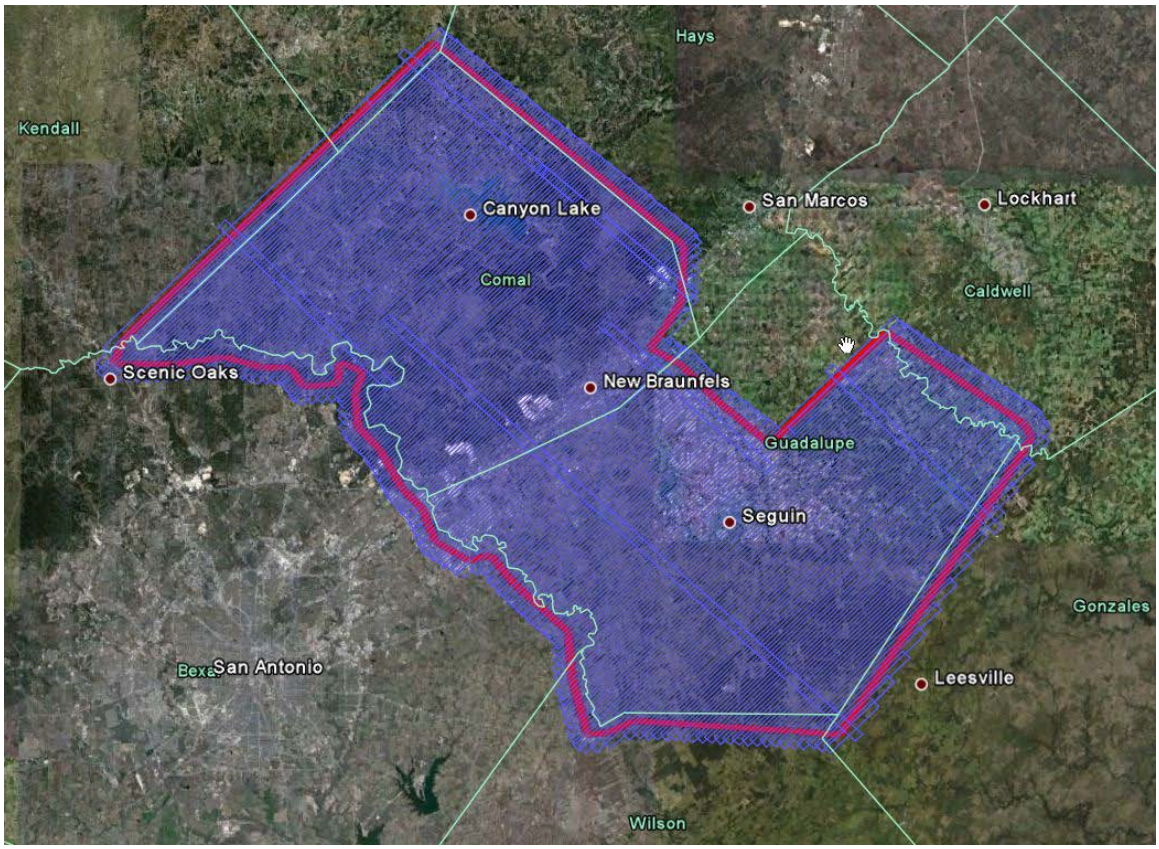
A JV of Dewberry, URS, and ESP
RAMPP
Risk Assessment, Mapping, and Planning Partners

Central Texas
Area of Interest

INDEPENDENT QUALITY CONTROL REPORT



Task Order HSFEHQ-10-J-0006

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Risk Assessment, Mapping, and Planning Partners

Central Texas Independent Quality Control Report

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1 Executive Summary

Risk Assessment, Mapping, and Planning Partners (RAMPP) performed a limited review of the Central Texas dataset. 100% of the data was checked for completeness and 5% of the data was visually examined at the micro level for qualitative issues according to the scope of work. During the review, several issues were identified that needed to be addressed; including some classification errors in the LAS files and missing breaklines (hydro-line) in the breakline geodatabase. A vertical accuracy assessment was performed on the first return points in the Level 1-processed dataset and the full point cloud in the Level 2-processed dataset. Both datasets meet the Federal Emergency Management Agency's (FEMA) vertical accuracy specifications.

2 Overview

The Independent Quality Control for the Central Texas Area of Interest (AOI) was performed by RAMPP. This review validates the quality of the Light Detection and Ranging (LiDAR) data for use in flood risk mapping products in support of the National Flood Insurance Program. This document outlines the quality review of LiDAR data and LiDAR-derived mapping products covering the Central Texas AOI developed by RAMPP subcontractors Fugro EarthData, Inc. (FEDI) and Tuck Mapping Solution, Inc. (Tuck). FEDI was responsible for acquiring the LiDAR data for this AOI and producing the Level 1-processed dataset. Level 1 processing was completed by FEDI in January of 2011. Tuck was responsible for processing the Level 1 data to the Level 2 product and completed processing in September of 2011.

2.1 Project Area

LiDAR data was acquired by FEDI for the Central Texas AOI, which covers a contiguous area of approximately 1,305 square miles, encompassing portions of Comal, Kendall, Blanco, Hays, Bexar, Caldwell, Gonzales, Wilson and Guadalupe Counties, TX plus a 100-meter buffer around the perimeter of the AOI boundary.

The Level-1 data was delivered as full-swath, calibrated, and boresighted flight lines in LAS format. The same area was processed to Level 2 to classify bare-earth ground points and hydro features and was delivered as a tiled, classified, point cloud in LAS format using the following classification scheme:

- Class 1 – Processed, but unclassified
- Class 2 – Bare-earth ground
- Class 7 – Low points and noise
- Class 9 – Water
- Class 11 – Withheld

Figure 1 shows the acquisition and processing areas for the Central Texas AOI dataset. The purple lines depict the swath boundaries acquired and processed to Level 1, and the red boundary shows the extent of the data that was processed to Level 2.

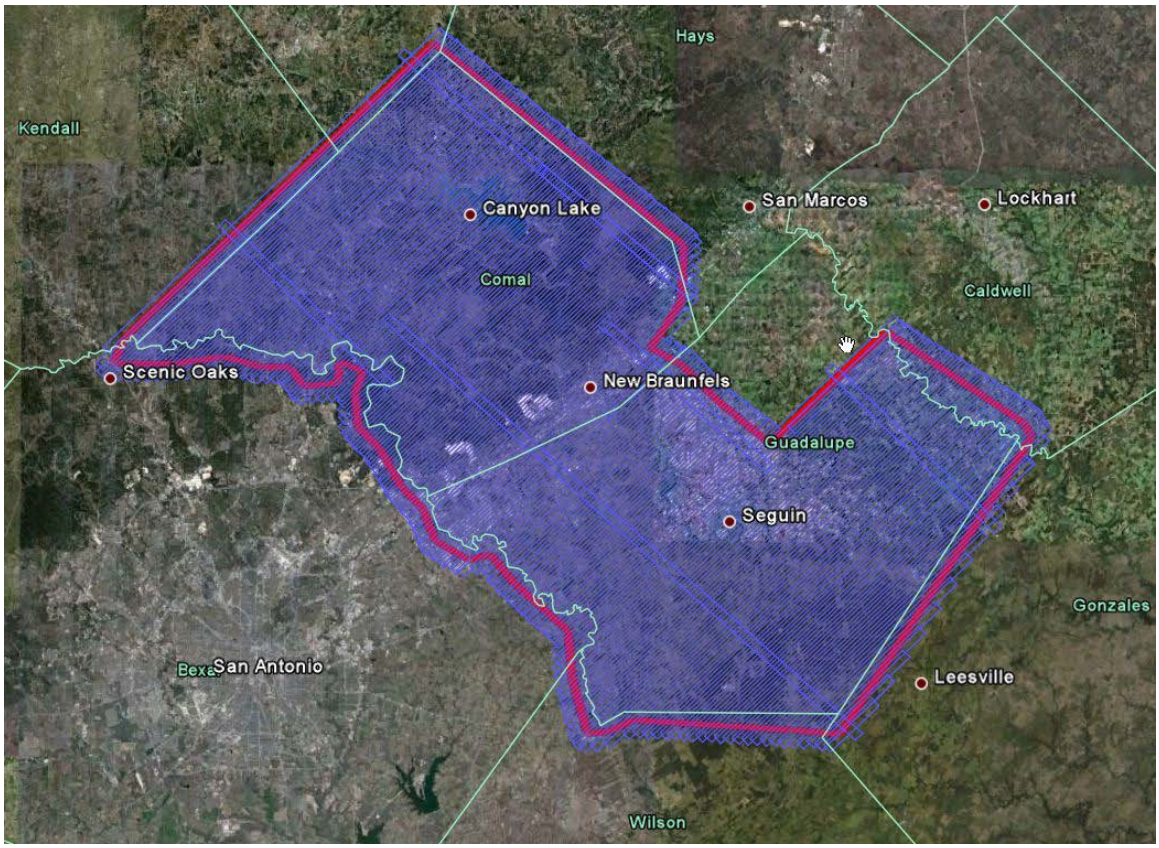

Figure 1: Central Texas AOI data coverage

2.2 Applicable Specifications & Guidelines

The following specifications/guidelines are applicable to this report:

1. Federal Emergency Management Agency, Procedure Memorandum No. 61 – Standards for LiDAR and Other High Quality Digital Topography, http://www.fema.gov/library/viewRecord.do?id=4345

3 Project Initiation Plan

The following quality control actions were taken prior to the aerial acquisition of the LiDAR data for this AOI and upon receipt of the Project Initiation Plan from FEDI.

3.1 Review of Project Initiation Plan

FEDI was required to submit a Project Initiation Plan to RAMPP for approval, prior to the commencement of data collection operations. FEDI delivered their Project Initiation Plan as part of their "Operation Plan". The submitted Operations Plan is dated November 23, 2010.

The required content for this plan included:

- Schedule (data acquisition, data processing, data delivery), including contact information for the project and field operation manager(s)
- Proposed flight lines in ESRI shapefile or graphic format
- GPS base station locations in ESRI shapefile and graphic format, as well as supporting National Geodetic Survey (NGS) control information
- Proposed baseline lengths for aerial collection
- Calibration testing methodology
- LiDAR collection parameters (flying height, scan field of view, angle, pulse rate, scanner frequency, side-lap percentage, point density, etc.)
- Proposed acquisition windows including maximum position dilution of precision (PDOP) values
- Description of internal verification quality control processes:
    - Data validation
    - Pre-processing and accuracy check
    - Processing quality control
    - Product delivery quality control
- Communication of any issues that might affect the acquisition or processing of the intended project (such as restricted airspace)

3.1.1 Results

The following table outlines the results of the QA review of the Project Initiation Plan:

Table 1: QA of Project Initiation Plan – Central Texas AOI

Items Reviewed	Pass / Fail	Comments
Schedule provided for data acquisition, processing and delivery	Pass	None
Proposed flight lines submitted in GIS or graphic format	Pass	None
Base station location submitted in GIS and graphic format along with NGS control information	Pass	Base station locations provided in graphic format only
Proposed baseline lengths for aerial data	Pass	None

Table 1: QA of Project Initiation Plan – Central Texas AOI		
collection		
Calibration testing methodology(s) described	Pass	None
LiDAR collection parameters described	Pass	None
Proposed acquisition windows and maximum PDOP values outlined	Pass	None
Description of internal verification QC processes:		
Data validation	Pass	None
Pre-processing and accuracy check	Pass	None
Processing quality control	Pass	None
Product delivery quality control	Pass	None
Description of any potential issues that may affect the acquisition or processing of data	Pass	None

4 QA Process

RAMPP employs a suite of commercial software and proprietary scripts when reviewing LiDAR data. These tools are incorporated into the RAMPP quality control review workflow, as described in section 4.2 below.

4.1 Software

The main software programs used by RAMPP in performing the qualitative assessment are as follows:

- *GeoCue:* a geospatial data/process management system especially suited to managing large LiDAR data sets
- *Terrascan:* runs inside Bentley Microstation; used for point classification checks and points file generation
- *Proprietary tools:* developed in-house to conduct a statistical analysis of .LAS files
- *QT Modeler:* used for vertical accuracy assessment and visual analysis of classified LiDAR data

4.2 Qualitative Assessment Process

The following systematic approach was used for performing the qualitative assessment of this delivery.

4.2.1 Macro Checks (100% of Level 1 and Level 2-Processed Data)

Boresighted flight lines and classified LiDAR data received from FEDI and Tuck were reviewed for completeness and formatting issues.

4.2.1.1 LAS Header Review

A proprietary LAS parser was used to read the LAS header, Variable Length Records, and individual point data records for accurate echo (return), classification, intensity values, etc. The header review confirmed that tile naming conventions were followed correctly and that deliverable formats are correct.

4.2.1.2 LiDAR Ortho Rasters

“LiDAR Intensity Ortho” rasters (Figure 2) created from the point cloud intensity values are created for the entire project area and reviewed at a small scale (project level) for data voids. LiDAR Intensity Orthos were created from the boresighted flight lines (AOI-1). The LiDAR Ortho review confirmed that there are no data voids or other missing data except in legitimate hydro areas.

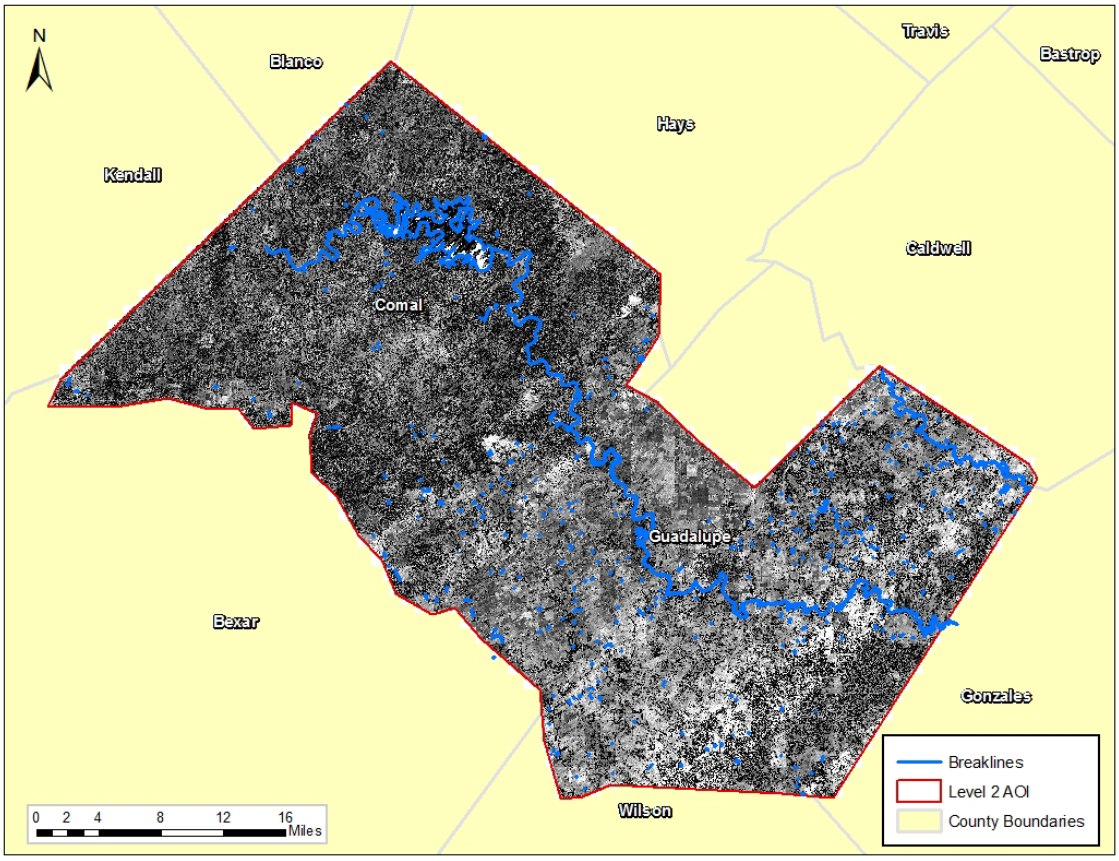

Figure 2: LiDAR Ortho Rasters of project area (Blue void is a legitimate hydro feature)

"Delta-Z Ortho" rasters were created in GeoCue by comparing the elevation of ground classified points from overlapping flight lines and applying a red-yellow-green color scale based on the elevation difference. The maximum acceptable tolerance for the Delta-Z Orthos is equal to the fundamental vertical accuracy requirement (0.245 meters). More information on fundamental vertical accuracy can be found in Section 7 of this report.

4.2.2 Micro Checks (5% of the Level 2-Processed Data)

Ground density models are created in QT Modeler that use a red-green color scale based on the minimum acceptable point density (equal to 2x the Nominal Point Spacing) (Figure 3). Density models are effective in showing misclassifications, poor LiDAR penetration, and other point density issues. These models can also be color scaled by elevation to highlight issues such as "artifacts" or features misclassified as ground, spikes, and divots, and flight line ridges in the overlap areas.

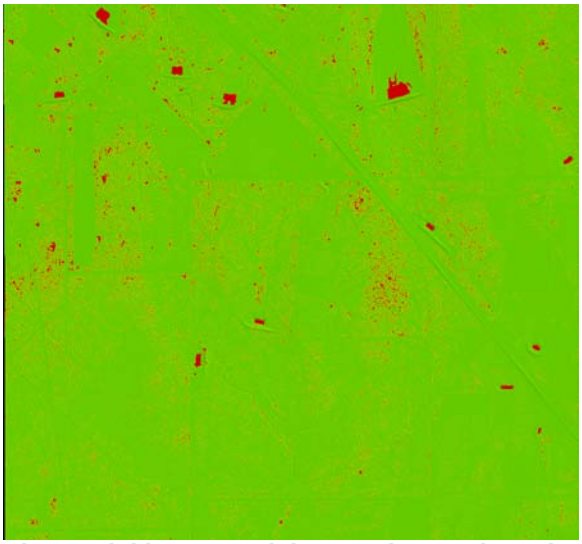

Figure 3: Ground density model in QT Modeler. Red areas have less than 2 meters NPS

4.2.2.1 Reviewed 5% of the Level 2-Processed data for anomalies to include:

1. Buildings, bridges, and vegetation misclassified as ground
2. Proper definition of roads and drainage patterns
3. Areas that have been “shaved off’ or “over-smoothed” during filtering
4. Point density specification is met

4.2.2.2 Swath Overlap

Project specifications stipulate that the LiDAR acquisition is planned with a minimum of 20% overlap between flight lines. A spot check of the overlap was done by coloring the point cloud by source ID (flight line number) and measuring the width of the overlap. The swath overlap review confirmed that there is at least a 20% overlap between flight lines throughout the project area (Figure 4).

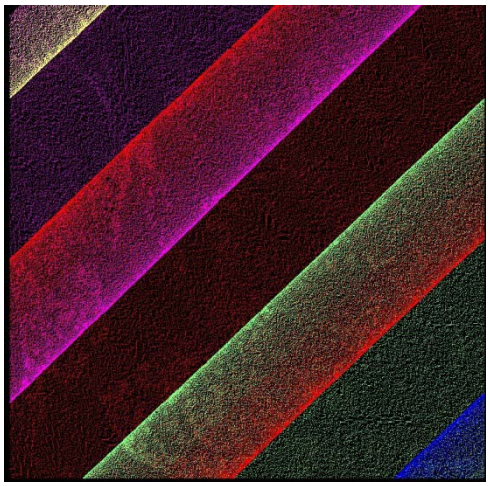

Figure 4: Point cloud colored by Source ID (Flight line Number)

5 Ground Survey and Data Acquisition

The following quality control actions were taken after the aerial acquisition of LiDAR data for this AOI and upon receipt of the following reports:

- Acquisition Report – RAMPP LiDAR Acquisition, Central TX, dated April 5, 2011
- Report of Survey – Comal and Guadalupe Counties, Central Texas, dated February 23, 2011

5.1 Review of Ground Survey Report

FEDI was tasked by RAMPP to perform a ground control survey in support of data collection efforts in the Central Texas AOI.

The survey conducted in support of data collection efforts was required to meet the following specifications for this project:

- All surveys conducted shall be referenced to NGS control monuments in the National Spatial Reference System (NSRS) using appropriate horizontal and vertical control
- Base station locations should be the "best" horizontal (second order or better) and vertical (third order or better) available and have a stability of "C" or better
- New control established where suitable monuments do not exist shall conform to the Standards and Specifications for Geodetic Control Networks (1984), Federal Geodetic Control Committee (FGCC)
- Primary control monuments established with GPS shall meet or exceed NOS NGS-58 "Guidelines for Establishing GPS-Derived Ellipsoidal Heights (Standards: 2 cm and 5 cm)" using the appropriate and latest geoid model, and should be monumented to maintain stability and reoccupation if necessary
- Ground control stations are expected to have local network accuracy at the 95% accuracy level of 2 cm horizontally and vertically
- Supporting documentation such as processing reports, minimally and constrained 3-D least squares adjustment, pictures of the stations, etc.

5.1.1 Results

The following table outlines the results of the QA review of the Report of Survey for the Central Texas AOI:

Table 2: QA of Report of Survey – Central Texas AOI

Items Reviewed	Pass / Fail	Comments
Survey is referenced to NGS control monuments in the NSRS using appropriate horizontal and vertical control	Pass	None
Base station locations are the "best" horizontal (second order or better) and vertical (third order or better) available and have a stability of "C" or better	Pass	None
New control conforms to the Standards and Specifications for Geodetic Control Networks (1984), FGCC	Pass	None
Primary control monuments established with GPS meet or exceed NOS NGS-58 "Guidelines for Establishing GPS-Derived	Pass	None

Table 2: QA of Report of Survey – Central Texas AOI		
Ellipsoidal Heights (Standards: 2 cm and 5 cm)" using the appropriate and latest geoid model and should be monumented to maintain stability and reoccupation if necessary		
Ground control stations meet local network accuracy at the 95% accuracy level of 2 cm horizontally and vertically	Pass	None
Supporting documentation submitted such as processing reports, minimally and constrained 3-D least squares adjustment, pictures of the stations, etc.	Pass	None

5.1.2 Notes and Comments

The following exceptions and clarifications regarding the ground survey were submitted by FEDI in the Operations Plan and approved by RAMPP:

1. New control will meet the NOS NGS-58 Standards for occupation only
2. A stable control point will be set; however, the NOS NGS-58 monumentation standards will not be met
3. Existing and/or new base station control points are expected to have a local network accuracy at the 95% confidence level of 2 cm horizontally and vertically

5.2 Data Acquisition Review

The following project specifications related to the data acquisition were checked by RAMPP for compliance:

- LiDAR is to be collected for the Central Texas AOI with a 100 meter buffer for a combined area of 1,305 square miles:
- LiDAR is to be collected using sensors capable of a minimum of three multiple discrete returns containing range and intensity values for first, intermediate, and last returns for each emitted pulse
- The nominal post spacing (NPS) for all identified areas of interest within FEMA Region VI will be one meter. 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 point spacing will be comparable.
- Data Voids [areas => $(4*NPS)^2$, measured using 1^{st} returns only] within a single swath will be deemed unacceptable; except where caused by water bodies, areas of low near infra-red reflectivity, or where filled appropriately by another swath.
- Consistent with Section 1.6 of the USGS LiDAR Guidelines and Specification, V.13, a regular grid with a cell size of equal to the design NPS*2 will be laid over the first return data within the geometrically usable center portion of each swath and at least 90% of the grid cells shall contain at least one LiDAR point
- The nominal side-lap between adjacent flight lines will be no less than 30%
- The scan angle total Field of View (FOV) shall not exceed 40º (+/- 20º off nadir) with an oscillating mirror scanner
- Relative accuracy shall be <=7cm RMSEz within individual swaths; <=10cm RMSEz within swath overlap areas
- The project area shall be fully and sufficiently covered with no data voids caused by gaps between flight lines and/or sensor malfunctions

- Acquisition window and constraints:
  - Leaf-off conditions required
  - Area shall be free of snow and of flood condition with rivers remaining in their channels and near average heights or lower
  - Extraneous environmental conditions such as rain, fog, or smoke shall be avoided
- Base stations used in support of acquisition shall be set for collecting dual frequency data at one Hz intervals
- Baseline lengths of base stations shall not exceed 30 miles unless the LiDAR provider can provide definitive proof that longer baseline length for this project can support the project accuracy requirements
- Quality statistics from the airborne GPS/IMU processing shall be made available upon request
- Ground surveys conducted in support of the boresight and processing of the LiDAR shall be tied into the base stations used for acquisition
- All collected swaths shall be delivered as part of the raw data deliverable. Swaths shall be split into segments no greater than 2 GB each, with each swath assigned a unique File Source ID.

5.2.1 Results

The following table outlines the results of the QA review of the data acquisition phase for the Central Texas AOI:

Table 3: QA of Data Acquisition – Central Texas AOI		
Items Reviewed	**Pass / Fail**	**Comments**
LiDAR is to be collected for the Central Texas AOI with a 100-meter buffer for a combined area of 1,305 square miles	Pass	None
LiDAR is to be collected using an approved, fully calibrated system capable of collecting multiple echoes per pulse with a minimum of first, last, and one intermediate echo	Pass	None
The system shall be capable of collecting the intensity (LiDAR pulse signal strength) for each echo signal at a minimum 8-bit depth	Pass	None
The nominal post spacing shall be no greater than 1 meter. 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 spacing should be comparable.	Pass	None
The nominal side-lap between adjacent flight lines will be no less than 30%	Pass	None
Total FOV shall not exceed 40º (+/- 20º off nadir) with an oscillating mirror scanner (60 º for Regal sensors)	Pass	None
The project area shall be fully and sufficiently covered with no data voids caused by gaps between flight lines and/or sensor malfunctions.	Pass	None
Data Voids [areas => $(4*NPS)^2$, measured using 1st returns only] within a single swath will be deemed unacceptable, except where caused by water bodies, areas of low near infrared reflectivity, or where filled appropriately by another swath	Pass	None
Base stations used in support of acquisition shall be set for collecting dual frequency data at 1 Hz intervals	Pass	None
Baseline lengths of base stations shall not exceed 30 miles unless the LiDAR provider can provide definitive proof that longer baseline length for this project can support the project accuracy requirements	Pass	None
Quality statistics from the airborne GPS/IMU processing shall be provided	Pass	None
Relative accuracy – no flight line to flight line or point to point offsets present due to sensor anomalies or mismatches. •Relative accuracy shall be <=7cm RMSEz within individual swaths; <=10cm RMSEz within swath overlap areas	Pass	None
Ground surveys conducted in support of the boresight and processing of the LiDAR shall be tied into the base stations used for acquisition	Pass	None
Swaths split into segments no greater than 2 GB each with each having a unique File Source ID	Pass	None
Acquisition window and constraints:		
Leaf-off conditions required	Pass	None
Area shall be free of snow and of flood condition with rivers remaining in their channels and near average heights or lower	Pass	None
Extraneous environmental conditions such as rain, fog, or smoke	Pass	None

Table 3: QA of Data Acquisition – Central Texas AOI		
Items Reviewed	**Pass / Fail**	**Comments**
shall be avoided		
Reports reviewed:		
Flight logs encompassing all collection dates	Pass	None
Aerial acquisition report	Pass	None
Ground survey report	Pass	None

6 Project Data Deliverables

6.1 Review of AOI Processed to Level 1

The full acquisition LiDAR dataset, covering 1,305 square miles, was processed to Level 1, which is a fully calibrated, boresighted flight lines dataset with files in LAS format. A 100% completeness review and vertical accuracy assessment of the first-return points in open terrain was performed. No quality issues were identified. A vertical accuracy assessment was performed on the first-return points in open terrain and the data meets FEMA's vertical accuracy requirements. Vertical accuracy assessment tables are provided in Section 7 of this report.

6.2 Review of AOI Processed to Level 2

The classified LiDAR dataset, covering the same area as the Level 1 dataset was processed to Level 2, in which the point cloud is classified to bare-earth ground points, hydro, and overlap/noise. A 100% completeness review, 5% visual review, and vertical accuracy assessment was performed. Several minor quality errors were identified and are noted in Section 6.3.2 of this report. The vertical accuracy assessment meets FEMA's vertical accuracy requirements and the results are provided in Section 7 of this report.

Figure 5 shows the coverage of the data for AOI-2.

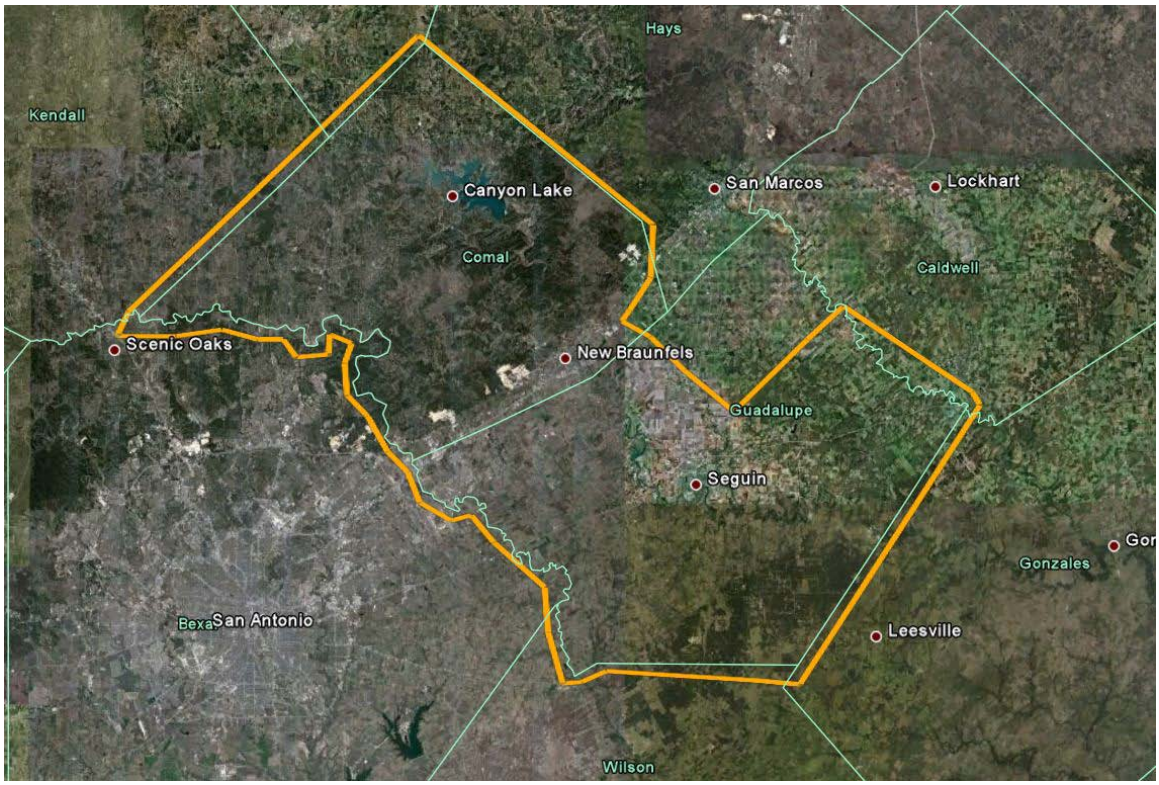

Figure 5: Outline of AOI-2 coverage

6.3 Macro and Micro Assessments

The following project specifications for the data delivery were checked for compliance using a combination of macro and micro checks:

Macro checks (used to verify the following for 100% of the data):

- Data will be processed and delivered in LAS 1.2, where all the required data structure is maintained by the LiDAR processing software, and the current version of Terrascan. All major fields will be maintained.
- The header file shall contain, at a minimum, the "File Creation Year Day" and "File Creation Year" which shall represent the final deliverable LAS date.
- Projection information for the point data shall be specified in the Variable Length Record using the appropriate GeoTIFF tags
- The horizontal datum shall be referenced to the North American Datum NAD83 using the latest adjustment revision (NSRS 2007)
- The vertical datum shall be referenced to the North American Vertical Datum of 1988 (NAVD88)
- The most recent NGS-approved Geoid shall be used to convert ellipsoidal heights to orthometric heights
- The coordinate system shall be UTM, NAD83, meters, using the predominant UTM Zone for the collection area
- All units will be to 1 cm resolution
- Tiles shall align and contain no buffers or over-edges
- Classification codes shall follow the ASPRS Standard LiDAR Point Classes utilizing only the following:
    - Class 1 – Processed but unclassified
    - Class 2 – Bare-earth ground
    - Class 7 – Low points and noise
    - Class 9 – Water
    - Class 11 - Withheld
- No points shall be deleted from the LAS file (all points must be included)

Micro checks (used to verify the following for 5% of the data)-

- Consistent with section 1.6 of the U.S. Geological Survey (USGS) LiDAR Guidelines and Specification, V.13, a regular grid with a cell size of equal to the design NPS*2 will be laid over the first return data within the geometrically usable center portion of each swath and at least 90% of the grid cells shall contain at least one LiDAR point
- Classifications shall adhere to the following guidelines through the use of automated and manual filtering routines:
    - 90% of artifacts classified
    - 95% of outliers classified
    - 95% of vegetation classified
    - 98% of buildings classified
- Channel geometry of streams and drainage features shall be maintained

- Dense vegetation data voids shall be minimized by the filtering process and "over smoothing" due to aggressive classification filters shall be avoided
- Outliers, blunders, noise points, etc., classified as Class 7 or 1 unless current version of Terrascan allows for use of Class 12 "Withheld"

6.3.1 Macro Check Results

Macro checks are conducted on 100% of both datasets. The following table outlines the results of the Macro Check QA review of the data set provided for the Central Texas AOI:

Table 4: Macro Check QA of AOI – Central Texas

Items Reviewed	Pass / Fail	Comments
Masspoint data delivered in LAS files utilizing the latest LAS specification (currently LAS 1.2) containing all LAS items of point data record format 1	Pass	None
The header file contains, at a minimum, the "File Creation Year Day" and "File Creation Year" and represents the final deliverable LAS date	Pass	None
Projection information for the point data specified in the Variable Length Record using the appropriate GeoTIFF tags	Pass	None
The horizontal datum referenced to the North American Datum NAD83 using the latest adjustment revision (NSRS 2007)	Pass	None
The vertical datum referenced to the NAVD88	Pass	None
The latest geoid used to convert ellipsoidal heights to orthometric heights	Pass	None
The project data is in UTM, NAD83, Meters using the predominate UTM zone for the collection area	Pass	None
All units reported to 1 cm resolution or 1/100 of a foot	Pass	None
Tiles shall align and contain no buffers or over-edges	Pass	None
Classification codes shall follow the ASPRS Standard LiDAR Point Classes utilizing only the following:		
Class 1 – Processed but not classified	Pass	None
Class 2 – Bare-earth ground	Pass	None
Class 7 – Low points and noise	Pass	None
Class 9 – Water	Pass	None
Class 11 – Withheld	Pass	None
No points shall be deleted from the LAS file (all points must be included)	Pass	None

6.3.2 Micro Check Results

Micro checks are conducted on 5 percent of the Level 2 dataset. The data selected for review was chosen semi-randomly to review data throughout the project area, while focusing on areas of urban development and hydrographic significance when possible. Figure 6 depicts the locations of the tiles that were selected to conduct the 5% micro review.

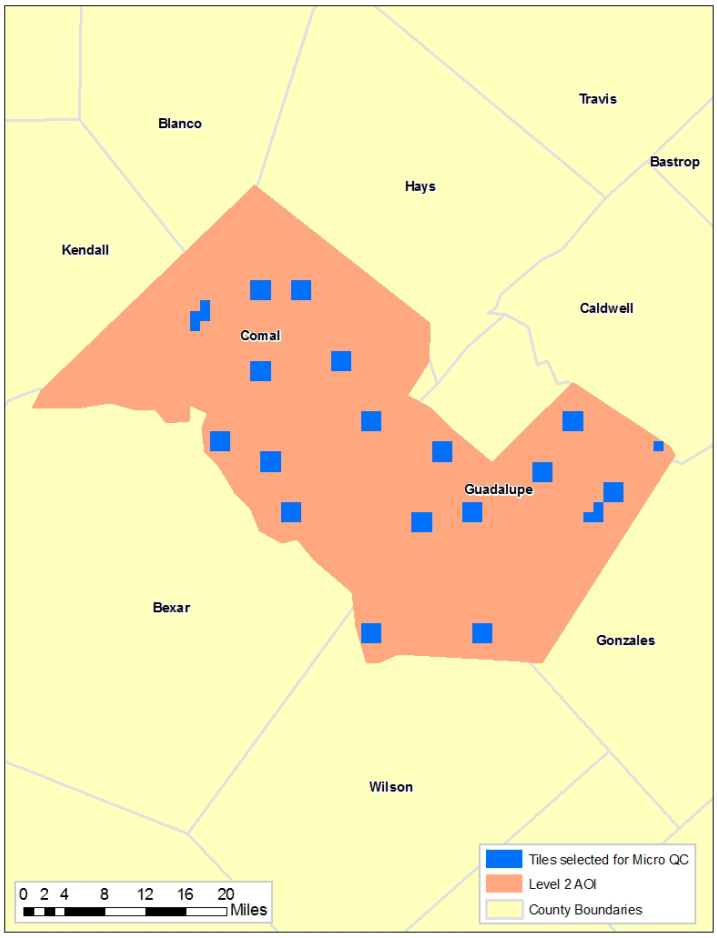

Figure 6: The figure depicts the location of tiles selected for the 5% micro review

The following table outlines the results of the Micro Check QA review of the data set provided for the Central Texas AOI:

Table 5: Micro Check QA of AOI – Central Texas		
Items Reviewed	**Pass / Fail**	**Comments**
Outliers, blunders, noise points, etc. classified as Class 7 or 1 unless current version of Terrascan allows for use of Class 11 "Withheld"	Pass	None
Classifications shall adhere to the following guidelines through the use of automated and manual filtering routines:		
90 percent of artifacts classified	Pass	None
95% of outliers classified	Pass	None

Table 5: Micro Check QA of AOI – Central Texas		
Items Reviewed	**Pass / Fail**	**Comments**
95% of vegetation classified	Pass	None
98% of buildings classified	Pass	None
Channel geometry of streams and drainage features shall be maintained	Pass	None
Dense vegetation data voids shall be minimized by the filtering process and "over smoothing" due to aggressive classification filters shall be avoided	Pass	None

6.3.3 Notes and Comments

During the 5% Micro Check QA review of the Level 2 dataset (1,077 tiles), no errors were discovered:

The 5% data review also determined that channel geometry and drainage features present within the Level 2 dataset were properly maintained and that no features were lost through overly-aggressive filtering.

6.4 Intensity Images

Intensity images derived from the LiDAR point cloud were not required for this scope of work. However, intensity values were provided in the LAS files.

6.5 3D Breaklines

Breakline (hydro-line) generation was conducted in order to classify water points in the LAS and to meet the USGS V.13 specifications for flattening. The following project specifications for the data delivery were checked for compliance by conducting a 5% review of the delivered line work:

- Inland ponds, lakes, and boundary waters greater than 2 acres or greater surface area (~350' diameter for a round pond) at the time of collection will be collected in the appropriate hydro-line feature class
- Inland streams and rivers with a 100' nominal width will be collected in the appropriate hydro-line feature class
- Hydro-lines will be delivered as an ESRI feature class (Polyline or Polygon format as appropriate to the type of feature represented and the methodology used) in a geodatabase
- Each feature class or shape file will include properly formatted and accurate georeferencing information in the standard location. All feature classes must include a projection
- Breaklines must use the same coordinate reference system (horizontal and vertical) and units as the LiDAR points 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 the vertical.

Table 6: Breakline Check QA of AOI – Central Texas		
Items Reviewed	**Pass / Fail**	**Comments**
Inland ponds, lakes, and boundary waters greater than 2 acres or greater surface area (~350' diameter for a round pond) at the time of collection collected in the appropriate hydro-line feature class	Pass	None
Inland streams and rivers with a 100' nominal width collected in the appropriate hydro-line feature class	Pass	None
Hydro-lines delivered as an ESRI feature class (Polyline or Polygon format as appropriate to the type of feature represented and the methodology used) in a geodatabase	Pass	See Section 6.5.1 Notes and Comments
Each feature class or shape file includes properly formatted and accurate georeferencing information in the standard location. All feature classes include a projection	Pass	None
Breaklines use the same coordinate reference system (horizontal and vertical) and units as the LiDAR points delivery	Pass	None
Breaklines delivered as a continuous layer or in tiles. If tiled deliveries, tiles edge-match seamlessly in both the horizontal and the vertical	Pass	None
Topology rules were validated as specified in FEMA Procedure Memorandum #61	Pass	None

6.5.1 Notes and Comments

FEMA has no minimum breakline requirements. Breaklines for the Central Texas AOI were delivered in a geodatabase.

The following feature classes were provided:

- Ponds and Lakes (Polyline ZM)
- Hydrographic feature (Polyline ZM)
- Islands (Polyline ZM)

Topology rules were validated and the following errors were returned:

- 3,362 overlapping line errors
- 3,362 intersecting errors

Corrections were applied by Tuck and the corrections validated and passed by RAMPP.

6.6 Low Confidence Areas

Low Confidence Areas were compiled by the data provider in the areas where the vertical data may not meet the data accuracy requirements due to heavy vegetation even though the specified nominal point spacing was met. RAMPP delivered low confidence areas as polygons in accordance with a database schema.

Table 7: Low Confidence Check for AOI – Central Texas		
Items Reviewed	**Pass / Fail**	**Comments**
Low confidence areas are captured as polygons in accordance with a database schema	Pass	None

7 Data Accuracy Report

RAMPP performed the LiDAR vertical accuracy assessment for the Central Texas AOI in accordance with ASPRS/NDEP and NSSDA/FEMA specifications and guidelines.

The LiDAR data produced for this project adheres to the ASPRS/NDEP and NSSDA/FEMA accuracy standards, as referenced in the accuracy section of the IDIQ Subcontract #: HSFEHQ-09-D-0369-U005, Task Order HSFEHQ-10-J-0006, dated September 3, 2010.

7.1 Data Accuracy Assessment

The data accuracy assessment for the Central Texas AOI was conducted for each of the two AOIs. A full vertical accuracy assessment was performed on the Level 2-processed data using all surveyed checkpoints against the ground classified LiDAR.

7.1.1 Software Used

- *GeoCue:* a geospatial data/process management system especially suited to managing large LiDAR data sets
- *QT-Modeler:* used for direct comparison of the QC checkpoints against the LiDAR Class 2 or ground points
- *Microsoft Excel:* used to calculate accuracy values and statistics from the vertical accuracy assessment.

7.1.2 Vertical Accuracy Testing Process

The primary quantitative assessment steps were as follows:

1. FEDI acquired new raw LiDAR data from November 20, 2010 to December 6, 2010, and Tuck performed post-processing to derive the bare-earth digital terrain model.
2. ESP Associates (ESP) surveyed 83 ground checkpoints in four land cover categories in accordance with FEMA specifications and guidelines. All project survey work performed by ESP adhered to the rules and regulations for providing professional land surveying services.
3. ESP provided RAMPP with a table of horizontal coordinates and orthometric heights for all surveyed checkpoints, classified by land cover category. RAMPP created a triangulated irregular network (TIN) from the bare-earth LiDAR points, and interpolated a z-value at each of the survey point locations.
4. RAMPP compared the LiDAR-derived elevations of the check points to the surveyed check point orthometric heights and computed the vertical accuracy assessment according to FEMA/NSSDA and ASPRS/NDEP specifications.

The spatial distribution of ground checkpoints surveyed by ESP is shown in Figure 7.

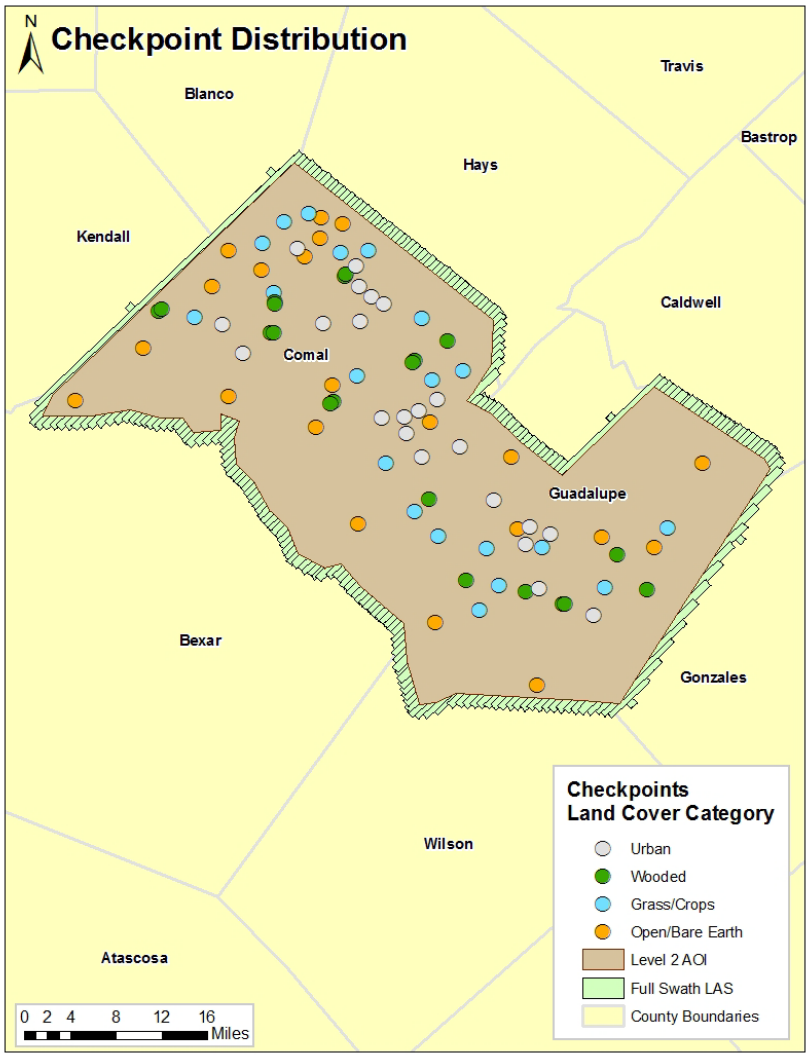

Figure 7: Central Texas checkpoints surveyed by ESP and used for testing vertical accuracy.

7.1.3 Vertical Accuracy Testing – NDEP and ASPRS Procedures

A vertical accuracy assessment was conducted to determine how well the LiDAR sensor performed in the various land cover categories present within the Central Texas project area. RAMPP tested the data using methodologies proscribed by FEMA/NSSDA for vertical accuracy in open terrain, as well as methodologies proscribed by ASPRS/NDEP for vertical accuracy in multiple land cover categories.

Fundamental Vertical Accuracy (FVA) in open terrain was tested on the Level 1 and Level 2 datasets. Checkpoints in the Open Terrain land cover category were tested against the first return LiDAR points in open terrain across the entire acquisition area. FVA is reported at the 95% confidence level, which is computed as the root mean square error of the checkpoint elevations (RMSEz) x 1.9600. The maximum tolerance

was 12.5 centimeters RMSE x 1.9600; the resulting fundamental vertical accuracy tolerance was 24.5 centimeters.

Supplemental Vertical Accuracy (SVA), though not a requirement for this project, was calculated separately for each land cover category in the Level 2 dataset, including Open Terrain (Bare Earth), High Grass, Forest, and Urban categories. Post-processing procedures performed on LiDAR, such as classification algorithms, may yield elevation errors that do not follow a normal error distribution; therefore the SVA at the 95% confidence level equals the 95th percentile error for all checkpoints in each individual land cover category.

Consolidated Vertical Accuracy (CVA) within the entire Level 2 dataset was determined by using all checkpoints in all land cover categories combined. Like the SVA methodology, the CVA methodology assumes that LiDAR errors may not follow a normal distribution in vegetated categories and, at the 95% confidence level, equals the 95th percentile error for all checkpoints in all land cover categories combined.

Tables 8 and 9 summarize the vertical accuracy by fundamental, consolidated, and supplemental methods for this AOI:

Table 8: Level 1 Data - Vertical Accuracy at 95% Confidence Level

Land Cover Category	# of Points	Fundamental Vertical Accuracy (RMSEz x 1.9600) Spec = 24.5 cm
Open Terrain	21	4.08

Table 9: Level 2 Data - Vertical Accuracy at 95% Confidence Level and 95th Percentile

Land Cover Category	# of Points	Fundamental Vertical Accuracy (RMSEz x 1.9600) Spec = 24.5 cm	Consolidated Vertical Accuracy (95th Percentile) Spec = 36.3 cm	Supplemental Vertical Accuracy (95th Percentile) Spec = 36.5 cm
Consolidated	83		16.39	
Open Terrain	21	6.84		6.71
High Grass	20	19.82		21.17
Forested	20	25.32		28.19
Urban	22	5.11		3.95

Figure 8 illustrates the magnitude of differences between the QC checkpoints and the processed LiDAR data by specific land cover category:

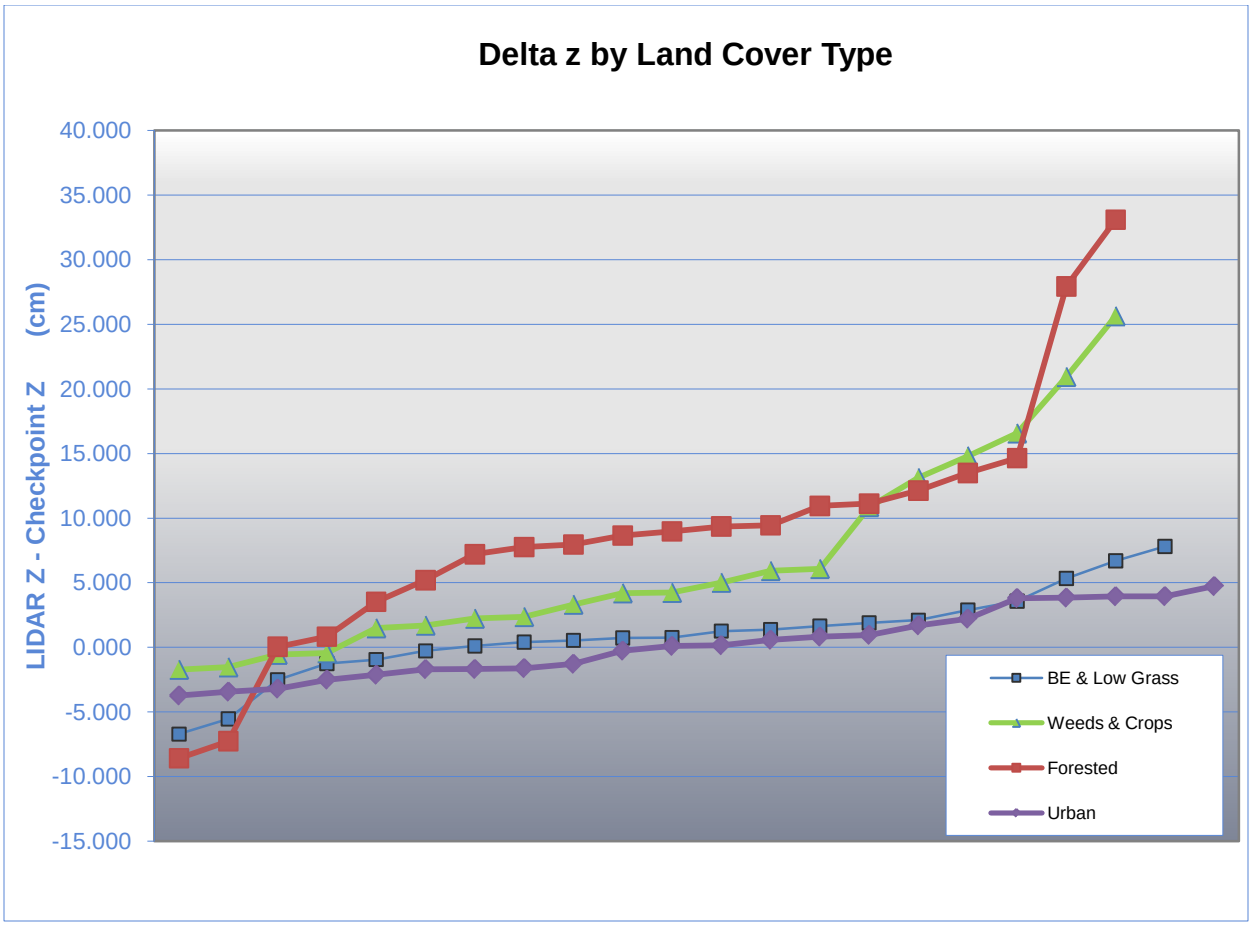

Figure 8: Magnitude of elevation discrepancies by land cover category for this AOI

7.1.3.1 Analysis of the 95th Percentile

The following checkpoints were used to calculate the vertical accuracy and exceeded the 95th percentile for the Level 2-processed dataset. They were not excluded from the assessment, but are identified here for user reference. No checkpoints exceeded the 95th percentile for the Level 1-processed dataset.

Point No	Easting	Northing	Elevation	Z LiDAR	Delta Z
GC_B_03	562,696.204	3,312,730.540	369.385	369.533	0.148
GC_B_04	565,725.398	3,315,821.852	405.418	405.674	0.256
GC_B_38	579,947.695	3,281,913.043	200.790	200.956	0.166
GC_B_57	564,304.440	3,305,824.829	308.616	308.825	0.209
GC_D_67	604,822.149	3,261,974.485	163.396	163.675	0.279
GC_D_68	605,131.084	3,261,986.246	169.896	170.042	0.146
GC_D_78	583,706.478	3,296,052.140	255.779	256.110	0.331
GC_D_80	572,212.009	3,290,168.050	316.849	316.984	0.135

7.1.4 Vertical Accuracy Testing – NSSDA and FEMA Procedures

To comply with current FEMA guidelines, RMSEz statistics were computed in the relevant land cover categories, individually and combined, as well as other recommended statistics for each level of processed data. This process assists in the analysis by checking for any anomalous characteristics that may be present in the LiDAR data. These statistics are summarized in Tables 10 and 11 below.

Table 10: Level 1 Data- Descriptive Statistics

100% of Totals	Points	RMSE Spec=12.5 cm	Mean Error (cm)	Median Error (cm)	SKEW	STDEV (cm)	95th Percentile Spec=36.3 cm
Consolidated	21	4.08	0.60	-0.20	0.617	4.10	6.60
Open Terrain	21	4.08	0.60	-0.20	0.617	4.10	6.60

Table 11: Level 2 Data - Descriptive Statistics

100% of Totals	Points	RMSE Spec=0.125 m	Mean Error (m)	Median Error (m)	SKEW	STDEV (m)	95th Percentile Spec=0.363 m
Consolidated	83	8.349	4.045	2.102	1.615	7.349	16.388
Open Terrain	21	3.490	0.945	0.749	-0.212	3.443	6.714
High Grass	20	10.109	6.709	4.212	1.133	7.759	21.171
Forest	20	12.917	8.822	8.806	0.697	9.680	28.192
Urban	22	2.606	0.238	0.128	0.238	2.656	3.951

Figure 9 illustrates the histogram of the associated elevation discrepancies between the QC checkpoints and elevations as interpolated from the LiDAR TIN for this AOI. The frequency of elevation differences is distributed within each band of elevation differences.

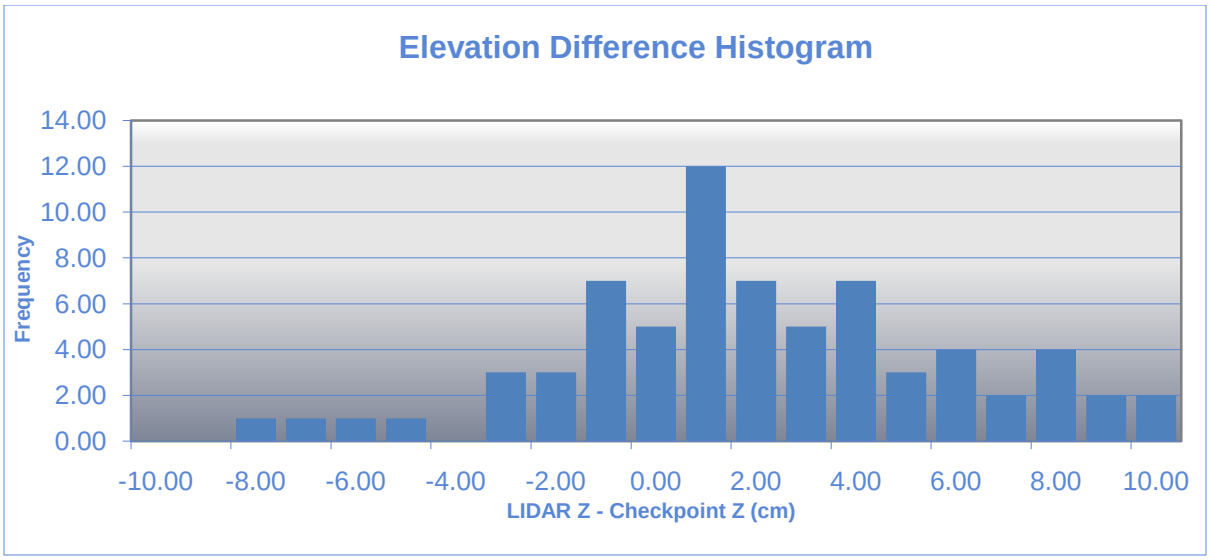

Figure 9: Histogram of elevation discrepancies for this AOI

7.1.5 Checkpoints not used

During the vertical accuracy assessment, all checkpoints were used.

8 Metadata

The project metadata was reviewed and checked using the following methods:

- Structure of the metadata file was compared against Federal Geographic Data Committee standards by using the USGS Geospatial Metadata Validation Service:
  http://geo-nsdi.er.usgs.gov/validation/
- Metadata content was reviewed using a visual check for accuracy.

9 Conclusion

Based on the limited qualitative and vertical accuracy assessments conducted by RAMPP on the data delivered, the Central Texas delivery meets the applicable project specifications as set forth by the IDIQ Subcontract # HSFEHQ-09-D-0369-U005, Task Order HSFEHQ-10-J-0006, revised September 3, 2010.

9.1 Credits

Organizations involved in the procurement, acquisition, processing, and quality control of the Central Texas LiDAR dataset are identified below.

Function	Responsible Organization
LiDAR procurement	FEMA
LiDAR acquisition and processing	Tuck
Checkpoint surveys	Tuck
Accuracy assessment and reporting	RAMPP
Independent Technical Review	RAMPP

Vertical Accuracy Assessment Conducted by:

Robert Ryan CP, PLS
Project Manager

Qualitative Assessment Conducted by:

Jesse Pinchot
GIS Analyst