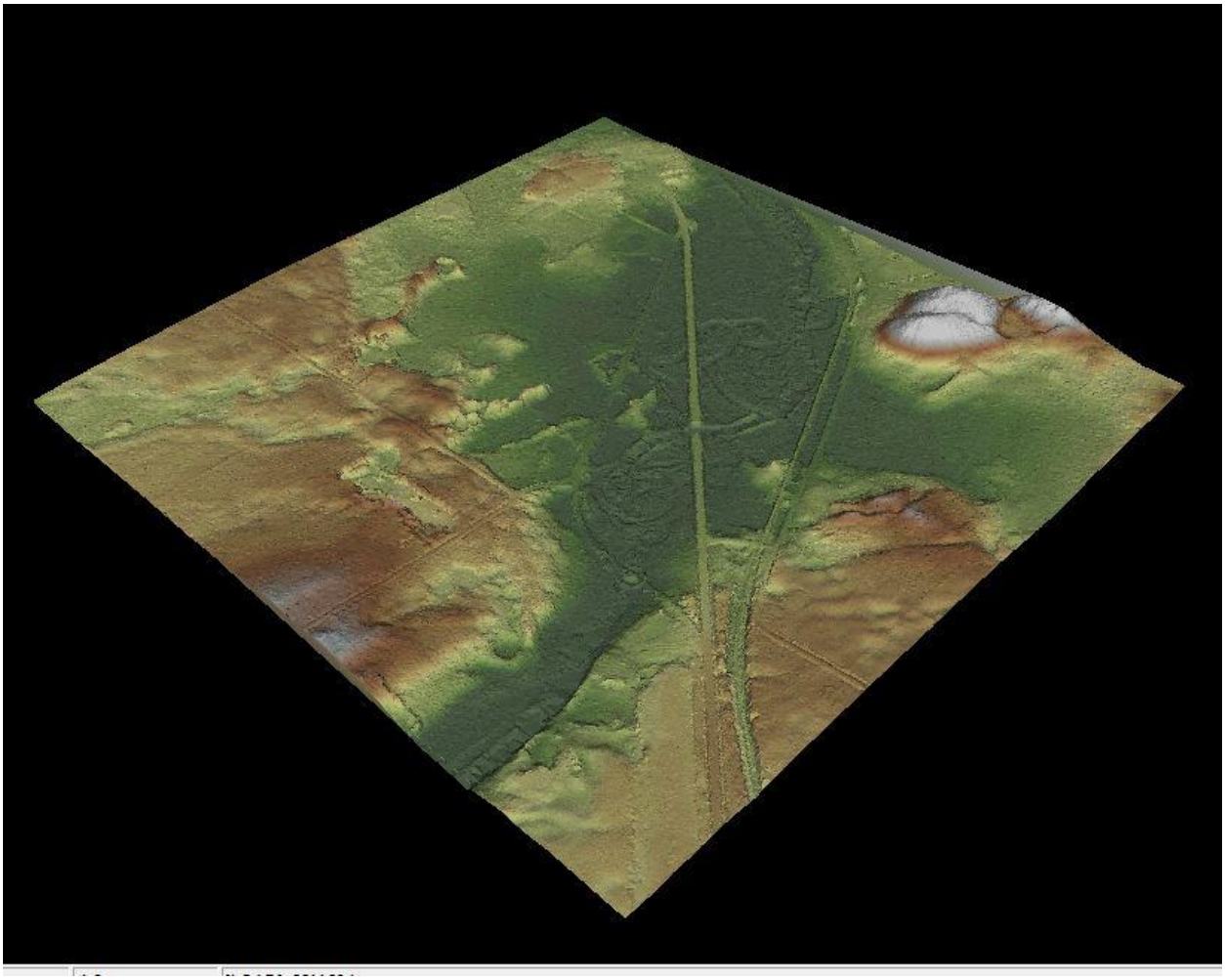
# Elevation Data Quality Assurance Report
## Ashland County, Wisconsin
## October 30, 2015



Submitted to:

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# Contents

# 1. Executive Summary

Under FEMA task order HSFE05-14-J-0037, STARR has completed elevation data acquisition, and post processing for approximately 1,000 square miles in Ashland County, Wisconsin. The goal of this project is to create an unclassified point cloud dataset with a nominal point spacing of < 1 meter, a fundamental vertical accuracy Root Mean Square Error of <= 12.5cm, and a fully classified point cloud dataset with a 95$^{th}$ percentile consolidated vertical accuracy of <= 36.3cm. Deliverables for this project task include tiled unclassified (class 1) and fully classified bare earth (class 2) LiDAR point cloud datasets in the ASPRS LASer file format (ASPRS, LAS 1.2 Format Specification, 2-13), acquisition reports, survey reports including vertical accuracy assessments, project metadata, and breaklines.

**Figure 1: Ashland County, Wisconsin Project Area**

This report documents the independent quality control of data acquisition and post processing deliverables including vertical accuracy assessments for Ashland County, Wisconsin in order to validate the quality of LiDAR data for use in FEMA Risk MAP projects. Requirements from the Ashland County scope of work mandate that all LiDAR collection activities meet the vertical accuracy criteria, listed above, provided in the USGS LiDAR Base Specifications Version 1.0.

The ASPRS LAS version 1.2 standards, USGS LiDAR Base Specifications 1.0, and FEMA guidance, standards and technical references were used as the basis for this quality review.

**Table 1: Ashland County LiDAR Acquisition Project Details**

| Ashland County, Wisconsin | |
|---|---|
| Collection/Processing Area | Approximately 1,000 square miles |
| LiDAR Acquisition Date(s) | 11/1/2014, 11/2/2014, and 4/17/2015 |
| Breaklines Required | Yes |
| LAS Version | 1.2 |
| Nominal Pulse Spacing | 1 m |
| RMSEz | < 12.5 cm |
| Vertical Accuracy, 95% Confidence Level FVA/CVA | 24.5 cm/ 36.3 cm |
| Coordinate System | UTM, Zone 15 |
| Horizontal Datum and Linear Units | NAD83 2011, Meters |
| Vertical Datum and Linear Units | NAVD88, Geoid12A, US Survey Feet |

# 2. Unclassified Point Cloud LiDAR Data Review

This review is conducted on the all return unclassified point cloud datasets. The purpose of this review is to determine whether this dataset was produced in a manner consistent with requirements set forth in the aforementioned guidelines and specifications. The individual review components and results are discussed in the following sections.

## 2.1 Vendor Submittal

This task is a thorough examination of all information provided by the vendor that ensures that the required data are present, meet project expectations and function properly. All data delivered has been accounted for and tested.

**Table 2: Ashland County LiDAR Acquisition Data Submittal Summary**

| Item | Included | Comments |
|---|---|---|
| Pre-Flight Planning Report | Yes | |
| Post-Flight Report | Yes | Includes processing, flight logs and quality control |
| Swaths | N/A | Data delivered in tiled format |
| Survey Report | Yes | |
| Geospatial datasets | Yes | Flight Lines, Control Points, Project extent, Tile Index |
| FVA vertical accuracy results | Yes | Included as spreadsheet with RMSEz and 95% |
| LAS v1.2 files | Yes | 1,431 files delivered |
| Project metadata | Yes | XML file documenting collection activities |
| FEMA compliance form | Yes | Signed and sealed |

## 2.2 LiDAR Coverage

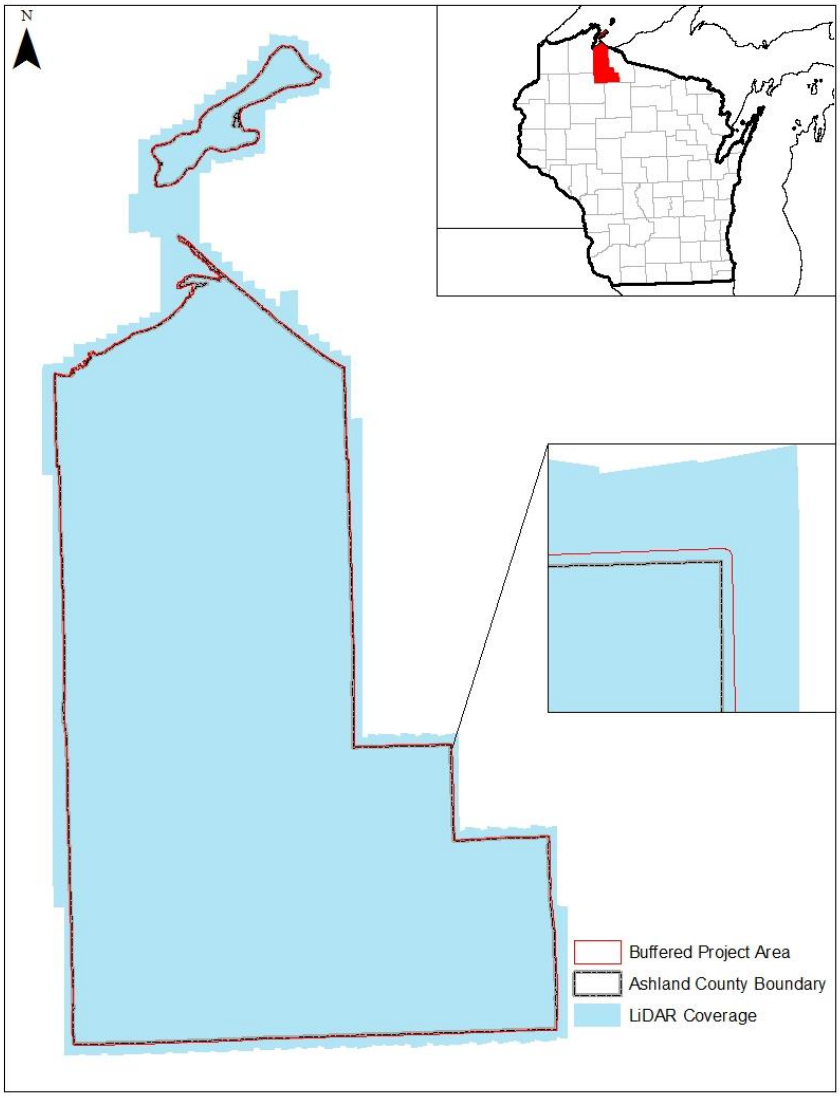
The purpose of this task is to confirm that the collection conditions, spatial references and the project area meet USGS LiDAR Base Specifications 1.0 requirements.

Collection Conditions: The required collection conditions described in the USGS Base LiDAR Specifications 1.0 have been met. Details pertaining to the flight conditions are included with the post-flight acquisition report flight logs.

Coordinate Reference System: By examining the information provided in the LAS files and geospatial data, the project scope of work requirements for acquisition have been met. Both horizontal and vertical datums, linear and vertical units, and projection are correct.

Collection Area: The collection area for this project area has been buffered by 100 meters and all acquired data has been generated to the limit of the buffered project area.

**Figure 2: LiDAR Data Coverage**



Flight line Overlap: The required flight line overlap requirement of > 10% described in the USGS Base LiDAR Specifications 1.0 has been met. The planned sidelap was 25% and on average the measured overlap between flight lines is approximately 25-30%. There are no gaps or voids between flight lines.

## 2.3 First Return Point Density and Nominal Point Spacing

The point density of a LiDAR data set is the number of pulses emitted by the LiDAR system within a given area commonly expressed as Points per Square Foot (ppsft) or Points per Square Meter (ppsm). Nominal pulse spacing refers to the typical or average lateral distance between points in a LiDAR dataset. This is calculated as the square root of the LiDAR density (ppsm = $1/NPS^2$).

The nominal pulse spacing requirement for this project is approximately 1 m or 3.2808 ft. USGS and FEMA require NPS to be a minimum of 2 meters.

**Table 3: Pont Density and Nominal Pulse Spacing Summary Statistics for first return unclassified LiDAR point cloud**

| LiDAR Density and Nominal Pulse Spacing ($m^2$) | | n = 1,431 LAS Files |
|---|---|---|
| LiDAR Point Density (ppsm) | 2.73 | PASS |
| Nominal Point Spacing | 0.61m | PASS |

## 2.4 First Return LiDAR Point Spatial Distribution

From Section 1.6 of the USGS LiDAR Guidelines and Base Specification Version 1.0:

> *The spatial distribution of geometrically usable points is expected to be uniform and free from clustering. In order to ensure uniform densities throughout the dataset:*
> - *A regular grid, with cell size equal to the design NPS*2 will be laid over the data.*
> - *At least 90% of the cells in the grid shall contain at least 1 LiDAR point.*
> - *Assessment to be made against single swath, first return data located within the geometrically usable center portion (typically ~90%) of each swath (tile).*

To test the Ashland project, a 2-meter grid was created from first returns for the point cloud data. The percentage of cells with counts greater than or equal to one complies with the USGS specification of 90%.

**Table 4: Spatial Distribution QC Results**

| Test Parameters | Point Count | Percent of Total |
|---|---|---|
| Grid cells with at least 1 LiDAR point | 648,787,561 | 99.08 |
| Grid cells without a LiDAR point | 6,029,768 | 0.92 |
| Total cells tested | 654,817,329 | 100 |

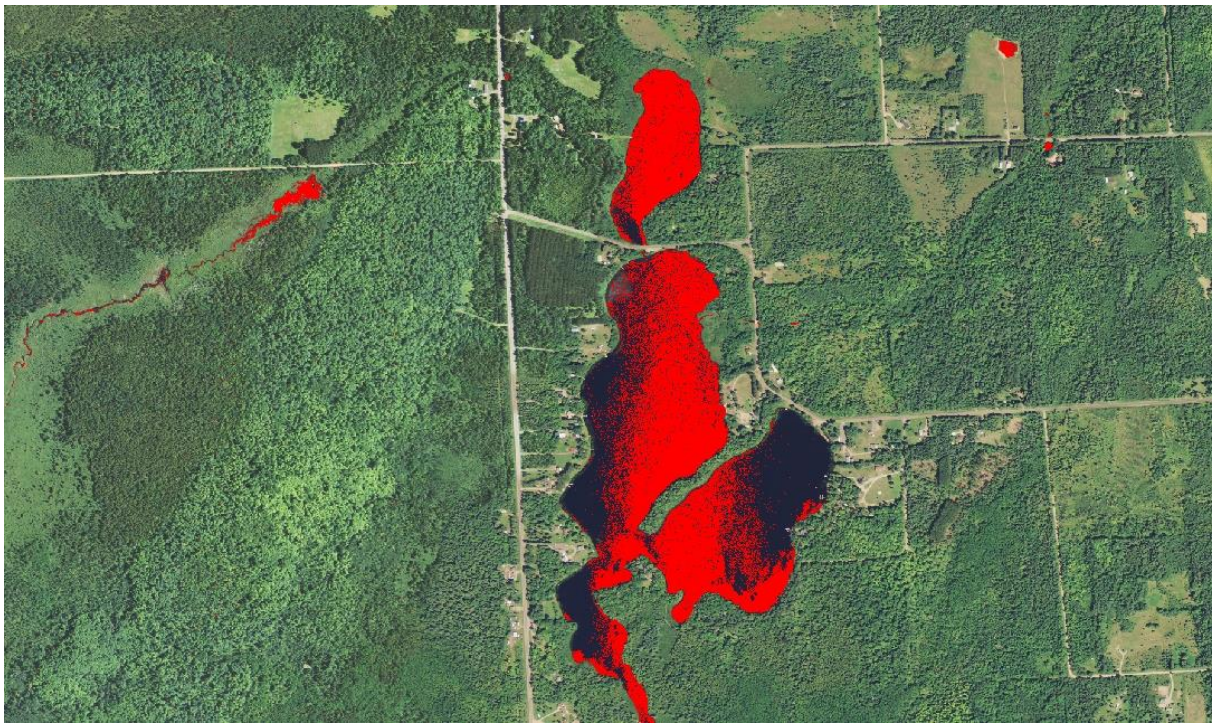
## 2.5 Data Voids

From section 1.5 of the USGS LiDAR Guidelines and Base Specification version 1.0:

> *Data Voids [areas => $(4*NPS)^2$, measured using 1st-returns only] within a single swath (tile) are not acceptable, except:*
>
> - *where caused by water bodies*
> - *where caused by areas of low near infra-red (NIR) reflectivity such as asphalt or composition roofing*
> - *where appropriately filled-in by another swath*

All areas were found to be in compliance with the USGS specification. The review confirmed that the data voids occur in legitimate areas (water bodies). The following figures provide samples of data voids found within the Ashland County dataset.

**Figure 3: Three Examples of Legitimate Data Voids**



## 2.6 LAS files

A total of 1,431 LAS files were delivered via external hard drive. All Point Cloud LAS files submitted for review are compliant with ASPRS LAS specifications version 1.2 and USGS Lidar Base Specification Version 1.0. Each LAS file contains appropriate public block headers, variable length records , multiple discrete returns, intensity values, min and maximum scan angles, adjusted GPS time, the correct coordinate reference system, swath ID, and point families.

Table 5: USGS Lidar Base Specification Version 1.0 Summary

| Item | USGS Specification | Y/N/NA |
|---|---|---|
| Multiple Discrete Returns | *3 per pulse* | Y |
| Intensity Value | *Native radiometric resolution* | Y |
| Scan Angle | *Supports vertical and horizontal accuracy requirements (recommended to not exceed 40 degrees)* | Y |
| Full Waveform | *Uses extension .wdp (if collected)* | NA |
| GPS Times | *Adjusted GPS Time (standard GPS time minus 1 x $10^9$)* | Y |
| Datum | *NAD83 HARN; NAVD 88* | Y |
| Units of Reference | *"Feet" or "Foot" specified as "International", "Intl", "U.S. Survey", or "US"* | Y |
| Swath ID | *Unique File Source ID for each swath* | Y |
| Point Families | *Multiple returns remain intact through all processing* | Y |
| Consistency | *All files are consistent with one another and contain data according to ASPRS LAS Specification Version 1.2* | Y |

## 2.7 Unclassified LiDAR Accuracy Verification

### 2.7.1 Relative Accuracy

USGS LiDAR Base Specification Version 1.0 states two requirements for relative accuracy of LiDAR Point Cloud data. Relative accuracy will be measured within each individual swath and within the overlap between adjacent swaths. The requirements are as follows:

- *Within individual swaths:<= 7 cm RMSEz*
- *Within overlap between adjacent swaths:<=10 cm RMSEz*

Data for Ashland County, Wisconsin was delivered in a tiled format and thereby rendering a relative accuracy check according to swath unattainable. Before being delivered in a tiled format, the vendor completed a relative accuracy check of the data collection within swaths. To review the relative accuracy check, please see the Post-flight Lidar Report for Ashland County, Wisconsin.

### 2.7.2 Fundamental Vertical Accuracy

The Fundamental Vertical Accuracy (FVA) requirement for unclassified point cloud data under the NDEP/ASPRS methodology according to USGS LiDAR Base Specification version 1.0 is stated below:

- *FVA <= 24.5 cm Accuracyz ($ACC_z$), 95 percent (12.5 cm Root Mean Square Error $(RMSE)_z$)*

The FVA accuracy is to be tested against a Triangulated Irregular Network (TIN). The TIN is constructed from lidar points where at least 5 times the NPS exists in a clear and open area, with less than 1/3 of the RMSE deviation from a low-slope plan not exceeding 10%. The FVA checkpoints should be well-distributed throughout the land cover and avoid any grounds disturbed from activity, area of low NIR reflectivity, or area that may have an obstruction 45 degrees from the horizon present that could diminish the accuracy of the TIN.

USGS specifications described the following exceptions to the FVA requirement for unclassified point cloud data:

- *Where there exists a demonstrable and substantial increase in cost to obtain this accuracy.*
- *Where an alternate specification is needed to conform to previously contracted phases of a single larger overall collection effort, for example, multi-year statewide collections.*
- *Where the USGS agrees that it is reasonable and in the best interest of all stakeholders to use an alternate specification.*

The formerly mentioned exceptions do not apply to Ashland County's point cloud data. The Ashland County unclassified point cloud data meets all FVA requirements stated in USGS LiDAR Base Specification Version 1.0.

**Graph 1. Frequency of values for the Unclassified Point Cloud FVA Accuracy Assessment.**

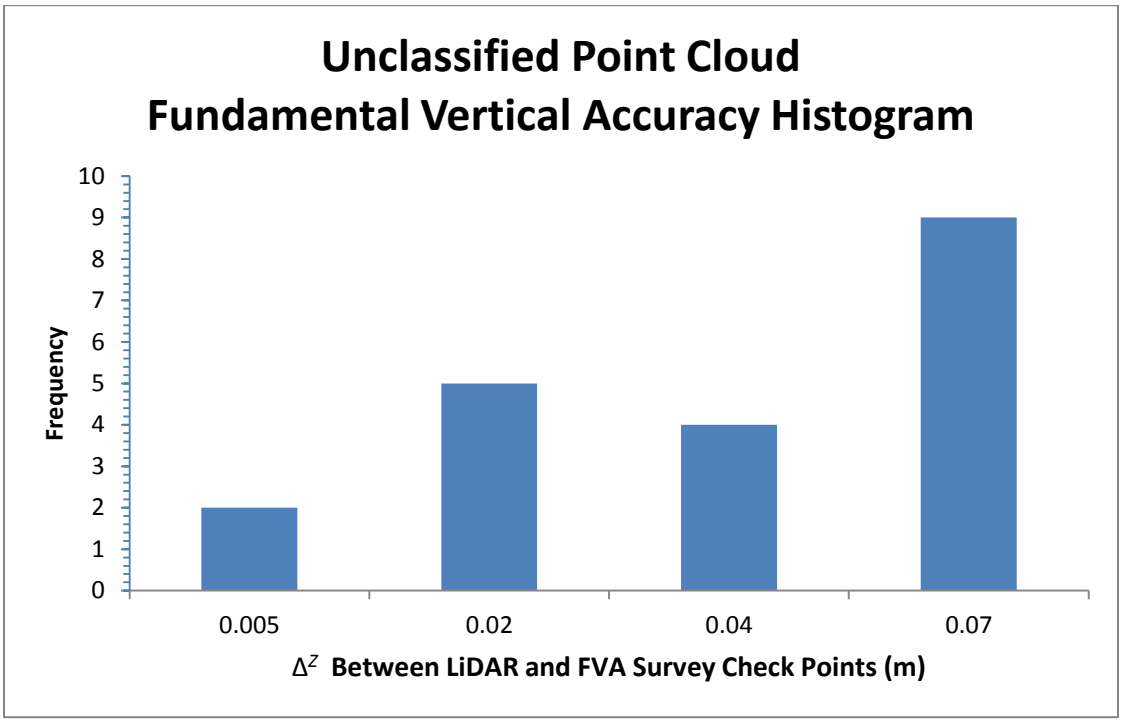


**Figure 9: FVA Survey Checkpoint locations.**

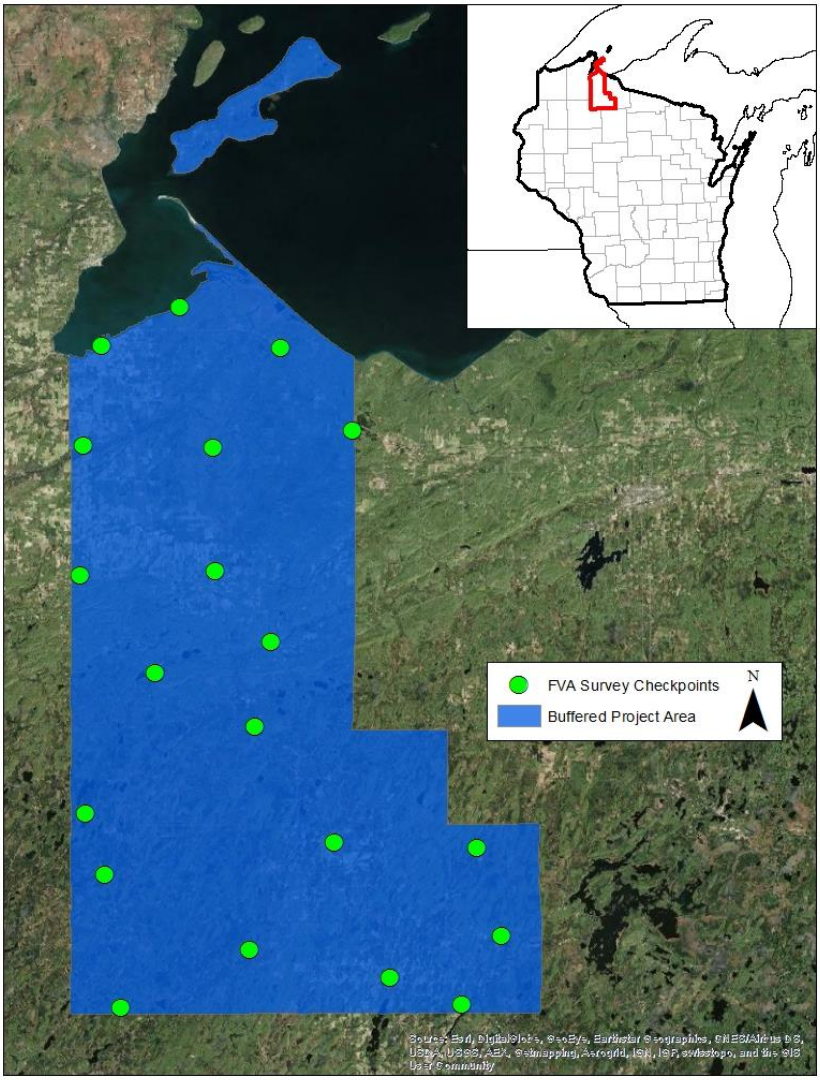


Table 6

| GCP | MSL_LiDAR_m | MSL_FVA_m | ΔZ m | Δ $Z^2$ m |
|---|---|---|---|---|
| ASH301 | 187.693 | 187.690 | -0.002 | 0.000 |
| ASH302 | 198.221 | 198.173 | -0.047 | 0.002 |
| ASH303 | 329.321 | 329.389 | 0.067 | 0.005 |
| ASH304 | 222.385 | 222.343 | -0.042 | 0.002 |
| ASH305 | 246.458 | 246.462 | 0.003 | 0.000 |
| ASH306 | 193.710 | 193.653 | -0.057 | 0.003 |
| ASH307 | 322.649 | 322.678 | 0.029 | 0.001 |
| ASH308 | 306.833 | 306.766 | -0.067 | 0.004 |
| ASH309 | 376.492 | 376.469 | -0.023 | 0.001 |
| ASH310 | 441.987 | 441.975 | -0.013 | 0.000 |
| ASH311 | 482.757 | 482.816 | 0.059 | 0.003 |
| ASH312 | 438.875 | 438.860 | -0.015 | 0.000 |
| ASH313 | 438.604 | 438.552 | -0.052 | 0.003 |
| ASH314 | 441.402 | 441.351 | -0.051 | 0.003 |
| ASH315 | 465.113 | 465.053 | -0.060 | 0.004 |
| ASH316 | 478.219 | 478.210 | -0.009 | 0.000 |
| ASH317 | 471.224 | 471.214 | -0.010 | 0.000 |
| ASH318 | 481.340 | 481.308 | -0.032 | 0.001 |
| ASH319 | 500.820 | 500.812 | -0.008 | 0.000 |
| ASH320 | 442.356 | 442.326 | -0.030 | 0.001 |

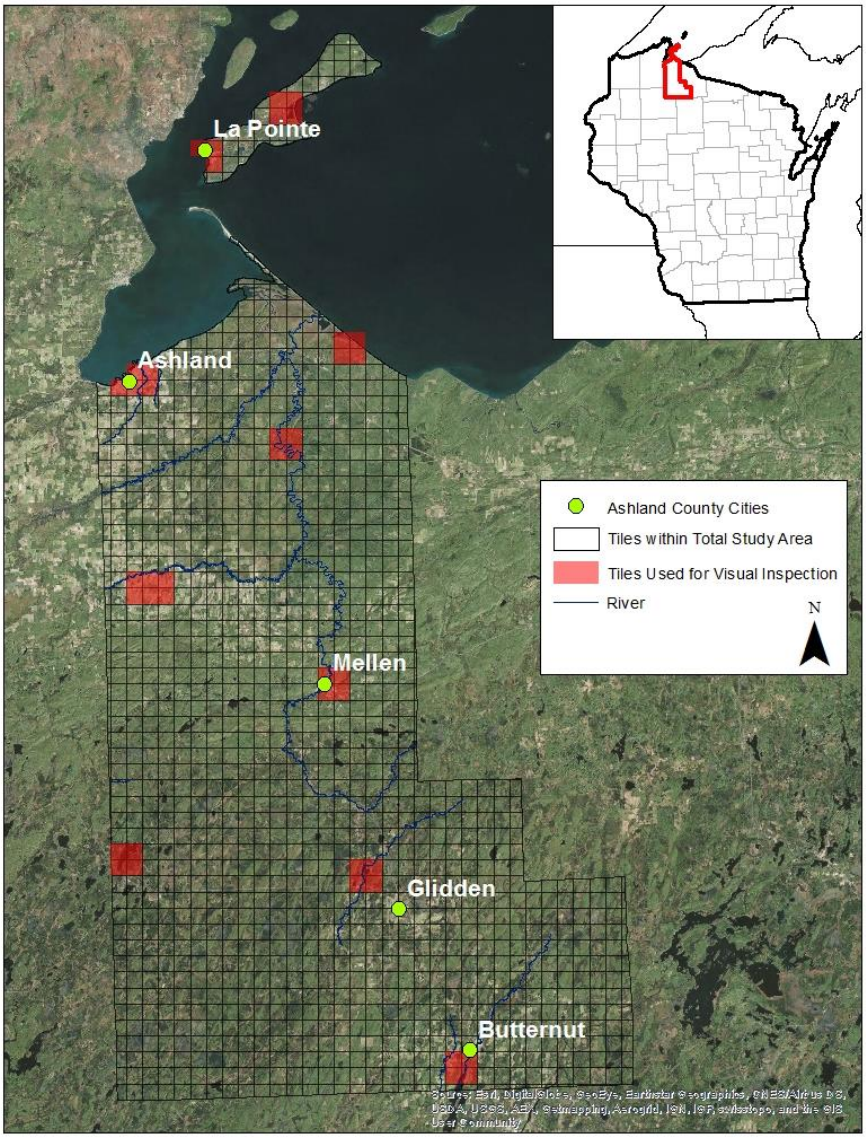
| FVA QC Results Meters (ΔZ values converted to absolute value) | | | |
|---|---|---|---|
| **ΔZ Mean** | 0.03 | **RMSE** | 0.04 |
| **ΔZ Min** | 0.002 | **95 percent (*1.9600)** | 0.08 |
| **ΔZ Max** | 0.07 | | |

## 2.8 Visual Review

Micro reviews were completed on 42 of the unclassified point cloud tiles. Tiles selected for review were chosen throughout the project area with a focus on areas of urban development and hydrographic significance. Each tile was reviewed to ensure:

- Multiple Discrete Returns exist
- Intensity values exist and are correct
- Edge matching between tiles is appropriate and consistent;
- Voids are only found in acceptable areas as noted in Section 3.5;
- Blunders and other anomalies do not exist.

Figure 10: 42 tiles chosen for Visual Review.




All tiles reviewed meet project requirements for unclassified LiDAR data and can be used for post processing.

# 3. Fully Classified Point Cloud LiDAR Data Review

## 3.1 Vendor Submittal

Just as with the submittal review for the Point Cloud data, the review and examination of Classified LiDAR data is to ensure that all data required for project expectations is accounted for and functions properly. All data delivered by the vendor has been accounted for and tested according to USGS LiDAR Base Specification v1.0 and ASPRS LAS Specification v1.2.

Table 7: Ashland County Classified LiDAR Acquisition Data Submittal Summary

| Item | Included | Comments |
|---|---|---|
| Point Data QA/QC Report | Yes | |
| LAS Tiles | Yes | |
| Breaklines | Yes | |
| Product Metadata | Yes | |
| Consolidated Vertical Accuracy (CVA) Results | Yes | |

## 3.2 LiDAR Coverage

The purpose of this task is to confirm that the tiling scheme and spatial references agreed upon by the data producer and USGS prior to collection meet USGS LiDAR Base Specifications v1.0 requirements.

Tiles: A single non-overlapping tiling scheme, meeting required specifications of USGS Base Specification v1.0 for tile size, x-y dimensions, and edge-matching has been acquired. Tile size is an integer of the deliverable raster's cell size and is indexed in a multiple of the individual tile's x-y dimensions. Tiles edge match seamlessly and without gaps.

Coordinate Reference System: The USGS requirement for use of the Universal Transverse Mercator (UTM) projection and the North American Datum 1983 has been met. The UTM zone for Ashland County, Wisconsin is 15 North. The North American Datum 1983 2011 ellipsoid GRS 1980 horizontal datum was used and the North American Vertical Datum 1988 (NAVD88) Geoid 12A vertical datum were used. The x,y linear units are meters and the z units are us survey feet.

## 3.3 LAS Files and Classifications

After the complete 1,431 Unclassified LAS files were clipped to the appropriate study area, 155 Unclassified LAS files were removed. A total of 1,276 LAS files were classified and delivered via external hard drive. Another 222 Classified files were intersected by the study area boundary, thereby reducing their coverage area and point count totals at various levels. The 222 intersected files are included in the 1,276 Classified LAS files total which were reviewed for meeting USGS and ASPRS specification requirements. The review of the Classified LAS files included matching the point count totals with original Unclassified LAS file data (an exception for intersected tiles), accurate classification assignment of points, ensuring appropriate assignment of characteristics according to ASPRS LAS Specifications Version 1.2 definitions, and establish there were not any unnecessary

alterations from original Unclassified Point Cloud data resulting in inaccurate representations of the LAS data.

All Classified Point Cloud LAS files submitted for review is compliant with ASPRS LAS Specifications Version 1.2 and USGS Lidar Base Specification Version 1.0. Point Count totals match the Unclassified Point Count totals, except where expected in files intersected by the study area boundary.

ASPRS classifications are present and correct for all tiles submitted. The following classifications were used for this project:

- Class 1 = Unclassified. This class includes vegetation, buildings, noise etc.
- Class 2 = Ground
- Class 7 = Low Point (noise)
- Class 8 = Model Key-point (mass point)
- Class 9 = Water
- Class 10 = Ignored Ground

## 3.4 Classified LiDAR Vertical Accuracy Verification

The minimum vertical accuracy requirement for classified point cloud data and the derived DEM (Digital Elevation Model), under the NDEP/ASPRS methodology according to USGS LiDAR Base Specification version 1.0 is stated below:

- *FVA <= 24.5 cm Accuracyz ($ACC_z$), 95 percent (12.5 cm Root Mean Square Error ($RMSE)_z$)*
- *Consolidated Vertical Accuracy (CVA)<= 36.3cm, 95th percentile*
- *Supplemental Vertical Accuracy (SVA)<= 36.3 cm, 95th percentile.*

According to USGS Specification 1.0, the Consolidated Vertical Accuracy (CVA) is the result of the LIDAR digital terrain model's accuracy using 3-D Quality Assurance/Quality Control (QA/QC) checkpoints in multiple land cover categories, combining the SVA and the FVA. This assessment will include areas of open terrain (FVA), and areas of vegetated terrain (SVA) representative of the predominant land cover type for the tested area. The CVA is always accompanied by a separate individual measure of the FVA, which was included in section 3.7.2 Fundamental Vertical Accuracy Assessment, of this document. The vertical accuracy is computed using a nonparametric testing method ($95^{th}$ percentile) and is to be tested between a DEM of the bare earth elevation values built from the classified LIDAR points, and the recorded elevation measures from a ground survey team. The vertical accuracy checkpoints should be well-distributed throughout the study area.

USGS specifications described the following exceptions to the vertical accuracy requirements for classified point cloud data:

- *Where there exists a demonstrable and substantial increase in cost to obtain this accuracy.*
- *Where an alternate specification is needed to conform to previously contracted phases of a single larger overall collection effort, for example, multi-year statewide collections.*

- *Where the USGS agrees that it is reasonable and in the best interest of all stakeholders to use an alternate specification.*

These exceptions do not apply to this classified dataset. The Ashland County classified point cloud data meets all vertical accuracy requirements stated in USGS LiDAR Base Specification Version1.0. The classified LIDAR vertical accuracy assessment is summarized in the graph and table below.

**Graph 2. Frequency of values for the Classified Point Cloud Vertical Accuracy Assessment.**

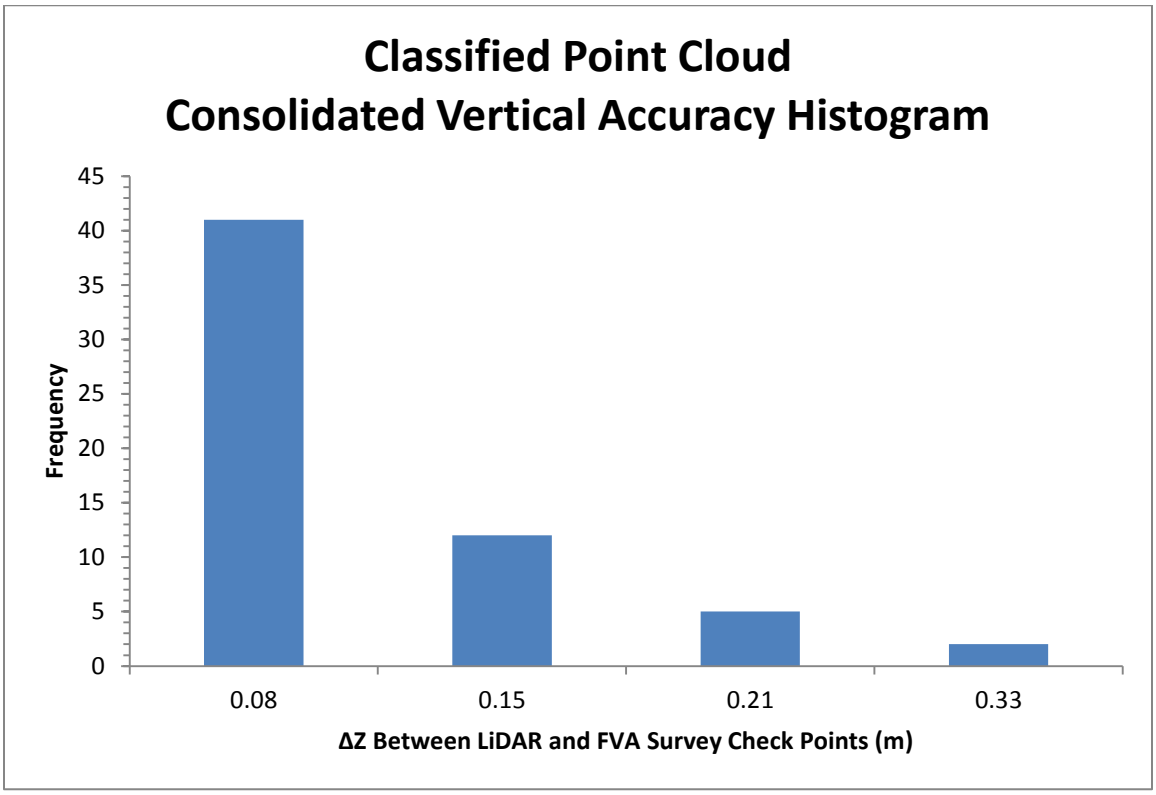


Figure 11: CVA Survey Checkpoint locations.

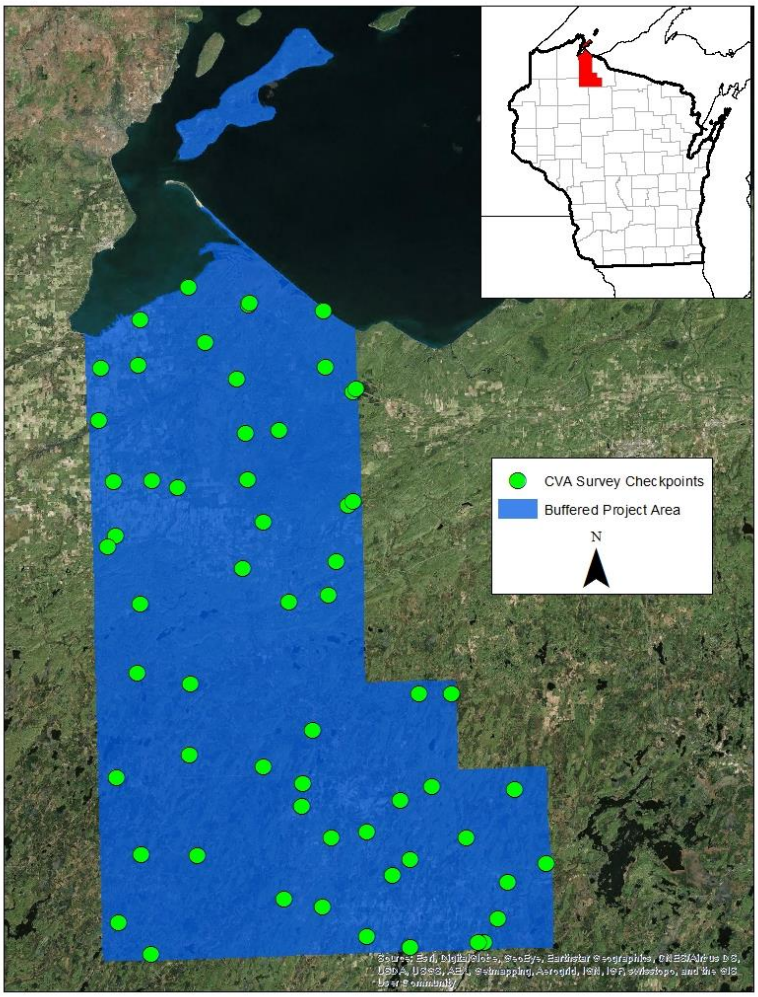



Table 8

| Vertical Accuracy QC Results in Meters (ΔZ values converted to absolute value) | | | |
|---|---|---|---|
| **ΔZ Mean:** | 0.07 | **RMSE:** | 0.096 |
| **ΔZ Min:** | 0.001 | **95 Percent (*1.9600)** | 0.189 |
| **ΔZ Max:** | 0.32 | **95 Percentile** | 0.08 |

## 3.5 Breaklines

Topographic Breaklines are necessary when performing hydrologic and hydraulic modeling. When creating a DEM, the Breaklines will be used to hydro-flatten all significant water bodies within certain parameters, defining the change in continuity of the terrain's surface. The USGS LiDAR Base Specification Version 1.0, lists the requirements of accurate hydro-flattening techniques under section 4 on page 7.

To test the Breaklines, a TIN was created from the LiDAR, incorporating the delivered Breaklines. The TIN was converted to a 2 meter bare earth DEM. A hands-on visual review process was then conducted focusing on use of Breaklines and if USGS specifications were met. The visual review process determined that all specifications were met and the Breaklines are satisfactory.

## 3.6 Visual Review

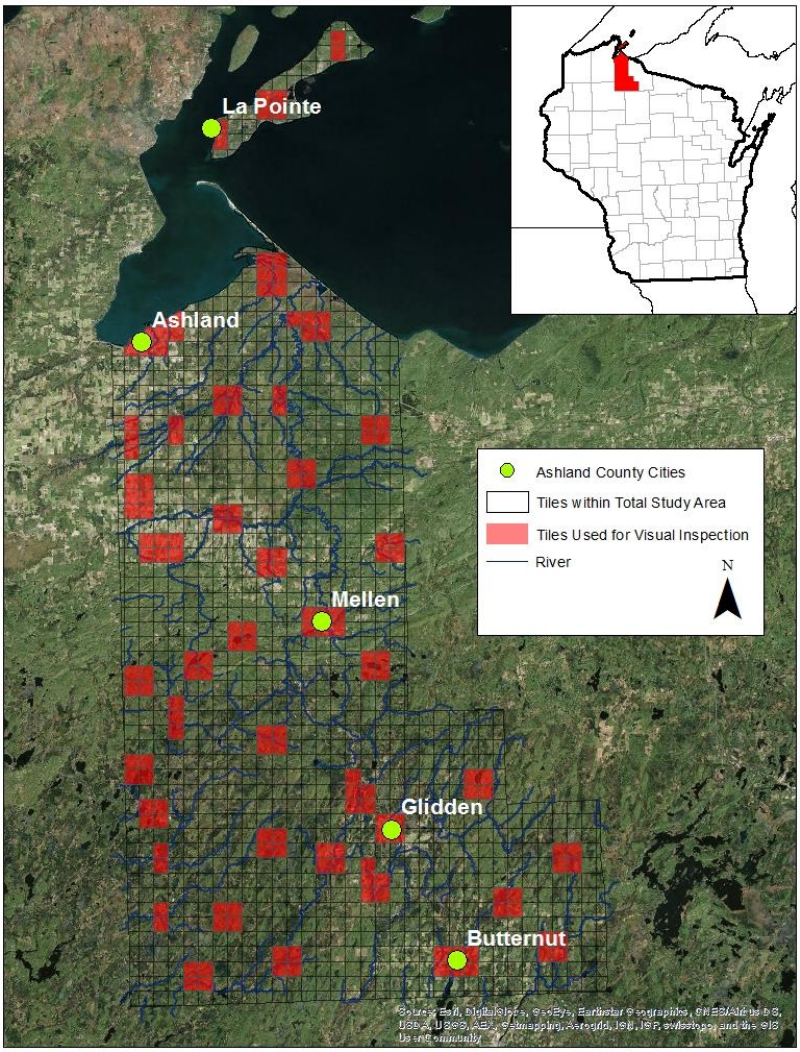
A LiDAR micro review was conducted on a sample of 169 fully classified point cloud tiles. Tiles selected for review were chosen throughout the project area focusing on combined urban development and hydrographic significance, inclusion of Breaklines and hydro-flattening techniques, various land cover types, and prime areas of stream confluence.

Classifications of the point cloud data within each tile should be consistent, without any unnatural variation in character, texture, or quality of the data between tiles, swaths, lifts, or other non-natural divisions. Any distinguishable differences will be reason for the entire deliverable to be rejected. Each tile was reviewed to ensure:

- Scan lines were removed from bare earth
- No excessive noise in the bare earth
- No elevation steps in data
- Voids are only found in acceptable areas as noted in Section 3.5
- Seamless edgematching between tiles
- All artifacts removed (vegetation, bridges, buildings, etc.)
- Proper definition of roads and drainage patterns
- No areas "over-smoothed" during filtering
- No existence of corn row effects
- Absence of mounds and divots
- Any other anomaly resulting with reduced accuracy of terrain representation
- Within any 1 kilometer (km) x 1 km area, no more than 2 percent of non-withheld points will possess a demonstrably erroneous classification value

All data within each sample tile were reviewed by comparing hillshades developed from first return Digital Surface Models and Digital Elevation Models. In addition, profiles were created using a LiDAR viewer and ESRI 3D analyst. The visual review determined the sample set meets project requirements for classified LiDAR data and the full dataset can be used for terrain analysis. Erroneous points were well within the 2% tolerance specification.

Figure 12: 169 tiles chosen for Classified Visual Review.



## 4. Conclusions

Based upon the submittal verification, acquisition reports, macro/micro reviews and vertical accuracy confirmation, Ashland County, Wisconsin dataset meets all applicable project specifications defined in FEMA task order HSFE05-14-J-0037 dated August 14, 2014. This data meets all project requirements for FEMA Risk MAP elevation acquisition and can be used for flood risk analysis.

**Approvals**

**QA Team Lead:** **James L. Huffines Date:** **10/30/2015**

## 5. References

Guidelines and specifications used in production of the LiDAR datasets included in Supporting Documents:


1. Federal Emergency Management Agency, Standards for Flood Risk Analysis and Mapping, November 18, 2014, Standard ID 40, 43-49,
2. U.S. Geological Survey, LiDAR Guidelines and Base Specification, Version 1.0 2012
3. American Society for Photogrammetry and Remote Sensing, LAS v1.2,
4. Federal Emergency Management Agency, Technical Reference Data Capture (Nov 2014), http://www.fema.gov/media-library/assets/documents/3451