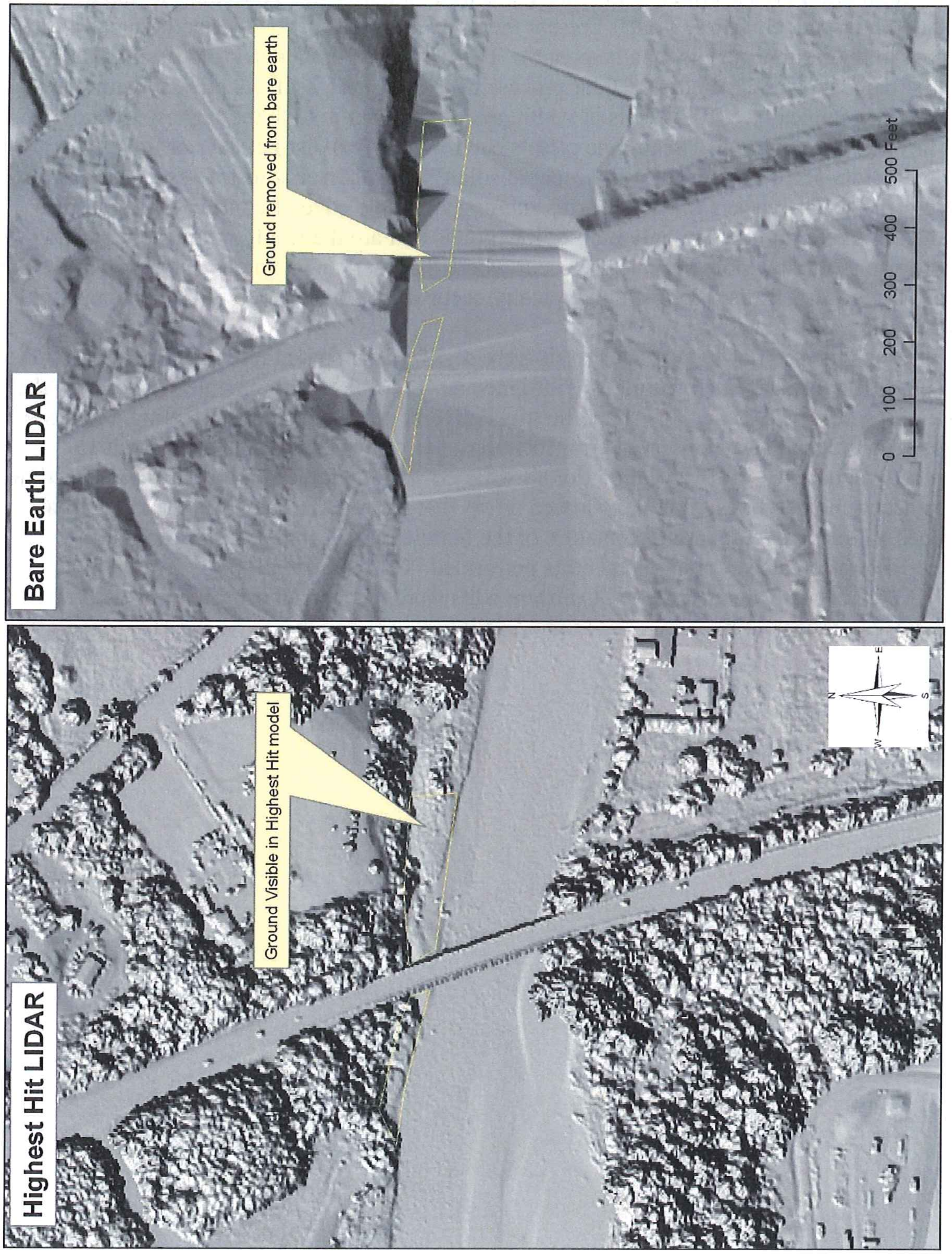
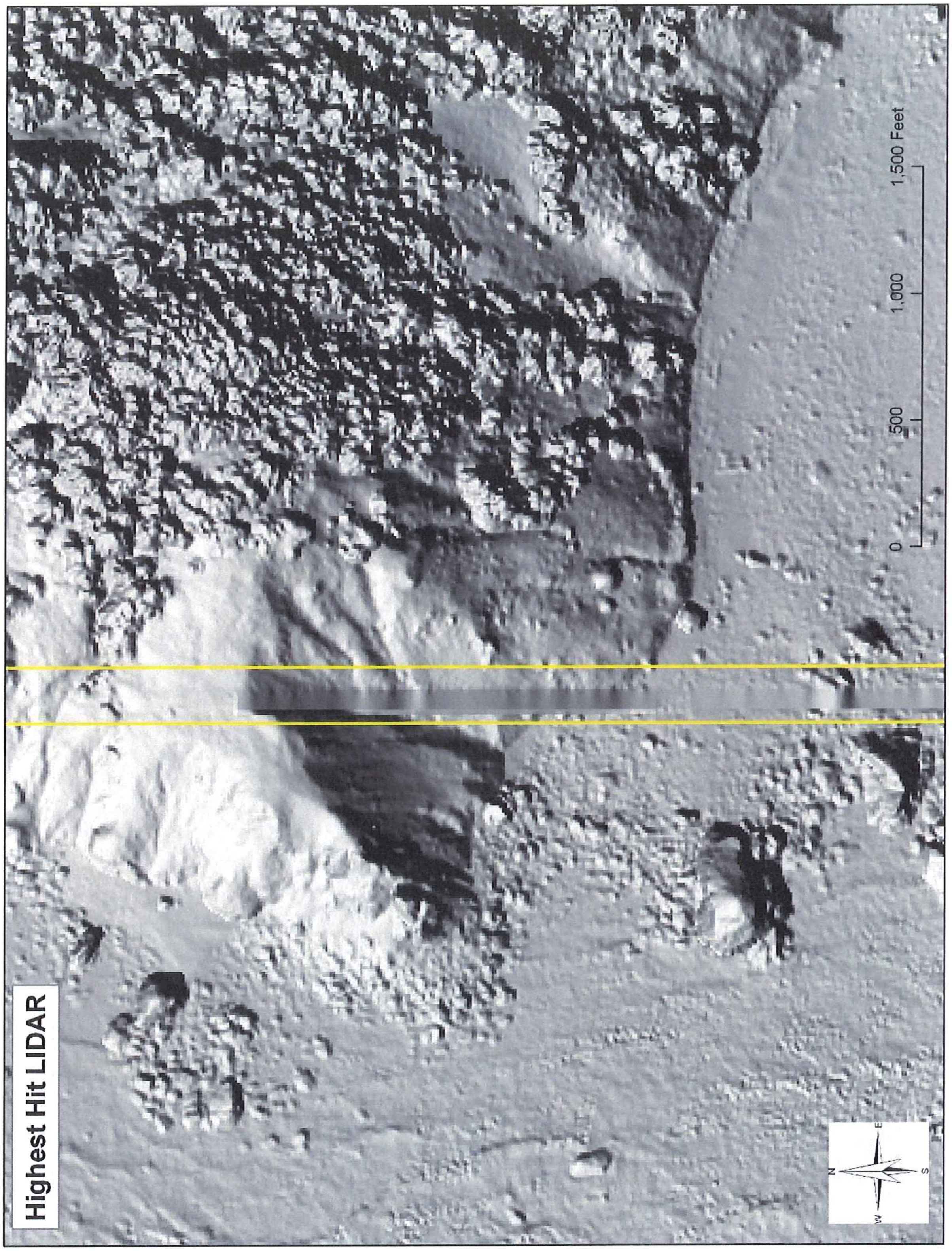


Figure 5. Example of missing ground in lidar bare earth data. Ground is clearly visible in highest hit model, but has been removed from the bare earth model. This type of classification error is common near water body features.



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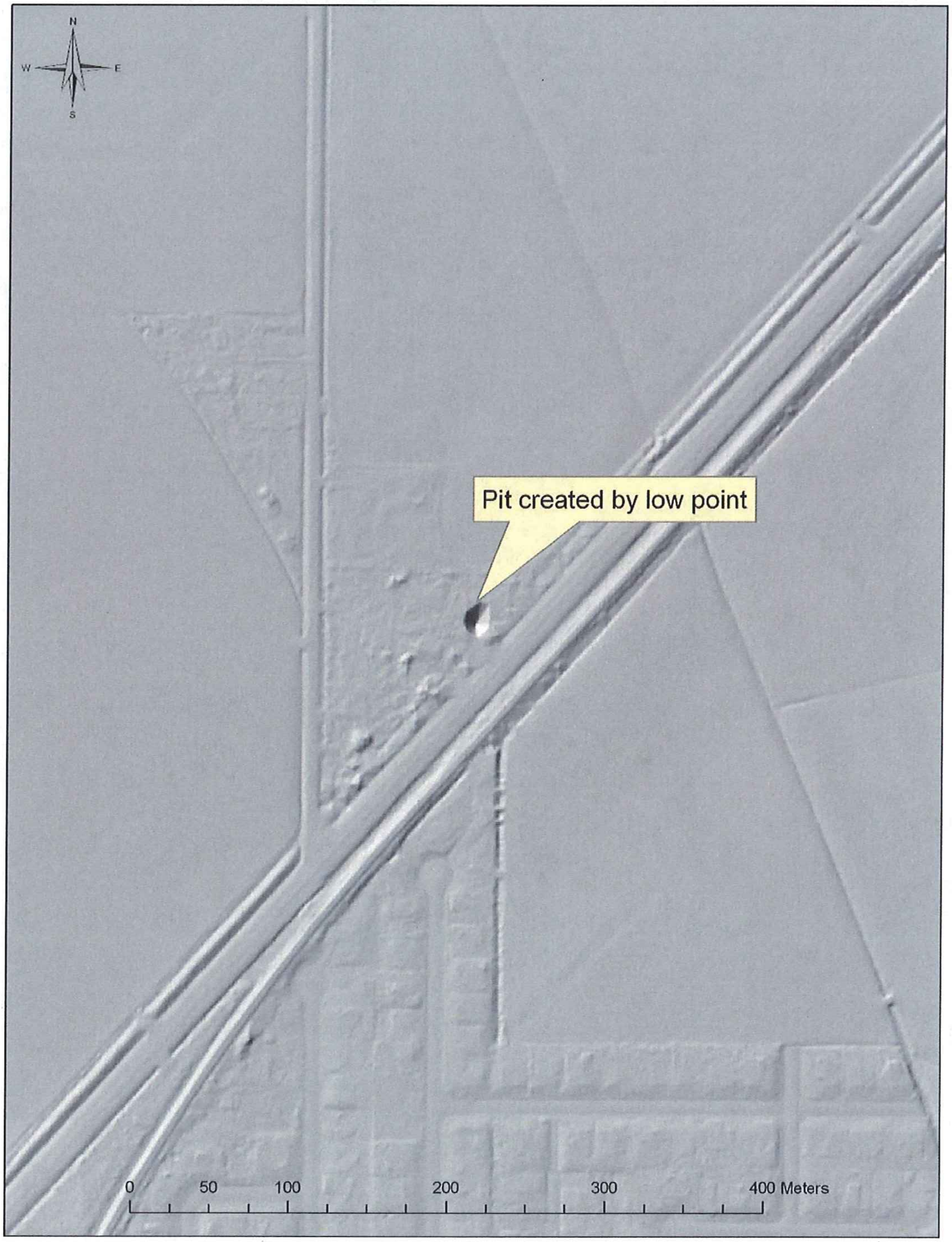

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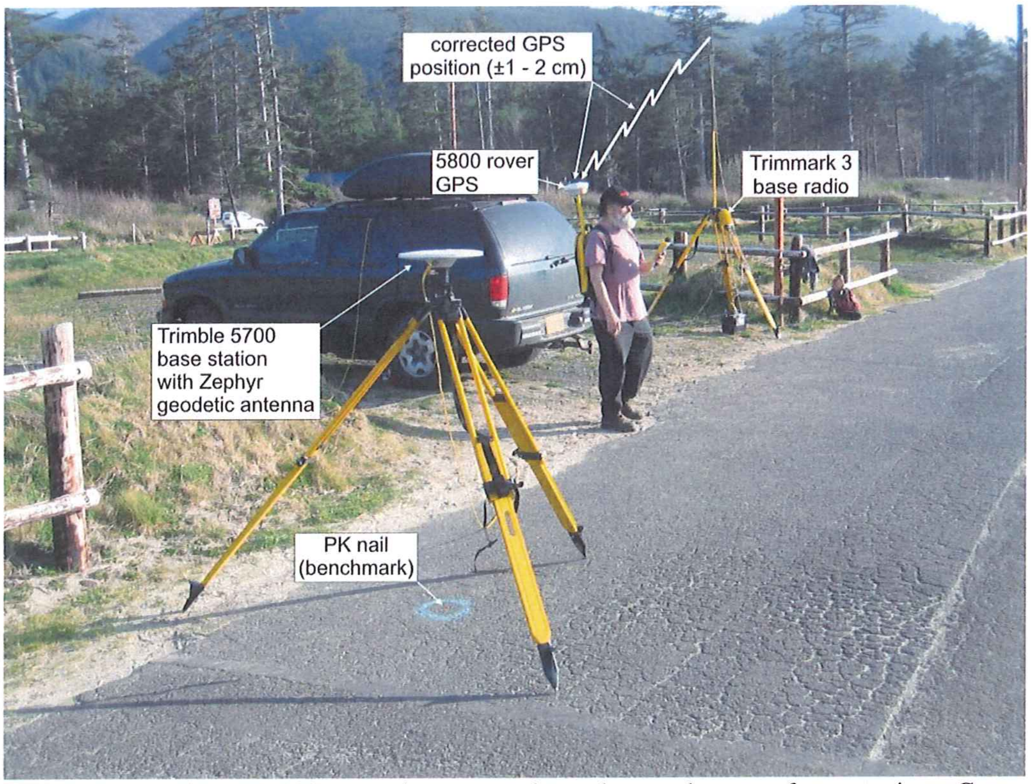
Absolute accuracy refers to the mean vertical offset of lidar data relative to measured ground-control points (GCP) obtained throughout the lidar sampling area. The contractor used a surveying system (Figure 8) to measure GCP's. GPS survey techniques allow surveyors to collect many precisely located GCP's which can be used as a control comparison with LiDAR elevations. 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). A licensed surveyor is often able to post process GPS survey data to accuracies less than 1cm in both horizontal and vertical axes.



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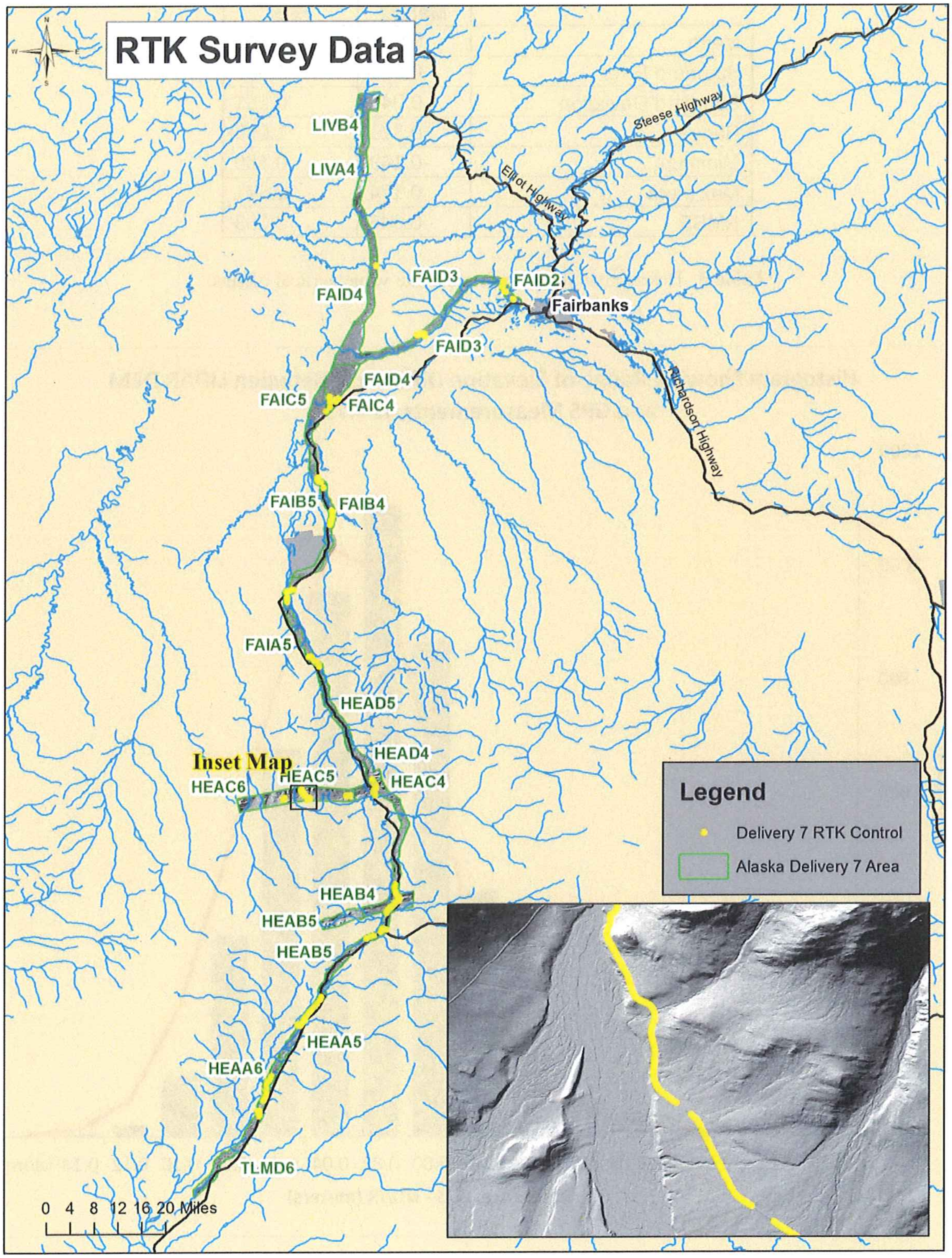

Figure 9. Locations of RTK control surveyed by Contractor. Data was used to test absolute accuracy for the Alaska DNR lidar survey within the Delivery7 extent.

	Meters	*Feet*
Mean	0.005	0.018
Standard Error	0.001	0.003
Standard Deviation	0.046	0.151
Range	0.323	1.060
Minimum	-0.149	-0.489
Maximum	0.174	0.571
RMSE	0.046	0.153

Table 3. Descriptive Statistics for absolute value vertical offsets.

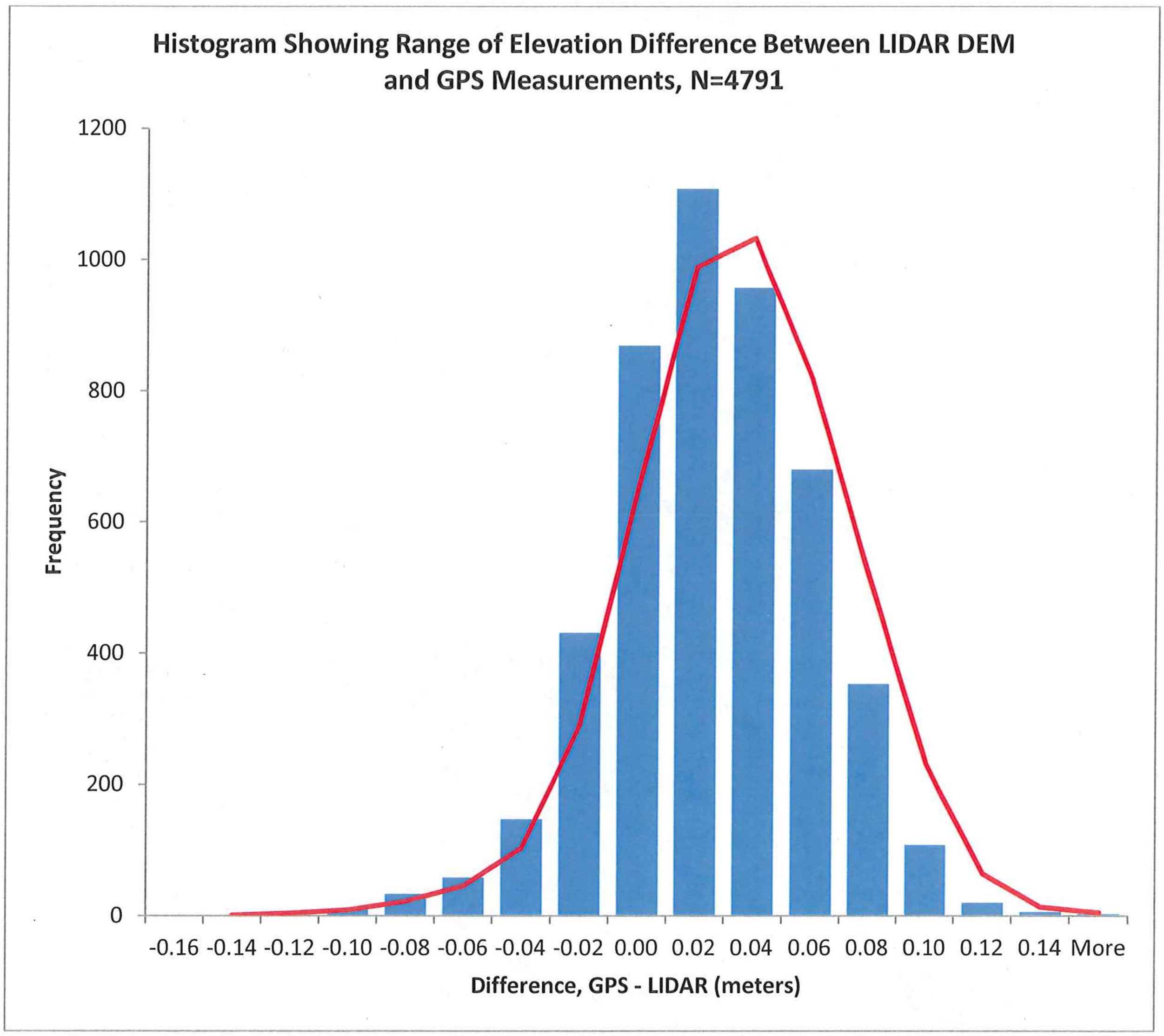

Figure 10. Histogram of elevation difference between Lidar DEM and GPS survey data.

Acceptance

The data described in this report meets or exceeds project specifications laid out in the contracted data standards agreement. All the required files for the delivery have been received as of December 9th, 2011, and are correctly named and useable. 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 quality control 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 Signature

________________________________ Date: 12/9/2011

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

________________________________ Date: 12/9/2011

Ian Madin
Chief Scientist – Department of Geology & Mineral Industries

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

Alaska DNR LIDAR Project, 2011 – Delivery 8 QC Analysis

LIDAR QC Report – December 16th, 2011

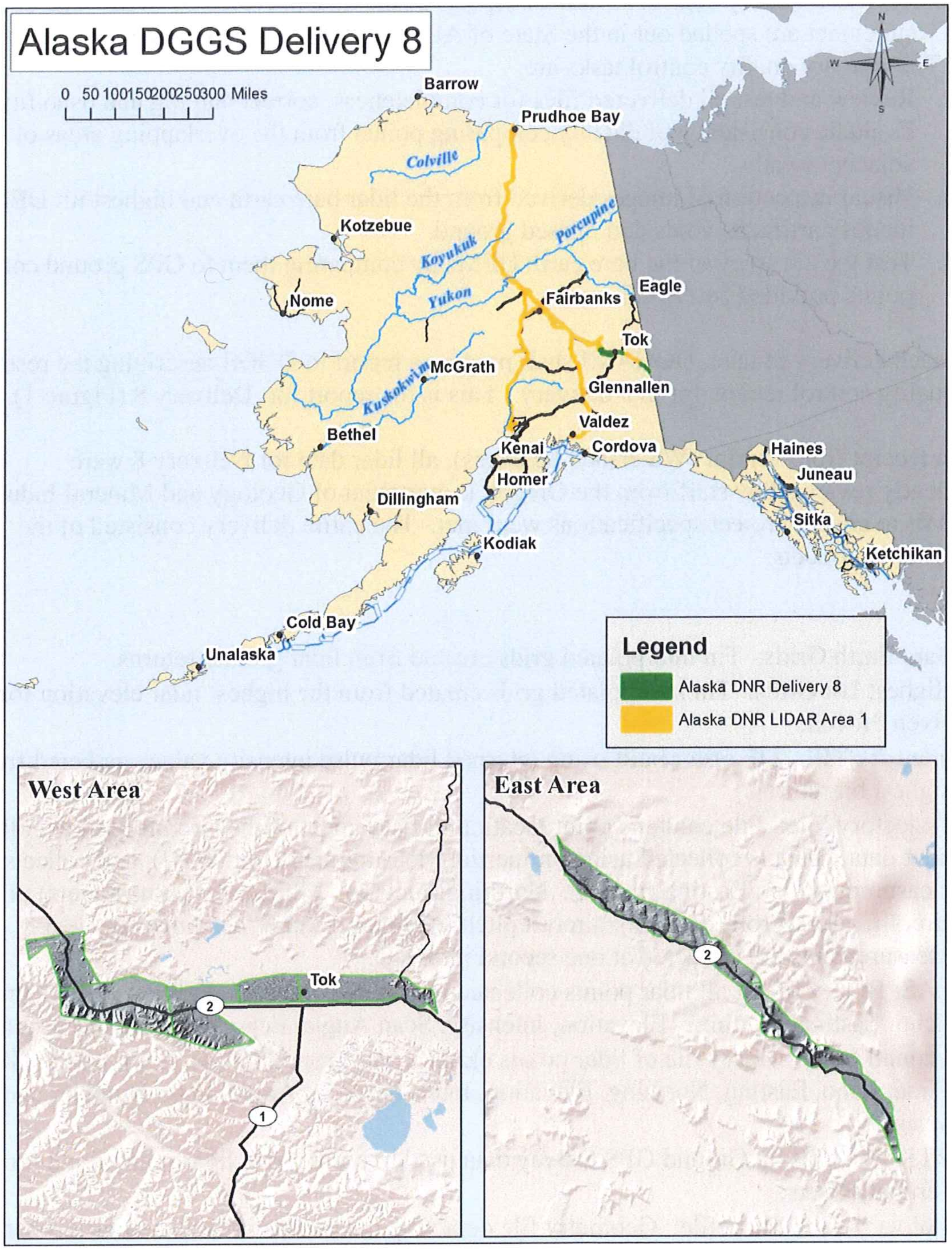

Figure 1. Map featuring Alaska DNR Delivery 8 data extent.

The Alaska Department of Natural Resources, Division of Geological and Geophysical Survey (DGGS) has contracted with Watershed Sciences, Inc (WSI) to collect high resolution lidar topographic data for a swath roughly parallel to proposed future pipeline rights of way. DGGS has specified the exact areas of data collection as well as a detailed description of data products to be delivered. The complete specifications are detailed in the September 14, 2010 Standard Agreement Form for Professional Services signed by DGGS and WSI.

The Oregon Department of Geology and Mineral Industries has contracted with DGGS to provide independent quality control review of aspects of the data provided by WSI. The details of the QC agreement are spelled out in the State of Alaska Cooperative Agreement Number MI-11-006. The primary quality control tasks are:

1. Review and test all delivered files for completeness, correct naming and usability.
2. Evaluate consistency of data by comparing points from the overlapping areas of adjacent swaths.
3. Visual inspection of images derived from the lidar bare earth and highest hit DEMs to identify artifacts, voids and missed ground.
4. Test the accuracy of the bare earth DEMs by comparing them to GPS ground control points provided by DGGS.

For each delivery of data, DOGAMI shall prepare a report to DGGS describing the results of the quality control review for that delivery. This is the report for Delivery 8 (Figure 1).

Upon receipt from vendor (Watershed Sciences), all lidar data for Delivery 8 were independently reviewed by staff from the Oregon Department of Geology and Mineral Industries (DOGAMI) to ensure project specifications were met. The entire delivery consisted of the following data products:

- 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.
- 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 Universal Transverse Mercator (Zones 6), NAD83 CORS96 meters.

Data Completeness

Data for Alaska DNR Delivery 8 area were collected between October 1st – 3rd, 2010 and June 29th through July 22nd, 2011. Total area of delivered data totals 244.86 square miles. Delivery 8 (Figure 2a and 2b) includes data in the format of grids, trajectory files, intensity images, Lidar ASCII Standard (LAS) point files, 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 1 meter cell size. Lidar point data are delivered in LAS binary format for ground classified returns as well as the entire lidar point cloud. Georeferenced intensity images of 1 meter cell size are supplied in geoTIF format. Supplementary data include 1 meter cell size vegetation rasters displaying canopy and other vegetation metrics. Real time kinematic ground survey data (used for absolute vertical adjustment) are supplied in shapefile format. This delivery contains data for the following USGS 7.5 minute quads (listed by quadrangle tile name within the boundary of the Alaska DNR Survey collection area (Figure 2):

Delivery 8 Quadrangles: NABC1, NABD1, TNXB4, TNXB5, TNXB6

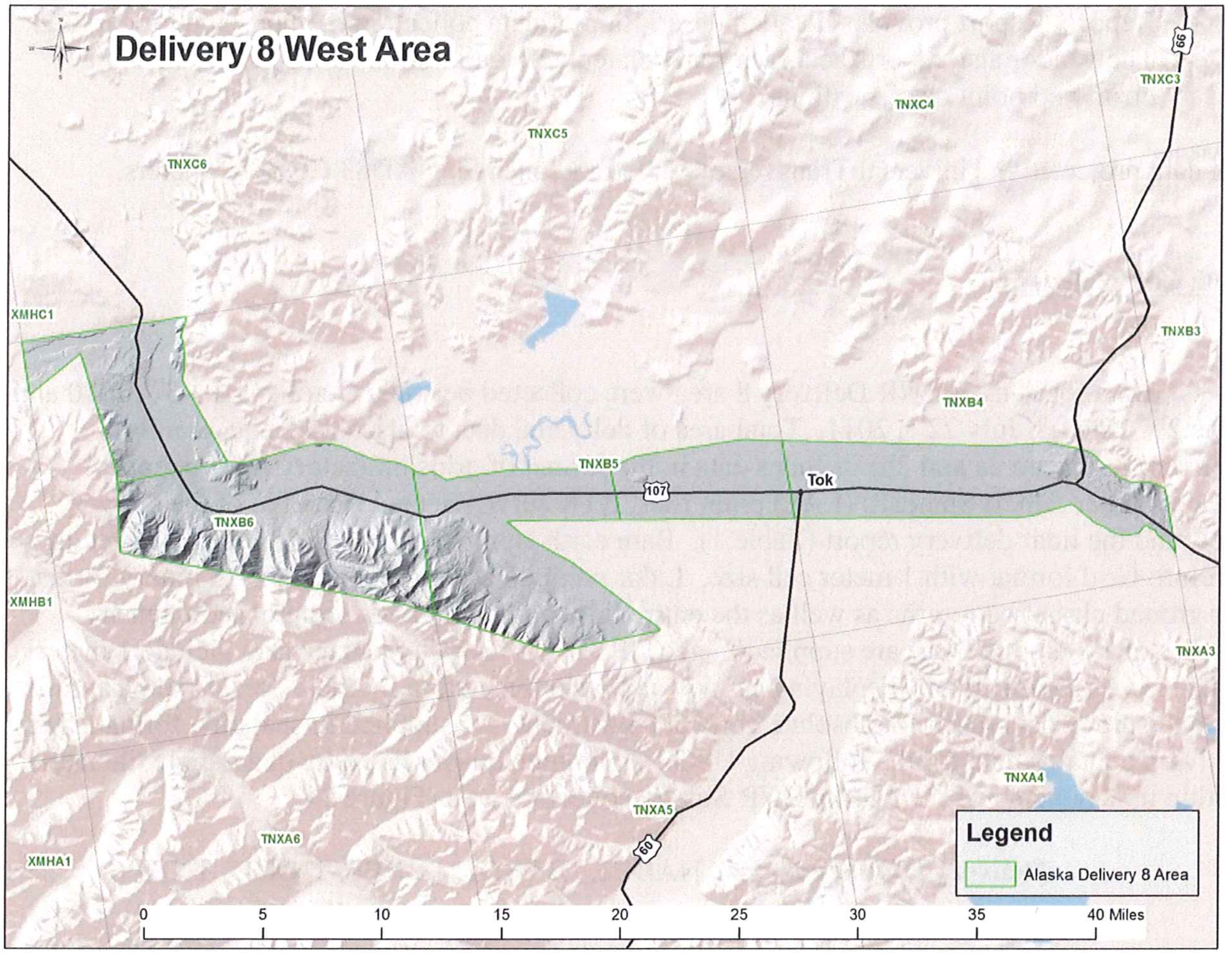

Figure 2a. Delivery 8 West Section location area. Data is referenced to USGS 7.5 minute quadrangles within the extents of the Alaska DNR Survey collection area.

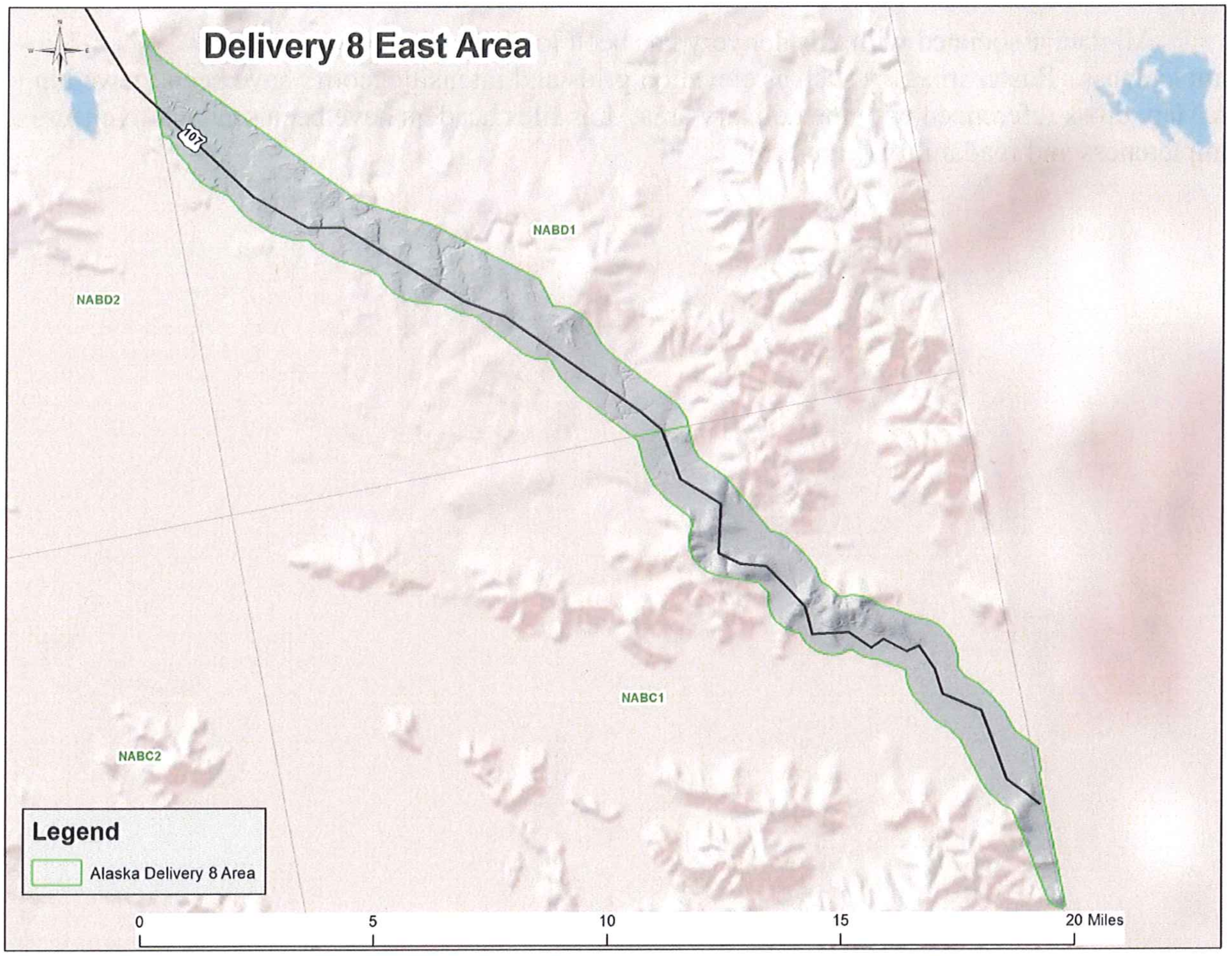

Figure 2b. Delivery 8 East Section location area. Data is referenced to USGS 7.5 minute quadrangles within the extents of the Alaska DNR Survey collection area.

FINAL Delivery	Resolution	Format	Tiling	
Bare Earth DEMs	1 meter	grid	quad	x
Highest Hit DEMs	1 meter	grid	quad	x
Trajectory files	1 sec	sbet /shape	flight	x
Intensity Images	1 meter?	tif	quad	x
LAS	8pts/m^2	las	tiled	x
Ground Returns	N/A	las	tiled	x
First return Vegetation Raster	1 meter	grid	quad	x
RTK point data		shape		x
Delivery Area shapefile		shape	quad	x
Report		pdf		x

Miscellaneous		Format	Tiling	
Processing bins		Shape dxf/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 headers have been scanned to ensure completeness and readability (Figure 3).

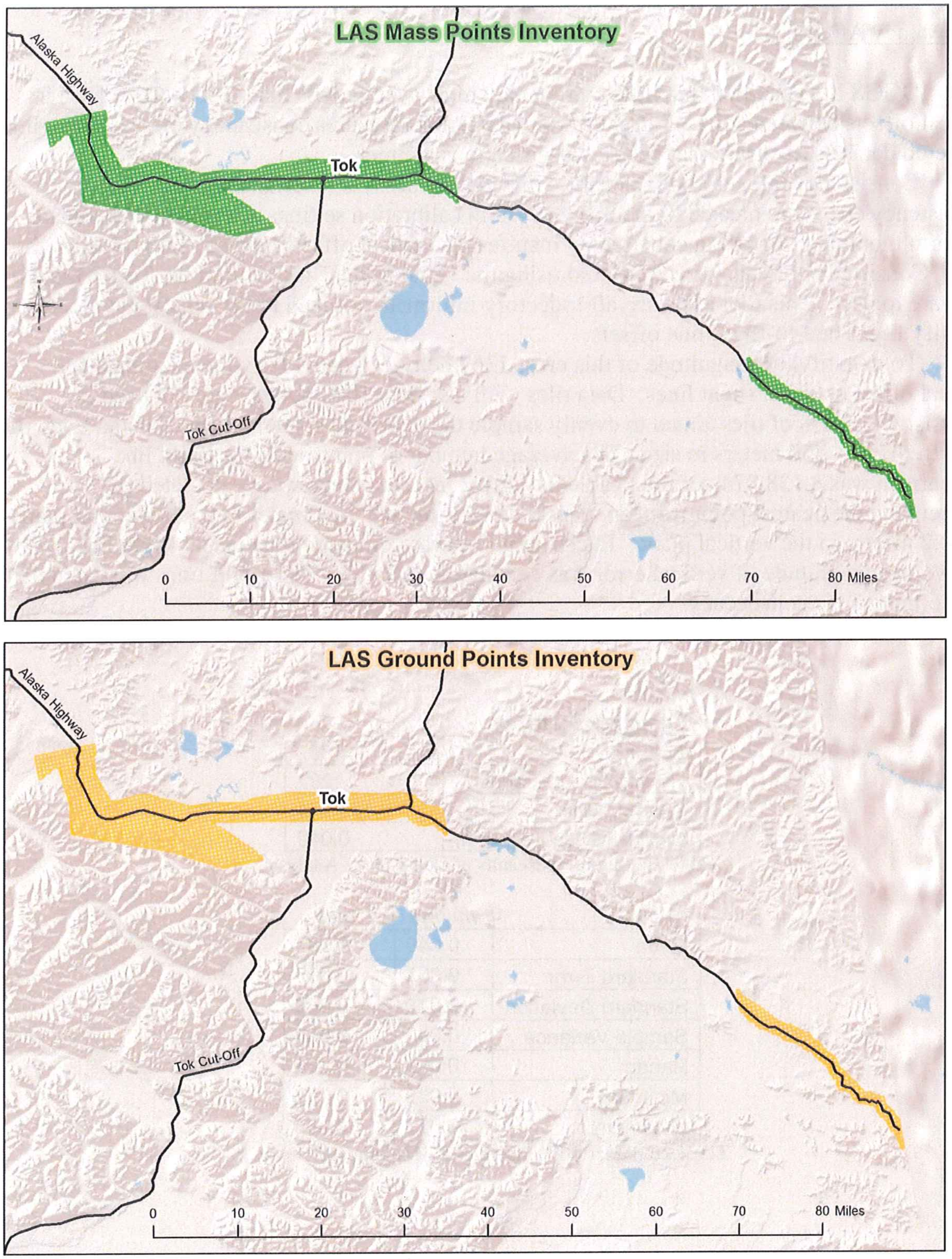

Figure 3. LIDAR Point Inventory graphic representing complete coverage of point data for both mass points and ground LAS files.

Consistency Analysis:

DGGS has specified that lidar consistency must average less than 0.15m (0.49 feet) in vertical offsets between adjacent 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 1367 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 8,138,874 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 291 flight lines were sampled and compared for consistency.

Summary Statistics

# of Tiles	1367
# of Flight Line Sections	291
Avg # of Points	8,138,874
Avg. Magnitude Z error (m)	0.040

Table 2a. Summary Results of Consistency Analysis

	meters	***feet***
Mean	0.040	0.132
Standard Error	0.001	0.002
Standard Deviation	0.012	0.040
Sample Variance	0.000	0.000
Range	0.051	0.166
Minimum	0.021	0.067
Maximum	0.071	0.233

Table 2b. Descriptive Statistics for Magnitude Z Error.

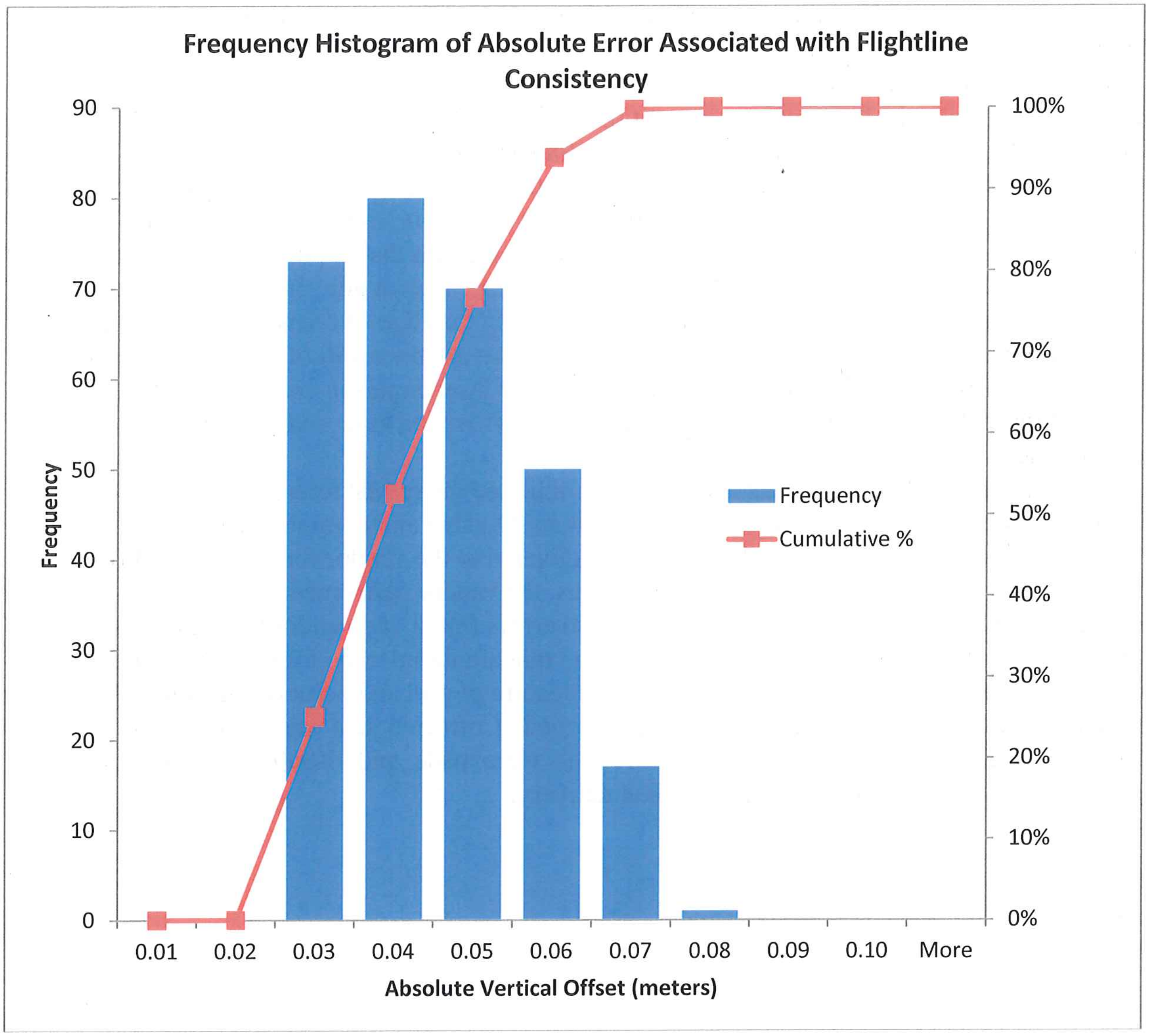

Figure 4. Histogram of flight line offsets values.

Results of the consistency analysis found the average flight line offset to be 0.040 meters with a maximum error of 0.071m (Table 2b). Distribution of error showed over 93% of all error was less than 0.06m and 99% was less than 0.07m (Figure 4). These results show that all data are within tolerances of data consistency according to contract agreement.

Visual Analysis

Lidar 1m 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 5). Both bare earth and highest hit

models were examined for calibration offsets, tiling artifacts (Figure 6), seam line offsets, pits (Figure 6), 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 5). 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 7). 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 5. 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.

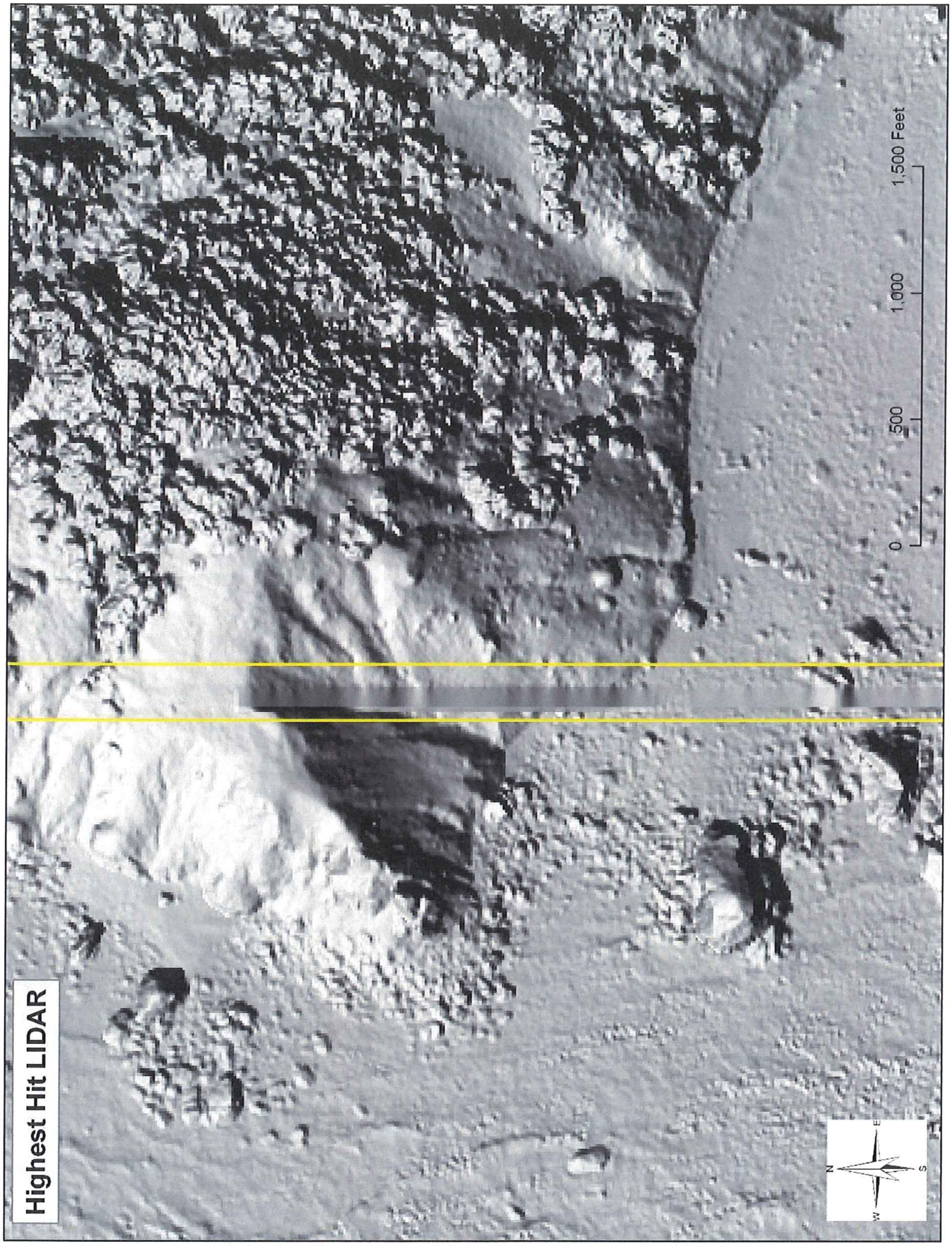

Figure 6. Example of tile artifact found in highest hit lidar data. Artifact is a seam line error created due to misclassification of ground at edge of lidar processing tiles.

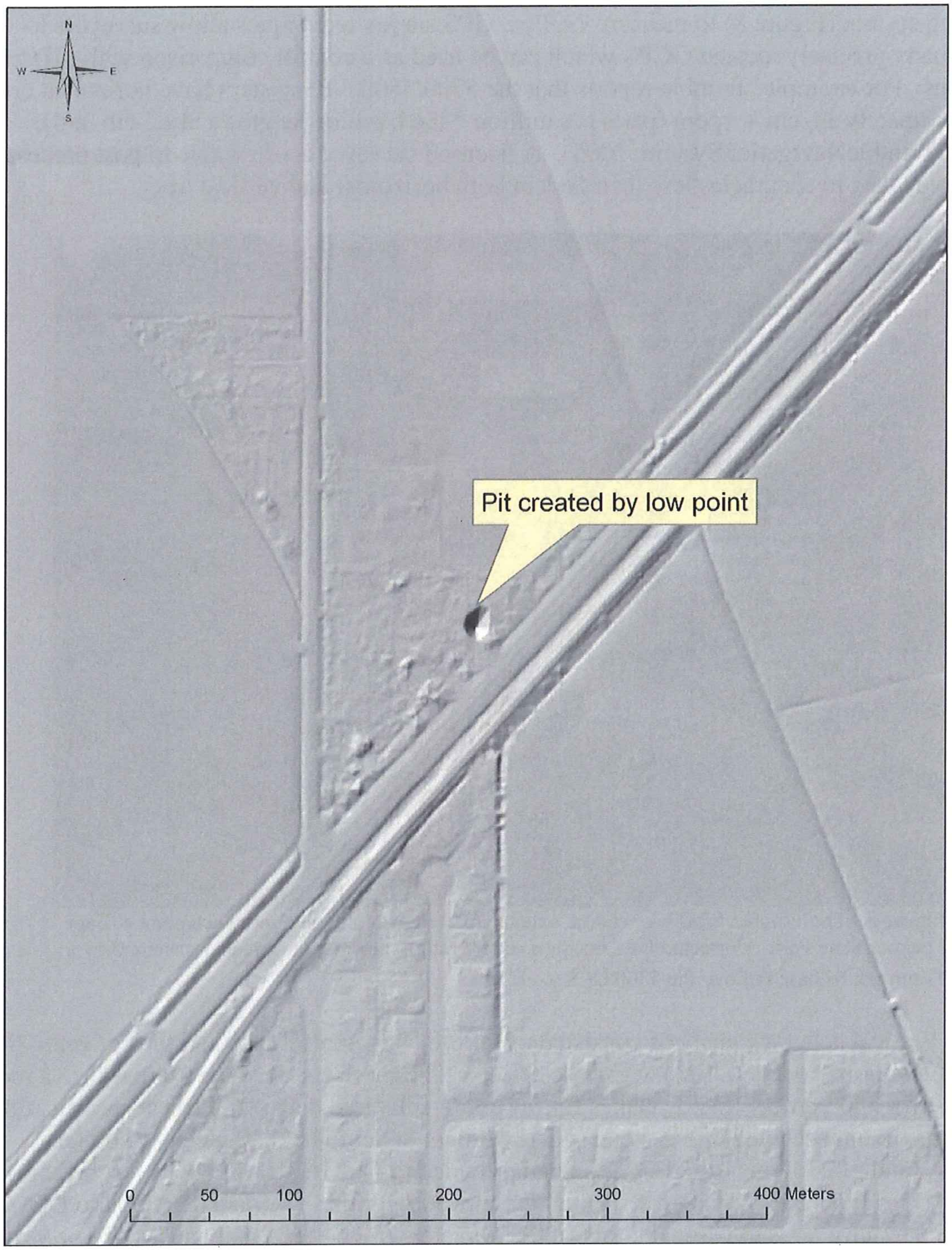

Figure 7. Example of "Pit" caused by low point in ground model. Pits are caused when standing water absorbs the lidar pulse. Pits are evident in ground model as the lowest point elevation is assigned to the grid cell value. Inversely the pit is not observable in the highest hit model as the highest point 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. The contractor used a surveying system (Figure 8) to measure GCP's. GPS survey techniques allow surveyors to collect many precisely located GCP's which can be used as a control comparison with LiDAR elevations. 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). A licensed surveyor is often able to post process GPS survey data to accuracies less than 1cm in both horizontal and vertical axes.

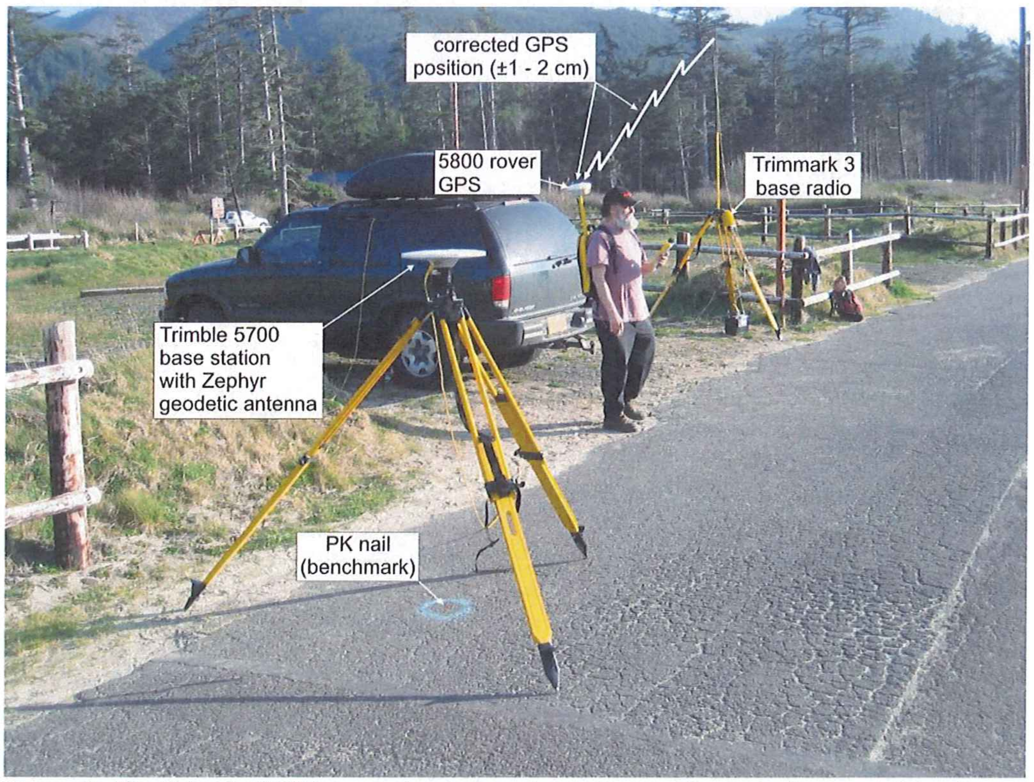

Figure 8. The Trimble 5700 base station antenna located over a known reference point at Cape Lookout State Park. Corrected GPS position and elevation information is then transmitted by a Trimmark III base radio to the 5800 GPS rover unit.

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 values for the entire delivered data set. Project specifications list the maximum acceptable root mean square vertical offset to be 0.20 meters (0.65 feet).

A total of 2442 measured GCP's were provided to DOGAMI by DGGS for the Delivery 8 region (Figure 9) and compared with the lidar elevation grids. The data delivered to DOGAMI was found to have a mean vertical offset of 0.020 meters (0.064 feet) and an RMSE value of 0.037 meters (0.122 ft). Offset values ranged from -0.105 to 0.137 meters (Table 3 and Figure 10).

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.

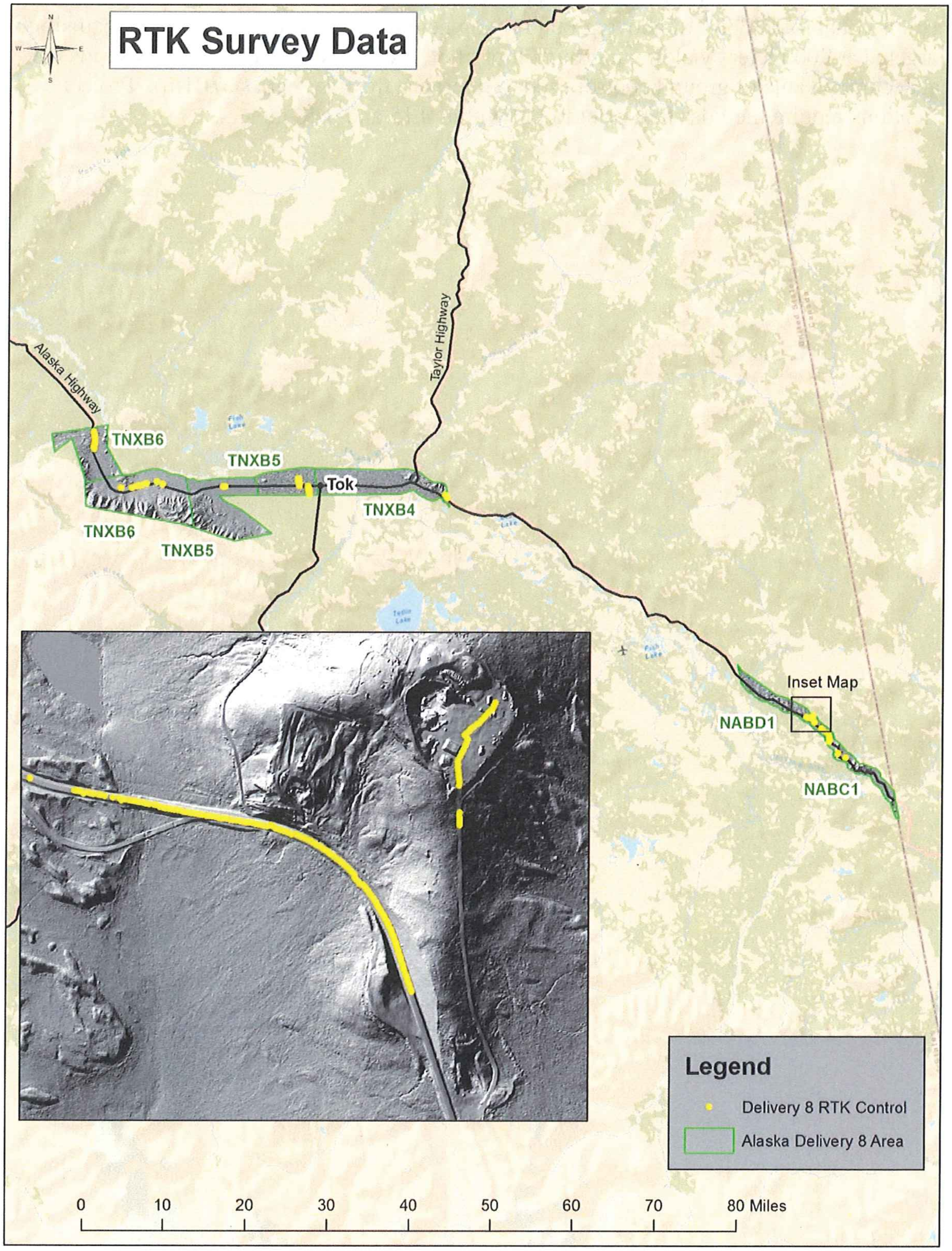

Figure 9. Locations of RTK control surveyed by Contractor. Data was used to test absolute accuracy for the Alaska DNR lidar survey within the Delivery 8 extent.

	Meters	*Feet*
Mean	0.020	0.064
Standard Error	0.001	0.002
Standard Deviation	0.032	0.104
Range	0.242	0.794
Minimum	-0.105	-0.344
Maximum	0.137	0.450
RMSE	0.037	0.122

Table 3. Descriptive Statistics for absolute value vertical offsets.

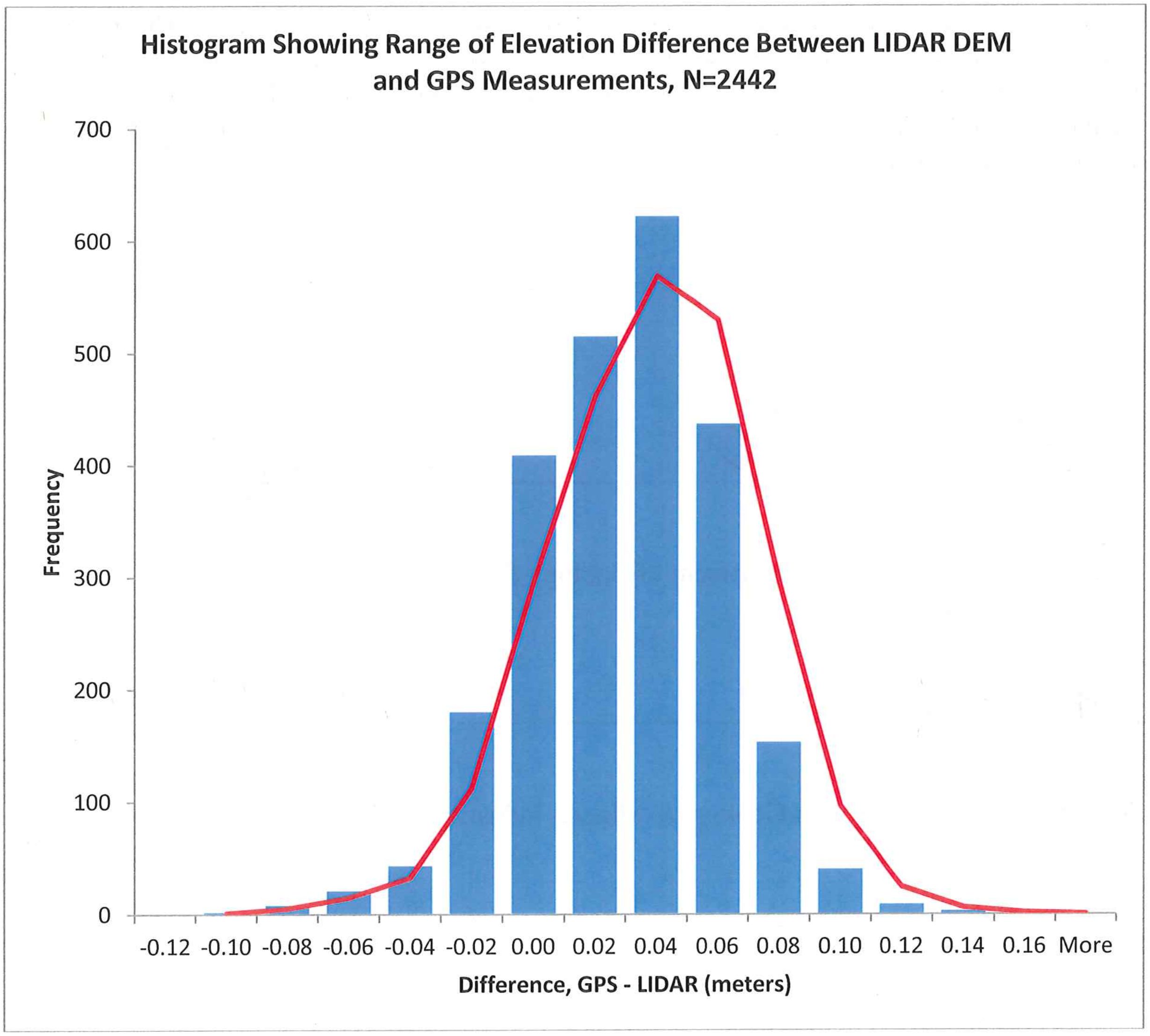

Figure 10. Histogram of elevation difference between Lidar DEM and GPS survey data.

Acceptance

The data described in this report meets or exceeds project specifications laid out in the contracted data standards agreement. All the required files for the delivery have been received as of December 16th, 2011, and are correctly named and useable. 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 quality control 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 Signature

________________________________ Date: 12/16/2011

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

________________________________ Date: 12/16/2011

Ian Madin
Chief Scientist – Department of Geology & Mineral Industries

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

Alaska DNR LIDAR Project, 2011 – Delivery 9 QC Analysis

LIDAR QC Report – January 13thth, 2012

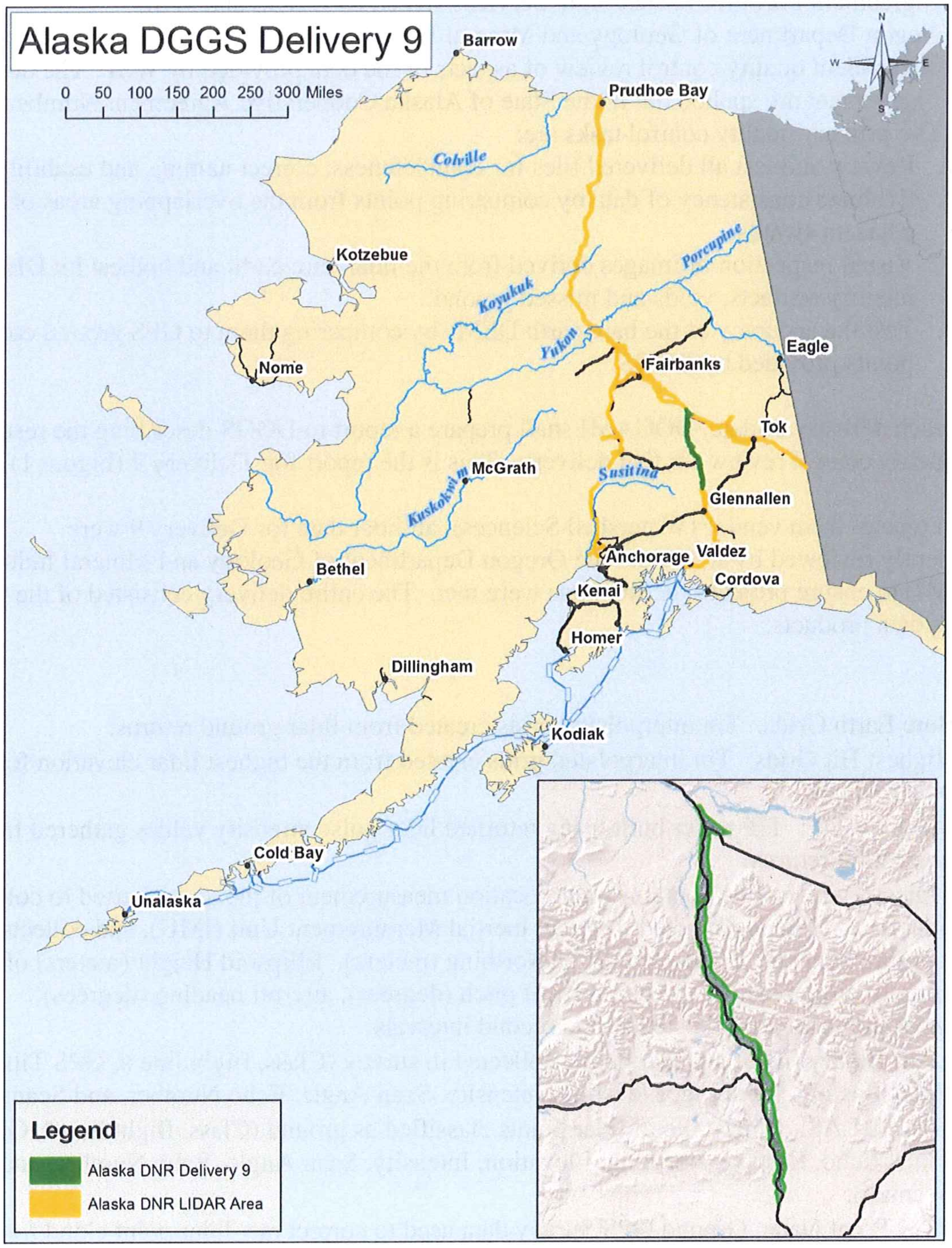

Figure 1. Map featuring Alaska DNR Delivery 9 data extent.

The Alaska Department of Natural Resources, Division of Geological and Geophysical Survey (DGGS) has contracted with Watershed Sciences, Inc (WSI) to collect high resolution lidar topographic data for a swath roughly parallel to proposed future pipeline rights of way. DGGS has specified the exact areas of data collection as well as a detailed description of data products to be delivered. The complete specifications are detailed in the September 14, 2010 Standard Agreement Form for Professional Services signed by DGGS and WSI.

The Oregon Department of Geology and Mineral Industries has contracted with DGGS to provide independent quality control review of aspects of the data provided by WSI. The details of the QC agreement are spelled out in the State of Alaska Cooperative Agreement Number MI-11-006. The primary quality control tasks are:

1. Review and test all delivered files for completeness, correct naming and usability.
2. Evaluate consistency of data by comparing points from the overlapping areas of adjacent swaths.
3. Visual inspection of images derived from the lidar bare earth and highest hit DEMs to identify artifacts, voids and missed ground.
4. Test the accuracy of the bare earth DEMs by comparing them to GPS ground control points provided by DGGS.

For each delivery of data, DOGAMI shall prepare a report to DGGS describing the results of the quality control review for that delivery. This is the report for Delivery 9 (Figure 1).

Upon receipt from vendor (Watershed Sciences), all lidar data for Delivery 9 were independently reviewed by staff from the Oregon Department of Geology and Mineral Industries (DOGAMI) to ensure project specifications were met. The entire delivery consisted of the following data products:

- 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.
- 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 Universal Transverse Mercator (Zones 6), NAD83 CORS96 meters.

Data Completeness

Data for Alaska DNR Delivery 9 area were collected between May20th and July 6th, 2011. Total area of delivered data totals 276.22 square miles. Delivery 9 (Figure 2) includes data in the format of grids, trajectory files, intensity images, Lidar ASCII Standard (LAS) point files, 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 1 meter cell size. Lidar point data are delivered in LAS binary format for ground classified returns as well as the entire lidar point cloud. Georeferenced intensity images of 1 meter cell size are supplied in geoTIF format. Supplementary data include 1 meter cell size vegetation rasters displaying canopy and other vegetation metrics. Real time kinematic ground survey data (used for absolute vertical adjustment) are supplied in shapefile format. This delivery contains data for the following USGS 7.5 minute quads (listed by quadrangle tile name within the boundary of the Alaska DNR Survey collection area (Figure 2):

Delivery 9 Quadrangles: GULC3, GULC4, GULD3, GULD4, XBDA4, XMHA3, XMHA4, XMHB4, XMHC4, XMHD4

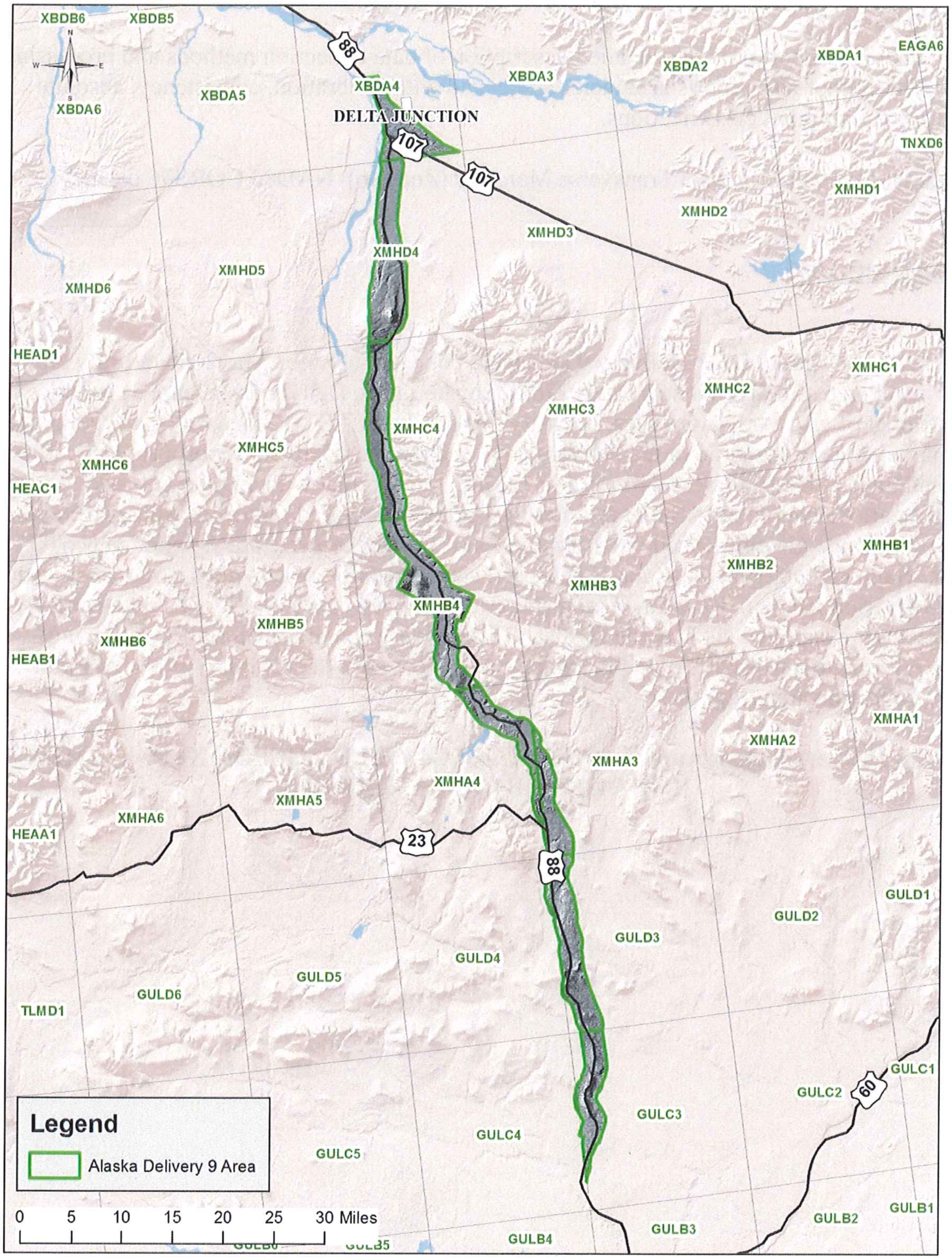

Figure 2. Delivery 9 location area. Data is referenced to USGS 7.5 minute quadrangles within the extents of the Alaska DNR Survey collection area

FINAL Delivery	Resolution	Format	Tiling	
Bare Earth DEMs	1 meter	grid	quad	x
Highest Hit DEMs	1 meter	grid	quad	x
Trajectory files	1 sec	sbet /shape	flight	x
Intensity Images	1 meter?	tif	quad	x
LAS	8pts/m^2	las	tiled	x
Ground Returns	N/A	las	tiled	x
First return Vegetation Raster	1 meter	grid	quad	x
RTK point data		shape		x
Delivery Area shapefile		shape	quad	x
Report		pdf		x

Miscellaneous		Format	Tiling	
Processing bins		Shape dxf/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 headers have been scanned to ensure completeness and readability (Figure 3).

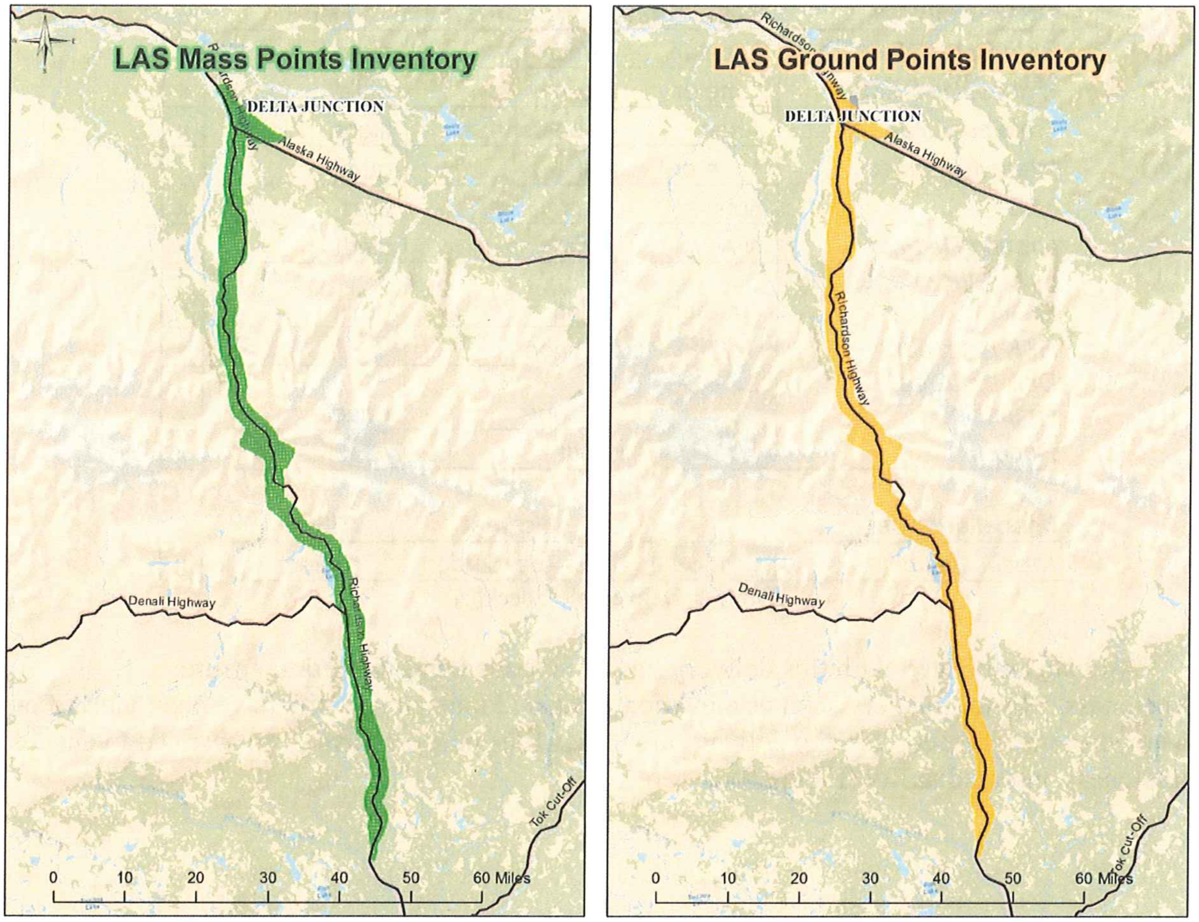

Figure 3. LIDAR Point Inventory graphic representing complete coverage of point data for both mass points and ground LAS files.

Consistency Analysis:

DGGS has specified that lidar consistency must average less than 0.15m (0.49 feet) in vertical offsets between adjacent 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 1555 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 1,277,206 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 311 flight lines were sampled and compared for consistency.

Summary Statistics

# of Tiles	1555
# of Flight Line Sections	311
Avg # of Points	1,277,206
Avg. Magnitude Z error (m)	0.017

Table 2a. Summary Results of Consistency Analysis

	meters	***feet***
Mean	0.017	0.056
Standard Error	0.000	0.001
Standard Deviation	0.003	0.010
Sample Variance	0.000	0.000
Range	0.021	0.070
Minimum	0.010	0.032
Maximum	0.031	0.103

Table 2b. Descriptive Statistics for Magnitude Z Error.

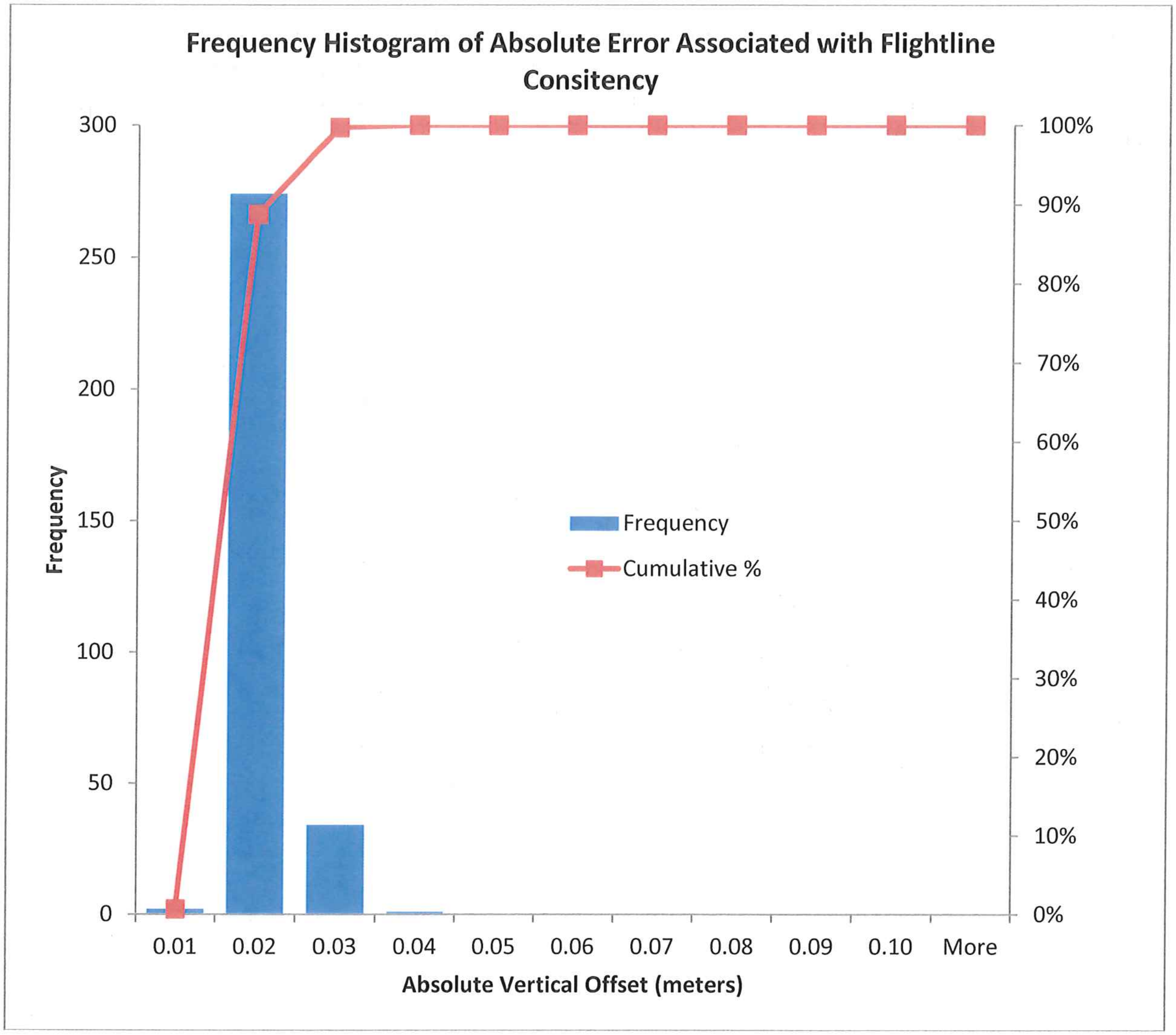

Figure 4. Histogram of flight line offsets values.

Results of the consistency analysis found the average flight line offset to be 0.017 meters with a maximum error of 0.031m (Table 2b). Distribution of error showed over 99% of all error was less than 0.03m (Figure 4). These results show that all data are within tolerances of data consistency according to contract agreement.

Visual Analysis

Lidar 1m 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 5). Both bare earth and highest hit models were examined for calibration offsets, tiling artifacts (Figure 6), seam line offsets, pits (Figure 6), 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 5). 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 7). 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 5. 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.

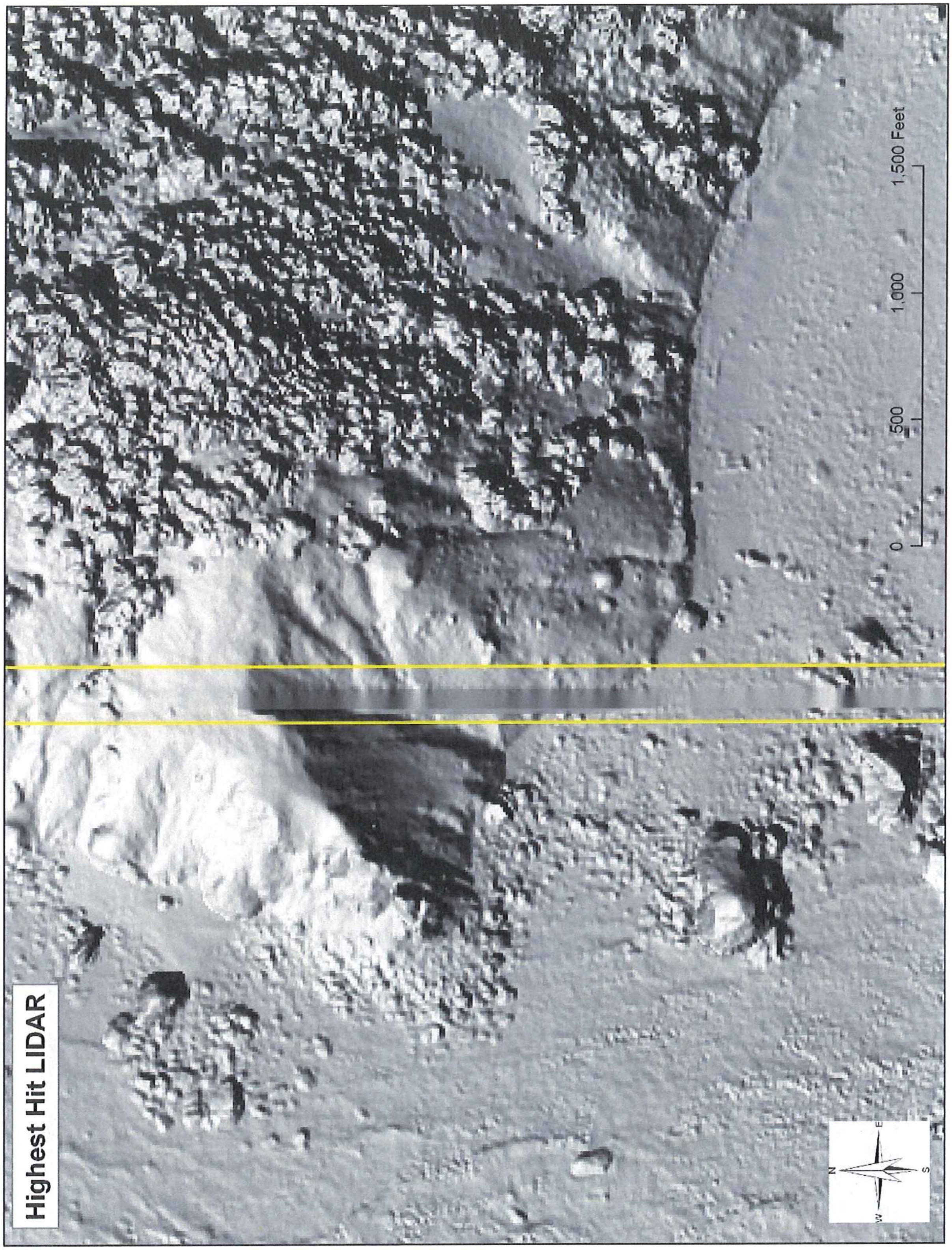

Figure 6. Example of tile artifact found in highest hit lidar data. Artifact is a seam line error created due to misclassification of ground at edge of lidar processing tiles.

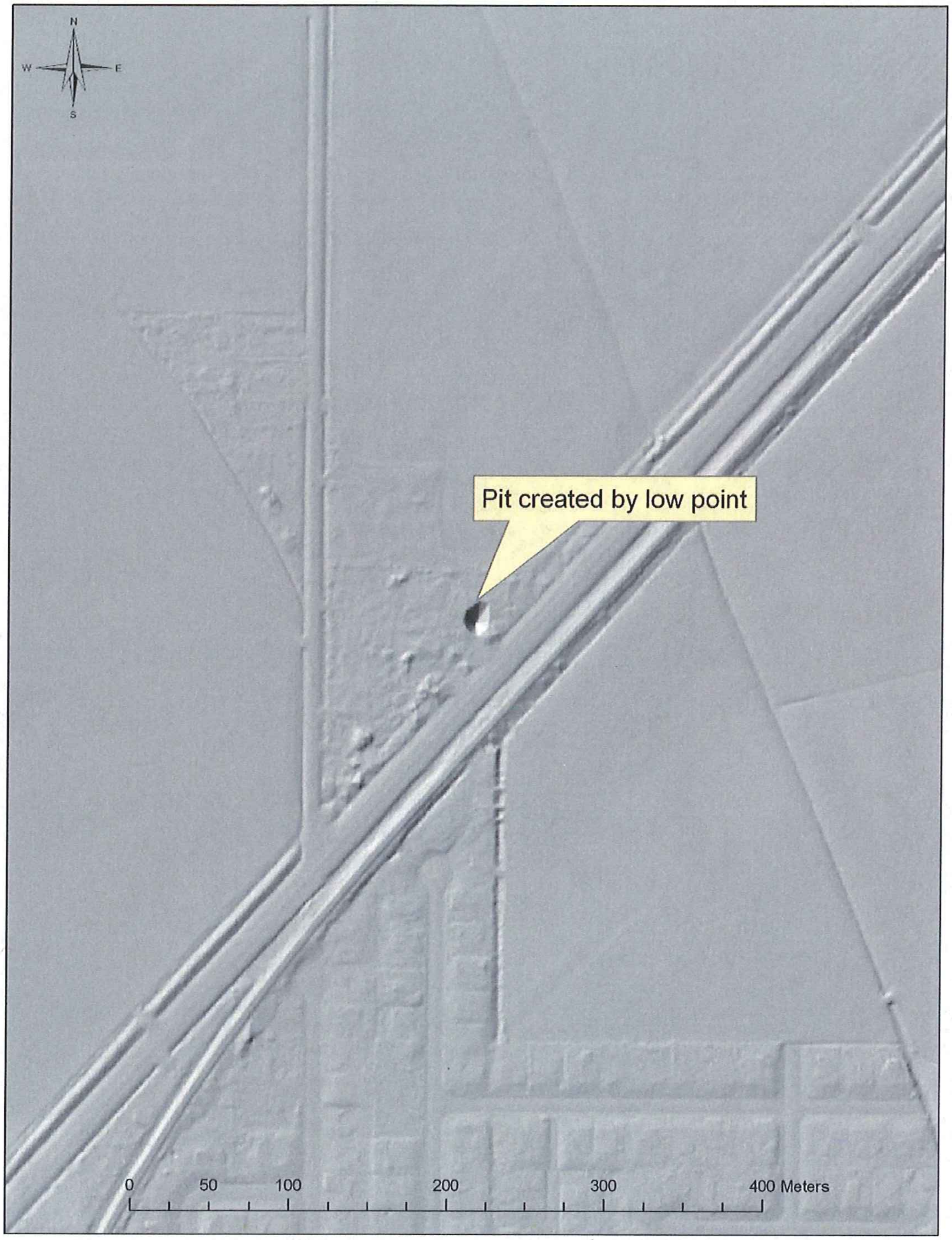

Figure 7. Example of "Pit" caused by low point in ground model. Pits are caused when standing water absorbs the lidar pulse. Pits are evident in ground model as the lowest point elevation is assigned to the grid cell value. Inversely the pit is not observable in the highest hit model as the highest point 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. The contractor used a surveying system (Figure 8) to measure GCP's. GPS survey techniques allow surveyors to collect many precisely located GCP's which can be used as a control comparison with LiDAR elevations. 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). A licensed surveyor is often able to post process GPS survey data to accuracies less than 1cm in both horizontal and vertical axes.

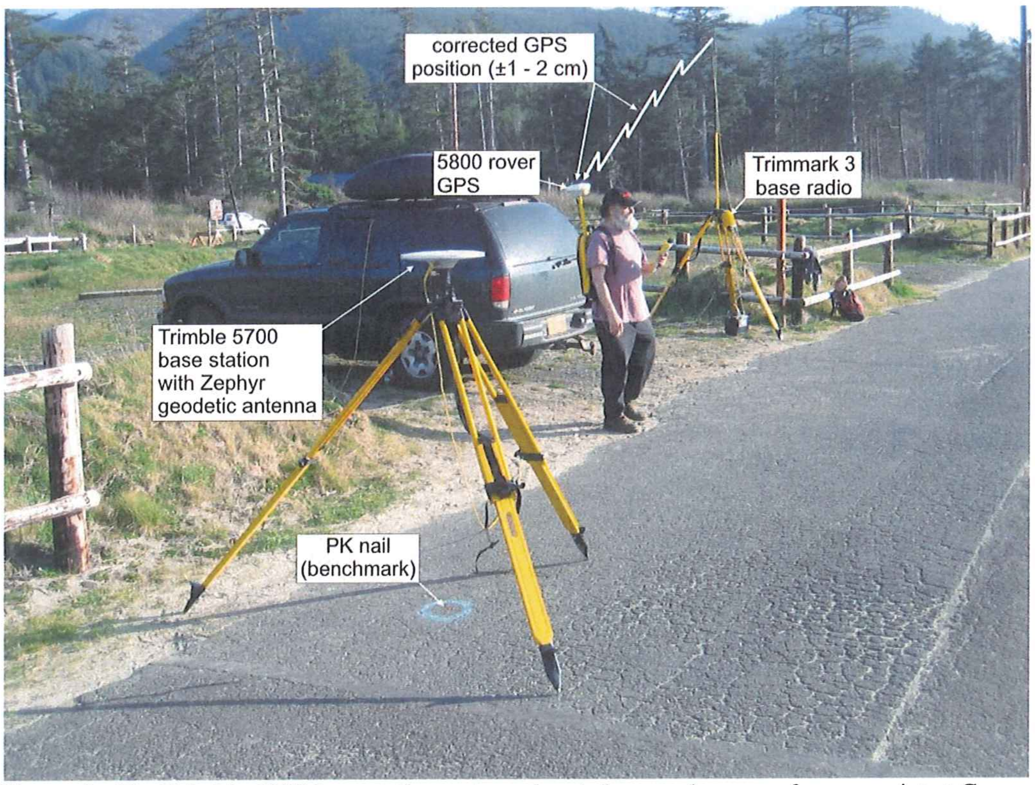

Figure 8. The Trimble 5700 base station antenna located over a known reference point at Cape Lookout State Park. Corrected GPS position and elevation information is then transmitted by a Trimmark III base radio to the 5800 GPS rover unit.

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 values for the entire delivered data set. Project specifications list the maximum acceptable root mean square vertical offset to be 0.20 meters (0.65 feet).

A total of 1663 measured GCP's were provided to DOGAMI by DGGS for the Delivery 9 region (Figure 9) and compared with the lidar elevation grids. The data delivered to DOGAMI was found to have a mean vertical offset of -0.014 meters (-0.047 feet) and an RMSE value of 0.041 meters (0.133 ft). Offset values ranged from -0.113 to 0.135 meters (Table 3 and Figure 10).

The distribution of error for this delivery shows two peaks, one centered around 0.04 meters and another centered around -0.10 meters (Figure 10). This double peak is due to an isolated area (Figure 9 upper inset) of error associated with either airborne GPS Z drift, vertical change due to freeze thaw mechanics, or simple survey error. Other survey control data near the place of isolated area is accurate within a mean 0.027 meters and there is no detectable step in the data.

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.

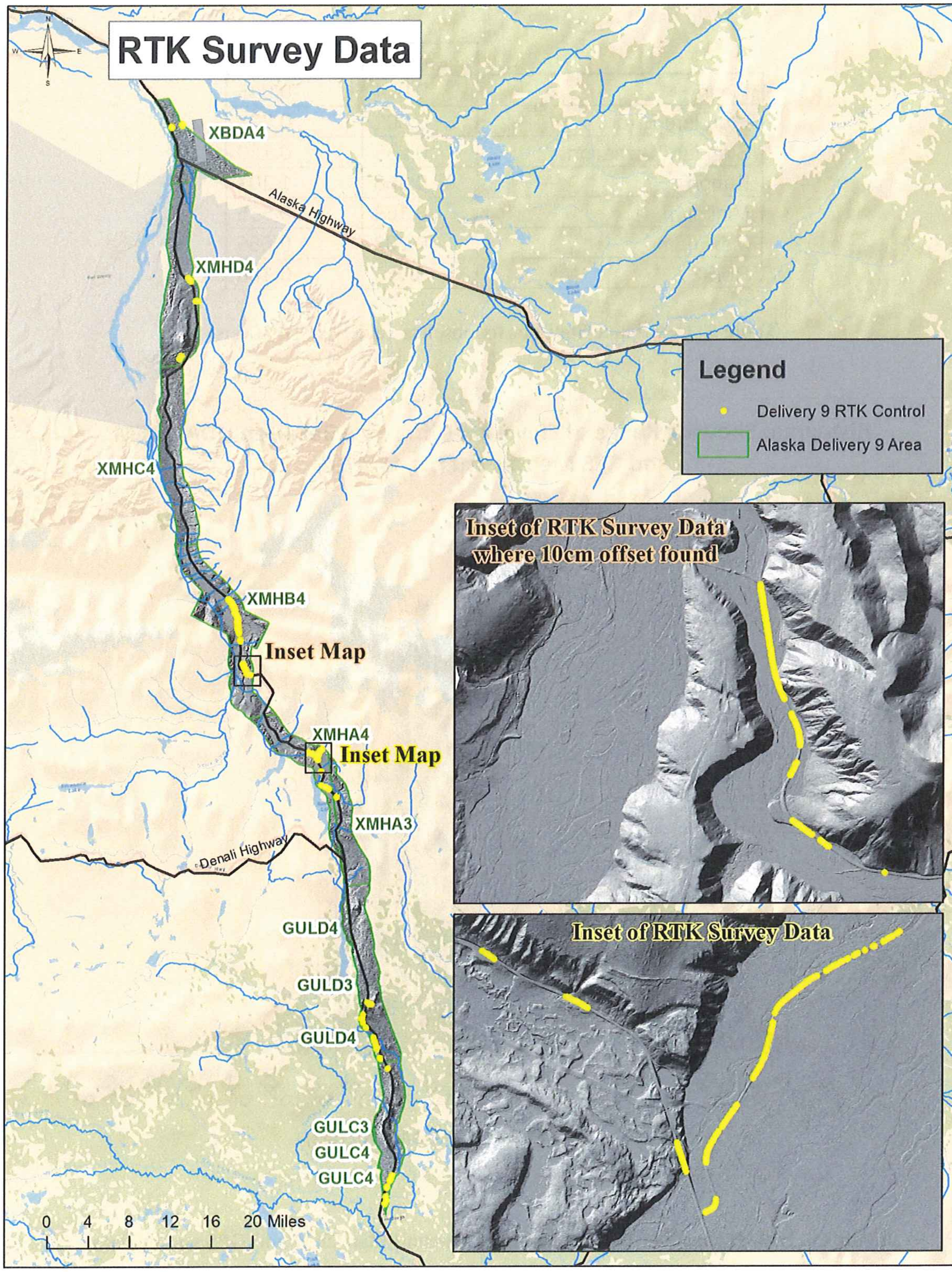

Figure 9. Locations of RTK control surveyed by Contractor. Data was used to test absolute accuracy for the Alaska DNR lidar survey within the Delivery 9 extent.

	Meters	*Feet*
Mean	0.014	0.045
Standard Error	0.001	0.003
Standard Deviation	0.055	0.180
Range	0.366	1.201
Minimum	-0.163	-0.535
Maximum	0.203	0.666
RMSE	0.057	0.186

Table 3. Descriptive Statistics for absolute value vertical offsets.

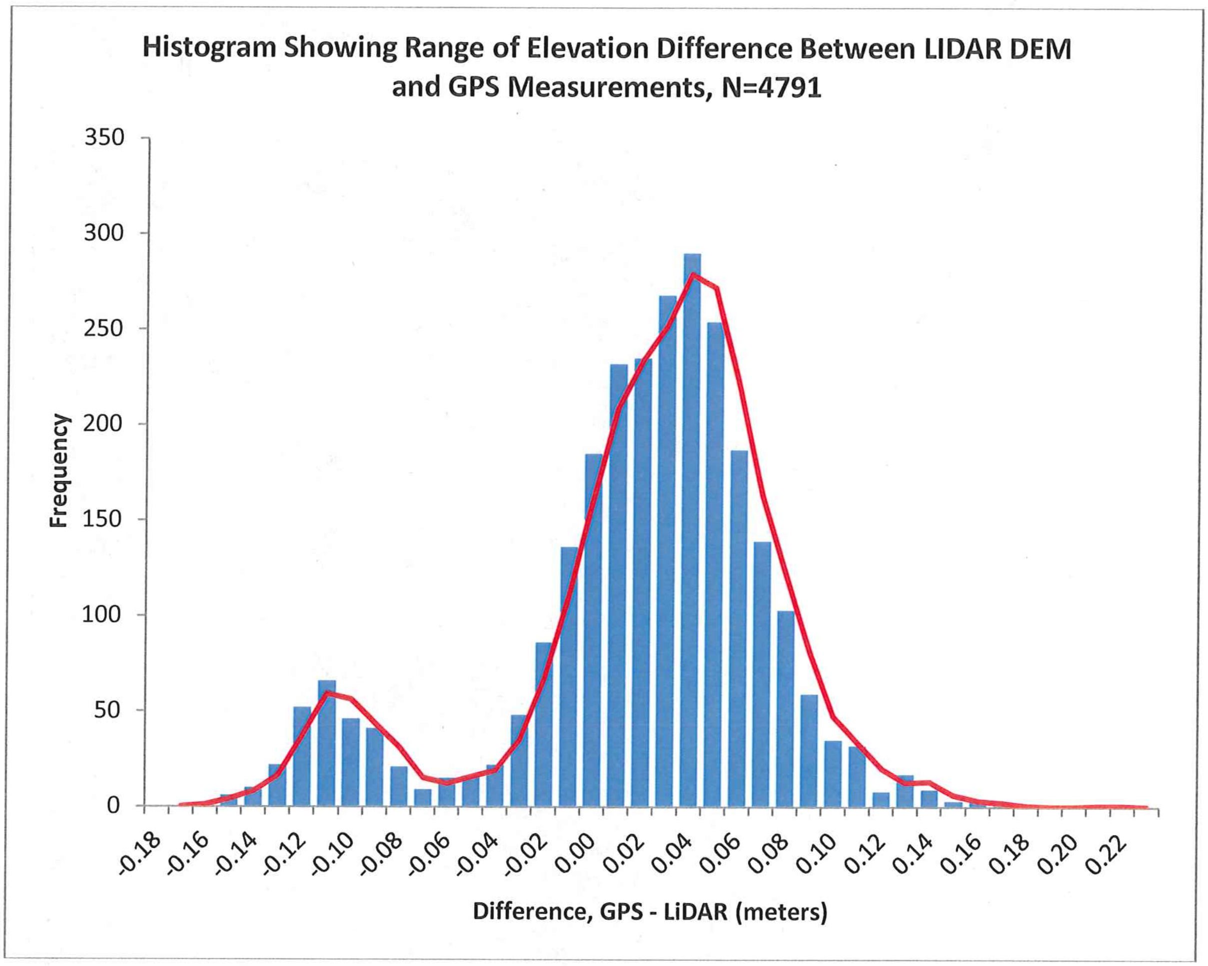

Figure 10. Histogram of elevation difference between Lidar DEM and GPS survey data.

Acceptance

The data described in this report meets or exceeds project specifications laid out in the contracted data standards agreement. All the required files for the delivery have been received as of January 13th, 2012, and are correctly named and useable. 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 quality control 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 Signature

____ Date: 1/13/2012

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

____ Date: 1/13/2012

Ian Madin
Chief Scientist – Department of Geology & Mineral Industries

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

Alaska DNR LIDAR Project, 2011 – Delivery 10 QC Analysis

LIDAR QC Report – March 19th, 2012

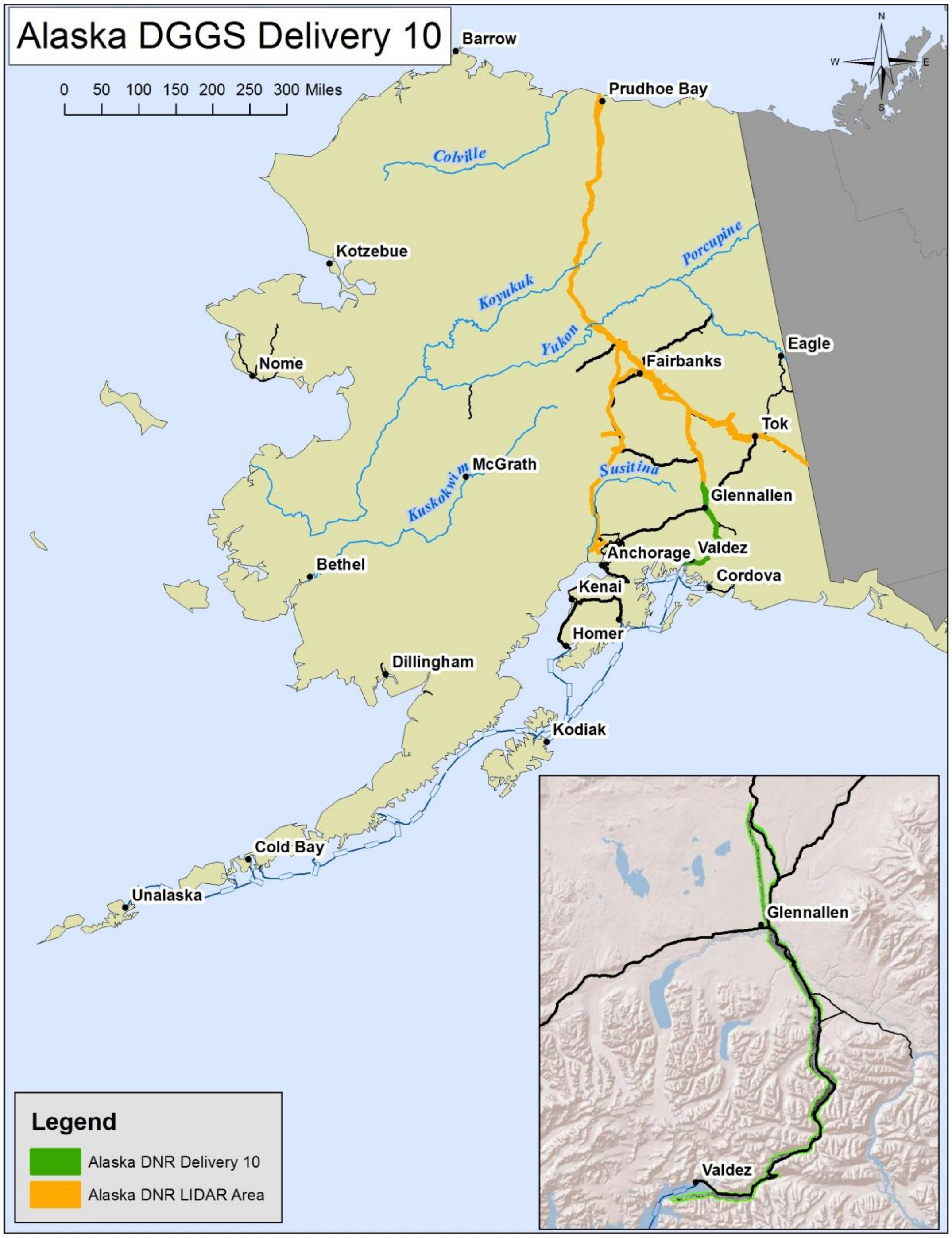

Figure 1. Map featuring Alaska DNR Delivery 10 data extent.

The Alaska Department of Natural Resources, Division of Geological and Geophysical Survey (DGGS) has contracted with Watershed Sciences, Inc (WSI) to collect high resolution lidar topographic data for a swath roughly parallel to proposed future pipeline rights of way. DGGS has specified the exact areas of data collection as well as a detailed description of data products to be delivered. The complete specifications are detailed in the September 14, 2010 Standard Agreement Form for Professional Services signed by DGGS and WSI.

The Oregon Department of Geology and Mineral Industries has contracted with DGGS to provide independent quality control review of aspects of the data provided by WSI. The details of the QC agreement are spelled out in the State of Alaska Cooperative Agreement Number MI-11-006. The primary quality control tasks are:

1. Review and test all delivered files for completeness, correct naming and usability.
2. Evaluate consistency of data by comparing points from the overlapping areas of adjacent swaths.
3. Visual inspection of images derived from the lidar bare earth and highest hit DEMs to identify artifacts, voids and missed ground.
4. Test the accuracy of the bare earth DEMs by comparing them to GPS ground control points provided by DGGS.

For each delivery of data, DOGAMI shall prepare a report to DGGS describing the results of the quality control review for that delivery. This is the report for Delivery 10 (Figure 1).

Upon receipt from vendor (Watershed Sciences), all lidar data for Delivery 10 were independently reviewed by staff from the Oregon Department of Geology and Mineral Industries (DOGAMI) to ensure project specifications were met. The entire delivery consisted of the following data products:

- 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.
- 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 Universal Transverse Mercator (Zones 6), NAD83 CORS96 meters.

Data Completeness

Data for Alaska DNR Delivery 10 area were collected between May 31st and July 15th, 2011. Total area of delivered data totals 277.71 square miles. Delivery 10 (Figure 2) includes data in the format of grids, trajectory files, intensity images, Lidar ASCII Standard (LAS) point files, 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 1 meter cell size. Lidar point data are delivered in LAS binary format for ground classified returns as well as the entire lidar point cloud. Georeferenced intensity images of 1 meter cell size are supplied in geoTIF format. Supplementary data include 1 meter cell size vegetation rasters displaying canopy and other vegetation metrics. Real time kinematic ground survey data (used for absolute vertical adjustment) are supplied in shapefile format. This delivery contains data for the following USGS 7.5 minute quads (listed by quadrangle tile name within the boundary of the Alaska DNR Survey collection area (Figure 2):

Delivery 10 Quadrangles: GULA3, GULA4, GULB3, GULB4, GULC3, GULC4, VALA4, VALA5, VALA6, VALA7, VALB3, VALB4, VAC4, VALD4

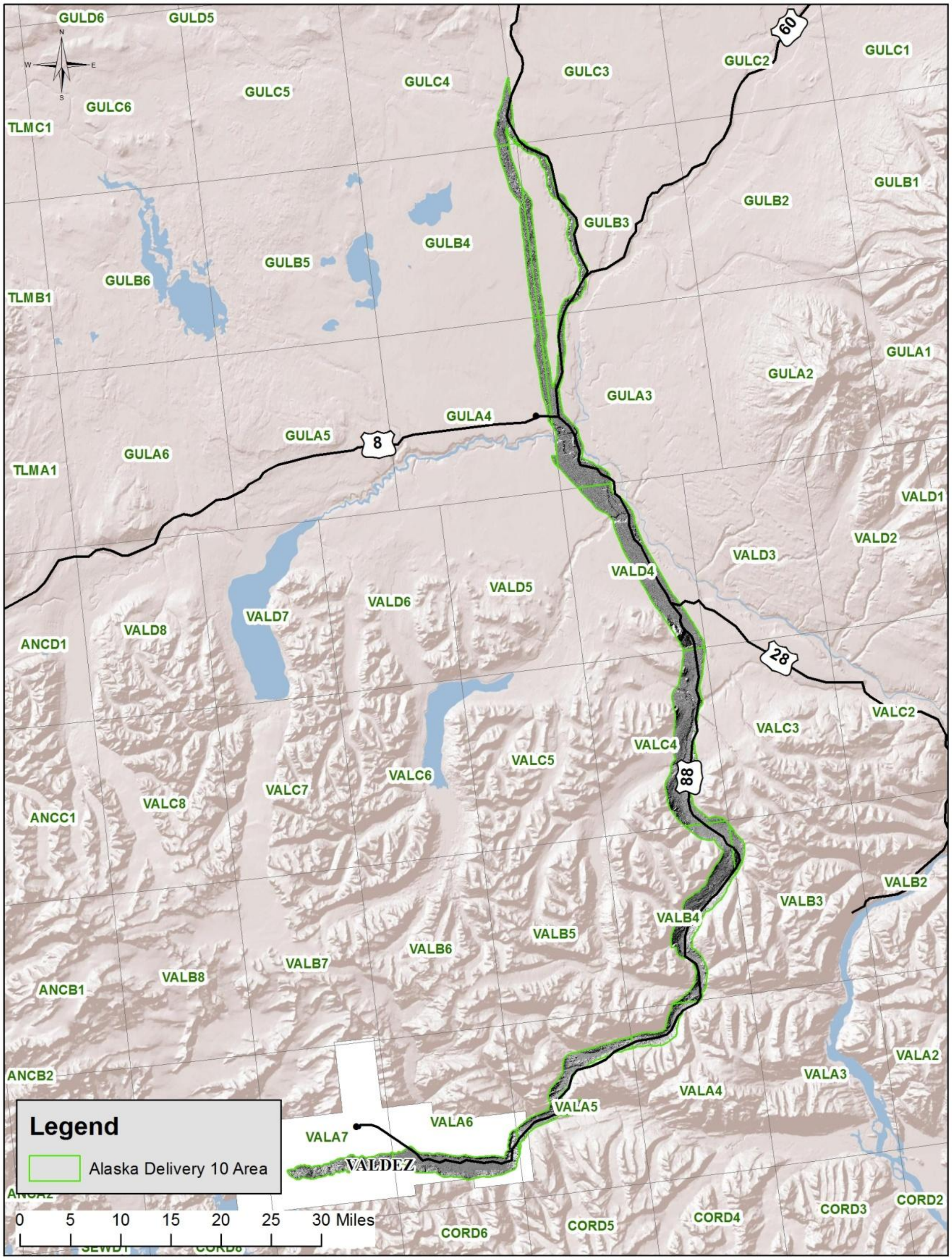

Figure 2. Delivery 10 location area. Data is referenced to USGS 7.5 minute quadrangles within the extents of the Alaska DNR Survey collection area

FINAL Delivery	Resolution	Format	Tiling	
Bare Earth DEMs	1 meter	grid	quad	x
Highest Hit DEMs	1 meter	grid	quad	x
Trajectory files	1 sec	sbet /shape	flight	x
Intensity Images	1 meter?	tif	quad	x
LAS	8pts/m^2	las	tiled	x
Ground Returns	N/A	las	tiled	x
First return Vegetation Raster	1 meter	grid	quad	x
RTK point data		shape		x
Delivery Area shapefile		shape	quad	x
Report		pdf		x

Miscellaneous		Format	Tiling	
Processing bins		Shape dxf/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 headers have been scanned to ensure completeness and readability (Figure 3).

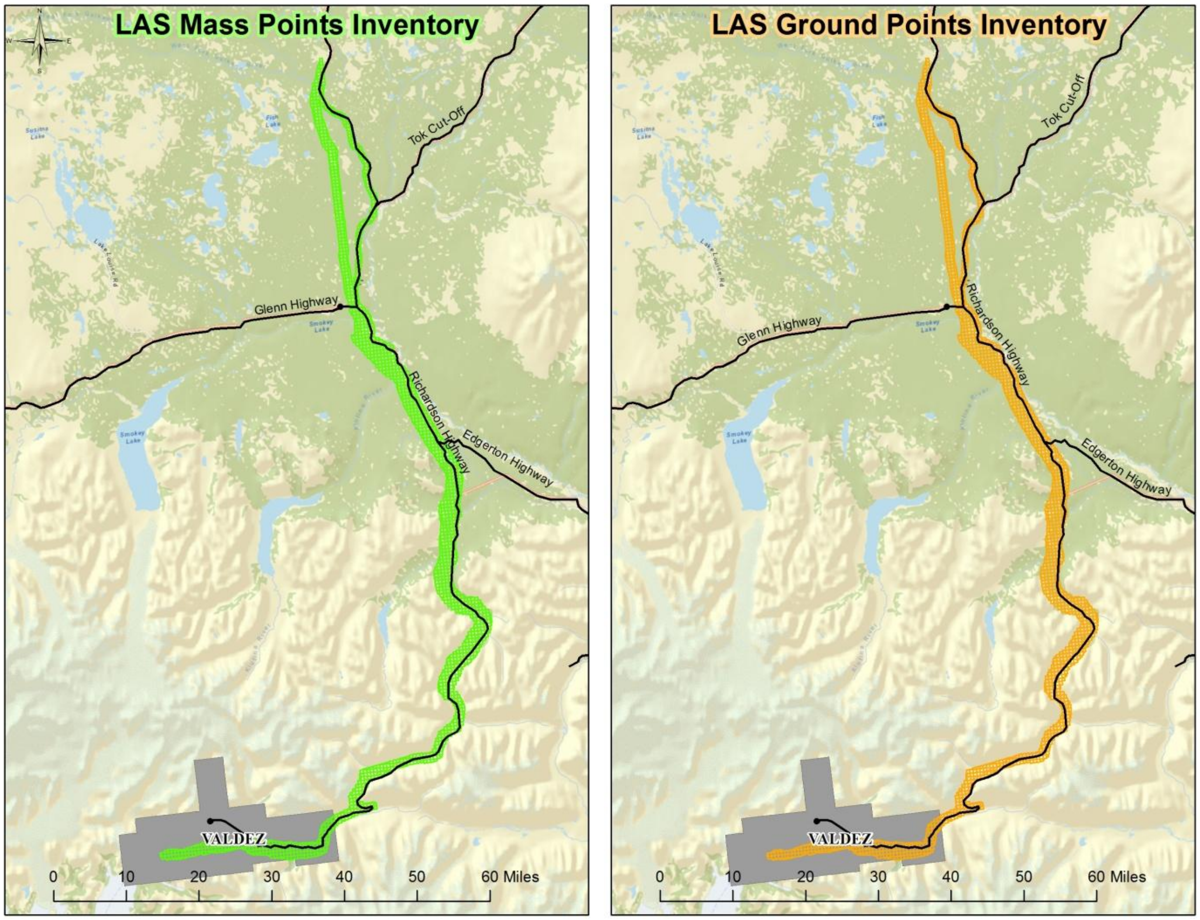

Figure 3. LIDAR Point Inventory graphic representing complete coverage of point data for both mass points and ground LAS files.

Consistency Analysis:

DGGS has specified that lidar consistency must average less than 0.15m (0.49 feet) in vertical offsets between adjacent 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 1746 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 3,517,476 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 483 flight lines were sampled and compared for consistency.

Summary Statistics

# of Tiles	1746
# of Flight Line Sections	483
Avg # of Points	3,517,476
Avg. Magnitude Z error (m)	0.041

Table 2a. Summary Results of Consistency Analysis

	meters	***feet***
Mean	0.041	0.136
Standard Error	0.000	0.002
Standard Deviation	0.010	0.034
Sample Variance	0.000	0.000
Range	0.054	0.177
Minimum	0.025	0.082
Maximum	0.079	0.260

Table 2b. Descriptive Statistics for Magnitude Z Error.

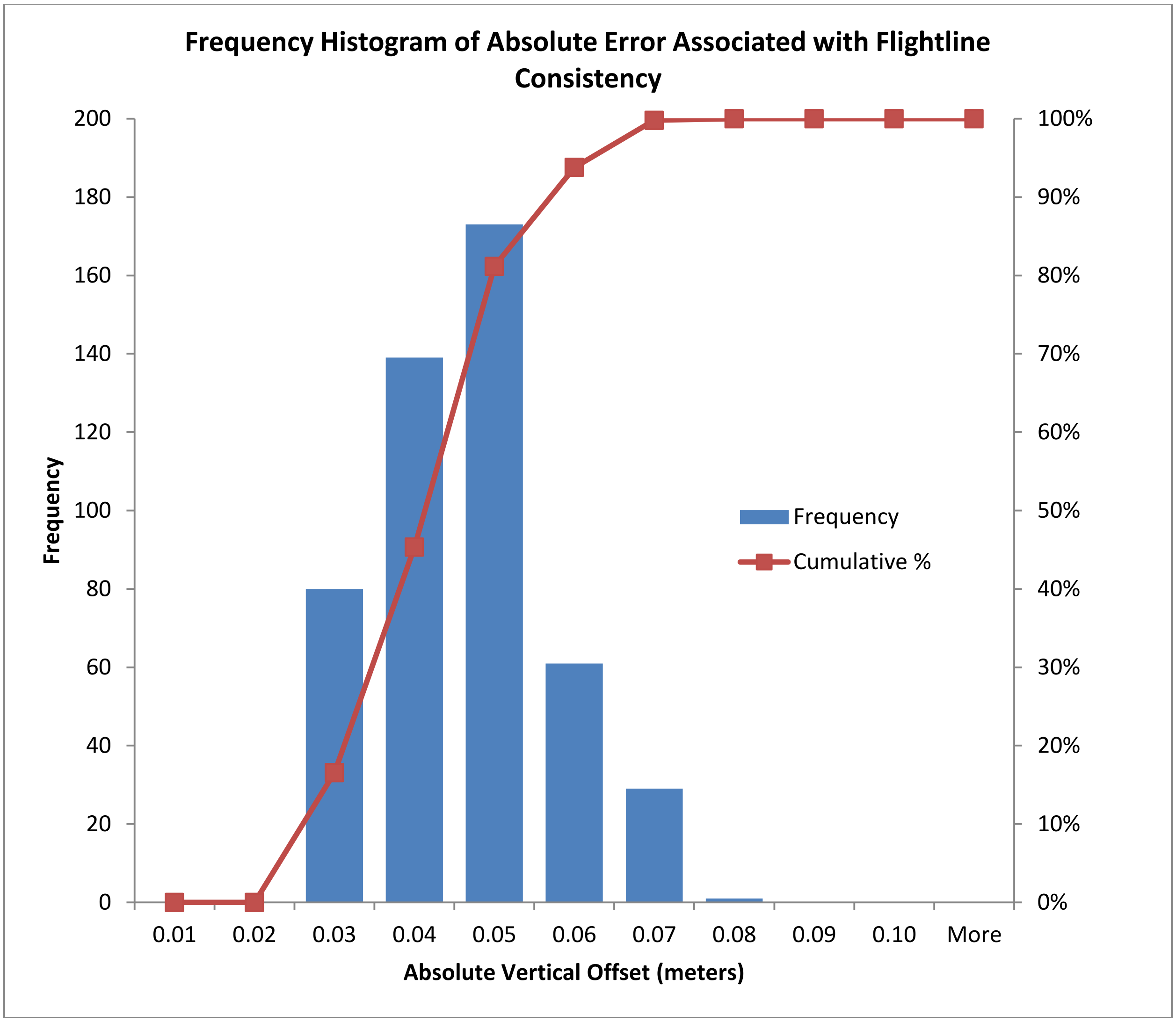

Figure 4. Histogram of flight line offsets values.

Results of the consistency analysis found the average flight line offset to be 0.041 meters with a maximum error of 0.079m (Table 2b). Distribution of error showed over 93% of all error was less than 0.06m and 99% less than 0.07m (Figure 4). These results show that all data are within tolerances of data consistency according to contract agreement.

Visual Analysis

Lidar 1m 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 5). Both bare earth and highest hit models were examined for calibration offsets, tiling artifacts (Figure 6), seam line offsets, pits (Figure 6), 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 5). 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 7). 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.

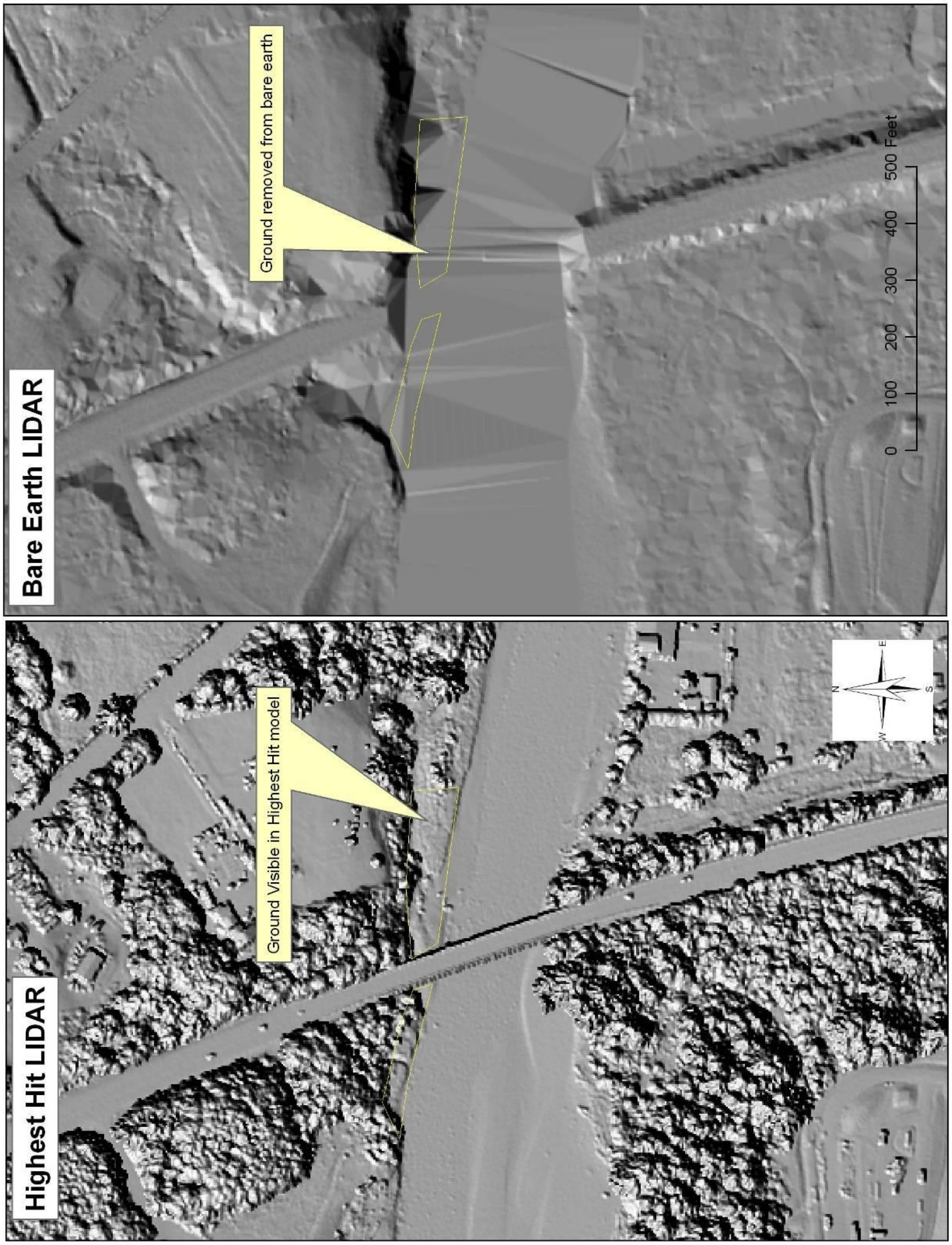

Figure 5. Example of missing ground in lidar bare earth data. Ground is clearly visible in highest hit model, but has been removed from the bare earth model. This type of classification error is common near water body features.

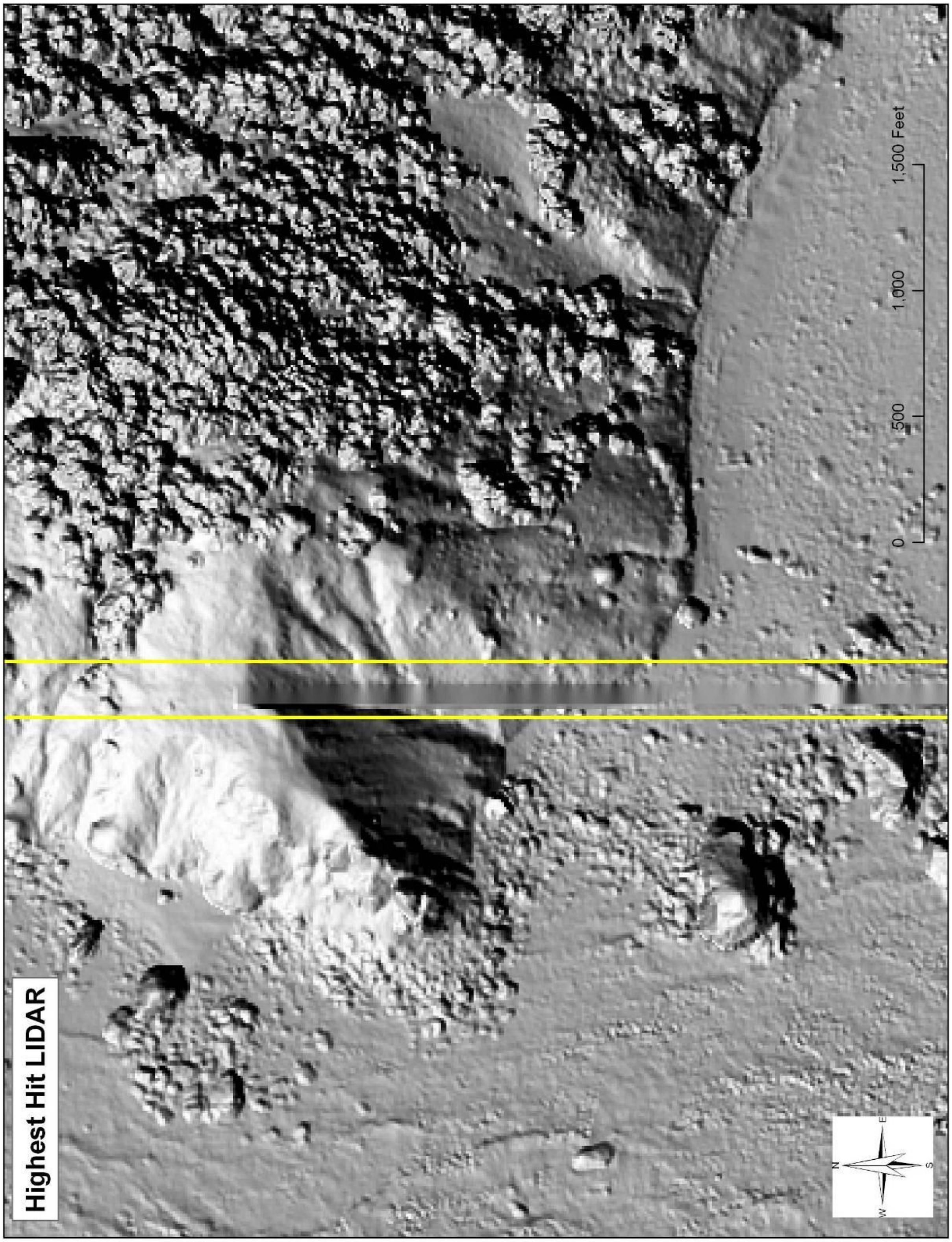

Figure 6. Example of tile artifact found in highest hit lidar data. Artifact is a seam line error created due to misclassification of ground at edge of lidar processing tiles.

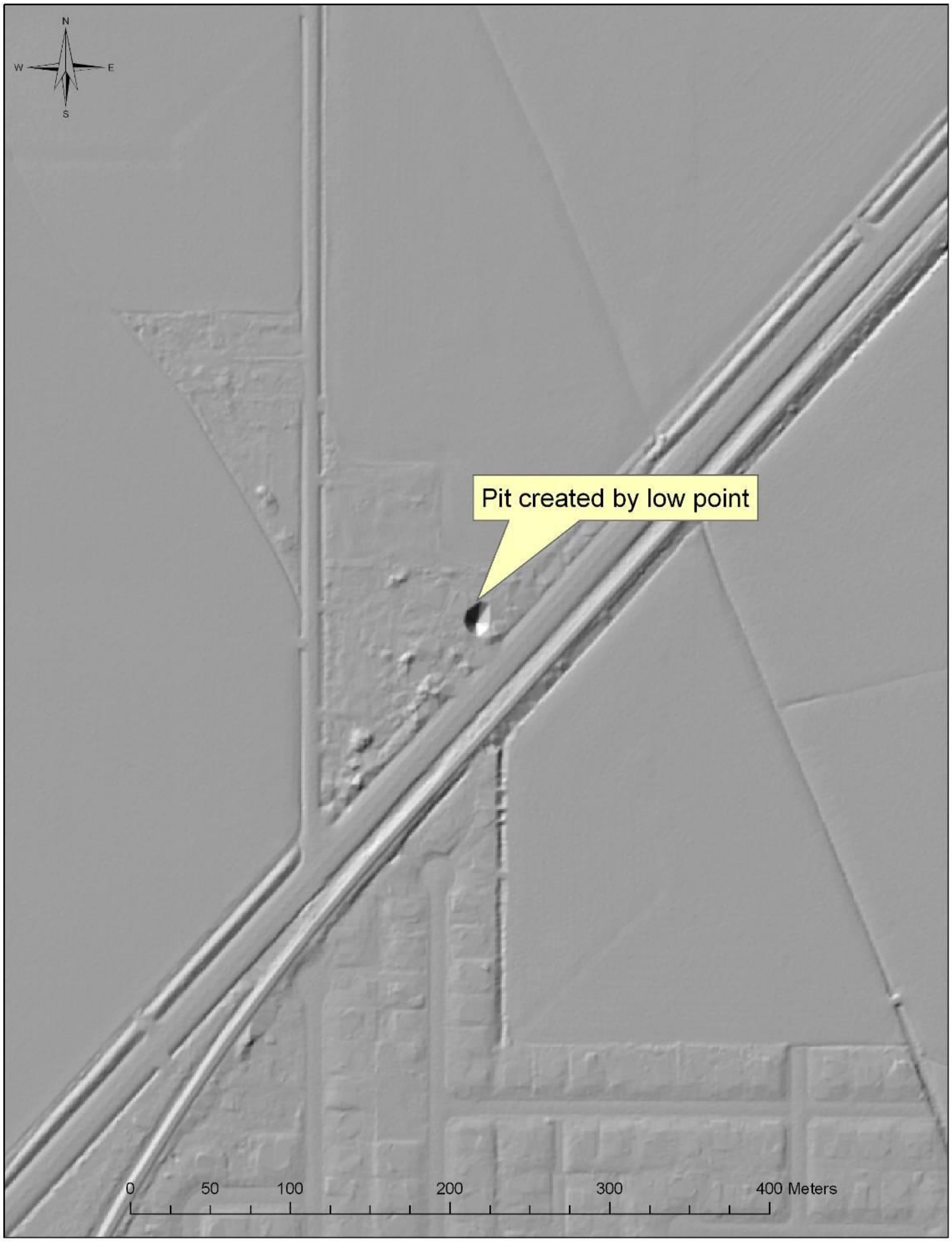

Figure 7. Example of "Pit" caused by low point in ground model. Pits are caused when standing water absorbs the lidar pulse. Pits are evident in ground model as the lowest point elevation is assigned to the grid cell value. Inversely the pit is not observable in the highest hit model as the highest point 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. The contractor used a surveying system (Figure 8) to measure GCP's. GPS survey techniques allow surveyors to collect many precisely located GCP's which can be used as a control comparison with LiDAR elevations. 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). A licensed surveyor is often able to post process GPS survey data to accuracies less than 1cm in both horizontal and vertical axes.

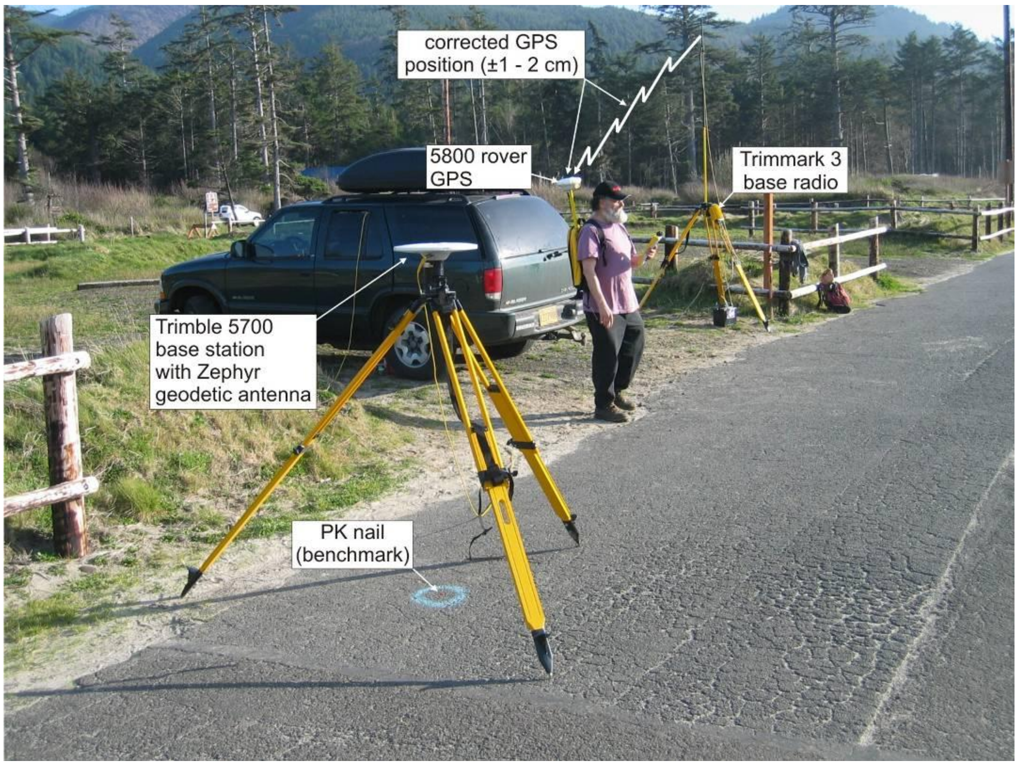

Figure 8. The Trimble 5700 base station antenna located over a known reference point at Cape Lookout State Park. Corrected GPS position and elevation information is then transmitted by a Trimmark III base radio to the 5800 GPS rover unit.

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 values for the entire delivered data set. Project specifications list the maximum acceptable root mean square vertical offset to be 0.20 meters (0.65 feet).

A total of 4446 measured GCP's were provided to DOGAMI by DGGS for the Delivery 10 region (Figure 9) and compared with the lidar elevation grids. The data delivered to DOGAMI was found to have a mean vertical offset of 0.010 meters (0.033 feet) and an RMSE value of 0.043 meters (0.142 ft). Offset values ranged from -0.125 to 0.146 meters (Table 3 and Figure 10).

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.

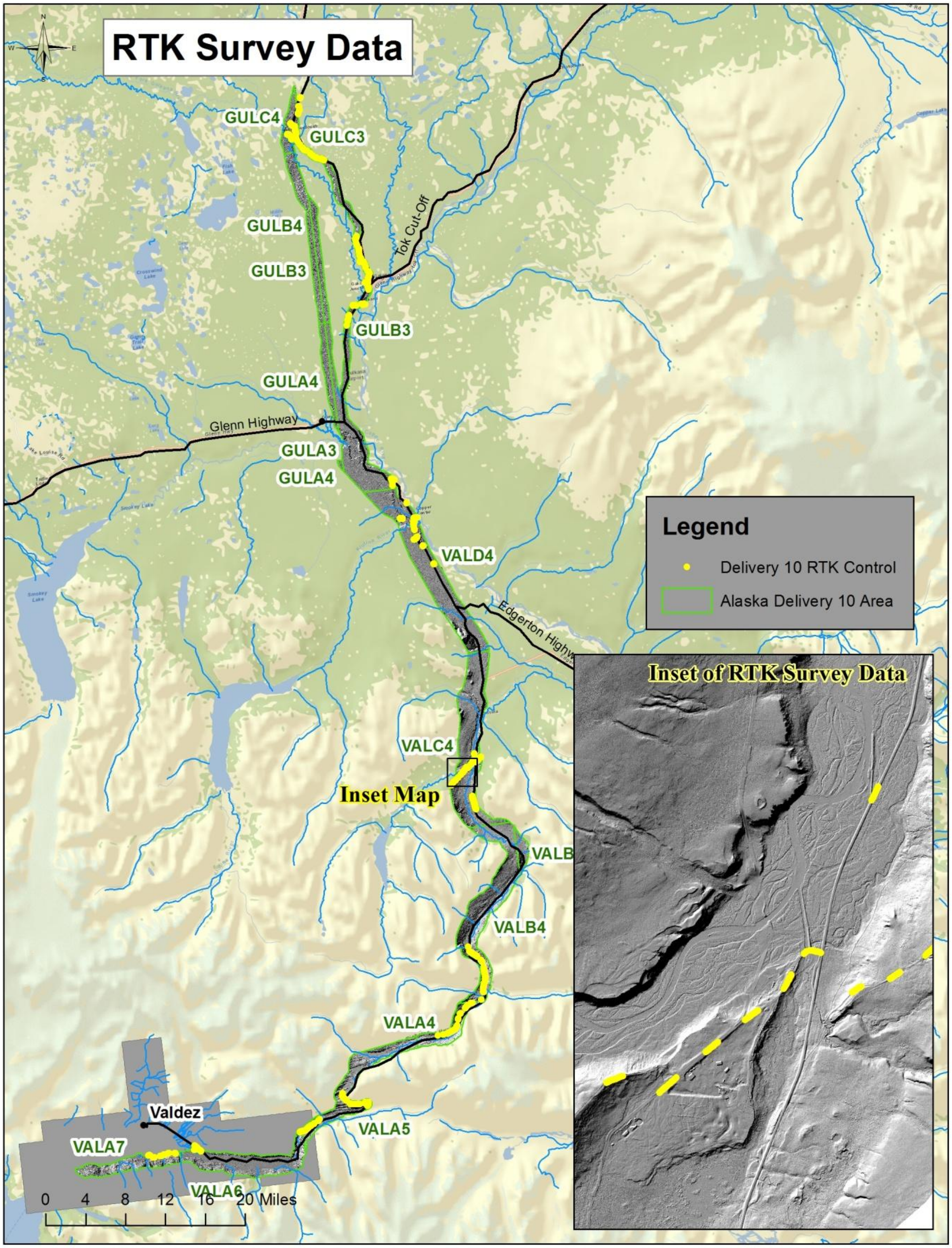

Figure 9. Locations of RTK control surveyed by Contractor. Data was used to test absolute accuracy for the Alaska DNR lidar survey within the Delivery 10 extent.

	Meters	Feet
Mean	0.010	0.033
Standard Error	0.001	0.002
Standard Deviation	0.042	0.138
Range	0.271	0.889
Minimum	-0.125	-0.410
Maximum	0.146	0.479
RMSE	0.043	0.142

Table 3. Descriptive Statistics for absolute value vertical offsets.

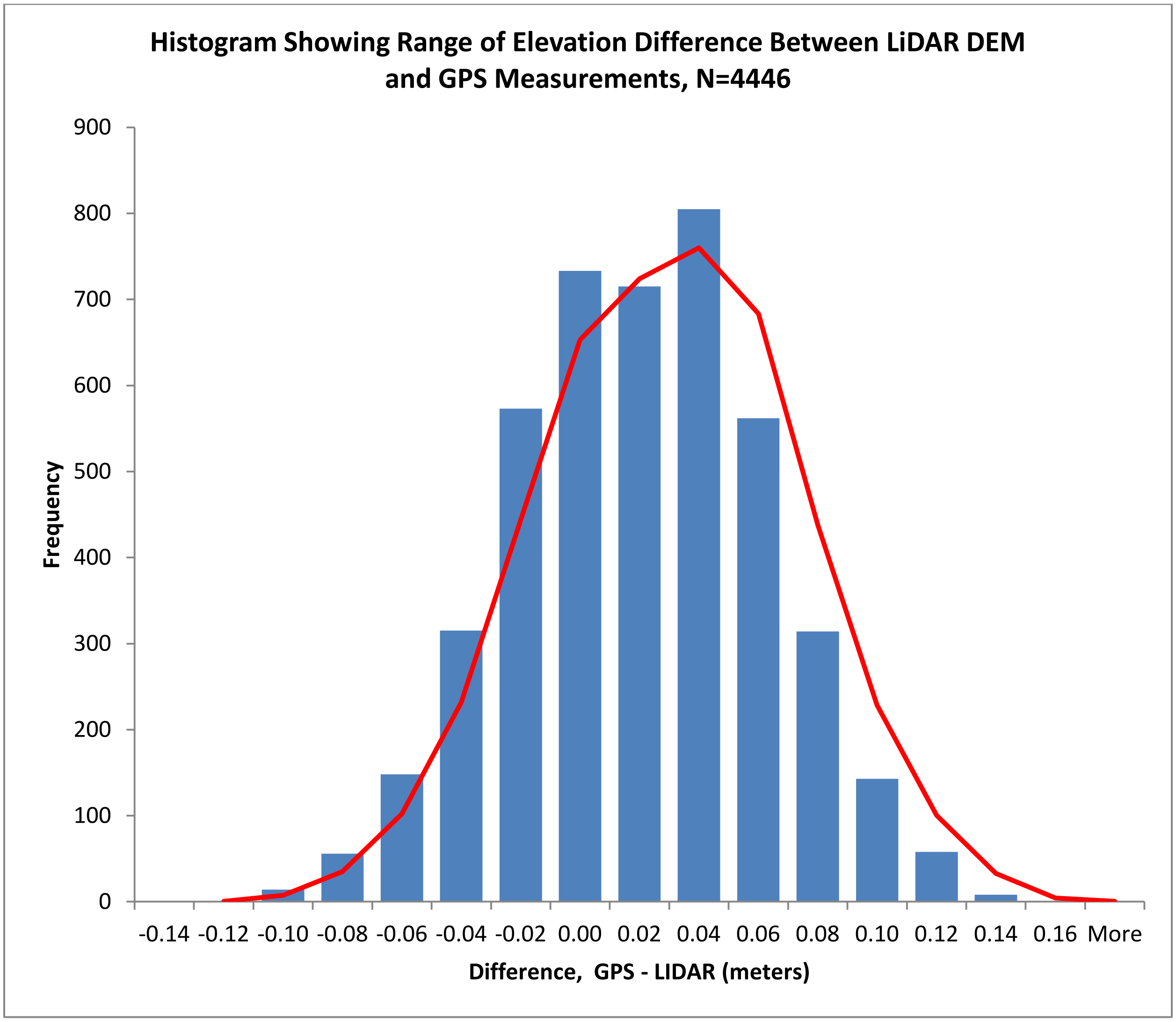

Figure 10. Histogram of elevation difference between Lidar DEM and GPS survey data.

Acceptance

The data described in this report meets or exceeds project specifications laid out in the contracted data standards agreement. All the required files for the delivery have been received as of March 19th, 2012, and are correctly named and useable. 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 quality control 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 Signature

________________________________ Date: 3/21/2012

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

________________________________ Date: 3/20/2012

Ian Madin
Chief Scientist – Department of Geology & Mineral Industries

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

Alaska DNR LIDAR Project, 2011 – Delivery 11 QC Analysis

LIDAR QC Report – March 19th, 2012

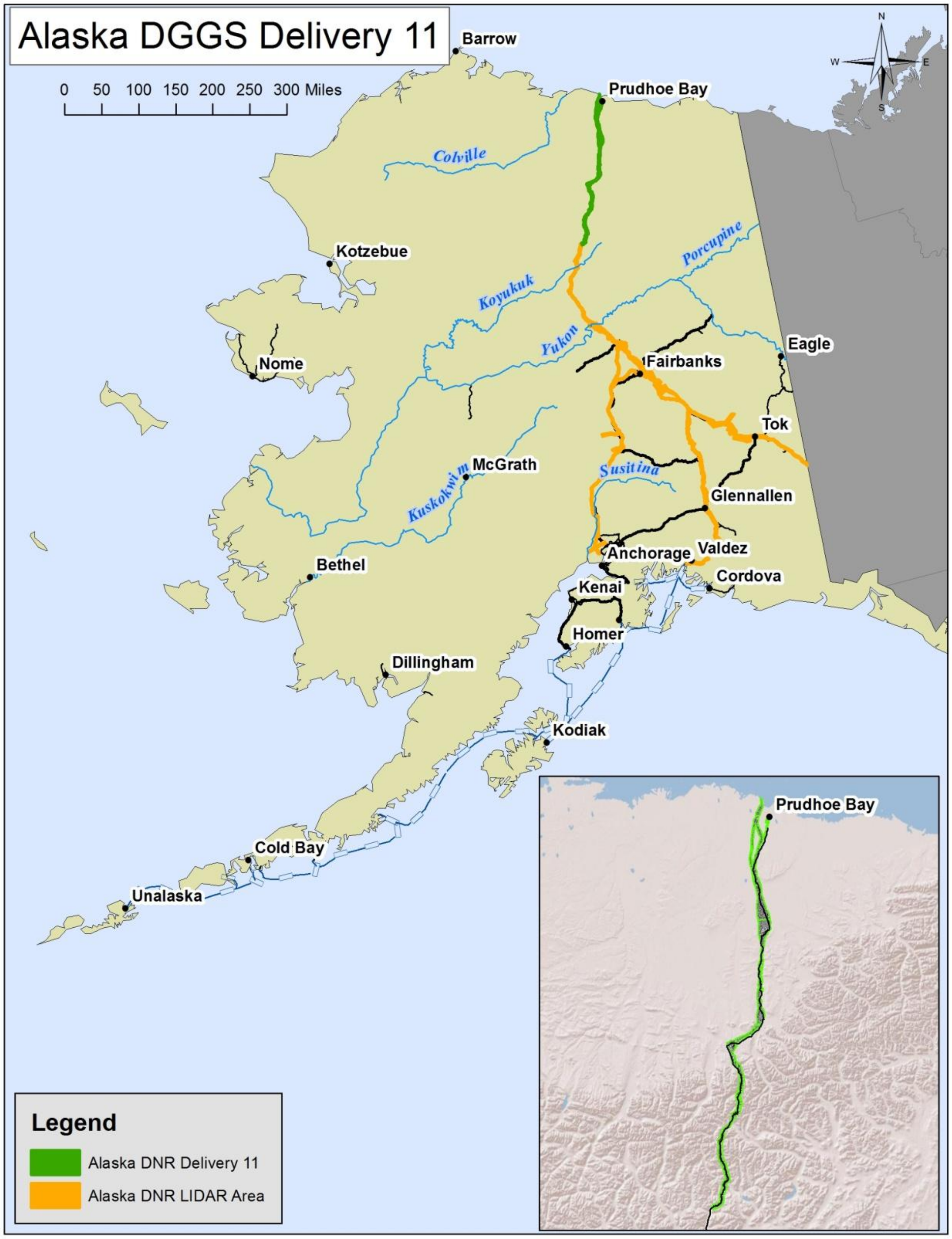

Figure 1. Map featuring Alaska DNR Delivery 11 data extent.

The Alaska Department of Natural Resources, Division of Geological and Geophysical Survey (DGGS) has contracted with Watershed Sciences, Inc (WSI) to collect high resolution lidar topographic data for a swath roughly parallel to proposed future pipeline rights of way. DGGS has specified the exact areas of data collection as well as a detailed description of data products to be delivered. The complete specifications are detailed in the September 14, 2010 Standard Agreement Form for Professional Services signed by DGGS and WSI.

The Oregon Department of Geology and Mineral Industries has contracted with DGGS to provide independent quality control review of aspects of the data provided by WSI. The details of the QC agreement are spelled out in the State of Alaska Cooperative Agreement Number MI-11-006. The primary quality control tasks are:

1. Review and test all delivered files for completeness, correct naming and usability.
2. Evaluate consistency of data by comparing points from the overlapping areas of adjacent swaths.
3. Visual inspection of images derived from the lidar bare earth and highest hit DEMs to identify artifacts, voids and missed ground.
4. Test the accuracy of the bare earth DEMs by comparing them to GPS ground control points provided by DGGS.

For each delivery of data, DOGAMI shall prepare a report to DGGS describing the results of the quality control review for that delivery. This is the report for Delivery 11 (Figure 1).

Upon receipt from vendor (Watershed Sciences), all lidar data for Delivery 11 were independently reviewed by staff from the Oregon Department of Geology and Mineral Industries (DOGAMI) to ensure project specifications were met. The entire delivery consisted of the following data products:

- 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.
- 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 Universal Transverse Mercator (Zones 6), NAD83 CORS96 meters.

Data Completeness

Data for Alaska DNR Delivery 11 area were collected between June 6th and July 2nd, 2011. Total area of delivered data totals 533.69 square miles. Delivery 11 (Figure 2) includes data in the format of grids, trajectory files, intensity images, Lidar ASCII Standard (LAS) point files, 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 1 meter cell size. Lidar point data are delivered in LAS binary format for ground classified returns as well as the entire lidar point cloud. Georeferenced intensity images of 1 meter cell size are supplied in geoTIF format. Supplementary data include 1 meter cell size vegetation rasters displaying canopy and other vegetation metrics. Real time kinematic ground survey data (used for absolute vertical adjustment) are supplied in shapefile format. This delivery contains data for the following USGS 7.5 minute quads (listed by quadrangle tile name within the boundary of the Alaska DNR Survey collection area (Figure 2):

Delivery 11 Quadrangles: CHNB6, CHNC6, CHND6, PSMA4, PSMA5, PSMB4, PSMB5, PSMC4, PSMC5, PSMD3, PSMD4, SAGA3, SAGA4, SAGB3, SAGC3, SAGD3, SAGD4, WISB1, XBPA3, XBPA4, XBPB3

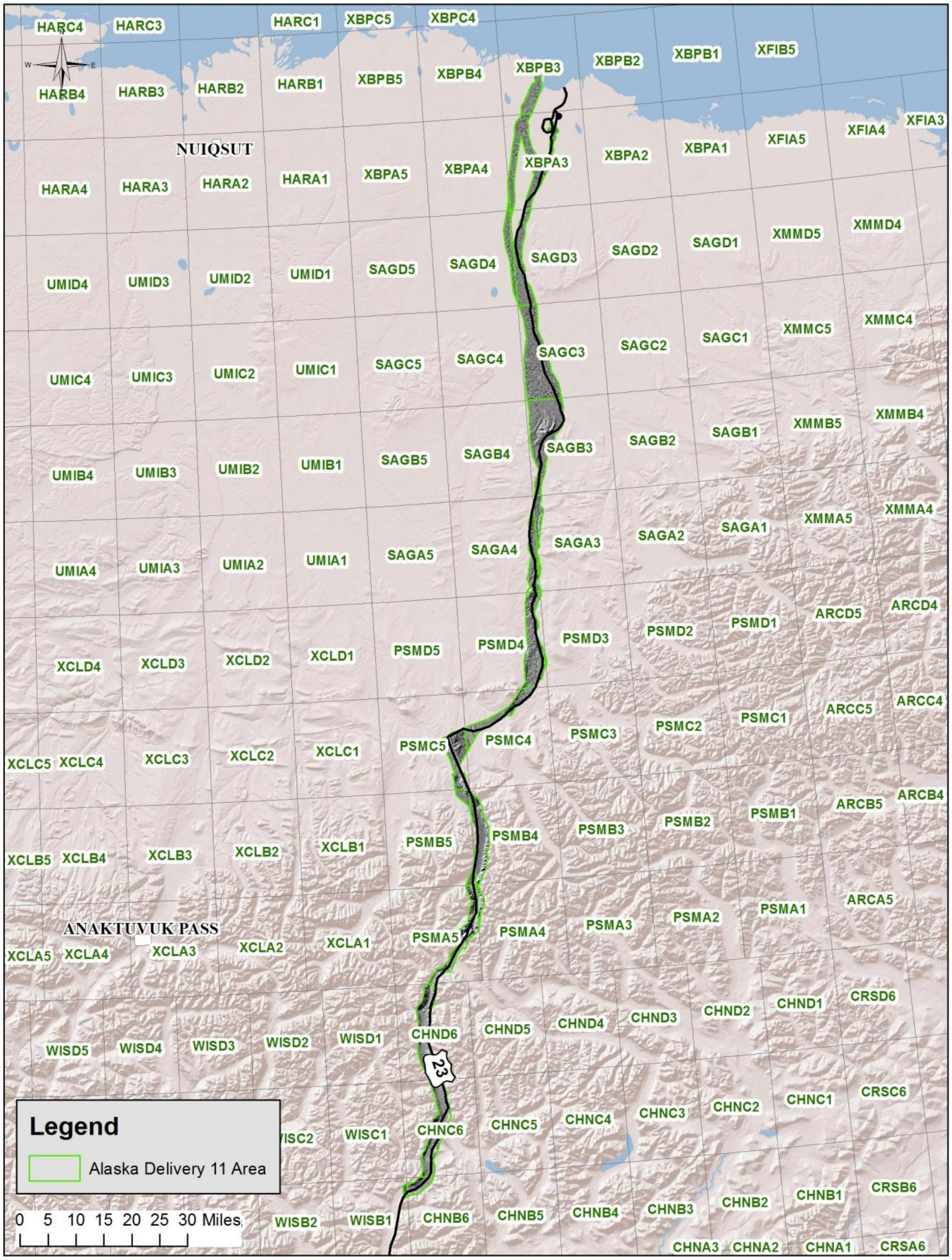

Figure 2. Delivery 11 location area. Data is referenced to USGS 7.5 minute quadrangles within the extents of the Alaska DNR Survey collection area

FINAL Delivery	Resolution	Format	Tiling	
Bare Earth DEMs	1 meter	grid	quad	x
Highest Hit DEMs	1 meter	grid	quad	x
Trajectory files	1 sec	sbet /shape	flight	x
Intensity Images	1 meter?	tif	quad	x
LAS	8pts/m^2	las	tiled	x
Ground Returns	N/A	las	tiled	x
First return Vegetation Raster	1 meter	grid	quad	x
RTK point data		shape		x
Delivery Area shapefile		shape	quad	x
Report		pdf		x

Miscellaneous		Format	Tiling	
Processing bins		Shape dxf/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 headers have been scanned to ensure completeness and readability (Figure 3).

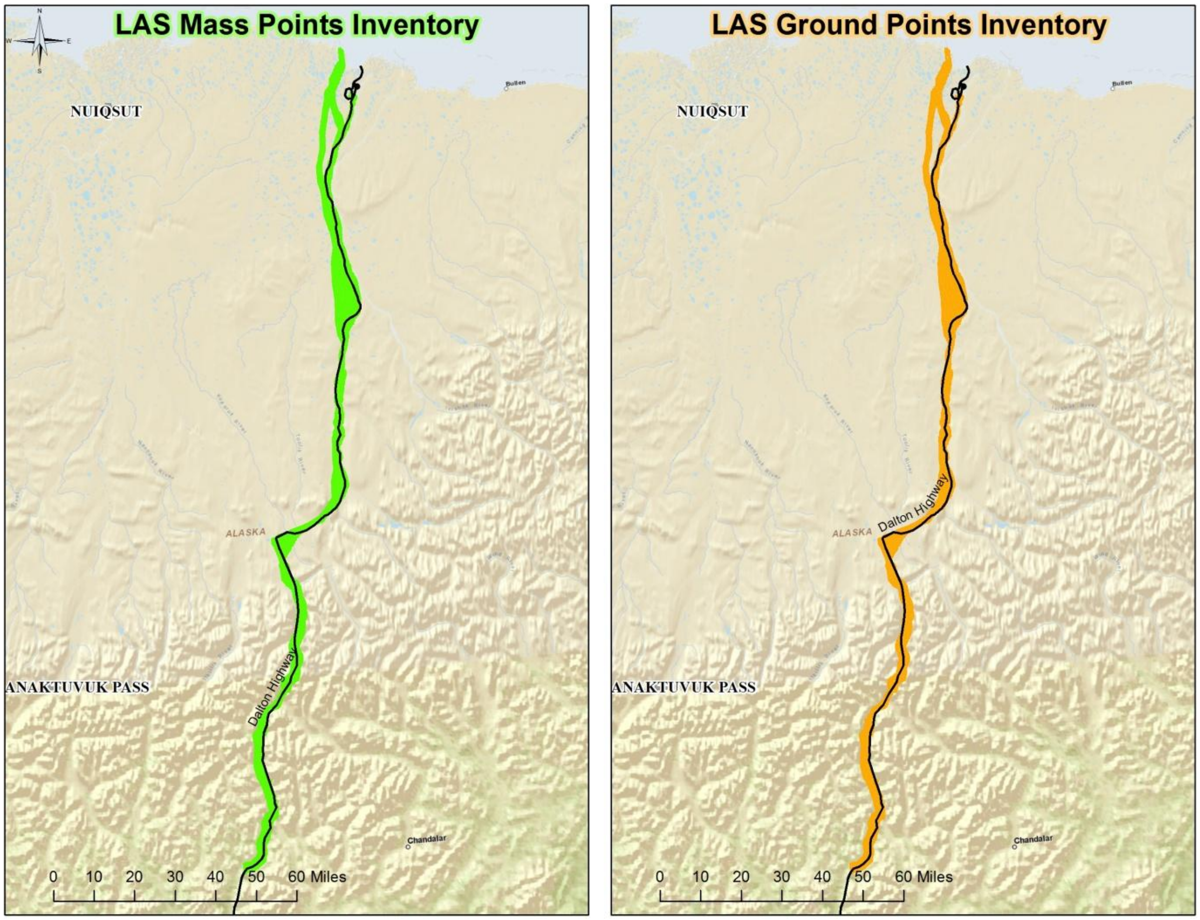

Figure 3. LIDAR Point Inventory graphic representing complete coverage of point data for both mass points and ground LAS files.

Consistency Analysis:

DGGS has specified that lidar consistency must average less than 0.15m (0.49 feet) in vertical offsets between adjacent 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 3078 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 13,454,510 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 628 flight lines were sampled and compared for consistency.

Summary Statistics	
# of Tiles	3078
# of Flight Line Sections	628
Avg # of Points	13,454,510
Avg. Magnitude Z error (m)	0.034

Table 2a. Summary Results of Consistency Analysis

	meters	***feet***
Mean	0.034	0.112
Standard Error	0.000	0.002
Standard Deviation	0.012	0.039
Sample Variance	0.000	0.000
Range	0.053	0.175
Minimum	0.016	0.051
Maximum	0.069	0.226

Table 2b. Descriptive Statistics for Magnitude Z Error.

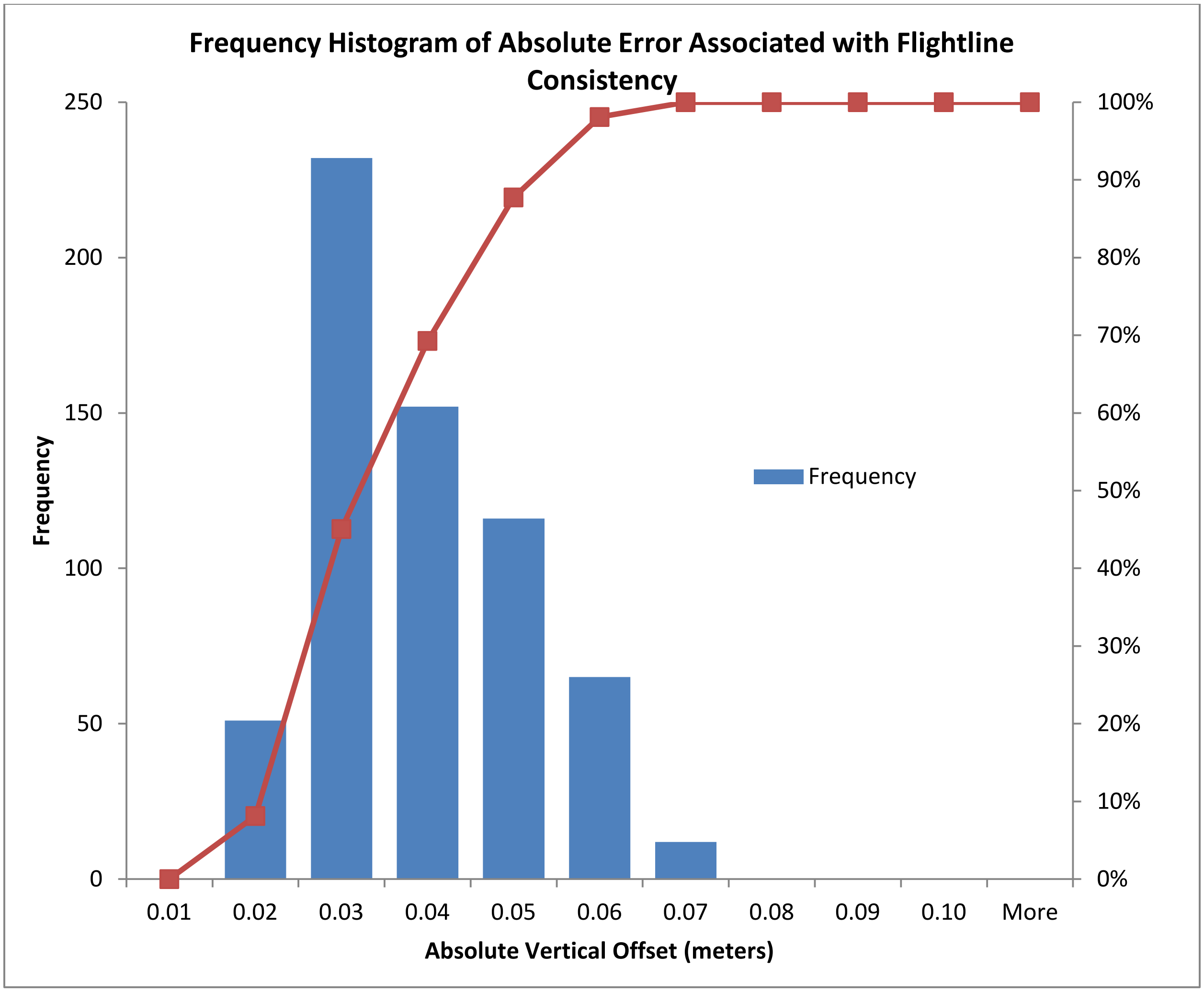

Figure 4. Histogram of flight line offsets values.

Results of the consistency analysis found the average flight line offset to be 0.034 meters with a maximum error of 0.069m (Table 2b). Distribution of error showed over 98% of all error was less than 0.06m (Figure 4). These results show that all data are within tolerances of data consistency according to contract agreement.

Visual Analysis

Lidar 1m 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 5). Both bare earth and highest hit models were examined for calibration offsets, tiling artifacts (Figure 6), seam line offsets, pits (Figure 6), 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 5). 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 7). 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.

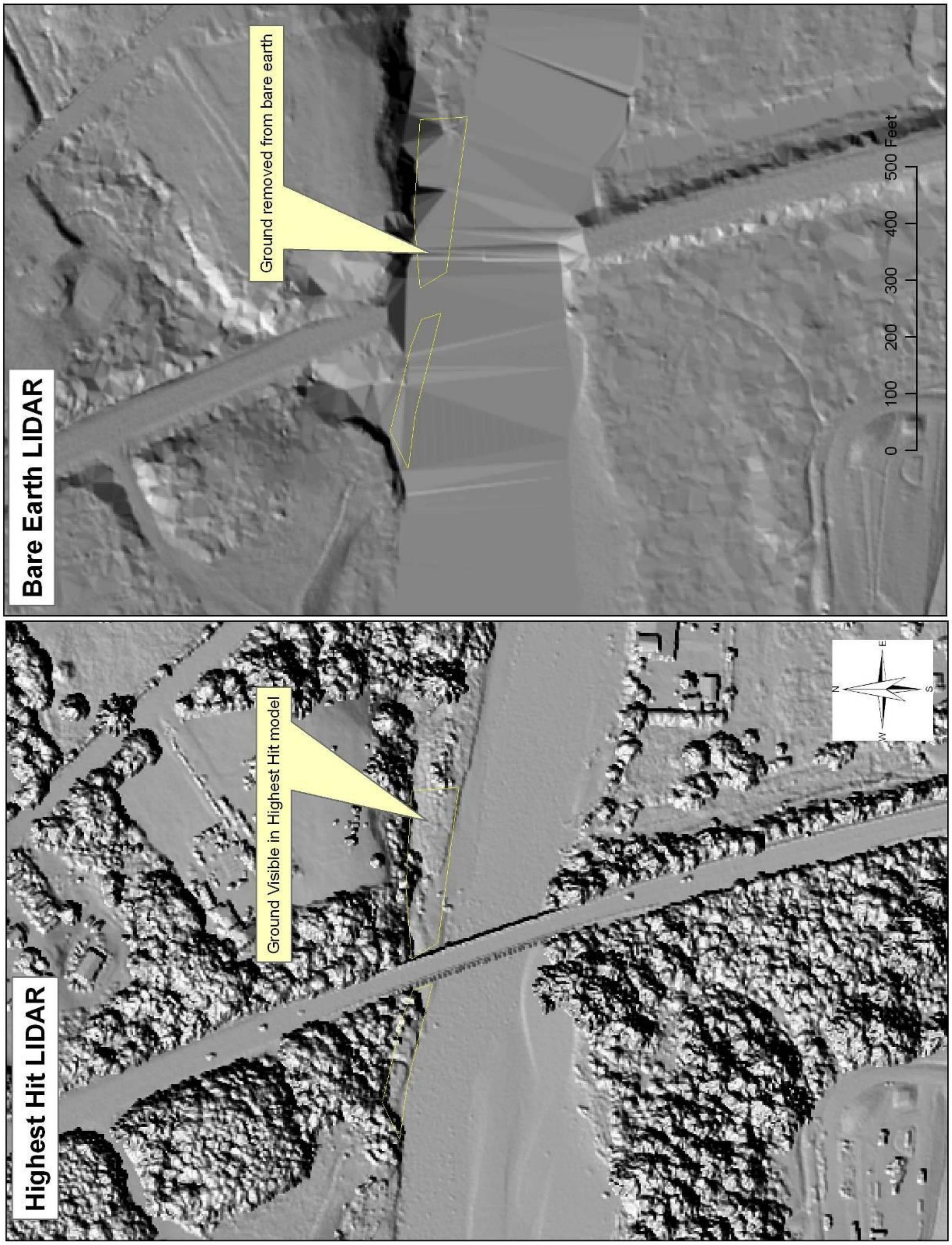

Figure 5. Example of missing ground in lidar bare earth data. Ground is clearly visible in highest hit model, but has been removed from the bare earth model. This type of classification error is common near water body features.

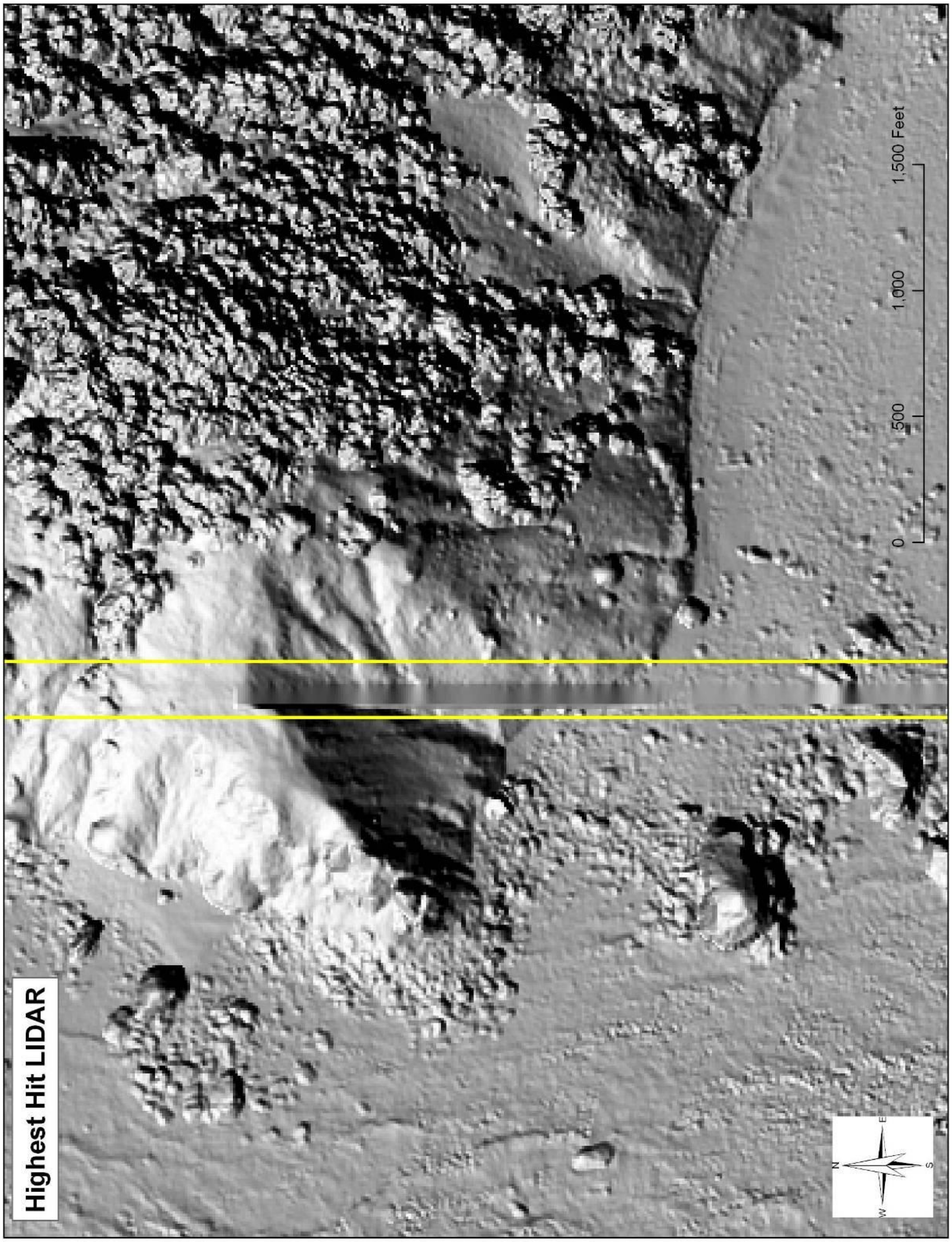

Figure 6. Example of tile artifact found in highest hit lidar data. Artifact is a seam line error created due to misclassification of ground at edge of lidar processing tiles.

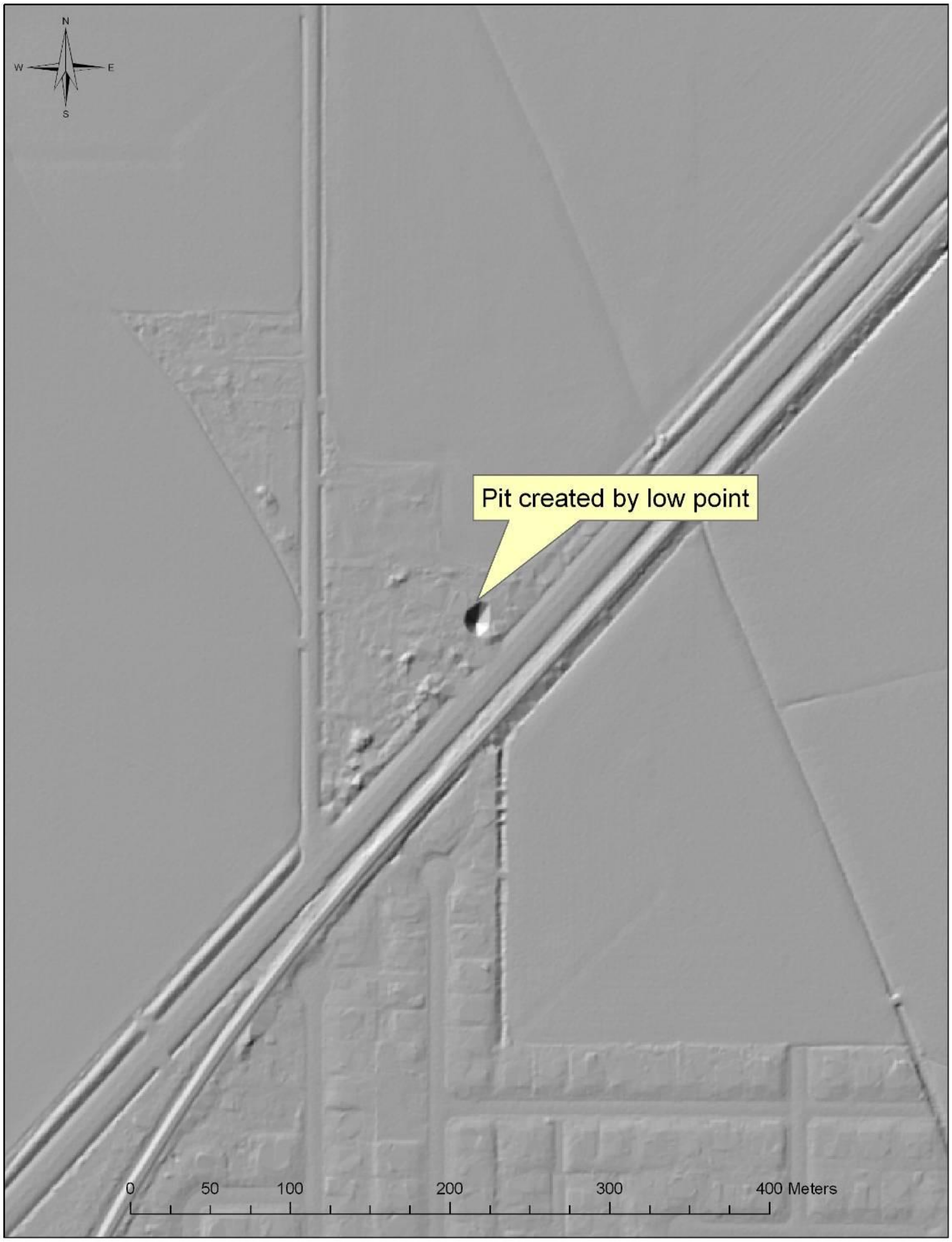

Figure 7. Example of "Pit" caused by low point in ground model. Pits are caused when standing water absorbs the lidar pulse. Pits are evident in ground model as the lowest point elevation is assigned to the grid cell value. Inversely the pit is not observable in the highest hit model as the highest point 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. The contractor used a surveying system (Figure 8) to measure GCP's. GPS survey techniques allow surveyors to collect many precisely located GCP's which can be used as a control comparison with LiDAR elevations. 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). A licensed surveyor is often able to post process GPS survey data to accuracies less than 1cm in both horizontal and vertical axes.

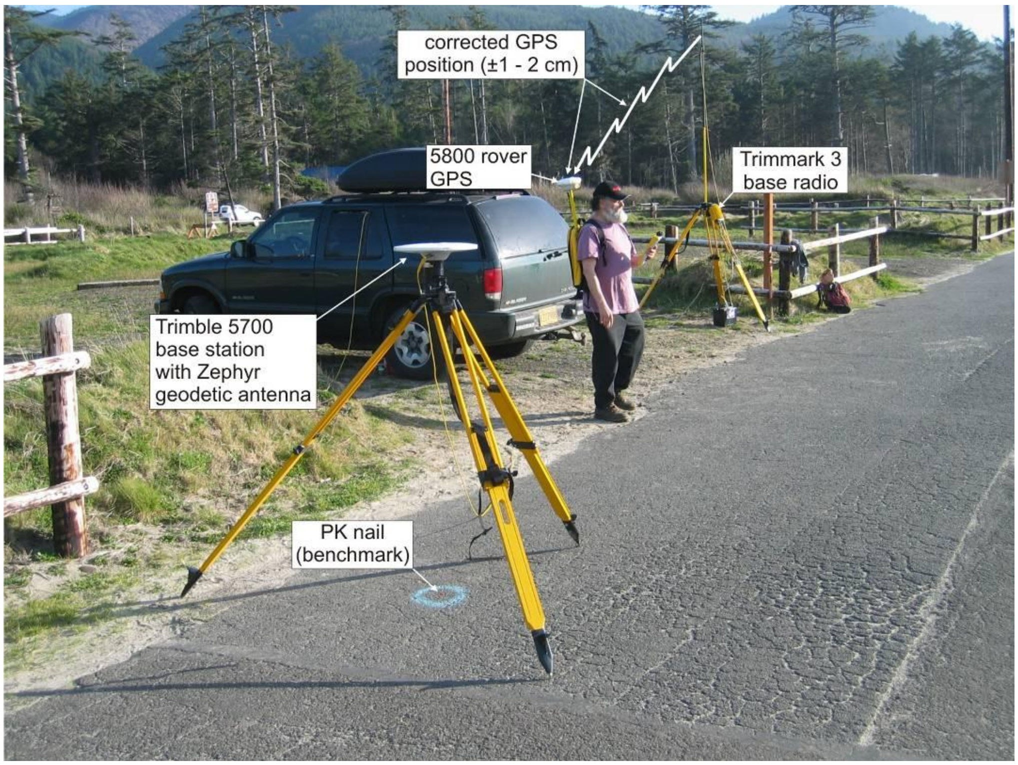

Figure 8. The Trimble 5700 base station antenna located over a known reference point at Cape Lookout State Park. Corrected GPS position and elevation information is then transmitted by a Trimmark III base radio to the 5800 GPS rover unit.

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 values for the entire delivered data set. Project specifications list the maximum acceptable root mean square vertical offset to be 0.20 meters (0.65 feet).

A total of 5571 measured GCP's were provided to DOGAMI by DGGS for the Delivery 11 region (Figure 9) and compared with the lidar elevation grids. The data delivered to DOGAMI was found to have a mean vertical offset of 0.020 meters (0.066 feet) and an RMSE value of 0.040 meters (0.133 ft). Offset values ranged from -0.129 to 0.166 meters (Table 3 and Figure 10).

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.

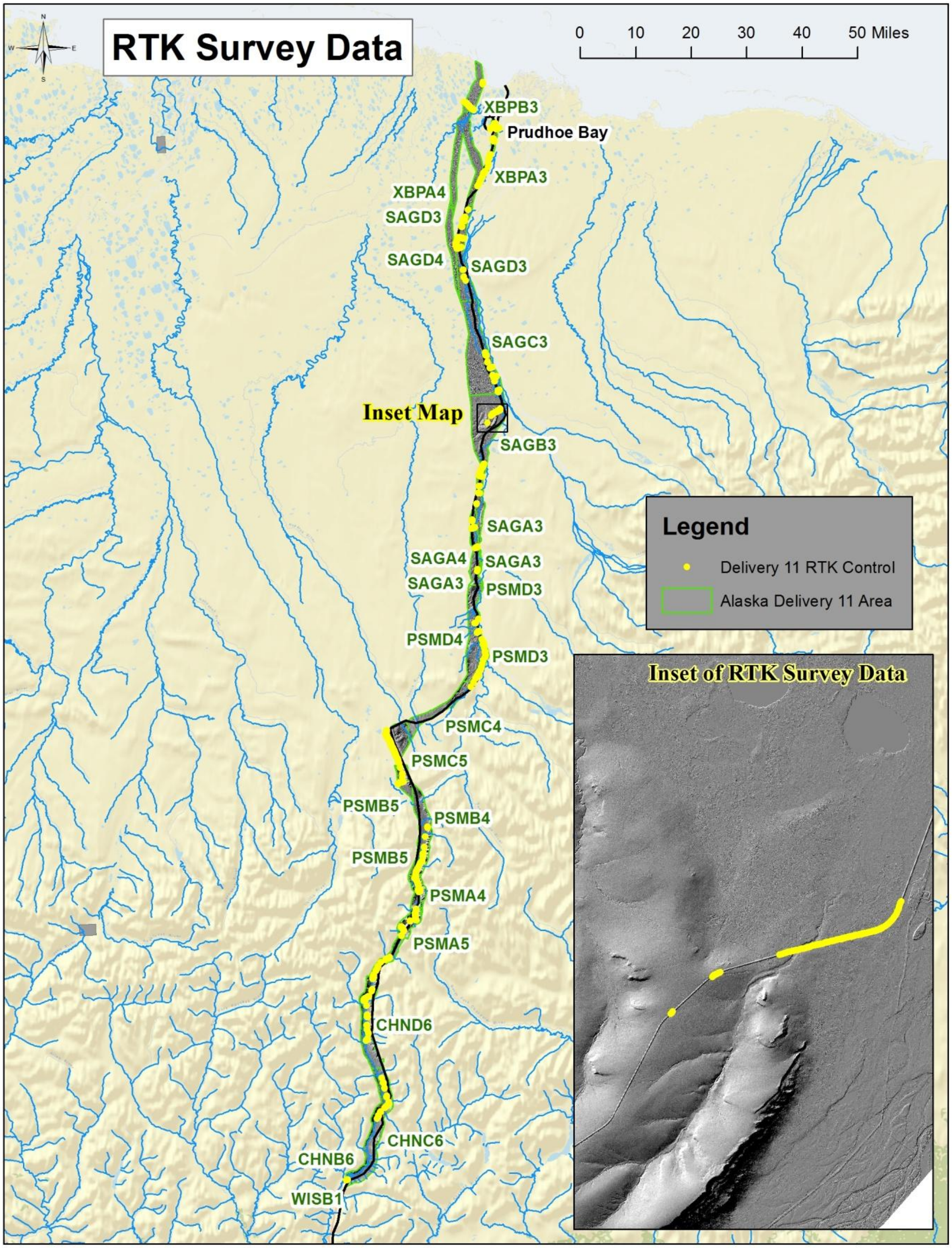

Figure 9. Locations of RTK control surveyed by Contractor. Data was used to test absolute accuracy for the Alaska DNR lidar survey within the Delivery 11 extent.

	Meters	*Feet*
Mean	0.020	0.066
Standard Error	0.000	0.002
Standard Deviation	0.035	0.115
Range	0.295	0.968
Minimum	-0.129	-0.423
Maximum	0.166	0.545
RMSE	0.040	0.133

Table 3. Descriptive Statistics for absolute value vertical offsets.

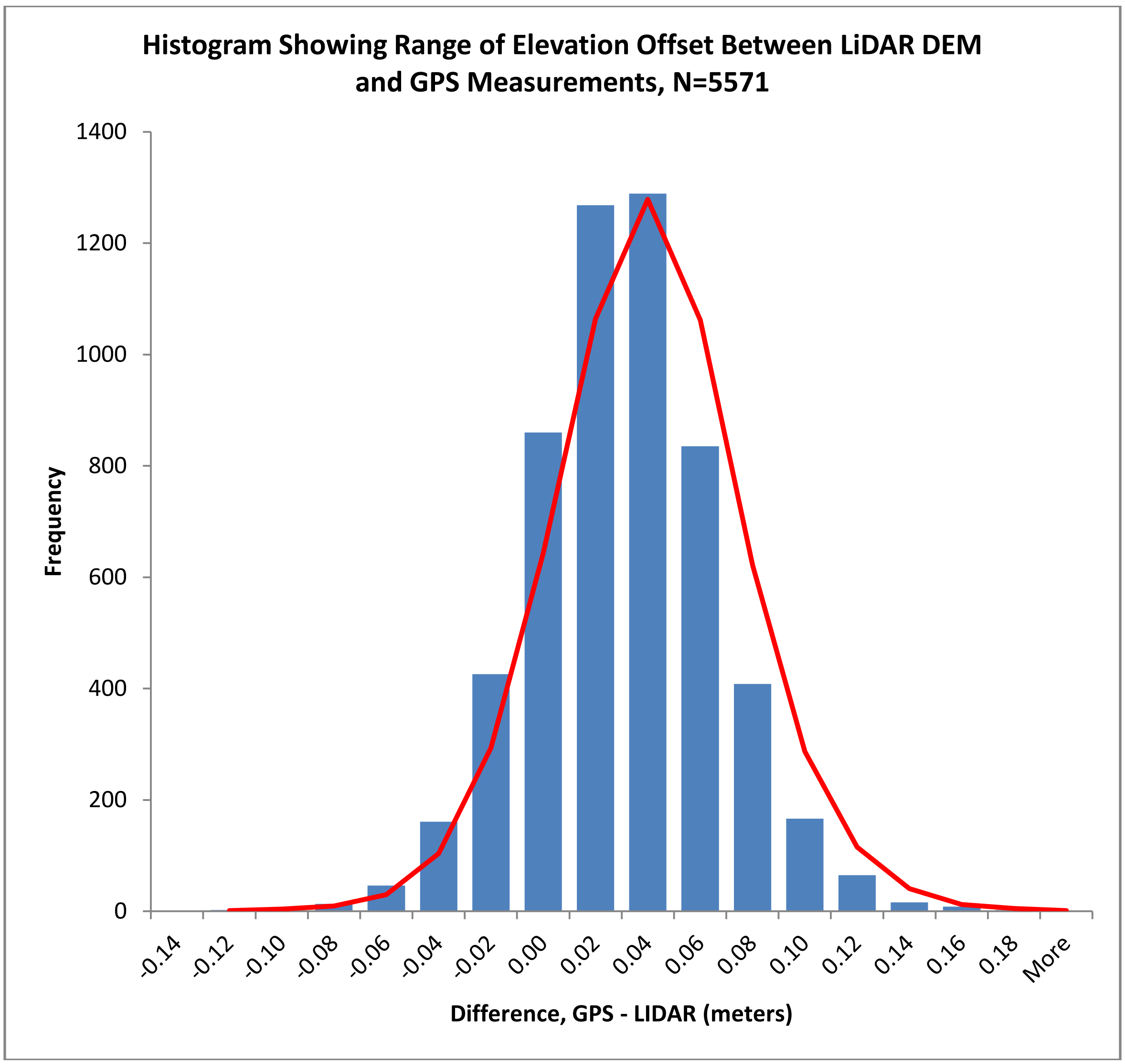

Figure 10. Histogram of elevation difference between Lidar DEM and GPS survey data.

Acceptance

The data described in this report meets or exceeds project specifications laid out in the contracted data standards agreement. All the required files for the delivery have been received as of March 19th, 2012, and are correctly named and useable. 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 quality control 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 Signature

______________________________ Date: 3/21/2012

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

______________________________ Date: 3/20/2012

Ian Madin
Chief Scientist – Department of Geology & Mineral Industries