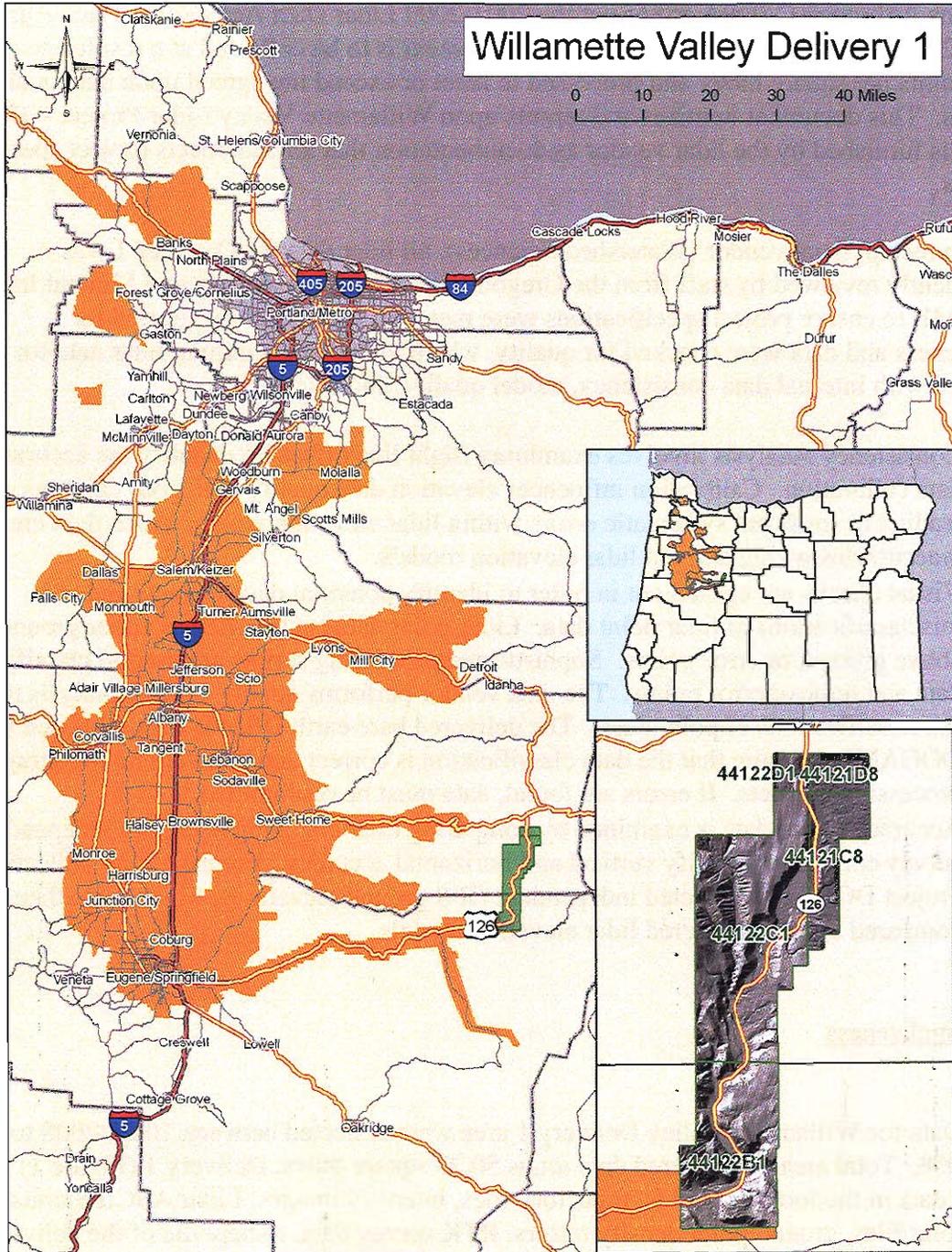


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Willamette Valley LIDAR Project, 2009 – Delivery 1 QC Analysis
LIDAR QC Report – January 2nd, 2009



Map featuring Willamette Valley Delivery 1 data extent.

The Oregon Department of Geology & Mineral Industries has contracted with Watershed Sciences to collect high resolution lidar topographic data for multiple areas within the State of Oregon. Areas for lidar data collection have been designed as part of a collaborative effort of State, Federal, and Local agencies in order to meet a wide range of project goals. The vendor has agreed to certain conditions of data quality and standards for all lidar data deliverables listed in sections A through C (OPA #8865) of the 2007-2009 Lidar Data Acquisition Price Agreement (pgs 14-23). Data submitted under this price agreement is to be collected at a resolution of at least 8 points per square meter and processed to meet or exceed the agreed upon data quality standards. This document itemizes and reports upon Willamette Valley Lidar Project – Delivery 1 products furnished by the lidar vendor as documentation that all data meets project specific standards.

Upon receipt from vendor (Watershed Sciences), all lidar data for Delivery 1 was independently reviewed by staff from the Oregon Department of Geology and Mineral Industries (DOGAMI) to ensure project specifications were met. All data were inventoried for completeness and data were checked for quality, which included examining lidar data for errors associated with internal data consistency, model quality, and accuracy.

- Consistency Analysis involves examining flight line offsets to quantify the accuracy of data calibration. Calibration influences elevation data quality with poor calibration leading to small but systematic errors within lidar elevation points, which then create inaccuracies within derived lidar elevation models.
- Visual checks are carried out in order to identify potential data artifacts and misclassifications of lidar point data. Lidar point data is classified as either ground, above ground, or error points. Sophisticated processing scripts are used to classify point data and remove error points. The data vendor performs quality control analysis to fix misclassifications of point data. The delivered bare earth DEM is then reviewed by DOGAMI to ensure that the data classification is correct and there are no topographic processing artifacts. If errors are found, data must be resubmitted.
- Accuracy of the data is examined by comparing lidar elevation data with independent survey control to quantify vertical and horizontal accuracy. For each lidar collection project DOGAMI collected independent GPS ground elevations, which were then compared against delivered lidar elevation models.

Data Completeness

Data for Willamette Valley Delivery 1 area were collected between 10/22/2008 to 10/24/2008. Total area of delivered data totals 50.23 square miles. Delivery 1 (Figure 1) includes data in the format of grids, trajectory files, intensity images, Lidar ASCII Standard (LAS) point files, ground point density rasters, RTK survey data, a shapefile of the delivery area, and the lidar delivery report (Table 1). Bare earth and highest hit grids were delivered in ArcInfo Grid format with 3ft cell size. Lidar point data is delivered in LAS binary format for ground

classified returns as well as the entire lidar point cloud. Georeferenced intensity images are supplied in TIF format. Supplementary data includes ground density rasters displaying locations where ground returns are low. Real time kinematic ground survey data (used for absolute vertical adjustment) is supplied in shapefile format. This delivery contains data for the following USGS 7.5 minute quads (listed by Ohio Code #) within the boundary of the Willamette Valley Survey collection area: 44121c8, 44121d8, 44122b1, 44122c1, 44122d1 (Figure 1).

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

Table 1. Deliverable Checklist

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

Deliverable Descriptions: (All data projected in Oregon Lambert, NAD83 (HARN), Intl Feet with exception of trajectory files).

- Bare Earth Grids: Tin interpolated grids created from lidar ground returns.
- Highest Hit Grids: Tin interpolated grids created from the highest lidar elevation for a given 3ft cell.
- Intensity TIF: TIF raster built using returned lidar pulse intensity values gathered from highest hit returns.
- Trajectory File: File contains point location measurement of the aircraft used to collect lidar data. Data is collected using an Inertial Measurement Unit (IMU), and collects measurements of: Easting(meters), Northing (meters), Ellipsoid Height (meters) of aircraft, aircraft roll (degrees), aircraft pitch (degrees), aircraft heading (degrees). Measurements are collected at one second intervals. Data is projected in UTM zone 10, NAD83 (HARN).

- LAS: Binary file of all lidar points collected in survey (Class, flight line #, GPS Time, Echo, Easting, Northing, Elevation, Intensity, Scan Angle, Echo Number, and Scanner).
- Ground LAS: Binary file of lidar points classified as ground (Class, flight line #, GPS Time, Echo, Easting, Northing, Elevation, Intensity, Scan Angle, Echo Number, and Scanner).
- RTK Point Data: Ground GPS Survey data used to correct raw lidar point cloud for vertical offsets.
- Delivery Area Shapefile: Geometry file depicting the geospatial area associated with deliverables.
- Report: Report provides detailed description of data collection methods and processing. The vendor also reports accuracies associated with calibration, consistency, absolute error, and point classifications.

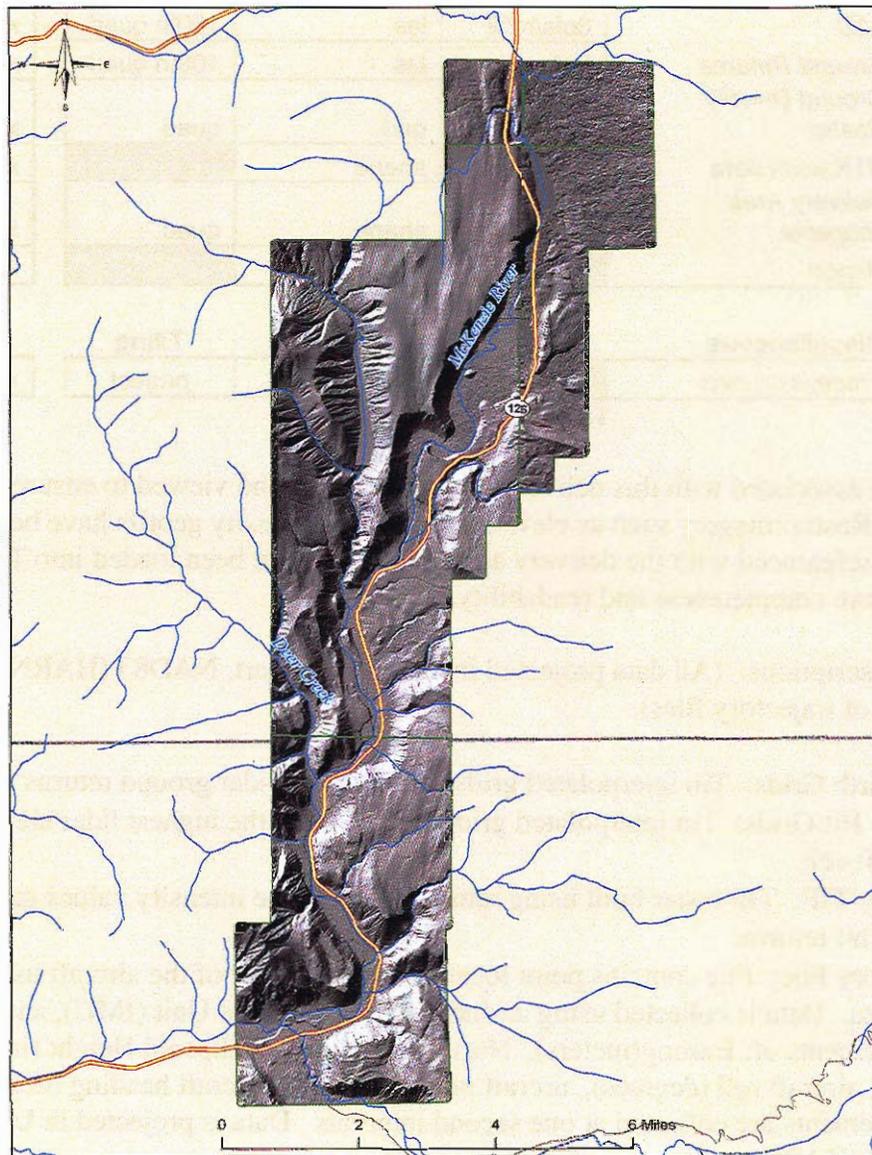


Figure 1. Delivery 1 location area. Data is referenced to USGS 7.5 minute quadrangles within the extents of the Willamette Valley Survey collection area.

Consistency Analysis:

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

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

To quantify the magnitude of this error 243 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 965,542 per tile (Table 2a). Error measurements were calculated by differencing the nearest point from an adjacent flight line within 1 meters in the horizontal plane and 0.2 meters in the vertical plane. Each flight line was compared to adjacent flight lines, and the average magnitude of vertical error was calculated. A total of 60 flight lines were sampled and compared for consistency.

Summary Statistics

# of Tiles	243
# of Flight Line Sections	60
Avg # of Points	359,317
Avg. Magnitude Z error (m)	0.052

Table 2a. Summary Results of Consistency Analysis

	<i>meters</i>	<i>feet</i>
Mean	0.052	0.170
Standard Error	0.001	0.002
Standard Deviation	0.005	0.017
Sample Variance	0.000	0.000
Range	0.022	0.073
Minimum	0.042	0.136
Maximum	0.064	0.210

Table 2b. Descriptive Statistics for Magnitude Z Error.

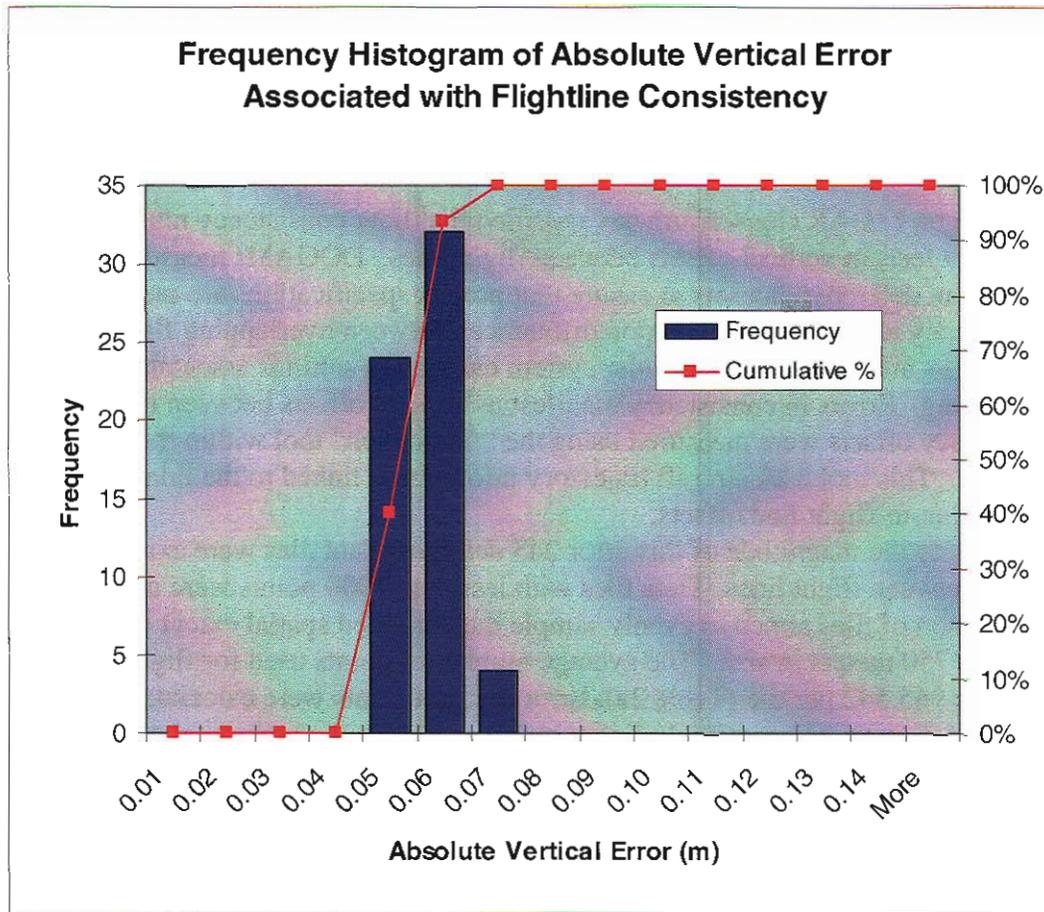


Figure 2.

Results of the consistency analysis found the average flight line offset to be 0.052 meters with a maximum error of 0.064m (Table 2b). Distribution of error showed over 93% of all error was less than 0.07m and 100% was less than 0.08m (Figure 2). These results show that all data fell well within tolerances of data consistency according to contract agreement.

Visual Analysis

Lidar 3ft grids were loaded into ArcGIS software for visual analysis. Data were examined through slope and hillshade models of bare earth returns. Hillshades of the highest hit models were used to identify areas of missing ground (Figure 3). Both bare earth and highest hit models were examined for calibration offsets, tiling artifacts (Figure 4), seam line offsets, pits (Figure 5), and birds.

Calibration offsets typically are visualized as a corduroy-like patterning within a hillshaded lidar model. These offsets present themselves along steep slopes and typically stand out more in highest hit models than bare earth. Tiling artifacts are a result of missing or misclassified data along the edge of lidar processing tiles. These artifacts present themselves as linear features typically 1-2 grid cells in width, and are present in both the highest hit and bare

earth models (e.g. Figure 3). Seam line offsets occur where two distinct days of lidar data overlap. Errors occur as a result of improper absolute vertical error adjustments. These errors are typically visualized as a linear stair step running along the edge of connecting flight lines. Pits and birds refer to uncommonly high or low points that are the result of atmospheric and sensor noise. Pits (low points) typically occur where the laser comes in contact with water on the ground (Figure 5). Birds (high points) typically occur where the laser comes into contact with atmospherics¹.

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

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

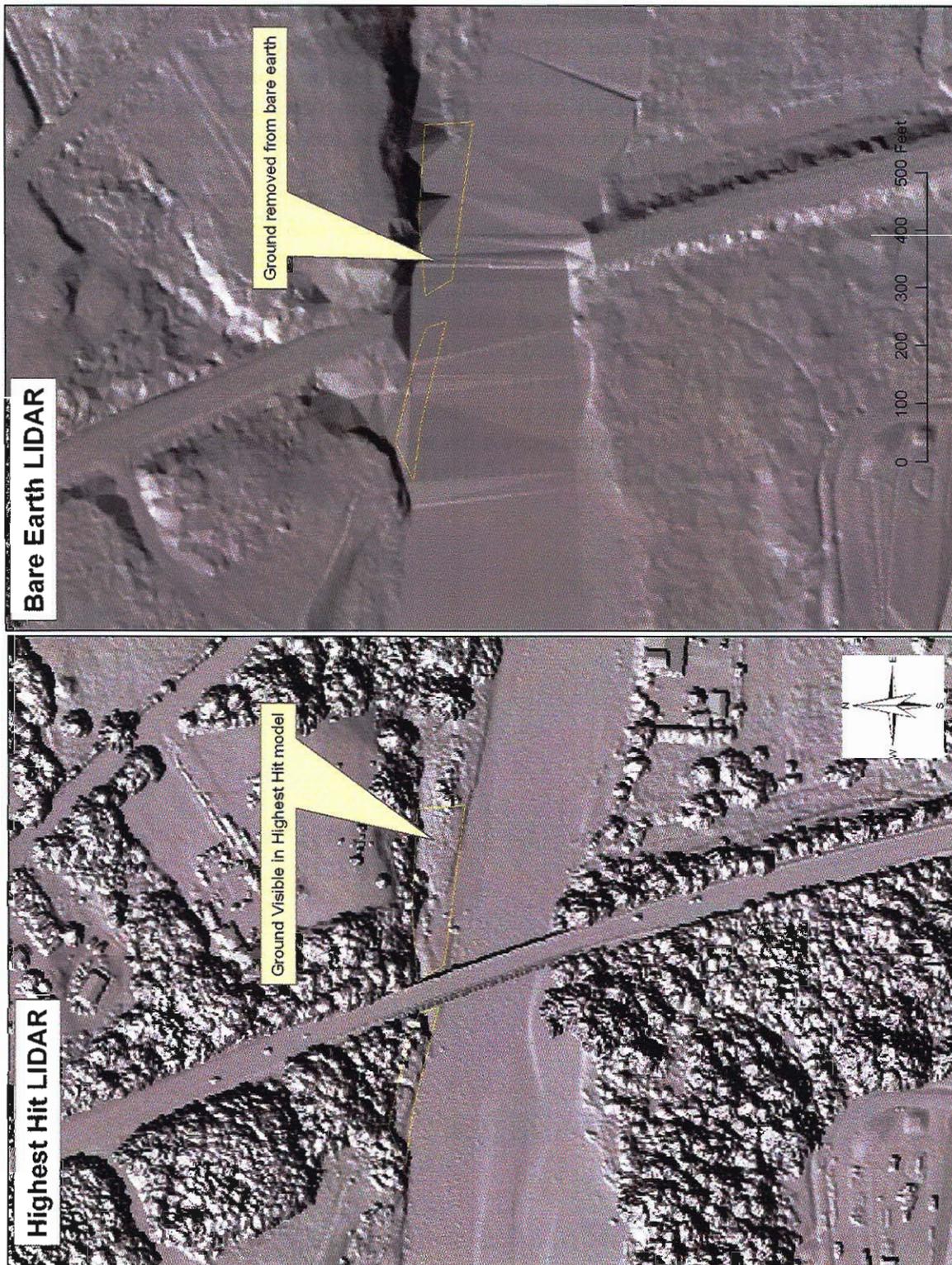


Figure 3. Example of missing ground in lidar bare earth data. Ground is clearly visible in highest hit model, but has been removed from the bare earth model. This type of classification error is common near water body features.

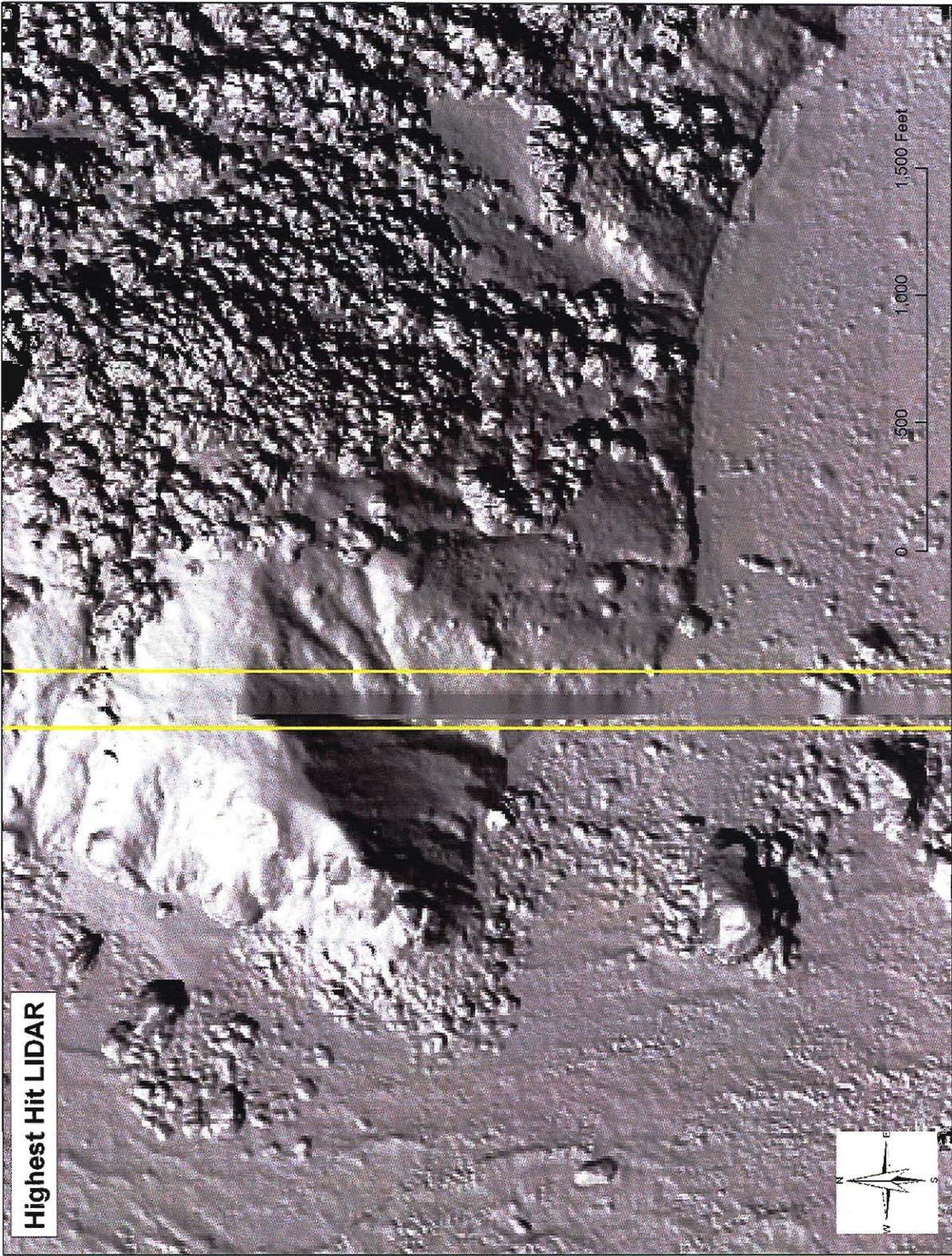


Figure 4. Example of tile artifact found in highest hit lidar data. Artifact is a seam line error created due to misclassification of ground at edge of lidar processing tiles.

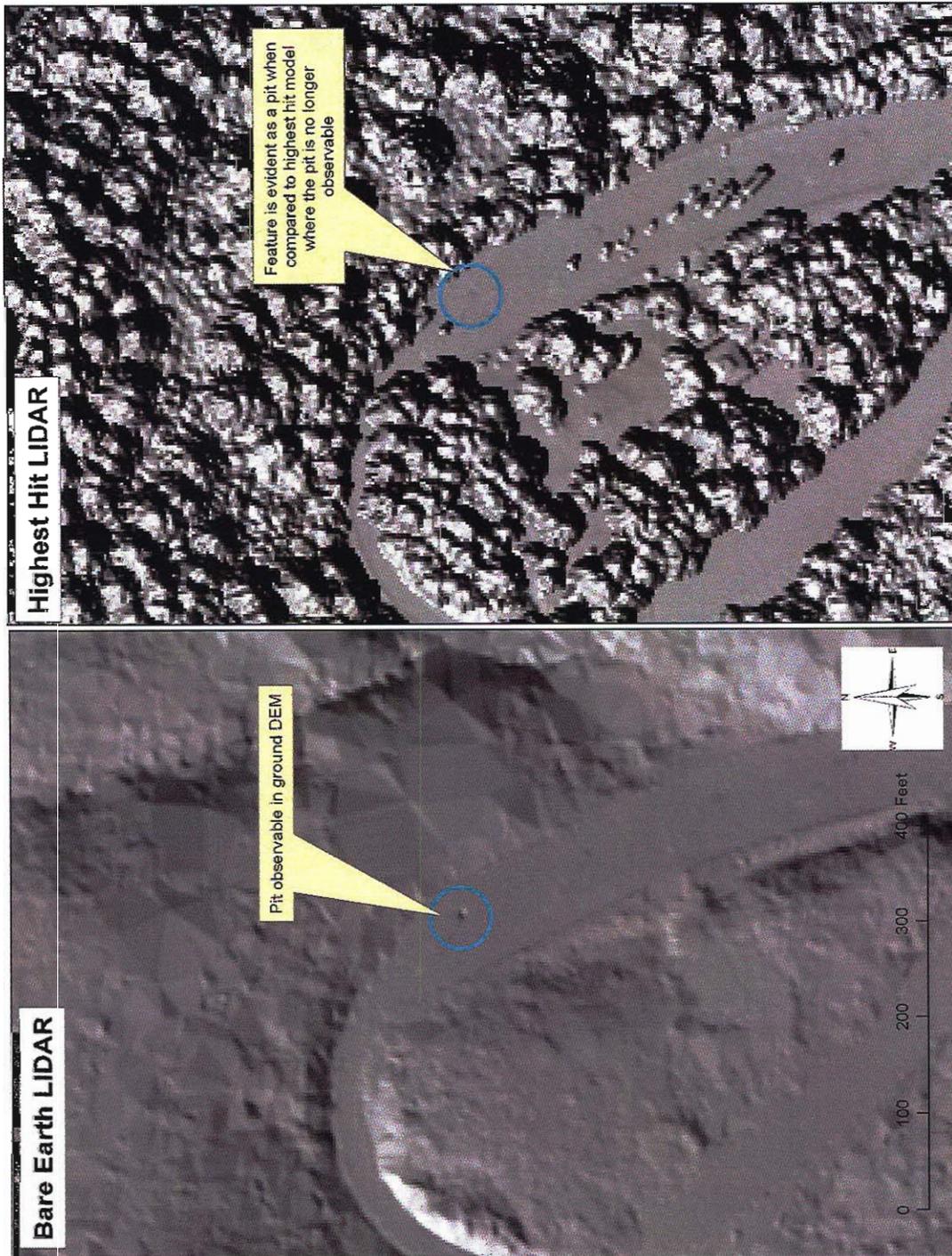


Figure 5. Example of “Pit” observable when comparing bare earth to highest hit models. Pits are caused when standing water absorbs the lidar pulse. Pits are evident in ground model as the lowest point elevation is assigned to the grid cell value. Inversely the pit is not observable in the highest hit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

Absolute Accuracy Analysis:

Absolute accuracy refers to the mean vertical offset of lidar data relative to measured ground-control points (GCP) obtained throughout the lidar sampling area. DOGAMI used a Trimble™ 5700/5800 Total Station GPS surveying system (Figure 5) to measure GCP's. This system consisted of a GPS base station (5700 unit), Zephyr Geodetic antenna, Trimmark 3 radio, and 5800 "rover". The 5700 base station was mounted on a fixed height (typically 2.0 m) tripod and located over a known geodetic survey monument followed by a site calibration on several adjacent benchmarks to precisely establish a local coordinate system. This step is critical in order to eliminate various survey errors. For example, Trimble reports that the 5700/5800 GPS system have horizontal errors of approximately $\pm 1\text{-cm} + 1\text{ppm}$ (parts per million * the baseline length) and $\pm 2\text{-cm}$ in the vertical (TrimbleNavigationSystem, 2005). These errors may be compounded by other factors such as poor satellite geometry, multipath, and poor atmospheric conditions, combining to increase the total error to several centimeters. Thus, the site calibration process is critical in order to minimize these uncertainties.

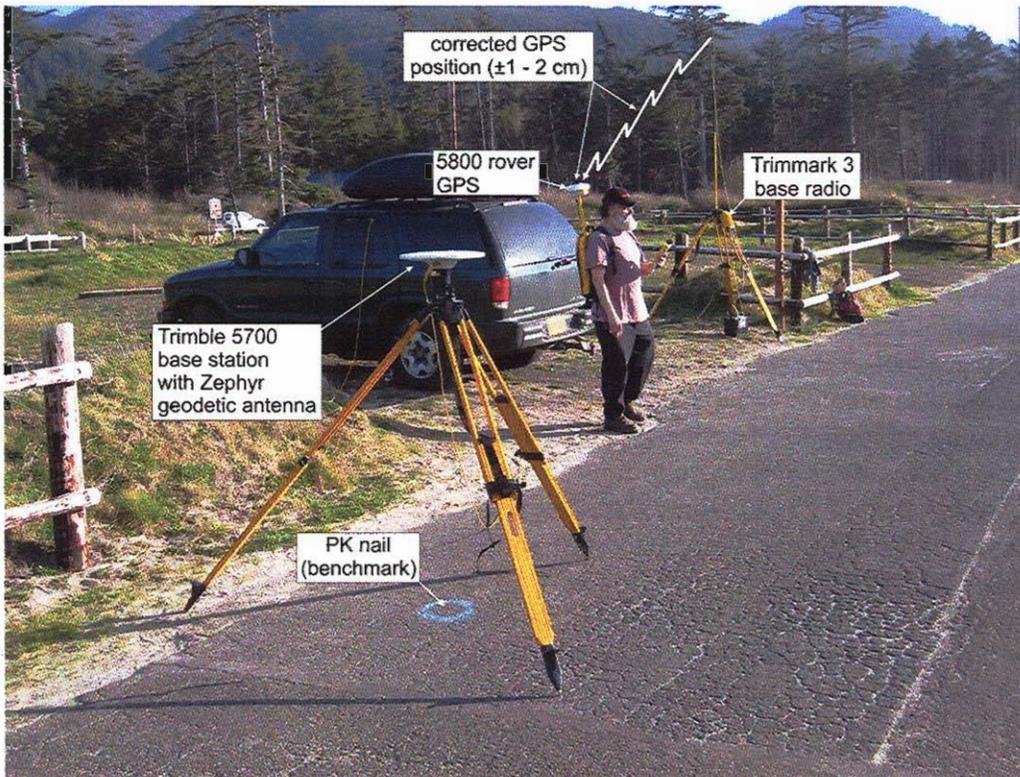


Figure 5. The Trimble 5700 base station antenna located over a known reference point at Cape Lookout State Park. Corrected GPS position and elevation information is then transmitted by a Trimmark III base radio to the 5800 GPS rover unit.

The approach adopted for the Southern Oregon coast lidar survey was comprised of three components:

- 1) Verify the horizontal and vertical coordinates established by Watershed Sciences for a select number of survey monuments used to calibrate the lidar survey. These surveys typically involved a minimum of two hours of GPS occupation over a known point. The collected data were then submitted to the

- National Geodetic Survey (NGS) Online Positioning User Service (OPUS) for post-processing against several Continuously Operating Reference Stations (CORS) operated by the NGS.
- 2) Collect GCP's along relatively flat surfaces (roads, paths, parking lots etc.). This step involved the collection of both continuous measurements (from a vehicle as well as from a backpack) as well as static measurements (typically 5 epics).

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

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

Out of a total of 17 measured GCP's obtained in the Delivery 1 region, and compared with the lidar elevation grids. The data delivered to DOGAMI was found to have a mean vertical offset of +/-0.024 meters (0.081 feet) and an RMSE value of 0.030 meters (0.099 ft). Offset values ranged from 0 to 0.061 meters (Table 3 and Figure 7).

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

DOGAMI was able to test the horizontal accuracy of survey monuments used to reference the lidar data while conducting vertical control measurements. For internal purposes only, the XY coordinates of survey monuments surveyed by DOGAMI were compared to the survey monuments provided by the vender and in almost every case, the reported results were consistent with those obtained by DOGAMI staff.

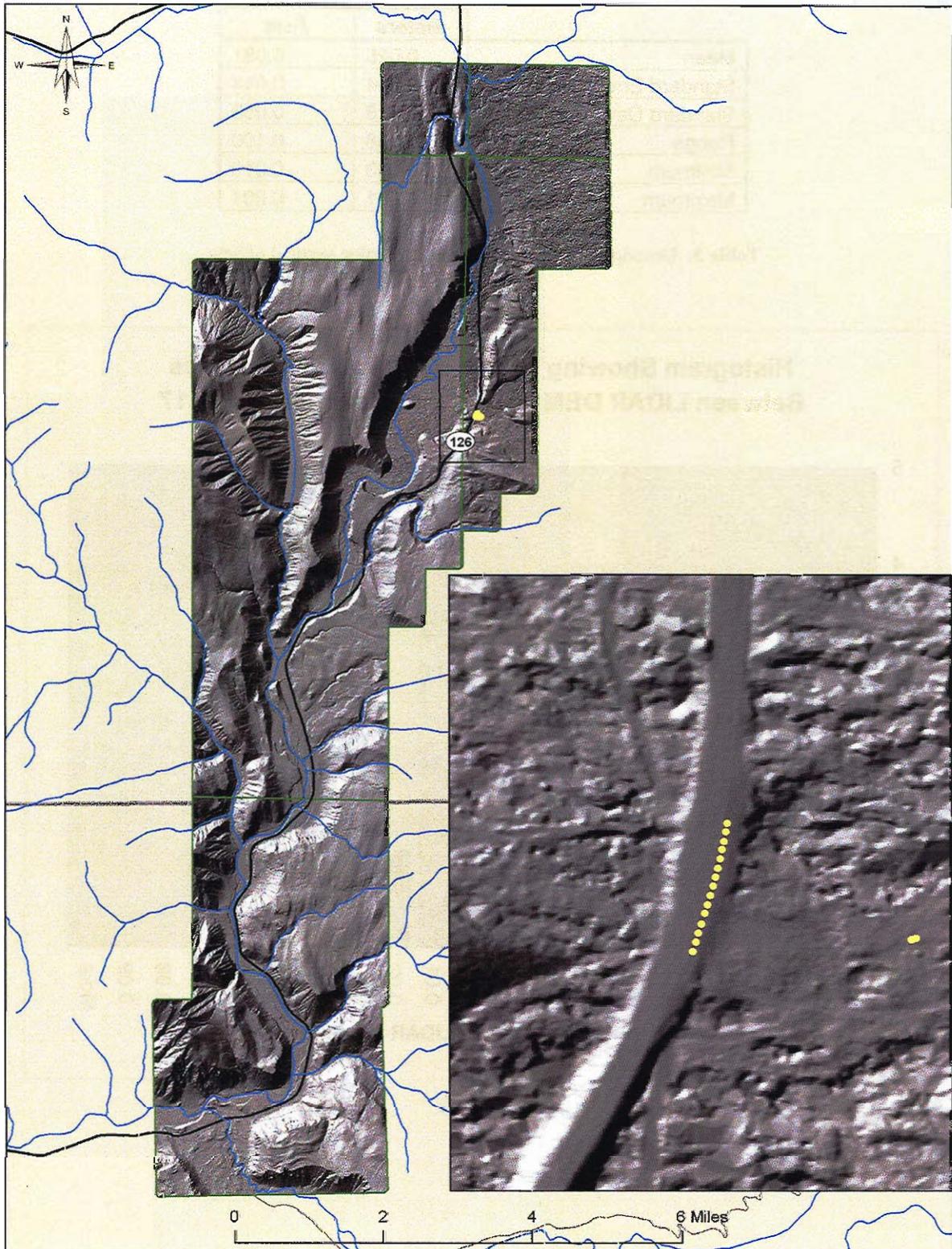


Figure 6. Locations of RTK control surveyed by DOGAMI. Data was used to test absolute accuracy for the Willamette Valley lidar survey within the Delivery 1 extent.

	<i>Meters</i>	<i>Feet</i>
Mean	0.025	0.081
Standard Error	0.004	0.014
Standard Deviation	0.018	0.058
Range	0.058	0.190
Minimum	0.003	0.010
Maximum	0.061	0.201

Table 3. Descriptive Statistics for absolute value vertical offsets.

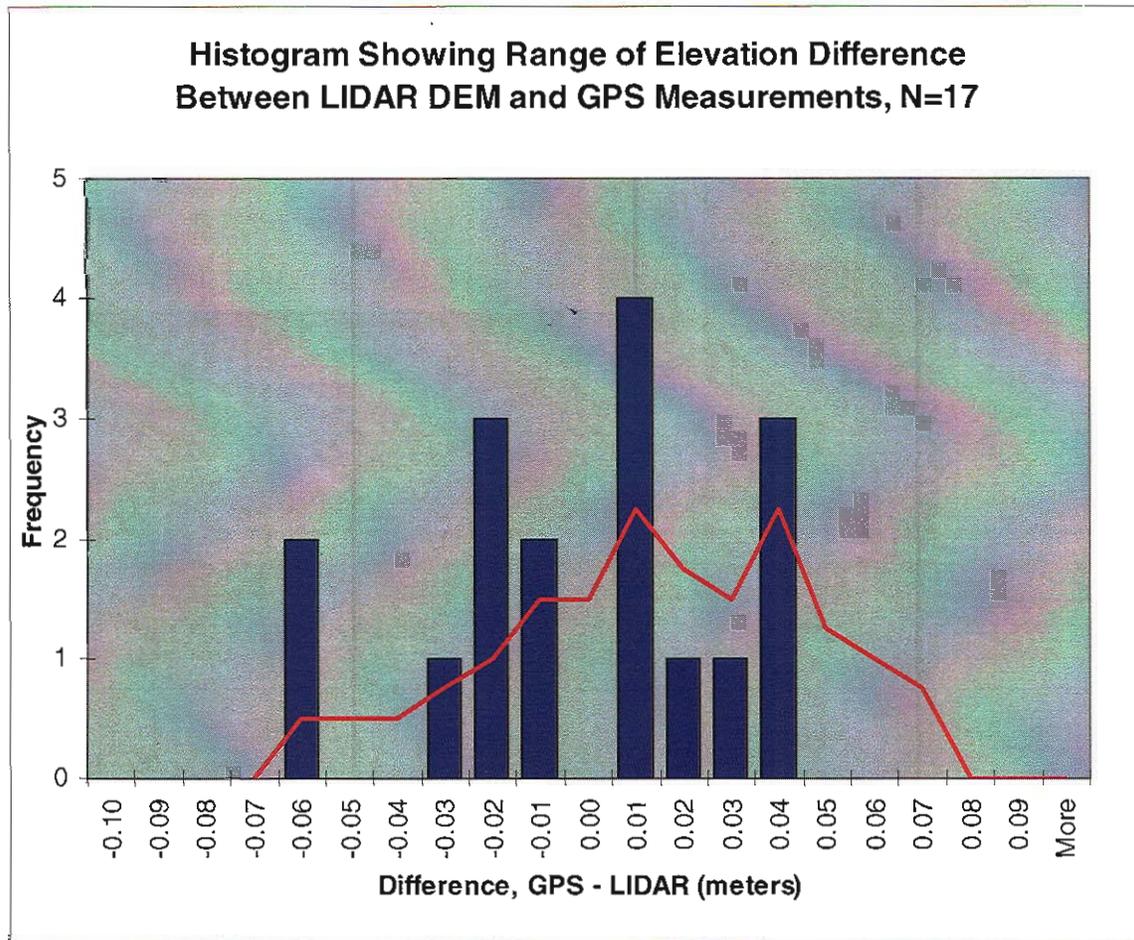


Figure 7.

Acceptance

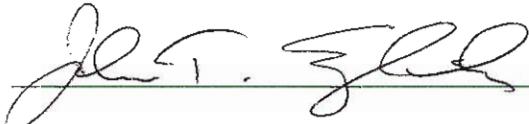
The data described in this report meets and exceeds project specifications laid out in the contracted data standards agreement. All components of data to be delivered have been received as of January 22nd, 2008. Consistency analysis has concluded that all data contains flight line to flight line vertical offset less than the threshold of 0.15 meters as specified in agreement. The vendor has adequately responded to all fixable errors identified as part of the visual analysis. Perceived grid errors identified by DOGAMI that were found to be false have been documented by the vendor and explained to the satisfaction of DOGAMI reviewers. Absolute accuracy analysis of the data has concluded that absolute vertical error of lidar data is less than the specified tolerance of 0.20 meters as specified in the data standards agreement.

Approval Signatures



Date: 4/1/09

Ian Madin
Chief Scientist – Department of Geology & Mineral Industries



Date: 4/1/09

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

The Oregon Department of Geology & Mineral Industries has contracted with Watershed Sciences to collect high resolution lidar topographic data for multiple areas within the State of Oregon. Areas for lidar data collection have been designed as part of a collaborative effort of State, Federal, and Local agencies in order to meet a wide range of project goals. The vendor has agreed to certain conditions of data quality and standards for all lidar data deliverables listed in sections A through C (OPA #8865) of the 2007-2009 Lidar Data Acquisition Price Agreement (pgs 14-23). Data submitted under this price agreement is to be collected at a resolution of at least 8 points per square meter and processed to meet or exceed the agreed upon data quality standards. This document itemizes and reports upon Willamette Valley Lidar Project – Delivery 2 & 3 products furnished by the lidar vendor as documentation that all data meets project specific standards.

Upon receipt from vendor (Watershed Sciences), all lidar data for Delivery 2 & 3 were independently reviewed by staff from the Oregon Department of Geology and Mineral Industries (DOGAMI) to ensure project specifications were met. All data were inventoried for completeness and data were checked for quality, which included examining lidar data for errors associated with internal data consistency, model quality, and accuracy.

- Consistency Analysis involves examining flight line offsets to quantify the accuracy of data calibration. Calibration influences elevation data quality with poor calibration leading to small but systematic errors within lidar elevation points, which then create inaccuracies within derived lidar elevation models.
- Visual checks are carried out in order to identify potential data artifacts and misclassifications of lidar point data. Lidar point data is classified as either ground, above ground, or error points. Sophisticated processing scripts are used to classify point data and remove error points. The data vendor performs quality control analysis to fix misclassifications of point data. The delivered bare earth DEM is then reviewed by DOGAMI to ensure that the data classification is correct and there are no topographic processing artifacts. If errors are found, data must be resubmitted.
- Accuracy of the data is examined by comparing lidar elevation data with independent survey control to quantify vertical and horizontal accuracy. For each lidar collection project DOGAMI collected independent GPS ground elevations, which were then compared against delivered lidar elevation models.

Data Completeness

Data for Willamette Valley Delivery 2 & 3 area were collected between 08/31/2008 to 02/22/2009. Total area of delivered data totals 245.86 square miles (Delivery 2 = 105.25, Delivery 3 = 140.50). Delivery 2 & 3 (Figure 1) includes data in the format of grids, trajectory files, intensity images, Lidar ASCII Standard (LAS) point files, ground point density rasters, RTK survey data, a shapefile of the delivery area, and the lidar delivery report (Table 1). Bare earth and highest hit grids were delivered in ArcInfo Grid format with 3ft cell size. Lidar point

data is delivered in LAS binary format for ground classified returns as well as the entire lidar point cloud. Georeferenced intensity images are supplied in TIF format. Supplementary data includes ground density rasters displaying locations where ground returns are low. Real time kinematic ground survey data (used for absolute vertical adjustment) is supplied in shapefile format. This delivery contains data for the following USGS 7.5 minute quads (listed by Ohio Code #) within the boundary of the Willamette Valley Survey collection area (Figure 1).

Delivery 2: 44123b3, 44123b4, 44124c3, 44123c4

Delivery 3: 44123d3, 44123d4, 44123e3, 44123e4, 44123f3

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

Table 1. Deliverable Checklist

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

Deliverable Descriptions: (All data projected in Oregon Lambert, NAD83 (HARN), Intl Feet with exception of trajectory files).

- Bare Earth Grids: Tin interpolated grids created from lidar ground returns.
- Highest Hit Grids: Tin interpolated grids created from the highest lidar elevation for a given 3ft cell.
- Intensity TIF: TIF raster built using returned lidar pulse intensity values gathered from highest hit returns.
- Trajectory File: File contains point location measurement of the aircraft used to collect lidar data. Data is collected using an Inertial Measurement Unit (IMU), and collects measurements of: Easting(meters), Northing (meters), Ellipsoid Height (meters) of

aircraft, aircraft roll (degrees), aircraft pitch (degrees), aircraft heading (degrees). Measurements are collected at one second intervals. Data is projected in UTM zone 10, NAD83 (HARN).

- LAS: Binary file of all lidar points collected in survey (Class, flight line #, GPS Time, Echo, Easting, Northing, Elevation, Intensity, Scan Angle, Echo Number, and Scanner).
- Ground LAS: Binary file of lidar points classified as ground (Class, flight line #, GPS Time, Echo, Easting, Northing, Elevation, Intensity, Scan Angle, Echo Number, and Scanner).
- RTK Point Data: Ground GPS Survey data used to correct raw lidar point cloud for vertical offsets.
- Delivery Area Shapefile: Geometry file depicting the geospatial area associated with deliverables.
- Report: Report provides detailed description of data collection methods and processing. The vendor also reports accuracies associated with calibration, consistency, absolute error, and point classifications.

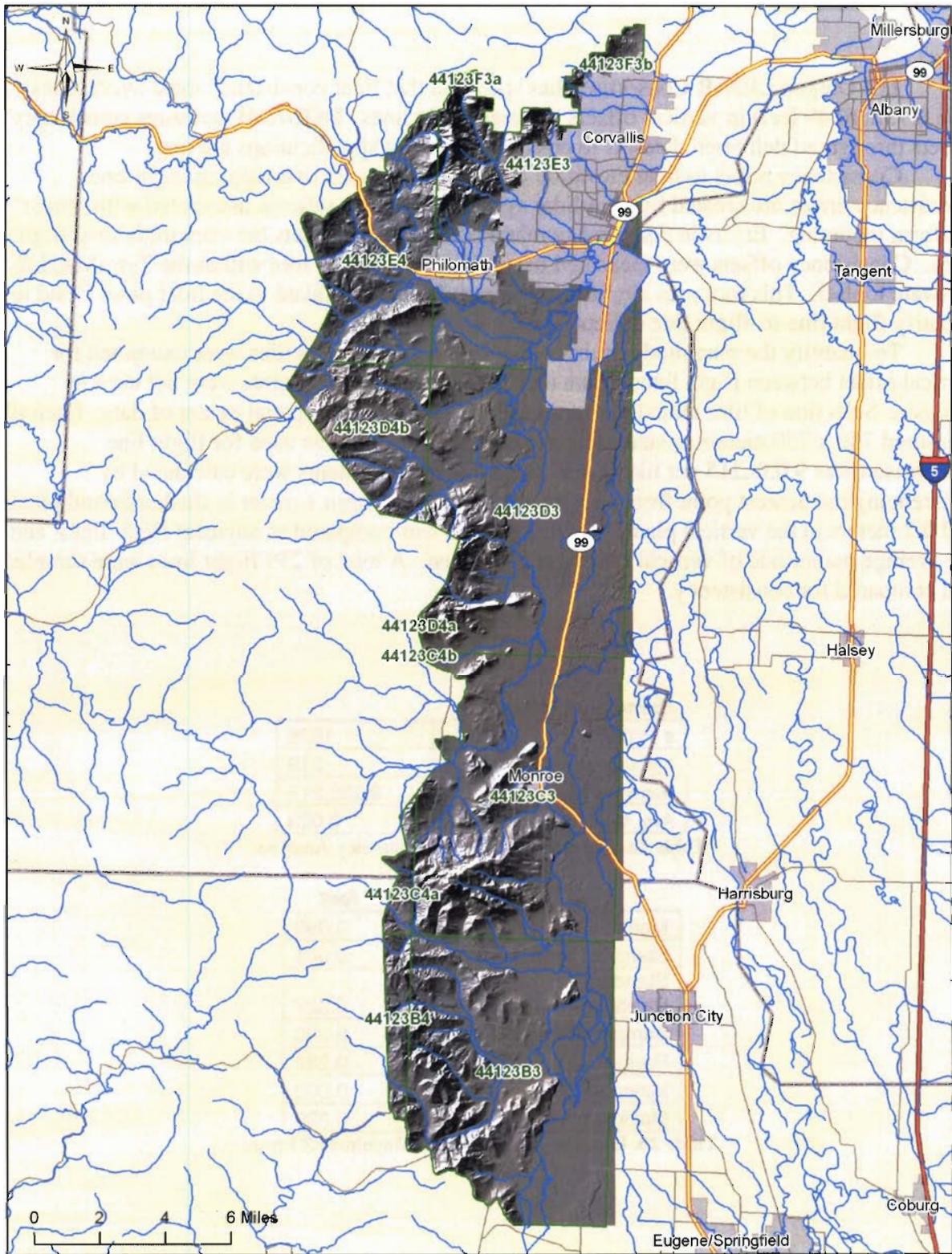


Figure 1. Delivery 2 & 3 location area. Data is referenced to USGS 7.5 minute quadrangles within the extents of the Willamette Valley Survey collection area.

Consistency Analysis:

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

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

To quantify the magnitude of this error 1828 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 9,038,215 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 219 flight lines were sampled and compared for consistency.

Summary Statistics

# of Tiles	1828
# of Flight Line Sections	219
Avg # of Points	9,038,215
Avg. Magnitude Z error (m)	0.029

Table 2a. Summary Results of Consistency Analysis

	<i>meters</i>	<i>feet</i>
Mean	0.029	0.096
Standard Error	0.000	0.001
Standard Deviation	0.008	0.027
Sample Variance	0.000	0.000
Range	0.073	0.239
Minimum	0.000	0.000
Maximum	0.073	0.239

Table 2b. Descriptive Statistics for Magnitude Z Error.

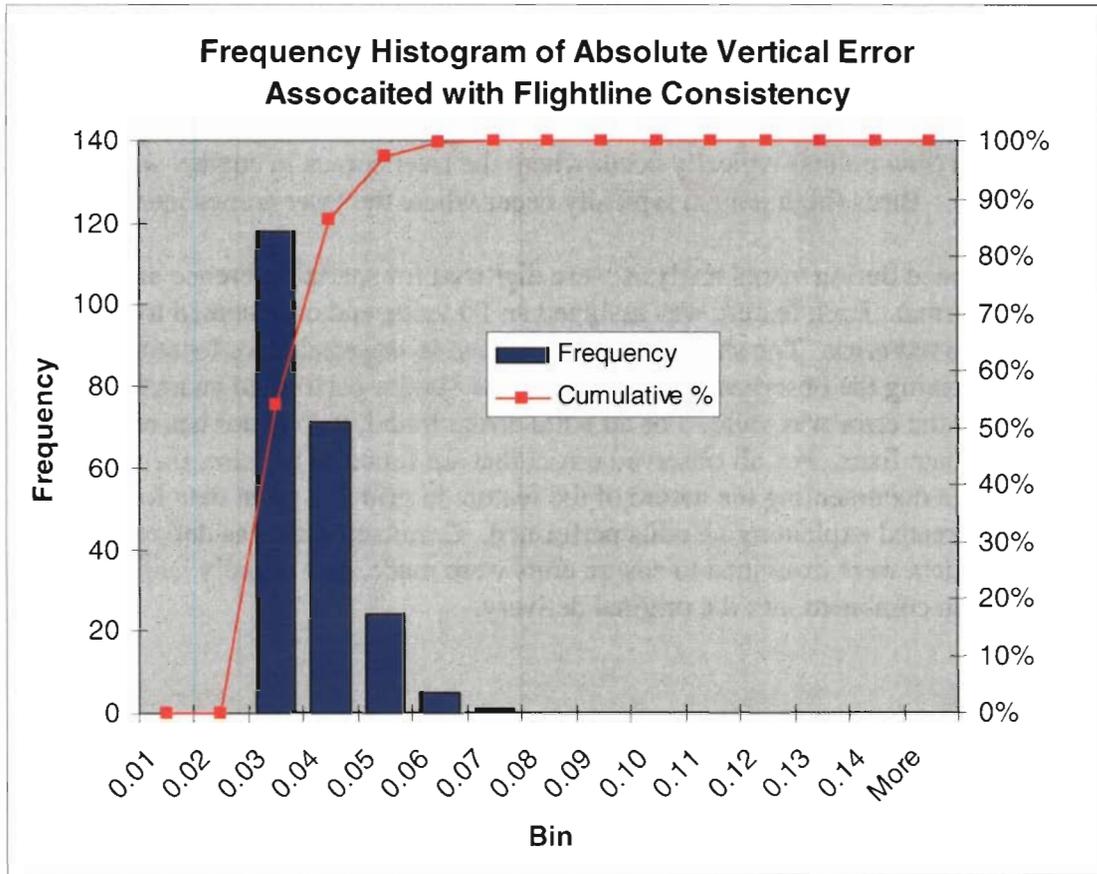


Figure 2.

Results of the consistency analysis found the average flight line offset to be 0.029 meters with a maximum average flight line offset of 0.073m (Table 2b). Distribution of error showed over 97% of all error was less than 0.05m and 99% was less than 0.06m (Figure 2). These results show that all data were within tolerances of data consistency according to contract agreement.

Visual Analysis

Lidar 3ft grids were loaded into ArcGIS software for visual analysis. Data were examined through slope and hillshade models of bare earth returns. Hillshades of the highest hit models were used to identify areas of missing ground (Figure 3). Both bare earth and highest hit models were examined for calibration offsets, tiling artifacts (Figure 4), seam line offsets, pits (Figure 5), and birds.

Calibration offsets typically are visualized as a corduroy-like patterning within a hillshaded lidar model. These offsets present themselves along steep slopes and typically stand out more in highest hit models than bare earth. Tiling artifacts are a result of missing or misclassified data along the edge of lidar processing tiles. These artifacts present themselves as linear features typically 1-2 grid cells in width, and are present in both the highest hit and bare

earth models (e.g. Figure 3). Seam line offsets occur where two distinct days of lidar data overlap. Errors occur as a result of improper absolute vertical error adjustments. These errors are typically visualized as a linear stair step running along the edge of connecting flight lines. Pits and birds refer to uncommonly high or low points that are the result of atmospheric and sensor noise. Pits (low points) typically occur where the laser comes in contact with water on the ground (Figure 5). Birds (high points) typically occur where the laser comes into contact with atmospherics¹.

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

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



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

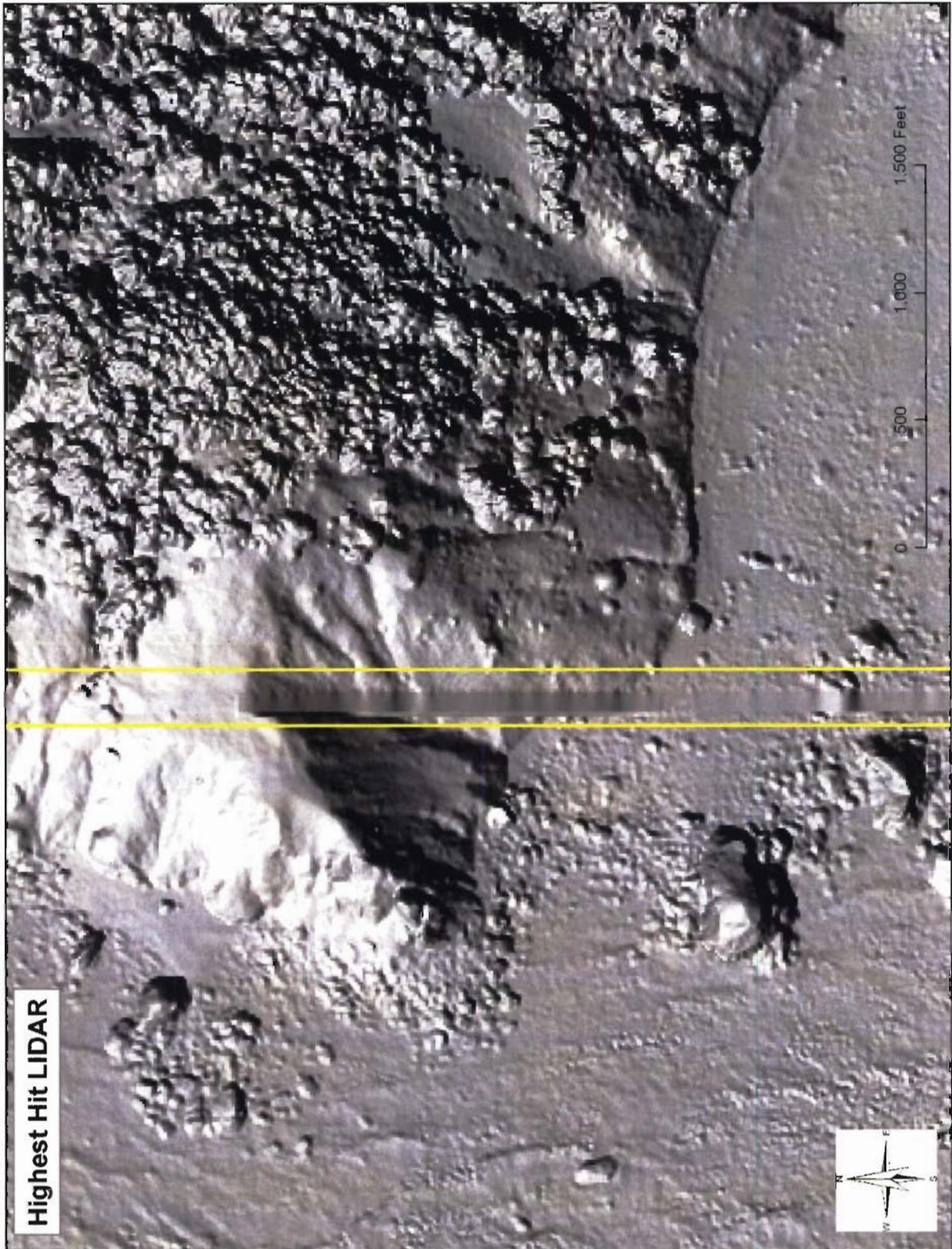


Figure 4. Example of tile artifact found in highest hit lidar data. Artifact is a seam line error created due to misclassification of ground at edge of lidar processing tiles.

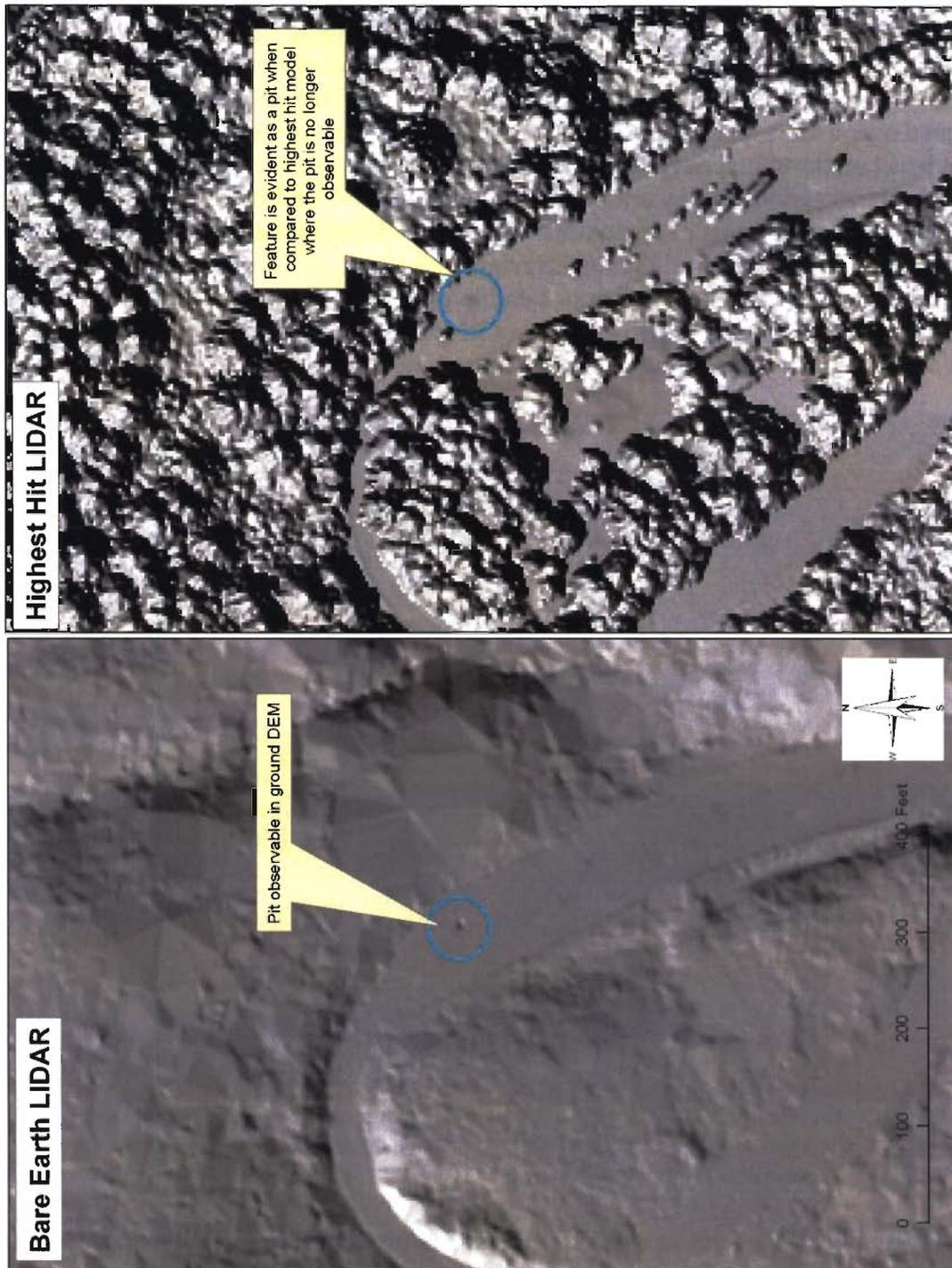


Figure 5. Example of “Pit” observable when comparing bare earth to highest hit models. Pits are caused when standing water absorbs the lidar pulse. Pits are evident in ground model as the lowest point elevation is assigned to the grid cell value. Inversely the pit is not observable in the highest hit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

Absolute Accuracy Analysis:

Absolute accuracy refers to the mean vertical offset of lidar data relative to measured ground-control points (GCP) obtained throughout the lidar sampling area. DOGAMI used a Trimble™ 5700/5800 Total Station GPS surveying system (Figure 5) to measure GCP's. This system consisted of a GPS base station (5700 unit), Zephyr Geodetic antenna, Trimmark 3 radio, and 5800 "rover". The 5700 base station was mounted on a fixed height (typically 2.0 m) tripod and located over a known geodetic survey monument followed by a site calibration on several adjacent benchmarks to precisely establish a local coordinate system. This step is critical in order to eliminate various survey errors. For example, Trimble reports that the 5700/5800 GPS system have horizontal errors of approximately $\pm 1\text{-cm} + 1\text{ppm}$ (parts per million * the baseline length) and $\pm 2\text{-cm}$ in the vertical (TrimbleNavigationSystem, 2005). These errors may be compounded by other factors such as poor satellite geometry, multipath, and poor atmospheric conditions, combining to increase the total error to several centimeters. Thus, the site calibration process is critical in order to minimize these uncertainties.

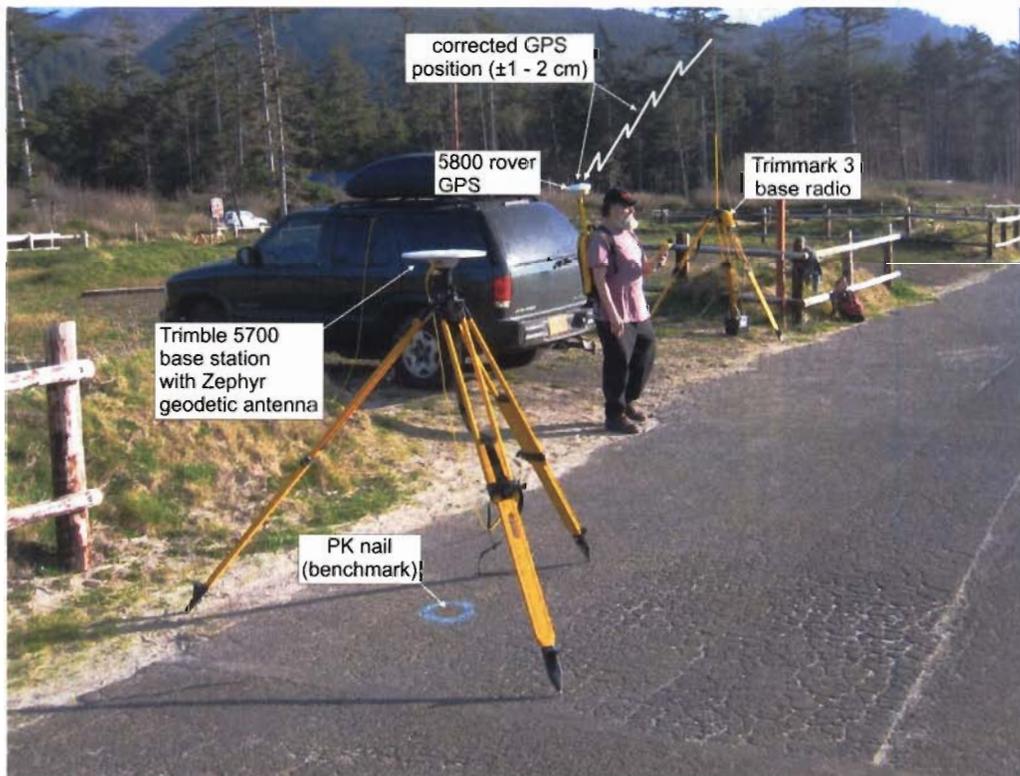


Figure 5. The Trimble 5700 base station antenna located over a known reference point at Cape Lookout State Park. Corrected GPS position and elevation information is then transmitted by a Trimmark III base radio to the 5800 GPS rover unit.

The approach adopted for Oregon LiDAR Consortium surveys was comprised of three components:

- 1) Verify the horizontal and vertical coordinates established by Watershed Sciences for a select number of survey monuments used to calibrate the lidar survey. These surveys typically involved a minimum of two hours of GPS occupation over a known point. The collected data were then submitted to the

National Geodetic Survey (NGS) Online Positioning User Service (OPUS) for post-processing against several Continuously Operating Reference Stations (CORS) operated by the NGS.

- 2) Collect GCP's along relatively flat surfaces (roads, paths, parking lots etc.). This step involved the collection of both continuous measurements (from a vehicle as well as from a backpack) as well as static measurements (typically 5 epics).

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

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

A total of 1753 measured GCP's were obtained in the Delivery 2 & 3 region, and compared with the lidar elevation grids. The data delivered to DOGAMI was found to have a mean vertical offset of +/-0.033 meters (0.11 feet) and an RMSE value of 0.041 meters (0.136 ft). Offset values ranged from -0.143 to 0.140 meters (Table 3 and Figure 7).

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

DOGAMI was able to test the horizontal accuracy of survey monuments used to reference the lidar data while conducting vertical control measurements. For internal purposes only, the XY coordinates of survey monuments surveyed by DOGAMI were compared to the survey monuments provided by the vender and in almost every case, the reported results were consistent with those obtained by DOGAMI staff.

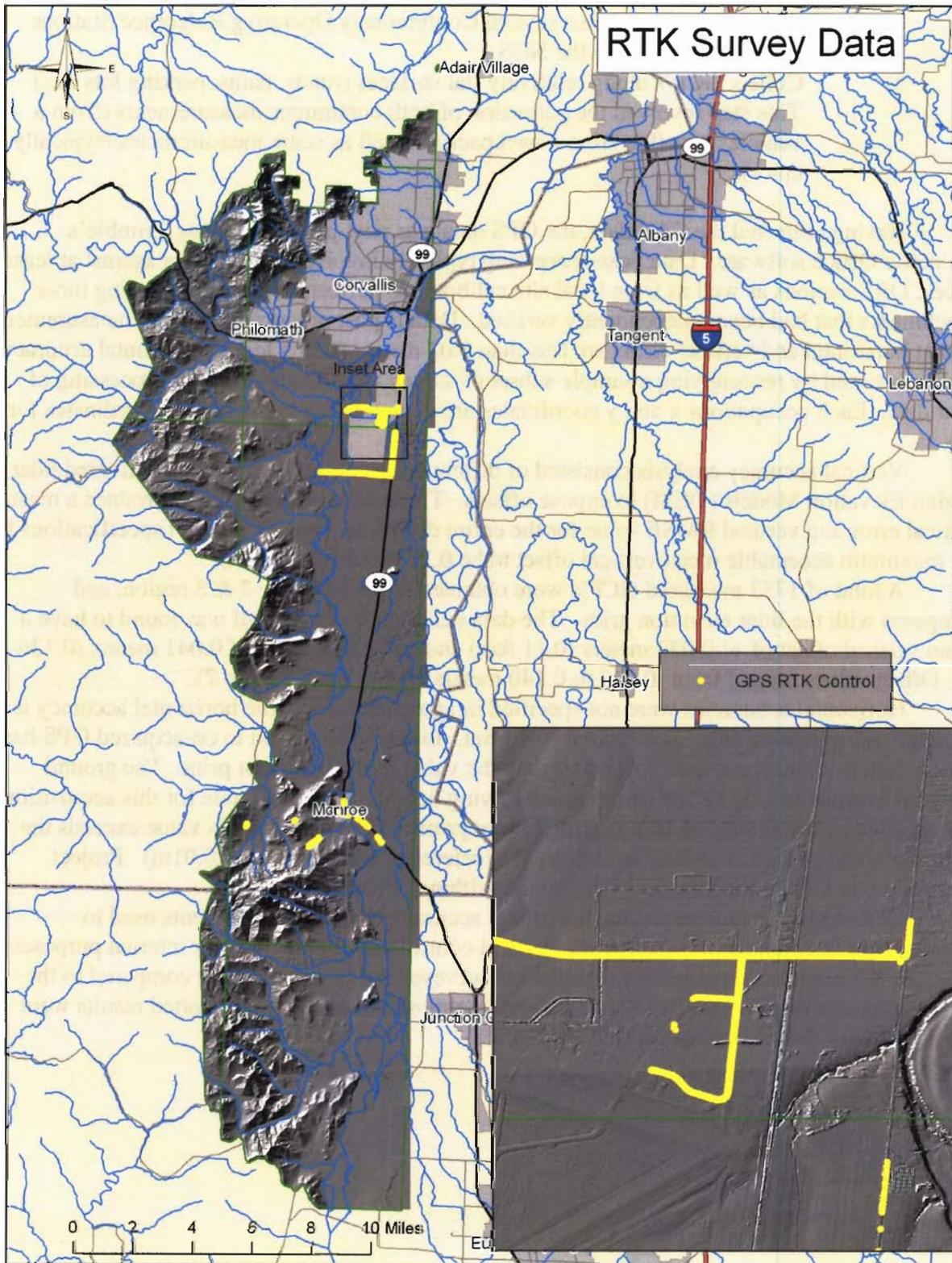


Figure 6. Locations of RTK control surveyed by DOGAMI. Data was used to test absolute accuracy for the Willamette Valley lidar survey within the Delivery 2 & 3 extent.

	<i>Meters</i>	<i>Feet</i>
Mean	0.033	0.110
Standard Error	0.001	0.003
Standard Deviation	0.041	0.134
Range	0.282	0.927
Minimum	-0.143	-0.468
Maximum	0.140	0.459

Table 3. Descriptive Statistics for absolute value vertical offsets.

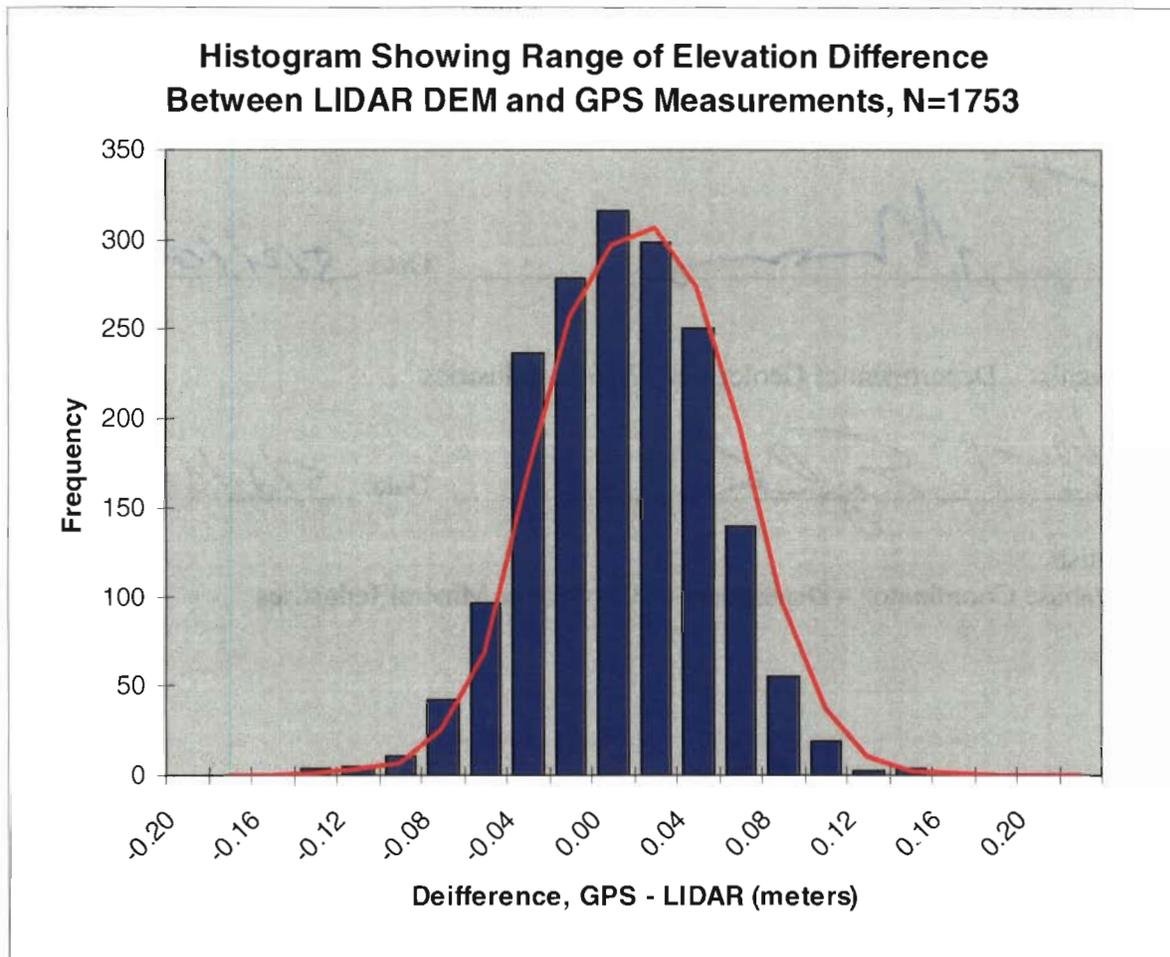


Figure 7.

Acceptance

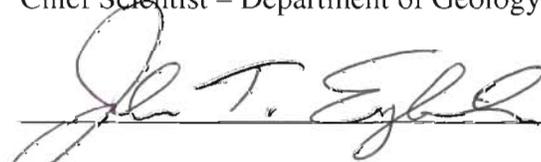
The data described in this report meets and exceeds project specifications laid out in the contracted data standards agreement. All components of data to be delivered have been received as of May 13th, 2008. Consistency analysis has concluded that all data contains flight line to flight line vertical offset less than the threshold of 0.15 meters as specified in agreement. The vendor has adequately responded to all fixable errors identified as part of the visual analysis. Perceived grid errors identified by DOGAMI that were found to be false have been documented by the vendor and explained to the satisfaction of DOGAMI reviewers. Absolute accuracy analysis of the data has concluded that absolute vertical error of lidar data is less than the specified tolerance of 0.20 meters as specified in the data standards agreement.

Approval Signatures



Date: 5/21/09

Ian Madin
Chief Scientist – Department of Geology & Mineral Industries



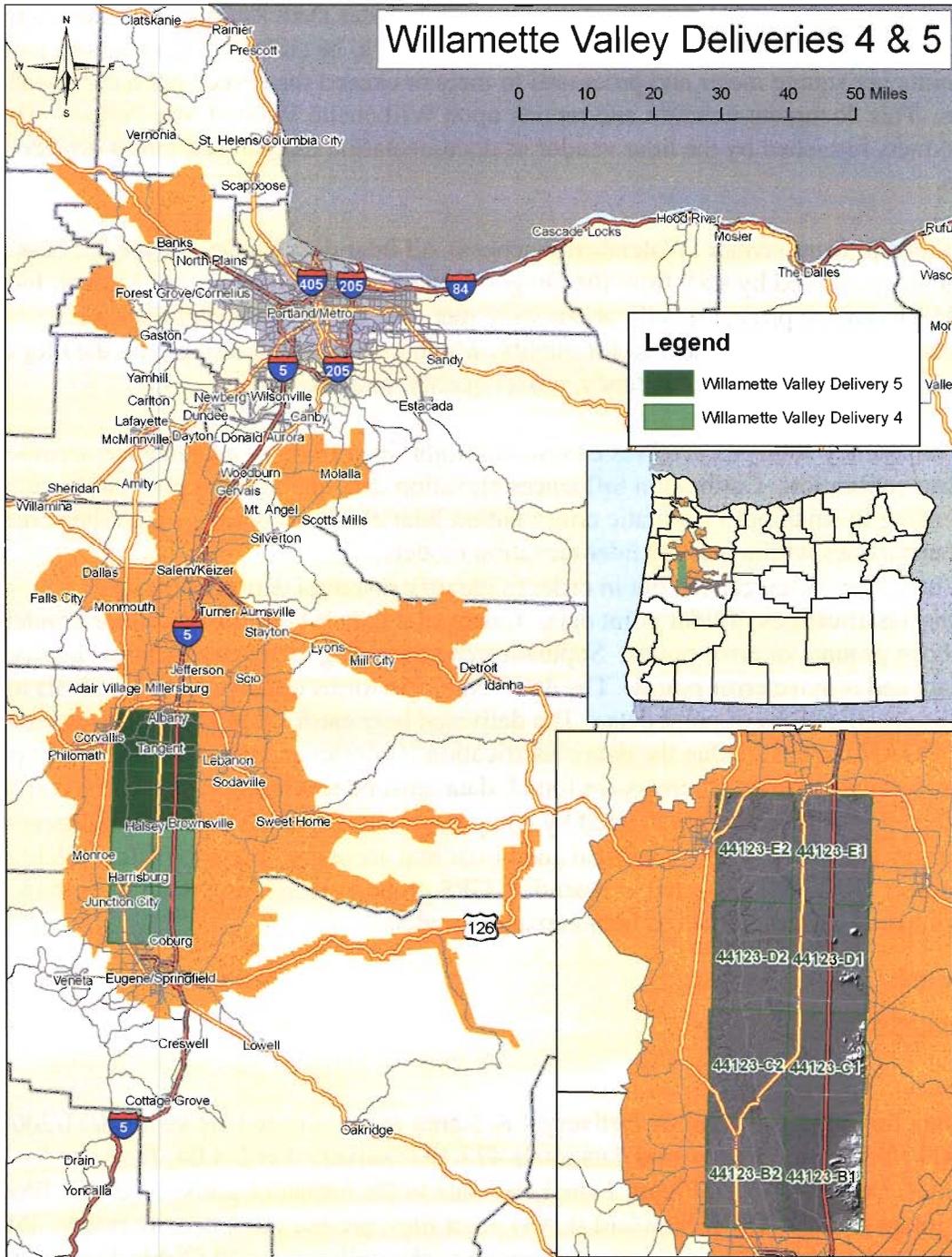
Date: 5/21/09

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

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



Willamette Valley LIDAR Project, 2009 – Delivery 4 & 5 QC Analysis
LIDAR QC Report – June 29th, 2009



Map featuring Willamette Valley Delivery 4 & 5 data extent.

The Oregon Department of Geology & Mineral Industries has contracted with Watershed Sciences to collect high resolution lidar topographic data for multiple areas within the State of Oregon. Areas for lidar data collection have been designed as part of a collaborative effort of State, Federal, and Local agencies in order to meet a wide range of project goals. The vendor has agreed to certain conditions of data quality and standards for all lidar data deliverables listed in sections A through C (OPA #8865) of the 2007-2009 Lidar Data Acquisition Price Agreement (pgs 14-23). Data submitted under this price agreement is to be collected at a resolution of at least 8 points per square meter and processed to meet or exceed the agreed upon data quality standards. This document itemizes and reports upon Willamette Valley Lidar Project – Delivery 4 & 5 products furnished by the lidar vendor as documentation that all data meets project specific standards.

Upon receipt from vendor (Watershed Sciences), all lidar data for Delivery 4 & 5 was independently reviewed by staff from the Oregon Department of Geology and Mineral Industries (DOGAMI) to ensure project specifications were met. All data were inventoried for completeness and data were checked for quality, which included examining lidar data for errors associated with internal data consistency, model quality, and accuracy.

- Consistency Analysis involves examining flight line offsets to quantify the accuracy of data calibration. Calibration influences elevation data quality with poor calibration leading to small but systematic errors within lidar elevation points, which then create inaccuracies within derived lidar elevation models.
- Visual checks are carried out in order to identify potential data artifacts and misclassifications of lidar point data. Lidar point data is classified as either ground, above ground, or error points. Sophisticated processing scripts are used to classify point data and remove error points. The data vendor performs quality control analysis to fix misclassifications of point data. The delivered bare earth DEM is then reviewed by DOGAMI to ensure that the data classification is correct and there are no topographic processing artifacts. If errors are found, data must be resubmitted.
- Accuracy of the data is examined by comparing lidar elevation data with independent survey control to quantify vertical and horizontal accuracy. For each lidar collection project DOGAMI collected independent GPS ground elevations, which were then compared against delivered lidar elevation models.

Data Completeness

Data for Willamette Valley Delivery 4 & 5 area were collected between 08/31/2008 to 02/22/2009. Total area of delivered data totals 427.19 (Delivery 4 = 214.04, Delivery 5 = 213.15 square miles. Delivery 4 & 5 (Figure 1) includes data in the format of grids, trajectory files, intensity images, Lidar ASCII Standard (LAS) point files, ground point density rasters, RTK survey data, a shapefile of the delivery area, and the lidar delivery report (Table 1). Bare earth and highest hit grids were delivered in ArcInfo Grid format with 3ft cell size. Lidar point data is

delivered in LAS binary format for ground classified returns as well as the entire lidar point cloud. Georeferenced intensity images are supplied in TIF format. Supplementary data includes ground density rasters displaying locations where ground returns are low. Real time kinematic ground survey data (used for absolute vertical adjustment) is supplied in shapefile format. This delivery contains data for the following USGS 7.5 minute quads (listed by Ohio Code #) within the boundary of the Willamette Valley Survey collection area (Figure 1):

Delivery 4: 44123b1, 44123b2, 44123c1, 44123c2

Delivery 5: 44123d1, 44123d2, 44123e1, 44123e2

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

Table 1. Deliverable Checklist

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

Deliverable Descriptions: (All data projected in Oregon Lambert, NAD83 (HARN), Intl Feet with exception of trajectory files).

- Bare Earth Grids: Tin interpolated grids created from lidar ground returns.
- Highest Hit Grids: Tin interpolated grids created from the highest lidar elevation for a given 3ft cell.
- Intensity TIF: TIF raster built using returned lidar pulse intensity values gathered from highest hit returns.
- Trajectory File: File contains point location measurement of the aircraft used to collect lidar data. Data is collected using an Inertial Measurement Unit (IMU), and collects measurements of: Easting(meters), Northing (meters), Ellipsoid Height (meters) of

aircraft, aircraft roll (degrees), aircraft pitch (degrees), aircraft heading (degrees). Measurements are collected at one second intervals. Data is projected in UTM zone 10, NAD83 (HARN).

- LAS: Binary file of all lidar points collected in survey (Class, flight line #, GPS Time, Echo, Easting, Northing, Elevation, Intensity, Scan Angle, Echo Number, and Scanner).
- Ground LAS: Binary file of lidar points classified as ground (Class, flight line #, GPS Time, Echo, Easting, Northing, Elevation, Intensity, Scan Angle, Echo Number, and Scanner).
- RTK Point Data: Ground GPS Survey data used to correct raw lidar point cloud for vertical offsets.
- Delivery Area Shapefile: Geometry file depicting the geospatial area associated with deliverables.
- Report: Report provides detailed description of data collection methods and processing. The vendor also reports accuracies associated with calibration, consistency, absolute error, and point classifications.

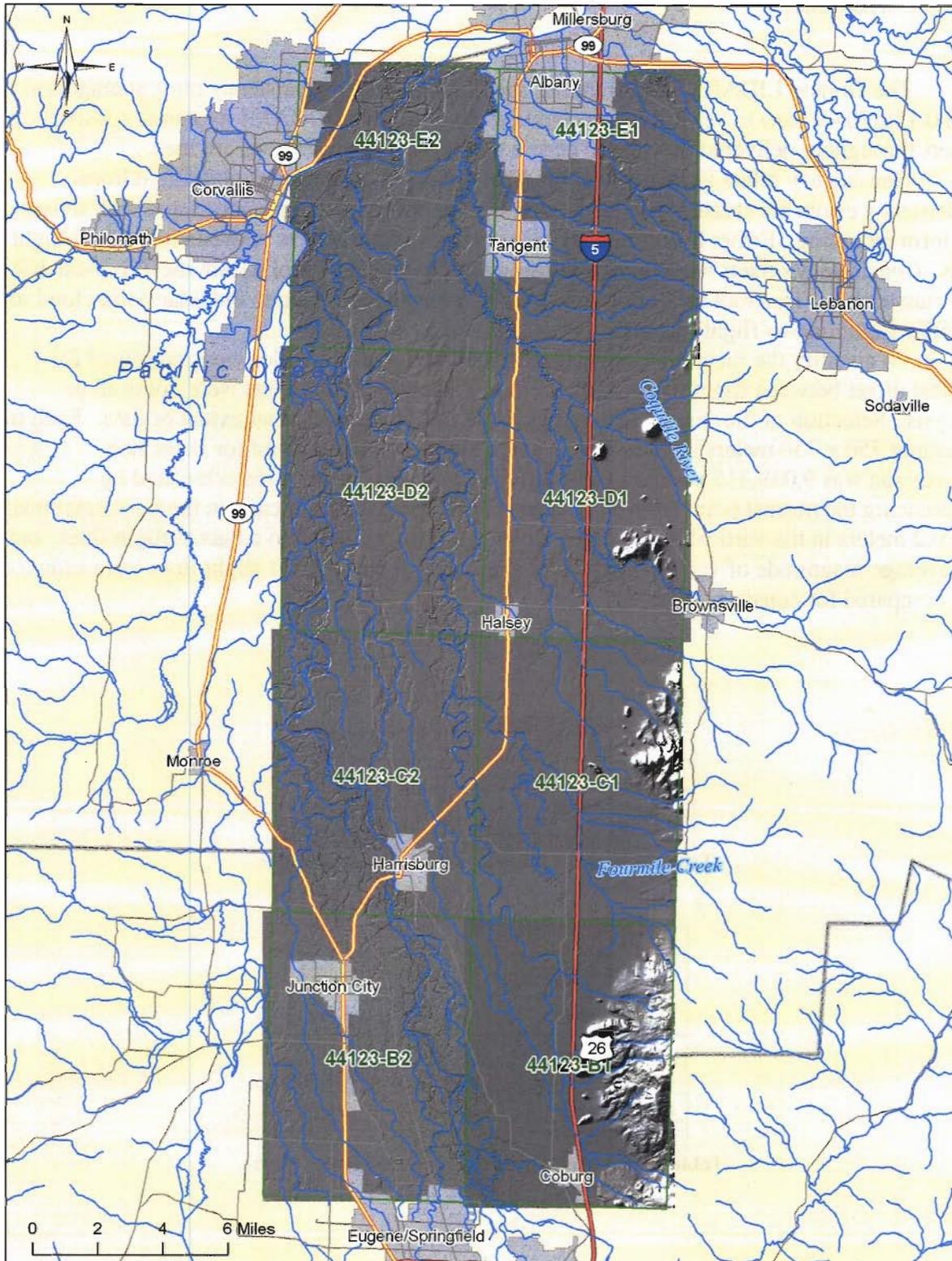


Figure 1. Delivery 4 & 5 location area. Data is referenced to USGS 7.5 minute quadrangles within the extents of the Willamette Valley Survey collection area.

Consistency Analysis:

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

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

To quantify the magnitude of this error 2098 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 9,038,215 per tile (Table 2a). Error measurements were calculated by differencing the nearest point from an adjacent flight line within 1 meters in the horizontal plane and 0.2 meters in the vertical plane. Each flight line was compared to adjacent flight lines, and the average magnitude of vertical error was calculated. A total of 251 flight lines were sampled and compared for consistency.

Summary Statistics

# of Tiles	243
# of Flight Line Sections	251
Avg # of Points	9,038,215
Avg. Magnitude Z error (m)	0.029

Table 2a. Summary Results of Consistency Analysis

	<i>meters</i>	<i>feet</i>
Mean	0.029	0.096
Standard Error	0.000	0.001
Standard Deviation	0.008	0.027
Sample Variance	0.000	0.000
Range	0.073	0.239
Minimum	0.000	0.000
Maximum	0.073	0.239

Table 2b. Descriptive Statistics for Magnitude Z Error.

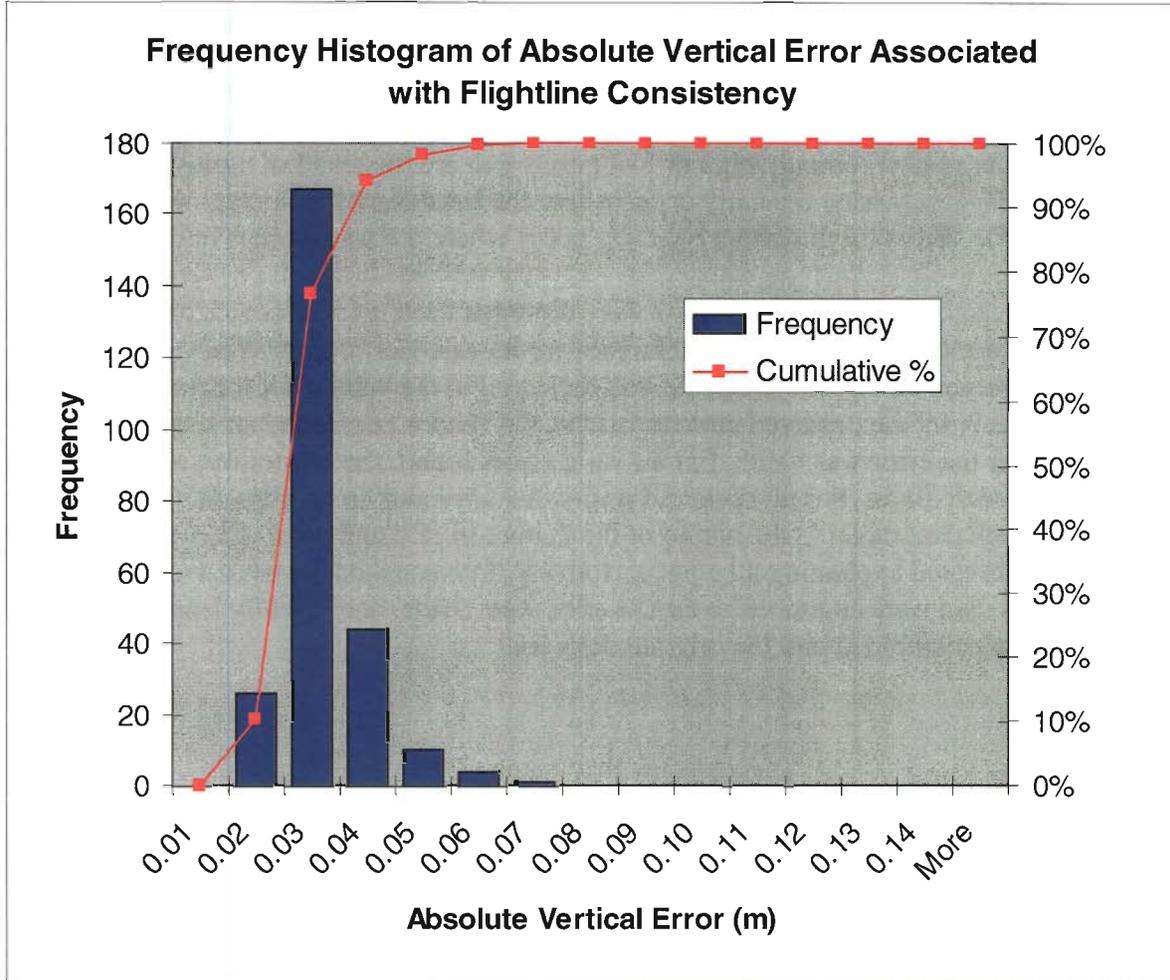


Figure 2.

Results of the consistency analysis found the average flight line offset to be 0.029 meters with a maximum error of 0.073m (Table 2b). Distribution of error showed over 94% of all error was less than 0.04m and 98% was less than 0.05m (Figure 2). These results show that all data were within tolerances of data consistency according to contract agreement.

Visual Analysis

Lidar 3ft grids were loaded into ArcGIS software for visual analysis. Data were examined through slope and hillshade models of bare earth returns. Hillshades of the highest hit models were used to identify areas of missing ground (Figure 3). Both bare earth and highest hit models were examined for calibration offsets, tiling artifacts (Figure 4), seam line offsets, pits (Figure 5), and birds.

Calibration offsets typically are visualized as a corduroy-like patterning within a hillshaded lidar model. These offsets present themselves along steep slopes and typically stand out more in highest hit models than bare earth. Tiling artifacts are a result of missing or misclassified data along the edge of lidar processing tiles. These artifacts present themselves as

linear features typically 1-2 grid cells in width, and are present in both the highest hit and bare earth models (e.g. Figure 3). Seam line offsets occur where two distinct days of lidar data overlap. Errors occur as a result of improper absolute vertical error adjustments. These errors are typically visualized as a linear stair step running along the edge of connecting flight lines. Pits and birds refer to uncommonly high or low points that are the result of atmospheric and sensor noise. Pits (low points) typically occur where the laser comes in contact with water on the ground (Figure 5). Birds (high points) typically occur where the laser comes into contact with atmospherics¹.

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

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



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

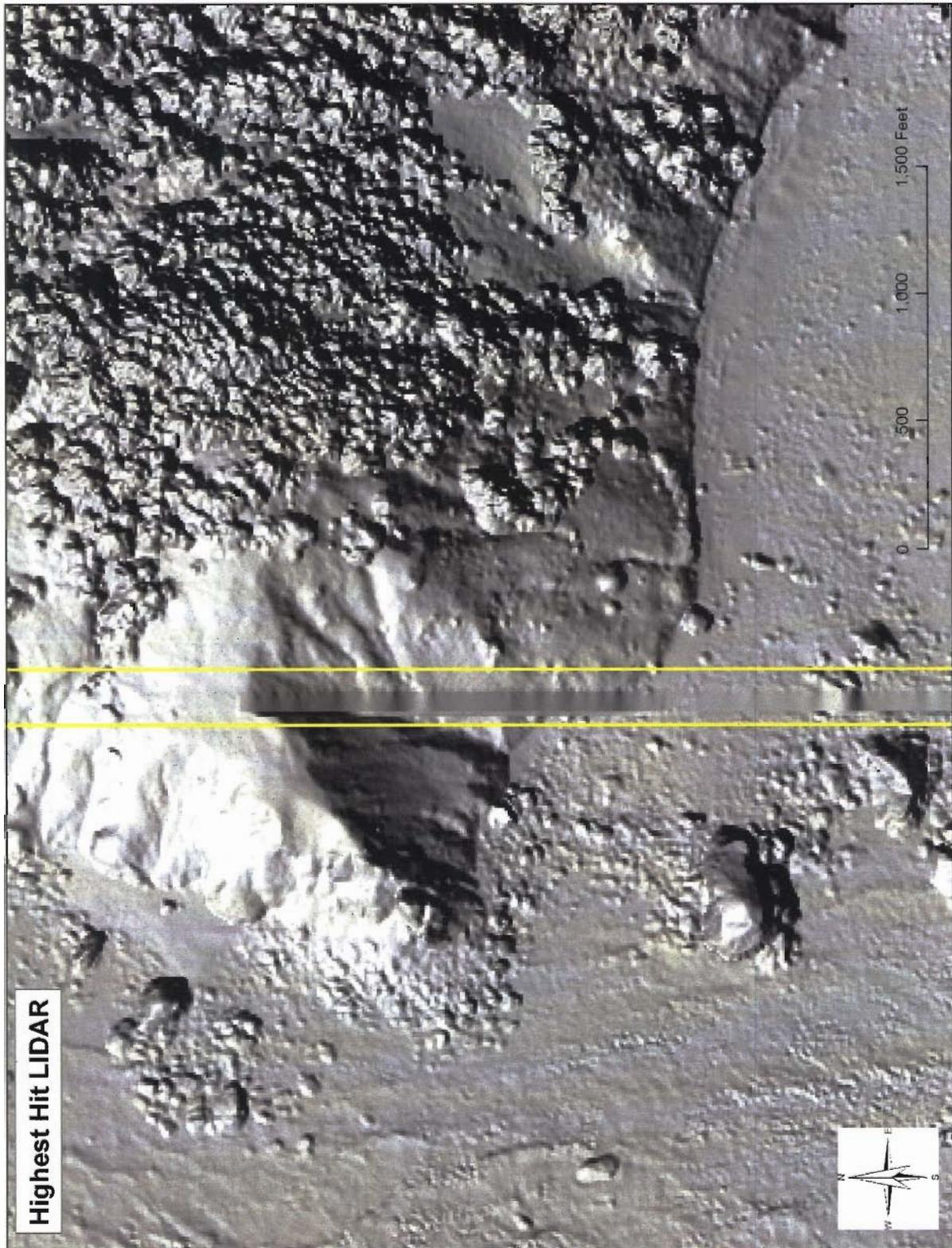


Figure 4. Example of tile artifact found in highest hit lidar data. Artifact is a seam line error created due to misclassification of ground at edge of lidar processing tiles.

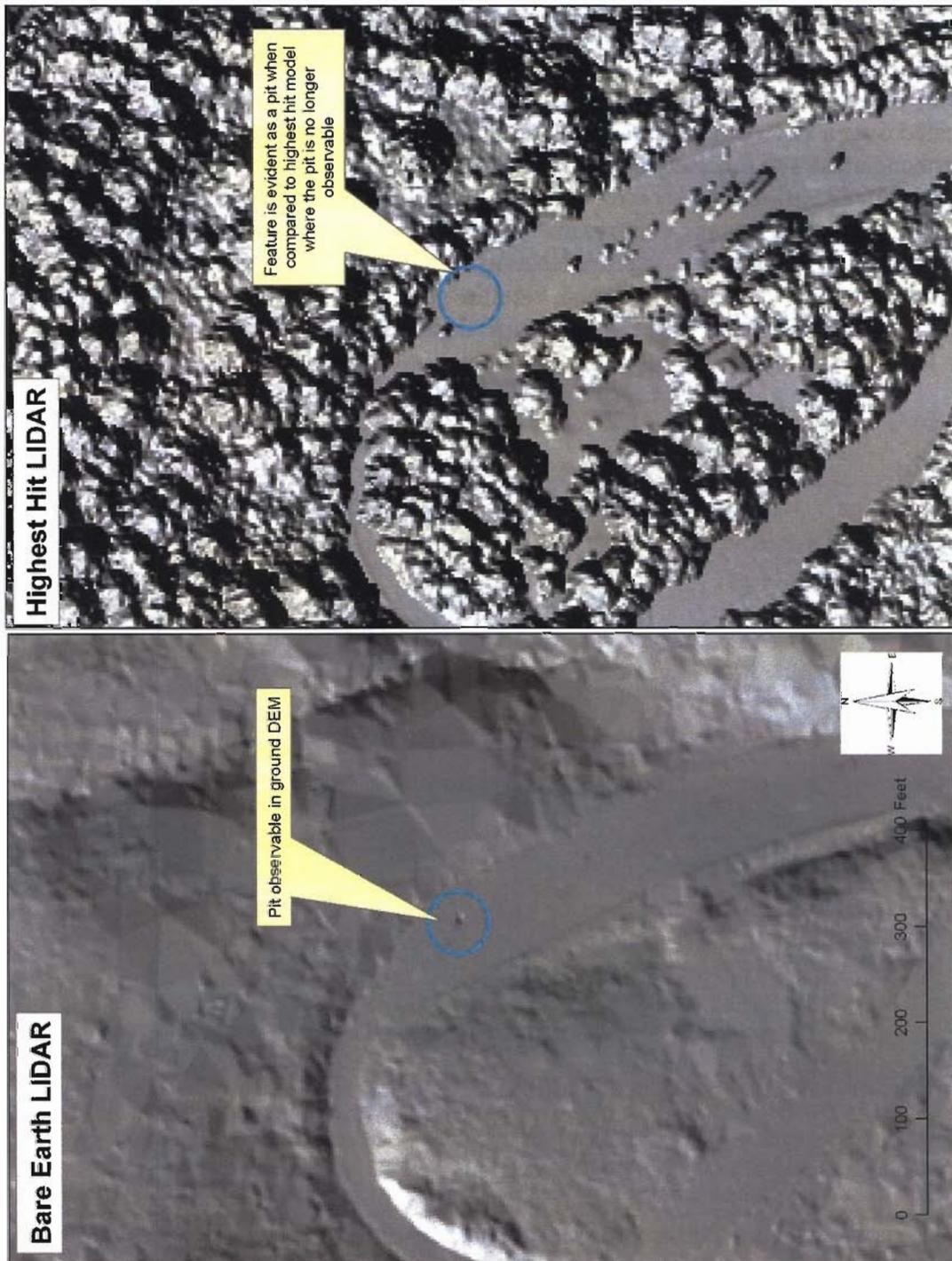


Figure 5. Example of “Pit” observable when comparing bare earth to highest hit models. Pits are caused when standing water absorbs the lidar pulse. Pits are evident in ground model as the lowest point elevation is assigned to the grid cell value. Inversely the pit is not observable in the highest hit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

Absolute Accuracy Analysis:

Absolute accuracy refers to the mean vertical offset of lidar data relative to measured ground-control points (GCP) obtained throughout the lidar sampling area. DOGAMI used a Trimble™ 5700/5800 Total Station GPS surveying system (Figure 5) to measure GCP's. This system consisted of a GPS base station (5700 unit), Zephyr Geodetic antenna, Trimmark 3 radio, and 5800 "rover". The 5700 base station was mounted on a fixed height (typically 2.0 m) tripod and located over a known geodetic survey monument followed by a site calibration on several adjacent benchmarks to precisely establish a local coordinate system. This step is critical in order to eliminate various survey errors. For example, Trimble reports that the 5700/5800 GPS system have horizontal errors of approximately $\pm 1\text{-cm} + 1\text{ppm}$ (parts per million * the baseline length) and $\pm 2\text{-cm}$ in the vertical (TrimbleNavigationSystem, 2005). These errors may be compounded by other factors such as poor satellite geometry, multipath, and poor atmospheric conditions, combining to increase the total error to several centimeters. Thus, the site calibration process is critical in order to minimize these uncertainties.

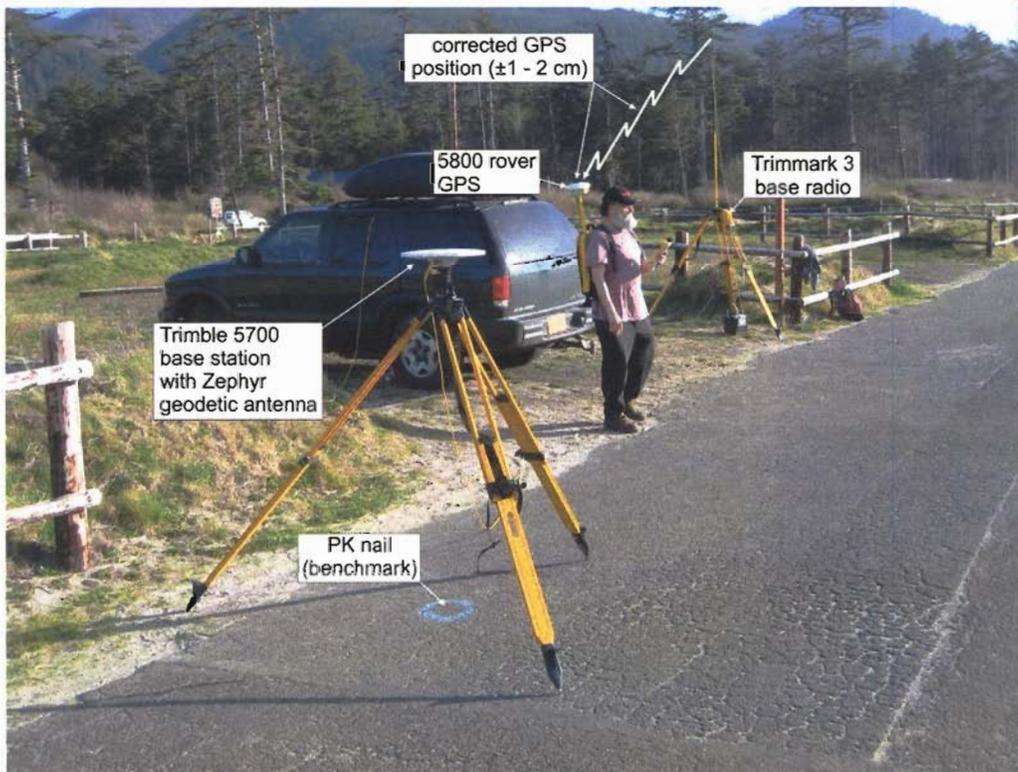


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- 1) Verify the horizontal and vertical coordinates established by Watershed Sciences for a select number of survey monuments used to calibrate the lidar survey. These surveys typically involved a minimum of two hours of GPS occupation over a known point. The collected data were then submitted to the

National Geodetic Survey (NGS) Online Positioning User Service (OPUS) for post-processing against several Continuously Operating Reference Stations (CORS) operated by the NGS.

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

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

Out of a total of 1918 measured GCP's were obtained in the Delivery 4 & 5 region, and compared with the lidar elevation grids. The data delivered to DOGAMI was found to have a mean vertical offset of +/-0.009 meters (0.029 feet) and an RMSE value of 0.037 meters (0.123 ft). Offset values ranged from 0 to 0.304 meters (Table 3 and Figure 7).

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

DOGAMI was able to test the horizontal accuracy of survey monuments used to reference the lidar data while conducting vertical control measurements. For internal purposes only, the XY coordinates of survey monuments surveyed by DOGAMI were compared to the survey monuments provided by the vender and in almost every case, the reported results were consistent with those obtained by DOGAMI staff.

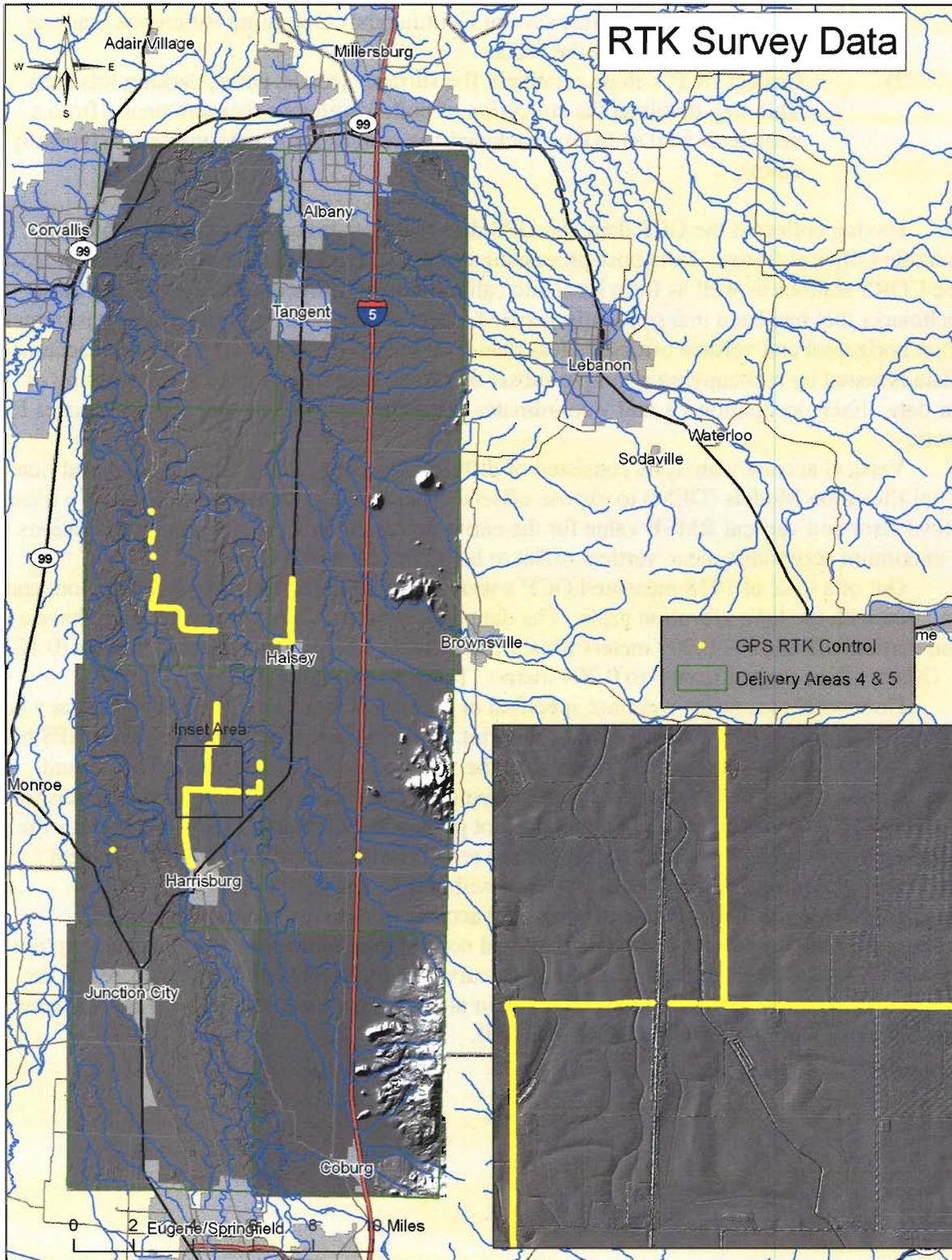
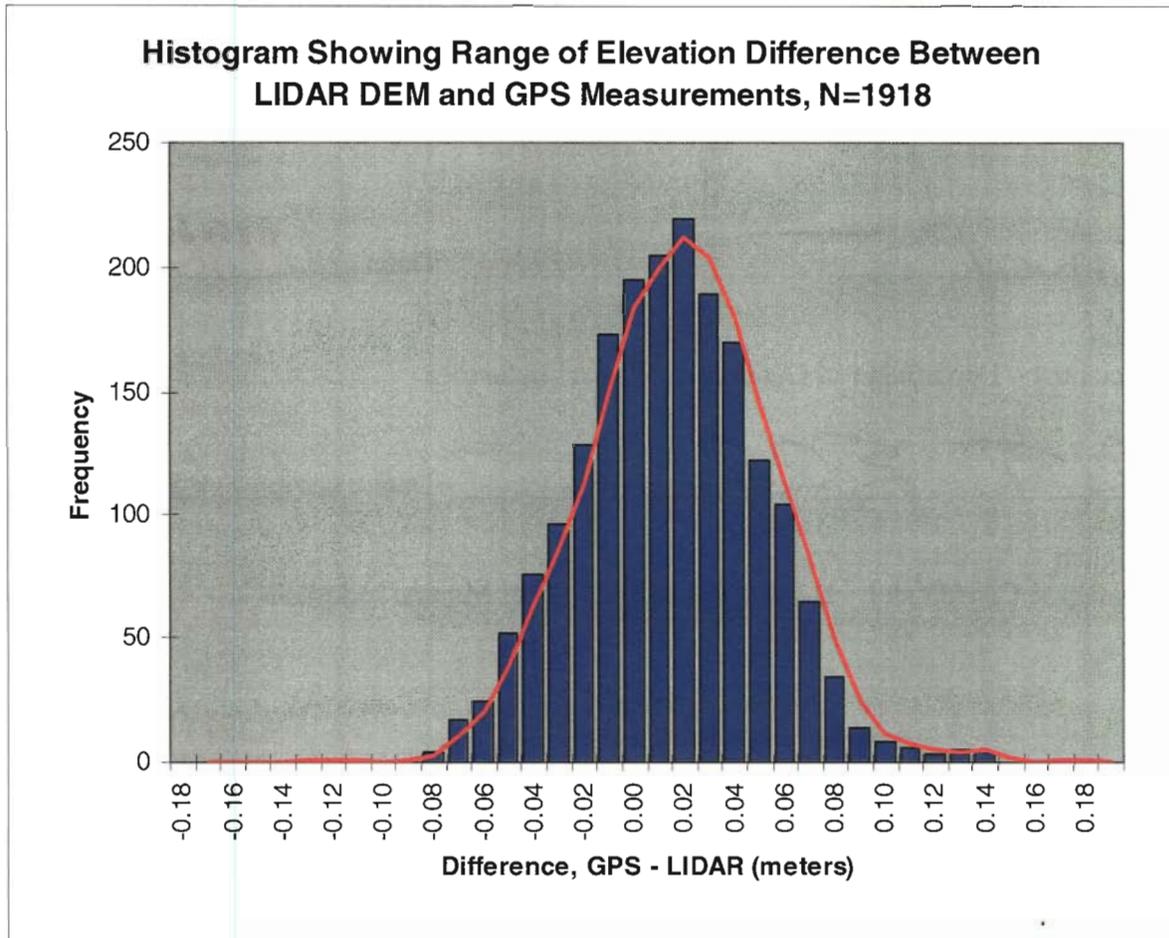


Figure 6. Locations of RTK control surveyed by DOGAMI. Data was used to test absolute accuracy for the Willamette Valley lidar survey within the Delivery 4 & 5 extent.

	<i>Meters</i>	<i>Feet</i>
Mean	0.009	0.029
Standard Error	0.001	0.003
Standard Deviation	0.036	0.119
Range	0.304	0.996
Minimum	-0.135	-0.443
Maximum	0.169	0.553

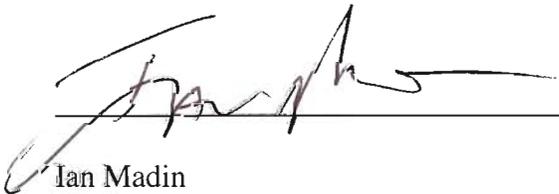
Table 3. Descriptive Statistics for absolute value vertical offsets.



Acceptance

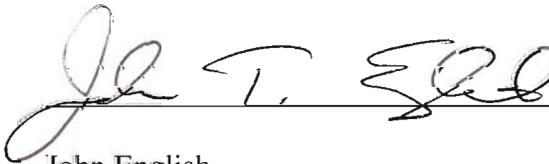
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Approval Signatures



Date: 6/29/09

Ian Madin
Chief Scientist – Department of Geology & Mineral Industries



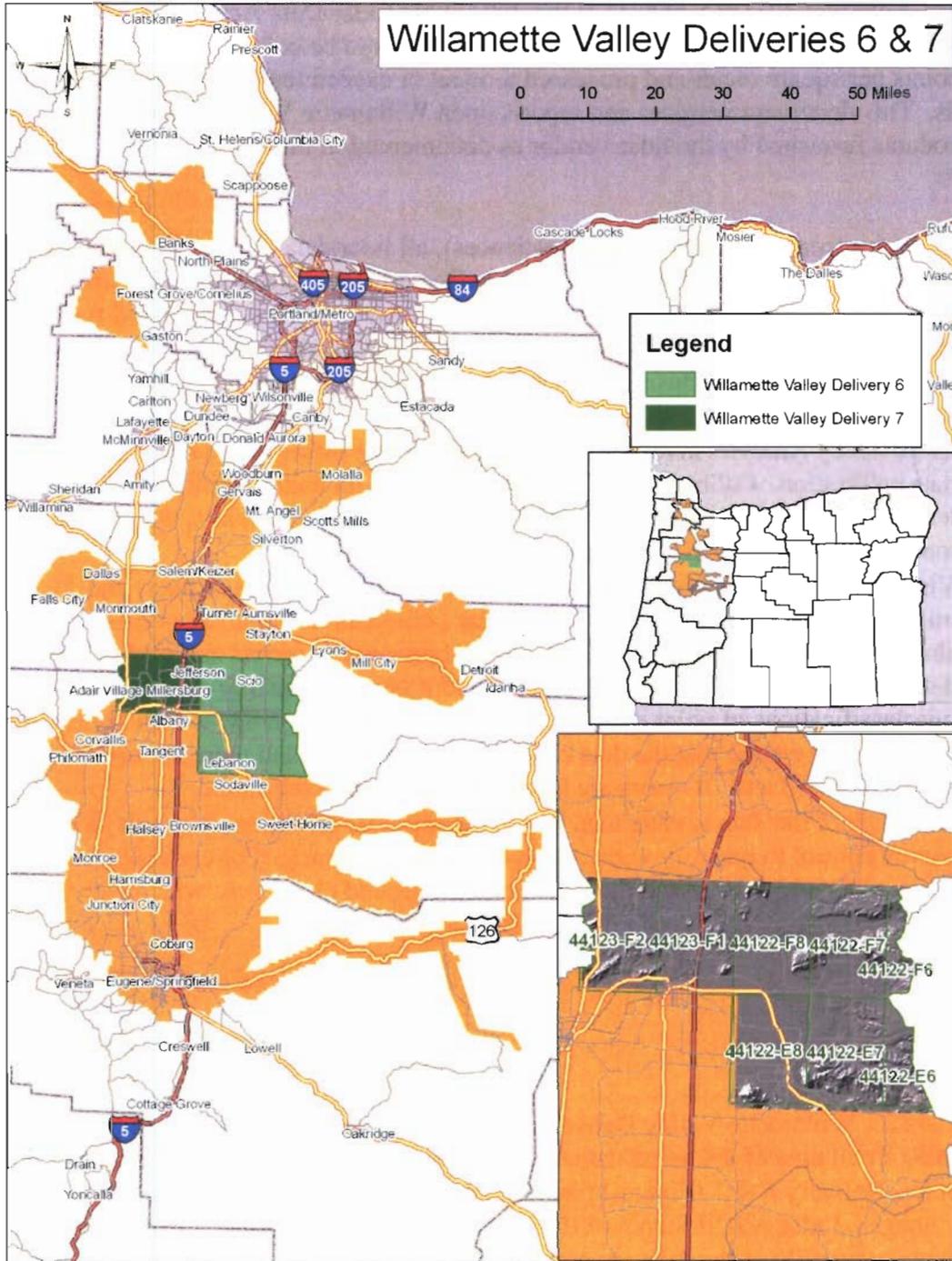
Date: 6/29/09

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

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



Willamette Valley LIDAR Project, 2009 – Delivery 6 & 7 QC Analysis
LIDAR QC Report – July 22nd, 2009



Map featuring Willamette Valley Delivery 6 & 7 data extent.

The Oregon Department of Geology & Mineral Industries has contracted with Watershed Sciences to collect high resolution lidar topographic data for multiple areas within the State of Oregon. Areas for lidar data collection have been designed as part of a collaborative effort of State, Federal, and Local agencies in order to meet a wide range of project goals. The vendor has agreed to certain conditions of data quality and standards for all lidar data deliverables listed in sections A through C (OPA #8865) of the 2007-2009 Lidar Data Acquisition Price Agreement (pgs 14-23). Data submitted under this price agreement is to be collected at a resolution of at least 8 points per square meter and processed to meet or exceed the agreed upon data quality standards. This document itemizes and reports upon Willamette Valley Lidar Project – Delivery 6 & 7 products furnished by the lidar vendor as documentation that all data meets project specific standards.

Upon receipt from vendor (Watershed Sciences), all lidar data for Delivery 6 & 7 was independently reviewed by staff from the Oregon Department of Geology and Mineral Industries (DOGAMI) to ensure project specifications were met. All data were inventoried for completeness and data were checked for quality, which included examining lidar data for errors associated with internal data consistency, model quality, and accuracy.

- Consistency Analysis involves examining flight line offsets to quantify the accuracy of data calibration. Calibration influences elevation data quality with poor calibration leading to small but systematic errors within lidar elevation points, which then create inaccuracies within derived lidar elevation models.
- Visual checks are carried out in order to identify potential data artifacts and misclassifications of lidar point data. Lidar point data is classified as either ground, above ground, or error points. Sophisticated processing scripts are used to classify point data and remove error points. The data vendor performs quality control analysis to fix misclassifications of point data. The delivered bare earth DEM is then reviewed by DOGAMI to ensure that the data classification is correct and there are no topographic processing artifacts. If errors are found, data must be resubmitted.
- Accuracy of the data is examined by comparing lidar elevation data with independent survey control to quantify vertical and horizontal accuracy. For each lidar collection project DOGAMI collected independent GPS ground elevations, which were then compared against delivered lidar elevation models.

Data Completeness

Data for Willamette Valley Delivery 6 & 7 area were collected between 08/31/2008 to 09/21/2008. Total area of delivered data totals 346.4 (Delivery 6 = 245.24, Delivery 7 = 101.16 square miles. Delivery 6 & 7 (Figure 1) includes data in the format of grids, trajectory files, intensity images, Lidar ASCII Standard (LAS) point files, ground point density rasters, RTK survey data, a shapefile of the delivery area, and the lidar delivery report (Table 1). Bare earth and highest hit grids were delivered in ArcInfo Grid format with 3ft cell size. Lidar point data is

delivered in LAS binary format for ground classified returns as well as the entire lidar point cloud. Georeferenced intensity images are supplied in TIF format. Supplementary data includes ground density rasters displaying locations where ground returns are low. Real time kinematic ground survey data (used for absolute vertical adjustment) is supplied in shapefile format. This delivery contains data for the following USGS 7.5 minute quads (listed by Ohio Code #) within the boundary of the Willamette Valley Survey collection area (Figure 1):

Delivery 6: 44122e6, 44122e7, 44122e8, 44122f6, 44122f7, 44122f8

Delivery 7: 44123f1, 44123f2

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

Table 1. Deliverable Checklist

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

Deliverable Descriptions: (All data projected in Oregon Lambert, NAD83 (HARN), Intl Feet with exception of trajectory files).

- Bare Earth Grids: Tin interpolated grids created from lidar ground returns.
- Highest Hit Grids: Tin interpolated grids created from the highest lidar elevation for a given 3ft cell.
- Intensity TIF: TIF raster built using returned lidar pulse intensity values gathered from highest hit returns.
- Trajectory File: File contains point location measurement of the aircraft used to collect lidar data. Data is collected using an Inertial Measurement Unit (IMU), and collects measurements of: Easting(meters), Northing (meters), Ellipsoid Height (meters) of

aircraft, aircraft roll (degrees), aircraft pitch (degrees), aircraft heading (degrees).

Measurements are collected at one second intervals. Data is projected in UTM zone 10, NAD83 (HARN).

- LAS: Binary file of all lidar points collected in survey (Class, flight line #, GPS Time, Echo, Easting, Northing, Elevation, Intensity, Scan Angle, Echo Number, and Scanner).
- Ground LAS: Binary file of lidar points classified as ground (Class, flight line #, GPS Time, Echo, Easting, Northing, Elevation, Intensity, Scan Angle, Echo Number, and Scanner).
- RTK Point Data: Ground GPS Survey data used to correct raw lidar point cloud for vertical offsets.
- Delivery Area Shapefile: Geometry file depicting the geospatial area associated with deliverables.
- Report: Report provides detailed description of data collection methods and processing. The vendor also reports accuracies associated with calibration, consistency, absolute error, and point classifications.

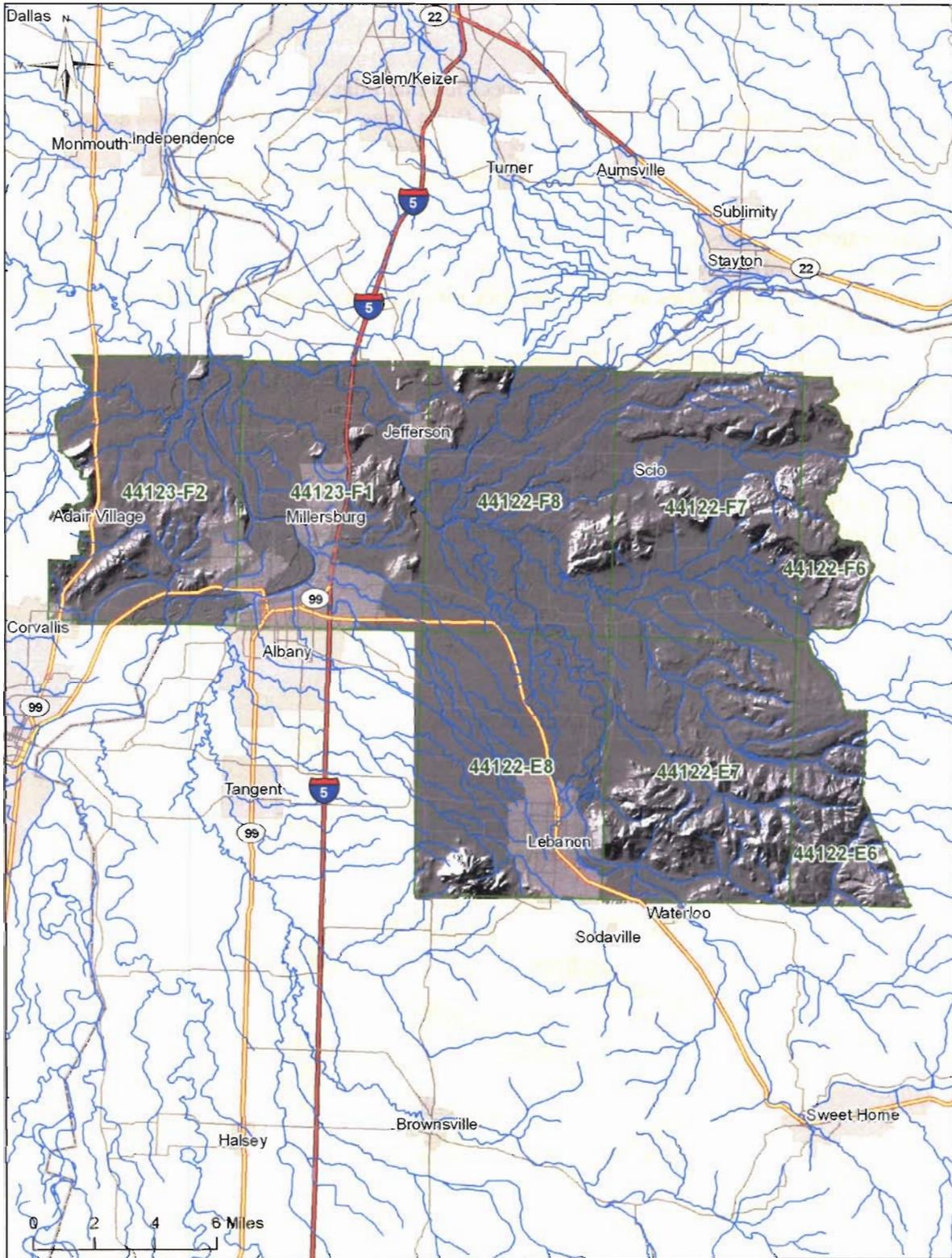


Figure 1. Delivery 6 & 7 location area. Data is referenced to USGS 7.5 minute quadrangles within the extents of the Willamette Valley Survey collection area.

Consistency Analysis:

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

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

To quantify the magnitude of this error 1701 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 7,486,915 per tile (Table 2a). Error measurements were calculated by differencing the nearest point from an adjacent flight line within 1 meters in the horizontal plane and 0.2 meters in the vertical plane. Each flight line was compared to adjacent flight lines, and the average magnitude of vertical error was calculated. A total of 204 flight lines were sampled and compared for consistency.

Summary Statistics

# of Tiles	1701
# of Flight Line Sections	204
Avg # of Points	7,486,915
Avg. Magnitude Z error (m)	0.027

Table 2a. Summary Results of Consistency Analysis

	<i>meters</i>	<i>feet</i>
Mean	0.027	0.088
Standard Error	0.001	0.002
Standard Deviation	0.008	0.026
Sample Variance	0.000	0.000
Range	0.055	0.179
Minimum	0.018	0.060
Maximum	0.073	0.239

Table 2b. Descriptive Statistics for Magnitude Z Error.

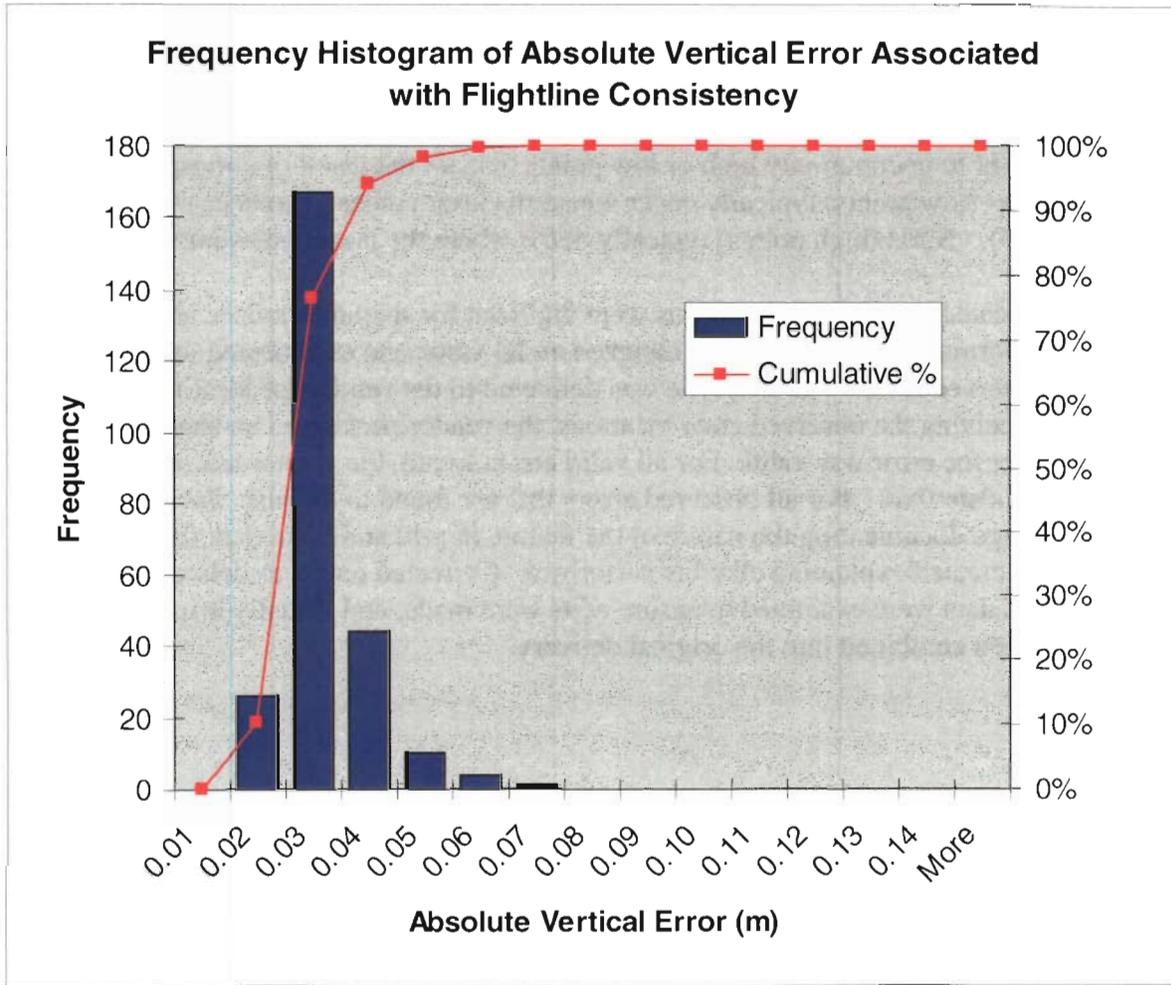


Figure 2.

Results of the consistency analysis found the average flight line offset to be 0.027 meters with a maximum error of 0.07m (Table 2b). Distribution of error showed over 94% of all error was less than 0.04m and 99% was less than 0.07m (Figure 2). These results show that all data were within tolerances of data consistency according to contract agreement.

Visual Analysis

Lidar 3ft grids were loaded into ArcGIS software for visual analysis. Data were examined through slope and hillshade models of bare earth returns. Hillshades of the highest hit models were used to identify areas of missing ground (Figure 3). Both bare earth and highest hit models were examined for calibration offsets, tiling artifacts (Figure 4), seam line offsets, pits (Figure 5), and birds.

Calibration offsets typically are visualized as a corduroy-like patterning within a hillshaded lidar model. These offsets present themselves along steep slopes and typically stand out more in highest hit models than bare earth. Tiling artifacts are a result of missing or misclassified data along the edge of lidar processing tiles. These artifacts present themselves as

linear features typically 1-2 grid cells in width, and are present in both the highest hit and bare earth models (e.g. Figure 3). Seam line offsets occur where two distinct days of lidar data overlap. Errors occur as a result of improper absolute vertical error adjustments. These errors are typically visualized as a linear stair step running along the edge of connecting flight lines. Pits and birds refer to uncommonly high or low points that are the result of atmospheric and sensor noise. Pits (low points) typically occur where the laser comes in contact with water on the ground (Figure 5). Birds (high points) typically occur where the laser comes into contact with atmospherics¹.

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

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



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

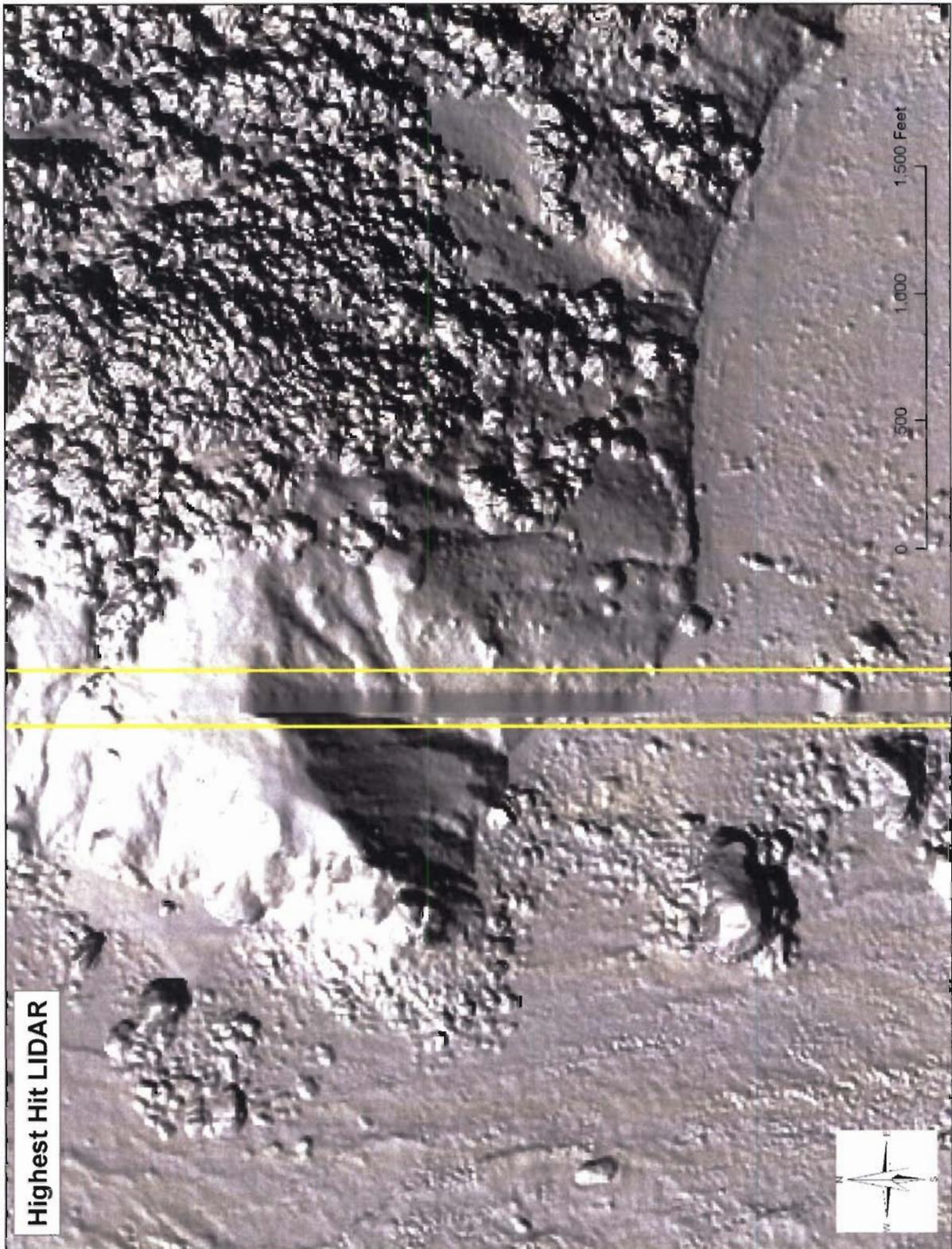


Figure 4. Example of tile artifact found in highest hit lidar data. Artifact is a seam line error created due to misclassification of ground at edge of lidar processing tiles.

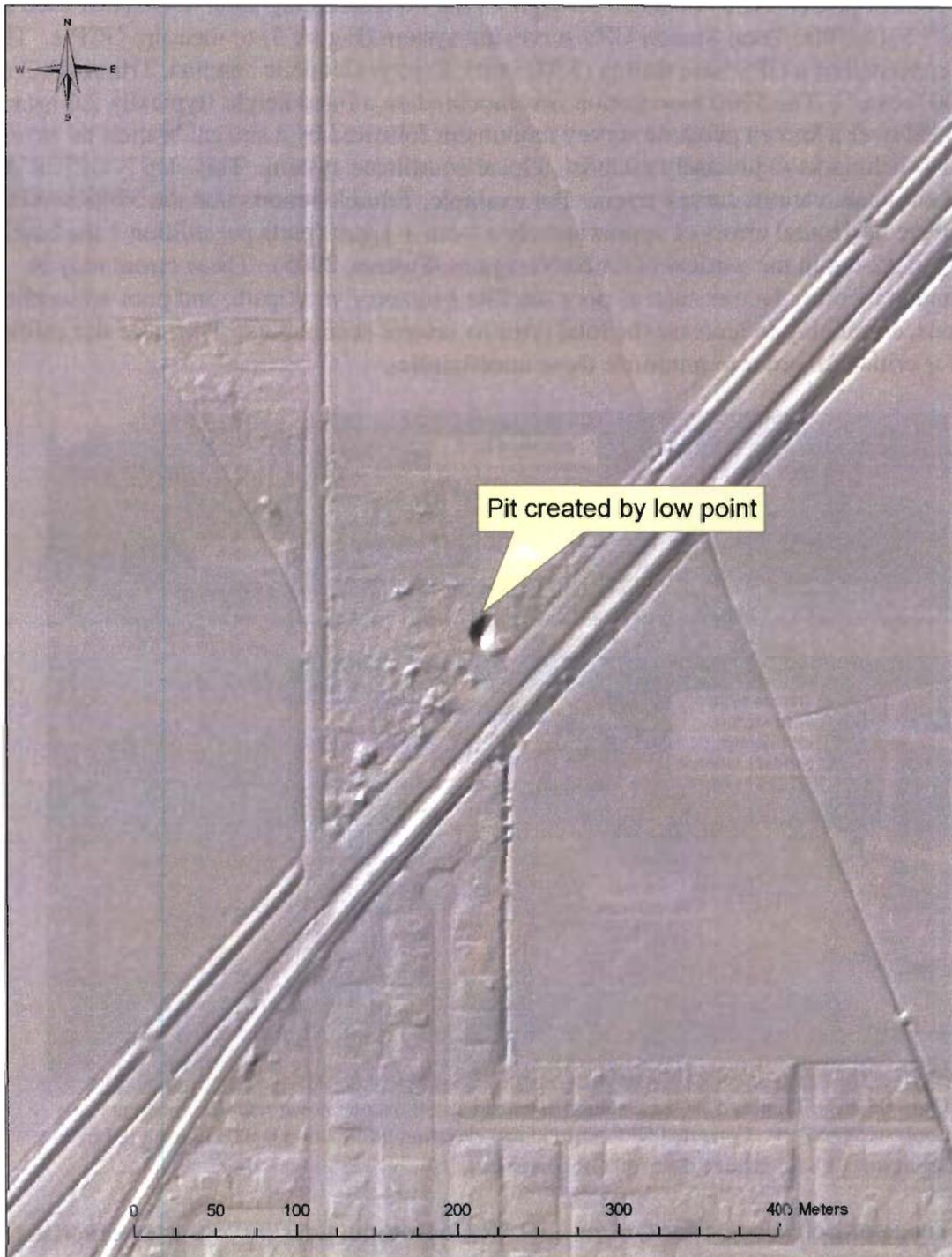


Figure 5. Example of “Pit” caused by low point in ground model. Pits are caused when standing water absorbs the lidar pulse. Pits are evident in ground model as the lowest point elevation is assigned to the grid cell value. Inversely the pit is not observable in the highest hit model as the highest point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

Absolute Accuracy Analysis:

Absolute accuracy refers to the mean vertical offset of lidar data relative to measured ground-control points (GCP) obtained throughout the lidar sampling area. DOGAMI used a Trimble™ 5700/5800 Total Station GPS surveying system (Figure 5) to measure GCP's. This system consisted of a GPS base station (5700 unit), Zephyr Geodetic antenna, Trimmark 3 radio, and 5800 "rover". The 5700 base station was mounted on a fixed height (typically 2.0 m) tripod and located over a known geodetic survey monument followed by a site calibration on several adjacent benchmarks to precisely establish a local coordinate system. This step is critical in order to eliminate various survey errors. For example, Trimble reports that the 5700/5800 GPS system have horizontal errors of approximately $\pm 1\text{-cm} + 1\text{ppm}$ (parts per million * the baseline length) and $\pm 2\text{-cm}$ in the vertical (TrimbleNavigationSystem, 2005). These errors may be compounded by other factors such as poor satellite geometry, multipath, and poor atmospheric conditions, combining to increase the total error to several centimeters. Thus, the site calibration process is critical in order to minimize these uncertainties.

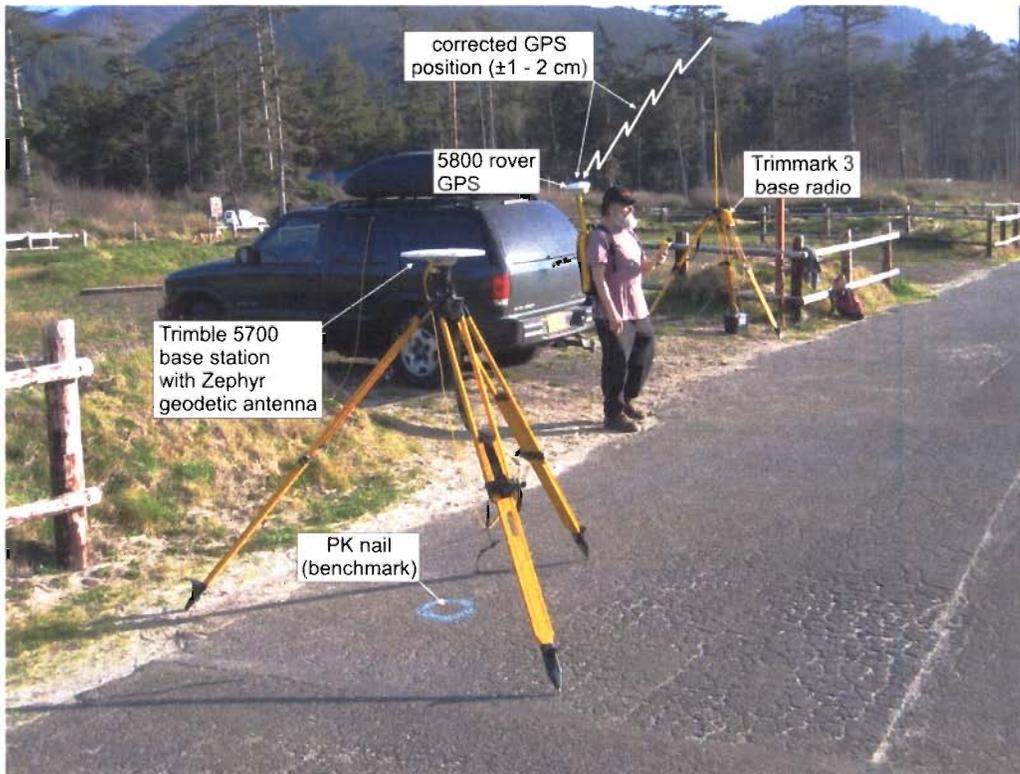


Figure 5. The Trimble 5700 base station antenna located over a known reference point at Cape Lookout State Park. Corrected GPS position and elevation information is then transmitted by a Trimmark III base radio to the 5800 GPS rover unit.

The approach adopted for Oregon LiDAR Consortium lidar surveys was comprised of three components:

- 1) Verify the horizontal and vertical coordinates established by Watershed Sciences for a select number of survey monuments used to calibrate the lidar survey. These surveys typically involved a minimum of two hours of GPS occupation over a known point. The collected data were then submitted to the

National Geodetic Survey (NGS) Online Positioning User Service (OPUS) for post-processing against several Continuously Operating Reference Stations (CORS) operated by the NGS.

- 2) Collect GCP's along relatively flat surfaces (roads, paths, parking lots etc.). This step involved the collection of both continuous measurements (from a vehicle as well as from a backpack) as well as static measurements (typically 5 epics).

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

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

A total of 572 measured GCP's were obtained in the Delivery 6 & 7 region, and compared with the lidar elevation grids. The data delivered to DOGAMI was found to have a mean vertical offset of +/-0.02 meters (0.067 feet) and an RMSE value of 0.049 meters (0.16 ft). Offset values ranged from 0 to 0.235 meters (Table 3 and Figure 7).

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

DOGAMI was able to test the horizontal accuracy of survey monuments used to reference the lidar data while conducting vertical control measurements. For internal purposes only, the XY coordinates of survey monuments surveyed by DOGAMI were compared to the survey monuments provided by the vender and in almost every case, the reported results were consistent with those obtained by DOGAMI staff.

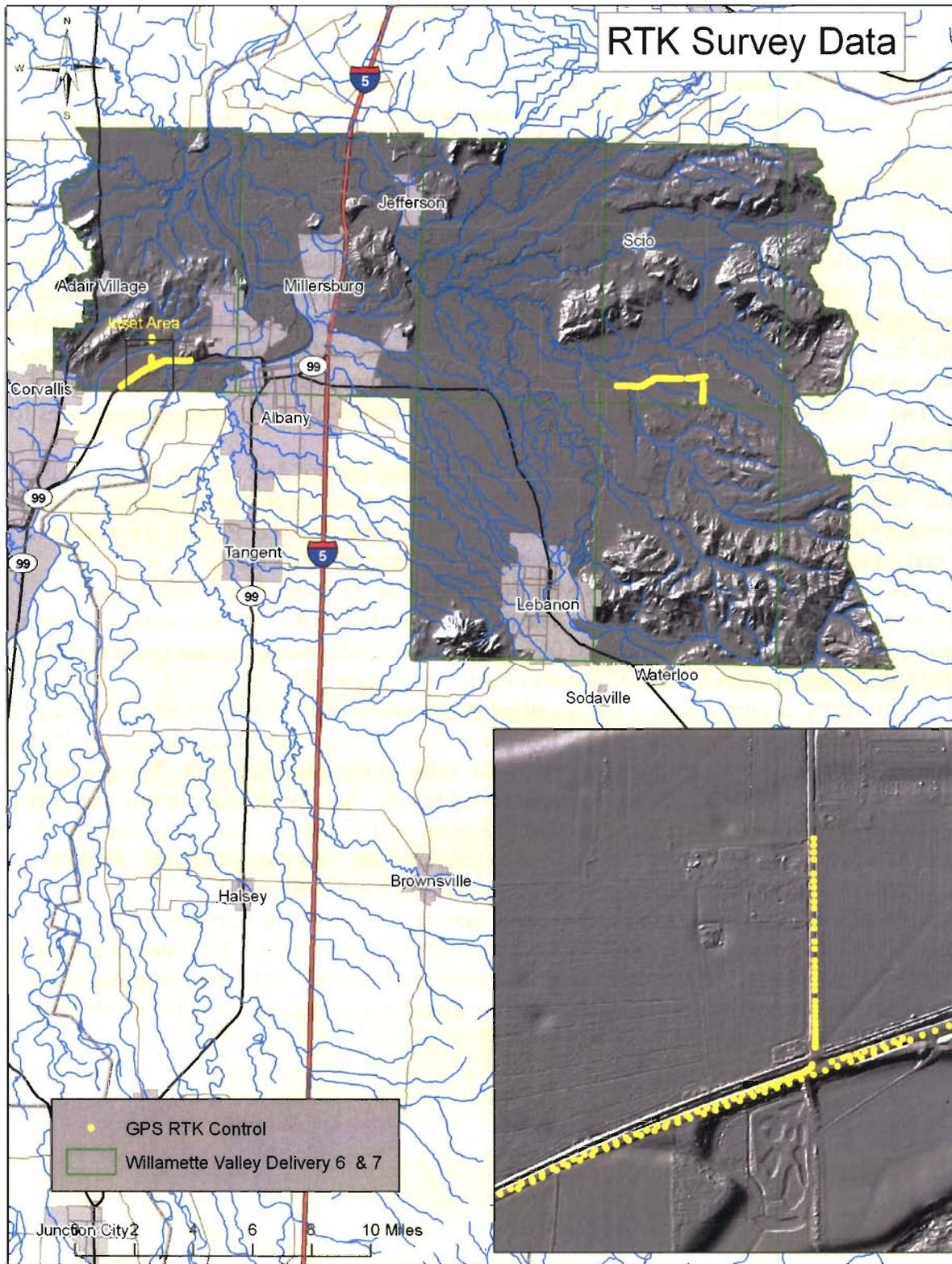


Figure 6. Locations of RTK control surveyed by DOGAMI. Data was used to test absolute accuracy for the Willamette Valley lidar survey within the Delivery 6 & 7 extent.

	<i>Meters</i>	<i>Feet</i>
Mean	0.020	0.067
Standard Error	0.002	0.006
Standard Deviation	0.045	0.147
Range	0.235	0.772
Minimum	-0.076	-0.251
Maximum	0.159	0.521

Table 3. Descriptive Statistics for absolute value vertical offsets.

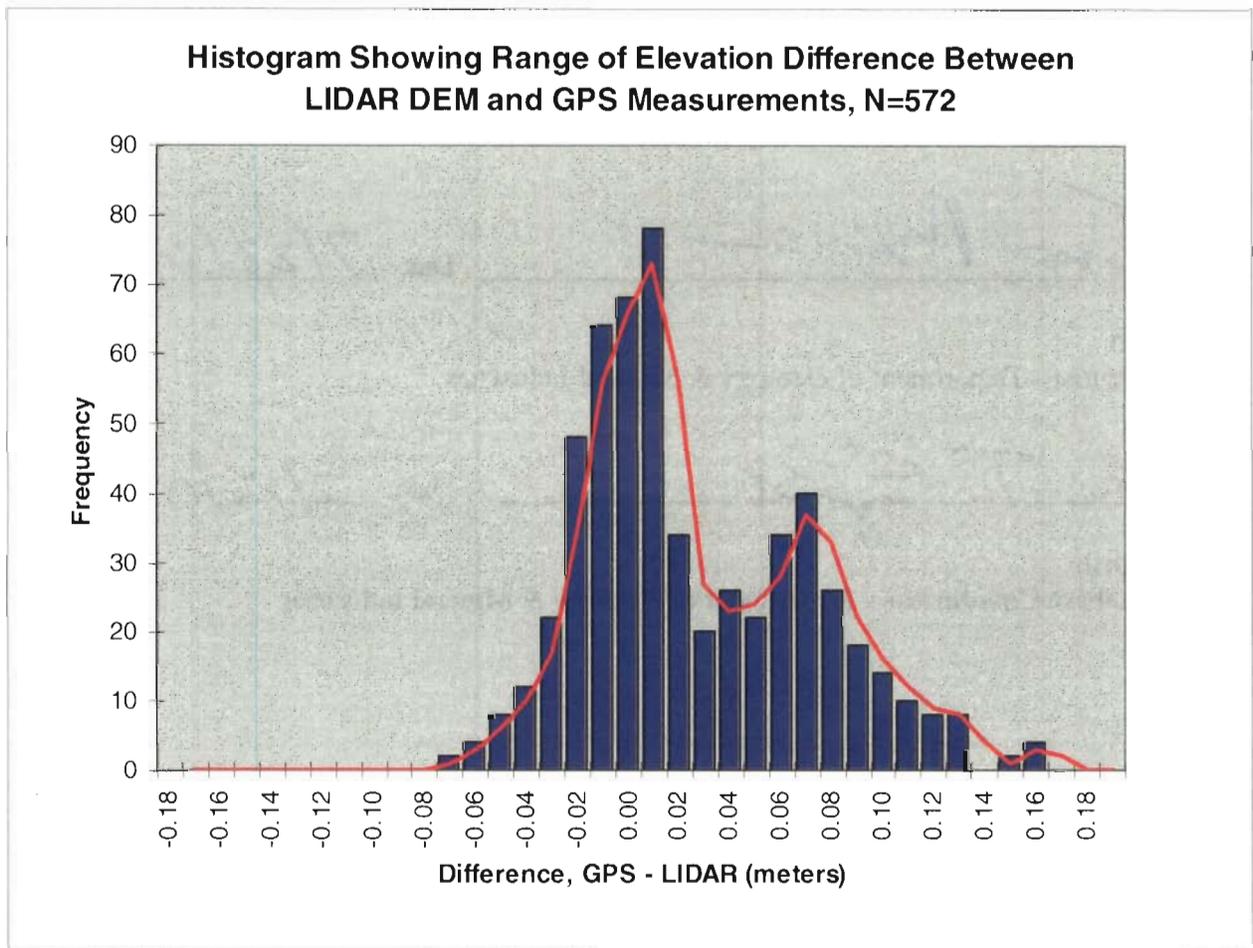
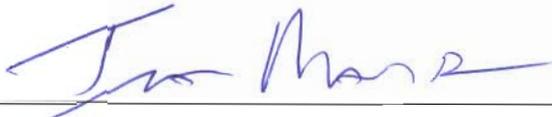


Figure 7.

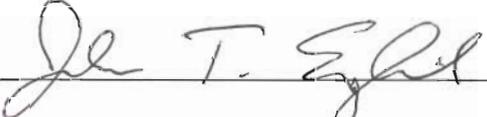
Acceptance

The data described in this report meets and exceeds project specifications laid out in the contracted data standards agreement. All components of data to be delivered have been received as of July 22nd, 2009. Consistency analysis has concluded that all data contains flight line to flight line vertical offset less than the threshold of 0.15 meters as specified in agreement. The vendor has adequately responded to all fixable errors identified as part of the visual analysis. Perceived grid errors identified by DOGAMI that were found to be false have been documented by the vendor and explained to the satisfaction of DOGAMI reviewers. Absolute accuracy analysis of the data has concluded that absolute vertical error of lidar data is less than the specified tolerance of 0.20 meters as specified in the data standards agreement.

Approval Signatures


Date: 7/22/09

Ian Madin
Chief Scientist – Department of Geology & Mineral Industries

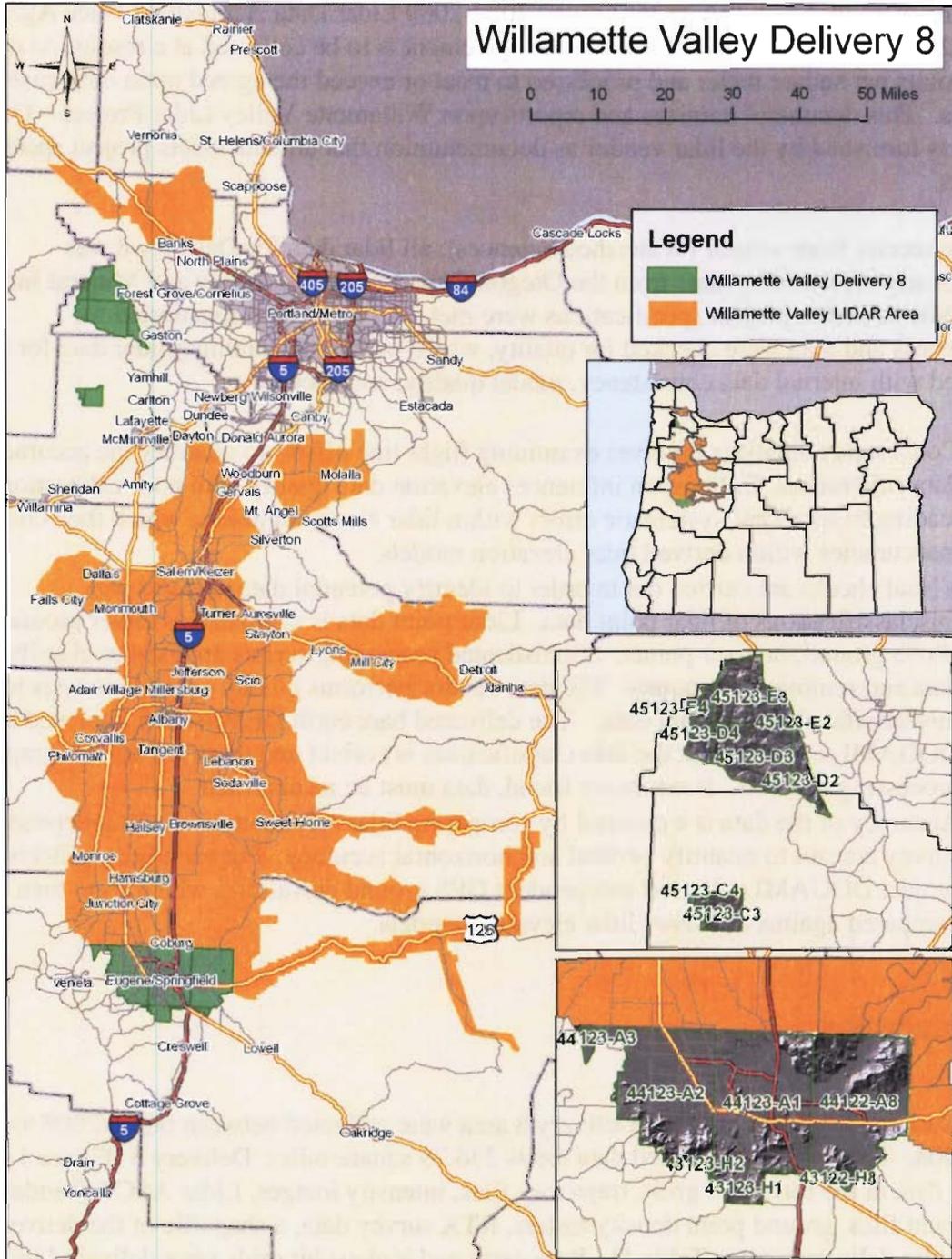

Date: 7/22/09

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

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



Willamette Valley LIDAR Project, 2009 – Delivery 8 QC Analysis
LIDAR QC Report – July 22nd, 2009



Map featuring Willamette Valley Delivery 8 data extent.

The Oregon Department of Geology & Mineral Industries has contracted with Watershed Sciences to collect high resolution lidar topographic data for multiple areas within the State of Oregon. Areas for lidar data collection have been designed as part of a collaborative effort of State, Federal, and Local agencies in order to meet a wide range of project goals. The vendor has agreed to certain conditions of data quality and standards for all lidar data deliverables listed in sections A through C (OPA #8865) of the 2007-2009 Lidar Data Acquisition Price Agreement (pgs 14-23). Data submitted under this price agreement is to be collected at a resolution of at least 8 points per square meter and processed to meet or exceed the agreed upon data quality standards. This document itemizes and reports upon Willamette Valley Lidar Project – Delivery 8 products furnished by the lidar vendor as documentation that all data meets project specific standards.

Upon receipt from vendor (Watershed Sciences), all lidar data for Delivery 8 was independently reviewed by staff from the Oregon Department of Geology and Mineral Industries (DOGAMI) to ensure project specifications were met. All data were inventoried for completeness and data were checked for quality, which included examining lidar data for errors associated with internal data consistency, model quality, and accuracy.

- Consistency Analysis involves examining flight line offsets to quantify the accuracy of data calibration. Calibration influences elevation data quality with poor calibration leading to small but systematic errors within lidar elevation points, which then create inaccuracies within derived lidar elevation models.
- Visual checks are carried out in order to identify potential data artifacts and misclassifications of lidar point data. Lidar point data is classified as either ground, above ground, or error points. Sophisticated processing scripts are used to classify point data and remove error points. The data vendor performs quality control analysis to fix misclassifications of point data. The delivered bare earth DEM is then reviewed by DOGAMI to ensure that the data classification is correct and there are no topographic processing artifacts. If errors are found, data must be resubmitted.
- Accuracy of the data is examined by comparing lidar elevation data with independent survey control to quantify vertical and horizontal accuracy. For each lidar collection project DOGAMI collected independent GPS ground elevations, which were then compared against delivered lidar elevation models.

Data Completeness

Data for Willamette Valley Delivery 8 area were collected between 08/31/2008 to 09/21/2008. Total area of delivered data totals 236.79 square miles. Delivery 8 (Figure 1) includes data in the format of grids, trajectory files, intensity images, Lidar ASCII Standard (LAS) point files, ground point density rasters, RTK survey data, a shapefile of the delivery area, and the lidar delivery report (Table 1). Bare earth and highest hit grids were delivered in ArcInfo Grid format with 3ft cell size. Lidar point data is delivered in LAS binary format for ground

classified returns as well as the entire lidar point cloud. Georeferenced intensity images are supplied in TIF format. Supplementary data includes ground density rasters displaying locations where ground returns are low. Real time kinematic ground survey data (used for absolute vertical adjustment) is supplied in shapefile format. This delivery contains data for the following USGS 7.5 minute quads (listed by Ohio Code #) within the boundary of the Willamette Valley Survey collection area (Figure 1):

Delivery 8: 43122h8, 43123h1, 43123h2, 44123a1,44123a2, 44123a3, 44123a8, 45123c3, 45123c4, 45123d2, 45123d3, 45123d4, 45123e2, 45123e3, 45123e4

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

Table 1. Deliverable Checklist

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

Deliverable Descriptions: (All data projected in Oregon Lambert, NAD83 (HARN), Intl Feet with exception of trajectory files).

- Bare Earth Grids: Tin interpolated grids created from lidar ground returns.
- Highest Hit Grids: Tin interpolated grids created from the highest lidar elevation for a given 3ft cell.
- Intensity TIF: TIF raster built using returned lidar pulse intensity values gathered from highest hit returns.
- Trajectory File: File contains point location measurement of the aircraft used to collect lidar data. Data is collected using an Inertial Measurement Unit (IMU), and collects measurements of: Easting(meters), Northing (meters), Ellipsoid Height (meters) of aircraft, aircraft roll (degrees), aircraft pitch (degrees), aircraft heading (degrees).

OLC Willamette Valley Delivery 8 Acceptance Report.

Measurements are collected at one second intervals. Data is projected in UTM zone 10, NAD83 (HARN).

- LAS: Binary file of all lidar points collected in survey (Class, flight line #, GPS Time, Echo, Easting, Northing, Elevation, Intensity, Scan Angle, Echo Number, and Scanner).
- Ground LAS: Binary file of lidar points classified as ground (Class, flight line #, GPS Time, Echo, Easting, Northing, Elevation, Intensity, Scan Angle, Echo Number, and Scanner).
- RTK Point Data: Ground GPS Survey data used to correct raw lidar point cloud for vertical offsets.
- Delivery Area Shapefile: Geometry file depicting the geospatial area associated with deliverables.
- Report: Report provides detailed description of data collection methods and processing. The vendor also reports accuracies associated with calibration, consistency, absolute error, and point classifications.

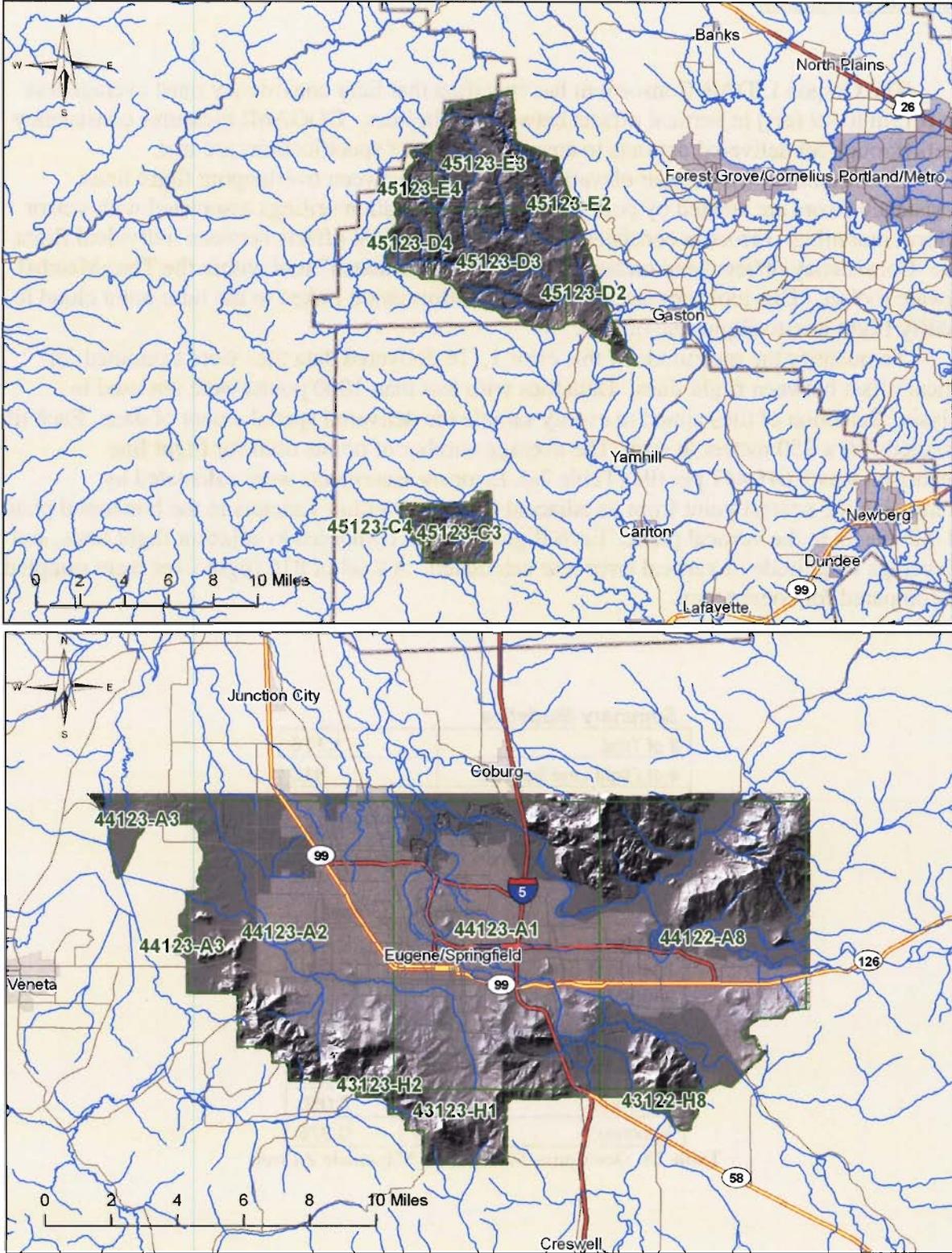


Figure 1. Delivery 8 location area. Data is referenced to USGS 7.5 minute quadrangles within the extents of the Willamette Valley Survey collection area.

Consistency Analysis:

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

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

To quantify the magnitude of this error 1,116 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 3,648,447 per tile (Table 2a). Error measurements were calculated by differencing the nearest point from an adjacent flight line within 1 meters in the horizontal plane and 0.2 meters in the vertical plane. Each flight line was compared to adjacent flight lines, and the average magnitude of vertical error was calculated. A total of 816 flight lines were sampled and compared for consistency.

Summary Statistics

# of Tiles	1,116
# of Flight Line Sections	816
Avg # of Points	3,648,447
Avg. Magnitude Z error (m)	0.033

Table 2a. Summary Results of Consistency Analysis

	<i>meters</i>	<i>feet</i>
Mean	0.033	0.108
Standard Error	0.000	0.001
Standard Deviation	0.009	0.030
Sample Variance	0.000	0.000
Range	0.099	0.326
Minimum	0.015	0.050
Maximum	0.115	0.376

Table 2b. Descriptive Statistics for Magnitude Z Error.

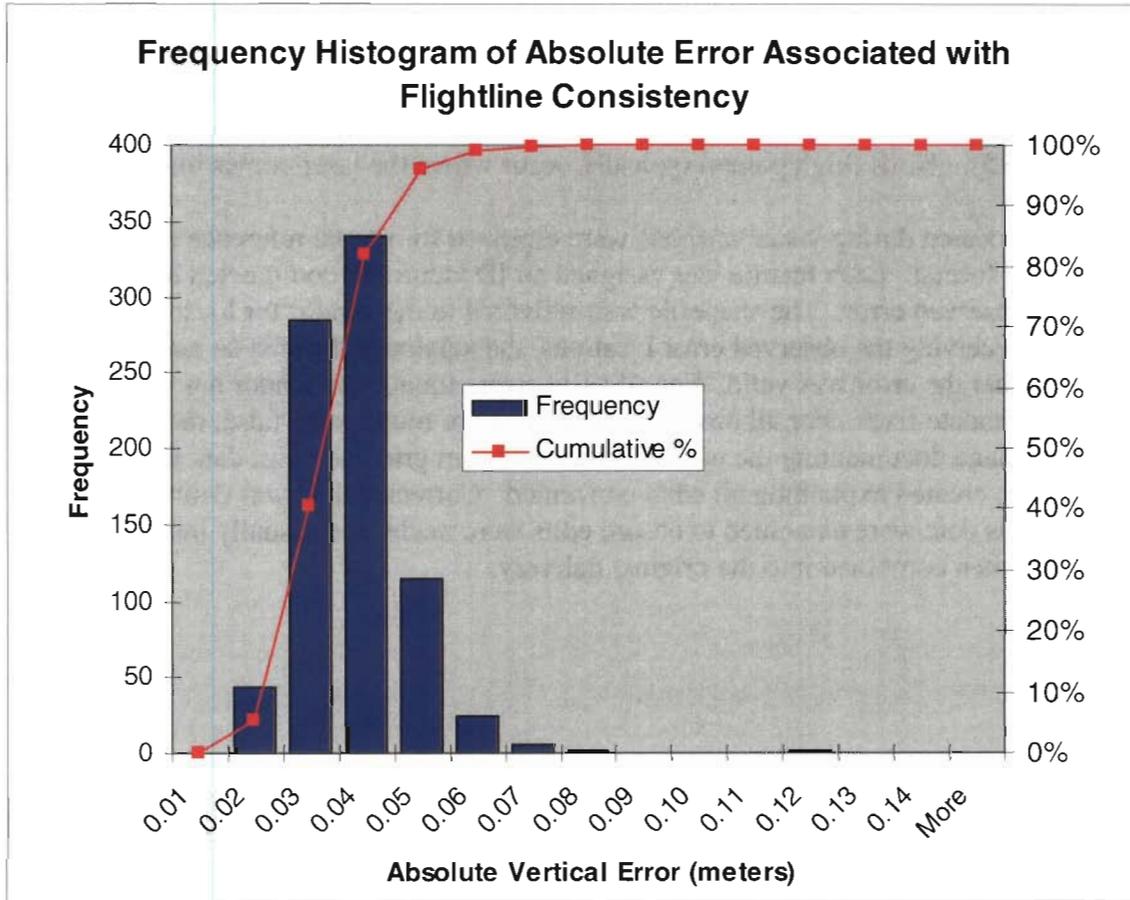


Figure 2.

Results of the consistency analysis found the average flight line offset to be 0.033 meters with a maximum error of 0.115m (Table 2b). Distribution of error showed over 95% of all error was less than 0.05m and 99% was less than 0.06m (Figure 2). These results show that all data are within tolerances of data consistency according to contract agreement.

Visual Analysis

Lidar 3ft grids were loaded into ArcGIS software for visual analysis. Data were examined through slope and hillshade models of bare earth returns. Hillshades of the highest hit models were used to identify areas of missing ground (Figure 3). Both bare earth and highest hit models were examined for calibration offsets, tiling artifacts (Figure 4), seam line offsets, pits (Figure 5), and birds.

Calibration offsets typically are visualized as a corduroy-like patterning within a hillshaded lidar model. These offsets present themselves along steep slopes and typically stand out more in highest hit models than bare earth. Tiling artifacts are a result of missing or misclassified data along the edge of lidar processing tiles. These artifacts present themselves as linear features typically 1-2 grid cells in width, and are present in both the highest hit and bare earth models (e.g. Figure 3). Seam line offsets occur where two distinct days of lidar data

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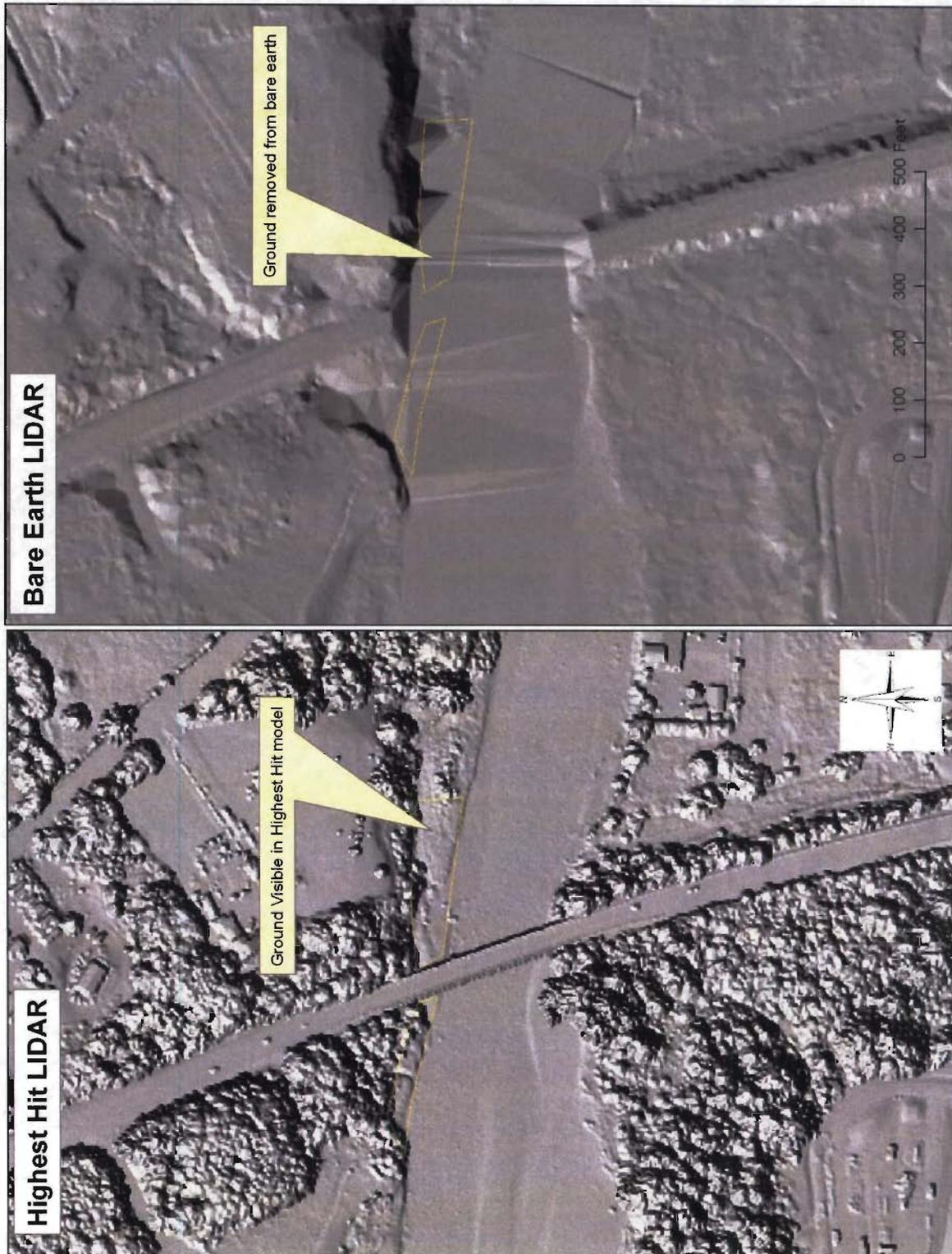


Figure 3. Example of missing ground in lidar bare earth data. Ground is clearly visible in highest hit model, but has been removed from the bare earth model. This type of classification error is common near water body features.

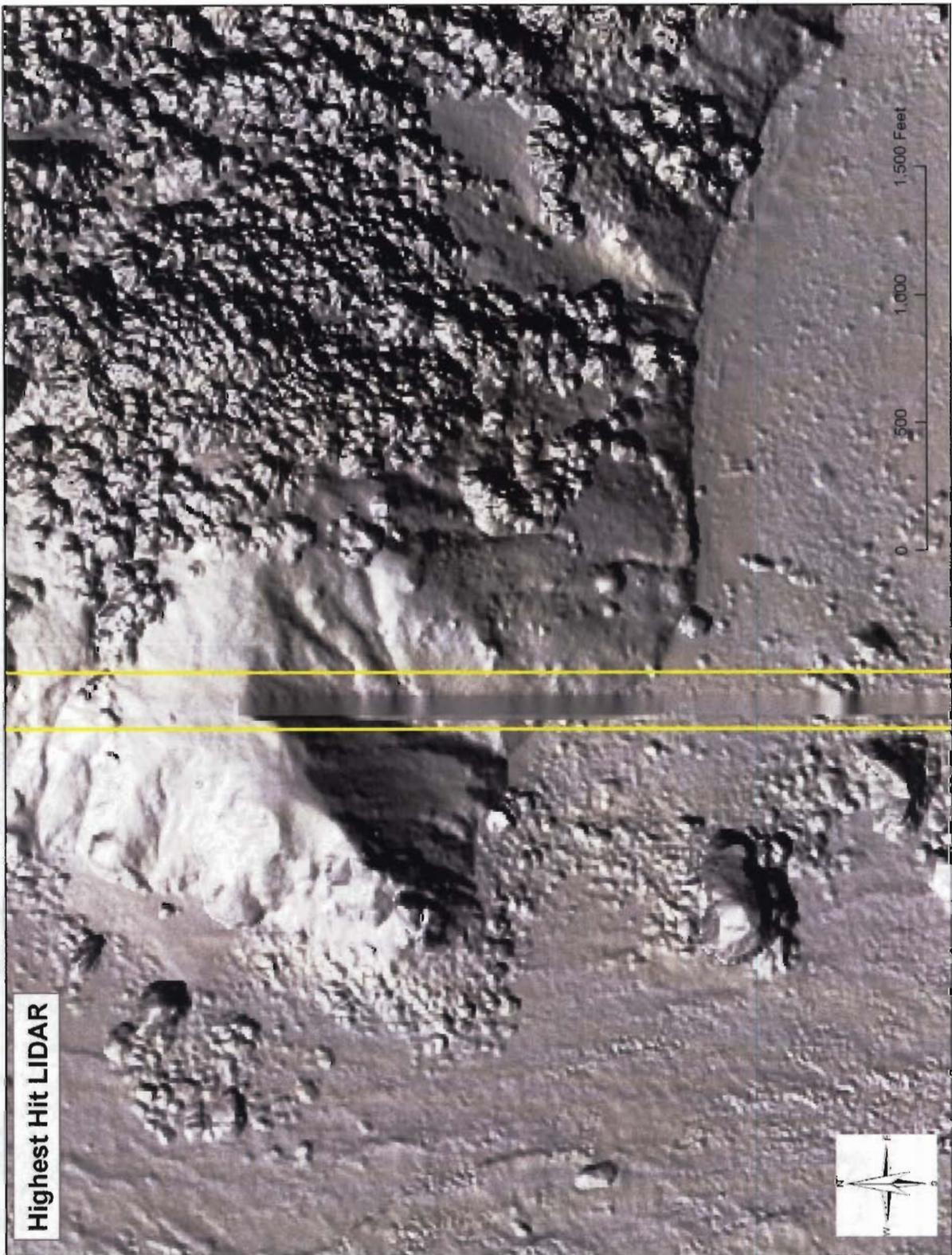


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Absolute Accuracy Analysis:

Absolute accuracy refers to the mean vertical offset of lidar data relative to measured ground-control points (GCP) obtained throughout the lidar sampling area. DOGAMI used a Trimble™ 5700/5800 Total Station GPS surveying system (Figure 5) to measure GCP's. This system consisted of a GPS base station (5700 unit), Zephyr Geodetic antenna, Trimmark 3 radio, and 5800 "rover". The 5700 base station was mounted on a fixed height (typically 2.0 m) tripod and located over a known geodetic survey monument followed by a site calibration on several adjacent benchmarks to precisely establish a local coordinate system. This step is critical in order to eliminate various survey errors. For example, Trimble reports that the 5700/5800 GPS system have horizontal errors of approximately $\pm 1\text{-cm} + 1\text{ppm}$ (parts per million * the baseline length) and $\pm 2\text{-cm}$ in the vertical (TrimbleNavigationSystem, 2005). These errors may be compounded by other factors such as poor satellite geometry, multipath, and poor atmospheric conditions, combining to increase the total error to several centimeters. Thus, the site calibration process is critical in order to minimize these uncertainties.

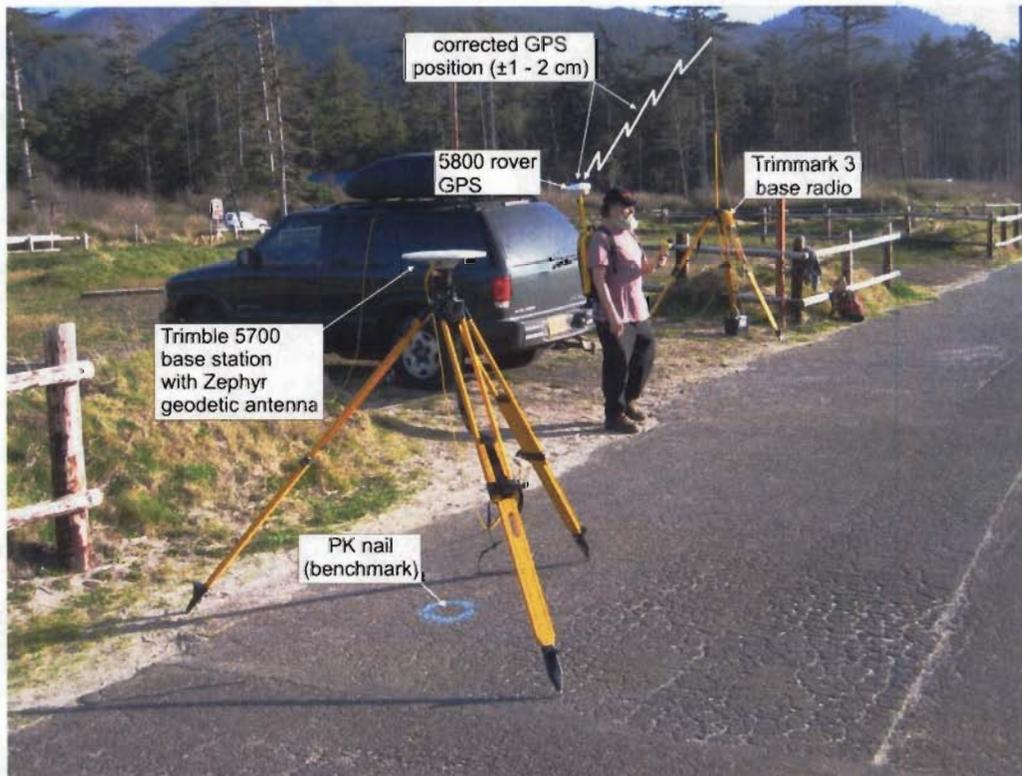


Figure 5. The Trimble 5700 base station antenna located over a known reference point at Cape Lookout State Park. Corrected GPS position and elevation information is then transmitted by a Trimmark III base radio to the 5800 GPS rover unit.

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

A total of 847 measured GCP's were obtained in the Delivery 8 region, and compared with the lidar elevation grids. The data delivered to DOGAMI was found to have a mean vertical offset of +/-0.028 meters (0.093 feet) and an RMSE value of 0.059 meters (0.193 ft). Offset values ranged from 0 to 0.175 meters (Table 3 and Figure 7).

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

DOGAMI was able to test the horizontal accuracy of survey monuments used to reference the lidar data while conducting vertical control measurements. For internal purposes only, the XY coordinates of survey monuments surveyed by DOGAMI were compared to the survey monuments provided by the vender and in almost every case, the reported results were consistent with those obtained by DOGAMI staff.

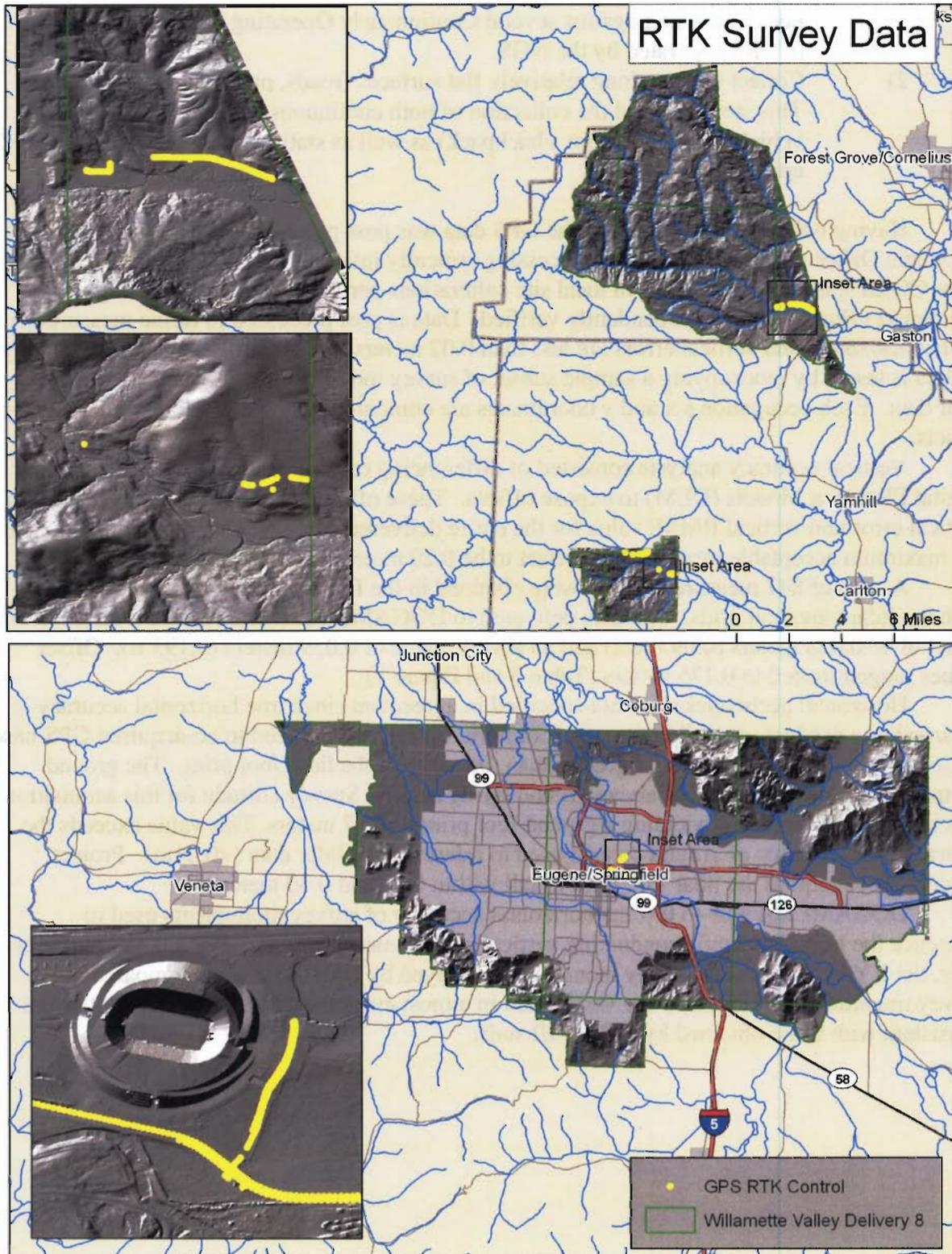


Figure 6. Locations of RTK control surveyed by DOGAMI. Data was used to test absolute accuracy for the Willamette Valley lidar survey within the Delivery 8 extent.

	<i>Meters</i>	<i>Feet</i>
Mean	0.028	0.093
Standard Error	0.002	0.006
Standard Deviation	0.052	0.170
Range	0.338	1.109
Minimum	-0.163	-0.536
Maximum	0.175	0.573

Table 3. Descriptive Statistics for absolute value vertical offsets.

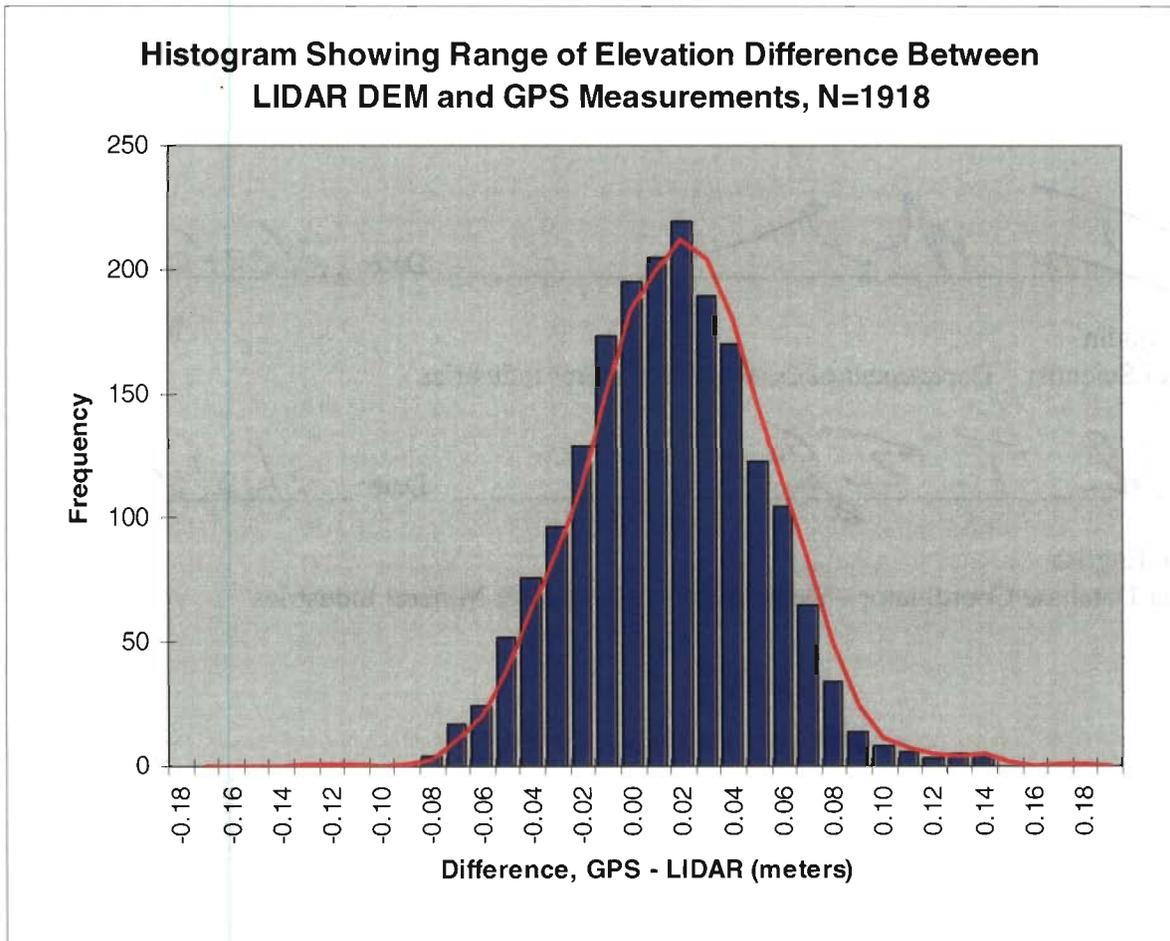
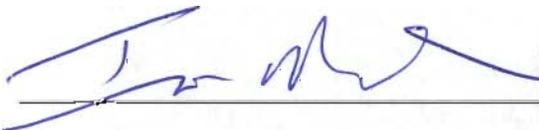


Figure 7.

Acceptance

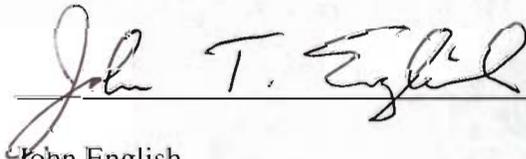
The data described in this report meets and exceeds project specifications laid out in the contracted data standards agreement. All components of data to be delivered have been received as of July 22nd, 2009. Consistency analysis has concluded that all data contains flight line to flight line vertical offset less than the threshold of 0.15 meters as specified in agreement. The vendor has adequately responded to all fixable errors identified as part of the visual analysis. Perceived grid errors identified by DOGAMI that were found to be false have been documented by the vendor and explained to the satisfaction of DOGAMI reviewers. Absolute accuracy analysis of the data has concluded that absolute vertical error of lidar data is less than the specified tolerance of 0.20 meters as specified in the data standards agreement.

Approval Signatures



Date: 7/22/09

Ian Madin
Chief Scientist – Department of Geology & Mineral Industries



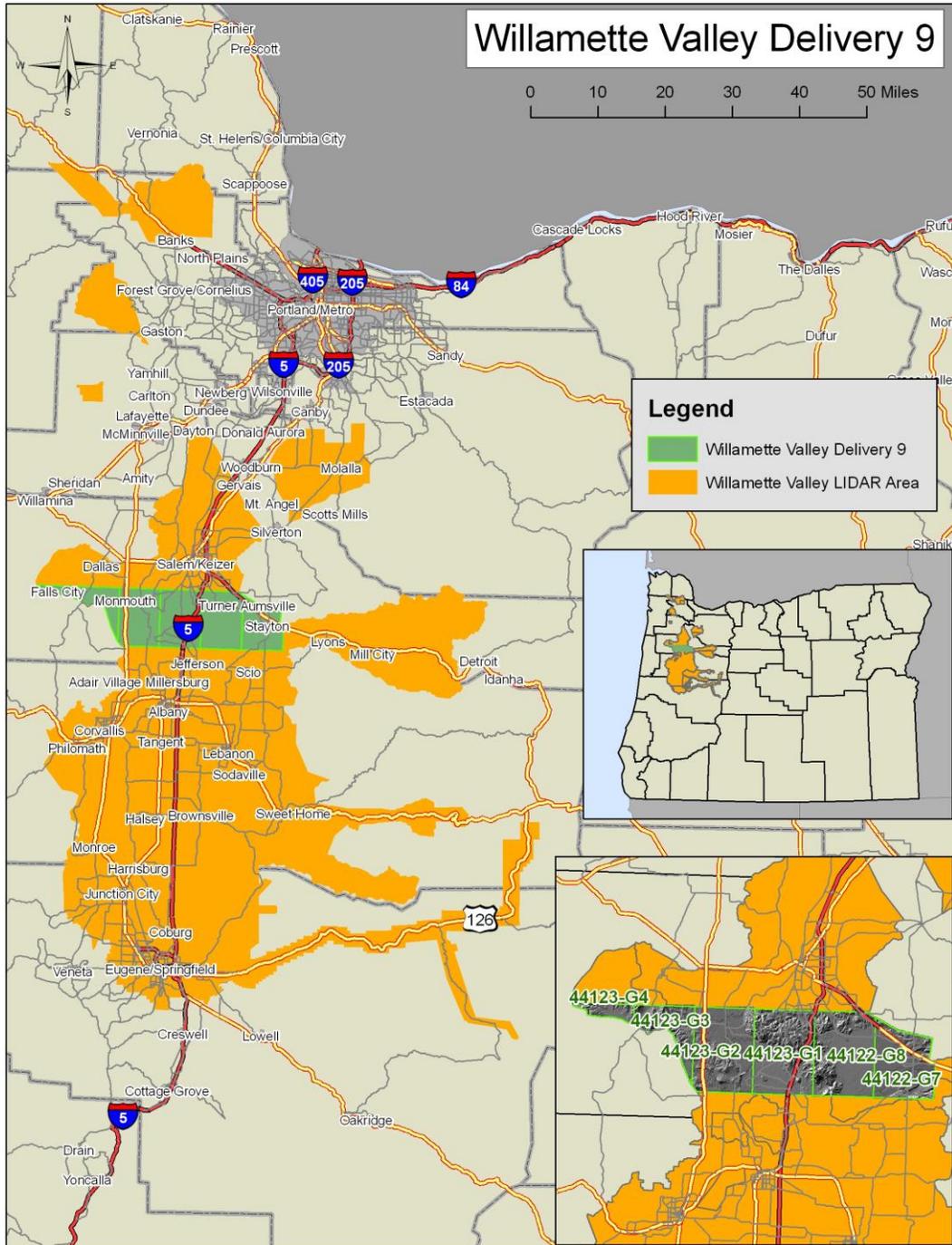
Date: 7/22/09

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

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



Willamette Valley LIDAR Project, 2009 – Delivery 9 QC Analysis
LIDAR QC Report – July 23rd, 2009



Map featuring Willamette Valley Delivery 9 data extent.

The Oregon Department of Geology & Mineral Industries has contracted with Watershed Sciences to collect high resolution lidar topographic data for multiple areas within the State of Oregon. Areas for lidar data collection have been designed as part of a collaborative effort of State, Federal, and Local agencies in order to meet a wide range of project goals. The vendor has agreed to certain conditions of data quality and standards for all lidar data deliverables listed in sections A through C (OPA #8865) of the 2007-2009 Lidar Data Acquisition Price Agreement (pgs 14-23). Data submitted under this price agreement is to be collected at a resolution of at least 8 points per square meter and processed to meet or exceed the agreed upon data quality standards. This document itemizes and reports upon Willamette Valley Lidar Project – Delivery 9 products furnished by the lidar vendor as documentation that all data meets project specific standards.

Upon receipt from vendor (Watershed Sciences), all lidar data for Delivery 9 was independently reviewed by staff from the Oregon Department of Geology and Mineral Industries (DOGAMI) to ensure project specifications were met. All data were inventoried for completeness and data were checked for quality, which included examining lidar data for errors associated with internal data consistency, model quality, and accuracy.

- Consistency Analysis involves examining flight line offsets to quantify the accuracy of data calibration. Calibration influences elevation data quality with poor calibration leading to small but systematic errors within lidar elevation points, which then create inaccuracies within derived lidar elevation models.
- Visual checks are carried out in order to identify potential data artifacts and misclassifications of lidar point data. Lidar point data is classified as either ground, above ground, or error points. Sophisticated processing scripts are used to classify point data and remove error points. The data vendor performs quality control analysis to fix misclassifications of point data. The delivered bare earth DEM is then reviewed by DOGAMI to ensure that the data classification is correct and there are no topographic processing artifacts. If errors are found, data must be resubmitted.
- Accuracy of the data is examined by comparing lidar elevation data with independent survey control to quantify vertical and horizontal accuracy. For each lidar collection project DOGAMI collected independent GPS ground elevations, which were then compared against delivered lidar elevation models.

Data Completeness

Data for Willamette Valley Delivery 9 area were collected between 09/14/2008 to 03/03/2009. Total area of delivered data totals 229.09 square miles. Delivery 9 (Figure 1) includes data in the format of grids, trajectory files, intensity images, Lidar ASCII Standard (LAS) point files, ground point density rasters, RTK survey data, a shapefile of the delivery area, and the lidar delivery report (Table 1). Bare earth and highest hit grids were delivered in ArcInfo Grid format with 3ft cell size. Lidar point data is delivered in LAS binary format for ground

classified returns as well as the entire lidar point cloud. Georeferenced intensity images are supplied in TIF format. Supplementary data includes ground density rasters displaying locations where ground returns are low. Real time kinematic ground survey data (used for absolute vertical adjustment) is supplied in shapefile format. This delivery contains data for the following USGS 7.5 minute quads (listed by Ohio Code #) within the boundary of the Willamette Valley Survey collection area (Figure 1):

Delivery 9: 44122g7, 44122g8, 44123g1, 44123g2, 44123g3, 44123g4

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

Table 1. Deliverable Checklist

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

Deliverable Descriptions: (All data projected in Oregon Lambert, NAD83 (HARN), Intl Feet with exception of trajectory files).

- Bare Earth Grids: Tin interpolated grids created from lidar ground returns.
- Highest Hit Grids: Tin interpolated grids created from the highest lidar elevation for a given 3ft cell.
- Intensity TIF: TIF raster built using returned lidar pulse intensity values gathered from highest hit returns.
- Trajectory File: File contains point location measurement of the aircraft used to collect lidar data. Data is collected using an Inertial Measurement Unit (IMU), and collects measurements of: Easting(meters), Northing (meters), Ellipsoid Height (meters) of aircraft, aircraft roll (degrees), aircraft pitch (degrees), aircraft heading (degrees).

Measurements are collected at one second intervals. Data is projected in UTM zone 10, NAD83 (HARN).

- LAS: Binary file of all lidar points collected in survey (Class, flight line #, GPS Time, Echo, Easting, Northing, Elevation, Intensity, Scan Angle, Echo Number, and Scanner).
- Ground LAS: Binary file of lidar points classified as ground (Class, flight line #, GPS Time, Echo, Easting, Northing, Elevation, Intensity, Scan Angle, Echo Number, and Scanner).
- RTK Point Data: Ground GPS Survey data used to correct raw lidar point cloud for vertical offsets.
- Delivery Area Shapefile: Geometry file depicting the geospatial area associated with deliverables.
- Report: Report provides detailed description of data collection methods and processing. The vendor also reports accuracies associated with calibration, consistency, absolute error, and point classifications.

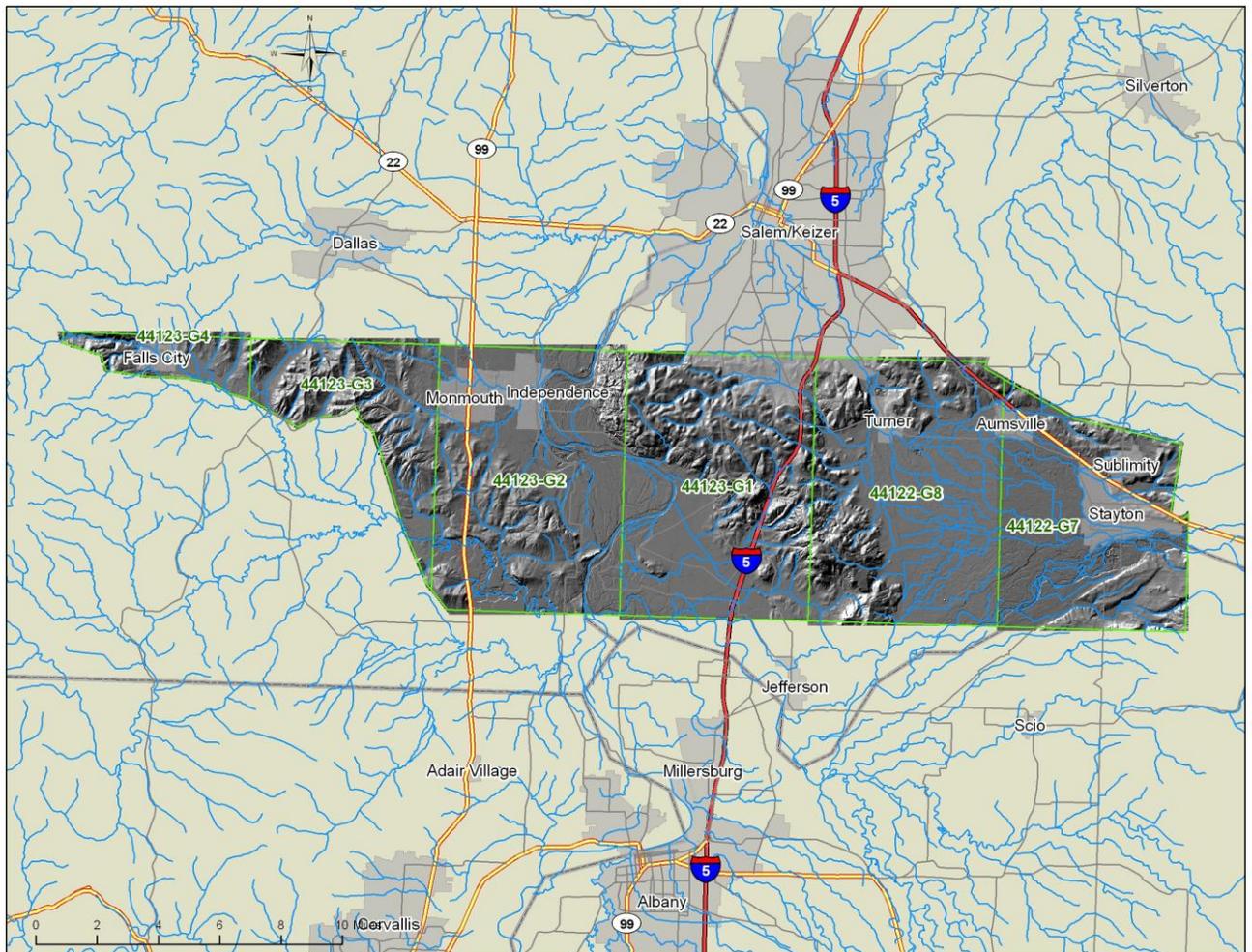


Figure 1. Delivery 9 location area. Data is referenced to USGS 7.5 minute quadrangles within the extents of the Willamette Valley Survey collection area.

Consistency Analysis:

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

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

To quantify the magnitude of this error 1,100 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 4,812,699 per tile (Table 2a). Error measurements were calculated by differencing the nearest point from an adjacent flight line within 1 meters in the horizontal plane and 0.2 meters in the vertical plane. Each flight line was compared to adjacent flight lines, and the average magnitude of vertical error was calculated. A total of 234 flight lines were sampled and compared for consistency.

Summary Statistics

# of Tiles	1,100
# of Flight Line Sections	234
Avg # of Points	4,812,699
Avg. Magnitude Z error (m)	0.029

Table 2a. Summary Results of Consistency Analysis

	<i>meters</i>	<i>feet</i>
Mean	0.029	0.094
Standard Error	0.000	0.001
Standard Deviation	0.006	0.019
Sample Variance	0.000	0.000
Range	0.030	0.099
Minimum	0.015	0.050
Maximum	0.045	0.149

Table 2b. Descriptive Statistics for Magnitude Z Error.

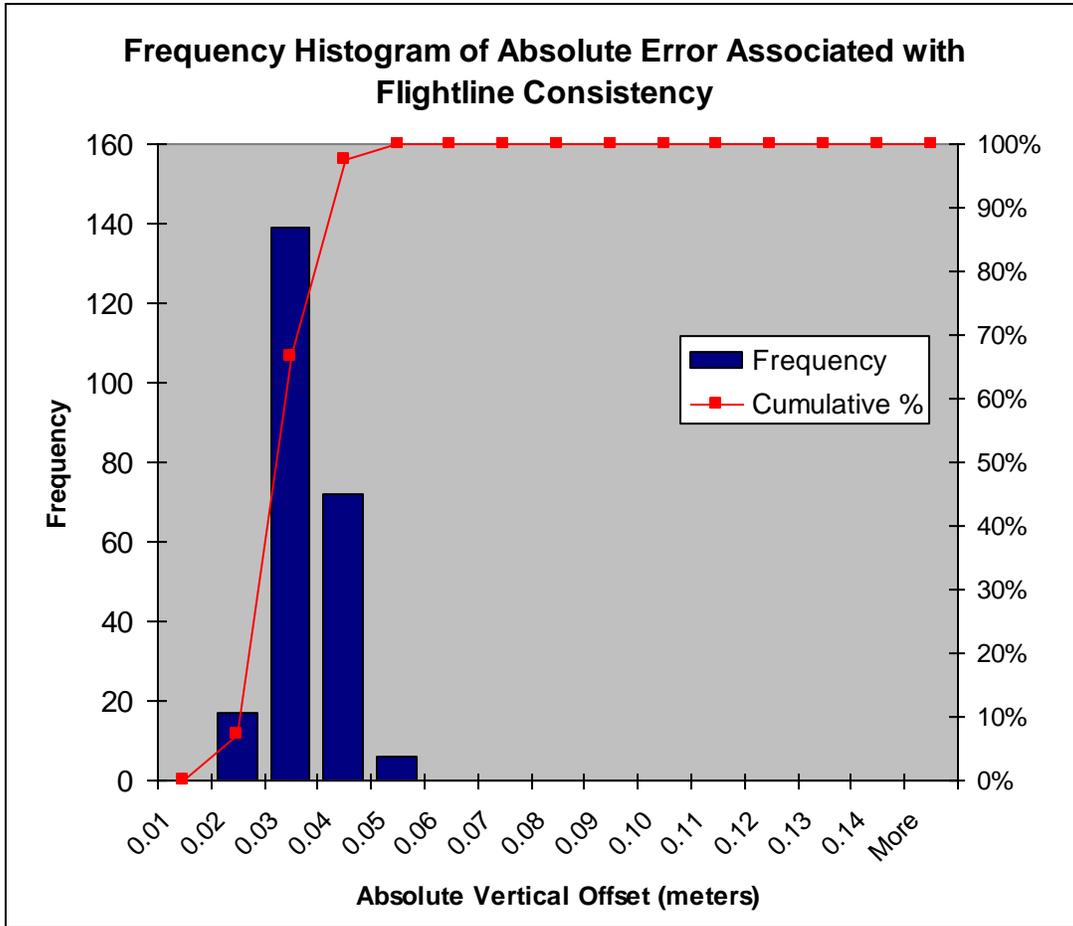


Figure 2.

Results of the consistency analysis found the average flight line offset to be 0.029 meters with a maximum error of 0.115m (Table 2b). Distribution of error showed over 97% of all error was less than 0.04m and 99.99% was less than 0.05m (Figure 2). These results show that all data are within tolerances of data consistency according to contract agreement.

Visual Analysis

Lidar 3ft grids were loaded into ArcGIS software for visual analysis. Data were examined through slope and hillshade models of bare earth returns. Hillshades of the highest hit models were used to identify areas of missing ground (Figure 3). Both bare earth and highest hit models were examined for calibration offsets, tiling artifacts (Figure 4), seam line offsets, pits (Figure 5), and birds.

Calibration offsets typically are visualized as a corduroy-like patterning within a hillshaded lidar model. These offsets present themselves along steep slopes and typically stand out more in highest hit models than bare earth. Tiling artifacts are a result of missing or misclassified data along the edge of lidar processing tiles. These artifacts present themselves as linear features typically 1-2 grid cells in width, and are present in both the highest hit and bare

earth models (e.g. Figure 3). Seam line offsets occur where two distinct days of lidar data overlap. Errors occur as a result of improper absolute vertical error adjustments. These errors are typically visualized as a linear stair step running along the edge of connecting flight lines. Pits and birds refer to uncommonly high or low points that are the result of atmospheric and sensor noise. Pits (low points) typically occur where the laser comes in contact with water on the ground (Figure 5). Birds (high points) typically occur where the laser comes into contact with atmospherics¹.

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

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

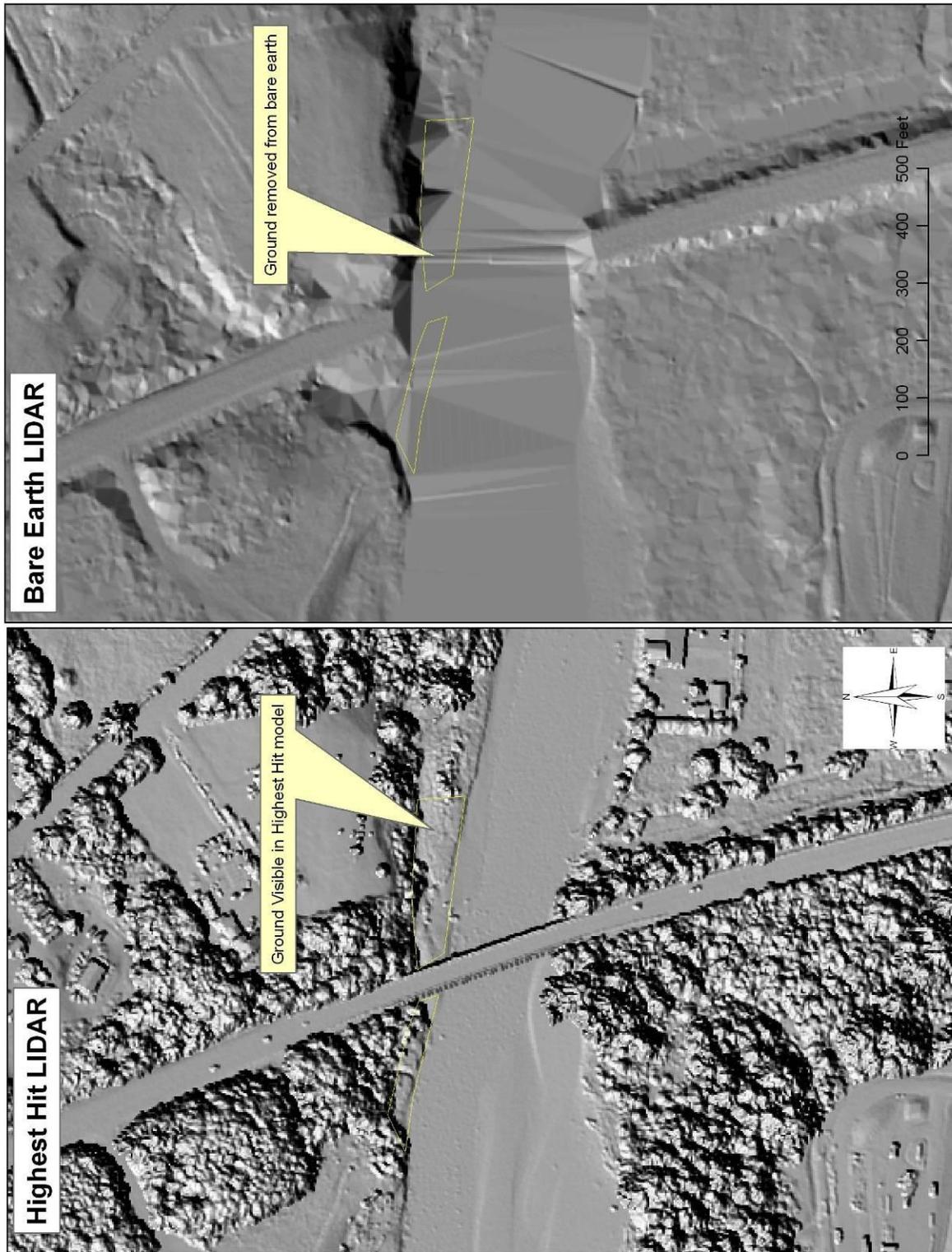


Figure 3. Example of missing ground in lidar bare earth data. Ground is clearly visible in highest hit model, but has been removed from the bare earth model. This type of classification error is common near water body features.

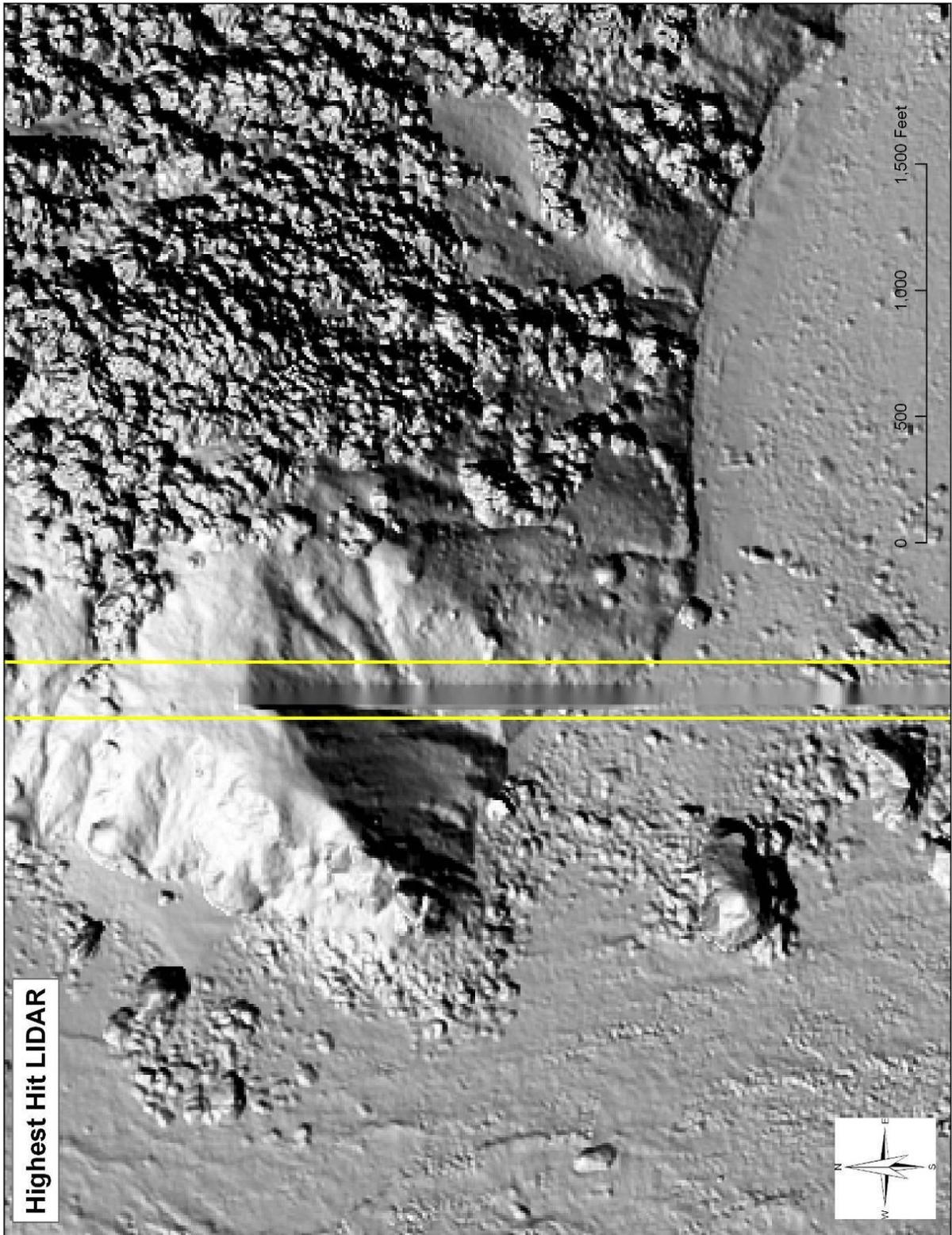


Figure 4. Example of tile artifact found in highest hit lidar data. Artifact is a seam line error created due to misclassification of ground at edge of lidar processing tiles.



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

Absolute Accuracy Analysis:

Absolute accuracy refers to the mean vertical offset of lidar data relative to measured ground-control points (GCP) obtained throughout the lidar sampling area. DOGAMI used a Trimble™ 5700/5800 Total Station GPS surveying system (Figure 5) to measure GCP's. This system consisted of a GPS base station (5700 unit), Zephyr Geodetic antenna, Trimmark 3 radio, and 5800 "rover". The 5700 base station was mounted on a fixed height (typically 2.0 m) tripod and located over a known geodetic survey monument followed by a site calibration on several adjacent benchmarks to precisely establish a local coordinate system. This step is critical in order to eliminate various survey errors. For example, Trimble reports that the 5700/5800 GPS system have horizontal errors of approximately $\pm 1\text{-cm} + 1\text{ppm}$ (parts per million * the baseline length) and $\pm 2\text{-cm}$ in the vertical (TrimbleNavigationSystem, 2005). These errors may be compounded by other factors such as poor satellite geometry, multipath, and poor atmospheric conditions, combining to increase the total error to several centimeters. Thus, the site calibration process is critical in order to minimize these uncertainties.

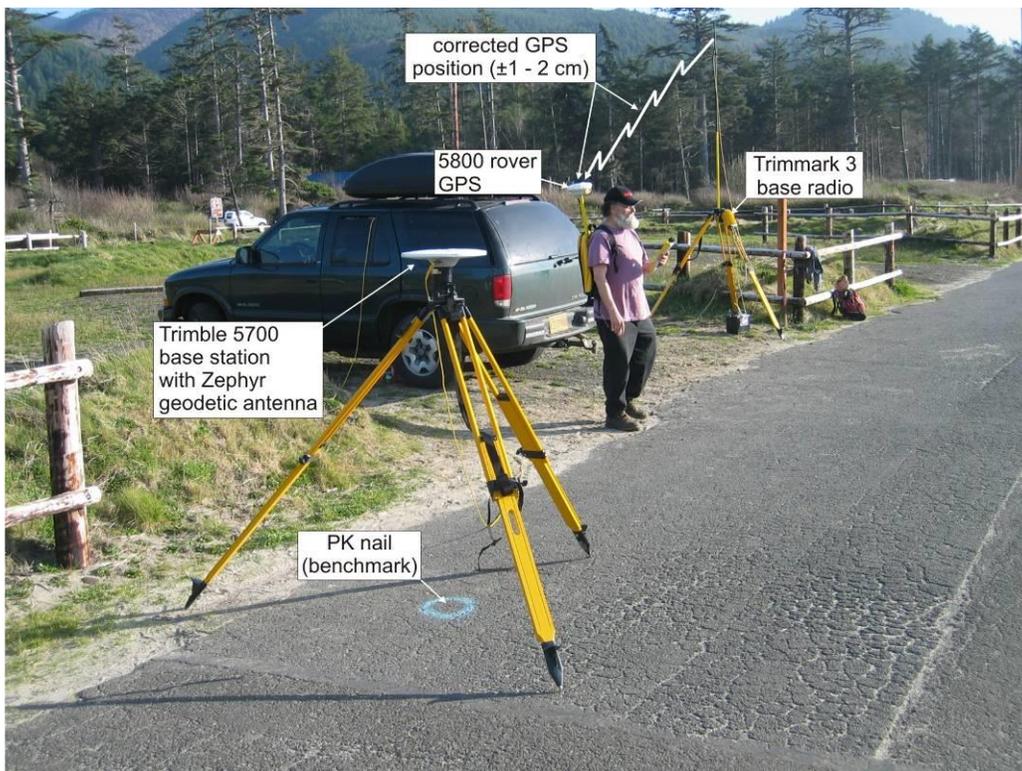


Figure 5. The Trimble 5700 base station antenna located over a known reference point at Cape Lookout State Park. Corrected GPS position and elevation information is then transmitted by a Trimmark III base radio to the 5800 GPS rover unit.

The approach adopted for Oregon LiDAR Consortium lidar surveys was comprised of two components:

- 1) Verify the horizontal and vertical coordinates established by Watershed Sciences for a select number of survey monuments used to calibrate the lidar survey. These surveys typically involved a minimum of two hours of GPS occupation over a known point. The collected data were then submitted to the

National Geodetic Survey (NGS) Online Positioning User Service (OPUS) for post-processing against several Continuously Operating Reference Stations (CORS) operated by the NGS.

- 2) Collect GCP's along relatively flat surfaces (roads, paths, parking lots etc.). This step involved the collection of both continuous measurements (from a vehicle as well as from a backpack) as well as static measurements (typically 5 epics).

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

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

A total of 444 measured GCP's were obtained in the Delivery 9 region, and compared with the lidar elevation grids. The data delivered to DOGAMI was found to have a mean vertical offset of +/-0.037 meters (0.12 feet) and an RMSE value of 0.053 meters (0.175 ft). Offset values ranged from 0 to 0.148 meters (Table 3 and Figure 7).

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

DOGAMI was able to test the horizontal accuracy of survey monuments used to reference the lidar data while conducting vertical control measurements. For internal purposes only, the XY coordinates of survey monuments surveyed by DOGAMI were compared to the survey monuments provided by the vender and in almost every case, the reported results were consistent with those obtained by DOGAMI staff.

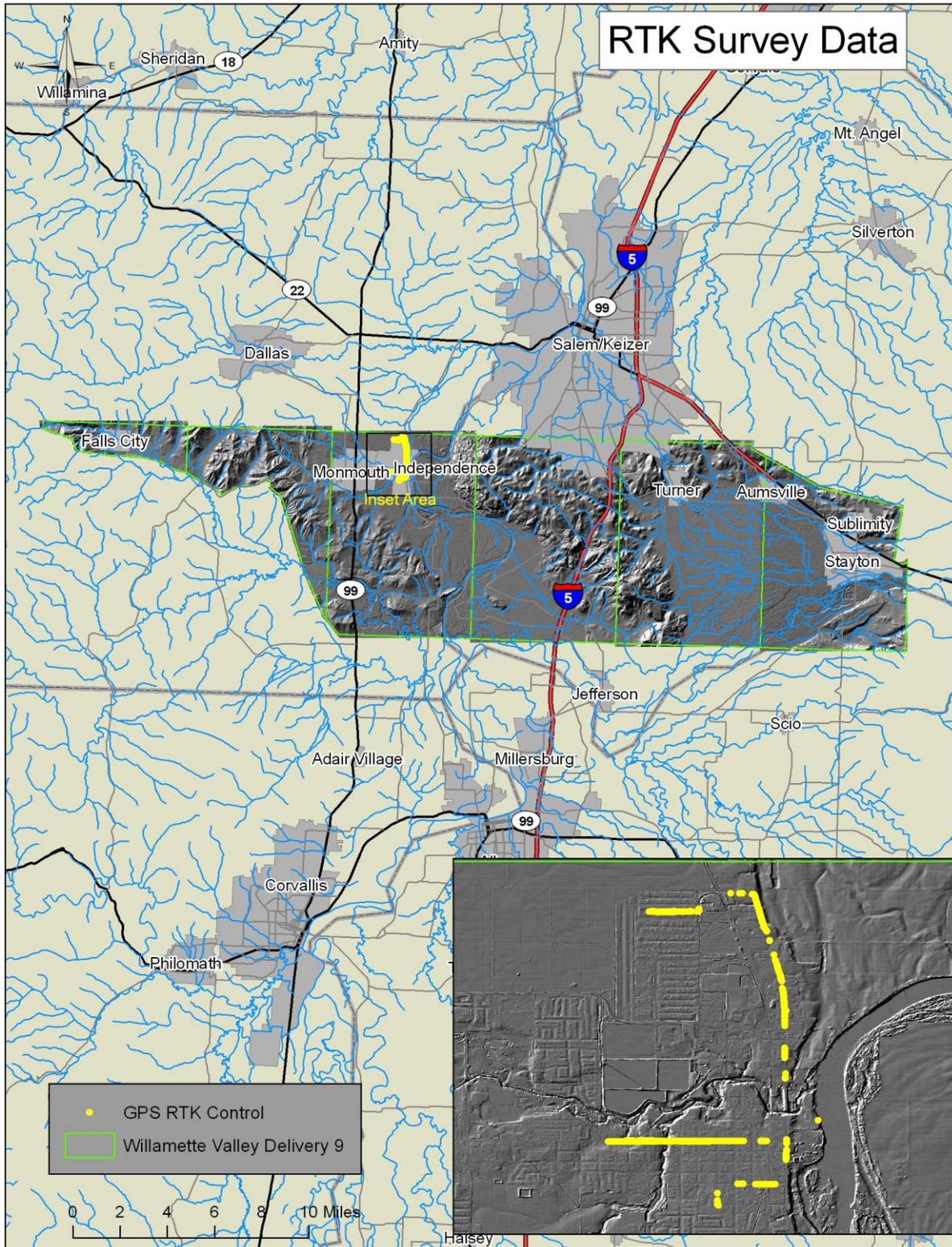


Figure 6. Locations of RTK control surveyed by DOGAMI. Data was used to test absolute accuracy for the Willamette Valley lidar survey within the Delivery 9 extent.

	<i>Meters</i>	<i>Feet</i>
Mean	0.037	0.120
Standard Error	0.002	0.006
Standard Deviation	0.039	0.128
Range	0.241	0.789
Minimum	-0.093	-0.304
Maximum	0.148	0.485

Table 3. Descriptive Statistics for absolute value vertical offsets.

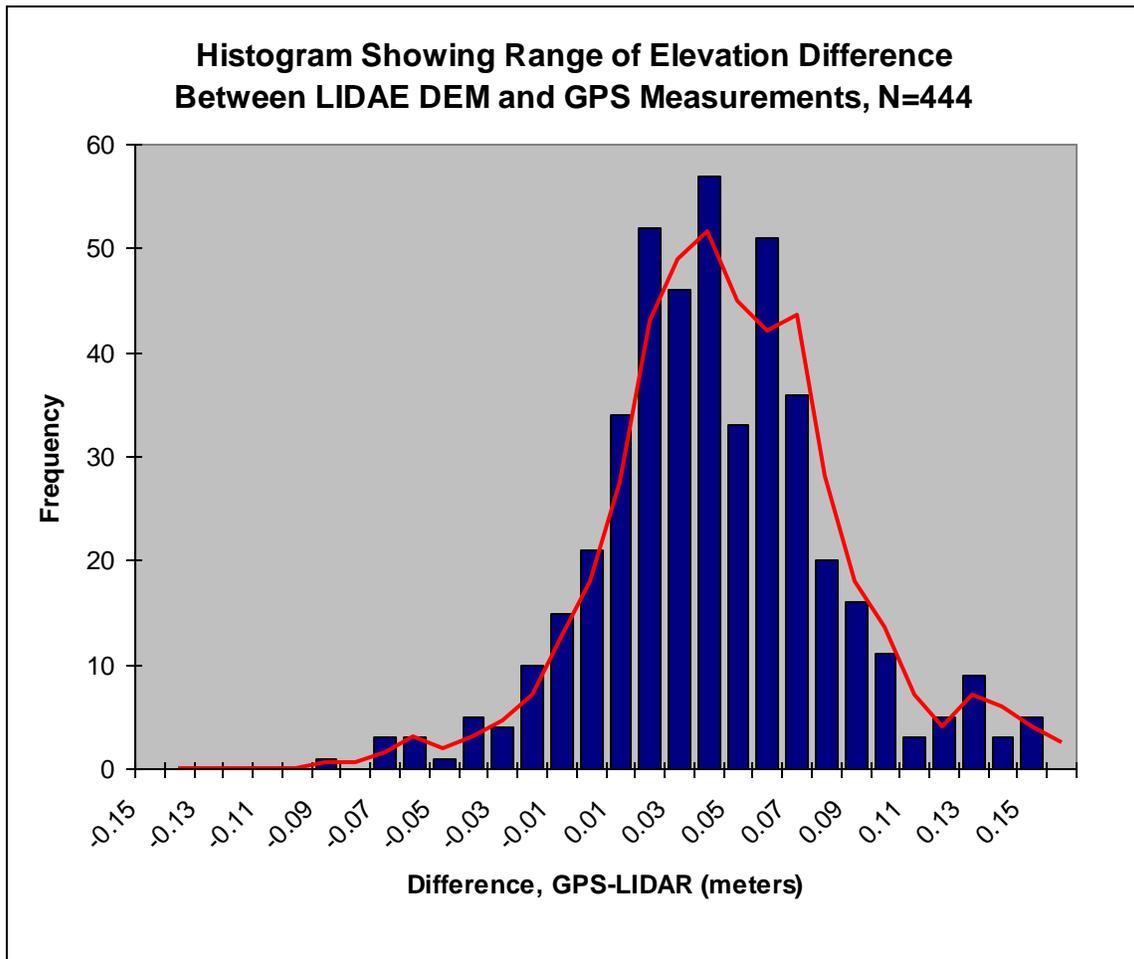


Figure 7.

Acceptance

The data described in this report meets and exceeds project specifications laid out in the contracted data standards agreement. All components of data to be delivered have been received as of July 23rd, 2009. Consistency analysis has concluded that all data contains flight line to flight line vertical offset less than the threshold of 0.15 meters as specified in agreement. The vendor has adequately responded to all fixable errors identified as part of the visual analysis. Perceived grid errors identified by DOGAMI that were found to be false have been documented by the vendor and explained to the satisfaction of DOGAMI reviewers. Absolute accuracy analysis of the data has concluded that absolute vertical error of lidar data is less than the specified tolerance of 0.20 meters as specified in the data standards agreement.

Approval Signatures

_____ Date: _____

Ian Madin
Chief Scientist – Department of Geology & Mineral Industries

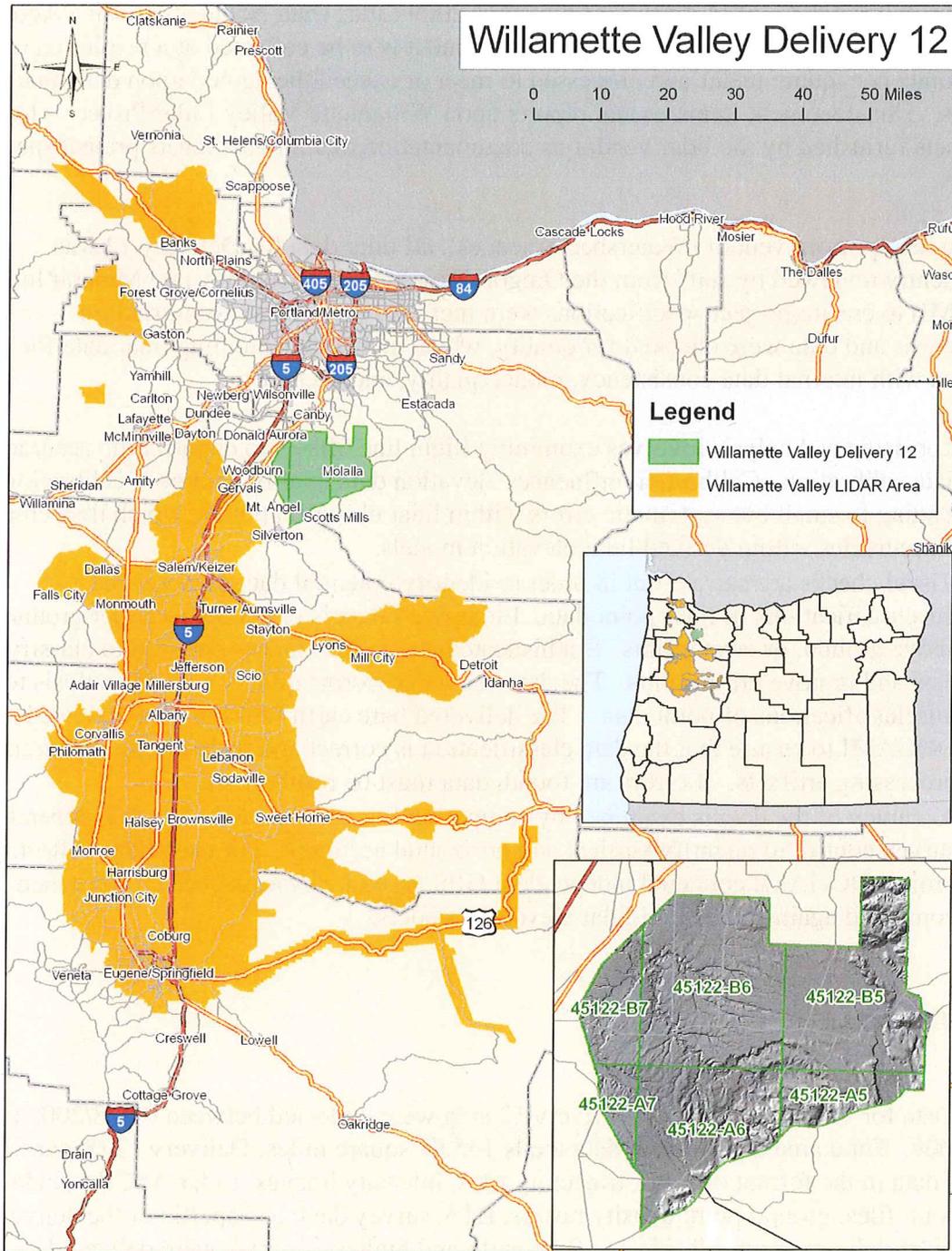
_____ Date: _____

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

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



Willamette Valley LIDAR Project, 2009 – Delivery 12 QC Analysis
LIDAR QC Report – July 23rd, 2009



Map featuring Willamette Valley Delivery 12 data extent.

The Oregon Department of Geology & Mineral Industries has contracted with Watershed Sciences to collect high resolution lidar topographic data for multiple areas within the State of Oregon. Areas for lidar data collection have been designed as part of a collaborative effort of State, Federal, and Local agencies in order to meet a wide range of project goals. The vendor has agreed to certain conditions of data quality and standards for all lidar data deliverables listed in sections A through C (OPA #8865) of the 2007-2009 Lidar Data Acquisition Price Agreement (pgs 14-23). Data submitted under this price agreement is to be collected at a resolution of at least 8 points per square meter and processed to meet or exceed the agreed upon data quality standards. This document itemizes and reports upon Willamette Valley Lidar Project – Delivery 12 products furnished by the lidar vendor as documentation that all data meets project specific standards.

Upon receipt from vendor (Watershed Sciences), all lidar data for Delivery 12 was independently reviewed by staff from the Oregon Department of Geology and Mineral Industries (DOGAMI) to ensure project specifications were met. All data were inventoried for completeness and data were checked for quality, which included examining lidar data for errors associated with internal data consistency, model quality, and accuracy.

- Consistency Analysis involves examining flight line offsets to quantify the accuracy of data calibration. Calibration influences elevation data quality with poor calibration leading to small but systematic errors within lidar elevation points, which then create inaccuracies within derived lidar elevation models.
- Visual checks are carried out in order to identify potential data artifacts and misclassifications of lidar point data. Lidar point data is classified as either ground, above ground, or error points. Sophisticated processing scripts are used to classify point data and remove error points. The data vendor performs quality control analysis to fix misclassifications of point data. The delivered bare earth DEM is then reviewed by DOGAMI to ensure that the data classification is correct and there are no topographic processing artifacts. If errors are found, data must be resubmitted.
- Accuracy of the data is examined by comparing lidar elevation data with independent survey control to quantify vertical and horizontal accuracy. For each lidar collection project DOGAMI collected independent GPS ground elevations, which were then compared against delivered lidar elevation models.

Data Completeness

Data for Willamette Valley Delivery 12 area were collected between 09/28/2008 to 03/15/2009. Total area of delivered data totals 135.67 square miles. Delivery 12 (Figure 1) includes data in the format of grids, trajectory files, intensity images, Lidar ASCII Standard (LAS) point files, ground point density rasters, RTK survey data, a shapefile of the delivery area, and the lidar delivery report (Table 1). Bare earth and highest hit grids were delivered in ArcInfo Grid format with 3ft cell size. Lidar point data is delivered in LAS binary format for ground

classified returns as well as the entire lidar point cloud. Georeferenced intensity images are supplied in TIF format. Supplementary data includes ground density rasters displaying locations where ground returns are low. Real time kinematic ground survey data (used for absolute vertical adjustment) is supplied in shapefile format. This delivery contains data for the following USGS 7.5 minute quads (listed by Ohio Code #) within the boundary of the Willamette Valley Survey collection area (Figure 1):

Delivery 12: 45122a5, 45122a6, 45122a7, 45123b5, 45123b6, 45123b7

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

Table 1. Deliverable Checklist

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

Deliverable Descriptions: (All data projected in Oregon Lambert, NAD83 (HARN), Intl Feet with exception of trajectory files).

- Bare Earth Grids: Tin interpolated grids created from lidar ground returns.
- Highest Hit Grids: Tin interpolated grids created from the highest lidar elevation for a given 3ft cell.
- Intensity TIF: TIF raster built using returned lidar pulse intensity values gathered from highest hit returns.
- Trajectory File: File contains point location measurement of the aircraft used to collect lidar data. Data is collected using an Inertial Measurement Unit (IMU), and collects measurements of: Easting(meters), Northing (meters), Ellipsoid Height (meters) of aircraft, aircraft roll (degrees), aircraft pitch (degrees), aircraft heading (degrees).

Measurements are collected at one second intervals. Data is projected in UTM zone 10, NAD83 (HARN).

- LAS: Binary file of all lidar points collected in survey (Class, flight line #, GPS Time, Echo, Easting, Northing, Elevation, Intensity, Scan Angle, Echo Number, and Scanner).
- Ground LAS: Binary file of lidar points classified as ground (Class, flight line #, GPS Time, Echo, Easting, Northing, Elevation, Intensity, Scan Angle, Echo Number, and Scanner).
- RTK Point Data: Ground GPS Survey data used to correct raw lidar point cloud for vertical offsets.
- Delivery Area Shapefile: Geometry file depicting the geospatial area associated with deliverables.
- Report: Report provides detailed description of data collection methods and processing. The vendor also reports accuracies associated with calibration, consistency, absolute error, and point classifications.

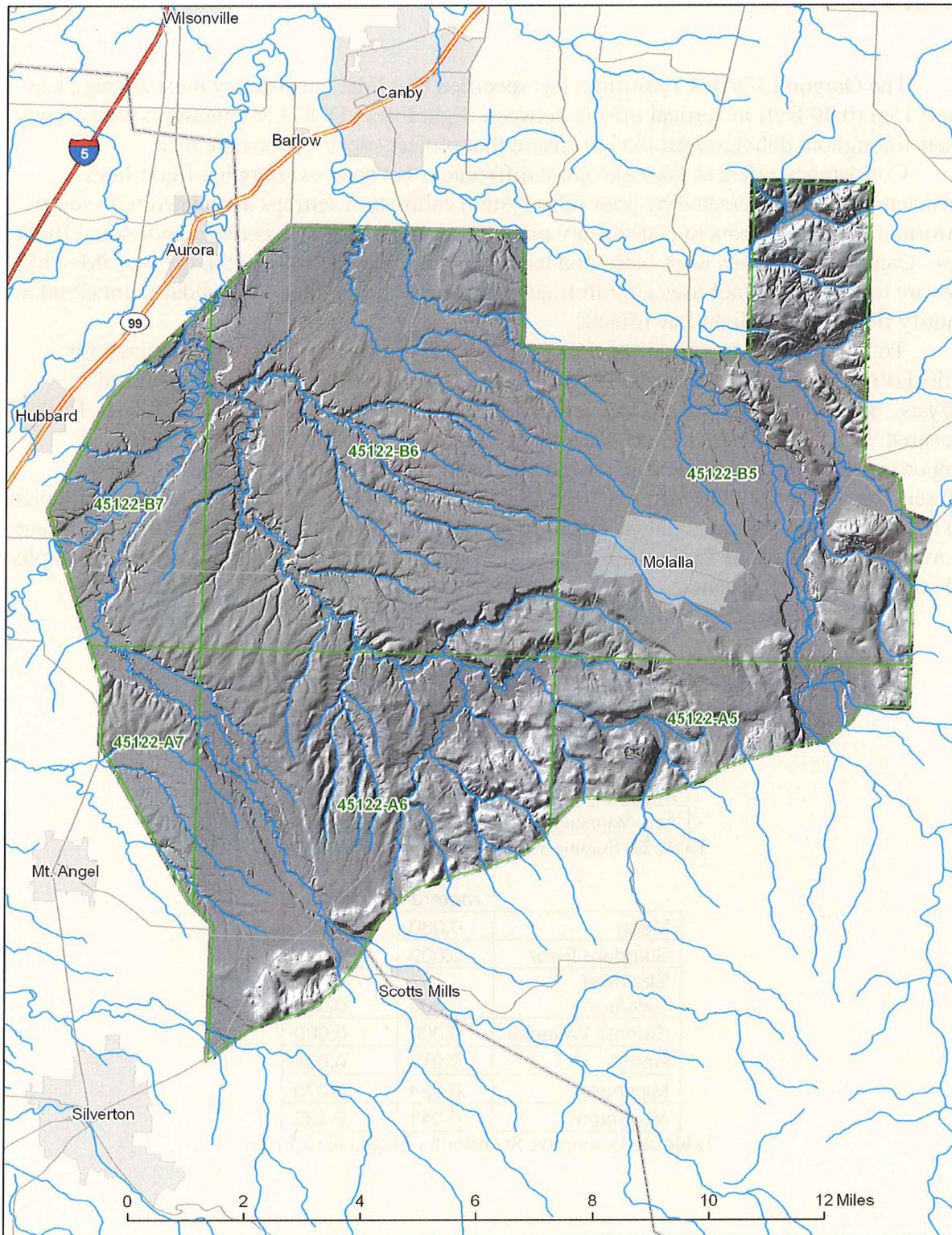


Figure 1. Delivery 12 location area. Data is referenced to USGS 7.5 minute quadrangles within the extents of the Willamette Valley Survey collection area.

Consistency Analysis:

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

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

To quantify the magnitude of this error 670 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 11,114,721 per tile (Table 2a). Error measurements were calculated by differencing the nearest point from an adjacent flight line within 1 meters in the horizontal plane and 0.2 meters in the vertical plane. Each flight line was compared to adjacent flight lines, and the average magnitude of vertical error was calculated. A total of 127 flight lines were sampled and compared for consistency.

Summary Statistics

# of Tiles	670
# of Flight Line Sections	127
Avg # of Points	11,114,721
Avg. Magnitude Z error (m)	0.029

Table 2a. Summary Results of Consistency Analysis

	<i>meters</i>	<i>feet</i>
Mean	0.030	0.097
Standard Error	0.000	0.001
Standard Deviation	0.004	0.014
Sample Variance	0.000	0.000
Range	0.017	0.054
Minimum	0.024	0.079
Maximum	0.041	0.133

Table 2b. Descriptive Statistics for Magnitude Z Error.

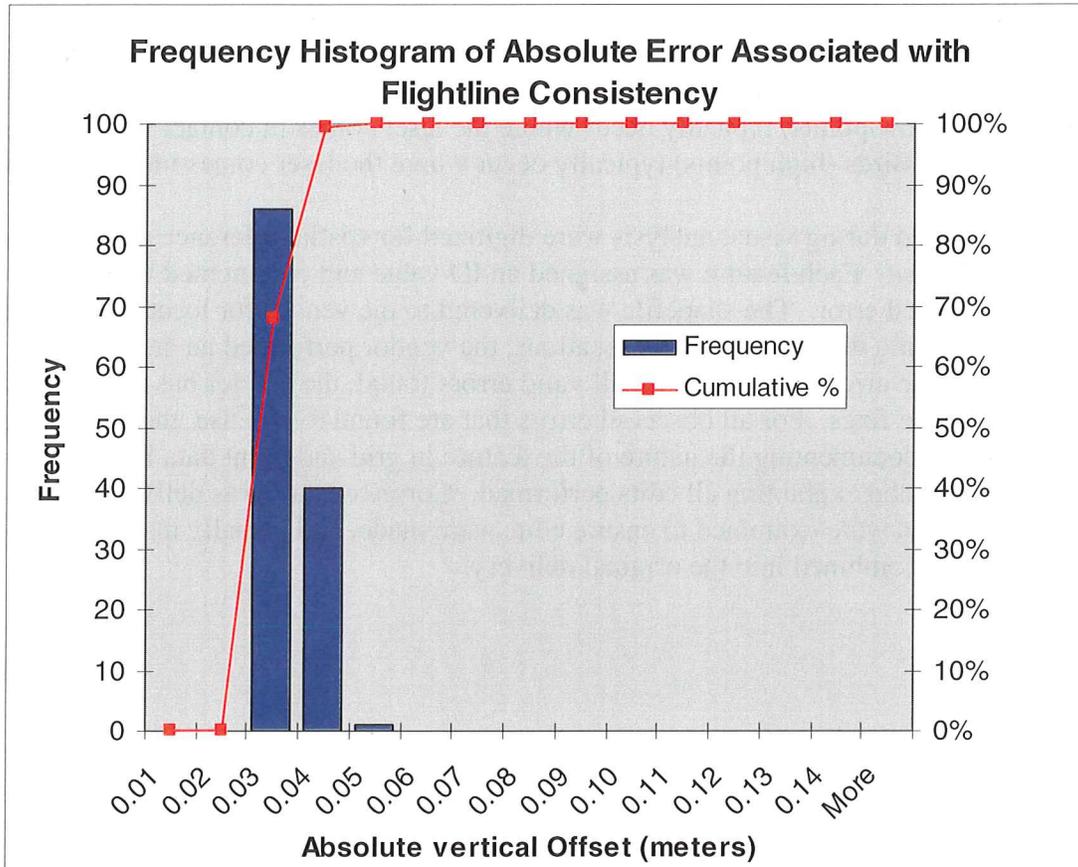


Figure 2.

Results of the consistency analysis found the average flight line offset to be 0.029 meters with a maximum error of 0.041m (Table 2b). Distribution of error showed over 99% of all error was less than 0.04m and 100% was less than 0.05m (Figure 2). These results show that all data are within tolerances of data consistency according to contract agreement.

Visual Analysis

Lidar 3ft grids were loaded into ArcGIS software for visual analysis. Data were examined through slope and hillshade models of bare earth returns. Hillshades of the highest hit models were used to identify areas of missing ground (Figure 3). Both bare earth and highest hit models were examined for calibration offsets, tiling artifacts (Figure 4), seam line offsets, pits (Figure 5), and birds.

Calibration offsets typically are visualized as a corduroy-like patterning within a hillshaded lidar model. These offsets present themselves along steep slopes and typically stand out more in highest hit models than bare earth. Tiling artifacts are a result of missing or misclassified data along the edge of lidar processing tiles. These artifacts present themselves as linear features typically 1-2 grid cells in width, and are present in both the highest hit and bare earth models (e.g. Figure 3). Seam line offsets occur where two distinct days of lidar data

overlap. Errors occur as a result of improper absolute vertical error adjustments. These errors are typically visualized as a linear stair step running along the edge of connecting flight lines. Pits and birds refer to uncommonly high or low points that are the result of atmospheric and sensor noise. Pits (low points) typically occur where the laser comes in contact with water on the ground (Figure 5). Birds (high points) typically occur where the laser comes into contact with atmospherics¹.

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

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

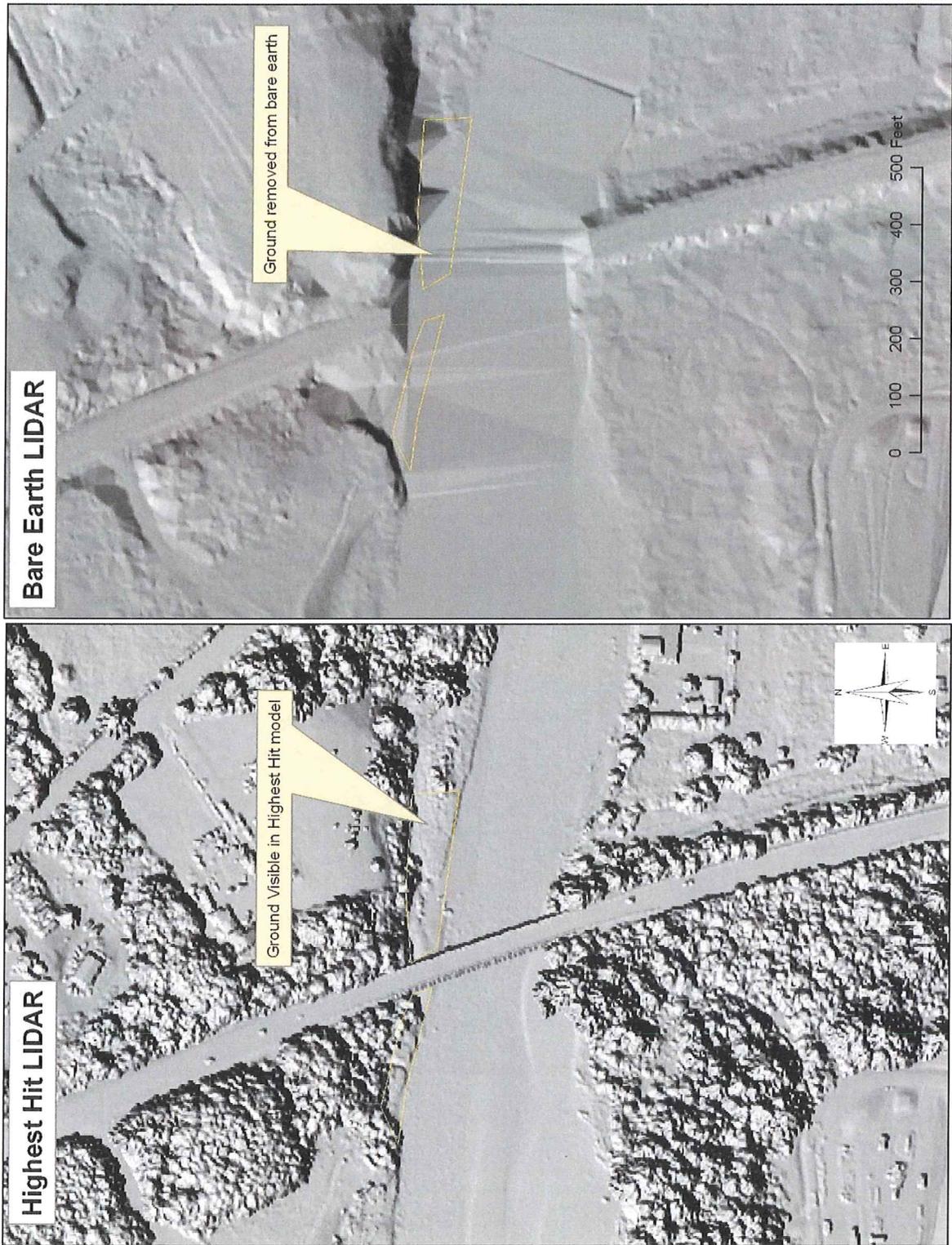


Figure 3. Example of missing ground in lidar bare earth data. Ground is clearly visible in highest hit model, but has been removed from the bare earth model. This type of classification error is common near water body features.

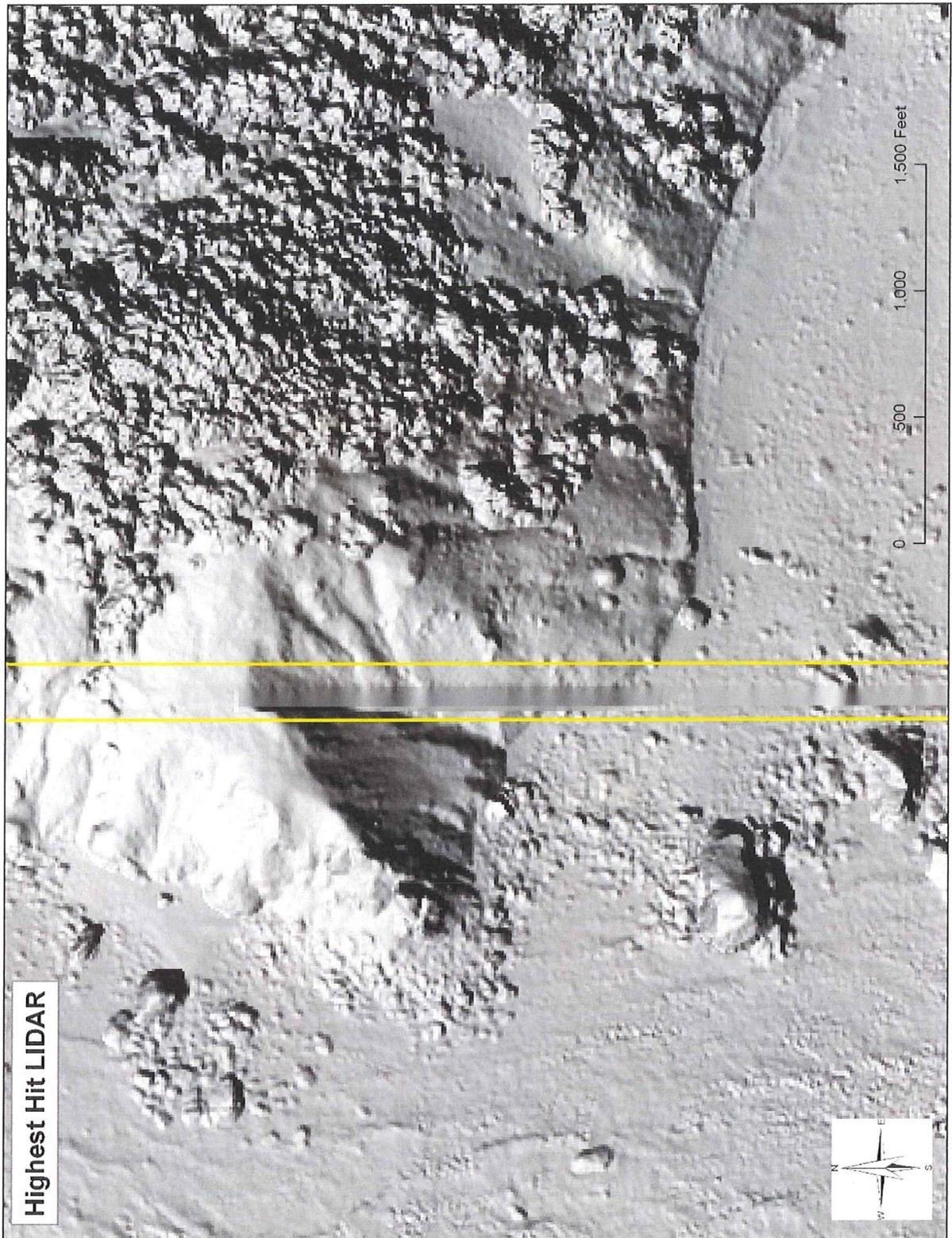


Figure 4. Example of tile artifact found in highest hit lidar data. Artifact is a seam line error created due to misclassification of ground at edge of lidar processing tiles.



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

Absolute Accuracy Analysis:

Absolute accuracy refers to the mean vertical offset of lidar data relative to measured ground-control points (GCP) obtained throughout the lidar sampling area. DOGAMI used a Trimble™ 5700/5800 Total Station GPS surveying system (Figure 5) to measure GCP's. This system consisted of a GPS base station (5700 unit), Zephyr Geodetic antenna, Trimmark 3 radio, and 5800 "rover". The 5700 base station was mounted on a fixed height (typically 2.0 m) tripod and located over a known geodetic survey monument followed by a site calibration on several adjacent benchmarks to precisely establish a local coordinate system. This step is critical in order to eliminate various survey errors. For example, Trimble reports that the 5700/5800 GPS system have horizontal errors of approximately $\pm 1\text{-cm} + 1\text{ppm}$ (parts per million * the baseline length) and $\pm 2\text{-cm}$ in the vertical (TrimbleNavigationSystem, 2005). These errors may be compounded by other factors such as poor satellite geometry, multipath, and poor atmospheric conditions, combining to increase the total error to several centimeters. Thus, the site calibration process is critical in order to minimize these uncertainties.

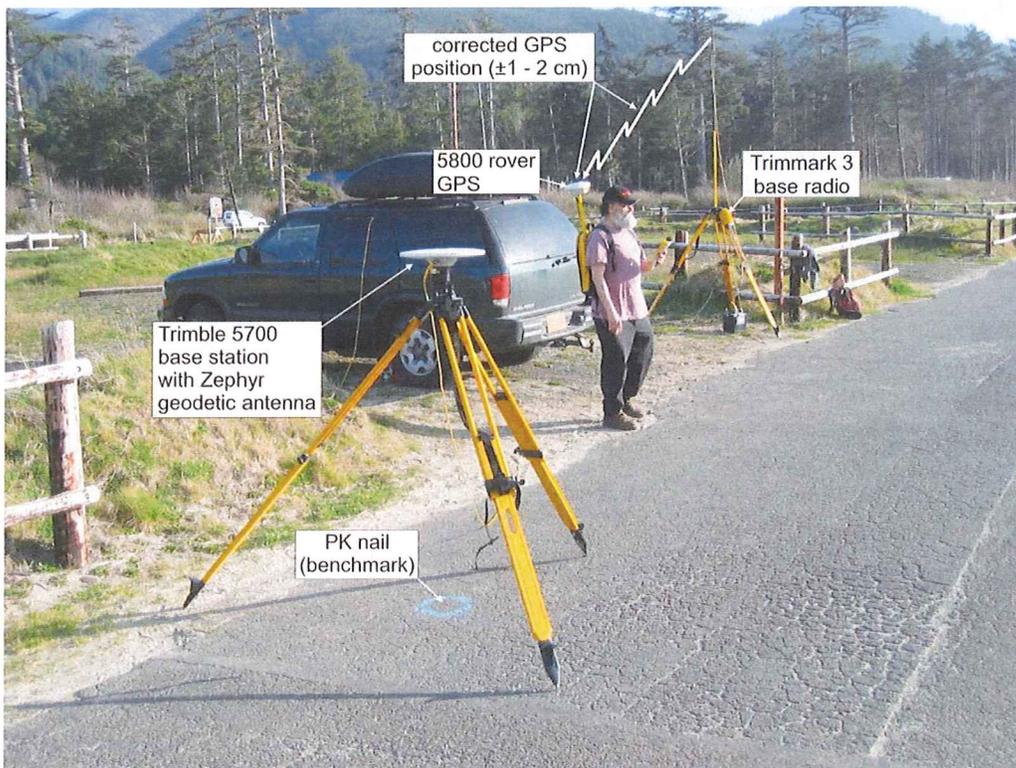


Figure 5. The Trimble 5700 base station antenna located over a known reference point at Cape Lookout State Park. Corrected GPS position and elevation information is then transmitted by a Trimmark III base radio to the 5800 GPS rover unit.

The approach adopted for Oregon LiDAR Consortium lidar surveys was comprised of two components:

- 1) Verify the horizontal and vertical coordinates established by Watershed Sciences for a select number of survey monuments used to calibrate the lidar survey. These surveys typically involved a minimum of two hours of GPS occupation over a known point. The collected data were then submitted to the

- National Geodetic Survey (NGS) Online Positioning User Service (OPUS) for post-processing against several Continuously Operating Reference Stations (CORS) operated by the NGS.
- 2) Collect GCP's along relatively flat surfaces (roads, paths, parking lots etc.). This step involved the collection of both continuous measurements (from a vehicle as well as from a backpack) as well as static measurements (typically 5 epics).

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

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

A total of 589 measured GCP's were obtained in the Delivery 12 region, and compared with the lidar elevation grids. The data delivered to DOGAMI was found to have a mean vertical offset of 0.081 meters (0.0267 feet) and an RMSE value of 0.092 meters (0.302 ft). Offset values ranged from -0.051 to 0.199 meters (Table 3 and Figure 7).

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

DOGAMI was able to test the horizontal accuracy of survey monuments used to reference the lidar data while conducting vertical control measurements. For internal purposes only, the XY coordinates of survey monuments surveyed by DOGAMI were compared to the survey monuments provided by the vender and in almost every case, the reported results were consistent with those obtained by DOGAMI staff.

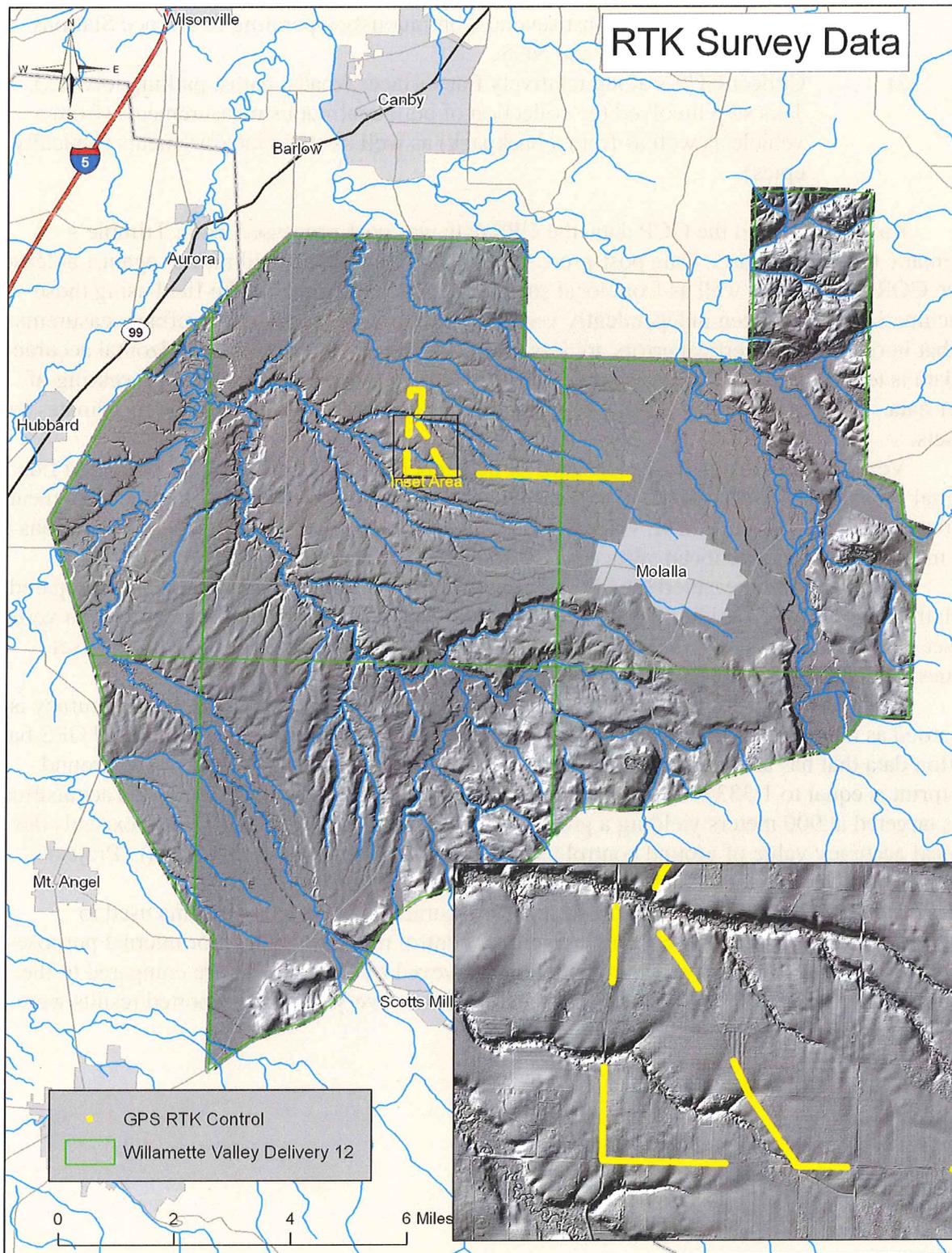


Figure 6. Locations of RTK control surveyed by DOGAMI. Data was used to test absolute accuracy for the Willamette Valley lidar survey within the Delivery 12 extent.

	<i>Meters</i>	<i>Feet</i>
Mean	0.081	0.267
Standard Error	0.002	0.006
Standard Deviation	0.043	0.141
Range	0.249	0.818
Minimum	-0.051	-0.166
Maximum	0.199	0.652

Table 3. Descriptive Statistics for absolute value vertical offsets.

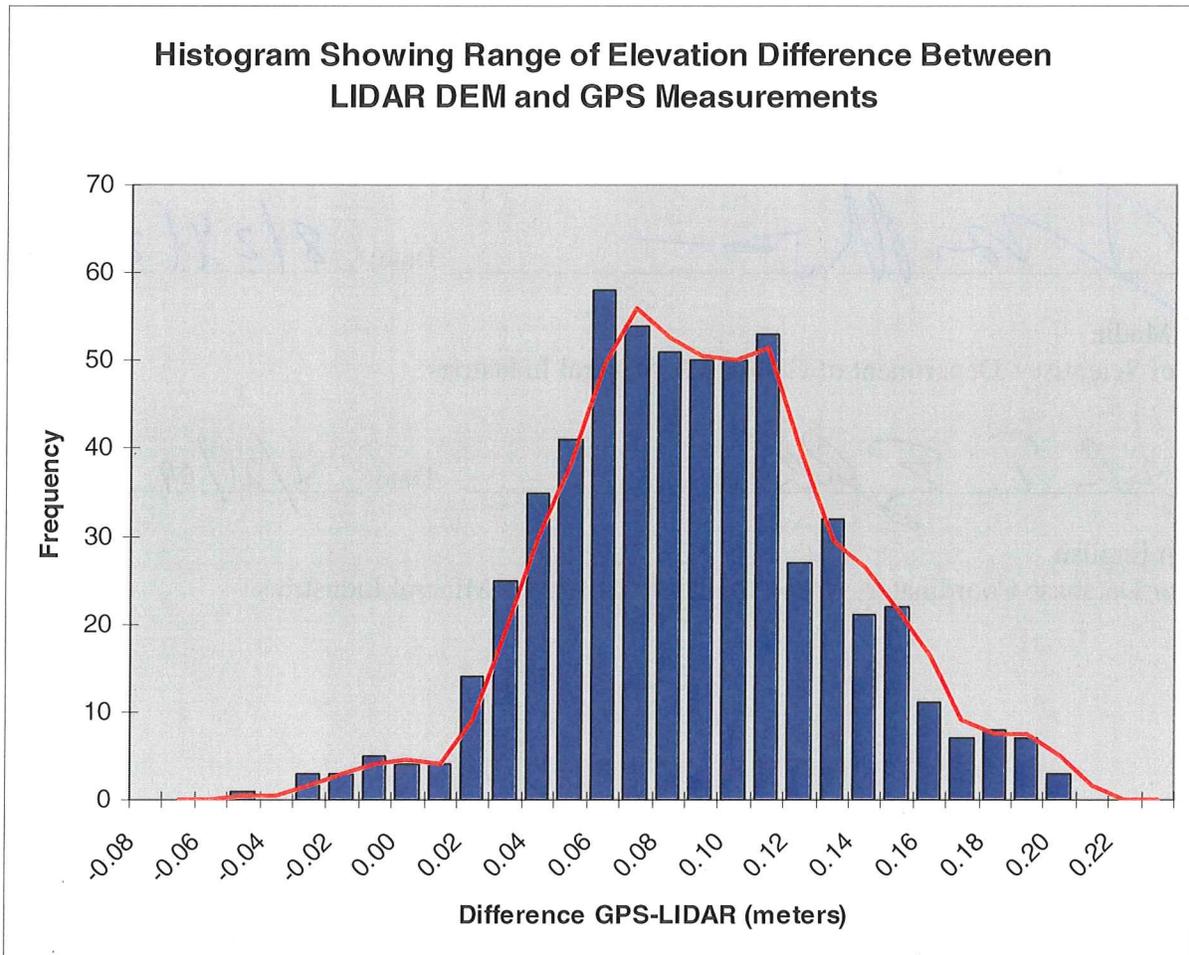


Figure 7.

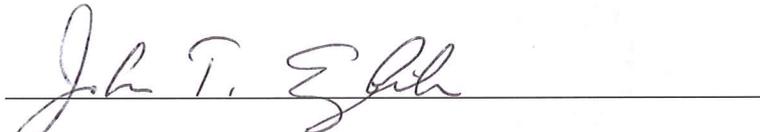
Acceptance

The data described in this report meets and exceeds project specifications laid out in the contracted data standards agreement. All components of data to be delivered have been received as of August 20th, 2009. Consistency analysis has concluded that all data contains flight line to flight line vertical offset less than the threshold of 0.15 meters as specified in agreement. The vendor has adequately responded to all fixable errors identified as part of the visual analysis. Perceived grid errors identified by DOGAMI that were found to be false have been documented by the vendor and explained to the satisfaction of DOGAMI reviewers. Absolute accuracy analysis of the data has concluded that absolute vertical error of lidar data is less than the specified tolerance of 0.20 meters as specified in the data standards agreement.

Approval Signatures

 _____ Date: 8/24/2009

Ian Madin
Chief Scientist – Department of Geology & Mineral Industries

 _____ Date: 8/21/09

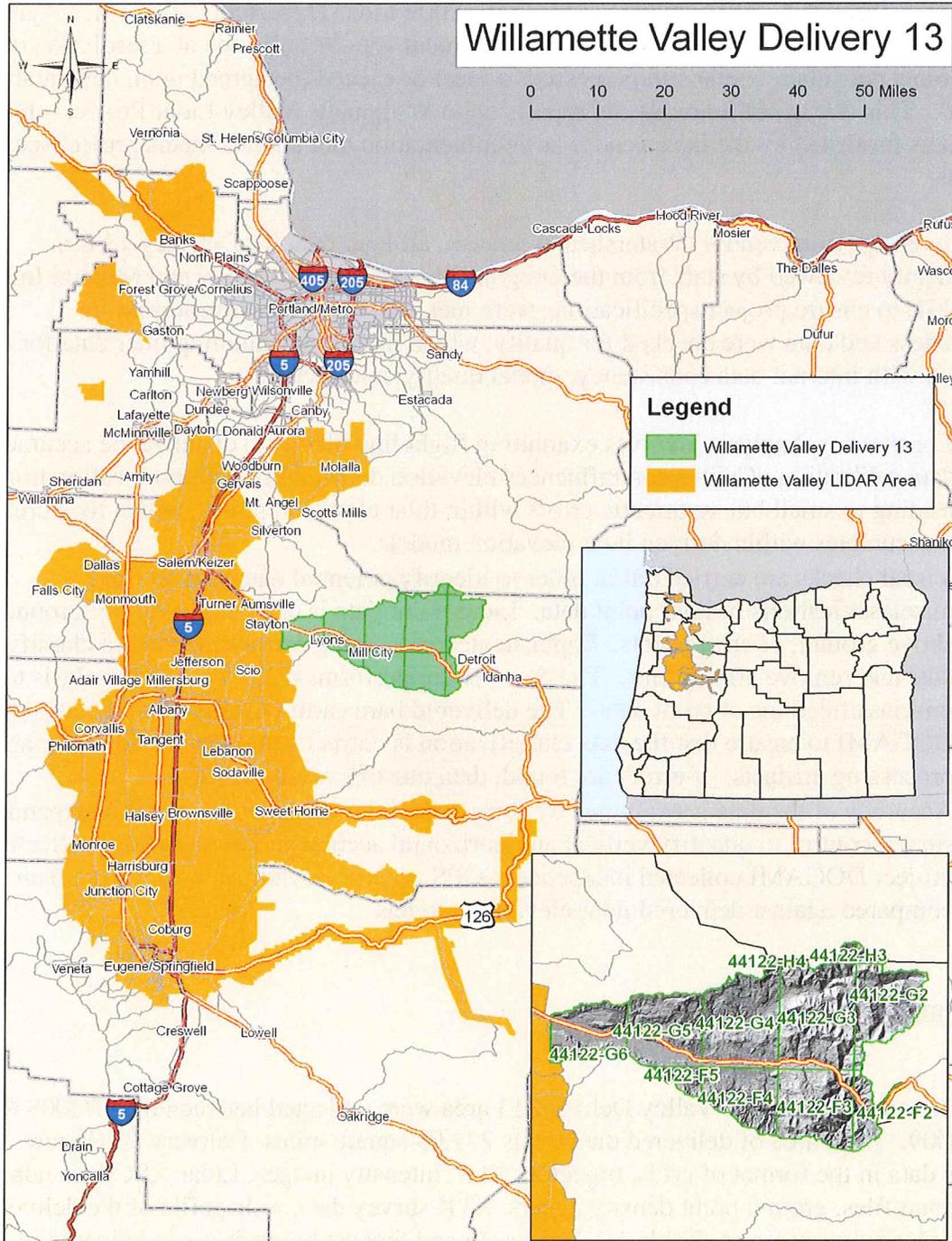
John English
Lidar Database Coordinator – Department of Geology & Mineral Industries



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



Willamette Valley LIDAR Project, 2009 – Delivery 13 QC Analysis
LIDAR QC Report – September 29th, 2009



Map featuring Willamette Valley Delivery 13 data extent.

The Oregon Department of Geology & Mineral Industries has contracted with Watershed Sciences to collect high resolution lidar topographic data for multiple areas within the State of Oregon. Areas for lidar data collection have been designed as part of a collaborative effort of State, Federal, and Local agencies in order to meet a wide range of project goals. The vendor has agreed to certain conditions of data quality and standards for all lidar data deliverables listed in sections A through C (OPA #8865) of the 2007-2009 Lidar Data Acquisition Price Agreement (pgs 14-23). Data submitted under this price agreement is to be collected at a resolution of at least 8 points per square meter and processed to meet or exceed the agreed upon data quality standards. This document itemizes and reports upon Willamette Valley Lidar Project – Delivery 13 products furnished by the lidar vendor as documentation that all data meets project specific standards.

Upon receipt from vendor (Watershed Sciences), all lidar data for Delivery 13 was independently reviewed by staff from the Oregon Department of Geology and Mineral Industries (DOGAMI) to ensure project specifications were met. All data were inventoried for completeness and data were checked for quality, which included examining lidar data for errors associated with internal data consistency, model quality, and accuracy.

- Consistency Analysis involves examining flight line offsets to quantify the accuracy of data calibration. Calibration influences elevation data quality with poor calibration leading to small but systematic errors within lidar elevation points, which then create inaccuracies within derived lidar elevation models.
- Visual checks are carried out in order to identify potential data artifacts and misclassifications of lidar point data. Lidar point data is classified as either ground, above ground, or error points. Sophisticated processing scripts are used to classify point data and remove error points. The data vendor performs quality control analysis to fix misclassifications of point data. The delivered bare earth DEM is then reviewed by DOGAMI to ensure that the data classification is correct and there are no topographic processing artifacts. If errors are found, data must be resubmitted.
- Accuracy of the data is examined by comparing lidar elevation data with independent survey control to quantify vertical and horizontal accuracy. For each lidar collection project DOGAMI collected independent GPS ground elevations, which were then compared against delivered lidar elevation models.

Data Completeness

Data for Willamette Valley Delivery 13 area were collected between 09/17/2008 to 07/01/2009. Total area of delivered data totals 271.09 square miles. Delivery 13 (Figure 1) includes data in the format of grids, trajectory files, intensity images, Lidar ASCII Standard (LAS) point files, ground point density rasters, RTK survey data, a shapefile of the delivery area, and the lidar delivery report (Table 1). Bare earth and highest hit grids were delivered in ArcInfo Grid format with 3ft cell size. Lidar point data is delivered in LAS binary format for ground

classified returns as well as the entire lidar point cloud. Georeferenced intensity images are supplied in TIF format. Supplementary data includes ground density rasters displaying locations where ground returns are low. Real time kinematic ground survey data (used for absolute vertical adjustment) is supplied in shapefile format. This delivery contains data for the following USGS 7.5 minute quads (listed by Ohio Code #) within the boundary of the Willamette Valley Survey collection area (Figure 1):

Delivery 13: 44122f2, 44122f3, 44122f4, 44122f5, 44122g2, 44122g3, 44122g4, 44122g5, 44122g6, 44122h2, 44122h3, 44122h4

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

Table 1. Deliverable Checklist

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

Deliverable Descriptions: (All data projected in Oregon Lambert, NAD83 (HARN), Intl Feet with exception of trajectory files).

- Bare Earth Grids: Tin interpolated grids created from lidar ground returns.
- Highest Hit Grids: Tin interpolated grids created from the highest lidar elevation for a given 3ft cell.
- Intensity TIF: TIF raster built using returned lidar pulse intensity values gathered from highest hit returns.
- Trajectory File: File contains point location measurement of the aircraft used to collect lidar data. Data is collected using an Inertial Measurement Unit (IMU), and collects measurements of: Easting(meters), Northing (meters), Ellipsoid Height (meters) of aircraft, aircraft roll (degrees), aircraft pitch (degrees), aircraft heading (degrees).

Measurements are collected at one second intervals. Data is projected in UTM zone 10, NAD83 (HARN).

- LAS: Binary file of all lidar points collected in survey (Class, flight line #, GPS Time, Echo, Easting, Northing, Elevation, Intensity, Scan Angle, Echo Number, and Scanner).
- Ground LAS: Binary file of lidar points classified as ground (Class, flight line #, GPS Time, Echo, Easting, Northing, Elevation, Intensity, Scan Angle, Echo Number, and Scanner).
- RTK Point Data: Ground GPS Survey data used to correct raw lidar point cloud for vertical offsets.
- Delivery Area Shapefile: Geometry file depicting the geospatial area associated with deliverables.
- Report: Report provides detailed description of data collection methods and processing. The vendor also reports accuracies associated with calibration, consistency, absolute error, and point classifications.

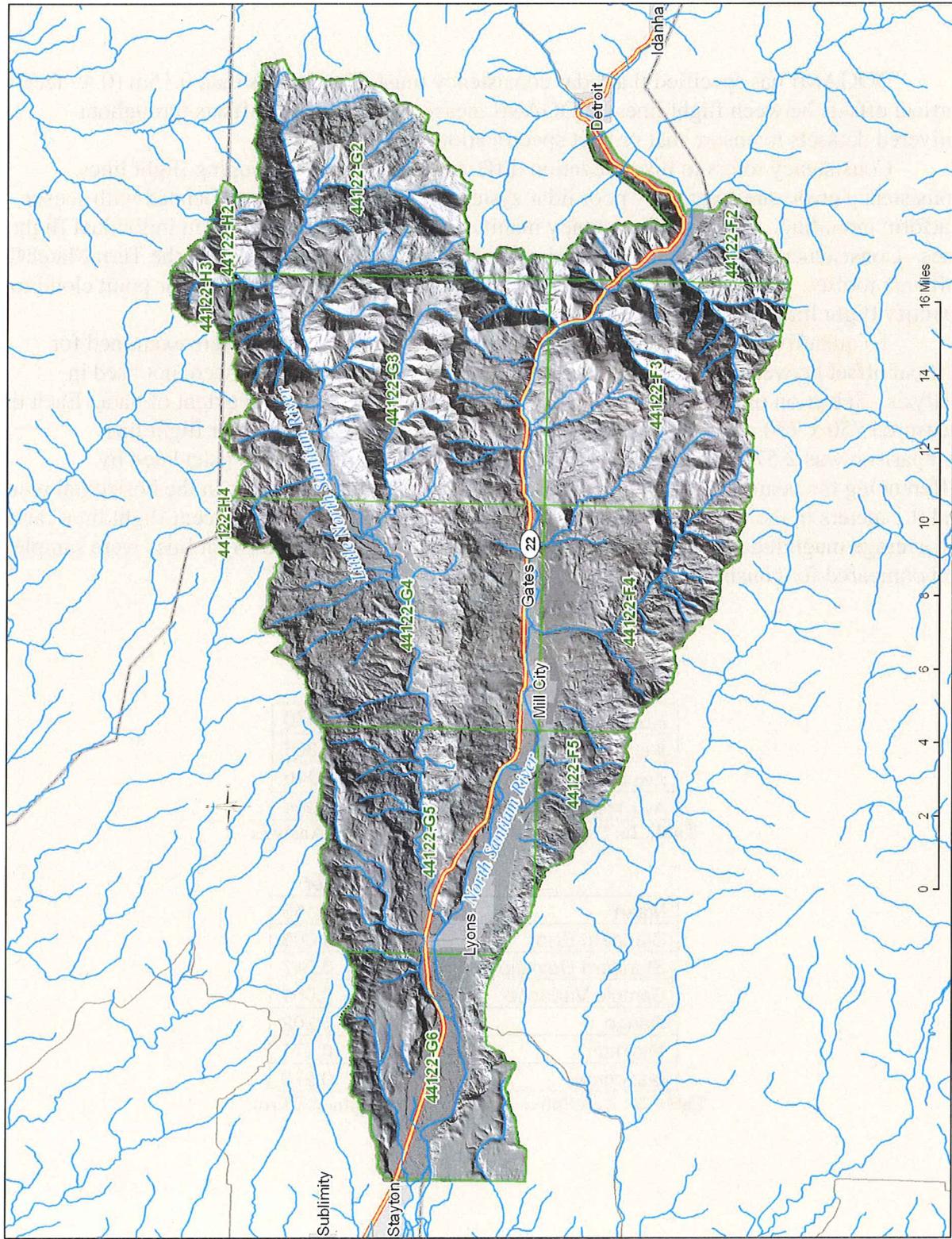


Figure 1. Delivery 13 location area. Data is referenced to USGS 7.5 minute quadrangles within the extents of the Willamette Valley Survey collection area.

Consistency Analysis:

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

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

To quantify the magnitude of this error 1460 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 2,579,046 per tile (Table 2a). Error measurements were calculated by differencing the nearest point from an adjacent flight line within 1 meters in the horizontal plane and 0.2 meters in the vertical plane. Each flight line was compared to adjacent flight lines, and the average magnitude of vertical error was calculated. A total of 305 flight lines were sampled and compared for consistency.

Summary Statistics

# of Tiles	670
# of Flight Line Sections	305
Avg # of Points	2,579,046
Avg. Magnitude Z error (m)	0.049

Table 2a. Summary Results of Consistency Analysis

	<i>meters</i>	<i>feet</i>
Mean	0.049	0.160
Standard Error	0.001	0.003
Standard Deviation	0.014	0.047
Sample Variance	0.000	0.001
Range	0.062	0.202
Minimum	0.022	0.071
Maximum	0.083	0.273

Table 2b. Descriptive Statistics for Magnitude Z Error.

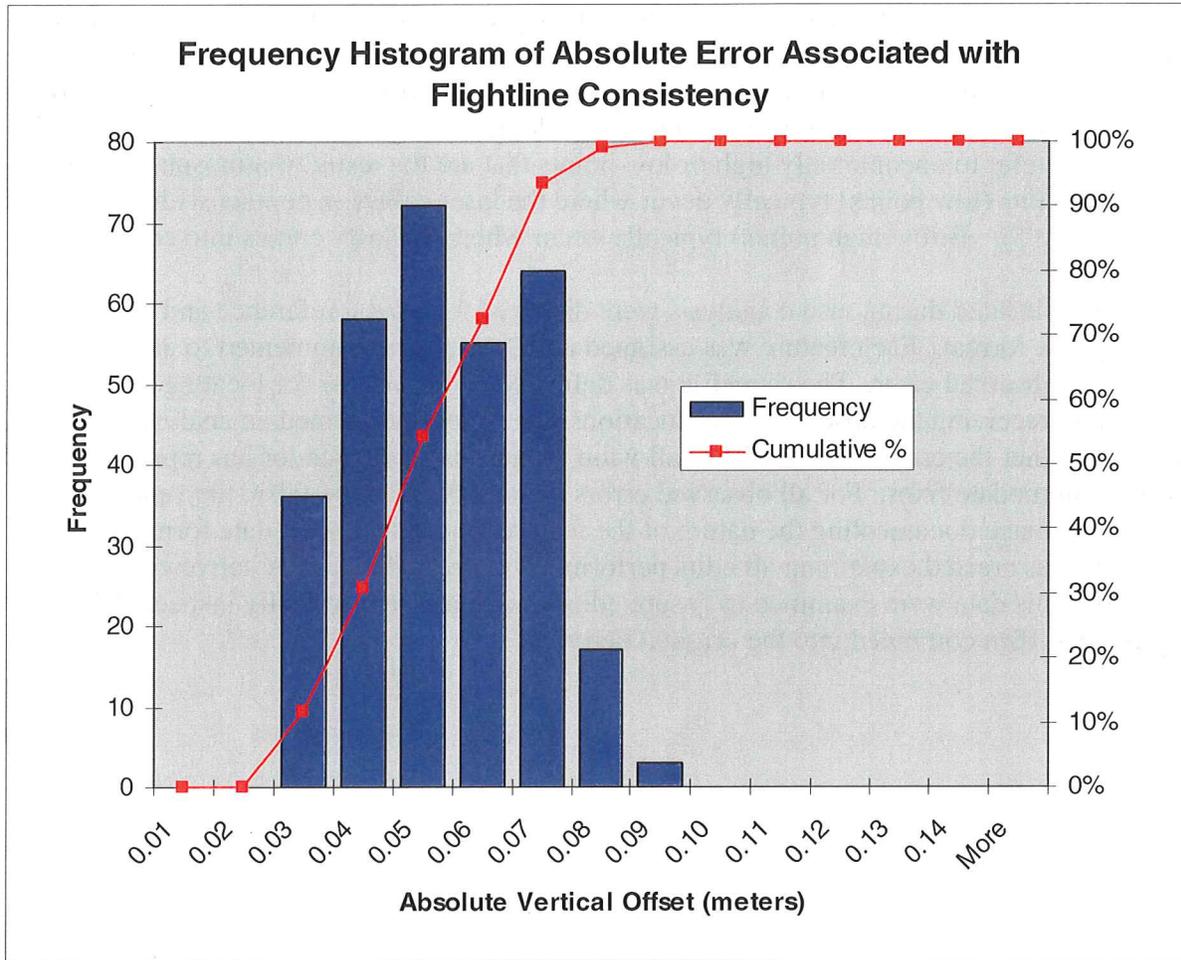


Figure 2.

Results of the consistency analysis found the average flight line offset to be 0.049 meters with a maximum error of 0.083m (Table 2b). Distribution of error showed over 93% of all error was less than 0.07m and 99% was less than 0.08m (Figure 2). These results show that all data are within tolerances of data consistency according to contract agreement.

Visual Analysis

Lidar 3ft grids were loaded into ArcGIS software for visual analysis. Data were examined through slope and hillshade models of bare earth returns. Hillshades of the highest hit models were used to identify areas of missing ground (Figure 3). Both bare earth and highest hit models were examined for calibration offsets, tiling artifacts (Figure 4), seam line offsets, pits (Figure 5), and birds.

Calibration offsets typically are visualized as a corduroy-like patterning within a hillshaded lidar model. These offsets present themselves along steep slopes and typically stand out more in highest hit models than bare earth. Tiling artifacts are a result of missing or misclassified data along the edge of lidar processing tiles. These artifacts present themselves as

linear features typically 1-2 grid cells in width, and are present in both the highest hit and bare earth models (e.g. Figure 3). Seam line offsets occur where two distinct days of lidar data overlap. Errors occur as a result of improper absolute vertical error adjustments. These errors are typically visualized as a linear stair step running along the edge of connecting flight lines. Pits and birds refer to uncommonly high or low points that are the result of atmospheric and sensor noise. Pits (low points) typically occur where the laser comes in contact with water on the ground (Figure 5). Birds (high points) typically occur where the laser comes into contact with atmospherics¹.

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



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

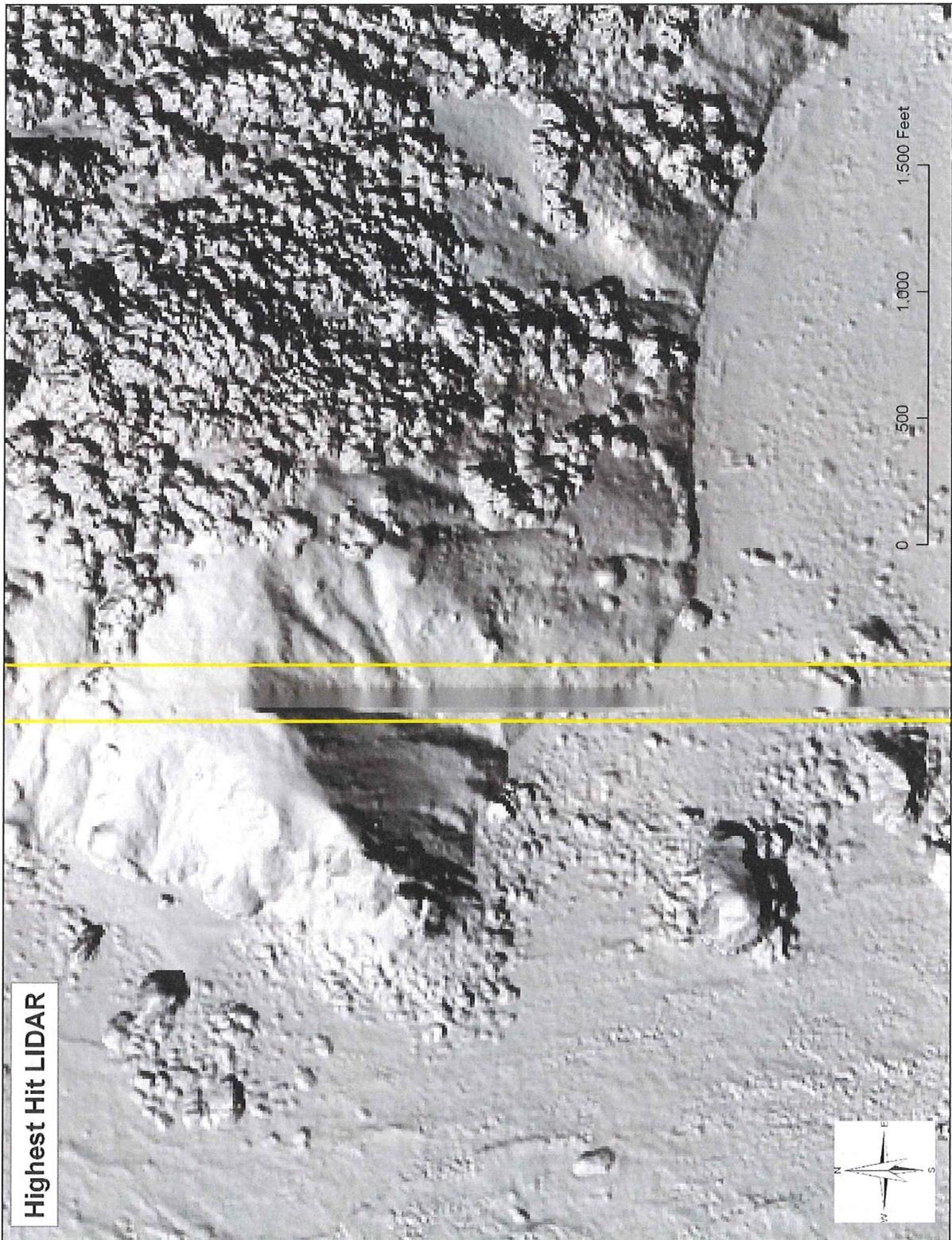


Figure 4. Example of tile artifact found in highest hit lidar data. Artifact is a seam line error created due to misclassification of ground at edge of lidar processing tiles.



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

Absolute Accuracy Analysis:

Absolute accuracy refers to the mean vertical offset of lidar data relative to measured ground-control points (GCP) obtained throughout the lidar sampling area. DOGAMI used a Trimble™ 5700/5800 Total Station GPS surveying system (Figure 5) to measure GCP's. This system consisted of a GPS base station (5700 unit), Zephyr Geodetic antenna, Trimmark 3 radio, and 5800 "rover". The 5700 base station was mounted on a fixed height (typically 2.0 m) tripod and located over a known geodetic survey monument followed by a site calibration on several adjacent benchmarks to precisely establish a local coordinate system. This step is critical in order to eliminate various survey errors. For example, Trimble reports that the 5700/5800 GPS system have horizontal errors of approximately $\pm 1\text{-cm} + 1\text{ppm}$ (parts per million * the baseline length) and $\pm 2\text{-cm}$ in the vertical (TrimbleNavigationSystem, 2005). These errors may be compounded by other factors such as poor satellite geometry, multipath, and poor atmospheric conditions, combining to increase the total error to several centimeters. Thus, the site calibration process is critical in order to minimize these uncertainties.

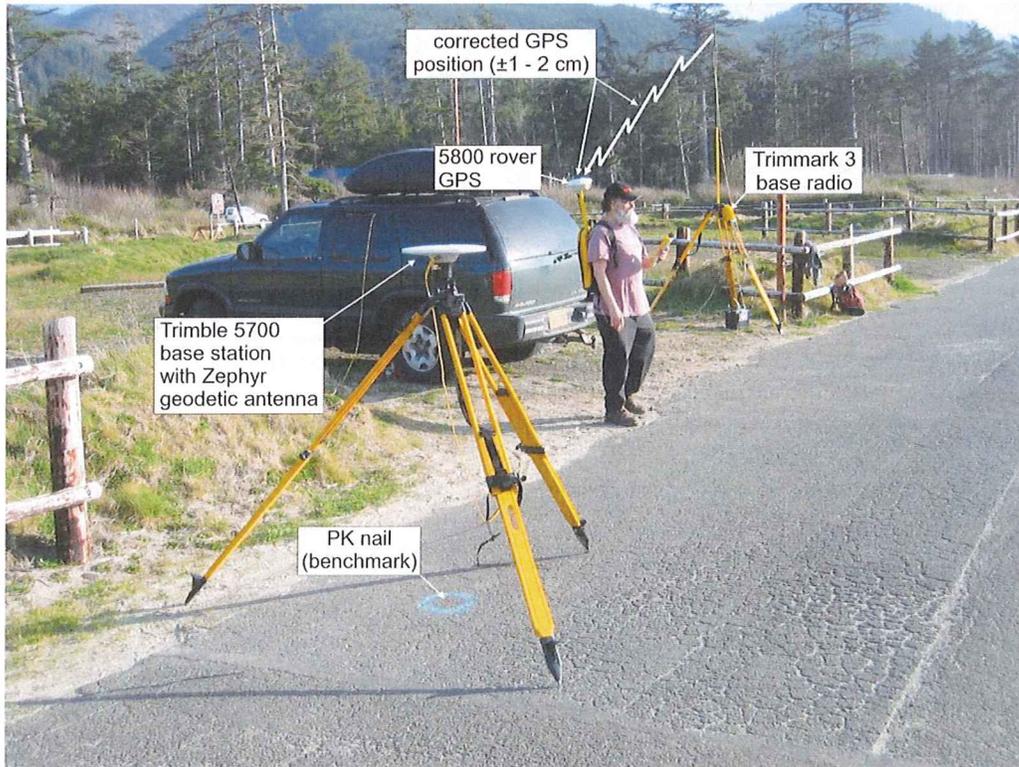


Figure 5. The Trimble 5700 base station antenna located over a known reference point at Cape Lookout State Park. Corrected GPS position and elevation information is then transmitted by a Trimmark III base radio to the 5800 GPS rover unit.

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- 1) Verify the horizontal and vertical coordinates established by Watershed Sciences for a select number of survey monuments used to calibrate the lidar survey. These surveys typically involved a minimum of two hours of GPS occupation over a known point. The collected data were then submitted to the National Geodetic Survey (NGS) Online Positioning User Service (OPUS) for

- post-processing against several Continuously Operating Reference Stations (CORS) operated by the NGS.
- 2) Collect GCP's along relatively flat surfaces (roads, paths, parking lots etc.). This step involved the collection of both continuous measurements (from a vehicle as well as from a backpack) as well as static measurements (typically 5 epics).

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

A total of 62 measured GCP's were obtained in the Delivery 13 region and compared with the lidar elevation grids. The data delivered to DOGAMI was found to have a mean vertical offset of 0.041 meters (0.133 feet) and an RMSE value of 0.049 meters (0.162 ft). Offset values ranged from -0.035 to 0.102 meters (Table 3 and Figure 7).

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

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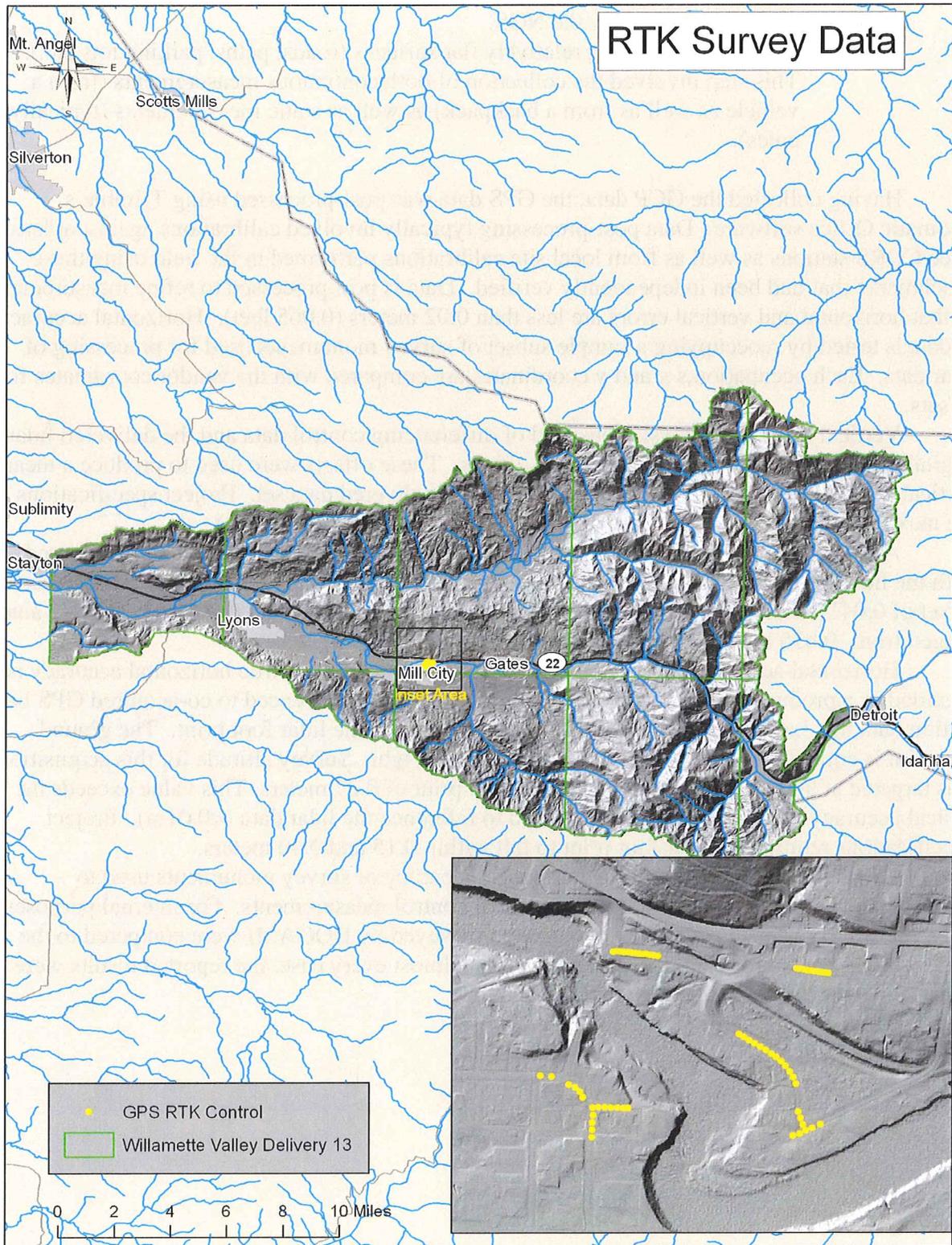


Figure 6. Locations of RTK control surveyed by DOGAMI. Data was used to test absolute accuracy for the Willamette Valley lidar survey within the Delivery 13 extent.

	<i>Meters</i>	<i>Feet</i>
Mean	0.041	0.133
Standard Error	0.004	0.012
Standard Deviation	0.028	0.093
Range	0.138	0.452
Minimum	-0.035	-0.116
Maximum	0.102	0.336

Table 3. Descriptive Statistics for absolute value vertical offsets.

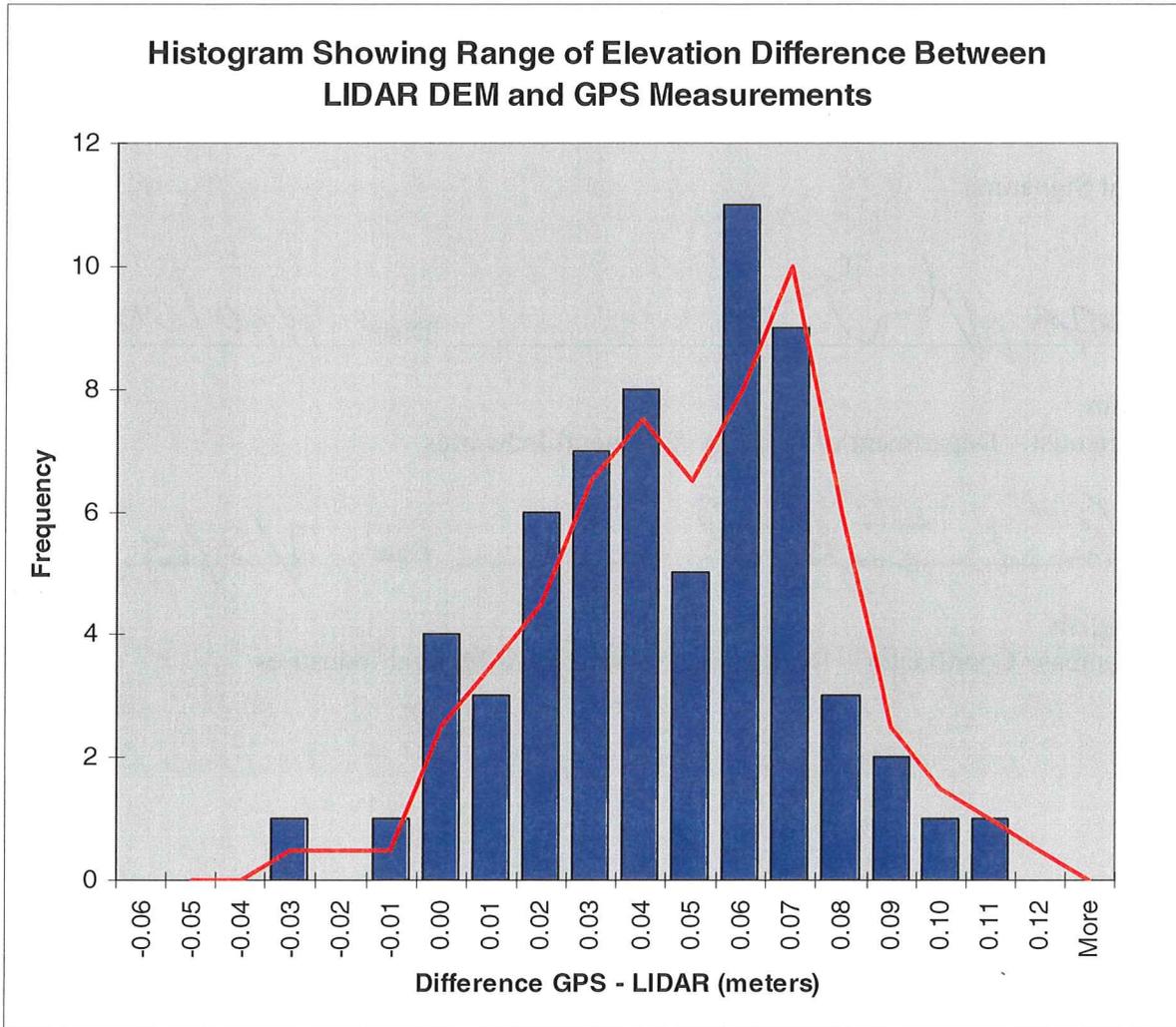


Figure 7.

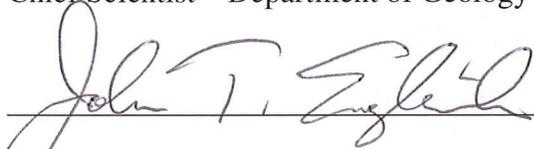
Acceptance

The data described in this report meets and exceeds project specifications laid out in the contracted data standards agreement. All components of data to be delivered have been received as of September 29th, 2009. Consistency analysis has concluded that all data contains flight line to flight line vertical offset less than the threshold of 0.15 meters as specified in agreement. The vendor has adequately responded to all fixable errors identified as part of the visual analysis. Perceived grid errors identified by DOGAMI that were found to be false have been documented by the vendor and explained to the satisfaction of DOGAMI reviewers. Absolute accuracy analysis of the data has concluded that absolute vertical error of lidar data is less than the specified tolerance of 0.20 meters as specified in the data standards agreement.

Approval Signatures

 _____ Date: 9/30/09

Ian Madin
Chief Scientist – Department of Geology & Mineral Industries

 _____ Date: 9/30/09

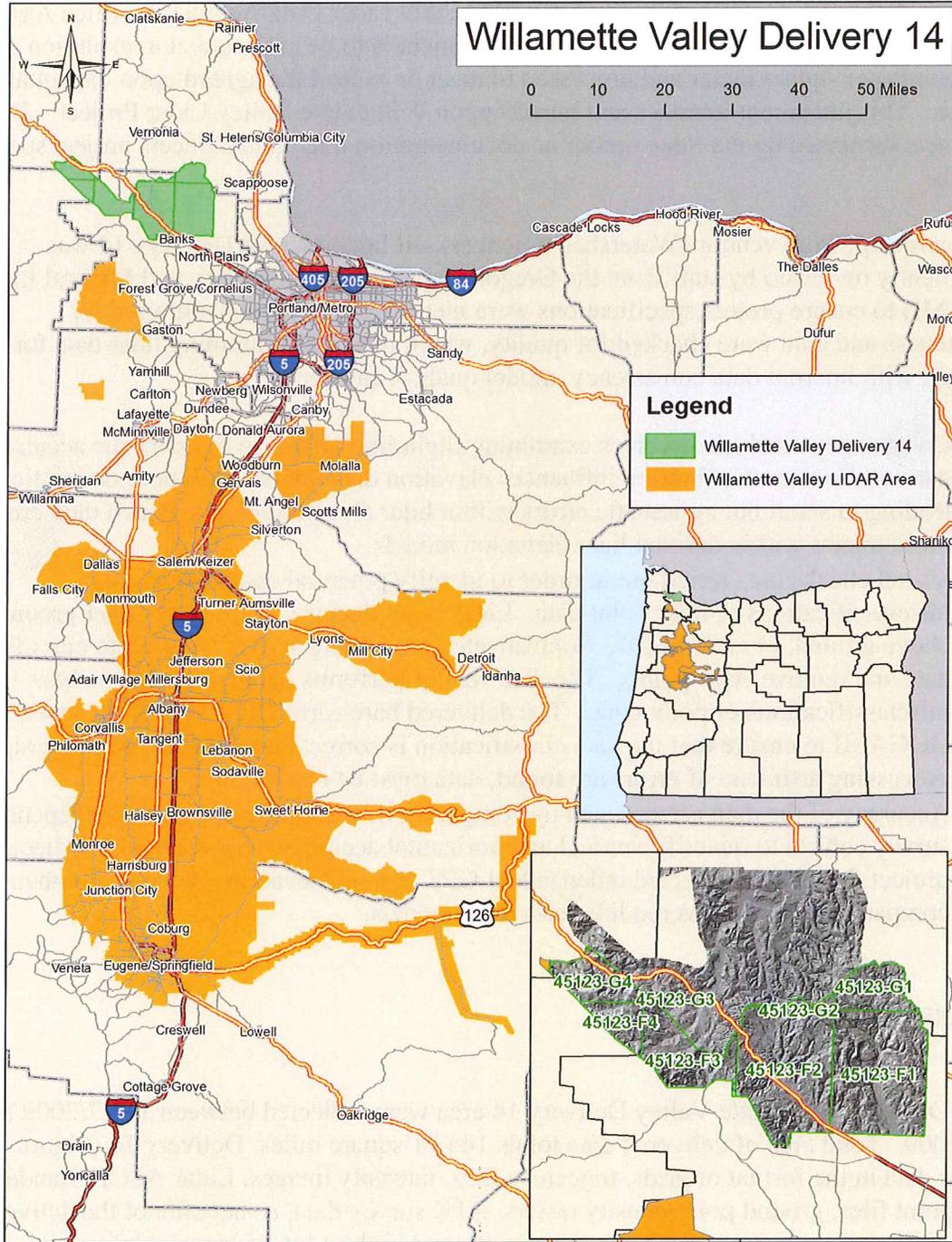
John English
Lidar Database Coordinator – Department of Geology & Mineral Industries



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



Willamette Valley LIDAR Project, 2009 – Delivery 14 QC Analysis
LIDAR QC Report – November 30th, 2009



Map featuring Willamette Valley Delivery 14 data extent.

The Oregon Department of Geology & Mineral Industries has contracted with Watershed Sciences to collect high resolution lidar topographic data for multiple areas within the State of Oregon. Areas for lidar data collection have been designed as part of a collaborative effort of State, Federal, and Local agencies in order to meet a wide range of project goals. The vendor has agreed to certain conditions of data quality and standards for all lidar data deliverables listed in sections A through C (OPA #8865) of the 2007-2009 Lidar Data Acquisition Price Agreement (pgs 14-23). Data submitted under this price agreement is to be collected at a resolution of at least 8 points per square meter and processed to meet or exceed the agreed upon data quality standards. This document itemizes and reports upon Willamette Valley Lidar Project – Delivery 14 products furnished by the lidar vendor as documentation that all data meets project specific standards.

Upon receipt from vendor (Watershed Sciences), all lidar data for Delivery 14 was independently reviewed by staff from the Oregon Department of Geology and Mineral Industries (DOGAMI) to ensure project specifications were met. All data were inventoried for completeness and data were checked for quality, which included examining lidar data for errors associated with internal data consistency, model quality, and accuracy.

- Consistency Analysis involves examining flight line offsets to quantify the accuracy of data calibration. Calibration influences elevation data quality with poor calibration leading to small but systematic errors within lidar elevation points, which then create inaccuracies within derived lidar elevation models.
- Visual checks are carried out in order to identify potential data artifacts and misclassifications of lidar point data. Lidar point data is classified as either ground, above ground, or error points. Sophisticated processing scripts are used to classify point data and remove error points. The data vendor performs quality control analysis to fix misclassifications of point data. The delivered bare earth DEM is then reviewed by DOGAMI to ensure that the data classification is correct and there are no topographic processing artifacts. If errors are found, data must be resubmitted.
- Accuracy of the data is examined by comparing lidar elevation data with independent survey control to quantify vertical and horizontal accuracy. For each lidar collection project DOGAMI collected independent GPS ground elevations, which were then compared against delivered lidar elevation models.

Data Completeness

Data for Willamette Valley Delivery 14 area were collected between 11/17/2009 to 05/18/2009. Total area of delivered data totals 144.71 square miles. Delivery 14 (Figure 1) includes data in the format of grids, trajectory files, intensity images, Lidar ASCII Standard (LAS) point files, ground point density rasters, RTK survey data, a shapefile of the delivery area, and the lidar delivery report (Table 1). Bare earth and highest hit grids were delivered in ArcInfo Grid format with 3ft cell size. Lidar point data is delivered in LAS binary format for ground

classified returns as well as the entire lidar point cloud. Georeferenced intensity images are supplied in TIF format. Supplementary data includes ground density rasters displaying locations where ground returns are low. Real time kinematic ground survey data (used for absolute vertical adjustment) is supplied in shapefile format. This delivery contains data for the following USGS 7.5 minute quads (listed by Ohio Code #) within the boundary of the Willamette Valley Survey collection area (Figure 1):

Delivery 14: 45123f1, 45123f2, 45123f3, 45123f4, 45123g1, 45123g2, 45123g3, 45123g4

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

Table 1. Deliverable Checklist

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

Deliverable Descriptions: (All data projected in Oregon Lambert, NAD83 (HARN), Intl Feet with exception of trajectory files).

- Bare Earth Grids: Tin interpolated grids created from lidar ground returns.
- Highest Hit Grids: Tin interpolated grids created from the highest lidar elevation for a given 3ft cell.
- Intensity TIF: TIF raster built using returned lidar pulse intensity values gathered from highest hit returns.
- Trajectory File: File contains point location measurement of the aircraft used to collect lidar data. Data is collected using an Inertial Measurement Unit (IMU), and collects measurements of: Easting(meters), Northing (meters), Ellipsoid Height (meters) of aircraft, aircraft roll (degrees), aircraft pitch (degrees), aircraft heading (degrees).

Measurements are collected at one second intervals. Data is projected in UTM zone 10, NAD83 (HARN).

- LAS: Binary file of all lidar points collected in survey (Class, flight line #, GPS Time, Echo, Easting, Northing, Elevation, Intensity, Scan Angle, Echo Number, and Scanner).
- Ground LAS: Binary file of lidar points classified as ground (Class, flight line #, GPS Time, Echo, Easting, Northing, Elevation, Intensity, Scan Angle, Echo Number, and Scanner).
- RTK Point Data: Ground GPS Survey data used to correct raw lidar point cloud for vertical offsets.
- Delivery Area Shapefile: Geometry file depicting the geospatial area associated with deliverables.
- Report: Report provides detailed description of data collection methods and processing. The vendor also reports accuracies associated with calibration, consistency, absolute error, and point classifications.

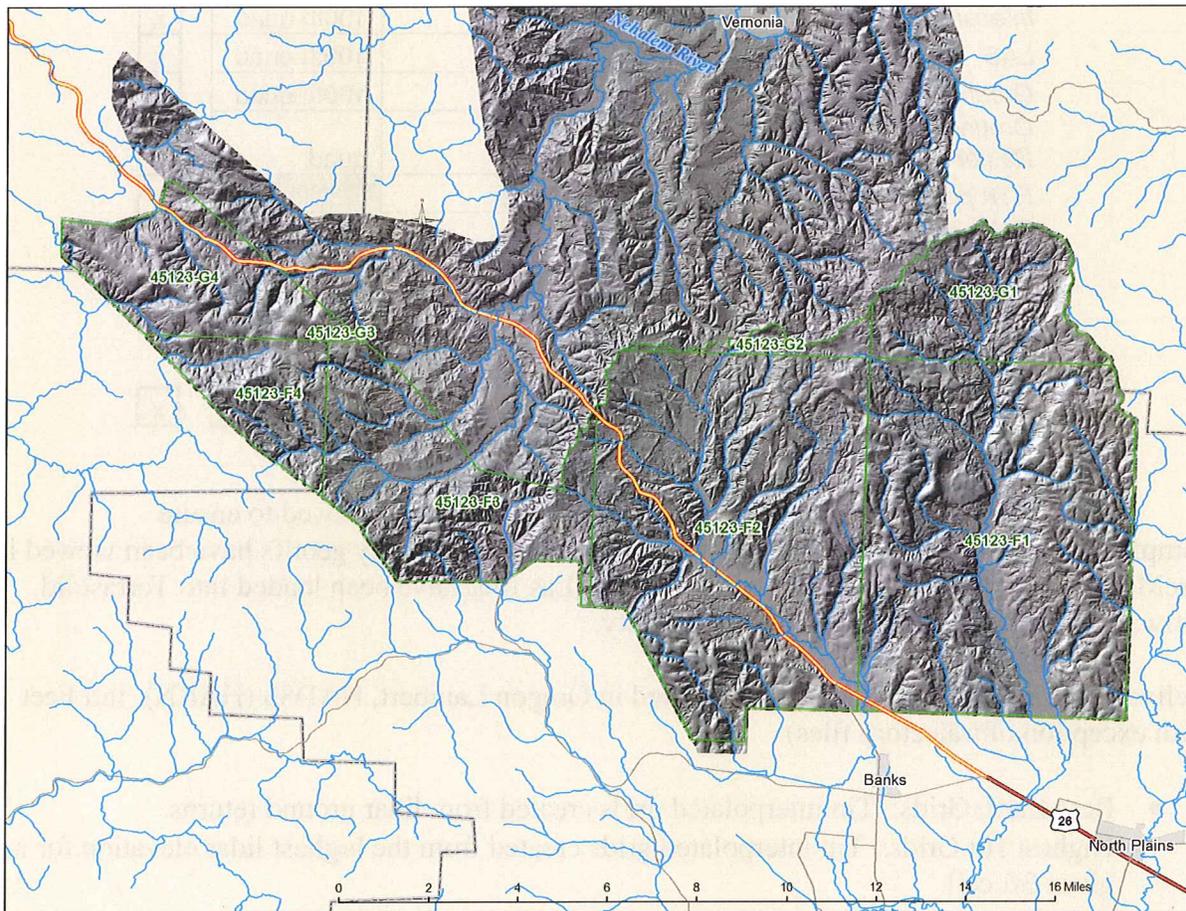


Figure 1. Delivery 14 location area. Data is referenced to USGS 7.5 minute quadrangles within the extents of the Willamette Valley Survey collection area.

Consistency Analysis:

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

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

To quantify the magnitude of this error 723 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 3,729,799 per tile (Table 2a). Error measurements were calculated by differencing the nearest point from an adjacent flight line within 1 meters in the horizontal plane and 0.2 meters in the vertical plane. Each flight line was compared to adjacent flight lines, and the average magnitude of vertical error was calculated. A total of 157 flight lines were sampled and compared for consistency.

Summary Statistics

# of Tiles	723
# of Flight Line Sections	157
Avg # of Points	3,729,799
Avg. Magnitude Z error (m)	0.052

Table 2a. Summary Results of Consistency Analysis

	<i>meters</i>	<i>feet</i>
Mean	0.052	0.172
Standard Error	0.001	0.003
Standard Deviation	0.013	0.043
Sample Variance	0.000	0.001
Range	0.090	0.295
Minimum	0.028	0.090
Maximum	0.117	0.385

Table 2b. Descriptive Statistics for Magnitude Z Error.

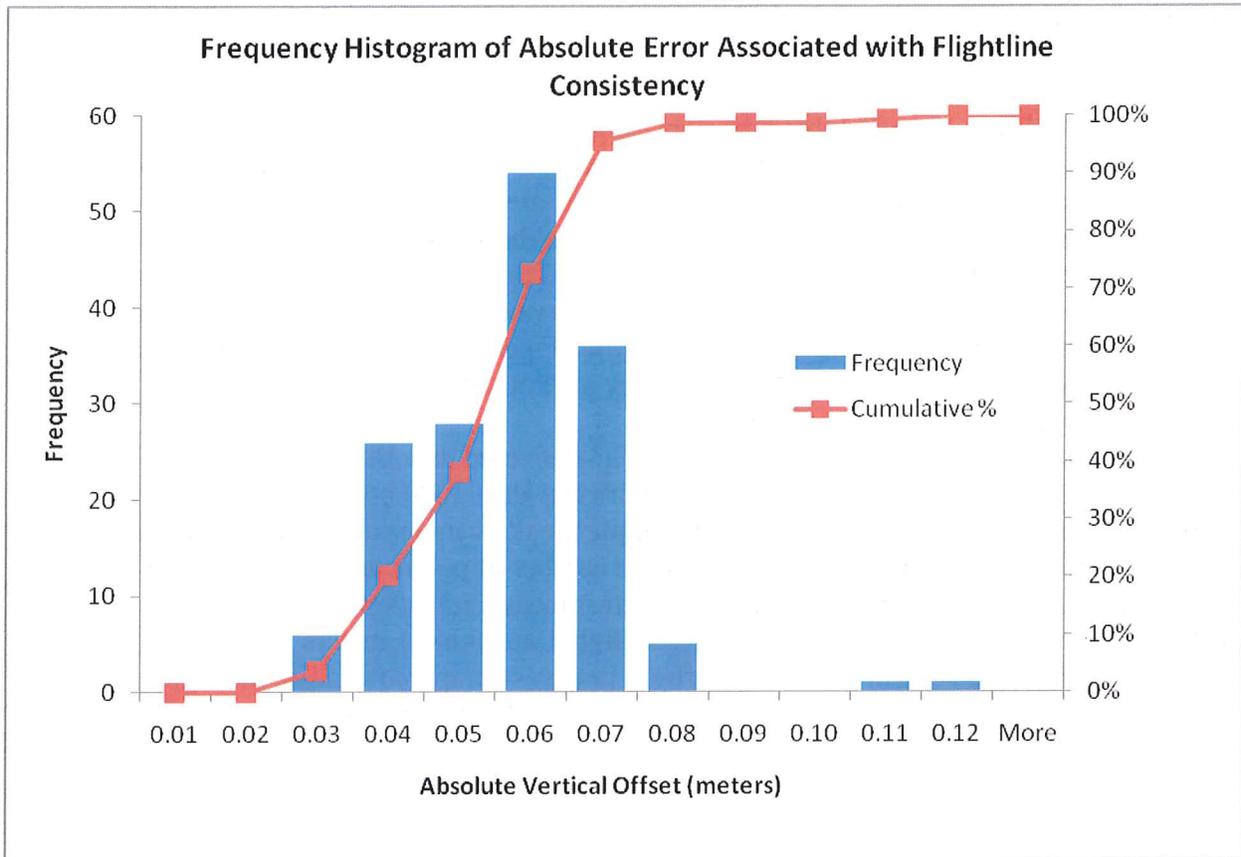


Figure 2.

Results of the consistency analysis found the average flight line offset to be 0.052 meters with a maximum error of 0.083m (Table 2b). Distribution of error showed over 95% of all error was less than 0.07m and 98% was less than 0.08m (Figure 2). These results show that all data are within tolerances of data consistency according to contract agreement.

Visual Analysis

Lidar 3ft grids were loaded into ArcGIS software for visual analysis. Data were examined through slope and hillshade models of bare earth returns. Hillshades of the highest hit models were used to identify areas of missing ground (Figure 3). Both bare earth and highest hit models were examined for calibration offsets, tiling artifacts (Figure 4), seam line offsets, pits (Figure 5), and birds.

Calibration offsets typically are visualized as a corduroy-like patterning within a hillshaded lidar model. These offsets present themselves along steep slopes and typically stand out more in highest hit models than bare earth. Tiling artifacts are a result of missing or misclassified data along the edge of lidar processing tiles. These artifacts present themselves as linear features typically 1-2 grid cells in width, and are present in both the highest hit and bare earth models (e.g. Figure 3). Seam line offsets occur where two distinct days of lidar data overlap. Errors occur as a result of improper absolute vertical error adjustments. These errors

are typically visualized as a linear stair step running along the edge of connecting flight lines. Pits and birds refer to uncommonly high or low points that are the result of atmospheric and sensor noise. Pits (low points) typically occur where the laser comes in contact with water on the ground (Figure 5). Birds (high points) typically occur where the laser comes into contact with atmospherics¹.

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

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



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

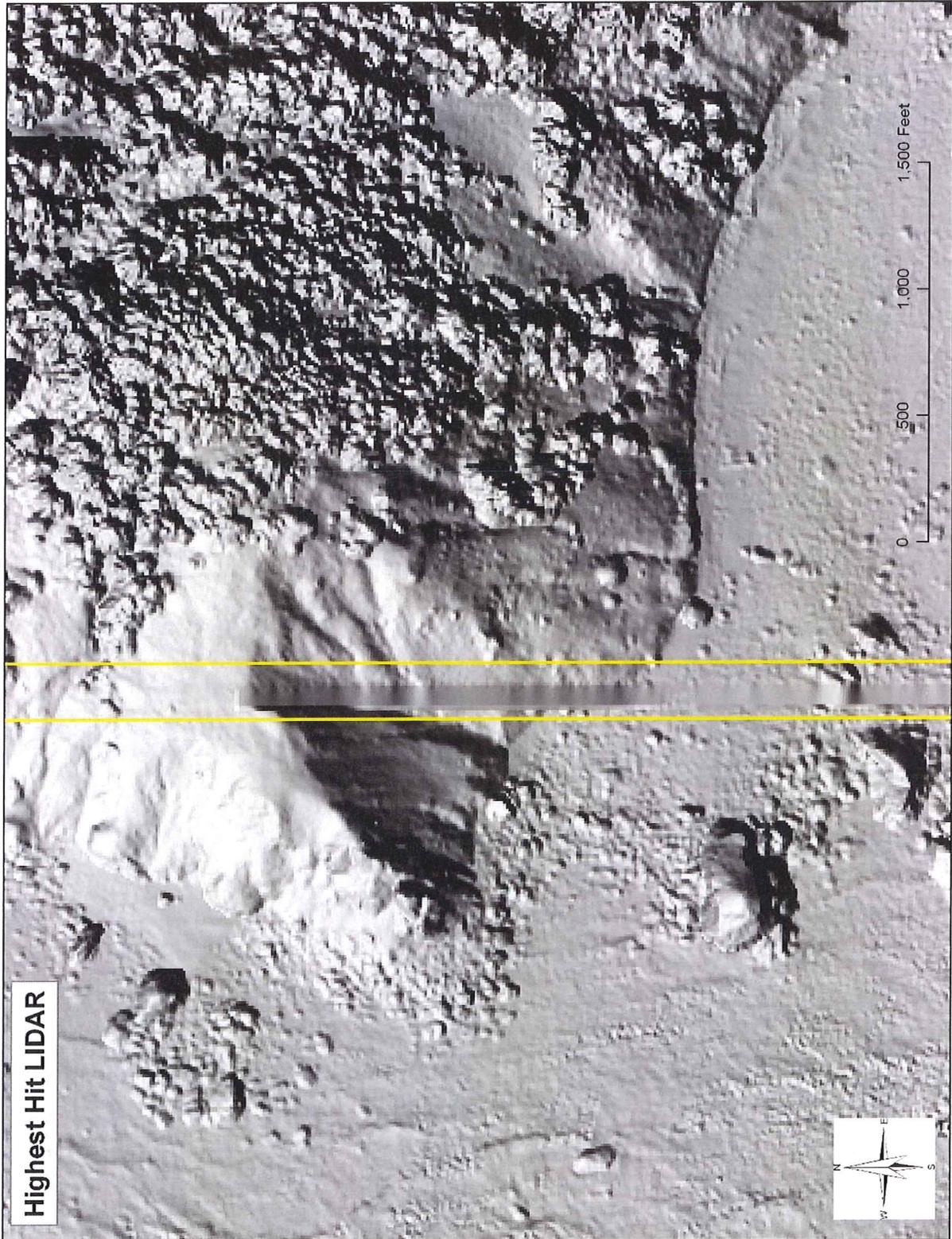


Figure 4. Example of tile artifact found in highest hit lidar data. Artifact is a seam line error created due to misclassification of ground at edge of lidar processing tiles.



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

Absolute Accuracy Analysis:

Absolute accuracy refers to the mean vertical offset of lidar data relative to measured ground-control points (GCP) obtained throughout the lidar sampling area. DOGAMI used a Trimble™ 5700/5800 Total Station GPS surveying system (Figure 5) to measure GCP's. This system consisted of a GPS base station (5700 unit), Zephyr Geodetic antenna, Trimmark 3 radio, and 5800 “rover”. The 5700 base station was mounted on a fixed height (typically 2.0 m) tripod and located over a known geodetic survey monument followed by a site calibration on several adjacent benchmarks to precisely establish a local coordinate system. This step is critical in order to eliminate various survey errors. For example, Trimble reports that the 5700/5800 GPS system have horizontal errors of approximately $\pm 1\text{-cm} + 1\text{ppm}$ (parts per million * the baseline length) and $\pm 2\text{-cm}$ in the vertical (TrimbleNavigationSystem, 2005). These errors may be compounded by other factors such as poor satellite geometry, multipath, and poor atmospheric conditions, combining to increase the total error to several centimeters. Thus, the site calibration process is critical in order to minimize these uncertainties.

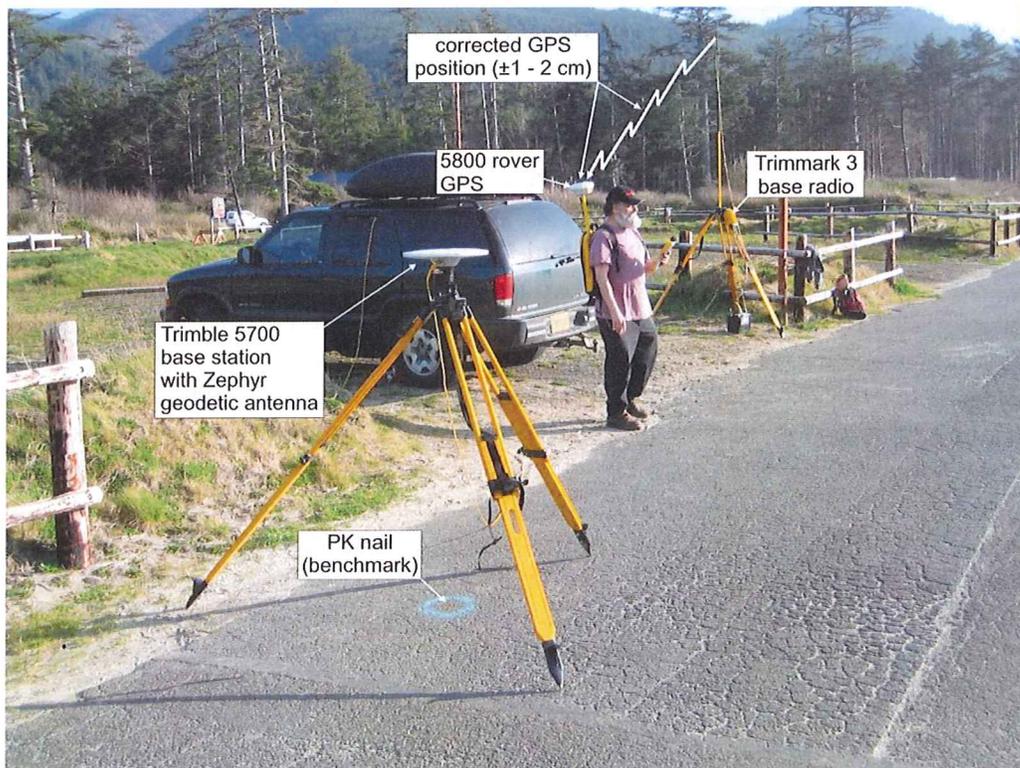


Figure 5. The Trimble 5700 base station antenna located over a known reference point at Cape Lookout State Park. Corrected GPS position and elevation information is then transmitted by a Trimmark III base radio to the 5800 GPS rover unit.

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

- 1) Verify the horizontal and vertical coordinates established by Watershed Sciences for a select number of survey monuments used to calibrate the lidar survey. These surveys typically involved a minimum of two hours of GPS occupation over a known point. The collected data were then submitted to the National Geodetic Survey (NGS) Online Positioning User Service (OPUS) for

- post-processing against several Continuously Operating Reference Stations (CORS) operated by the NGS.
- 2) Collect GCP's along relatively flat surfaces (roads, paths, parking lots etc.). This step involved the collection of both continuous measurements (from a vehicle as well as from a backpack) as well as static measurements (typically 5 epics).

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

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

A total of 395 measured GCP's were obtained in the Delivery 14 region and compared with the lidar elevation grids. The data delivered to DOGAMI was found to have a mean vertical offset of 0.035 meters (0.114 feet) and an RMSE value of 0.050 meters (0.165 ft). Offset values ranged from -0.070 to 0.150 meters (Table 3 and Figure 7).

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

DOGAMI was able to test the horizontal accuracy of survey monuments used to reference the lidar data while conducting vertical control measurements. For internal purposes only, the XY coordinates of survey monuments surveyed by DOGAMI were compared to the survey monuments provided by the vendor and in almost every case, the reported results were consistent with those obtained by DOGAMI staff.

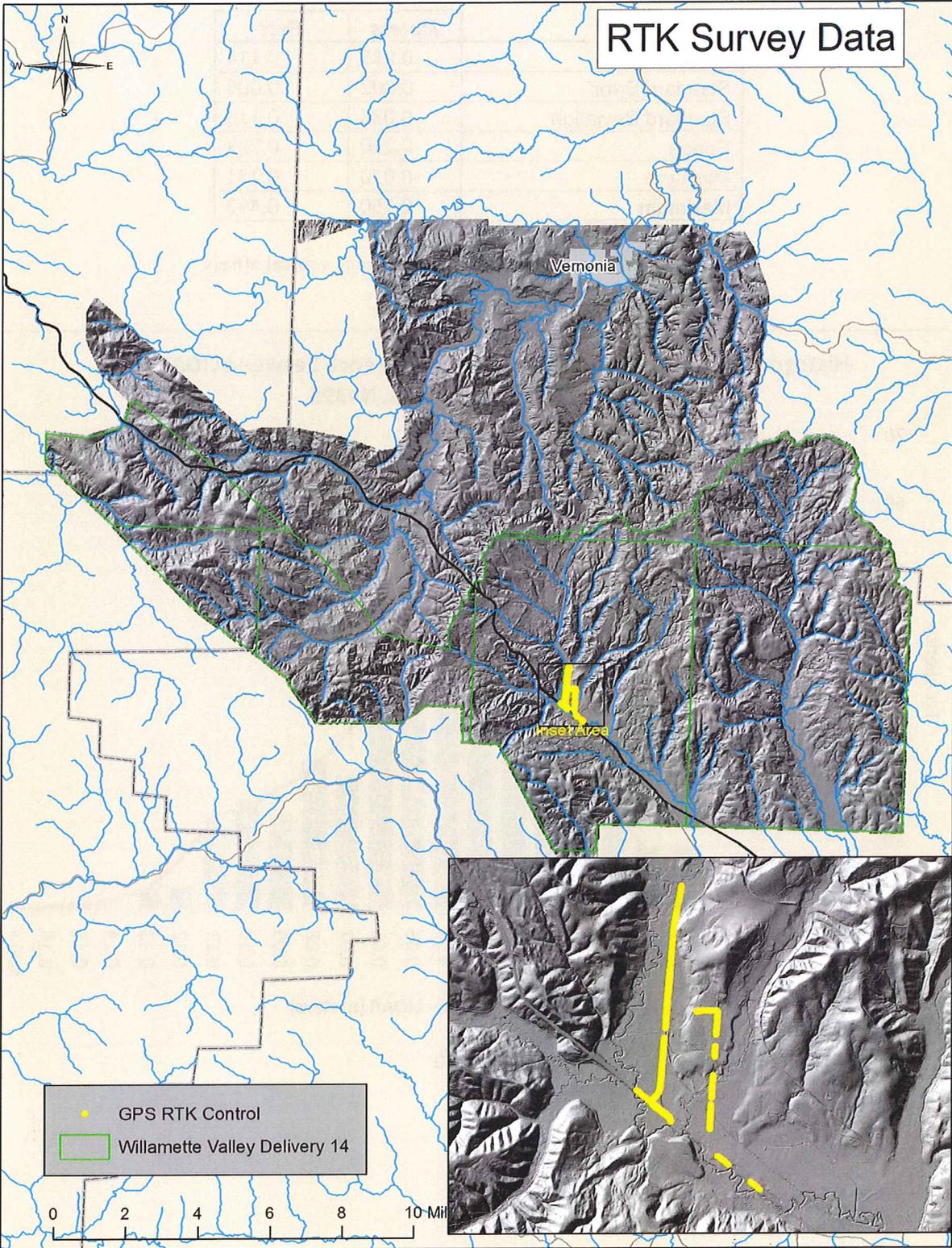


Figure 6. Locations of RTK control surveyed by DOGAMI. Data was used to test absolute accuracy for the Willamette Valley lidar survey within the Delivery 14 extent.

	<i>Meters</i>	<i>Feet</i>
Mean	0.035	0.114
Standard Error	0.002	0.006
Standard Deviation	0.036	0.119
Range	0.220	0.723
Minimum	-0.070	-0.231
Maximum	0.150	0.492

Table 3. Descriptive Statistics for absolute value vertical offsets.

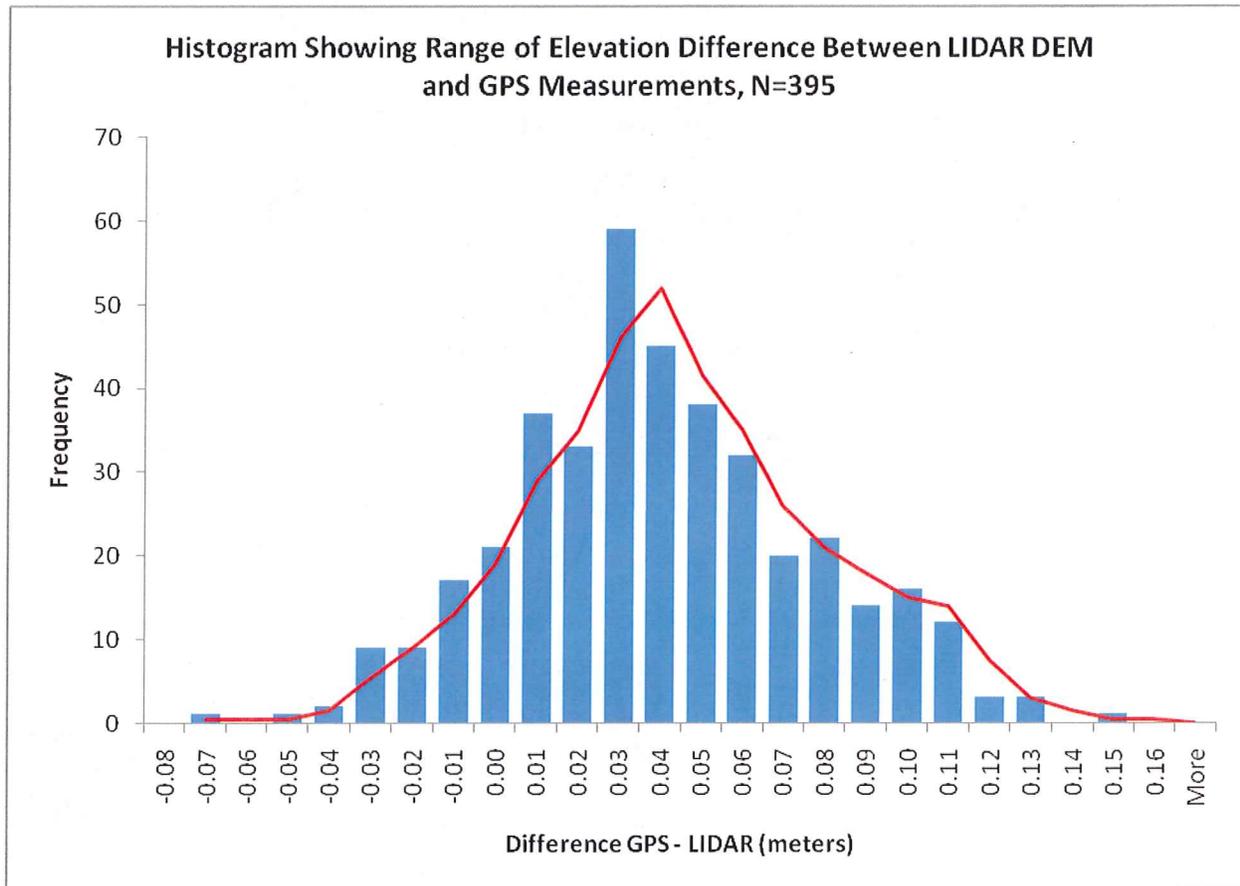


Figure 7.

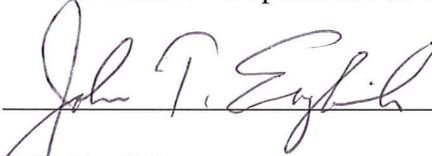
Acceptance

The data described in this report meets and exceeds project specifications laid out in the contracted data standards agreement. All components of data to be delivered have been received as of November 30th, 2009. Consistency analysis has concluded that all data contains flight line to flight line vertical offset less than the threshold of 0.15 meters as specified in agreement. The vendor has adequately responded to all fixable errors identified as part of the visual analysis. Perceived grid errors identified by DOGAMI that were found to be false have been documented by the vendor and explained to the satisfaction of DOGAMI reviewers. Absolute accuracy analysis of the data has concluded that absolute vertical error of lidar data is less than the specified tolerance of 0.20 meters as specified in the data standards agreement.

Approval Signatures

 _____ Date: 12/3/09.

Ian Madin
Chief Scientist – Department of Geology & Mineral Industries

 _____ Date: 12/3/09

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

The Oregon Department of Geology & Mineral Industries has contracted with Watershed Sciences to collect high resolution lidar topographic data for multiple areas within the State of Oregon. Areas for lidar data collection have been designed as part of a collaborative effort of State, Federal, and Local agencies in order to meet a wide range of project goals. The vendor has agreed to certain conditions of data quality and standards for all lidar data deliverables listed in sections A through C (OPA #8865) of the 2007-2009 Lidar Data Acquisition Price Agreement (pgs 14-23). Data submitted under this price agreement is to be collected at a resolution of at least 8 points per square meter and processed to meet or exceed the agreed upon data quality standards. This document itemizes and reports upon Willamette Valley Lidar Project – Delivery 15 products furnished by the lidar vendor as documentation that all data meets project specific standards.

Upon receipt from vendor (Watershed Sciences), all lidar data for Delivery 15 was independently reviewed by staff from the Oregon Department of Geology and Mineral Industries (DOGAMI) to ensure project specifications were met. All data were inventoried for completeness and data were checked for quality, which included examining lidar data for errors associated with internal data consistency, model quality, and accuracy.

- Consistency Analysis involves examining flight line offsets to quantify the accuracy of data calibration. Calibration influences elevation data quality with poor calibration leading to small but systematic errors within lidar elevation points, which then create inaccuracies within derived lidar elevation models.
- Visual checks are carried out in order to identify potential data artifacts and misclassifications of lidar point data. Lidar point data is classified as either ground, above ground, or error points. Sophisticated processing scripts are used to classify point data and remove error points. The data vendor performs quality control analysis to fix misclassifications of point data. The delivered bare earth DEM is then reviewed by DOGAMI to ensure that the data classification is correct and there are no topographic processing artifacts. If errors are found, data must be resubmitted.
- Accuracy of the data is examined by comparing lidar elevation data with independent survey control to quantify vertical and horizontal accuracy. For each lidar collection project DOGAMI collected independent GPS ground elevations, which were then compared against delivered lidar elevation models.

Data Completeness

Data for Willamette Valley Delivery 15 area were collected between 10/10/2008 to 06/07/2009. Total area of delivered data totals 297.83 square miles. Delivery 15 (Figure 1) includes data in the format of grids, trajectory files, intensity images, Lidar ASCII Standard (LAS) point files, ground point density rasters, RTK survey data, a shapefile of the delivery area, and the lidar delivery report (Table 1). Bare earth and highest hit grids were delivered in ArcInfo Grid format with 3ft cell size. Lidar point data is delivered in LAS binary format for ground

classified returns as well as the entire lidar point cloud. Georeferenced intensity images are supplied in TIF format. Supplementary data includes ground density rasters displaying locations where ground returns are low. Real time kinematic ground survey data (used for absolute vertical adjustment) is supplied in shapefile format. This delivery contains data for the following USGS 7.5 minute quads (listed by Ohio Code #) within the boundary of the Willamette Valley Survey collection area (Figure 1):

Delivery 15: 44122b7,44122b8, 44122c7, 44122c8, 44122d7, 44122d8

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

Table 1. Deliverable Checklist

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

Deliverable Descriptions: (All data projected in Oregon Lambert, NAD83 (HARN), Intl Feet with exception of trajectory files).

- Bare Earth Grids: Tin interpolated grids created from lidar ground returns.
- Highest Hit Grids: Tin interpolated grids created from the highest lidar elevation for a given 3ft cell.
- Intensity TIF: TIF raster built using returned lidar pulse intensity values gathered from highest hit returns.
- Trajectory File: File contains point location measurement of the aircraft used to collect lidar data. Data is collected using an Inertial Measurement Unit (IMU), and collects measurements of: Easting(meters), Northing (meters), Ellipsoid Height (meters) of aircraft, aircraft roll (degrees), aircraft pitch (degrees), aircraft heading (degrees).

Measurements are collected at one second intervals. Data is projected in UTM zone 10, NAD83 (HARN).

- LAS: Binary file of all lidar points collected in survey (Class, flight line #, GPS Time, Echo, Easting, Northing, Elevation, Intensity, Scan Angle, Echo Number, and Scanner).
- Ground LAS: Binary file of lidar points classified as ground (Class, flight line #, GPS Time, Echo, Easting, Northing, Elevation, Intensity, Scan Angle, Echo Number, and Scanner).
- RTK Point Data: Ground GPS Survey data used to correct raw lidar point cloud for vertical offsets.
- Delivery Area Shapefile: Geometry file depicting the geospatial area associated with deliverables.
- Report: Report provides detailed description of data collection methods and processing. The vendor also reports accuracies associated with calibration, consistency, absolute error, and point classifications.

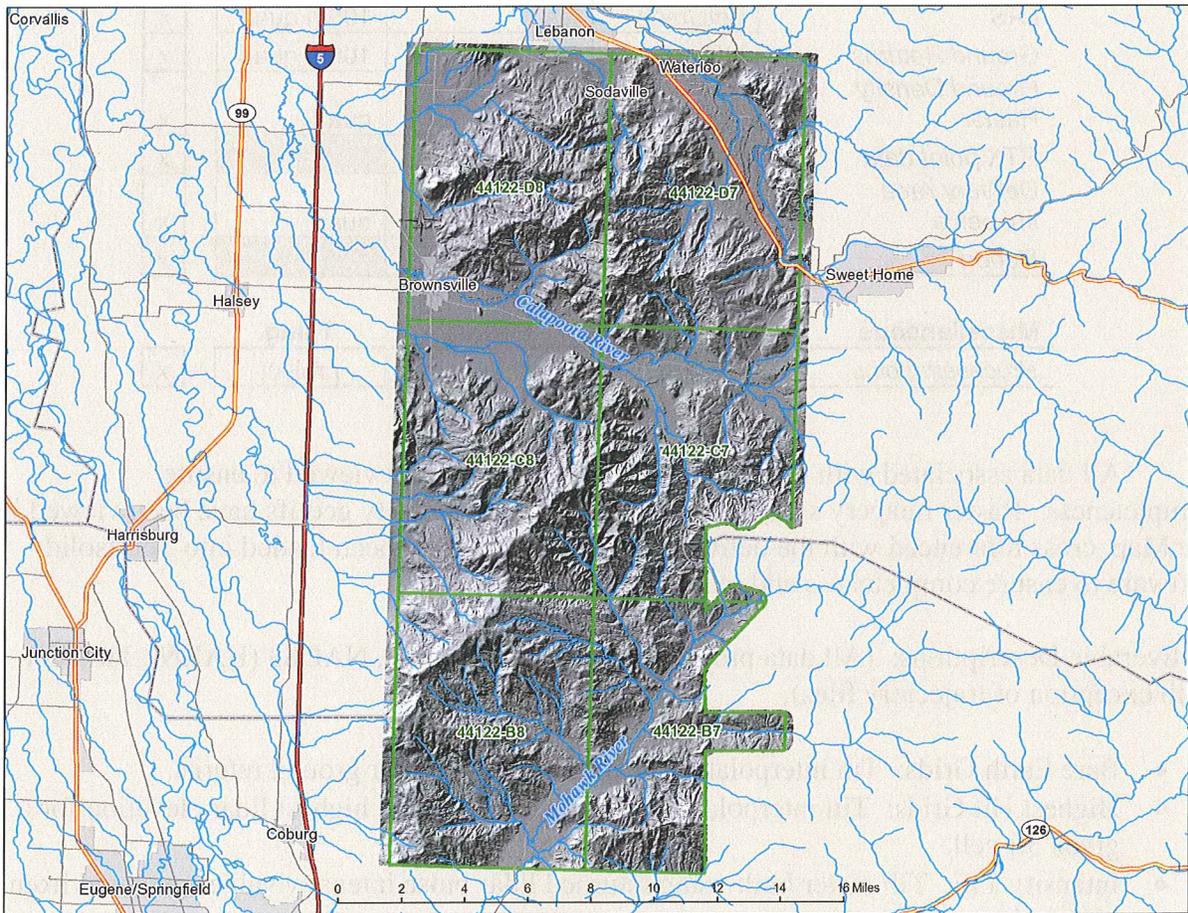


Figure 1. Delivery 15 location area. Data is referenced to USGS 7.5 minute quadrangles within the extents of the Willamette Valley Survey collection area.

Consistency Analysis:

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

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

To quantify the magnitude of this error 1478 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 8,529,906 per tile (Table 2a). Error measurements were calculated by differencing the nearest point from an adjacent flight line within 1 meters in the horizontal plane and 0.2 meters in the vertical plane. Each flight line was compared to adjacent flight lines, and the average magnitude of vertical error was calculated. A total of 305 flight lines were sampled and compared for consistency.

Summary Statistics

# of Tiles	1478
# of Flight Line Sections	305
Avg # of Points	8,529,906
Avg. Magnitude Z error (m)	0.037

Table 2a. Summary Results of Consistency Analysis

	<i>meters</i>	<i>feet</i>
Mean	0.037	0.122
Standard Error	0.000	0.002
Standard Deviation	0.008	0.027
Sample Variance	0.000	0.000
Range	0.056	0.184
Minimum	0.021	0.069
Maximum	0.077	0.254

Table 2b. Descriptive Statistics for Magnitude Z Error.

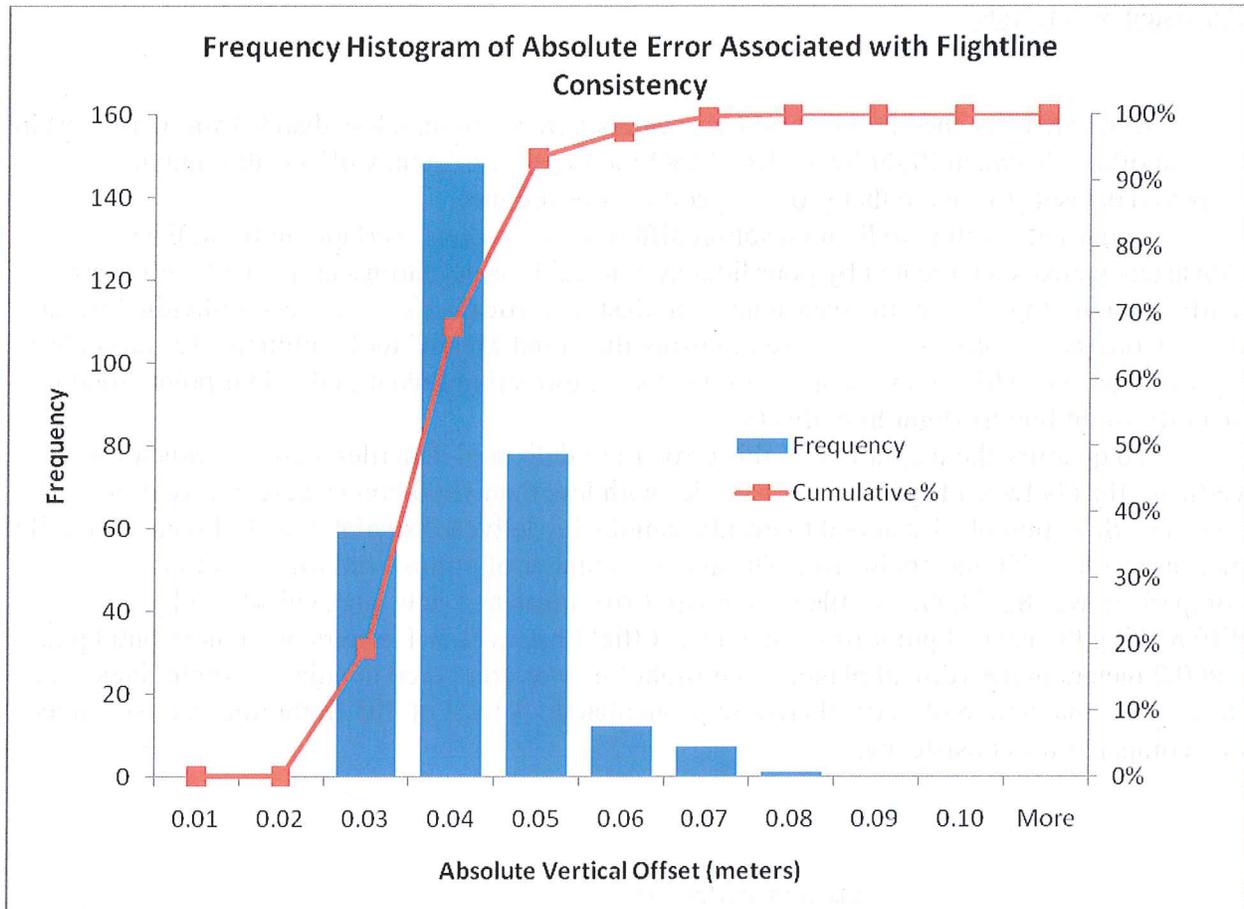


Figure 2.

Results of the consistency analysis found the average flight line offset to be 0.037 meters with a maximum error of 0.083m (Table 2b). Distribution of error showed over 97% of all error was less than 0.06m and 99% was less than 0.07m (Figure 2). These results show that all data are within tolerances of data consistency according to contract agreement.

Visual Analysis

Lidar 3ft grids were loaded into ArcGIS software for visual analysis. Data were examined through slope and hillshade models of bare earth returns. Hillshades of the highest hit models were used to identify areas of missing ground (Figure 3). Both bare earth and highest hit models were examined for calibration offsets, tiling artifacts (Figure 4), seam line offsets, pits (Figure 5), and birds.

Calibration offsets typically are visualized as a corduroy-like patterning within a hillshaded lidar model. These offsets present themselves along steep slopes and typically stand out more in highest hit models than bare earth. Tiling artifacts are a result of missing or misclassified data along the edge of lidar processing tiles. These artifacts present themselves as linear features typically 1-2 grid cells in width, and are present in both the highest hit and bare earth models (e.g. Figure 3). Seam line offsets occur where two distinct days of lidar data

overlap. Errors occur as a result of improper absolute vertical error adjustments. These errors are typically visualized as a linear stair step running along the edge of connecting flight lines. Pits and birds refer to uncommonly high or low points that are the result of atmospheric and sensor noise. Pits (low points) typically occur where the laser comes in contact with water on the ground (Figure 5). Birds (high points) typically occur where the laser comes into contact with atmospherics¹.

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

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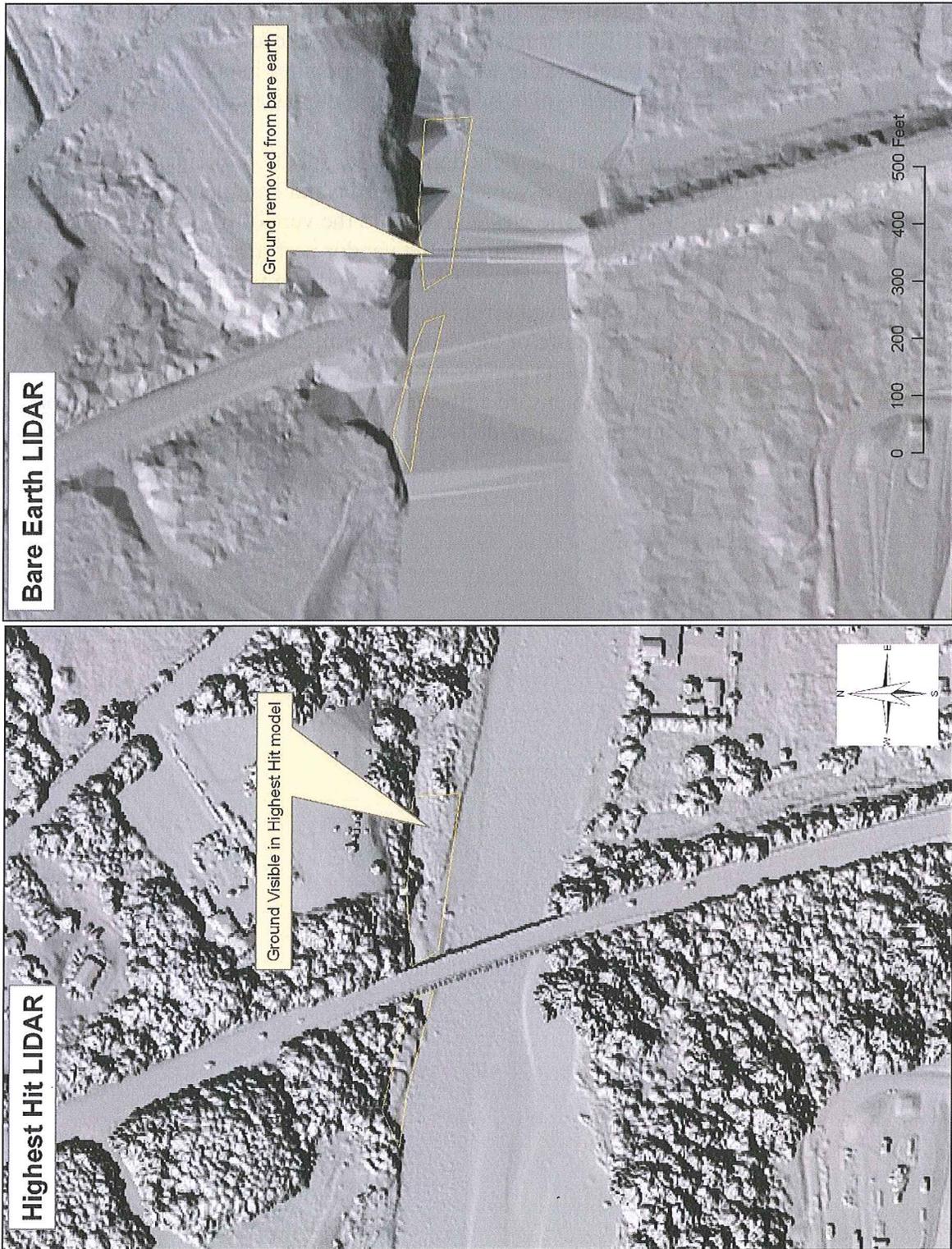


Figure 3. Example of missing ground in lidar bare earth data. Ground is clearly visible in highest hit model, but has been removed from the bare earth model. This type of classification error is common near water body features.

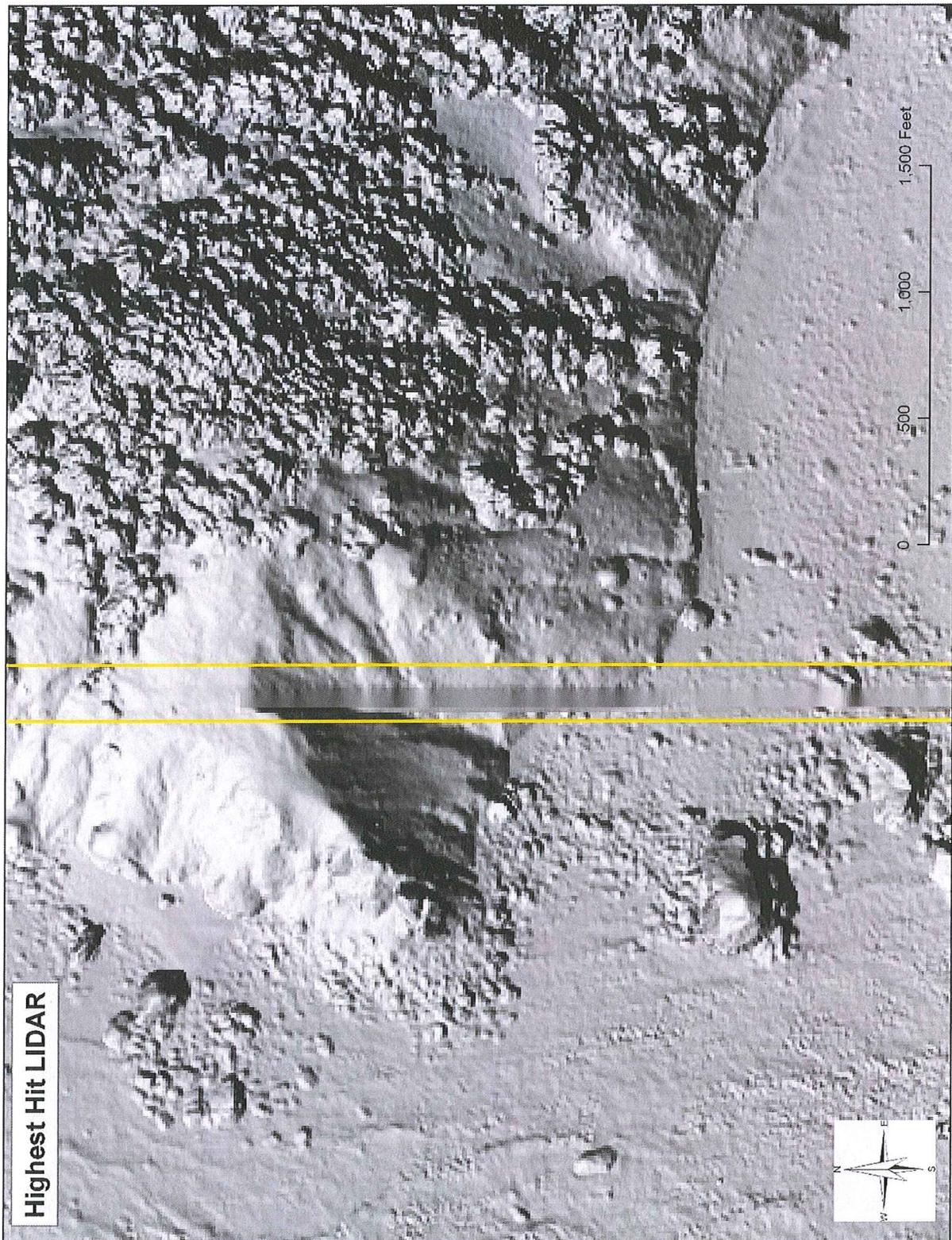


Figure 4. Example of tile artifact found in highest hit lidar data. Artifact is a seam line error created due to misclassification of ground at edge of lidar processing tiles.



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

Absolute Accuracy Analysis:

Absolute accuracy refers to the mean vertical offset of lidar data relative to measured ground-control points (GCP) obtained throughout the lidar sampling area. DOGAMI used a Trimble™ 5700/5800 Total Station GPS surveying system (Figure 5) to measure GCP's. This system consisted of a GPS base station (5700 unit), Zephyr Geodetic antenna, Trimmark 3 radio, and 5800 "rover". The 5700 base station was mounted on a fixed height (typically 2.0 m) tripod and located over a known geodetic survey monument followed by a site calibration on several adjacent benchmarks to precisely establish a local coordinate system. This step is critical in order to eliminate various survey errors. For example, Trimble reports that the 5700/5800 GPS system have horizontal errors of approximately $\pm 1\text{-cm} + 1\text{ppm}$ (parts per million * the baseline length) and $\pm 2\text{-cm}$ in the vertical (TrimbleNavigationSystem, 2005). These errors may be compounded by other factors such as poor satellite geometry, multipath, and poor atmospheric conditions, combining to increase the total error to several centimeters. Thus, the site calibration process is critical in order to minimize these uncertainties.



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

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

- 1) Verify the horizontal and vertical coordinates established by Watershed Sciences for a select number of survey monuments used to calibrate the lidar survey. These surveys typically involved a minimum of two hours of GPS occupation over a known point. The collected data were then submitted to the National Geodetic Survey (NGS) Online Positioning User Service (OPUS) for

- post-processing against several Continuously Operating Reference Stations (CORS) operated by the NGS.
- 2) Collect GCP's along relatively flat surfaces (roads, paths, parking lots etc.). This step involved the collection of both continuous measurements (from a vehicle as well as from a backpack) as well as static measurements (typically 5 epics).

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

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

A total of 496 measured GCP's were obtained in the Delivery 15 region and compared with the lidar elevation grids. The data delivered to DOGAMI was found to have a mean vertical offset of 0.011 meters (0.037 feet) and an RMSE value of 0.039 meters (0.127 ft). Offset values ranged from -0.112 to 0.115 meters (Table 3 and Figure 7).

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

DOGAMI was able to test the horizontal accuracy of survey monuments used to reference the lidar data while conducting vertical control measurements. For internal purposes only, the XY coordinates of survey monuments surveyed by DOGAMI were compared to the survey monuments provided by the vender and in almost every case, the reported results were consistent with those obtained by DOGAMI staff.

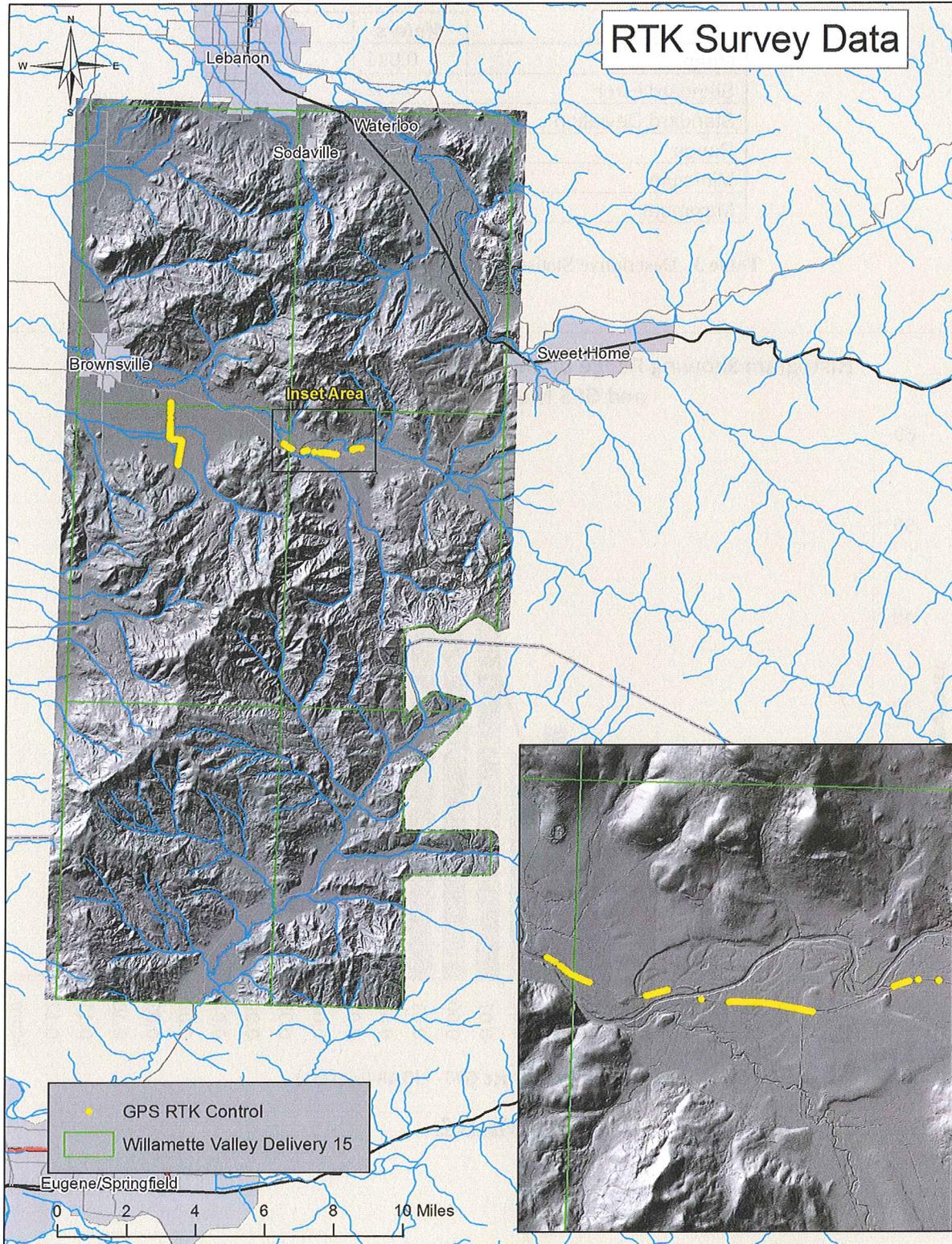


Figure 6. Locations of RTK control surveyed by DOGAMI. Data was used to test absolute accuracy for the Willamette Valley lidar survey within the Delivery 15 extent.

	<i>Meters</i>	<i>Feet</i>
Mean	0.011	0.037
Standard Error	0.002	0.005
Standard Deviation	0.037	0.122
Range	0.227	0.745
Minimum	-0.112	-0.367
Maximum	0.115	0.377

Table 3. Descriptive Statistics for absolute value vertical offsets.

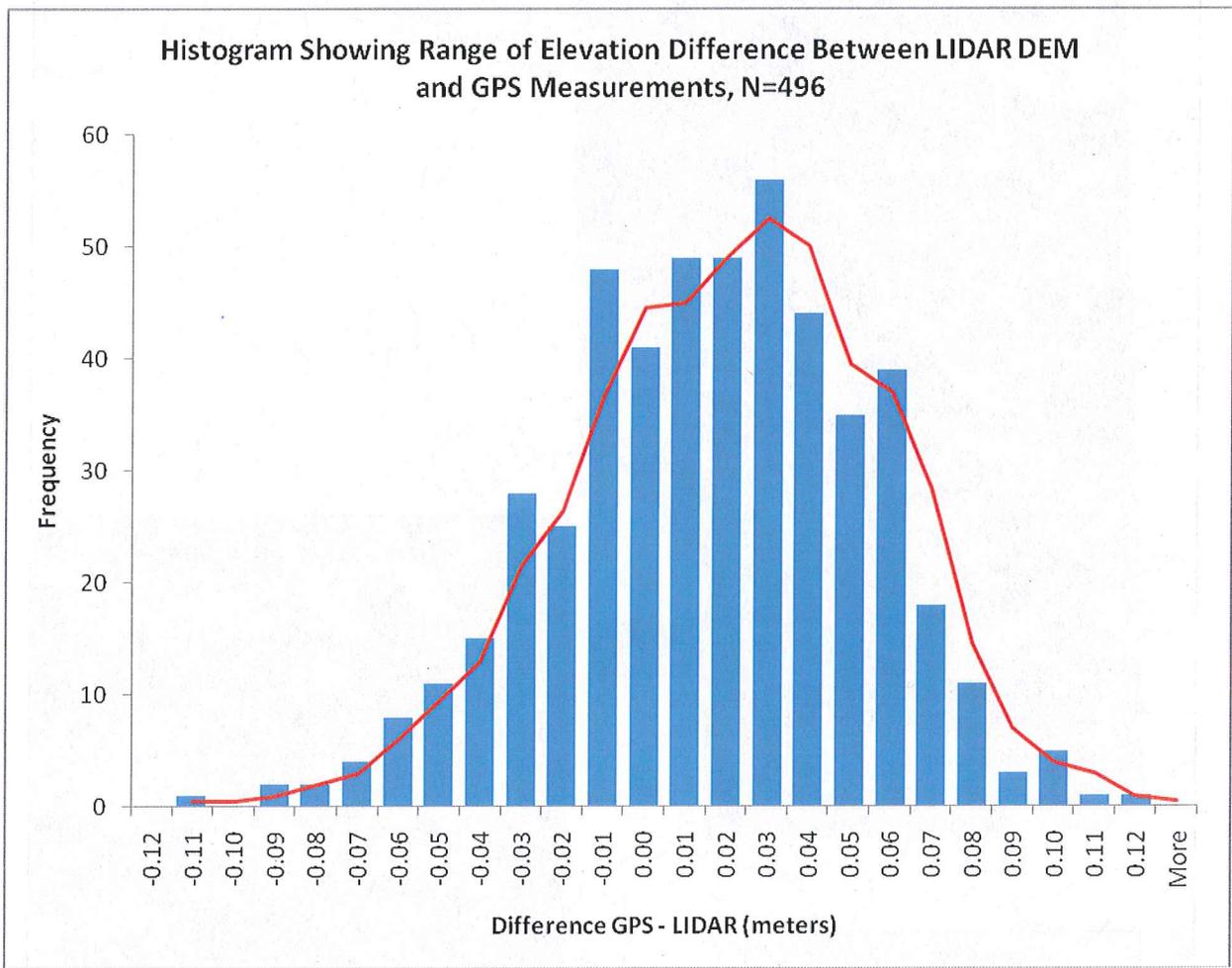


Figure 7.

Acceptance

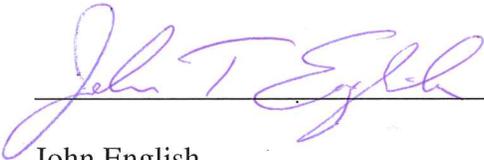
The data described in this report meets and exceeds project specifications laid out in the contracted data standards agreement. All components of data to be delivered have been received as of January 10th, 2010. Consistency analysis has concluded that all data contains flight line to flight line vertical offset less than the threshold of 0.15 meters as specified in agreement. The vendor has adequately responded to all fixable errors identified as part of the visual analysis. Perceived grid errors identified by DOGAMI that were found to be false have been documented by the vendor and explained to the satisfaction of DOGAMI reviewers. Absolute accuracy analysis of the data has concluded that absolute vertical error of lidar data is less than the specified tolerance of 0.20 meters as specified in the data standards agreement.

Approval Signatures



Date: 1/8/2010

Ian Madin
Chief Scientist – Department of Geology & Mineral Industries



Date: 1/8/2010

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

The first part of the report deals with the general situation in the country. It is noted that the economy is still in a state of depression and that the government is facing a serious financial crisis. The report also mentions that the population is suffering from widespread poverty and unemployment.

1/15/48

J. A. [Signature]

Director, [Organization]

1/15/48

[Signature]

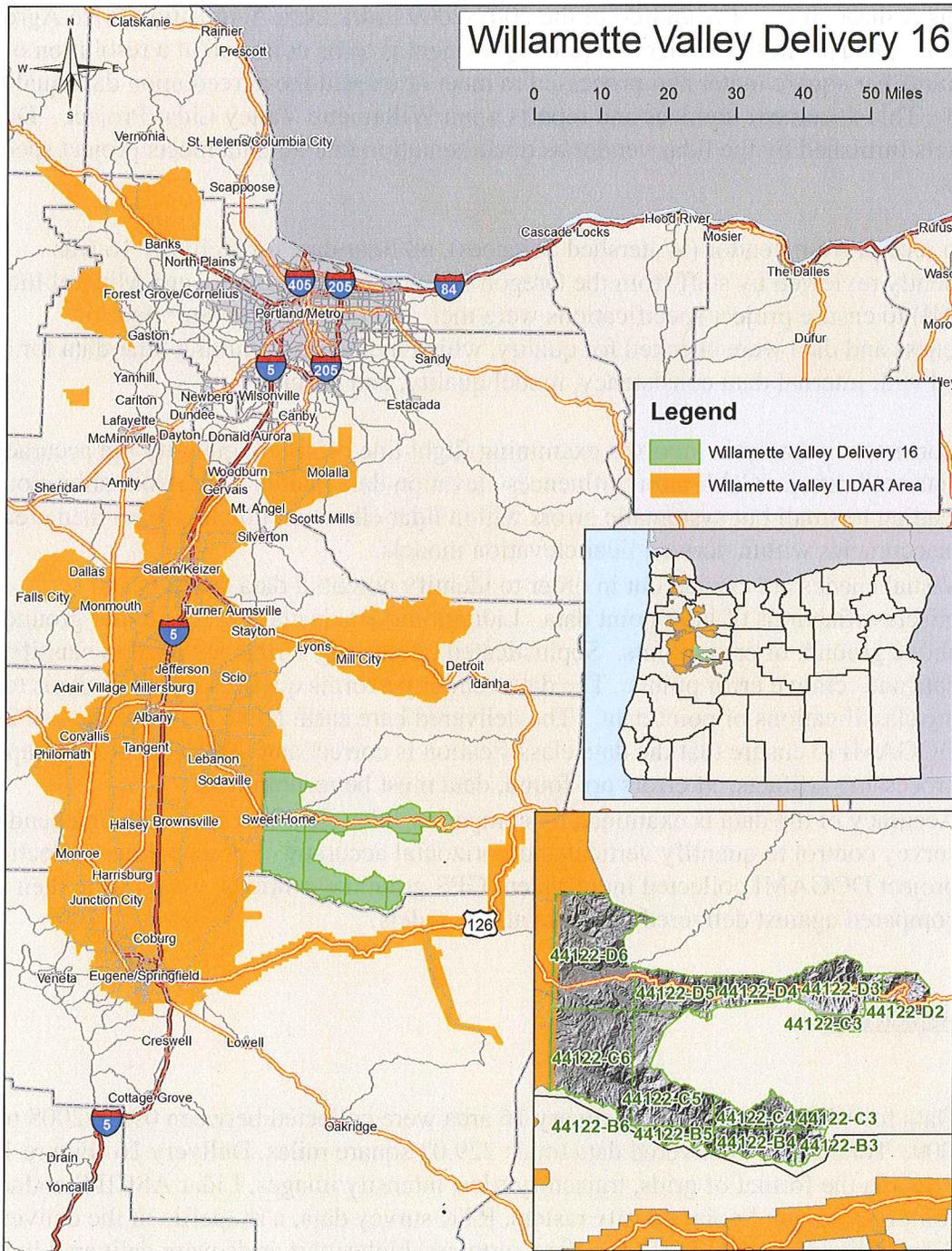
Director, [Organization]



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



Willamette Valley LIDAR Project, 2009 – Delivery 16 QC Analysis
LIDAR QC Report – January 4th, 2010



Map featuring Willamette Valley Delivery 16 data extent.

The Oregon Department of Geology & Mineral Industries has contracted with Watershed Sciences to collect high resolution lidar topographic data for multiple areas within the State of Oregon. Areas for lidar data collection have been designed as part of a collaborative effort of State, Federal, and Local agencies in order to meet a wide range of project goals. The vendor has agreed to certain conditions of data quality and standards for all lidar data deliverables listed in sections A through C (OPA #8865) of the 2007-2009 Lidar Data Acquisition Price Agreement (pgs 14-23). Data submitted under this price agreement is to be collected at a resolution of at least 8 points per square meter and processed to meet or exceed the agreed upon data quality standards. This document itemizes and reports upon Willamette Valley Lidar Project – Delivery 16 products furnished by the lidar vendor as documentation that all data meets project specific standards.

Upon receipt from vendor (Watershed Sciences), all lidar data for Delivery 16 was independently reviewed by staff from the Oregon Department of Geology and Mineral Industries (DOGAMI) to ensure project specifications were met. All data were inventoried for completeness and data were checked for quality, which included examining lidar data for errors associated with internal data consistency, model quality, and accuracy.

- Consistency Analysis involves examining flight line offsets to quantify the accuracy of data calibration. Calibration influences elevation data quality with poor calibration leading to small but systematic errors within lidar elevation points, which then create inaccuracies within derived lidar elevation models.
- Visual checks are carried out in order to identify potential data artifacts and misclassifications of lidar point data. Lidar point data is classified as either ground, above ground, or error points. Sophisticated processing scripts are used to classify point data and remove error points. The data vendor performs quality control analysis to fix misclassifications of point data. The delivered bare earth DEM is then reviewed by DOGAMI to ensure that the data classification is correct and there are no topographic processing artifacts. If errors are found, data must be resubmitted.
- Accuracy of the data is examined by comparing lidar elevation data with independent survey control to quantify vertical and horizontal accuracy. For each lidar collection project DOGAMI collected independent GPS ground elevations, which were then compared against delivered lidar elevation models.

Data Completeness

Data for Willamette Valley Delivery 16 area were collected between 09/07/2008 to 06/27/2009. Total area of delivered data totals 229.03 square miles. Delivery 16 (Figure 1) includes data in the format of grids, trajectory files, intensity images, Lidar ASCII Standard (LAS) point files, ground point density rasters, RTK survey data, a shapefile of the delivery area, and the lidar delivery report (Table 1). Bare earth and highest hit grids were delivered in ArcInfo Grid format with 3ft cell size. Lidar point data is delivered in LAS binary format for ground

classified returns as well as the entire lidar point cloud. Georeferenced intensity images are supplied in TIF format. Supplementary data includes ground density rasters displaying locations where ground returns are low. Real time kinematic ground survey data (used for absolute vertical adjustment) is supplied in shapefile format. This delivery contains data for the following USGS 7.5 minute quads (listed by Ohio Code #) within the boundary of the Willamette Valley Survey collection area (Figure 1):

Delivery 16: 44122b3, 44122b4, 44122b5, 44122b6, 44122c3, 44122c4, 44122c5, 44122c6, 44122d2, 44122d3, 44122d4, 44122d5, 44122d6.

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

Table 1. Deliverable Checklist

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

Deliverable Descriptions: (All data projected in Oregon Lambert, NAD83 (HARN), Intl Feet with exception of trajectory files).

- Bare Earth Grids: Tin interpolated grids created from lidar ground returns.
- Highest Hit Grids: Tin interpolated grids created from the highest lidar elevation for a given 3ft cell.
- Intensity TIF: TIF raster built using returned lidar pulse intensity values gathered from highest hit returns.
- Trajectory File: File contains point location measurement of the aircraft used to collect lidar data. Data is collected using an Inertial Measurement Unit (IMU), and collects measurements of: Easting(meters), Northing (meters), Ellipsoid Height (meters) of aircraft, aircraft roll (degrees), aircraft pitch (degrees), aircraft heading (degrees).

Measurements are collected at one second intervals. Data is projected in UTM zone 10, NAD83 (HARN).

- LAS: Binary file of all lidar points collected in survey (Class, flight line #, GPS Time, Echo, Easting, Northing, Elevation, Intensity, Scan Angle, Echo Number, and Scanner).
- Ground LAS: Binary file of lidar points classified as ground (Class, flight line #, GPS Time, Echo, Easting, Northing, Elevation, Intensity, Scan Angle, Echo Number, and Scanner).
- RTK Point Data: Ground GPS Survey data used to correct raw lidar point cloud for vertical offsets.
- Delivery Area Shapefile: Geometry file depicting the geospatial area associated with deliverables.
- Report: Report provides detailed description of data collection methods and processing. The vendor also reports accuracies associated with calibration, consistency, absolute error, and point classifications.

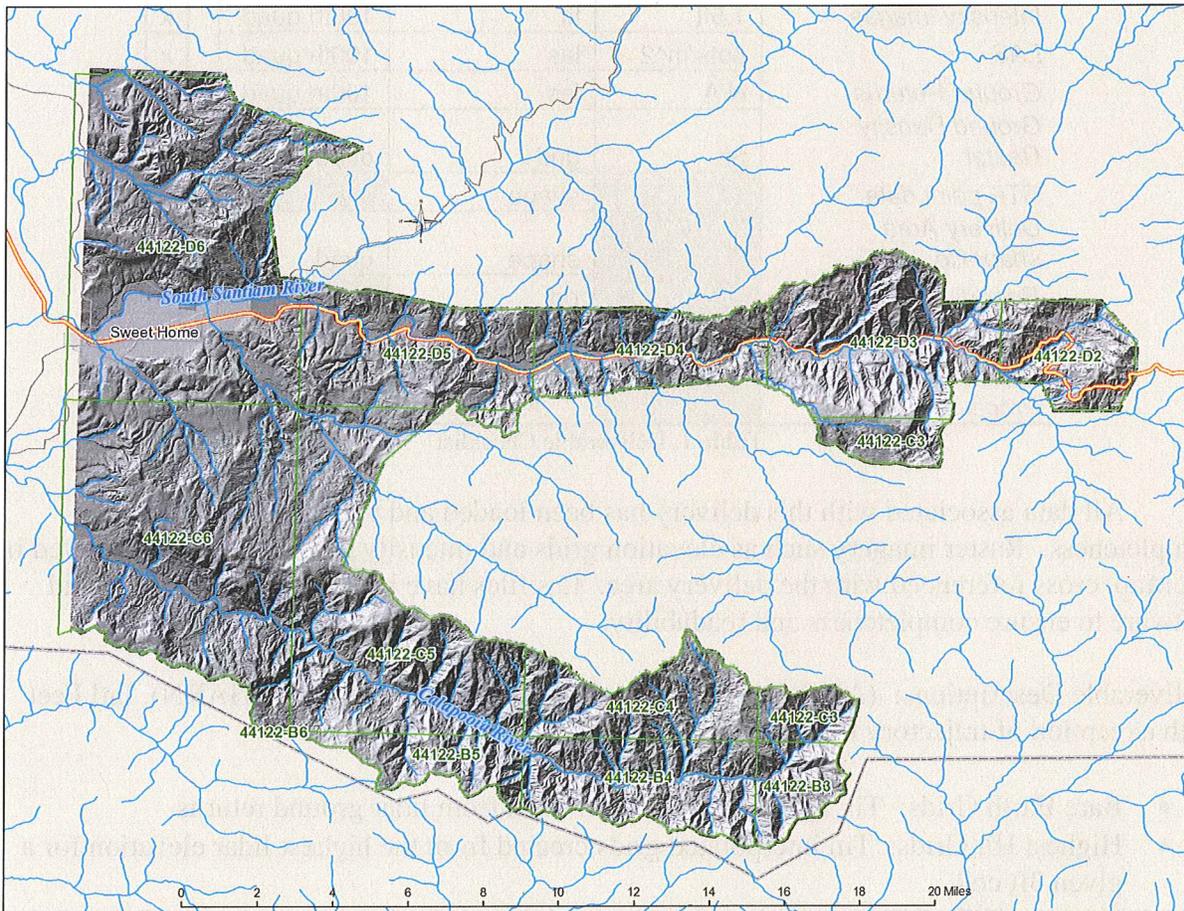


Figure 1. Delivery 16 location area. Data is referenced to USGS 7.5 minute quadrangles within the extents of the Willamette Valley Survey collection area.

Consistency Analysis:

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

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

To quantify the magnitude of this error 1209 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 1,901,997 per tile (Table 2a). Error measurements were calculated by differencing the nearest point from an adjacent flight line within 1 meters in the horizontal plane and 0.2 meters in the vertical plane. Each flight line was compared to adjacent flight lines, and the average magnitude of vertical error was calculated. A total of 288 flight lines were sampled and compared for consistency.

Summary Statistics

# of Tiles	1209
# of Flight Line Sections	288
Avg # of Points	1,901,997
Avg. Magnitude Z error (m)	0.045

Table 2a. Summary Results of Consistency Analysis

	<i>meters</i>	<i>feet</i>
Mean	0.045	0.148
Standard Error	0.001	0.002
Standard Deviation	0.009	0.031
Sample Variance	0.000	0.000
Range	0.050	0.164
Minimum	0.029	0.096
Maximum	0.079	0.260

Table 2b. Descriptive Statistics for Magnitude Z Error.

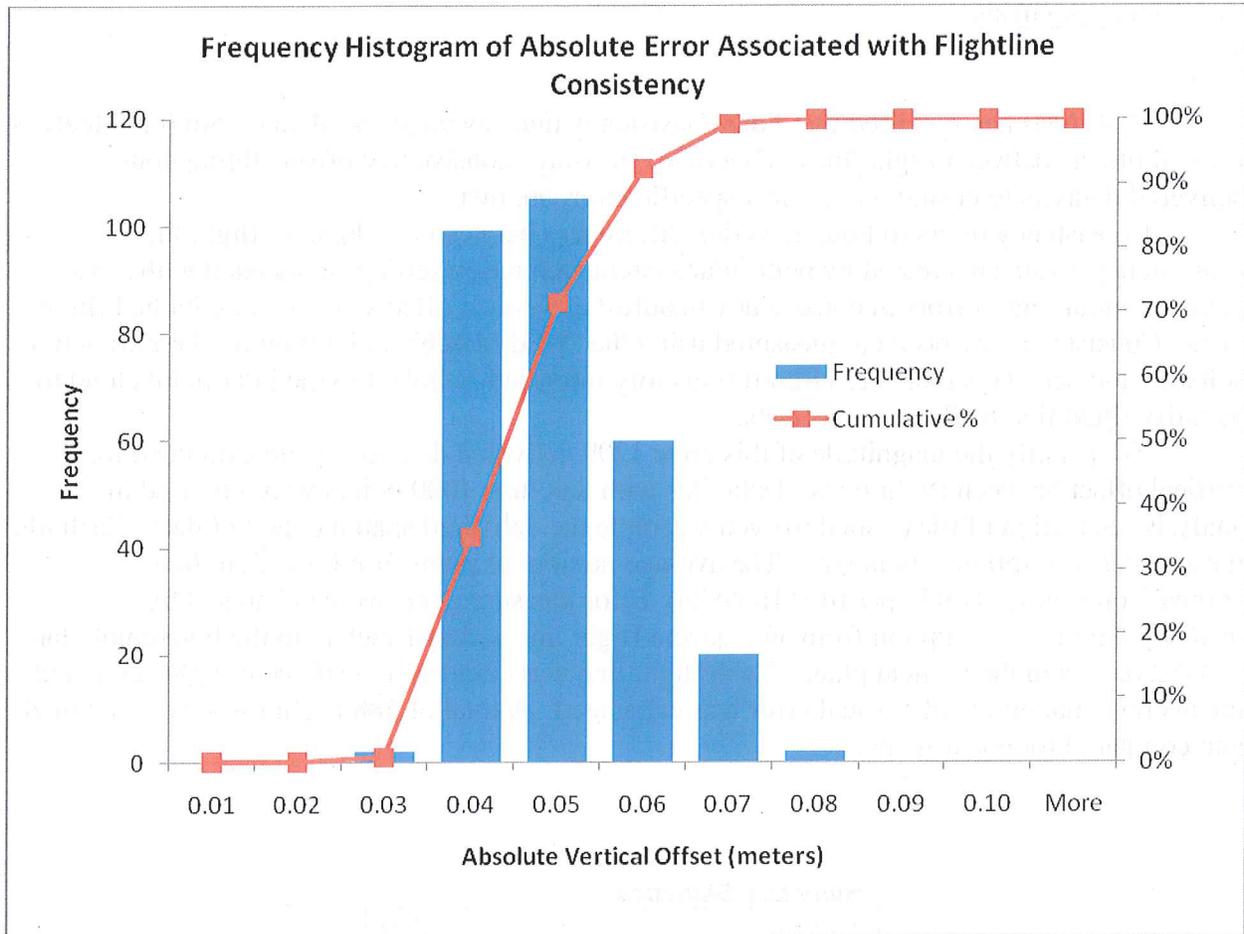


Figure 2.

Results of the consistency analysis found the average flight line offset to be 0.045 meters with a maximum error of 0.079m (Table 2b). Distribution of error showed over 92% of all error was less than 0.06m and 99% was less than 0.07m (Figure 2). These results show that all data are within tolerances of data consistency according to contract agreement.

Visual Analysis

Lidar 3ft grids were loaded into ArcGIS software for visual analysis. Data were examined through slope and hillshade models of bare earth returns. Hillshades of the highest hit models were used to identify areas of missing ground (Figure 3). Both bare earth and highest hit models were examined for calibration offsets, tiling artifacts (Figure 4), seam line offsets, pits (Figure 5), and birds.

Calibration offsets typically are visualized as a corduroy-like patterning within a hillshaded lidar model. These offsets present themselves along steep slopes and typically stand out more in highest hit models than bare earth. Tiling artifacts are a result of missing or misclassified data along the edge of lidar processing tiles. These artifacts present themselves as linear features typically 1-2 grid cells in width, and are present in both the highest hit and bare

earth models (e.g. Figure 3). Seam line offsets occur where two distinct days of lidar data overlap. Errors occur as a result of improper absolute vertical error adjustments. These errors are typically visualized as a linear stair step running along the edge of connecting flight lines. Pits and birds refer to uncommonly high or low points that are the result of atmospheric and sensor noise. Pits (low points) typically occur where the laser comes in contact with water on the ground (Figure 5). Birds (high points) typically occur where the laser comes into contact with atmospherics¹.

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

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



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

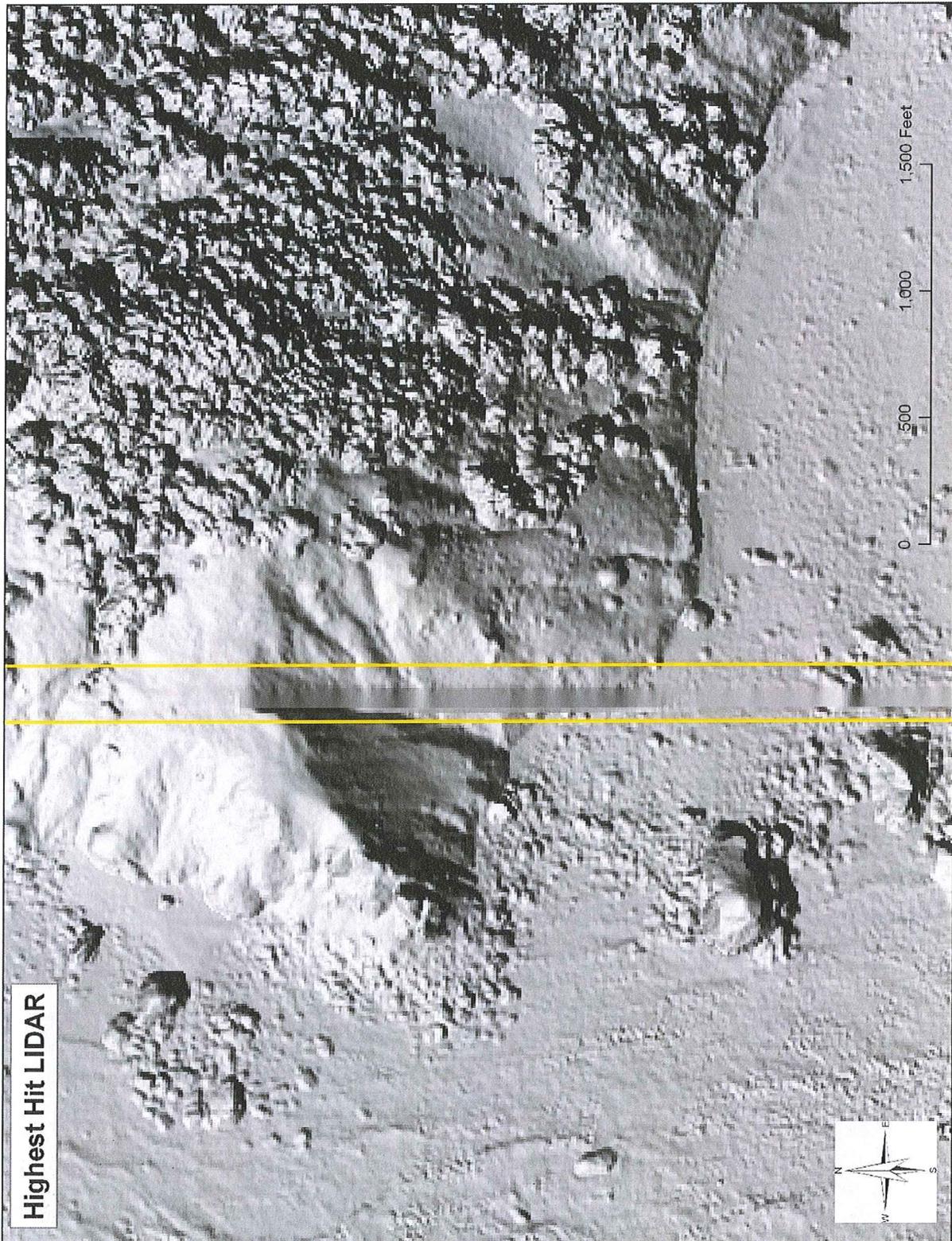


Figure 4. Example of tile artifact found in highest hit lidar data. Artifact is a seam line error created due to misclassification of ground at edge of lidar processing tiles.



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

Absolute Accuracy Analysis:

Absolute accuracy refers to the mean vertical offset of lidar data relative to measured ground-control points (GCP) obtained throughout the lidar sampling area. DOGAMI used a Trimble™ 5700/5800 Total Station GPS surveying system (Figure 5) to measure GCP's. This system consisted of a GPS base station (5700 unit), Zephyr Geodetic antenna, Trimmark 3 radio, and 5800 "rover". The 5700 base station was mounted on a fixed height (typically 2.0 m) tripod and located over a known geodetic survey monument followed by a site calibration on several adjacent benchmarks to precisely establish a local coordinate system. This step is critical in order to eliminate various survey errors. For example, Trimble reports that the 5700/5800 GPS system have horizontal errors of approximately $\pm 1\text{-cm} + 1\text{ppm}$ (parts per million * the baseline length) and $\pm 2\text{-cm}$ in the vertical (TrimbleNavigationSystem, 2005). These errors may be compounded by other factors such as poor satellite geometry, multipath, and poor atmospheric conditions, combining to increase the total error to several centimeters. Thus, the site calibration process is critical in order to minimize these uncertainties.

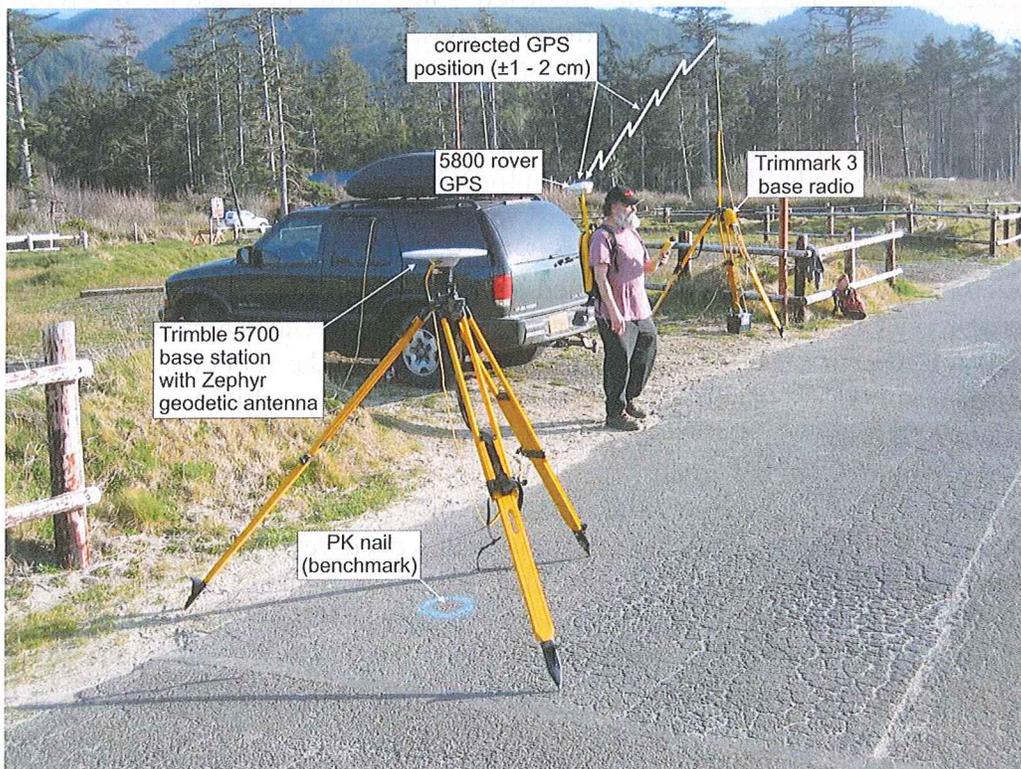


Figure 5. The Trimble 5700 base station antenna located over a known reference point at Cape Lookout State Park. Corrected GPS position and elevation information is then transmitted by a Trimmark III base radio to the 5800 GPS rover unit.

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

- 1) Verify the horizontal and vertical coordinates established by Watershed Sciences for a select number of survey monuments used to calibrate the lidar survey. These surveys typically involved a minimum of two hours of GPS occupation over a known point. The collected data were then submitted to the National Geodetic Survey (NGS) Online Positioning User Service (OPUS) for

- post-processing against several Continuously Operating Reference Stations (CORS) operated by the NGS.
- 2) Collect GCP's along relatively flat surfaces (roads, paths, parking lots etc.). This step involved the collection of both continuous measurements (from a vehicle as well as from a backpack) as well as static measurements (typically 5 epics).

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

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

A total of 600 measured GCP's were obtained in the Delivery 16 region and compared with the lidar elevation grids. The data delivered to DOGAMI was found to have a mean vertical offset of 0.037 meters (0.120 feet) and an RMSE value of 0.050 meters (0.162 ft). Offset values ranged from -0.075 to 0.133 meters (Table 3 and Figure 7).

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

DOGAMI was able to test the horizontal accuracy of survey monuments used to reference the lidar data while conducting vertical control measurements. For internal purposes only, the XY coordinates of survey monuments surveyed by DOGAMI were compared to the survey monuments provided by the vender and in almost every case, the reported results were consistent with those obtained by DOGAMI staff.

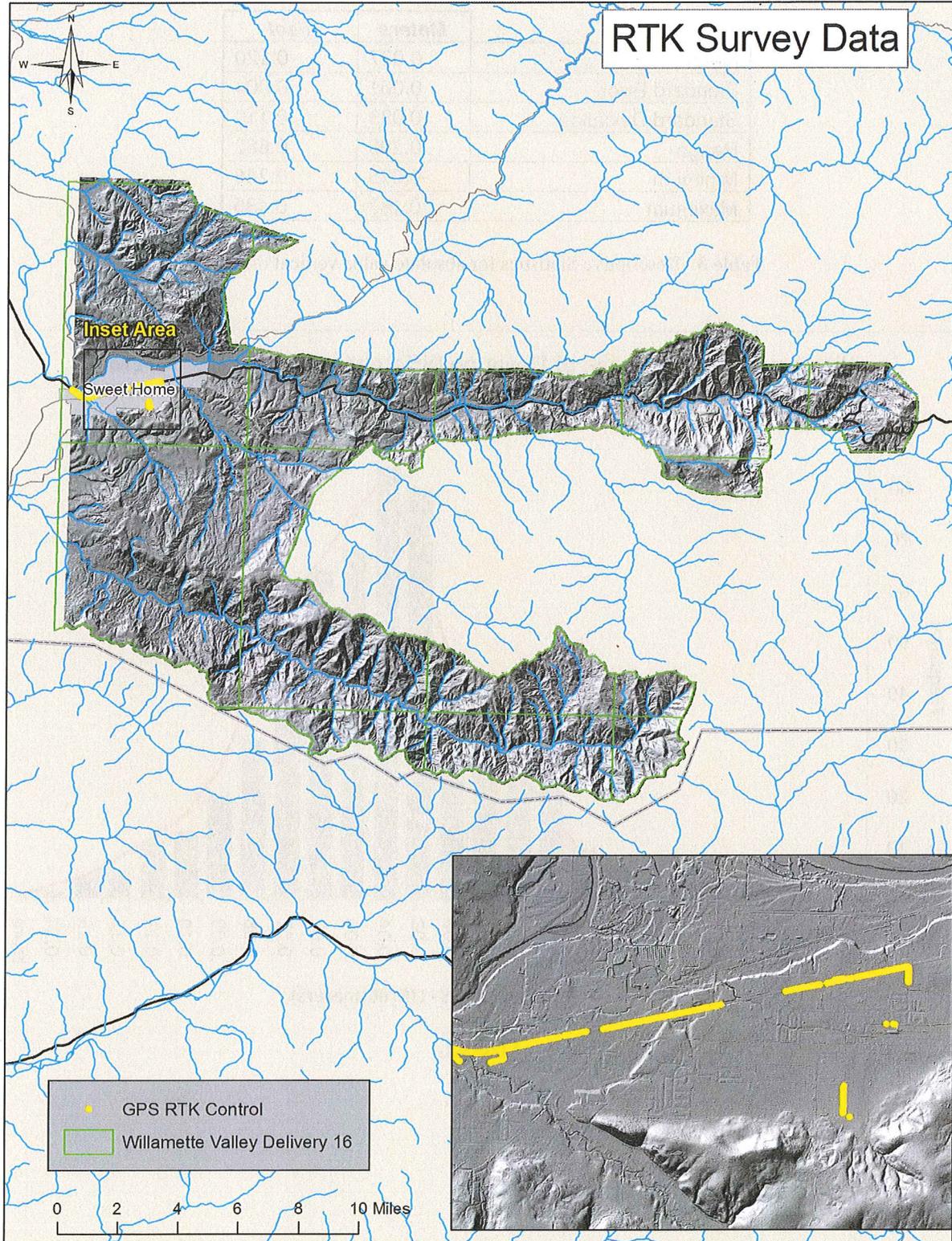


Figure 6. Locations of RTK control surveyed by DOGAMI. Data was used to test absolute accuracy for the Willamette Valley lidar survey within the Delivery 16 extent.

	<i>Meters</i>	<i>Feet</i>
Mean	0.037	0.120
Standard Error	0.001	0.004
Standard Deviation	0.033	0.110
Range	0.208	0.682
Minimum	-0.075	-0.246
Maximum	0.133	0.436

Table 3. Descriptive Statistics for absolute value vertical offsets.

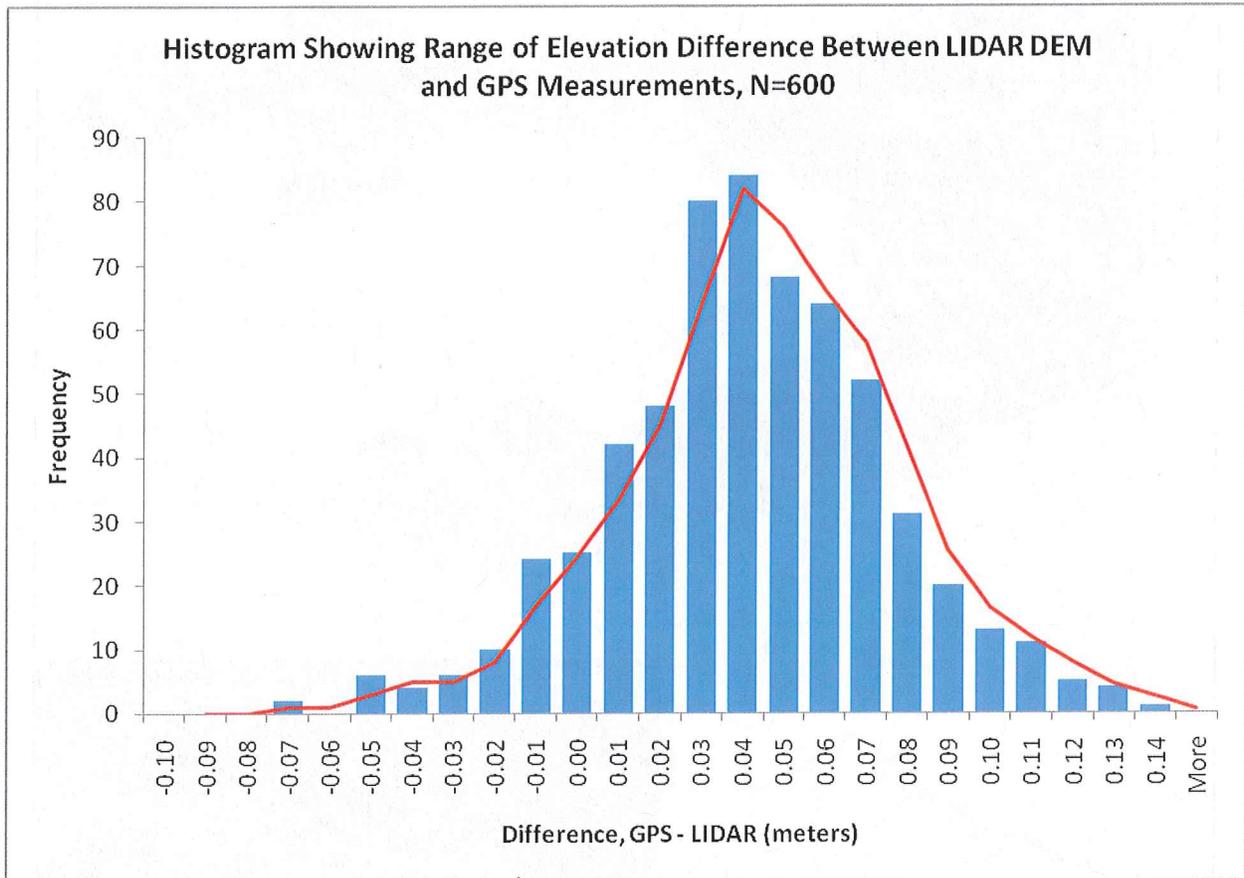


Figure 7.

Acceptance

The data described in this report meets and exceeds project specifications laid out in the contracted data standards agreement. All components of data to be delivered have been received as of January 4th, 2010. Consistency analysis has concluded that all data contains flight line to flight line vertical offset less than the threshold of 0.15 meters as specified in agreement. The vendor has adequately responded to all fixable errors identified as part of the visual analysis. Perceived grid errors identified by DOGAMI that were found to be false have been documented by the vendor and explained to the satisfaction of DOGAMI reviewers. Absolute accuracy analysis of the data has concluded that absolute vertical error of lidar data is less than the specified tolerance of 0.20 meters as specified in the data standards agreement.

Approval Signatures


_____ Date: 1/8/2010

Ian Madin
Chief Scientist – Department of Geology & Mineral Industries


_____ Date: 1/8/2010

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

