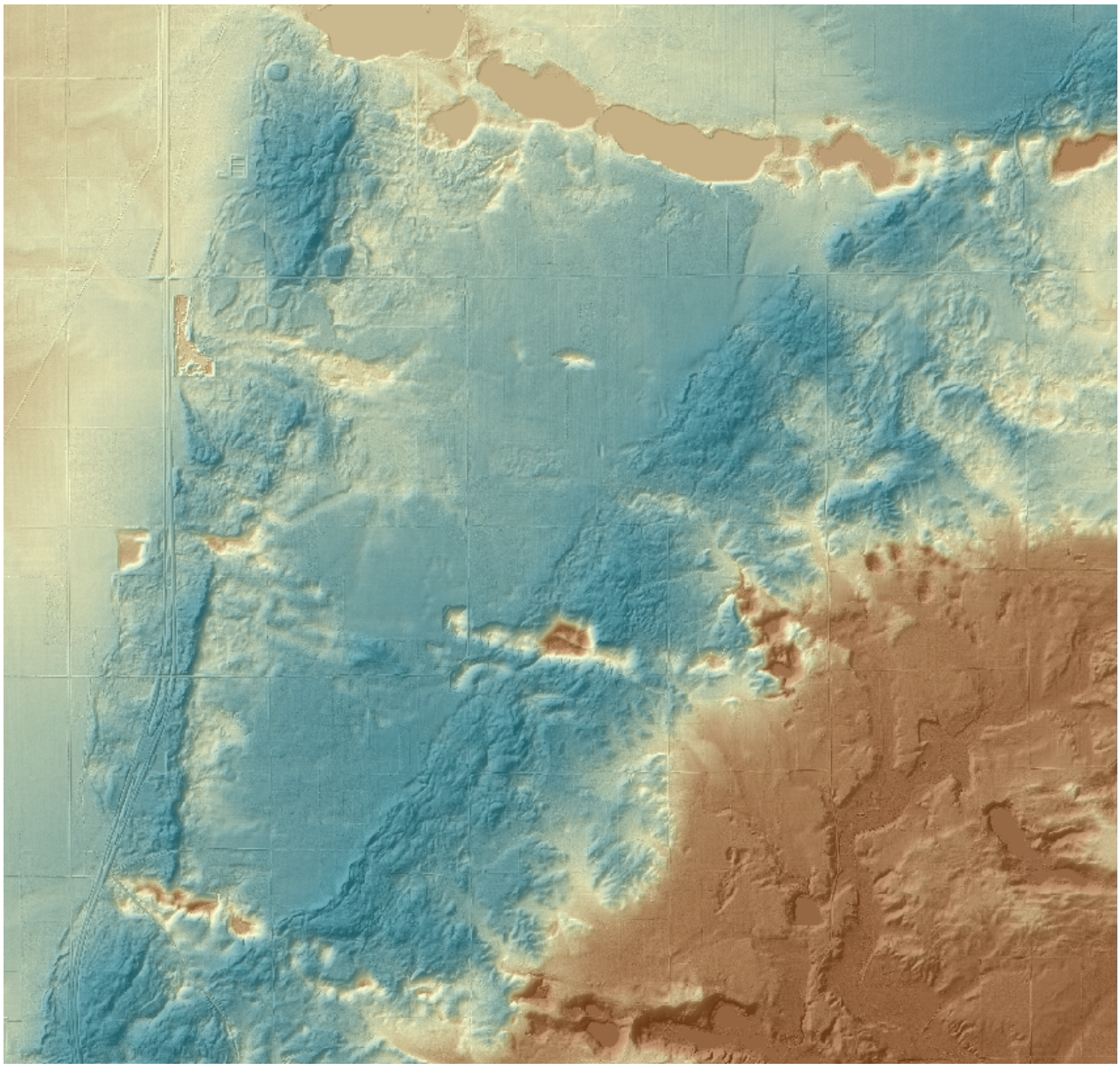
New Topographic Data, Independent QA/QC Report Waushara County, WI November 2018

STARR II Strategic Alliance for Risk Reduction



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FEMA

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1. INTRODUCTION

The purpose of this project is to provide the Federal Emergency Management Agency (FEMA) accurate high-quality elevation datasets derived from Light Detection and Ranging (LiDAR) point clouds. STARR II is responsible for the collection, post processing, and independent quality control of all datasets and derived products. The goal of these tasks is to assure all LiDAR related data meet the USGS 3DEP Quality Level 2 (QL2) requirements and are able to be used for future FEMA Risk MAP projects.

This report summarizes all quality assurance and quality control testing completed on the LiDAR datasets based on the following specifications:

- USGS Lidar Base Specification Version 1.2, November 2014.
- ASPRS LAS Specification Version 1.4 – R13 July 15, 2013.
- ASPRS Positional Accuracy Standards for Digital Geospatial Data (Edition 1, Version 1.0. – November 2014).
- FEMA Data Capture Technical Reference February 2018
- Open Geospatial Consortium Geographic information-Well known text representation of coordinate reference systems Version 1.0

General Information

FEMA TASK Number	HSFE05-17-J-0005
Project Name	55137 Waushara County Wisconsin FEMA 2017
Project Type	FEMA NFIP New Acquisition Terrain Data to be contributed to USGS 3DEP
USGS 3DEP Quality Level	2
Required Point Spacing	0.71 meters
Required Point Density	2 pulses per square meter
Required NVA Swath	<= 10 cm RMSE and <=19.6 cm 95-percent confidence level
Required NVA Bare Earth	<= 10 cm RMSE and <=19.6 cm 95-percent confidence level
Required VVA Bare Earth	<= 29.4 at 95th Percentile
Project Location	Waushara County, Wisconsin
Project Area	647 square miles (1676 square kilometers)
Point Data Cloud Collected	November 7, 2017 through November 8, 2017
LAS Version	1.4
Point Format	6
Field Survey	Compass-Data, Inc
Point Cloud Acquisition	Kucera International Inc.
Point Cloud Post Processing	Continental Mapping Consultants, Inc.
Independent QA/QC	STARR II
Licensing	Public Domain

1.1 PROJECT SUMMARY

The Waushara County, Wisconsin project is a countywide LiDAR acquisition encompassing an area of approximately 647 square miles or 1676 square kilometers. LiDAR was collected in 3 lifts from November 7, 2017 through November 8, 2017 and processed in compliance with USGS Quality Level 2 data specifications. LAS 1.4 swath files, Classified LAS 1.4 5,000 x 5,000-foot tiles, Breaklines, and Hydro-flattened bare earth DEMs have been produced for the project area. For additional information regarding the scope of work, please refer to the project narrative included with this submission.

Data for this project was created using the following Coordinate Reference System:

Coordinate System: Wisconsin State Plane South, FIPS 4803
Horizontal Datum: NAD83 (2011), Epoch 2010.00
X, Y Linear Units: US Survey Feet
Vertical Datum: NAVD88, Geoid 12B
Z Linear Units: US Survey Feet

The Deliverables for this project are listed below:

1. Collection Report Including Mission Planning and Flight Logs
2. Survey Report Including Ground Control Precision and Absolute Vertical Accuracy Test Results
3. Ground Control and Check Points Shapefiles
4. Point Cloud Processing and Product Generation Reports
5. Indices and Project Extent Shapefiles
6. Metadata Files in XML Format
7. Raw Point Cloud Swaths
8. Tiled Classified Point Cloud
9. 3D Breaklines
10. Hydro-flattened DEMs
11. FEMA Certificate of Compliance/Completion, Terrain Metadata XML, and Project Narrative
12. Project Independent QA/QC Report and supporting documentation.

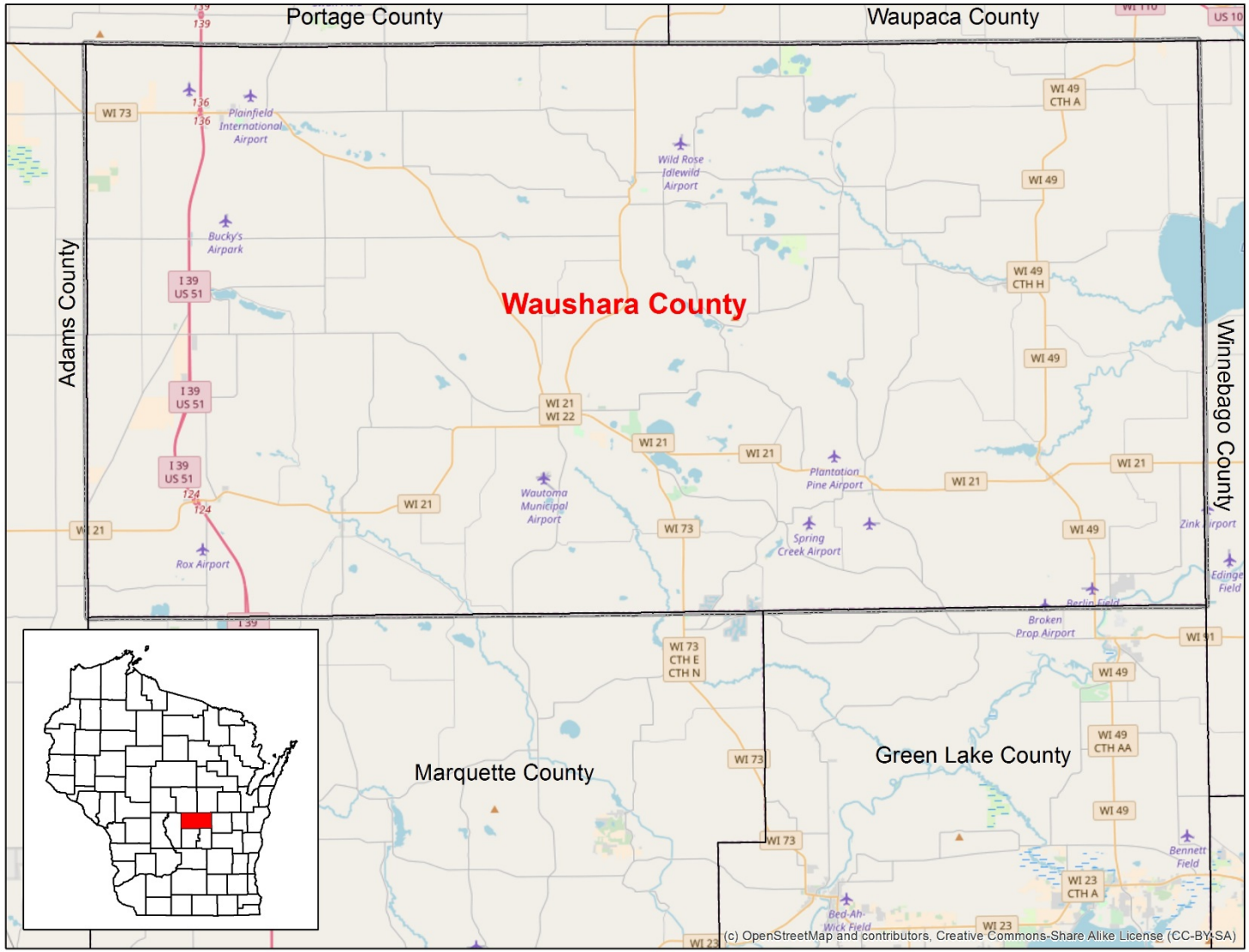

Figure 1. Project Location

2.0 PROJECT DATA INVENTORY

Project deliverables are submitted per FEMA project requirements and USGS specifications. To initiate the independent quality assurance and control task, all required datasets and documentation deliverables are inventoried, and coordinate reference systems confirmed.

Table 1. Project Data Inventory

Deliverable	Included	Format	#	Notes
Documentation and Metadata				
FEMA Compliance Form	☑	PDF	1	Signed and Sealed
Mission Planning Report	☑	PDF	1	Combined with Collection Report
Collection Report and Logs	☑	PDF	1	Flight Logs Included with Flight Report
LiDAR Sensor Specifications	☑	PDF	1	Leica ALS70 Product Specifications
Survey Reports	☑	PDF	2	Ground Control and Vertical Accuracy
Vertical Accuracy Validation	☑	XLSX	2	NVA/VVA Calculation Spreadsheets
Processing Reports	☑	PDF	4	Calibration, Classification, Breakline, and Hydro-Flattened DEM
Relative Accuracy Reports	☑	PDF	2	Interswath and Smooth Surface
Project Level Metadata	☑	XML	1	
Lift(s) Metadata	☑	XML	3	
Classified Metadata	☑	XML	1	
Breakline Metadata	☑	XML	1	
DEM Metadata	☑	XML	1	
Other	☐	XML	0	N/A
Survey Data				
Monument Datasheets	☑	PDF	3	
Monument Images	☑	JPEG	15	
Control Calibration Photos	☑	JPEG	100	
NVA Checkpoint Photos	☑	JPEG	200	Image chips also included
VVA Checkpoint Photos	☑	JPEG	150	Image chips also included
Geospatial Vector Data				
Buffered Project Area	☑	SHP	1	100-meter buffer
Base Station(s)	☑	SHP	1	
Flight Lines	☑	SHP	1	
As Flown Trajectories (SBET)	☑	SOL	3	One per lift
Survey Monument	☑	SHP	1	kmz also included
Survey Ground Control	☑	SHP	1	20 control points
Survey Checkpoint	☑	SHP	2	40 NVA points and 30 VVA points
Indices	☑	SHP	3	Swath, Classified, and DEM
Low Confidence	☑	SHP	1	Areas found to have a low number of returns
LiDAR Data				
Swath Point Cloud Files	☑	LAS	35	Includes Cross Flights
Tiled Classified Point Cloud	☑	LAS	760	5000'x5000' tiles
LiDAR Derived Data				
Breaklines	☑	SHP, GDB	2	Polygon Z shapefile and ESRI Feature Class
Hydro-flattened DEMs	☑	IMG	760	Has pyramids and statistics

2.1 Inventory Projection Coordinate Reference System Check.

Project deliverables were checked for proper projection upon delivery. For Waushara Wisconsin, the proper Coordinate Reference System is NAD 1983 2011 State Plane Wisconsin South FIPS 4803 projected in Lambert Conformal Conical with vertical datum set to NAVD88 (Geoid 12B).

Table 2. Coordinate Reference System Checklist

Project Data	Pass/Fail
LiDAR Project Area	Pass
Buffered Project Area	Pass
LiDAR Base Station	Pass
Flight Line Trajectory	Pass
LiDAR Control	Pass
NVA Checkpoints	Pass
VVA Checkpoints	Pass
LiDAR LAS 1.4 Swath Files (35)	Pass
Classified LAS 1.4 Files (760)	Pass
DEM Tiles (760)	Pass
LiDAR Low Confidence Areas	Pass
LiDAR Breaklines GDB	Pass
LiDAR breaklines SHP	Pass
Swath and Tile Indices	Pass
Bare Earth DEM XML Metadata	Pass
Breaklines XML Metadata	Pass
Classified XML Metadata	Pass
Lift 1110717 XML Metadata	Pass
Lift 1110717A XML Metadata	Pass
Lift 1110717B XML Metadata	Pass

3 PROJECT DOCUMENTATION

To confirm the project documentation meets the specification standards, reports and metadata undergo an editorial review. Reports are reviewed to ensure they are complete and comprehendible. Metadata are reviewed to ensure correct FGDC formatted xml, provide the necessary project details, include LiDAR tags, and pass the USGS metadata parser.

Table 3. Metadata QC Checklist

Metadata File	**QC**	**MP**	**Pass/Fail**
Project Level	☑	☑	Pass
Lifts (3)	☑	☑	Pass
Classified LiDAR	☑	☑	Pass
Breaklines	☑	☑	Pass
Hydro-flattened DEM	☑	☑	Pass

Table 4. Report QC Checklist

Report	QC	Pass/Fail
Preflight Collection Report Detailing Mission Planning	☑	Pass
Post Flight collection report	☑	Pass
Flight Logs	☑	Pass
Ground Control Survey Report	☑	Pass
Check Point Survey Report	☑	Pass
Calibration Processing and QA Report	☑	Pass
Classification Processing and QA Report	☑	Pass
Breakline Processing and QA Report	☑	Pass
Hydro-flattened DEM Processing and QA Report	☑	Pass
Absolute NVA Vertical Accuracy Test Results	☑	Pass
Relative Vertical Accuracy	☑	Pass
Bare-Earth Surface Absolute Accuracy NVA and VVA Test Results	☑	Pass
FEMA Certificate of Compliance	☑	Pass

4 RAW POINT CLOUD SWATH DATA

Quality control procedures for swath data evaluate the LiDAR system performance. This provides vital information in determining if the proper quality assurance and calibration procedures were used during the acquisition. Several checks are performed on the raw point cloud to confirm the data meet planned LiDAR collection expectations.

Table 5. Swath Raw Point Cloud Checklist

Swath Raw Point Cloud	QC	Pass/Fail
Complete Coverage of Buffered Project Area	☑	Pass
NVA Absolute Vertical Accuracy	☑	Pass
Relative Accuracy	☑	Pass
Point Density	☑	Pass
Point Spacing	☑	Pass
Spatial Distribution	☑	Pass
Visual Review and Data Voids	☑	Pass
LAS file formatting	☑	Pass
Coordinate Reference System WKT	☑	Pass

4.1 PROJECT AREA COVERAGE

The USGS LiDAR Base Specification Version 1.2 requires that data collection for the defined project area be buffered by a minimum of 100 meters. The purpose of this section is to show LiDAR coverage to the extent of a 100-meter buffer of the project boundary.

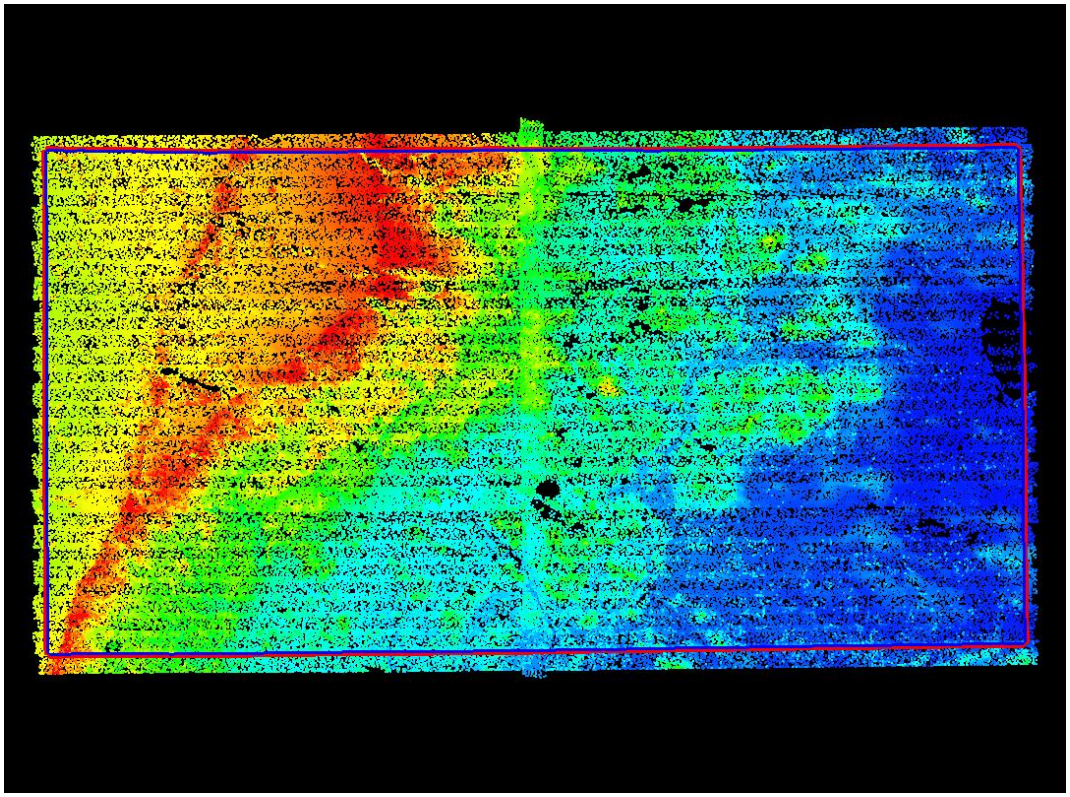

Figure 2. Project Area LiDAR Coverage

4.2 ABSOLUTE VERTICAL ACCURACY NVA

To assess the absolute vertical accuracy of the raw point cloud, a collection of discreet checkpoints was surveyed and dispersed throughout the project area in non-vegetated, clear open spaces. A TIN created from the irregularly spaced LiDAR points was utilized to determine the interpolated elevation at the checkpoint location, and the interpolated elevation was compared to the surveyed elevation. The differences between the interpolated surface and checkpoint elevations are used to statistically determine the vertical error compared with ASPRS Positional Accuracy Standards for Digital Geospatial Data and USGS Base Specification v1.2, QL2 requirements (RMSEZ <= 10 cm, 95% confidence level <= 19.6 cm). The results of this test for raw point cloud data must meet the specified requirements for absolute vertical accuracy before any LiDAR post processing can begin.

Table 6. USGS Absolute Vertical Accuracy Requirements for Quality Levels 0-3.

Quality Level (QL)	RMSE$_z$ (nonvegetated) (cm)	NVA at 95-percent confidence level (cm)
QL0	≤5.0	≤9.8
QL1	≤10.0	≤19.6
QL2	≤10.0	≤19.6
QL3	≤20.0	≤39.2

STARR II tested the raw point cloud data using forty non-vegetated surveyed check points dispersed across the project area in clear and open spaces. A total of 40 NVA surveyed checkpoints were distributed across the project area of 1676 square kilometers. This meets the requirement set in ASPRS Positional Accuracy Standards for Digital Geospatial Data (Edition 1, Version 1.0. – November 2014) on Table C.1. Independent test results verify the raw point cloud absolute vertical accuracy is within the specified requirements. Survey data included with this deliverable provide detailed documentation and photos of each location surveyed.

Table 7. Table C.1 Recommended Number of Checkpoint Based on Area

Project Area (Square Kilometers)	Horizontal Accuracy Testing of Orthoimagery	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
≤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

Table 8. Absolute Vertical Accuracy for NVA Swath from Survey

LiDAR Swath NVA Summary Statistics	Test Results (US Survey Feet / Meter)
Number of Check Points	40
Points with Swath Coverage and Required Accuracy	40
Average Z Error	0.096/0.029
Maximum Z Error	0.474/0.144
Minimum Z Error	-0.113/-0.034
NVA RMSEz <= 10 cm	0.157/0.048 **PASS**
NVA AccuracyZ <= 19.6 cm at 95% Confidence	0.308/0.094 **PASS**

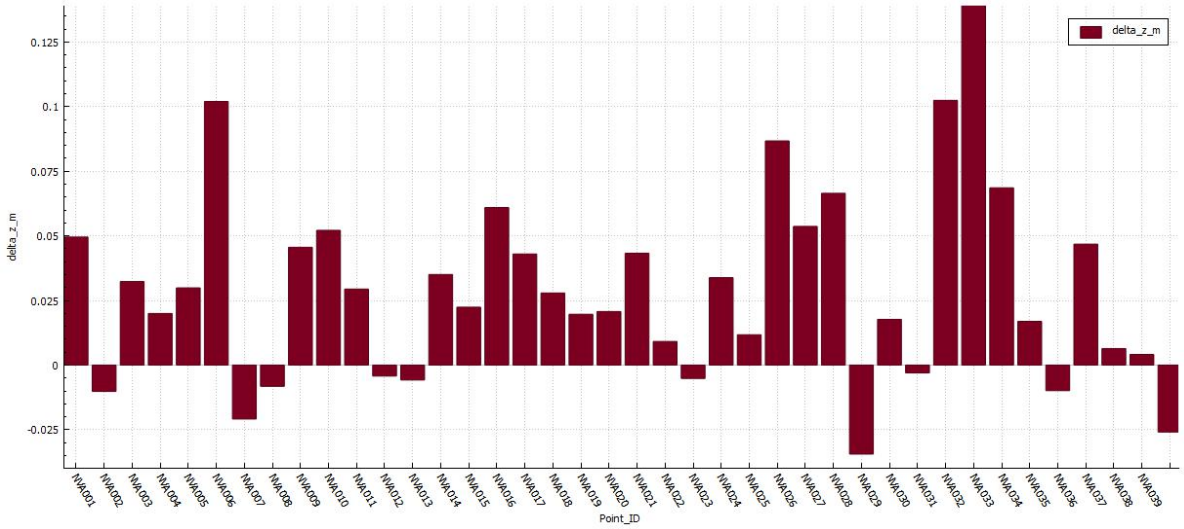

Figure 3. Histogram of Survey NVA Test Results

Table 9. Absolute Vertical Accuracy for NVA Swath from Independent QC

LiDAR Swath NVA Summary Statistics	Test Results (US Survey Feet / Meter)
Number of Check Points	40
Points with Swath Coverage and Required Accuracy	40
Average Z Error	0.041/0.012
Maximum Z Error	0.442/0.135
Minimum Z Error	-0.219/-0.067
NVA RMSEz <= 10 cm	0.146/0.045 **PASS**
NVA AccuracyZ <= 19.6 cm at 95% Confidence	0.287/0.087 **PASS**

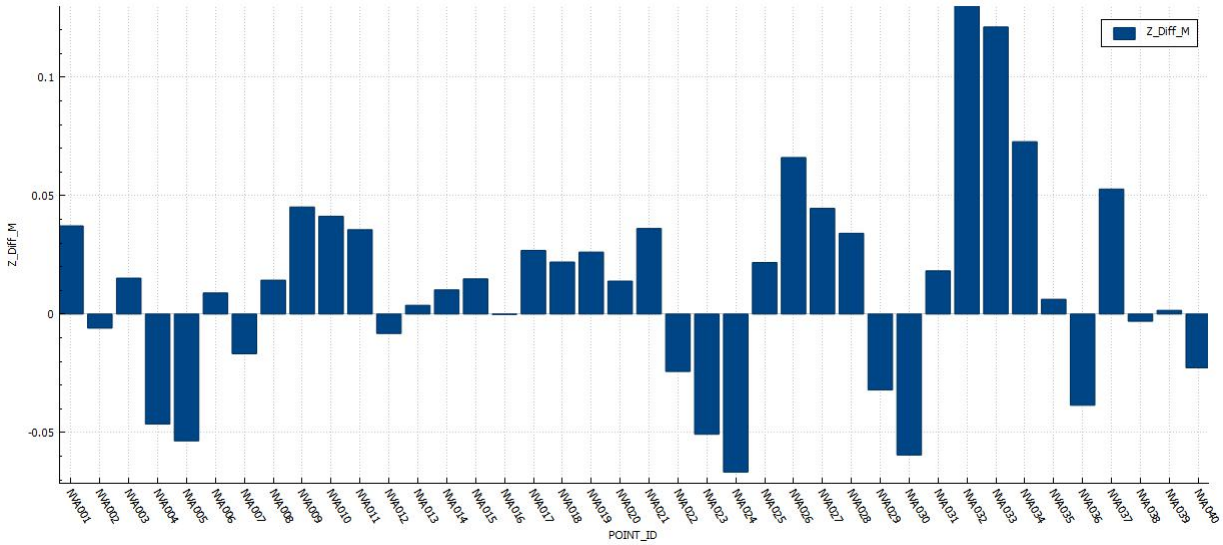

Figure 4. Histogram of Independent QC NVA Test Results

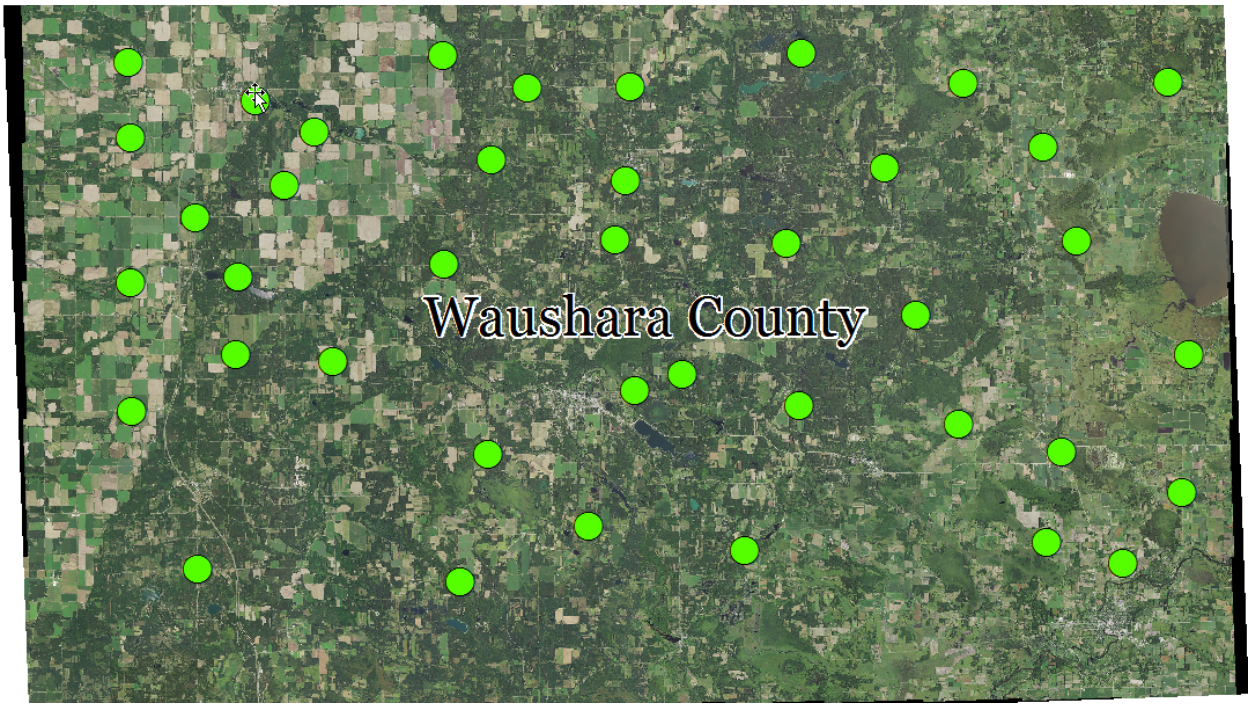

Figure 5. NVA Survey Check Point Distribution

4.3 RELATIVE ACCURACY

The USGS LiDAR Base Specifications v1.2 for quality level 2 data requires an inter-swath relative accuracy of 8 cm RMSDz with maximum differences less than 16 cm. STARR II tested the inter-swath relative accuracy by analyzing the flight line separation within swath overlaps in non-vegetated open terrain.

DeltaZ images were created to examine swath alignment and quantify elevation differences between overlapping swaths. Elevation differences are summarized and the RMSDz is calculated to verify that the swath data meet the quality level 2 relative accuracy requirements. Test results confirm this project meets the criteria for relative accuracy.

Table 10. Inter-Swath Relative Vertical accuracy requirements and results.

Requirements	
Swath overlap difference RMSDz (m)	<= to 0.08 m
Maximum Difference	<16 cm
Reported	
Swath overlap difference RMSDz (m)	0.091 ft /0.027 m /2.7 cm
Maximum Difference	0.095 ft / 0.028 m/2.8 cm
Independent results	
Swath overlap difference RMSDz (m)	0.231 ft / 0.07 m/7 cm **PASS**
Maximum Difference	0.287 ft/0.087 m/8.7 cm **PASS**

Terrasolid's LP360 Planar Statistics point cloud task was utilized to evaluate best-fitting of laser points to a plane within each flight. It computes the quality of fit values, which are stored as attributes in a shapefile. This shapfile was then loaded into LP360 using single returns only. The results are then written into the shapefile in terms of standard deviation from the plane into the StdDev field. Lesser standard deviation means the points are more tightly clustered about the plane. Instead of large flat impervious surfaces open agriculture fields where then utilized due to the lack of large development.

Table 11. LP360 standard deviations results for each lift

Lift ID	No. of Sample Sites	Standard Deviation
110717A	19	5.84 cm
110717B	44	5.43 cm
110817	27	4.47 cm

Horizontal alignment between adjacent overlapping swaths was tested by drawing cross-sections across locations such as rooftops and embankments. An example of Profiles derived from the cross sections were analyzed and confirm proper alignment. Smooth surface repeatability (intraswath) testing was performed throughout the project using a minimum of 50 square meter areas. Samples were taken from developed areas and included rooftops, airport tarmac, baseball infield, and cul-de-sacs located within swaths. The single return LiDAR points are extracted using LAS tools las2las for each area. The extracted LAS files are loaded into an ArcGIS LAS dataset. Minimum and maximum elevation rasters are created and subtracted to create a difference raster. USGS quality level 2 data must meet an intraswath relative accuracy of less than or equal to 6 centimeters. This project meets these criteria for flat open areas with moderate slope.

Figure 6. Intraswath (Smooth surface) test areas.

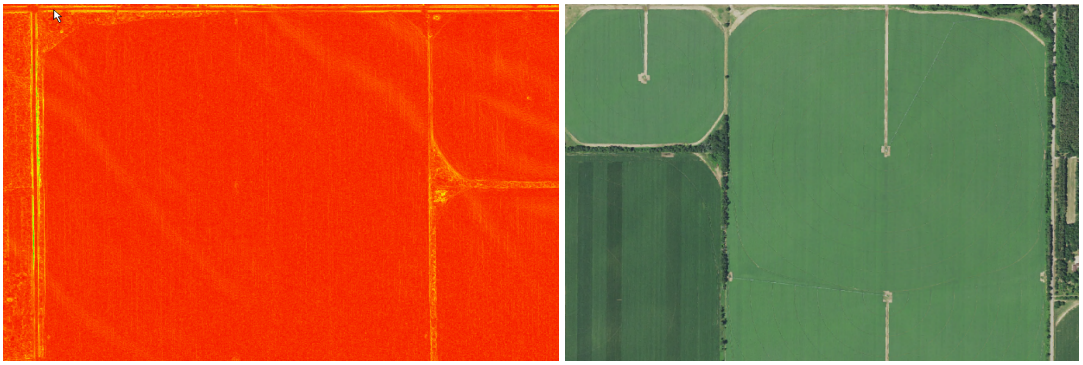

Figure 7. Intraswath testing at a farm field. Red areas are within specifications and yellow areas are sloped terrain.

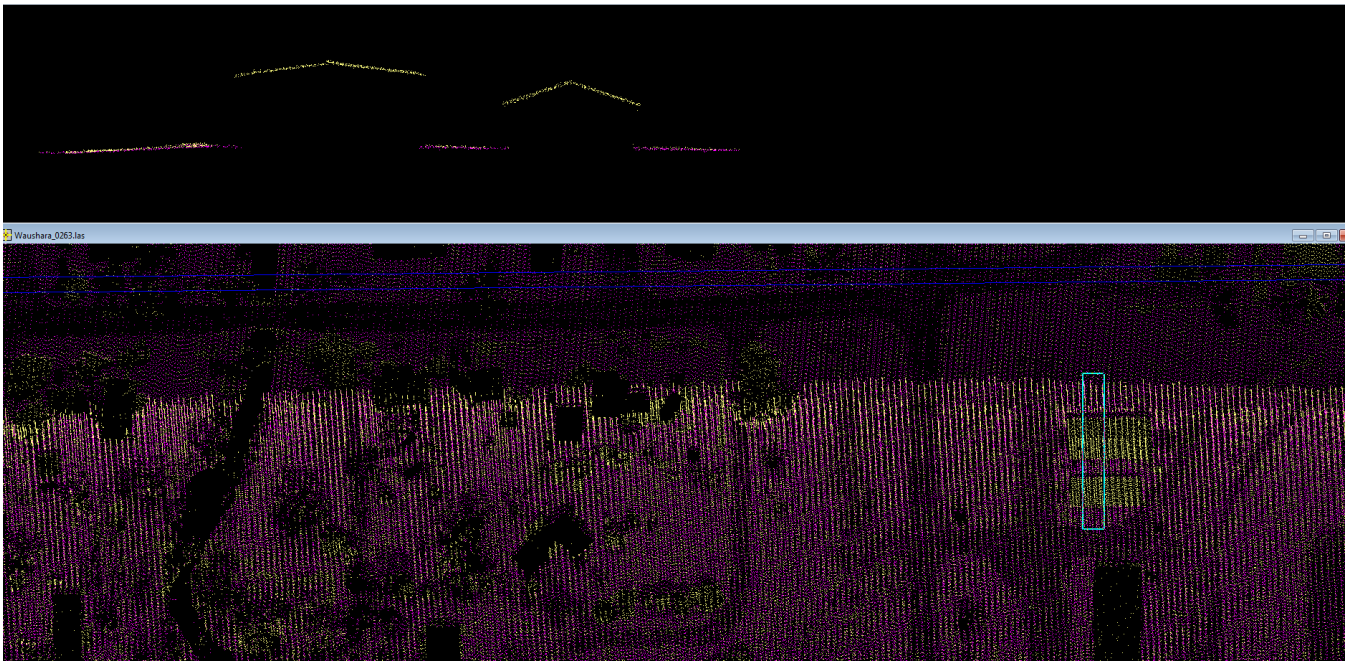

Figure 8. Example of Roof Top Matching in an Overlapping Swath Area

4.4 POINT DENSITY, SPACING, AND SPATIAL DISTRIBUTION

The USGS LiDAR Base Specifications v1.2 for quality level 2 data requires a minimum Aggregated Nominal Point Density of 2 pulses per square meter with a maximum Aggregated Nominal Point Spacing of 0.71 meters. Testing was completed using single swath, single instrument, first return only data, including only the geometrically usable part of the swath (typically the center 95 percent) and excluding acceptable data voids. Test results are presented in the table below.

Table 12. Aggregate Nominal Point Density and Spacing (Raw Laser data) reported.

Requirements	Test Results (Reported)	Test Results (Independent)
>= 2 points per m^2	2.25 points per square meter	2.162 points per square meter **PASS**
<= 0.71-meter point spacing	0.665 meter point spacing	0.681 meter point spacing **PASS**

The spatial distribution of geometrically usable points is expected to be uniform. To test the project area a density grid from the data with cell sizes equal to the design ANPS times 2, using a radius equal to the design ANPS. A minimum of 90 percent of the cells must contain 1 LiDAR point to meet specifications. This project meets the requirements for spatial distribution.

Table 13. Spatial Distribution

File	Cells with No Data	Cells with Point	Percentage
102	852558	33649899	97.53
103	649327	34013181	98.13
104	539483	33901136	98.43
105	517546	34173250	98.51
106	634239	33758963	98.16
107	1058436	33443288	96.93
108	1596447	32706647	95.35
109	1965638	32455883	94.29
110	2067108	32058407	93.94
111	3049913	30783077	90.99
112	2753663	30912408	91.82
113	2178729	31585949	93.55
114	2417030	31367470	92.85
117	977673	33606225	97.17
203	938161	32525355	97.20
204	1165966	32750583	96.56
205	1499800	31968237	95.52
206	1501872	32102865	95.53
207	1575438	31859727	95.29
208	1349480	32248150	95.98
209	967453	32541356	97.11
210	1416167	17233865	92.41
211	654927	16138546	96.10
212	1658840	32197435	95.10
213	1276180	32777492	96.25
214	1364725	32611963	95.98
216	690772	32955466	97.95
303	726376	33226167	97.86
304	781728	33371213	97.71

305	1619946	32350615	95.23
306	1867524	32265980	94.53
307	1633985	32187889	95.17
308	51668	5912185	99.13
311	489601	16176980	97.06
313	885907	33174908	97.40
Total	45374306	1066992760	**95.92 PASS**

No data grid cells from the spatial distribution testing are considered data voids. These cells were converted into a polygon shapefile and visually reviewed. It was determined that no unacceptable voids are present in the project. The voids were determined to be caused by bodies of water and areas of low near infrared reflectivity.

The example void shown in Figure 9 is a data void caused by an area of low infrared reflectivity. The Asphalt of a driveway had absorbed LiDAR pulses and did not produce any returns.

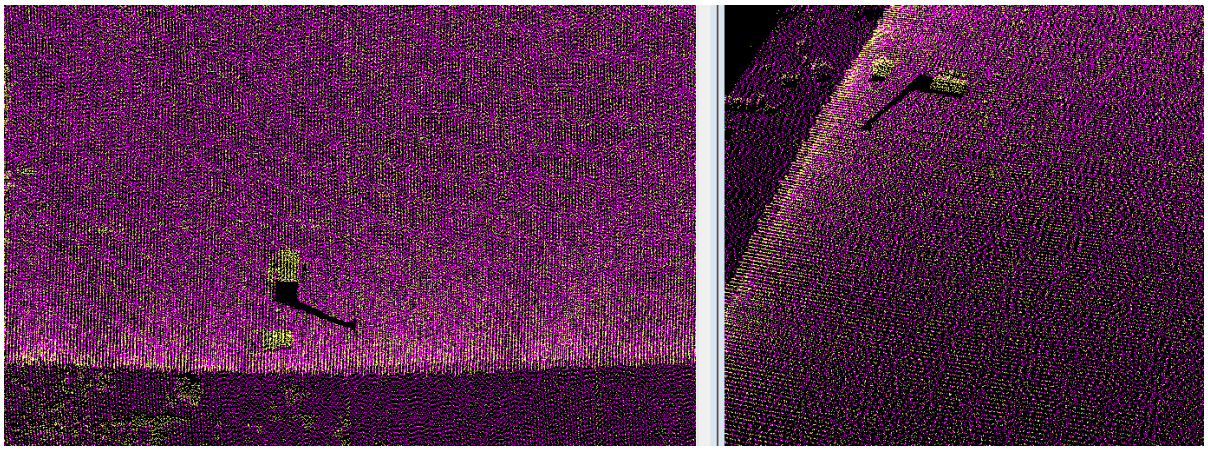

Figure 9. Void caused by Light absorbance from the asphalt of a driveway

The void examples shown in Figure 10 and 11 are agriculture fields that accumulate a lot of surface drainage from surrounding areas. The soil is dark and saturated which resulted in low point density.

Figure 10. Agricultural field in a low lying area with saturated soil.

Figure 11. Agriculture field with dark saturated soil.

4.5 LAS FILES

All submitted LAS files meet USGS and ASPRS specification requirements. File headers are consistent and the OGC WKT georeferencing information is correct.

Table 14. Swath LAS Checklist

Swath Raw Point Cloud LAS	QC	Pass/Fail	Notes
LAS Format 1.4	☑	Pass	
Point Record Format 6-10	☑	Pass	Format 6 (Point data Length 30)
Adjusted GPS Time	☑	Pass	Global Encoding 17
File Creation Date	☑	Pass	117/2018
Multiple returns (Minimum of 3)	☑	Pass	
Point Families Present	☑	Pass	
Waveform Data Present	☑	N/A	No Waveform data
WKT georeferencing	☑	Pass	
Coordinate Reference System	☑	Pass	State Plane Wisconsin South
Horizontal Datum	☑	Pass	NAD83(2011)
Horizontal Units	☑	Pass	US Survey Foot
Vertical Datum	☑	Pass	NAVD88 – Geoid 12b
Vertical Units	☑	Pass	US Survey Foot
Intensity Normalized 16 bit	☑	Pass	
Swath ID matches Point ID	☑	Pass	
No points classified as class 0	☑	Pass	
Withheld and Overlap Flags Set	☑	Pass	

4.6 WKT coordinate reference example and checks

Well Known Text (WKT) is a representation of geometric areas translated in a redundant manner so its readable by both machine and human readers. All EPSG codes were confirmed using the online catalog located at epsg.io. The WKT coordinate reference was checked for all Point cloud data to confirm LAS files are in accordance with USGS Lidar Base Specification Version 1.2, November 2014, Open Geospatial Consortium Version 1.0 and American Society for Photogrammetry and Remote Sensing (ASPERS) Las Specifications Version 1.4-R13.

Table 15. WKT Coordinate Reference Checklist

USGS Specification Requirements	Pass/Fail
No ESRI WKT formats	Pass
No Whitespace unless in quotes. Ex VERT DATUM[]	Pass
All on one line	Pass
No “EXTENSION[]” tag within the “VERT_DATUM[]”	Pass
EPSG AUTHORITY names are preferred	Pass
“AXIS["X", EAST] AXIS["Y", NORTH]” is preferred rather then “Easting and Northing”	Pass
US unit conventions is preferred. “METER of US SURVEY FOOT”	Pass
VERT_CS[] must be included along with full name (“NAVD88 height (ftUS)-Geoid12B”)	Pass
Horizontal and Vertical Datums must be within “COMPLD_CS []”	Pass
No “AUTHORITY[]” code for “COMPD_CS[]”	Pass
An “AUTHORITY[]” tag for each component within “COMPD_CS[]” if they exist	Pass
No user defined information	Pass

```
COMPD_CS["NAD83(2011) / Wisconsin South (ftUS) + NAVD88 height - Geoid12B (ftUS)",
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    AXIS["Y",NORTH],
    AUTHORITY["EPSG","6609"]],
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    VERT_DATUM["North American Vertical Datum 1988",2005,
        AUTHORITY["EPSG","5103"]],
    UNIT["US survey foot",0.3048006096012192,
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    AUTHORITY["EPSG","6360"]]]
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Figure 12. Example of LAS header OGC WKT Coordinate Reference System

5 CLASSIFIED POINT CLOUD DATA

Quality control for tiled classified data evaluate LiDAR post processing procedures. ASPRS and USGS specification details provide a framework for the confirmation of data reliability. Classification of all LiDAR swath points not identified as withheld must meet the ASPRS LAS 1.4 standards. Several data checks are performed on the classified point cloud data to confirm the data meet applicable standards. Outputs from testing results, geospatial files, and comment responses are included with quality assurance supporting documentation.

5.1 GENERAL DATA REVIEW

All data received is functional and adheres to the ASPRS LAS 1.4 specifications for point record format 6 with multiple discreet returns, point families, adjusted GPS time, and intensity values present. The data have the correct tile extents and are properly clipped at the buffered project boundary. Classifications are correct and correspond with the minimum classification scheme and include withheld and overage flags. The coordinate system is correct and in OGC WKT format.

Table 16. ASPRS 1.4 Classifications

Tiled LAS Classification Test Results	
Classes Expected: 1,2,7,9,10,17,18	Classes Present: 1,2,7,9,10,17,18
Use of LAS Withheld Flag	TRUE
Use of LAS Overlap Flag	TRUE
Use of LAS Class 0	FALSE
Total Class Numbers	
Class 1- Processed but not classified	2,600,184,426
Class 2 - Ground	2,463,216,634
Class 7 – Low Noise	3,827,849
Class 9 - Water	9,142,244
Class 10 – Ignored Ground	340,221
Class 17 – Bridge Decks	37,929
Class 18 – High Noise	1,026

The LAS files are statistically evaluated by reading each tile and checking the point density and spacing, total number of points and returns, X Y Z values, GPS timestamps, intensity ranges, and flight lines present in each tile. All points are accounted for and no issues or anomalies were identified. A single non-overlapping tile scheme polygon shapefile was evaluated and found to meet USGS LiDAR Base Specification v1.2.

5.2 VISUAL REVIEW

The scope of work required a visual review for 20 percent of submitted tiles. A detailed examination of 190 tiles out of 760 were completed for the project area. Tiles selected for review were chosen focusing on combined urban development and hydrographic significance, diverse land cover types, and areas of stream confluence.

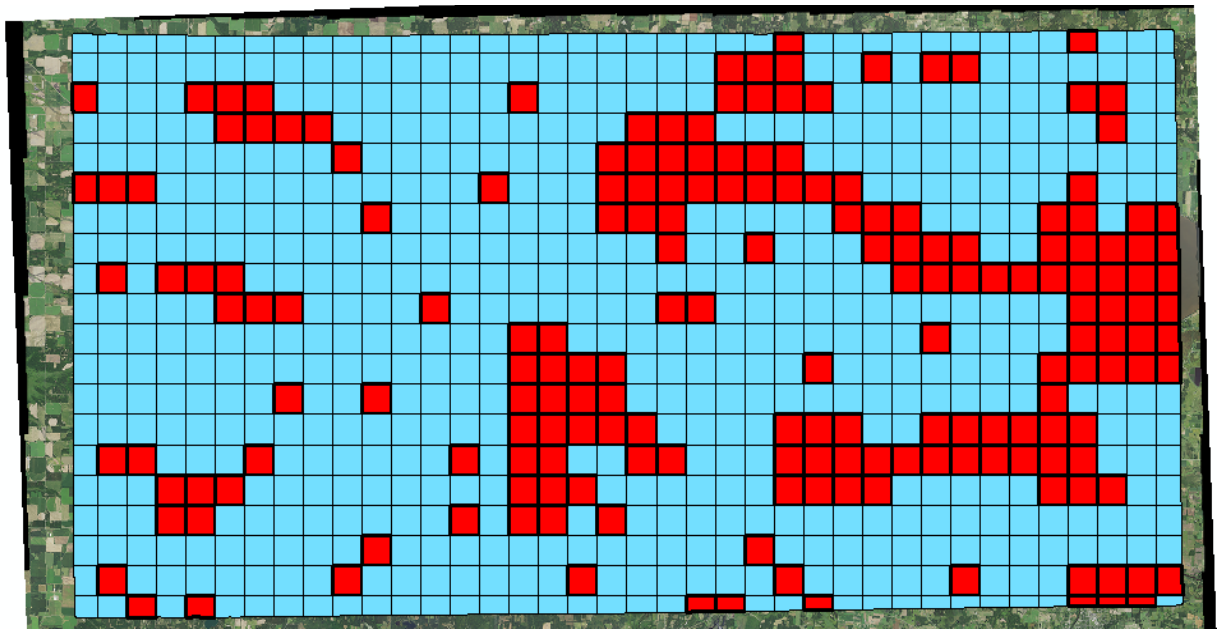

Figure 13. Classified LiDAR Tiles Reviewed

Point classifications must be accurate and consistent across the entire project. Within a 1-square kilometer area, no more than 1 percent of non-withheld will have classification errors. There cannot be any noticeable variations in the character, texture or quality between swaths or tiles.

Using a LiDAR viewer, to turn on and off classifications, analysts can evaluate point classification assignment consistency. For example, making class 17 (bridges) the only class visible, all points should be located over roads that span over water or other roads. Class 9 (water) points should only be located within water bodies and so on. Profiling bare earth (Class 2) allows verification of error free surfaces. Edge matching adjacent LAS tiles ensure that classifications are consistent from tile to tile.

All data reviewed for classification accuracy and consistency are compliant with specification requirements. The visual review documentation is included with this submittal.

5.3 AREAS OF LOW CONFIDENCE

ASPRS Positional Accuracy Standards for Digital Geospatial Data defines low confidence areas within LIDAR data as locations where the bare earth model might not meet the overall data accuracy requirements. This usually occurs where ground conditions affect the pulse returns. These areas are easily identifiable by the reduced bare-earth points density and spacing. A few examples of this are heavy vegetation, snow and wetlands.

Current ASPRS recommendations for determining low confidence areas are based upon the following criteria:

1. Nominal Ground Point Density
2. Cell size for raster analysis
3. Search Radius to determine average ground point densities
4. Minimum area appropriate to ground point density.

Table 17. Values for Determining Low Confidence Areas

Vertical Accuracy Class	Recommended Project Min NPD (pls/m²) (Max NPS (m))	Recommended Low Confidence Min NGPD (pts/m²) (Max NGPS (m))	Search Radius and Cell Size for Computing NGPD (m)	Low Confidence Polygons Min Area (acres (m²))
1-cm	20 (0.22)	5 (0.45)	0.67	0.5 (2,000)
2.5-cm	16 (0.25)	4 (0.50)	0.75	1 (4,000)
5-cm	8 (0.35)	2 (0.71)	1.06	2 (8,000)
10-cm	2 (0.71)	0.5 (1.41)	2.12	5 (20,000)
15-cm	1 (1.0)	0.25 (2.0)	3.00	5 (20,000)
20-cm	0.5 (1.4)	0.125 (2.8)	4.24	5 (20,000)
33.3-cm	0.25 (2.0)	0.0625 (4.0)	6.0	10 (40,000)
66.7-cm	0.1 (3.2)	0.025 (6.3)	9.5	15 (60,000)
100-cm	0.05 (4.5)	0.0125 (8.9)	13.4	20 (80,000)
333.3-cm	0.01 (10.0)	0.0025 (20.0)	30.0	25 (100,000)

During the review, one area was determined to meet the criteria for low confidence in Waushara County. The classified ground point density at this location is approximately 0.02 pulses per square meter, has 1.3-meter point spacing, and is greater than five acres. A 2D polygon has been included with this submission.

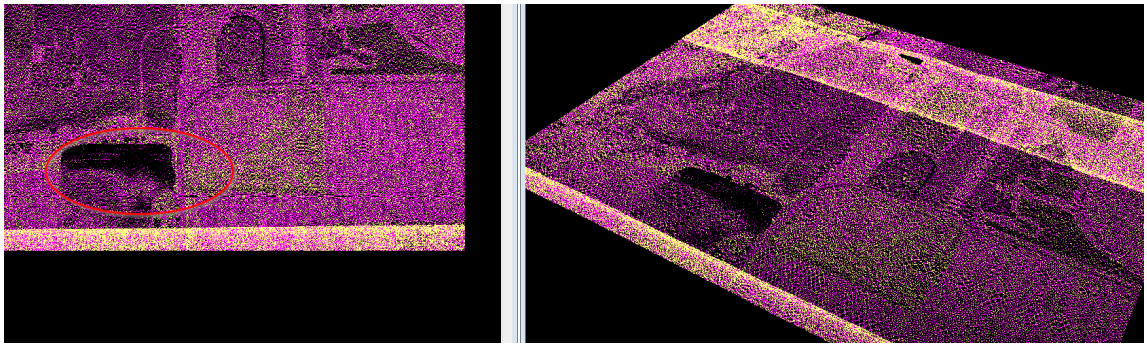

Figure 14. Low density in the ground point data caused by water saturated soil lying in low elevation.

Figure 15. Photo of area shown in Figure 9.

6 BREAKLINES AND HYDRO-FLATTENED DEMS

The creation of LiDAR derived bare earth DEMs requires hydro flattening. Waterbodies such as ponds, lakes, inland streams, and tidal areas existing within stated USGS thresholds are expected to have uniform elevations and appear flat on the final DEM. The goal is to create topographic DEMs that contain water surfaces free of unnatural triangulation effects and other elevation inconsistencies. DEMs produced in this manner allow for greater accuracy in hydrologic and hydraulic modeling, resulting in high quality floodplain and floodway delineations.

USGS requirements for hydro flattening provide detailed guidance for the creation of DEMs and breaklines. USGS organizes requirements into five distinct water body categories: inland ponds and lakes, inland streams and rivers, non-tidal boundary waters, tidal waters, and islands.

A combination of visual inspection and automated data testing are performed to confirm products comply with specifications. Breakline checks for elevation monotonicity and connectivity include topology, visual inspection, and vertex testing. A visual inspection of breaklines confirms proper placement based upon hydro flattening requirements using either intensity or ortho imagery. Finally, breakline vertices compared against adjacent elevations provide confirmation of static water surface for ponds and lakes and stream or river bank-to-bank elevation gradients.

Bare earth surface evaluation in combination with the breakline placement visual inspection provides a comprehensive evaluation of hydro flattened surface. The DEM surface is hillshaded and visually compared with a hillshade derived from a first return Digital Surface Model (DSM). This comparison confirms the proper removal of artifacts such as vegetation, buildings, and bridges. Each breakline reviewed using the bare earth hillshade reveals any triangulation or unusual elevation changes. Cross section and centerline profiles created in hydro flattened areas within the DEM confirm proper elevation values and they are at or below the surrounding terrain.

Table 18. Breakline Quality Control Checklist

Breaklines	**Pass/Fail**
Functional Polygon/Polyline Z aware shapefile or ESRI Feature Class	Pass
Correct Georeferencing	Pass
Topologically Correct	Pass
Complete coverage with no missing hydrographic features	Pass
Elevations are consistent, flattened, and are at or below surrounding terrain	Pass

Table 19. Hydro Flattened DEM Quality Control Checklist

Bare Earth Surface	**Pass/Fail**
All rasters delivered, tiled, complete coverage and functional	Pass
No overlaps or quilted appearance and generated to the limits of the BPA	Pass
DEM as 32-bit floating point ERDAS imagine format with 2-foot resolution	Pass
Correct georeferencing	Pass
Artifacts have been properly removed from the bare earth surface and edge match correctly	Pass
Bridges removed from bare earth surface with continuous flattened streams and rivers	Pass
Culverts intact in the bare earth surface with breaks in flattened streams and rivers	Pass

Ponds and lakes have a minimum surface area of 2 acres	Pass
Inland streams and rivers have a nominal width of 100 feet	Pass
Long impoundments treated as inland streams and rivers	Pass
Streams, rivers, lakes, and ponds are flattened and at or below surrounding terrain	Pass
Flattened streams and rivers have a gradient downhill water surface following surrounding	Pass
Permanent islands greater than or equal to 1 acre are delineated within waterbodies	Pass

7 ABSOLUTE VERTICAL ACCURACY NVA AND VVA

To finalize the LiDAR data submission, an absolute vertical accuracy test for both non-vegetated and vegetated areas for the DEM is required. NVA checkpoints tested against the DEM use the same QL2 requirements as for validating the unclassified LiDAR vertical accuracy. This confirms no significant changes to surface elevations occurred during post processing.

The vegetated checkpoints for the VVA (vegetated vertical accuracy) assessment are collected in tall grass, brush, and forested land cover. Testing vegetated locations against the bare earth surface also validate the post processing and must meet USGS QL2 requirements for VVA at the 95th percentile (<= 29.4 cm). Meeting the QL2 requirements for both assessments validate the surface consistency and reliability of elevation values.

Table 20. NVA Absolute Vertical Accuracy for DEMs

Bare Earth NVA Summary Statistics	Test Results (US Survey Feet /Meter)
Number of Check Points	40
Points with Swath Coverage and required accuracy	40
Average Z Error	0.07/0.02
Maximum Z Error	0.29/0.09
Minimum Z Error	-0.21/-0.06
NVA RMSEz <= 10 cm	0.13/0.04 **PASS**
NVA AccuracyZ <= 19.6 cm at 95% Confidence	0.31/0.08 **PASS**

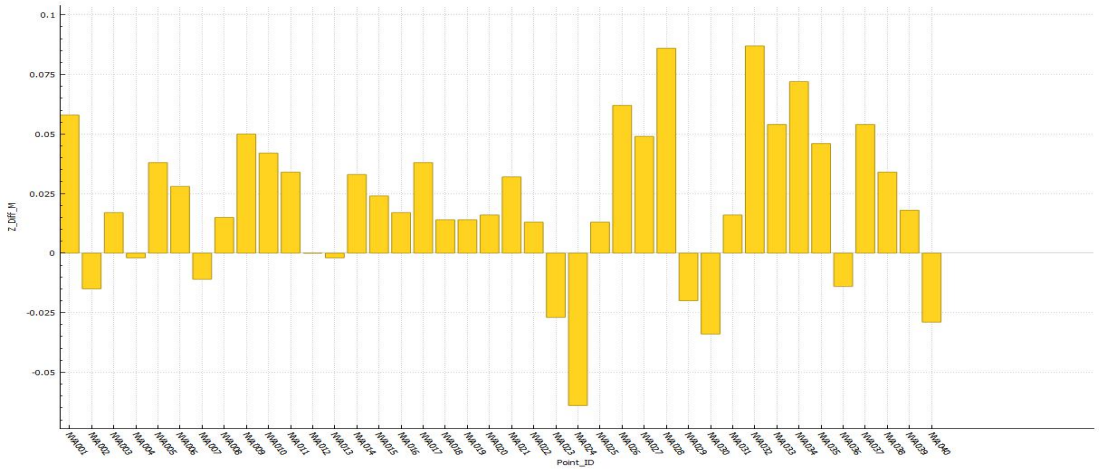

Figure 16. Bare Earth NVA Histogram

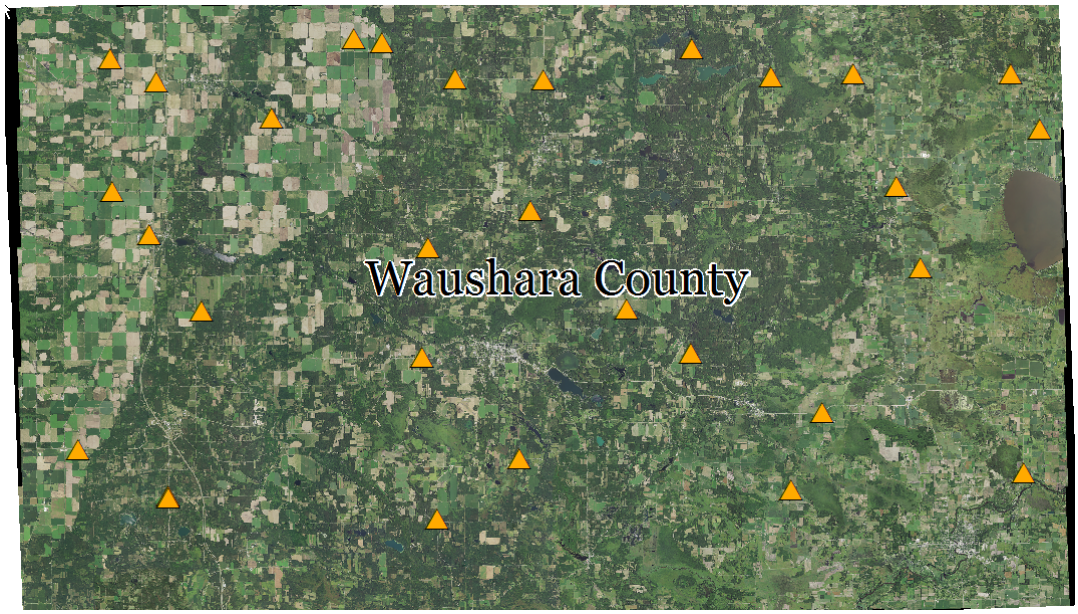

Figure 17. Vegetated Vertical Accuracy Checkpoint Distribution

Table 21. VVA Absolute Vertical Accuracy for DEMs

Bare Earth VVA Summary Statistics	Test Results (US Survey Feet /Meter)
Number of Check Points	30
Points with Bare Earth Coverage	30
Average Z Error	-0.26/0.08
Maximum Z Error	0.32/0.10
Minimum Z Error	-0.89/-0.27
VVA at 95th Percentile <=29.4 cm	0.128/0.039 **PASS**

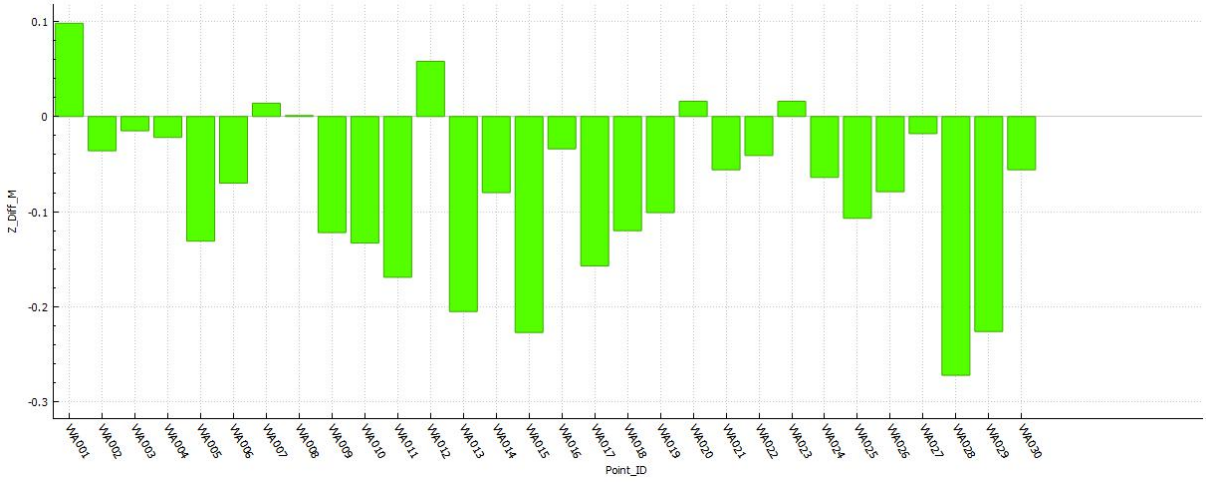

Figure 18 Bare Earth VVA Histogram

8 CONCLUSION

Under task order HSFE05-17-J-0005, STARR II completed an independent quality assurance and quality control review for Waushara County, WI. All data meets the requirements for use in flood risk analysis based upon the vertical accuracy test results, project documentation, unclassified swaths, classified tiles, breaklines, and hydro-flattened DEMs reviews. In addition, this data conforms to the USGS QL2 specifications for integration with the National Map for public use.

LiDAR product deliverables follow the FEMA Data Capture Standards for New Topographic Data Capture format and includes all relevant ancillary information.

Approvals

QA Team Lead: James L. Huffines Date: 11/28/2018