NE_CherryBrownCuster_South_Block_QC

Summary USGS National Geospatial Program Lidar Base Specification Version 2.1 Report

Quality level tested: QL2

Report generated on 9/16/2021

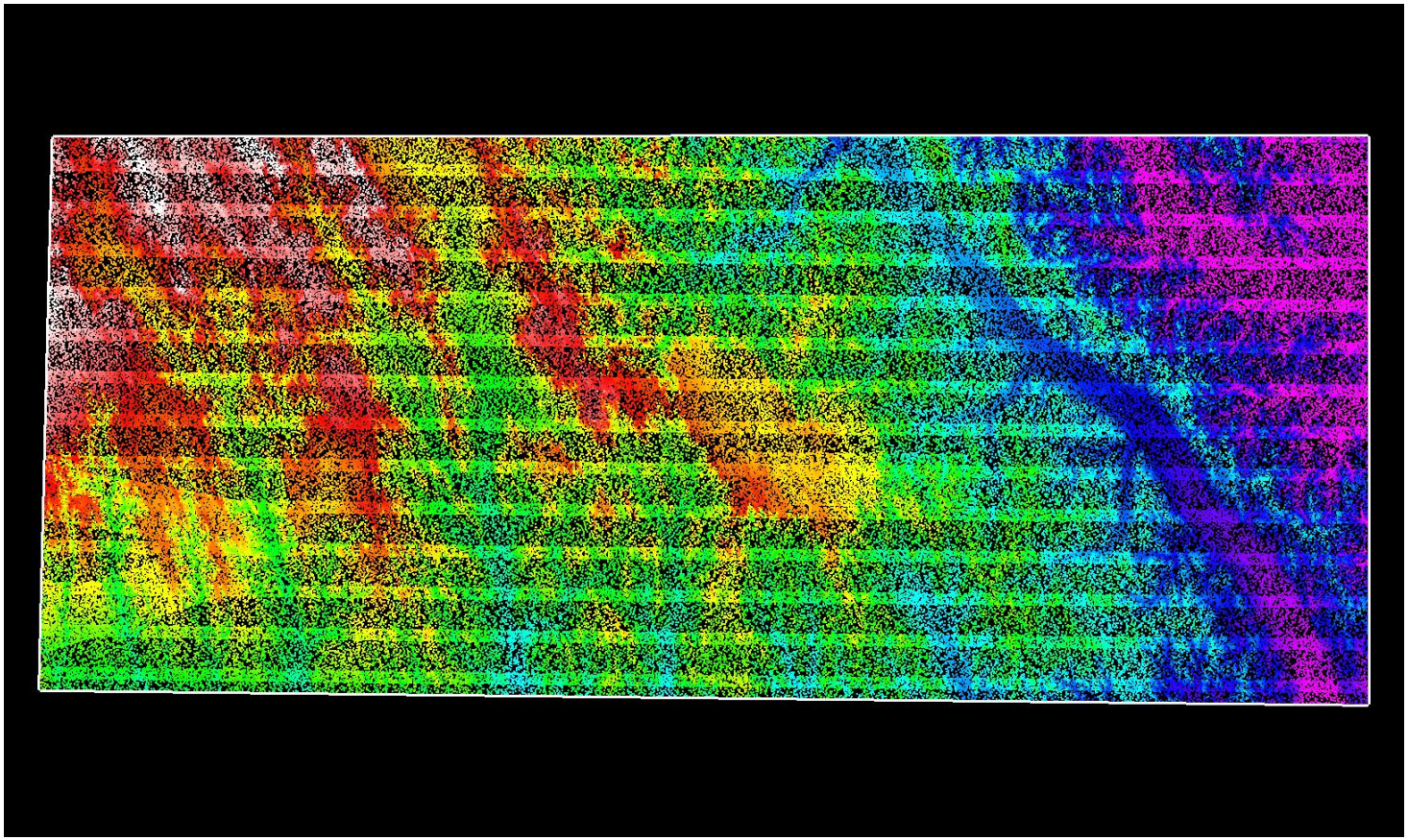
This document reports on compliance with the USGS National Geospatial Program Lidar Base Specification Version 2.1. The complete specification, which also contains a list of abbreviations, acronyms, and a glossary of related terms, can be found here.

Test Number	No Issue Points Identified	Test Results Need Review	Unable to Grade See Report Content
C-1			X
C-2			X
C-3			X
C-4.1	X		
C-5			X
C-6.1	X		
C-6.2	X		
C-7			X
DPH-1.1	X		
DPH-1.2	X		
DPH-1.3			X
DPH-1.4			X
DPH-2			Skipped
DPH-3	X		
DPH-4	X		
DPH-5	X		
DPH-6	X		
DPH-7.1	X		
DPH-7.2		X	
DPH-8			X
DPH-9.1	X		
DPH-9.2			Skipped
DPH-10			X
DPH-11	X		
DPH-12			X
DPH-13			X
DPH-14			X
DPH-15			X
DPH-16			X

C-1 Report on Collection Area

The USGS Lidar Base Specification Version 2.1 states: "The Defined Project Area (DPA) shall be the Area of Interest (AOI) plus a 100-meter buffer. Data collection is required for the full extent of the DPA. All products shall be produced to 3DEP and Task Order requirements up the edge of the DPA. All data and products shall be delivered to the customer for the full extent of the DPA. All products, including checkpoints, shall be located within or otherwise clipped to DPA extents."

The purpose of this section is to show lidar coverage to the extent of a 100 meter buffer of the defined project area (DPA) boundary.



White polygon is defined project area (DPA) boundary

C-2 Report on Multiple Discrete Returns

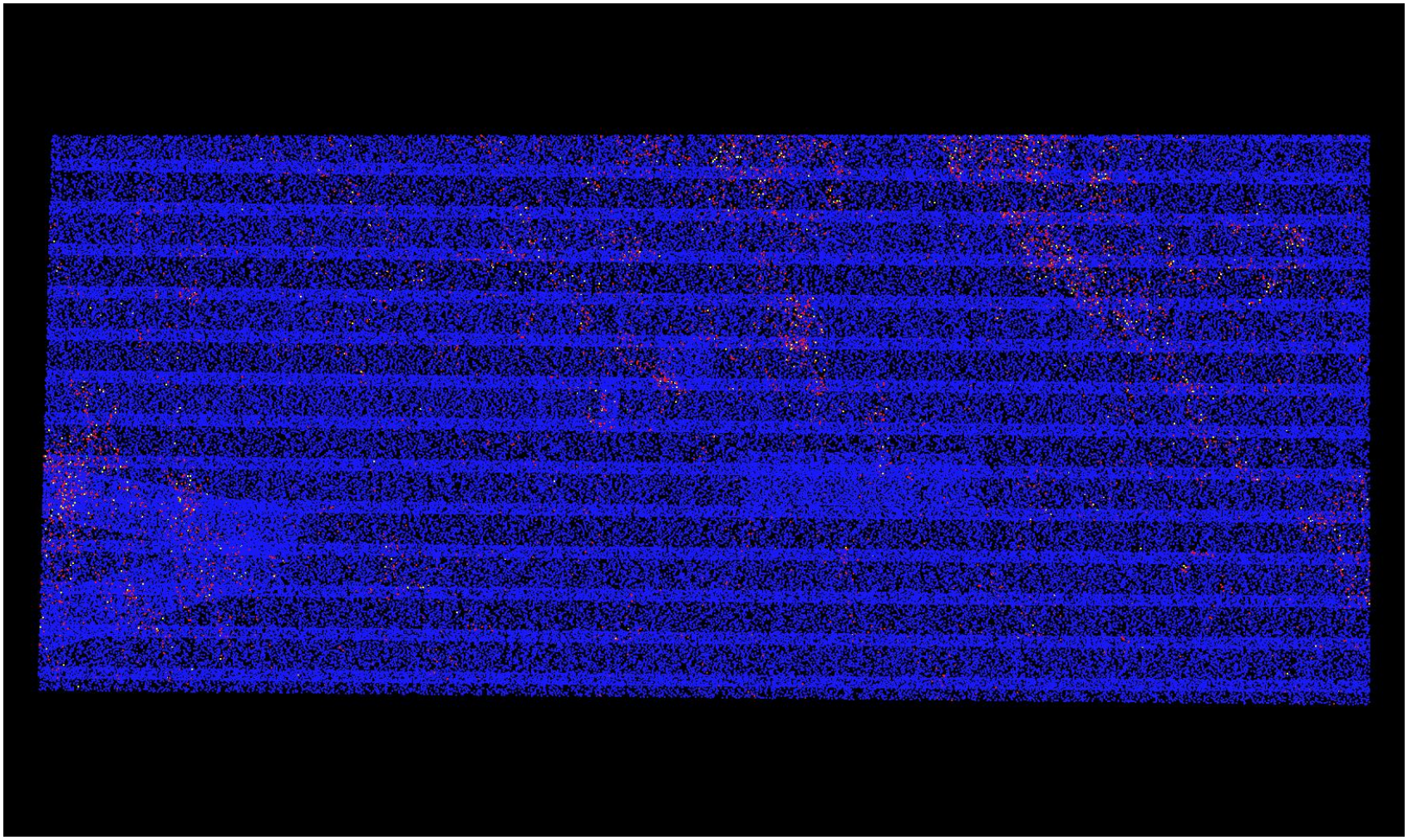
The USGS Lidar Base Specification Version 2.1 states: "Deriving and delivering multiple discrete returns are required in all conventional lidar data collection efforts. Data collection shall be capable of at least three returns per pulse. Full waveform collection is acceptable and is promoted; however, full waveform data are regarded as supplemental information."

The purpose of this section is to report on the presence and quantities of lidar returns in the LAS data. Empty return columns can indicate a collection or processing problem dealing with lidar return attribute information.

File	First return	Second return	Third return	Other returns	Total points
Total	4,438,251,584	114,581,447	15,258,853	724,994	4,568,816,878

C-2 Report on Multiple Discrete Returns - All Returns

The purpose of this section is to show a graphic of lidar data points colored by all returns. Blank flight lines can indicate a collection or processing problem dealing with lidar return attribute information.



C-3 Report on Intensity Values

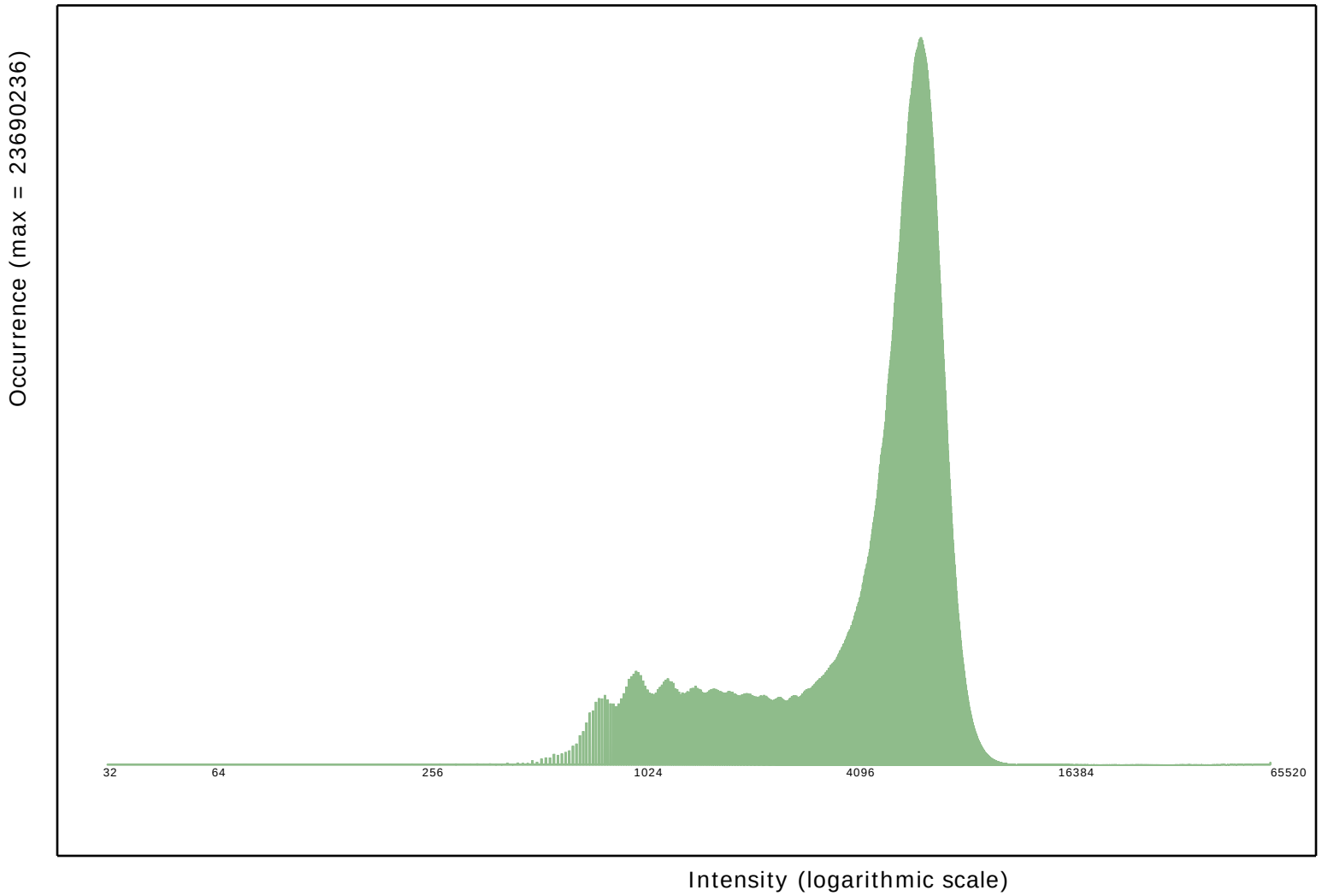
The USGS Lidar Base Specification Version 2.1 states: "Intensity values are required for each multiple discrete return. The intensity values recorded in the LAS files shall be normalized to 16 bit, as required by the LAS Specification version 1.4-R13 (ASPRS, 2011). Intensity normalization should be strictly linear. Common image stretches (minimum-maximum, standard deviations, percent clip, histogram, and so forth) are expressly forbidden."

The purpose of this section is to report on the presence and quantities of lidar intensity in the LAS data.

File	Minimum	Maximum	Mean	Median	Mode
Overall Statistics	32	65,520	6,143	6,432	6,688

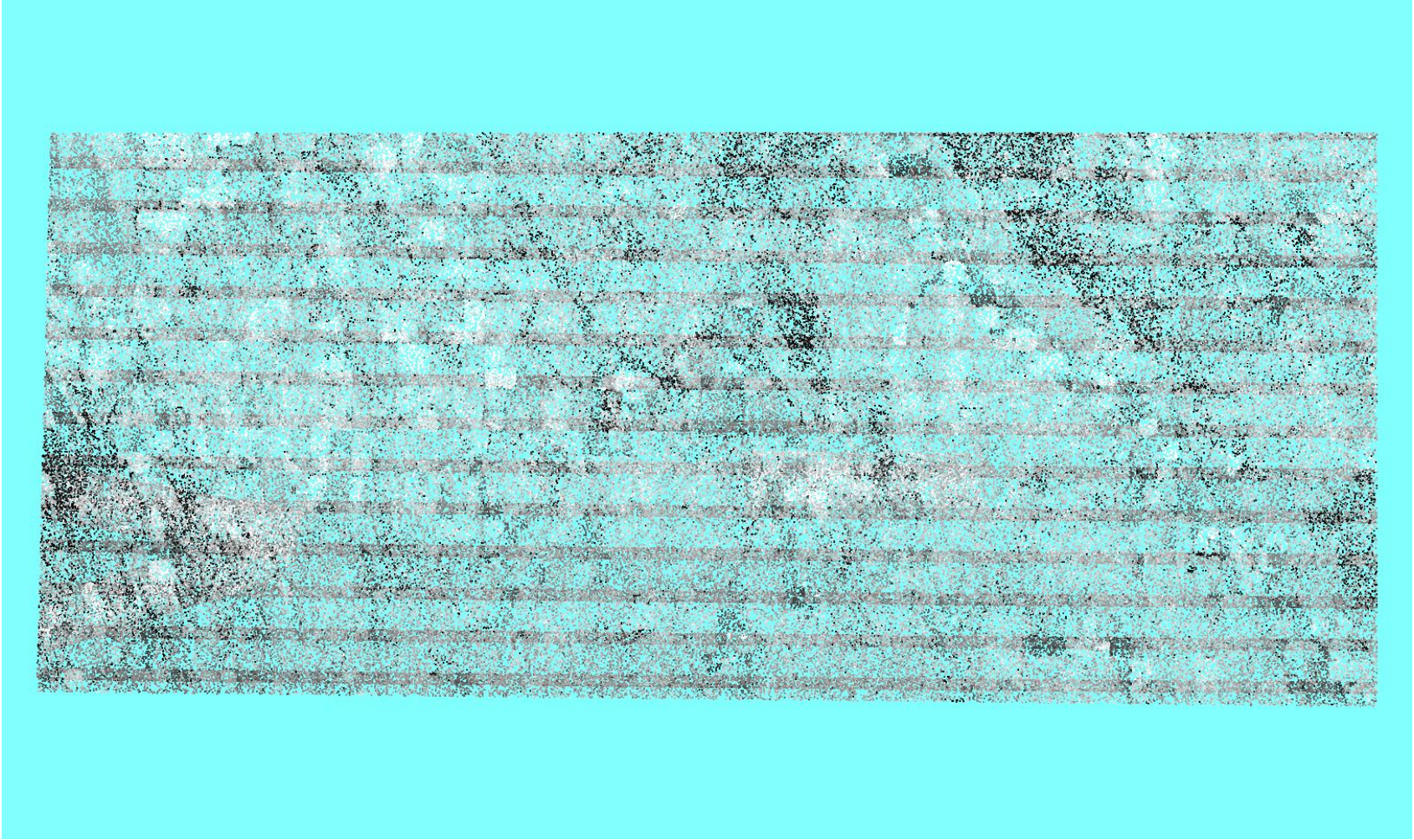
C-3 Report on Intensity Values - continued

The purpose of this section is to show a frequency distribution chart of intensities throughout all of the lidar files.



C-3 Report on Intensity Values - continued

The purpose of this section is to show a graphic of lidar data points colored by intensity. Blank flight lines can indicate a collection or processing problem dealing with lidar intensity attribute information.



C-4.1 Report on Nominal Pulse Spacing (NPS)

The USGS Lidar Base Specification Version 1.3 states: "Assessment and reporting of the NPS are made against single swath, single instrument, first-return-only data, including only the geometrically usable part of the swath and excluding acceptable data voids. Higher net densities of lidar point measurements are being achieved more often by flying multiple passes of the lidar instrument over the project area or flying with large amounts (greater than [>] 50 percent) of overlap between swaths, creating a need for a new term to describe total pulse density without being confused with NPS and NPD. This specification will use the terms aggregate nominal pulse spacing (ANPS) and aggregate nominal pulse density (ANPD) to describe the net overall pulse spacing and density, respectively. The required ANPS and ANPD by QL are listed in Table 1. Dependent on the local terrain and land cover conditions in a project, a greater pulse density may be required on specific projects."

Table 1. Aggregate nominal pulse spacing and density.

[QL, quality level; pls/m^2, pulses per square meter; m, meter; ≤, less than or equal to; ≥, greater than or equal to]

Quality level	Aggregate nominal pulse spacing (m)	Aggregate nominal pulse density (pls/m^2)
QL0	≤0.35	≥8.0
QL1	≤0.35	≥8.0
QL2	≤0.71	≥2.0
QL3	≤1.41	≥0.5

The purpose of this section is to report on the lidar point density and nominal point spacing by LAS file. Averages by files (not including overlap), project boundary polygons (including overlap), and aggregate project boundary polygons (including overlap) are reported.

Quality level tested: QL2

Units: Meter

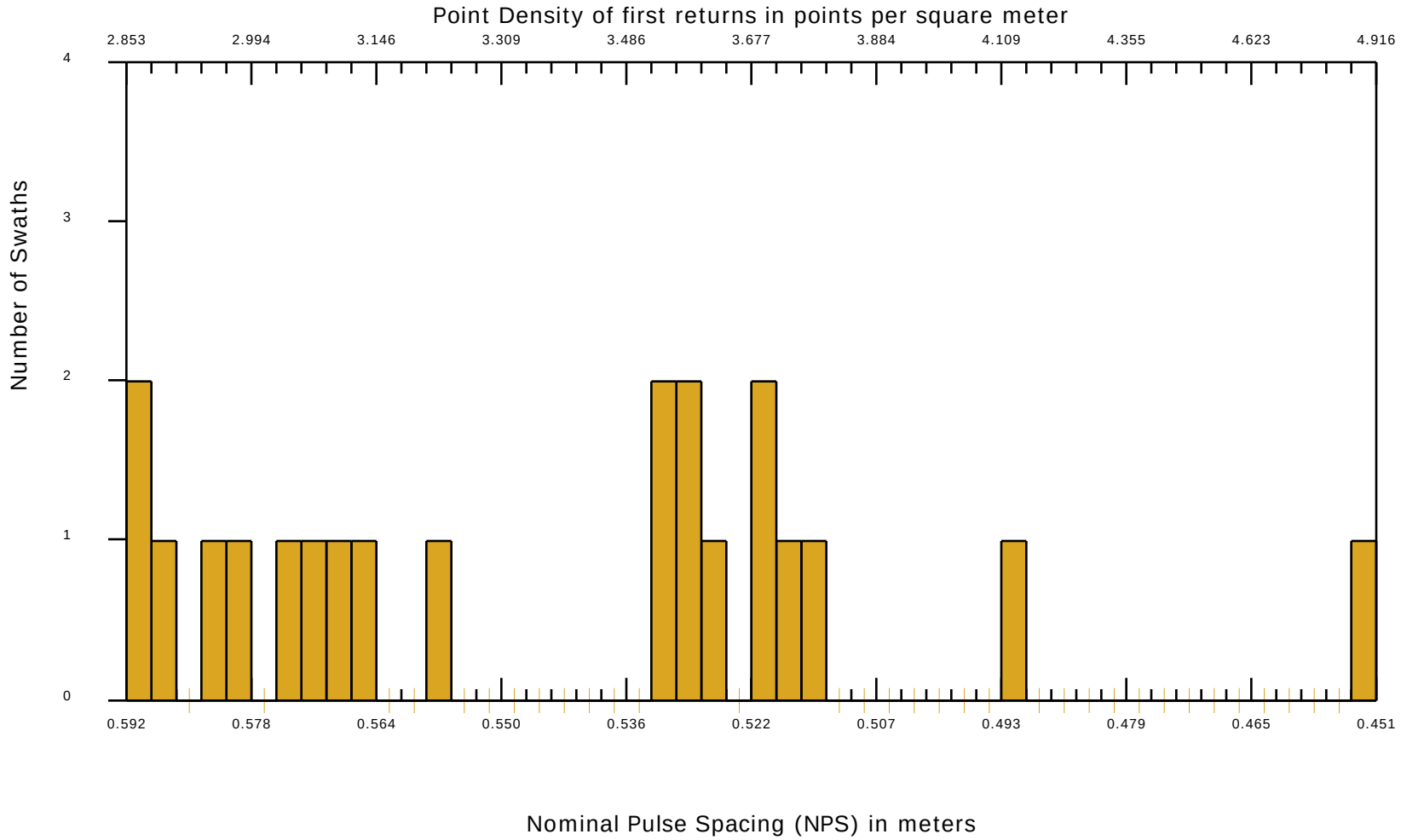
File	Number of First Returns	Area	Point Density	NPS
Average			3.380/0.314 pp Square Meter/ pp Square US Survey Foot	0.544/1.785 Meter/ US Survey Feet

C-4.1 Report on Nominal Pulse Spacing (NPS) - continued

Boundary ID	Number of First Returns	Area	Point Density	NPS
Aggregate	4,437,997,450	1,019,518,931	4.353/0.404 pp Square Meter/ pp Square US Survey Foot	0.479/1.572 Meter/ US Survey Feet

C-4.1 Report on Nominal Pulse Spacing (NPS) - continued

The purpose of this section is to show a frequency distribution chart of Point Density and Nominal Pulse Spacing (NPS) for the generated LAS swaths.



C-5 Report on Data Voids

The USGS Lidar Base Specification Version 2.1 states: "A data void is considered to be any area greater than or equal to (4 × ANPS) squared, which is measured using first returns only. Data voids within a single swath are not acceptable, except in the following circumstances:

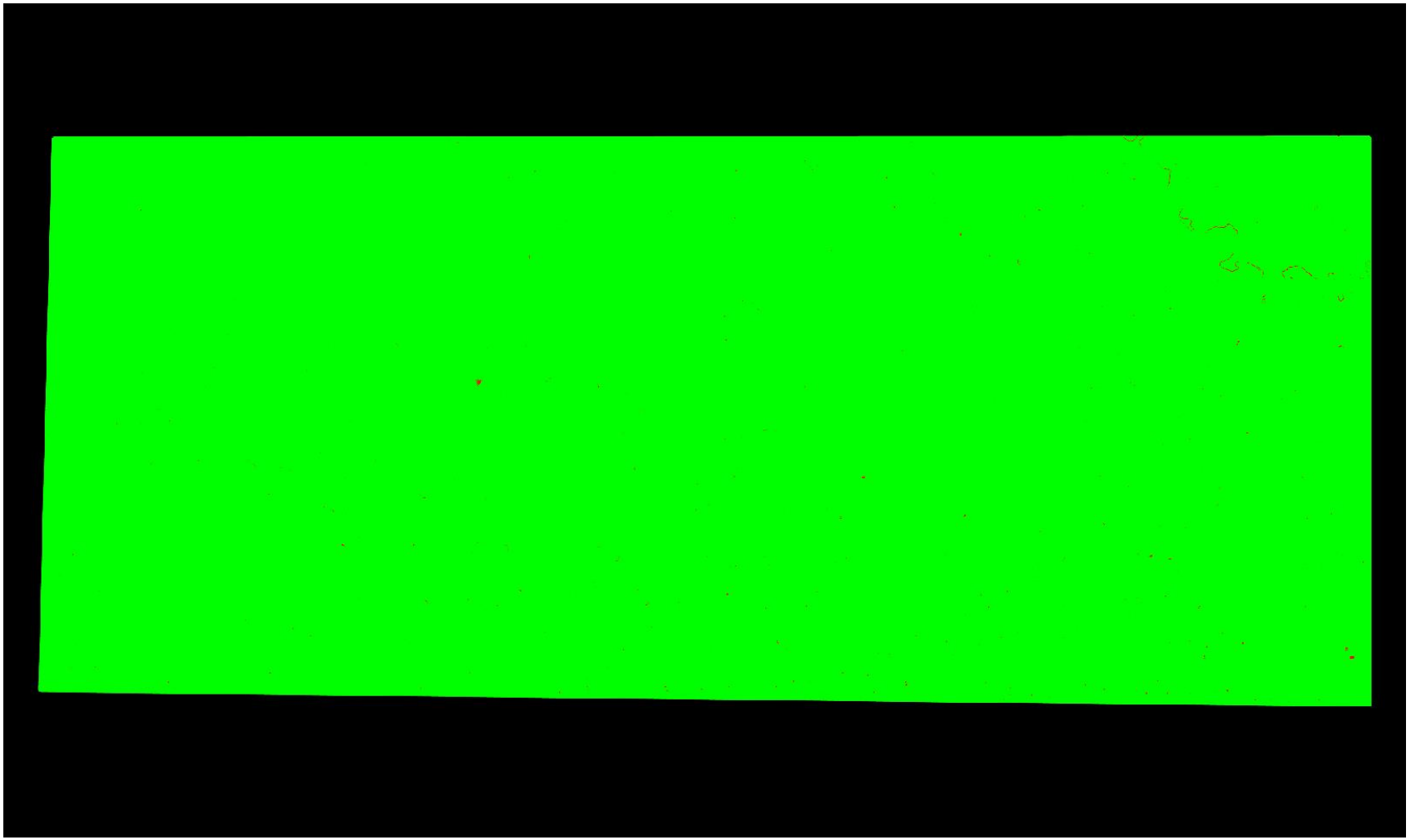
(1) where caused by waterbodies;
(2) where caused by areas of low near infrared reflectivity, such as asphalt or composition roofing;
(3) where caused by lidar shadowing from buildings or other features; or
(4) where appropriately filled in by another swath.

For projects designed to achieve the required ANPS through multiple coverage, the entire DPA shall be covered with the designed number of swaths. Areas meeting the size threshold defined above for single coverage that are not covered by the designed number of swaths are data voids."

The purpose of this section is to show graphically where possible lidar data voids are located. Data voids can be caused by a lack of coverage at the time of collection, water bodies not reflecting the laser beam back to the receiver, lidar occlusions caused by objects above ground like tall buildings, etc. Not all data voids are problematic. The intention of this test is to isolate the first example of lidar data voids - a lack of coverage at the time of collection. A close inspection must be done on the results to determine if the lidar coverage was collected and processed to meet the intended specifications.

Data Source - D:\00_Cherry\swaths

C-5 Report on Data Voids



Cell size: 2.840 Meter

- Green: Cells containing at least 1 first return lidar point (number of cells = 252,723,732)
- Red: Cells containing no first return lidar points (number of cells = 60,059)
- Background Color: Null data

C-6.1 Report on Spatial Distribution and Regularity

The USGS Lidar Base Specification Version 2.1 states: "The process described in this section relates only to regular and uniform point distribution. The process does not relate to, nor can it be used for, the assessment of NPS, ANPS, or data voids. The spatial distribution of geometrically usable points will be uniform and regular. Collections will be planned and executed to produce an aggregate first return point data that approaches a uniform, regular lattice of points. The regularity of the point pattern and density throughout the dataset is important and will be assessed by using the following method:

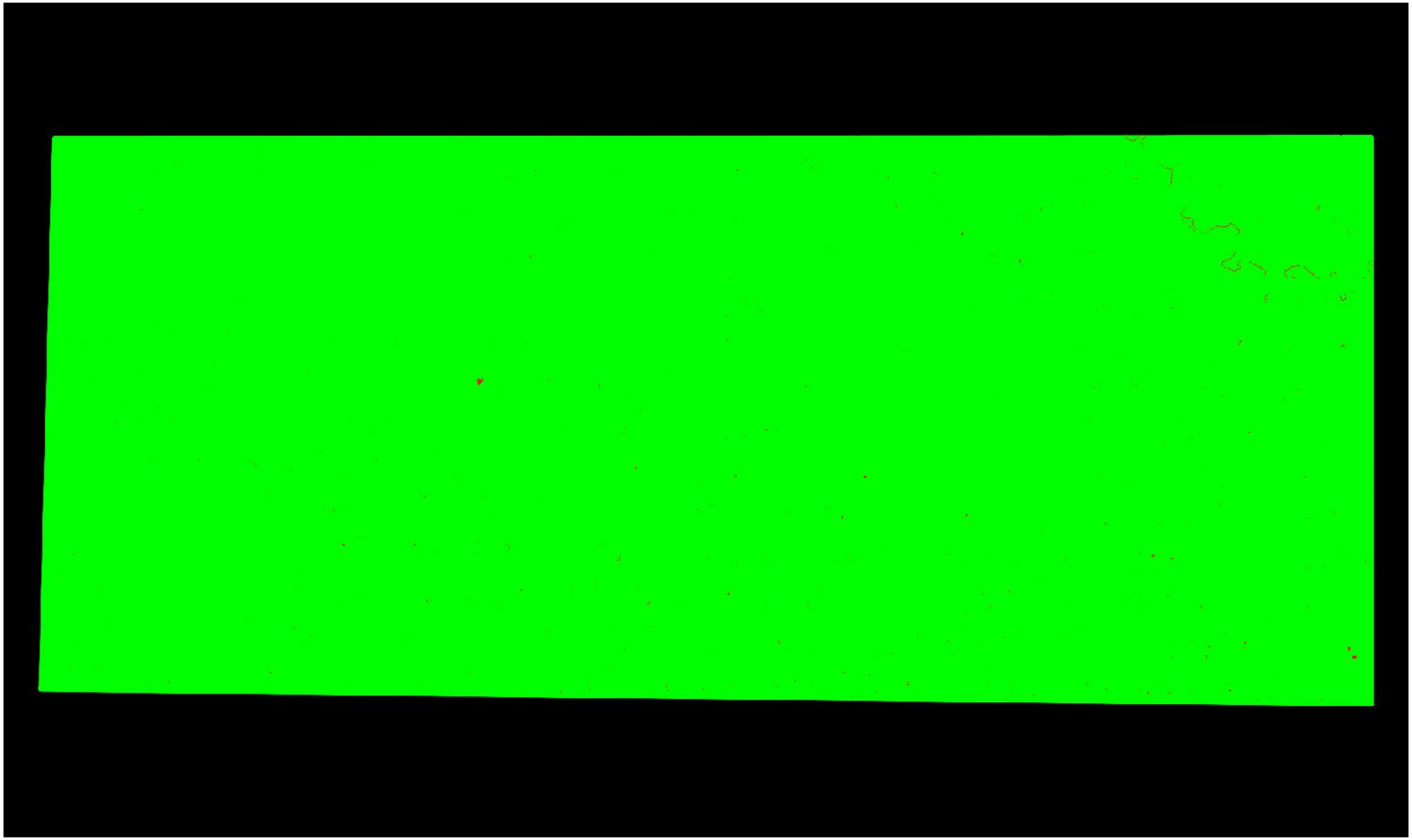
(1) Assess only nonwithheld, first return points of a single File Source ID.
(2) Exclude acceptable data voids previously identified in this specification.
(3) Generate a density raster from the data with a cell size equal to twice the design ANPS.
(4) Populate the raster using a count of points within each cell.
(5) Ensure that at least 90 percent of the cells in the grid contain at least one lidar point.

The USGS–NGP may allow lower passing thresholds for this requirement in areas of substantial relief where maintaining a regular and uniform point distribution is impractical."

The purpose of this section is to show graphically where unacceptable lidar spatial distributions are located. Lidar spatial distribution can be affected by problems in flight planning (e.g., incorrect scan frequency / pulse rate pairing) or flight execution (e.g., strong headwinds or tailwinds), a lack of coverage at the time of collection, water bodies not reflecting the laser beam back to the receiver, lidar occlusions caused by objects above ground like tall buildings, etc. Not all lidar spatial distribution violations are truly problematic. The intention of this test is to isolate the first example of lidar spatial distribution violations - problems in flight planning or flight execution. A close inspection must be done on the results to determine if the lidar spatial distribution was collected and processed to meet the intended specifications.

Data Source - D:\00_Cherry\swaths

C-6.1 Report on Spatial Distribution and Regularity - continued



Cell size: 1.420 Meter

Green: Cells containing at least one first return lidar point (number of cells = 1,010,593,940)
Red: Cells not containing at least one first return lidar point (number of cells = 362,573)
Background Color: Null data
Percentage of cells in the grid that contain at least one first return lidar point = 99.96% (Requirement is typically 90%)
See JPG2000 file for full resolution results

C-6.2 Report on Spatial Distribution and Regularity of Individual Swaths

File	Percentage of Cells that Contain >= 1

Pass: 21 files (percentage >= 90%)
Fail: 0 files (percentage < 90%)

C-7 Report on Collection Conditions

The USGS Lidar Base Specification Version 2.1 states: "Atmospheric conditions shall be cloud and fog free between the aircraft and ground during all collection operations. Ground conditions will be snow free. Very light, undrifted snow may be acceptable with prior approval. Ground conditions shall be free of extensive flooding or any other type of inundation. Leaf-off vegetation conditions are preferred. Penetration to the ground shall be adequate to produce an accurate and reliable bare-earth surface for the prescribed QL. Collections planned for leaf-on collections shall be approved by the USGS–NGP/3DEP prior to issuance of a task order or contract."

Note: Not all collection condition requirements can be checked with this reporting tool.

The purpose of this section is to provide a hyperlink to a NOAA website that shows the snow depth map for the extent of the lidar at the time of collection.

Ground Conditions:

Flight Date: 03/19/2021
http://www.nohrsc.noaa.gov/interactive/html/map.html?mode=pan&extents=us&zoom=&loc=41.1380910690606+N%2C+99.9471803303449+W&ql=station&var=ssm_depth&dy=2021&dm=3&dd=19&dh=19&snap=1&o5=1&o6=1&o11=1&o9=1&o13=1&lbl=m&o7=1&min_x=-100.239243948201&min_y=41.0407489040458&max_x=-99.6551167124886&max_y=41.2354332340754&coord_x=-99.9471803303449&coord_y=41.1380910690606&zbox_n=&zbox_s=&zbox_e=&zbox_w=&metric=0&bgvar=dem&shdvar=shading&width=800&height=450&nw=800&nh=450&h_o=0&font=0&js=1&uc=0

Flight Date: 04/08/2021
http://www.nohrsc.noaa.gov/interactive/html/map.html?mode=pan&extents=us&zoom=&loc=41.1380910690606+N%2C+99.9471803303449+W&ql=station&var=ssm_depth&dy=2021&dm=4&dd=8&dh=17&snap=1&o5=1&o6=1&o11=1&o9=1&o13=1&lbl=m&o7=1&min_x=-100.239243948201&min_y=41.0407489040458&max_x=-99.6551167124886&max_y=41.2354332340754&coord_x=-99.9471803303449&coord_y=41.1380910690606&zbox_n=&zbox_s=&zbox_e=&zbox_w=&metric=0&bgvar=dem&shdvar=shading&width=800&height=450&nw=800&nh=450&h_o=0&font=0&js=1&uc=0

DPH-1.1 Report on ASPRS LAS File Format (Tiled Data) - Compliance

The USGS Lidar Base Specification Version 2.1 states: "All point deliverables shall be in LAS format, version 1.4-R13, using Point Data Record Format 6, 7, 8, 9, or 10. Data producers are encouraged to review the LAS specification version 1.4-R13 in detail (ASPRS, 2011)."

The purpose of this section is to show a table of LAS 1.4 compliance test results for each tiled file.

File	LAS Version/PDRF	System ID	Legacy Point Count	Legacy Return Counts	File Source ID	Global Encoding	VLRs / EVLRs	WKT	Intensity	Point Count with Bad Return Info

Pass: 1108 files
Fail: 0 files

DPH-1.2 Report on ASPRS LAS File Format (Tiled Data) - File Integrity

The purpose of this section is to show a table of LAS 1.4 file integrity test results for each tiled file.

File	Number of Points Outside Extent	Offset To Point Data	Offset To EVLR	Number Of Points	Number of Points by Return	Number of Duplicate Points	Return Counts in LAS Header

Pass: 1108 files
Fail: 0 files

DPH-1.3 Report on ASPRS LAS File Format (Tiled Data) - Informational

The purpose of this section is to show a table of LAS 1.4 file informational test results for each tiled file.

File	GPS Time min	GPS Time max	Extended Scan Angle	Scan Angle Rank	Scanner Channel	Scan Direction	Edge of Flight Line	User Data	Counts for Synthetic	Key-points	Withheld	Overlap
	300201769.61	301934999.79	[-3397, 3347]	[-20.382, 20.082]	[0, 0]	[0, 1]	[0, 1]	[0, 0]	0	0	9972	0

DPH-1.4 Report on Elevation by Class for Tiled Data

The purpose of this section is to show a table of the Minimum and Maximum elevation (Z) values by Class for each tiled file.

File	Class	Z Min	Z Max
	1	714.675	994.69
	2	715.499	939.299
	7	620.869	917.123
	9	715.532	912.297
	17	719.188	859.968
	18	721.134	1336.002
	20	715.56	912.356

DPH-3 Report on Time of Global Positioning System Data

The USGS Lidar Base Specification Version 2.1 states: "GPS data shall be recorded as Adjusted GPS Time (Standard [satellite] GPS time minus 1*10 power of 9) at a precision sufficient to allow unique timestamps for each pulse. The encoding tag in the LAS header shall be properly set. See LAS specification version 1.4–R13 (ASPRS, 2011).

The purpose of this section is to show the GPS time type within the LAS files for the lidar data.

All LAS files are formatted as Adjusted GPS Time.

DPH-4 Report on Datums

The USGS Lidar Base Specification Version 2.1 states: "All data collected shall be tied to the datums listed below:

For the CONUS, unless otherwise specified by the user and agreed to in advance by the USGS–NGP:

- The horizontal datum for latitude and longitude and ellipsoid heights will be the North American Datum of 1983 (NAD 83) using the most recently NGS-published adjustment (currently NAD 83, epoch 2010.00, realization of 2011).
- The vertical datum for orthometric heights will be the North American Vertical Datum of 1988 (NAVD 88).
- The geoid model used to convert between ellipsoid heights and orthometric heights will be the latest hybrid geoid model of NGS, supporting the latest realization of NAD 83 (currently [2017] Geoid12b model)."

Note: See the specification document for requirements concerning non-contiguous areas of the United States.

The purpose of this section is to show the datums of the LAS files for the lidar tiled data. The project specifications should be reviewed to ensure that the Datums listed in this report are as expected.

All LAS tiled files are defined as:

Horizontal Datum = NAD83 (National Spatial Reference System 2011)
Horizontal EPSG Code = 1116
Vertical Datum = North American Vertical Datum 1988
Vertical EPSG Code = 5103

DPH-5 Report on Coordinate Reference System

The USGS Lidar Base Specification Version 2.1 states: "Lidar data and all related or derived data and products shall be processed and delivered in a single CRS agreed upon in advance of data collection by the USGS–NGP and all project partners and cooperators. The complete CRS definition and its WKT representation, both horizontal and vertical, shall be documented as part of the agreement. In all cases, the CRS used shall be recognized and published by the European Petroleum Survey Group (EPSG). Each project shall be processed and delivered in a single CRS, except in cases where a project area covers multiple CRSs such that processing in a single CRS would introduce unacceptable distortions in part of the project area. In such cases, the project area is to be split into subareas appropriate for each CRS. The following requirements apply to the subareas:

- Each subarea shall be processed and delivered as a separate subproject with its own CRS.
- All requirements for a single project will apply to each subproject.
- The DPA boundaries of adjacent subareas shall have topologically coincident boundaries along their common borders.
- For each project or subarea, all spatial data within the area shall be in the same CRS.
- An additional CRS delivery, arranged in advance, may also be required on specific projects."

The purpose of this section is to show the coordinate reference systems of the LAS files for the lidar data. The project specifications should be reviewed to ensure that the Coordinate Reference Systems listed in this report are as expected.

All LAS files are defined as:

Horizontal CRS = NAD83(2011) / UTM zone 14N
EPSG Code = 6343
Vertical CRS = NAVD88 height
EPSG Code = 5703
Geoid Model = US Geoid Model of 2018

DPH-6 Report on Units of Reference

The USGS Lidar Base Specification Version 2.1 states: "All references to the units of measure 'Feet' and 'Foot' shall specify 'International', 'Intl', 'U.S. Survey', or 'US'."

The purpose of this section is to show the horizontal and vertical units of the LAS files for the lidar data. The project specifications should be reviewed to ensure that the Units listed in this report are as expected.

All LAS files are defined as:

Horizontal Unit = Meter
Vertical Unit = Meter

DPH-7.1 Report on File Source ID

The USGS Lidar Base Specification Version 2.1 states: "At the time of its creation and prior to any further processing, each swath shall be assigned a unique file source ID, and each point within the swath shall be assigned a point source ID equal to the file source ID. The point source ID on each point shall be persisted unchanged throughout all processing and delivery. The file source ID for tiled LAS files shall be set to 0. See LAS specification version 1.4-R13 (ASPRS, 2011)."

The purpose of this section is to report on the File Source ID for the lidar data.

0 tiled files are in violation with non-zero File Source ID.

DPH-7.2 Report on Swath Geographic Locations

The purpose of this section is to report on geographic locations for the generated swaths. Each generated swath is named based on unique Point Source IDs from the tiled data and should not exist in more than one contiguous geographic location unless separated by water within the swath. Manual inspection of failing swaths is recommended.

20 generated swaths PASS Location Testing.
1 generated swaths FAIL Location Testing.

DPH-8 Report on Smooth Surface Precision (intraswath)

The USGS Lidar Base Specification Version 2.1 states: "Precision will be calculated as: Precision = Range - (Slope x Cellsize x 1.414) where:
- Precision, Range, and Slope are rasters (square cells assumed);
- Range is the difference between the highest and lowest lidar points in each pixel;
- Slope is the maximum slope of the cell to its 8 neighbors, expressed as a decimal value, calculated from the minimum elevation in each cell; and
- Cellsize is the edge dimension of the cell. 1.414 is the factor to compute the diagonal dimension of the pixel.
- Cellsize is set to the ANPS, rounded up to the next integer, and then doubled:
  Cellsize ? CEILING(ANPS) × 2, where CEILING is a function to round ANPS up to the next integer.

Assessment of precision will be made on hard surfaced areas (for example, parking lots or large rooftops) containing only single return lidar points. Sample areas for assessment of precision will be approximately 100 pixels. To the degree allowed by the data and the project environment, multiple sample areas representing the full width of the swath(s) (left, center, and right) will be examined. Multiple single swaths from a single lift may be used if needed to sample the full swath width. At a minimum, precision shall be assessed against for each lift of each aircraft/instrument combination used on the project. Additional areas may be checked at the discretion of the USGS–NGP. Each test area will be evaluated using a signed difference raster with a cell size equal to the ANPS, rounded up to the next integer, then doubled (Cellsize=CEILING(ANPS)×2). The difference rasters will be statistically summarized to verify that root mean square difference in the z -direction (RMSDz) values do not exceed the limits set forth in table 2 for the QL of information that is being collected."

Table 2. Relative vertical accuracy for light detection and ranging swath data.

[QL, quality level; $RMSD_z$, root mean square difference in the z direction; m, meter; ≤, less than or equal to]

Quality level	Smooth surface repeatability, $RMSD_z$ (m)	Swath overlap difference, $RMSD_z$ (m)
QL0	≤0.03	≤0.04
QL1	≤0.06	≤0.08
QL2	≤0.06	≤0.08
QL3	≤0.12	≤0.16

The purpose of this section is to evaluate smooth surface repeatability / intraswath precision by measuring departures from planarity of single returns from hard planar surfaces, normalizing for actual variation in the surface elevation. Repeatability of clusters of single returns is then assessed at multiple locations within hard surfaced areas (for example, parking lots or large rooftops).

DPH-8 Report on Smooth Surface Precision (intraswath) - continued

0	0.060	0.600 (Meter)
0	0.197	1.969 (Feet)

A maximum vertical separation cutoff has been applied to this graphic for the purpose of masking out disruptive features that are not applicable for depicting sensor noise within individual swaths (e.g., trees, moving cars, etc.).

DPH-9.1 Report on Overlap Consistency (interswath)

The USGS Lidar Base Specification Version 2.1 states: "Overlap consistency will be assessed at multiple locations within overlap in nonvegetated areas of only single returns and with slopes of less than 10 degrees. To the degree that the data allow, test areas should be located such that the full width of the overlap is represented. The overlap areas that will be tested are those between the following:

- adjacent, overlapping parallel swaths within a project,
- cross-tie swaths and a sample of intersecting project swaths in both flight directions; and
- adjacent, overlapping lifts.

Each overlap area will be evaluated using a signed difference raster with a cell size equal to the ANPS, rounded up to the next integer, then doubled (Cellsize=CEILING(ANPS)×2). The difference rasters will be statistically summarized to verify that RMSDz values do not exceed the limits set forth in table 2 for the QL of information that is being collected."

Table 2. Relative vertical accuracy for light detection and ranging swath data.

[QL, quality level; $RMSD_z$, root mean square difference in the z direction; m, meter; ≤, less than or equal to]

Quality level	Smooth surface repeatability, $RMSD_z$ (m)	Swath overlap difference, $RMSD_z$ (m)
QL0	≤0.03	≤0.04
QL1	≤0.06	≤0.08
QL2	≤0.06	≤0.08
QL3	≤0.12	≤0.16

The purpose of this section is to show two separate mosaicked versions of a thematically rendered map of swath separation for all of the data processed.

For the first – known as a Measurable Flightline Separation Raster (FSR) - processing has been done to isolate measurements to clusters of single returns and is limited to areas of < 10 degree slope. The colors are gradated by the selected QL's swath overlap difference RMSDz limits. Only swath overlap areas are shown in the raster. The color is overlaid on a lidar intensity background to show land cover features. A frequency distribution chart of RMSDz raster values can be found on the page following the raster graphic.

For the second raster – known as a Swath Separation Image and found at the end of this test section – there are no limitations on slope angles and return types are user defined. The colors are gradated by the selected QL's swath overlap difference RMSDz limits. Only swath overlap areas are shown in the RGB raster. The color is overlaid on a lidar intensity background to show land cover features. Tiled GeoTIFFs of this mosaicked raster can be found in the output folder for this test.

DPH-9.1 Report on Overlap Consistency (interswath) - Measurable FSR

Description of the process that generates the Measurable Flightline Separation Raster (FSR):

a. Areas of swath overlap are determined within each delivery tile.

b. A TIN is created for the overlap areas of each swath within a tile, and a Grid is overlaid on those TINs. Grid cell sizes are 3x the aggregate nominal pulse spacing (ANPS) as shown in Table 1 of the USGS Lidar Base Specification v 2.1. ANPS varies depending on the Quality Level of the data.

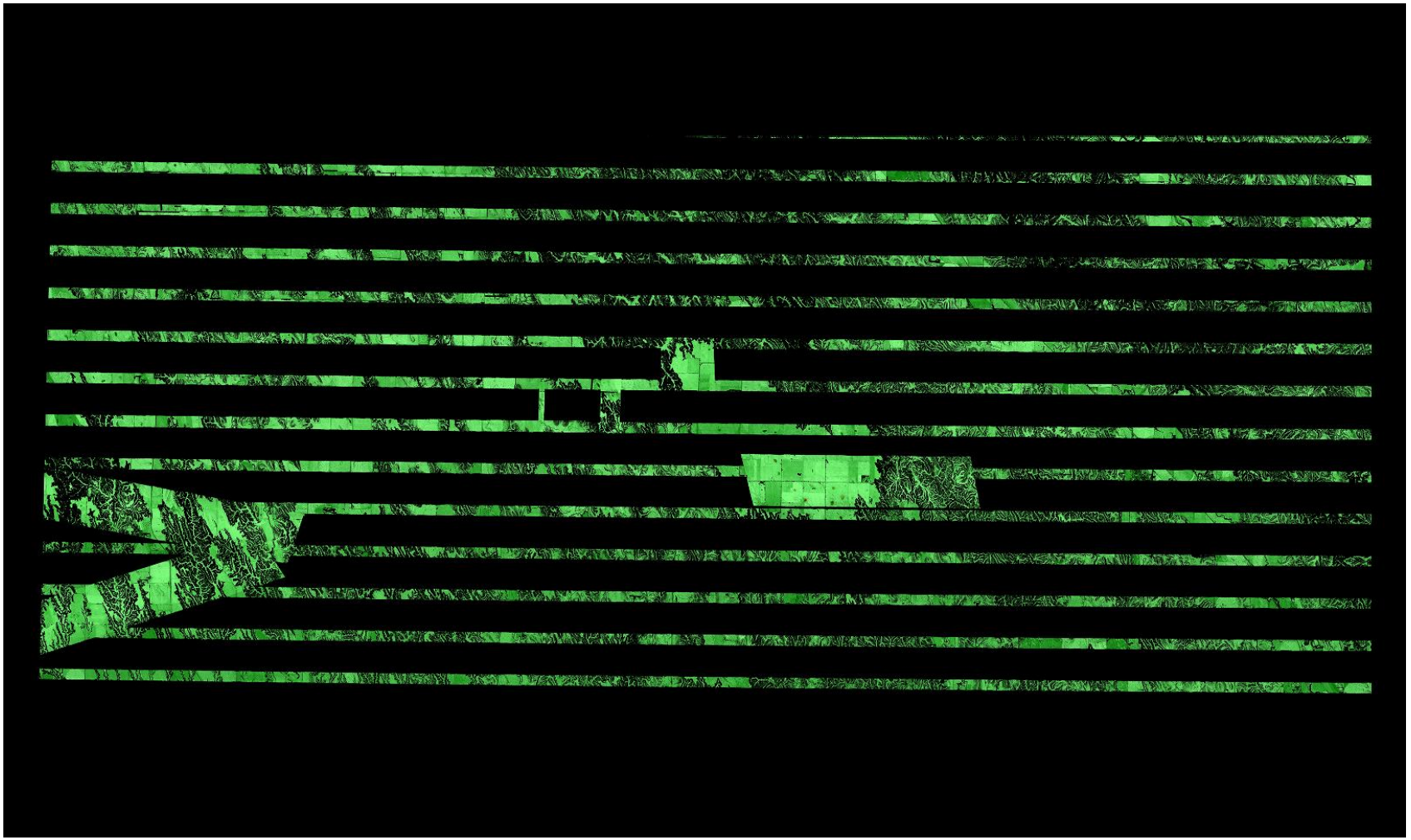
c. The grid cells are populated with the vertical separation values between the underlying TINs as measured at the centroid of each grid cell. When three or more swaths coincide with a cell, the value is set to the difference between the maximum and minimum of all elevations. Only areas of slope < 10 degrees are measured. Points flagged as Withheld, including those points classed as High or Low Noise, are excluded from this analysis.

d. The Measurable FSR uses a pre-filtering algorithm that selects only clusters of single returns for use in the RMSDz analysis. The algorithm's purpose is to find areas for measurement that are in the open, away from roof edges, trees, etc. - it is not designed to find ground below vegetation canopy. By using only clusters of single returns (at a minimum distance from any multiple returns) and ignoring cells with NODATA values, reliable RMSDz values are produced.

e. A vertical separation cut-off is used to remove values that are not appropriate for separation measurements (e.g., trees, moving objects, etc.). This cut-off is set to 10 times the color gradation interval value.

f. The tiled rasters are mosaicked into a single project-wide flight separation raster. A single, aggregate RMSDz is calculated from this complete grid, and the final thematic raster is generated. This raster graphic is found on the following page.

DPH-9.1 Report on Overlap Consistency (interswath) - Measurable



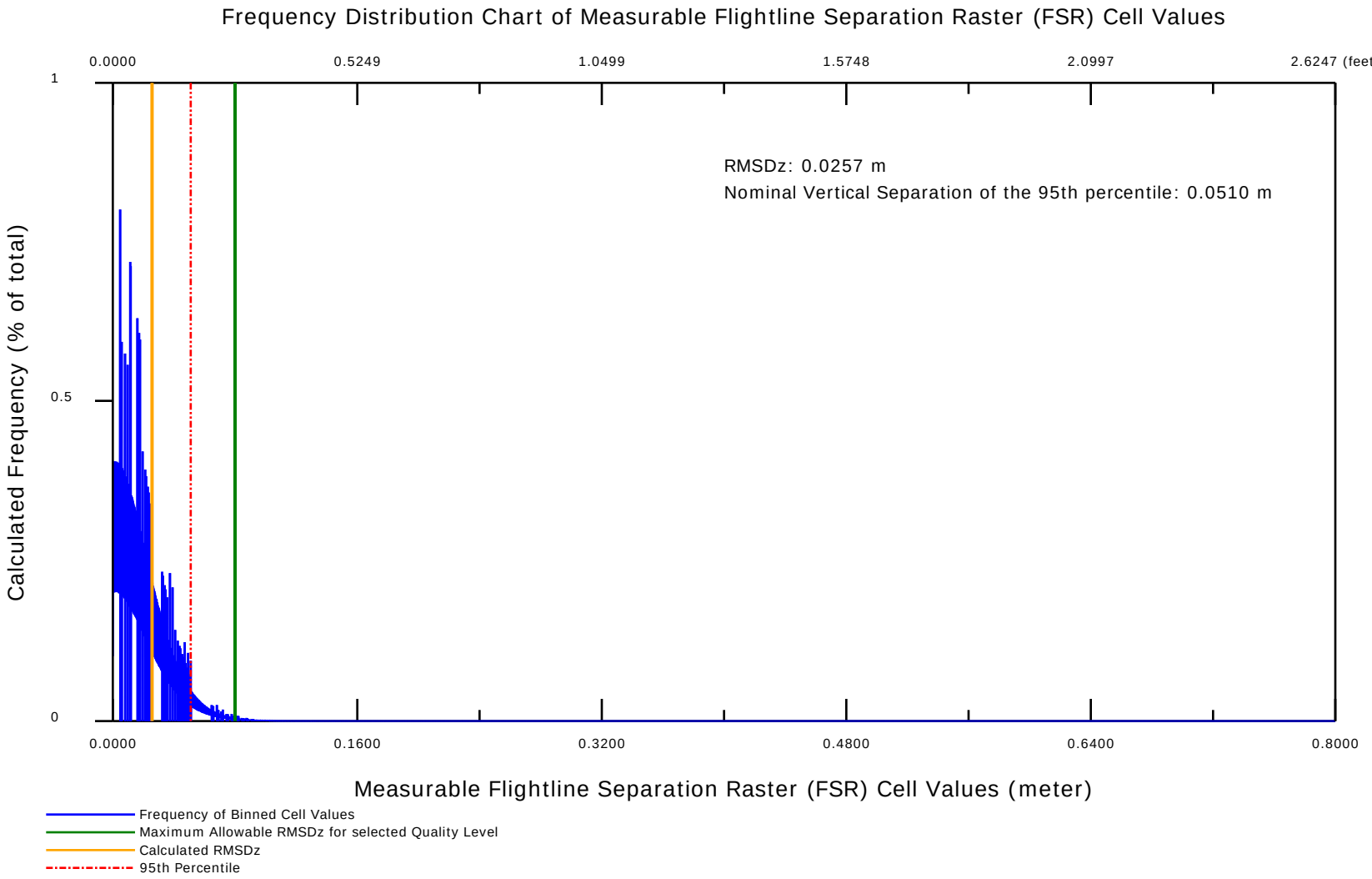
0	0.080	0.160	0.240	0.800 (Meter)
0	0.262	0.525	0.787	2.625 (Feet)

A maximum vertical separation cutoff has been applied to this graphic for the purpose of masking out disruptive features that do not show calibration issues between flight lines (e.g., trees, moving cars, etc.).

DPH-9.1 Report on Measurable RMSDz

The purpose of this section is to show a frequency distribution chart of pixel values (RMSDz) for the entire dataset.

Data Source - D:\00_Cherry\tilecls



DPH-9.1 USGS Swath Separation Image

Image creation:

a. All returns shall be used to create the images.
b. All point classes and flags shall be enabled when creating the images and points flagged as withheld or classified as noise shall be excluded.
c. Elevation values and differences shall not be subjected to a threshold or otherwise clipped so all differences are represented.
d. The images will be derived from TINs to reduce the number of false difference values on slopes; however, other algorithms are acceptable.
e. The images shall consist of a 50 percent transparent RGB layer overlaying the lidar intensity image.
f. The images shall use at least three color levels wherever two or more swaths overlap within a pixel.
g. Where two or more swaths overlap within a pixel (based on point source ID),
   i. pixel color shall be based on vertical difference of swaths using the following breaks (based on multiples of the Swath Overlap Difference for the QL):
      1. 0-8 cm: GREEN;
      2. 8-16 cm: YELLOW;
      3. > 16 cm or > last additional color ramp bin value: RED (for example, addition of ORANGE pixels for the range of 16-24 cm would require red pixels to represent > 24 cm).
   ii. color choice of green, yellow, and red is suggested but not required.
   iii. no pixel shall remain uncolored (transparent) in the overlap areas.
h. Where swaths do not overlap, pixel values shall be intensity alone.

Image file formats and version control:

a. Swath difference image format may be delivered as GeoTIFF or JPEG (with world file) by tile or as a single compressed JPEG 2000 (JP2) image mosaic.
b. The point cloud geometry and intensity data delivered shall be identical to the point cloud geometry and intensity data used to create the difference images. Changes in the point cloud geometry or intensity requires recreation of the difference images.

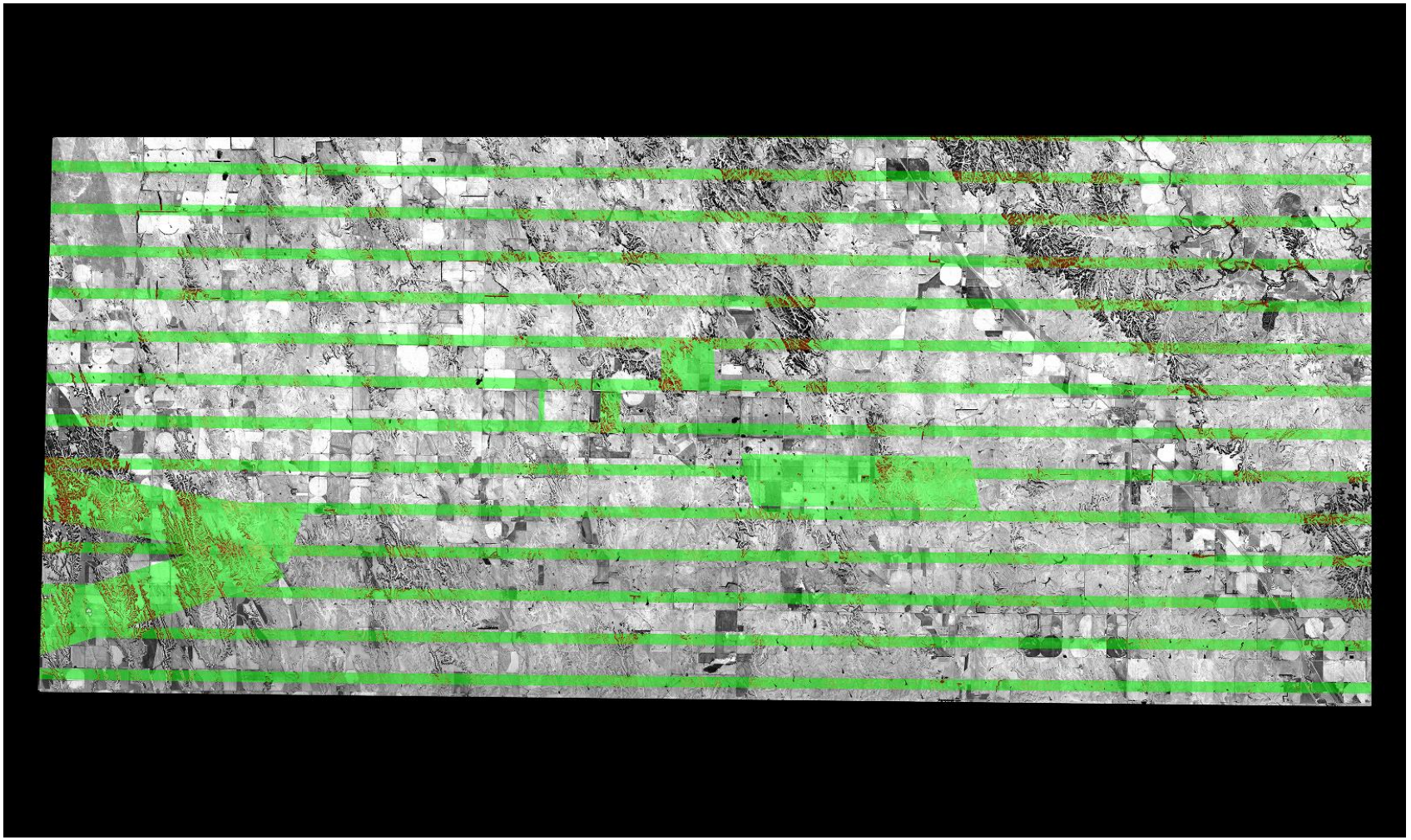
Spatial extent and coordinate reference system:

a. Spatial resolution (pixel dimension) of the images shall be between 2 and 4 times the Nominal Pulse Spacing (2-4 x NPS) in the project's linear unit (meters or feet).
b. The difference images must be representative of the associated data delivery.
c. The images shall be in the same CRS as the point cloud data to ensure alignment with the point cloud.

Description of the process that generates the Swath Separation Image:

a. Areas of swath overlap are determined within each delivery tile.
b. A Grid is created for each overlap area. Grid cell sizes are 3x the aggregate nominal pulse spacing (ANPS) as shown in Table 1 of the USGS Lidar Base Specification v 2.1. ANPS varies depending on the Quality Level of the data. The grid cells are then populated with the maximum vertical separation values of the underlying points. Points flagged as Withheld, including those points classed as High or Low Noise, are excluded from this analysis.
c. No vertical separation cut-off is used for this raster.
d. The tiled rasters are mosaicked into a single project-wide swath separation raster, with the grid cells colored based on the separation values. For QL1 and QL2, a green cell indicates an elevation difference of 8 cm or less, yellow indicates greater than 8 cm but LTE 16 cm, orange indicates greater than 16 cm but LTE 24 cm, and red is any value greater than 24 cm. The mosaicked raster graphic is found on the following page, and tiled GeoTIFFs of the complete project can be found in the output folder for this test.

DPH-9.1 USGS Swath Separation Image - continued



0	0.080	0.160	0.240	9999.000 (Meter)
0	0.262	0.525	0.787	32805.052 (US Survey Feet)

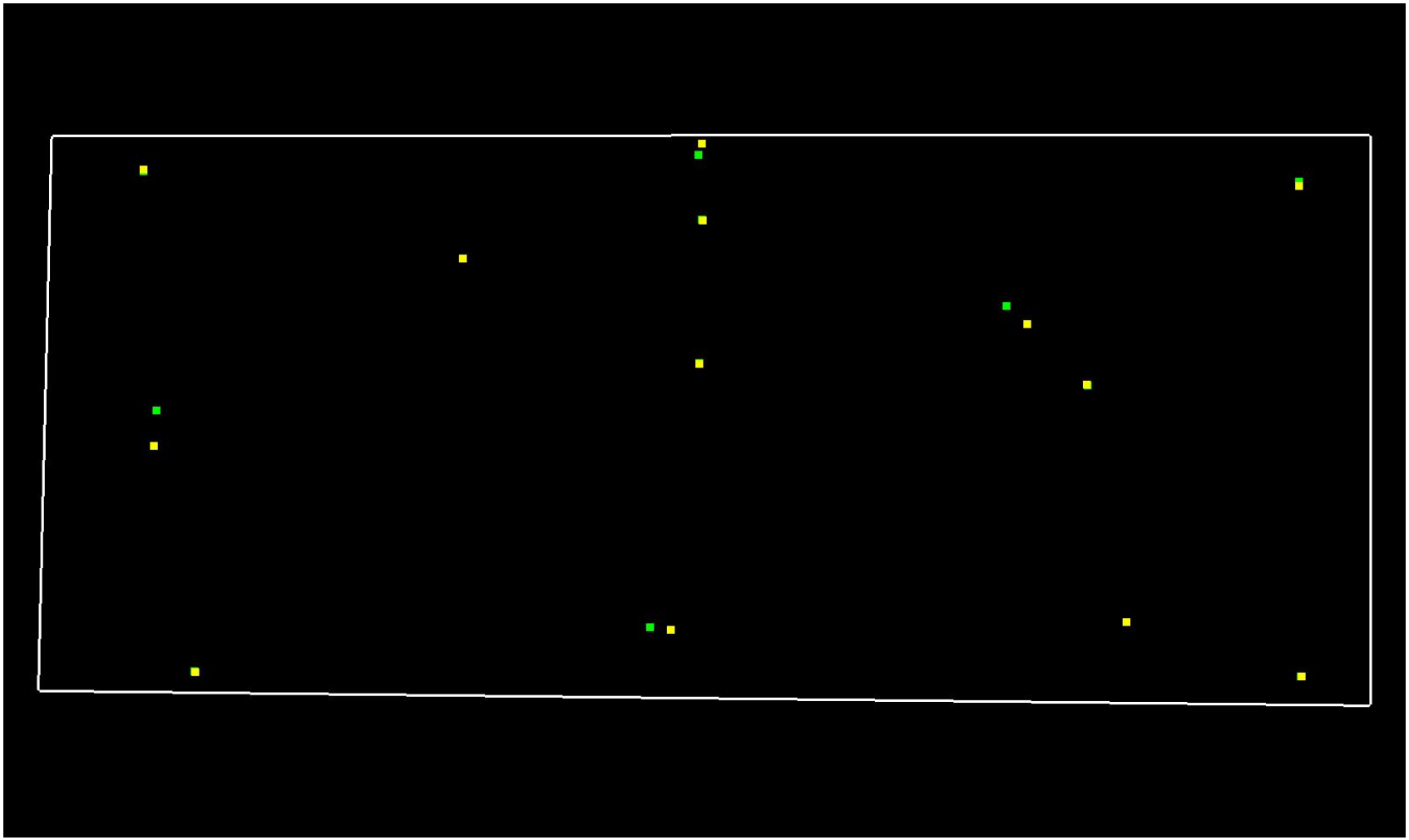
DPH-10 Report on Check Points

The USGS Lidar Base Specification Version 2.1 states: "Data producers are encouraged to carefully review the requirements in the "Positional Accuracy Standards for Digital Geospatial Data" (ASPRS, 2014). Check points for NVA assessments shall be surveyed in clear, open areas (which typically produce only single lidar returns) devoid of vegetation and other vertical artifacts (such as boulders, large riser pipes, and vehicles). Check points shall not be located on ground that has been plowed or otherwise disturbed. The same check points may be used for NVA assessment of the point data and DEM. Check points for VVA assessments shall be surveyed in vegetated areas (typically characterized by multiple return lidar). Check points will be located in areas having a minimum homogeneous area of (ANPS*5)2, with less than one-third of the required RMSEz deviation from a low-slope (<10 degree) plane. In land covers other than forested and dense urban, the tested check point will have no obstructions above 15 degrees over the horizon. All tested locations will be photographed showing the position of the survey tripod and the ground condition of the surrounding area. Control points used in the calibration process for data acquisition shall not be used as check points. Check points shall be an independent set of points used for the sole purpose of assessing the vertical accuracy of the project. The quantity and location of check points shall meet the following requirements, unless alternative criteria are approved by the 3DEP in advance (see ASPRS 2014 for additional information.):

- The ASPRS-recommended total number of check points for a given project size shall be met.
- The ASPRS-recommended distribution of the total number of check points between NVA and VVA assessments shall be met.
- Check points within each assessment type (NVA and VVA) will be well-distributed across the entire project area. See "Glossary" section at the end of this specification for a definition of "well-distributed."
- Within each assessment type, check points will be distributed among all constituent land cover types in approximate proportion to the areas of those land cover types (ASPRS, 2014)."

The purpose of this section is to show check points (NVA and VVA).

DPH-10 Report on Check Points - continued



Yellow points are NVA, green points are VVA.
White polygon is defined project area (DPA) boundary

DPH-10 Report on Check Points - continued

Total check points: 24

Check points in defined project area (DPA): 24

Total NVA check points in defined project area (DPA): 13

Total VVA check points in defined project area (DPA): 11

Total defined project area (DPA): 1019.519 square KM

Density of check points in defined project area (DPA): 0.024 points per square KM

TABLE C.1 RECOMMENDED NUMBER OF CHECKPOINTS BASED ON AREA

Project Area (Square Kilometers)	Horizontal Accuracy Testing of Orthoimagery and Planimetrics	Vertical and Horizontal Accuracy Testing of Elevation Data sets		
	Total Number of Static 2D/3D Checkpoints (clearly-defined points)	Number of Static 3D Checkpoints in NVA[9]	Number of Static 3D Checkpoints in VVA	Total Number of Static 3D Checkpoints
≤500	20	20	5	25
501-750	25	20	10	30
751-1000	30	25	15	40
1001-1250	35	30	20	50
1251-1500	40	35	25	60
1501-1750	45	40	30	70
1751-2000	50	45	35	80
2001-2250	55	50	40	90
2251-2500	60	55	45	100

[9]Although vertical check points are normally not well defined, where feasible, the horizontal accuracy of lidar data sets should be tested by surveying approximately half of all NVA check points at the ends of paint stripes or other point features that are visible and can be measured on lidar intensity returns.

Source: ASPRS Positional Accuracy Standards for Digital Geospatial Data (Edition 1, Version 1.0. - November 2014)

DPH-11 Report on Absolute Vertical Accuracy

The USGS Lidar Base Specification Version 2.1 states: "Absolute vertical accuracy of the lidar data and the derived DEM will be assessed and reported in accordance with ASPRS (2014). Vegetated and nonvegetated land cover types shall be assessed for absolute vertical accuracy.
Three absolute accuracy values shall be assessed and reported:

1. NVA for the point data
2. VVA for the point data
3. NVA for the DEM
4. VVA for the DEM

The minimum NVA and VVA requirements for all data, using the ASPRS methodology, are listed in table 4. Both the NVA and VVA required values shall be met. NVA for the point data shall be assessed by comparing check points surveyed for NVA assessment to a triangulated irregular network (TIN) constructed from ground-classified lidar points in those areas. VVA for the point data shall be assessed by comparing check points surveyed for VVA assessment to a triangulated irregular network (TIN) constructed from ground-classified lidar points in those areas. NVA and VVA for the DEM are assessed by comparing check points to the final bare-earth surface. The minimum required thresholds for absolute and relative accuracy may be increased by the USGS–NGP when any of the following conditions are met:

- A demonstrable, substantial, and prohibitive increase in cost is needed to obtain this accuracy, which is often the case in heavily vegetated project areas.
- An alternate specification is needed to conform to previously contracted phases of a single larger overall collection effort such as for multiyear statewide collections
- The USGS–NGP agrees that the use of an alternate specification is reasonable and in the best interest of all stakeholders."

Table 4. Absolute vertical accuracy for light detection and ranging data and digital elevation models.

[QL, quality level, $RMSE_z$, root mean square error in the z direction; NVA, nonvegetated vertical accuracy; VVA, vegetated vertical accuracy; m, meter; ≤, less than or equal to]

Quality level	$RMSE_z$ (nonvegetated) (m)	NVA at the 95-percent confidence level (m)	VVA at the 95th percentile (m)
QL0	≤0.050	≤0.098	≤0.15
QL1	≤0.100	≤0.196	≤0.30
QL2	≤0.100	≤0.196	≤0.30
QL3	≤0.200	≤0.392	≤0.60

The purpose of this section is to report on the absolute vertical accuracy of the lidar data and DEMs generated from it by testing for NVA (Nonvegetated Vertical Accuracy) and VVA (Vegetated Vertical Accuracy) against surveyed ground check points.

DPH-11 Report on Absolute Vertical Accuracy - continued

Units: Meter (/Feet)

Vertical Accuracy Class tested: 10-cm

Check Points in defined project area (DPA):	24
Check Points with Lidar Coverage	24
Check Points with Lidar Coverage (NVA)	13
Check Points with Lidar Coverage (VVA)	11
Average Z Error (NVA)	-0.004/-0.014
Maximum Z Error (NVA)	0.034/0.111
Median Z Error (NVA)	0.004/0.014
Minimum Z Error (NVA)	-0.057/-0.189
Standard deviation of Vertical Error (NVA)	0.029/0.095
Skewness of Vertical Error (NVA)	-0.634
Kurtosis of Vertical Error (NVA)	-0.741
Non-vegetated Vertical Accuracy (NVA) RMSE(z) [1]	0.028/0.092 PASS
Non-vegetated Vertical Accuracy (NVA) at the 95% Confidence Level +/- [1]	0.055/0.180 PASS
FGDC/NSSDA Vertical Accuracy at the 95% Confidence Level +/-	0.055/0.180
Non-vegetated Vertical Accuracy (NVA) RMSE(z) (DEM) [2]	0.031/0.103 PASS
Non-vegetated Vertical Accuracy (NVA) at the 95% Confidence Level (DEM) +/- [2]	0.061/0.201 PASS
Vegetated Vertical Accuracy (VVA) at the 95th Percentile (TIN) +/- [1]	0.168/0.551 PASS
Vegetated Vertical Accuracy (VVA) at the 95th Percentile (DEM) +/- [2]	0.157/0.514 PASS

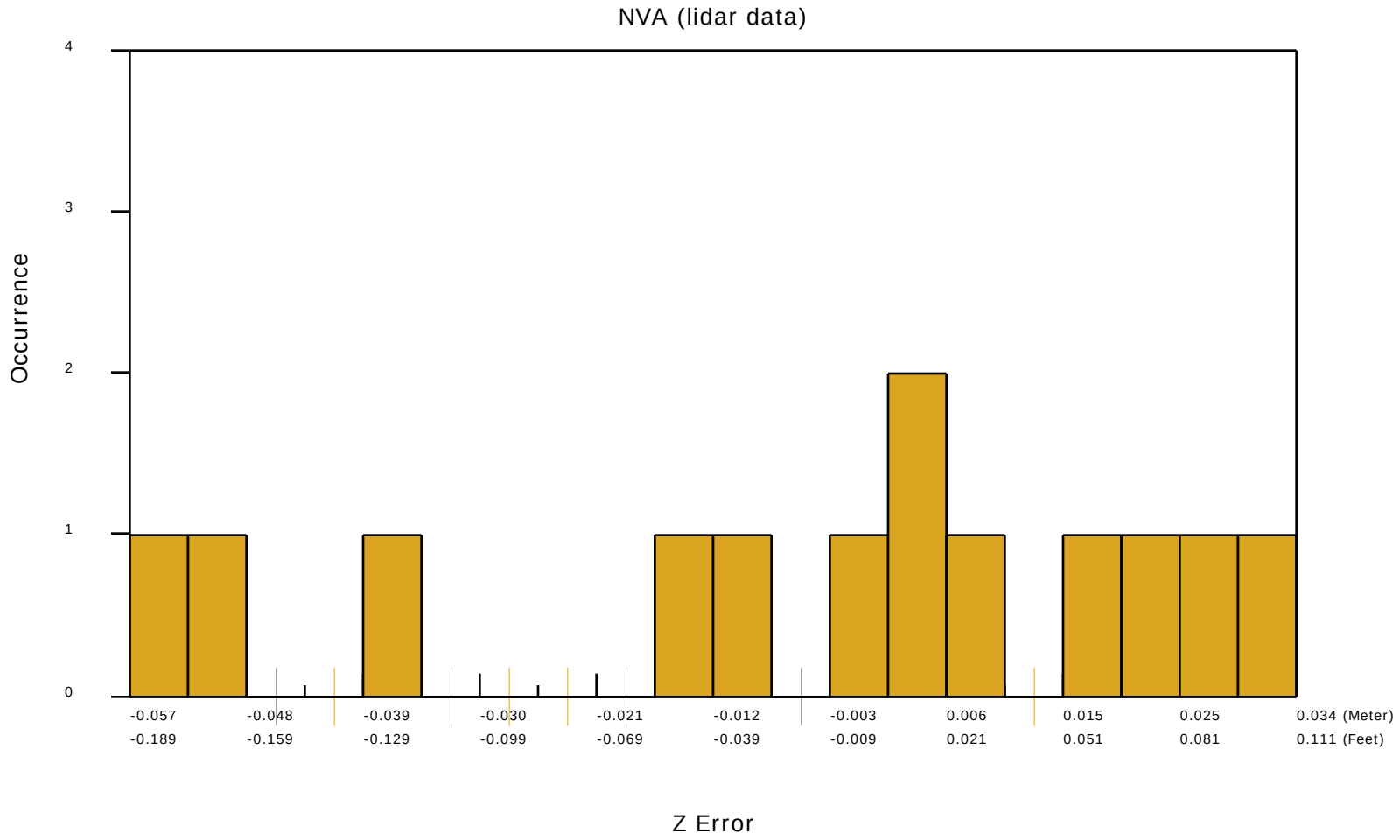
This data set was tested to meet ASPRS Positional Accuracy Standard for Digital Geospatial Data (2014) for a 10-cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be RMSEz = 2.8cm, equating to +/- 5.5cm at the 95% confidence level. Actual VVA accuracy was found to be +/- 15.7cm at the 95th percentile.

[1] This value is calculated from TIN-based testing of the lidar point cloud data.

[2] This value is calculated from RAM-based grid testing of the lidar data. The grid cells are sized according to the Quality Level selected, and are defined in the USGS NGP Lidar Base Specification Version 2.1 (Table 6).

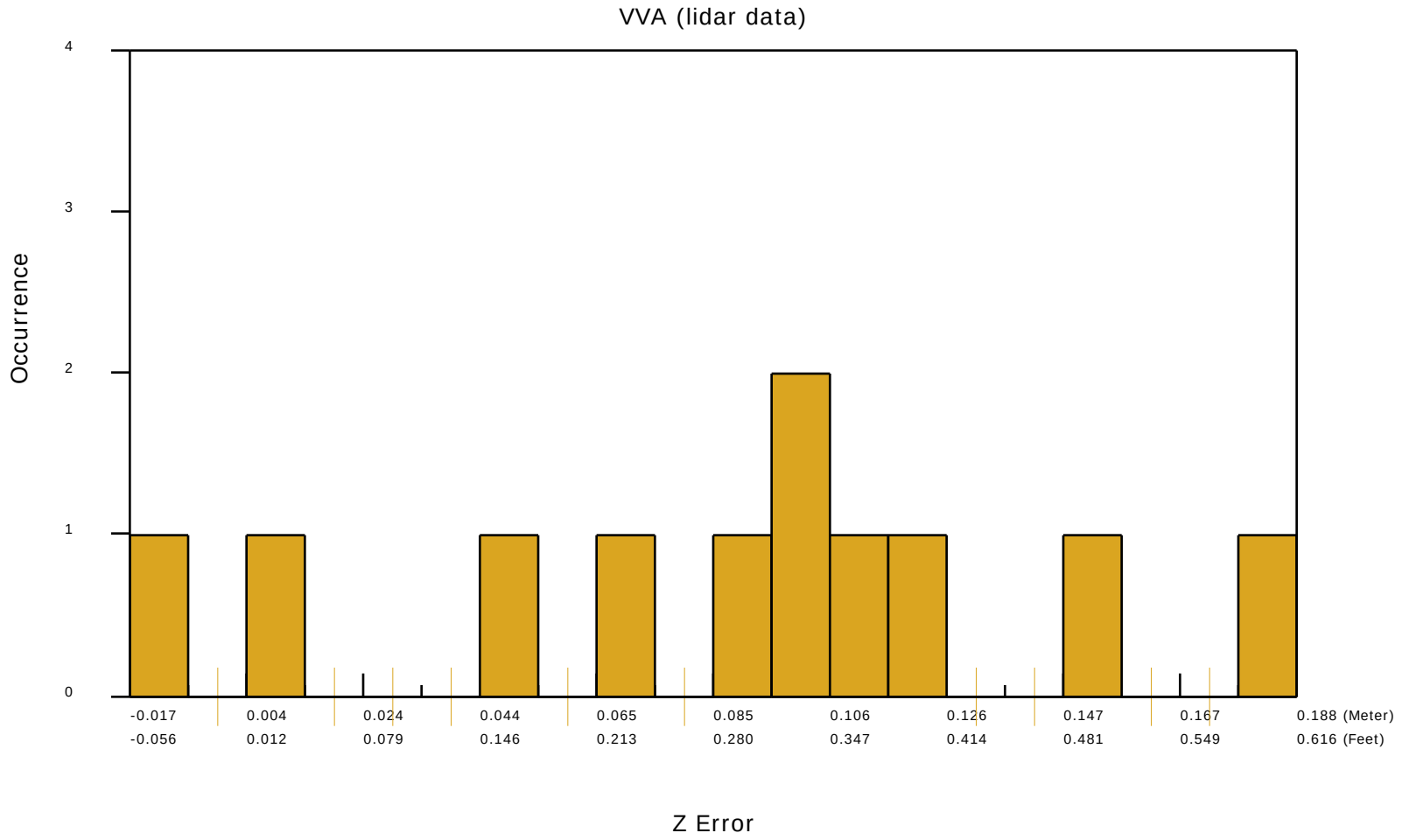
DPH-11 Report on Absolute Vertical Accuracy - continued

The purpose of this section is to show a frequency distribution chart of the non-vegetated vertical accuracy (NVA) of the lidar point cloud data measured against surveyed ground check points.



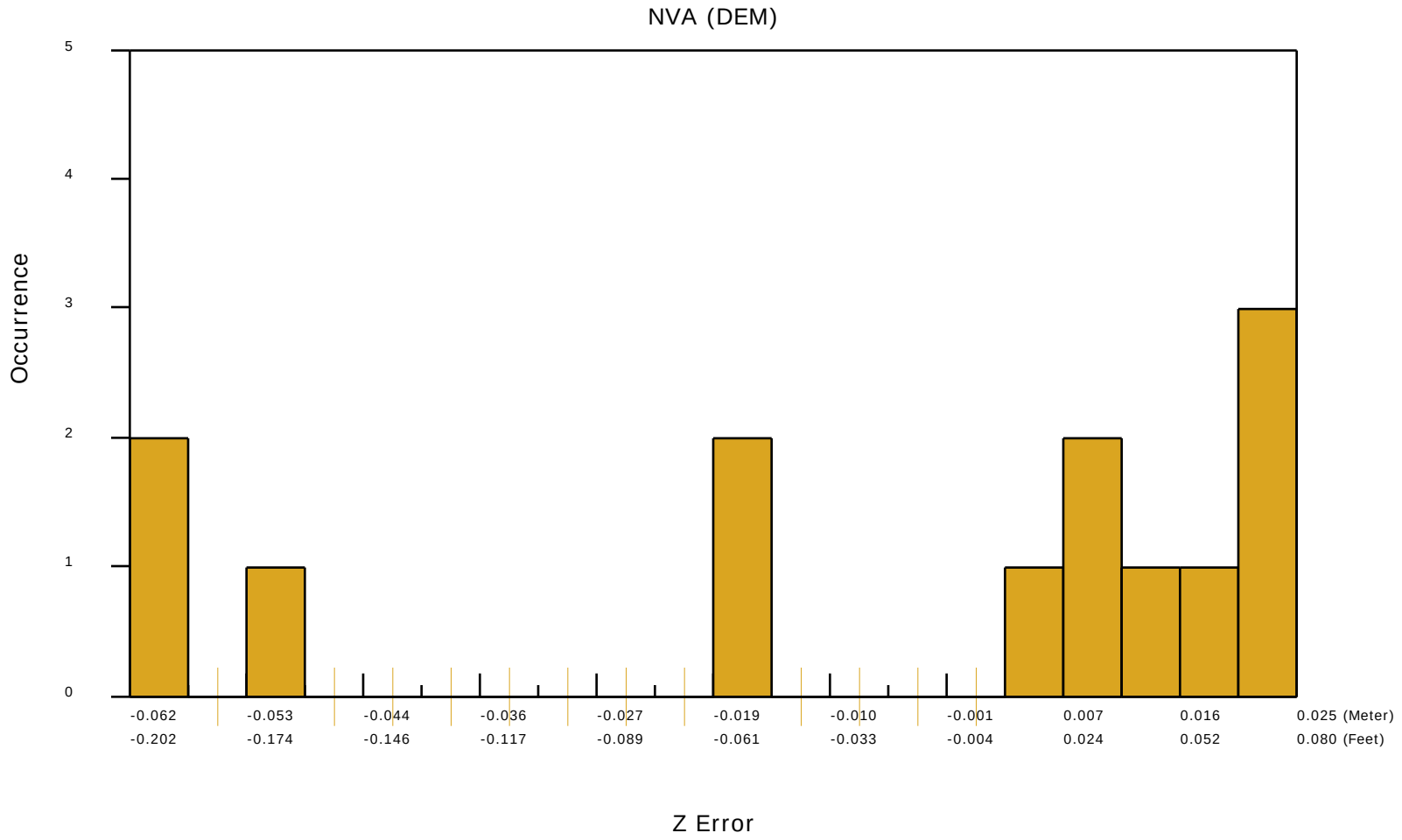
DPH-11 Report on Absolute Vertical Accuracy - continued

The purpose of this section is to show a frequency distribution chart of the vegetated vertical accuracy (VVA) of the lidar point cloud data measured against surveyed ground check points.



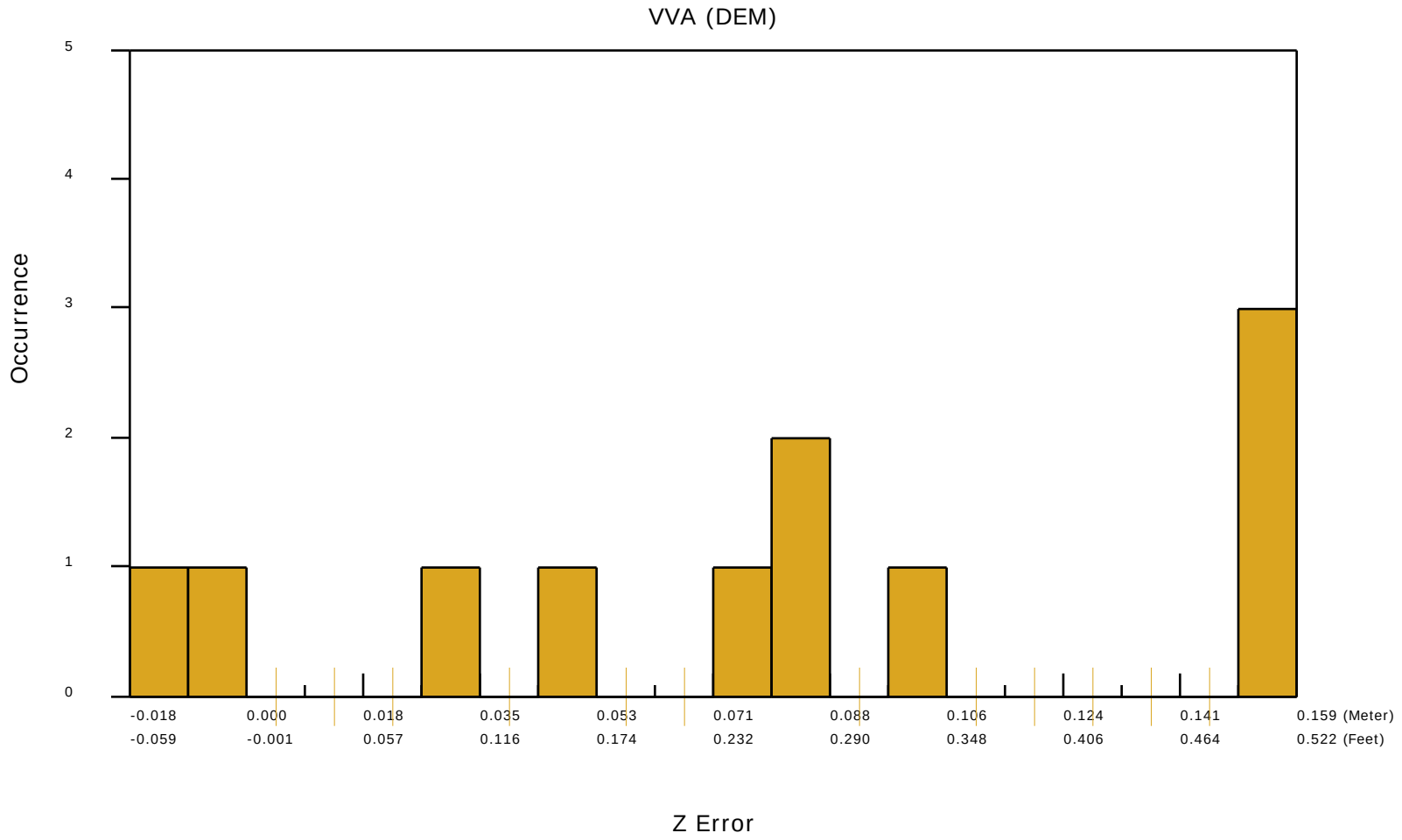
DPH-11 Report on Absolute Vertical Accuracy - continued

The purpose of this section is to show a frequency distribution chart of the non-vegetated vertical accuracy (NVA) of the DEM data measured against surveyed ground check points.



DPH-11 Report on Absolute Vertical Accuracy - continued

The purpose of this section is to show a frequency distribution chart of the vegetated vertical accuracy (VVA) of the DEM data measured against surveyed ground check points.



DPH-12 Report on Use of the LAS Withheld Flag

The USGS Lidar Base Specification Version 2.1 states: "The withheld bit flag, as defined in LAS specification version 1.4–R15 (ASPRS, 2011), shall only be used to identify points that cannot be reasonably interpreted as valid surface returns. Examples include outliers, blunders, geometrically unreliable points, aerosol back-scatter, laser multi-path, airborne objects, and sensor anomalies. The withheld flag may be used in conjunction with other classification codes (low/high noise for example), but it should be used in all cases where the previously mentioned criteria are met."

The purpose of this section is to list the presence and quantities of points flagged as Withheld for all lidar data files.

Total Withheld points (all classes, all files)	9972

DPH-13 Report on Use of the LAS Overlap Flag

The USGS Lidar Base Specification Version 2.1 states: "If overage points must be excluded to produce a uniform DEM then those overage points shall be identified using the LAS overlap bit flag in all point cloud deliverables. For more information on the difference between overlap and overage, refer to figures 4–5 and the "Glossary" section. Identification of overage points allows their simple exclusion from subsequent processes where the increased density and elevation variability they introduce is unwanted (that is, DEM generation)."

The purpose of this section is to list the presence and quantities of points flagged as Overlap for all lidar data files.

Total Overlap points (all classes, all files)	0

DPH-14 Report on Point Classification

The USGS Lidar Base Specification Version 2.1 states: "The minimum, required classification scheme for lidar data is found in table 5. The following requirements apply to point classification:

- All points that fall within the minimum classification scheme (table 5) and not flagged as withheld shall be properly classified.
- Additional classes may be used on specific projects.
- Accuracy of point classification into classes beyond the minimum scheme (table 5) will not be assessed by the USGS, as documented in metadata.
- Assessing and verifying accuracy of point classification into classes beyond the minimum scheme will be the responsibility of the partner requesting the additional classes.
- No points in the classified LAS deliverable may remain assigned to Class 0, unless these points are flagged as withheld.
- Points classified as water will only be checked when associated with a breakline.
- If it is necessary to identify overage points in overlap areas, the overage points shall be identified using the overlap bit flag as defined in LAS Specification Version 1.2-R13 (ASPRS, 2011).
  classified.
- No classification code may be used to identify points as overage points.
- Model key points, if calculated, shall be identified using the key point bit flag as defined in LAS specification version 1.4–R13 (ASPRS, 2011). Model key points may, in addition, be identified using class 8 at the discretion of the data producer."

Table 5. Minimum light detection and ranging data classification scheme.

Code	Description
1	Processed, but unclassified
2	Bare earth
7	Low noise
9	Water
17	Bridge deck
18	High noise
20	Ignored ground (*typically breakline proximity*)
21	Snow (*if present and identifiable*)
22	Temporal exclusion (*typically nonfavored data in intertidal zones*)

The purpose of this section is to report total numbers of points for each class within the LAS files.

DPH-14 Report on Point Classification - Class Totals

The purpose of this section is to list the number of points in each classification so the user can determine if any points exist in unintended classes or contain incorrect bit flags.

Class	Total	MKP	WH	Class	Total	MKP	WH	Class	Total	MKP	WH	Class	Total	MKP	WH
0	00	00	00	64	00	00	00	128	00	00	00	192	00	00	00
1	498,396,715	00	00	65	00	00	00	129	00	00	00	193	00	00	00
2	4,068,147,938	00	00	66	00	00	00	130	00	00	00	194	00	00	00
3	00	00	00	67	00	00	00	131	00	00	00	195	00	00	00
4	00	00	00	68	00	00	00	132	00	00	00	196	00	00	00
5	00	00	00	69	00	00	00	133	00	00	00	197	00	00	00
6	00	00	00	70	00	00	00	134	00	00	00	198	00	00	00
7	5,595	00	5,595	71	00	00	00	135	00	00	00	199	00	00	00
8	00	00	00	72	00	00	00	136	00	00	00	200	00	00	00
9	2,111,622	00	00	73	00	00	00	137	00	00	00	201	00	00	00
10	00	00	00	74	00	00	00	138	00	00	00	202	00	00	00
11	00	00	00	75	00	00	00	139	00	00	00	203	00	00	00
12	00	00	00	76	00	00	00	140	00	00	00	204	00	00	00
13	00	00	00	77	00	00	00	141	00	00	00	205	00	00	00
14	00	00	00	78	00	00	00	142	00	00	00	206	00	00	00
15	00	00	00	79	00	00	00	143	00	00	00	207	00	00	00
16	00	00	00	80	00	00	00	144	00	00	00	208	00	00	00
17	23,450	00	00	81	00	00	00	145	00	00	00	209	00	00	00
18	4,377	00	4,377	82	00	00	00	146	00	00	00	210	00	00	00
19	00	00	00	83	00	00	00	147	00	00	00	211	00	00	00
20	137,153	00	00	84	00	00	00	148	00	00	00	212	00	00	00
21	00	00	00	85	00	00	00	149	00	00	00	213	00	00	00
22	00	00	00	86	00	00	00	150	00	00	00	214	00	00	00
23	00	00	00	87	00	00	00	151	00	00	00	215	00	00	00
24	00	00	00	88	00	00	00	152	00	00	00	216	00	00	00
25	00	00	00	89	00	00	00	153	00	00	00	217	00	00	00
26	00	00	00	90	00	00	00	154	00	00	00	218	00	00	00
27	00	00	00	91	00	00	00	155	00	00	00	219	00	00	00
28	00	00	00	92	00	00	00	156	00	00	00	220	00	00	00
29	00	00	00	93	00	00	00	157	00	00	00	221	00	00	00
30	00	00	00	94	00	00	00	158	00	00	00	222	00	00	00
31	00	00	00	95	00	00	00	159	00	00	00	223	00	00	00
32	00	00	00	96	00	00	00	160	00	00	00	224	00	00	00
33	00	00	00	97	00	00	00	161	00	00	00	225	00	00	00
34	00	00	00	98	00	00	00	162	00	00	00	226	00	00	00
35	00	00	00	99	00	00	00	163	00	00	00	227	00	00	00
36	00	00	00	100	00	00	00	164	00	00	00	228	00	00	00
37	00	00	00	101	00	00	00	165	00	00	00	229	00	00	00
38	00	00	00	102	00	00	00	166	00	00	00	230	00	00	00
39	00	00	00	103	00	00	00	167	00	00	00	231	00	00	00
40	00	00	00	104	00	00	00	168	00	00	00	232	00	00	00
41	00	00	00	105	00	00	00	169	00	00	00	233	00	00	00
42	00	00	00	106	00	00	00	170	00	00	00	234	00	00	00
43	00	00	00	107	00	00	00	171	00	00	00	235	00	00	00
44	00	00	00	108	00	00	00	172	00	00	00	236	00	00	00
45	00	00	00	109	00	00	00	173	00	00	00	237	00	00	00
46	00	00	00	110	00	00	00	174	00	00	00	238	00	00	00
47	00	00	00	111	00	00	00	175	00	00	00	239	00	00	00
48	00	00	00	112	00	00	00	176	00	00	00	240	00	00	00
49	00	00	00	113	00	00	00	177	00	00	00	241	00	00	00
50	00	00	00	114	00	00	00	178	00	00	00	242	00	00	00
51	00	00	00	115	00	00	00	179	00	00	00	243	00	00	00
52	00	00	00	116	00	00	00	180	00	00	00	244	00	00	00
53	00	00	00	117	00	00	00	181	00	00	00	245	00	00	00
54	00	00	00	118	00	00	00	182	00	00	00	246	00	00	00
55	00	00	00	119	00	00	00	183	00	00	00	247	00	00	00
56	00	00	00	120	00	00	00	184	00	00	00	248	00	00	00
57	00	00	00	121	00	00	00	185	00	00	00	249	00	00	00
58	00	00	00	122	00	00	00	186	00	00	00	250	00	00	00
59	00	00	00	123	00	00	00	187	00	00	00	251	00	00	00
60	00	00	00	124	00	00	00	188	00	00	00	252	00	00	00
61	00	00	00	125	00	00	00	189	00	00	00	253	00	00	00
62	00	00	00	126	00	00	00	190	00	00	00	254	00	00	00
63	00	00	00	127	00	00	00	191	00	00	00	255	00	00	00

Bold – point counts in 'Minimum classified point cloud classification scheme' (see table on previous page)

– point counts in Classes beyond the minimum

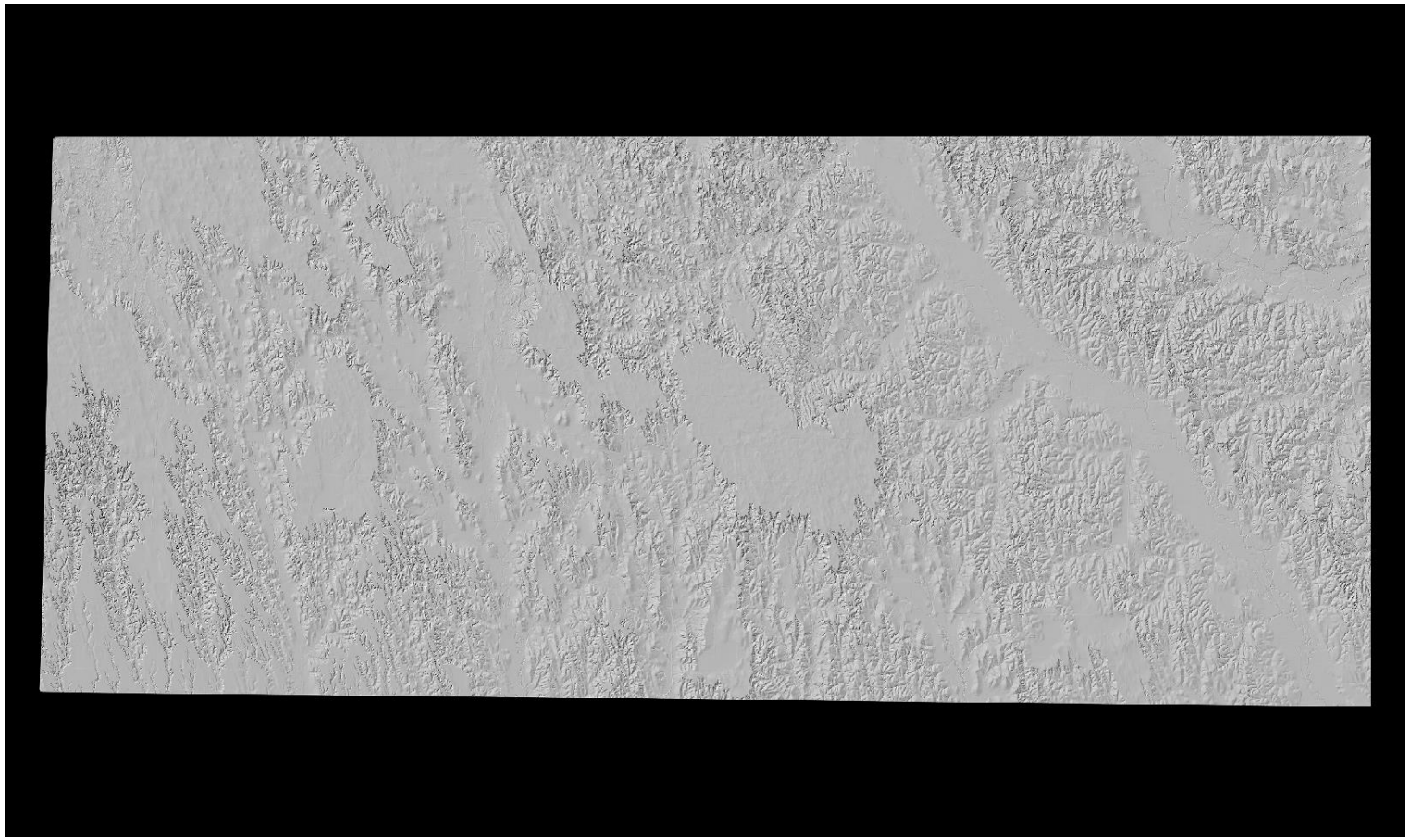
– disallowed point counts or bit flags per USGS spec

– not all Class 0, Class 7, and Class 18 points flagged as Withheld

DPH-15 Report on Classification Consistency

The USGS Lidar Base Specification Version 2.1 states: "Point classification is to be consistent across the entire project. Noticeable variations in the character, texture, or quality of the classification between tiles, swaths, lifts, or other non-natural divisions will be cause for rejection of the entire deliverable."

The purpose of this section is to show the bare earth surface hillshade product for classification consistency inspection.



DPH-16 Report on Tiles

The USGS Lidar Base Specification Version 2.1 states: "A single nonoverlapping project tiling scheme will be established and agreed upon by the data producer and the USGS–NGP before collection. The tiling scheme will be used for all tiled deliverables:
- The tiling scheme shall use the same coordinate reference system and units as the data.
- The tile size shall be an integer multiple of the cell size for raster deliverables.
- The tiles shall be indexed in x and y to an integer multiple of the x and y dimensions of the tile.
- The tiled deliverables shall edge-match seamlessly and without gaps.
- The tiled deliverables shall conform to the project tiling scheme without added overlap."

The purpose of this section is to report on the unallowed presence of overlap in the project tile scheme.

Units: Meter

The following lists tiles that are overlapped.

Tile	Approx. Width	Approx. Height	Overlap

NONE

Skipped Tests

DPH-2 Report on Waveform Data
DPH-9.2 DQM - Overlap Consistency (interswath)

USGS LBS 2.1 QC Module Input Requirements Matrix

Test number and Description	Classified LAS (final filtered tiled data)	Tile Scheme Shapefile	DPA Boundary Shapefile	Lidar Check Points
C-1 Collection Area	X		X	
C-2 Returns	X	X		
C-3 Intensity	X	X		
C-4 Nominal Pulse Spacing (NPS)	X		O	
C-5 Data Voids	X		X	
C-6 Spatial Distribution	X		X	
C-7 Collection Conditions	X			
DPH-1 LAS Format	X	X		
DPH-2 Waveform Data	X			
DPH-3 GPS Time Type	X			
DPH-4 Datums	X			
DPH-5 Coordinate Reference Systems	X			
DPH-6 Units of Reference	X			
DPH-7 File Source ID	X	X		
DPH-8 Smooth Surface Precision (intraswath)	X	X		X
DPH-9.1 Overlap Consistency (interswath)	X	X	X	
DPH-9.2 DQM-Overlap Consistency (interswath)	X			
DPH-10 Check Points			X	X
DPH-11 Absolute Vertical Accuracy	X		X	X
DPH-12 Use of the LAS Withheld Flag	X	X		
DPH-13 Use of the LAS Overlap Flag	X	X		
DPH-14 Point Classifications	X	X		
DPH-15 Classification Consistency	X			
DPH-16 Tiles		X		

X = Required to run test

O = Optional for single project area density reporting, but required for multi-area (multiple boundary) reporting of individual and aggregate areas