LiDAR Quality Inspection Report

Municipality of Anchorage

IR LiDAR Data Collection

October 31, 2015

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Acronyms and Abbreviations

cm	centimeter
CVA	Consolidated Vertical Accuracy
DEM	Digital Elevation Model
FEMA	Federal Emergency Management Agency
ft	foot/feet
FVA	Fundamental Vertical Accuracy
GSD	Ground Sample Distance
IR	Infrared
LiDAR	Light Detection and Ranging
m	meter
MOA	Municipality of Anchorage
NED	National Elevation Data Set
NGP	National Geospatial Program
NPS	Nominal Pulse Spacing
NSSDA	National Standard for Spatial Data Accuracy
NVA	Nonvegetated Vertical Accuracy
PM	Procedure Memorandum
QC	Quality Control
QL	Quality Level
RSME	Root Mean Square Error
SVA	Supplemental Vertical Accuracy
USGS	United States Geological Survey
VVA	Vegetated Vertical Accuracy

Executive Summary

The report documents HDR's review of an aerial Light Detection and Ranging (LiDAR) dataset collected by Merrick over the greater Anchorage area and surrounding nearby communities of Girdwood and Chugiak. This review is an independent third party assessment to check for any collection and /or processing errors and to check for compliance with industry standards for aerial LiDAR data. The data were acquired in the late spring of 2015 during at least partial leaf on conditions with some apparent snow at higher elevations.

Survey check points, primarily used to check for vertical accuracy, were provided with the aerial LiDAR data. They were presumably collected by Merrick or a subcontractor for this project. In addition, HDR previously flew LiDAR over Anchorage in 2010 and the checkpoints used for that data collection were recycled for this assessment. Both sets of quality control (QC) points were collected in urbanized areas, usually on flat and open terrain, and therefore reflect the expected accuracy of the LiDAR data over flat open terrain.

The assessments in this report found that at a minimum the LiDAR data meet the United States Geological Survey (USGS) Quality Level (QL) 3 based on vertical accuracy. The LiDAR data meet QL 2 based on the HDR checkpoints; however, the data do not meet QL 2 based on the checkpoints provided by Merrick. This discrepancy may indicate a deficiency in the quality of the checkpoints provided with the LiDAR and not the LiDAR data itself. Additional checkpoints may be warranted if achieving QL 2 is a requirement. The data also meet Federal Emergency Management Agency (FEMA) specifications for 2 foot contours in flat and open areas; however, QC points were not collected in representative land cover categories, so an appropriate contour interval cannot be determined in forested and mountainous regions. A small (7 centimeters [cm]) and potentially localized sensor calibration error was observed over the city of Anchorage. The error may result in some noise on sloped planar surfaces, but is not expected to cause any issues by end users of the data, nor should it be cause for rejection of the data.

Embedded attribute information in the individual LAS files contains significant digits and is complete. The LAS files themselves are named based on the lower left coordinate (State Plane) of each tile. Overall, classification of the data (ground, vegetation, water) is very good throughout the dataset. There are no duplicate points and all points fall within the tiling scheme provided with the LiDAR.

1 Introduction

This report documents an independent assessment performed by HDR of aerial Light Detection and Ranging (LiDAR) data collected on behalf of the Municipality of Anchorage (MOA). The data were collected by Merrick in the spring of 2015. The LiDAR data covers the municipality of Anchorage and extends east past Chugiak, South past Girdwood, and includes Fire Island.

A total of 401 flight lines were acquired over a period of several days. A Leica ALS70 was reportedly used to collect the data. Two datasets were provided, one adjusted to the NAVD88 vertical datum (referred to as the NAVD88 dataset for the rest of this document) and the other adjusted to the Municipality of Anchorage (MOA) vertical datum, 1972 (referred to as the MOA72 dataset for the rest of this document). Both datasets were derived from the same aerial LiDAR data acquisition and therefore are identical in every other way. Each dataset was delivered as 2850 separate non-overlapping .las (1.2) files (standard LiDAR data format). There was no delivery report available for this assessment and no indication of the Geoid model used to adjust the NAVD88 dataset.

The data analyses documented in this report are useful for several reasons, to check for gross collection or processing errors, but also to check for compliance with LiDAR industry standards and to determine an appropriate resolution model based on the data. Additional checks such as maximum scan angle and attribute information are intended to assist qualified data analysts with their work.

1.1 Project Area

Approximately 530,000 acres of high resolution LiDAR data were collected over Anchorage and the surrounding area. The collection includes a buffer zone extending into the tidal waters. **Figure 1** contains a location map of the project area.

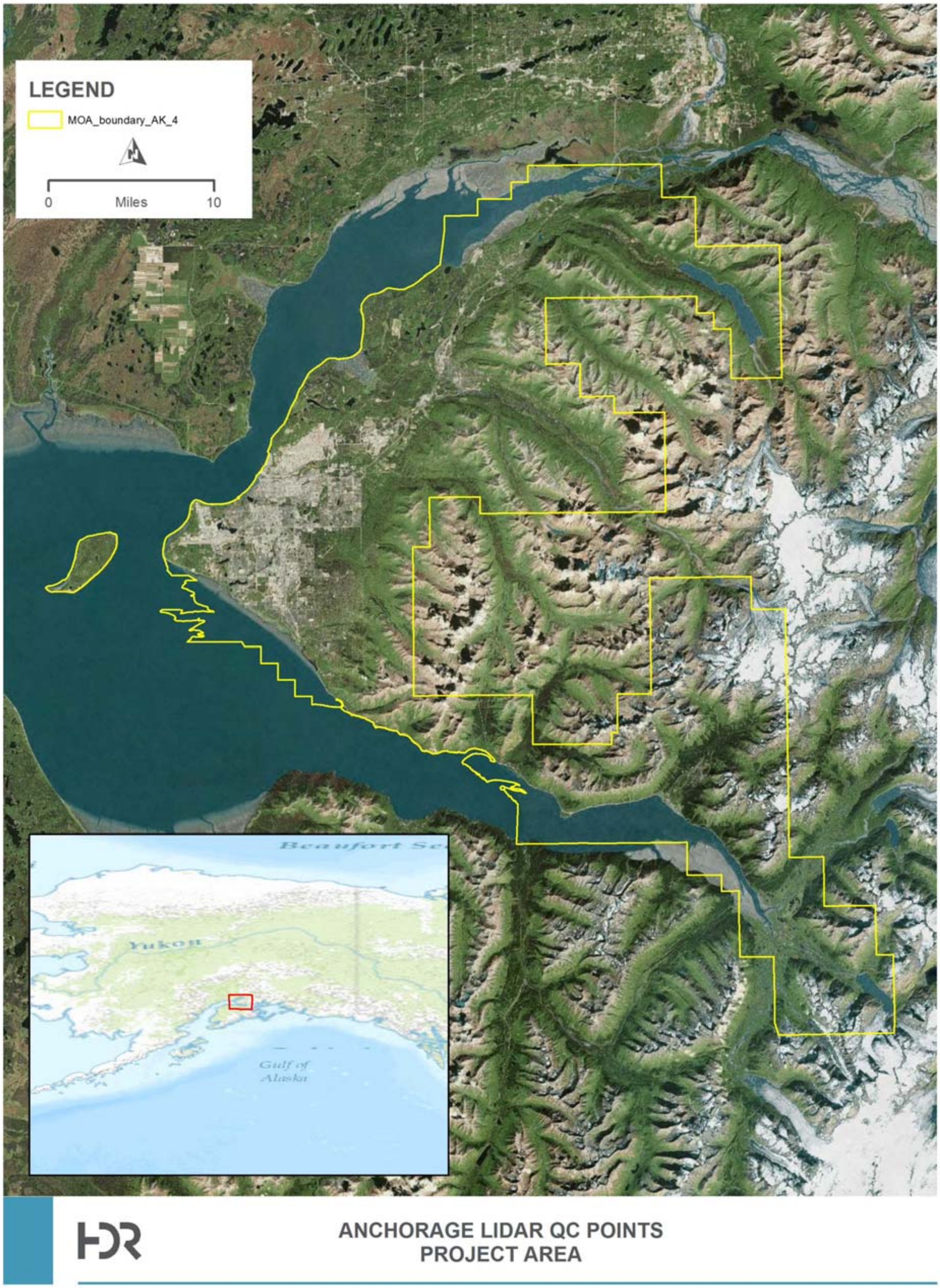

Figure 1 Location map and extent of the aerial LiDAR data.

2 Standards and Guidelines

Numerous standards and guidelines have been published to support a variety of aerial mapping technologies. A few of these specifically target Infrared (IR) aerial LiDAR.

2.1 Relevant Standards and Guidelines

The following contains a list of guidelines used to assess aerial LiDAR data in this report.

Procedure Memorandum No. 61—Federal Emergency Management Agency (FEMA) Standards for LiDAR and Other High Quality Digital Topography
http://www.fema.gov/media-library-data/1388780431699-c5e577ea3d1da878b40e20b776804736/Procedure+Memorandum+61-Standards+for+Lidar+and+Other+High+Quality+Digital+Topography+(Sept+2010).pdf

FGDC-STD-007.3-1998: Geospatial Positioning Accuracy Standards Part 3: NSSDA
http://www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/part3/chapter3

National Geospatial Program LiDAR Base Specification Version 1.0 Chapter 4 of Section B, U.S. Geological Survey (USGS) Standards Book 11, Collection and Delineation of Spatial Data
http://pubs.usgs.gov/tm/11b4/TM11-B4.pdf

LAS Specification Version 1.2, ASPRS
http://www.asprs.org/society/committees/LiDAR/Downloads/Vertical_Accuracy_Reporting_for_Lidar_Data.pdf

2.2 Description of Relevant Standards/Guidelines

- FEMA Procedure Memorandum (PM) 61, Standards for LiDAR and Other High Quality Digital Topography, provides the specifications for elevation data for regulatory flood mapping projects. The specifications were developed for FEMA's RiskMAP program and are widely adopted by other agencies for assessing aerial LiDAR data to support H&H modeling.
- Federal Geographic Data Committee, National Standard for Spatial Data Accuracy, Chapter 3, provides guidelines for calculating and reporting the vertical accuracy of aerial LiDAR. The methodologies contained in this document provide the basic equations upon which several other standards are based on including FEMA and National Geospatial Program (NGP).
- USGS, LiDAR Base Specification Version 1.2, was designed to create consistency among data incorporated into the National Geospatial Program (NGP) including the National Elevation Data Set (NED). The document also includes guidelines for preparing LiDAR point cloud data for inclusion into H&H models as well as guidelines for hydro flattening hydro enforcement of the resultant surface models.

3 Software Used for Data Assessment

- Microstation: A Computer Aided Drafting program designed for generating engineering drawings.
- TerraScan: Runs inside of Microstation. This is an industry standard program for point cloud classification and data accuracy assessment.
- ArcGIS: A geographic information system used for working with maps and other geospatial data.
- Quick Terrain Modeler: Software tool used for rapid creation of surface models.

4 Data Attributes and Collection Specifications

The following conditions were either checked after receipt of the data (tested) or copied from the survey control report (reported).

4.1 Data Collection Parameters (Tested)

Table 1 Data collection parameters including line overlap

Parameter	IR LiDAR
Scan Angle	+/- 32 Degrees off NADIR (Cross Track Scan Pattern)
Pulse Returns	Up to 4 returns per pulse
Swath Overlap	≥ 50% Overlap
Coverage	No voids between swaths due to sensor or pilot error
Collection Conditions	Possible clouds on some days. Some snow at higher elevations. Partial leaf on.

4.2 Spatial Reference Framework (Reported)

Table 2 Spatial reference information including units for all .las files

Specification	IR LiDAR
Coordinate System	Alaska State Plane Zone 4
Horizontal Datum	Nad83
Vertical Datum (two datasets)	NAVD88 (unknown Geoid) / Municipality of Anchorage 1972 adjustment
Horizontal Units	US Survey Feet
Vertical Units	US Survey Feet

4.3 Data Attributes (Tested)

Table 3 Attribute information contained in the .las files for each laser return.

Attribute	NIR
Scan Return	Each return contains easting, northing, elevation, scan angle, intensity, flightline #, scanner ID, classification, GPS second, and echo return
Precision	Easting, northing, and elevation reported to the nearest 0.01ft
GPS Time	Adjusted GPS time. Reported to the nearest microsecond
File Format	Las 1.2
Tile Names	Lower Left coordinates of each tile
LAS Header Information	Contains coordinate system, reference datum, horizontal and vertical units

4.4 Point Cloud Classification (Tested)

The classification codes were assessed by using the “summary statistics” function available in TerraScan. Below is a summary of our findings.

Table 4 Summary point cloud classification information.

Classification	IR LiDAR
Default (class 1)	X
Ground (class 2)	X
Low Vegetation (class 3)	--
Medium Vegetation (class 4)	--
High Vegetation (class 5)	--
Building(class 6)	--
Noise (class 7)	X
Model Keypoints (class 8)	--
Water (class 9)	X
Reserved (Near Breaklines) (class 10)	X
Withheld (class 11)	--
Reserved (Bridges) (class 17)	X

4.5 Tiling Scheme

Merrick used a regular tiling scheme to subset the LiDAR data. It appears to have been created by generating a fishnet in ArcGIS measuring 3000’ by 3000’. The tiles extend beyond the collection polygon by as much as 3,000 feet. The tiles are numbered using the first four values of the easting and northing coordinates (Alaska State Plane) for the lower left corner of each tile.

5 Quantitative Analyses and Methods:

Due to the rapid turnaround time for this assessment, many of the tests were performed on subsets of the data as described in section 7 of this document.

LiDAR data was tested to meet industry standard specifications for the following:

1. Nominal Pulse Spacing (NPS)
2. Ground Sample Distance (GSD)
3. Vertical Accuracy
4. Precision
5. Spatial Distribution (Symmetry)

5.1 Nominal Pulse Spacing

NPS refers to the point density for single swath (non-overlapping) first return data points. As outlined in FEMA PM61 Standards, the NPS shall be determined when deciding an appropriate contour interval according to **Table 5** (below).

Table 5 FEMA vertical accuracy requirements based on potential flood risk and terrain slope.

Level of Flood Risk	Typical Slopes	Specification Level	Vertical Accuracy, 95% Confidence Level FVA/CVA	LiDAR Nominal Pulse Spacing
High (Deciles 1,2,3)	Flattest	Highest	24.5 cm/36.3 cm	≤1 meter
High (Deciles 1,2,3)	Rolling or Hilly	High	49.0 cm/72.6 cm	≤2 meters
High (Deciles 2,3,4,5)	Hilly	Medium	98.0 cm/145 cm	≤3.5 meters
Medium (Deciles 3,4,5,6,7)	Flattest	High	49.0 cm/72.6 cm	≤2 meters
Medium (Deciles 3,4,5,6,7)	Rolling	Medium	98.0 cm/145 cm	≤3.5 meters

Notes:
cm = centimeter
CVA = Consolidated Vertical Accuracy
FVA = Fundamental Vertical Accuracy
LiDAR = Light Detection and Ranging

Per FEMA standards “The NPS assessment is made against single swath first return data located in the geometrically usable portion (typically 90 percent) of each swath, acceptable data voids excluded” (such as water).

NPS was derived as follows; first, a copy of the original data was created. The data were then filtered by echo return. All “first return” echoes were reclassified as “model keypoints”. The data were then output by individual flightlines and saved in .las format for further analysis.

A polygon was then created for each flightline outlining the geometrically usable portion of individual flight lines as defined above. Each flightline was then subset to this polygon and the area of the polygon was measured and recorded. A mask was then applied to the polygon to remove areas of surface water from the calculations. The sum of the "model keypoints" per tile (first return echoes) was divided by the area of the bounding polygon (minus the water) to derive an average spot density. This in turn was converted to NPS by the following equation:

$$\text{NPS} = 1/\sqrt{Points/meter^2}$$

Statistics from this analysis are summarized in section 7.1. A complete report is provided in **Appendix A** of this document.

As outlined in the USGS Base Specifications version 1.2, The Aggregate NPS (ANPS) shall be used to determine an appropriate QL for the data. ANPS is simply the collective NPS from overlapping swaths of data.

Table 6 USGS Aggregate NPS requirements based on Quality Level.

Quality Level (QL)	Aggregate nominal pulse spacing (ANPS)	Aggregate nominal pulse density (ANPD)
QL0	≤0.35	≥8.0
QL1	≤0.35	≥8.0
QL2	≤0.71	≥2.0
QL3	≤1.41	≥0.5

5.2 Ground Sample Distance

A Digital Elevation Model (DEM) has bare-earth "z" values at regularly spaced intervals in the x and y directions. According to FEMA It is standard industry practice to have:

> 1-meter DEM post spacing for elevation data with 1-foot equivalent contour accuracy;

> 2-meter DEM post spacing for elevation data with 2-foot equivalent contour accuracy;

> 5-meter DEM post spacing for elevation data with 5-foot equivalent contour accuracy

The resolution of a DEM should be comparable to the GSD of the ground class in the LiDAR point cloud. The ground sample distance was computed from the ground class to determine the appropriate DEM resolution using the following equation:

$$\text{GSD} = 1/\sqrt{Points/meter^2}$$

The ground points per square meter was calculated using all points classified as "ground" including points from overlapping regions of adjacent flight lines. This is commonly referred to as the "aggregate point density" and sometimes erroneously confused with NPS. Statistics from this analysis are summarized in section 7.2. A complete report is provided in **Appendix B** of this document.

5.3 Vertical Accuracy

The vertical accuracy assessment compares the measured survey checkpoint elevations with those of the LiDAR point cloud by interpolating between nearby laser returns. The interpolated Z values are then compared with the survey checkpoint Z values and this difference represents the amount of error between the measurements. Once all the Z values are recorded, the Root Mean Square Error (RMSE) is calculated according to the following equation:

$$\text{RMSE} = sqrt[\sum(Z_{data\ i} - Z_{check\ i})^2/n]$$

Where

- $Z_{data\ i}$ is the vertical coordinate of the i th check point in the dataset.
- $Z_{check\ i}$ is the vertical coordinate of the i th check point in the independent source of higher accuracy
- n = the number of points being checked
- i is an integer from 1 to n

The National Standard for Spatial Data Accuracy (NSSDA) specifies that vertical accuracy should be reported at the 95 percent confidence level for data tested by an independent source of higher accuracy using the following equation:

$$\textbf{Accuracy} = \textbf{1.9600} * \textbf{RMSE}_z$$

According to FEMA (FEMA PM61 Standards), the vertical accuracy shall be determined in compliance with the NSSDA when deciding an appropriate contour interval as stated in **Table 6** (below).

Table 7 FEMA requirements for equivalent contour interval based on vertical accuracy flood risk specification interval.

Equivalent Contour Accuracy	FEMA Specification Level	$RMSE_z$	NSSDA Accuracy 95% Confidence Interval	SVA (target)	CVA (mandatory)
1ft		0.30ft or 9.25 cm	0.60ft or 18.2 cm	0.60ft or 18.2 cm	0.60ft or 18.2 cm
2ft	Highest	0.61ft or 18.5 cm	1.19ft or 36.3 cm	1.19ft or 36.3 cm	1.19ft or 36.3 cm
4ft	High	1.22ft or 37.1 cm	2.38ft or 72.6 cm	2.38ft or 72.6 cm	2.38ft or 72.6 cm
5ft		1.52ft or 46.3 cm	2.98ft or 90.8 cm	2.98ft or 90.8 cm	2.98ft or 90.8 cm

Table 7 FEMA requirements for equivalent contour interval based on vertical accuracy flood risk specification interval. (Continued)

Equivalent Contour Accuracy	FEMA Specification Level	$RMSE_z$	NSSDA Accuracy 95% Confidence Interval	SVA (target)	CVA (mandatory)
8ft	Medium	2.43ft or 73.9 cm	4.77ft or 1.45 m	4.77ft or 1.45 m	4.77ft or 1.45 m
10ft		3.04ft or 92.7 cm	5.86ft or 1.82 m	5.86ft or 1.82 m	5.86ft or 1.82 m
12ft	Low	3.65ft or 1.11 m	7.15ft or 2.18m	7.15ft or 2.18m	7.15ft or 2.18m

Notes:
cm = centimeter
CVA = Consolidated Vertical Accuracy
FEMA = Federal Emergency Management Agency
ft = feet/foot
NSSDA = National Standard for Spatial Data Accuracy
RMSE = Root Mean Square Error
SVA = Supplemental Vertical Accuracy

The Fundamental Vertical Accuracy is determined by comparison with checkpoints located on flat surfaces in open terrain. This is often the “best case” scenario and generally represents the highest achievable accuracy of the entire dataset. All other land cover categories constitute the Supplemental Vertical Accuracy (SVA). The combined Fundamental Vertical Accuracy (FVA) and SVA constitute the Consolidated Vertical Accuracy (CVA). Additional information is contained in the glossary of this document.

The USGS LiDAR Base Specifications version 1.2 associates the vertical accuracy with the Quality Level of the data. The USGS uses the term Nonvegetated Vertical Accuracy (NVA) interchangeably with FVA and Vegetated Vertical Accuracy (VVA) with SVA.

Table 8 USGS Base Specification version 1.2 associating vertical accuracy with the Quality Level of digital elevation data.

Quality Level (QL)	$RMSE_z$ (nonvegetated) (cm)	NVA at the 95-percent confidence level (cm)	VVA at the 95th Percentile (cm)
QL0	$\leq$5.0	$\leq$9.8	$\leq$14.7
QL1	$\leq$10.0	$\leq$19.6	$\leq$29.4
QL2	$\leq$10.0	$\leq$19.6	$\leq$29.4
QL3	$\leq$20.0	$\leq$39.2	$\leq$58.8

Notes:
cm = centimeter
RMSE = Root Mean Square Error
SVA = Supplemental Vertical Accuracy
VVA = Vegetated Vertical Accuracy

5.4 Precision

The precision of a dataset is directly affected by calibration of the sensor / Inertial Measurement Unit (IMU) combination and the quality of GPS data. A poorly calibrated instrument results in a consistent directional misalignment relative to the travel path of the aircraft. This can be observed in overlapping swaths of data. Poor GPS often results in random errors that are sometimes difficult to detect. To test for precision, numerous cross sectional profiles were drawn over flat roads and pitched roofs. Any apparent offsets were then measured using the mensuration tools available in Microstation.

5.5 Spatial Distribution of Points (Symmetry)

Regular spacing of primary or "first return" echoes helps to ensure adequate coverage of features on or near the ground. This is often referred to as "spot symmetry". The symmetry of first return points is controlled by the vendor during flight planning. Ideally, laser returns within a single swath of data will have equal spacing in the X (cross track) and the Y (down track) directions.

Like NPS, the spatial distribution of first return points is checked against *individual* swaths of data. The density of first return points will therefore be much higher in areas of overlapping flightlines.

As outlined in the USGS base 1 specifications, symmetry of the LiDAR data was tested by overlaying a regularly spaced 2 dimensional grid with a cell size of 2 x NPS on single swaths of data that have been filtered to isolate first return echoes.

Cells that contained at least one laser return were assigned a value of "1". Cells that did not contain a laser return were assigned a value of "0". Next, a mask was applied to the grid to remove areas of water from the calculations. A statistical query was then performed on the grid to determine the percentage of cells containing at least one laser return.

According to USGS specifications, "at least 90 percent of the cells in the grid should contain at least one LiDAR point", excluding water and other acceptable voids.

6 Qualitative Analyses and Methods

The first step in the assessment was a visual inspection of the data to check for any obvious errors such as missing or incomplete tiles, gross outliers, or other evidence of mishandling.

In addition to the quantitative checks described above, the following qualitative analyses were performed:

- A gap analysis was performed by visual inspection of the data
- The classification was checked for consistency by drawing cross sections at randomly chosen areas in the dataset

7 Results

7.1 Nominal Pulse Spacing

The NPS was calculated for the LiDAR only using methods discussed in the previous section. Due to the fast turnaround time of this project, twenty two flightlines were selected for evaluation (**Figure 3**). The flightlines were randomly chosen throughout the dataset in an effort to sample data from separate collections. Results from the test are reported as the average distance between first return points of non-overlapping data per sampled flight line. The following frequency diagram is intended to provide a brief synopsis of our findings. Detailed information is contained in **Appendix A** of this document.

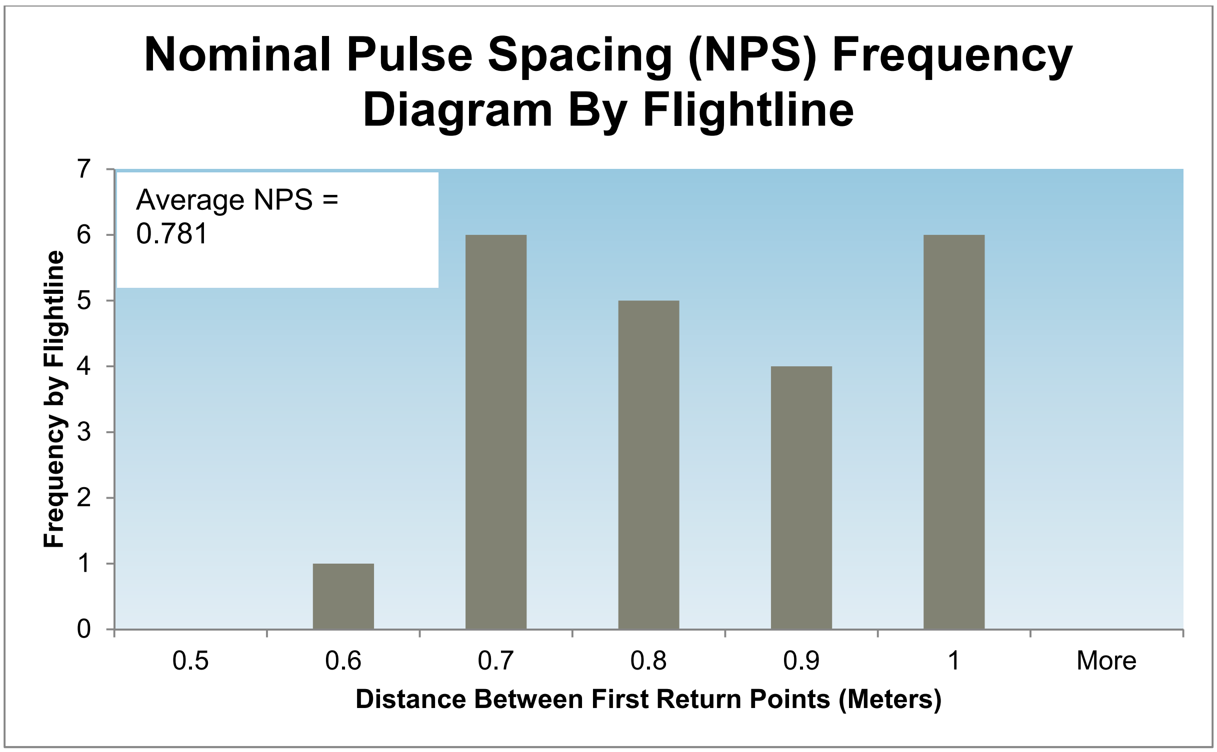

Figure 2 Average distance (meters) between first return points per flight line.

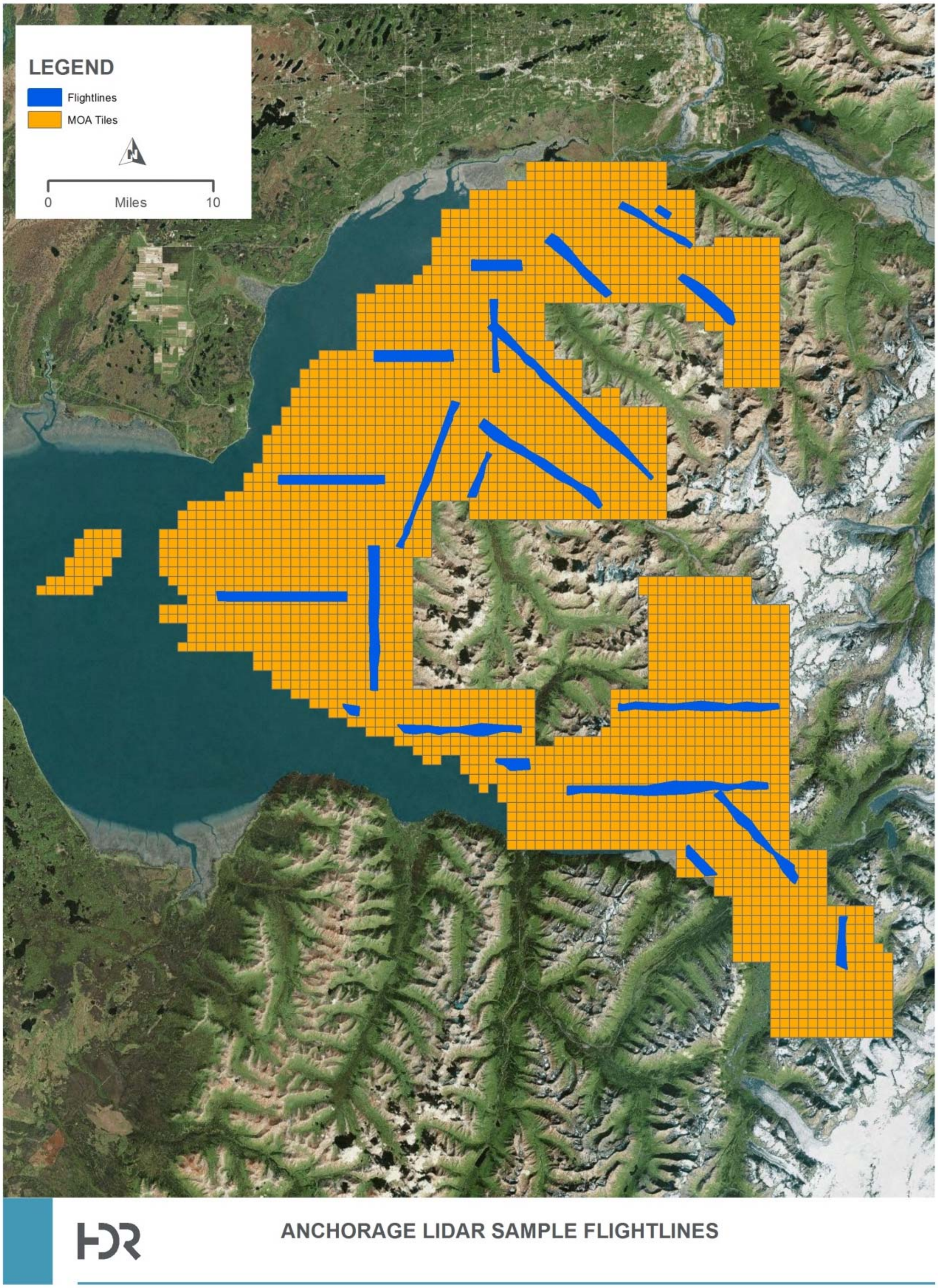

Figure 3 Selected flightlines (blue) used in this assessment overlain on the LiDAR tiling scheme.

7.2 Ground Sample Distance

The GSD was calculated for the IR LiDAR only using methods discussed in the previous section. Due to the fast turnaround time of this project, 121 tiles were randomly chosen throughout the dataset in an effort to rapidly evaluate the GSD in various land cover categories (**Figure 4**). Results from the test are reported as the average distance in meters between ground points, per tile of data. The following frequency diagram is intended to provide a brief synopsis of our findings. Detailed information is contained in **Appendix B** of this document.

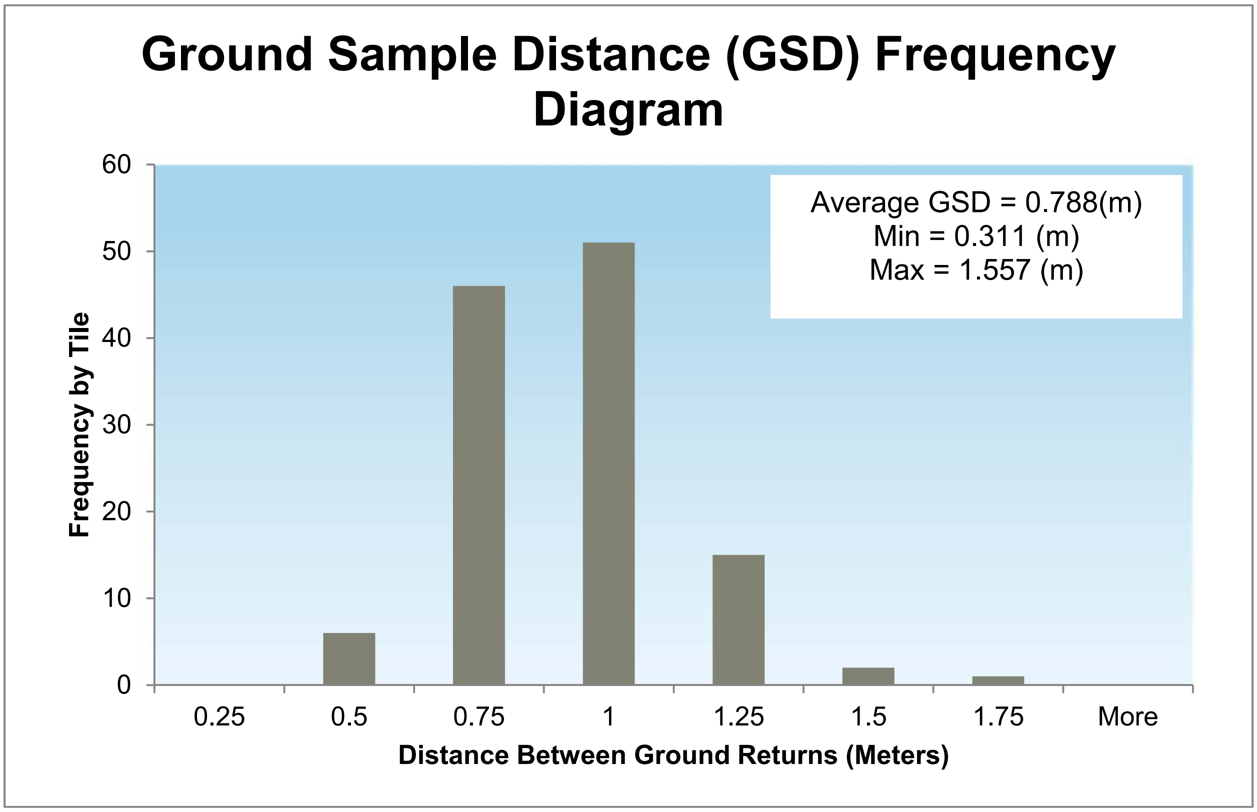

Figure 4 Average distance (meters) between laser returns classified as ground per tile.

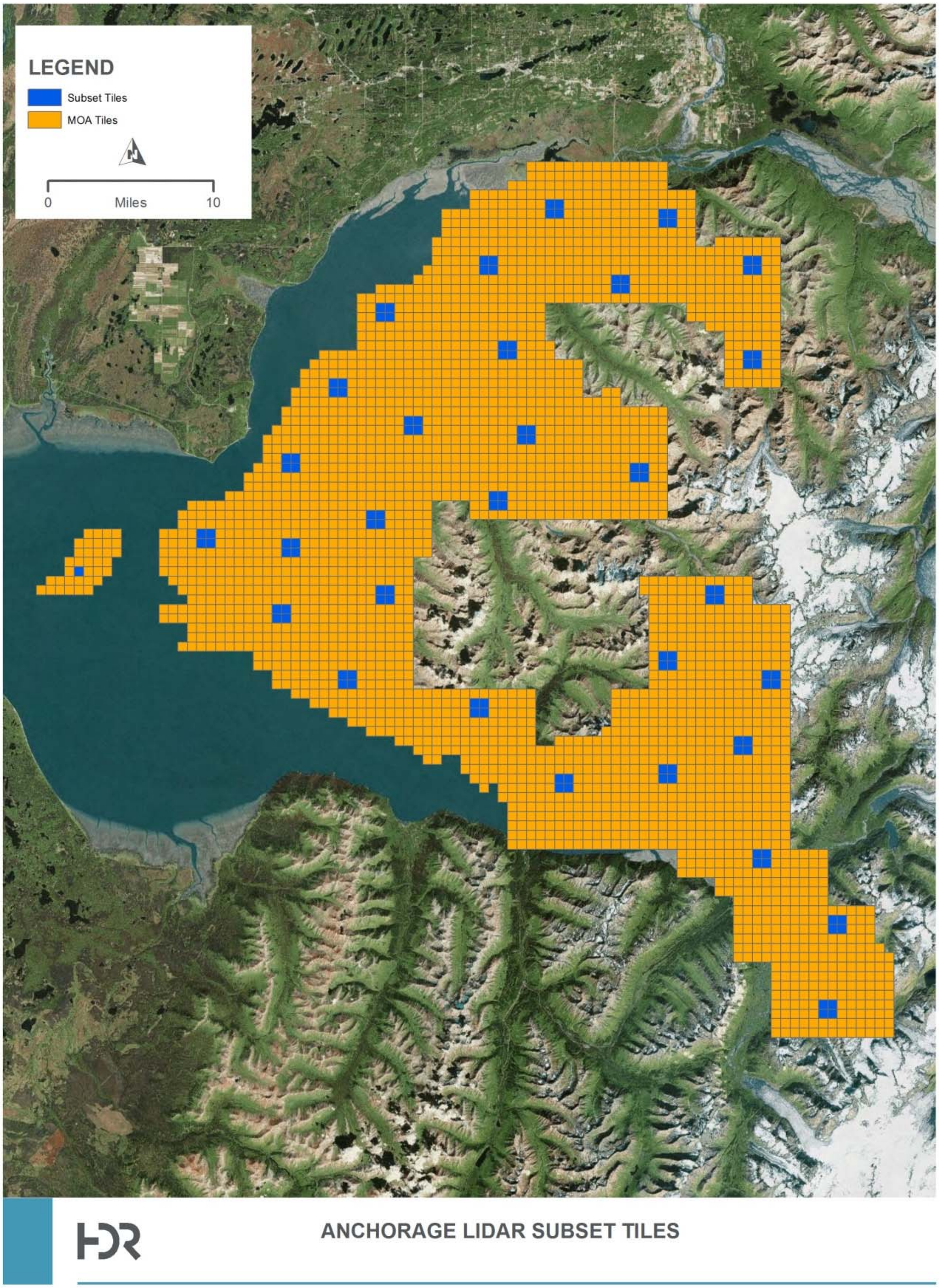

Figure 5 Selected tiles (blue) used in this assessment overlain on the LiDAR tiling scheme.

7.3 Vertical Accuracy

Vertical accuracy was assessed for the MOA72 LiDAR dataset using checkpoints provided with the data. The codes embedded in the data table indicate that most of the points were collected along roadways and in suburban neighborhoods, as indicated by the green points in **Figure 6**. Therefore, the accuracy for this dataset will simply be considered as Fundamental Vertical Accuracy (FVA) meaning it represents the accuracy over flat and open terrain. Two of the QC points were withheld from the reporting below because they were considered outliers, likely caused by survey points collected at the edge of a vertical feature such as on the top of a wall or stairs and may have skewed the results.

Table 9 Vertical Accuracy of the MOA72 dataset.

Code	# of Points	Land Cover Type	Average DZ	RMSE	STDV	Accuracy (1.96 * RMSE)
FVA	212	Edge of road	0.000(m)	0.105(m)	0.105(m)	0.205(m)

QC points were not provided in the NAVD88 vertical datum to check the NAVD88 LiDAR; however, HDR previously collected aerial LiDAR data around Anchorage in 2010. The QC points from the previous survey conducted by HDR were used to test the new NAVD88 aerial LiDAR data. The points were originally collected by a licensed surveyor experienced with LiDAR.

For this test the recycled QC points were adjusted from Geoid 06 to Geoid 12B, *assumed* to be the Geoid model used to adjust the new aerial LiDAR data to the NAVD88 vertical datum. All of the points were collected on hard flat surfaces, primarily on roads and parking lots. A few were collected on flat and level dirt in open terrain.

Table 10 Vertical Accuracy of the NAVD88 dataset

Code	# of Points	Land Cover Type	Average DZ	RMSE	STDV	Accuracy (1.96 * RMSE)
FVA	75	Flat and level surfaces	-0.077(m)	0.097(m)	0.060(m)	0.190(m)

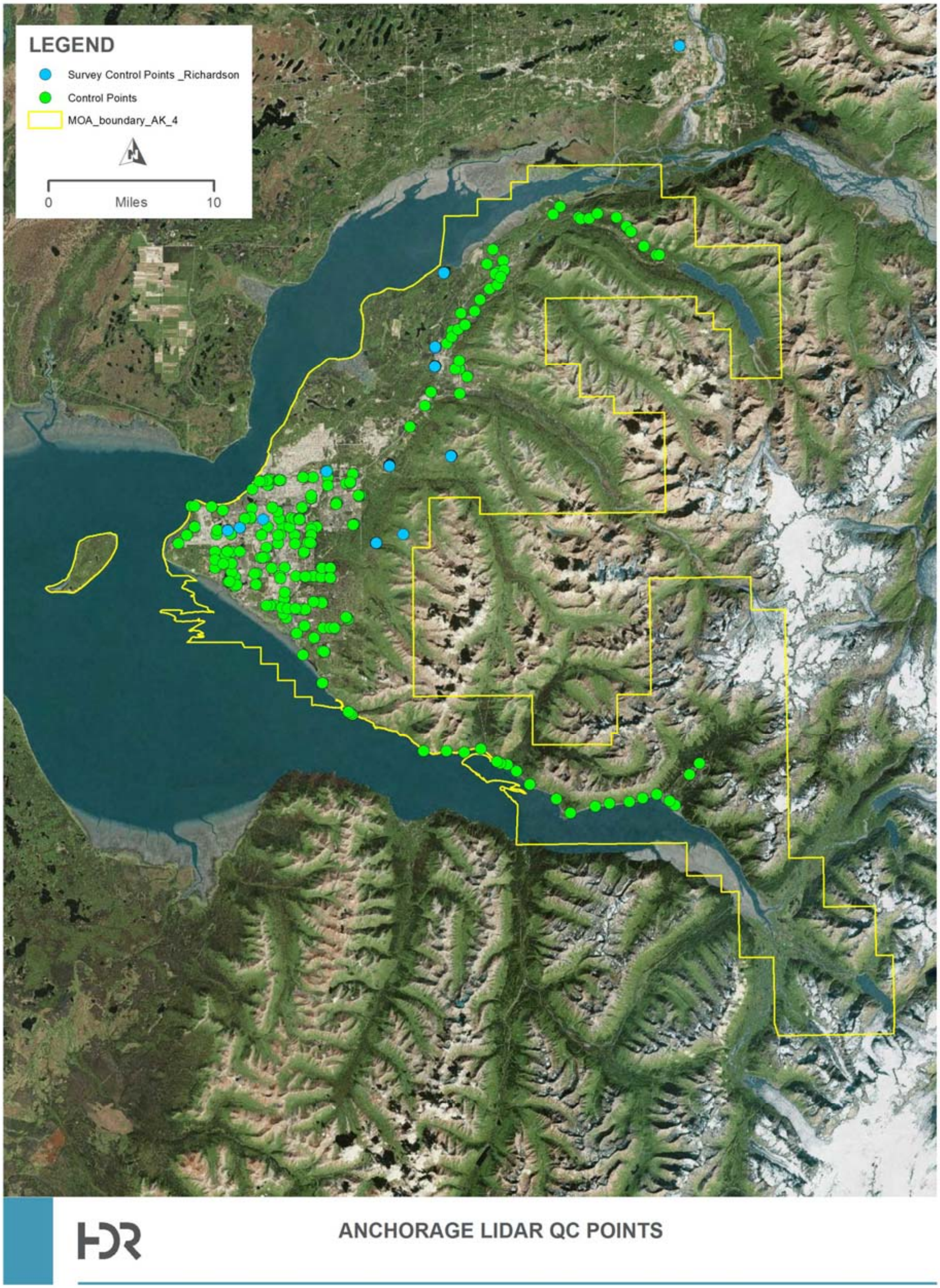

Figure 6 **Location of survey checkpoints provided with the data to assess the MOA72 dataset (green) and checkpoints previously collected by HDR used to assess the NAVD88 dataset.**

7.4 LiDAR Coverage

A visual analysis was performed to check for gaps between adjacent flightlines, often the result of a sensor malfunction or pilot error. HDR reviewed 100% of the tiles by loading all points and inspecting the edges of flightlines and boundaries of adjacent tiles. The no gaps were found in the final data; however there were several holes within individual flightlines (**Figure 8**) that were later filled. Some of the holes occur over the tops of mountains and may have been caused by the eye-safe shutoff being triggered when ground rapidly rose up to the aircraft.

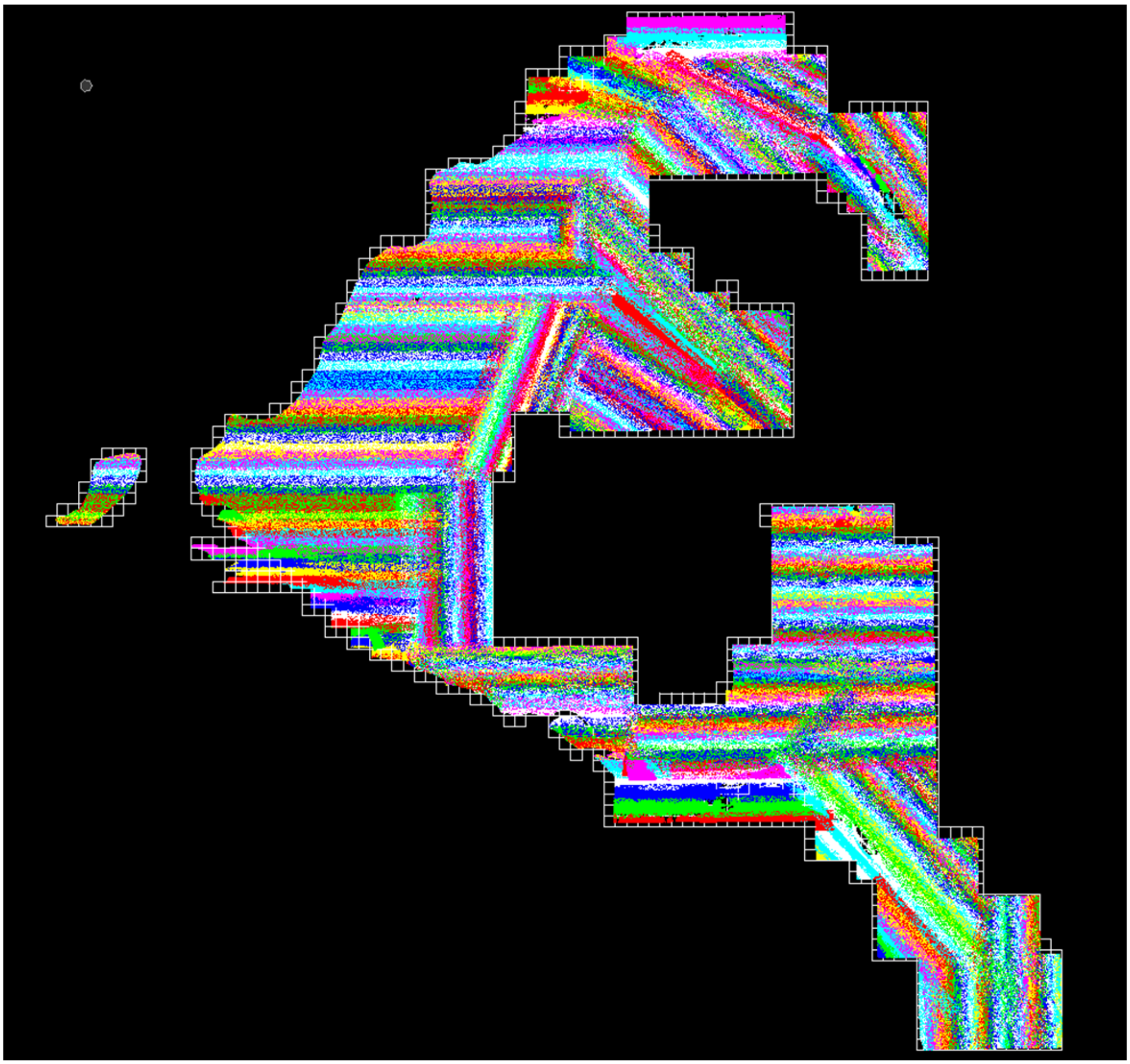

Figure 7 All flightlines color coded for display purposes.

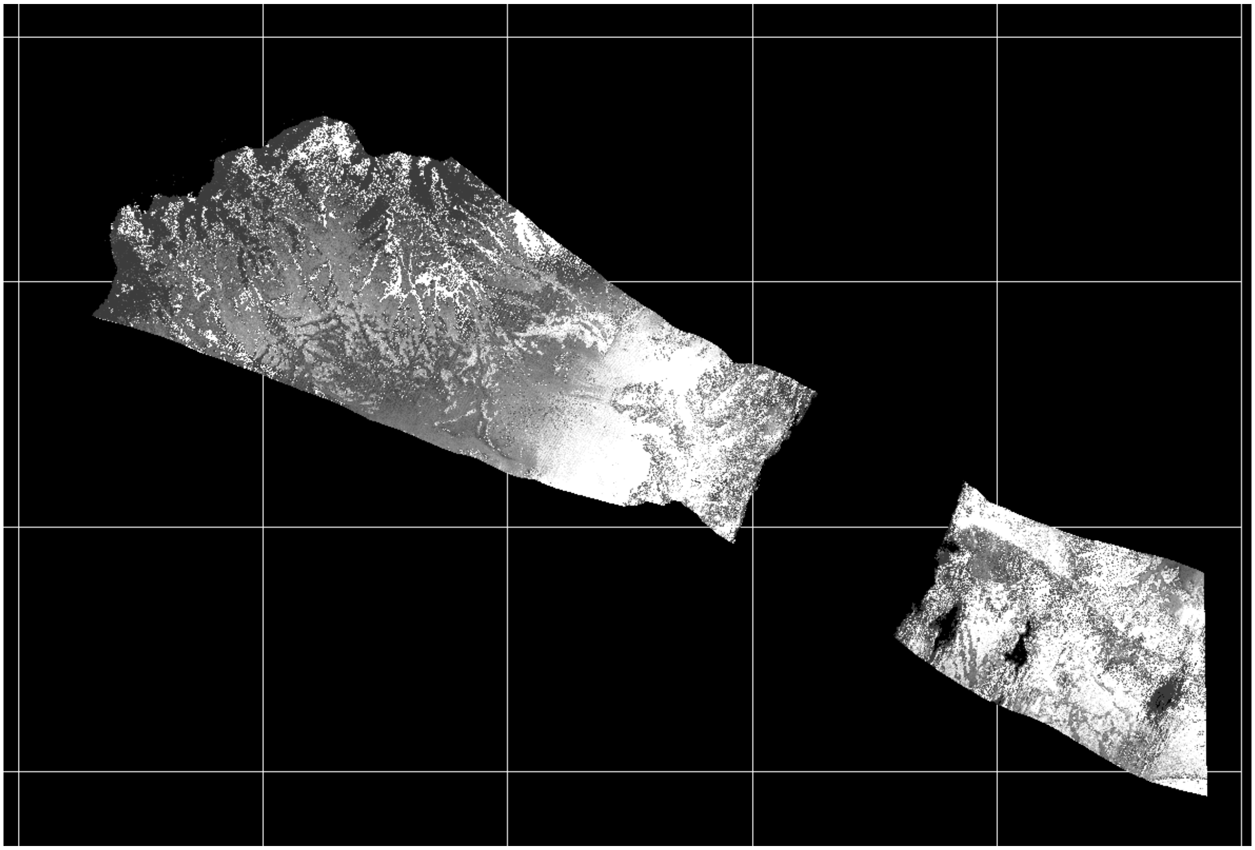

Figure 8 Top down view of a gap or hole in a single swath of data. The hole was later filled by another flightline. Tiles measuring 3'000 feet x 3'000 feet were included in the scene for scale.

7.5 Precision

To test the data for precision, numerous cross sectional profiles were drawn over rooftops in the city of Anchorage. A small bias was observed in the pitch and yaw (sometimes referred to as "crab") of the IMU resulting in a slight loss of precision. A few measurements were taken and a relative horizontal offset of approximately 0.7 feet was determined. **Figure 9** shows a screen capture of one such offset.

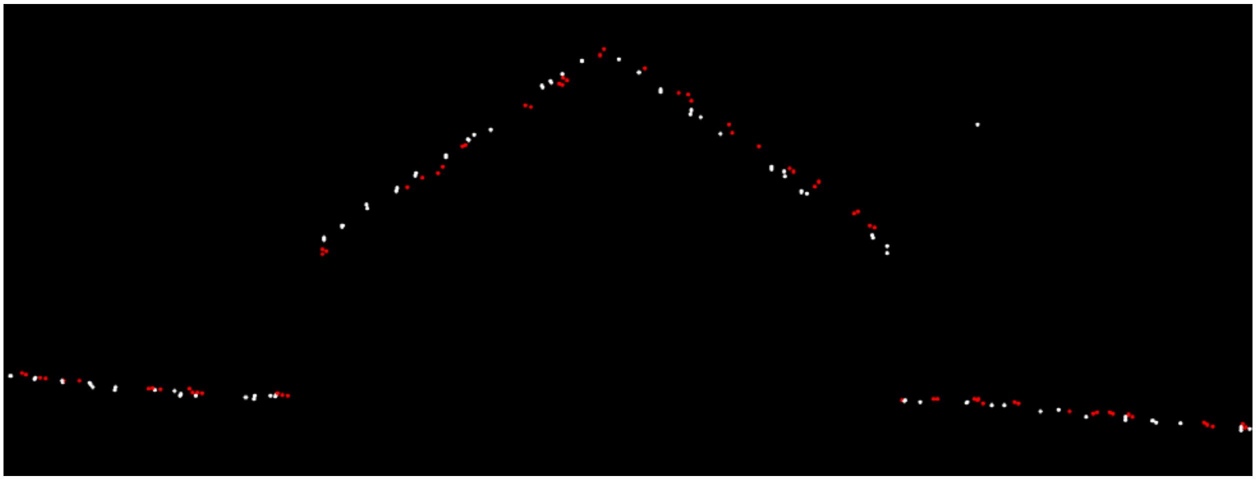

Figure 9 A small misalignment between overlapping swaths of data caused by a calibration error. The flightlines occur in opposing directions orthogonal to the apex of the rooftop and are color coded for illustration purposes.

7.6 Spatial Distribution of Points

A regularly spaced grid measuring 2 meters square was overlain on selected flightlines. Results from the test are reported as the percentage of cells with at least one first return echo, per flight line. Summary statistics are provided below. Detailed information is presented in **Appendix E**.

Table 11 Summary statistics for the spatial distribution of first return points by flightline.

Number of Flightlines tested	% Cells ≥ 1 Return	Standard Deviation	Max % Cells ≤1 Return	Max % Cells ≥ 1 Return
22	99.96%	0.0008	0.32%	100.00%

7.7 Classification

A visual inspection was preformed on the data to check for classification errors. The automated ground routine was fairly aggressive yet ground points were not observed in the vegetation as is often the case with an aggressive classification. Furthermore, the edges of cliffs and other areas of abrupt topographic change, which are often difficult to classify correctly through automation, were correctly classified as *ground* during the QC process. Bridges and elevated roads were manually classified as class 17 *bridge* by very careful review of the data during the QC process.

8 Discussion

The aerial LiDAR meets USGS specifications for QL 3 data based on vertical accuracy and tested to meet QL 2 based on survey data collected by HDR in 2010. The LiDAR data missed the USGS specification for vertical accuracy for QL2 data by 0.5cm when tested against survey data provided by Merrick.

The SOW provided by Merrick states that *"USGS QL2 calls for a 10cm absolute vertical accuracy"*. It is critical to point out that The USGS specifications call for 10cm *RMSE* and that vertical accuracy (defined as 2 x the RMSE) will be <20cm. Based on the QC points collected by HDR the data passes the specifications required by the USGS for QL2.

The NPS of the data varies between 1 point per square meter and better than 2 points per square meter in different geographic regions of the project. This may be the result of a change in data collection parameters during the course of the project.

The SOW states that "*USGS QL 2 calls for nominal LiDAR pulse spacing of no greater than 0.7 meter,"* which equates to a spot *density* of 2 points per square meter. This value actually represents the aggregate NPS from multiple swaths of data according to the USGS base specifications. Because the actual NPS tested > than 1 point per square meter and because the data was flown with ≥ 50% overlap the aggregate point density is > 2 points per square meter, so the data passes the specification required by the USGS, but technically does not pass the specification in the SOW.

The LiDAR data meets FEMA specifications for 2 foot contours based on vertical accuracy and NPS in flat and open areas; however, because the QC points were not collected in various land cover categories it is uncertain what contour interval will be supported in these (vegetated) areas.

Validation of the horizontal accuracy was not performed and is assumed to be correct. Horizontal checks are not as common as vertical checks and require special QC points based on topographic corners or well defined features clearly visible in the intensity data, which were not provided. ASPRS recommends using the sensor manufactures published horizontal accuracy estimates when determining horizontal accuracy. Primary factors involved in horizontal accuracy are collection altitude, proper data processing, and accuracy of the coordinates assigned to base station(s) used to post-process the LiDAR data.

A small (7cm) sensor / IMU calibration error was observed over suburbs in Anchorage. The error may present itself as noise on steeply pitched surfaces such as rooftops and rock faces, but should be negligible on roads and other flat terrain.

The point cloud classification schema is consistent with ASPRS and USGS standards for classification. It appears that a thorough QC of the classification (ground, vegetation, water, etc…) was performed on the data. Areas that exhibit rapid change in topography, such as cliffs, were correctly classified as ground despite these areas being difficult to classify through automation. A statistical test was not performed on the classification; however the data likely meet the common “95% correct” standard, which is the standard classification accuracy requirement for a majority of LiDAR projects.

The attribute information for each .las file is correct. In particular, attributes such as easting, northing, elevation, intensity, and GPS time are present and contain adequate significant figures. The .las file header information is present and contains the correct spatial reference information.

9 Glossary of Terms

American Society of Photogrammetry and Remote Sensing (ASPRS) Classification – A set of classification codes defined by the ASPRS used to flag LiDAR data by land coverage categories, e.g. ground, buildings, vegetation, and water.

Contours – Lines of equal elevation on a surface.

Consolidated Vertical Accuracy (CVA) – The result of a test of the accuracy of vertical checkpoints (z-values) consolidated for two or more of the major land cover categories, representing both open terrain and other land cover categories. Computed by using the 95th percentile, CVA is always accompanied by Fundamental Vertical Accuracy (FVA).

Digital Elevation Model (DEM) – An elevation model created for use in computer software where bare-earth elevation values have regularly spaced intervals in latitude and longitude (x and y).

DEM Post Spacing – Sometimes confused with Nominal Pulse Spacing, the DEM Post Spacing is defined as the constant sampling interval in x- and y-directions of a DEM lattice or grid. This is also called the horizontal resolution of a gridded DEM or the DEM grid spacing. It is standard industry practice to have:

- 1-meter DEM post spacing for elevation data with 1-foot equivalent contour accuracy;
- 2-meter DEM post spacing for elevation data with 2-foot equivalent contour accuracy;
- 5-meter DEM post spacing for elevation data with 5-foot equivalent contour accuracy.

Echo Return – Each of the multiple returns from an emitted laser pulse in a multiple-pulse-return laser scanning system (e.g. first, intermediate……..last).

Fundamental Vertical Accuracy (FVA) – The value by which vertical accuracy can be equitably assessed and compared among datasets. The FVA is determined with vertical checkpoints located only in open terrain, where there is a very high probability that the sensor will have detected the ground surface. FVA is calculated at the 95 percent (%) confidence level in open terrain only, using RMSEz x 1.9600

LAS – The LAS file format is a public file format for the interchange of 3-dimensional point cloud data between data users.

LiDAR – Light Detection and Ranging

Nominal Pulse Spacing (NPS) – Single swath first return values located within the geometrically usable portion (typically 90%) of each swath.

Point Cloud – Post-processed spatially organized LiDAR data. The initial point clouds are large collections of 3-D elevation points, which include x, y, and z, along with additional attributes such as GPS time stamps.

Point Density – The number of laser returns per unit area.

Post Processed Kinematic (PPK) Survey – A survey technique that surveys store raw observations and process them later.

Supplemental Vertical Accuracy (SVA) – The result of a test of the accuracy of z-values over areas with ground cover categories or combination of categories other than open terrain. Computed by using the 95th percentile, SVA is always accompanied by FVA. SVA values are computed individually for different land cover categories. Each land cover type representing 10% of more of the total project area is typically tested and reported as an SVA. SVA specifications are normally target values that may be exceeded so long as overall CVA requirements are satisfied.

National Standard for Spatial Data (NSSDA) Vertical Accuracy - The NSSDA reporting standard in the vertical component that equals the linear uncertainty value, such that the true or theoretical vertical location of the point falls within that linear uncertainty value 95% of the time. Accuracyz = 1.9600 x RMSEz. Vertical accuracy is defined as the positional accuracy of a dataset with respect to a vertical datum.

Root Mean Square Error (RMSE) – The square root of the average of the set of squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy for identical points.

Tile – A subset of LiDAR point cloud data.

Z-Values – The elevations of the 3-D surface above the vertical datum at designated x/y locations.

95% Confidence Level – Accuracy reported at the 95% confidence level means that 95% of the positions in the dataset will have an error with respect to true ground position that is equal to or smaller than the reported accuracy value. The reported accuracy value reflects all uncertainties, including those introduced by geodetic control coordinates, compilation, and final computation of ground coordinate values in the product.

A

Appendix A

Nominal Pulse Spacing By Flightline

Line #	Area (Square Feet)	Area (Square Meters)	Model Keypoints	Density (m)	NPS (m)
13	84754880	7873728.352	15626553	1.984644669	0.70983698
38	113918114	10582992.79	20025391	1.892223816	0.72696541
66	11518465	1070065.399	2924053	2.732592797	0.60494033
99	28847294	2679913.613	5376213	2.006114292	0.70602839
120	51388905	4774029.275	9918610	2.077618177	0.69377258
147	9088923	844360.9467	1696990	2.009792147	0.70538209
170	36240473	3366739.942	8057173	2.393167616	0.646418
201	80490971	7477611.206	15508562	2.073999513	0.69437756
230	36617322	3401749.214	3965160	1.165623845	0.92623415
252	30661567	2848459.574	5263477	1.847832789	0.73564564
284	86406358	8027150.658	11273917	1.404473079	0.84380732
309	107042740	9944270.546	10553815	1.061296045	0.97069262
337	159383781	14806753.25	19281558	1.302213772	0.8763122
366	87592968	8137386.727	10464039	1.28592131	0.88184611
399	41482688	3853741.715	10615923	2.754705371	0.60250745
426	66774610	6203361.269	6839767	1.102590467	0.95234188
455	71871119	6676826.955	8067323	1.208257014	0.90974638
484	127055403	11803446.94	13173127	1.116040684	0.9465858
511	120904010	11231982.53	12798440	1.139464023	0.93680606
544	154064288	14312572.36	19130583	1.336627863	0.86495745
569	83282155	7736912.2	18032005	2.330646198	0.65503096
588	24751930	2299454.297	6515694	2.833582737	0.59406238

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B

Appendix B

Ground Sample Distance By Tile

Tile ID	Area (m)	Ground Points	Point Density (m)	GSD (m)
80	836127.36	1311326	1.568	0.799
81	836127.36	2031864	2.430	0.641
107	836127.36	2696016	3.224	0.557
108	836127.36	1540943	1.843	0.737
119	836127.36	6073964	7.264	0.371
120	836127.36	4491330	5.372	0.431
146	836127.36	6623539	7.922	0.355
147	836127.36	8660032	10.357	0.311
254	836127.36	2574560	3.079	0.570
255	836127.36	2404444	2.876	0.590
282	836127.36	2076500	2.483	0.635
283	836127.36	2494339	2.983	0.579
292	836127.36	2603586	3.114	0.567
293	836127.36	2726668	3.261	0.554
320	836127.36	2410117	2.882	0.589
321	836127.36	2379598	2.846	0.593
345	836127.36	1590003	1.902	0.725
346	836127.36	1388989	1.661	0.776
388	836127.36	2009659	2.404	0.645
389	836127.36	1809800	2.165	0.680
453	836127.36	984554	1.178	0.922
454	836127.36	1025280	1.226	0.903
483	836127.36	1107066	1.324	0.869
484	836127.36	1168862	1.398	0.846
580	836127.36	3487077	4.171	0.490
581	836127.36	3683411	4.405	0.476
611	836127.36	1888125	2.258	0.665
612	836127.36	2882401	3.447	0.539
619	836127.36	1180232	1.412	0.842
620	836127.36	2565523	3.068	0.571
654	836127.36	1054562	1.261	0.890
655	836127.36	2129366	2.547	0.627
697	836127.36	1038064	1.242	0.897
698	836127.36	1108777	1.326	0.868
734	836127.36	1094857	1.309	0.874
735	836127.36	1106186	1.323	0.869

Tile ID	Area (m)	Ground Points	Point Density (m)	GSD (m)
852	836127.36	2746005	3.284	0.552
853	836127.36	2750905	3.290	0.551
894	836127.36	2539043	3.037	0.574
895	836127.36	1613153	1.929	0.720
906	836127.36	501753	0.600	1.291
907	836127.36	669869	0.801	1.117
949	836127.36	965058	1.154	0.931
950	836127.36	806532	0.965	1.018
1010	836127.36	3115533	3.726	0.518
1011	836127.36	3002094	3.590	0.528
1054	836127.36	2768624	3.311	0.550
1055	836127.36	2143022	2.563	0.625
1091	836127.36	1840313	2.201	0.674
1092	836127.36	1580213	1.890	0.727
1136	836127.36	1500114	1.794	0.747
1137	836127.36	1665487	1.992	0.709
1213	836127.36	831619	0.995	1.003
1214	836127.36	1014858	1.214	0.908
1260	836127.36	649672	0.777	1.134
1261	836127.36	1047633	1.253	0.893
1299	836127.36	1318572	1.577	0.796
1300	836127.36	1121577	1.341	0.863
1347	836127.36	1261168	1.508	0.814
1348	836127.36	1119907	1.339	0.864
1362	836127.36	2972981	3.556	0.530
1363	836127.36	2862547	3.424	0.540
1396	836127.36	2742328	3.280	0.552
1397	836127.36	3092211	3.698	0.520
1405	836127.36	2286247	2.734	0.605
1406	836127.36	2284094	2.732	0.605
1439	836127.36	2151226	2.573	0.623
1440	836127.36	2039920	2.440	0.640
1488	836127.36	1836319	2.196	0.675
1590	836127.36	1043736	1.248	0.895
1591	836127.36	1097387	1.312	0.873
1601	836127.36	675406	0.808	1.113

Tile ID	Area (m)	Ground Points	Point Density (m)	GSD (m)
1602	836127.36	487249	0.583	1.310
1626	836127.36	732986	0.877	1.068
1627	836127.36	922613	1.103	0.952
1636	836127.36	911645	1.090	0.958
1637	836127.36	911359	1.090	0.958
1653	836127.36	2159333	2.583	0.622
1654	836127.36	2210299	2.643	0.615
1695	836127.36	1871049	2.238	0.668
1696	836127.36	1906368	2.280	0.662
1861	836127.36	824631	0.986	1.007
1862	836127.36	798314	0.955	1.023
1893	836127.36	849474	1.016	0.992
1894	836127.36	870905	1.042	0.980
1914	836127.36	1299058	1.554	0.802
1915	836127.36	643996	0.770	1.139
1934	836127.36	1151262	1.377	0.852
1935	836127.36	1185459	1.418	0.840
1944	836127.36	1294046	1.548	0.804
1945	836127.36	616369	0.737	1.165
1964	836127.36	1110234	1.328	0.868
1965	836127.36	1277530	1.528	0.809
2029	836127.36	1440154	1.722	0.762
2030	836127.36	970682	1.161	0.928
2070	836127.36	825230	0.987	1.007
2071	836127.36	823468	0.985	1.008
2207	836127.36	344926	0.413	1.557
2208	836127.36	593176	0.709	1.187
2247	836127.36	764426	0.914	1.046
2248	836127.36	997647	1.193	0.915
2311	836127.36	956014	1.143	0.935
2312	836127.36	710191	0.849	1.085
2334	836127.36	1495635	1.789	0.748
2335	836127.36	1308773	1.565	0.799
2345	836127.36	1061323	1.269	0.888
2346	836127.36	1224065	1.464	0.826
2366	836127.36	936131	1.120	0.945

Tile ID	Area (m)	Ground Points	Point Density (m)	GSD (m)
2367	836127.36	1385598	1.657	0.777
2580	836127.36	1031609	1.234	0.900
2581	836127.36	1396710	1.670	0.774
2596	836127.36	1333187	1.594	0.792
2597	836127.36	1591784	1.904	0.725
2679	836127.36	1143329	1.367	0.855
2680	836127.36	922218	1.103	0.952
2694	836127.36	1488053	1.780	0.750
2695	836127.36	1280243	1.531	0.808
2804	836127.36	1425238	1.705	0.766
2805	836127.36	1392338	1.665	0.775
2817	836127.36	1368451	1.637	0.782
2818	836127.36	1383394	1.655	0.777

C

Appendix C

Vertical Accuracy
(MOA72 LiDAR)

QC Point Name	Easting(ft)	Northing(ft)	Known(ft)	Laser Z(ft)	DZ(ft)	DZ(m)
839	1685593.236	2594529.755	950.77	950.74	-0.03	-0.009
3101	1721427.462	2673923.659	592.68	592.14	-0.54	-0.165
3172	1723309.435	2688019.615	480.99	removed	*	*
3108	1675007.567	2599532.098	419.11	419.58	0.47	0.143
3109	1675148.84	2588033.198	384.77	385.14	0.37	0.113
3085	1688017.282	2624518.279	328.17	327.9	-0.27	-0.082
3086	1687704.141	2624394.988	325.26	325.21	-0.05	-0.015
3087	1687601.092	2624251.781	323.94	323.67	-0.27	-0.082
3055	1689910.028	2633544.517	282.78	282.45	-0.33	-0.101
3056	1689440.534	2633279.247	282.62	282.24	-0.38	-0.116
3057	1689439.419	2633542.22	280.18	279.75	-0.43	-0.131
3081	1735618.086	2705254.064	277.89	277.05	-0.84	-0.256
3058	1689310.07	2633536.487	277.79	277.65	-0.14	-0.043
3107	1672122.978	2591915.58	274.8	275.29	0.49	0.149
850	1687421.622	2640405.841	270.62	outside	*	*
3113	1673859.888	2618546.406	184.12	184.16	0.04	0.012
3112	1673141.776	2618485.37	183.41	183.33	-0.08	-0.024
975	1668402.158	2626214.526	172.92	172.62	-0.3	-0.091
3080	1730206.75	2707254.032	168.29	167.32	-0.97	-0.296
3061	1674721.488	2639439.121	163.45	163.23	-0.22	-0.067
3030	1669041.414	2618199.18	153.01	153.16	0.15	0.046
559	1669614.01	2589418.68	150.68	151.04	0.36	0.110
3	1665830.987	2610429.446	147.47	147.08	-0.39	-0.119
3152	1665830.987	2610429.446	147.47	147.08	-0.39	-0.119
3029	1674248.604	2633648.108	145.96	145.71	-0.25	-0.076
3163	1666275.024	2594398.09	145.8	145.42	-0.38	-0.116
3164	1665430.029	2595687.689	145.08	144.8	-0.28	-0.085
3028	1674246.905	2632829.191	141.78	141.55	-0.23	-0.070
3027	1674252.892	2632508.038	139.61	139.37	-0.24	-0.073
3026	1667348.009	2623494.473	137.78	137.87	0.09	0.027
3008	1671395.972	2629751.475	133.59	133.27	-0.32	-0.098
3093	1646929.565	2614581.476	125.95	126.12	0.17	0.052
3047	1661229.764	2598276.564	122.83	122.89	0.06	0.018
672	1658434.413	2620892.95	120.29	121.2	0.91	0.277
93	1648877.317	2611806.276	118.74	118.51	-0.23	-0.070
3092	1646929.03	2615352.627	114.83	115.05	0.22	0.067
3048	1659961.739	2598270.195	113.39	outside	*	*
10	1664066.594	2626228.139	110.99	110.81	-0.18	-0.055
3040	1663614.508	2628377.246	109.44	109.09	-0.35	-0.107

QC Point Name	Easting(ft)	Northing(ft)	Known(ft)	Laser Z(ft)	DZ(ft)	DZ(m)
3133	1733428.355	2548584.746	108.31	108.46	0.15	0.046
3031	1659925.025	2616896.389	107.76	108.11	0.35	0.107
3088	1661833.363	2629796.548	106.58	106.38	-0.2	-0.061
3003	1660593.247	2636909.123	106.27	106	-0.27	-0.082
3004	1660322.305	2636905.047	105.9	105.64	-0.26	-0.079
1802	1651552.359	2615600.972	92.86	93.01	0.15	0.046
91	1648948.915	2609041.072	88.65	88.62	-0.03	-0.009
3140	1743785.339	2541269.978	79.47	79.5	0.03	0.009
3131	1736680.919	2547563.945	75.03	75.31	0.28	0.085
3130	1739628.7	2545457.259	72.37	72.67	0.3	0.091
3141	1756770.214	2532161.506	62.8	62.86	0.06	0.018
3132	1734463.492	2548041.239	62.31	62.7	0.39	0.119
3054	1650461.311	2604972.377	59.92	60.16	0.24	0.073
3053	1650023.624	2604533.039	56.63	56.52	-0.11	-0.034
3052	1649962.397	2604811.107	55.23	55.81	0.58	0.177
3143	1723027.59	2551518.2	54.54	54.69	0.15	0.046
3089	1647761.766	2605793.943	53.24	53.2	-0.04	-0.012
3134	1728297.958	2552593.485	52.95	53.09	0.14	0.043
3091	1648241.614	2605982.659	48.5	48.69	0.19	0.058
3090	1648002.256	2605929.291	48.1	48.21	0.11	0.034
3144	1709999.63	2551979.02	46.97	46.6	-0.37	-0.113
3135	1717307.714	2552028.104	43.34	43.54	0.2	0.061
3136	1687295.733	2563574.017	37.62	37.89	0.27	0.082
3138	1686104.639	2564496.297	36.21	36.62	0.41	0.125
3139	1677845.561	2573738.09	33.56	34.05	0.49	0.149
3137	1686759.461	2563941.544	33.52	34.02	0.5	0.152
3124	1784274.42	2538172.929	29.83	30.11	0.28	0.085
3123	1790121.395	2534721.259	27.58	28.08	0.5	0.152
3129	1752239.347	2536650.795	26.54	26.54	0	0.000
3127	1769218.935	2535147.549	26.3	26.57	0.27	0.082
3125	1779758.795	2536945.339	26.09	26.46	0.37	0.113
3126	1775522.156	2535797.151	25.33	outside	*	*
3128	1764687.758	2534241.866	23.5	removed	*	*
554	1671654.3	2582745.39	17.32	17.25	-0.07	-0.021
3045	1660585.515	2638790.721	16.94	16.59	-0.35	-0.107

D

Appendix D

Vertical Accuracy (NAVD88 LiDAR)

QC Point Name	Easting (ft)	Northing (ft)	Known (ft)	Laser Z (ft)	DZ (ft)	Dz (m)
pi200	1713706	2680985.6	274.53	274.19	-0.34	-0.10363
pi201	1713751	2680989.5	274.336	274.03	-0.306	-0.09327
pi202	1713747	2680936.2	272.837	272.64	-0.197	-0.06005
pi203	1699143	2643098.9	429.782	429.98	0.198	0.06035
pi204	1699151	2643215.6	431.242	431.46	0.218	0.066446
pi207	1713627	2674742.3	310.96	310.6	-0.36	-0.10973
pi208	1716638	2704646	38.464	outside	*	*
pp205	1718860	2646168.3	2235.646	2235.3	-0.346	-0.10546
pp206	1694799	2618394	960.503	960.55	0.047	0.014326
pp209	1703568	2621143.6	2835.607	2835.44	-0.167	-0.0509
qc1000	1713727	2680960.1	273.962	273.6	-0.362	-0.11034
qc1001	1713726	2680686.4	262.696	262.23	-0.466	-0.14204
qc1002	1713736	2680685.1	262.568	262.11	-0.458	-0.1396
qc1003	1713748	2680685.6	262.453	262.06	-0.393	-0.11979
qc1004	1713758	2680686.6	262.378	262.02	-0.358	-0.10912
qc1005	1713772	2680688.3	262.253	261.86	-0.393	-0.11979
qc1006	1713787	2680691	262.42	261.97	-0.45	-0.13716
qc1007	1713785	2680679.2	262.145	261.61	-0.535	-0.16307
qc1008	1713777	2680671.4	262.036	261.52	-0.516	-0.15728
qc1009	1713768	2680665.3	262.043	261.52	-0.523	-0.15941
qc1010	1713761	2680662	261.988	261.53	-0.458	-0.1396
qc1011	1713750	2680661.7	262.145	261.61	-0.535	-0.16307
qc1012	1713740	2680664.4	262.171	261.81	-0.361	-0.11003
qc1013	1699143	2643098.9	429.805	429.98	0.175	0.05334
qc1014	1699166	2643212.7	431.702	431.63	-0.072	-0.02195
qc1015	1699168	2643187.8	431.462	431.55	0.088	0.026822
qc1016	1699166	2643164.9	431.042	431.17	0.128	0.039014
qc1017	1699165	2643140.4	430.704	430.54	-0.164	-0.04999
qc1018	1699164	2643116.8	430.353	430.23	-0.123	-0.03749
qc1019	1699163	2643097.9	430.061	429.97	-0.091	-0.02774
qc1020	1699162	2643080	429.704	429.48	-0.224	-0.06828
qc1021	1699161	2643062.7	429.359	429.38	0.021	0.006401
qc1022	1699157	2643042.7	428.828	428.6	-0.228	-0.06949
qc1023	1699155	2643025.9	428.424	428.47	0.046	0.014021
qc1024	1699153	2643007.9	428.017	428.25	0.233	0.071018
qc1025	1718860	2646168.3	2235.603	2235.29	-0.313	-0.0954
qc1026	1718880	2646096.3	2229.848	2229.48	-0.368	-0.11217
qc1027	1718870	2646092	2229.395	2229.11	-0.285	-0.08687

QC Point Name	Easting (ft)	Northing (ft)	Known (ft)	Laser Z (ft)	DZ (ft)	Dz (m)
qc1028	1718857	2646085.4	2228.812	2228.49	-0.322	-0.09815
qc1029	1718842	2646079.2	2228.165	2227.84	-0.325	-0.09906
qc1030	1718829	2646072.6	2227.257	2227.22	-0.037	-0.01128
qc1031	1718817	2646067.2	2226.574	2226.37	-0.204	-0.06218
qc1032	1718806	2646058.9	2225.596	2225.52	-0.076	-0.02316
qc1033	1718794	2646052.6	2224.914	2224.66	-0.254	-0.07742
qc1034	1718783	2646046.7	2224.104	2223.78	-0.324	-0.09876
qc1035	1718772	2646040.8	2223.306	2223.16	-0.146	-0.0445
qc1036	1718762	2646036.2	2222.713	2222.49	-0.223	-0.06797
qc1037	1694799	2618394	960.411	960.55	0.139	0.042367
qc1038	1694810	2618320.5	959.053	958.88	-0.173	-0.05273
qc1039	1694834	2618327.4	959.155	958.85	-0.305	-0.09296
qc1040	1694859	2618333.1	959.319	outside	*	*
qc1041	1694908	2618340.1	960.037	959.89	-0.147	-0.04481
qc1042	1694924	2618341	960.503	960.3	-0.203	-0.06187
qc1043	1694937	2618339.8	960.887	960.71	-0.177	-0.05395
qc1044	1694949	2618340.7	961.425	961.18	-0.245	-0.07468
qc1045	1694949	2618340.7	961.451	961.18	-0.271	-0.0826
qc1046	1694959	2618340.4	961.894	961.71	-0.184	-0.05608
qc1047	1694971	2618340.2	962.534	962.36	-0.174	-0.05304
qc1048	1694984	2618340.8	963.262	963.06	-0.202	-0.06157
qc1050	1713635	2674742.4	310.95	310.5	-0.45	-0.13716
qc1051	1713641	2674742.5	311.098	310.7	-0.398	-0.12131
qc1052	1713647	2674742.5	311.114	310.79	-0.324	-0.09876
qc1053	1713654	2674742.5	311.279	310.88	-0.399	-0.12162
qc1054	1713662	2674742.6	311.383	311.01	-0.373	-0.11369
qc1055	1713668	2674742.6	311.498	311.01	-0.488	-0.14874
qc1056	1713679	2674742.8	311.623	311.26	-0.363	-0.11064
qc1057	1713689	2674742.9	311.741	311.33	-0.411	-0.12527
qc1058	1713681	2674716.7	312.105	311.79	-0.315	-0.09601
qc1059	1713666	2674715.8	311.938	311.66	-0.278	-0.08473
qc1060	1713649	2674716	311.679	311.31	-0.369	-0.11247
qc1070	1716558	2704486.4	37.729	37.2	-0.529	-0.16124
skycp1	1651489	2623285.4	76.148	75.75	-0.398	-0.12131
skycp100	1713727	2680960.1	273.952	273.6	-0.352	-0.10729
skycp2	1647634	2622457.2	83.507	82.99	-0.517	-0.15758
skycp3	1647641	2622407.5	83.576	83.24	-0.336	-0.10241