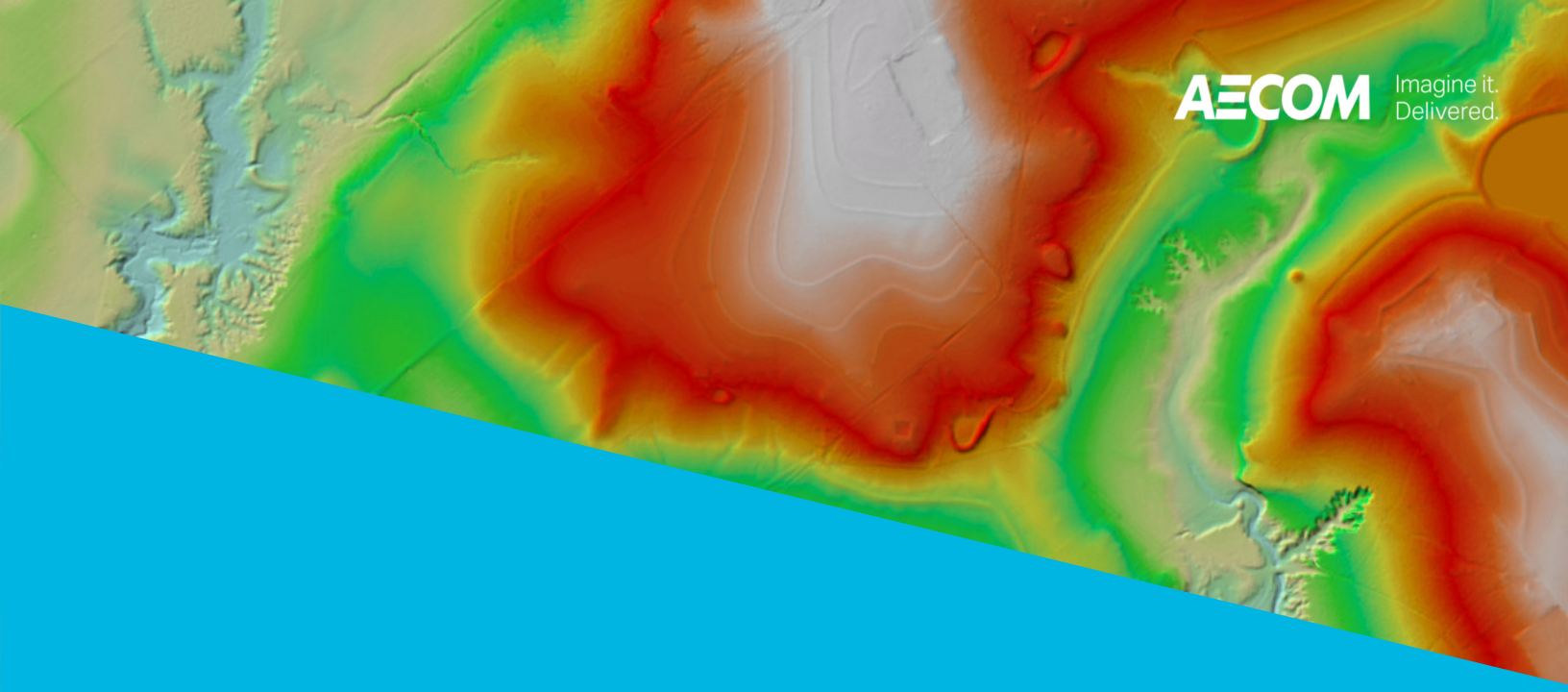


TNRIS Central Texas Final QA Report

LIDAR QA/QC FOR CENTRAL TEXAS
STATEMENT OF WORK #580170806

TEXAS WATER DEVELOPMENT BOARD

Draft Report Submitted December 14, 2017
Final Report Submitted January 5, 2018

Prepared for:

TEXAS WATER DEVELOPMENT BOARD
Joey Thomas
Joey.Thomas@twdb.texas.gov
P.O. Box 13231
Austin, TX 78711-3231
Phone: 512-463-7979
Fax: 512-475-3009

Prepared by:

AECOM Technical Services, Inc.

Table of Contents

1 Overview

The Independent Quality Control for Texas Water Development Board (TWDB) Project 580170806 (Quality Assurance / Quality Control of the Acquisition and Production of Lidar Elevation Data for Central Texas) was performed by AECOM to validate the LiDAR data, and various derivative products, meet project specifications, expectations, and quality.

Project stakeholders included the included the Texas Natural Resources Information System (TNRIS), a part of the Texas Water Development Board (TWDB). Other stakeholders included Williamson County, United States Fish and Wildlife Service (USFWS), City of Austin (COA), and the San Antonio River Authority (SARA).

> *"The project AOI (~6066 square miles) is located in Central Texas around the I-35 corridor from Williamson County to Bexar County. The AOI includes large metropolitan areas as well as various vegetation classifications spanning farmland to dense forest.*
>
> *The data acquired will become part of an ongoing geospatial data collection program by the State of Texas to support regional and local mapping needs".* - from TWDB Project Solicitation #580170806.
>
> An additional 456 mi^2 was appended to the project as part of optional tasks.

USGS Quality Level 2 (QL2) LiDAR specifications are required as a minimum but some aspects of the data will exceed these requirements, most notably, LiDAR pulse density of ≥ 4 pts/m^2 having an RMSE vertical accuracy ≤ 10 cm in Non Vegetated Areas.

LiDAR derivative products included Hydro Breaklines, Hydroflattened DEM rasters, and Intensity rasters.

Data must be processed to meet or exceed TWDB requirements and the referenced ASPRS and USGS specifications.

All project data products were acquired and processed by Fugro Geospatial ("Fugro").

This report covers data deliverables received December 2016 to December 2017.

Listed below are the following review QA aspects, some of which were reported upon in preliminary reports during the course of the project and have been incorporated into this final report for completeness:

- Overview of independent quality control scope of work
- Pre-acquisition planning assessment
- Post-acquisition data assessment
- Vendor production reviews
- Quality control checkpoint survey data
- Assessment practices and methodologies
- Data accuracy assessment
- Conclusions and lessons learned

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

1.1 Independent Quality Control Scope of Work

The following scope of work (SOW) was completed during the project:

Table 1: AECOM – Independent Quality Control Tasks

Phase	Tasks
Phase I **Pre-flight Planning**	1. Participate in Kick-Off Meeting 2. Review timeline and projected milestones 3. Review Fugro's LiDAR flight plans and survey maps 4. Review sensor calibration reports 5. Prepare and submit QA reports
Phase II **Data Acquisition**	1. Collect QA checkpoints 2. Review Flight Trajectories and associated data acquisition reporting files 3. Review Fugro's Survey Report and associated reporting files 4. Prepare and submit QA reports
Phase III **Data Processing**	1. Review LiDAR and derivative datasets including a. Classified point cloud tiles b. Hydroflattened breaklines c. Intensity rasters d. Metadata 3. Review revised data 4. Prepare and submit QA reports
Phase IV **Final Product** **Development**	1. Review Hydroflattened DEM rasters and metadata 2. Review revised datasets 3. Prepare and submit QA reports 3. Prepare and submit Final QA report

1.2 Project Area and Deliverables Received

The project area for this task order consisted of two AOI's covering ~6,522 mi^2 in Central Texas.

Northern AOI = "La Grange" AOI
Southwestern AOI – "San Antonio" AOI

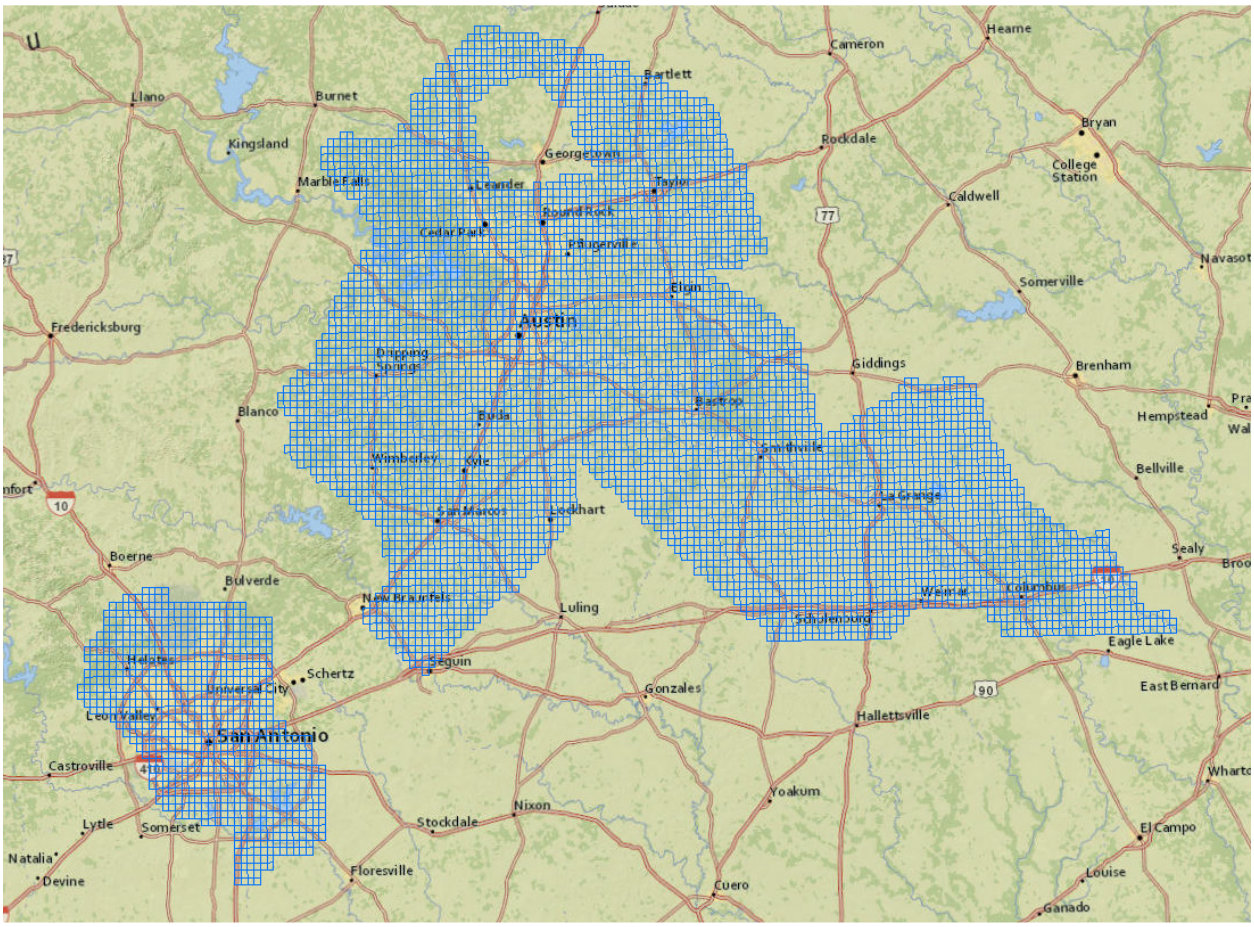


Figure 1 – TNRIS Central Texas Areas of Interest

Deliverables were received in the following formats in UTM Zone 14, NAD83 (2011), NAVD88 (Geoid 12B), Meters.

Table 2: Data Deliverables Received

Deliverable	San Antonio	La Grange
LiDAR files in .LAS v1.4 format	Y	Y
Hydroflattened Bare Earth DEM files in .IMG format	Y	Y
LiDAR intensity images in GeoTIF/TFW format	Y	Y
LiDAR, DEM-Intensity Tile layouts in ESRI SHP format	Y	Y
3D Breaklines in ESRI Geodatabase format	Y	Y
Project and Tile level metadata in XML format	Y	Y

1.3 Applicable Specifications & Guidelines

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

A. TWDB/TNRIS SOW - SM_580170806_QAQC_Central_Texas.pdf
B. American Society for Photogrammetry and Remote Sensing. 2013. ASPRS Accuracy Standards for Digital Geospatial Data. Photogrammetric Engineering & Remote Sensing 79, no. 12: 1073-1085.
C. American Society for Photogrammetry & Remote Sensing. ASPRS Guidelines Vertical Accuracy Reporting for Lidar Data. 24 May 2004. http://www.asprs.org/a/society/committees/lidar/Downloads/Vertical_Accuracy_Reporting_for_Lidar_Data.pdf
D. American Society for Photogrammetry & Remote Sensing. LAS Specification Version 1.4-R6. 10 June 2012. http://www.asprs.org/a/society/committees/standards/LAS_1_4_r12.pdf
E. Federal Geographic Data Committee. Geospatial Positioning Accuracy Standards Part 3: National Standard for Spatial Data Accuracy. 1998. http://www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/part3/chapter3
F. Maune, David F. Digital Elevation Model Technologies and Applications: The DEM Users Manual, 2nd Edition. 2007.
G. Maune, David F. FEMA's Mapping and Surveying Guidelines and Specifications. 2003. http://w.psadewberry.com/Libraries/Documents/FEMAs_Mapping_and_Surveying_Guidelines_and_Specifications_ASPRSFall2003.pdf
H. National Digital Elevation Program. Guidelines for Digital Elevations Data (Version 1.0). 10 May 2004. http://www.ndep.gov/NDEP_Elevation_Guidelines_Ver1_10May2004.pdf
I. The National Geodetic Survey. The NGS Geoid Page. 11 September 2012. http://www.ngs.noaa.gov/GEOID/

2 Phase I: Pre-flight Planning Review

During the Kick-Off meeting between the project stakeholders and Fugro AECOM reviewed project QA specifications that will be employed and responded to questions. Subsequent to the Kick-Off meeting AECOM utilized previous established Phase I review procedures to provide reporting on quality control tasks.

For Phase I (Pre-Flight Planning Phase), AECOM conducted a review of the proposed flight operations and plan files submitted by Fugro 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 location
- Calibration plans
- Schedule
- Terrain consideration
- Quality procedures
- Planned scan set (sensor settings)
- Type of aircraft
- Procedure for re-flights
- 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 and processing tasks of the project.

2.1 Aerial Acquisition Pre-flight Planning Review

For the purpose of this review, Fugro provided AECOM with planned flight lines and ground control locations, base station locations, sensor settings, and field calibration plans.

A review was conducted to validate aerial acquisition flight planning and reporting requirements in accordance with Project 580170806 SOW. AECOM sent clarifying questions to Fugro, the responses to which were deemed acceptable.

The overall control layout, including QC checkpoints, acquisition base stations, and nearest CORS stations was reviewed by AECOM to ensure adequate project coverage and distribution of points.

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

Table 3: Pre-flight Planning Review

Items Reviewed	Meets Specifications
Planned lines – sufficient coverage, spacing, and length	Yes
Planned GPS basestations – collecting at 1 Hz, at least 2 in range of all missions (baseline 40 km or less)	See section 3.2
Planned ground control – sufficient to control and boresight	Yes
Planned airports – within reasonable distance of AOI	Yes
Schedule	Yes
Quality procedures	Yes
Aircraft utilizes ABGPS at 2 Hz	Yes
Sensor parameters support project design pulse density	Yes
Type of aircraft – supports project design parameters	Yes
Re-flight procedure – tracking, documenting, processing	Yes
Project design supports accuracy requirements of project	Yes
Project design accounts for land cover and terrain types	Yes
Aerial Acquisition Report	Yes

2.2 QA Checkpoint Survey Plan Review

The ground survey layout for the QA checkpoints was developed by AECOM referencing USGS and ASPRS specifications with respect to distribution and vegetative cover. An accuracy requirement of 1.67 cm $RMSE_z$ (3.3 cm CE95) was required.

Publically available aerial imagery was referenced to confirm that control point locations were accessible and to ensure that the locations chosen conformed to project specifications and guidelines.

CompassData, working as a subcontractor to AECOM, executed the field survey.

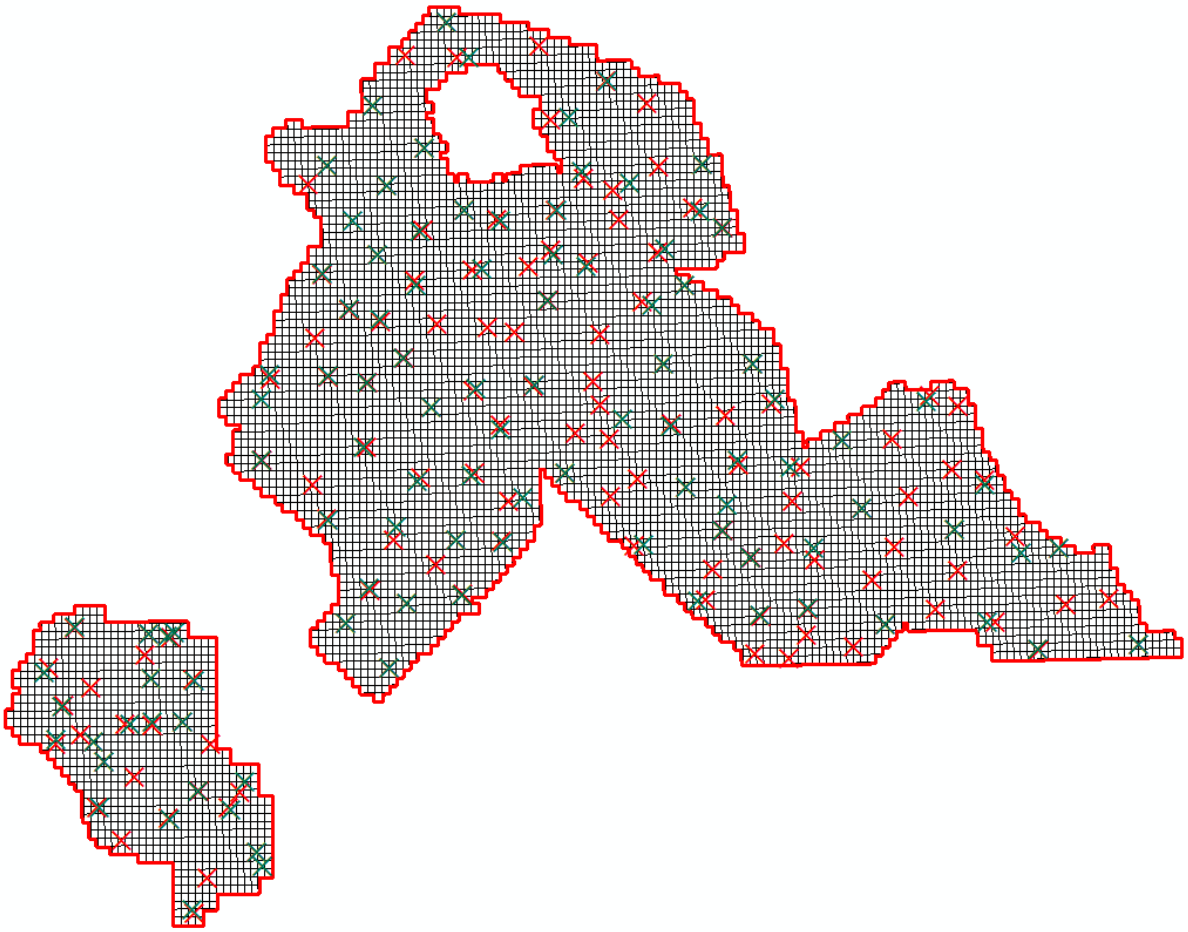


Figure 2 – AECOM QA Checkpoint Plan
(San Antonio AOI Lower Left, La Grange AOI Upper Right)

A total of 142 NVA and 103 VVA checkpoints were established across both AOIs.

- NVA and VVA checkpoints supported the vertical accuracy assessments of the LiDAR and DEM datasets.
- Five NVA checkpoints served a dual purpose as horizontal accuracy assessment of the San Antonio AOI. Sixteen NVA checkpoints served a dual purpose as horizontal accuracy assessment of the La Grange AOI.

3 Phase II: Data Acquisition Review

The following quality control actions were performed after the aerial acquisition of the LiDAR data.

3.1 Post-flight: Aerial Acquisition Review

Following the aerial acquisition of the LiDAR data Fugro provided AECOM with trajectory files as well as a variety of other related data files associated with the LiDAR acquisition effort.

The trajectory data captured from the aircraft's GPS, collected at 2 second intervals, were compared against the planned flight plans. A comparison of the planned flight lines and trajectories as they we flown are below. The as-flown data aligned well with the planned datasets.

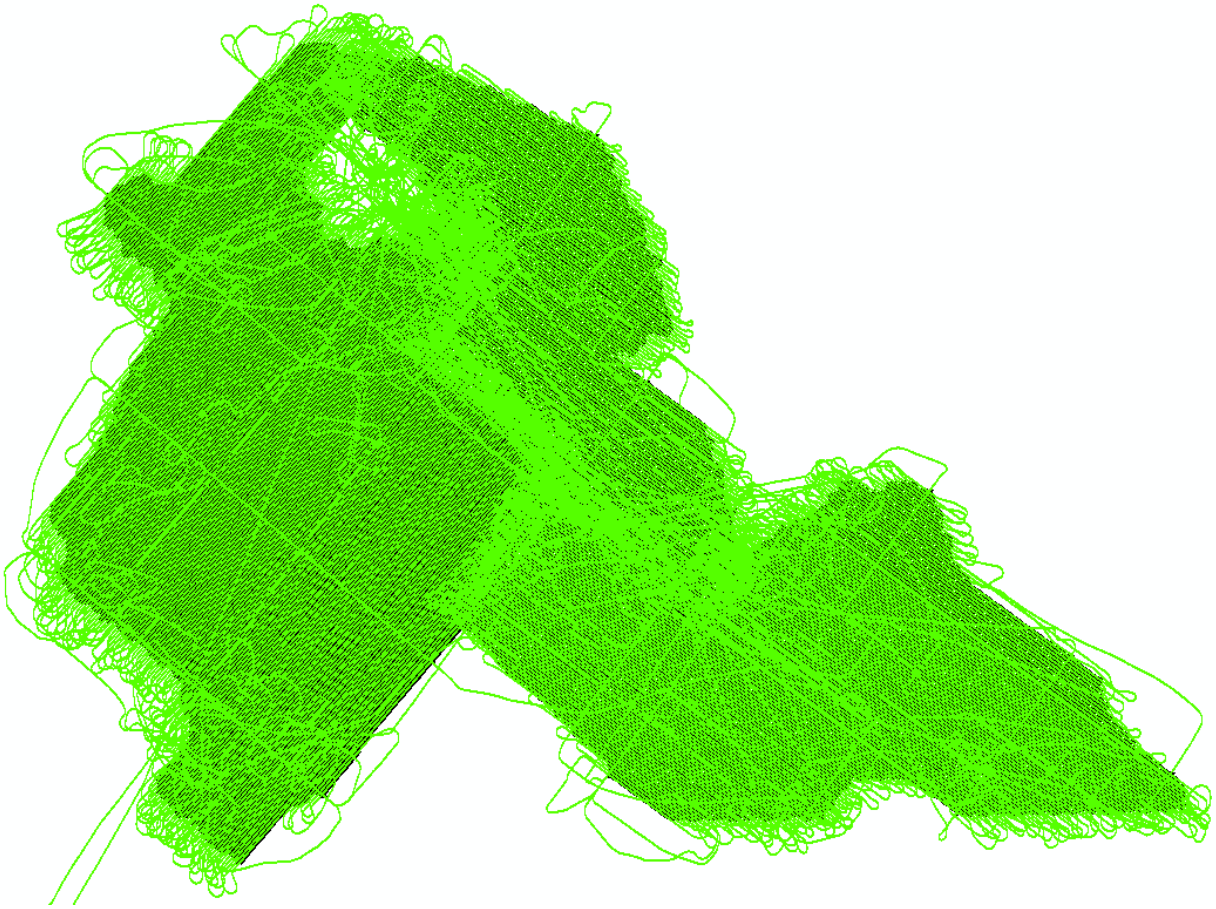


Figure 3 – La Grange Block LiDAR Planned Flight lines (Black) overlaid Trajectories (Green)

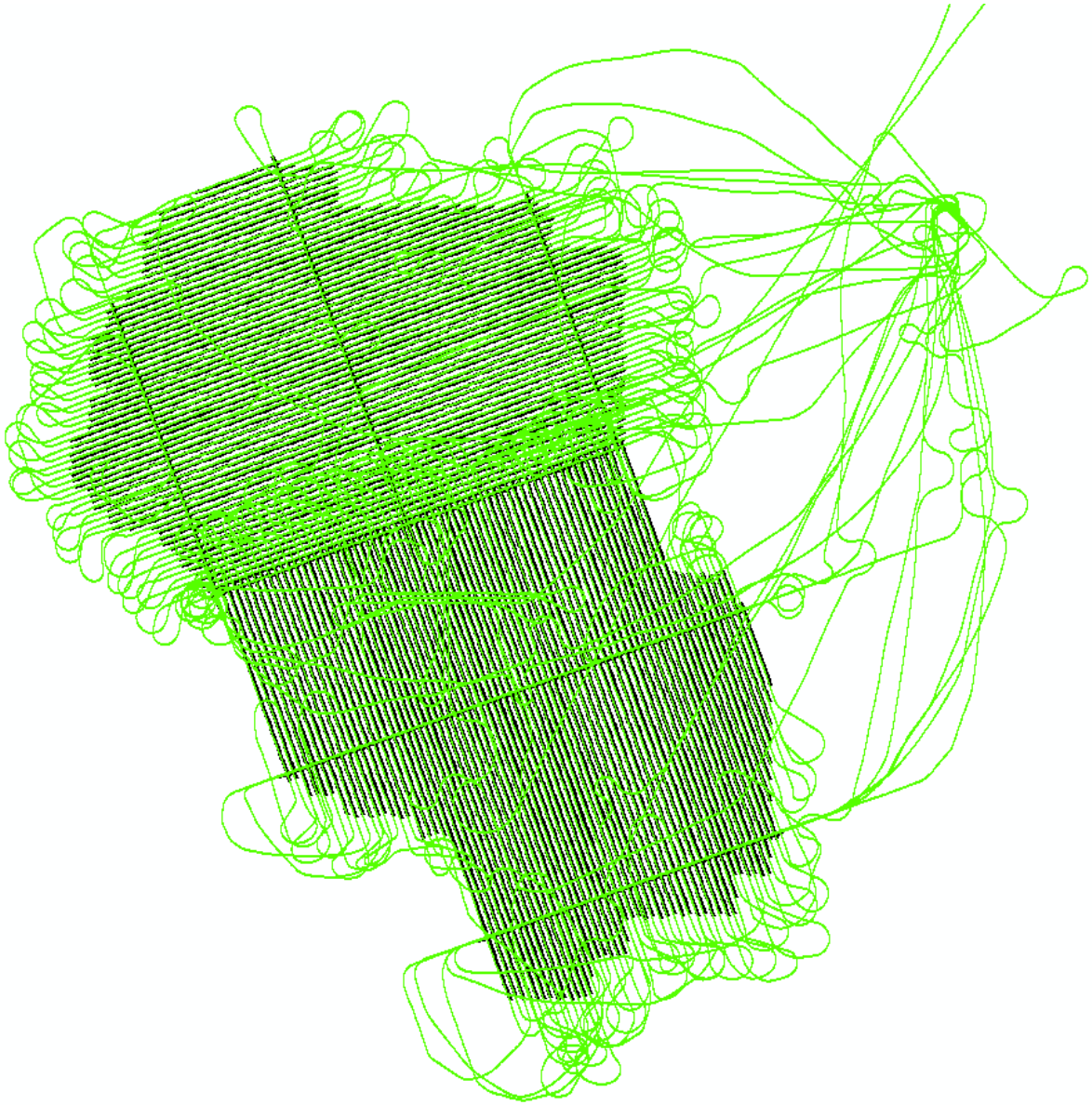


Figure 4 – San Antonio Block LiDAR Planned Flight lines (Black) overlaid Trajectories (Green)

GNSS Plot Reviews

- Number of satellites tracked during acquisition altitude exceeded 6 satellites.
- There were instances where PDOP exceeded 4.0 however these instances were outside the on-line data acquisition window.
- Supporting flight logs and ancillary documentation suggested data acquisition met specifications.

Data acquisition status updates

- Fugro provided daily acquisition updates via the TNRIS project email thread system from acquisition commencement to completion.

Note: As part of Fugro's internal checks a concern was discovered where the level of swath overlap may be too low. As result Fugro flew additional swaths over the section of San Antonio where there were taller structures in an effort of ensure no LiDAR shadows persisted in the final data. Graphics of the additional sortie is presented below in cyan.

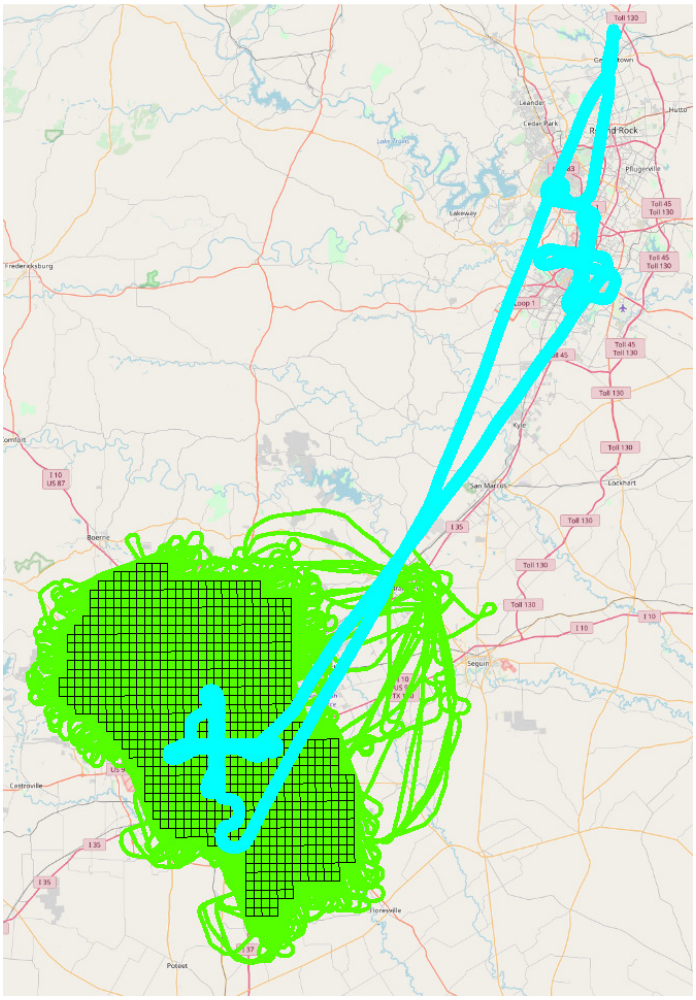


Figure 5 – Reflight required to mitigate narrow swath overlap

3.2 Post-flight: Ground Control Review

Fugro provided a detailed survey report identifying the control network used and the spatial parameters associated with the control network.

It was noted the baseline distances of the control points exceeded 40 km in some instances. AECOM queried Fugro how frequently Fugro utilized control points with similar baselines. Fugro indicated that utilizing control derived from similar baselines was part of their common procedures and Fugro has not encountered accuracy issues in the past. Fugro sent inquires to Gorrondona if there were any concerns regarding the baseline lengths reported and the control meeting the accuracy of the data. Gorrondona indicated confidence in the accuracy of the data meeting project requirements. The reported estimated accuracy of the adjusted coordinates is ±0.005m at CE95.

Within the GPS Data Processing table, “H. Precision (95%)” and “V. Precision (95%)” refer to the Horizontal and Vertical precision estimates (sphere of uncertainty) of the GPS vectors at a 95% confidence level. The estimate accuracy was generated by Trimble Business Center, the software that was used for processing their survey field data.

Fugro’s control report included tabular data in XLS, CSV, and SHP format containing coordinate and elevation information to 3 decimal places in the project spatial reference framework. Land cover type descriptions were also included for each point, as were images of each survey point.

Survey points were evenly spaced, well dispersed, and closely mimics the planned control point locations, as can be seen in the graphics below.

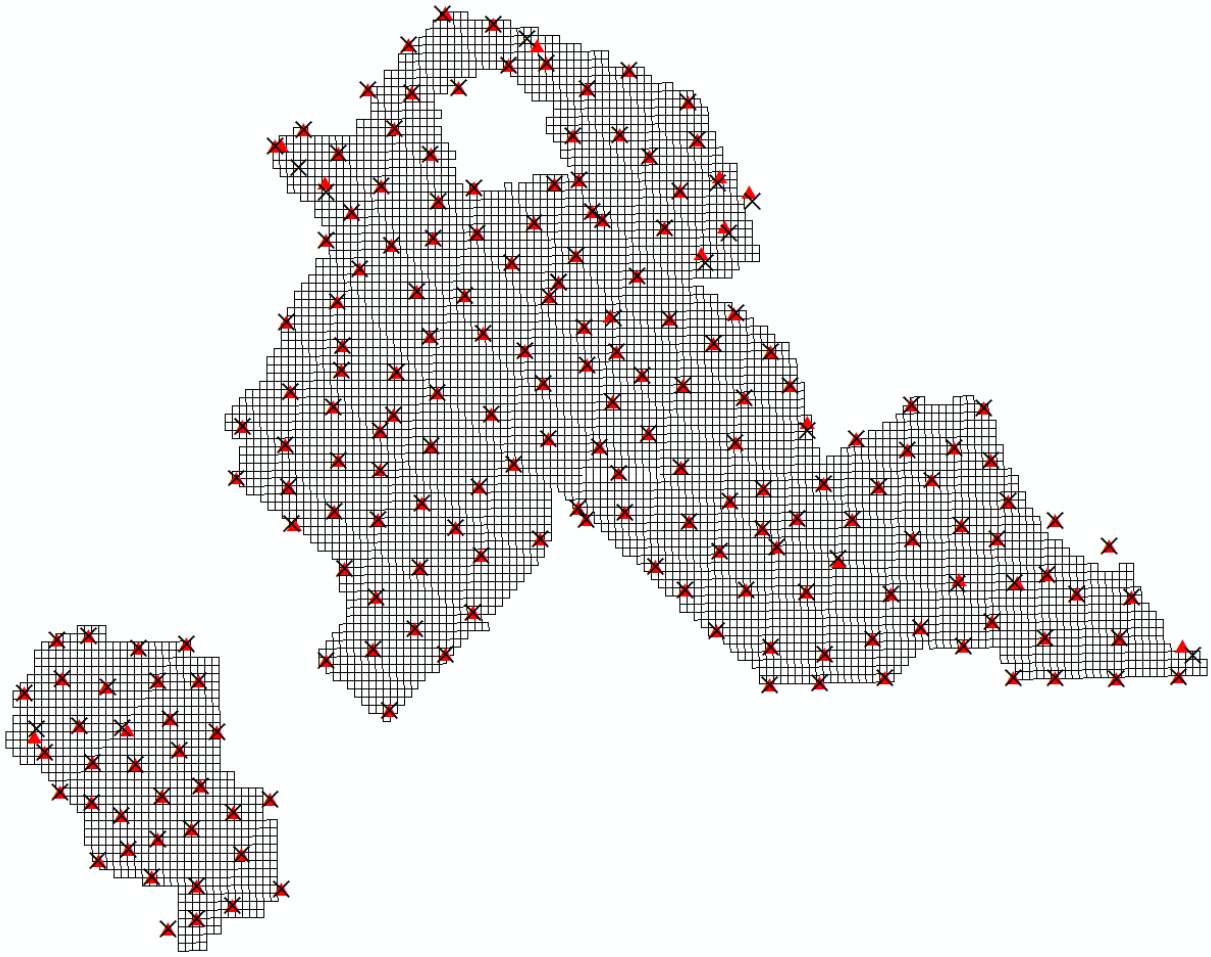


Figure 6 - Fugro LiDAR Planned Control Locations (X) and Actual Control Locations (▲)

3.3 Review & Delivery of QA Checkpoint Survey

During the planning and establishment of QA checkpoints, AECOM and CompassData frequently coordinated regarding status. CompassData completed survey field work on January 2017.

A total of 142 NVA and 103 VVA checkpoints were established across both AOIs.

- NVA and VVA checkpoints supported the vertical accuracy assessments of the LiDAR and DEM datasets.
- Five NVA checkpoints served a dual purpose as horizontal accuracy assessment of the San Antonio AOI. Sixteen NVA checkpoints served a dual purpose as horizontal accuracy assessment of the La Grange AOI.

AECOM reviewed all pertinent documentation submitted by CompassData at the conclusion of the field collection of the QA checkpoints. Reported QA point locations were verified against project specifications and control plan layouts. All survey related documentation was then delivered to TNRIS February 2017.

Table 4: Vertical Checkpoint Types and Coordinates
UTMZ14 NAD83(2011) Geoid12B Meters

AOI	Check Point Type	Ground Cover	Point ID	X	Y	Z
San Antonio	NVA	Asphalt	NVA002	533142.658	3286736.101	394.403
San Antonio	NVA	Asphalt	NVA003	529073.871	3261348.155	276.669
San Antonio	NVA	Asphalt	NVA004	556742.164	3266202.699	223.617
San Antonio	NVA	Asphalt	NVA005	569197.415	3250753.811	176.402
San Antonio	NVA	Asphalt	NVA006	543323.578	3240396.991	176.516
San Antonio	NVA	Asphalt	NVA007	572839.358	3237768.343	184.898
San Antonio	NVA	Concrete	NVA008	559143.266	3224531.285	186.897
San Antonio	NVA	Asphalt	NVA009	560263.456	3251066.983	191.581
San Antonio	NVA	Asphalt	NVA010	536641.225	3273571.713	311.457
San Antonio	NVA	Asphalt	NVA011	554026.224	3284558.487	349.878
San Antonio	NVA	Asphalt	NVA012	527507.713	3277932.96	411.585
San Antonio	NVA	Gravel	NVA013	558986.42	3275398.272	271.854
San Antonio	NVA	Asphalt	NVA014	544111.742	3265628.051	256.416
San Antonio	NVA	Asphalt	NVA015	539486.26	3257375.768	225.705
San Antonio	NVA	Asphalt	NVA016	549832	3275556.247	287.167
San Antonio	NVA	Gravel	NVA017	561990.049	3232306.42	135.024
San Antonio	NVA	Asphalt	NVA018	553748.007	3245190.261	173.138
San Antonio	NVA	Asphalt	NVA019	530808.31	3269714.385	301.354
San Antonio	NVA	Asphalt	NVA020	549203.345	3285338.511	378.535
San Antonio	NVA	Asphalt	NVA021	566730.249	3247572.448	179.466
San Antonio	NVA	Asphalt	NVA022	537929.564	3247556.925	214.505
San Antonio	NVA	Asphalt	NVA023	537309.551	3261847.316	254.312
San Antonio	NVA	Asphalt	NVA024	550130.14	3265497.909	232.5
San Antonio	NVA	Asphalt	NVA143	548526.941	3280855.225	344.539
San Antonio	NVA	Asphalt	NVA144	534336.909	3263368.764	255.849
San Antonio	NVA	Asphalt	NVA145	546196.835	3254178.353	199.996
San Antonio	NVA	Asphalt	NVA146	562703.373	3261225.25	230.379
San Antonio	VVA	Mixed grass	VVA001	533113.768	3286812.996	392.053
San Antonio	VVA	Short grass/Trees	VVA002	529201.394	3262378.358	260.832
San Antonio	VVA	Mixed grass	VVA004	574050.342	3234712.973	167.187

San Antonio	VVA	Mixed grass	VVA005	570159.591	3253051.732	181.722
San Antonio	VVA	Short grass	VVA006	556684.985	3266164.65	222.706
San Antonio	VVA	Mixed grass/Shrubs	VVA007	559147.313	3275021.792	276.784
San Antonio	VVA	Mixed grass/Trees	VVA008	549868.869	3275529.87	288.311
San Antonio	VVA	Short grass/Shrub/Trees	VVA010	553931.908	3245083.894	169.683
San Antonio	VVA	Short grass/Trees	VVA011	549233.434	3285389.717	379.707
San Antonio	VVA	Mixed grass	VVA012	553331.411	3284743.616	351.428
San Antonio	VVA	Mixed grass	VVA013	567107.497	3247019.295	174.668
San Antonio	VVA	Mixed grass/Trees	VVA014	572773.539	3237878.909	190.419
San Antonio	VVA	Mixed grass/Shrubs	VVA015	560036.244	3251002.255	187.548
San Antonio	VVA	Mixed grass	VVA016	558723.609	3225268.113	181.589
San Antonio	VVA	Short grass	VVA018	554838.44	3285669.344	369.718
San Antonio	VVA	Shrubs/Trees	VVA019	526438.915	3276855.878	384.579
San Antonio	VVA	Mixed grass/Trees	VVA020	545136.22	3265683.153	262.135
San Antonio	VVA	Shrubs/Trees	VVA021	539549.206	3257435.528	225.865
San Antonio	VVA	Shrubs/Trees	VVA022	530346.744	3269629.641	304.098
San Antonio	VVA	Shrubs/Trees	VVA023	538536.933	3247589.681	218.706
San Antonio	VVA	Shrubs/Trees	VVA024	549951.23	3266260.186	238.712
San Antonio	VVA	Mixed Grass	VVA025	537303.45	3261870.831	253.347
La Grange	NVA	Gravel	NVA026	627797.863	3314132.414	175.118
La Grange	NVA	Asphalt	NVA027	601740.836	3278043.767	167.703
La Grange	NVA	Asphalt	NVA028	592235.113	3287593.959	197.347
La Grange	NVA	Asphalt	NVA030	608549.973	3319397.455	222.939
La Grange	NVA	Asphalt	NVA031	620023.37	3338326.383	164.843
La Grange	NVA	Gravel	NVA032	587117.896	3363635.371	250.66
La Grange	NVA	Asphalt	NVA033	575791.906	3340715.433	404.293
La Grange	NVA	Asphalt	NVA034	625845.634	3330753.07	176.618
La Grange	NVA	Asphalt	NVA035	597000.997	3340119.987	349.635
La Grange	NVA	Asphalt	NVA036	612039.944	3352847.315	265.031
La Grange	NVA	Asphalt	NVA037	619763.388	3364581.599	235.178
La Grange	NVA	Asphalt	NVA038	599859.505	3353423.233	279.857
La Grange	NVA	Asphalt	NVA039	609185.102	3373313.099	305.122
La Grange	NVA	Asphalt	NVA040	626205.446	3305571.428	165.543
La Grange	NVA	Gravel	NVA041	588387.695	3341373.652	367.94
La Grange	NVA	Gravel	NVA043	617719.738	3293948.092	138.364
La Grange	NVA	Asphalt	NVA044	605614.658	3291992.608	172.056
La Grange	NVA	Asphalt	NVA045	610811.225	3334561.89	209.449
La Grange	NVA	Asphalt	NVA046	574021.885	3323217.919	331.096
La Grange	NVA	Asphalt	NVA047	588114.268	3310280.613	312.219
La Grange	NVA	Asphalt	NVA049	623020.603	3352094.332	187.217
La Grange	NVA	Asphalt	NVA050	620294.458	3320388.076	181.143
La Grange	NVA	Asphalt	NVA051	596708.591	3326092.933	286.209
La Grange	NVA	Asphalt	NVA053	585516.114	3349791.746	405.181

La Grange	NVA	Gravel	NVA054	616269.045	3305755.528	187.816
La Grange	NVA	Gravel	NVA056	604882.375	3345325.471	326.155
La Grange	NVA	Asphalt	NVA057	599134.457	3367895.418	271.769
La Grange	NVA	Asphalt	NVA058	632965.991	3339213.294	149.262
La Grange	NVA	Asphalt	NVA059	585165.502	3317791.448	295.249
La Grange	NVA	Asphalt	NVA060	597539.726	3294753.69	188.881
La Grange	NVA	Asphalt	NVA061	592972.431	3355978.048	289.557
La Grange	NVA	Asphalt	NVA062	611939.628	3300338.173	160.043
La Grange	NVA	Asphalt	NVA147	607198.079	3362265.359	234.836
La Grange	NVA	Asphalt	NVA149	602790.774	3305768.884	175.808
La Grange	NVA	Asphalt	NVA150	629089.619	3351073.533	150.542
La Grange	NVA	Asphalt	NVA063	638030.199	3377655.228	186.505
La Grange	NVA	Asphalt	NVA064	625049.838	3375528.889	226.484
La Grange	NVA	Asphalt	NVA066	648961.455	3405721.585	182.37
La Grange	NVA	Gravel	NVA067	614252.069	3418412.388	294.405
La Grange	NVA	Asphalt	NVA068	605227.022	3411355.509	338.971
La Grange	NVA	Gravel	NVA069	598000.18	3400269.899	324.776
La Grange	NVA	Gravel	NVA070	656821.882	3357568.465	173.408
La Grange	NVA	Asphalt	NVA071	669936.219	3387506.04	142.351
La Grange	NVA	Asphalt	NVA072	634491.515	3413414.282	267.145
La Grange	NVA	Gravel	NVA074	636312.987	3357891.172	162.175
La Grange	NVA	Gravel	NVA075	657764.86	3400789.892	158.293
La Grange	NVA	Asphalt	NVA076	667919.677	3378226.46	138.737
La Grange	NVA	Asphalt	NVA077	645127.154	3366199.043	168.54
La Grange	NVA	Asphalt	NVA078	601152.837	3382961.608	279.589
La Grange	NVA	Gravel	NVA079	584038.856	3383100.953	287.964
La Grange	NVA	Asphalt	NVA080	660216.991	3368366.877	170.065
La Grange	NVA	Gravel/Asphalt	NVA081	666047.593	3361329.053	162.524
La Grange	NVA	Asphalt	NVA082	636926.927	3397234.569	233.333
La Grange	NVA	Gravel	NVA083	609279.803	3391031.096	297.961
La Grange	NVA	Gravel	NVA084	674401.56	3373688.3	147.496
La Grange	NVA	Asphalt	NVA085	660375.979	3386936.276	177.168
La Grange	NVA	Asphalt	NVA086	636998.185	3368859.429	197.902
La Grange	NVA	Asphalt	NVA087	617917.652	3377503.566	270.725
La Grange	NVA	Asphalt	NVA089	644088.52	3384425.718	183.466
La Grange	NVA	Gravel	NVA090	588192.284	3387232.551	346.486
La Grange	NVA	Asphalt	NVA091	647689.195	3350428.037	143.39
La Grange	NVA	Asphalt	NVA092	651727.078	3375565.884	169.637
La Grange	NVA	Asphalt	NVA151	616430.503	3410748.134	291.145
La Grange	NVA	Asphalt	NVA153	632013.851	3365306.877	218.376
La Grange	NVA	Asphalt	NVA154	650476.504	3382055.908	164.046
La Grange	NVA	Asphalt	NVA093	682765.928	3289073.474	121.827
La Grange	NVA	Asphalt	NVA094	689453.822	3314173.654	103.903

La Grange	NVA	Asphalt	NVA095	677736.466	3322065.36	94.063
La Grange	NVA	Asphalt	NVA096	663360.63	3331198.575	139.74
La Grange	NVA	Gravel	NVA097	680779.369	3344019.253	168.269
La Grange	NVA	Asphalt	NVA098	661483.827	3344059.46	135.135
La Grange	NVA	Asphalt	NVA101	674381.465	3307798.834	124.292
La Grange	NVA	Asphalt	NVA102	646243.369	3340279.205	123.594
La Grange	NVA	Asphalt	NVA103	655779.2	3318973.196	144.378
La Grange	NVA	Asphalt	NVA104	694353.811	3301354.524	116.966
La Grange	NVA	Gravel	NVA105	655102.355	3304569.808	163.504
La Grange	NVA	Gravel	NVA106	642187.361	3329077.323	135.653
La Grange	NVA	Asphalt	NVA107	691462.372	3321515.254	99.244
La Grange	NVA	Asphalt	NVA108	681269.856	3281119.087	171.49
La Grange	NVA	Gravel	NVA109	680578.988	3302050.768	118.069
La Grange	NVA	Asphalt	NVA110	639948.039	3320251.821	161.919
La Grange	NVA	Asphalt	NVA111	666260.35	3317198.045	133.643
La Grange	NVA	Asphalt	NVA112	672178.912	3299274.697	133.769
La Grange	NVA	Gravel	NVA113	674913.496	3332753.115	149.223
La Grange	NVA	Asphalt	NVA114	692785.504	3290766.465	112.165
La Grange	NVA	Gravel	NVA115	687702.508	3305024.626	106.3
La Grange	NVA	Gravel	NVA116	649793.334	3327855.471	147.791
La Grange	NVA	Gravel	NVA117	670563.499	3292871.418	111.099
La Grange	NVA	Asphalt	NVA118	684982.732	3335550.696	133.878
La Grange	NVA	Asphalt	NVA119	688840.927	3280023.106	144.306
La Grange	NVA	Asphalt	NVA155	692640.566	3285120.686	112.779
La Grange	NVA	Asphalt	NVA157	650020.32	3315288.207	148.015
La Grange	NVA	Asphalt	NVA158	647719.644	3335235.303	162.007
La Grange	NVA	Gravel	NVA100	700219.106	3327575.721	113.298
La Grange	NVA	Asphalt	NVA120	709845.857	3287332.87	102.704
La Grange	NVA	Gravel	NVA122	758549.53	3292900.487	70.091
La Grange	NVA	Gravel	NVA123	764957.121	3283086.166	52.053
La Grange	NVA	Asphalt	NVA124	704545.337	3312648.513	107.033
La Grange	NVA	Gravel	NVA125	702933.022	3282603.342	107.708
La Grange	NVA	Gravel	NVA126	731462.466	3318784.491	129.836
La Grange	NVA	Asphalt	NVA127	725523.89	3335032.426	154.388
La Grange	NVA	Gravel	NVA128	719488.681	3337137.894	134.111
La Grange	NVA	Gravel	NVA129	725611.654	3299128.136	89.438
La Grange	NVA	Gravel	NVA130	724267.232	3321181.584	97.623
La Grange	NVA	Asphalt	NVA132	711720.763	3304333.813	72.66
La Grange	NVA	Gravel	NVA133	747433.861	3303882.955	100.905
La Grange	NVA	Asphalt	NVA135	743221.18	3281845.569	63.121
La Grange	NVA	Asphalt	NVA136	724895.002	3308100.453	116.272
La Grange	NVA	Asphalt	NVA137	706931.322	3297132.599	122.011
La Grange	NVA	Asphalt	NVA138	749141.519	3291765.001	87.31

La Grange	NVA	Gravel	NVA139	714844.822	3315295.593	135.466
La Grange	NVA	Asphalt	NVA140	711219.079	3327667.049	134.939
La Grange	NVA	Asphalt	NVA141	720691.322	3290651.944	107.339
La Grange	NVA	Gravel/Asphalt	NVA142	733655.792	3288029.955	71.178
La Grange	NVA	Asphalt	NVA161	738141.163	3306507.748	110.189
La Grange	VVA	Short grass	VVA026	626459.363	3305317.1	163.161
La Grange	VVA	Mixed grass	VVA027	573759.529	3336537.949	400.899
La Grange	VVA	Mixed grass/Trees	VVA028	573938.522	3323116.83	331.197
La Grange	VVA	Mixed grass	VVA029	588268.615	3310256.646	308.722
La Grange	VVA	Mixed grass/Trees	VVA030	595950.768	3325902.964	293.604
La Grange	VVA	Short grass/Trees	VVA031	620673.719	3338772.652	162.348
La Grange	VVA	Short grass/Trees	VVA032	621889.367	3364823.252	239.645
La Grange	VVA	Mixed grass	VVA033	607590.101	3361112.733	282.132
La Grange	VVA	Mixed grass/Shrubs	VVA034	599162.13	3367880.503	271.884
La Grange	VVA	Shrubs/Trees	VVA035	603191.222	3308539.398	199.524
La Grange	VVA	Mixed grass	VVA036	616217.733	3305828.177	186.723
La Grange	VVA	Short grass	VVA037	605592.108	3291957.667	170.842
La Grange	VVA	Shrubs/Trees	VVA038	599627.56	3353898.254	308.013
La Grange	VVA	Shrubs	VVA040	630697.403	3314871.311	163.996
La Grange	VVA	Mixed grass/Trees	VVA041	608274.91	3372894.495	325.321
La Grange	VVA	Mixed grass/Shrubs	VVA042	633398.955	3339546.483	151.902
La Grange	VVA	Short grass	VVA043	610799.167	3334542.134	209.816
La Grange	VVA	Short grass	VVA045	601760.802	3278029.078	168.219
La Grange	VVA	Short grass	VVA046	592253.714	3287692.322	196.374
La Grange	VVA	Mixed grass/Shrubs	VVA047	607677.948	3318642.445	233.312
La Grange	VVA	Mixed grass	VVA049	587108.006	3363721.38	252.518
La Grange	VVA	Mixed grass/Shrubs	VVA050	575681.171	3341773.661	399.117
La Grange	VVA	Short grass	VVA051	625905.757	3329700.936	192.601
La Grange	VVA	Mixed grass/Shrubs	VVA052	596842.028	3340070.605	353.242
La Grange	VVA	Short grass	VVA054	617449.183	3293692.602	133.954
La Grange	VVA	Short grass	VVA056	619560.592	3319942.902	183.576
La Grange	VVA	Mixed grass/Trees	VVA057	604820.239	3345317.91	326.012
La Grange	VVA	Short grass	VVA059	597367.769	3295293.799	191.39
La Grange	VVA	Shrubs	VVA060	592952.265	3356009.871	289.454
La Grange	VVA	Mixed grass/Trees	VVA061	588376.648	3341438.753	368.308
La Grange	VVA	Shrubs/Trees	VVA062	666077.857	3361331.256	162.066
La Grange	VVA	Short grass	VVA063	674351.765	3373685.076	147.303
La Grange	VVA	Mixed grass/Trees	VVA064	597960.968	3400291.713	323.07
La Grange	VVA	Short grass	VVA065	593702.809	3375190.54	212.909
La Grange	VVA	Short grass	VVA066	644681.641	3365342.695	161.587
La Grange	VVA	Mixed grass	VVA067	601174.193	3382921.293	279.217
La Grange	VVA	Shrubs/Trees	VVA068	609219.154	3391049.972	297.044
La Grange	VVA	Mixed grass	VVA069	640797.636	3397662.555	225.399

La Grange	VVA	Short grass	VVA070	625835.976	3375250.029	228.019
La Grange	VVA	Mixed grass	VVA071	654169.106	3383477.141	172.232
La Grange	VVA	Mixed grass	VVA073	649065.454	3405659.476	181.872
La Grange	VVA	Short grass	VVA074	669994.701	3387430.926	140.061
La Grange	VVA	Mixed grass/Trees	VVA075	638196.126	3377695.263	182.474
La Grange	VVA	Mixed grass/Shrubs	VVA076	614217.709	3418468.916	291.973
La Grange	VVA	Shrubs	VVA077	658869.626	3357004.195	167.414
La Grange	VVA	Shrubs	VVA078	636247.553	3357916	165.595
La Grange	VVA	Short grass	VVA080_ALT	669459.799	3377457.369	154.288
La Grange	VVA	Short grass	VVA081	661625.262	3369264.224	173.687
La Grange	VVA	Mixed grass	VVA082	637462.476	3367928.327	193.928
La Grange	VVA	Mixed grass/Trees	VVA083	617984.895	3377495.554	269.131
La Grange	VVA	Mixed grass/Trees	VVA084	619046.128	3410772.939	293.341
La Grange	VVA	Mixed grass/Shrubs	VVA085	588203.205	3387266.001	345.298
La Grange	VVA	Mixed grass	VVA086	643492.176	3386003.946	199.833
La Grange	VVA	Short grass	VVA087	657191.589	3304684.848	161.058
La Grange	VVA	Mixed grass	VVA088	661474.154	3344084.784	134.666
La Grange	VVA	Mixed grass/Shrubs/Trees	VVA089	663029.699	3330694.792	122.813
La Grange	VVA	Mixed grass/Shrubs/Trees	VVA090	689125.801	3321568.17	93.899
La Grange	VVA	Short grass	VVA091	680241.615	3301996.094	119.836
La Grange	VVA	Mixed grass	VVA092	694245.175	3303905.636	106.521
La Grange	VVA	Short grass	VVA093	677640.778	3323204.439	95.596
La Grange	VVA	Mixed Grass	VVA095	682460.516	3289466.249	120.755
La Grange	VVA	Shrubs/Trees	VVA096	680803.265	3344044.364	168.344
La Grange	VVA	Shrubs/Trees	VVA097	652489.347	3332087.657	128.429
La Grange	VVA	Mixed grass	VVA099	675359.353	3313499.78	118.792
La Grange	VVA	Mixed grass	VVA100	666271.534	3317173.829	133.677
La Grange	VVA	Mixed grass/Shrubs	VVA101	639978.705	3320248.059	161.387
La Grange	VVA	Mixed grass/Shrubs	VVA102	692833.583	3290995.734	115.026
La Grange	VVA	Mixed grass	VVA103	668856.301	3292390.326	106.82
La Grange	VVA	Mixed grass/Trees	VVA105	685697.959	3336365.431	137.388
La Grange	VVA	Mixed grass/Trees	VVA106	674353.949	3307754.956	123.119
La Grange	VVA	Mixed grass/Shrubs	VVA209	700195.265	3327562.12	112.882
La Grange	VVA	Short grass	VVA107	732074.341	3287859.125	84.67
La Grange	VVA	Mixed grass	VVA109	704546.29	3312750.499	106.567
La Grange	VVA	Short grass	VVA110	742863.935	3282003.895	65.002
La Grange	VVA	Mixed grass/Shrubs	VVA111	718571.059	3336034.862	128.413
La Grange	VVA	Short grass	VVA112	709868.403	3287357.587	102.598
La Grange	VVA	Mixed grass	VVA113	765023.677	3283103.532	51.915
La Grange	VVA	Mixed grass	VVA114	731498.904	3317873.438	128.981
La Grange	VVA	Mixed grass	VVA115	739404.88	3302902.578	95.747
La Grange	VVA	Mixed grass/Shrubs	VVA116	747475.761	3303890.306	101.723
La Grange	VVA	Short grass	VVA118	724866.735	3308088.301	115.601

Horizontal Checkpoints – Twenty-one NVA checkpoints served a dual purpose as horizontal accuracy assessment of the San Antonio and La Grange AOIs.

Table 5: Horizontal Checkpoint Coordinates
UTMZ14 NAD83(2011) Geoid12B Meters

AOI	Check Point Type	Point ID	X	Y
San Antonio	Horizontal	NVA008	559143.266	3224531.285
San Antonio	Horizontal	NVA143	548526.941	3280855.225
San Antonio	Horizontal	NVA144	534336.909	3263368.764
San Antonio	Horizontal	NVA145	546196.835	3254178.353
San Antonio	Horizontal	NVA146	562703.373	3261225.25
La Grange	Horizontal	NVA147	607198.079	3362265.359
La Grange	Horizontal	NVA148	612028.021	3340092.523
La Grange	Horizontal	NVA149	602790.774	3305768.884
La Grange	Horizontal	NVA150	629089.619	3351073.533
La Grange	Horizontal	NVA076	667919.677	3378226.46
La Grange	Horizontal	NVA151	616430.503	3410748.134
La Grange	Horizontal	NVA153	632013.851	3365306.877
La Grange	Horizontal	NVA154	650476.504	3382055.908
La Grange	Horizontal	NVA112	672178.912	3299274.697
La Grange	Horizontal	NVA155	692640.566	3285120.686
La Grange	Horizontal	NVA156	696512.626	3312574.283
La Grange	Horizontal	NVA157	650020.32	3315288.207
La Grange	Horizontal	NVA158	647719.644	3335235.303
La Grange	Horizontal	NVA121	739896.357	3288447.899
La Grange	Horizontal	NVA159	722698.227	3337584.744
La Grange	Horizontal	NVA160	720145.886	3303904.114

4 Phase III: Data Processing

The following quality control reviews were conducted during the Data Processing and Final Product Development phases.

4.1 Quality Assessment

This section describes the specifications checked, the methods and tools used, and the results of the quality assessment of the AOI deliverables.

4.1.1 Software Used

Primary software programs used by AECOM in performing the quality assessment were as follows:

- *TerraSolid TerraScan* - used for point classification checks and point file generation as needed
- *ESRI ArcMap/ArcCatalog* - general GIS analysis software used to run automated QA models and support manual data review
- *QCoherent LP360 standalone and ArcGIS extension* – LiDAR specific software used to run automated QA processes and support manual data review
- *FugroViewer* – used for data visualization and manual data assessments
- *Proprietary tools* - developed in-house to conduct statistical analyses and data extractions of .LAS files

4.1.2 Quality Assessment Process

The following systematic Macro and Micro QA review approach was used for performing quantitative and qualitative assessments. A full list of checks for each dataset type is presented in the following sections.

Macro Reviews

- Deliveries were reviewed for completeness of content
- Performed coverage/gap check to ensure proper coverage of the tiles submitted
    - Verified that tile naming conventions were followed
    - Verified that deliverable formats were correct
    - Created a spatial distribution raster to check that delivery meets data distribution requirements
    - Conducted a statistical analysis of delivery to check point classifications, variable-length record values, and maximum/minimum x,y,z ranges
    - QA processing models were run on the DEM files to isolate data voids, pits and spikes
    - QA processing of breaklines to ensure closed polygon vertices were consistent and direction of flow was accurate

Micro Reviews

- Performed tile-by-tile analysis
    - ArcGIS to review LAS bare earth surface as a raster
    - Using FugroViewer and LP360, checked for errors in profile mode (noise, high and low points)
    - Conducted measurements to determine if delivery met applicable specifications outlined in 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 SHP format and accompanied by comments and relevant screenshots in the report.

- Reports prepared and submitted to TNRIS and Fugro

4.1.3 San Antonio Macro and Micro Review Quality Assessment Results

A 100% review of the data was performed using automated, semi-automated, and manual review processes. Below is a tabular summary of the review which includes the review status as well as any pertinent notes associated with each QA check. Reporting reflects the status of the final data deliverables after all revised data had been submitted for review.

Classified LiDAR point cloud

Macro QA Checks		
	Review Status	**Comments to Fugro & TNRIS**
Inventory Assessment		
Conduct file inventory	Meets Specifications	
Verify readability of media	Meets Specifications	
Coverage/Gap check	Meets Specifications	
No tile/data overlap	Meets Specifications	
Tile Naming Convention		
Tile name match index	Meets Specifications	
Metadata Review		
Project Level metadata - Content check	Meets Specifications	
USGS metadata parser check	Meets Specifications	
USGS Lidar tags present	Meets Specifications	
Tile Level metadata - Content check	Meets Specifications	
USGS metadata parser check	Meets Specifications	
USGS Lidar tags present	Meets Specifications	
LAS Header Check		
LAS format (LAS 1.4)	Meets Specifications	
GPS Times is Adjusted GPS time	Meets Specifications	
GPS times (0.01 m)	Meets Specifications	
LAS X,Y,Z scale factors 0.01 precision	Meets Specifications	
File source ID assigned	Meets Specifications	
LAS Number Variable Length Records Present	Meets Specifications	
Point Source ID equal to the File Source ID	Meets Specifications	
LAS Point Data Record Format - 6	Meets Specifications	
NAVD88, Geoid 12B, NAD83(2011), UTM Z15, meters	Meets Specifications	
At least 3 returns per pulse	Meets Specifications	
Acceptable classes - 1,2,3,4,5,6,7,9,10,13,14	Meets Specifications	
Analysis		
LAS Overlap Flag - Overage points flagged as Overlap in Classified point clouds Class 12 should NOT be used	Meets Specifications	1,204,469,336 points tagged as Overlap
LAS Withheld Flag - Geometrically unreliable points flagged as Withheld in Classified point clouds	Meets Specifications	No points tagged as Withheld
Horizontal Accuracy Check - RMSE ≤ 0.25 m	Meets Specifications	See La Grange for results

Vertical Accuracy Check - NVA (RMSE ≤ 0.1 m, 95% CI ≤ 0.196 m)	Meets Specifications	RMSEz = 0.03 m referencing 27 checkpoints
Vertical Accuracy Check - VVA (≤ 0.294 m 95th Percentile)	Meets Specifications	RMSEz = 0.04 m 95th Percentile = 0.08 m referencing 22 checkpoints
Intra-swath Accuracy (≤ 0.06 m)	Meets Specifications	4,128 points tested on 4 dispersed airport tarmacs. All have Z difference of less than 6 cm.
Inter-swath Accuracy (≤ 0.08 m, MAX +/- 0.16 m)	Meets Specifications	Measuring 21,360 interswath points, and excluding 281 points that exceeded 0.16 m that resided in vegetated or steep areas, an RMSEz = 0.04m was calculated.
ANPS ≤ 0.5 m ***OR*** ANPD ≥ 4.0 pts/m^2	Meets Specifications	ANPD = 4.71 pts/m^2 or ANPS = 0.46 m Project area had one large waterbody. Had the waterbody not been present the ANPD/ANPS would be higher (better).
Spatial Distribution and Uniformity (At least 90 percent of the cells in a 1.0 m grid contain at least one single swath, FR lidar point)	Meets Specifications	98.0% of 1m^2 pixels contain at least 1 FR, SS point. Project area had one large waterbody. Had the waterbody not been present the results would be higher (better).
Duplicate Points (X, Y, Z, AND TIME)	Meets Specifications	Observation – 360,820 points have repeating XYZ values. Random sampling suggests time is unique
Gross Anomaly Check		
Extreme intensity values	Meets Specifications	
Systematic data dropouts	Meets Specifications	

Micro QA Checks

	Review Status	Comments to Fugro & TNRIS
Classification Review (1=unclassified, 2=bare earth ground, 3=low vegetation, 4=medium vegetation, 5=high vegetation, 6=buildings, 7=low point/noise, 9=water, 10=ignored ground ((1*NPS) near BL), 13=bridges, 14=culverts)		
Consistency in filtering	Meets Specifications	
Classification accuracy (misclassification)	Meets Specifications	
Building facades are primarily C6, not veg	Meets Specifications	
Data voids/gaps ≥ $(4x\ ANPS)^2$ = 4.0 m^2	Meets Specifications	
Ridges/steps	Meets Specifications	
Cornrows	Meets Specifications	
Spikes/Divots (noise)	Meets Specifications	
No LiDAR shadowing (sliver gaps) around taller structures	Meets Specifications	

Intensity rasters

Macro QA Checks

	Review Status	Comments to Fugro & TNRIS
Inventory Assessment		
Conduct file inventory	Meets specifications	
Verify readability of media	Meets specifications	
Coverage/Gap check	Meets specifications	
50 meter tile overlap with 90 degree corners	Meets specifications	
Tile Naming Convention		

Tile name match index	Meets specifications	
Metadata Review		
Project Level metadata - Content check	Meets specifications	
USGS metadata parser check	Meets specifications	
Tile Level metadata - Content check	Meets specifications	
USGS metadata parser check	Meets specifications	
INTENSITY Header Check		
GeoTIFF format, 16bit U	Meets specifications	
Resolution ≤ 0.5 m	Meets specifications	
Geoid 12B, NAD83(2011), UTM Z15, meters	Meets specifications	
Analysis		
NODATA value set to 0	Meets specifications	
Micro QA Checks		
	Review Status	**Comments to Fugro & TNRIS**
Micro Review		
Uniformity/consistency across swath	Meets specifications	
No over or under saturation/Extreme intensity values	Meets specifications	

Hydroflattened Breaklines

Macro QA Checks		
	Review Status	**Comments to Fugro & TNRIS**
Inventory Assessment		
Conduct file inventory	Meets specifications	
Verify readability of media	Meets specifications	
Coverage/Gap check	Meets specifications	
Breaklines can extend just beyond AOI limits	Meets specifications	
Metadata Review		
Project Level metadata - Content check	Meets specifications	
USGS metadata parser check	Meets specifications	
Tile Level metadata - Content check	Meets specifications	
USGS metadata parser check	Meets specifications	
Breakline Header Checks		
Seamless or Tile based PolylineZ or PolygonZ GDB format v10.3	Meets specifications	
.PRJ file present	NA, GDB provided	
NAVD88, Geoid 12B, NAD83(2011), UTM Z15, meters	Meets specifications	
Analysis		
No duplicate features	Meets specifications	
No topology issues (overlapping features, snapping issues, or open polygons)	Meets specifications	
Expresses monotonicity	Meets specifications	

Relative Vertical Accuracy Check	Meets specifications	AECOM reviewed 23,596 breakline vertices. A number of the vertices with relatively high deltas were reviewed and explainable or were in areas of significant slope along the river bank or near breaks in the river breakline having vegetative overgrowth.
Micro QA Checks		
	Review Status	**Comments to Fugro & TNRIS**
Micro Review		
Streams/Rivers break at culverts	Meets specifications	
Streams/Rivers continuous at bridges	Meets specifications	
All inland streams and rivers should have been captured and flattened that have a 15.25 m nominal width	Meets specifications	
Water bodies greater than 10,000 m^2 collected	Meets specifications	
Islands greater than 5,000 m^2 collected	Meets specifications	
Breaklines extend just PAST project limits	Meets specifications	

4.1.3.1 Vertical Accuracy Assessments

4.1.3.1.1 Relative Vertical Accuracy

Intraswath Relative Accuracy – Intraswath vertical relative accuracy was tested using 4,128 points on a 1m grid residing in an airport tarmac setting. All First Return, Single Swath points tested having a Z delta of less than 6cm. For the sake of brevity a table has not be included in this report.

Interswath Relative Accuracy - Measuring 21,360 interswath points, and excluding 281 points that exceeded 0.16 m that resided in vegetation areas, an RMSEz = 0.04m was calculated. For the sake of brevity a table has not be included in this report.

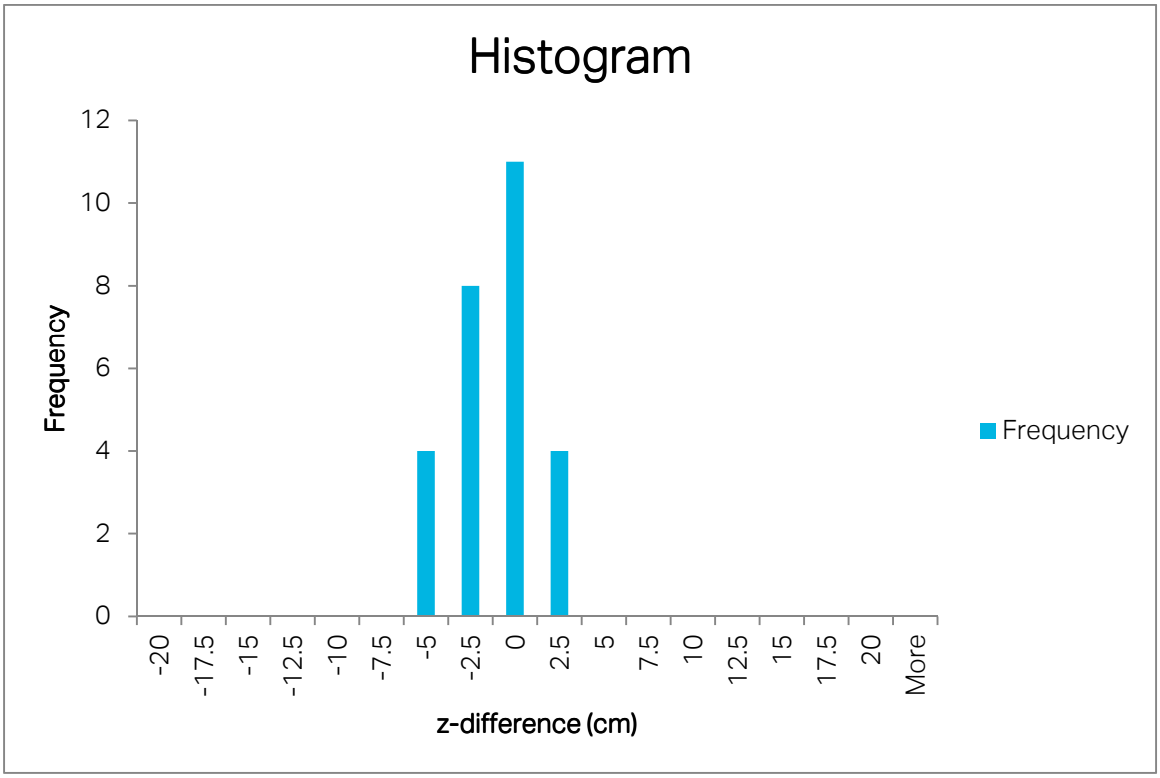
4.1.3.1.2 Absolute Vertical Accuracy – San Antonio

Vertical accuracy of LiDAR data will be achieved by comparing the elevation of Class 2 Bare Earth points against the QA checkpoint elevation values. Deviations were reported as an RMSE and @95% confidence for NVA assessments and @95th Percentile for VVA assessments.

Table 6: LiDAR NVA Assessment
UTM Z14N, NAVD88, Geoid 12B, NAD83(2011), Meters

GPS Point Name	Survey Elevation	LiDAR Elevation	Difference
NVA002	394.403	394.372	-0.031
NVA003	276.669	276.605	-0.064
NVA004	223.617	223.582	-0.035
NVA005	176.402	176.372	-0.030
NVA006	176.516	176.47	-0.046
NVA007	184.898	184.88	-0.018
NVA008	186.897	186.92	0.023
NVA009	191.581	191.547	-0.034
NVA010	311.457	311.472	0.015
NVA011	349.878	349.897	0.019
NVA012	411.585	411.575	-0.010
NVA013	271.854	271.799	-0.055
NVA014	256.416	256.409	-0.007
NVA015	225.705	225.667	-0.038
NVA016	287.167	287.154	-0.013
NVA017	135.024	135.009	-0.015
NVA018	173.138	173.106	-0.032
NVA019	301.354	301.344	-0.010
NVA020	378.535	378.502	-0.033
NVA021	179.466	179.394	-0.072
NVA022	214.505	214.511	0.006
NVA023	254.312	254.304	-0.008
NVA024	232.5	232.476	-0.024
NVA143	344.539	344.525	-0.014
NVA144	255.849	255.778	-0.071
NVA145	199.996	199.972	-0.024
NVA146	230.379	230.374	-0.005

Vertical Accuracy Statistics - NSSDA								
Land Cover	# of Pts	RMSEz (cm)	Std Dev (cm)	Mean (cm)	Median (cm)	Skew	Min (cm)	Max (cm)
Bare Earth	27	3.378	2.504	-2.319	2.400	0.189	-7.200	2.300
Accuracy Assessment Results								
PASS	Tested 6.175 cm vertical accuracy at 95 percent confidence level in bare earth using RMSEz x 1.9600							


Histogram
Frequency
12
10
8
6
4
2
0
-20
-17.5
-15
-12.5
-10
-7.5
-5
-2.5
0
2.5
5
7.5
10
12.5
15
17.5
20
More
z-difference (cm)
Frequency

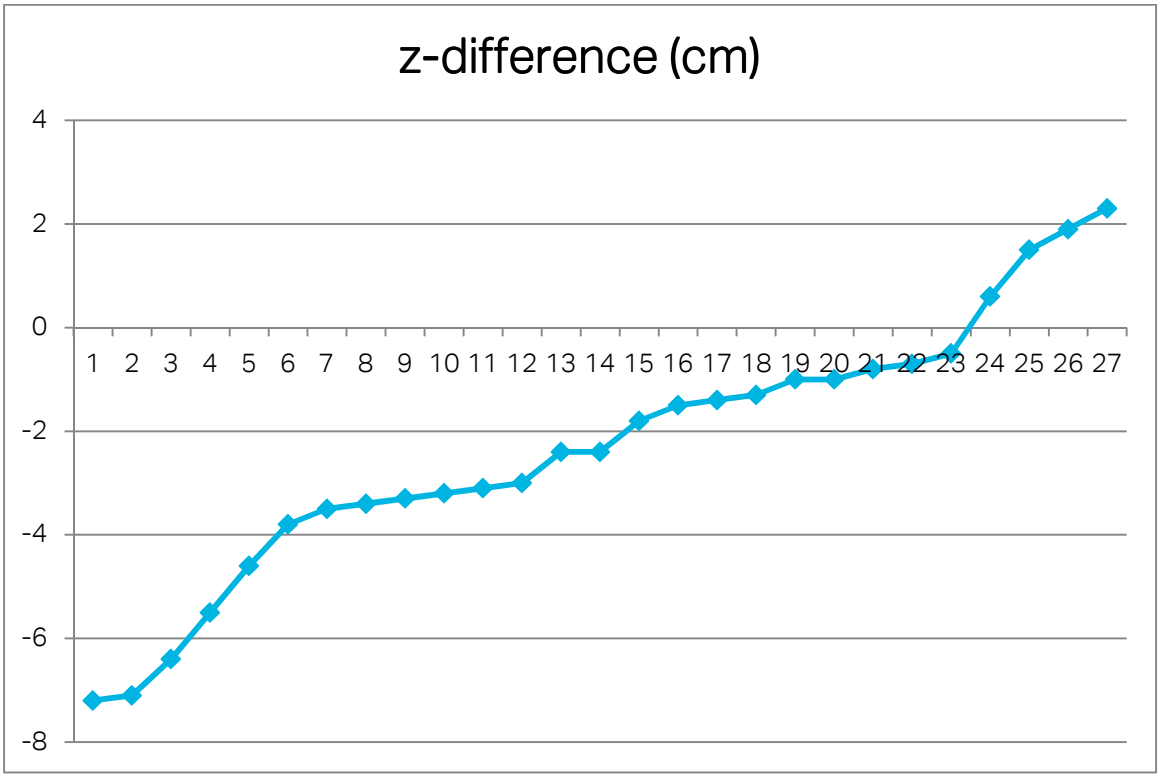
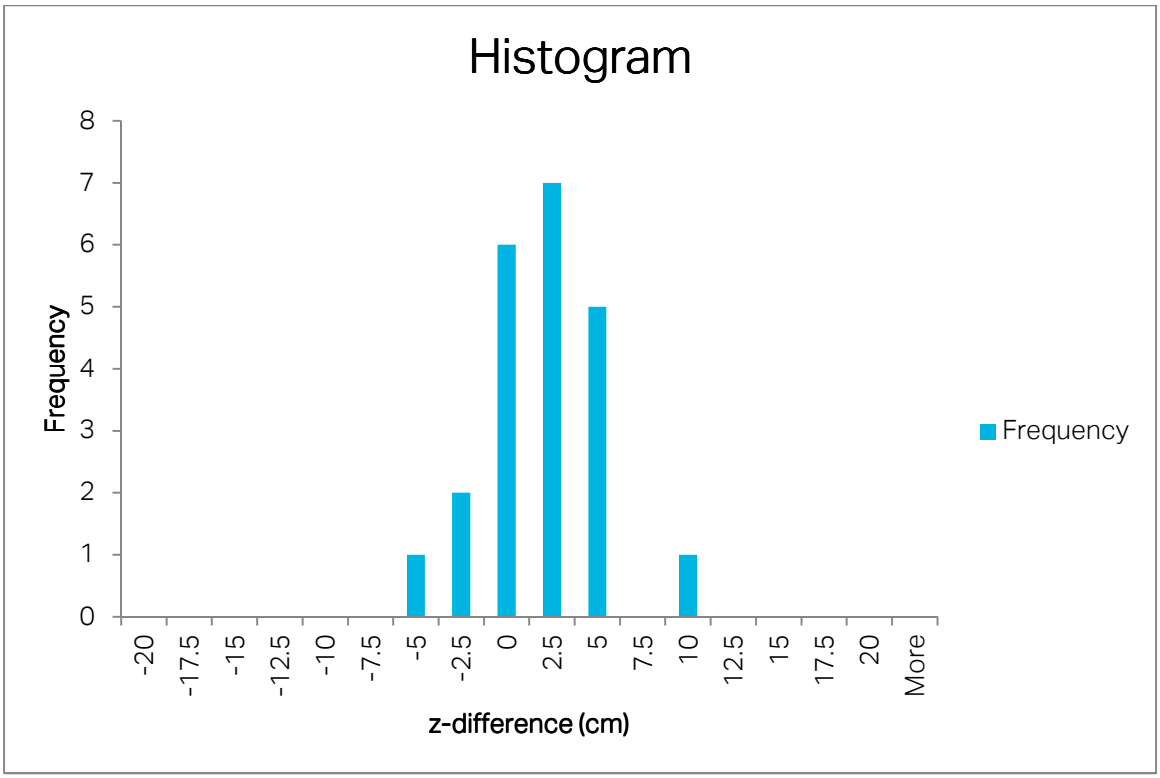
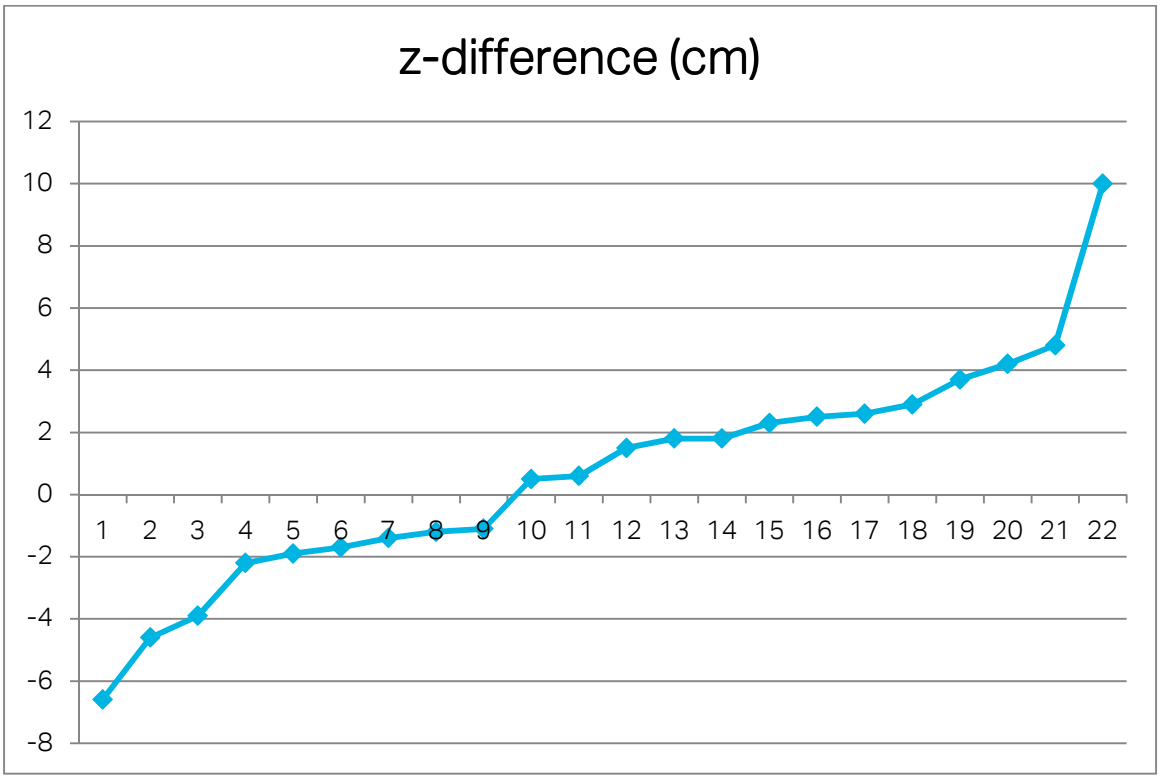

z-difference (cm)
4
2
0
-2
-4
-6
-8
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27

Table 7: LiDAR VVA Assessment UTM Z14N, NAVD88, Geoid 12B, NAD83(2011), Meters			
GPS Point Name	Survey Elevation	LiDAR Elevation	Difference
VVA001	392.053	392.079	0.026
VVA002	260.832	260.786	-0.046
VVA004	167.187	167.121	-0.066
VVA005	181.722	181.759	0.037
VVA006	222.706	222.689	-0.017
VVA007	276.784	276.832	0.048
VVA008	288.311	288.326	0.015
VVA010	169.683	169.725	0.042
VVA011	379.707	379.685	-0.022
VVA012	351.428	351.453	0.025
VVA013	174.668	174.674	0.006
VVA014	190.419	190.437	0.018
VVA015	187.548	187.577	0.029
VVA016	181.589	181.607	0.018
VVA018	369.718	369.706	-0.012
VVA019	384.579	384.54	-0.039
VVA020	262.135	262.124	-0.011
VVA021	225.865	225.846	-0.019
VVA022	304.098	304.103	0.005
VVA023	218.706	218.729	0.023
VVA024	238.712	238.698	-0.014
VVA025	253.347	253.447	0.100

Vertical Accuracy Statistics - NSSDA								
Land Cover	# of Pts	RMSEz (cm)	Std Dev (cm)	Mean (cm)	Median (cm)	Skew	Min (cm)	Max (cm)
Bare Earth	22	3.607	3.629	0.664	-1.050	-0.319	-6.600	10.000

Accuracy Assessment Results	
PASS	Tested 6.510 cm vertical accuracy at 95th percentile in vegetated areas.


Histogram
Frequency
8
7
6
5
4
3
2
1
0
-20
-17.5
-15
-12.5
-10
-7.5
-5
-2.5
0
2.5
5
7.5
10
12.5
15
17.5
20
More
z-difference (cm)
Frequency


z-difference (cm)
12
10
8
6
4
2
0
-2
-4
-6
-8
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22

4.1.3.2 Point Density and Spatial Distribution Analysis

Table 8: Aggregated Nominal Point Density (ANPD) / Aggregated Nominal Point Spacing (ANPS) Check		
Project AOI M^2	2,297,705,987	
Number of First Return(FR), Single Swath(SS) Points	10,822,648,614	
Specification Acceptance		
Specification Threshold	Calculated Result	Status
Number of FR, SS Points/m^2 ≥ 4.00	4.71 pts/m^2	**PASS**

ANPD = 4.71pts/m^2 or ANPS = 0.46 m

Table 9: Spatial Distribution of Points (Uniformity Grid Analysis)		
Project AOI M^2	2,297,705,987	
# 1m X 1m cells in project AOI with ≥ 1 FR, SS point	2,257,576,054	
Specification Acceptance		
Specification Threshold	Calculated Result	Status
≥90% of 1m X 1m cells contain at least one single swath, FR point	98.0%	**PASS**

4.1.3.3 LiDAR Horizontal Accuracy Assessment

See La Grange, section 4.1.4.3

4.1.4 La Grange Macro and Micro Review Quality Assessment Results

A 100% review of the data was performed using automated, semi-automated, and manual review processes. Below is a tabular summary of the review which includes the review status as well as any pertinent notes associated with each QA check. Reporting reflects the status of the final data deliverables after all revised data had been submitted for review.

Classified LiDAR point cloud

Macro QA Checks		
	Review Status	**Comments to Fugro & TNRIS**
Inventory Assessment		
Conduct file inventory	Meets Specifications	
Verify readability of media	Meets Specifications	
Coverage/Gap check	Meets Specifications	
No tile/data overlap	Meets Specifications	
Tile Naming Convention		
Tile name match index	Meets Specifications	
Metadata Review		
Project Level metadata - Content check	Meets Specifications	
USGS metadata parser check	Meets Specifications	
USGS Lidar tags present	Meets Specifications	
Tile Level metadata - Content check	Meets Specifications	
USGS metadata parser check	Meets Specifications	
USGS Lidar tags present	Meets Specifications	
LAS Header Check		
LAS format (LAS 1.4)	Meets Specifications	
GPS Times is Adjusted GPS time	Meets Specifications	
GPS times (0.01 m)	Meets Specifications	
LAS X,Y,Z scale factors 0.01 precision	Meets Specifications	
File source ID assigned	Meets Specifications	
LAS Number Variable Length Records Present	Meets Specifications	
Point Source ID equal to the File Source ID	Meets Specifications	
LAS Point Data Record Format - 6	Meets Specifications	
NAVD88, Geoid 12B, NAD83(2011), UTM Z15, meters	Meets Specifications	
At least 3 returns per pulse	Meets Specifications	
Acceptable classes - 1,2,3,4,5,6,7,9,10,13,14	Meets Specifications	
Analysis		
LAS Overlap Flag - Overage points flagged as Overlap in Classified point clouds Class 12 should NOT be used	Meets Specifications	5,921,194,210 points tagged as Overlap

LAS Withheld Flag - Geometrically unreliable points flagged as Withheld in Classified point clouds	Meets Specifications	No points tagged as Withheld
Horizontal Accuracy Check - RMSE ≤ 0.25 m	Meets Specifications	RMSEx= 0.189 m RMSEy= 0.186 m Referencing 16 points across both San Antonio and La Grange AOIs
Vertical Accuracy Check - NVA (RMSE ≤ 0.1 m, 95% CI ≤ 0.196 m)	Meets Specifications	RMSEz = 0.05 m referencing 115 checkpoints
Vertical Accuracy Check - VVA (≤ 0.294 m 95th Percentile)	Meets Specifications	RMSEz = 0.05 m 95th Percentile = 0.11 m referencing 81 checkpoints
Intra-swath Accuracy (≤ 0.06 m)	Meets Specifications	8,050 points tested on 6 dispersed airport tarmacs. No point exceeded 0.06 m.
Inter-swath Accuracy (≤ 0.08 m, MAX +/- 0.16 m)	Meets Specifications	Measuring 599,216 interswath points, and excluding 10,611 points that exceeded 0.16 m that resided in vegetated or steep areas, an $RMSE_z$ = 0.04 m was calculated.
ANPS ≤ 0.5 m ***OR*** ANPD ≥ 4.0 pts/m^2	Meets Specifications	ANPD = 4.39 pts/m^2 or ANPS = 0.48 m
Spatial Distribution and Uniformity (At least 90 percent of the cells in a 1.0 m grid contain at least one single swath, FR lidar point)	Meets Specifications	98.2% of 1m^2 pixels contain at least 1 FR, SS point.
Duplicate Points (X, Y, Z, AND TIME)	Meets Specifications	Observation – 360,820 points have repeating XYZ values. Random sampling suggests time is unique
Gross Anomaly Check		
Extreme intensity values	Meets Specifications	
Systematic data dropouts	Meets Specifications	
Micro QA Checks		
	Review Status	**Comments to Fugro & TNRIS**
Classification Review (1=unclassified, 2=bare earth ground, 3=low vegetation, 4=medium vegetation, 5=high vegetation, 6=buildings, 7=low point/noise, 9=water, 10=ignored ground ((1*NPS) near BL), 13=bridges, 14=culverts)		
Consistency in filtering	Meets Specifications	
Classification accuracy (misclassification)	Meets Specifications	
Building facades are primarily C6, not veg	Meets Specifications	
Data voids/gaps ≥ $(4x\ ANPS)^2$ = 4.0 m^2	Meets Specifications	
Ridges/steps	Meets Specifications	
Cornrows	Meets Specifications	
Spikes/Divots (noise)	Meets Specifications	
No LiDAR shadowing (sliver gaps) around taller structures	Meets Specifications	

Intensity rasters

Macro QA Checks		
	Review Status	**Comments to Fugro & TNRIS**
Inventory Assessment		
Conduct file inventory	Meets specifications	
Verify readability of media	Meets specifications	
Coverage/Gap check	Meets specifications	
50 meter tile overlap with 90 degree corners	Meets specifications	
Tile Naming Convention		
Tile name match index	Meets specifications	
Metadata Review		
Project Level metadata - Content check	Meets specifications	
USGS metadata parser check	Meets specifications	
Tile Level metadata - Content check	Meets specifications	
USGS metadata parser check	Meets specifications	
INTENSITY Header Check		
GeoTIFF format, 16bit U	Meets specifications	
Resolution ≤ 0.5 m	Meets specifications	
Geoid 12B, NAD83(2011), UTM Z15, meters	Meets specifications	
Analysis		
NODATA value set to 0	Meets specifications	
Micro QA Checks		
	Review Status	**Comments to Fugro & TNRIS**
Micro Review		
Uniformity/consistency across swath	Meets specifications	
No over or under saturation/Extreme intensity values	Meets specifications	

Hydroflattened Breaklines

Macro QA Checks		
	Review Status	**Comments to Fugro & TNRIS**
Inventory Assessment		
Conduct file inventory	Meets specifications	
Verify readability of media	Meets specifications	
Coverage/Gap check	Meets specifications	
Breaklines can extend just beyond AOI limits	Meets specifications	
Metadata Review		
Project Level metadata - Content check	Meets specifications	
USGS metadata parser check	Meets specifications	
Tile Level metadata - Content check	Meets specifications	
USGS metadata parser check	Meets specifications	
Breakline Header Checks		
Seamless or Tile based PolylineZ or PolygonZ GDB format v10.3	Meets specifications	
.PRJ file present	NA, GDB provided	
NAVD88, Geoid 12B, NAD83(2011), UTM Z15, meters	Meets specifications	
Analysis		
No duplicate features	Meets specifications	
No topology issues (overlapping features, snapping issues, or open polygons)	Meets specifications	
Expresses monotonicity	Meets specifications	
Relative Vertical Accuracy Check	Meets specifications	AECOM reviewed 127,489 breakline vertices (approximately every 20th point). 92,977 vertices resided within 2 meters of a C2 point. Vertices with relatively high deltas were reviewed and explainable or were in areas of significant slope along the river bank or near breaks in the river breakline having vegetative overgrowth.
Micro QA Checks		
	Review Status	**Comments to Fugro & TNRIS**
Micro Review		
Streams/Rivers break at culverts	Meets specifications	
Streams/Rivers continuous at bridges	Meets specifications	
All inland streams and rivers should have been captured and flattened that have a 15.25 m nominal width	Meets specifications	
Water bodies greater than 10,000 m^2 collected	Meets Specifications	
Islands greater than 5,000 m^2 collected	Meets specifications	
Breaklines extend just PAST project limits	Meets specifications	

4.1.4.1 Vertical Accuracy Assessments

4.1.4.1.1 Relative Vertical Accuracy

Intraswath Relative Accuracy – Intraswath vertical relative accuracy was tested using 8,050 points on a 1m grid residing in an airport tarmac setting. All First Return, Single Swath points tested ≤ 6 cm. For the sake of brevity a table has not be included in this report.

Interswath Relative Accuracy - Measuring 599,216 interswath points, and excluding 10,611 points that exceeded 0.16 m that resided in vegetation areas, an RMSEz = 0.04m was calculated. For the sake of brevity a table has not be included in this report.

4.1.4.1.2 Absolute Vertical Accuracy – La Grange

Vertical accuracy of LiDAR data will be achieved by comparing the elevation of Class 2 Bare Earth points against the QA checkpoint elevation values. Deviations were reported as an RMSE and @95% confidence for NVA assessments and @95th Percentile for VVA assessments.

Table 10: LiDAR NVA Assessment
UTM Z14N, NAVD88, Geoid 12B, NAD83(2011), Meters

GPS Point Name	Survey Elevation	LiDAR Elevation	Difference
NVA026	175.118	175.130	0.012
NVA027	167.703	167.697	-0.006
NVA028	197.347	197.314	-0.033
NVA030	222.939	222.956	0.017
NVA031	164.843	164.770	-0.073
NVA032	250.660	250.572	-0.088
NVA033	404.293	404.269	-0.024
NVA034	176.618	176.571	-0.047
NVA035	349.635	349.681	0.046
NVA036	265.031	264.961	-0.070
NVA037	235.178	235.209	0.031
NVA038	279.857	279.825	-0.032
NVA039	305.122	305.163	0.041
NVA040	165.543	165.549	0.006
NVA041	367.940	368.000	0.060
NVA043	138.364	138.350	-0.014
NVA044	172.056	172.042	-0.014
NVA045	209.449	209.504	0.055
NVA046	331.096	331.074	-0.022
NVA047	312.219	312.250	0.031
NVA049	187.217	187.213	-0.004
NVA050	181.143	181.116	-0.027
NVA051	286.209	286.275	0.066
NVA053	405.181	405.143	-0.038
NVA054	187.816	187.789	-0.027
NVA056	326.155	326.128	-0.027

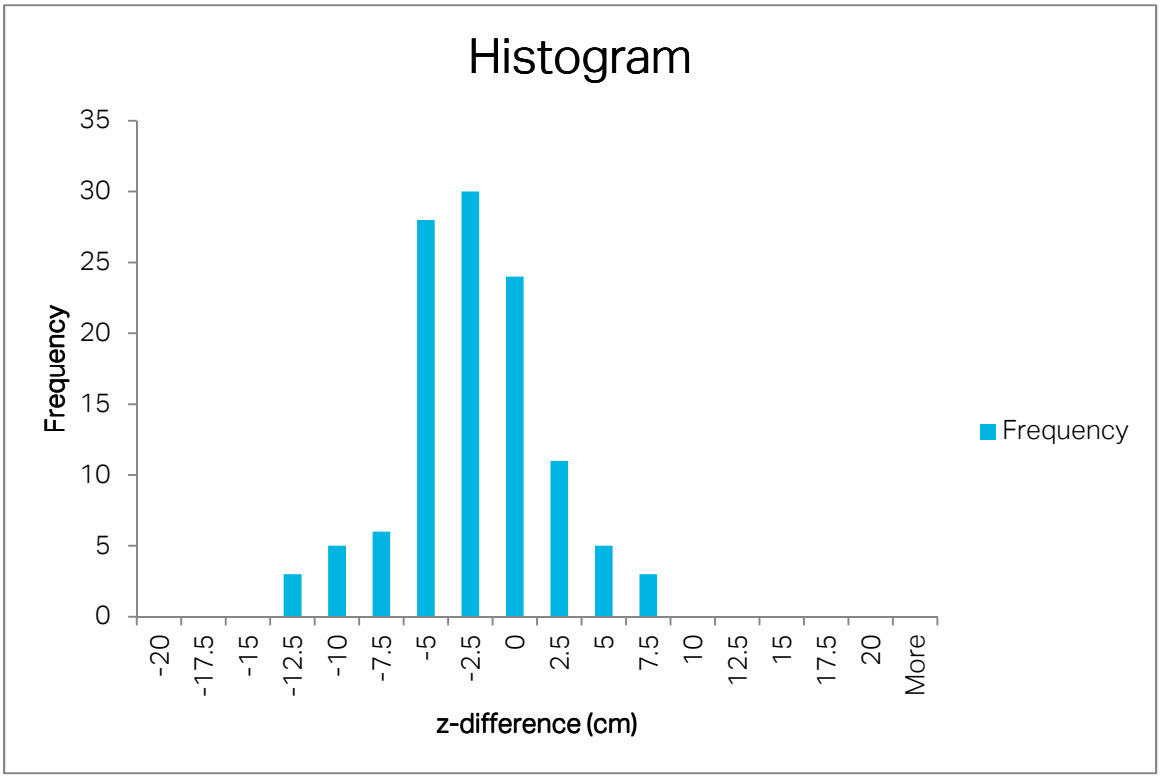
NVA057	271.769	271.711	-0.058
NVA058	149.262	149.202	-0.060
NVA059	295.249	295.173	-0.076
NVA060	188.881	188.842	-0.039
NVA061	289.557	289.492	-0.065
NVA062	160.043	160.059	0.016
NVA147	234.836	234.780	-0.056
NVA149	175.808	175.787	-0.021
NVA150	150.542	150.473	-0.069
NVA063	186.505	186.516	0.011
NVA064	226.484	226.464	-0.020
NVA066	182.370	182.316	-0.054
NVA067	294.405	294.352	-0.053
NVA068	338.971	338.909	-0.062
NVA069	324.776	324.758	-0.018
NVA070	173.408	173.441	0.033
NVA071	142.351	142.335	-0.016
NVA072	267.145	267.098	-0.047
NVA074	162.175	162.046	-0.129
NVA075	158.293	158.281	-0.012
NVA076	138.737	138.664	-0.073
NVA077	168.540	168.495	-0.045
NVA078	279.589	279.520	-0.069
NVA079	287.964	287.894	-0.070
NVA080	170.065	170.044	-0.021
NVA081	162.524	162.481	-0.043
NVA082	233.333	233.230	-0.103
NVA083	297.961	297.937	-0.024
NVA084	147.496	147.480	-0.016
NVA085	177.168	177.120	-0.048
NVA086	197.902	197.919	0.017
NVA087	270.725	270.720	-0.005
NVA089	183.466	183.440	-0.026
NVA090	346.486	346.483	-0.003
NVA091	143.390	143.396	0.006
NVA092	169.637	169.614	-0.023
NVA151	291.145	291.132	-0.013
NVA153	218.376	218.376	0.000
NVA154	164.046	164.028	-0.018
NVA093	121.827	121.776	-0.051
NVA094	103.903	103.829	-0.074
NVA095	94.063	94.031	-0.032
NVA096	139.740	139.752	0.012

NVA097	168.269	168.211	-0.058
NVA098	135.135	135.090	-0.045
NVA101	124.292	124.298	0.006
NVA102	123.594	123.550	-0.044
NVA103	144.378	144.342	-0.036
NVA104	116.966	116.865	-0.101
NVA105	163.504	163.466	-0.038
NVA106	135.653	135.627	-0.026
NVA107	99.244	99.180	-0.064
NVA108	171.490	171.447	-0.043
NVA109	118.069	118.080	0.011
NVA110	161.919	161.862	-0.057
NVA111	133.643	133.636	-0.007
NVA112	133.769	133.757	-0.012
NVA113	149.223	149.152	-0.071
NVA114	112.165	112.136	-0.029
NVA115	106.300	106.272	-0.028
NVA116	147.791	147.760	-0.031
NVA117	111.099	111.082	-0.017
NVA118	133.878	133.833	-0.045
NVA119	144.306	144.276	-0.030
NVA155	112.779	112.745	-0.034
NVA157	148.015	147.977	-0.038
NVA158	162.007	162.010	0.003
NVA100	113.298	113.233	-0.065
NVA120	102.704	102.651	-0.053
NVA122	70.091	70.028	-0.063
NVA123	52.053	51.947	-0.106
NVA124	107.033	106.982	-0.051
NVA125	107.708	107.653	-0.055
NVA126	129.836	129.754	-0.082
NVA127	154.388	154.361	-0.027
NVA128	134.111	134.077	-0.034
NVA129	89.438	89.339	-0.099
NVA130	97.623	97.564	-0.059
NVA132	72.660	72.560	-0.100
NVA133	100.905	100.832	-0.073
NVA135	63.121	63.024	-0.097
NVA136	116.272	116.255	-0.017
NVA137	122.011	121.866	-0.145
NVA138	87.310	87.220	-0.090
NVA139	135.466	135.413	-0.053
NVA140	134.939	134.886	-0.053

NVA141	107.339	107.303	-0.036
NVA142	71.178	71.070	-0.108
NVA161	110.189	110.062	-0.127

Vertical Accuracy Statistics - NSSDA								
Land Cover	# of Pts	RMSEz (cm)	Std Dev (cm)	Mean (cm)	Median (cm)	Skew	Min (cm)	Max (cm)
Bare Earth	115	5.351	3.989	-3.587	3.400	-0.011	-14.500	6.600

Accuracy Assessment Results	
PASS	Tested 11.248 cm vertical accuracy at 95 percent confidence level in bare earth using RMSEz x 1.9600.



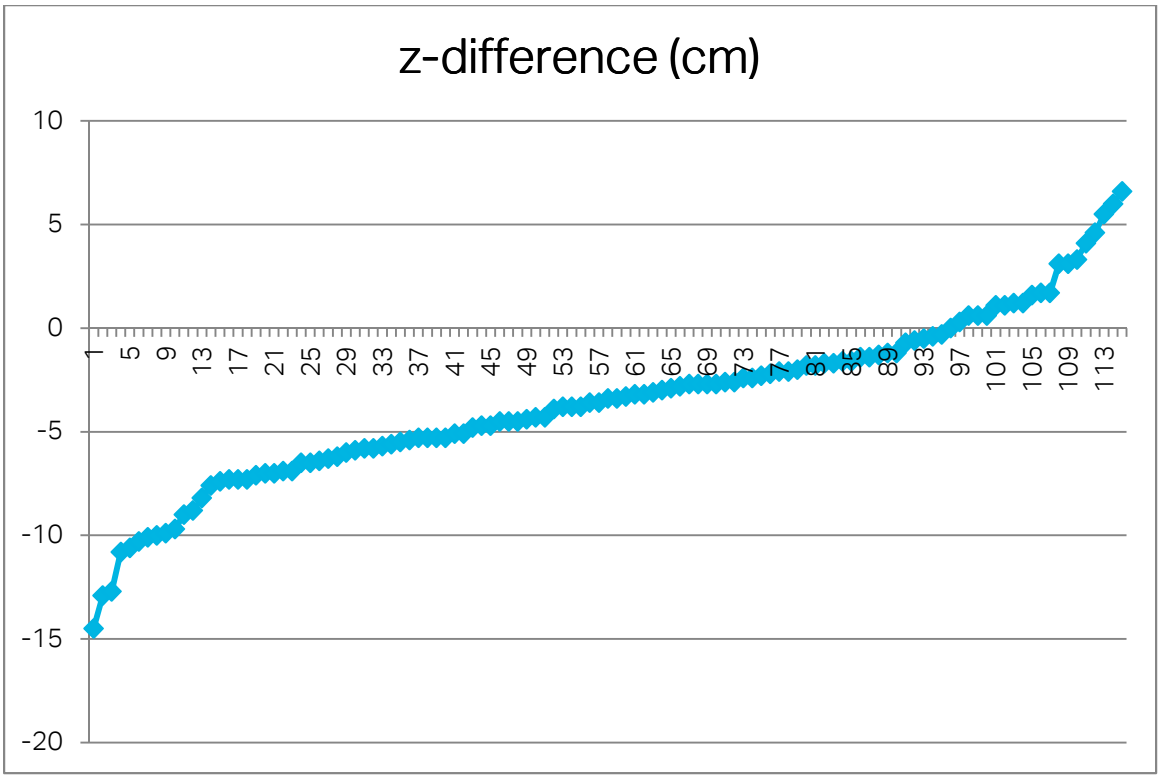
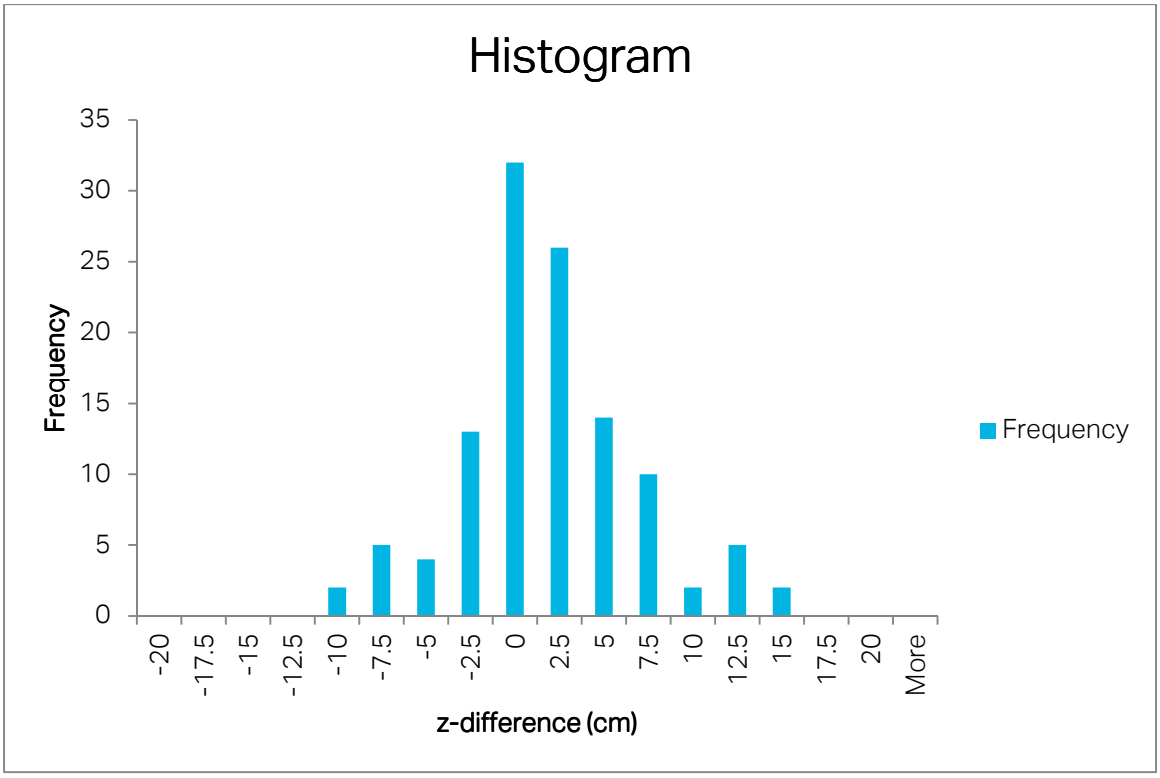
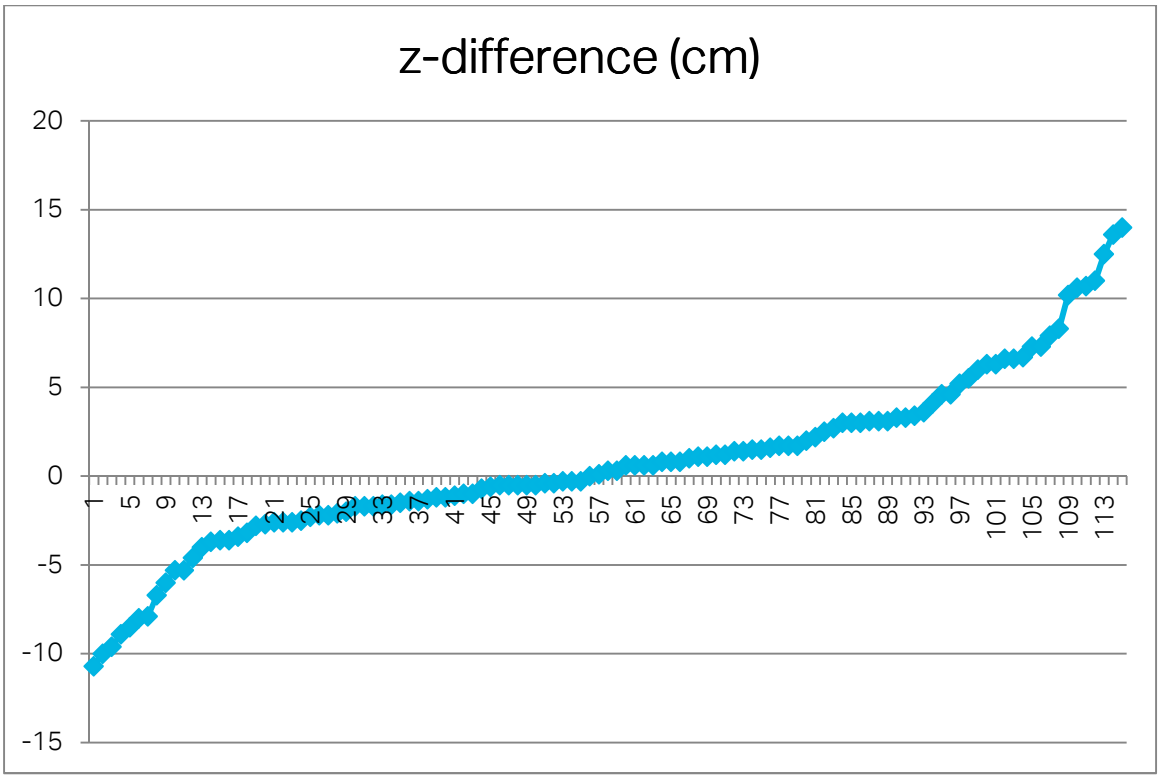

z-difference (cm)
10
5
0
-5
-10
-15
-20
1
5
9
13
17
21
25
29
33
37
41
45
49
53
57
61
65
69
73
77
81
85
89
93
97
101
105
109
113

Table 11: LiDAR VVA Assessment UTM Z14N, NAVD88, Geoid 12B, NAD83(2011), Meters			
GPS Point Name	Survey Elevation	LiDAR Elevation	Difference
VVA095	120.755	120.895	0.140
VVA064	323.070	323.206	0.136
VVA088	134.666	134.791	0.125
VVA077	167.414	167.524	0.110
VVA031	162.348	162.455	0.107
VVA029	308.722	308.828	0.106
VVA061	368.308	368.410	0.102
VVA042	151.902	151.985	0.083
VVA035	199.524	199.603	0.079
VVA045	168.219	168.292	0.073
VVA100	133.677	133.750	0.073
VVA041	325.321	325.388	0.067
VVA069	225.399	225.465	0.066
VVA114	128.981	129.044	0.063
VVA082	193.928	193.991	0.063
VVA027	400.899	400.951	0.052
VVA040	163.996	164.042	0.046
VVA030	293.604	293.640	0.036
VVA052	353.242	353.276	0.034
VVA073	181.872	181.905	0.033
VVA091	119.836	119.867	0.031
VVA084	293.341	293.371	0.030
VVA047	233.312	233.342	0.030
VVA033	282.132	282.162	0.030
VVA057	326.012	326.039	0.027
VVA032	239.645	239.670	0.025
VVA209	112.882	112.904	0.022
VVA099	118.792	118.812	0.020
VVA046	196.374	196.391	0.017
VVA101	161.387	161.402	0.015
VVA103	106.820	106.835	0.015
VVA070	228.019	228.033	0.014
VVA102	115.026	115.040	0.014
VVA074	140.061	140.071	0.010
VVA059	191.390	191.398	0.008
VVA085	345.298	345.306	0.008
VVA086	199.833	199.841	0.008
VVA054	133.954	133.960	0.006
VVA071	172.232	172.235	0.003

VVA075	182.474	182.475	0.001
VVA043	209.816	209.813	-0.003
VVA105	137.388	137.385	-0.003
VVA083	269.131	269.127	-0.004
VVA036	186.723	186.718	-0.005
VVA068	297.044	297.039	-0.005
VVA037	170.842	170.837	-0.005
VVA097	128.429	128.424	-0.005
VVA051	192.601	192.591	-0.010
VVA106	123.119	123.109	-0.010
VVA090	93.899	93.888	-0.011
VVA092	106.521	106.506	-0.015
VVA066	161.058	161.041	-0.017
VVA081	173.687	173.667	-0.020
VVA109	106.567	106.546	-0.021
VVA089	122.813	122.791	-0.022
VVA065	212.909	212.887	-0.022
VVA056	183.576	183.553	-0.023
VVA096	168.344	168.319	-0.025
VVA076	291.973	291.947	-0.026
VVA102	115.601	115.575	-0.026
VVA050	399.117	399.091	-0.026
VVA110	65.002	64.975	-0.027
VVA112	102.598	102.570	-0.028
VVA026	163.161	163.129	-0.032
VVA028	331.197	331.163	-0.034
VVA093	95.596	95.560	-0.036
VVA067	279.217	279.181	-0.036
VVA113	51.915	51.878	-0.037
VVA080_ALT	154.288	154.248	-0.040
VVA063	147.303	147.257	-0.046
VVA034	271.884	271.831	-0.053
VVA107	84.670	84.617	-0.053
VVA116	101.723	101.663	-0.060
VVA029	308.013	307.946	-0.067
VVA111	128.413	128.334	-0.079
VVA049	252.518	252.438	-0.080
VVA060	289.454	289.369	-0.085
VVA078	165.595	165.506	-0.089
VVA066	161.587	161.491	-0.096
VVA062	162.066	161.966	-0.100
VVA115	95.747	95.640	-0.107

Vertical Accuracy Statistics - NSSDA								
Land Cover	# of Pts	RMSEz (cm)	Std Dev (cm)	Mean (cm)	Median (cm)	Skew	Min (cm)	Max (cm)
Bare Earth	81	5.496	5.504	0.542	0.300	-0.365	-10.700	14.000
Accuracy Assessment Results								
PASS	Tested 10.700 cm vertical accuracy at 95th percentile in vegetated areas.							





4.1.4.2 Point Density and Spatial Distribution Analysis

Table 12: Aggregated Nominal Point Density (ANPD) / Aggregated Nominal Point Spacing (ANPS) Check		
Project AOI M^2	3,018,838,213.04	
Number of First Return(FR), Single Swath(SS) Points	66,660,339,352	
Specification Acceptance		
Specification Threshold	Calculated Result	Status
Number of FR, SS Points/m^2 ≥ 4.00	4.39 pts/m^2	**PASS**

ANPD = 4.39 pts/m^2 or ANPS = 0.48 m

Table 13: Spatial Distribution of Points (Uniformity Grid Analysis)		
Project AOI M^2	3,018,838,213.04	
# 1m X 1m cells in project AOI with ≥ 1 FR, SS point	14,875,131,449	
Specification Acceptance		
Specification Threshold	Calculated Result	Status
≥90% of 1m X 1m cells contain at least one single swath, FR point	98.2%	**PASS**

4.1.4.3 LiDAR Horizontal Accuracy Assessment

Horizontal accuracy of LiDAR data will be achieved by identifying coincident locations between the Intensity rasters and the horizontal checkpoints. Deviations exhibited by the LiDAR Intensity rasters relative to the checkpoints were reported as an RMSE.

Table 14: LiDAR Horizontal Accuracy Assessment

UTM Z14N, NAVD88, Geoid 12B, NAD83(2011), Meters

POINT ID	CHK PT X	CHK PT Y	INTENSITY X	INTENSITY Y	X DELTA	Y DELTA
NVA143	548526.941	3280855.225	548527.404	3280855.523	-0.463	-0.298
NVA144	534336.909	3263368.764	534336.909	3263368.863	0.000	-0.099
NVA145	546196.835	3254178.353	546196.570	3254178.446	0.265	-0.093
NVA146	562703.373	3261225.250	562703.373	3261225.171	0.000	0.079
NVA148	612028.021	3340092.523	612028.360	3340092.442	-0.339	0.081
NVA149	602790.774	3305768.884	602790.774	3305768.884	0.000	0.000
NVA150	629089.619	3351073.533	629089.619	3351073.533	0.000	0.000
NVA151	616430.503	3410748.134	616430.503	3410748.134	0.000	0.000
NVA154	650476.504	3382055.908	650476.504	3382055.908	0.000	0.000
NVA112	672178.912	3299274.697	672178.952	3299275.253	-0.040	-0.556
NVA155	692640.566	3285120.686	692640.209	3285120.408	0.357	0.278
NVA156	696512.626	3312574.283	696512.626	3312574.283	0.000	0.000
NVA157	650020.320	3315288.207	650020.320	3315288.207	0.000	0.000
NVA158	647719.644	3335235.303	647719.492	3335235.495	0.152	-0.192
NVA159	722698.227	3337584.744	722698.081	3337584.757	0.146	-0.013
NVA160	720145.886	3303904.114	720145.856	3303904.221	0.030	-0.107
Specification Acceptance						
Specification Threshold	**Calculated Result**	**Status**				
$RMSE_x \leq 0.25$ m	0.189 m	**PASS**				
RMSEy ≤ 0.25 m	0..186 m	**PASS**				

Twenty-one horizontal checkpoints were planned, however only 16 were confidently visible and measureable in the Intensity imagery.

5 Phase IV: Product Development

5.1.1 San Antonio DEM Macro and Micro Quality Assessment Results

A 100% review of the data was performed using automated, semi-automated, and manual review processes. Below is a tabular summary of the review which includes the review status as well as any pertinent notes associated with each QA check. Reporting reflects the status of the final data deliverables after all revised data had been submitted for review.

Macro QA Checks		
	Review Status	**Comments to Fugro & TNRIS**
Inventory Assessment		
Conduct file inventory	Meets specifications	
Verify readability of media	Meets specifications	
Coverage/Gap check	Meets specifications	
50 meter tile overlap with 90 degree corners	Meets specifications	
Tile Naming Convention		
Tile name match index	Meets specifications	
Metadata Review		
Project Level metadata - Content check	Meets Specifications	
USGS metadata parser check	Meets Specifications	
Tile Level metadata - Content check	Meets Specifications	
USGS metadata parser check	Meets Specifications	
DEM Header Check		
.IMG format, 32bit U	Meets specifications	
Resolution ≤ 1.0 m	Meets specifications	
X,Y,Z 0.01 meter precision	Meets specifications	
NAVD88, Geoid 12B, NAD83(2011), UTM Z15, meters	Meets specifications	
Analysis		
NODATA value = -9999	Meets specifications	
Vertical Accuracy Check - NVA (RMSE ≤ 0.10 m, 95% CI ≤ 0.196 m)	Meets specifications	RMSEz = 0.03 m using 27 points
Vertical Accuracy Check - VVA (≤ 0.294 m 95th Percentile)	Meets specifications	0.06 m at 95th Percentile using 22 points
Micro QA Checks		
	Review Status	**Comments to Fugro & TNRIS**
Micro Review		
Bridges not in DEM (Culverts in DEM bare earth surface)	Meets specifications	
Extreme elevation values	Meets specifications	
No floating or sunken waterbodies	Meets specifications	
Water bodies greater than 10,000m^2 flattened	Meets specifications	

Islands greater than 5,000 m^2 collected	Meets specifications	
Data voids/gaps	Meets specifications	
Ridges/steps between tiles	Meets specifications	
Over or Under aggressive filtering anomalies	Meets specifications	
Spikes/Divots (noise)	Meets specifications	

5.1.1.1 Vertical Accuracy Assessments

5.1.1.1.1 Absolute Vertical Accuracy – San Antonio

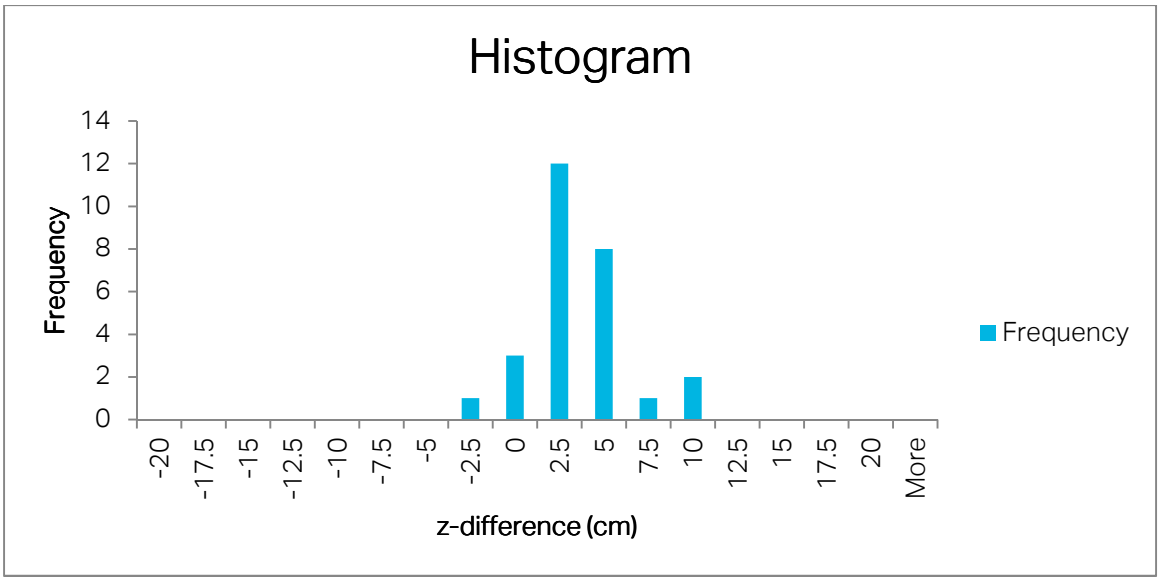
Vertical accuracy of DEM raster data will be achieved by comparing the rasterized version of Class 2 Bare Earth points against the QA checkpoint elevation values. Deviations were reported as an RMSE and @ 95% confidence for NVA assessments and @ 95th Percentile for VVA assessments.

Table 15: DEM NVA Assessment
UTM Z14N, NAVD88, Geoid 12B, NAD83(2011), Meters

GPS Point Name	Survey Elevation	DEM Elevation	Difference
NVA002	394.403	394.379	0.024
NVA003	276.669	276.587	0.082
NVA004	223.617	223.596	0.021
NVA005	176.402	176.376	0.026
NVA006	176.516	176.468	0.048
NVA007	184.898	184.874	0.024
NVA008	186.897	186.918	-0.021
NVA009	191.581	191.542	0.039
NVA010	311.457	311.498	-0.041
NVA011	349.878	349.897	-0.019
NVA012	411.585	411.570	0.015
NVA013	271.854	271.801	0.053
NVA014	256.416	256.409	0.007
NVA015	225.705	225.700	0.005
NVA016	287.167	287.156	0.011
NVA017	135.024	134.998	0.026
NVA018	173.138	173.149	-0.011
NVA019	301.354	301.342	0.012
NVA020	378.535	378.506	0.029
NVA021	179.466	179.390	0.076
NVA022	214.505	214.495	0.010
NVA023	254.312	254.308	0.004
NVA024	232.5	232.496	0.004
NVA143	344.539	344.527	0.012
NVA144	255.849	255.802	0.047
NVA145	199.996	199.968	0.028
NVA146	230.379	230.346	0.033

Vertical Accuracy Statistics - NSSDA								
Land Cover	# of Pts	RMSEz (cm)	Std Dev (cm)	Mean (cm)	Median (cm)	Skew	Min (cm)	Max (cm)
Bare Earth	27	3.358	2.738	2.015	-2.100	-0.186	-4.100	8.200

Accuracy Assessment Results	
PASS	Tested 6.582 cm vertical accuracy at 95 percent confidence level in bare earth using RMSEz x 1.9600.



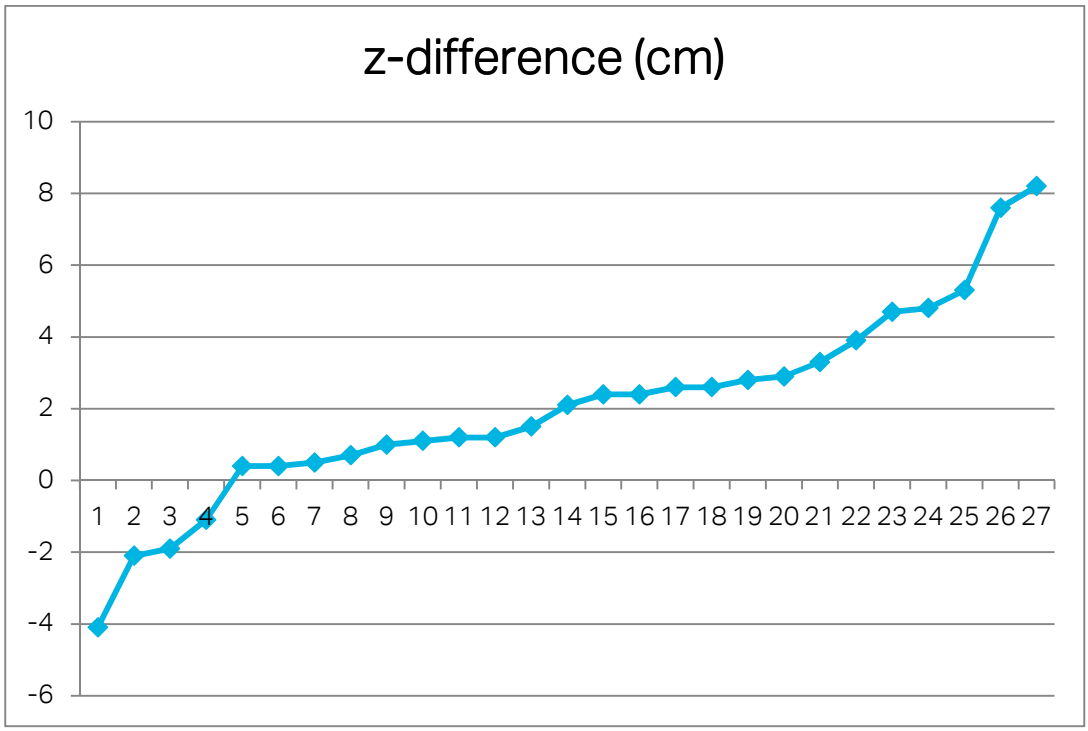
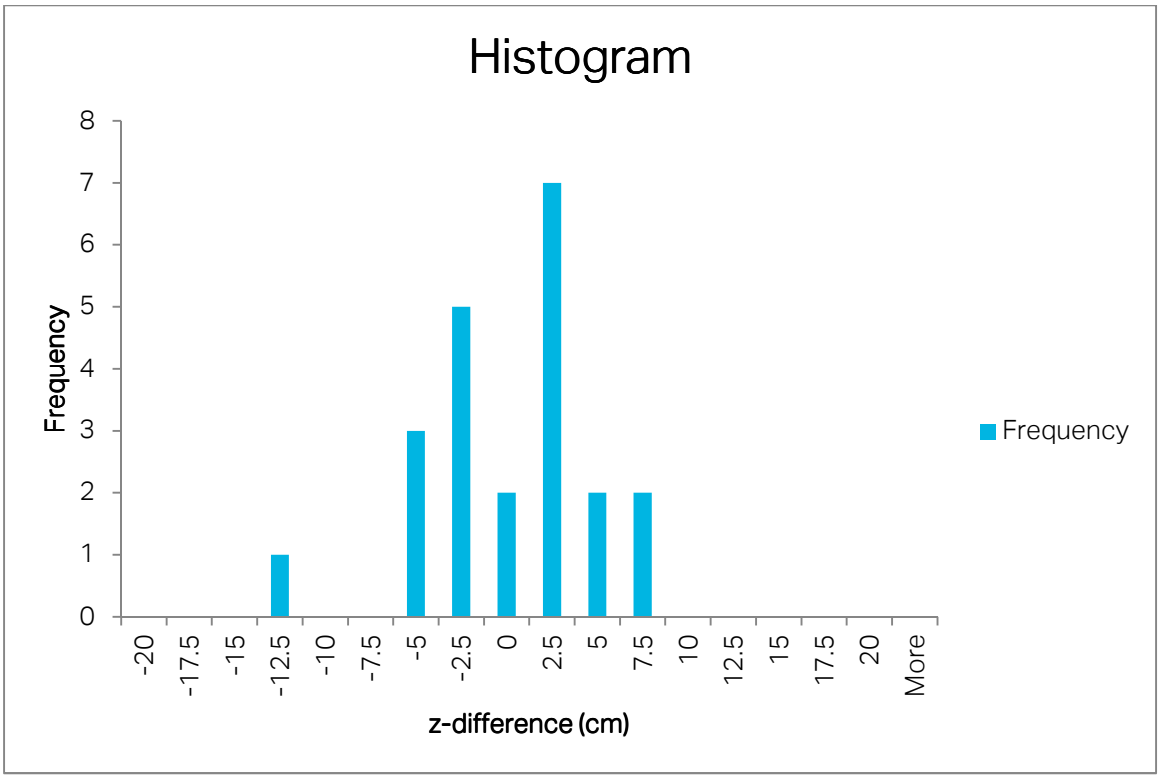
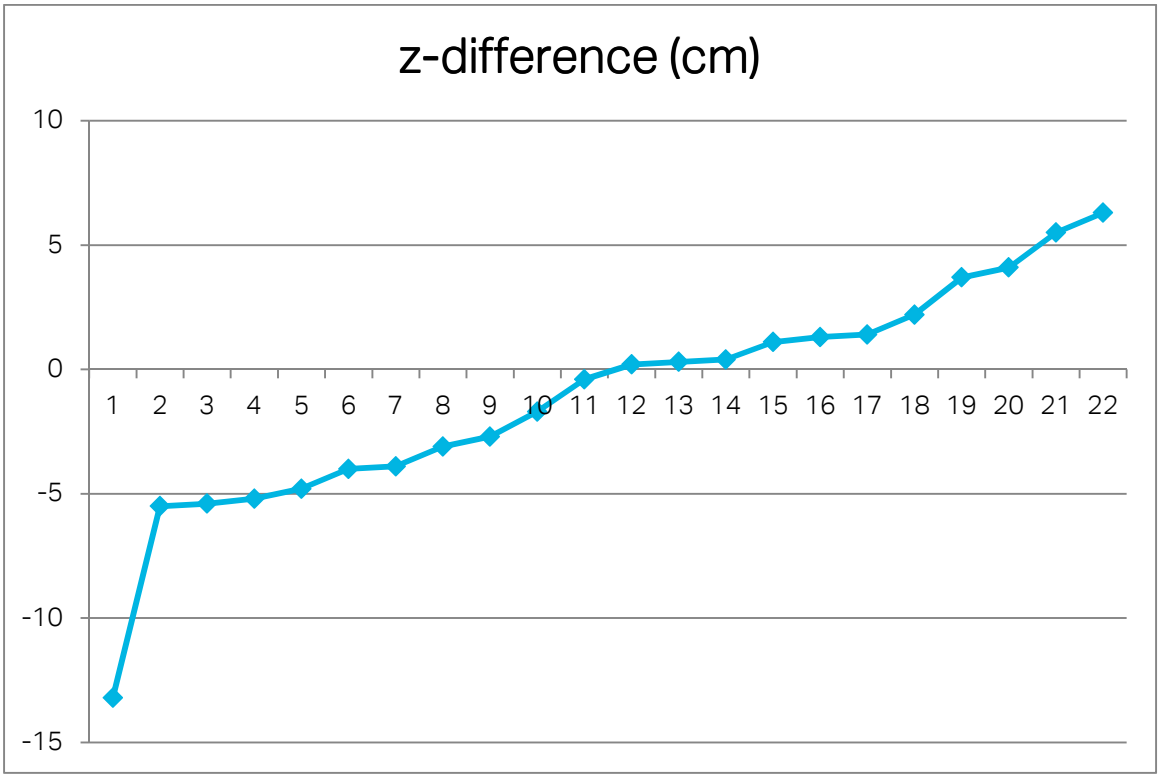


Table 16: DEM VVA Assessment UTM Z14N, NAVD88, Geoid 12B, NAD83(2011), Meters			
GPS Point Name	Survey Elevation	DEM Elevation	Difference
VVA001	392.053	392.107	-0.054
VVA004	167.187	167.124	0.063
VVA005	181.722	181.770	-0.048
VVA012	351.428	351.424	0.004
VVA013	174.668	174.666	0.002
VVA016	181.589	181.641	-0.052
VVA025	253.347	253.479	-0.132
VVA007	276.784	276.823	-0.039
VVA015	187.548	187.603	-0.055
VVA008	288.311	288.342	-0.031
VVA014	190.419	190.436	-0.017
VVA020	262.135	262.122	0.013
VVA006	222.706	222.710	-0.004
VVA018	369.718	369.715	0.003
VVA010	169.683	169.710	-0.027
VVA002	260.832	260.777	0.055
VVA011	379.707	379.666	0.041
VVA019	384.579	384.557	0.022
VVA021	225.865	225.828	0.037
VVA022	304.098	304.087	0.011
VVA023	218.706	218.746	-0.040
VVA024	238.712	238.698	0.014

Vertical Accuracy Statistics - NSSDA								
Land Cover	# of Pts	RMSEz (cm)	Std Dev (cm)	Mean (cm)	Median (cm)	Skew	Min (cm)	Max (cm)
VVA	22	4.499	4.474	-1.064	0.100	0.662	-13.200	6.300

Accuracy Assessment Results	
PASS	Tested 6.260 cm vertical accuracy at 95th percentile in vegetated areas


Histogram
Frequency
8
7
6
5
4
3
2
1
0
-20
-17.5
-15
-12.5
-10
-7.5
-5
-2.5
0
2.5
5
7.5
10
12.5
15
17.5
20
More
z-difference (cm)
Frequency


z-difference (cm)
10
5
0
-5
-10
-15
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22

5.1.2 La Grange UTM Zone 14 DEM Macro and Micro Quality Assessment Results

A 100% review of the data was performed using automated, semi-automated, and manual review processes. Below is a tabular summary of the review which includes the review status as well as any pertinent notes associated with each QA check. Reporting reflects the status of the final data deliverables after all revised data had been submitted for review.

Macro QA Checks		
	Review Status	**Comments to Fugro & TNRIS**
Inventory Assessment		
Conduct file inventory	Meets Specifications	
Verify readability of media	Meets Specifications	
Coverage/Gap check	Meets Specifications	
50 meter tile overlap with 90 degree corners	Meets Specifications	
Tile Naming Convention		
Tile name match index	Meets Specifications	
Metadata Review		
Project Level metadata - Content check	Meets Specifications	
USGS metadata parser check	Meets Specifications	
Tile Level metadata - Content check	Meets Specifications	
USGS metadata parser check	Meets Specifications	
DEM Header Check		
.IMG format, 32bit U	Meets Specifications	
Resolution ≤ 1.0 m	Meets Specifications	
X,Y,Z 0.01 meter precision	Meets Specifications	
NAVD88, Geoid 12B, NAD83(2011), UTM Z15, meters	Meets Specifications	
Analysis		
NODATA value = -9999	Meets Specifications	
Vertical Accuracy Check - NVA (RMSE ≤ 0.1 m, 95% CI ≤ 0.196 m)	Meets Specifications	RMSE = 0.051m or 95%CI = 0.101m using 115 points
Vertical Accuracy Check - VVA (≤ 0.294 m 95th Percentile)	Meets Specifications	95th Percentile = 0.104m using 81 points
Micro QA Checks		
	Review Status	**Comments to Fugro & TNRIS**
Micro Review		
Bridges not in DEM (Culverts in DEM bare earth surface)	Meets Specifications	
Extreme elevation values	Meets Specifications	
No floating or sunken waterbodies	Meets Specifications	
Water bodies greater than 10,000m^2 flattened	Meets Specifications	
Islands greater than 5,000 m^2 collected	Meets Specifications	
Data voids/gaps	Meets Specifications	
Ridges/steps between tiles	Meets Specifications	
Over or Under aggressive filtering anomalies	Meets Specifications	
Spikes/Divots (noise)	Meets Specifications	

5.1.2.1 Vertical Accuracy Assessments

5.1.2.1.1 Absolute Vertical Accuracy – La Grange

Vertical accuracy of DEM raster data will be achieved by comparing the rasterized version of Class 2 Bare Earth points against the QA checkpoint elevation values. Deviations were reported as an RMSE and @95% confidence for NVA assessments and @95th Percentile for VVA assessments.

Table 17: DEM NVA Assessment

UTM Z14N, NAVD88, Geoid 12B, NAD83(2011), Meters

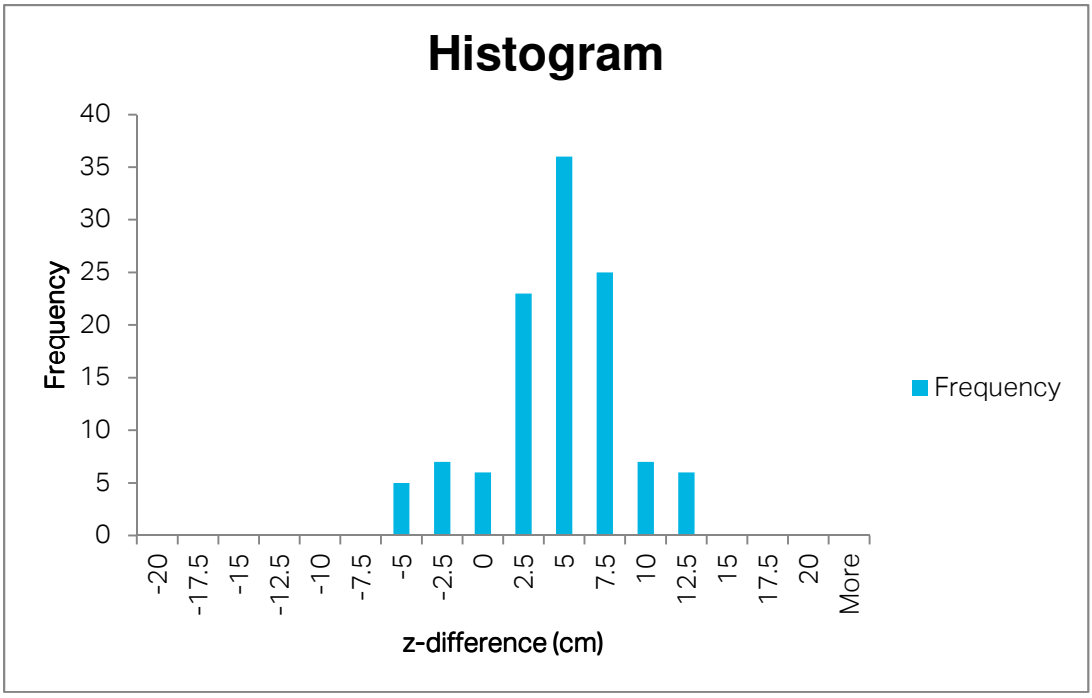
GPS Point Name	Survey Elevation	DEM Elevation	Difference
NVA026	175.118	175.189	-0.071
NVA027	167.703	167.755	-0.052
NVA028	197.347	197.343	0.004
NVA030	222.939	222.930	0.009
NVA031	164.843	164.769	0.074
NVA032	250.660	250.608	0.052
NVA033	404.293	404.252	0.041
NVA034	176.618	176.570	0.048
NVA035	349.635	349.676	-0.041
NVA036	265.031	264.965	0.066
NVA037	235.178	235.205	-0.027
NVA038	279.857	279.829	0.028
NVA039	305.122	305.160	-0.038
NVA040	165.543	165.549	-0.006
NVA041	367.940	368.005	-0.065
NVA043	138.364	138.349	0.015
NVA044	172.056	172.052	0.004
NVA045	209.449	209.501	-0.052
NVA046	331.096	331.083	0.013
NVA047	312.219	312.247	-0.028
NVA049	187.217	187.212	0.005
NVA050	181.143	181.121	0.022
NVA051	286.209	286.272	-0.063
NVA053	405.181	405.134	0.047
NVA054	187.816	187.786	0.030
NVA056	326.155	326.131	0.024
NVA057	271.769	271.709	0.060
NVA058	149.262	149.198	0.064
NVA059	295.249	295.174	0.075
NVA060	188.881	188.849	0.032
NVA061	289.557	289.488	0.069
NVA062	160.043	160.080	-0.037
NVA147	234.836	234.775	0.061
NVA149	175.808	175.786	0.022
NVA150	150.542	150.478	0.064
NVA063	186.505	186.505	0.000
NVA064	226.484	226.461	0.023
NVA066	182.370	182.317	0.053
NVA067	294.405	294.359	0.046
NVA068	338.971	338.910	0.061
NVA069	324.776	324.747	0.029
NVA070	173.408	173.444	-0.036
NVA071	142.351	142.327	0.024
NVA072	267.145	267.097	0.048

NVA074	162.175	162.094	0.081
NVA075	158.293	158.292	0.001
NVA076	138.737	138.659	0.078
NVA077	168.540	168.489	0.051
NVA078	279.589	279.519	0.070
NVA079	287.964	287.897	0.067
NVA080	170.065	170.040	0.025
NVA081	162.524	162.487	0.037
NVA082	233.333	233.230	0.103
NVA083	297.961	297.935	0.026
NVA084	147.496	147.471	0.025
NVA085	177.168	177.122	0.046
NVA086	197.902	197.931	-0.029
NVA087	270.725	270.716	0.009
NVA089	183.466	183.438	0.028
NVA090	346.486	346.482	0.004
NVA091	143.390	143.388	0.002
NVA092	169.637	169.617	0.020
NVA151	291.145	291.135	0.010
NVA153	218.376	218.370	0.006
NVA154	164.046	164.029	0.017
NVA093	121.827	121.776	0.051
NVA094	103.903	103.831	0.072
NVA095	94.063	94.031	0.032
NVA096	139.740	139.751	-0.011
NVA097	168.269	168.218	0.051
NVA098	135.135	135.085	0.050
NVA101	124.292	124.289	0.003
NVA102	123.594	123.552	0.042
NVA103	144.378	144.343	0.035
NVA104	116.966	116.873	0.093
NVA105	163.504	163.468	0.036
NVA106	135.653	135.622	0.031
NVA107	99.244	99.187	0.057
NVA108	171.490	171.440	0.050
NVA109	118.069	118.075	-0.006
NVA110	161.919	161.862	0.057
NVA111	133.643	133.631	0.012
NVA112	133.769	133.773	-0.004
NVA113	149.223	149.154	0.069
NVA114	112.165	112.136	0.029
NVA115	106.300	106.272	0.028
NVA116	147.791	147.758	0.033
NVA117	111.099	111.070	0.029
NVA118	133.878	133.830	0.048
NVA119	144.306	144.271	0.035
NVA155	112.779	112.747	0.032
NVA157	148.015	147.986	0.029
NVA158	162.007	162.012	-0.005
NVA100	113.298	113.258	0.040
NVA120	102.704	102.658	0.046
NVA122	70.091	70.027	0.064
NVA123	52.053	52.004	0.049
NVA124	107.033	106.983	0.050
NVA125	107.708	107.657	0.051
NVA126	129.836	129.754	0.082
NVA127	154.388	154.358	0.030

NVA128	134.111	134.075	0.036
NVA129	89.438	89.335	0.103
NVA130	97.623	97.564	0.059
NVA132	72.660	72.556	0.104
NVA133	100.905	100.831	0.074
NVA135	63.121	63.023	0.098
NVA136	116.272	116.244	0.028
NVA137	122.011	121.898	0.113
NVA138	87.310	87.211	0.099
NVA139	135.466	135.414	0.052
NVA140	134.939	134.894	0.045
NVA141	107.339	107.317	0.022
NVA142	71.178	71.069	0.109
NVA161	110.189	110.064	0.125

NVA Vertical Accuracy Statistics - NSSDA								
Land Cover	# of Pts	RMSEz (cm)	Std Dev (cm)	Mean (cm)	Median (cm)	Skew	Min (cm)	Max (cm)
Bare Earth	115	5.130	3.918	3.332	-3.300	-0.362	-7.100	12.500

NVA Accuracy Assessment Results	
PASS	Tested 10.065 cm vertical accuracy at 95 percent confidence level in bare earth using RMSEz x 1.9600



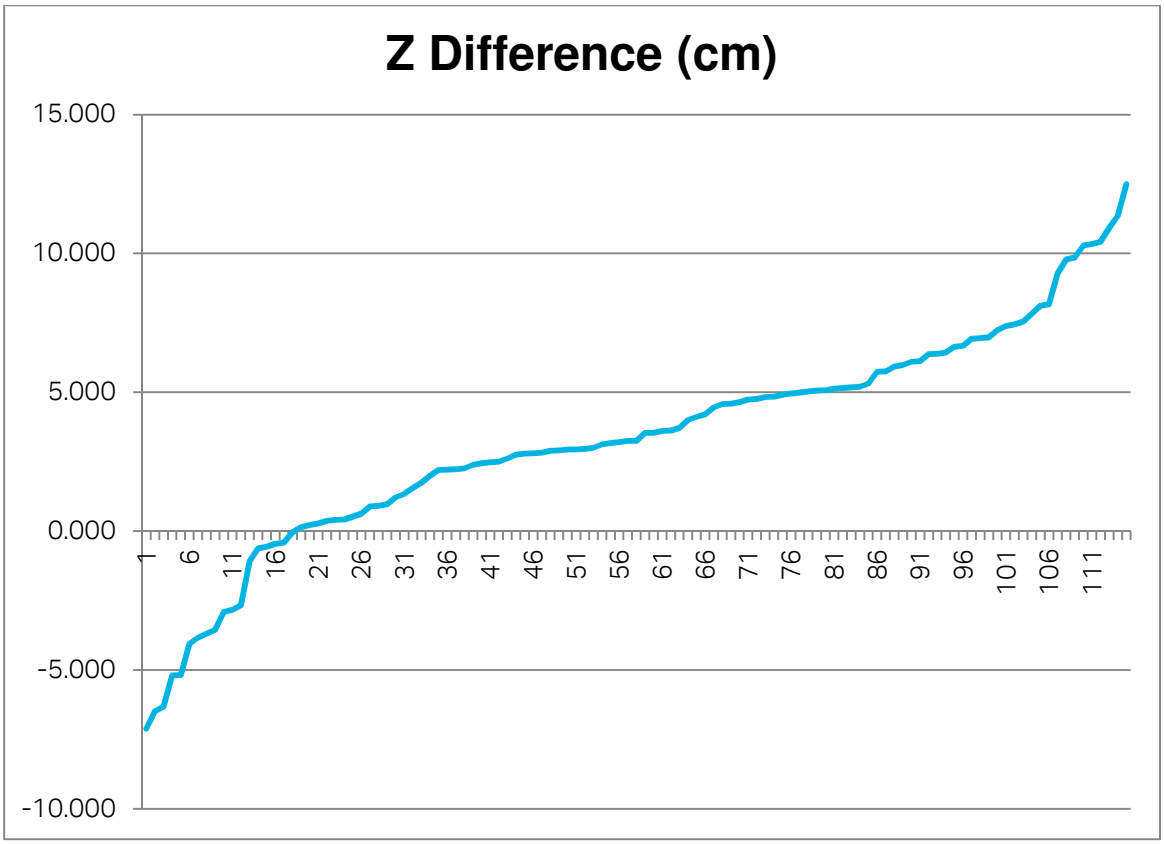
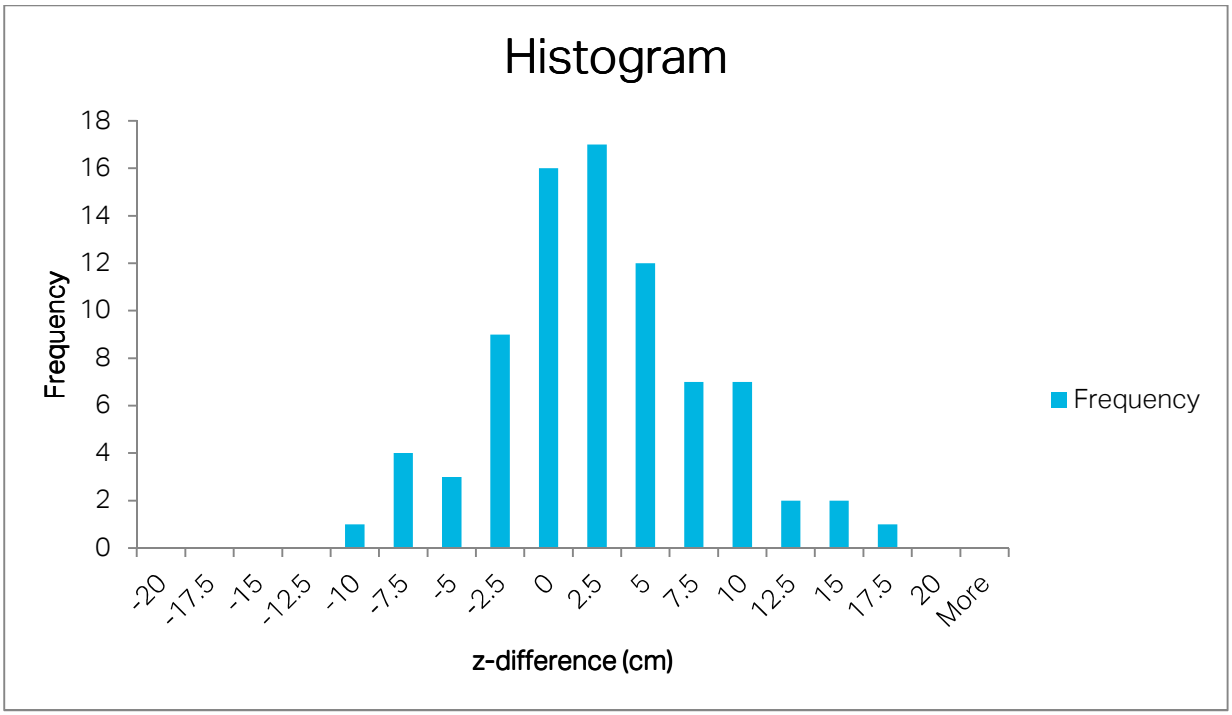

Z Difference (cm)
15.000
10.000
5.000
0.000
-5.000
-10.000
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111

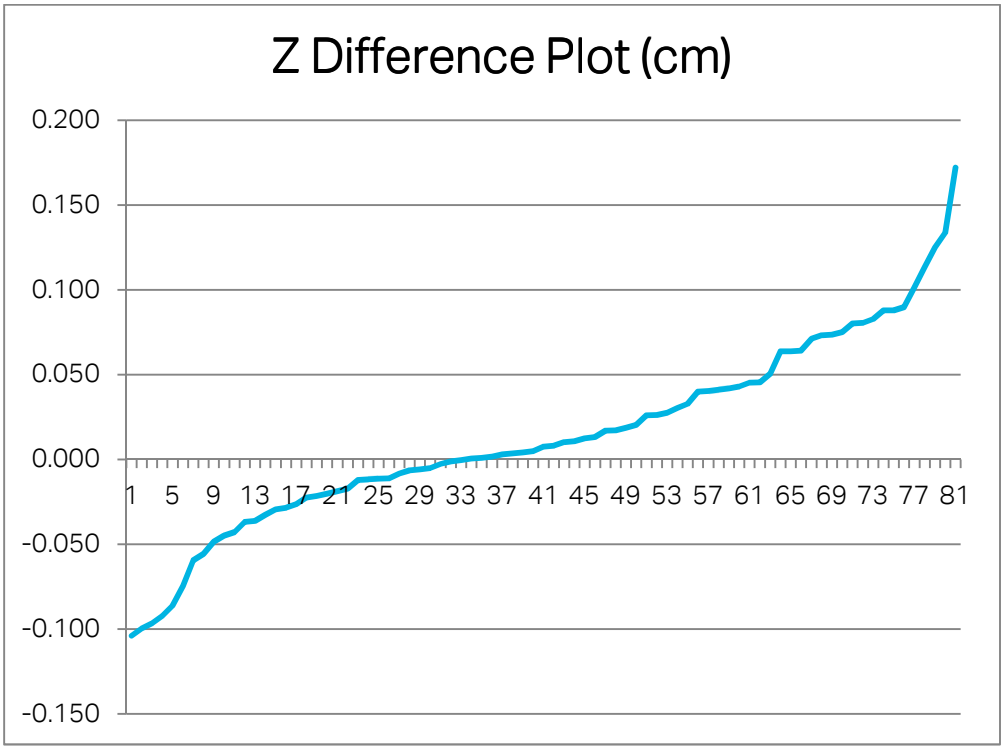
Table 18: DEM VVA Assessment			
UTM Z14N, NAVD88, Geoid 12B, NAD83(2011), Meters			
GPS Point Name	Survey Elevation	DEM Elevation	Difference
VVA027	400.899	400.940	0.041
VVA029	308.722	308.810	0.088
VVA033	282.132	282.196	0.064
VVA036	186.723	186.712	-0.011
VVA049	252.518	252.512	-0.006
VVA067	279.217	279.214	-0.003
VVA069	225.399	225.473	0.074
VVA071	172.232	172.249	0.017
VVA073	181.872	181.902	0.030
VVA082	193.928	194.008	0.080
VVA086	199.833	199.833	0.000
VVA088	134.666	134.791	0.125
VVA092	106.521	106.534	0.013
VVA095	120.755	120.869	0.114
VVA099	118.792	118.809	0.017
VVA100	133.677	133.757	0.080
VVA103	106.820	106.824	0.004
VVA109	106.567	106.577	0.010
VVA113	51.915	51.979	0.064
VVA114	128.981	129.153	0.172
VVA115	95.747	95.643	-0.104
VVA034	271.884	271.835	-0.049
VVA042	151.902	151.973	0.071
VVA047	233.312	233.340	0.028
VVA050	399.117	399.100	-0.017
VVA052	353.242	353.275	0.033
VVA076	291.973	291.953	-0.020
VVA085	345.298	345.338	0.040
VVA101	161.387	161.432	0.045
VVA102	115.026	115.045	0.019
VVA209	112.882	112.924	0.042
VVA111	128.413	128.338	-0.075
VVA116	101.723	101.723	0.000
VVA089	122.813	122.757	-0.056
VVA090	93.899	93.903	0.004
VVA028	331.197	331.186	-0.011
VVA030	293.604	293.649	0.045
VVA041	325.321	325.409	0.088
VVA057	326.012	326.017	0.005
VVA061	368.308	368.442	0.134
VVA064	323.070	323.153	0.083
VVA075	182.474	182.475	0.001
VVA083	269.131	269.171	0.040
VVA084	293.341	293.384	0.043
VVA105	137.388	137.414	0.026
VVA106	123.119	123.121	0.002
VVA026	163.161	163.125	-0.036
VVA037	170.842	170.850	0.008
VVA043	209.816	209.880	0.064
VVA045	168.219	168.292	0.073
VVA046	196.374	196.400	0.026
VVA051	192.601	192.589	-0.012

VVA054	133.954	133.949	-0.005
VVA056	183.576	183.555	-0.021
VVA059	191.390	191.402	0.012
VVA063	147.303	147.217	-0.086
VVA065	212.909	212.876	-0.033
VVA066	161.587	161.487	-0.100
VVA070	228.019	228.030	0.011
VVA074	140.061	140.064	0.003
VVA080_ALT	154.288	154.261	-0.027
VVA081	173.687	173.668	-0.019
VVA087	161.058	161.066	0.008
VVA091	119.836	119.830	-0.006
VVA093	95.596	95.567	-0.029
VVA107	84.670	84.633	-0.037
VVA110	65.002	64.980	-0.022
VVA112	102.598	102.553	-0.045
VVA118	115.601	115.573	-0.028
VVA031	162.348	162.438	0.090
VVA032	239.645	239.665	0.020
VVA040	163.996	164.071	0.075
VVA060	289.454	289.362	-0.092
VVA077	167.414	167.465	0.051
VVA078	165.595	165.552	-0.043
VVA035	199.524	199.625	0.101
VVA038	308.013	307.954	-0.059
VVA062	162.066	161.969	-0.097
VVA068	297.044	297.043	-0.001
VVA096	168.344	168.336	-0.008
VVA097	128.429	128.417	-0.012

Vertical Accuracy Statistics - NSSDA								
Land Cover	# of Pts	RMSEz (cm)	Std Dev (cm)	Mean (cm)	Median (cm)	Skew	Min (cm)	Max (cm)
Bare Earth	81	5.643	5.507	1.373	-0.754	0.217	-10.395	17.214

VVA Accuracy Assessment Results	
PASS	Tested 10.395 cm vertical accuracy at 95th percentile in vegetated areas.


Histogram
Frequency
18
16
14
12
10
8
6
4
2
0
-20
-17.5
-15
-12.5
-10
-7.5
-5
-2.5
0
2.5
5
7.5
10
12.5
15
17.5
20
More
z-difference (cm)
Frequency


Z Difference Plot (cm)
0.200
0.150
0.100
0.050
0.000
-0.050
-0.100
-0.150
1 5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73 77 81

5.1.3 Credits

Organizations involved in the procurement, acquisition, processing, and quality control of this project are identified below.

Table 19: Project Participants

Project Function	Participant
LiDAR procurement	Texas Natural Resources Information System (TNRIS) Texas Water Development Board (TWDB) Williamson County City of Austin (COA), United States Fish and Wildlife Service (USFW) San Antonio River Authority (SARA)
LiDAR acquisition and processing	Fugro
QA checkpoint ground surveys	AECOM subcontractor - CompassData & Associates, L.P.
Accuracy assessment, QA review, and reporting	AECOM Technical Services, Inc.

6 Conclusions

The Central Texas project was a relatively large project having standard TNRIS and USGS QL2 specifications and deliverable requirements. The primary challenge associated with project was the very narrow window within which to acquire, process, QA, and ultimately accept the data. All deadlines were achieved and the data produced was found to be of high quality.

Primary challenges encountered and addressed in the project were the following:

- A sensor issue detected by Fugro which resulted in reacquiring a single lift encompassing several flightlines across the San Antonio AOI.
- Eleven very small LiDAR shadows were detected as part of the QA process. The LiDAR shadows were the result of very tall structures near the edge of LiDAR swaths. It was AECOM's estimation that the size and location of the LiDAR shadows had insignificant impact on the terrain surface in and around these areas.
- Within a very localized area within the LaGrange AOI a missing scan line was detected by Fugro. The terrain in the area of concern is pasture land and/or treed and therefore does not appear to have changed since the 2011 acquisition. The void created by this issue was found to have no significant impact on the resulting digital elevation model created from the point cloud. TNRIS made the USGS aware of this item after which the USGS did not express concern since the area in question was identified, isolated to a single DO4Q tile, and rural.

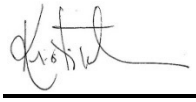
Despite the laborious flight planning steps utilizing the LiDAR manufacturer's planning software, and the numerous subsequent internal checks performed by Fugro, anomalies sometimes present themselves. AECOM's recommends elevating the communication regarding these types of anomalies as part of the Planning Reviews in the future.

All QA issues reported were satisfactorily addressed by Fugro or deemed insignificant and acceptable by TNRIS. Fugro was responsible to prepare and deliver the completed accepted datasets to TNRIS via mobile drive.

The final data sets reviewed by AECOM meet all contractual expectations and be a valuable resource for all project stakeholders.

Geospatial quality assessment conducted by:

Robert T. Riley, PMP, ASPRS CP
AECOM Geospatial QA Manager



Kristi Teykl, GISP
AECOM Project Manager

Kristi Teykl
Project Manager
T: 512.784.2116
E: kristi.teykl@aecom.com

AECOM
9400 Amerglen Blvd.
Austin, Texas 78729

aecom.com