URS

QUALITY CONTROL REPORT

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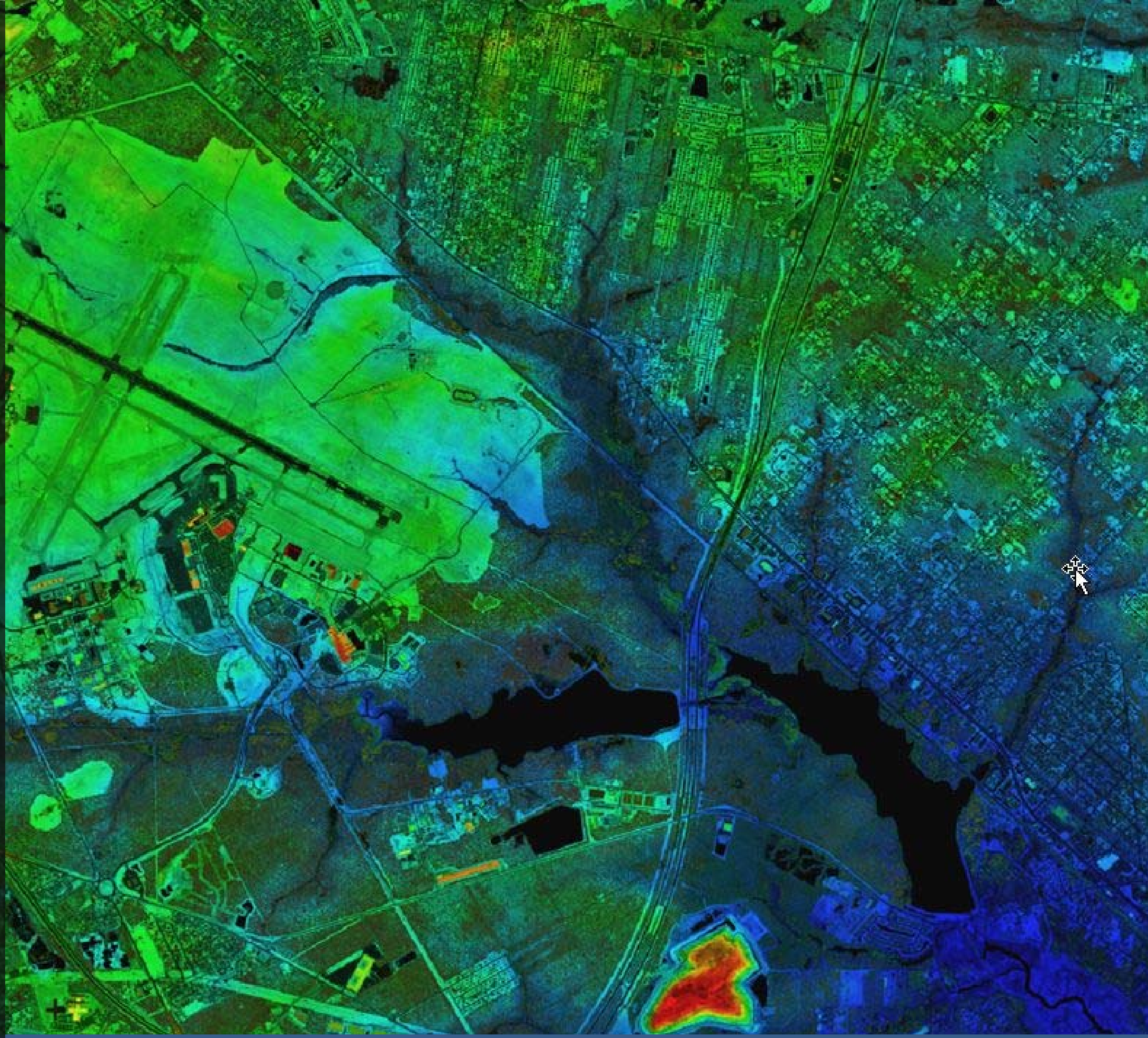
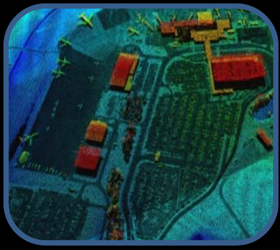


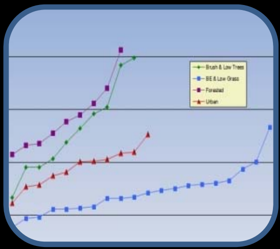
March 23, 2012

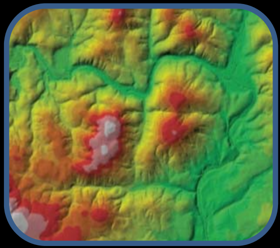
Independent Quality Control Report

Bell, Burnet, Coryell, Falls, Lampasas, and McLennan Counties Areas of Interest

HPIDS Project Number 580-11-1213
TWDB Task Order 19417169083







Bell, Burnet, Coryell, Falls, Lampasas, and McLennan Counties Independent QC Report

1 Overview

The Independent Quality Control for HPIDS Project Number 580-11-1213 was performed by URS to validate LiDAR data quality for use in developing new flood hazard information that will be used in the update and creation of accurate flood zone maps in support of the National Flood Insurance Program. This document reports on the Bell, Burnet, Coryell, Falls, Lampasas, and McLennan Counties Area of Interest (AOI) covered under this HPIDS Project. The report covers data deliveries received between 07/14/11 and 02/17/12, as well as 4 redeliveries of corrections the last being delivered on 03/13/12.

Included in this report are the following items, some of which were reported in preliminary reports during the course of the project:

- Overview of independent quality control scope of work
- Pre-acquisition assessment
- Quality control checkpoint survey data
- LiDAR provider production workflow review
- Aerial acquisition assessment
- Post-acquisition assessment
- Data accuracy assessment
- Assessment practices and methodologies
- Lessons learned

For convenience, this report is organized by the major phases of project work as outlined in Section 1.1.

1.1 Independent Quality Control Scope of Work

For the Bell, Burnet, Coryell, Falls, Lampasas, and McLennan Counties AOI, the following scope of work tasks were completed during the project:

URS – Independent Quality Control Tasks	
Phase	**Tasks**
Phase I: Pre-flight Planning	1. Review specifications and establish sign-off procedures 2. Review flight operations plan and procedures 3. Develop field calibration and control procedures
Phase II: Data Acquisition	1. Establish ground survey control checkpoints 2. Review daily flight operations reports
Phase III: Data Processing	1. Perform LiDAR production system review 2. Data inspection 3. Produce accuracy report
Phase IV: Product Development	1. Review data product tiles 2. Review metadata 3. Produce project report of quality practices and accuracy assessments

Table 1 Independent quality control tasks

1.2 Project Area and Deliverables Received

The project area for this task order consists of one contiguous AOI denoted in the below figure as white tile layouts. This AOI covers ~2349 square miles in the State of Texas. Additionally, the AOI adjoins areas of existing LiDAR coverage (red transparency layer in below image).

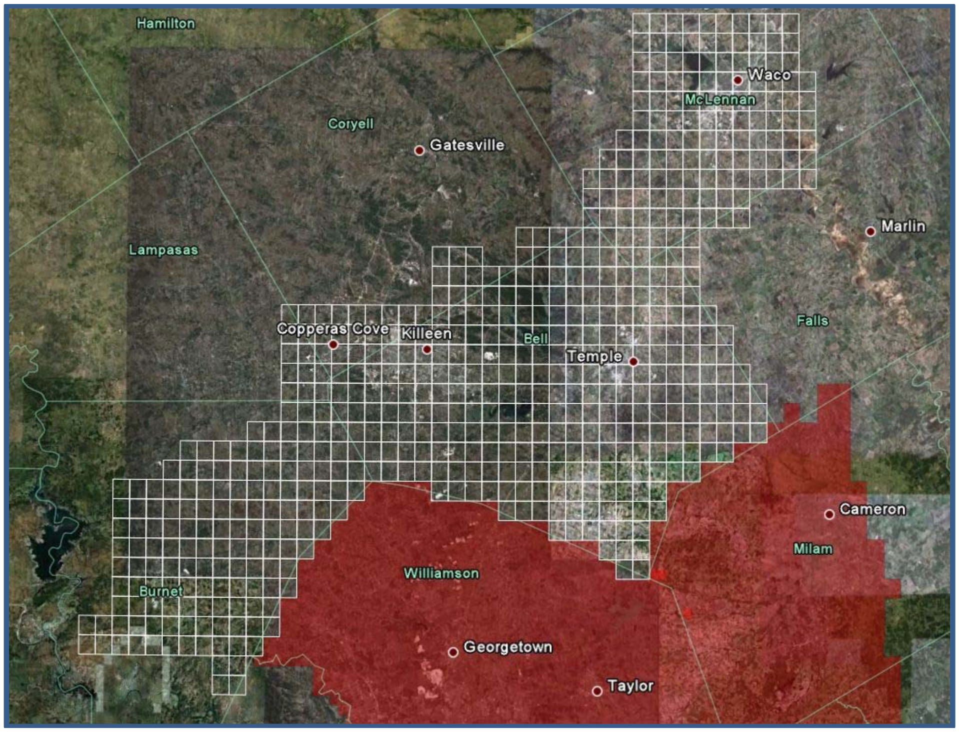


Figure 1 Project area of interest

For this AOI the deliverables were received in the following formats:

Deliverables Received	
Deliverable	**Number of units**
All-return LiDAR tiles in LAS 1.2 format	589 files
Ground point DEM files in ESRI GRID format	589 files
LiDAR intensity images in .TIF format with associated .TFW files	1,178 files
Shape files of the SBET trajectory lines and tile layout	71 files
File-level metadata	1,768 total files

Table 2 Deliverables received for this project

1.3 Applicable Specifications & Guidelines

The following guidelines, specifications, and standards are applicable to this report:

A. Texas Water Development Board (TWDB), HPIDS: LiDAR Delivery and Quality Control Statement of Work – Version 1.1, May 4, 2009

B. Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix A: Guidance for Aerial Mapping and Surveying, FEMA, April 2003
http://fema.gov/plan/prevent/fhm/dl_cgs.shtm

C. American Society for Photogrammetry and Remote Sensing (ASPRS) Guidelines, Vertical Accuracy Reporting for LiDAR Data, May 24, 2004
http://www.asprs.org/society/committees/lidar/Downloads/Vertical_Accuracy_Reporting_for_Lidar_Data.pdf

D. FGDC-STD-007.3-1998: Geospatial Positioning Accuracy Standards, Part 3: National Standard for Spatial Data Accuracy (NSSDA)
http://www.fgdc.gov/standards/projects/FGC-standards-projects/accuracy/part3/chapter3

E. FGDC-STD-001-1998: Content Standard for Digital Geospatial Metadata (version 2.0)
http://www.fgdc.gov/metadata/csdgm/

2 Phase I: Pre-flight Planning QA Tasks

Pre-flight planning QA was conducted to assist the planning process as well as to ensure that no significant issues were present prior to data acquisition. During a series of kick-off meetings between the URS team, Photo Science, and TNRIS, URS reviewed the initial project specifications and established sign-off procedures. These procedures were then used throughout the project to provide comprehensive reporting on quality controls. For the pre-flight planning phase, URS conducted a review of flight operations and plan files submitted by Photo Science prior to the mobilization of data collection flights. These files included, but were not limited to:

- Planned flight lines
- Planned GPS base stations
- Planned airport locations
- Calibration plans
- Schedule
- Terrain consideration
- Quality procedures
- Planned scanset (sensor settings)
- Type of aircraft
- Procedure for reflights
- Land cover considerations

All files and planning documents generated for this phase were reviewed against the project specifications and guidelines provided. Planning documents further facilitated the QA process during the acquisition, survey and processing tasks of the project.

2.1 Aerial Acquisition Reporting Guidelines

During the planning phase, URS provided a set of aerial acquisition reporting guidelines to Photo Science. These guidelines incorporated reporting guidelines from the project scope of work as well as additional report items to help facilitate quality control reviews post-acquisition.

The following table outlines the reporting guidelines communicated to Photo Science during the planning phase:

Minimum Aerial Acquisition Reporting Guideline for Vendors		
Item	**Content**	**Format**
	Pre-flight reporting guidance	
Flight operations plan	• Planned flight lines • Planned GPS stations • Planned control • Planned airport locations • Calibration plans • Quality procedures for flight crew • Planned scanset (sensor settings and altitude) • Type of aircraft • Schedule for flights • Procedure for tracking, executing, and checking reflights • Considerations for terrain, cover, and weather in AOI's	MS Word or PDF
	Flight progress reporting guidance	
Flight logs	• Job # / name • Lift # • Block or AOI designator • Date • Aircraft tail number, type • Flight lines: 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	Excel, MS Word, or PDF
Daily activity reports	Summary of flight activities for the day and map of area/s covered	Web-based, PDF, MS Word, or Excel
	Post-flight reporting guidance (Final Acquisition Report)	
GPS base station information	• Base station name • Latitude/longitude (ddd-mm-ss.sss) • Base height (ellipsoidal meters) • Maximum 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)	MS Word or PDF with screenshots

Minimum Aerial Acquisition Reporting Guideline for Vendors		
Item	**Content**	**Format**
	• 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	
Coverage	Verification of project coverage	ESRI shape files and/or screenshots
Flights	• As-flown trajectories • Calibration lines	ESRI shape files or .trj
Flight logs	Incorporated as appendix	Excel or MS Word
Project survey control	Ground control and base station layouts	Excel or ESRI shape file
Internal data QA	• Description of data verification/QC process • Results of verification and QC steps	MS Word, Excel or PDF

Table 3 Aerial acquisition reporting guidelines

2.2 Aerial Acquisition Pre-flight Planning Review

A review was conducted by URS to validate aerial acquisition flight planning and reporting requirements in accordance with HPIDS Project Number 580-11-1213 SOW. For the purpose of this review, Photo Science provided URS with planned flight lines and GPS stations, sensor settings (scan set), control points, and field calibration plans.

The following table reports the results of the URS review for the planning phase of the aerial acquisition effort:

QA Checks and Results – Flight Operations Planning and Procedures		
Items Reviewed	**Checked Yes/No**	**Comments**
Planned lines – sufficient coverage, spacing, and length	Yes	None
Planned GPS stations – at least 2 in range of all missions (baseline 40km or less)	Yes	None
Planned ground control – sufficient to control and boresight	Yes	None
Planned airports – within reasonable distance of AOI	Yes	None
Calibration plans	Yes	None
Schedule	Yes	None
Quality procedures	Yes	None
LiDAR sensor scan set – planned for proper scan angle, sidelap, design pulse	Yes	None
Aircraft utilizes ABGPS	Yes	None

QA Checks and Results – Flight Operations Planning and Procedures		
Items Reviewed	**Checked Yes/No**	**Comments**
Sensor supports project design pulse density	Yes	None
Type of aircraft – supports project design parameters	Yes	None
Re-flight procedure – tracking, documenting, processing	Yes	None
Project design supports accuracy requirements of project	Yes	None
Project design accounts for land cover and terrain types	Yes	None
Daily / weekly communications plan in place	Yes	None
Planned lines – sufficient coverage, spacing, and length	Yes	None
Planned GPS stations – at least 2 in range of all missions Baseline 40km or less	Yes	None

Table 4 QA checks and results for the flight operations phase

2.3 QC Checkpoint Survey Guidelines

During the planning phase URS provided a set of guidelines to Woolpert, a member of the URS team providing survey services, outlining the reporting and placement requirements for the QC checkpoints. These guidelines incorporated items from the project scope of work, as well as guidelines derived from URS experience on similar projects.

2.4 QC Checkpoint Survey Planning Review

The ground survey layout for the quality control checkpoints was developed by URS by selecting control point locations on a project layout and by reviewing and adjusting the locations using aerial imagery as a reference. The aerial imagery was referenced to confirm that control point locations were accessible, in the relevant land cover categories, and to ensure that the locations chosen conformed to project specifications and guidelines.

The overall control layout, including QC checkpoints, acquisition base stations, and nearest CORS stations was then reviewed to ensure adequate project coverage and distribution of points. Odd-numbered checkpoints are later shared with the LiDAR vendor once they have completed flight line boresights.

QA Survey Checkpoints Legend	
Checkpoint color	**Land cover category**
Green	Flood/Soils, odd-numbered, shared with vendor
Yellow	Flood/Soils, even-numbered, withheld from vendor

Table 5 QA checkpoint legend for this project

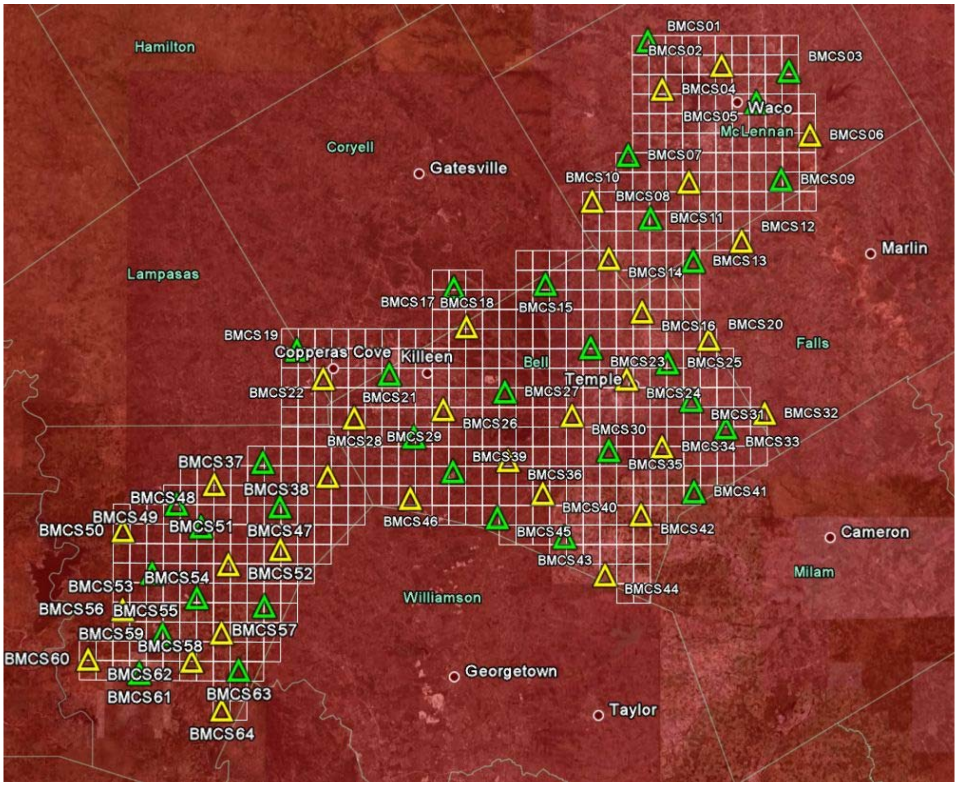


Figure 2 QA checkpoint planned layout for Bell-McLennan AOI

In accordance with URS internal procedures for independent technical reviews, the QC checkpoint plan was reviewed by a second URS employee not affiliated with the development of the plan. The survey QC checkpoint plan was then communicated to Woolpert and TNRIS prior to commencement of field surveys.

3 Phase II: Data Acquisition

The following quality control actions were taken during and immediately after the aerial acquisition of LiDAR data for this AOI.

3.1 Review of Ground Survey QC Checkpoints

During the establishment of QC checkpoints in the Bell, Burnet, Coryell, Falls, Lampasas, and McLennan Counties AOI, URS and Woolpert coordinated on a daily basis with status checks. This close coordination allowed for quick resolution of placement problems typically caused by accessibility issues. In addition, Woolpert remained in close contact with Photo Science in order to ensure that the aerial vendor’s base stations were correctly tied into the overall plan.

URS reviewed all documentation delivered by Woolpert at the conclusion of the field collection of QC checkpoints. Reported QC checkpoint locations were verified against project specifications and control plan layouts and project documents were updated to reflect actual coordinates. All QC checkpoint documentation was then delivered to TNRIS. For the Bell, Burnet, Coryell, Falls, Lampasas, and McLennan Counties AOI, even-numbered QC control points were withheld from Photo Science.

Woolpert completed field work, processed the points, and provided the survey results for the Bell, Burnet, Coryell, Falls, Lampasas, and McLennan Counties AOI to URS on May 18, 2011.

3.2 Review of Aerial Acquisition Operations

URS plans all QA/QC projects to include a review of acquisition progress and daily records kept by the flight crews. The following table outlines the checklist list utilized by URS for this review and the results obtained during this projects execution:

QA Checklist for Aerial Acquisition Phase		
Deliverable	**Included (Yes/No)**	**Comments**
Daily activity reports	Yes	None
Flight logs – job #/name	Yes	None
Flight logs – block or AOI	Yes	None
Flight logs – date	Yes	None
Flight logs – aircraft tail #	Yes	None
Flight logs – lines - #	Yes	None
Flight logs – lines - direction	Yes	None
Flight logs – lines – start/stop	Yes	None
Flight logs – lines – altitude	Yes	None
Flight logs – lines – scan angle	Yes	None
Flight logs – lines – speed	Yes	None
Flight logs – conditions	Yes	None
Flight logs – comments	Yes	None
Flight logs - pilot name	Yes	None
Flight logs - operator name	Yes	None
Flight logs - AGC switch	Yes	None
Flight logs – GPS base stations	Yes	None

Table 6 QA checklist and results table for acquisition phase

3.3 Post-flight: Aerial Acquisition Report

For the post-flight QA review, URS conducted a review of the vendor's report titled: "*LiDAR Acquisition Report: Bell-McLennan Area of Interest, TX"* submitted by Photo Science, as well as National Geodetic Survey datasheets, Photo Science's calibration reports and Photo Science's flight logs. The following table outlines the checklist and results for the post-flight review:

QA Checklist for the Aerial Post-acquisition Vendor Report		
Deliverable	**Included (Yes/No)**	**Comments**
GPS base station - name	Yes	See flight logs and NGS datasheets
GPS base station – lat/long	Yes	See flight logs and NGS datasheets

GPS base station – height	Yes	See flight logs and NGS datasheets
GPS base station – map	Yes	See flight logs and NGS datasheets
GPS quality - separation	Yes	Not included in acquisition report, delivered separately in trajectory reports
GPS quality – PDOP	Yes	Not included in acquisition report, delivered separately in trajectory reports
GPS quality - horizontal accuracy	Yes	Not included in acquisition report, delivered separately in trajectory reports
GPS quality - vertical accuracy	Yes	Not included in acquisition report, delivered separately in trajectory reports
Sensor calibration	Yes	See calibration reports
Verification of AOI coverage	Yes	See Figure 3
As-flown trajectories included	Yes	None
Ground control layout	Yes	See Appendix A of acquisition report
Data verification	Yes	See Figure 3

Table 7 QA checklist for post-acquisition report

URS verified the differential baseline lengths of the aerial vendor's base stations used for the project. Based on a mutual agreement between project stakeholders at the project kick-off meeting, the baseline length specification of 30km was relaxed to 40km. To ensure that baseline length did not exceed the 40km specification of the project, URS plotted the base station coordinates provided in the aerial acquisition report from the vendor by generating 40km range rings around each point and comparing them against the AOI tile layout.

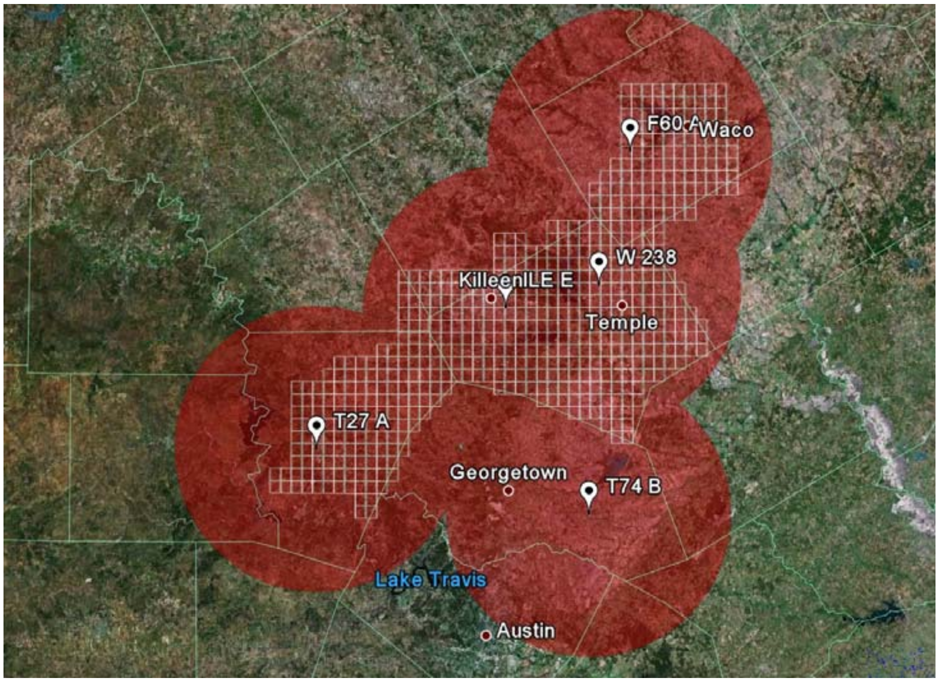


Figure 3 Bell, Burnet, Coryell, Falls, Lampasas, and McLennan Counties AOI GPS base station baseline check

As a final check and assurance of this, URS inspected the delivered LiDAR LAS files in this area to ensure that a GPS time-stamp was present.

3.4 Post-flight: Notes

None.

4 Phase III: Data Processing

The following quality control reviews were conducted during the data processing phase for the Bell, Burnet, Coryell, Falls, Lampasas, and McLennan Counties AOI.

4.1 Review of Photo Science Production Work Flow

URS conducted a review of the production workflow utilized by Photo Science for this project based on the project kick-off meeting. The majority of the workflow utilized methods and processes that are standard for the industry. This includes commercial, off the shelf software as well as proprietary macros used for the filtering of the LiDAR data.

URS did not make any recommendations regarding the LiDAR processing workflow as the workflow adequately addressed the specifications and goals of the project.

4.2 Qualitative Assessment

This section describes the specifications checked, the methods and tools used and the results of the quality assessment of the Bell, Burnet, Coryell, Falls, Lampasas, and McLennan Counties AOI delivery.

4.2.1 Specifications Checked: Aerial Acquisition

The following list outlines the checks against the project specifications and indicates whether or not the check was conducted for this particular delivery.

QA Checklist for Aerial Acquisition Phase			
Deliverable	**Specification/Description**	**Checked for this delivery? Yes/No**	**Comments**
Pulse returns	LiDAR sensor used -capable of recording up to 3 returns per pulse including 1st and last returns	Yes	See acquisition report
Scan angle	$\leq \pm$ 20 degrees	Yes	See acquisition report
Swath overlap – Flood/Soils land cover	Tiles in Flood/Soils category - nominal 30% sidelap on adjoining swaths	Yes	Verified during visual inspection of .las data
Design pulse density	For all land cover categories pulses per m² $\geq$ 2 pulses/m² in each swath or $\geq$ 4 for project.	Yes	None
GPS procedures	2 GPS ref. stations during missions, operating at 1 Hz or higher, ABGPS at 2 Hz or higher, GPS PDOP $\leq$ 3.5 with at least 6 satellites in view.	Yes	Verified during review of trajectory reports
Survey conditions	Leaf-off and no significant snow cover	Yes	None
Coverage	No voids between swaths due to cloud cover or instrument failure	Yes	Instrument failure did occur for one Gemini sensor, which resulted in portions of the AOI being reflown.
Swath overlap	< 40% no-overlap area per project	Yes	Verified during visual inspection of .las data
Aggregate 1st return density	Barring non-scattering areas; $\geq$ 85% design pulse density (dpd) for entire project area, within 30m x 30m area in swath overlap, $\geq$ 50% dpd	Yes	None

Table 8 QA checklist for aerial acquisition phase

4.2.2 Specifications Checked: Processing

4.2.2.1 All-Return Point Cloud

The following checklist outlines the standard checks for the all-return point cloud product and indicates whether or not the check was conducted for this particular delivery.

QA Checklist for Processing phase: All-Return Point Cloud			
Deliverable	**Specification/Description**	**Checked for this delivery? Yes/No**	**Comments**
Vertical datum	NAVD88, Geoid03	Yes	None
Horizontal datum	NAD83	Yes	None
Projection	UTM	Yes	Zone 14
Vertical units	Meters (orthometric, NAVD88)	Yes	None
Horizontal units	Meters (UTM)	Yes	None
Attributes	Returns contain – GPS week and second, easting/northing, elevation, intensity, return # and classification	Yes	None
Attributes	No duplicate entries	Yes	None
Attributes	GPS second reported to nearest microsecond	Yes	None
Attributes	Easting, northing, and elevation reported to nearest 0.01 m or 0.01 ft	Yes	None
Attributes	Correct classes – 1. Unclassified; 2. Ground; 4. Vegetation 6. Building; 7. Low point; 9. Water; and 13. Bridges-culverts	Yes	None
Attributes	Cloud file structure conforms to 1/16th USGS 7.5-minute quadrangle (1.875 minute by 1.875 minute)	Yes	None
Attributes	Naming conforms to USGS Quad, Quarter-Quad, and Quarter-Quarter-Quad codes	Yes	None

Table 9 QA checklist for all-return point cloud

4.2.2.2 Bare-Earth DEM

The following list outlines the standard checks for the bare-earth DEM product and indicates whether or not the check was conducted for this particular delivery.

QA Checklist for Processing Phase: Bare-Earth DEM			
Deliverable	**Specification/Description**	**Checked for this delivery? Yes/No**	**Comments**
Vertical datum	NAVD88, Geoid03	Yes	None
Horizontal datum	NAD83	Yes	None
Projection	UTM	Yes	Zone 14
Vertical units	Meters (orthometric, NAVD88)	Yes	None
Horizontal units	Meters (UTM)	Yes	None
Attributes	Each return contains – GPS week, GPS second, easting, northing, elevation intensity, return # and classification	Yes	None
Attributes	No duplicate entries	Yes	None

QA Checklist for Processing Phase: Bare-Earth DEM			
Deliverable	Specification/Description	Checked for this delivery? Yes/No	Comments
Attributes	GPS second reported to nearest microsecond	Yes	None
Attributes	Easting, northing, and elevation reported to nearest 0.01 m or 0.01 ft	Yes	None
Attributes	Cloud file structure conforms to 1/16th USGS 7.5-minute quadrangle (1.875 minute by 1.875 minute)	Yes	None
Attributes	Naming conforms to USGS Quad, Quarter-Quad, and Quarter-Quarter-Quad codes	Yes	None
Gaps	Deliverable tiles checked for gaps not covered by aerial acquisition and/or caused by processing	Yes	None
Hydro-breaklines	Hydro-breaklines used in the generation of DEM	Yes	None

Table 10 QA checklist for bare-earth DEM

4.2.2.3 Intensity Images

The following list outlines the standard checks for the intensity image product and indicates whether or not the check was conducted for this particular delivery.

QA Checklist for Processing Phase: Intensity Images			
Deliverable	Specification/Description	Checked for this delivery? Yes/No	Comments
Vertical datum	NAVD88, Geoid03	Yes	None
Horizontal datum	NAD83	Yes	None
Projection	UTM	Yes	Zone 14
Vertical units	Meters (orthometric, NAVD88)	Yes	None
Horizontal units	Meters (UTM)	Yes	None
Pixel size	~ 1m (3 ft)	Yes	None
Attributes	Intensity file structure conforms to 1/4th USGS 7.5-minute quadrangle (3.75 minute by 3.75 minute)	Yes	None
Attributes	Naming conforms to USGS Quad, Quarter-Quad, and Quarter-Quarter-Quad codes	Yes	None
Gaps	Deliverable tiles checked for significant gaps not covered by aerial acquisition checks and/or caused by processing	Yes	None

Table 11 QA checklist for intensity images

4.2.2.4 3D Breaklines

The following list outlines the standard checks for the hydro-flattening breakline product and indicates whether or not the check was conducted for this particular delivery.

QA Checklist for Processing Phase: Hydro-Flattening Breaklines			
Deliverable	**Specification/Description**	**Checked for this delivery? Yes/No**	**Comments**
Vertical datum	NAVD88, Geoid03	Yes	None
Horizontal datum	NAD83	Yes	None
Projection	UTM	Yes	Zone 14
Vertical units	Meters (orthometric, NAVD88)	Yes	None
Horizontal units	Meters (UTM)	Yes	None
Shapefile	Delivered as a 3D shapefile	Yes	None
.prj file	Companion .prj file includes properly formatted and accurate georeference information	Yes	None
Matches LiDAR	Hydro-flattening breaklines match LiDAR surface and point classifications (water)	Yes	None
Hydro-breaklines	Hydro-breaklines correctly delineate hydrographic features	Yes	None

Table 12 QA checklist for hydro flattened Breaklines

4.2.3 Software Used

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

- *GeoCue:* a geospatial data/process management system especially suited to managing large LiDAR data sets
- *TerraModeler:* used for analysis and visualization
- *TerraScan:* runs inside of Bentley Microstation; used for point classification checks and points file generation
- *Proprietary tool:* developed in-house to conduct a statistical analysis of .LAS files

4.2.4 Qualitative Assessment Process

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

- Delivery was reviewed for completeness of content
- Delivery was uploaded to the GeoCue data warehouse
    - Projection of data was verified
    - Aerial imagery from ancillary sources was referenced to facilitate data review
- Performed coverage/gap check to ensure proper coverage of the tiles submitted
    - Created a density grid to check that delivery meets data density requirements
    - Conducted a statistical analysis of delivery to check point classifications, variable-length record values, and maximum/minimum x,y,z ranges
- Performed tile-by-tile analysis

    - Verified that tile naming conventions were followed
    - Verified that deliverable formats were correct
    - Using TerraScan, checked for errors in profile mode (noise, high and low points)
    - Conducted measurements to determine if delivery met applicable specifications outlined in aerial acquisition specifications (overlap, gaps, etc.)
    - Reviewed hydro-breakline data for accuracy and completeness
    - Reviewed each tile for anomalies; if problems were found, the areas were identified using polygons in ESRI shape file format and accompanied by comments and relevant screenshots in the report. Aerial imagery was used to verify QC calls made in the following cases or when the issue was not evident by merely reviewing the LiDAR:
        - Buildings left in the bare-earth points
        - Vegetation left in the bare-earth points
        - Water points left in the bare-earth points
        - Proper definition of roads and drainage patterns
        - Bridges and large box culverts removed from bare-earth points
        - Areas that have been “shaved off” or “over-smoothed” during filtering
- Reports generated and submitted to TNRIS and Photo Science

4.2.5 Qualitative Assessment Results

The following sections outline the results of the quality assessment conducted during the data processing phase of this project.

4.2.5.1 Against LiDAR Aerial Acquisition Specifications

QA Results – Aerial Acquisition			
Deliverable	**Specification/Description**	**Pass/Fail**	**Comments**
Pulse returns	LiDAR sensor used -capable of recording up to 3 returns per pulse including 1st and last returns	Pass	Sensor capable of returning up to 4 returns per pulse
Scan angle	< + 20 degrees	Pass	Full scan angle of 37 degrees
Swath overlap – Flood/Soils land cover	Tiles in Flood/Soils category - nominal 30% sidelap on adjoining swaths	Pass	None
Design pulse density	For all land cover categories pulses per $m^2 \geq 2$ pulses/m^2 in each swath or ≥ 4 for project.	Pass	See Figures 4, 5, & 6 for pulse density analysis
GPS procedures	2 GPS ref. stations during missions, operating at 1 Hz or higher, ABGPS at 2 Hz or higher, GPS PDOP ≤ 3.5 with at least 6 satellites in view.	-	Not checked
Survey conditions	Leaf-off and no significant snow cover	Pass	None
Coverage	No voids between swaths due to cloud cover or instrument failure	Pass	No voids were observed between swaths.
Swath overlap	< 40% no-overlap area per project	Pass	None

QA Results – Aerial Acquisition			
Deliverable	**Specification/Description**	**Pass/Fail**	**Comments**
Aggregate 1st return density	Barring non-scattering areas; ≥ 85% design pulse density (dpd) for entire project area, within 30m x 30m area in swath overlap, ≥ 50% dpd	Pass	None

Table 13 QA results - aerial acquisition

Using QT Modeler, URS created density grids that analyzed the number of LiDAR points in each 1m cell of the .las tile. This process was performed on a subset of the .las data (see Figure 4). Six tiles from the AOI were sampled for the density grid analysis. The sample tiles selected for the density grid analysis did not contain any unusual land features and were similar in land cover classification to the AOI. The results from this analysis were aggregated into Figures 5 & 6. They also represent different flightlines and the point density determined from these tiles should be similar to other tiles in the AOI. Table 14 expresses the average point density and pulse spacing of the selected sample tiles. The average point density was determined by dividing tile point count (derived from .las header) by tile area. The average pulse spacing was determined by dividing total tile pulses (derived from 1st return density grid) by tile area.

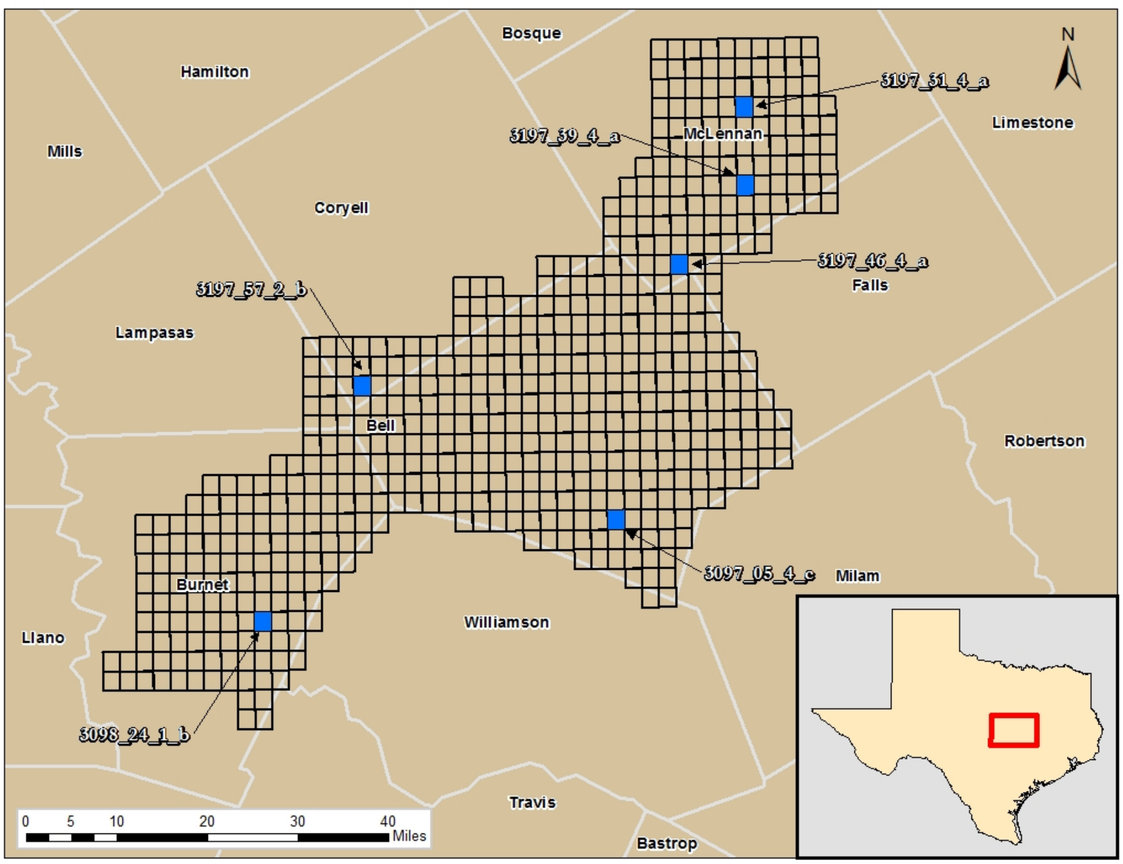


Figure 4 Tiles used for All-Return Point Cloud Density Analysis.

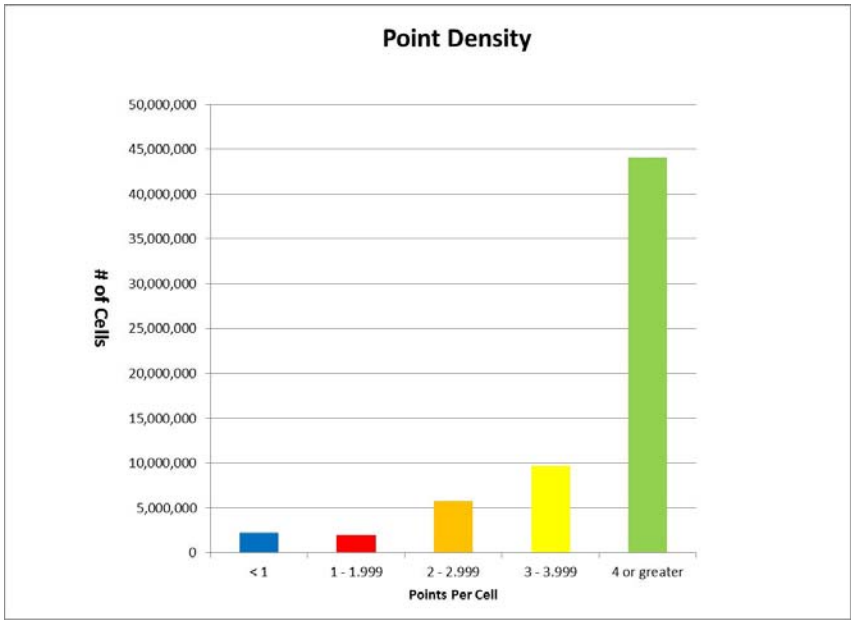


Figure 5 All-Return Point Cloud Density for Sampled Tiles. The cell size for the density grids was set at 1 m^2. The total number of cells sampled was 63,636,561. Of these, 44,083,611 cells had 4 or more points per cell or ppsm.

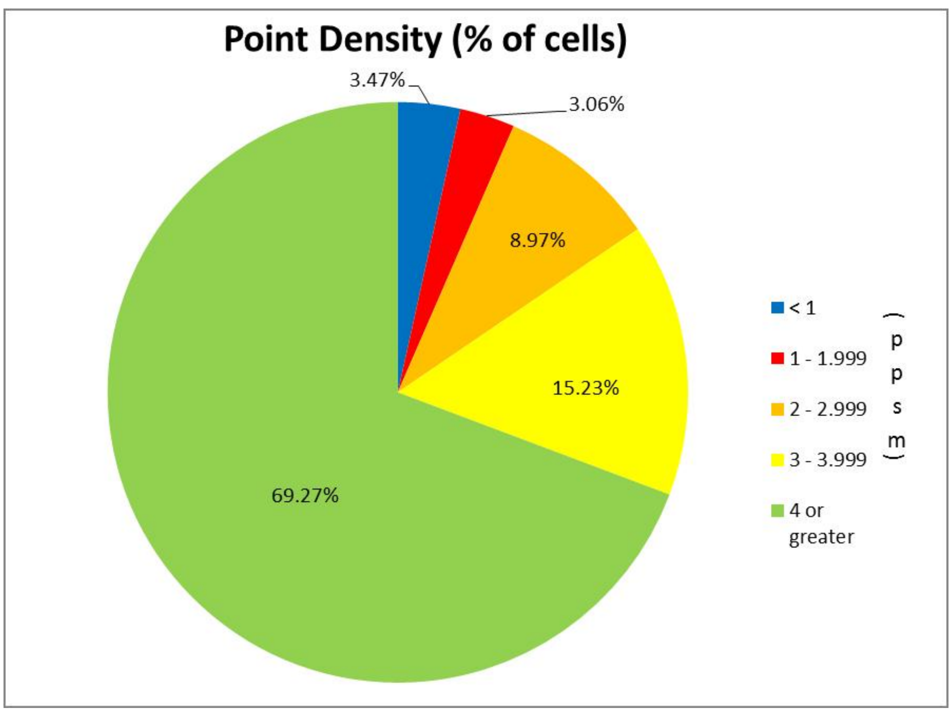


Figure 6 All-Return Point Cloud Density for Sampled Tiles. This is another method for visualizing the data from Figure 5. 69.27% of the cells sampled from the density grid analysis have ≥4 ppsm.

Tile	Average Point Density (points per m^2)	Average Pulse Spacing (pulses per m^2)
3097_05_4_C	4.96	0.45
3098_24_1_B	5.05	0.44
3197_31_4_A	4.34	0.48
3197_39_4_C	4.27	0.48
3197_46_4_A	5.53	0.43
3097_57_2_B	4.42	0.48

Table 14 Average Point Density and Pulse Spacing of Sampled Tiles.

A check of the swath overlap criteria was made by colorizing the LiDAR tiles by source identification (flight line) and making direct measurements in multiple locations of the tile. The following figure is an example from the AOI.

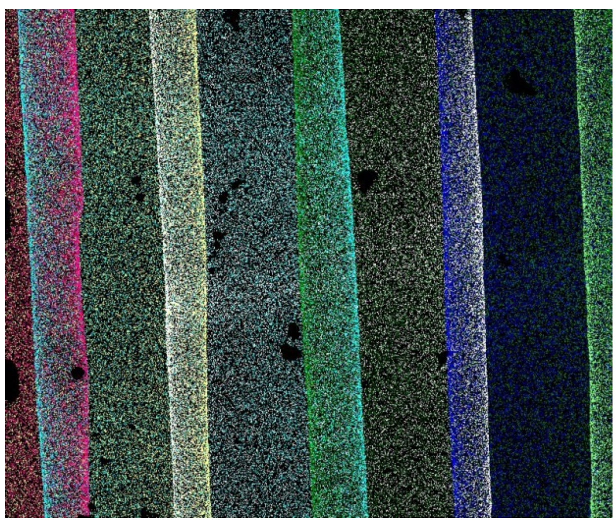


Figure 7 Example of LiDAR points in tile 3197_31_4_c colorized by source identification

4.2.5.2 All-Return Point Clouds

QA Results – All-Return Point Clouds			
Deliverable	**Specification/Description**	**Pass/Fail**	**Comments**
Vertical datum	NAVD88, Geoid03	Pass	None
Horizontal datum	NAD83	Pass	None
Projection	UTM	Pass	Zone 14
Vertical units	Meters (orthometric, NAVD88)	Pass	None
Horizontal units	Meters (UTM)	Pass	None
Attributes	Returns contain – GPS week and	Pass	None

QA Results – All-Return Point Clouds			
Deliverable	**Specification/Description**	**Pass/Fail**	**Comments**
	second, easting/northing, elevation, intensity, return # and classification		
Attributes	No duplicate entries	Pass	None
Attributes	GPS second reported to nearest microsecond	Pass	None
Attributes	Easting, northing, and elevation reported to nearest 0.01 m or 0.01 ft	Pass	None
Attributes	Correct classes – 1. Unclassified; 2. Ground; 4. Vegetation 6. Building; 7. Low point; 9. Water; and 13. Bridges-culverts	Fail	Initial delivery received on 07/14/2011 failed Macro QA for point classification and was returned to Photo Science for reprocessing and redelivery. All subsequent deliveries passed Macro QA checks for this issue. In addition to classes listed under the specifications, Photo Science also used class 3 & 5 to classify both low and high vegetation.
Attributes	Cloud file structure conforms to 1/16th USGS 7.5-minute quadrangle (1.875 minute by 1.875 minute)	Pass	None
Attributes	Naming conforms to USGS Quad, Quarter-Quad, and Quarter-Quarter-Quad codes	Pass	None

Table 14 QA results - all-return point cloud files

It was noted during the visual inspection of the all return point cloud data that there were multiple instances of areas of high point density. During the course of the review, it was determined by URS that these instances of high point density did not affect the overall quality of the data. An explanation of these instances was not provided by Photo Science.

Figure 8 depicts a void/gap check conducted on both AOIs using LiDAR orthophotos generated in GeoCue. The imported .LAS files were used to create LiDAR "orthos." The LiDAR orthos were one of the tools used to verify data coverage and point density, to check for gross data voids or gaps, and to use as reference data during checks for data anomalies and artifacts. These LiDAR orthos are not intended to be a project deliverable. The orthos were derived from the full point cloud elevations and LiDAR pulse return intensity values. The intensity values were used as delivered, with no normalization applied. Due to the point density of the original collection, the orthos were produced at a 1m pixel for the entire area of interest. Acceptable voids are those found over water features and some areas of dense vegetation. Any unacceptable voids identified by the void/gap check would be passed on to Photo Science and verified as corrected upon redelivery.

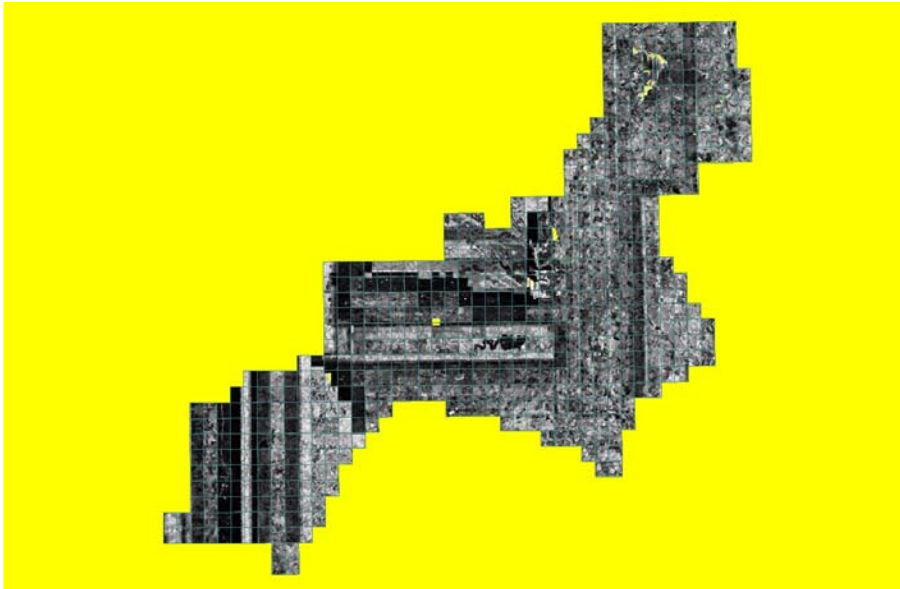


Figure 8 Void/gap check on the AOIs. Intensity image is overlaid onto a colored background (in this case yellow) to allow thorough identification of gross gaps and voids

Figure 9 demonstrates the quality of the filtering to bare ground. Profiles like this were taken across the project area to check the quality of the filtering.

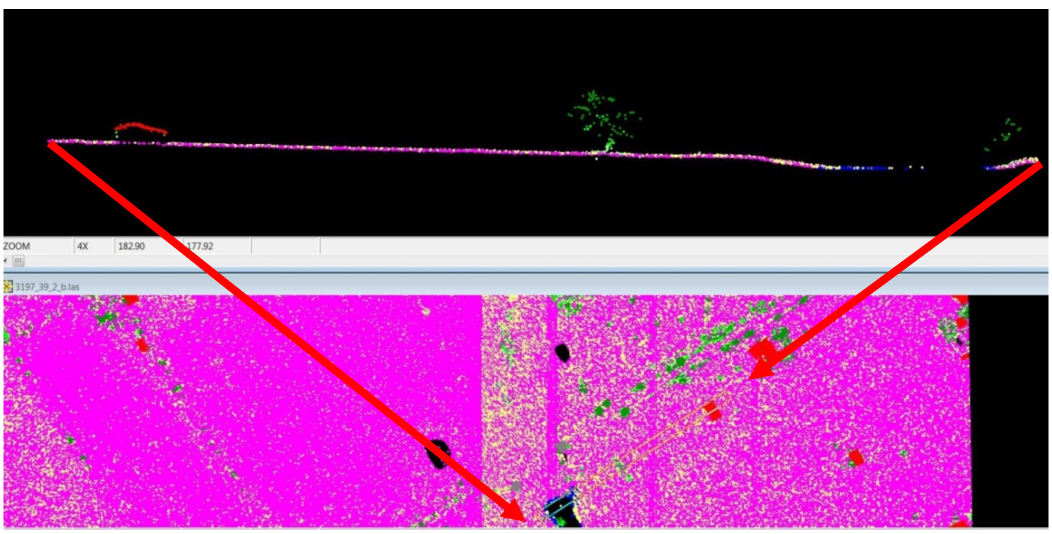


Figure 9 Profile in tile 3197_39_2_b to check filtering quality. Pink denotes ground points; green denotes above-ground vegetation; red denotes building; yellow denotes unclassified; blue denotes water.

4.2.5.3 Bare-Earth DEM

QA Results – Bare-Earth DEM			
Deliverable	**Specification/Description**	**Pass/Fail**	**Comments**
Vertical datum	NAVD88, Geoid03	Pass	None
Horizontal datum	NAD83	Pass	None

QA Results – Bare-Earth DEM			
Deliverable	**Specification/Description**	**Pass/Fail**	**Comments**
Projection	UTM	Pass	None
Vertical units	Meters (orthometric, NAVD88)	Pass	None
Horizontal units	Meters (UTM)	Pass	None
Attributes	Each return contains – GPS week, GPS second, easting, northing, elevation intensity, return # and classification	Pass	None
Attributes	No duplicate entries	Pass	None
Attributes	GPS second reported to nearest microsecond	Pass	None
Attributes	Easting, northing, and elevation reported to nearest 0.01 m or 0.01 ft	Pass	None
Attributes	Cloud file structure conforms to 1/16th USGS 7.5-minute quadrangle (1.875 minute by 1.875 minute)	Pass	None
Attributes	Naming conforms to USGS Quad, Quarter-Quad, and Quarter-Quarter-Quad codes	Pass	GRID files do not include "be" in the file naming convention
Gaps	Deliverable tiles checked for gaps not covered by aerial acquisition and/or caused by processing	Fail	11 data gaps in bare-earth DEM were identified in initial deliveries
Hydro-breaklines	Hydro-breaklines used in the generation of DEM	Pass	None

Table 15 QA results - bare-earth DEM

Hydro-breaklines were used in the processing of the bare-earth DEM. To check these, URS requested a copy of the breaklines collected. URS checked the breaklines for horizontal placement, completeness, and continuity by reviewing the original breakline files as well as by overlaying the breakline files over the LiDAR intensity files. Figure 10 depicts a breakline check conducted for tile 3197_30_2_a.

Figure 10 – Hydro breakline check for tile 3197_30_2_a.las. Yellow lines are collected hydro features.

4.2.5.4 Intensity Images

QA Results – Intensity Images			
Deliverable	**Specification/Description**	**Pass/Fail**	**Comments**
Vertical datum	NAVD88, Geoid03	Pass	None
Horizontal datum	NAD83	Pass	None
Projection	UTM	Pass	Zone 14
Vertical units	Meters (orthometric, NAVD88)	Pass	None
Horizontal units	Meters (UTM)	Pass	None
Pixel size	~ 1m (3 ft)	Pass	None
Attributes	Intensity file structure conforms to 1/4th USGS 7.5-minute quadrangle (3.75 minute by 3.75 minute)	Pass	Intensity file structure conforms to 1/16th USGS 7.5-minute quadrangle (1.875 minute by 1.875 minute) instead of 1/4th USGS 7.5-minute quadrangle
Attributes	Naming conforms to USGS Quad, Quarter-Quad, and Quarter-Quarter-Quad codes	Pass	Naming conforms to USGS Quad, Quarter-Quad, and Quarter-Quarter-Quad codes
Gaps	Deliverable tiles checked for significant gaps not covered by aerial acquisition checks and/or caused by processing	Fail	11 data gaps in bare-earth DEM were identified in initial deliveries

Table 16 QA results - intensity images

4.2.5.5 3D Breaklines

QA Checklist for Processing Phase: Hydro-Flattening Breaklines			
Deliverable	**Specification/Description**	**Pass/Fail**	**Comments**
Vertical datum	NAVD88, Geoid03	Pass	None
Horizontal datum	NAD83	Pass	None
Projection	UTM	Pass	Zone 14
Vertical units	Meters (orthometric, NAVD88)	Pass	None
Horizontal units	Meters (UTM)	Pass	None
Shapefile	Delivered as a 3D shapefile	Pass	None
.prj file	Companion .prj file includes properly formatted and accurate georeference information	Pass	None
Matches LiDAR	Hydro-flattening breaklines match LiDAR surface and point classifications (water)	Fail	Initial deliveries identified 47 edit calls where breaklines did not match LiDAR surface and point classifications
Hydro-breaklines	Hydro-breaklines correctly delineate hydrographic features	Fail	Initial deliveries identified 8 edit calls where breaklines did not correctly delineate hydrographic features

Table 17 QA Results - 3D Breaklines

4.2.5.6 Failed Items for Initial Delivery

The initial delivery from Photo Science on 07/14/2011 failed Macro QA checks for correct point classification and was returned for reprocessing and redelivery. After this initial delivery, Photo Science delivered project data to URS as four separate initial lots. The items discussed below are discussed as separate lots. As summarized by the QA tables in the previous sections of this report, the following items failed initial QA inspections and were subsequently corrected and redelivered to URS:

- Initial Delivery (148 Tiles):
  - Statistical Analysis - The statistical analysis of the all return point cloud data identified an issue with the classification scheme used by Photo Science. The .las data included points classified as Class 12 (Overlap), which was not specified in the scope of work. Photo Science was notified that the Class 12 points would need to be reclassified to match the project point classification scheme.
- Lot 1 (102 Tiles):
  - LAS Classification Issues – the initial delivery of LAS point clouds for this lot contained some points that were not classified to the correct classification scheme. These issues include:
    - Ground points misclassified as water points
    - Misclassified vegetation points
  - Hydro-Flattening Breaklines – the initial delivery of breaklines for this lot was missing four hydrologic features.
  - A total of 23 edit calls were identified from this lot
- Lot 2 (85 tiles):
  - Data Gap – One data gap was identified in tile 3197_47_3_a
  - LAS Classification Issues - the initial delivery of LAS point clouds for this lot contained some points that were not classified to the correct classification scheme. These issues include:
    - Artifacts in the bare earth
    - Two sections of the point cloud with excessive unclassified points
    - Water points misclassified as ground
    - Misclassified vegetation points
  - Hydro-Flattening Breaklines – One breakline was missing around an island classified as ground. One hydrologic feature was missing from initial breakline delivery.
  - A total of 11 edit calls were identified from this lot.
- Lot 3 (271 tiles):
  - Data Gaps – Nine data gaps were identified in this lot
  - LAS Classification Issues - the initial delivery of LAS point clouds for this lot contained some points that were not classified to the correct classification scheme. These issues include:
    - Ground points misclassified as water
    - Water points misclassified as ground
    - Ground points misclassified as building/unclassified
    - Large swaths of ground points misclassified as building on tiles 3197_44_4_b, 3197_59_2_b 3197_60_1_a, and 3197_60_1_b

        - Bridge/culvert points misclassified as ground on tiles 3197_58_2_b, 3197_59_1_a, and 3197_59_1_b
    - Hydro-Flattening Breaklines – One breakline was missing from a hydrologic feature classified as water. One hydrologic feature was from the initial breakline delivery. One breakline feature had incorrect geometry.
    - A total of 91 edit calls were identified from this lot.
- Lot 4 (131 tiles):
    - Data Gap – One data gap was identified on tile 3097_01_1_c
    - LAS Classification Issues - the initial delivery of LAS point clouds for this lot contained some points that were not classified to the correct classification scheme. These issues include:
        - Misclassified noise points
        - Water points misclassified as ground
    - Hydro-Flattening Breaklines – Visual inspection of this breakline dataset identified one instance of incorrect breakline geometry.
    - A total of 4 edit calls were identified from this lot.

The breaklines, LAS point clouds, bare earth DEMs, and Intensity Images for these delivery lots were corrected, redelivered, and passed subsequent inspections.

4.3 Quantitative Assessment (Accuracy Report)

URS performed the LiDAR vertical accuracy assessment in accordance with ASPRS and NSSDA specifications and guidelines.

The LiDAR data produced for this project adheres to the ASPRS and NSSDA accuracy standards, as referenced in the Texas Water Development Board Project Number 580-11-1213.

4.3.1 Specifications Checked

The following specifications were checked for the Bell, Burnet, Coryell, Falls, Lampasas, and McLennan Counties AOI. The AOI consisted of the Flood/Soils land cover category. The results are documented in **Section 4.3.4** of this report.

Vertical Accuracy Specification – Flood/Soils		
Standard	**Description**	**Accuracy Threshold**
NSSDA	Horizontal accuracy at 90% confidence	75cm
ASPRS	Horizontal accuracy at 95% confidence	75cm
NSSDA	Vertical accuracy at 90% confidence	15cm
ASPRS	Vertical accuracy at 95% confidence	15cm

Table 18 Vertical accuracy thresholds for flood/soils land cover category

4.3.2 Software Used

- *GeoCue:* a geospatial data/process management system especially suited to managing large LiDAR data sets

- *Z-probe:* A program within GeoCue 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 measurements

4.3.3 Quantitative Assessment Process

The primary quantitative assessment steps were as follows:

1. Under a separate contract with the Texas Water Development Board, Photo Science, acquired new raw LiDAR data between March 11, 2011 through July 31, 2011 and performed post-processing to derive the bare-earth digital terrain model.
2. Under subcontract to URS, Woolpert, surveyed 64 ground checkpoints in accordance with the specifications cited in Texas Water Development Board Project Number 580-11-1213. All project survey work performed by Woolpert adhered to the rules and regulations for providing professional land surveying services as established by the Texas Board of Land Surveying and to the standards established by the Texas Society of Professional Land Surveyors. Survey report documentation has been provided as a separate deliverable.
3. Woolpert provided URS with a table of horizontal coordinates and orthometric heights for all surveyed checkpoints, classified by land cover category. URS 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. URS compared the LiDAR-derived elevations of the check points to the surveyed check point orthometric heights and computed the vertical accuracy assessment according to ASPRS and NSSDA specifications.

The spatial distribution of ground checkpoints surveyed by Woolpert is shown in Figure 11.

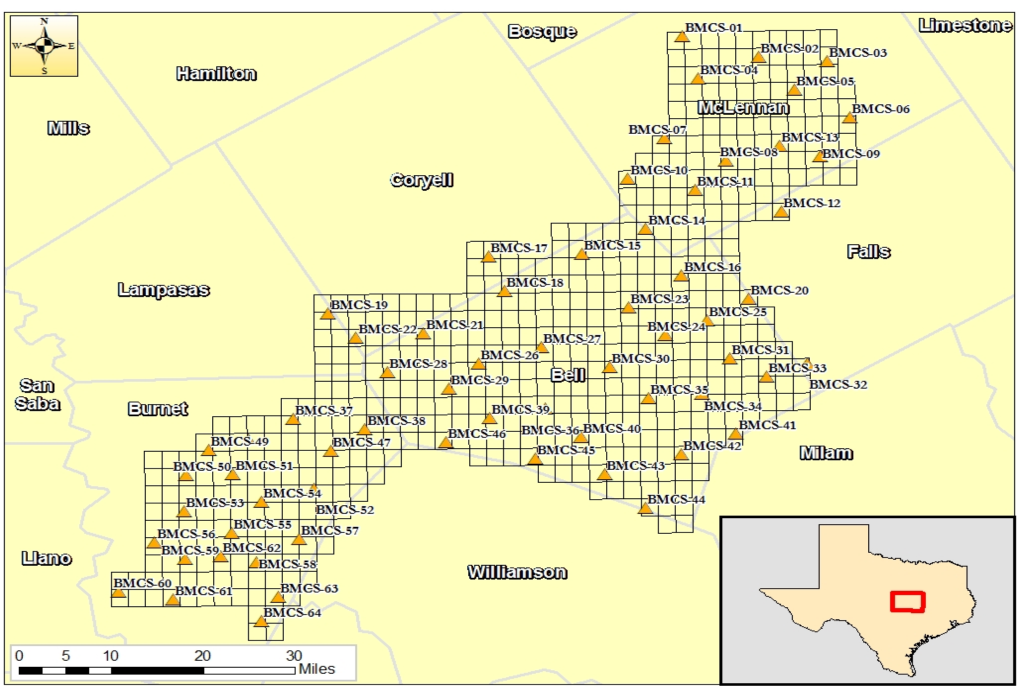


Figure 11 QA checkpoint survey locations

4.3.4 Descriptive Statistics

Descriptive statistics and 95th percentile calculation for the flood/soils land cover classifications found in the AOI are summarized in the following table:

Summary of Descriptive Statistics and 95th Percentile Calculations								
Land Cover Category	No. of Points	RMSE (cm)	Actual RMSEz (cm)	Mean Error (cm)	Median Error (cm)	Skew	STDEV (cm)	95th Percentile (cm)
Urban	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Forest	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Coastal	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Flood/Soils	64	9.445	18.513	-1.842	-3.800	39.766	9.337	16.680

Table 19 Summary of descriptive characteristics

Detailed statistics and survey checkpoint comparisons are outlined in the following tables by the land cover categories present in the AOI:

Detailed Comparison Against Survey Checkpoints – Flood/Soils Category								
Point No	Land Cover Class	Survey X Coord.	Survey Y Coord.	DTM Height	Survey - Z	ΔZ	ΔZ*2	ABS ΔZ
BMCS-01	Flood/Soils	659,823.892	3,502,700.714	184.588	184.595	-0.007	0.000	0.007
BMCS-02	Flood/Soils	673,074.583	3,498,488.968	136.212	136.303	-0.091	0.008	0.091
BMCS-03	Flood/Soils	685,129.832	3,497,656.167	120.948	120.986	-0.038	0.001	0.038
BMCS-04	Flood/Soils	662,505.725	3,494,190.710	173.683	173.771	-0.088	0.008	0.088
BMCS-05	Flood/Soils	679,342.320	3,491,888.883	119.829	119.893	-0.063	0.004	0.063
BMCS-06	Flood/Soils	689,039.188	3,486,378.507	125.767	125.750	0.017	0.000	0.017
BMCS-07	Flood/Soils	656,635.957	3,482,260.670	195.750	195.856	-0.106	0.011	0.106
BMCS-08	Flood/Soils	667,455.309	3,477,694.244	216.684	216.820	-0.136	0.018	0.136
BMCS-09	Flood/Soils	683,916.469	3,478,599.273	119.121	119.052	0.069	0.005	0.069
BMCS-10	Flood/Soils	650,267.412	3,474,079.068	224.535	224.694	-0.159	0.025	0.159
BMCS-11	Flood/Soils	662,024.009	3,471,863.035	199.720	199.684	0.036	0.001	0.036
BMCS-12	Flood/Soils	677,084.942	3,467,432.968	144.952	144.890	0.062	0.004	0.062
BMCS-13	Flood/Soils	668,329.713	3,463,739.170	192.113	192.181	-0.068	0.005	0.068
BMCS-14	Flood/Soils	653,426.635	3,464,008.526	209.401	209.406	-0.005	0.000	0.005
BMCS-15	Flood/Soils	642,241.385	3,458,997.558	238.319	238.465	-0.146	0.021	0.146
BMCS-16	Flood/Soils	659,689.567	3,454,593.243	236.198	236.214	-0.016	0.000	0.016
BMCS-17	Flood/Soils	625,957.027	3,458,409.767	234.710	234.612	0.099	0.010	0.099
BMCS-18	Flood/Soils	628,671.092	3,451,475.101	223.188	223.246	-0.058	0.003	0.058
BMCS-19	Flood/Soils	597,972.958	3,447,086.485	344.298	344.246	0.053	0.003	0.053
BMCS-20	Flood/Soils	671,400.588	3,449,913.794	167.683	167.612	0.071	0.005	0.071
BMCS-21	Flood/Soils	614,575.568	3,443,012.975	297.195	297.162	0.034	0.001	0.034
BMCS-22	Flood/Soils	602,827.727	3,442,205.263	344.826	344.769	0.057	0.003	0.057
BMCS-23	Flood/Soils	650,357.891	3,448,262.933	199.112	198.995	0.118	0.014	0.118
BMCS-24	Flood/Soils	656,842.364	3,442,728.453	211.587	211.667	-0.079	0.006	0.079

Detailed Comparison Against Survey Checkpoints – Flood/Soils Category								
Point No	**Land Cover Class**	**Survey X Coord.**	**Survey Y Coord.**	**DTM Height**	**Survey - Z**	**ΔZ**	**ΔZ*2**	**ABS ΔZ**
BMCS-25	Flood/Soils	664,084.166	3,445,611.006	182.490	182.530	-0.040	0.002	0.040
BMCS-26	Flood/Soils	624,187.885	3,436,985.800	250.994	250.940	0.054	0.003	0.054
BMCS-27	Flood/Soils	635,153.042	3,440,160.517	218.898	218.936	-0.037	0.001	0.037
BMCS-28	Flood/Soils	608,382.955	3,435,222.722	316.375	316.446	-0.070	0.005	0.070
BMCS-29	Flood/Soils	619,089.176	3,431,977.723	277.537	277.749	-0.212	0.045	0.212
BMCS-30	Flood/Soils	647,141.586	3,436,260.195	152.287	152.329	-0.042	0.002	0.042
BMCS-31	Flood/Soils	668,098.212	3,438,055.048	148.271	148.326	-0.054	0.003	0.054
BMCS-32	Flood/Soils	681,605.697	3,436,918.300	146.778	146.669	0.109	0.012	0.109
BMCS-33	Flood/Soils	674,590.850	3,434,332.723	138.180	138.046	0.135	0.018	0.135
BMCS-34	Flood/Soils	663,288.268	3,430,812.479	160.017	160.090	-0.073	0.005	0.073
BMCS-35	Flood/Soils	653,847.882	3,430,036.751	153.706	153.750	-0.044	0.002	0.044
BMCS-36	Flood/Soils	635,940.046	3,428,003.813	230.680	230.638	0.042	0.002	0.042
BMCS-37	Flood/Soils	591,827.434	3,425,877.785	336.427	336.289	0.139	0.019	0.139
BMCS-38	Flood/Soils	604,388.134	3,423,770.831	317.207	317.161	0.046	0.002	0.046
BMCS-39	Flood/Soils	626,091.449	3,426,020.937	240.836	240.835	0.002	0.000	0.002
BMCS-40	Flood/Soils	642,090.234	3,422,270.670	217.482	217.413	0.070	0.005	0.070
BMCS-41	Flood/Soils	669,181.815	3,422,900.068	158.688	158.753	-0.064	0.004	0.064
BMCS-42	Flood/Soils	659,619.781	3,418,814.014	135.426	135.474	-0.048	0.002	0.048
BMCS-43	Flood/Soils	646,186.501	3,414,679.515	197.617	197.644	-0.026	0.001	0.026
BMCS-44	Flood/Soils	653,409.810	3,407,966.666	166.045	166.127	-0.082	0.007	0.082
BMCS-45	Flood/Soils	634,109.552	3,417,871.286	223.956	223.901	0.055	0.003	0.055
BMCS-46	Flood/Soils	618,592.990	3,421,090.485	257.942	258.037	-0.095	0.009	0.095
BMCS-47	Flood/Soils	598,375.489	3,419,457.290	339.188	338.961	0.227	0.052	0.227
BMCS-48	Flood/Soils	583,936.684	3,421,706.322	367.838	367.911	-0.072	0.005	0.072
BMCS-49	Flood/Soils	577,004.874	3,419,588.861	424.678	424.774	-0.096	0.009	0.096
BMCS-50	Flood/Soils	573,110.984	3,414,629.354	456.993	457.108	-0.115	0.013	0.115
BMCS-51	Flood/Soils	581,324.944	3,414,820.407	398.813	398.676	0.137	0.019	0.137
BMCS-52	Flood/Soils	595,457.513	3,411,815.850	336.362	336.261	0.102	0.010	0.102
BMCS-53	Flood/Soils	572,824.411	3,407,367.833	436.318	436.420	-0.102	0.010	0.102
BMCS-54	Flood/Soils	586,200.236	3,409,170.296	369.329	369.413	-0.084	0.007	0.084
BMCS-55	Flood/Soils	581,023.042	3,402,893.869	430.501	430.659	-0.158	0.025	0.158
BMCS-56	Flood/Soils	567,633.537	3,401,118.677	416.524	416.638	-0.114	0.013	0.114
BMCS-57	Flood/Soils	592,819.511	3,401,731.834	358.144	358.119	0.025	0.001	0.025
BMCS-58	Flood/Soils	585,447.176	3,397,049.081	383.893	383.699	0.195	0.038	0.195
BMCS-59	Flood/Soils	572,841.141	3,397,714.980	357.230	357.390	-0.160	0.026	0.160
BMCS-60	Flood/Soils	561,248.741	3,391,208.191	306.543	306.598	-0.055	0.003	0.055
BMCS-61	Flood/Soils	570,776.678	3,389,602.967	340.192	340.360	-0.168	0.028	0.168
BMCS-62	Flood/Soils	579,130.311	3,398,316.905	380.552	380.543	0.010	0.000	0.010
BMCS-63	Flood/Soils	589,242.335	3,390,121.150	409.865	409.895	-0.029	0.001	0.029
BMCS-64	Flood/Soils	586,286.740	3,385,273.188	374.392	374.430	-0.038	0.001	0.038

Table 20 Detailed comparisons against QA checkpoints for portion of AOI in the flood/soils land cover category

Detailed Statistics for this AOI – Flood/Soils Category	
Geo-referencing	
Horizontal	NAD83, UTM Zone 14
Vertical	NAVD88 (Geoid03), Unless otherwise stated
Units	Meters (Orthometric)

Statistics	
Sum of dz² (cm)	57.096
Count	64
Sum dz2/count (cm)	0.892
RMSE (cm)	9.445
1.96 * RMSE (cm)	0.185
Mean (cm)	18.513
Median (cm)	-3.800
Skew (cm)	39.766
Std. dev. (cm)	9.337
95th percentile (cm)	16.68

RMSE Calculation

Square Root of ∑(Zn-Z'n)²/N

Zn = LiDAR DEM heights

Z'n = Checkpoint heights

N = The number of check points

Accuracy Targets and Results

Land Cover	Target RMSEz (cm) ≤	Target Accuracy (cm) ≤	Actual RMSEz (cm)	95% Conf. Acc Z (cm)	Dz Min (cm)	Dz Max (cm)
Flood/Soils	15.00	29.40	9.45	18.51	-21.15	22.75

Table 21 Detailed statistics for flood/soils land cover category

4.3.4.1 Analysis of the 95th Percentile

No individual checkpoints have errors exceeding the 95th percentile. The 95th percentile method allows for up to 3 points in a dataset of 64 points to exceed the target criterion. Therefore, the LiDAR dataset for this AOI passes the final accuracy assessment test.

Errors Exceeding the 95th Percentile – AOI 1

Land Cover Category	Point Number	Explanation
N/A	N/A	No individual points exceed the 95% percentile

Table 22 Listing of individual errors that exceed the 95th percentile

4.3.4.2 Accuracy Statements

The LiDAR data for Bell, Burnet, Coryell, Falls, Lampasas, and McLennan Counties AOI meets the project specifications, as demonstrated by the following accuracy statements.

1. For the Flood/Soils land cover category, tested 18.51 cm at 95 percent confidence level in open terrain using RMSE * 1.96 and tested 16.68 cm at the 95th percentile method.

4.3.5 Credits

Organizations involved in the procurement, acquisition, processing, and quality control of the Bell, Burnet, Coryell, Falls, Lampasas, and McLennan Counties AOI LiDAR dataset are identified below.

Credits	
Project Function	**Responsible Organization**
LiDAR procurement	Texas Water Development Board
LiDAR acquisition and processing	Photo Science
QA checkpoint ground surveys	Woolpert
Accuracy assessment and QA review and reporting	URS Corporation

Table 23 Credits

4.3.6 References

American Society for Photogrammetry and Remote Sensing (May 2004), *ASPRS Guidelines: Vertical Accuracy Reporting for LiDAR Data*, Version 1.0, http://www.asprs.org/society/committees/lidar/Downloads/Vertical_Accuracy_Reporting_for_Lidar_Data.pdf

Federal Emergency Management Agency (May 2003), *Guidelines and Specifications for Flood Hazard Mapping Partners*, Appendix A: Guidance for Aerial Mapping and Surveying, http://www.fema.gov/pdf/fhm/frm_gsaa.pdf

Federal Geographic Data Committee, Sub Committee for Base Cartographic Data, Geospatial Positioning Accuracy Standards, PART3: National Standard for Spatial Data Accuracy (NSSDA), FGDC-STD-007-1998, http://www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/part3/chapter3

National Digital Elevation Program (May 2004), *Guidelines for Digital Elevation Data*, Version 1.0, http://www.ndep.gov/NDEP_Elevation_Guidelines_Ver1_10May2004.pdf

4.3.7 Horizontal Checks

URS conducted a basic check for horizontal alignment issues in the LiDAR data set by identifying several areas in the AOI with linear features that were visible both in the LiDAR and the 2010 NAIP photography. This was sufficient to check for gross horizontal alignment issues but not accurate enough to check a linear distance as small as 75cm.

URS used the following process:

- Based on a review of the imagery and LiDAR, URS selected several areas containing linear features that could be mapped
- LiDAR intensity images that contained the selected linear features were brought into ArcMap 10
- The 2D linear features were digitized from the LiDAR intensity images
- The resultant shape file was referenced to the 2010 NAIP orthophotography and the general horizontal alignment was verified

The following screenshots (Figures 12 – 14) illustrate one such comparison using tiles 3097_05_4_c and 3197_59_2_c. In this particular case the tiles were selected because they contained a track, an airfield, and well defined cul-de-sacs; all visible in both the 2010 NAIP photography and the LiDAR.

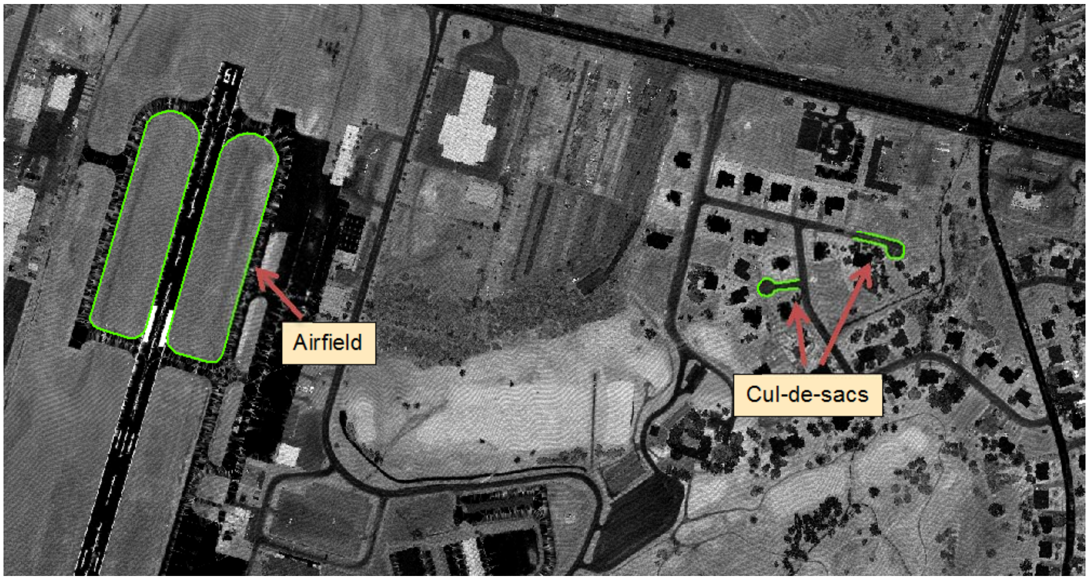


Figure 12 Identification of linear features – tile 3197_59_2_c

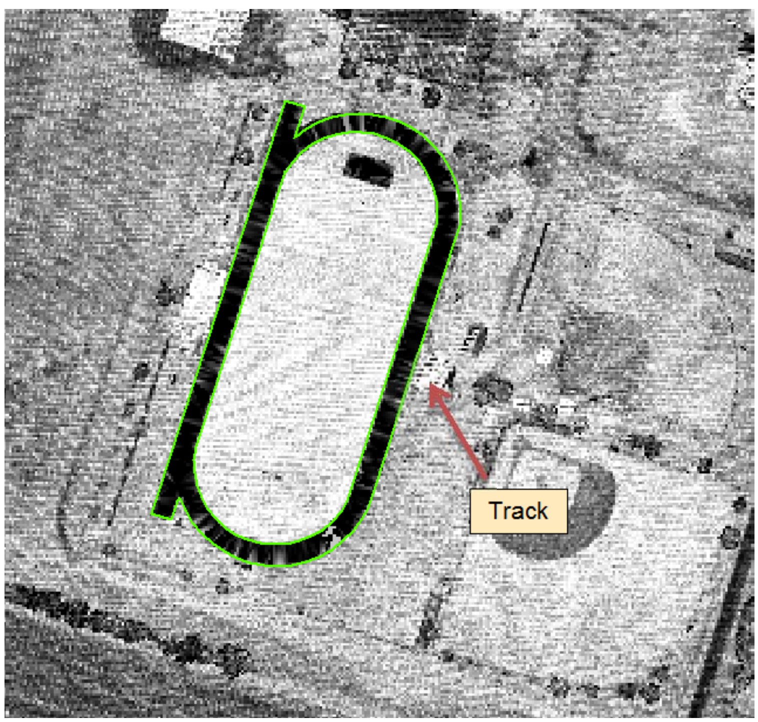


Figure 13 Linear features collected into a shape file using 2D digitizing tile 3097_05_4_c (green lines)

Figure 14 Features compared against NAIP photography

5 Phase IV: Product Development

URS conducted all delivery and redelivery quality checks during Phase III of this project. The remaining tasks for URS during Phase IV involved a check of the project metadata provided by Photo Science and the completion and submission of this report.

5.1 Metadata

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

- Structure of the metadata file was compared against FGDC standards by using the USGS Geospatial Metadata Validation Service: http://geo-nsdi.er.usgs.gov/validation/
- Metadata content was reviewed by using a visual check
- 177 metadata files representing 10% of the files for both AOIs were checked.

No structure issues were found when validating the compliance of the metadata to FGDC standards. Several errors were found in the metadata content for all initial metadata deliverables. These include:

- Breakline
    - Missing UTM Zone information
- Intensity Images
    - Missing UTM Zone information
    - <geoform> listed as “LAS”
- Ground Elevation Model
    - Missing UTM Zone information
- All Return Point Cloud

    - Title formatting did not match other metadata deliverables
    - No significant acquisition or processing details were contained in the All Return Point Cloud metadata
- All metadata deliverables had ".las.xml" as part of their file-naming convention

Metadata deliverables were corrected, redelivered, and verified to no longer contain the issues listed above.

6 Conclusions

A systematic problem related to the point classification scheme used by Photo Science was found in the initial data set delivery during the statistical analysis. The systematic problem, consisting of points classified as Class 12 (overlap), is described in **Section 4.2.5.6** of this report. Photo Science reprocessed and redelivered the data as four separate delivery lots. This, along with the reported sensor malfunctions reported in Photo Science's acquisition report, resulted in the delayed delivery to TNRIS. URS conducted a statistical analysis of all delivery lots and determined that this issue was corrected.

Each delivery lot contained non-systematic problems, also described in **Section 4.2.5.6.** In total, 129 edit calls were identified during the visual inspection of the data. Of the edit calls that required correction, all were addressed over the course of 4 redeliveries. URS subsequently checked the tiles to ensure that the corrections were made.

Based on the qualitative and quantitative assessment conducted by URS on the initial data delivered as well as all redeliveries, the Bell, Burnet, Coryell, Falls, Lampasas, and McLennan Counties AOI delivery meets the applicable project specifications as set forth by HPIDS Project 580-11-1213/Task Order 61-1183895.

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