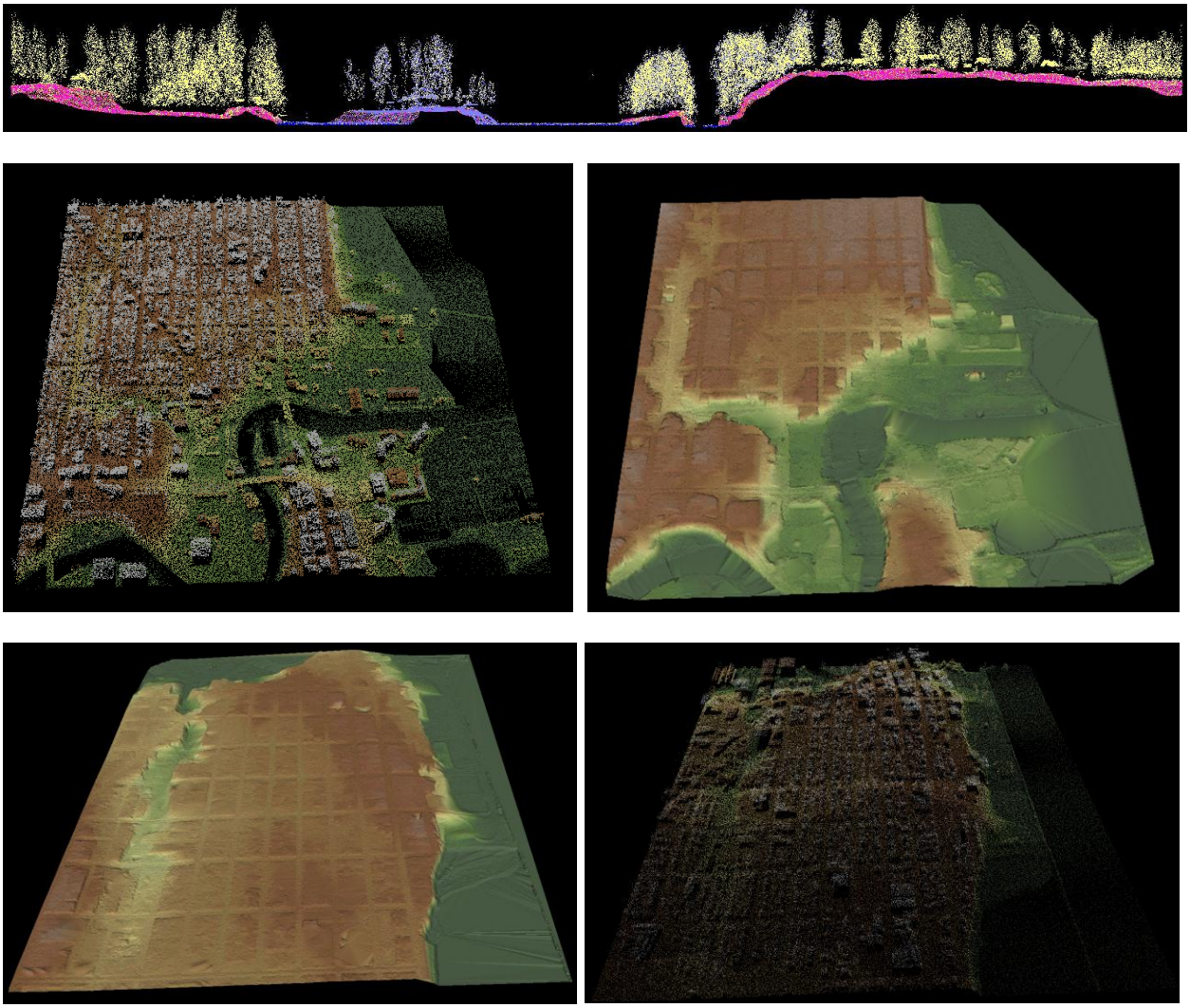
# Elevation Data Quality Assurance Report
## Racine County, Wisconsin
## March 4, 2014



Submitted to:

Federal Emergency Management Agency, Region 5
Department of Homeland Security
536 South Clark St., 6th Floor
Chicago, IL 60605

Prepared by:

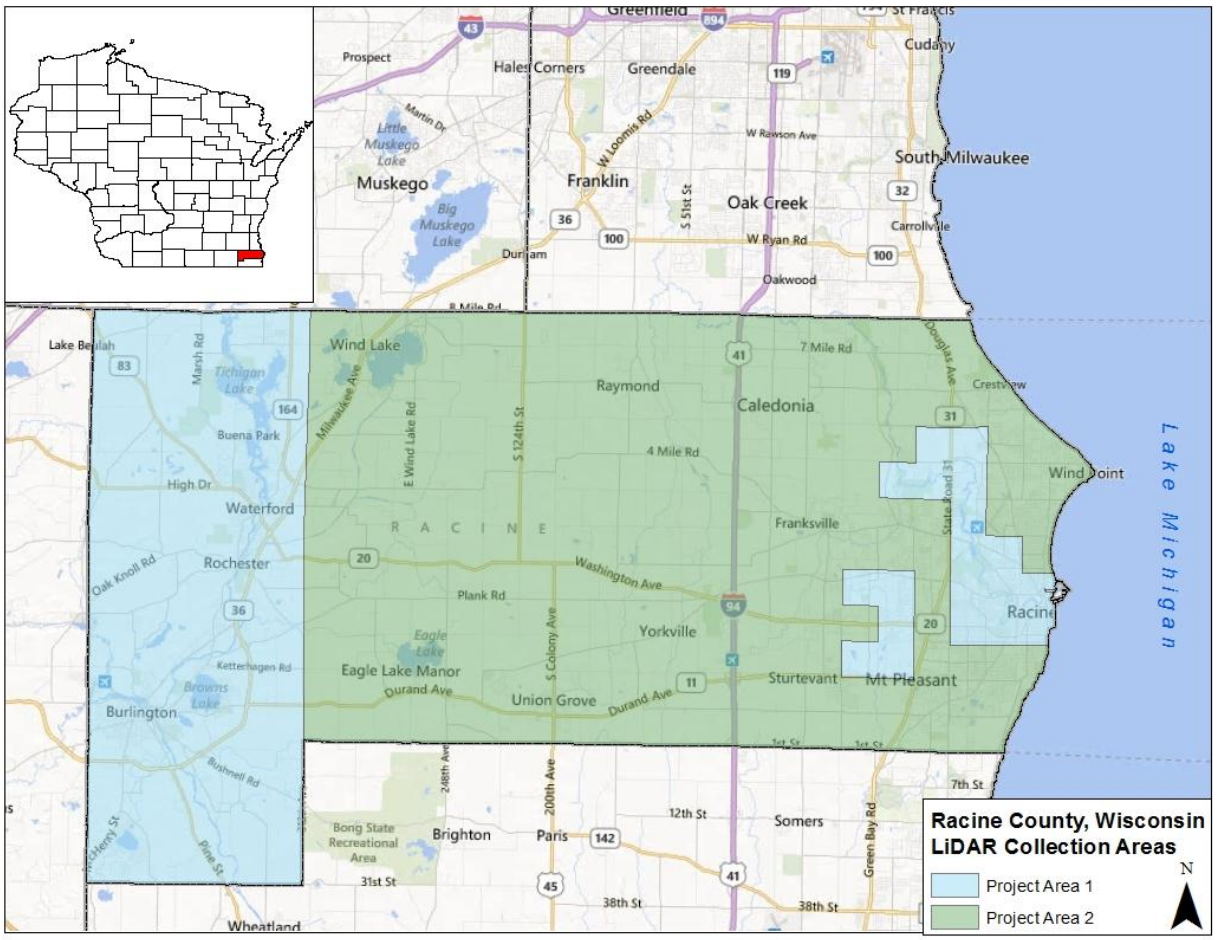
STARR Strategic Alliance for Risk Reduction
Raleigh, NC

# Contents

# 1. Executive Summary

The Southeastern Wisconsin Regional Planning Commission (http://www.sewrpc.org/SEWRPC.htm) or SEWRPC contracted STARR sub-contractor Quantum Spatial (http://quantumspatial.com/) for LiDAR data collection, digital terrain modeling, and digital elevation mapping for Racine County, Wisconsin in the spring of 2010. Racine County LiDAR data acquisition occurred in two distinct project areas. Project area 1 consists of an approximately115 square mile area organized by U.S. Public Land Survey System (USPLSS) Township and Ranges. Deliverables for this area included unclassified, classified, and bare earth LiDAR point cloud data in the American Society for Photogrammetry and Remote Sensing (ASPRS) LASer file format (ASPRS, LAS 1.2 Format Specification, 2-13), Digital Terrain Model (DTM) files, and Digital Elevation Model (DEM) datasets. Project area 2 constitutes the remainder of the County not included in project area 1 (approximately 225 square miles). Deliverables for this area included only non-classified raw point cloud data LAS files from the acquisition.

**Figure 1: Racine County Project Areas**




Requirements from the SEWPRC contract scope of work mandated that all LiDAR collection activities meet the accuracy criteria provided in the Federal Emergency Management Agency (FEMA) Guidelines and Specifications (FEMA, Procedure Memorandum Number 61, 10-22).

**Table 1: SEWPRC LiDAR Acquisition Project Requirements Area 1 and 2**

| | |
|---|---|
| Collection Area | Approximately 340 square miles total |
| Coordinate System | Wisconsin State Plane Coordinate System, South Zone, in US Survey Feet |
| Horizontal Datum | North American Datum of 1927 (NAD27) |
| Vertical Datum | National Geodetic Vertical Datum of 1929 (NGVD29), in US Survey Feet |
| Nominal Pulse Spacing (NPS) | Approximately 3ft |
| Root Mean Square Error (RMSE) | 0.5 feet or better relative to NGVD29 |

For specific information pertaining to the project area 1 DTM, DEM, and contour files see the Racine County 2010 LiDAR and elevation mapping contract (00203187).PDF Section F included in the supplemental data directory.

In the fall of 2013, under task order HSFE05-11-J-0009 assigned to STARR, FEMA Region 5 asked for the completion of the Racine County topographic data in a countywide format. The agreed upon scope of work includes the following:

1. Complete processing of Racine Area 2 following SEWRPC contract specifications such that the countywide datasets are seamless.
    a. processing of the point cloud data to the bare earth deliverable
    b. survey to collect additional accuracy assessment points in five ground cover categories for Area 2
    c. conduct vertical accuracy assessment testing
    d. prepare reports
2. Convert all data to the NAD83 High Accuracy reference Network (HARN) horizontal datum, NAVD88 vertical datum, and Universal Traverse Mercator (UTM) coordinate system.
    a. UTM zone 16 N
    b. horizontal units are in meters
    c. vertical units remain in US Survey Feet
3. Quality Assurance (QA) testing conducted over the countywide dataset.
    a. seamless dataset
    b. quality requirements of FEMA procedure memorandum 61 are met
    c. produce QA report
4. Countywide deliverables in both SEWRPC and FEMA format
    a. metadata
    b. project narrative
    c. LAS point cloud data
        i. unclassified
        ii. fully classified that include bare earth
    d. breaklines
    e. DEMs
    f. contours
    g. accuracy assessment report (excel spreadsheets showing calculations)
    h. processing report

## 2. Overview

This report documents the independent quality control of data acquisition, processing methods, accuracy assessment, and deliverables for Racine County, Wisconsin in order to validate the quality of LiDAR data for use in FEMA Risk MAP projects.

Table 2 LiDAR Project Requirements

| FEMA Region 5 Racine Countywide LiDAR | |
|---|---|
| **Collection/Processing Area** | Approximately 340 square miles |
| **Breaklines Required** | Yes |
| **Specification Level** | Highest |
| **Nominal Pulse Spacing** | 1 m |
| **DEM Post Spacing** | 2 m DEM with 2 ft. contour accuracy |
| **RMSE** | < 18.5 cm |
| **Vertical Accuracy, 95% Confidence Level FVA/CVA** | 24.5 cm/ 36.3 cm |
| **Coordinate System** | UTM Zone 16N |
| **Horizontal Datum and Linear Units** | NAD 83 Meters |
| **Vertical Datum and Linear Units** | NAVD 88 US Survey Foot |

Table 3 QA Activity and Guideline and Specifications Matrix

| QA Activity | PM 61 | USGS LiDAR Base Spec v13 | ASPRS LAS v1.2 | Appendix A | Appendix M |
|---|---|---|---|---|---|
| **Vendor Submittal** | X | X | X | | X |
| **Macro Review** | X | X | | X | |
| **Micro Review** | X | X | X | X | |
| **Vertical Accuracy** | X | X | | X | X |

# 3. LiDAR Data Review

STARR utilizes commercial software and proprietary scripts/applications to review LiDAR data. These tools, combined with guidelines and specifications, are incorporated into a standardized quality assurance workflow. The following table summarizes software and proprietary scripts/applications used in the review.

Table 4 Software/Tools used in Quality Assurance Review

| Software/Tools | QA Process |
|---|---|
| ESRI ArcGIS ArcInfo | LiDAR Data Processing |
| ESRI 3D Analyst Extension | Visual Analysis of LiDAR Data |
| ESRI Spatial Analyst Extension | Grid Analysis for LiDAR Data |
| LP360 ArcMap Extension | Visual Analysis of LiDAR Data |
| SIS Topo Analyst | Vertical Accuracy Quality Assurance |
| Proprietary Scripts/Applications | Working with LAS files |

## 3.1 Vendor Submittal

All project data has been delivered and is accounted for. The completed Vendor Submittal Quality Assurance checklists are included in Appendix A of this document.

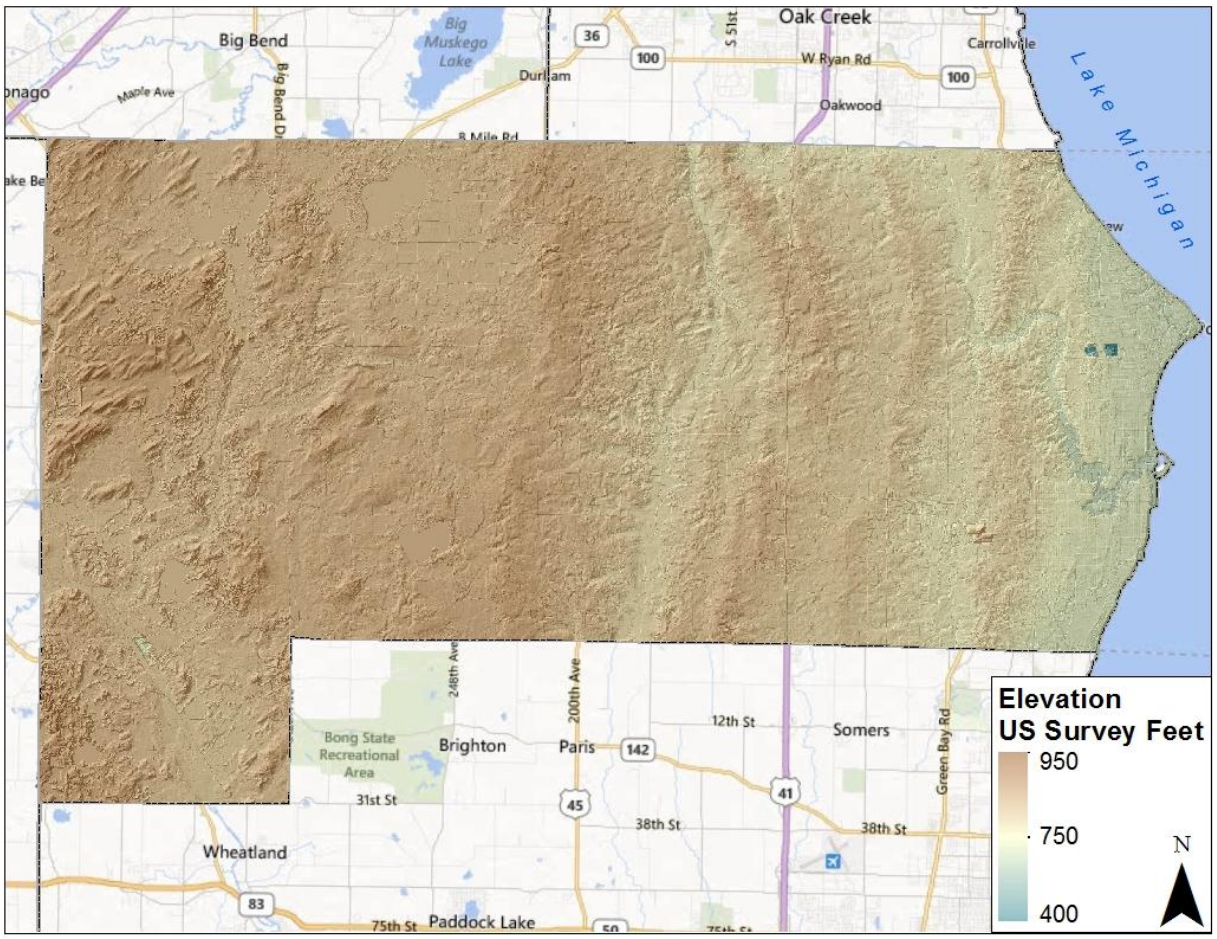
## 3.2 Macro Data Review

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

### 3.2.1 LiDAR Coverage and Completeness

All LiDAR data collected for Racine County, Wisconsin covers the area of interest and has an area of approximately 340 square miles. All LAS files and LiDAR derived products are included and have the correct projection and datum information for both SEWRPC and FEMA deliverables. All LiDAR derived products are seamless and consistent to the edge of the defined countywide project area.

Figure 2: LiDAR Data Coverage




### 3.2.2 LAS File Review

All LAS files submitted for review have header information that is compliant with ASPRS LAS specifications version 1.2. Each LAS file contains multiple discrete returns and has intensity values. The completed LAS Header Quality Assurance results are included Appendix A of this document.

### 3.2.3 Nominal Pulse Spacing, Point Density, Spatial Distribution and Data Voids

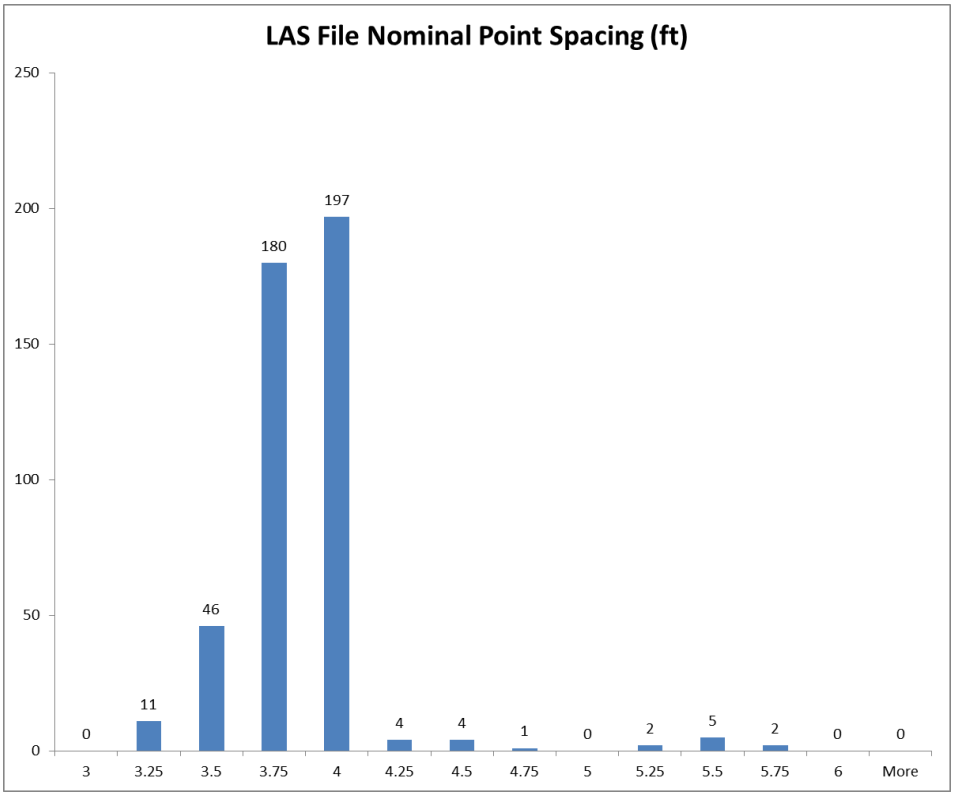
Nominal pulse spacing refers to the generalized point-to-point distance between irregularly spaced LiDAR pulse returns. The nominal pulse spacing requirement for this project is approximately 1.3 m or 4.26ft. USGS and FEMA require NPS to be a minimum of 2 meters. The NPS of the LAS data calculated as the square root of the average area per point was determined to be on average 3.75ft or 1.14 m.

Table 5: Nominal Pulse Spacing Summary Statistics for Classified LiDAR

| LiDAR Nominal Pulse Spacing (ft) | |
|---|---|
| **Count** | 452 LAS files |

| | |
|---|---|
| **Minimum** | 3.03 |
| **Maximum** | 5.63 |
| **Range** | 2.59 |
| **Mean** | 3.75 |
| **Standard Error** | 0.01 |
| **Median** | 3.74 |
| **Mode** | 3.84 |
| **Standard Deviation** | 0.30 |
| **Sample Variance** | 0.09 |
| **Kurtosis** | 15.62 |
| **Skewness** | 2.90 |

Figure 3: Nominal Pulse Spacing Frequency Histogram

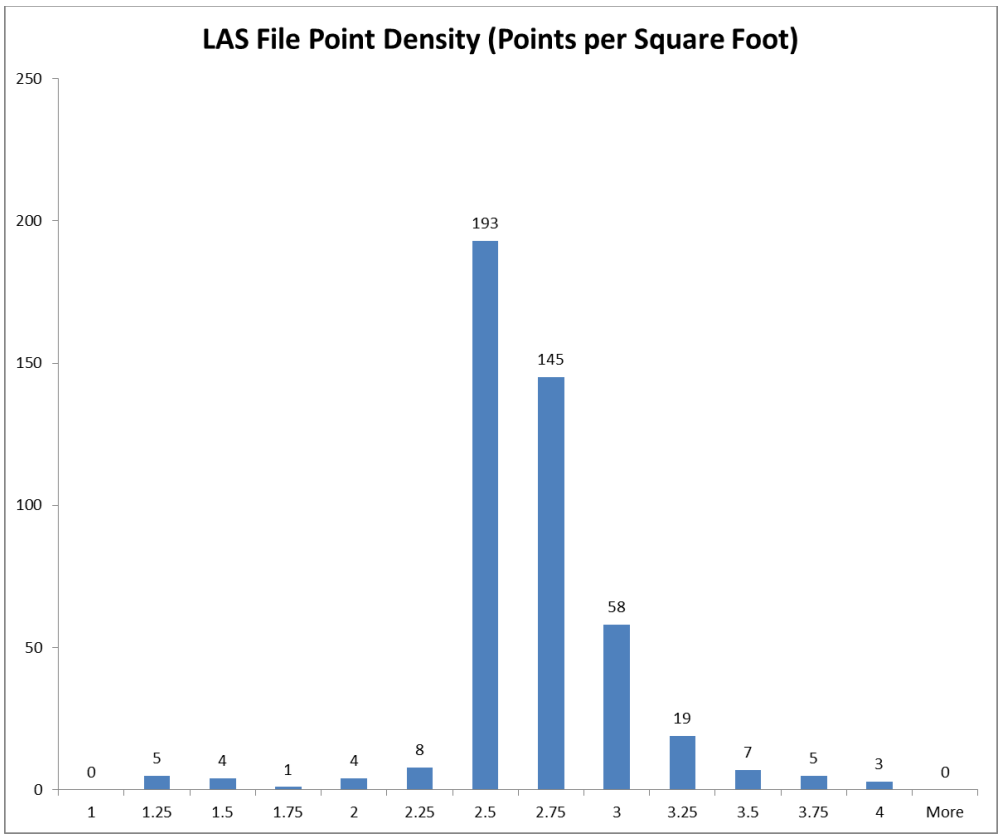


The pulse density of a LiDAR data set is the number of pulses emitted by the LiDAR system commonly expressed as Pulses per Square Foot (ppsft) or Pulses per Square Meter (ppsm). This value is derived from "box counting" the points within the boundary of the LAS file.

Table 6: Point Density Summary Statistics for Classified LiDAR

| LiDAR Pulse Density (points per square foot) | |
|---|---|
| **Count** | 452 LAS files |
| **Minimum** | 1.12 |
| **Maximum** | 3.84 |
| **Range** | 2.72 |
| **Mean** | 2.55 |
| **Standard Error** | 0.02 |
| **Median** | 2.53 |
| **Mode** | 2.39 |
| **Standard Deviation** | 0.34 |
| **Sample Variance** | 0.12 |
| **Kurtosis** | 5.08 |
| **Skewness** | -0.16 |

Figure 4: Point Density Frequency Histogram




From Section 1.6 of the USGS LiDAR Guidelines and Base Specification Version 13:

> 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 Racine project, a 4-meter box count grid was created for the unclassified raw LiDAR point cloud data. The percentage of cells with counts greater than or equal to one complies with the USGS specification of 90%.

Table 7: Spatial Distribution QC Results

| Test Parameters | Point Count | Percent of Total |
|---|---|---|
| **Grid cells with at least 1 LiDAR point** | 55,461,378 | 99.1597 |

| | | |
|---|---|---|
| **Grid cells without a LiDAR point** | 469,989 | 0.8402 |
| **Total cells tested** | 55,931,367 | 100 |

### 3.2.4 Data Voids

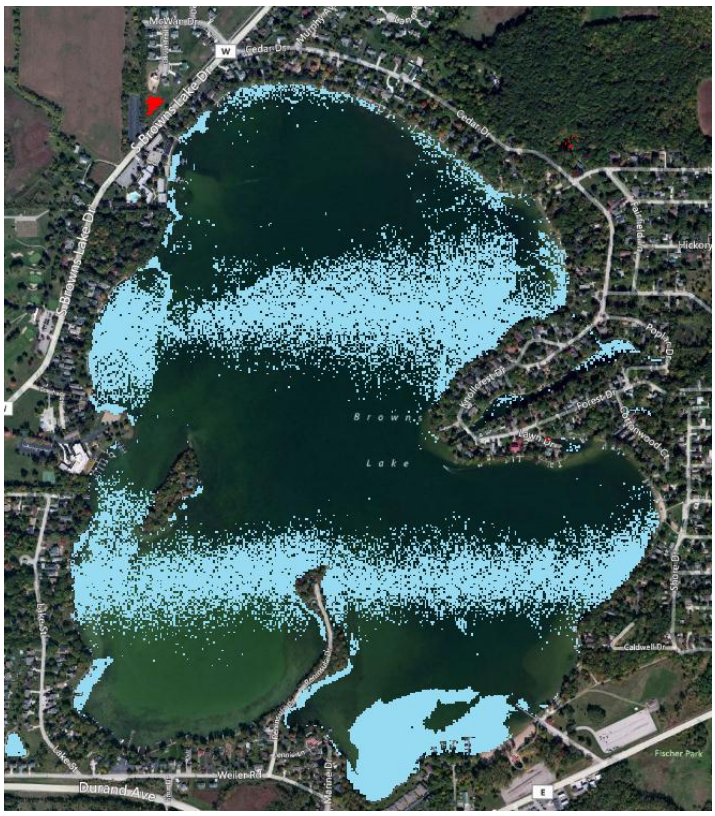
From section 1.5 of the USGS LiDAR Guidelines and Base Specification version 13:

> 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.

Figure 5: Example of Legitimate Data Voids Blue Areas represent Water Bodies and Red Areas are NIR Reflectivity

Figure 6: Example of Legitimate Data Voids Blue Areas represent Water Bodies and Red Areas are NIR Reflectivity




## 3.3 Micro Data Review

Micro reviews were completed on 5% of the fully classified point cloud tiles. Tiles selected for review were chosen throughout the project area with a focus on areas of urban development and hydrographic significance. The following criteria were examined:

- Scan lines removed from bare earth
- Excessive Noise in bare earth
- Elevation Steps
- Gaps/Voids
- Edge matching between tiles
- Artifacts have been removed from bare earth (vegetation, buildings, bridges, etc.)
- Proper definition of roads and drainage patterns
- "Over-smoothed" areas during filtering
- Corn Row Effects, Mounds and Divots, and Other anomalies

All tiles reviewed meet project requirements for classified LiDAR data and can be used for floodplain mapping activities. The completed Micro Data Review Quality Assurance checklist is included in Appendix A of this document.

# 4. Vertical Accuracy Verification

An independent review and verification of submitted FVA and CVA survey data with vendor provided LAS files was completed to insure reported vertical accuracy is correct. Survey data points containing field collected GPS elevation values were buffered by 10 meters. LiDAR points contained within the buffered areas are selected and used to create a TIN. The TIN facet z value closest to the x and y control point location is compared to the height of the survey point. The height difference is evaluated statistically and compared to the submitted FVA and CVA testing results to insure the vertical accuracy meets project expectations. All FVA and CVA survey data submitted for this project has been confirmed to meet project requirements.

Table 8: CVA Summary Statistics

| GPS Survey Bare Earth LiDAR TIN Surface Elevation Difference (ft) | |
|---|---|
| **Count** | 221 points |
| **Minimum** | -1.15 |
| **Maximum** | 0.96 |
| **Range** | 2.11 |
| **Mean** | -0.24 |
| **Standard Deviation** | 0.42 |
| **Sample Variance** | 0.17 |
| **Standard Error** | 0.03 |
| **Median** | -0.19 |
| **Kurtosis** | -0.57 |
| **Skewness** | 0.06 |

Figure 7: CVA Test Histogram

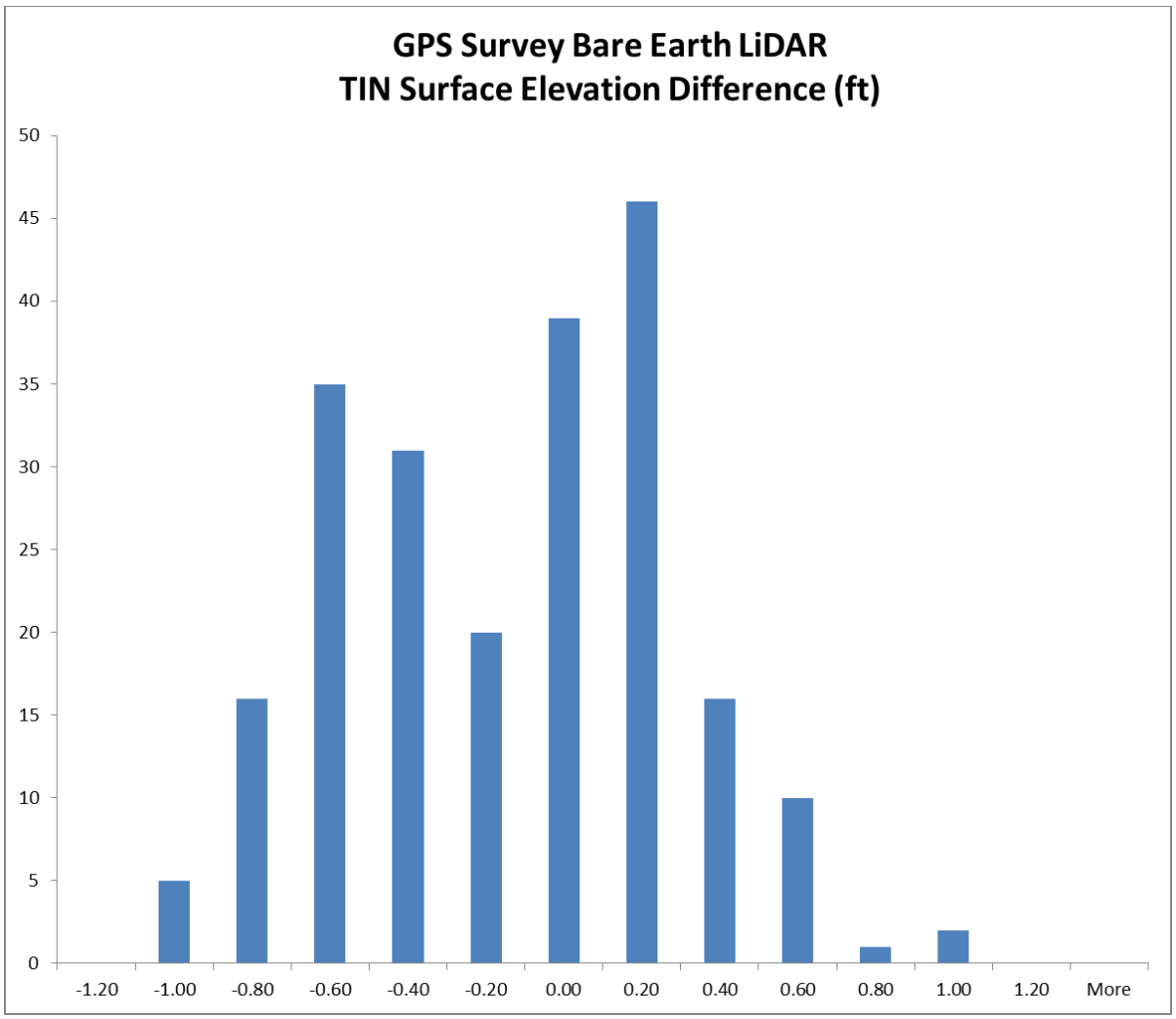


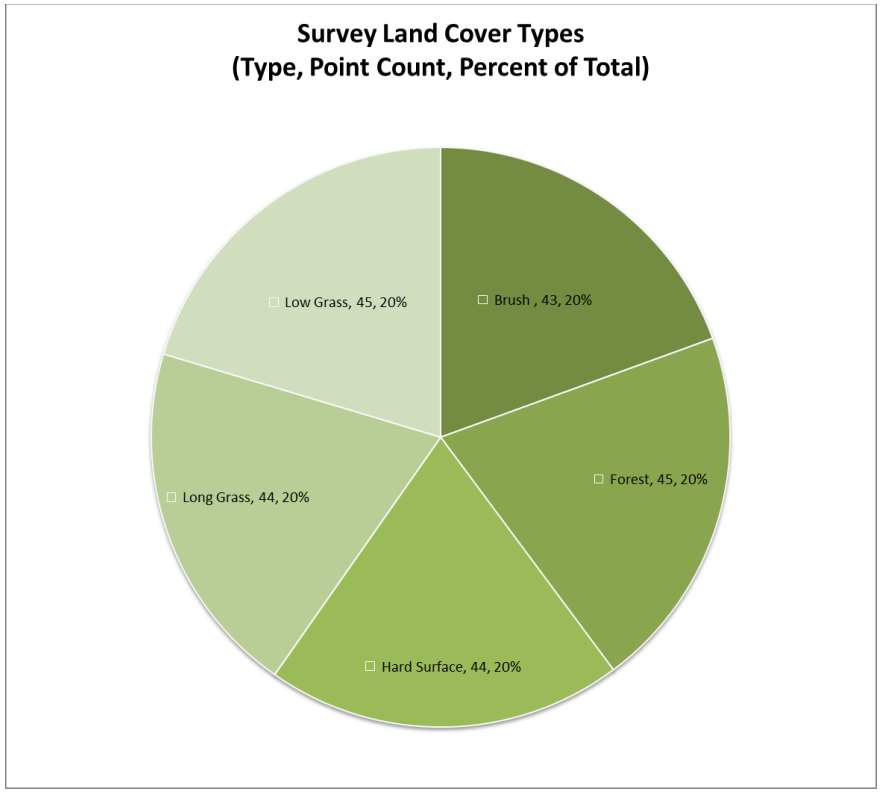

Table 9: CVA Test Results

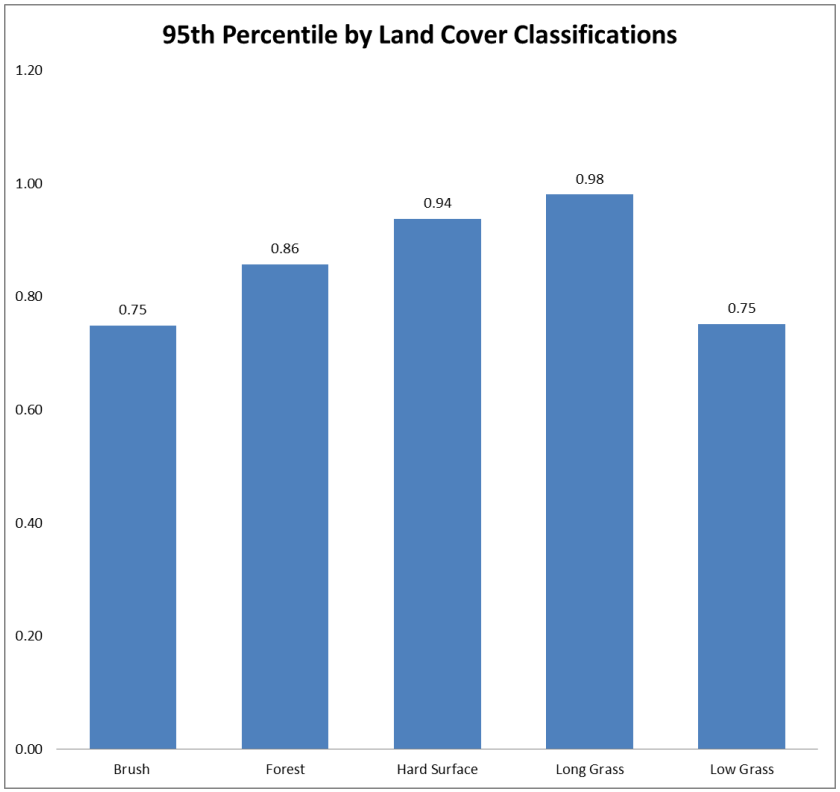
| | | |
|---|---|---|
| **95th Percentile(CVA)** | **0.93** | |
| **Target RMSE** | **0.61 ft** | **18.5 cm** |
| **RMSE** | **0.48 ft** | **14.63 cm** |

Table 10: Summary FVA/SVA Results

| Land Cover | Points | Min Dz (ft) | Max Dz (ft) | Mean Dz (ft) | Median Dz (ft) | Std Deviation Dz (ft) | Skew | 95th Percentile | RMSE | FVA (RMSE * 1.96) |
|---|---|---|---|---|---|---|---|---|---|---|
| **Brush** | 43 | -0.758 | 0.933 | -0.131 | -0.062 | 0.45 | 0.34 | 0.75 | 0.47 | 0.91 |
| **Forest** | 45 | -1.090 | 0.465 | -0.222 | -0.141 | 0.46 | -0.23 | 0.86 | 0.51 | 0.99 |
| **Hard Surface** | 44 | -1.151 | 0.091 | -0.351 | -0.239 | 0.36 | -0.58 | 0.94 | 0.50 | 0.98 |
| **Long Grass** | 44 | -1.036 | 0.545 | -0.279 | -0.278 | 0.40 | -0.16 | 0.98 | 0.49 | 0.96 |
| **Low Grass** | 45 | -0.815 | 0.964 | -0.202 | -0.155 | 0.39 | 0.44 | 0.75 | 0.44 | 0.86 |
| **Consolidated** | 221 | -1.151 | 0.964 | -0.237 | -0.155 | 0.04 | -0.03 | 0.93 | 0.48 | 0.94 |

Figure 8: FVA/SAVA Quality Assurance Results



## 5. Conclusions

Based upon the submittal verification, acquisition reports, macro/micro reviews and vertical accuracy confirmation, Racine County, Wisconsin dataset meets all applicable project specifications defined in FEMA task order HSFE05-11-J-0009 CR 393 dated September 12, 2013. 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: 3/10/2014**

## 6. References

Links to guidelines and specifications used in production of the LiDAR datasets:


1. Federal Emergency Management Agency, Procedure Memorandum No. 61 - Standards for LiDAR and Other High Quality Digital Topography, http://www.fema.gov/vi/media-library/assets/documents/34953
2. U.S. Geological Survey National Geospatial Program, LiDAR Guidelines and Base Specification, Version 13-ILMF 2010, http://lidar.cr.usgs.gov/USGS-NGP%20Lidar%20Guidelines%20and%20Base%20Specification%20v13%28ILMF%29.pdf
3. Heidemann, Hans Karl, 2012, LiDAR base specification version 1.0: U.S. Geological Survey Techniques and Methods, book 11, chap. B4, 63 p, http://pubs.usgs.gov/tm/11b4/TM11-B4.pdf
4. American Society for Photogrammetry and Remote Sensing, LAS v1.2, http://www.asprs.org/a/society/committees/standards/asprs_las_format_v12.pdf
5. Federal Emergency Management Agency, Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix A: Guidance for Aerial Mapping and Surveying [includes guidance on Light Detection and Ranging Systems (LIDAR)] http://www.fema.gov/library/file;jsessionid=1E39C93AF9CD18EE125B3DFCA5A874B8.Worker2Library?type=publishedFile&file=frm__gsaa.pdf&fileid=2daefcd0-df08-11e0-9bf5-001cc4568fb6
6. Federal Emergency Management Agency, Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix M: data Capture Standards http://www.fema.gov/library/file;jsessionid=1E39C93AF9CD18EE125B3DFCA5A874B8.Worker2Library?type=publishedFile&file=frm__gsam.pdf&fileid=cf85c9b0-df0f-11e0-9bf5-001cc4568fb6

# Appendix A: Supporting Documentation

# Vendor Submittal Verification

LiDAR Data Submittal Requirements:

1. Descriptive Project Information
    a. Metadata process steps and FEMA Compliance Form
    b. Pre-flight operations report
    c. Post-flight report
        i. GPS Base Station Shapefile
        ii. Project Coverage Shapefile
        iii. As-Flown Trajectories and Calibration line Shapefiles
        iv. Flight Logs
2. Survey Data
    a. Metadata and FEMA Compliance Form
    b. Ground Control
        i. Accuracy Report
        ii. Image Chips and Survey Pictures
        iii. Spatial Data (Shapefile, kml/kmz, and csv containing coordinates)
        iv. Final Report and Final Coordinates
    c. FVA/CVA
        i. Accuracy Report
        ii. Image Chips and Survey Pictures
        iii. Spatial Data (Shapefile, kml/kmz, and csv containing coordinates)
        iv. Final Report and Final Coordinates
        v. Vertical Accuracy Testing Results
3. Raw Point Cloud LiDAR
    a. All Returns Swath Data
        i. LAS v1.2 or v1.3 files
            1. No file greater than 2GB
        ii. Swath Index Shapefile
            1. Includes Calibration and Cross-Ties
4. Post Processed LiDAR
    a. Bare-Earth Data
        i. Tiled LAS v1.2 or v1.3 files
        ii. Tile Index Shapefile

| LiDAR Submittal Checklist | | |
|---|---|---|
| Project Name: Racine County, Wisconsin | Date Delivered: 1/14/2014 | |
| Acquisition: | LiDAR: Quantum Spatial, Inc. | |
| Post Processing: | Breaklines: Y | Topographic Products: Y |
| Acquisition/Processing Point of Contact:<br><br>Name: James Young<br><br>Mailing Address: 4020 Technology Parkway, Sheboygan, WI<br><br>Phone Number: 920-457-3631<br><br>Email: jyoung@quantumspatial.com | Point of Contact:<br><br>Name: James Young<br><br>Mailing Address:4020 Technology Parkway Sheboygan, WI<br><br>Phone Number: 920-457-3631<br><br>Email: jyoung@quantumspatial.com | |

| Dataset | Included | Comments |
|---|---|---|
| **Descriptive Project Information** | | |
| Metadata | X | |
| Compliance Form | X | |
| Pre-Flight Report | | |
| Post Flight Report | X | -see LiDAR_Report |
| GPS Base Station Shapefile | X | -see LiDAR_Report\Appendix\Control\GPS_Base |
| Project Coverage Shapefile | | -see LiDAR_Report\Appendix\Coverage\Project_Shape_Coverage |
| As-Flown Trajectories | X | -see LiDAR_Report\Appendix\Coverage\Trajectories |
| Final Flight Lines | X | -see LiDAR_Report\Appendix\Coverage\Flightlines |
| Flight Logs | X | -see LiDAR_Report\Appendix\Coverage\Flightlogs |
| **Survey Data** | | |
| Metadata | X | -see Metadata |

| | | |
|---|---|---|
| Compliance Form | | |
| Ground Control | | |
| Accuracy Report | X | -see GPS Report |
| Image Chips | | |
| Survey Pictures | | |
| Shapefile and Final Coords | | -see GPS Report |
| Final Report | X | -see GPS Report |
| FVA/CVA | | |
| Accuracy Report | X | -see Vertical_Accuracy |
| Image Chips | | |
| Survey Pictures | | |
| Shapefile and Final Coords | | -see Vertical_Accuracy |
| Final Report | X | -see Vertical_Accuracy |
| Testing Results | X | -see Vertical_Accuracy |
| **Raw Point Cloud LiDAR** | | |
| LAS v1.2 or 1.3 Files < 2GB | X | LAS 1.2 |
| Swath Index | X | -see Breaklines |
| **Post Processed LiDAR** | | |
| LAS Files v1.2 or 1.3 | X | LAS 1.2 |
| LAS Tile Index | X | -see Breaklines |
| Notes: Survey Field Notes in GPS_Report folder | | |

## Post-Flight Operations Report

| Post Flight Report Checklist | | |
|---|---|---|
| Project: Racine County, Wisconsin | Vendor: Aerometric, Inc | |
| Date Submitted: 1/1/2014 | Date Reviewed: 02/24/2014 | |
| | | |
| Checklist | Included | Comments |
| **GPS Base Station Information** | | |
| Name | X | |
| Latitude/Longitude Coordinates | X | |
| Heights | X | |
| Maximum PDOP description in text | X | |
| Location Map | X | |
| Correct Shapefile | X | |
| **GPS/IMU** | | |
| GPS quality - Max horizontal variance (cm) | X | |
| GPS quality - Max vertical variance (cm) | X | |
| Description of GPS Quality in text | X | |
| GPS Separation Plot | X | |
| GPS Altitude Plot | X | |
| PDOP Plot | X | |
| GPS Distance From Base Stations Plot | X | |
| **Coverage** | | |
| Verification of Area of Interest Coverage | X | |

| | | |
|---|---|---|
| Correct Shapefile of coverage area | X | |
| **Flights** | | |
| Final Flight Lines Shape File | X | |
| Calibration Lines Shape File | X | |
| As-Flown Trajectories Shape File | X | |
| List of settings for flights/LiDAR | X | |
| **Control** | | |
| Ground Control and Base Station Layout | X | |
| Ground Control point Shapefile | X | |
| **Calibration** | | |
| Description of calibration process in text | X | |
| Description of actual issues found/corrected in dataset | X | |
| **Data Verification and Quality Control** | | |
| Verification Process Documented | X | |
| Quality Control Procedures Documented | X | |
| Notes: | | |

## Flight Logs

| Flight Log Checklist | | |
|---|---|---|
| Project: Racine County, Wisconsin | Vendor: Quantum Spatial, Inc. | |
| Date Received: 1/14/2014 | Date Reviewed:2/24/2014 | |
| | | |
| Checklist | Included | Comments |
| Job Number and Name | X | |
| Lift Number | X | |
| Block or Area of Interest Designator | X | |
| Date | X | |
| Aircraft Type | X | |
| Aircraft Tail Number | X | |
| Pilot Name | X | |
| Operator Name | X | |
| Airport of Operations | X | |
| GPS Base Station Names | | Not Used |
| Flight Line Number | X | |
| Flight Line Direction | X | |
| Flight Line Start | X | |
| Flight Line Stop | X | |
| Flight Line Altitude | X | |
| Flight Line Scan Angle | X | |
| Flight Line Scan Rate | X | |

| | | |
|---|---|---|
| Flight Line Speed | X | |
| Flight Line Conditions | X | |
| Flight Line Comments | X | |
| AGC Switch Settings | X | |
| Laser Pulse Rate Settings | X | |
| Mirror Rate Settings | X | |
| Field of View Settings | X | |
| Settings Comments | X | |
| Notes:<br><br>Wisconsin Continuously Operating Reference Stations (WISCORS) were used for base stations. | | |

| Survey Data Checklist | | Project: Racine County |
|---|---|---|
| **Vendor: Quantum Spatial (Aerometic)** | | **Reviewed By: James L. Huffines** |
| | | |
| **Section: Main** | | **Date: 10MAR2014** |
| **Item** | **Included (Y/N)** | **Comments** |
| Survey is referenced to NGS control monuments in the NSRS using appropriate horizontal and vertical control | **Y** | |
| Base station locations are the "best" horizontal (second order or better) and vertical (third order or better) available and have a stability of "C" or better | **Y** | |
| New control conforms to the Standards and Specifications for Geodetic Control Networks (1984), FGCC | **Y** | |
| Primary control monuments established with GPS meet or exceed NOS NGS-58 "Guidelines for Establishing GPS-Derived Ellipsoidal Heights (Standards: 2 cm and 5 cm)" using the appropriate and latest geoid model and should be monumented to maintain stability and reoccupation if necessary | **Y** | |
| Ground control stations meet local network accuracy at the 95% accuracy level of 2 cm horizontally and vertically | **Y** | |
| Supporting documentation submitted such as processing reports, minimally and constrained 3-D least squares adjustment, pictures, of the stations, etc. | **Y** | Did not see images for each survey location |
| Description of process used to test the points | **Y** | |
| A graphic depicting the spatial distribution of the ground survey points | **Y** | |
| FVA checkpoints must exist in the project area | **Y** | |
| FVA checkpoints as open area | **Y** | |
| SVA for up to three significant land cover categories | **Y** | |
| SVA checkpoints must exist in the area where bare-earth processing occurred | **Y** | |
| An analysis of checkpoints that have errors exceeding the 95th percentile in SVA and CVA calculations | **Y** | |
| Descriptive statistics and RMSE in FVA and/or CVA calculations. | **Y** | |

| LAS Header Checklist | | Racine County |
|---|---|---|
| **Vendor: Quantum Spatial (Aerometric)** | | **Reviewed By: James L. Huffines** |
| **Files Reviewed: All classified LAS** | | |
| | | |
| **Section: Public Block** | | **Date: 10MAR2014** |
| **Item** | **Included** | **Comments** |
| File Signature ("LASF") | Y | |
| File Source ID | Y | Zero means an ID has not been assigned |
| Global Encoding | Y | Encoded as GPS Week Time |
| Version Major\Minor | Y | Version 1.2 |
| System Identifier | Y | MODIFICATION, EXTRACTION, OTHER, etc. |
| Generating Software | Y | |
| Header Size | Y | |
| Offset to point data | Y | |
| Number of Variable Length Records | Y | 5…Zero suggests no VLR present in LAS file |
| Point Data Format ID (0-99 for spec) | Y | Format 1 |
| Point Data Record Length | Y | |
| Number of point records | Y | |
| Number of points by return | Y | 4 returns |
| X, Y, and Z scale factor | Y | |
| X, Y, and Z offset | Y | |
| X, Y, and Z Max | Y | Appears to be have Z values as feet |
| X, Y, and Z Min | Y | Appears to be have Z values as feet |
| Any field in the Public Header Block that is not required and is not used must be zero filled. | Y | File creation is 10/2014 |

Required Public Block Item Definitions:

**File Signature** - The file signature must contain the four characters "LASF", and it is required by the LAS specification.

**File Source ID** (Flight Line Number if this file was derived from an original flight line) - This field should be set to a value between 1 and 65,535, inclusive. A value of zero (0) is interpreted to mean that an ID has not been assigned. In this case, processing software is free to assign any valid number. Note that this scheme allows a LIDAR project to contain up to 65,535 unique sources. A source can be considered an original flight line or it can be the result of merge and/or extract operations. All of the sources are the results of processing and are not based on the flight line number.

**Global Encoding** - This is a bit field used to indicate certain global properties about the file. The meaning of GPS Time in the Point Records 0 (not set) -> GPS time in the point record fields is GPS Week Time (the same as previous versions of LAS) 1 (set) -> GPS Time is standard GPS Time (satellite GPS Time) minus 1 x 109 . The offset moves the time back to near zero to improve floating point resolution.

**Version Major\Minor** - The version number consists of a major and minor field. The major and minor fields combine to form the number that indicates the format number of the current specification itself.

**System Identifier** - files often result from extraction, merging or modifying existing data files. Values should include: String identifying hardware ("ALS50"), "MERGE", "MODIFICATION", "EXTRACTION", "TRANSFORMATION", "OTHER" or a string up to 32 characters identifying the operation.

**Generating Software –** provides a mechanism for specifying which generating software package and version was used during LAS file creation (e.g. "TerraScan V-10.8", "REALM V-4.2" and etc.).

**Header Size** - The size, in bytes, of the Public Header Block itself

**Offset to point data** - The actual number of bytes from the beginning of the file to the first field of the first point record data field. This data offset must be updated if any software adds data from the Public Header Block or adds/removes data to/from the Variable Length Records.

**Number of Variable Length Records** - This field contains the current number of Variable Length Records. This number must be updated if the number of Variable Length Records changes at any time.

**Point Data Format ID** - The point data format ID corresponds to the point data record format type. LAS 1.2 define types 0, 1, 2 and 3.

**Point Data Record Length** - The size, in bytes, of the Point Data Record

**Number of point records –** The total number of point records within the file

**Number of points by return** - This field contains an array of the total point records per return. The first unsigned long value will be the total number of records from the first return, and the second contains the total number for return two, and so forth up to five returns.

**X, Y, and Z scale factor** - The scale factor fields contain a double floating point value that is used to scale the corresponding X, Y, and Z long values within the point records. The corresponding X, Y, and Z scale factor must be multiplied by the X, Y, or Z point record value to get the actual X, Y, or Z coordinate. For example, if the X, Y, and Z coordinates are intended to have two decimal point values, then each scale factor will contain the number 0.01.

**X, Y, and Z offset** - The offset fields should be used to set the overall offset for the point records. In general these numbers will be zero, but for certain cases the resolution of the point data may not be large enough for a given projection system. However, it should always be assumed that these numbers are used. So to scale a given X from the point record, take the point record X multiplied by the X scale factor, and then add the X offset. (Xcoordinate = (Xrecord * Xscale) + Xoffset, Ycoordinate = (Yrecord * Yscale) + Yoffset, Zcoordinate = (Zrecord * Zscale) + Zoffset)

**Max and Min X, Y, and Z** - The max and min data fields are the actual unscaled extents of the LAS point file data, specified in the coordinate system of the LAS data.

| LAS Header Checklist | | |
|---|---|---|
| | | |
| **Section: Variable Length Records** | | **Date: 10MAR2014** |
| **Item** | **Included (Y/N)** | **Comments** |
| GeoKeyDirectoryTag | Y | VLR present in LAS header |
| User ID 'LASF_Projection' | Y | VLR present in LAS header |
| Record ID: 34735 | Y | VLR present in LAS header |
| Length after Header | Y | VLR present in LAS header |
| 'GeoTiff Projection Keys' | Y | VLR present in LAS header |

Required Variable Length Record Definitions:

**Georeferencing Information** - Georeferencing for the LAS format will use the same robust mechanism that was developed for the GeoTIFF standard. The variable length header records section will contain the same data that would be contained in the GeoTIFF key tags of a TIFF file. Since LAS is not a

raster format and each point contains its own absolute location information, only 3 of the 6 GeoTIFF tags are necessary. The GeoKeyDirectoryTag (34735),

GeoDoubleParamsTag (34736), and GeoASCIIParamsTag (34737) records are used. Only the GeoKeyDirectoryTag record is required. The GeoDoubleParamsTag and GeoASCIIParamsTag records may or may not be present, depending on the content of the GeoKeyDirectoryTag record.

**GeoKeyDirectoryTag Record (mandatory)** - User ID: LASF_Projection, Record ID: 34735. This record contains the key values that define the coordinate system.

**GeoDoubleParamsTag Record (Optional)** - User ID: LASF_Projection, Record ID: 34736. This record is simply an array of doubles that contain values referenced by tag sets in the GeoKeyDirectoryTag record.

**GeoAsciiParamsTag Record (Optional)** - User ID: LASF_Projection, Record ID: 34737. This record is simply an array of ASCII data. It contains many strings separated by null terminator characters which are referenced by position from data in the GeoKeyDirectoryTag record.

| LAS Header Checklist | | |
|---|---|---|
| | | |
| **Section: Point Data Record** | | **Date: 10MAR2014** |
| **Item** | **Included (Y/N)** | **Comments** |
| Point record format 1,3,4, or 5 | Y | |
| X, Y, Z | Y | |
| Intensity | Y | |
| Edge of Flight Line | Y | |
| Scan Direction Flag | Y | |
| Return Number | Y | |
| Number of Returns (given pulse) | Y | |
| Classification | Y | 1, 2, 7, 8, 9, 10 and 12 |
| Scan Angle Rank (-90 to +90) | Y | - 23 and 26 |
| Point Source ID | Y | |
| GPS Time | Y | GPS week time |

Required Point Data Record Definitions:

**X, Y, and Z** – The X, Y, and Z values are stored as long integers. The X, Y, and Z values are used in conjunction with the scale values and the offset values to determine the coordinate for each point as described in the Public Header Block section.

**Intensity** – The integer representation of the pulse return magnitude

**Edge of Flight Line** – The Edge of Flight Line data bit has a value of 1 only when the point is at the end of a scan. It is the last point on a given scan line before it changes direction.

**Scan Direction Flag** – denotes the direction at which the scanner mirror was traveling at the time of the output pulse. A bit value of 1 is a positive scan direction, and a bit value of 0 is a negative scan direction (where positive scan direction is a scan moving from the left side of the in-track direction to the right side and negative the opposite).

**Return Number** – The Return Number is the pulse return number for a given output pulse. A given output laser pulse can have many returns, and they must be marked in sequence of return. The first return will have a Return Number of one, the second a Return Number of two, and so on up to five returns.

**Number of Returns (for this emitted pulse)** – The Number of Returns is the total number of returns for a given pulse. For example, a laser data point may be return two (Return Number) within a total number of five returns.

**Scan Angle Rank** – The Scan Angle Rank is a signed one-byte number with a valid range from -90 to +90. The Scan Angle Rank is the angle (rounded to the nearest integer in the absolute value sense) at which the laser point was output from the laser system including the roll of the aircraft. The scan angle is within 1 degree of accuracy from +90 to –90 degrees. The scan angle is an angle based on 0 degrees being nadir, and –90 degrees to the left side of the aircraft in the direction of flight.

**Point Source ID** – This value indicates the file from which this point originated. Valid values for this field are 1 to 65,535 inclusive with zero being used for a special case discussed below. The numerical value corresponds to the File Source ID from which this point originated. Zero is reserved as a convenience to system implementers. A Point Source ID of zero implies that this point originated in this file. This implies that processing software should set the Point Source ID equal to the File Source ID of the file containing this point at some time during processing.

**GPS Time** – The GPS Time is the double floating point time tag value at which the point was acquired. It is GPS Week Time if the Global Encoding low bit is clear and POSIX Time if the Global Encoding low bit is set (see Global Encoding in the Public Header Block description).

**Classification** – Standard set of ASPRS classifications

| Classification Value | Definition |
|---|---|
| 0 | Created, Never Classified |
| 1 | Unclassified |
| 2 | Ground |
| 3 | Low Vegetation |
| 4 | Medium Vegetation |
| 5 | High Vegetation |
| 6 | Building |
| 7 | Low Point (noise) |
| 8 | Model Key-point (mass point) |
| 9 | Water |
| 10 | Ignored Ground (breakline proximity) |
| 11 | Withheld if Withheld bit is not implemented in processing software |
| 12 | Overlap (Should not be included) |
| 13-31 | Reserved for ASPRS Definition |

LAS File Review

**********

Friday February 21,2014 03:48 PM----->LAS Header Review

LAS Directory: D:\FEMA\FEMA_REGION_5\Racine_WI\LAS\classified\Classified_LAS

Total Files Reviewed: 452

**********

LAS Version: 1.2

Horizontal Datum: NAD83(HARN)

Projection: UTM zone 16N

XY (Horizontal) Units: Linear Meter

Vertical Datum: NAVD88 - Geoid09 (Feet)

Z Units: Vertical Foot US Survey

**!!!Use of the ASPRS/LAS Overlap classification (Class=12) is prohibited (USGS LiDAR Spec p.6)!!!**

*** Since this project was originally planned through** Southeast Wisconsin Regional Planning Commission (SEWRPC) on behalf of Racine County Class 12 is acceptable

**********

LAS Header Errors

| LAS File | Error | Resolution |
|---|---|---|
| 03914735.las | 3 returns required per pulse | Tile is less than 1500m x 1500m with a low point count (59)…occurs at the edge of project area |
| 04354725.las | 3 returns required per pulse | Tile is less than 1500m x 1500m with a low point count (10885)…occurs at the edge of project area |
| 04354740.las | 3 returns required per pulse | Tile is less than 1500m x 1500m with a low point count (260)…occurs at the edge of project area |
| 04364728.las | 3 returns required per pulse | Tile is less than 1500m x 1500m with a low point count (30097)…occurs at the edge of project area |
| 04364729.las | 3 returns required per pulse | Tile is less than 1500m x 1500m with a low point count (103873)…occurs at the edge of project area |
| 04364731.las | 3 returns required per pulse | Tile is less than 1500m x 1500m with a low point count (103873)…occurs at the edge of project area |
| 04364738.las | 3 returns required per pulse | Tile is less than 1500m x 1500m with a low point count (3782)…occurs at the edge of project area |
| 04384737.las | 3 returns required per pulse | Tile is less than 1500m x 1500m with a low point count (1254)…occurs at the edge of project area |

STARR

# FEMA Region V
# Racine County, Wisconsin
# LiDAR Dataset

Classified LiDAR Micro Review

Quality Assurance Forms
3/10/2014

| Classified Point Cloud Data Visual Checklist | | Project: Racine County, Wisconsin |
|---|---|---|
| **Vendor: Quantum Spatial (Aerometric)** | | **Reviewed By: JLH** |
| **LAS File: 03944719.las** | | **Date: 10MAR2014** |
| **Item** | **P/F/NA** | **Comments** |
| Scan lines removed from bare earth | P | |
| Excessive Noise in bare earth | P | |
| Elevation Steps | P | |
| Gaps/Voids | P | |
| Edge matching between tiles | P | |
| Artifacts have been removed from bare earth (vegetation, buildings, bridges, etc.) | P | |
| Proper definition of roads and drainage patterns | P | |
| "Over-smoothed" areas during filtering | P | |
| Corn Row Effects | P | |
| Mounds and Divots | P | |
| Other anomalies | NA | |

PASS

| Classified Point Cloud Data Visual Checklist | | Project: Racine County, Wisconsin |
|---|---|---|
| **Vendor: Quantum Spatial (Aerometric)** | | **Reviewed By: JLH** |
| **LAS File: 03944723.las** | | **Date: 10MAR2014** |
| **Item** | **P/F/NA** | **Comments** |
| Scan lines removed from bare earth | P | |
| Excessive Noise in bare earth | P | |
| Elevation Steps | P | |
| Gaps/Voids | P | |
| Edge matching between tiles | P | |
| Artifacts have been removed from bare earth (vegetation, buildings, bridges, etc.) | P | |
| Proper definition of roads and drainage patterns | P | |
| "Over-smoothed" areas during filtering | P | |
| Corn Row Effects | P | |
| Mounds and Divots | P | |
| Other anomalies | NA | |

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| Corn Row Effects | P | |
| Mounds and Divots | P | |
| Other anomalies | NA | |

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| Corn Row Effects | P | |
| Mounds and Divots | P | |
| Other anomalies | NA | |

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| Other anomalies | NA | |

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| Other anomalies | NA | |

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| Other anomalies | NA | |

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| Other anomalies | NA | |

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| Proper definition of roads and drainage patterns | P | |
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| Corn Row Effects | P | |
| Mounds and Divots | P | |
| Other anomalies | NA | |

PASS

| Classified Point Cloud Data Visual Checklist | | Project: Racine County, Wisconsin |
|---|---|---|
| **Vendor: Quantum Spatial (Aerometric)** | | **Reviewed By: JLH** |
| **LAS File: 03944719.las** | | **Date: 10MAR2014** |
| **Item** | **P/F/NA** | **Comments** |
| Scanlines removed from bare earth | P | |
| Excessive Noise in bare earth | P | |
| Elevation Steps | P | |
| Gaps/Voids | P | |
| Edge matching between tiles | P | |
| Artifacts have been removed from bare earth (vegetation, buildings, bridges, etc.) | P | |
| Proper definition of roads and drainage patterns | P | |
| "Over-smoothed" areas during filtering | P | |
| Corn Row Effects | P | |
| Mounds and Divots | P | |
| Other anomalies | NA | |

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| Corn Row Effects | P | |
| Mounds and Divots | P | |
| Other anomalies | NA | |

PASS

| FEMA Final Deliverable Checklist | | Project: Racine County, Wisconsin | Date:10MAR2014 |
|---|---|---|---|
| Guidance: FEMA PM61 and G&S Appendix M 2011 | | Reviewed By: James L. Huffines | |
| | | | |
| Section: FEMA DCS Compliance | | | |
| **Item** | **P/F/NA** | **Comments** | |
| Folder Structure | P | | |
| **Correspondence** | NA | | |
| **General** | | | |
| Metadata (txt and xml) | P | | |
| Correct naming convention (12345C_Terrain_metadata) | P | | |
| Correct title and case number | P | | |
| Purpose clearly describes floodplain mapping intention | P | | |
| Bounding Coordinates match LAS tile index | P | | |
| Place Keyword matches metadata naming convention | P | | |
| Logical Consistency describes the LAS classifications | P | | |
| All items listed in lineage are included in deliverable | P | | |
| Process step matches the LAS classifications | P | | |
| Projection information is correct | P | | |
| Distribution information is correct | P | | |
| Contact information is correct | P | | |
| Project Narrative | | | |
| Purpose clearly describes floodplain mapping intention | P | | |
| Text describes the LAS classifications | P | | |
| Text includes spatial reference | P | | |
| Text includes vertical accuracy test results | P | | |
| Text includes scope of work | P | | |
| Text includes MIP location | P | | |
| LiDAR Compliance Form | P | | |
| Survey Compliance Form | NA | Included with LiDAR Compliance | |
| **Supplemental Data** | | | |
| Survey Data and Vertical Accuracy Test Results | P | | |
| LiDAR Collection Area | P | | |
| QA Report and supporting documentation | P | | |
| Pre and Post Flight Reports and supporting data | P | Pre flight report not part of the scope of work | |
| LiDAR Project Tile Index | | | |
| All tiles listed in tile index are accounted for and have correct names | P | | |
| Index does not have gaps or overlapping tiles | P | | |
| Spatial reference is correct | P | | |

| FEMA Final Deliverable Checklist | | Project: Racine County, Wisconsin | Date:10MAR2014 |
|---|---|---|---|
| Guidance: FEMA PM61 and G&S Appendix M 2011 | | Reviewed By: James L. Huffines | |
| | | | |
| Section: FEMA DCS Compliance Continued | | | |
| **Item** | **P/F/NA** | **Comments** | |
| Folder Structure | P | | |
| **Source** | P | | |
| Raw Point Cloud Data | P | | |
| All tiles are present and accounted for | P | | |
| Include tile index with all tiles included with correct names | P | | |
| Index does not have gaps or overlapping tiles | P | | |
| Spatial reference is correct | P | | |
| **Final** | | | |
| Breaklines | P | | |
| File is complete and covers project area | P | | |
| Spatial reference is correct | P | | |
| Classified Point Cloud Data | P | | |
| All tiles are present and accounted for | P | | |
| Include tile index with all tiles included with correct names | P | | |
| Index does not have gaps or overlapping tiles | P | | |
| Spatial reference is correct | P | | |
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