Federal Emergency Management Agency

Ozaukee County, Wisconsin

Technical Support Data Notebook

Terrain Project Narrative

Elevation Data Acquisition

CID 55089C

CASE NO. 11-05-22245
CONTRACT NO. HSFEHQ-09-D-0370
TASK ORDER NO. HSFEHQ-10-J-0005

Date April 15, 2011

Prepared By:

STARR
Strategic Alliance for Risk Reduction

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1. Introduction

Beginning in Fiscal Year 2010, FEMA initiated a five-year program for Risk Mapping, Assessment, and Planning (Risk MAP). The vision for Risk MAP is to deliver quality data that increases public awareness and leads to action that reduces risk to life and property. In order to realize the Risk MAP vision FEMA is acquiring high resolution terrain elevation and land cover elevation data to increase production efficiencies for NFIP regulatory products and support risk assessment data development. FEMA has made a commitment through Risk MAP to work closely with NDEP (National Digital Elevation Program) partners to obtain and support the collection of terrain data throughout the United States.

Terrain data, collected under the Risk MAP program, will be required to meet minimum specifications outlined in the *Draft Procedure Memorandum No. 61—Standards for LiDAR and Other High Quality Digital Topography dated August 1st, 2010*[1]. FEMA also requires all deliverables for topographic data collection be submitted in accordance with *Appendix M: Data Capture Standards March 2009*[2]. All relevant project materials have been reviewed to insure that these requirements are met.

The objectives for the elevation data acquisition project in Ozaukee County Wisconsin are as follows:

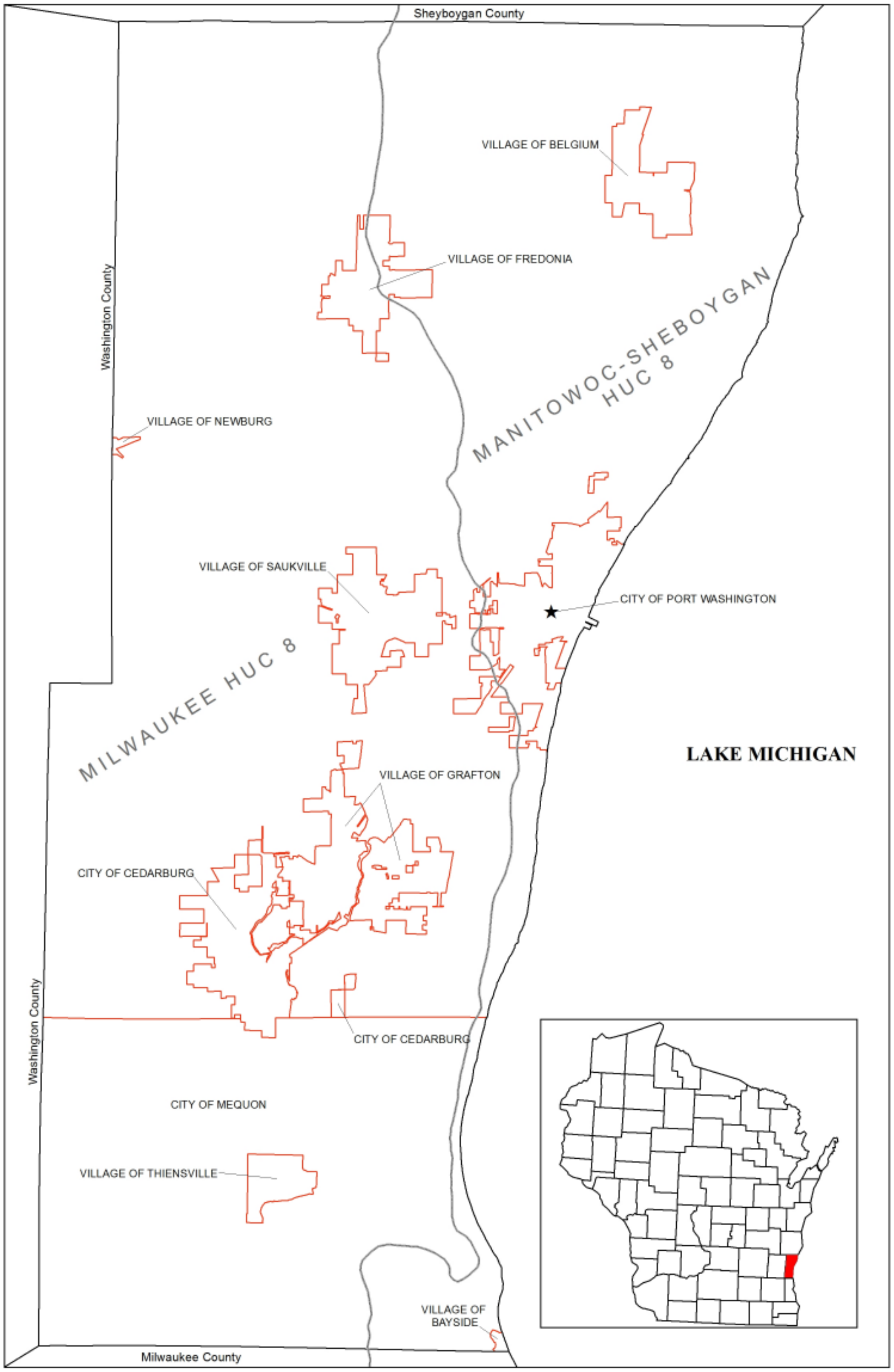
1. LAS point cloud files collected for 248 square miles
2. LAS point cloud files captured using the “Highest” vertical accuracy requirements
3. LAS point cloud files collected at equivalent of a 2-foot contour accuracy
4. LAS point cloud files collected using a nominal pulse spacing of 1-meter
5. LAS classified as Bare Earth processed for 111 square miles

Table 1 Vertical Accuracy Requirements

Contour Accuracy	Specification Level	$RMSE_z$	FVA	CVA
2ft	Highest	18.5 cm	24.5 cm	36.3 cm

Ozaukee County is located along Lake Michigan in the state of Wisconsin. It is bordered by Sheboygan County to the north, Milwaukee County to the south, Waukesha County to the southwest, Washington County to the west, and Lake Michigan to the east. The project area has 10 NFIP participating communities. Ozaukee County is located within the Milwaukee and Manitowoc-Sheboygan HUC8 watersheds.

Figure 1 Project Location



2. Scope of Work

Statement of Priorities
PTS Elevation Data Acquisition
STARR – Contract # HSFEHQ-09-D-0370

The contractor shall acquire elevation data to support flood hazard data updates based on the minimum requirements shown of the attached ordering sheet. Elevation data shall comply with the draft FEMA Procedure Memorandum: Standards for LiDAR and Other High Quality Elevation Data.

The contractor shall respond with pricing for the minimum elevation collections and bare earth processing specified the attached ordering sheet. The contractor's proposal shall identify any breakline creation or other post-processing that is required to use the elevation data for the flood hazard data updates based on the risk, terrain type, anticipated engineering methods and other relevant factors. The proposal must explain the reasons this additional processing is needed.

The contractor will also be responsible for performing QA of the elevation data as specified in the Standards for LiDAR and Other High Quality Elevation Data procedure memo.

The contractor shall also propose collection and processing alternatives that group the collections into larger, more cost effective collection blocks or other collection and processing alternatives that may be more advantageous for the government as an alternative option.

Scope Details:

LiDAR acquisition of Ozaukee, consisting of 248 square miles, captured to the "Highest" vertical accuracy requirement. This collection specification is the equivalent of a 2-foot contour accuracy and will be collected with a nominal pulse spacing of 1-meter. Post processing is required for 111 square miles.

3. Issues

A. Special Problem Reports

None

B. Project Modifications

At the time the contract was awarded the collection area for post processing had not been determined. Working closely with FEMA region 5, STARR aided in determining the areas to be post processed. These decisions were made based upon population and known flood risks.

4. Information for the Next Mapping Partner

The Ozaukee LiDAR collection AOI consists of one area encompassing the entire county. This project included both LiDAR point cloud development and Bare Earth post processing. Point Cloud LiDAR data for this project is partially classified LAS 1.2 binary file format. The Bare Earth LiDAR for this project has been classified using ASPRS LiDAR classifications. Bare Earth classified as class 2 is considered to be Bare Earth and points classified as class 8 are Model Key. All data for this project has been collected using the following spatial reference information:

Projection: Universal Transverse Mercator
UTM Zone: 16
Linear units: meter
Horizontal Datum: North American Datum 1983
Vertical Datum: North American Vertical Datum of 1988
Vertical units: feet

LAS point files are named according to the UTM Coordinates at the southwest corner of the tile, following the zz_0xxxyyy convention, where z is the UTM zone number, x and y are the UTM coordinates.

Table 2 LAS file information

Product	# Tiles	Total File Size	Point Count	Avg. Point Spacing
Point Cloud	222	42 GB	1,615,640,442	0.81 m
Bare Earth	121	18 GB	697,078,263	0.73 m

Details about the storage of this dataset can be found within Appendix F of this document.

Ground control and quality control checkpoints were collected by CompassData, Inc. AeroMetric, Inc. performed LiDAR acquisition flights and automated processing under contract to Tuck Mapping, Inc. Bare Earth manual edits were performed by Tuck Mapping, Inc. Independent QC of the point cloud and bare earth surface was performed by CompassData, Inc. Quality Assurance testing was conducted by Greenhorne & O'Mara, Inc. All firms were under contract to STARR, A Joint Venture which held the FEMA Professional Technical Services contract and task order for this work. All contact information for the project team can be found in Appendix A of this document.

A. Ground Control Survey

Ground Control is collected throughout the AOI for use in the processing of LiDAR data to ensure data accurately represents the ground surface. QA/QC checkpoints, also collected throughout the AOI, are used for independent quality checks of the processed LiDAR data.

GPS –based surveys were utilized to support both processing and testing of designated FEMA Areas of Interest LiDAR data collection.
Geographically distinct ground points were surveyed using GPS technology throughout the AOIs included in the 2010 Region 5 FEMA LiDAR Tasking to provide support for three distinct tasks.

Task 1 was to provide Vertical Ground Control to support the aerial Vendors tasked with collecting LiDAR point clouds and subsequent bare earth models for the AOIs within Region 5. To accomplish this, CompassData used survey-grade Trimble R-8 GPS receivers to collect a series of control points located on open areas, free of excessive or significant slope, and at least 5 meters away from any significant terrain break. Most if not all control points were collected at street/road intersections on bare level pavement.

Task 2 was to collect Fundamental Vertical Accuracy checkpoints to evaluate the initial quality of the collected point cloud and to ensure that the collected data was satisfactory for further processing to meet FEMA specifications. For all intents and purposes, the FVA points were collected in identical fashion to the Vertical Ground Control Points, but segregated from the point pool to ensure independent quality testing without prior knowledge of FVA locations by the aerial vendors.

Task 3 was to collect Consolidated Vertical Accuracy checkpoints to allow vertical testing of the bare-earth processed LiDAR data in different classes of land cover, including:

Open – pavement, open dirt, short grass
High Grass and Crops
Brush and Low Trees
Forest
Urban

CVA points were collected in similar fashion as Control and FVA points with emphasis on establishing point locations within the predominant land cover classes within each AOI or Functional AOI Group. In order to successfully collect the Forest land cover class, it was necessary to establish a Backsight and Initial Point with the R8 receiver, and then employ a Nikon Total Station to observe a retroreflective prism stationed under tree canopy. This was necessary due to the reduced GPS performance and degradation of signal under tree canopy.

The R-8 receivers were equipped with cellular modems to receive real-time correction signals from the WisCORS Precision Virtual Reference Station network encompassing the Region 5 Ozaukee County Area of Interest. Use of the VRS network allowed rapid collection times (~3 minutes/point) at 2.54 cm (1 inch) initial accuracy. VRS network operations allow similar or better accuracies as compared to radio-based RTK operations with the added advantage of covering a much broader geographic area.

All points collected were below the 8cm specification for testing 24cm highest category LiDAR data. To ensure valid in-field collections, an NGS monument with suitable vertical reporting was measured using the same equipment and procedures used for Control, FVA and CVA points on a daily basis. The CompassData measurement was compared to the NGS published values to ensure that the GPS collection schema was producing valid data and as a physical proof point of quality of collection. Those monument measurements are summarized in the Accuracy report provided in the Data Deliverables provided to FEMA.

In order to meet FEMA requirements, FVA and CVA points were collected according to specification; 20 FVA points and 15 additional CVA points were collected in a well-distributed fashion across the County to allow testing to CE95 – 1 point out of 20 may fail vertical testing and still allow the entire dataset to meet 95% accuracy requirements.

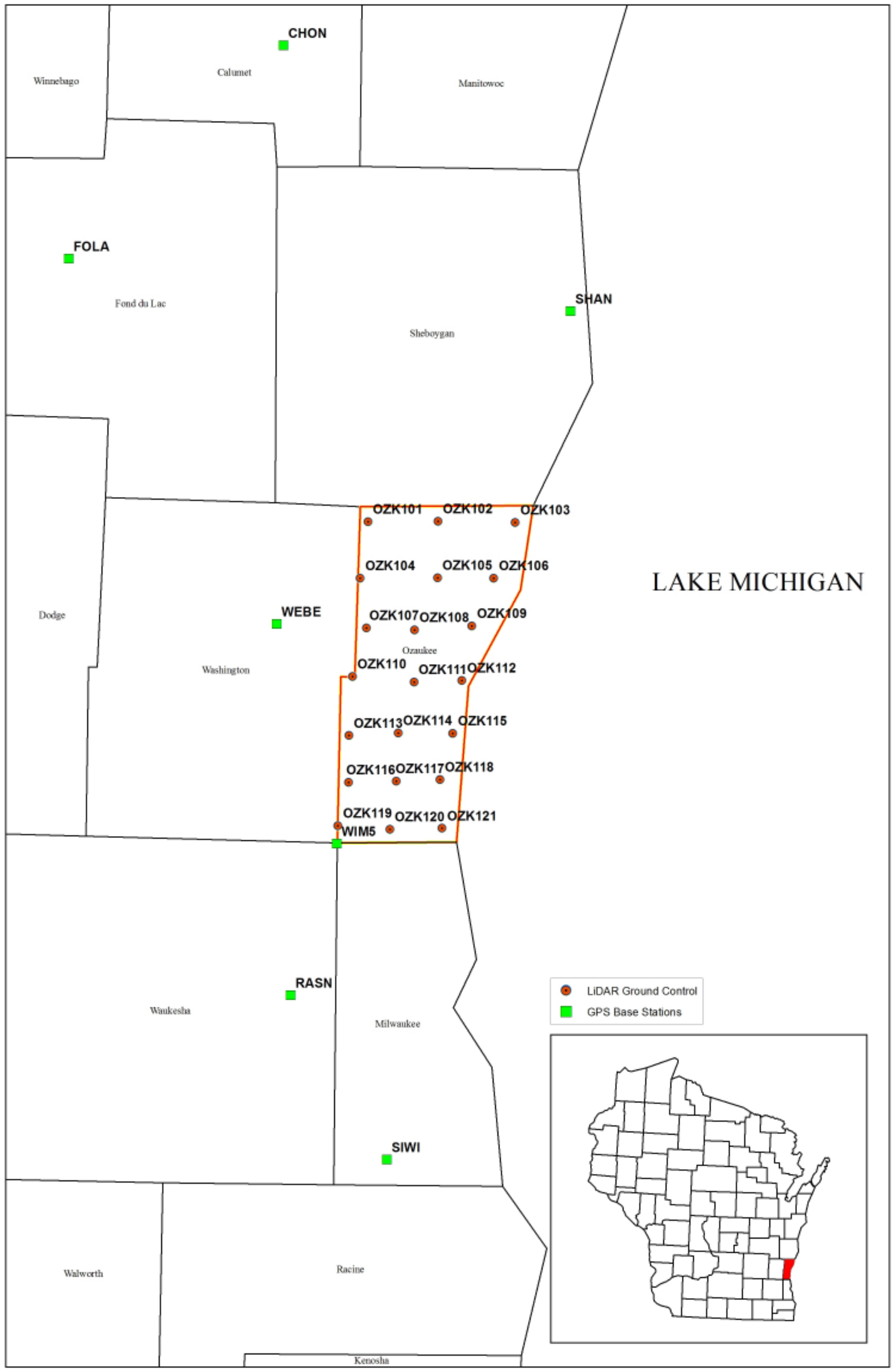
The 15 CVA points and 5 of the FVA points were collected within a FEMA-provided boundary for CVA testing within a restricted geographical area with the intention at the outset that the 5 FVA points would perform double –duty as Open-class CVA points, to total 20 CVAs for the Ozaukee AOI.

The following software packages and utilities were used to control the GPS receiver in the field during data collection, and then ingest and export the collected GPS data for all points:

Trimble Survey Controller
Trimble Pathfinder Office

The following software utilities were used to translate the collected Latitude/Longitude Decimal Degree HAE GPS data for all points into Latitude/Longitude Degrees/Minutes/Seconds for checking the collected monument data against the published NGS Datasheet Lat/Long DMS values and into UTM NAD83 Northings/Eastings: U.S. Army Corps of Engineers CorpsCon, National Geodetic Survey Geoid09NAVD88. MSL values were determined using the most recent NGS-approved geoid model to generate geoid separation values for each Lat/Long coordinate pair. In this fashion, Orthometric heights were determined for each Control, FVA and CVA point by subtracting the generated Geoid Separation value from the Ellipsoidal Height (HAE) for publication and use as MSL NAVD88(09).

Figure 2 Ground Control Survey Coverage



C. Data Acquisition

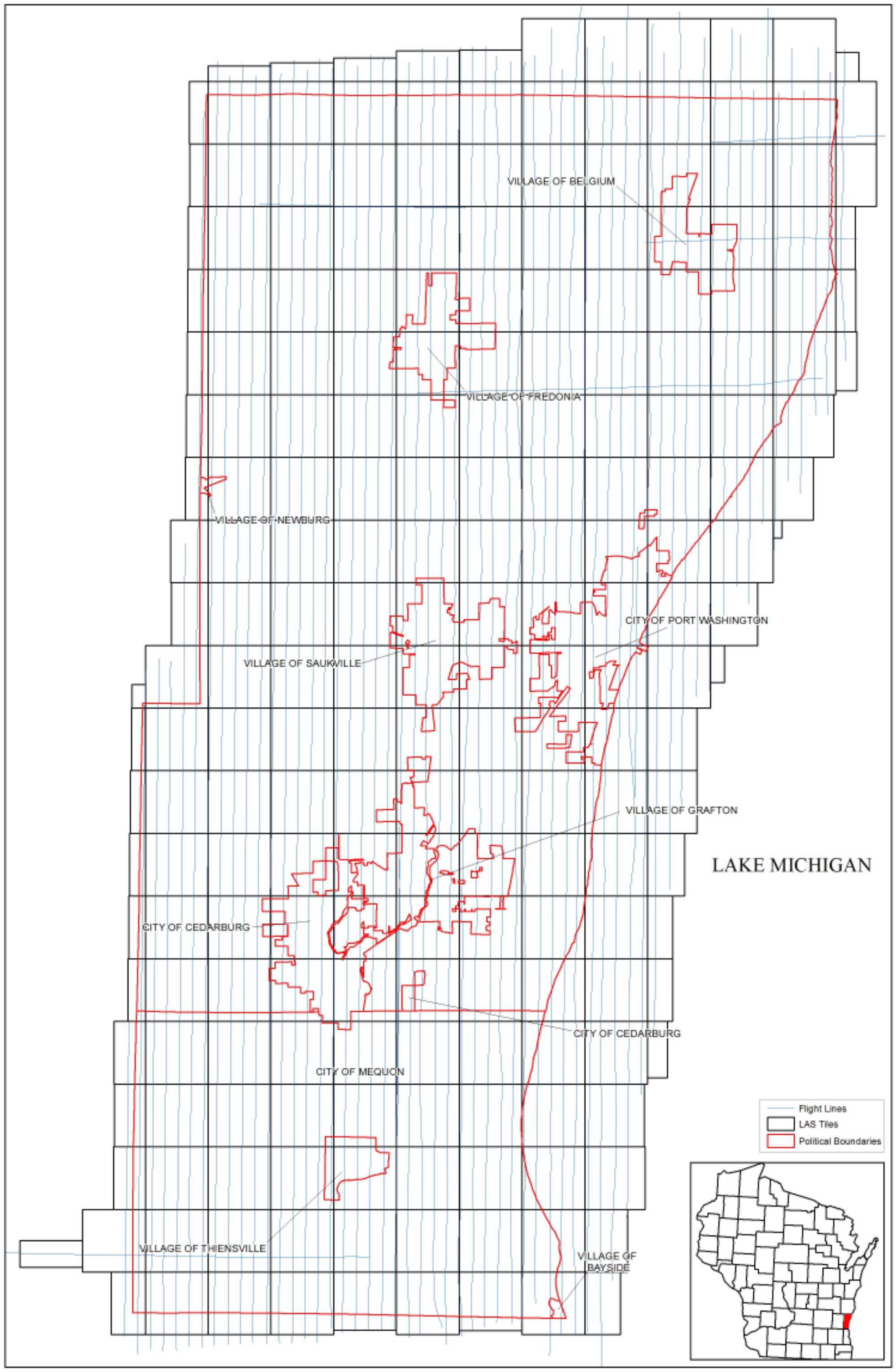
Using an Optech Gemini LiDAR system, 56 flight lines of highest density (Nominal Pulse Spacing of 1.0m) were collected over the Ozaukee area. A total of five missions were flown: November 11, 2010, November 15, 2010, 2 on November 16, 2010, November 23, 2010. Seven airborne global positioning system (GPS) base stations were used to support the LiDAR data acquisition: WIM5, SHAN, CHON, FOLA, WEBE, RASN, SIWI. Coordinates are available in the Post-Flight Aerial Acquisition Report.

Raw airborne GPS and IMU data were extracted from Applanix CARD. The GPS data was differentially processed in PosGPS and integrated with the IMU data in PosPAC. The GPS/IMU data is processed in Applanix to derive a smoothed best estimate of trajectory (SBET).The SBET was used to reduce the LiDAR slant range measurements to derive the Return measurement for each LiDAR pulse for all LiDAR pulses within for each flight line. The coverage was imported into TerraScan and tiled into 1500m x 1500m tiles.

An initial accuracy assessment is done using the ground point survey data. The data then is classified to extract a bare earth digital elevation model (DEM). Once all project data was imported and classified, the survey ground control data was imported again and calculated against teh LAS Class 2 (Ground) data for an accuracy assessment.

As a QC measure, a routine was used to generate accuracy statistical reports by comparison among LiDAR points, ground control, and triangulated irregular networks (TIN). Any systematic bias in the data is removed to meet or exceed the vertical accuracy requirements.

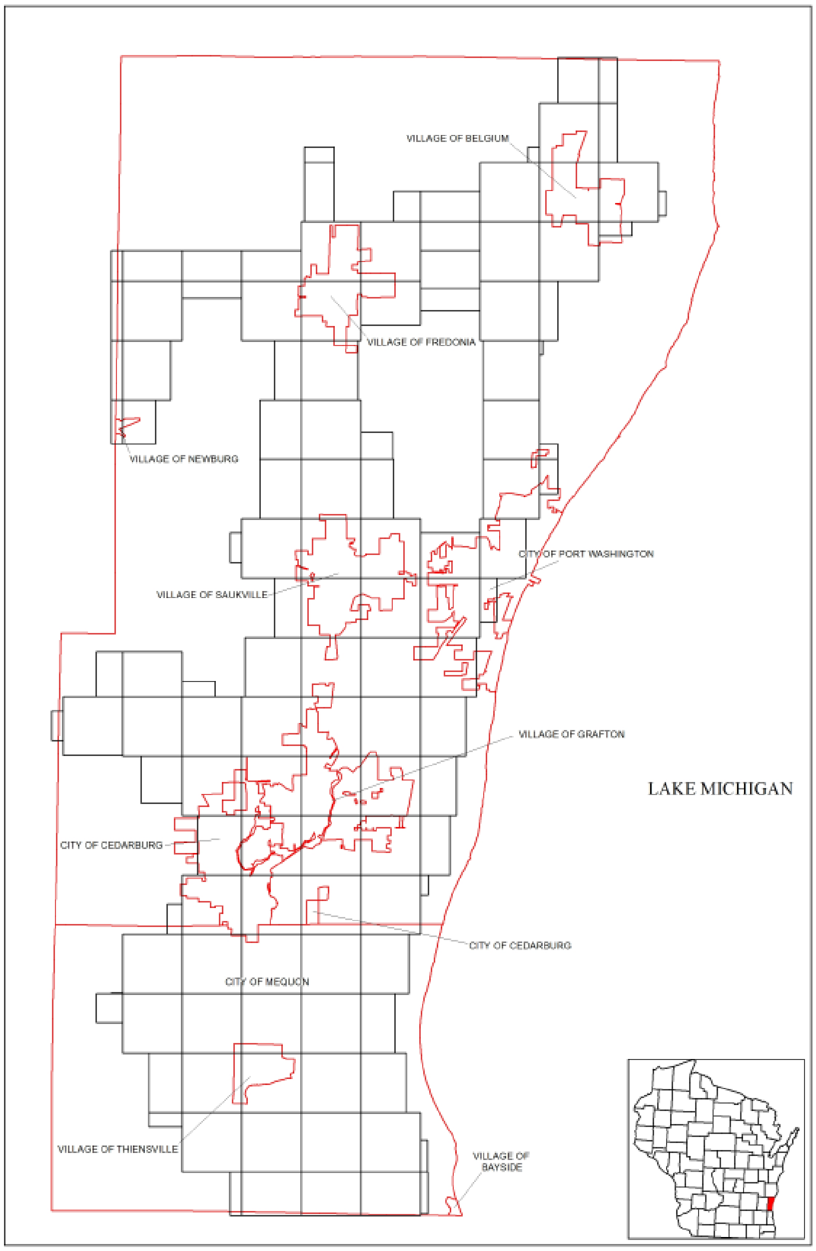
Figure 3 Point Cloud Collection Area



D. Post Processing

The calibrated and filtered LiDAR point cloud was hand checked for accuracy. All points were placed in one of the following categories: 1 Unclassified, 2 Ground, 7 Noise, and 12 Overlap Points. Model Key points were then generated from the Ground points and placed in Category 8. Requested elevation values were then provided to CompassData for their evaluation of the Consolidated Vertical Accuracy (CVA).

Figure 4 Post Processing Area



E. Quality Control

Fundamental Vertical Accuracy (FVA) checkpoints are located only in open terrain, where there is a high probability that the sensor will have detected the ground surface without influence from surrounding vegetation and/or buildings. Checkpoints are located on flat or uniformly sloping terrain and at least five (5) meters away from an break line where there is a change in slope. Checkpoints are located randomly across the acquisition area. At least 20 FVA points were collected for each test.

Consolidated Vertical Accuracy (CVA) checkpoints are collected randomly across different land use types using the ASPRS NSSDA land cover types. The points are located in flat areas with no substantial elevation breaks within a five meter radius. The CVA assessment incorporates a representative sample of the FVA assessment points into the dataset to save on the total number of points collected. CVA points were not collected for any land class comprising less that 10% of the total project area; this may have resulted in less than 4 land classes being collected in a particular area. At least 15 CVA points were collected and 5 FVA points used, for a total of at least 20 points for the CVA testing.

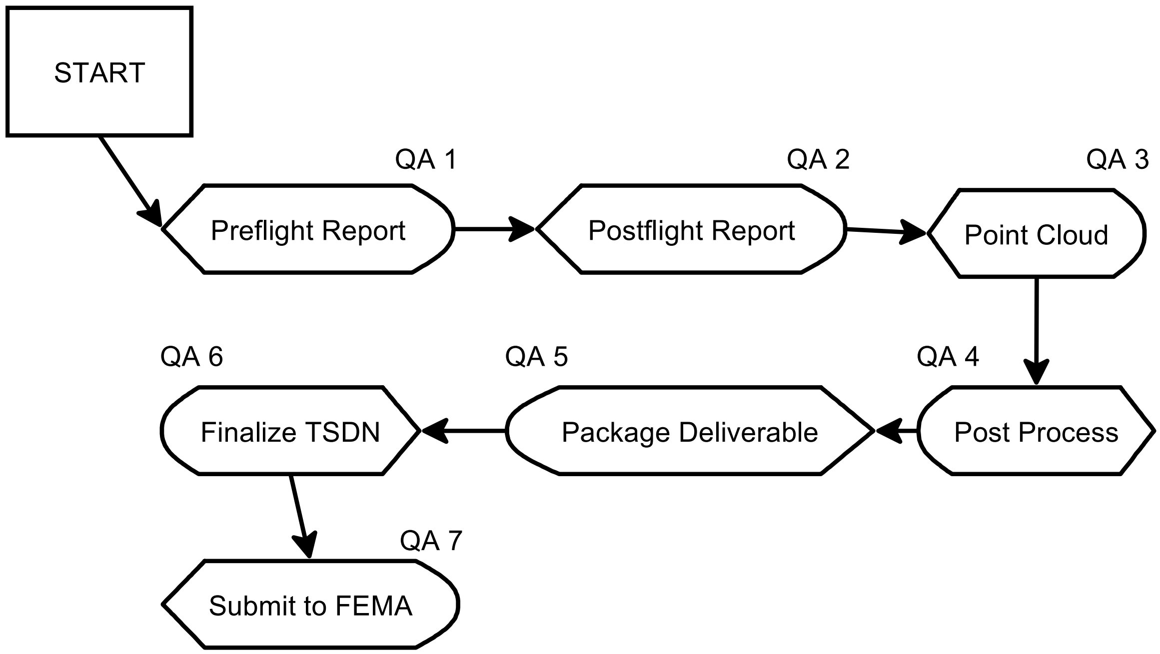
All checkpoints were collected by CompassData to ensure the 'independence' of the quality control check. All points were collected at three times the accuracy of the surface being checked. Thus to check a 24.5cm surface the points were collected accurate to 8cm.

Tests were conducted when processing by the LiDAR vendor was complete and points were called for. CompassData provided the point coordinates in an excel spreadsheet to the LiDAR vendor. Tthe LiDAR vendor found the corresponding elevation from a surface created from the LiDAR points, filled in the spreadsheet and returned it to CompassData. CompassData compared the elevation of the LiDAR data with that of the accuracy check point, calculated the difference and reported their findings both in terms of $RMSE_z$ and at the 95% confidence level (computed as $RMSE_z$ x 1.9600). LiDAR datasets passing the quality control checks were delivered to STARR for quality assurance approval.

F. Quality Assurance

Quality assurance for all elevation data collected for this project has been completed using *FEMA Draft PM61*[1], *FEMA Appendix M*[2], *USGS LiDAR Guidelines and Base Specifications v13*[3], and *FEMA Appendix A*[4] as guidance. Products generated during this project are checked for conformance to the aforementioned guidance and specifications before submittal to FEMA.

Figure 5 Quality Assurance Workflow



QA1: Preflight Planning and Reporting

Project preflight operations planning were delivered as a report. This report was reviewed for completeness based on: *Table 4.1 and checklists provided in section 4.2.1in PM61*[1]. The report was reviewed and is compliant with FEMA guidance and specifications. This report is included within Appendix C of this document. Appendix G contains information about the location of report data on the MIP.

QA2: Post flight Report

Post flight reporting for this project has been reviewed for both content and completeness based upon: *Table 4.2 and checklists provided in section 4.2.1in PM61*[1]. The report is included with Appendix E of this document. The report is complete and all content meets the guidance and specifications.

QA3: Raw Point Cloud Review

Fully calibrated raw point cloud data has been reviewed at both a macro and micro level using *Table 4.3 and checklists provided in section 4.2.1in PM61*[1], and USGS *LiDAR Guidelines and Base Specifications v13*[3]. 5% of the total number of project tiles was reviewed for compliance with USGS and FEMA specifications. All tiles reviewed for this project passed both the macro and micro reviews. Quality assurance results for the point cloud are contained within Appendix F of this document.

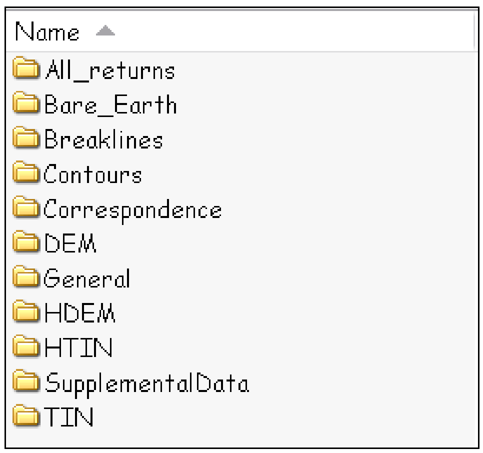
QA4: Bare Earth Review

Post-processed data has been reviewed at both a macro and micro level using *Table 4.4 and checklists provided in section 4.2.1in PM61*[1], and USGS *LiDAR Guidelines and Base Specifications v13*[3]. 10% of the total number of project tiles was reviewed for compliance with USGS and FEMA specifications. All tiles reviewed for this project passed both the macro and micro reviews. Quality assurance results for the bare earth are contained within Appendix F of this document.

QA5: Create Delivery Package

All deliverables have been organized in accordance with *Appendix M: Data Capture Standards March 2009 Section M.4.2.8*[2].

Figure 6 Terrain Deliverable Directory Structure



QA6: Finalization of Deliverables and TSDN

All data to be submitted for delivery has been reviewed for completeness based on the map activity statement, scope of work, and FEMA deliverable requirements. Quality assurance checklists are included in Appendix F of this document.

QA7: FEMA submission

All data for the elevation data acquisition task was delivered to FEMA on April 15, 2011. A transmittal of this submission is included in Appendix G of this document.

5. References

1. Draft Procedure Memorandum 61 included in Appendix H
2. FEMA Appendix M section M.4 included in Appendix H
3. USGS LiDAR Guidelines and Base Specifications v13 included in Appendix H
4. Appendix A: Guidance for Aerial Mapping and Surveying [includes guidance on Light Detection and Ranging Systems (LIDAR)] http://www.fema.gov/library/viewRecord.do?id=2206

Appendix A: Contact Information

STARR Contacts:

Project Management and Quality Assurance

Company	Greenhorne & O'Mara, Inc.
Name	Diane Rogers
Email	drogers@g-and-o.com
Phone	301-982-2800
Mailing Address	5565 Centerview Drive, Suite 107 Raleigh, NC 27606

LiDAR data acquisition

Company	Aerometric, Inc.
Name	Robert Merry
Email	rmerry@aerometric.com
Phone	920-457-3631
Mailing Address	4020 Technology Parkway Sheboygan, WI 53081

LiDAR ground control and QC survey

Company	Compass Data, Inc.
Name	Hayden Howard
Email	haydenh@compassdatainc.com
Phone	303-627-4058
Mailing Address	12353 East Easter Avenue, Suite 200 Centennial, CO 80112

LiDAR Post Processing

Company	Tuck Mapping Solutions, Inc.
Name	Steven Jones
Email	sjones@tuckmapping.com
Phone	276-523-4669
Mailing Address	1928 Wildcat Road, P.O. Box 760 Big Stone Gap, VA 24219

Appendix B: FEMA Compliance Form and Metadata

Project Name:	Ozaukee County, Wisconsin
Statement of Work No.:	Contract HSFEHQ-09-D-0370, Task Order HSFEHQ-10-J-0005
Interagency Agreement No.:	N/A
CTP Agreement No.:	N/A
Statement/Agreement Date:	30 Sep 2010
Certification Date:	24 Feb 2011

	Tasks/Activities Covered by This Certification (Check All That Apply)
☐	Base Map
☒	Topographic Data Development
☐	Survey
☐	Hydrologic Analysis
☐	Hydraulic Analysis
☐	Alluvial Fan Analysis
☐	Coastal Analysis
☐	Floodplain Mapping
	This is to certify that the work summarized above was completed in accordance with the statement/agreement cited above and all amendments thereto, together with all such modifications, either written or oral, as the Regional Project Officer and/or Assistance Officer or their representative have directed, as such modifications affect the statement/agreement, and that all such work has been accomplished in accordance with the provisions contained in *Guidelines and Specifications for Flood Hazard Mapping Partners* cited in the contract document, and in accordance with sound and accepted engineering practices within the contract provisions for respective phases of the work. This is also to certify that data files submitted for the work summarized above are complete and final. Any revisions made to the already submitted data are included in the final submittal.

Name:	Robert H. Tuck, PE, PLS, CP
Title:	President
Firm/Agency Represented:	Tuck Mapping Solutions, Inc.
Registration No.:	CP# 907
Signature:	Robert H. Tuck

This form must be signed by a representative of the firm or agency contracted to perform the work, who must be a registered or certified professional in the area of work performed, in compliance with Federal and State regulations.

Project Name:	**Region 5: Ozaukee County, Wisconsin – Elevation Data Acquisition**
Statement of Work No.:	FEMA TASK ORDER NUMBER: HSFEHQ-10-J-0005 WORK ORDER NUMBER: CP HQ 10 001
Interagency Agreement No.:	STARR PROJECT NUMBER: 400000058 STARR PARTNER TRACKING NUMBER: CP HQ 10 001
CTP Agreement No.:	N/A
Statement/Agreement Date:	10/ 10/10
Certification Date:	5/16/11

	Tasks/Activities Covered by This Certification (Check All That Apply)
☐	Base Map
☐	Topographic Data Development
X	Survey: Including Ground Control Points (GCPs), Fundamental Vertical Accuracy Testing (FVA), and Consolidated Vertical Accuracy Testing (CVA).
☐	Hydrologic Analysis
☐	Hydraulic Analysis
☐	Alluvial Fan Analysis
☐	Coastal Analysis
☐	Floodplain Mapping

This is to certify that the work summarized above was completed in accordance with the statement/agreement cited above and all amendments thereto, together with all such modifications, either written or oral, as the Regional Project Officer and/or Assistance Officer or their representative have directed, as such modifications affect the statement/agreement, and that all such work has been accomplished in accordance with the provisions contained in *Guidelines and Specifications for Flood Hazard Mapping Partners* cited in the contract document, and in accordance with sound and accepted engineering practices within the contract provisions for respective phases of the work. This is also to certify that data files submitted for the work summarized above are complete and final. Any revisions made to the already submitted data are included in the final submittal.

Name:	Philipp H. Hummel, PLS
Title:	Professional Land Surveyor, Geodesist
Firm Represented:	Compass Data, Inc.
Registration No.:	38155
Signature:	Philipp Hummel

COLORADO LICENSED PHILIPP H. HUMMEL 38155 PROFESSIONAL LAND SURVEYOR

April 16, 2011

For and on behalf of Compass Data, Inc.
Job. No.: 1520

This form must be signed by a representative of the firm or agency contracted to perform the work, who must be a registered or certified professional in the area of work performed, in compliance with Federal and State regulations.

Metadata

Identification_Information:
  Citation:
    Citation_Information:
      Originator: Federal Emergency Management Agency
      Publication_Date: 20110131
      Title: TERRAIN, Ozaukee, Wisconsin
      Geospatial_Data_Presentation_Form: FEMA-DCS-Terrain
      Publication_Information:
        Publication_Place: Washington, DC
        Publisher: Federal Emergency Management Agency
      Online_Linkage: http://hazards.fema.gov
      Larger_Work_Citation:
        Citation_Information:
          Originator: Federal Emergency Management Agency
          Publication_Date: 20110131
        Title: FEMA CASE 11-05-2224S
  Description:
    Abstract: The Ozaukee AOI consists of one area encompassing the entire county. Ground Control is collected throughout the AOI for use in the processing of LiDAR data to ensure data accurately represents the ground surface. QA/QC checkpoints, (FVA and CVA - see Ground Control process step for further information) also collected throughout the AOI, are used for independent quality checks of the processed LiDAR data.
LiDAR acquisition products include Pre- and Post- flight reports which contain information on the flightlines, equipment parameters, and other pertinant acquisition details. The LiDAR Point Cloud product consists of tiles of LAS points which are partially classified such that the bare earth points can be calibrated to the ground surface and tested via the independent QC to ensure the ground surface is accurately represented.
The LiDAR processing product consists of LAS points which are fully classified with the bare earth points tested via the independent QC to ensure the ground surface is accurately represented.
    Purpose: Provide high resolution terrain elevation and land cover elevation data. Terrain data is used to represent the topography of a watershed and/or floodplain environment and to extract useful information for hydraulic and hydrologic models.

  Time_Period_of_Content:
    Time_Period_Information:
      Single_Date/Time:
        Calendar_Date: 20110131
    Currentness_Reference: ground condition
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    Progress: Complete

Maintenance_and_Update_Frequency: Unknown
Spatial_Domain:
Bounding_Coordinates:
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East_Bounding_Coordinate: -87.787129
North_Bounding_Coordinate: 43.547961
South_Bounding_Coordinate: 43.190498
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Theme_Keyword: elevation
Theme:
Theme_Keyword_Thesaurus: FEMA NFIP Topic Category
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Theme_Keyword: Topography
Theme_Keyword: Digital Terrain Model
Theme_Keyword: Elevation Data
Theme_Keyword: LIDAR
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Theme_Keyword: All Returns
Theme_Keyword: Bare Earth
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Place_Keyword: COMMUNITY MEQUON, CITY OF
Place_Keyword: FEMA-CID 555564

Access_Constraints: None

Use_Constraints: Acknowledgement of FEMA would be appreciated in products derived from these data. This digital data is produced for the purposes of updating/creating a DFIRM database.

Data_Set_Credit: Ground control and quality control checkpoints were collected by CompassData, Inc. AeroMetric, Inc. performed LiDAR acquisition flights and automated processing under contract to Tuck Mapping, Inc. Bare Earth manual edits were performed by Tuck Mapping, Inc. Independent QC of the bare earth surface was performed by CompassData, Inc. Quality Assurance testing was conducted by Greenhorne & O'Mara, Inc. All firms were under contract to STARR, A Joint Venture which held the FEMA contract and task order for this work.

Data_Quality_Information:

Logical_Consistency_Report: Survey data have been confirmed to be in proper units, coordinate systems and format. The terrain data have been confirmed as complete LAS format data files. Header files are in proper LAS format with content as specified by FEMA Procedural Memo No. 61.

Completeness_Report: Survey data have been checked for completeness, points have been collected in correct vegetation units, and distributed throughout the AOI. The terrain data have been checked for completeness against AOI polygons. No gaps as defined by FEMA Procedural Memo No. 61 are known to exist within the dataset.

Positional_Accuracy:

Vertical_Positional_Accuracy:

Vertical_Positional_Accuracy_Report: Deliverables were tested by for both vertical and horizontal accuracy. The vertical unit of the data file is in meters with 2-decimal point precision.

Quantitative_Vertical_Positional_Accuracy_Assessment:

Vertical_Positional_Accuracy_Value: 0.223

Vertical_Positional_Accuracy_Explanation: Consolidated Vertical Accuracy (CVA) equal to the 95th Percentile confidence level (RMSE[z] x 1.9600) calculated against the bare earth surface in all ground cover classes. Reported in meters.

Lineage:

Source_Information:

Source_Citation:

Citation_Information:

Originator: STARR

Publication_Date: 2011

Title: GroundControl

Type_of_Source_Media: DIGITAL

Source_Time_Period_of_Content:

Time_Period_Information:

Single_Date/Time:

Calendar_Date: 20110131

Source_Currentness_Reference: ground condition

Source_Citation_Abbreviation: Other1

Source_Contribution: Control points for tying LiDAR data to the ground surface.
Source_Information:
Source_Citation:
Citation_Information:
Originator: STARR
Publication_Date: 2011
Title: FVA_CVA
Type_of_Source_Media: DIGITAL
Source_Time_Period_of_Content:
Time_Period_Information:
Single_Date/Time:
Calendar_Date: 20110131
Source_Currentness_Reference: ground condition
Source_Citation_Abbreviation: Other2
Source_Contribution: Quality Assurance points to confirm LiDAR data meets vertical accuracy requirements.
Source_Information:
Source_Citation:
Citation_Information:
Originator: STARR
Publication_Date: 2011
Title: Ozaukee_Collection_Area
Type_of_Source_Media: DIGITAL
Source_Time_Period_of_Content:
Time_Period_Information:
Single_Date/Time:
Calendar_Date: 20110131
Source_Currentness_Reference: publication date
Source_Citation_Abbreviation: Other3
Source_Contribution: Shapefile of Ozaukee LiDAR Acquisition Area.
Source_Information:
Source_Citation:
Citation_Information:
Originator: STARR
Publication_Date: 2011
Title: All_Returns
Type_of_Source_Media: DIGITAL
Source_Time_Period_of_Content:
Time_Period_Information:
Single_Date/Time:
Calendar_Date: 20110131
Source_Currentness_Reference: ground condition
Source_Citation_Abbreviation: Other4
Source_Contribution: Point Cloud (All Returns) LAS point files named according to the UTM Coordinates at the southwest corner of the tile, following the zz_0xxxyyy convention, where z is the UTM zone number, x and y are the UTM coordinates.

Source_Information:
Source_Citation:
Citation_Information:
Originator: STARR
Publication_Date: 2011
Title: PreFlightReport
Type_of_Source_Media: DIGITAL
Source_Time_Period_of_Content:
Time_Period_Information:
Single_Date/Time:
Calendar_Date: 20110131
Source_Currentness_Reference: ground condition
Source_Citation_Abbreviation: Other5
Source_Contribution: document contains the operation plans for the LiDAR acquisition.
Source_Information:
Source_Citation:
Citation_Information:
Originator: STARR
Publication_Date: 2011
Title: PostFlightReport
Type_of_Source_Media: DIGITAL
Source_Time_Period_of_Content:
Time_Period_Information:
Single_Date/Time:
Calendar_Date: 20110131
Source_Currentness_Reference: ground condition
Source_Citation_Abbreviation: Other6
Source_Contribution: Document contains the acquisition and calibration report for the LiDAR acquisition.
Source_Information:
Source_Citation:
Citation_Information:
Originator: STARR
Publication_Date: 2011
Title: Ozaukee_Tile_Index
Type_of_Source_Media: DIGITAL
Source_Time_Period_of_Content:
Time_Period_Information:
Single_Date/Time:
Calendar_Date: 20110131
Source_Currentness_Reference: ground condition
Source_Citation_Abbreviation: Other7
Source_Contribution: shapefile of tile index used to populate and reference the LAS tiled data.
Source_Information:

Source_Citation:
Citation_Information:
Originator: STARR
Publication_Date: 2011
Title: Region 5 Ozaukee Testing Results FVA CVA
Type_of_Source_Media: DIGITAL
Source_Time_Period_of_Content:
Time_Period_Information:
Single_Date/Time:
Calendar_Date: 20110131
Source_Currentness_Reference: ground condition
Source_Citation_Abbreviation: Other8
Source_Contribution: document contains QC test results for both FVA CVA blind checkpoint tests against the bare earth surface generated from the bare earth LAS points.
Source_Information:
Source_Citation:
Citation_Information:
Originator: STARR
Publication_Date: 2011
Title: R5_Ozaukee_County_Terrain_TSDN
Type_of_Source_Media: DIGITAL
Source_Time_Period_of_Content:
Time_Period_Information:
Single_Date/Time:
Calendar_Date: 20110415
Source_Currentness_Reference: ground condition
Source_Citation_Abbreviation: Other9
Source_Contribution: Technical Support Data Notebook contains complete narrative on the acquisition and processing of the LiDAR dataset, including area diagram, reports, metadata and other supporting documentation.
Source_Information:
Source_Citation:
Citation_Information:
Originator: STARR
Publication_Date: 2011
Title: Bare_Earth
Type_of_Source_Media: DIGITAL
Source_Time_Period_of_Content:
Time_Period_Information:
Single_Date/Time:
Calendar_Date: 20110131
Source_Currentness_Reference: ground condition
Source_Citation_Abbreviation: Other10
Source_Contribution: bare earth LAS point file named according to the UTM coordinates at the southwest corner of tile.

Process_Step:
Process_Description: GPS based surveys were utilized to support both processing and testing of LiDAR data within FEMA designated Areas of Interest (AOIs). Geographically distinct ground points were surveyed using GPS technology throughout the AOIs to provide support for three distinct tasks.
Task 1 was to provide Vertical Ground Control to support the aerial acquisition and subsequent bare earth model processing. To accomplish this, survey-grade Trimble R-8 GPS receivers were used to collect a series of control points located on open areas, free of excessive or significant slope, and at least 5 meters away from any significant terrain break. Most if not all control points were collected at street/road intersections on bare level pavement.
Task 2 was to collect Fundamental Vertical Accuracy (FVA) checkpoints to evaluate the initial quality of the collected point cloud and to ensure that the collected data was satisfactory for further processing to meet FEMA specifications. The FVA points were collected in identical fashion to the Vertical Ground Control Points, but segregated from the point pool to ensure independent quality testing without prior knowledge of FVA locations by the aerial vendors.
Task 3 was to collect Consolidated Vertical Accuracy CVA) checkpoints to allow vertical testing of the bare-earth processed LiDAR data in different classes of land cover, including: Open (pavement, open dirt, short grass), High Grass and Crops, Brush and Low Trees, Forest, Urban. CVA points were collected in similar fashion as Control and FVA points with emphasis on establishing point locations within the predominant land cover classes within each AOI or Functional AOI Group. In order to successfully collect the Forest land cover class, it was necessary to establish a Backsight and Initial Point with the R8 receiver, and then employ a Nikon Total Station to observe a retroreflective prism stationed under tree canopy. This was necessary due to the reduced GPS performance and degradation of signal under tree canopy.
The R-8 receivers were equipped with cellular modems to receive real-time correction signals from the Keystone Precision Virtual Reference Station (VRS) network encompassing the Region 1 AOIs. Use of the VRS network allowed rapid collection times (~3 minutes/point) at 2.54 cm (1 inch) initial accuracy.
All points collected were below the 8cm specification for testing 24cm, Highest category LiDAR data. To ensure valid in-field collections, an NGS monument with suitable vertical reporting was measured using the same equipment and procedures used for Control, FVA and CVA points on a daily basis. The measurement was compared to the NGS published values to ensure that the GPS collection schema was producing valid data and as a physical proof point of quality of collection. Those monument measurements are summarized in the Accuracy report included in the data delivered to FEMA.
20 FVA points and 15 additional CVA points across the group of AOIs were collected. 20 FVA points are necessary to allow testing to CE95 – 1 point out of 20 may fail vertical testing and still allow the entire dataset to meet 95% accuracy requirements.In similar fashion, 20 CVA points are necessary to test to CE95 as discussed above. 15 CVA points were collected with the intention at the outset that 5

of the collected FVAs would perform double–duty as Open-class CVA points, to total 20 CVAs per AOI.

The following software packages and utilities were used to control the GPS receiver in the field during data collection, and then ingest and export the collected GPS data for all points: Trimble Survey Controller, Trimble Pathfinder Office.

The following software utilities were used to translate the collected Latitude/Longitude Decimal Degree HAE GPS data for all points into Latitude/Longitude Degrees/Minutes/Seconds for checking the collected monument data against the published NGS Datasheet Lat/Long DMS values and into UTM NAD83 Northings/Eastings: U.S. Army Corps of Engineers CorpsCon, National Geodetic Survey Geoid09NAVD88.

MSL values were determined using the most recent NGS-approved geoid model to generate geoid separation values for each Lat/Long coordinate pair. In this fashion, Orthometric heights were determined for each Control, FVA and CVA point by subtracting the generated Geoid Separation value from the Ellipsoidal Height (HAE) for publication and use as MSL NAVD88(09).

Process_Date: 2010

Process_Step:

Process_Description: Using a Optech Gemini LiDAR system, 56 flight lines of highest density (Nominal Pulse Spacing of 1.0m) were collected over the Ozaukee area. A total of five missions were flown: November 11, 2010, November 15, 2010, 2 on November 16, 2010, November 23, 2010. Seven airborne global positioning system (GPS) base stations were used to support the LiDAR data acquisition: WIM5, SHAN, CHON, FOLA, WEBE, RASN, SIWI. Coordinates are available in the Post-Flight Aerial Acquisition Report.

Process_Date: 2010

Process_Step:

Process_Description:Raw airborne GPS and IMU data were extracted from Applanix CARD. The GPS data was differentially processed in PosGPS and integrated with the IMU data in PosPAC. The GPS/IMU data is processed in Applanix to derive a smoothed best estimate of trajectory (SBET).The SBET was used to reduce the LiDAR slant range measurements to derive the Return measurement for each LiDAR pulse for all LiDAR pulses within for each flight line. The coverage was imported into TerraScan and tiled into 1500m x 1500m tiles. An initial accuracy assessment is done using the ground point survey data. The data then is classified to extract a bare earth digital elevation model (DEM). Once all project data was imported and classified, the survey ground control data was imported again and calculated against teh LAS Class 2 (Ground) data for an accuracy assessment. As a QC measure, a routine was used to generate accuracy statistical reports by comparison among LiDAR points, ground control, and triangulated irregular networks (TIN). Any systematic bias in the data is removed to meet or exceed the vertical accuracy requirements.

Process_Date: 2011

Process_Step:

Process_Description: The calibrated and filtered LiDAR point cloud was hand checked for accuracy. All points were placed in one of the following categories: 1

Unclassified, 2 Ground, 7 Noise, and 12 Overlap Points. Model Key points were then generated from the Ground points and placed in Category 8. Requested elevation values to were then provided to CompassData for their evaluation of the Consolidated Vertical Accuracy (CVA).

Process_Date: 2011

Spatial_Reference_Information:
Horizontal_Coordinate_System_Definition:
Planar:
Grid_Coordinate_System:
Grid_Coordinate_System_Name: Universal Transverse Mercator
Universal_Transverse_Mercator:
UTM_Zone_Number: 16
Transverse_Mercator:
Scale_Factor_at_Central_Meridian: 0.999600
Longitude_of_Central_Meridian: -87.000000
Latitude_of_Projection_Origin: 0.000000
False_Easting: 500000.000000
False_Northing: 0.000000
Planar_Coordinate_Information:
Planar_Coordinate_Encoding_Method: coordinate pair
Coordinate_Representation:
Abscissa_Resolution: 0.000010
Ordinate_Resolution: 0.000010
Planar_Distance_Units: meters
Geodetic_Model:
Horizontal_Datum_Name: North American Datum 1983
Ellipsoid_Name: Geodetic Reference System 80
Semi-major_Axis: 6378137.00
Denominator_of_Flattening_Ratio: 298.257222
Vertical_Coordinate_System_Definition:
Altitude_System_Definition:
Altitude_Datum_Name: North American Vertical Datum of 1988
Altitude_Resolution: 0.01
Altitude_Distance_Units: feet
Altitude_Encoding_Method: Attribute Values

Entity_and_Attribute_Information:
Detailed_Description:
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Entity_Type_Label: Terrain\2143493\SuplementalData\GroundControl
Entity_Type_Definition: Ground Control Survey for LiDAR collection
Entity_Type_Definition_Source: FEMA Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix M: Data Capture Standards and Data Capture Guidelines (available at http://www.fema.gov/fhm/dl_cgs.shtm)
Detailed_Description:

Entity_Type:
Entity_Type_Label: Terrain\2143493\SupplementalData\FVA_CVA
Entity_Type_Definition: Survey for Horizontal and Vertical LiDAR QC
Entity_Type_Definition_Source: FEMA Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix M: Data Capture Standards and Data Capture Guidelines (available at http://www.fema.gov/fhm/dl_cgs.shtm)
Detailed_Description:
Entity_Type:
Entity_Type_Label: Terrrain\2143494\Ozaukee_Collection_Area
Entity_Type_Definition: Area Spatial File
Entity_Type_Definition_Source: FEMA Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix M: Data Capture Standards and Data Capture Guidelines (available at http://www.fema.gov/fhm/dl_cgs.shtm)
Detailed_Description:
Entity_Type:
Entity_Type_Label: All_Returns
Entity_Type_Definition: LAS 1.3 files
Entity_Type_Definition_Source: FEMA Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix M: Data Capture Standards and Data Capture Guidelines (available at http://www.fema.gov/fhm/dl_cgs.shtm)
Detailed_Description:
Entity_Type:
Entity_Type_Label: Terrain\2143493\SupplementalData\PreFlightReport
Entity_Type_Definition: Digital Document
Entity_Type_Definition_Source: FEMA Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix M: Data Capture Standards and Data Capture Guidelines (available at http://www.fema.gov/fhm/dl_cgs.shtm)
Detailed_Description:
Entity_Type:
Entity_Type_Label: Terrain\2143494\SupplementalData\PostFlightReport
Entity_Type_Definition: Digital Document
Entity_Type_Definition_Source: FEMA Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix M: Data Capture Standards and Data Capture Guidelines (available at http://www.fema.gov/fhm/dl_cgs.shtm)
Detailed_Description:
Entity_Type:
Entity_Type_Label: Terrain\2143494\Ozau_Tile_Index
Entity_Type_Definition: Area Spatial File
Entity_Type_Definition_Source: FEMA Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix M: Data Capture Standards and Data Capture Guidelines (available at http://www.fema.gov/fhm/dl_cgs.shtm)
Detailed_Description:
Entity_Type:
Entity_Type_Label: Terrain\2143494\SupplementalData\Region 5 Ozaukee Testing Results FVA CVA
Entity_Type_Definition: Digital Document

Entity_Type_Definition_Source: FEMA Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix M: Data Capture Standards and Data Capture Guidelines (available at http://www.fema.gov/fhm/dl_cgs.shtm)
Detailed_Description:
Entity_Type:
Entity_Type_Label: Terrain\2143494\General\R5_Ozaukee_County_Terrain_TSDN
Entity_Type_Definition: Digital Document
Entity_Type_Definition_Source: FEMA Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix M: Data Capture Standards and Data Capture Guidelines (available at http://www.fema.gov/fhm/dl_cgs.shtm)
Detailed_Description:
Entity_Type:
Entity_Type_Label: Bare_Earth
Entity_Type_Definition: LAS 1.3 files
Entity_Type_Definition_Source: FEMA Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix M: Data Capture Standards and Data Capture Guidelines (available at http://www.fema.gov/fhm/dl_cgs.shtm)
Overview_Description:
Entity_and_Attribute_Overview: The Terrain data package is made up of several data themes containing primarily spatial information, and descriptive reports. These data combined create the elevation dataset.
Entity_and_Attribute_Detail_Citation: Appendix M of FEMA Guidelines and Specifications for FEMA Flood Hazard Mapping Partners contains a detailed description of the data themes and references to other relevant information.

Distribution_Information:
Distributor:
Contact_Information:
Contact_Organization_Primary:
Contact_Organization: Federal Emergency Management Agency
Contact_Address:
Address_Type: mailing address
Address: 500 C Street, S.W.
City: Washington
State_or_Province: District of Columbia
Postal_Code: 20472
Country: USA
Contact_Voice_Telephone: 1-877-336-2627
Contact_Electronic_Mail_Address: miphelp@mapmodteam.com

Distribution_Liability: No warranty expressed or implied is made by FEMA regarding the utility of the data on any other system nor shall the act of distribution constitute any such warranty.
Standard_Order_Process:
Digital_Form:

Digital_Transfer_Information:
Format_Name: FEMA-DCS-Terrain
Digital_Transfer_Option:
Online_Option:
Computer_Contact_Information:
Network_Address:
Network_Resource_Name: external hard drive
Fees: Contact Distributor

Metadata_Reference_Information:
Metadata_Date: 20110415
Metadata_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Person: FEMA Representative
Contact_Organization: Federal Emergency Management Agency
Contact_Address:
Address_Type: mailing address
Address: 500 C Street, S.W.
City: Washington
State_or_Province: District of Columbia
Postal_Code: 20472
Country: USA
Contact_Voice_Telephone: 1-877-336-2627
Contact_Electronic_Mail_Address: miphelp@mapmodteam.com
Metadata_Standard_Name: FGDC Content Standards for Digital Geospatial Metadata
Metadata_Standard_Version: FGDC-STD-001-1998
Metadata_Extensions:
Online_Linkage: http://hazards.fema.gov
Online_Linkage: http://www.epsg.org
Profile_Name: FEMA NFIP Metadata Content and Format Standard

Appendix C: Pre Flight Planning Report

Ozaukee & Rock, Wisconsin

Pre-Flight Operations Plan

November 2010

Introduction

The following is the pre-flight operations plan for the Wisconsin (FEMA Region 5) Rock and Ozaukee project areas. The report will cover GPS, control plans, airport locations and Aircraft used, calibration procedures as preformed by Aero-Metric, quality procedures, and procedures for tracking, executing and checking for re-flights. The planning of the project was based on the scope of work provided, FEMA Procedure Memorandum No. 61, and the USGS NGP V 13 specifications.

Airport Locations and Type of Aircraft Used

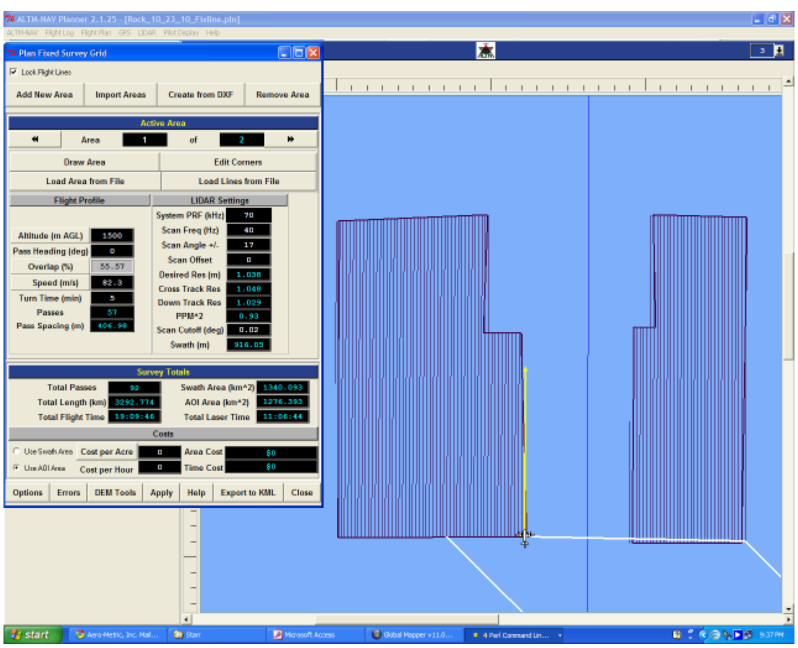
The airport locations for the Rock project area are Sheboygan County (KSBM), Monroe County (KEFT), Iowa County (KMRJ) and Southern Wisconsin Regional (KJVL) All airports should be suitable for base of operation and have suitable SAC\PAC GPS points. The exact location for base of operation will be determined based on the requirements of the aircraft selected for the collection. In addition, the airport hours of operation will be an important determining factor for planning the LiDAR collection.

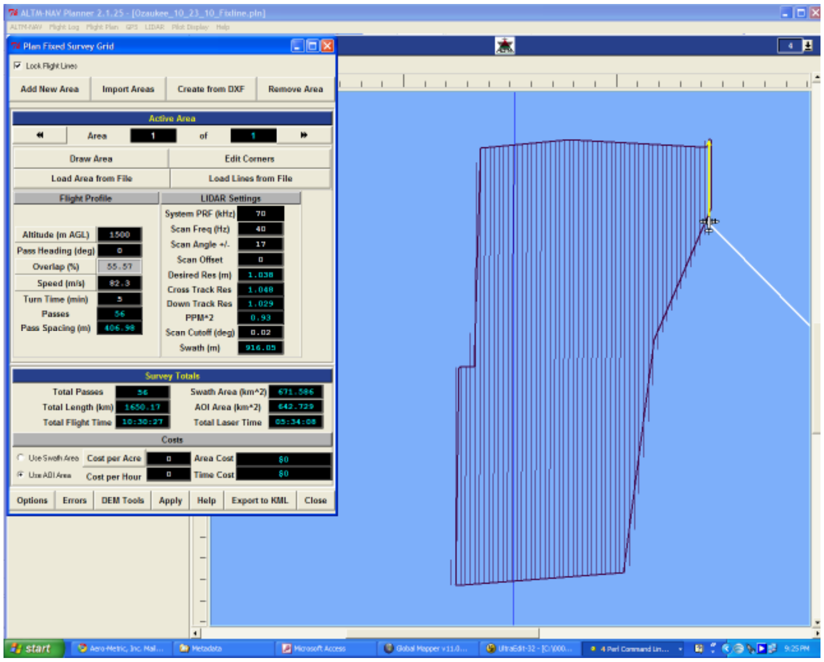
The Airport locations for the Ozaukee Project are Sheboygan County (KSBM), Dodge County (KUNU) Waskesha County (KUES) and Hartford Municipal (KHXF). All airports are suitable for base of operation but the best suitable airport will be selected prior to the collection based on the criteria stated above.

Aero-Metric has 4 LiDAR Aircraft used for LiDAR. The aircraft used by Aero-metric use for LiDAR are an Aztec, Navaho and Twin Commander 500s which are twin engine aircraft and a Cessna 210 which is a single engine aircraft. The tail numbers for these aircraft are N3443Q, N73TM, N280MB and N69WA, respectively.

Project Flight Plans

The following are the flight plans for the Rock and Ozaukee Project areas. The plans detail the LiDAR collection parameters and flight lines as represented in the ALTM_NAV software used during collection of the project areas. The first plan is the Rock area and the second is the Ozaukee Area





GPS Stations (base stations)

The GPS points provided below are suitable for selection as base station locations. Exact points for these collections are not detailed since the current recovery data provided may not be valid. Therefore the location of base stations will be assessed based on the reliability of the given point once on site. All points are suitable for GPS observations and will be provided to the field staff.

PID	LATITUDE	LONGITUDE	Horizontal	Vertical
		Ozaukee Area		
WEBE	43 25 13.9692	88 08 55.47243	WISCORS	WISCORS
RASN	43 02 10.93102	88 07 17.52878	WISCORS	WISCORS
SHAN	43 44 51.46198	87 44 05.22551	WISCORS	WISCORS
DI2110	43 11 37.96197	088 03 34.29790	A	
AF9585	43 00 09.120203	087 53 18.38602	A	H
AF9601	43 00 08.48301	087 53 17.55740	A	H
		Rock Area		
JALE	42 42 39.57468	089 01 45.2828	WISCORS	WISCORS
WATH	42 31 36.12582	088 35 36.3915	WISCORS	WISCORS
MOOE	42 37 09.51047	089 35 34.60902	WISCORS	WISCORS
DG4137	42 21 04.01601	087 03 28.85990	A	
DJ2701	42 16 22.66870	089 57 44.45806	B	

In the event that Aero-Metric has to establish a new point the information of the new point or points will be provided.

LiDAR System Calibration

As part of every LiDAR project, Aero-Metric performs system calibration upon sensor installation and at three month intervals in the event the LiDAR system remains in the aircraft. The system calibration is preformed to identify inconsistencies between the software corrections as they relate to the sensor hardware and its relationship to the GPS antenna location on the aircraft. Typically, a series of calibration lines (*figure 1*) are flown over a test range at verified attitudes to validate the calibration of the LiDAR sensor. The Aero-Metric team's main calibration sites include the following locations: Sheboygan County Airport in Sheboygan, Wisconsin, Boeing Field in Seattle, Washington and Merrill Field in Anchorage, Alaska.

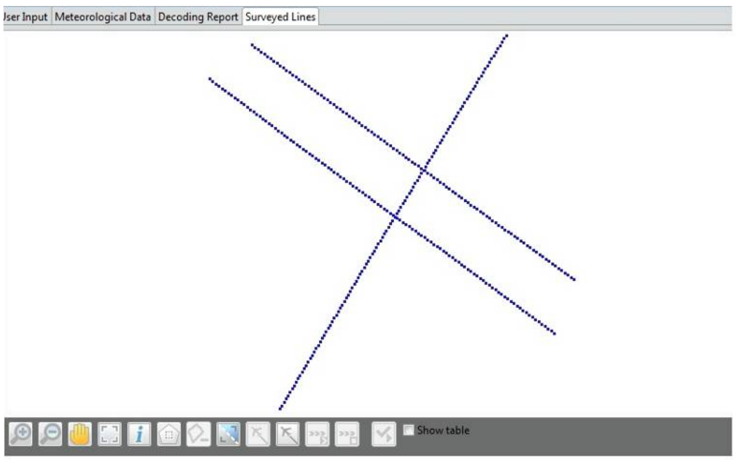


Figure 1: System LiDAR Calibration Configuration

The system calibration is preformed to validate and maintain the error budget associated with the Inertial Measurement Unit (IMU), mirror angle encoding, and pulse gate timing. In simple terms we correct the variations in roll, pitch, heading, scale scan factor and Z- bias as a result of the changes in the system information. The results of the calibration contribute to the tuning of the sensor prior to deployment of the LiDAR and aircraft to a project location.

Aero-Metric uses an innovative approach to calibration. The variables showing historic stability are held in the calibration process and variables such as roll are floated and redefined using the planar surfaces, or tie planes. The least squared adjustment is applied to the differences associated with the LiDAR data and the results are analyzed to provide consistence throughout the calibration and resulting data sets. In addition roof lines and roof surfaces are evaluated to further refine the calibration. The representation in Figure 2 depicts the tie planes of the calibration referenced above in figure 1.

Figure 2: Tie plane depiction of calibration

ALS-ID	scan-offset		scan-scale		scan-lag	
	value [deg]	std.dev. [deg]	value [-]	std.dev. [-]	value [deg]	std.dev. [deg]
SC1	-	-	0.000090	0.000018	0.000335	0.000056

ALS-ID	Ex-correction		Ey-correction		Ez-correction	
	value [deg]	std.dev. [deg]	value [deg]	std.dev. [deg]	value [deg]	std.dev. [deg]
SC1	0.002468	0.000331	-0.002754	0.000402	0.008868	0.003494

(c) GPS position corrections

GPS-ID	X-correction		Y-correction		Z-correction	
	value [m]	std.dev. [m]	value [m]	std.dev. [m]	value [m]	std.dev. [m]
PC1	0.000	0.0001	0.000	0.0001	0.019	0.0114
PC2	-0.000	0.0001	-0.000	0.0001	-0.050	0.0114
PC3	0.000	0.0001	0.000	0.0001	0.031	0.0114

Figure 3: example of calibration parameters

The statistics in figure 3 indicated and example of some of the corrections made in the system calibration. In addition to the historic calibrations corrections additional validation of the GPS information is preformed and evaluated to make sure that with a PDOP of 3 or better that the GPS data is usable and has integrity. The figure below (figure 4) indicates the correction of the tie planes.

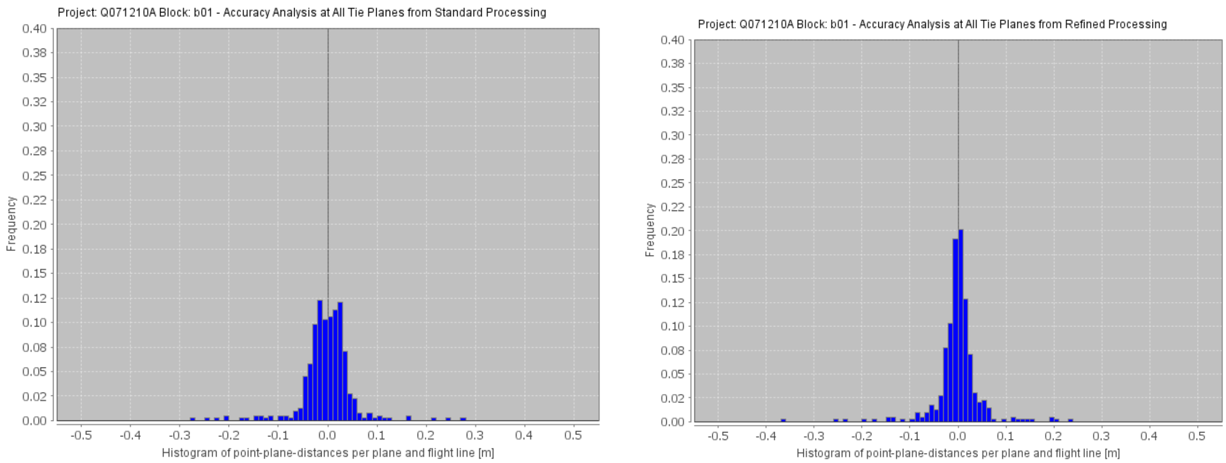


Figure 4: Tie planes before calibration correction and after calibration correction

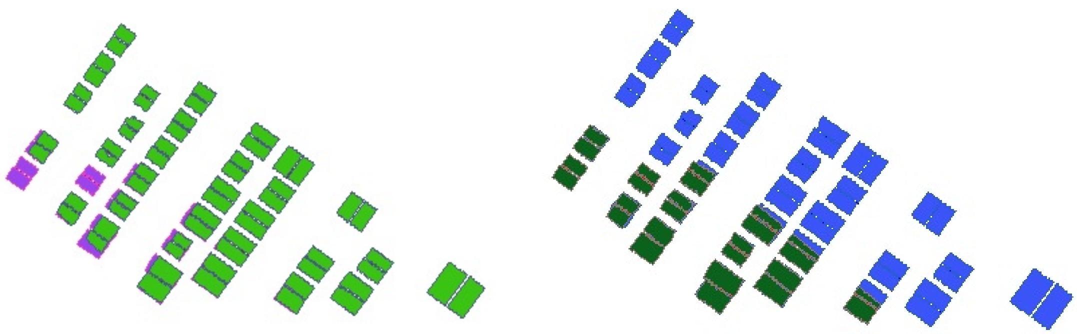


Figure 5: Roof lines prior to calibration correction and after calibration correction

The roof lines are analyzed and corrected in the calibration process as depicted in figure 5 above.

The Aero-Metric team currently has the most innovative and advanced calibration process in the industry. It is imperative that the calibration of the sensor is precise in all aspects of the complexity of the sensor. If the calibration of the system is not exact then the impact to the collection of the Wisconsin project will be significant. The Aero-Metric team understands the importance of calibration and takes major steps to insure the stability of all our sensors.

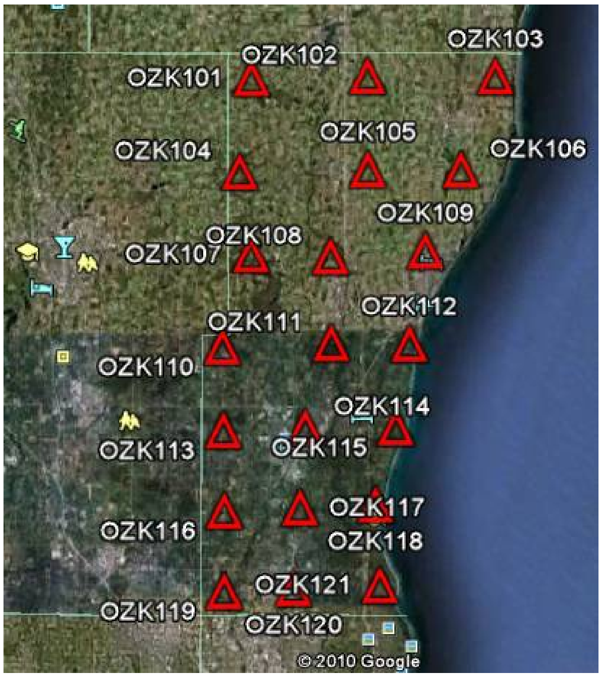
LiDAR In-Situ Data Calibration

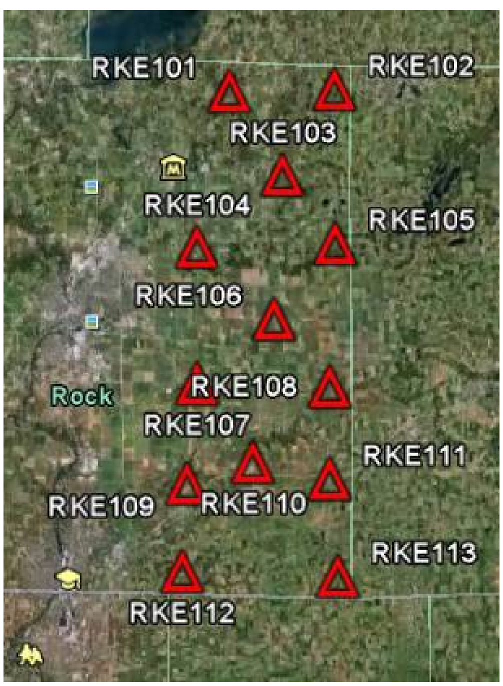
In addition to the system calibration, Aero-Metric performs project calibrations to further define the system parameters and improve the accuracies as they relate to the project location. During every mission a series of cross flight lines are flown perpendicular to the collection flight lines. This process enables the Aero-Metric's LiDAR group to check and analyze the flight line matching and if necessary apply a least squares adjustment to minimize or eliminate flight line differences which will improve the overall accuracy of the LiDAR data. The In-Situ calibration is as extensive as the system calibration and it is preformed on every mission as indicated. The following figure is a representation of an In-Situ calibration for a mission. The same configuration will be utilized on every mission during the collection of the Wisconsin LiDAR campaign.

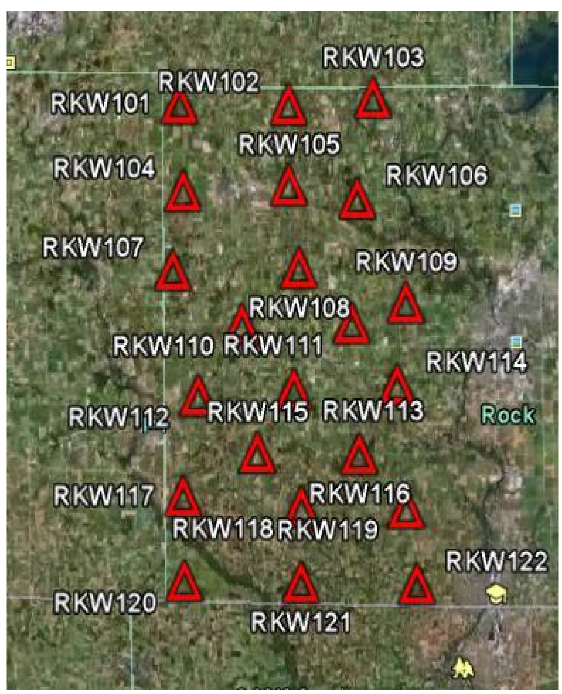
Figure 6: In-Situ Calibration

Planned Control

Aero-Metric has determined to 55 check points disturbed throughout the LiDAR project locations will be collected to verify the accuracy of the LiDAR collection per the FEMA guidelines and specifications for this project. The following are the control plans for the Wisconsin project. The first one is the Ozaukee area and the last two are the Rock East and Rock West Areas, respectively.







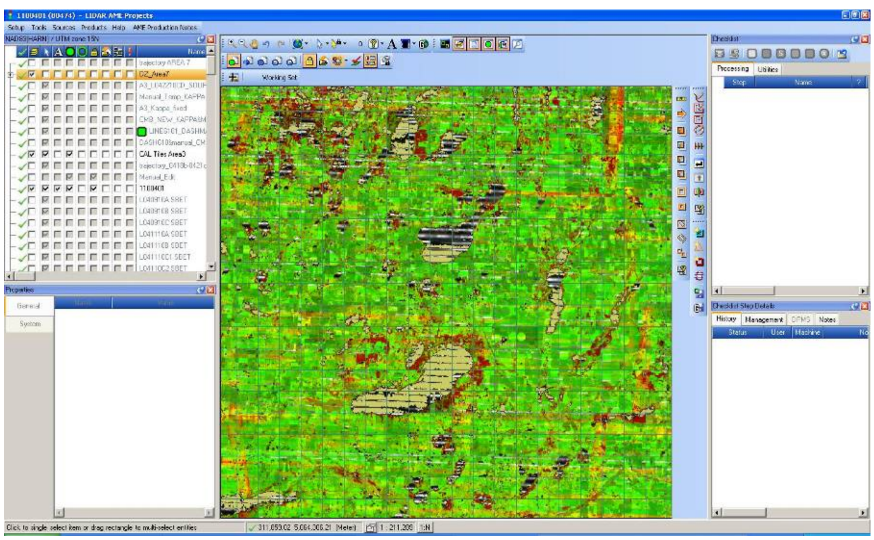
LiDAR QA/QC Procedures

As with all Aero-Metric production processes, extensive QA/QC testing will be applied to the data throughout the work flow. These tests will be designed in the project planning stage to ensure the efficacy of the critical processes necessary to meet final deliverable specifications. Any issues discovered by these QA/QC tests will be immediately addressed to ensure a satisfactory outcome and the generation of deliverables that will meet or exceed all project specifications.

Based on the tiling scheme agreed upon, each tile in the delivery will be examined for compliance with the established specifications. This testing will include, at a minimum, the following:

- Validate proper projection coordinate system and datum
- Verify interpolated elevations from DEM using field-derived blind QA point elevations
- Inspect LAS files for proper format
- Check for disjoints, overlap, or underlap
- Statistically sample files for compliance
- View TIN file and look for spikes
- Validate conformance with intended extent and naming convention
- Verify there is a smooth-edge match with adjacent tiles (slope and elevation)
- Confirm there are no voids in dataset

Aero-Metric employs a variety of methods to provide QA/QC for LiDAR projects. It is our policy to provide multiple QA/QC processes throughout the life of the project. The following are a representative sample of some of the QA/QC procedures used.



DZ ortho Validating Calibration of LiDAR data

Field QA/QC

Aero-Metric QA/QC procedures are designed with the intent that a project is complete the first time, without re-flights. Field QA/QC will consist of several steps to maintain accuracy of our mapping deliverables. When placed in a new platform, the LiDAR unit will be “surveyed in” to provide accurate offset information relating to the GPS and the LiDAR unit. Before starting a project, several test scans will be flown over a fixed object to verify calibration of the operating system. On the day of a survey flight, the flight time will be synchronized with GPS receivers on the ground to ensure a common observation “session.” Ground GPS receivers will be set up on the primary control monument at the local airport, which will be free of significant obstructions that may block GPS satellite signals. On-board information displayed on a laptop computer will provide information regarding navigation and overall operation of the LiDAR system, including real-time updates of scan coverage and ranging. Issues with the LiDAR system will be identified immediately while the plane is in flight. Aero-Metric will use multiple ground GPS base stations during a LiDAR survey, increasing redundancy in the data and decreasing the potential of an unrecoverable mishap in data collection. We will maintain a reasonably short distance from the ground GPS stations to the LiDAR system to ensure a fixed-integer solution at all times during the flight. It is our policy to acquire LiDAR only when there is a minimum of six NAVSTAR satellites visible with a positional dilution of precision (PDOP) value below four.

Office QA/QC

Data collected in the field will be processed in an Aero-Metric field office. Several methods will be used to verify the data captured in the field. For example, the instrument height and receiver/antennae combinations will be checked to verify the accuracy of each GPS setup. Field notes will be checked and verified in the office. During the processing phase, all data will be solved using least-squares, which will aid us in identifying and fixing problem data sets. Aero-Metric will confirm that all GPS vectors have achieved fixed-integer solutions. Using proprietary software, we will process the IMU data to verify and validate all roll, pitch, heading, trajectory, and offset measurements. After successful processing, the resulting data will then be independently compared against both the higher-order ground control survey and the precise photogrammetric survey. Further, a system of test patch areas scattered throughout the project, as well as kinematic GPS profiles along area roads to check the validity of the LiDAR data, will be used to validate the LiDAR data. These ground comparisons will be automated, giving statistics indicating the precision and accuracy of the LiDAR mapping. All steps and QA/QC results will be documented in a report.

Procedure for Tracking, Executing, and Checking for Re-flights

Checking Coverage

Aero-Metric plans all missions using a DEM to minimize the potential of gaps in the collection. The DEM is brought into the ALTM_planner software and potential gaps are identified by red. Once this is determined the flight altitude will be adjusted to eliminate the gap and maintain the required point density. The DEM is also used to plan the flights according to terrain and the flight parameters will be adjusted per flight line to account for terrain so we are still optimizing the NPS to meet the USGS NGS specifications required. Although, this usually eliminates the gaps certain flight conditions could exist that potentially cause a gap. The following is the process is used in the field to verify coverage and data usability. The ALTM_NAV software provides an output of the swath coverage and in addition the flight can be brought into Optech’s Zinview software if a potential gap is identified.

The GPS and IMU data will be processed to validate the data. This data is combined with the Laser Data and analyzed for usability. The swath data is saved and verified in the field. The data is transmitted to the office of operation on a regular basis and again verified in the office during collection.

Tracking and execution

The tracking of the flights are done using the swath data and log sheets. The log sheets are completed on a mission by mission basis and are tied to the flight plans generated for ALTM_NAV as provided in the flight plan section. The swath data from a previous mission loaded prior to a mission and verify the next line to be flown until all missions for the project are completed. The previous days logs will be referenced as well to verify at all lines are being flown for a project area. All the data will be saved on two separate Disk drives for redundancy to make sure that all data has been transmitted to the office of operation.

Re-flights

In the event that a re-flight is necessary, the line will be identified and logged as a re-flight. The line re-flown will be indicated as such on the flight log so the processing department will know that it is a re-flown line for a specific line.

Appendix D: Ground Control Survey and Vertical Testing Quality Control

FEMA Region 5 - Ozaukee County, WI
Ground Control Project Report for AeroMetric Inc.

December 6, 2010

Project Information

CDI Project Number: **FSG1530**
Geographic Location: **Ozaukee County, Wisconsin**
Number of GCPs Requested: **20**
Number of GCPs Collected: **21**

Project Specifications

Precision (Horizontal/Vertical): **CDI Precision-1 ≤ 8cm H/V**
Coordinate System: **UTM**
Datum: **NAD83**
Zone: **16 N**
Altitude Reference: **HAE (WGS84) and NAVD88 (09)**
Units: **Meters**

RTK GPS

All Ground Control Points for this project were collected within the boundaries of the WisCors Virtual Reference Station System, which provides continuous real-time broadcast correction signals within a network of 22 base stations encompassing the South-Central and Southeast Wisconsin region.

All Control Points were observed for 180 epochs to determine a coordinate location ≤ 8cm in both Horizontal and Vertical to support subsequent LiDAR post-processing and bare earth deliverables generation.

All data collected were well within the confines of the WisCors VRS system with multiple base locations providing position and correction data for each point collected.

Summary

The purpose of this project was to locate and survey photo-identifiable ground control points (GCPs) in multiple areas of interest as defined by FEMA-supplied shape and kml files. The GCP coordinates are to be used to control the vertical aspect of all newly-flown LiDAR data during post-processing and subsequent deliverables creation. CompassData visited the project area, found suitable GCPs, and determined accurate coordinates for each GCP according to the customer's specifications.

Equipment

CompassData used a Trimble R8-3 to perform the Control survey. This device is accurate to within 1 cm on a position-by-position basis per Trimble specifications. Operating within the VRS network provided accurate coordinate values at or around 3 cm H/V within 3-5 minutes observation times. CompassData has consistently demonstrated this level of accuracy on many GCP collection jobs across North and South America and Africa. Specifications for the Trimble R8 are available upon request.

Survey Methodology

CompassData has met the required precision for this project by using a high-quality GPS receiver with differential corrections provided by a VRS network surrounding the project area. The GPS antenna sat atop a bubble-leveled, fixed-height range pole that was placed over the center of the desired GCP. At least 180 positions (captured at a rate of one per second) were geometrically averaged to calculate a single coordinate for each GCP. All required field documentation was filled out and the points were identified on web-based imagery and diagrammed on the CompassData-supplied sketch sheets. Digital pictures of each GCP location were collected in the field.

Quality Control Procedures

CompassData collects GCPs with an unobstructed view of the sky to ensure proper GPS operation. CompassData works to avoid potential sources of multipath error such as trees, buildings, and fences that may adversely affect the GPS accuracy.

Additional quality control comes from the fact that at least 180 GPS positions are collected for each GCP. While operating within a VRS, valid solutions are reached within seconds; however, we continue to collect additional data to ensure meeting collection specifications. To ensure project integrity, a GCP will be reobserved or moved to a more suitable location if it does not meet project specifications.

In addition to the aforementioned procedures, CompassData observes existing geodetic control monuments to verify that our coordinates match the published coordinates to the required accuracy. These monuments are usually established by the National Geodetic Survey (NGS) in the United States. If it is found that our coordinates are outside the acceptable accuracy, the reason for the difference will be found or the GCPs will be reobserved under different GPS constellation constraints.   There are certain geodetic considerations that must be taken into account that affect whether a GPS-derived coordinate will line up with a survey monument, especially when these monuments reference local coordinate systems or the systems of another country. Sometimes the published coordinates for a monument are not accurate, although this is very infrequent.

CompassData visited multiple survey monuments during the course of this project. The results of those monument measurements are summarized in the Accuracy Report.

Deliverables

Deliverables for this project include:

- Coordinates (in spreadsheet format)
- Image Chips
- Sketch Sheets
- Digital Pictures
- QA/QC Data

Project Notes

All collected points were retrieved from the Trimble Survey Controller in Decimal Degrees, NAD83, HAE Meters.

CorpsCon was used to generate files in the following format:

Degrees Minutes Decimal Seconds, NAD83 HAE (QC purposes)
UTM Meters, NAD83 HAE

Geoid09 was then used to generate the geoid separation at every Lat/Long location. NAVD88(09) orthometric heights were then generated in spreadsheet form using the formula HAE - Geoid = Orthometric Height. Those values were then included into the final delivery coordinate CSV files and have been tested against NGS monuments collected during the course of this survey and are showing millimeter-level agreement.

The Horizontal and Vertical accuracies reported in the Final Coordinates file were obtained from the Survey Report generated by Trimble Survey Controller. The report contains all points collected during each daily survey deployment, including CVAs, FVAs and Ground Control. Copies of these reports can be provided upon request once the CVA and FVA data has been redacted.

Contact Information

Hayden Howard Phone: (303) 627-4058 E-mail: haydenh@compassdatainc.com

Ozaukee, Wisconsin

GCP	Date	Vert_Prec	Horz_Prec	Latitude	Longitude	Northing	Easting	HAE	MSL
OZK101	10/30/2010	0.0082	0.0058	43.52734872	-88.02055867	4819884.546	417530.639	234.277	269.469
OZK102	10/30/2010	0.0098	0.0061	43.52885974	-87.92092222	4819958.402	425583.963	218.248	253.539
OZK103	10/30/2010	0.0094	0.0067	43.52850211	-87.81086466	4819826.111	434476.92	177.573	212.986
OZK104	10/30/2010	0.0058	0.0043	43.46901556	-88.03048544	4813416.014	416648.26	222.098	257.208
OZK105	10/30/2010	0.0079	0.0055	43.47048734	-87.92060056	4813475.344	425538.249	212.1	247.35
OZK106	10/30/2010	0.0091	0.0055	43.47035363	-87.8405471	4813392.026	432013.161	187.542	222.892
OZK107	10/30/2010	0.0073	0.004	43.41749422	-88.02083121	4807684.542	417359.047	240.506	275.572
OZK108	10/30/2010	0.0094	0.0055	43.41624758	-87.95257908	4807480.688	422882.816	217.561	252.728
OZK109	10/30/2010	0.0082	0.0061	43.42105918	-87.87098181	4807942.795	429494.235	194.701	229.994
OZK110	10/29/2010	0.0058	0.004	43.36733215	-88.03998593	4802132.862	415738.901	228.824	263.83
OZK111	10/30/2010	0.0076	0.0046	43.36225616	-87.95194139	4801483.985	422866	205.254	240.4
OZK112	10/30/2010	0.0088	0.0055	43.3642333	-87.8842429	4801643.202	428353.833	177.475	212.741
OZK113	10/29/2010	0.0094	0.0052	43.30598676	-88.04396134	4795324.114	415331.605	236.618	271.595
OZK114	10/29/2010	0.0082	0.0055	43.30925776	-87.9740313	4795618.862	421007.412	214.679	249.777
OZK115	10/29/2010	0.0091	0.0058	43.30963502	-87.89659559	4795590.434	427287.823	180.449	215.694
OZK116	10/29/2010	0.0094	0.0061	43.2576447	-88.04334	4789954.86	415314.967	222.255	257.222
OZK117	10/29/2010	0.0101	0.0061	43.25960921	-87.97572771	4790106.757	420805.451	186.965	222.059
OZK118	10/29/2010	0.0091	0.0061	43.26153722	-87.91416435	4790264.391	425804.585	177.126	212.326
OZK119	10/29/2010	0.0091	0.0058	43.21259612	-88.05774167	4784966.722	414082.744	214.207	249.15
OZK120	10/29/2010	0.0079	0.0055	43.20936159	-87.98407065	4784534.5	420062.639	171.559	206.629
OZK121	10/29/2010	0.0091	0.0058	43.21118305	-87.91025348	4784668.905	426061.14	177.453	212.634

Survey Control

Survey Control	Date	Vert_Prec	Horz_Prec	Latitude	Longitude	Northing	Easting	HAE	MSL
NGS_DE7475	10/30/2010	0.007	0.0043	43.39925018	-87.98507883	4805623.585	420229.442	236.824	271.928
NGS_DF6124	10/29/2010	0.0104	0.0064	43.25086005	-87.99920278	4789157.631	418888.482	197.041	232.091
RASN	10/29/2010			43.03636973	-88.12153575	4765463.885	408638.995	234.374	269.2
WEBE	10/29/2010			43.42054699	-88.14874235	4808158.343	407008.653	771.58	188.655
SHAN	10/30/2010			43.74762833	-87.73478486	4844105.415	440840.068	501.79	270.119

Metadata

UTM 16 North, NAD83, NAVD88
All units in meters where applicable.
MSL = Geiod09

Ozaukee, Wisconsin

GCP	Date	Vert_Prec	Horz_Prec	Latitude	Longitude	Northing	Easting	HAE	MSL
OZK101	10/30/2010	0.0082	0.0058	43.52734872	-88.02055867	4819884.546	417530.639	234.277	269.469
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OZK103	10/30/2010	0.0094	0.0067	43.52850211	-87.81086466	4819826.111	434476.92	177.573	212.986
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OZK105	10/30/2010	0.0079	0.0055	43.47048734	-87.92060056	4813475.344	425538.249	212.1	247.35
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OZK108	10/30/2010	0.0094	0.0055	43.41624758	-87.95257908	4807480.688	422882.816	217.561	252.728
OZK109	10/30/2010	0.0082	0.0061	43.42105918	-87.87098181	4807942.795	429494.235	194.701	229.994
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OZK117	10/29/2010	0.0101	0.0061	43.25960921	-87.97572771	4790106.757	420805.451	186.965	222.059
OZK118	10/29/2010	0.0091	0.0061	43.26153722	-87.91416435	4790264.391	425804.585	177.126	212.326
OZK119	10/29/2010	0.0091	0.0058	43.21259612	-88.05774167	4784966.722	414082.744	214.207	249.15
OZK120	10/29/2010	0.0079	0.0055	43.20936159	-87.98407065	4784534.5	420062.639	171.559	206.629
OZK121	10/29/2010	0.0091	0.0058	43.21118305	-87.91025348	4784668.905	426061.14	177.453	212.634

Survey Control

NGS_DE7475	10/30/2010	0.007	0.0043	43.39925018	-87.98507883	4805623.585	420229.442	236.824	271.928
NGS_DF6124	10/29/2010	0.0104	0.0064	43.25086005	-87.99920278	4789157.631	418888.482	197.041	232.091
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SHAN	10/30/2010			43.74762833	-87.73478486	4844105.415	440840.068	501.79	270.119

Metadata

UTM 16 North, NAD83, NAVD88
All units in meters where applicable.
MSL = Geiod09

Region 5: Test results for Ozaukee, WI

Summary

In FEMA-Region 5 the Ozaukee area encompasses 244 square miles. A LiDAR data acquisition was ordered for a 2' equivalent contour accuracy, which equals the highest specification level. The area was flown by Aerometric and post-processed by Tuck Mapping Solutions. CompassData performed the quality control of the collected and processed LiDAR data with a fundamental vertical accuracy (FVA) and a consolidated vertical accuracy (CVA) assessment, respectively. The planning, data collection, data processing, and data testing were successfully accomplished by the STARR members.

Index

- Final Test Results
- FVA Test
- CVA Test
- Distribution of Testing Points
- FVA Test Details
- CVA Test Details

Final Test Results

The vertical accuracy requirements based on flood risk and terrain slope are met with 12.8 cm and 22.3 cm for both FVA and CVA testing. The mandatory requirements for the highest specification for vertical accuracy, 95% confidence level are for FVA < 24.5 cm and CVA < 36.3 cm.

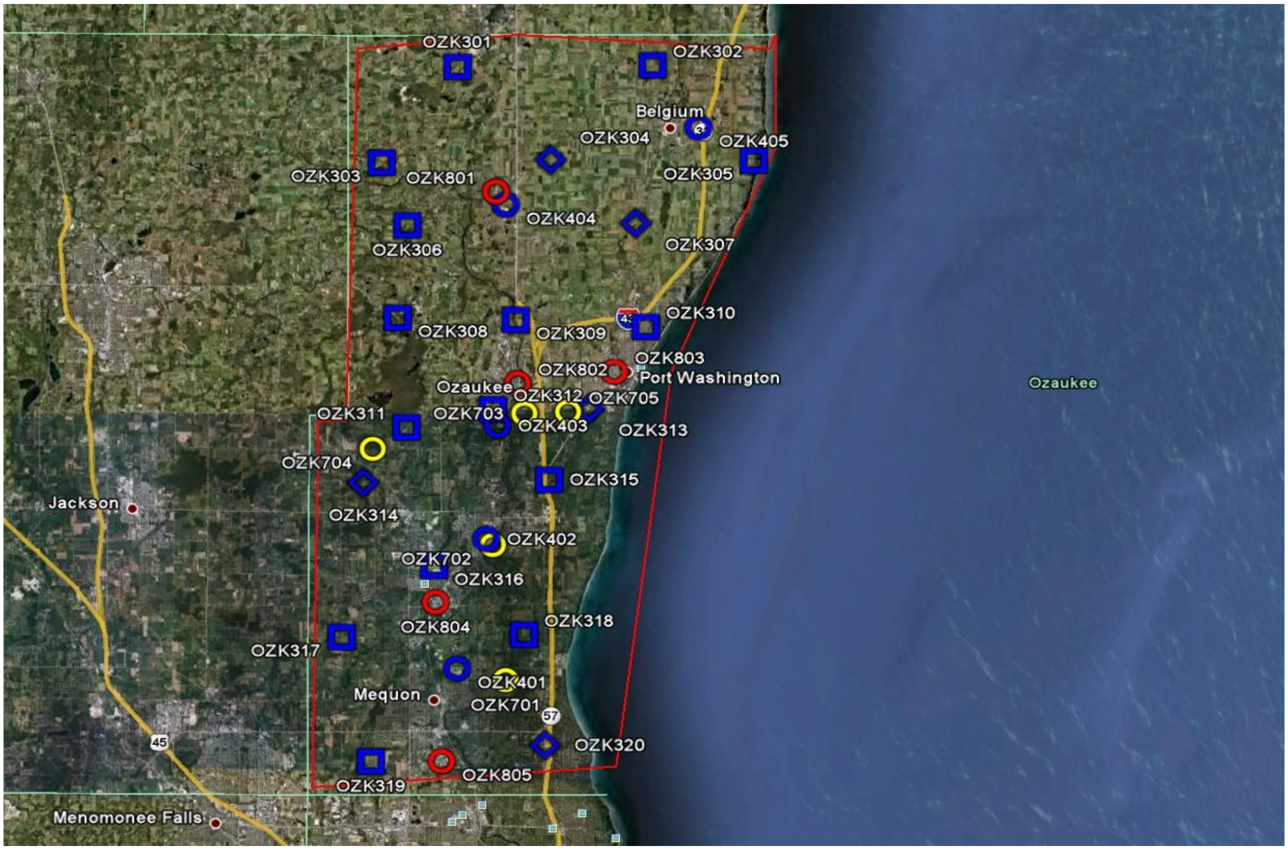
FVA Test

Tested 12.8 cm fundamental vertical accuracy at 95% confidence level in open terrain using $RMSE_{(z)}$ x 1.9600. The Root Mean Square Error for the elevation differences between GPS control points and LiDAR points is 6.6 cm calculated with 20 FVA points.

CVA Test

Tested 22.3 cm consolidated vertical accuracy at 95th percentile in: open terrain, forest terrain, and urban terrain. The Root Mean Square Error for the elevation differences between GPS control points and LiDAR points is 11.4 cm calculated with 5 FVA points and 15 supplemental vertical accuracy points (SVA).

Distribution of Testing Points



Region 5, Ozaukee County, WI

<u>Legend:</u>

FVA points in open terrain on hard surface

FVA points in open terrain used as well in CVA test

SVA points in open terrain

SVA points in urban terrain

SVA points in forest terrain

According to the area to be tested the 20 FVA points are evenly distributed. Additional 15 SVA points are distributed in respect to the available major land classes.

FVA Test Details

Point	Date	Northing (GPS)	Easting (GPS)	MSL (GPS)	MSL (LiDAR)	Δ Z
OZK301	10/30/2010	4819890.03	421143.68	268.55	268.54	**0.01**
OZK302	10/30/2010	4819882.71	430445.74	222.45	222.45	**0.00**
OZK303	10/30/2010	4815031.03	417478.60	258.87	258.92	**-0.05**
OZK304	10/30/2010	4815094.35	425552.34	245.29	245.24	**0.05**
OZK305	10/30/2010	4814965.34	435224.29	186.49	186.50	**-0.01**
OZK306	10/30/2010	4811798.37	418671.25	268.92	268.90	**0.02**
OZK307	10/30/2010	4811803.69	429575.73	221.94	221.94	**0.00**
OZK308	10/30/2010	4807070.43	418160.54	270.90	270.89	**0.01**
OZK309	10/30/2010	4806907.55	423790.40	231.07	230.87	**0.19**
OZK310	10/30/2010	4806489.55	429976.35	209.49	209.50	**-0.01**
OZK311	10/30/2010	4801454.76	418524.59	268.09	268.20	**-0.11**
OZK312	10/30/2010	4802335.89	422660.24	241.06	241.11	**-0.05**
OZK313	10/30/2010	4802330.41	427256.33	217.66	217.73	**-0.07**
OZK314	10/29/2010	4798660.86	416458.86	254.91	254.94	**-0.03**
OZK315	10/30/2010	4798707.15	425296.03	226.33	226.28	**0.05**
OZK316	10/29/2010	4794363.33	419757.35	239.98	240.10	**-0.12**
OZK317	10/29/2010	4790760.40	415315.62	265.45	265.49	**-0.04**
OZK318	10/29/2010	4790781.03	424007.40	202.70	202.76	**-0.06**
OZK319	10/29/2010	4784372.99	416634.02	227.48	227.52	**-0.04**
OZK320	10/29/2010	4785111.80	424971.82	209.68	209.68	**0.00**

ΔZ Mean	**0.05**		
ΔZ Min	**-0.11**	**$RMSE_{(z)}$**	**0.066**
ΔZ Max	**0.19**	*** 1.9600**	**0.128**

UTM Zone 16 North, NAD83, NAVD88
MSL = NAVD88/Geoid09
All units in meters

Note:

All 20 of the FVA points (open terrain) passed. 100% of the points are within the 24.5 cm confidence level. The FVA test is passed.

CVA Test Details

Point	Typ	Date	Northing (GPS)	Easting (GPS)	MSL (GPS)	MSL (LiDAR)	Δ Z
OZK304	O	10/30/2010	4815094.347	425552.344	245.289	245.23	**0.06**
OZK307	O	10/30/2010	4811803.687	429575.732	221.944	221.95	**-0.01**
OZK313	O	10/30/2010	4802330.408	427256.333	217.662	217.75	**-0.09**
OZK314	O	10/29/2010	4798660.859	416458.859	254.912	254.90	**0.01**
OZK320	O	10/29/2010	4785111.802	424971.818	209.68	209.64	**0.04**
OZK401	O	12/6/2010	4789066.62	420803.45	214.259	214.28	**-0.02**
OZK402	O	12/7/2010	4795691.65	422279.48	234.234	234.21	**0.02**
OZK403	O	12/7/2010	4801484.71	422866.1	240.405	240.34	**0.06**
OZK404	O	12/8/2010	4812791.52	423382.62	252.859	252.87	**-0.01**
OZK405	O	12/8/2010	4816667.72	432606.42	223.821	223.90	**-0.08**
OZK701	F	12/6/2010	4788449.55	423113.64	208.015	208.27	**-0.26**
OZK702	F	12/7/2010	4795378.93	422582.51	221.342	221.42	**-0.08**
OZK703	F	12/7/2010	4802101.06	424159.33	230.418	230.32	**0.10**
OZK704	F	12/7/2010	4800360.38	416911.59	252.756	252.39	**0.37**
OZK705	F	12/7/2010	4802164.63	426239.34	234.051	234.16	**-0.11**
OZK801	U	12/8/2010	4813470.94	422925.42	243.172	243.11	**0.06**
OZK802	U	12/7/2010	4803643.3	423848.65	230.17	230.12	**0.05**
OZK803	U	12/7/2010	4804194.72	428465.86	207.564	207.59	**-0.03**
OZK804	U	12/7/2010	4792478.94	419816.43	232.315	232.30	**0.01**
OZK805	U	12/6/2010	4784327.08	420009.83	204.34	204.38	**-0.04**

ΔZ Mean	**0.08**		
ΔZ Min	**-0.26**	**RMSE$_{(z)}$**	**0.114**
ΔZ Max	**0.37**	*** 1.9600**	**0.223**

Land Class Types: O = Open, F = Forest, U = Urban
UTM Zone 16 North, NAD83, NAVD88
MSL = NAVD88/Geoid09
All units in meters

Note:

The SVA point 'OZK704' exceeds the limit (36.3 cm) by 0.7 cm. Due to trees, bushes, and soft ground this can be accepted. 19 of the FVA+SVA points passed. 95% of the points are within the 36.3 cm confidence level. The CVA test is passed.

FEMA Region 5 inc. Rock and Ozaukee Counties WI FVA/CVA Project Report for FEMA.

December 29, 2010

Project Information

CDI Project Number: FSG1530
Geographic Location: Rock County, Wisconsin
Number of FVA/CVAs Requested: 70
Number of FVA/CVA Collected: 70

Project Specifications

Precision (Horizontal/Vertical): CDI Precision-1 ≤ 8cm H/V
Coordinate System: UTM
Datum: NAD83
Zone: 16 N
Altitude Reference: HAE (WGS84) and NAVD88 (09)
Units: Meters

RTK GPS

All FVA/CVA Points for this project were collected within the boundaries of the WisCors Virtual Reference Station System, which provides continuous real-time broadcast correction signals within a network of 22 base stations encompassing the South-Central and Southeast Wisconsin region.

All Points were observed for 180 epochs to determine a coordinate location ≤ 8cm in both Horizontal and Vertical to support subsequent LiDAR post-processing testing quality assurance.

All data collected were well within the confines of the WisCors VRS system with multiple base locations providing position and correction data for each point collected.

Summary

The purpose of this project was to locate and survey photo-identifiable ground reference points in multiple areas of interest as defined by FEMA-supplied shape and kml files. The point coordinates are to be used to verify vertical accuracy of all newly-flown LiDAR data during post-processing and subsequent deliverables creation. CompassData visited the project area, found suitable features, and determined accurate coordinates for each FVA/CVA according to the customer's specifications.

Equipment

CompassData used a Trimble R8-3 to perform the FVA/CVA survey. This device is accurate to within 1 cm on a position-by-position basis per Trimble specifications. Operating within the VRS network provided accurate coordinate values at or around 3 cm H/V within 3-5 minutes observation times. CompassData has consistently demonstrated this level of accuracy on many GCP collection jobs across North and South America and Africa. Specifications for the Trimble R8 are available upon request.

Survey Methodology

CompassData has met the required precision for this project by using a high-quality GPS receiver with differential corrections provided by a VRS network surrounding the project area. The GPS antenna sat atop a bubble-leveled, fixed-height range pole that was placed over the center of the desired point. At least 180 positions (captured at a rate of one per second) were geometrically averaged to calculate a single coordinate for each point. All required field documentation was filled out and the points were identified on web-based imagery and diagrammed on the CompassData-supplied sketch sheets. Digital pictures of each point location were collected in the field.

Quality Control Procedures

CompassData collects GCPs with an unobstructed view of the sky to ensure proper GPS operation. CompassData works to avoid potential sources of multipath error such as trees, buildings, and fences that may adversely affect the GPS accuracy.

Additional quality control comes from the fact that at least 180 GPS positions are collected for each point. While operating within a VRS, valid solutions are reached within seconds; however, we continue to collect additional data to ensure meeting collection specifications. To ensure project integrity, an FVA/CVA point will be reobserved or moved to a more suitable location if it does not meet project specifications.

In addition to the aforementioned procedures, CompassData observes existing geodetic control monuments to verify that our coordinates match the published coordinates to the required accuracy. These monuments are usually established by the National Geodetic Survey (NGS) in the United States. If it is found that our coordinates are outside the acceptable accuracy, the reason for the difference will be found or the points will be reobserved under different GPS constellation constraints. There are certain geodetic considerations that must be taken into account that affect whether a GPS-derived coordinate will line up with a survey monument, especially when these monuments reference local coordinate systems or the systems of another country. Sometimes the published coordinates for a monument are not accurate, although this is very infrequent.

CompassData visited multiple survey monuments during the course of this project. The results of those monument measurements are summarized in the Accuracy Report.

Deliverables

Deliverables for this project include:

- Coordinates (in spreadsheet format)
- Image Chips
- Sketch Sheets (FVAs only)
- Digital Pictures
- QA/QC Data

Project Notes

All collected points were retrieved from the Trimble Survey Controller in Decimal Degrees, NAD83, HAE Meters.

CorpsCon was used to generate files in the following format:

Degrees Minutes Decimal Seconds, NAD83 HAE (QC purposes)
UTM Meters, NAD83 HAE

Geoid09 was then used to generate the geoid separation at every Lat/Long location. NAVD88(09) orthometric heights were then generated in spreadsheet form using the formula HAE - Geoid = Orthometric Height. Those values were then included into the final delivery coordinate CSV files and have been tested against NGS monuments collected during the course of this survey and are showing millimeter-level agreement.

The Horizontal and Vertical accuracies reported in the Final Coordinates file were obtained from the Survey Report generated by Trimble Survey Controller. The report contains all points collected during each daily survey deployment, including CVAs, FVAs and Ground Control. Copies of these reports can be provided upon request.

Contact Information

Hayden Howard Phone: (303) 627-4058 E-mail: haydenh@compassdatainc.com

Ozaukee, Wisconsin

CVAs/FVAs	Date	Vert_Prec	Horz_Prec	Latitude	Longitude	Northing	Easting	HAE	MSL
OZK301	10/30/2010	0.0091	0.0061	43.52778838	-87.9758546	4819890.026	421143.679	233.32	268.55
OZK302	10/30/2010	0.0104	0.0067	43.52864698	-87.86075335	4819882.705	430445.744	187.084	222.445
OZK303	10/30/2010	0.0070	0.0052	43.48364743	-88.02046618	4815031.029	417478.597	223.734	258.872
OZK304	10/30/2010	0.0076	0.0055	43.48506489	-87.92064762	4815094.347	425552.344	210.028	245.289
OZK305	10/30/2010	0.0110	0.0055	43.48480381	-87.80103773	4814965.339	435224.289	151.096	186.494
OZK306	10/30/2010	0.0061	0.0046	43.45467459	-88.00523754	4811798.369	418671.247	233.795	268.916
OZK307	10/30/2010	0.0088	0.0055	43.45582784	-87.87047337	4811803.687	429575.732	186.636	221.944
OZK308	10/30/2010	0.0073	0.0043	43.41205328	-88.01084017	4807070.429	418160.544	235.824	270.899
OZK309	10/30/2010	0.0085	0.0055	43.41118033	-87.9412898	4806907.551	423790.404	195.883	231.065
OZK310	10/30/2010	0.0073	0.0061	43.40802024	-87.86484054	4806489.551	429976.349	174.188	209.487
OZK311	10/30/2010	0.0058	0.0043	43.36153452	-88.00550817	4801454.755	418524.594	233.038	268.092
OZK312	10/30/2010	0.0076	0.0046	43.3699049	-87.95460064	4802335.888	422660.243	205.917	241.06
OZK313	10/30/2010	0.0082	0.0049	43.37031497	-87.89787767	4802330.408	427256.333	182.419	217.662
OZK314	10/29/2010	0.0070	0.0046	43.33615389	-88.03057222	4798660.859	416458.859	219.906	254.912
OZK315	10/30/2010	0.0091	0.0058	43.33750093	-87.92157696	4798707.147	425296.027	191.133	226.331
OZK316	10/29/2010	0.0085	0.0058	43.29782159	-87.98925985	4794363.332	419757.349	204.912	239.982
OZK317	10/29/2010	0.0143	0.0094	43.26489719	-88.04345582	4790760.399	415315.62	230.48	265.448
OZK318	10/29/2010	0.0082	0.0058	43.2660097	-87.93637603	4790781.032	424007.395	167.536	202.699
OZK319	10/29/2010	0.0079	0.0055	43.20753668	-88.02624783	4784372.994	416634.022	192.485	227.483
OZK320	10/29/2010	0.0088	0.0061	43.21506322	-87.9237225	4785111.802	424971.818	174.518	209.68
OZK401	12/6/2010	0.0094	0.0058	43.25024424	-87.97560280	4789066.62	420803.45	179.166	214.259
OZK402	12/7/2010	0.0701	0.0049	43.31004555	-87.95835837	4795691.65	422279.48	199.108	234.234
OZK403	12/7/2010	0.0073	0.0055	43.36226273	-87.95194024	4801484.71	422866.1	205.259	240.405
OZK404	12/8/2010	0.0079	0.0049	43.46411309	-87.94715181	4812791.52	423382.62	217.651	252.859
OZK405	12/8/2010	0.0098	0.0055	43.49989955	-87.83361871	4816667.72	432606.42	188.447	223.821
OZK701	12/6/2010	0.0000	0.0000	43.24492763	-87.94706195	4788449.55	423113.64	172.875	208.015
OZK701a	12/6/2010	0.0122	0.0082	43.24489635	-87.94698108	4788446	423120.17	172.978	208.118
OZK701b	12/6/2010	0.0091	0.0067	43.24524221	-87.94715151	4788484.57	423106.77	173.427	208.567
OZK702	12/7/2010	0.0000	0.0000	43.30726126	-87.95457814	4795378.93	422582.51	186.209	221.342
OZK702a	12/7/2010	0.0082	0.0055	43.30730592	-87.95449281	4795383.81	422589.49	186.165	221.298
OZK702b	12/7/2010	0.0085	0.0055	43.30698944	-87.95451626	4795348.68	422587.19	186.541	221.674

OZK703	12/7/2010	0.0000	0.0000	43.36794363	-87.93606738	4802101.06	424159.33	195.243	230.418
OZK703a	12/7/2010	0.0119	0.0082	43.36797567	-87.93606957	4802104.62	424159.2	195.295	230.47
OZK703b	12/7/2010	0.0168	0.0113	43.36798370	-87.93567069	4802105.15	424191.52	195.453	230.629
OZK704	12/7/2010	0.0000	0.0000	43.35150504	-88.02524569	4800360.38	416911.59	217.737	252.756
OZK704a	12/7/2010	0.0085	0.0046	43.35137941	-88.02514729	4800346.33	416919.39	218.368	253.387
OZK704b	12/7/2010	0.0104	0.0052	43.35138717	-88.02473623	4800346.78	416952.71	218.477	253.497
OZK705	12/7/2010	0.0000	0.0000	43.36872316	-87.91040653	4802164.63	426239.34	198.829	234.051
OZK705a	12/7/2010	0.0158	0.0061	43.36873777	-87.91042682	4802166.27	426237.72	199.12	234.342
OZK705b	12/7/2010	0.0162	0.0061	43.36857742	-87.91070858	4802148.71	426214.7	199.404	234.625
OZK801	12/8/2010	0.0088	0.0049	43.47018304	-87.95289914	4813470.94	422925.42	207.967	243.172
OZK802	12/7/2010	0.0076	0.0064	43.38179741	-87.94011604	4803643.3	423848.65	194.998	230.17
OZK803	12/7/2010	0.0088	0.0064	43.38721640	-87.88319377	4804194.72	428465.86	172.294	207.564
OZK804	12/7/2010	0.0091	0.0055	43.28086216	-87.98825686	4792478.94	419816.43	197.243	232.315
OZK805	12/6/2010	0.0082	0.0058	43.20748851	-87.98469059	4784327.08	420009.83	169.272	204.34

Survey Control

NGS_DE7475	10/30/2010	0.0070	0.0043	43.39925018	-87.98507883	4805623.585	420229.442	236.824	271.928
NGS_DF6124	10/29/2010	0.0104	0.0064	43.25086005	-87.99920278	4789157.631	418888.482	197.041	232.091
NGS_DG4879	12/6/2010	0.0098	0.0052	43.14892250	-87.93847688	4777780.03	423691.07	172.445	207.55
NGS_DF6043	12/7/2010	0.0079	0.0046	43.35332231	-88.00540858	4800542.64	418521.68	225.087	260.138
NGS_DF9684	12/8/2010	0.0076	0.0058	42.77180333	-88.87605000	4737181.11	346519.42	240.539	274.458

Metadata

UTM 16 North, NAD83, NAVD88

All units in meters where applicable.

MSL = Geiod09

ID	Satellites	PDOP
OZK301	13	1.6
OZK302	13	1.6
OZK303	13	1.5
OZK304	14	1.6
OZK305	13	1.7
OZK306	14	1.4
OZK307	16	1.4
OZK308	12	1.5
OZK309	11	1.6
OZK310	13	1.3
OZK311	12	1.4
OZK312	14	1.6
OZK313	14	1.5
OZK314	13	1.6
OZK315	12	1.6
OZK316	15	1.3
OZK317	11	1.7
OZK318	13	1.5
OZK319	14	1.5
OZK320	14	1.6
OZK401	14	1.5
OZK402	16	1.5
OZK403	13	1.6
OZK404	15	1.5
OZK405	14	1.5
OZK701		
OZK701a	13	1.5
OZK701b	10	1.8
OZK702		
OZK702a	13	1.7
OZK702b	12	1.8

OZK703		
OZK703a	13	1.4
OZK703b	11	1.5
OZK704		
OZK704a	12	1.7
OZK704b	11	1.8
OZK705		
OZK705a	10	2.4
OZK705b	10	2.4
OZK801	14	1.6
OZK802	11	1.5
OZK803	13	1.5
OZK804	15	1.5
OZK805	14	1.3

NGS_DE7475	14	1.4
NGS_DF6124	12	1.6
NGS_DG4879	12	1.7
NGS_DF6043	14	1.4
NGS_DF9684	8	1.7

Ozaukee County, Wisconsin **FEMA Region 5**
UTM Meters **Zone 16 N**

GCP	Date	SV's	PDOP	Vert_Prec	Horz_Prec	Latitude	Longitude	Northing
OZK301	10/30/2010	13	1.6	0.0091	0.0061	43.52778838	-87.9758546	4819890.026
OZK302	10/30/2010	13	1.6	0.0104	0.0067	43.52864698	-87.86075335	4819882.705
OZK303	10/30/2010	13	1.5	0.0070	0.0052	43.48364743	-88.02046618	4815031.029
OZK304	10/30/2010	14	1.6	0.0076	0.0055	43.48506489	-87.92064762	4815094.347
OZK305	10/30/2010	13	1.7	0.0110	0.0055	43.48480381	-87.80103773	4814965.339
OZK306	10/30/2010	14	1.4	0.0061	0.0046	43.45467459	-88.00523754	4811798.369
OZK307	10/30/2010	16	1.4	0.0088	0.0055	43.45582784	-87.87047337	4811803.687
OZK308	10/30/2010	12	1.5	0.0073	0.0043	43.41205328	-88.01084017	4807070.429
OZK309	10/30/2010	11	1.6	0.0085	0.0055	43.41118033	-87.9412898	4806907.551
OZK310	10/30/2010	13	1.3	0.0073	0.0061	43.40802024	-87.86484054	4806489.551
OZK311	10/30/2010	12	1.4	0.0058	0.0043	43.36153452	-88.00550817	4801454.755
OZK312	10/30/2010	14	1.6	0.0076	0.0046	43.3699049	-87.95460064	4802335.888
OZK313	10/30/2010	14	1.5	0.0082	0.0049	43.37031497	-87.89787767	4802330.408
OZK314	10/29/2010	13	1.6	0.0070	0.0046	43.33615389	-88.03057222	4798660.859
OZK315	10/30/2010	12	1.6	0.0091	0.0058	43.33750093	-87.92157696	4798707.147
OZK316	10/29/2010	15	1.3	0.0085	0.0058	43.29782159	-87.98925985	4794363.332
OZK317	10/29/2010	11	1.7	0.0143	0.0094	43.26489719	-88.04345582	4790760.399
OZK318	10/29/2010	13	1.5	0.0082	0.0058	43.2660097	-87.93637603	4790781.032
OZK319	10/29/2010	14	1.5	0.0079	0.0055	43.20753668	-88.02624783	4784372.994
OZK320	10/29/2010	14	1.6	0.0088	0.0061	43.21506322	-87.9237225	4785111.802

Metadata

UTM 16 North, NAD83, NAVD88
All units in meters where applicable.
MSL = Geiod09

GCP	Easting	MSL(m)	MSL(o)	Δ Z	Δ Z^2
OZK301	421143.7	268.55	268.54	0.0100	1E-04
OZK302	430445.7	222.445	222.45	-0.0050	2.5E-05
OZK303	417478.6	258.872	258.92	-0.0480	0.002304
OZK304	425552.3	245.289	245.24	0.0490	0.002401
OZK305	435224.3	186.494	186.50	-0.0060	3.6E-05
OZK306	418671.2	268.916	268.90	0.0160	0.000256
OZK307	429575.7	221.944	221.94	0.0040	1.6E-05
OZK308	418160.5	270.899	270.89	0.0090	8.1E-05
OZK309	423790.4	231.065	230.87	0.1950	0.038025
OZK310	429976.3	209.487	209.50	-0.0130	0.000169
OZK311	418524.6	268.092	268.20	-0.1080	0.011664
OZK312	422660.2	241.06	241.11	-0.0500	0.0025
OZK313	427256.3	217.662	217.73	-0.0680	0.004624
OZK314	416458.9	254.912	254.94	-0.0280	0.000784
OZK315	425296	226.331	226.28	0.0510	0.002601
OZK316	419757.3	239.982	240.10	-0.1180	0.013924
OZK317	415315.6	265.448	265.49	-0.0420	0.001764
OZK318	424007.4	202.699	202.76	-0.0610	0.003721
OZK319	416634	227.483	227.52	-0.0370	0.001369
OZK320	424971.8	209.68	209.68	0.0000	0

		Sum:	0.086364
CE90:	0.14102	**Mean:**	0.0043182
CE95:	0.160846	**RMSE:**	0.065713012
NSSDA:	0.128798	**Z Min:**	-0.1180
		Z Max:	0.195

FEMA Region 5 Ozaukee County, Wisconsin

CVA Testing @ 36.3cm Req'd Accuracy

Point	Typ	Date	Latitude	Longitude	Northing (GPS)	Easting (GPS)	MSL (GPS)	MSL (LiDAR)	Δ Z	Δ Z^2
OZK304	O	10/30/2010	43.48506489	-87.92064762	4815094.347	425552.344	245.289	245.23	**0.06**	0.003481
OZK307	O	10/30/2010	43.45582784	-87.87047337	4811803.687	429575.732	221.944	221.95	**-0.01**	3.6E-05
OZK313	O	10/30/2010	43.37031497	-87.89787767	4802330.408	427256.333	217.662	217.75	**-0.09**	0.007744
OZK314	O	10/29/2010	43.33615389	-88.03057222	4798660.859	416458.859	254.912	254.90	**0.01**	0.000144
OZK320	O	10/29/2010	43.21506322	-87.9237225	4785111.802	424971.818	209.68	209.64	**0.04**	0.0016
OZK401	O	12/6/2010	43.25024424	-87.97560280	4789066.62	420803.45	214.259	214.28	**-0.02**	0.000441
OZK402	O	12/7/2010	43.31004555	-87.95835837	4795691.65	422279.48	234.234	234.21	**0.02**	0.000576
OZK403	O	12/7/2010	43.36226273	-87.95194024	4801484.71	422866.1	240.405	240.34	**0.06**	0.004225
OZK404	O	12/8/2010	43.46411309	-87.94715181	4812791.52	423382.62	252.859	252.87	**-0.01**	0.000121
OZK405	O	12/8/2010	43.49989955	-87.83361871	4816667.72	432606.42	223.821	223.90	**-0.08**	0.006241
OZK701	F	12/6/2010	43.24492763	-87.94706195	4788449.55	423113.64	208.015	208.27	**-0.26**	0.065025
OZK702	F	12/7/2010	43.30726126	-87.95457814	4795378.93	422582.51	221.342	221.42	**-0.08**	0.006084
OZK703	F	12/7/2010	43.36794363	-87.93606738	4802101.06	424159.33	230.418	230.32	**0.10**	0.009604
OZK704	F	12/7/2010	43.35150504	-88.02524569	4800360.38	416911.59	252.756	252.39	**0.37**	0.133956
OZK705	F	12/7/2010	43.36872316	-87.91040653	4802164.63	426239.34	234.051	234.16	**-0.11**	0.011881
OZK801	U	12/8/2010	43.47018304	-87.95289914	4813470.94	422925.42	243.172	243.11	**0.06**	0.003844
OZK802	U	12/7/2010	43.38179741	-87.94011604	4803643.3	423848.65	230.17	230.12	**0.05**	0.0025
OZK803	U	12/7/2010	43.38721640	-87.88319377	4804194.72	428465.86	207.564	207.59	**-0.03**	0.000676
OZK804	U	12/7/2010	43.28086216	-87.98825686	4792478.94	419816.43	232.315	232.30	**0.01**	0.000225
OZK805	U	12/6/2010	43.20748851	-87.98469059	4784327.08	420009.83	204.34	204.38	**-0.04**	0.0016

ΔZ Mean	**0.08**		
ΔZ Min	**-0.26**	**RMSE:**	**0.114**
ΔZ Max	**0.37**	**NSSDA:**	**0.223**

UTM 16 North, NAD83, NAVD88

All units in meters where applicable.

MSL = NAVD88/Geiod09

Appendix E: Post Flight Reports

STARR
Strategic Alliance for Risk Reduction

Ozaukee Post-Flight Aerial Acquisition Report

January 2011

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1.0 Introduction

This report contains a summary of the LiDAR data acquisition and processing for **STARR – Ozaukee County, Wisconsin**.

1.1 Contact Info

Questions regarding the technical aspects of this report should be addressed to:

Aerometric, Inc.
4020 Technology Parkway
Sheboygan, WI 53081

Attention: Robert Merry (Geomatics Manager)
Telephone: 920-457-3631
FAX: 920-457-0410
Email: rmerry@aerometric.com

1.2 Purpose

Aerometric acquired highly accurate Light Detection and Ranging (LiDAR) data for an area that comprises approximately 248 square miles for Tuck Mapping. Using Aerometric, Inc. Optech Gemini LiDAR system, data was collected at an altitude to support the project area's requirement.

1.3 Project Location

The project area is approximately 248 square miles and is located in Ozaukee County, WI. This project area was defined and supplied by STARR on September 10, 2010.

1.4 Time Period

LiDAR data acquisition was completed between October 31st, 2010 and November 23rd, 2010. A total of 5 flight missions were required to cover the project area. Mission 103110 was flown but the information from this flight was not used for the project. All the data used was flown between November 11, 2010 and November 23, 2010.

1.5 GPS Base Station Info

The maximum planned PDOP for the collection was set at 3.0 and below. The actual PDOP as indicated in the processing will be represented in the PDOP plots as provided for Section 1.6. The following is the base stations used for the collection for the five missions used for the collection. There are two different versions of software that are utilized for GPS and POS processing. Both the versions are provided by the manufacture APPLANIX but the reporting of the data is different. The graphs provided show the same information but the format has changed. The differences are reflected in the naming of the files for the required graphs.

The following is the Base Station information

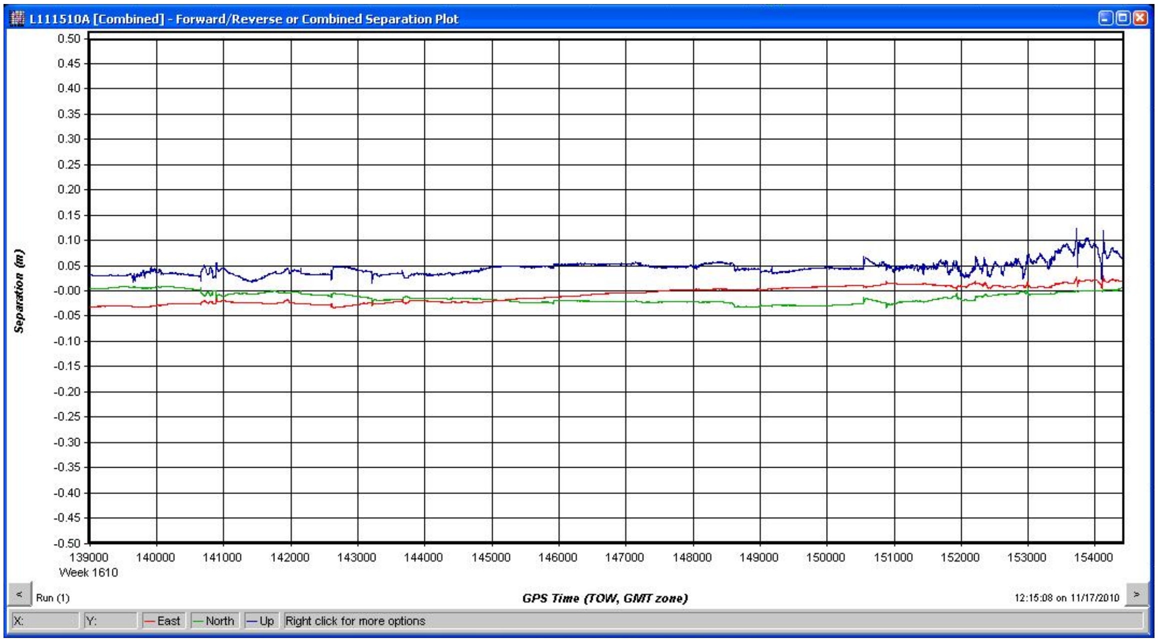
Point ID	LAT	LONG	Height
WIM5	43 11 37.9619	88 03 34.29788	206.482
SHAN	43 44 51.46199	87 44 05.22550	152.946
CHON	44 01 09.29280	88 09 00.96245	248.568
FOLA	43 47 41.73858	88 27 09.75480	196.727
WEBE	43 25 13.96920	88 08 55.47243	235.178
RASN	43 02 10.93102	88 07 17.52878	234.374
SIWI	42 52 04.53392	87 58 58.56228	190.72

The GPS location shape file is named as follows:
GPS_BASE_stations.shp

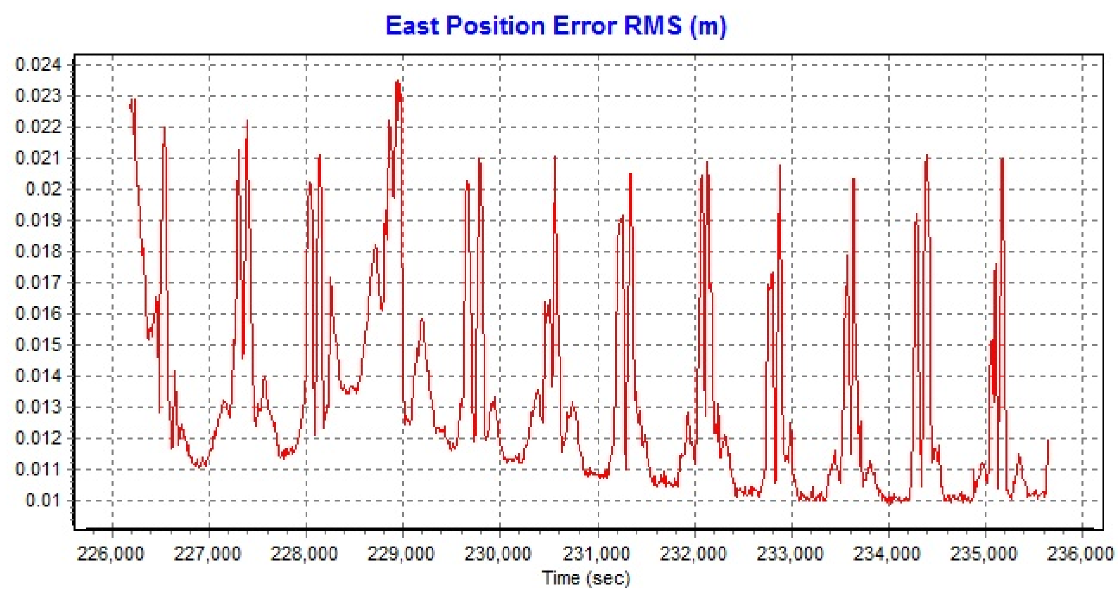
1.6 GPS IMU Processing Summary

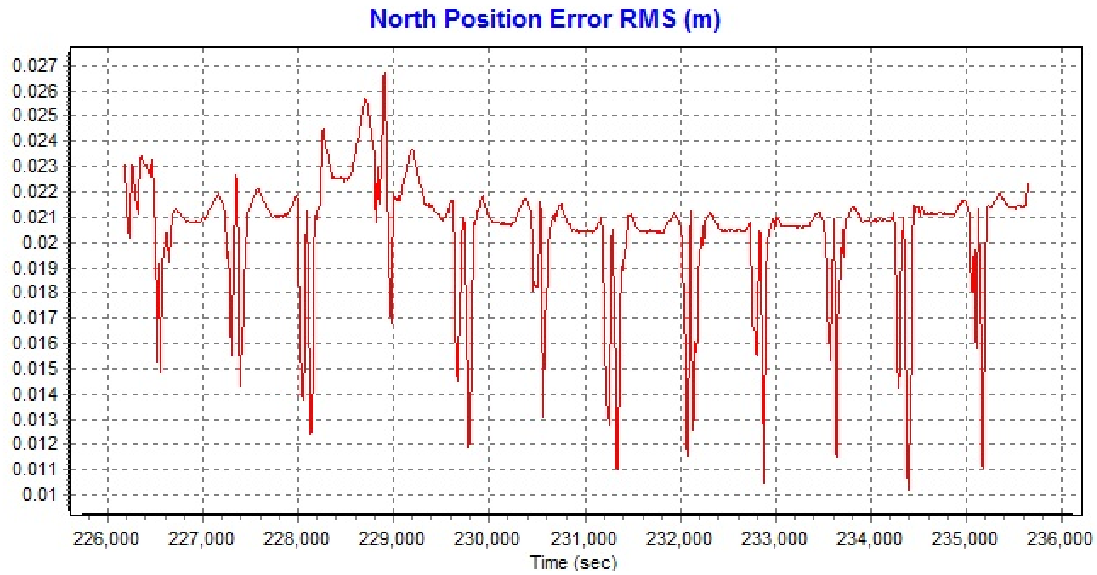
The GPS Quality for the Collection was very good and would be characterized as good to High as represented in the following plots and information in this section. The maximum horizontal variance for the project collection during the collection of mission lines was 4 centimeters. The maximum vertical variance for project collection was 11 centimeters, but it should be noted that this was not during the collection of the mission lines. The maximum vertical variance during collection of mission lines was 6 centimeters. These values are reflected in the plots below.

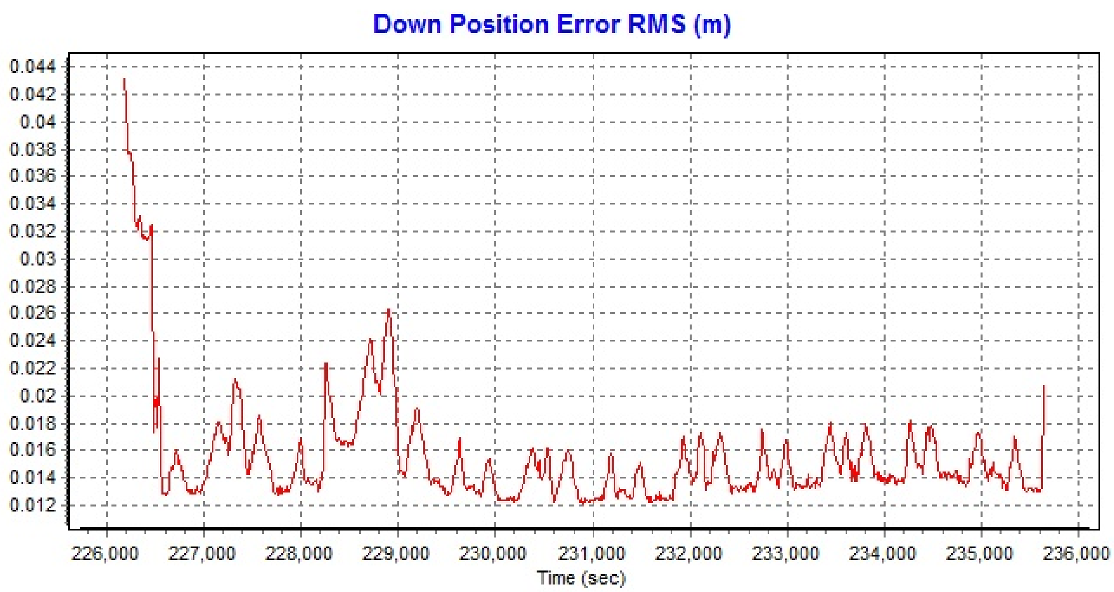
GPS Plots

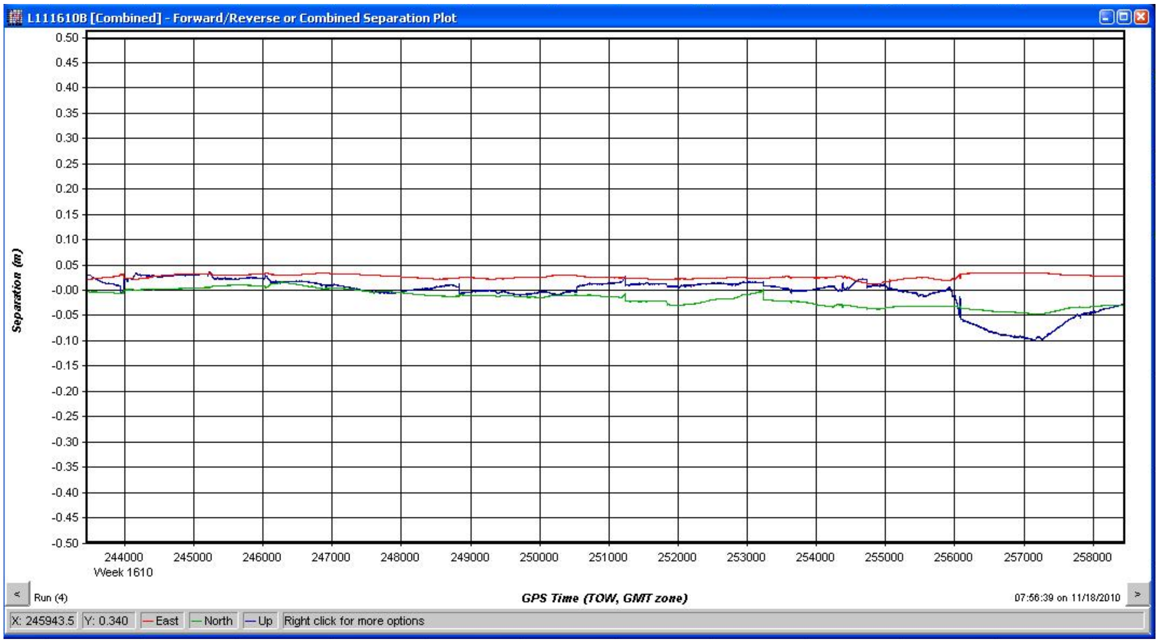


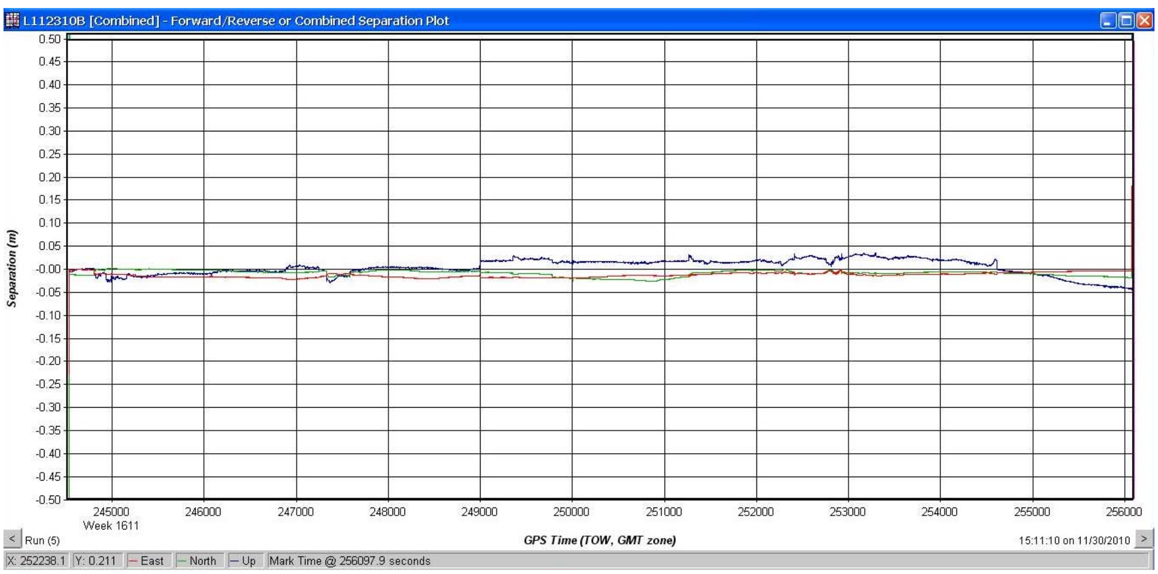
L111610A



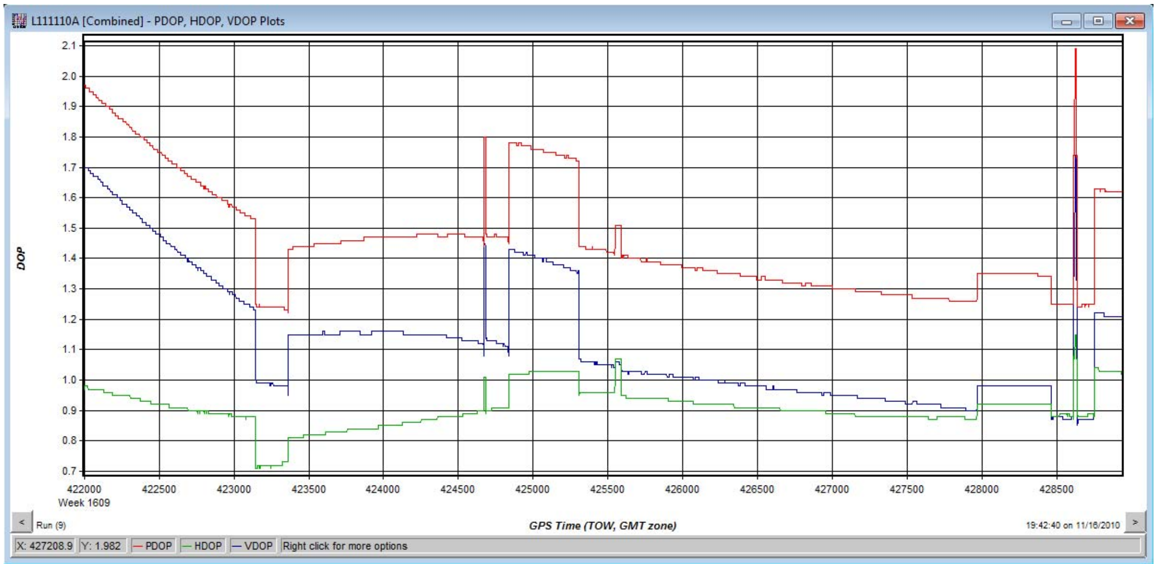

North Position Error RMS (m)
0.027
0.026
0.025
0.024
0.023
0.022
0.021
0.02
0.019
0.018
0.017
0.016
0.015
0.014
0.013
0.012
0.011
0.01
226,000
227,000
228,000
229,000
230,000
231,000
232,000
233,000
234,000
235,000
236,000
Time (sec)

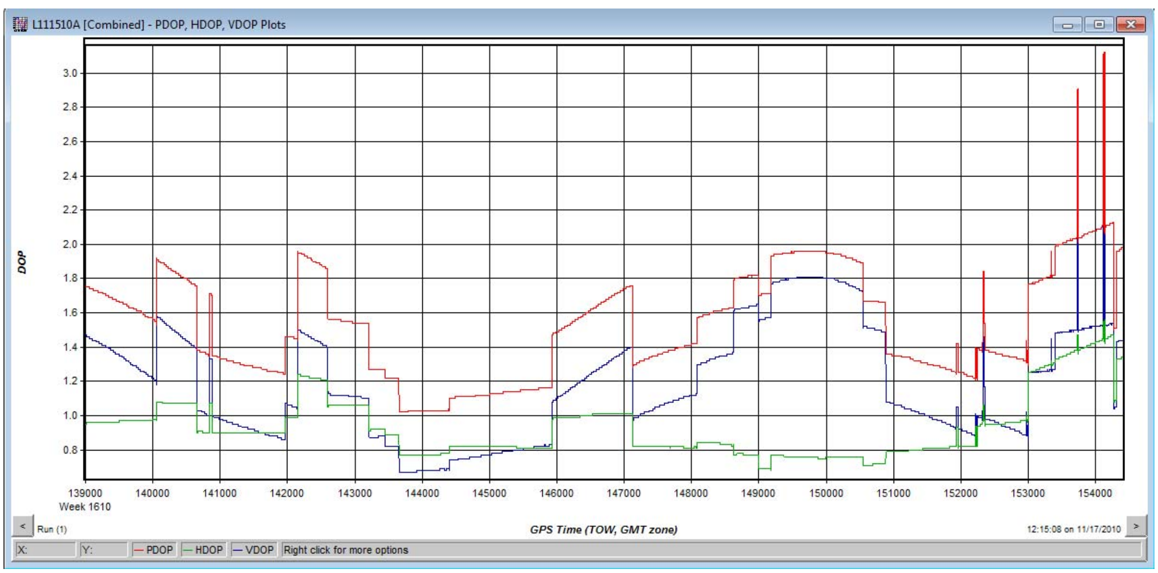

Down Position Error RMS (m)
0.044
0.042
0.04
0.038
0.036
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
0.012
226,000
227,000
228,000
229,000
230,000
231,000
232,000
233,000
234,000
235,000
236,000
Time (sec)


L111610B [Combined] - Forward/Reverse or Combined Separation Plot
Separation (m)
GPS Time (TOW, GMT zone)
Week 1610
Run (4)
07:56:39 on 11/18/2010
X: 245943.5
Y: 0.340
East
North
Up
Right click for more options


L112310B [Combined] - Forward/Reverse or Combined Separation Plot
Separation (m)
GPS Time (TOW, GMT zone)
Week 1611
Run (5)
15:11:10 on 11/30/2010
X: 252238.1
Y: 0.211
East
North
Up
Mark Time @ 256097.9 seconds

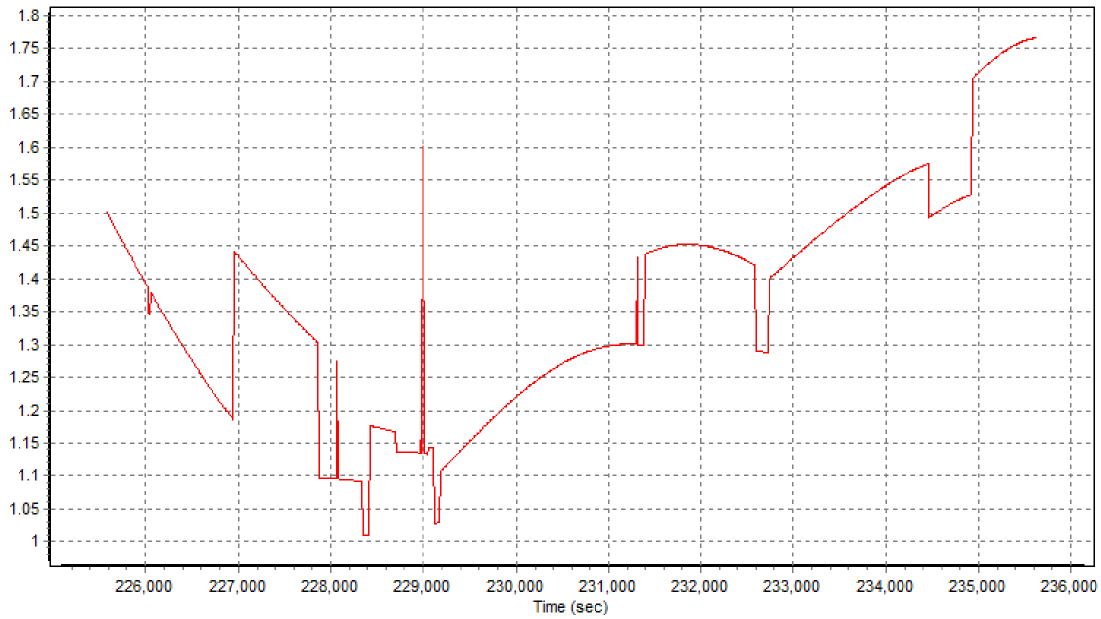
PDOP plots



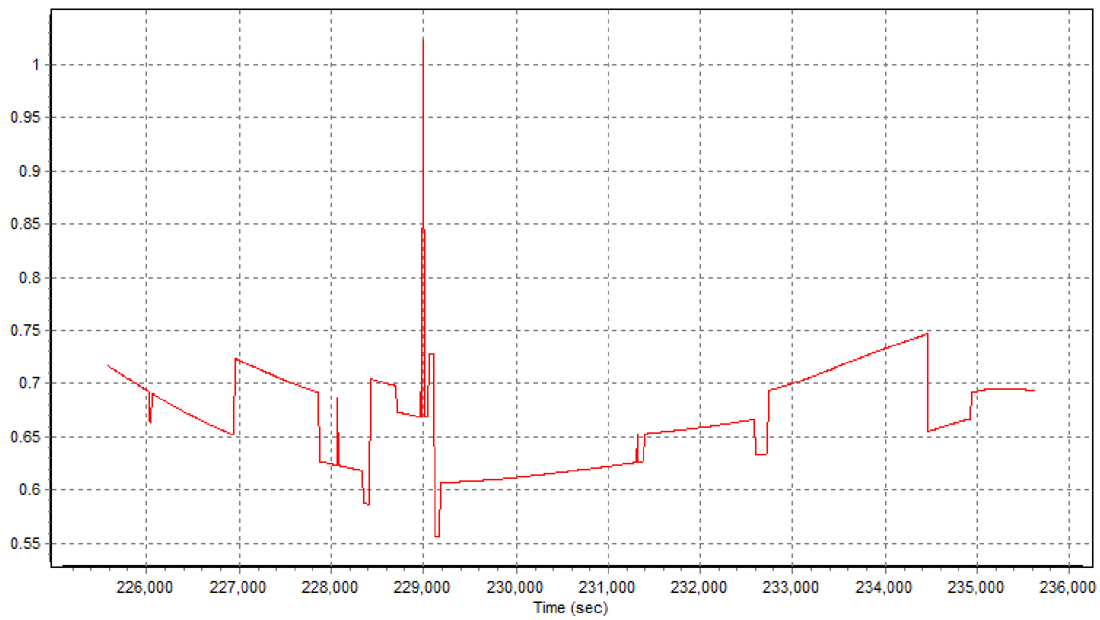


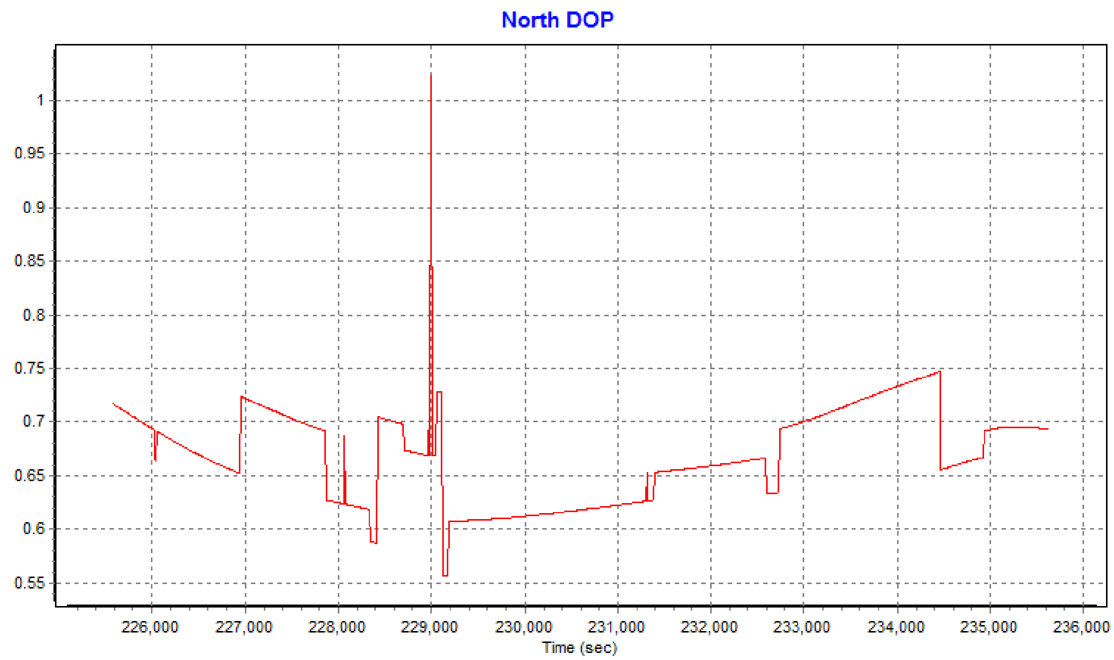
L111610A

Vertical DOP

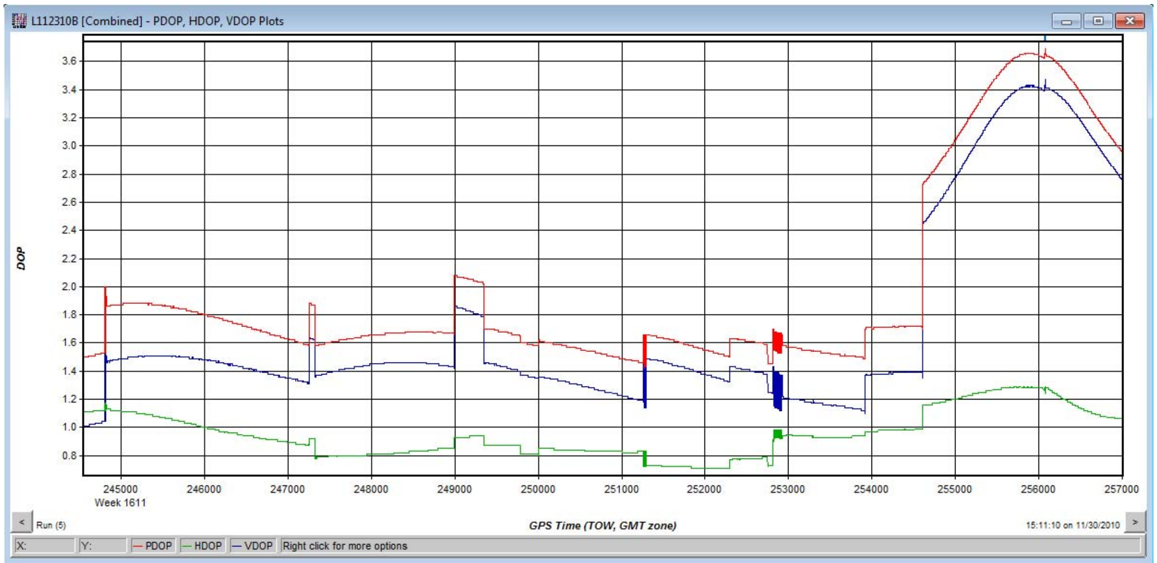


East DOP

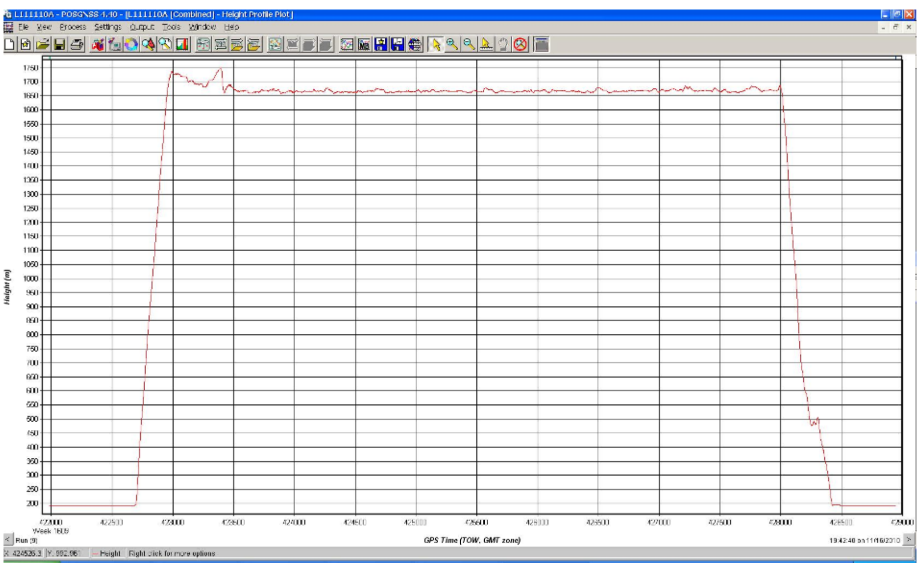


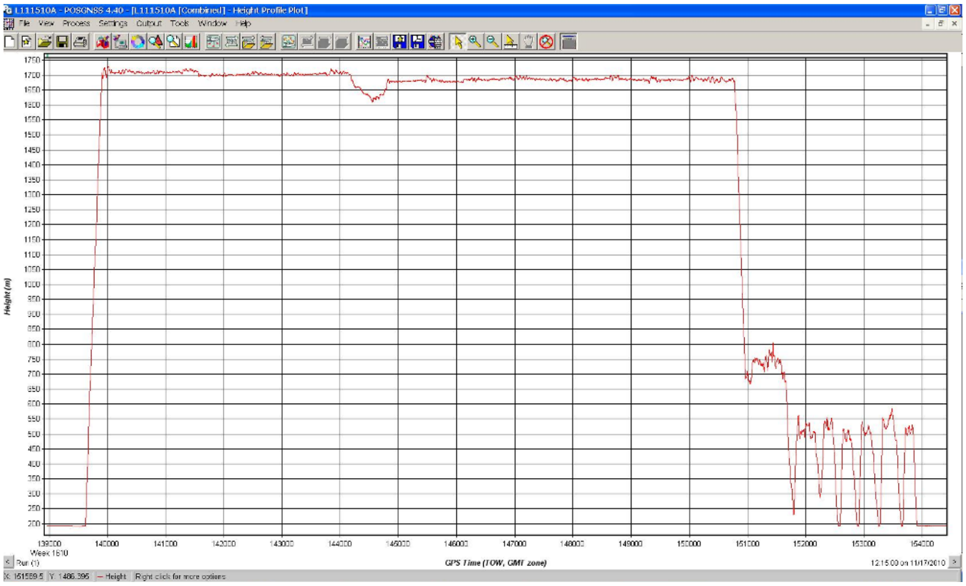

North DOP
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
226,000
227,000
228,000
229,000
230,000
231,000
232,000
233,000
234,000
235,000
236,000
Time (sec)


L111610B [Combined] - PDOP, HDOP, VDOP Plots
DOP
244000
Week 1610
GPS Time (TOW, GMT zone)
Run (4)
07:56:39 on 11/18/2010
X: 243460.7
Y: 3.375
PDOP
HDOP
VDOP
Right click for more options

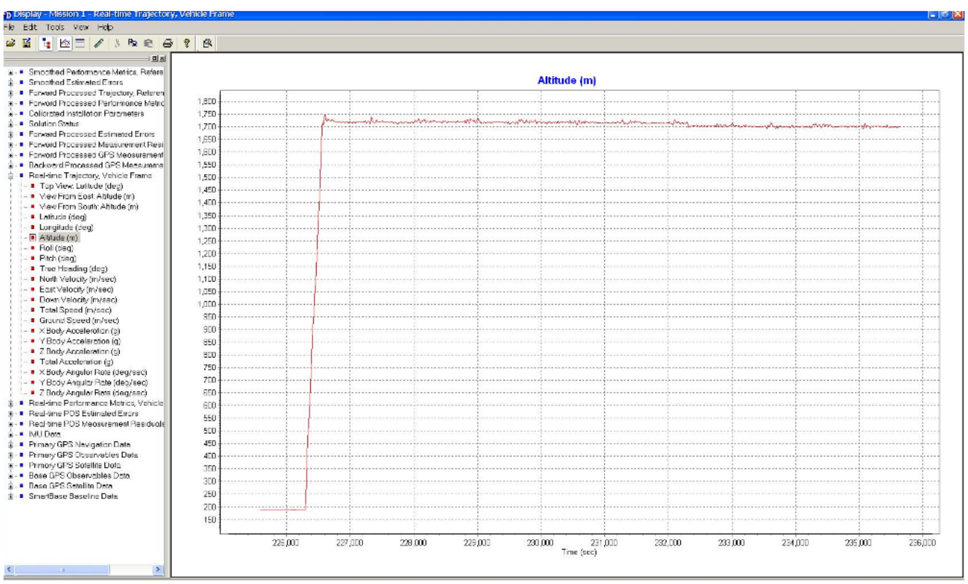


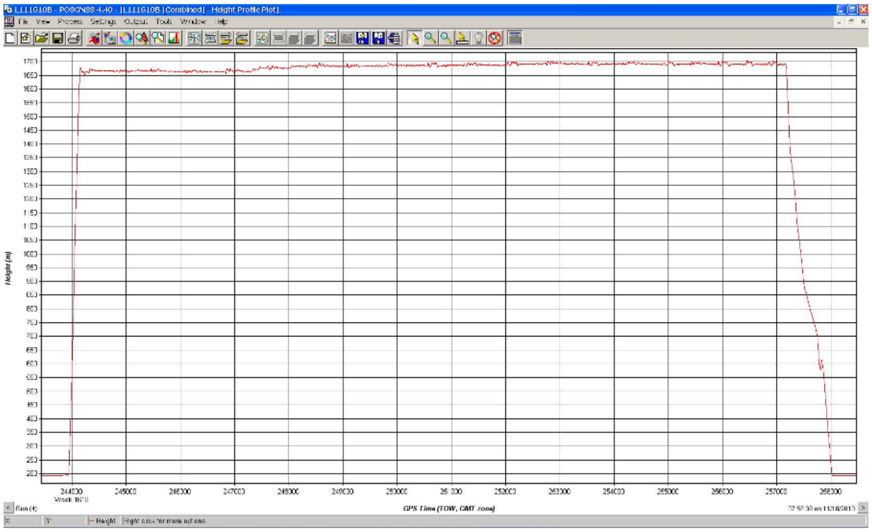
Altitude Plots

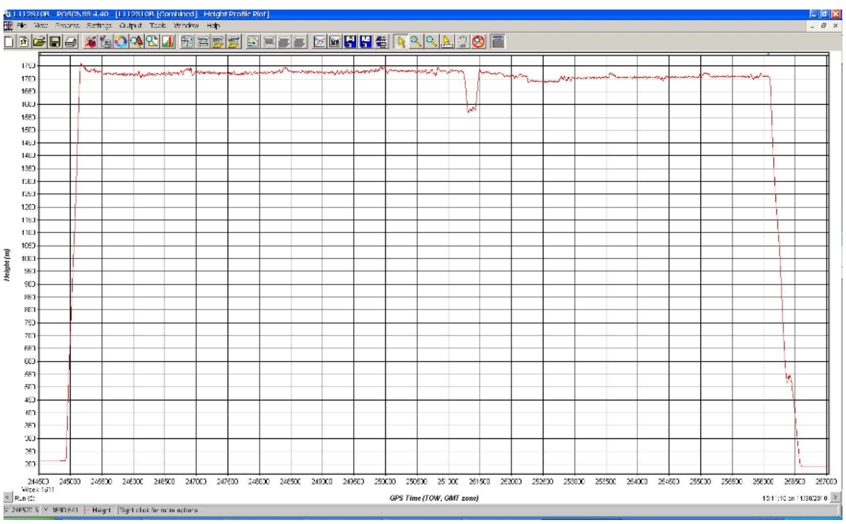




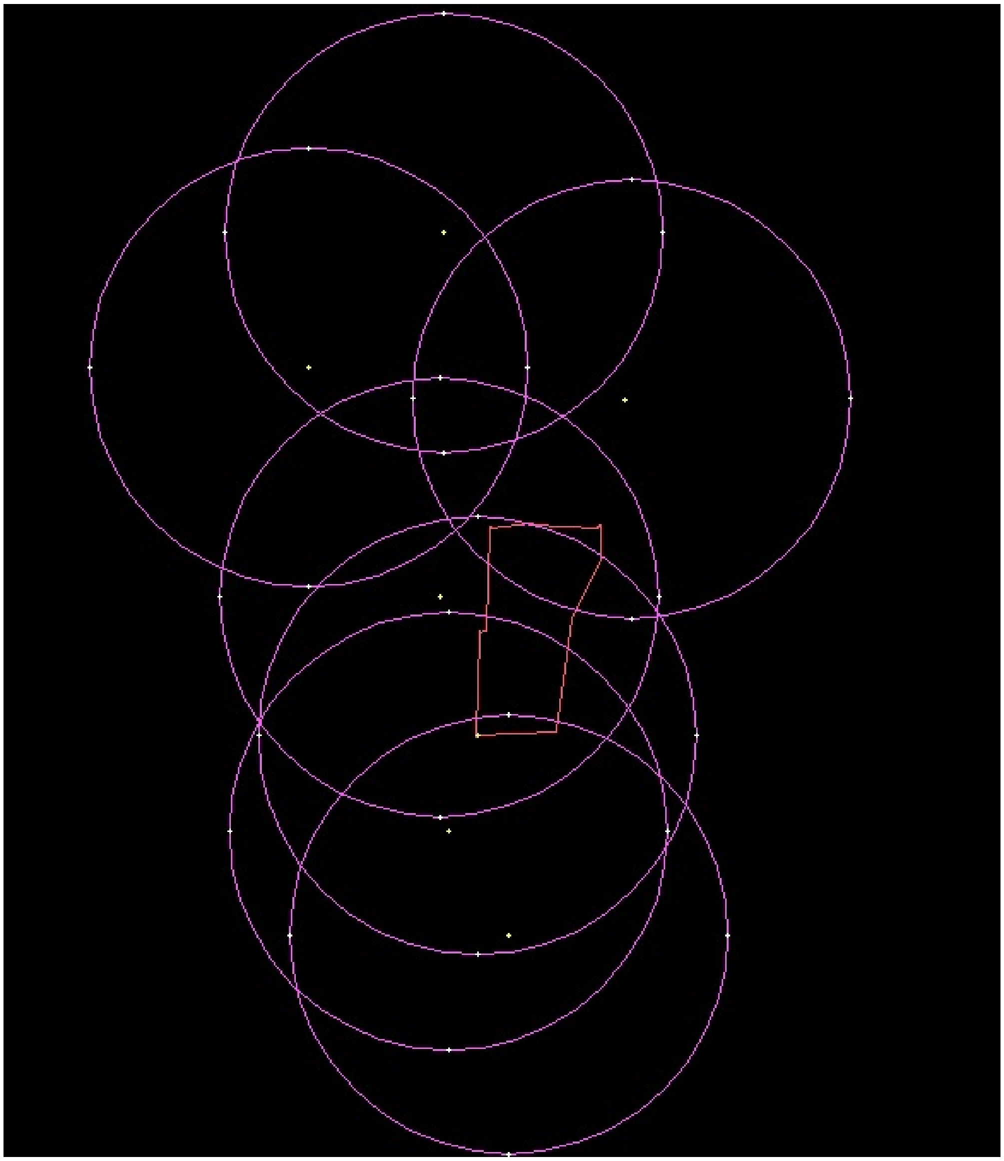
L111610A







The following is the Base Station information as it relates to the project area. The point radius' in the figure below are 40 Kilometers as represented by the purple circles in the graphic.

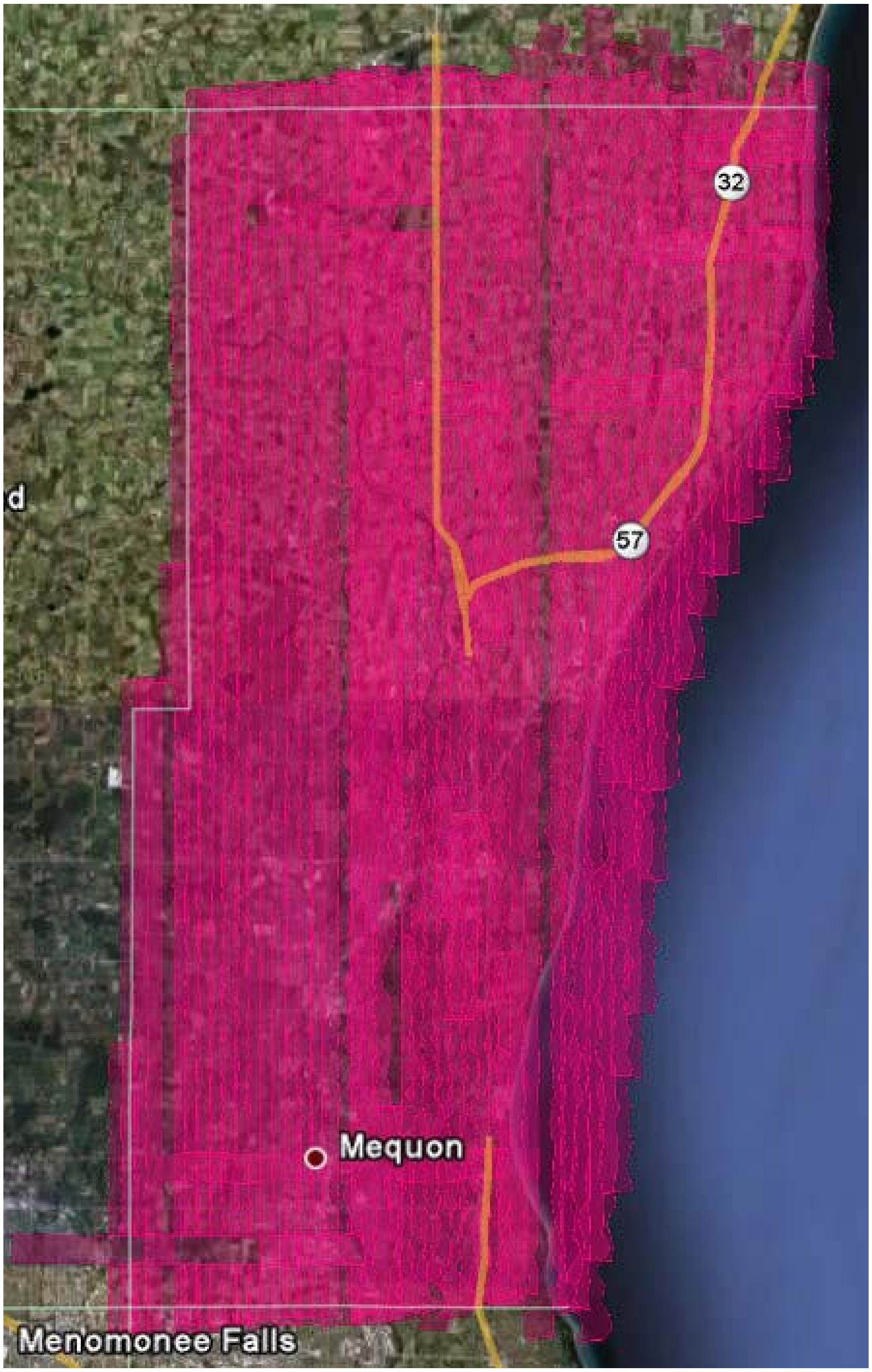


1.7 Coverage

The coverage is verified by file as named: Swath_ozaukee.shp

1.8 Flights – Trajectories

Trajectories file named as: Ozaukee_trajectories.shp



1.9 Flight Logs

Flight logs are provided but some information is standard for the project and is provided below. The system generated and operator flight logs are provided in text format for the system and Tiff format for the operator as listed below. Flight logs are found in Appendix A of this document.

Name	Date modified	Type	Size
11-11-2010@21-13-condensed.txt	11/11/2010 9:52 PM	TXT File	3 KB
11-15-2010@14-36-condensed.txt	11/15/2010 3:52 PM	TXT File	3 KB
11-16-2010@14-34-condensed.txt	11/16/2010 4:58 PM	TXT File	5 KB
11-16-2010@19-33-condensed.txt	11/16/2010 9:45 PM	TXT File	4 KB
11-23-2010@21-46-condensed.txt	11/23/2010 9:21 PM	TXT File	2 KB
1101025L_L111110A.TIF	11/12/2010 6:18 AM	TIFF image	54 KB
1101025L_L111510A.TIF	11/15/2010 12:27 ...	TIFF image	54 KB
1101025L_L111610A_2pgs.TIF	11/16/2010 1:09 PM	TIFF image	84 KB
1101025L_L111610B_2pgs.TIF	11/17/2010 6:14 AM	TIFF image	86 KB
1101025L_L112310B.TIF	11/26/2010 8:27 AM	TIFF image	50 KB

- Flying Height (Above Ground): 1500 meters
- Laser Pulse Rate: 70 kHz
- Mirror Scan Frequency: 40 Hz
- Scan Angle (+/-): 17°
- Side Lap: 50 %
- Ground Speed: 160 kts
- Nominal Point Spacing: 1 meter

2.0 Ground Control and base station layouts

Ground Control layout is provided in Ozaukee_20_Ground_Control.shp.
Base station layouts are provided in GPS_BASE_stations.shp.

2.1 Data Verification/QC Process

The data was verified using the ground control data collected by CompassData, Inc. Twenty Points were distributed throughout the project area and the points were compared to the Lidar data using TerraScan. TerraScan computes the vertical differences between the surveyed elevation and the LiDAR derived elevation for each point.

Results of Process

P:\1101025\Lidar\QAQC\Ozaukee County WI Control\Ozaukee.txt

Number	Easting	Northing	Known Z	Laser Z	Dz
OZK101	417530.639	4819884.546	269.469	269.500	+0.031
OZK102	425583.963	4819958.402	253.539	253.490	-0.049
OZK103	434476.920	4819826.111	212.986	213.040	+0.054
OZK104	416648.260	4813416.014	257.208	257.240	+0.032
OZK105	425538.249	4813475.344	247.350	247.370	+0.020
OZK106	432013.161	4813392.026	222.892	222.820	-0.072
OZK107	417359.047	4807684.542	275.572	275.600	+0.028
OZK108	422882.816	4807480.688	252.728	252.670	-0.058
OZK109	429494.235	4807942.795	229.994	229.970	-0.024
OZK110	415738.901	4802132.862	263.830	263.840	+0.010
OZK111	422866.000	4801483.985	240.400	240.370	-0.030
OZK112	428353.833	4801643.202	212.741	212.890	+0.149
OZK113	415331.605	4795324.114	271.595	271.610	+0.015
OZK114	421007.412	4795618.862	249.777	249.780	+0.003
OZK115	427287.823	4795590.434	215.694	215.750	+0.056
OZK116	415314.967	4789954.860	257.222	257.290	+0.068
OZK117	420805.451	4790106.757	222.059	222.030	-0.029
OZK118	425804.585	4790264.391	212.326	212.330	+0.004
OZK119	414082.744	4784966.722	249.150	249.180	+0.030
OZK120	420062.639	4784534.500	206.629	206.700	+0.071
OZK121	426061.140	4784668.905	212.634	212.640	+0.006

Average dz	+0.015
Minimum dz	-0.072
Maximum dz	+0.149
Average magnitude	0.040
Root mean square	0.051
Std deviation	0.050

Appendix

A. Condensed Flight Logs

B. Original Flight Logs

Flight Log

Project Number: 0
S/N : 0
Operator : ???
Pilot(s) : ???
Aircraft : ???
Airport : ???
Mission : ???
Wheels Up : ???
Flight Length :
HOBBS Start :
HOBBS End :

Weather

Date : November 11, 2010
Julian Day : 315
Temperature : ???
Visibility : ???
Clouds : ???
Precipitation : ???
Wind Dir : ???
Wind Speed : ???
Pressure : ???

Statistics

Laser Time : 00:23:33

START	STOP	LINE#	ALT	PRF	FREQ	ANGLE	MP	DIV	RC	HDG	Plan File
21:30:44.677	21:31:04.078	1	1719	70	40.00	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
21:31:18.878	21:31:33.178	1	1716	70	40.00	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
21:32:19.978	21:34:24.678	1	1680	70	40.00	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
21:39:11.879	21:41:31.879	2	1662	70	40.30	17.00	NAR	OFF	OFF	360.00	Ozaukee_10_23_10_Fixline.pln
21:46:29.08	21:48:56.28	3	1664	70	39.00	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
21:53:15.481	21:55:57.481	4	1662	70	39.00	17.00	NAR	OFF	OFF	360.00	Ozaukee_10_23_10_Fixline.pln
22:00:23.382	22:03:16.583	5	1665	70	39.00	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
22:07:34.583	22:10:36.484	6	1663	70	39.00	17.00	NAR	OFF	OFF	360.00	Ozaukee_10_23_10_Fixline.pln
22:15:10.385	22:18:37.486	7	1666	70	39.00	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
22:22:42.787	22:26:08.187	8	1662	70	39.00	17.00	NAR	OFF	OFF	360.00	Ozaukee_10_23_10_Fixline.pln
22:51:27.393	22:52:38.694	1	1670	70	39.00	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln

Flight Log

Project Number: 0
S/N : 0
Operator : ???
Pilot(s) : ???
Aircraft : ???
Airport : ???
Mission : ???
Wheels Up : ???
Flight Length :
HOBBS Start :
HOBBS End :

Weather

Date : November 15, 2010
Julian Day : 319
Temperature : ???
Visibility : ???
Clouds : ???
Precipitation : ???
Wind Dir : ???
Wind Speed : ???
Pressure : ???

Statistics

Laser Time : 01:37:39

START	STOP	LINE#	ALT	PRF	FREQ	ANGLE	MP	DIV	RC	HDG	Plan File
14:52:06.757	14:52:16.657	10	1719	70	40.00	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
14:52:28.857	14:52:33.957	10	1719	70	40.00	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
14:52:28.857	14:56:09.757	10	1704	70	40.00	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
15:00:47.157	15:04:23.857	11	1706	70	40.00	17.00	NAR	OFF	OFF	360.00	Ozaukee_10_23_10_Fixline.pln
15:09:34.657	15:13:39.657	12	1710	70	40.00	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
15:18:09.558	15:22:34.858	13	1696	70	40.00	17.00	NAR	OFF	OFF	360.00	Ozaukee_10_23_10_Fixline.pln
15:27:18.858	15:33:08.759	14	1701	70	40.00	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
15:37:06.259	15:43:02.26	15	1702	70	40.00	17.00	NAR	OFF	OFF	360.00	Ozaukee_10_23_10_Fixline.pln
15:48:17.66	15:55:22.961	16	1707	70	40.00	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
16:01:10.962	16:08:18.963	17	1628	70	40.00	17.00	NAR	OFF	OFF	360.00	Ozaukee_10_23_10_Fixline.pln
16:15:03.364	16:23:23.965	18	1681	70	40.00	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
16:26:27.166	16:34:33.367	19	1675	70	40.00	17.00	NAR	OFF	OFF	360.00	Ozaukee_10_23_10_Fixline.pln
16:39:55.168	16:48:08.17	20	1687	70	40.00	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
16:53:39.271	17:01:47.672	21	1682	70	40.00	17.00	NAR	OFF	OFF	360.00	Ozaukee_10_23_10_Fixline.pln
17:08:35.274	17:17:04.576	22	1687	70	40.00	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
17:19:58.876	17:28:07.578	23	1682	70	40.00	17.00	NAR	OFF	OFF	360.00	Ozaukee_10_23_10_Fixline.pln

17:31:16.679	17:39:36.081	24	1687	70	40.00	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
17:49:27.683	17:51:48.484	9	1678	70	40.00	17.00	NAR	OFF	OFF	360.00	Ozaukee_10_23_10_Fixline.pln

Flight Log

Project Number: 1101025
S/N : Ozaukee County
Operator : Jim
Pilot(s) : Glen
Aircraft : N73TM
Airport : KSBM
Mission : L111610A
Wheels Up : ???
Flight Length : 4.3
HOBBS Start : 14:40
HOBBS End : 19:01

Weather

Date : November 16, 2010
Julian Day : 320
Temperature : ???
Visibility : 4
Clouds : BKN-OVC 6K
Precipitation : ???
Wind Dir : ???
Wind Speed : ???
Pressure : ???

Statistics

Laser Time : 02:15:41

START	STOP	LINE#	ALT	PRF	FREQ	ANGLE	MP	DIV	RC	HDG	Plan File
14:56:33.763	14:57:06.063	25	1725	70	40.30	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
14:57:15.663	14:57:36.063	25	1731	70	40.30	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
14:58:43.263	15:06:52.764	25	1720	70	39.00	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
15:11:57.865	15:19:31.965	26	1719	70	39.00	17.00	NAR	OFF	OFF	360.00	Ozaukee_10_23_10_Fixline.pln
15:24:33.666	15:32:32.367	27	1721	70	39.60	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
15:38:39.268	15:46:43.87	28	1717	70	39.60	17.00	NAR	OFF	OFF	360.00	Ozaukee_10_23_10_Fixline.pln
15:52:30.671	16:00:32.072	29	1721	70	39.60	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
16:04:33.673	16:12:34.374	30	1716	70	39.60	17.00	NAR	OFF	OFF	360.00	Ozaukee_10_23_10_Fixline.pln
16:18:29.876	16:26:39.977	31	1714	70	39.60	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
16:30:39.178	16:38:39.58	32	1703	70	39.60	17.00	NAR	OFF	OFF	360.00	Ozaukee_10_23_10_Fixline.pln
16:43:45.781	16:51:39.783	33	1703	70	39.60	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
16:55:43.284	17:03:48.086	34	1699	70	39.60	17.00	NAR	OFF	OFF	360.00	Ozaukee_10_23_10_Fixline.pln
17:09:01.388	17:17:00.59	35	1701	70	39.60	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
17:21:16.991	17:29:16.593	36	1699	70	39.60	17.00	NAR	OFF	OFF	360.00	Ozaukee_10_23_10_Fixline.pln
17:33:58.094	17:41:58.896	37	1698	70	39.60	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
17:45:49.897	17:53:55.199	38	1695	70	39.60	17.00	NAR	OFF	OFF	360.00	Ozaukee_10_23_10_Fixline.pln

17:58:21.9	18:06:32.603	39	1708	70	39.60	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
18:10:47.404	18:13:34.605	24	1709	70	39.60	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
18:18:27.106	18:19:35.206	38	1705	70	39.60	17.00	NAR	OFF	OFF	360.00	Ozaukee_10_23_10_Fixline.pln
18:18:27.106	18:19:36.606	38	1705	70	39.60	17.00	NAR	OFF	OFF	360.00	Ozaukee_10_23_10_Fixline.pln
18:20:24.106	18:23:11.107	35	1705	70	39.60	17.00	NAR	OFF	OFF	360.00	Ozaukee_10_23_10_Fixline.pln
18:24:33.108	18:26:21.008	39	1707	70	39.60	17.00	NAR	OFF	OFF	360.00	Ozaukee_10_23_10_Fixline.pln
18:30:59.309	18:32:14.31	37	1713	70	39.60	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
18:33:21.81	18:34:20.71	33	1711	70	39.60	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
18:35:33.911	18:36:26.811	29	1712	70	39.60	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
18:40:45.612	18:42:06.712	28	1713	70	39.60	17.00	NAR	OFF	OFF	360.00	Ozaukee_10_23_10_Fixline.pln
18:43:15.413	18:44:56.913	26	1713	70	39.60	17.00	NAR	OFF	OFF	360.00	Ozaukee_10_23_10_Fixline.pln
18:45:49.313	18:46:59.314	24	1712	70	39.60	17.00	NAR	OFF	OFF	360.00	Ozaukee_10_23_10_Fixline.pln

Flight Log

Project Number: 1101025
S/N : Ozaukee County
Operator : Jim
Pilot(s) : Cam
Aircraft : N73TM
Airport : KSBM
Mission : L111610B
Wheels Up : ???
Flight Length : 4.2
HOBBS Start : 19:37
HOBBS End : 23:48

Weather

Date : November 16, 2010
Julian Day : 320
Temperature : ???
Visibility : 4
Clouds : Hi thick cirrus
Precipitation : ???
Wind Dir : ???
Wind Speed : ???
Pressure : ???

Statistics

Laser Time : 02:04:19

START	STOP	LINE#	ALT	PRF	FREQ	ANGLE	MP	DIV	RC	HDG	Plan File
19:51:40.618	19:52:00.918	16	1670	70	39.60	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
19:52:32.318	19:52:54.718	16	1665	70	39.60	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
19:56:45.219	19:58:09.719	16	1664	70	39.60	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
20:03:38.221	20:05:13.321	35	1664	70	39.60	17.00	NAR	OFF	OFF	360.00	Ozaukee_10_23_10_Fixline.pln
20:12:53.123	20:21:07.525	40	1659	70	39.60	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
20:25:24.426	20:33:45.028	41	1657	70	39.60	17.00	NAR	OFF	OFF	360.00	Ozaukee_10_23_10_Fixline.pln
20:38:20.329	20:46:36.231	42	1674	70	39.60	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
20:50:18.432	20:58:40.434	43	1675	70	39.60	17.00	NAR	OFF	OFF	360.00	Ozaukee_10_23_10_Fixline.pln
21:02:52.135	21:11:01.737	44	1681	70	39.60	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
21:15:00.538	21:23:16.24	45	1682	70	39.60	17.00	NAR	OFF	OFF	360.00	Ozaukee_10_23_10_Fixline.pln
21:27:27.241	21:35:45.443	46	1683	70	39.60	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
21:39:34.244	21:47:45.447	47	1683	70	39.60	17.00	NAR	OFF	OFF	360.00	Ozaukee_10_23_10_Fixline.pln
21:51:45.548	22:00:06.65	48	1684	70	39.60	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
22:04:17.151	22:12:30.153	49	1688	70	39.60	17.00	NAR	OFF	OFF	360.00	Ozaukee_10_23_10_Fixline.pln
22:16:44.754	22:25:08.556	50	1688	70	39.60	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
22:29:00.957	22:37:02.659	51	1687	70	39.60	17.00	NAR	OFF	OFF	360.00	Ozaukee_10_23_10_Fixline.pln

22:43:11.461	22:48:19.062	52	1685	70	39.60	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
22:52:15.464	22:56:41.565	53	1688	70	39.60	17.00	NAR	OFF	OFF	360.00	Ozaukee_10_23_10_Fixline.pln
23:00:39.366	23:04:57.967	54	1688	70	39.60	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
23:09:07.168	23:13:34.569	55	1689	70	39.60	17.00	NAR	OFF	OFF	360.00	Ozaukee_10_23_10_Fixline.pln
23:18:17.571	23:20:10.071	56	1687	70	39.60	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln
23:23:11.672	23:25:32.672	39	1689	70	39.60	17.00	NAR	OFF	OFF	180.00	Ozaukee_10_23_10_Fixline.pln

Flight Log

Project Number: 1101025
S/N : Ozaukee
Operator : Jim
Pilot(s) : Cam
Aircraft : N73TM
Airport : KJVL/KSBM
Mission : L112310B
Wheels Up : ???
Flight Length : 3.5
HOBBS Start : 19:55
HOBBS End : 23:24

Weather

Date : November 23, 2010
Julian Day : 327
Temperature : ???
Visibility : ???
Clouds : ???
Precipitation : ???
Wind Dir : ???
Wind Speed : ???
Pressure : ???

Statistics

Laser Time : 00:44:11

START	STOP	LINE#	ALT	PRF	FREQ	ANGLE	MP	DIV	RC	HDG	Plan File
21:52:22.166	21:52:52.266	35	1720	70	39.60	17.00	NAR	OFF	ON	360.00	Ozaukee_10_23_10_Fixline.pln
21:52:22.166	21:52:54.866	35	1721	70	39.60	17.00	NAR	OFF	ON	360.00	Ozaukee_10_23_10_Fixline.pln
22:03:52.968	22:12:35.171	35	1685	70	39.00	17.00	NAR	OFF	ON	360.00	Ozaukee_10_23_10_Fixline.pln
22:16:06.872	22:24:29.374	36	1699	70	39.00	17.00	NAR	OFF	ON	180.00	Ozaukee_10_23_10_Fixline.pln
22:28:45.575	22:37:23.377	37	1701	70	39.00	17.00	NAR	OFF	ON	360.00	Ozaukee_10_23_10_Fixline.pln
22:40:57.078	22:49:18.08	38	1701	70	39.00	17.00	NAR	OFF	ON	180.00	Ozaukee_10_23_10_Fixline.pln
22:54:05.681	23:02:45.983	39	1696	70	39.00	17.00	NAR	OFF	ON	360.00	Ozaukee_10_23_10_Fixline.pln
23:06:16.884	23:07:33.084	35	1702	70	39.60	17.00	NAR	OFF	ON	360.00	Ozaukee_10_23_10_Fixline.pln

LIDAR FLIGHT LOG

ALTM

RB1

MISSION: L111110A **DATE:** 11-10-2010 Veteran's Day

PILOT: CAM/KELLY **OPERATOR:** R. BOLL **AIRCRAFT:** 73TM

PROJECT NUMBER	LINE NO. & Hdg	GND SPEED (KTS)	SCAN FREQ	SCAN ANGLE	PRF	ALT (m)	TIME START	TIME STOP	Tranzpak Drive	REMARKS
1101025	—	—	≈40	17	70	1500m	2114	2120	180	STATIC / T/O SBM
Ozaukee	2 Test Fixes	152	39.3				2130	2132		
Fema Lidar	1 S	157	38.3				2132	2134		
	2 W	152	40.3				2139	2141		
29"	3 S	155	39.0				2146	2148		
23"	4 N	155	39.0				2153	2155		
	5 S	155	39.0				2200	2203		
	6 W	155	39.0				2207	2210		
	7 S	155	39.0				2215	2218		
	8 N	155	39.0				2222	2226		
	9 S	155	39.0				2230	2234		Virga (Laser shut off on after line)
	56 S	153	39.0				—	—		move west side prj (Rain)
East	X Tie	153	39.0				2246	2247		eye safe shut off
West	X Tie	153	39.0				2251	2252		
							2304	2309		LAND SBM / STATIC

STATUS	TOTAL LINES	FLOWN	LEFT	AIRCRAFT SITE	AIRCRAFT FERRY	STATIC START:	STATIC STOP:	NOTES:
1101025	56	9	45	1.7	—	2114	2309	
						WX OVC 6500 LT RN Devl'pd		

AERO-METRIC, INC. N.6216 Resource Drive Sheboygan Falls, WI. 53085 PHONE: 920-467-2655 **FAX: 920-457-1451** E-Mail: amephoto@aerometric.com

LIDAR FLIGHT LOG

ALTM

RB1

MISSION: L111510A
DATE: 11-15-2010

PILOT: G. Howe / J. Billington
OPERATOR: R. Boll
AIRCRAFT: 73TM

PROJECT NUMBER	LINE NO. & Hdg		GND SPEED (KTS)	SCAN FREQ	SCAN ANGLE	PRF	ALT (m)	TIME START	TIME STOP	Tranzpak Drive	REMARKS
1101025				40	17	70	1500m	1436	1441	180	STATIC / I/O SBM
Ozaukee	Test							1452			
Fema LIDAR	10	S	160	40	17	70	1500	1452	1456		
	11	N	165	40				1500	1504		
	12	S	165	40				1509	1513		
	13	N	165	40				1518	1522		
	14	S	165	40				1527	1533		
	15	N	165	40				1537	1543		
	16	S	165	40				1548	1555		
	17	N	165	40				1601	1608		
	18	S	165	40				1615	1623		
	19	N	165	40				1626	1634		
	20	S	165	40				1639	1648		
	21	N	165	40				1653	1701		
	22	S	165	40				1708	1717		
	23	N	165	40				1720	1728		
	24	S	165	40				1731	1739		
	25	N	165	40				1742	1749		Cu / no good Line
	X	Tie	165	40				1749	1751		
								1849	1854		Land SBM / STATIC

STATUS	TOTAL LINES	FLOWN	LEFT	AIRCRAFT SITE	AIRCRAFT FERRY	STATIC	START:	STOP:	NOTES:
1101025	56	15	32	4.0	—		1436	1854	
						WX High Cloud → Cu forming → LyR @ 5500 moved in			

LIDAR FLIGHT LOG

ALTM

J51

MISSION: L111610A
DATE: 11-16-10 TUE
PILOT: GLEN H.
OPERATOR: JIM
AIRCRAFT: N73TM

PROJECT NUMBER	LINE NO.	& Hdg	GND SPEED (KTS)	SCAN FREQ	SCAN ANGLE	PRF	ALT (m)	TIME START	TIME STOP	Tranzpak Drive	REMARKS
1101025							GMT	14:40	14:56	180	FERRY: SBM → SITE .2
OZAUKEE CO.	TEST				17	70	1500	14:56	14:57		
	TEST							14:57	14:57		
	25	180	155	39				14:58	15:06		
	26	360						15:11	15:19		
	27	180	160	39.6				15:24	15:32		
	28	360						15:38	15:46		
	29	180						15:52	16:00		
	30	360						16:04	16:12		
	31	180						16:18	16:26		
	32	360						16:30	16:38		
	33	180						16:43	16:51		
	34	360						16:55	17:03		
	35	180						17:09	17:17		
	36	360						17:21	17:29		
	37	180						17:33	17:41		
	38	360						17:45	17:53		
	39	180						17:58	18:06		
	CROSS	E						18:10	18:13		
	38.5	360						18:18	18:19		GAP AREAS → J52

STATUS	TOTAL LINES	FLOWN	LEFT	AIRCRAFT SITE	AIRCRAFT FERRY	STATIC	START:	STOP:	NOTES:
Ø 1101025						4.3	14:40	19:01	
Ø OZAUKEE	56	39	17	3.9	.4	BKN 6K TO OVC	VIS 4.5		
O									

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LIDAR FLIGHT LOG

ALTM | JS2

MISSION: L111610A **DATE:** 11-16-10 TUE

PILOT: GLEN H. **OPERATOR:** JIM **AIRCRAFT:** N73TM

PROJECT NUMBER	LINE NO. & Hdg		GND SPEED (KTS)	SCAN FREQ	SCAN ANGLE	PRF	ALT (m)	TIME START	TIME STOP	Tranzpak Drive	REMARKS
110025	35.5	360	160	39.6	17	70	GMT	18:20	18:23	180	GAP AREAS
OZAUKEE CO.	39	360						18:24	18:26		" "
	37	180						18:30	18:32		" "
	33.5	180						18:33	18:34		
	29.5	180						18:35	18:36		
	28.5	360						18:40	18:42		
	26.5	360						18:43	18:44		
	24.5	360						18:45	18:47		
									19:01		FERRY: SITE → SBM .2

STATUS	TOTAL LINES	FLOWN	LEFT	AIRCRAFT SITE	AIRCRAFT FERRY	STATIC START:	STATIC STOP:	NOTES:
						WX		

LIDAR FLIGHT LOG

ALTM J53

MISSION: L111610B **DATE:** 11-16-10 TUE

PILOT: CAM **OPERATOR:** JIM **AIRCRAFT:** N73TM

PROJECT NUMBER	LINE NO.	& Hdg	GND SPEED (KTS)	SCAN FREQ	SCAN ANGLE	PRF	ALT (m)	TIME START	TIME STOP	Tranzpak Drive	REMARKS
1101025							GMT	19:37	19:51	081	FERRY: SBA → SITE .2
OZAUKEE CO.	TEST		160	39.6	17	70	1500	19:51	19:52		
	TEST							19:52	19:52		
	16.5	180						19:52	19:58		GAP AREA (43:21:39, 87:52:06)
	35	360						20:03	20:05		GAP AREA (43:16 - 43:18)
	40	180						20:12	20:21		
	41	360						20:25	20:33		
	42	180						20:38	20:46		
	43	360						20:50	20:58		
	44	180						21:03	21:11		
	45	360						21:15	21:23		
	46	180						21:27	21:35		
	47	360						21:39	21:47		
	48	180						21:51	22:00		
	49	360						22:04	22:12		
	50	180						22:16	22:25		
	51	360						22:29	22:37		
	52	180						22:43	22:48		
	53	360						22:52	22:56		
	54	180						23:00	23:04		→ J54

STATUS		TOTAL LINES	FLOWN	LEFT	AIRCRAFT SITE	AIRCRAFT FERRY
⊘	1101025	[illegible]				
⊗	OZAUKEE	56	56	Ø	3.6	.6
○						

STATIC	START:	STOP:
4.2	19:37	23:48

WX HIGH THICK CIRRUS

VIS 14

NOTES:

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LIDAR FLIGHT LOG

ALTM

J54

MISSION: L111610B **DATE:** 11-16-10 TUE

PILOT: CAM **OPERATOR:** JIM **AIRCRAFT:** N73TM

PROJECT NUMBER	LINE NO.	& Hdg	GND SPEED (KTS)	SCAN FREQ	SCAN ANGLE	PRF	ALT (m)	TIME START	TIME STOP	Tranzpak Drive	REMARKS
1101025	55	360	160	39.6	17	70	1500	23:09	23:13	081	
OZAUKEE CO.	56	180	↓	↓	↓	↓	↓	23:18	23:20		
	CROSS	E	↓	↓	↓	↓	↓	23:23	23:25		
									23:48		FERRY: SITE → SBM .4

STATUS	TOTAL LINES	FLOWN	LEFT	AIRCRAFT SITE	AIRCRAFT FERRY	STATIC	START:	STOP:	NOTES:
○									
○						WX			
○									

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LIDAR FLIGHT LOG

ALTM | J53

MISSION: L112310B | **DATE:** 11-23-10 TUE

PILOT: CAM | **OPERATOR:** JIM | **AIRCRAFT:** N73TM

PROJECT NUMBER	LINE NO.	& Hdg	GND SPEED (KTS)	SCAN FREQ	SCAN ANGLE	PRF	ALT (m)	TIME START	TIME STOP	Tranzpak Drive	REMARKS
1101025							GMT	19:55	20:04	008 WD9564	FERRY: JVL → SITE .2
Rock	TEST				17	70	1500	20:06	20:07		
	TEST							20:07	20:07		
	12	360	155	39.0				20:11	20:20		
	13	180						20:23	20:32		
	14	360						20:36	20:45		
	15	180						20:49	20:58		
	16	360						21:02	21:11		
	17	180						21:15	21:23		
	18	360						21:28	21:37		
	CROSS	E	160	39.6				21:41	21:42		
OZAUKEE	[redacted]										
	TEST							21:52	21:52		
	35	360	155	39.0				22:03	22:12		
	36	180						22:16	22:24		
	37	360						22:28	22:37		
	38	180						22:40	22:49		
	39	360						22:54	23:02		
	CROSS	E	160	39.6				23:06	23:07		.3
									23:24		FERRY: SITE → SBM

STATUS		TOTAL LINES	FLOWN	LEFT	AIRCRAFT SITE	AIRCRAFT FERRY	STATIC	START:	STOP:	NOTES:
⊘	1101025	[redacted]					3.5	19:55	23:24	
⊘	Rock	92	53	39	1.6	.2	WX SKC VIS 10			
⊗	OZAUKEE	5 RETS	5	Ø	1.4	.3				

AERO-METRIC, INC. N.6216 Resource Drive Sheboygan Falls, WI. 53085 PHONE: 920-467-2655 FAX: 920-457-1451 E-Mail: amephoto@aerometric.com

Appendix F: Quality Assurance

Project Information

Project Name:	Ozaukee, WI	
Project Description:	Region 5 County wide LiDAR collection for Ozaukee County Wisconsin	
State:	Wisconsin	
HUC-8:		
Provider Name:	Aerometric/Tuck Mapping Solutions	
Collection Area:	248 square miles	
Specification Level:	Highest	
Contour Accuracy:	2ft	
NPS:	1 meter	
Media:	Portable Hard Drive	
Contents of Media:	DGN directory	
	Report Directory	
	Swath Directory	Ozaukee_seed.dgn
	Tiled_LAS Directory	65 page pdf report
		Flight Line LAS files
		LAS tiles
Reviewed By:	Dan Hoff	
Point of Contact:	Robert Merry	rmerry@aerometric.com

Post Flight Report

	Included	Comments
GPS Base Station INFO		
GPS base station - names	Y	
GPS base station - lat/longs	Y	
GPS base station - heights	Y	
GPS base station - Maximum PDOP	Y	
GPS base station - map	Y	
GPS base station - spatial data	Y	Not projected

GPS/IMU		
GPS quality - Max horizontal variance (cm).	Y	section 1.6 in graphs
GPS quality - Max vertical variance (cm).	Y	section 1.6 in graphs
GPS quality - Notes on GPS quality	Y	good to High
GPS quality - GPS separation plot	Y	
GPS quality - GPS altitude plot	Y	
GPS quality - PDOP plot	Y	
GPS quality - Plot of GPS distance from base stations	Y	
Coverage		
Coverage - Verification of AOI coverage	Y	
Coverage - Spatial data	Y	
Flights		
Flights - Calibration lines	Y	Attributes in the provided trajectory shapefile should specify each line type
Flights - As-flown trajectories	Y	Attributes in the provided trajectory shapefile should specify each line type
Flights - Spatial data	Y	Please improve attribution of trajectory data.
Control		
Control - Ground control and base station layout	Y	
Control - Spatial data	Y	Data was not projected
Data verification/QC		
Data verification process documented	Y	

Flight logs	Included	Comments
Incorporated as appendix	Y	
Job # / name	Y	
Lift #	Y	The mission number
Block or AOI designator	Y	
Date	Y	
Aircraft tail number, type	Y	
Pilot name	Y	
Operator name	Y	
Airport of operations	Y	
GPS base station names	Y	Included in the report, FEMA PM61 table 4.2 has them listed as part of the flight log
Flight lines		
Flight line	Y	
Line #	Y	
Direction	Y	
Start/stop	Y	
Altitude	Y	
Scan angle/rate	Y	
Speed	Y	
Conditions	Y	
Comments	Y	
Settings		
AGC switch setting	N/A	Automatic Gain Control…older systems
Laser pulse rate	Y	
Mirror rate	Y	
Field of view	Y	Double the scan angle is the field of view, please add to summary
Comments	Y	

Point File Information QC

LAS Version:	1.2	
Total Number of Tiles:	222	
Number of tiles to be reviewed:	**12**	

All LAS

Coverage Area SqMi	303.217475	From LAS boundary
Voids or Gaps	Pass	
Average Point Spacing	0.813	LASinfo mean
QC tiles with NPS > Spec Level	Pass	greater than 1 only on edge/over lake

5% LAS Review

Tile selection	Y	Included in .gdb
LASinfo	Y	Included in .gdb
LAS2DEM	Y	100% review, not included in .gdb

LAS Point Cloud Files

Macro Review	Pass/Fail	Comments
Projection	P	
Datum	P	
Units	P	Vertical units in meters
Area covered 100m buffer	P	
Data Voids	P	
Correct Header	P	
Correct NPS	P	
Returns Contain		
GPS time stamp	P	
GPS second in microsec	P	
Easting	P	
Northing	P	
Elevation	P	
Intensity	P	
Return #	P	
Classification	P	
Classification is correct	P	
Cloud file structure conforms to layout	P	
Cloud file naming conforms to project	P	
Tiles checked for gaps and voids	P	

Micro Review

Total Number of Tiles:		222
Number of tiles to be reviewed:		**12**

	Pass/Fail	
Excessive Noise	P	
Elevation Steps	P	
LP360 Scan and profile	P	LP360 ArcGIS Extension Used for Visual QA

LAS Bare Earth	Pass/Fail	Comments
Macro Review	Pass/Fail	Comments
Projection	P	
Datum	P	
Units	P	Meter
Area covered 100m buffer	P	
Data Voids	P	No data areas only within small bodies of water.
Correct Header	P	
Correct NPS	P	
Returns Contain		
GPS time stamp	P	
GPS second in microsec	P	
Easting	P	
Northing	P	
Elevation	P	
Intensity	P	
Return #	P	
Classification	P	
Classification is correct	P	
Cloud file structure conforms to layout	P	
Cloud file naming conforms to project	P	
Tiles checked for gaps and voids	P	No data areas only within small bodies of water.

Micro Review

Total Number of Tiles:		121
Number of tiles to be reviewed:		6
	Pass/Fail	
Excessive Noise	P	
Elevation Steps	P	
2% Artifacts	P	
LP360 Scan and profile	P	

Appendix G: Deliverables

Appendix H: Guidance

U.S. Department of Homeland Security
500 C Street, SW
Washington, DC 20472

FEMA

DATE

MEMORANDUM FOR: Mitigation Division Directors Regions I-X, CTPs, Mapping Partners

FROM: Doug Bellomo, Director
Risk Analysis Division

SUBJECT: Procedure Memorandum No. XX—Standards for Lidar and Other High Quality Digital Topography

EFFECTIVE DATES: August 1, 2010

Background: Beginning in Fiscal Year (FY) 2010, Federal Emergency Management Agency (FEMA) initiated a five-year program for Risk Mapping, Assessment, and Planning (Risk MAP). FEMA's vision for the Risk MAP program is to deliver quality data that increases public awareness and leads to mitigation actions that reduce risk to life and property. To achieve this vision, FEMA will transform its traditional flood identification and mapping efforts into a more integrated process of accurately identifying, assessing, communicating, planning for, and mitigating flood risks.

Under Risk MAP, FEMA seeks to:

- Deliver new data and products that expand risk awareness and promote mitigation planning that leads to risk reduction actions.
- Increase production efficiencies for Flood Insurance Rate Maps (FIRMs) and Flood Insurance Studies (FISs).

Issue: To implement FEMA's Risk MAP vision and provide the high quality topographic data necessary to meet Risk MAP's goals, FEMA Regions and Mapping Partners need upgraded guidance concerning the accuracy, and processing of high quality topographic data including Light Detection and Ranging (lidar) data. To that end, this Procedure Memorandum will supersede Appendix A: Guidance for Aerial Mapping and Surveying of the *Guidelines and Specifications for Flood Hazard Mapping Partners* (Guidelines) in key areas (defined in the Procedure Memorandum Attachments), and must be implemented beginning with all topographic data collected by FEMA beginning in FY 2010.

Actions Taken: When procuring topographic data under the Risk MAP Program the Mapping Partner assigned to obtain topographic data or perform independent QA of topographic data must meet the specifications detailed in this Procedure Memorandum's attachments. The attachments align FEMA's high quality topographic specifications, found in Appendix A of the Guidelines, with the United States Geological Survey (USGS) *Lidar Guidelines and Base Specifications* v13 so that data procured and used by the Federal government is consistent across agencies and is updated to industry standards. Further, adherence to these specifications will support the Risk MAP Program by closing gaps in existing flood hazard data; supporting risk assessments; and better communicating risks to community officials and the public.

Existing elevation data, not acquired by FEMA, but planned for use on a new flood hazard analysis must comply with the accuracy, density and the final product metadata requirements detailed in the attachments and, but is not required to comply with the other specifications included and referenced below.

Consistent with FEMA's overall approach to flood hazard identification, this Procedure Memorandum aligns FEMA topographic data specifications to level of risk, and accounts for different slopes in the terrain that can affect the accuracy of base flood elevations and the delineation of mapped floodplains. These specifications represent the minimum requirements. Where funding partners are involved or where the engineering requirements dictate, projects may use higher specification levels or include additional processing. Quality assurance requirements for high quality topographic data are also provided.

Attachments:
Attachment 1 – Definitions
Attachment 2 – Alignment of FEMA Appendix A to USGS *Lidar Guidelines and Base Specification* v13
Attachment 3 – Topographic Breakline and Hydro-Enforcement Specifications
Attachment 4 – Topographic Data Quality Review Process

Distribution List:

Attachment 1 – Definitions

Digital Elevation Data – Includes all of the following terms: mass points, point clouds, breaklines, contours, TINs, DEMs, DTMs or DSMs.

- **Breakline –** A linear feature demarking a change in the smoothness or continuity of a surface such as abrupt elevation changes or a stream line. The two most common forms of breaklines are as follows:
  - A **soft breakline** ensures that known elevations, or z-values, along a linear feature are maintained (e.g., elevations along a pipeline, road centerline or drainage ditch), and ensures the boundary of natural and man-made features on the Earth's surface are appropriately represented in the digital terrain data by use of linear features and polygon edges They are generally synonymous with 3-D breaklines because they are depicted with series of x/y/z coordinates.
  - A **hard breakline** defines interruptions in surface smoothness, e.g., to define streams, shorelines, dams, ridges, building footprints, and other locations with abrupt surface changes. Although some hard breaklines are three dimensional (3-D) breaklines, they are often depicted as two dimensional (2-D) breaklines because features such as shorelines and building footprints are normally depicted with a series of horizontal coordinates only which are often digitized from digital orthophotographs that include no elevation data.
- **Contours –** Lines of equal elevation on a surface. An imaginary line on the ground, all points of which are at the same elevation above or below a specified vertical datum.
- **Digital Elevation Model (DEM) –** An elevation model created for use in computer software where bare-earth elevation values have regularly spaced intervals in latitude and longitude (x and y). The Δx and Δy values are normally measured in feet or meters to even units; however, the National Elevation Dataset (NED) defines the spacing interval in terms of arc-seconds of latitude and longitude, e.g., 1/3rd arc-second.
- **Digital Surface Model (DSM) –** An elevation model created for use in computer software that is similar to DEMs or DTMs except that DSMs depict the elevations of the top surfaces of buildings, trees, towers, and other features elevated above the bare earth.
- **Digital Terrain Model (DTM) –** An elevation model created for use in computer software of bare-earth mass points and breaklines. DTMs are technically superior to a gridded DEM for many applications because distinctive terrain features are more clearly defined and precisely located, and contours generated from DTMs more closely approximate the real shape of the terrain.
- **Mass Points –** Irregularly spaced points, each with latitude and longitude location coordinates and elevation values typically used to form a TIN.
- **Metadata –** Project descriptive information about the elevation dataset.
- **Point Cloud –** Often referred to as the "raw point cloud", this is the first data product of a lidar instrument. In its crudest form, a lidar raw point cloud is a collection of range measurements and sensor orientation parameters. After initial processing, the range and orientation of each laser value is converted to a position in a three dimensional frame of reference and this spatially coherent cloud of points is the base for further processing and analysis. The raw point cloud typically includes first, last, and intermediate returns for each laser pulse. In addition to spatial information, lidar intensity returns provide texture or color information. The combination of three dimensional spatial information and spectral information contained

in the lidar dataset allows great flexibility for data manipulation and extraction. As used in this procedure memorandum, two additional lidar data processing terms are defined as follows:

- **Lidar Preliminary Processing –** The initial processing and analysis of laser data (GPS/IMU/laser ranges) to fully "calibrated point clouds" in some specified tile format. All lidar data will be set to ASPRS LAS Class 1 (unclassified) and must include testing for Fundamental Vertical Accuracy (FVA). The tile format can change later, if necessary.
- **Lidar Post-Processing –** The final processing and classification of lidar data to the required ASPRS LAS classes, per project specifications. This must include testing for Consolidated Vertical Accuracy (CVA). At this point, the datasets are referred to as the "classified point cloud."

- **Triangulated Irregular Network (TIN) –** A set of adjacent, non-overlapping triangles computed from irregularly-spaced points with lattitude, longitude, and elevation values. The TIN data structure is based on irregularly-spaced point, line, and polygon data interpreted as mass points and breaklines and stores the topological relationship between triangles and their adjacent neighbors. The TIN model may be preferable to a DEM when it is critical to preserve the precise location of narrow or small features, such as levees, ditch or stream centerlines, isolated peaks or pits in the data model.
- **Z-Values –** The elevations of the 3-D surface above the vertical datum at designated x/y locations.

Geospatial Accuracy Standard – A common accuracy testing and reporting methodology that facilitates sharing and interoperability of geospatial data. Published in 1998, the National Standard for Spatial Data Accuracy (NSSDA) is the Federal Geographic Data Committee (FGDC) standard relevant to digital elevation data when assuming that errors follow a normal error distribution. However, after it was learned that lidar datasets do not necessarily follow a normal distribution in vegetated terrain, the National Digital Elevation Program (NDEP) published its "Guidelines for Digital Elevation Data" and the American Society for Photogrammetry and Remote Sensing (ASPRS) published the "ASPRS Guidelines: Vertical Accuracy Reporting for Lidar Data," both of which were published in 2004 and use newer terms defined below as Fundamental Vertical Accuracy (FVA), Supplemental Vertical Accuracy (SVA) and Consolidated Vertical Accuracy (CVA). All of these standards, designed for digital elevation data, replace the National Map Accuracy Standard (NMAS) that is applicable only to graphic maps defined by map scale and contour interval.

Accuracy – The closeness of an estimated value (e.g., measured or computed) to a standard or accepted (true) value of a particular quantity. Note: With the exception of GPS Continuously Operating Reference Stations (CORS), assumed to be known with zero errors relative to established datums, the true locations of 3-D spatial coordinates or other points are not known, but only estimated. Therefore, the accuracy of other coordinate information is unknown and can only be estimated. Other accuracy definitions are as follows.

- **Absolute Accuracy –** A measure that accounts for all systematic and random errors in a data set. Absolute accuracy is stated with respect to a defied datum or reference system.
- **Accuracy$_{r}$ –** The NSSDA reporting standard in the horizontal component that equals the radius of a circle of uncertainty, such that the true or theoretical horizontal location of the

point falls within that circle 95-percent of the time. $Accuracy_r = 1.7308 \times RMSE_r$. Horizontal accuracy is defined as the positional accuracy of a dataset with respect to a horizontal datum.

- **$Accuracy_z$ —** The NSSDA reporting standard in the vertical component that equals the linear uncertainty value, such that the true or theoretical vertical location of the point falls within that linear uncertainty value 95-percent of the time. $Accuracy_z = 1.9600 \times RMSE_z$. Vertical accuracy is defined as the positional accuracy of a dataset with respect to a vertical datum.
- **Consolidated Vertical Accuracy (CVA) –** The result of a test of the accuracy of vertical checkpoints (z-values) consolidated for two or more of the major land cover categories, representing both open terrain and other land cover categories. Computed by using the 95^{th} percentile, CVA is always accompanied by Fundamental Vertical Accuracy (FVA).
- **Fundamental Vertical Accuracy (FVA) –** The value by which vertical accuracy can be equitably assessed and compared among datasets. The FVA is determined with vertical checkpoints located only in open terrain, where there is a very high probability that the sensor will have detected the ground surface. FVA is calculated at the 95% confidence level in open terrain only, using $RMSE_z \times 1.9600$,
- **Local Accuracy –** A value that represents the uncertainty in the coordinates of a control point relative to the coordinates of other directly-connected, adjacent control points at the 95-percent confidence level. The reported local accuracy is an approximate average of the individual local accuracy values between this control point and other observed control points used to establish the coordinates of the control point.
- **Network Accuracy –** A value that represents the uncertainty in the coordinates of a control point with respect to the geodetic datum at the 95-percent confidence level. For National Spatial Reference System (NSRS) network accuracy classification in the U.S., the datum is considered to be best expressed by the geodetic values at the CORS supported by the National Geodetic Survey (NGS). By this definition, the local and network accuracy values at CORS sites are considered to be infinitesimal, i.e., to approach zero.
- **Percentile –** Any of the values in a dataset of errors dividing the distribution of the individual errors in the dataset into one hundred groups of equal frequency. Any of those groups can specify a specific percentile, e.g., the 95^{th} percentile as defined below.
- **Precision –** A statistical measure of the tendency of a set of random numbers to cluster about a number determined by the dataset. *Precision* relates to the quality of the method by which the measurements were made and is distinguished from *accuracy* which relates to the quality of the result. The term "precision" not only applies to the fidelity with which required operations are performed, but, by custom, has been applied to methods and instruments employed in obtaining results of a high order of precision. Precision is exemplified by the number of decimal places to which a computation is carried and a result stated.
- **Positional Accuracy** – The accuracy of the position of features, including horizontal and/or vertical positions.
- **Relative Accuracy** – A measure that accounts for random errors in a data set. Relative accuracy may also be referred to as point-to-point accuracy. The general measure of relative accuracy is an evaluation of the random errors (systematic errors and blunders removed) in determining the positional orientation (e.g., distance, azimuth) of one point or feature with respect to another.
- **Root Mean Square Error (RMSE) –** The square root of the average of the set of squared differences between dataset coordinate values and coordinate values from an independent

source of higher accuracy for identical points. The vertical RMSE ($RMSE_z$), for example, is calculated as the square root of $\sum(Z_n - Z'_n)^2/N$, where:

- Z_n is the set of N z-values (elevations) being evaluated, normally interpolated (for TINs and DEMs) from dataset elevations of points surrounding the x/y coordinates of checkpoints
- Z'_n is the corresponding set of checkpoint elevations for the points being evaluated
- N is the number of checkpoints
- n is the identification number of each of the checkpoints from 1 through N.

- **Supplemental Vertical Accuracy (SVA) –** The result of a test of the accuracy of z-values over areas with ground cover categories or combination of categories other than open terrain. Computed by using the 95th percentile, SVA is always accompanied by Fundamental Vertical Accuracy (FVA). SVA values are computed individually for different land cover categories. Each land cover type representing 10% of more of the total project area is typically tested and reported as an SVA. SVA specifications are normally target values that may be exceeded so long as overall CVA requirements are satisfied.
- **95% Confidence Level** – Accuracy reported at the 95% confidence level means that 95% of the positions in the dataset will have an error with respect to true ground position that is equal to or smaller than the reported accuracy value. The reported accuracy value reflects all uncertainties, including those introduced by geodetic control coordinates, compilation, and final computation of ground coordinate values in the product. Where errors follow a normal error distribution, $Accuracy_z$ defines vertical accuracy at the 95% confidence level (computed as $RMSE_z$ x 1.9600), and $Accuracy_r$ defines horizontal (radial) accuracy at the 95% confidence level (computed as $RMSE_r$ x 1.7308).
- **95th Percentile –** Accuracy reported at the 95th percentile indicates that 95% of the errors will be of equal or lesser value and 5% of the errors will be of larger value. This term is used when errors may not follow a normal error distribution, e.g., in forested areas where the classification of bare-earth elevations may have a positive bias. Vertical accuracy at the 95% confidence level and 95th percentile may be compared to evaluate the degree to which actual errors approach a normal error distribution.

Resolution – In the context of elevation data, resolution is synonymous with the horizontal density of elevation data points for which two similar terms are used:

- **Nominal Pulse Spacing (NPS)** – The estimated average spacing of irregularly-spaced lidar points in both the along-track and cross-track directions resulting from: the laser pulse repetition frequency (e.g., 100,000 pulses of laser energy emitted in one second from a 100 kHz sensor); scan rate (sometimes viewed as the number of zigzags per second for this common scanning pattern); field-of-view; and flight airspeed. Lidar system developers currently provide "design NPS" as part of the design pulse density, although the American Society for Photogrammetry and Remote Sensing (ASPRS) is currently developing standard procedures to compute the "empirical NPS" which should be approximately the same as the "design NPS" when accepting statistically insignificant loss of returns and disregarding void areas, from water for example. The NPS assessment is made against single swath first return data located within the geometrically usable center portion (typically ~90%) of each swath. Average along-track and cross-track pulse spacing should be comparable. When point density is increased by relying on overlap or double-coverage it should be documented in metadata and not by changing the project's reported NPS. The NPS should be equal to or less than the Digital Elevation Model (DEM) post spacing when gridded DEMs are required as part of project specifications. This same definition for NPS could similarly apply to irregularly-spaced mass points from photogrammetry or Interferometric Synthetic Aperture Radar (IFSAR) data. NPS pertains to lidar only and is not intended to pertain to photogrammetry or IFSAR.

- **DEM Post Spacing –** Sometimes confused with Nominal Pulse Spacing, the DEM Post Spacing is defined as the constant sampling interval in x- and y-directions of a DEM lattice or grid. This is also called the horizontal resolution of a gridded DEM or the DEM grid spacing. It is standard industry practice to have:
  - 1-meter DEM post spacing for elevation data with 1-foot equivalent contour accuracy;
  - 2-meter DEM post spacing for elevation data with 2-foot equivalent contour accuracy;
  - 5-meter DEM post spacing for elevation data with 5-foot equivalent contour accuracy.

Attachment 2 – Alignment of FEMA Appendix A to USGS Lidar Specification v13

FEMA is aligning Appendix A of the *Guidelines and Specifications for Flood Hazard Mapping Partners* (Guidelines) to the USGS *Lidar Guidelines and Base Specification* v13 to modernize the FEMA specifications to current industry practice, leverage the expertise of the USGS Geography discipline, maintain Federal standards across agencies, and support the use of elevation products acquired as part of Risk MAP by other agencies for other purposes thus maximizing the Government's investment.

Overall, new elevation data purchased by FEMA must comply with the USGS *Lidar Guidelines and Base Specification* v13, except where specifically noted in this Procedure Memorandum.

Because FEMA's needs for elevation are specific to floodplain mapping, FEMA has some unique requirements that differ from the USGS specifications. To supplement the existing USGS specifications, FEMA-specific items such as cross section surveys, bridges, and other features in Appendix A of the Guidelines remain valid except where superseded by more current information provided in this attachment. Table 1 summarizes the sections in Appendix A that are fully superseded, partially superseded or not superseded by this Procedure Memorandum.

Table 2.1 Currency of Major Sections within FEMA's Appendix A: Guidance for Aerial Mapping and Surveying

Section	Name	Status
A.1	Introduction	Is not superseded and remains valid.
A.2	Industry Geospatial Standards	Remains valid but is appended by additional standards which use newer standards from the National Digital Elevation Program (NDEP) and American Society for Photogrammetry and Remote Sensing (ASPRS) to test elevation data for Fundamental Vertical Accuracy (FVA), Supplemental Vertical Accuracy (SVA), and Consolidated Vertical Accuracy (CVA).
A.3	Accuracy Guidelines	Partly superseded, especially Table 2, below, that specifies variable vertical accuracy standards and nominal pulse spacing (NPS), depending on the risk level and terrain slope within the floodplain being mapped.
A.4	Data Requirements	Major portions are superseded. Subsection A.4.2.3 pertaining to breaklines, subsection A.4.3 pertaining to elevation data vertical accuracy, and subsection A.4.5 pertaining to mapping area, are superseded. Subsection A.4.11 pertaining to other digital topographic data requirements, including Table A-3, Digital Topographic Data Requirements Checklist, is now superseded by other FEMA procurement guidelines. Subsection A.4.9 on data formats is partially superseded by the addition of lidar LAS formatted datasets. Subsections pertaining to cross sections (A.4.6) and hydraulic structures (A.4.7) remain valid.
A.5	Ground Control	Is not superseded and remains valid.
A.6	Ground Surveys	Is not superseded and remains valid.

Section	Name	Status
A.7	Photogrammetric Surveys	Remains valid but is appended by additional standards which require low confidence areas to be delineated for photogrammetry as well as lidar and interferometric synthetic aperture radar (IFSAR). The vast majority of section A.7 remains valid and unchanged.
A.8	Airborne LiDAR	Superseded with references the USGS *Lidar Guidelines and Base Specification* v13; and by NDEP and ASPRS guidelines for accuracy testing and reporting of lidar data.

2.1Elevation Specifications Based on Risk Levels

FEMA maintains a national dataset that estimates flood risk. The basic data is calculated at the Census Block Group level, and is also aggregated to the sub-watershed, watershed and county levels. These data assign a risk value and a risk rank to each area. The areas are grouped into 10 classes with an equal number of members based on risk rank. These 10 classes are called risk deciles.

The table below provides the minimum elevation standards for new engineering analyses produced by FEMA. The highest and high specifications are suitable for either basic or enhanced engineering analyses. The medium and low specifications are suitable for basic engineering analyses. Where more than 20% of the project area covered by the new elevation will have enhanced engineering analyses, the next higher elevation specification level may be appropriate. When the scope of the enhanced engineering analyses is not sufficient to justify increasing the overall project specification level, the bulk elevation data collection may be enhanced by field survey in areas of enhanced engineering analyses if necessary.

Table 2.2. Vertical Accuracy Requirements based on Flood Risk and Terrain Slope within the Floodplain being mapped

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

Medium (Deciles 4,5,6,7)	Hilly	Low	147 cm/218 cm	≤5 meters
Low (Deciles 7,8,9,10)	All	Low	147 cm/218 cm	≤5 meters

Whereas contour lines are for visual interpretation and are unnecessary for FEMA's automated H&H analyses, the term "equivalent contour accuracy" is used to show the accuracy of contour lines that could be produced from a DEM if needed for manual analysis; this is also for the benefit of those who do not understand NSSDA terminology that defines vertical accuracy at the 95% confidence level. Table 3 explains "equivalent contour accuracy" for various standard contour intervals, referenced also in terms of vertical root mean square error ($RMSE_z$), National Standard for Spatial Data Accuracy (NSSDA) $Accuracy_z$, SVA and CVA.

Table 2.3. Accuracy Terms that Equal "Equivalent Contour Accuracy"

Equivalent Contour Accuracy	FEMA Specification Level	$RMSE_z$	NSSDA $Accuracy_z$ 95% confidence level	SVA (target)	CVA (mandatory)
1 ft		0.30 ft or 9.25 cm	0.60 ft or18.2 cm	0.60 ft or18.2 cm	0.60 ft or18.2 cm
2 ft	Highest	0.61 ft or 18.5 cm	1.19 ft or 36.3 cm	1.19 ft or 36.3 cm	1.19 ft or 36.3 cm
4 ft	High	1.22 ft or 37.1 cm	2.38 ft or 72.6 cm	2.38 ft or 72.6 cm	2.38 ft or 72.6 cm
5 ft		1.52 ft or 46.3 cm	2.98 ft or 90.8 cm	2.98 ft or 90.8 cm	2.98 ft or 90.8 cm
8 ft	Medium	2.43 ft or 73.9 cm	4.77 ft or 1.45 m	4.77 ft or 1.45 m	4.77 ft or 1.45 m
10 ft		3.04 ft or 92.7 cm	5.96 ft or1.82 m	5.96 ft or1.82 m	5.96 ft or1.82 m
12 ft	Low	3.65 ft or 1.11m	7.15 ft or 2.18 m	7.15 ft or 2.18 m	7.15 ft or 2.18 m

FEMA's requirements for elevation data are specific to flood risk analysis. As a result, FEMA's requirements diverge from the USGS specification which is intended to serve a different purpose. Two of the key differences with the FEMA specifications are the requirements for vertical accuracy and nominal pulse spacing. The FEMA requirements in these areas are only similar to the USGS requirements in the highest specification level, but otherwise differ for the lower accuracy levels.

All data collected must go through lidar preliminary processing and the unclassified point cloud must be tested as specified in the USGS specification. Where the Mapping Activity Statement (MAS) requires bare earth post-processing of the floodplain area of interest (AOI), the elevation data must be tested and comply with both the FVA and CVA requirements. Where no bare earth post-processing is specified, only the FVA requirements apply for lidar preliminary processing.

Many other organizations require higher-accuracy lidar data for diverse applications and combine their resources to solve multiple needs with lidar. FEMA prefers to acquire elevation data through partnerships so that the resulting data will meet a broader variety of end user needs and be more consistent with the overall USGS specification. These partnership elevation collection activities will frequently utilize specifications that exceed the minimums described above in Table 2. Before committing funds to a new elevation mapping project, FEMA Regional staff should first determine whether funds could be spent more effectively by cooperating with other agencies to more cost-effectively acquire elevation data. FEMA is a member of the National Digital Elevation Program (NDEP) which was formed, in part, to avoid duplication of effort among state and federal government agencies acquiring digital elevation data. USGS maintains state geospatial liaisons that are a good source of information regarding the status of existing and/or planned mapping activities in their states.

2.2 Light Detection and Ranging (lidar)

Lidar is capable of delivering 1- foot equivalent contour accuracy with sub-meter NPS used to produce DEMs with 1-meter DEM gridded post spacing. Therefore, lidar could satisfy FEMA's requirements for elevation data in high risk, moderate risk, and low risk areas. Lidar is often the best technology for mapping the elevations of the bare earth terrain in dense vegetation.

If this technology is selected for high risk areas, lidar will be collected in accordance with the USGS *Lidar Guidelines and Base Specification*, v13, for the National Geospatial Program except as noted. FEMA does not require the data to be hydro-flattened, as specified in v13. Also, FEMA does not require all data to be processed to the bare earth terrain, but instead limits the area to be processed to areas in the vicinity of floodplains that will require hydraulic modeling. See FEMA's Procurement Guidelines for specifics on this topic.

The following USGS specifications are most relevant to FEMA and are consistent with FEMA requirements:

- Fundamental Vertical Accuracy (FVA) pertains only to open, non-vegetated terrain. The FVA is specified at a higher level of accuracy than other land cover categories. The FVA is a mandatory specification that must be satisfied in order to be usable by FEMA for flood risk mapping within the specified level of flood risk.
- Supplemental Vertical Accuracy (SVA) pertains to other major land cover categories representative of the floodplain being mapped. SVA values are target values, where one SVA category can test higher and another lower than the target SVA value so long as the overall CVA is satisfied for the consolidated equivalent contour accuracy.
- Consolidated Vertical Accuracy (CVA) pertains to all land cover categories combined. Compliance with the CVA specification is mandatory in order for an elevation dataset to qualify for satisfaction of a specified equivalent contour accuracy.
- For the highest specification level equivalent to 2 foot contour accuracy, the relative accuracy should be ≤ 7 cm $RMSE_z$ within individual swaths; ≤ 10 cm $RMSE_z$ within swath overlap (between adjacent swaths). These relative accuracy specifications double to 14 and 20 cm, respectively, for risk areas that utilize the high elevation specification with 4 foot equivalent contour accuracy. This specification is not applicable to lower risk areas.
- Consistent with USGS *Lidar Guidelines and Base Specification*, v13, a regular grid, with cell size equal to the design NPS*2 will be laid over the first return data within the geometrically usable center portion of each swath. At least 90% of the cells in the grid shall contain at least one lidar point.
- All data collected will be delivered consistent with the USGS Raw Point Cloud deliverable requirements.

- Where lidar post-processing is performed, the deliverables must also include the classified point cloud deliverable. The data will be delivered in full compliance with LAS classes 1 (processed, but unclassified), 2 (bare-earth ground), 7 (noise), 9 (water), 10 (ignored), and 11 (withheld). All points not identified as "withheld" are to be classified. "Overlap" classification (Class 12) shall not be used.
- The horizontal datum shall be referenced to the latest adjustment of the North American Datum of 1983 (NAD83 [NSRS2007]).
- The vertical datum shall be referenced to the North American Vertical Datum of 1988 (NAVD88) whenever available. Areas outside of the continental U.S. where NAVD88 is not available should be referenced to a reproducible local datum that can be used to support floodplain management.
- The most recent approved Geoid model from the National Geodetic Survey (NGS) shall be used to perform conversions from ellipsoidal heights to orthometric heights.
- The standard coordinate reference system and units shall be Universal Transverse Mercator (UTM), meters. Considerations for other standard coordinate systems such as State Plane can be made for projects which are contributed to by mapping partners.
- The single non-overlapped tiling scheme shall be established and agreed upon by the data producer and FEMA prior to collection, consistent with the USGS *Lidar Guidelines and Base Specifications,* v13.
- Specifications for breaklines and hydro-enforcement are addressed in Attachment B.
- Specifications for lidar accuracy testing by land cover categories within the floodplain being mapped are addressed in Attachment C.

Lidar dataset deliverables shall include the following:

1. Metadata should comply with the requirements in the USGS *Lidar Guidelines and Base Specification*, v13. In addition, the finished elevation product for hydraulic modeling should be documented by a FGDC-compliant metadata file that complies with the FEMA Elevation Metadata Profile. Project documentation must also include a Pre-flight Operations Plan and Post-flight Aerial Survey and Calibration Report as described in Attachment 4.
2. Raw point cloud data shall comply with the requirements in the USGS Lidar Guidelines and Base Specification, v13.
3. Classified point cloud data shall comply with requirements in the USGS Lidar Guidelines and Base Specification, v13.
4. Optional breaklines, when produced, shall be delivered in compliance with guidance in Attachment 3
5. Optional digital bare earth elevation data product(s) (e.g., DEM, DTM, contours) in file formats specified in the Statement of Work.

2.3 Photogrammetry

Photogrammetry is also capable of delivering 1-foot equivalent contour accuracy and a DEM with 1-meter post spacing. Therefore, photogrammetry could also satisfy FEMA's requirements for elevation data in high risk, moderate risk, and low risk areas. Except for the new requirement to delineate areas of low confidence, existing guidance published in section A.7, Photogrammetric Surveys, in Appendix A of FEMA's Guidelines, remain current for new aerial image acquisition with either film or digital cameras.

The USGS annually contracts for leaf-off orthoimagery of selected areas under the National Geospatial Program, typically producing digital orthophotographs with pixel resolution of 30 cm (~1 foot) or 15 cm (~6 inches), as do many states and local governments; and the USDA contracts for leaf-on orthoimagery of major areas of the U.S. annually under the National Agricultural Imagery Program (NAIP) with pixel resolution of 1 meter. Although intended for production of digital orthophotos, those same images could be reused for production of digital elevation data because the aerotriangulation (AT) solution for production of orthophotos can be reused for establishing stereo models from which DEMs can be produced by photogrammetric auto-correlation and/or manual compilation. Elevation accuracies typically achievable by reuse of digital imagery and AT metrics are as follows:

- Typically acquired at an elevation of approximately 4,800 feet above mean terrain, imagery and AT solutions used to produce digital orthophotos with 6-inch pixel resolution should be acceptable for elevation data with 2.5-foot equivalent contour accuracy
- Typically acquired at an elevation of approximately 9,600 feet above mean terrain, imagery and AT solutions used to produce digital orthophotos with 1-foot pixel resolution should be acceptable for elevation data with 5-foot equivalent contour accuracy
- Typically acquired at an elevation of approximately 30,000 feet above mean terrain, imagery and AT solutions used to produce digital orthophotos with 1-meter pixel resolution should be acceptable for elevation data with 15-foot equivalent contour accuracy.

Photogrammetric dataset deliverables shall include the following:

1. Metadata shall include:
   - Collection Report detailing mission planning and flight logs, flying heights, camera parameters, forward overlap and sidelap.
   - Survey Report detailing the collection of control and reference points used for calibration and QA/QC.
   - Aerial triangulation (AT) report detailing compliance with relevant accuracy statistics.
   - Processing Report detailing photogrammetric processed used to manually compile elevation data or to semi-automatically compile elevation data with automated image correlation or other techniques.
   - QA/QC reports.
   - Geo-referenced extents of each delivered dataset.
2. Digital bare earth elevation data product (DEM, DTM, mass points, breaklines, contours) specified in the Statement of Work.
3. Optional breaklines, when produced, shall be delivered in compliance with guidance in Attachment 3

2.4 Ground Surveys

All ground surveys must be performed in accordance with procedures in Section A.5, Ground Control, and Section A.6, Ground Surveys, in Appendix A of FEMA's Guidelines. Cross-section surveys and hydraulic structure surveys shall also be performed in accordance with sections A.4.6 and A.4.7, respectively, of Appendix A.

2.5 Low Confidence Areas

Regardless of technology used, FEMA requires that low confidence areas be delineated by the data provider to indicate areas where the vertical data may not meet the data accuracy requirements due to heavy vegetation even though the specified nominal pulse spacing was met or exceeded in those areas. The metadata must explain steps taken to minimize the areas delineated as low confidence areas. Accuracy test points are normally retained within such areas and are not discarded. The data provider must take reasonable steps to minimize areas delineated as low confidence areas, taking into consideration the density of the vegetation in the floodplain being mapped and other factors.

These low confidence areas must be delivered as polygons in accordance with a database schema. The database schema for polygons defining low confidence areas is as follows.

Feature Dataset: TOPOGRAPHIC **Feature Class:** CONFIDENCE
Feature Type: Polygon
Contains M Values: No **Contains Z Values:** No
Annotation Subclass: None
XY Resolution: Accept Default Setting **Z Resolution:** Accept Default Setting
XY Tolerance: 0.003 **Z Tolerance:** N/A

2.5.1 Description

This polygon feature class will depict areas where the ground is obscured by dense vegetation, meaning that the resultant bare-earth digital terrain model (DTM) may not meet the required accuracy specifications in these obscured areas. Low confidence areas can pertain to lidar, photogrammetry or IFSAR.

2.5.2 Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by Contractor
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Contractor
SHAPE_AREA	Double	Yes			0	0		Calculated by

								Contractor
TYPE	Long Integer	No	1	Obscure	0	0		Assigned by Contractor

2.5.3 Feature Definition

Code	Description	Definition	Capture Rules
1	Low Confidence Area	"Low confidence areas" are defined by the data provider to indicate areas where the vertical data may not meet the data accuracy requirements due to heavy vegetation even though the nominal pulse spacing was met or exceeded in those areas.	Capture as closed polygon. Compiler does not need t z-values of vertices; feature class will be 2-D only.

Attachment 3 – Topographic Breakline and Hydro-Enforcement Specifications

FEMA has no minimum breakline requirements; breaklines are optional and depend upon the procedures used to perform hydrologic and hydraulic modeling. The FEMA Project Manager should specify the breaklines requirements if desired based on the planned approach for hydraulic analysis or the mapping partner may propose breakline requirements based on the anticipated hydraulic modeling approach.

When optional breaklines are produced, the following breakline topology rules must be followed for the applicable feature classes. The topology must be validated by each contractor prior to delivery to FEMA.

Name: BREAKLINES_Topology			Cluster Tolerance: 0.003 Maximum Generated Error Count: Undefined State: Analyzed without errors	
Feature Class	**Weight**	**XY Rank**	**Z Rank**	**Event Notification**
COASTALSHORELINE	5	1	1	No
HYDROGRAPHICFEATURE	5	1	1	No
PONDS_AND_LAKES	5	1	1	No
HYDRAULICSTRUCTURE	5	1	1	No
ISLAND	5	1	1	No

Topology Rules

Name	Rule Type	Trigger Event	Orgin (FeatureClass::Subtype)	Destination (FeatureClass::Subtype)
Must not intersect	The rule is a line-no intersection rule	No	HYDRAULICSTRUCTURE::All	HYDRAULICSTRUCTURE::All
Must not intersect	The rule is a line-no intersection rule	No	HYDROGRAPHICFEATURE::All	HYDROGRAPHICFEATURE::All
Must not intersect	The rule is a line-no intersection rule	No	COASTALSHORELINE::All	COASTALSHORELINE::All
Must not intersect	The rule is a line-no intersection rule	No	PONDS_AND_LAKES::All	PONDS_AND_LAKES::All
Must not intersect	The rule is a line-no intersection rule	No	ISLAND::All	ISLAND::All
Must not overlap	The rule is a line-no overlap line rule	No	HYDROGRAPHICFEATURE::All	COASTALSHORELINE::All
Must not self-intersect	The rule is a line-no self intersect rule	No	HYDRAULICSTRUCTURE::All	HYDRAULICSTRUCTURE::All
Must not self-intersect	The rule is a line-no self intersect rule	No	HYDROGRAPHICFEATURE::All	HYDROGRAPHICFEATURE::All
Must not self-intersect	The rule is a line-no self intersect rule	No	COASTALSHORELINE::All	COASTALSHORELINE::All

Name	Rule Type	Trigger Event	Orgin (FeatureClass::Subtype)	Destination (FeatureClass::Subtype)
Must not self-intersect	The rule is a line-no self intersect rule	No	PONDS_AND_LAKES::All	PONDS_AND_LAKES::All
Must not self-intersect	The rule is a line-no self intersect rule	No	ISLAND::All	ISLAND::All

Attachment 4 – Topographic Data Quality Review and Reporting Process

To complement the topographic data specifications in this procedure memorandum, this attachment describes data quality review processes and reporting obligations to be performed on new topographic data procured by FEMA as part of a flood hazard study or Risk MAP project. The mapping partner responsible for producing the elevation data is responsible for the quality of the product. In addition, FEMA may assign another mapping partner to perform Independent QA/QC of Topographic Data

Existing topographic data leveraged by FEMA should be certified to meet or tested for the vertical accuracy requirements specified in this procedure memo. In addition, the quality reviews described here are best practices that may be applied to existing topographic data. However, some of the documentation needed to perform some of these reviews may not be readily available for existing data..

4.1 Quality Reviews and Reporting Performed by Data Provider

The mapping partner responsible for producing new elevation data must submit copies of QA reports as specified in USGS Lidar Guidelines and Base Specification version 13. Unless the responsibility for checkpoint surveys and vertical accuracy testing is specifically assigned to a different mapping partner performing Independent QA/QC, the mapping partner responsible for producing the elevation data must test the unclassified point cloud data for Fundamental Vertical Accuracy (FVA) and, when lidar post-processing is performed must also test the bare earth product for Supplemental Vertical Accuracy (SVA) and Consolidated Vertical Accuracy (CVA).

4.1.1 Ground Survey of Quality Review Checkpoints

Quality review checkpoint surveys shall be performed in accordance with procedures in Section A.6.4, Checkpoint Surveys and A.6.5 Survey Records, in Appendix A of FEMA's Guidelines.

Checkpoints surveyed for accuracy reporting shall not be used by the data provider in the calibration or adjustment of the topographic data.

4.1.2 Assessment of Initial Vertical Accuracy

Assessment of the fully calibrated, raw point cloud initial vertical accuracy is required to ensure data has successfully completed preliminary processing. The absolute and relative accuracy of the data, relative to known control, shall be verified prior to classification and subsequent product development , by calculating FVA, measured in open, non-vegetated terrain. The spatial distribution of checkpoints for FVA testing should be based on the entire project collection area, distributed to avoid clustering, and support vertical accuracy reporting that is representative of the whole project.

If the project area exceeds 2,000 square miles it must be divided into smaller blocks of 2,000 square miles or less and tested as individual areas. In addition, the division of large project areas should apply the following rules if applicable:

- Divide areas by vendor used
- Divide areas by sensor type (manufacturer)
- Divide areas by flight dates if significant temporal difference is present
- Other logical project divisions based factors that might have a systematic relationships to data quality.

Reporting of positional accuracy shall be in accordance with ASPRS/NDEP standards as well as the USGS *Lidar Guidelines and Base Specification*, v13, Section II.13 and shall use the following statement:

Tested ____ (meters) fundamental vertical accuracy at 95% confidence level

Reporting on the assessment of the point cloud initial vertical accuracy shall include the following at a minimum:

- ***A description of the process used to test the points***
- A graphic depicting the spatial distribution of the ground survey checkpoints
- Descriptive statistics and RMSEz in FVA calculations

4.1.3 Assessment of Bare Earth Vertical Accuracy

When bare earth post-processing is included in the project, assessment of the vertical accuracy for the delivered bare earth elevation product is required to ensure data has successfully completed post processing. Reporting of positional accuracy shall be in accordance with ASPRS/NDEP standards for FVA and CVA. Testing should be performed on the bare earth deliverable as specified in the mapping activity statement, along with the following guidance:

- If an assessment of initial vertical accuracy (FVA) was conducted prior to the processing of the data (section 4.1.2), the FVA checkpoints can again be used in the CVA computations if located within the area to be processed
- The SVA for up to three significant land cover categories, in terms of percentage of the project area covered, shall be tested in addition to the open/bare ground areas already tested for FVA Land cover categories making up 10% or more of the project area should be included in the SVA testing
- For smaller projects less than 1,000 square miles, fewer check points for SVA testing is acceptable. The number of checkpoints shall be reduced to control the QA cost to about 10% of the acquisition and processing cost. The checkpoints should be distributed evenly across the SVA land cover types.
- Processing areas greater than 2,000 square miles must be divided into smaller blocks of 2,000 square miles or less and tested as individual areas. In addition,

the division of large processing areas should apply the following rules if applicable:

- Divide areas by vendor used
- Divide areas by sensor type (manufacturer)
- Divide areas by flight dates if significant temporal difference is present
- Other logical project divisions based factors that might have a systematic relationships to data quality.

1.

- Each block of 2,000 square miles or less shall be tested for FVA, SVA, and CVA

Checkpoints used for testing SVA of the bare earth elevation product must be located in the areas where bare earth post-processing was performed, distributed to avoid clustering, and support vertical accuracy reporting that is representative of the post processed areas. The SVA results will then be combined with the FVA results to compute CVA for the entire project area.

Reporting on the assessment of the vertical accuracy of the post-processed, delivered elevation data shall include the following at a minimum:

- ***A description of the process used to test the points***
- A graphic depicting the spatial distribution of the ground survey checkpoints
- An analysis of checkpoints that have errors exceeding the 95th percentile in SVA and CVA calculations
- Descriptive statistics and RMSEz in FVA calculations

4.1.4 Aerial Data Acquisition and Calibration

The mapping partner responsible for producing new elevation data must also submit a pre-flight Operations Plan and a post-flight Aerial Acquisition and Calibration Report will be provided to FEMA and/or their representatives by the data acquisition provider and uploaded to the MIP by the data provider. This information will aid future quality review efforts. The required reporting includes the following, outlined in Tables 4.1 and 4.2.

Table 4.1. Pre-flight Operations Plan

Item	Contents	Format
Flight Operations	• Planned flight lines	MS Word or

Plan	• Planned GPS stations • Planned control • Planned airport locations • Calibration plans • Quality procedures for flight crew (project-related for pilot and operator) • Planned scanset (sensor settings and altitude) • Type of aircraft • Procedure for tracking, executing, and checking reflights • Considerations for terrain, cover, and weather in project	PDF

Table 4.2. Post-flight Aerial Acquisition and Calibration Report

Item	Contents	Format
GPS Base station info	• Base station name • Latitude/Longitude (ddd-mm-ss.sss) • Base height (Ellipsoidal meters) • Maximum Position Dilution of Precision PDOP • Map of locations	Excel, TXT, MS Word, or PDF for data; ESRI shape file for map of locations (data and info may be in attribute table)
GPS/IMU processing summary	• Max Horizontal GPS Variance (cm) • Max Vertical GPS Variance (cm) • Notes on GPS quality (High, Good, etc.) • GPS separation plot • GPS altitude plot • PDOP plot • Plot of GPS distance from base station/s	MS Word or PDF with screenshots
Coverage	• Verification of project coverage	ESRI shape files reflecting the actual coverage area and not the applicable tiles.
Flights	• As-flown trajectories • Calibration lines	ESRI shape files

Item	Contents	Format
Flight logs	• Incorporated as appendix Should include: • Job # / name • Lift # • Block or AOI designator • Date • Aircraft tail number, type • Flight line, line #, direction, start/stop, altitude, scan angle/rate, speed, conditions, comments • Pilot name • Operator name • AGC switch setting • Laser pulse rate • Mirror rate • Field of view • Airport of operations • GPS base station names or numbers Comments	
Control	• Ground control and base station layouts	ESRI shape files
Data verification/QC	• Description of data verification/QC process • Results of verification and QC steps	MS Word, Excel or PDF

4.2 Quality Reviews and Reporting Performed by Independent QA/QC

When a mapping partner is assigned to perform *Independent QA of Topographic Data* macro and micro reviews of the submitted reports and data shall be performed. Macro reviews are automated processes or are checks required to establish overall data quality and shall be applied to the entire project area. Micro reviews are typically manual in nature and shall be used to check no less than 3 project tiles or 5% of the total number of project tiles, whichever is the greater amount.

Tables 4.3 and 4.4 outline macro and micro reviews to be conducted on the raw point cloud and for data that is post-processed. Some reviews are duplicated between the raw point cloud and post-processing phases due to the potential for errors to be introduced into the data during post-processing.

Table 4.3. Review of fully calibrated raw point cloud

Macro Reviews	
Product	**Reviewed for**
Pre-flight Operations Plan	• Compliance with section 4.1.4 and checklists in 4.2.1 • Compliance with the specifications outlined in the Mapping Activity Statement
Post-flight Aerial Acquisition and Calibration Report	• Compliance with section 4.1.4 and checklists in 4.2.1 • Compliance with the specifications outlined in the Mapping Activity Statement

Macro Reviews	
Product	**Reviewed for**
LAS Point Cloud Files	• Project area coverage – buffered by a minimum of 100 meters • Data voids • Inclusion of GPS time stamp • Correct projection, datum and units • Multiple Discrete Returns (at least 3 returns per pulse) • Correct header information • Other LAS attributes required by Mapping Activity Statement such as intensity values • Correct nominal pulse spacing as required by specific risk and/or level of study and buy-up options.
Metadata	• Compliance with the FEMA Terrain Metadata Profile
Micro Reviews	
Product	**Reviewed for**
LAS Point Cloud Files	• Excessive noise • Elevation steps • Other anomalies present in the point cloud

Table 4.4. Review of post-processed data

Macro Reviews	
Product	**Reviewed for**
LAS Point Cloud Files	• Compliance with checklists in section 4.2.1 • Project area coverage – buffered by a minimum of 100 meters • Data voids • Inclusion of GPS time stamp • Correct projection, datum and units • Multiple Discrete Returns (at least 3 returns per pulse) • Correct header information • Other LAS attributes required by Mapping Activity Statement such as intensity values • Correct nominal pulse spacing as required by specific risk and/or level of study and buy-up options. • Easting, northing and elevation reported to nearest 0.01m or 0.01 ft • Correct file-naming convention
Metadata	• Compliance with the FEMA Terrain Metadata Profile

Macro Reviews	
Product	**Reviewed for**
Micro Reviews	
Product	**Reviewed for**
LAS Point Cloud Files	• Excessive noise • Elevation steps • Other anomalies present in the point cloud • Correct classification and cleanliness: no more than 2% of the project area classified to bare ground shall contain artifacts such as buildings, trees, overpasses or other above-ground features in the ground point classification (Class 2). In addition, no more than 2% of the project area shall contain incorrect classifications of points. (USGS *Lidar Guidelines and Base Specification*, v13, Section IV.14. •
Optional - Breaklines	• Correct topology • Horizontal placement • Completeness • Continuity *See Attachment 3 for breakline topology rules to be checked against*

If the mapping partner responsible *Independent QA of Topographic Data* is tasked to perform assessment of vertical accuracy of the elevation data as described above in sections 4.1.2 and 4.1.3:

- Assessment of FVA only for pre-processed data to be stored and FVA, SVA, and CVA for post-processed data
- Review of data provider vertical accuracy assessment reports

4.2.1 Recommended Checklists

The following checklists are recommended for use during Independent QA/QC review to facilitate the process.

Pre-flight review checklist

Checklist	Pass / Fail	Comments
Planned lines – sufficient coverage, spacing, and length		
Planned GPS stations		
Planned ground control – sufficient to control and boresight		
Calibration plans		
Vendor quality procedures		
Lidar sensor scan set – planned for proper scan angle, sidelap, design pulse.		
Aircraft utilizes ABGPS		

Sensor supports project design pulse density		
Type of aircraft – supports project design parameters		
Reflight procedure – tracking, documenting, processing		
Project design supports accuracy requirements of project		
Project design accounts for land cover and terrain types		

Post-flight review checklists

Checklist for QA of Flight Logs

Checklist	Included Yes/No	Comments
Flight logs – job #/name		
Flight logs – block or AOI		
Flight logs – date		
Flight logs – aircraft tail #		
Flight logs – lines - #		
Flight logs – lines - direction		
Flight logs – lines – start/stop		
Flight logs – lines – altitude		
Flight logs – lines – scan angle		
Flight logs – lines – speed		
Flight logs – conditions		
Flight logs – comments		
Flight logs - pilot name		
Flight logs - operator name		
Flight logs - AGC switch		
Flight logs – GPS base stations		

Checklist for Aerial Acquisition Report

Checklist	Included? Yes/No	Comments
GPS base station – names		
GPS base station – lat/longs		
GPS base station – heights		
GPS base station – map		
GPS quality – separation plot		
GPS quality – PDOP plot		

GPS quality - horizontal Acc.		
GPS quality - vertical Acc.		
Sensor calibration process		
Verification of AOI coverage		
As-flown trajectories		
Ground control layout		
Data verification process documented		

Final terrain product review checklists

Checklist for QA of Terrain Products		
Checklist	**Pass/Fail**	**Comments**
Vertical datum correct		
Horizontal datum correct		
Projection correct		
Vertical units correct		
Horizontal units correct		
Each return contains – GPS week, GPS second, easting, northing, elevation, intensity, return # and classification		
No duplicate entries		
GPS second reported to nearest microsecond		
Easting, northing, and elevation reported to nearest 0.01 m or 0.01 ft		
Classifications correct – 1. Unclassified; 2. Bare-earth ground; 7. Noise; 9. Water; 10. Ignored ground; 11. Withheld		
Cloud file structure conforms to project tile layout		
Naming conforms project requirements		
Deliverable tiles checked for significant gaps not covered by aerial acquisition checks and/or caused by data post-processing/filtering		

M.4 Terrain Submittal Standards

M.4.1 Overview

This section describes the format and type of terrain data required to be submitted to FEMA for FISs. All data must be submitted in digital format. The Mapping Partner performing "Develop Topographic Data" is required to submit the data in this section.

The Mapping Partner should refer to Appendix A of these Guidelines for guidance on terrain data production. This section is not intended to detail the specifications and procedures for coastal hydrographic surveys. The reader is referred to the following additional sources for details on coastal surveys:

- National Oceanic and Atmospheric Administration (NOAA) NOS Hydrographic Survey Specifications and Deliverables (April 2007);
- NOAA Office of Coast Survey Hydrographic Surveys Division Field Procedures Manual (March 2007); and
- U.S. Army Corps of Engineers (USACE) National Coastal Mapping Program Joint LiDAR Bathymetry Technical Center for Expertise.
- Appendix D of the *Guidelines and Specifications for Flood Hazard Mapping Partners* (February 2007).

The submitting Mapping Partner must retain copies of all Project-related data for a period of 3 years. The submitting Mapping Partner will need these data for responding to the following:

- Questions from FEMA or the receiving Mapping Partner during the review of the final draft materials;
- Comments and appeals submitted to FEMA during the 90-day appeal period following the issuance of preliminary maps; and
- Other concerns and issues that may develop during the processing of the new or revised FIS report and FIRM.

M.4.2 Requirements

M.4.2.1 Data Files

The minimum data required for the terrain data submission are the source terrain and topographic maps from the terrain data used in the study. These data can be contained in a single file or in tiled files. When tiled files are submitted, they must be accompanied by a tiling index file. If any processing has been performed, the original and final files must be submitted as well. For instance, if terrain data were blended from three different sources to create the final terrain data, the original of the three sources and the final terrain file that results from the blending process must be submitted. This information is required to be a georeferenced, digital submittal. The following information must be submitted when it is used to perform a study:

- LiDAR data (bare earth and all returns);
- Tiling index for data files;
- Breaklines and Mass Points;
- Contours;
- Bathymetry;
- Digital Elevation Models (DEMs);
- Hydro-corrected DEMs;
- Triangulated Irregular Networks (TINs);
- Hydro-corrected TINs;
- USGS topographic data;
- All other terrain data; and
- LiDAR data generated as part of the project must be submitted as two separate files: one for bare earth only, and one for all returns if bare earth processing was performed as part of this project. For existing LiDAR data not processed as part of the project, the bare earth data must be submitted, and the submittal of the all returns data (if available) is optional.

A project narrative describing the SOW, direction from FEMA, issues, information for next Mapping Partner, etc. (see DCS User Guide for additional details).

M.4.2.2 General Correspondence

A file that compiles general correspondence must be submitted by the Mapping Partner assigned to "Develop Topographic Data." General correspondence is the written correspondence generated or received by the Mapping Partner to fulfill the requirements of developing topographic data. Correspondence includes any documentation generated during this task such as letters; transmittals; memoranda; general status reports and queries; SPRs; technical issues that need to be documented; and direction given by FEMA.. Contractual documents, such as a signed SOW or MAS, are not to be submitted as a part of this appendix.

M.4.2.3 Certification of Work

FEMA-funded (including CTP-funded projects if they are a part of FEMA's flood mapping program) terrain data development must be certified using the Certification of Compliance Form provided in Figure M-11 in section M.10. Submittal of this certification at "Develop Topographic Data" workflow step is required if this is the only task performed by the Mapping Partner. Mapping Partners that are contracted to perform multiple mapping tasks can submit one certification form to certify all the work performed. A PDF file of this form with the original signature, data, and seal affixed to the form must be submitted digitally in the general directory identified in section M.4.2.8. This form must be signed by a registered or certified professional from the firm contracted to perform the work, or by the responsible official of a government agency. A digital version of this form is available at www.fema.gov.

M.4.2.4 Acceptable File Formats

Terrain data used to perform the study must be submitted in a georeferenced, digital format as listed below. These data can be contained in a single file or in a tiled set of files. Any tiled data must have an accompanying index spatial file.

- Contours, Masspoints, and breaklines – Personal geodatabase, DXF, or shapefile
- DEMs – ESRI grid, GeoTIFF, or ASCII grid
- LiDAR – LAS file, ASCII x, y, z file
- Terrain – ESRI ArcGIS
- Word – project narrative
- PDF – correspondence and certification

PDF files must be created using the source file (e.g., Word file), if the source file is created by the Mapping Partner, rather than raster scans of hard copy text documents. PDF files created must allow copying of text and pasting to another document. In addition, ESRI shapefiles must include .PRJ files.

M.4.2.5 Metadata

A metadata file in XML format that complies with the NFIP Terrain Metadata Profiles (provided in Section M.14) must be included with the submittal. The profiles follow the FGDC Content Standard for metadata and define additional domains and business rules for some elements that are mandatory for FEMA, based on the specific submittal type. For each spatial data source in the metadata file, the Mapping Partner must assign a Source Citation Abbreviation.

If metadata is available from an agency or organization that provided data for use in the study, it should be included in the metadata submittal in addition to the NFIP Terrain Metadata Profiles. Reference the data providers' original metadata record in the Lineage section of the NFIP metadata profile. If there is a Web-accessible metadata record for the original data set, the URL to the metadata may be provided in the optional Source Citation - Online Linkage element. Otherwise, the Source Contribution [free text] element may include information on how to access the metadata record for the data sets obtained.

M.4.2.6 Transfer Media

Mapping Partners must submit files via the internet by uploading to the MIP (http://www.hazards.fema.gov) or by mailing the files to FEMA on one or more of the following electronic media:

- CD-ROM;
- DVD; or
- External Hard Drive (for very large data submissions with a return label for shipment back to the partner).

In special situations or as technology changes, other media may be acceptable if coordinated with FEMA.

When data is mailed to FEMA, all submitted digital media must be labeled with at least the following information:

- Mapping Partner's name;
- Community name and State for which the FIS was prepared;
- Terrain Data;
- Date of submission (formatted mm/dd/yyyy); and
- Disk [*sequential number*] of [*number of disks*]. The media must be numbered sequentially, starting at Disk 1. [Number of disks] represents the total number of disks in the submission.

M.4.2.7 Transfer Methodology

Terrain artifacts can be uploaded to the MIP by following the guidelines for Data Submission and Validation located on the MIP (https://hazards.fema.gov) under "User Guidance" in the "Guides & Documentation" tab of "MIP User Care".

M.4.2.8 Directory Structure and Folder Naming Conventions

The files presented in section M.4.2 Requirements must be submitted to the MIP or mailed to FEMA within the following directory structure. Data files must be organized under an applicable 8-digit Hydrologic Unit Code (HUC-8). The following folders can be created either on a local work space (i.e., a personal computer) or within the work space for the community on the MIP. If the following folders are generated locally, these newly created folders and their contents must be uploaded to the MIP. Terrain files are arranged into appropriate directories based on data type.

- \HUC-8\General
  - Project narrative
  - Certification
- \HUC-8\Correspondence
  - Letters; transmittals; memoranda; general status reports and queries; SPRs; technical issues; direction by FEMA; and internal communications, routing slips, and notes.
- \HUC-8\All_Returns
  - LIDAR data – All Returns
  - LIDAR Tile Index spatial file (if used)
- \HUC-8\Bare_Earth
  - LIDAR data – Bare Earth Points
  - LIDAR Tile Index spatial file (if used)
- \HUC-8\Breaklines
  - 3D breakline spatial files
  - 3D breakline Tile Index spatial file (if used)

  - 2D breakline spatial files
  - 2D breakline Tile Index spatial file (if used)
  - Mass Points
- \HUC-8\Contours
  - Contour spatial files
  - Contour Tile Index spatial file (if used)
  - Bathymetric files
  - Bathymetric Tile Index spatial file (if used)
- \HUC-8\DEM
  - Uncorrected DEM files
  - Tile Index spatial file (if used)
- \HUC-8\HDEM
  - Hydrologically correct DEM files
  - Tile Index spatial file (if used)
- \HUC-8\TIN
  - Uncorrected TIN files
  - Terrain (ESRI ArcGIS format)
  - Tile index spatial file (if used)
- \HUC-8\HTIN
  - Hydrologically corrected TIN files
  - Terrain (ESRI ArcGIS format)
  - Tile Index spatial file (if used)
- \HUC-8\Supplemental Data
  - As-built drawings
  - GIS representation of structures

U.S. Geological Survey
National Geospatial Program
Lidar Guidelines and Base Specification

Version 13 – ILMF 2010

The U.S. Geological Survey National Geospatial Program (NGP) has cooperated in the collection of numerous lidar datasets across the nation for a wide array of applications. These collections have used a variety of specifications and required a diverse set of products, resulting in many incompatible datasets and making cross-project analysis extremely difficult. The need for a single base specification, defining minimum collection parameters and a consistent set of deliverables, is apparent.

Beginning in late 2009, an increase in the rate of lidar data collection due to American Reinvestment and Recovery Act (ARRA) funding for The National Map makes it imperative that a single data specification be implemented to ensure consistency and improve data utility. Although the development of this specification was prompted by the ARRA stimulus funding, the specification is intended to remain durable beyond ARRA funded NGP projects.

The primary intent of this specification is to create consistency across all NGP funded lidar collections, in particular those undertaken in support of the National Elevation Dataset (NED). Unlike most other “lidar specs” which focus on the derived bare-earth DEM product, this specification places unprecedented emphasis on the handling of the source lidar point cloud data. This is to assure that the complete source dataset collected remains intact and viable to support the wide variety of non-DEM science and mapping applications that benefit from lidar technology. In the absence of other comprehensive specifications or standards, it is hoped that this specification will, to the highest degree practical, be adopted by other USGS programs and disciplines, and by other Federal agencies.

Adherence to these minimum specifications ensures that bare-earth Digital Elevation Models (DEMs) derived from lidar data is suitable for ingestion into the NED (National Elevation Dataset) at the 1/9 arc-second resolution, and can be resampled for use in the 1/3 and 1 arc-second NED resolutions. It also ensures that the point cloud source data are handled in a consistent manner by all data providers and delivered to the USGS in clearly defined formats. This allows straight-forward ingest into CLICK (Center for Lidar Information, Coordination, and Knowledge) and simplifies subsequent use of the source data by the broader scientific community, particularly with regard to cross-collection analysis.

It must be stressed that this is a **base specification,** defining <u>minimum parameters</u>. It is expected that local conditions in any given project area, specialized applications for the data, or the preferences of cooperators, may mandate more stringent requirements. The

USGS encourages the collection of more detailed, accurate, or value-added data. A list of common upgrades to the minimum requirements defined here is provided in Appendix 1.

In addition, it is recognized that the USGS NGP also employs lidar technology for specialized scientific research and other projects whose requirements are incompatible with the provisions of this Specification. In such cases, and with properly documented justification supporting the need for the variance, waivers of any part or all of this Specification may be granted.

It is conceivable that in some cases, based on specific topography, land cover, intended application, or other factors, the USGS-NGP may require specifications more rigorous than those defined in this document. It is expected that this would be highly uncommon.

Lidar is still a relatively new technology; adolescent but not fully matured.. Advancements and improvements in instrumentation, software, processes, applications, and understanding are constantly being made. It would not be possible to develop a set of guidelines and specifications that address all of these advances. The current document is based on our understanding of and experience with the industry and technology at the present time. Furthermore, we acknowledge that there is a lack of commonly accepted "best practices" for numerous processes and technical assessments (i.e., measurement of NPS, point clustering, classification accuracy, etc.). The USGS encourages the development of such best practices through the appropriate industry and professional governance organizations, and we eagerly await the opportunity to include them in future revisions to this and other similar documents.

It is not the intention of the USGS to stifle the development of the lidar industry, nor to discourage innovation within the technology. Technical alternatives to any part of this document may be submitted with any proposal and will be given due professional consideration.

I. COLLECTION

1. Multiple Discrete Return, capable of at least 3 returns per pulse

   Note: Full waveform collection is both acceptable and welcomed; however, waveform data is regarded as supplemental information. The requirement for deriving and delivering multiple discrete returns remains in force in all cases.

2. Intensity values for each return.

3. Nominal **Pulse** Spacing (NPS) of 1-2 meters, dependent on the local terrain and landcover conditions. Assessment to be made against single swath, first return data located within the geometrically usable center portion (typically ~90%) of each swath. Average along-track and cross-track point spacings should be comparable.

4. Collections designed to achieve the NPS through swath overlap or multiple passes are generally discouraged. Such collections may be permitted with prior approval.

5. Data Voids [areas => $(4*NPS)^2$, measured using 1st-returns only] within a single swath 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

6. The spatial distribution of geometrically usable points is expected to be uniform and free from clustering. In order to ensure uniform densities throughout the data set:

   - 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.
   - Acceptable data voids identified previously in this specification are excluded.

   Note: This requirement may be relaxed in areas of significant relief where it is impractical to maintain a consistent NPS.

7. Scan Angle: Total FOV should not exceed 40^o (+/-20^o from nadir) USGS quality assurance on collections performed using scan angles wider than 34^o will be particularly rigorous in the edge-of-swath areas. Horizontal and vertical accuracy shall remain within the requirements as specified below.

   Note: This requirement is primarily applicable to oscillating mirror lidar systems. Other instrument technologies may be exempt from this requirement.

8. Vertical Accuracy of the lidar data will be assessed and reported in accordance with the guidelines developed by the NDEP and subsequently adopted by the ASPRS. The complete guidelines may be found in Section 1.5 of the Guidelines document. See:

   http://www.ndep.gov/NDEP_Elevation_Guidelines_Ver1_10May2004.pdf

   Vertical accuracy requirements using the NDEP/ASPRS methodology are:

   FVA <= 24.5cm ACCz, 95% (12.5cm RMSEz)
   CVA <= 36.3cm, 95th Percentile
   SVA <= 36.3cm, 95th Percentile

   - Accuracy for the lidar point cloud data is to be reported independently from accuracies of derivative products (i.e., DEMs). Point cloud data accuracy is to be tested against a TIN constructed from bare-earth lidar points.
   - Each landcover type representing 10% or more of the total project area must be tested and reported as an SVA.
   - For SVAs, the value is provided as a target. It is understood that in areas of dense vegetation, swamps, or extremely difficult terrain, this value may be exceeded. Overall CVA requirements must be met in spite of "busts" in individual SVAs.

   Note: These requirements may be relaxed in cases:

   - *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, i.e., multi-year statewide collections, etc.*
   - *where the USGS agrees that it is reasonable and in the best interest of all stakeholders to use an alternate specification.*

9. Relative accuracy <=7cm $RMSE_Z$ within individual swaths; <=10cm RMSEz within swath overlap (between adjacent swaths).
10. Flightline overlap 10% or greater, as required to ensure there are no data gaps between the usable portions of the swaths. Collections in high relief terrain are expected to require greater overlap. Any data with gaps between the geometrically usable portions of the swaths will be rejected.
11. Collection Area: Defined Project Area, buffered by a minimum of 100 meters.
12. Collection Conditions:
    - Atmospheric: Cloud and fog-free between the aircraft and ground
    - Ground:
      - Snow free. Very light, undrifted snow may be acceptable in special cases, with prior approval.

- No unusual flooding or inundation, except in cases where the goal of the collection is to map the inundation.

- Vegetation: Leaf-off is preferred, however:
  - As numerous factors will affect vegetative condition at the time of any collection, the USGS NGP only requires that penetration to the ground must be adequate to produce an accurate and reliable bare-earth surface suitable for incorporation into the 1/9 (3-meter) NED.
  - Collections for specific scientific research projects may be exempted from this requirement, with prior approval.

II. DATA PROCESSING and HANDLING

1. All processing should be carried out with the understanding that all point deliverables are required to be in fully compliant LAS format, v1.2 or v1.3. Data producers are encouraged to review the LAS specification in detail.
2. If full waveform data is collected, delivery of the waveform packets is required. LAS v1.3 deliverables with waveform data are to use external "auxiliary" files with the extension ".wdp" for the storage of waveform packet data. See the LAS v1.3 Specification for additional information.
3. GPS times are to be recorded as Adjusted GPS Time, at a precision sufficient to allow unique timestamps for each pulse. Adjusted GPS Time is defined to be Standard (or satellite) GPS time minus $1*10^9$. See the LAS Specification for more detail.
4. Horizontal datum shall be referenced to the North American Datum of 1983/HARN adjustment. Vertical datum shall be referenced to the North American Vertical Datum of 1988 (NAVD 88). The most recent NGS-approved Geoid model shall be used to perform conversions from ellipsoidal heights to orthometric heights.
5. The USGS preferred Coordinate Reference System for the Conterminous United States (CONUS) is: UTM, NAD83, Meters. Each discrete project is to be processed using the predominant UTM zone for the overall collection area.

   State Plane Coordinate Reference Systems that have been accepted by the European Petroleum Survey Group (EPSG) and that are recognized by ESRI GIS software may be used by prior agreement with the USGS.

   Alternative projected coordinate systems for collections in Alaska, Hawaii, and other areas Outside the Conterminous United States (OCONUS) must be approved by the USGS prior to collection.
6. All references to the Unit of Measure "Feet" or "Foot" must specify either "International" or "U.S. Survey"
7. Long swaths (those which result in a LAS file larger than 2GB) should be split into segments no greater than 2GB each. Each segment will thenceforth be

regarded as a unique swath and shall be assigned a unique File Source ID. Other swath segmentation approaches may be acceptable, with prior approval. Renaming schemes for split swaths are at the discretion of the data producer. The Processing Report shall include detailed information on swath segmentation sufficient to allow reconstruction of the original swaths if needed.

8. Each swath shall be assigned a unique File Source ID. The Point Source ID field for each point within each LAS swath file shall be set equal to the File Source ID prior to any processing of the data. See the LAS Specification.

9. Point Families (multiple return "children" of a single "parent" pulse) shall be maintained intact through all processing prior to tiling. Multiple returns from a given pulse shall be stored in sequential (collected) order.

10. All collected swaths are to be delivered as part of the "Raw Data Deliverable". This includes calibration swaths and cross-ties. All collected points are to be delivered. No points are to be deleted from the swath LAS files. <u>This in no way requires or implies that calibration swath data are to be included in product generation</u>. Excepted from this are extraneous data outside of the buffered project area (aircraft turns, transit between the collection area and airport, transit between fill-in areas, etc.). These points may be permanently removed.

11. Outliers, blunders, noise points, geometrically unreliable points near the extreme edge of the swath, and other points deemed unusable are to be identified using the "Withheld" flag, as defined in the LAS specification.
    - This applies primarily to points which are identified during pre-processing or through automated post-processing routines.
    - If processing software is not capable of populating the "Withheld" bit, these points may be identified using Class=11.
    - "Noise points" subsequently identified during manual Classification and Quality Assurance/Quality Control (QA/QC) may be assigned the standard LAS classification value for "Noise" (Class=7), regardless of whether the noise is "low" or "high" relative to the ground surface.

12. The ASPRS/LAS "Overlap" classification (Class=12) shall not be used. ALL points not identified as "Withheld" are to be classified.
    - If overlap points are required to be differentiated by the data producer or cooperating partner, they must be identified using a method that does not interfere with their classification, such as:
        - Overlap points are tagged using Bit:0 of the User Data byte, as defined in the LAS specification. (SET=Overlap).
        - Overlap points are classified using the Standard Class values + 16.
        - Other techniques as agreed upon in advance
    - The technique utilized must be clearly described in the project metadata files.

Note: A standard bit setting for identification of overlap points has been planned for a future version of LAS.

13. Positional Accuracy Validation: The absolute and relative accuracy of the data, both horizontal and vertical, and relative to known control, shall be verified prior to classification and subsequent product development. This validation is obviously limited to the Fundamental Vertical Accuracy, measured in clear, open areas. A detailed report of this validation is a required deliverable.

14. Classification Accuracy: It is expected that due diligence in the classification process will produce data that meets the following test:

    Within any 1km x 1km area, no more than 2% of non-withheld points will possess a demonstrably erroneous classification value.

    This includes points in Classes 0 and 1 that should correctly be included in a different Class as required by the contract.

    Note: This requirement may be relaxed to accommodate collections in areas where the USGS agrees classification to be particularly difficult.

15. Classification Consistency: Point classification is to be consistent across the entire project. Noticeable variations in the character, texture, or quality of the classification between tiles, swaths, lifts, or other non-natural divisions will be cause for rejection of the entire deliverable.

16. Tiles:

    Note: This section assumes a projected coordinate reference system.

    - A single non-overlapped tiling scheme will be established and agreed upon by the data producer and the USGS prior to collection. This scheme will be used for **all** tiled deliverables.
    - Tile size must be an integer multiple of the cell size of raster deliverables.
    - Tiles must be sized using the same units as the coordinate system of the data.
    - Tiled deliverables shall conform to the tiling scheme, without added overlap.
    - Tiled deliverables shall edge-match seamlessly and without gaps in both the horizontal and vertical.

III. HYDRO-FLATTENING REQUIREMENTS

Note: Please refer to Appendix 2 for reference information on hydro-flattening.

Hydro-flattening pertains only to the creation of derived DEMs. No manipulation of or changes to originally computed lidar point elevations are to be made. Breaklines may be used to help classify the point data.

1. Inland Ponds and Lakes:
    - ~2-acre or greater surface area (~350' diameter for a round pond) at the time of collection.
    - Flat and level water bodies (single elevation for every bank vertex defining a given water body).
    - The entire water surface edge must be at or below the immediately surrounding terrain.
    - Long impoundments such as reservoirs, inlets, and fjords, whose water surface elevations drop when moving downstream, should be treated as rivers.
2. Inland Streams and Rivers:
    - 100' **nominal** width: This should not unnecessarily break a stream or river into multiple segments. At times it may squeeze slightly below 100' for short segments. Data producers should use their best professional judgment.
    - Flat and level bank-to-bank (perpendicular to the apparent flow centerline); gradient to follow the immediately surrounding terrain.
    - The entire water surface edge must be at or below the immediately surrounding terrain.
    - Streams channels should break at road crossings (culvert locations). These road fills should not be removed from DEM. However, streams and rivers should **not** break at elevated bridges. Bridges should be removed from DEM. When the identification of a feature as a bridge or culvert cannot be made reliably, the feature should be regarded as a culvert.
3. Non-Tidal Boundary Waters:
    - Represented only as an edge or edges within the project area; collection does not include the opposing shore.
    - The entire water surface edge must be at or below the immediately surrounding terrain.
    - The elevation along the edge or edges should behave consistently throughout the project. May be a single elevation (i.e., lake) or gradient (i.e., river), as appropriate.

4. Tidal Waters:

   - Water bodies such as oceans, seas, gulfs, bays, inlets, salt marshes, very large lakes, etc. Includes any water body that is affected by tidal variations.
   - Tidal variations over the course of a collection or between different collections, will result in discontinuities along shorelines. This is considered normal and these "anomalies" should be retained. The final DEM should represent as much ground as the collected data permits.
   - Variations in water surface elevation resulting in tidal variations during a collection should NOT be removed or adjusted, as this would require either the removal of valid, measured ground points or the introduction of unmeasured ground into the DEM. The USGS NGP priority is on the ground surface, and accepts there may be occasional, unavoidable irregularities in water surface.
   - Scientific research projects in coastal areas often have very specific requirements with regard to how tidal land-water boundaries are to be handled. For such projects, the requirements of the research will take precedence.

Cooperating partners may require collection and integration of single-line streams within their lidar projects. While the USGS does not require these breaklines be collected or integrated, it does require that if used and incorporated into the DEMs, the following guidelines are met:

1. All vertices along single-line stream breaklines are at or below the immediately surrounding terrain.
2. Single-line stream breaklines are not to be used to introduce cuts into the DEM at road crossings (culverts), dams, or other such features. This is hydro-enforcement and as discussed in Section VI, creates a non-traditional DEM that is not suitable for integration into the NED.
3. All breaklines used to modify the surface are to be delivered to the USGS with the DEMs.

The USGS does not require any particular process or methodology be used for breakline collection, extraction, or integration. However, the following general guidelines must be adhered to:

1. Bare-earth lidar points that are in close proximity breaklines should be excluded from the DEM generation process. This is analogous to the removal of masspoints for the same reason in a traditional photogrammetrically compiled DTM.

   The proximity threshold for reclassification as "Ignored Ground" is at the discretion of the data producer, but in general should be approximately equal to the NPS.

2. These points are to be retained in the delivered lidar point dataset and shall be reclassified as "Ignored Ground" (class value = 10) so that they may be subsequently identified.
3. Delivered data must be sufficient for the USGS to effectively recreate the delivered DEMs using the lidar points and breaklines without significant further editing.

IV. DELIVERABLES

The USGS shall have unrestricted rights to all delivered data and reports, which will be placed in the public domain. This specification places no restrictions on the data provider's rights to resell data or derivative products as they see fit.

1. Metadata

Note: "Metadata" refers to all descriptive information about the project. This includes textual reports, graphics, supporting shapefiles, and FGDC-compliant metadata files.

- Collection Report detailing mission planning and flight logs.
- Survey Report detailing the collection of control and reference points used for calibration and QA/QC.
- Processing Report detailing calibration, classification, and product generation procedures including methodology used for breakline collection and hydro-flattening *(see Sections III and Appendix 1 for more information on hydro-flattening)*.
- QA/QC Reports (detailing the analysis, accuracy assessment and validation of:
    - The point data (absolute, within swath, and between swath)
    - The bare-earth surface (absolute)
    - Other optional deliverables as appropriate
- Control and Calibration points: All control and reference points used to calibrate, control, process, and validate the lidar point data or any derivative products are to be delivered.
- Geo-referenced, digital spatial representation of the precise extents of each delivered dataset. This should reflect the extents of the actual lidar source or derived product data, exclusive of Triangular Irregular Network (TIN) artifacts or raster NODATA areas. A union of tile boundaries or minimum bounding rectangle is not acceptable. ESRI Polygon shapefile or geodatabase is preferred.
- Product metadata (FGDC compliant, XML format metadata). One file for each:

    - Project
    - Lift
    - Tiled deliverable product group (classified point data, bare-earth DEMs, breaklines, etc.). Metadata files for individual tiles are not required.
- FGDC compliant metadata must pass the USGS metadata parser ("mp") with no errors or warnings.

2. Raw Point Cloud

- All returns, all collected points, fully calibrated and adjusted to ground, by swath.
- <u>Fully compliant</u> LAS v1.2 or v1.3, Point Record Format 1, 3, 4, or 5
- LAS v1.3 deliverables with waveform data are to use external "auxiliary" files with the extension ".wdp" for the storage of waveform packet data. See the LAS v1.3 Specification for additional information.
- Georeference information included in all LAS file headers
- GPS times are to be recorded as Adjusted GPS Time, at a precision sufficient to allow unique timestamps for each pulse.
- Intensity values (native radiometric resolution)
- 1 file per swath, 1 swath per file, file size not to exceed 2GB, as described in Section II, Paragraph 7.

3. Classified Point Cloud

Note: Delivery of a classified point cloud is a standard requirement for USGS NGP lidar projects. Specific scientific research projects may be exempted from this requirement.

- <u>Fully compliant</u> LAS v1.2 or v1.3, Point Record Format 1, 3, 4, or 5
- LAS v1.3 deliverables with waveform data are to use external "auxiliary" files with the extension ".wdp" for the storage of waveform packet data. See the LAS v1.3 Specification for additional information.
- Georeference information included in LAS header
- GPS times are to be recorded as Adjusted GPS Time, at a precision sufficient to allow unique timestamps for each pulse.
- Intensity values (native radiometric resolution)
- Tiled delivery, without overlap (tiling scheme TBD)

- Classification Scheme (minimum):

Code	Description
1	Processed, but unclassified
2	Bare-earth ground
7	Noise (low or high, manually identified, if needed)
9	Water
10	Ignored Ground (Breakline Proximity)
11	Withheld (if the "Withheld" bit is not implemented in processing software)

Note: Class 7, Noise, is included as an adjunct to the "Withheld" bit. All "noise points" are to be identified using one of these to methods.

Note: Class 10, Ignored Ground, is for points previously classified as bare-earth but whose proximity to a subsequently added breakline requires that it be excluded during Digital Elevation Model (DEM) generation.

4. **Bare Earth Surface (Raster DEM)**

Note: Delivery of a bare-earth DEM is a standard requirement for USGS NGP lidar projects. Specific scientific research projects may be exempted from this requirement.

- Cell Size no greater than 3 meters or 10 feet, and no less than the design Nominal Pulse Spacing (NPS).
- Delivery in an industry-standard, GIS-compatible, 32-bit floating point raster format (ERDAS .IMG preferred)
- Georeference information shall be included in each raster file
- Tiled delivery, without overlap
- DEM tiles will show no edge artifacts or mismatch. A quilted appearance in the overall project DEM surface, whether caused by differences in processing quality or character between tiles, swaths, lifts, or other non-natural divisions, will be cause for rejection of the entire DEM deliverable.
- Void areas (i.e., areas outside the project boundary but within the tiling scheme) shall be coded using a unique "NODATA" value. This value shall be identified in the appropriate location within the file header.
- Vertical Accuracy of the bare earth surface will be assessed and reported in accordance with the guidelines developed by the NDEP and subsequently adopted by the ASPRS. The complete guidelines may be found in Section 1.5 of the Guidelines document. See:

  http://www.ndep.gov/NDEP_Elevation_Guidelines_Ver1_10May2004.pdf

Vertical accuracy requirements using the NDEP/ASPRS methodology are:
FVA <= 24.5cm ACCz, 95% (12.5cm RMSEz)
CVA <= 36.3cm, 95th Percentile
SVA <= 36.3cm, 95th Percentile

All QA/QC analysis materials and results are to be delivered to the USGS.

- Depressions (sinks), natural or man-made, are **not** to be filled (as in hydro-conditioning and hydro-enforcement).
- Water Bodies (ponds and lakes), wide streams and rivers (“double-line”), and other non-tidal water bodies as defined in Section III are to be hydro-flattened within the DEM. Hydro-flattening shall be applied to all water impoundments, natural or man-made, that are larger than ~2 acre in area (equivalent to a round pond ~350’ in diameter), to all streams that are nominally wider than 100’, and to all non-tidal boundary waters bordering the project area regardless of size. The methodology used for hydro-flattening is at the discretion of the data producer.

  Note: Please refer to the Sections III and VI for detailed discussions of hydro-flattening.

5. **Breaklines**

Note: Delivery of the breaklines used in hydro-flattening is a standard requirement for USGS NGP lidar projects. Specific scientific research projects may be exempted from this requirement. If hydro-flattening is achieved through other means, this section may not apply.

- All breaklines developed for use in hydro-flattening shall be delivered as an ESRI feature class (PolylineZ or PolygonZ format, as appropriate to the type of feature represented and the methodology used by the data producer). Shapefile or geodatabase is preferred.
- Each feature class or shapefile will include properly formatted and accurate georeference information in the standard location. All shapefiles must include the companion .prj file.
- Breaklines must use the same coordinate reference system (horizontal and vertical) and units as the lidar point delivery.
- Breakline delivery may be as a continuous layer or in tiles, at the discretion of the data producer. Tiled deliveries must edge-match seamlessly in both the horizontal and vertical.

APPENDIX 1

COMMON DATA UPGRADES

1. Independent 3rd-Party QA/QC by another AE Contractor (encouraged)
2. Higher Nominal Pulse Spacing (point density)
3. Increased Vertical Accuracy
4. Full Waveform collection and delivery
5. Additional Environmental Constraints
    - Tidal coordination, flood stages, crop/plant growth cycles, etc.
    - Shorelines corrected for tidal variations within a collection
6. Top-of Canopy (First-Return) Raster Surface (tiled). Raster representing the highest return within each cell is preferred.
7. Intensity Images (8-bit gray scale, tiled)
8. Detailed Classification (additional classes):

Code	Description
3	Low vegetation
4	Medium vegetation (use for single vegetation class)
5	High vegetation
6	Buildings, bridges, other man-made structures
n	additional Class(es) as agreed upon in advance

9. Hydro-Enforced and/or Hydro-Conditioned DEMs
10. Breaklines (PolylineZ and PolygonZ) for single-line hydrographic features (narrow streams not collected as double-line, culverts, etc.), including appropriate integration into delivered DEMs
11. Breaklines (PolylineZ and PolygonZ) for other features (TBD), including appropriate integration into delivered DEMs
12. Extracted Buildings (PolygonZ): Footprints with maximum elevation and/or height above ground as an attribute.
13. Other products as defined by requirements and agreed upon in advance of funding commitment.

APPENDIX 2

HYDRO-FLATTENING REFERENCE

The subject of modifications to lidar-based DEMs is somewhat new, and although authoritative references are available, there remains significant variation in the understanding of the topic across the industry. The following material was developed to provide a definitive reference on the subject only as it relates to the creation of DEMs intended to be integrated into the USGS NED. The information presented here is not meant to supplant other reference materials and it should not be considered authoritative beyond its intended scope.

The term “**hydro-flattening**” is also new, coined for this document and to convey our specific needs. It is not, at this time, a known or accepted term across the industry. It is our hope that its use and acceptance will expand beyond the USGS with the assistance of other industry leaders.

Hydro-flattening of DEMs is predominantly accomplished through the use of breaklines, and this method is considered standard. Although other techniques may exist to achieve similar results, this section assumes the use of breaklines. The USGS does not require the use of any specific technique.

The Digital Elevation Model Technologies and Applications: The DEM Users Manual, 2nd Edition (Maune *et al.*, 2007) provides the following definitions related to the adjustment of DEM surfaces for hydrologic analyses:

1. **Hydrologically-Conditioned (Hydro-Conditioned)** – Processing of a DEM or TIN so that the flow of water is continuous across the entire terrain surface, including the removal of all spurious sinks or pits. The only sinks that are retained are the real ones on the landscape. Whereas “hydrologically-enforced” is relevant to drainage features that are generally mapped, “hydrologically-conditioned” is relevant to the entire land surface and is done so that water flow is continuous across the surface, whether that flow is in a stream channel or not. The purpose for continuous flow is so that relationships/links among basins/catchments can be known for large areas. This term is specifically used when describing EDNA (see Chapter 4), the dataset of NED derivatives made specifically for hydrologic modeling purposes.
2. **Hydrologically-Enforced (Hydro-Enforced)** – Processing of mapped water bodies so that lakes and reservoirs are level and so that streams flow downhill. For example, a DEM, TIN or topographic contour dataset with elevations removed from the tops of selected drainage structures (bridges and culverts) so as to depict the terrain under those structures. Hydro-enforcement enables hydrologic and hydraulic models to depict water flowing under these structures, rather than appearing in the computer model to be dammed by them because of road deck elevations higher than the water levels. Hydro-enforced TINs also utilize breaklines along shorelines and stream centerlines, for example, where these breaklines form the edges of TIN triangles along the alignment of drainage features. Shore breaklines for streams would be 3-D breaklines

with elevations that decrease as the stream flows downstream; however, shore breaklines for lakes or reservoirs would have the same elevation for the entire shoreline if the water surface is known or assumed to be level throughout. See figures 1.21 through 1.24. See also the definition for "hydrologically-conditioned" which has a slightly different meaning.

While these are important and useful modifications, they both result in surfaces that differ significantly from a traditional DEM. A "hydro-conditioned" surface has had its sinks filled and may have had its water bodies flattened. This is necessary for correct flow modeling within and across large drainage basins. "Hydro-enforcement" extends this conditioning by requiring water bodies be leveled and streams flattened with the appropriate downhill gradient, and also by cutting through road crossings over streams (culvert locations) to allow a continuous flow path for water within the drainage. Both treatments result in a surface on which water behaves as it physically does in the real world, and both are invaluable for specific types of hydraulic and hydrologic (H&H) modeling activities. Neither of these treatments is typical of a traditional DEM surface.

A traditional DEM such as the NED, on the other hand, attempts to represent the ground surface more the way a bird, or person in an airplane, sees it. On this surface, natural depressions exist, and road fills create apparent sinks because the road fill and surface is depicted without regard to the culvert beneath. Bridges, it should be noted, are removed in most all types of DEMs because they are man-made, above-ground structures that have been added to the landscape.

Note: DEMs developed solely for orthophoto production may include bridges, as their presence can prevent the "smearing" of structures and reduce the amount of post-production correction of the final orthophoto. These are "special use DEMs" and are not relevant to this discussion.

For years, raster Digital Elevation Models (DEMs), have been created from a Digital Surface Model (DSM) of masspoints and breaklines, which in turn were created through photogrammetric compilation from stereo imagery. Photogrammetric DSMs inherently contain breaklines defining the edges of water bodies, coastlines, single-line streams, and double-line streams and rivers, as well as numerous other surface features.

Lidar technology, however, does not inherently collect the breaklines necessary to produce traditional DEMs. Breaklines have to be developed separately through a variety of techniques, and either used with the lidar points in the generation of the DEM, or applied as a correction to DEMs generated without breaklines.

In order to maintain the consistent character of the NED as a traditional DEM, the USGS NGP requires that all DEMs delivered have their inland water bodies flattened. This does not imply that a complete network of topologically correct hydrologic breaklines be developed for every dataset; only those breaklines necessary to ensure that the conditions defined in Section III exist in the final DEM.

APPENDIX 3

SAMPLE METADATA TEMPLATE

[to be added]

APPENDIX 4

REFERENCES

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