AECOM

Lidar QA/QC for Hays and Williamson Counties

Final Report
580-24-SOW-0004

Texas Water Development Board

August 30, 2024

Delivering a better world

Prepared for:
Texas Water Development Board

Prepared by:
AECOM Technical Services, Inc.

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1. Introduction

1.1 Independent quality assurance and control (QA/QC) for Project 580-24-SOW-0004 was performed by AECOM to validate the lidar data, and various derivative products, meet project specifications, client expectations, and quality standards.

1.2 This project area of interest (AOI) encompasses ~7,000 km^2 in central Texas. Lidar capture requirements were defined as 0.50m nominal point spacing (NPS), or 4 points/m^2, and the NVA vertical accuracy requirement as 10cm RMSEz.

1.3 Project stakeholders included the Texas Water Development Board (TWDB) in cooperation with Hays County, Williamson County, and the cities of Cedar Park, Georgetown, Leander, Round Rock, and San Marcos. The project AOI (~ 2,538 DO4Q tiles) is within Williamson and Hays County, and intersects the Guadalupe, Little, and Middle Colorado-Llano watersheds. The data acquired will be used for dam safety, floodplain management and planning, feature extraction, water quality modeling, stream restoration potential analysis, change detection and emergency management services.

1.4 Fundamental project requirements were to meet, or exceed, TxGIO, 2014 ASPRS, 2024 USGS Lidar Base Specification (LBS) Quality Level (QL) 2. QL2 point density requirement is ≥4 pts/m^2 and an RMSE vertical accuracy ≤ 10 cm in Non-Vegetated Areas. Not all deliverables prescribed in the 2024 LBS were required to be delivered. Specific QA/QC requirements and the results obtained are outlined in the following report for the primary TxGIO data deliverables developed in the UTM projection, including Hydro-flattened Breaklines, Hydro-flattened DEM Rasters, Intensity Rasters, and Metadata.

1.5 All lidar data and derivative products were acquired and processed by Fugro. The findings of this report encompass data deliverables received January 2024 to August 2024.

1.6 Listed below are the QA/QC elements considered during this project, 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 QA/QC 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 Table 1 below.

Independent QA/QC Scope of Work

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

Table 1: AECOM – Independent QA/QC Tasks	
Phase	**Tasks**
Phase I Pre-flight Planning	1. Participate in Kickoff Meeting 2. Review timeline and projected milestones 3. Review Fugro's lidar flight plans and control survey maps 4. Review sensor calibration reports 5. Prepare and submit QA/QC reports
Phase II Data Acquisition	1. Collect QA/QC 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/QC reports
Phase III Data Processing	1. Review lidar and derivative datasets including: a. Classified point cloud tiles b. Swath Polygons c. Hydro-flattened breaklines d. Intensity rasters e. Metadata 3. Review revised data 4. Prepare and submit QA/QC reports
Phase IV Final Product Development	1. Review hydro-flattened DEM rasters and metadata 2. Review revised datasets 3. Prepare and submit QA/QC reports 4. Prepare and submit Final Report

Project Area and Deliverables Received

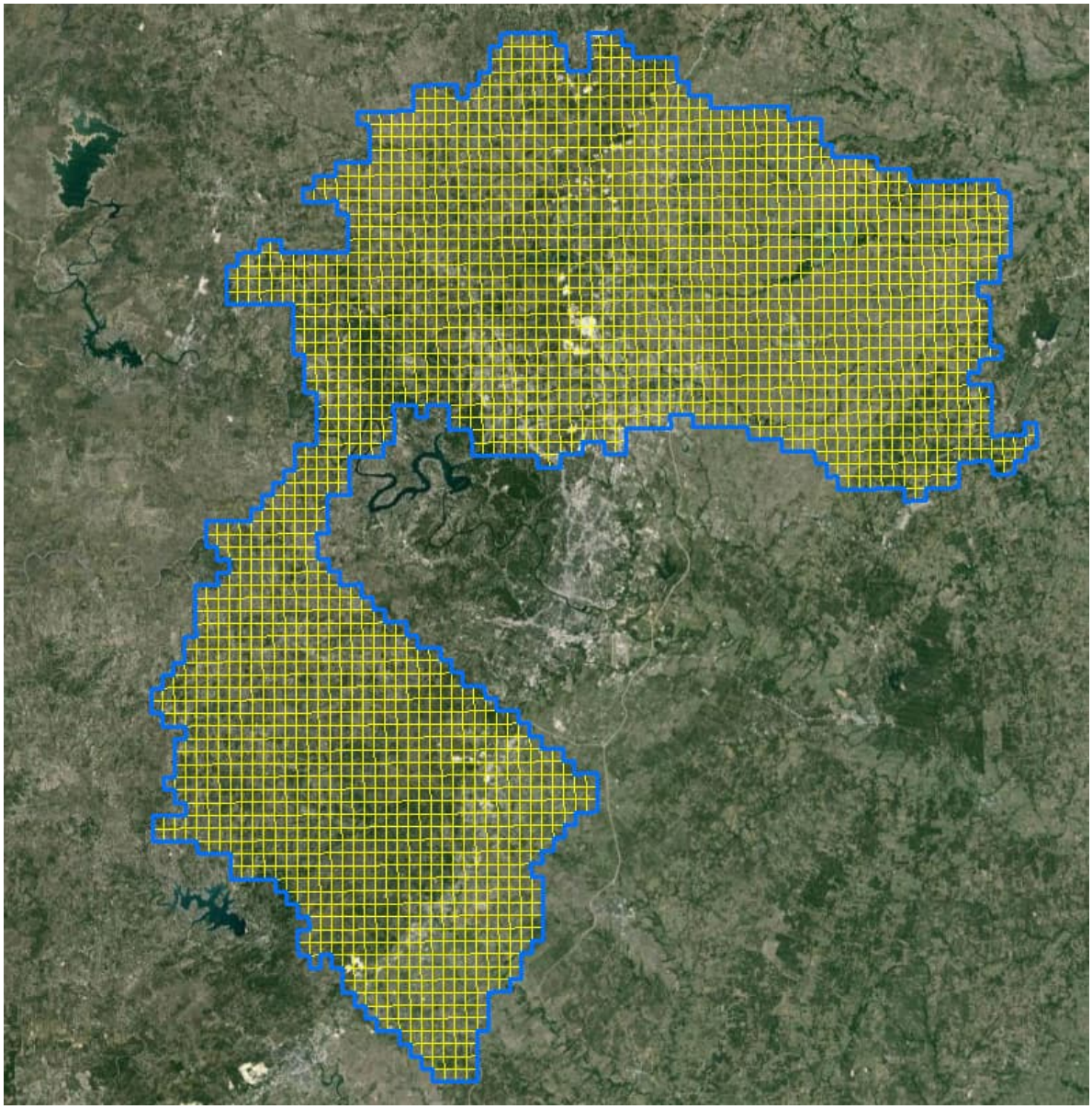


Figure 1 – Project AOI

A breakdown of the AOIs is presented below.

AOI	# TILES	AREA (KM^2)	PPSM	NVA RMSEz	USGS Quality Level
Hays and Williamson	2,681	6,967.84	**4**	≤10 cm	2

The spatial reference system for the project was UTM Zone 14, NAD83(2011), NAVD88 (Geoid18), Meters.

Table 2 lists the TxGIO data deliverables and associated formats AECOM received.

Table 2: Data Deliverables Received	
Deliverable	**Received**
Topographic lidar files in LAZ v1.4 format	Yes
Hydro-flattened bare earth DEM files in GeoPackage format	Yes
Lidar intensity images in GeoTIFF format	Yes
Lidar, DEM, and Intensity tile layouts in ESRI SHP format	Yes
3D breaklines in in GeoPackage format	Yes
Project and tile level metadata in XML format	Yes

Applicable Specifications and Guidelines

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

A. 580-24-SOW-0003.pdf
B. 580-24-SOW-0004.pdf
C. Lidar Base Specification 2023 rev. A
D. ASPRS Positional Accuracy Standards for Digital Geospatial Data (EDITION 1, VERSION 1.0. - NOV, 2014).
E. 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
F. 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
G. 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
H. Maune, David F. Digital Elevation Model Technologies and Applications: The DEM Users Manual, 2nd Edition. 2007.
I. 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
J. 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
K. The National Geodetic Survey. The NGS Geoid Page. 11 September 2012. http://www.ngs.noaa.gov/GEOID/
L. Ritter, Niles and Mike Ruth. GeoTiff Format Specification GeoTiff Revision 1.0. 28 December 2000. http://www.remotesensing.org/geotiff/spec/geotiffhome.html
M. GeoTiff Format Specification, GeoTiff Revision 1.0 (Version 1.8.2). 28 December 2000. http://www.remotesensing.org/geotiff/spec/geotiffhome.html

2. Phase I: Pre-flight Planning

During the project kickoff meeting AECOM reviewed project QA/QC specifications that would be employed and responded to questions. AECOM applied previous established Phase I review procedures to provide reporting on QA/QC tasks.

For Phase I (Pre-flight Planning), 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/QC process during the subsequent acquisition and processing tasks of the project.

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 SOW# 580-24-SOW-0004. AECOM sent clarifying questions to Fugro, the responses to which were deemed acceptable. The overall control layout, including any QA/QC checkpoints, acquisition base stations, and nearest CORS stations was reviewed by AECOM to ensure adequate project coverage and distribution of points.

Table 3 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 80 km or less)*	Yes
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

* Fugro received permission to extend baselines from 40km to 80km prior to data acquisition.

Review and Delivery of QA/QC Checkpoint Survey

The checkpoint survey layout for the QA/QC checkpoints was developed by AECOM referencing USGS and ASPRS specifications with respect to distribution and vegetative cover. ArcGIS basemap imagery was referenced to confirm that control point locations were accessible and to ensure that the locations chosen conformed to project specifications and guidelines.

A vertical accuracy requirement of ≤3.33 cm RMSEz was required for the QL2 NVA checkpoints and an RMSEz of 6.67 cm was required for QL2 VVA checkpoints. NVA and VVA checkpoints supported the vertical accuracy assessments of the lidar and DEM datasets. Where opportunities permitted, AECOM was as aggressive as possible in the utilization of NVA points as horizontal checkpoints. Horizontal NVA points are signified as "*NVA**H**-n*".

CompassData, working as a subcontractor to AECOM, executed the checkpoint field survey. During the planning and establishment of QA/QC checkpoints, AECOM and CompassData frequently coordinated regarding status. CompassData completed survey field work and data processing in February 2024.

Below is a tabular summary of the number of NVA and VVA checkpoints collected as well as their RMSE accuracy specification. A total of 87 NVA and 66 VVA checkpoints were established across the project AOI to assess the topographic lidar data.

Table 4: AOI Summary

AOI	# TILES	AREA (KM^2)	#NVA	#VVA	PPSM	NVA RMSEz	USGS Quality Level	NVA Survey Accuracy
Hays & Williamson	2,681	6,967.84	87	66	4	≤10 cm	2	≤3.33 cm

AECOM reviewed all pertinent documentation submitted by CompassData at the conclusion of the checkpoint collection. The 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. Reported QA/QC point locations were verified against project specifications and control plan layouts. All survey related documentation were delivered to TxGIO in March 2024.

Figure 2 illustrates the locations of NVA and VVA checkpoints distributed across the project AOI and Table 5 lists the types and coordinates and each checkpoint.

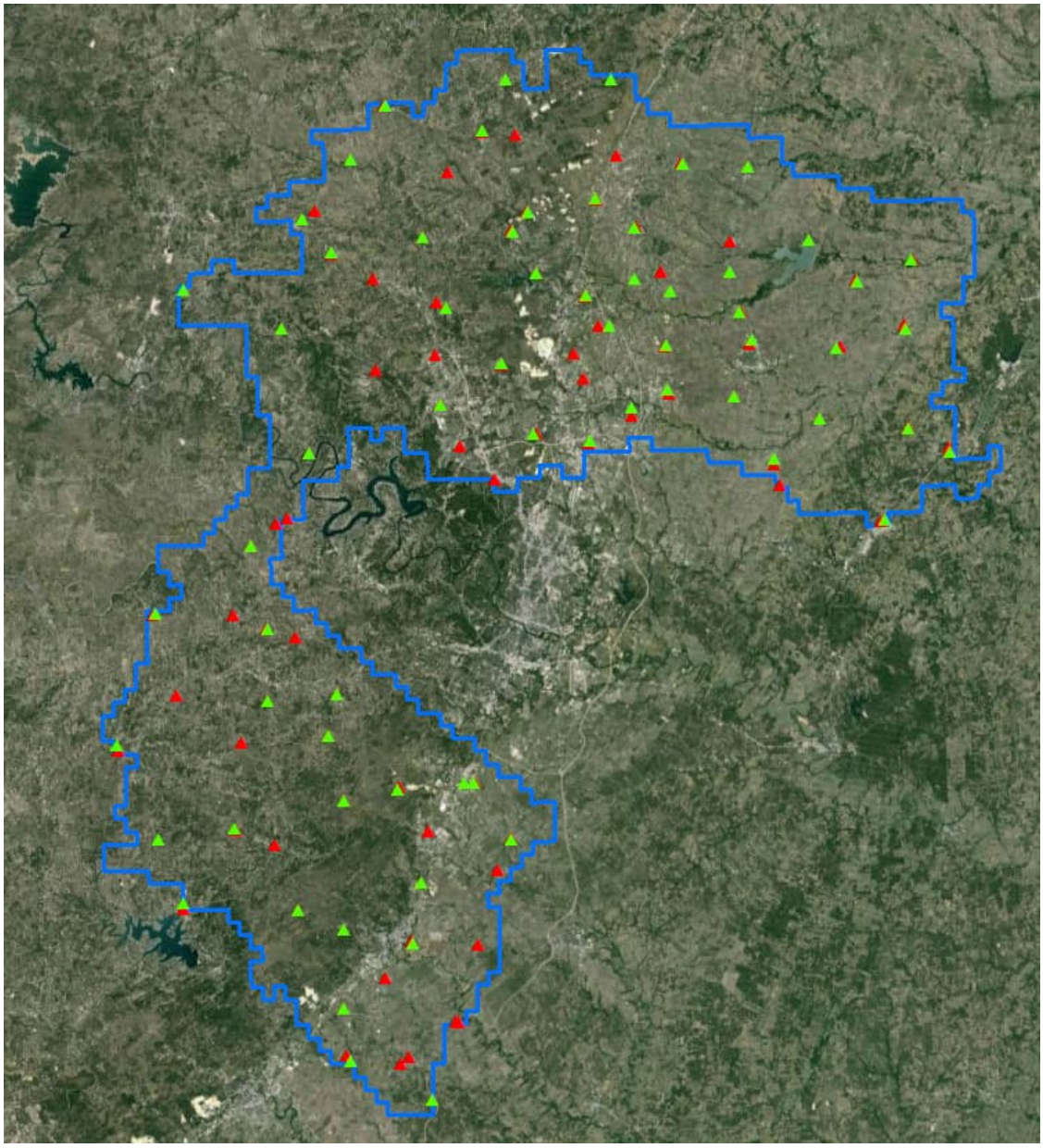


Figure 2 – NVA and VVA Checkpoint Locations

Table 5: Checkpoint Types and Coordinates				
UTM Zone 14, NAD83(2011), NAVD88 (Geoid18), Meters				
Check Point Type	**Point ID**	**X**	**Y**	**Z**
NVA	NVA11	619440.319	3319856.482	180.990
NVA	NVA113	596943.033	3325006.697	303.598
NVA	NVA124	655294.939	3367066.034	184.752
NVA	NVA125A	612292.756	3295366.302	161.432
NVA	NVA127	582305.945	3349666.232	368.430
NVA	NVA128	587772.438	3318988.733	267.153
NVA	NVA13	596992.528	3297207.669	186.432
NVA	NVA133	600868.380	3394591.693	317.553
NVA	NVA137	602579.721	3301265.718	182.853
NVA	NVA138	614885.821	3305706.055	179.981

NVA	NVA141	619859.647	3413899.583	286.323
NVA	NVA143	617518.506	3315717.321	184.657
NVA	NVA144A	587876.056	3361985.213	242.288
NVA	NVA145	628981.430	3381254.176	239.839
NVA	NVA17	609883.778	3377822.883	308.351
NVA	NVA28	571449.426	3349727.009	357.665
NVA	NVA29	651009.597	3409535.110	182.925
NVA	NVA35	582511.232	3321148.714	330.877
NVA	NVA37	607397.442	3314086.801	199.474
NVA	NVA39	604664.598	3289853.364	148.769
NVA	NVA41	597061.202	3307751.225	254.476
NVA	NVA45	595007.711	3333613.507	292.168
NVA	NVA58	648498.519	3399561.423	176.041
NVA	NVA66	659072.940	3399767.765	166.186
NVA	NVA70	588700.048	3387951.074	349.833
NVA	NVA72	592411.565	3371401.285	223.282
NVA	NVA77	597384.596	3290935.065	171.114
NVA	NVA9	614468.281	3327356.309	214.633
NVA	NVA91A	566970.427	3331596.580	409.117
NVA	NVAH1	629674.445	3372630.027	242.626
NVA	NVAH101	601231.444	3382312.330	279.776
NVA	NVAH103	619441.337	3401002.184	263.620
NVA	NVAH105	665394.067	3394401.482	153.057
NVA	NVAH107	649036.213	3378943.245	184.664
NVA	NVAH110	602279.681	3417763.803	342.498
NVA	NVAH115	590945.553	3310313.482	308.342
NVA	NVAH118	630773.133	3405169.371	280.166
NVA	NVAH119	609382.968	3391435.326	304.823
NVA	NVAH120	642129.400	3410087.189	209.151
NVA	NVAH122	622646.324	3395412.895	267.615
NVA	NVAH125	612043.368	3295555.443	162.837
NVA	NVAH126	608330.123	3320826.109	222.921
NVA	NVAH129	627762.476	3384640.970	272.960
NVA	NVAH130	617074.812	3367858.730	290.791
NVA	NVAH131	612452.137	3372185.201	289.981
NVA	NVAH132	583270.490	3332734.139	396.929
NVA	NVAH134	609174.300	3384369.867	306.472
NVA	NVAH135	590567.436	3346655.965	348.323
NVA	NVAH139	639799.192	3385615.925	209.995
NVA	NVAH140	639251.179	3395524.703	219.129
NVA	NVAH142	633378.169	3411060.810	267.826
NVA	NVAH144	589435.983	3362681.253	247.850
NVA	NVAH15	606027.178	3306339.381	178.965
NVA	NVAH21	618122.503	3383117.787	291.737
NVA	NVAH23	629224.522	3392288.356	208.939
NVA	NVAH25	651196.531	3385858.340	185.125
NVA	NVAH3	635459.406	3376317.784	220.350
NVA	NVAH31	622715.621	3373955.948	248.085
NVA	NVAH33	586778.989	3338237.595	347.470
NVA	NVAH36	608761.289	3285042.925	207.672
NVA	NVAH39	605600.007	3290772.310	160.861
NVA	NVAH43	575579.188	3310564.762	301.901
NVA	NVAH47	584593.153	3358913.077	253.999
NVA	NVAH49	615468.163	3414267.553	319.820
NVA	NVAH5	640424.924	3379262.154	196.090
NVA	NVAH51	593045.739	3403690.428	348.768
NVA	NVAH53	610789.599	3408742.828	312.942
NVA	NVAH54	607594.094	3400123.945	301.269
NVA	NVAH56	621352.759	3403522.926	269.531

NVA	NVAH60	654480.944	3369831.748	160.869
NVA	NVAH62	671883.694	3388475.318	138.663
NVA	NVAH64	672974.649	3397253.329	124.732
NVA	NVAH68	595353.374	3397994.708	342.846
NVA	NVAH7	596100.816	3339171.546	368.329
NVA	NVAH74	586707.723	3347887.996	380.261
NVA	NVAH76	574582.433	3338983.353	414.571
NVA	NVAH79	604150.755	3326427.021	249.738
NVA	NVAH79A	604335.611	3326802.057	248.285
NVA	NVAH81	668743.156	3362239.163	156.302
NVA	NVAH83	677774.260	3372071.996	141.729
NVA	NVAH85	672456.422	3374749.098	150.187
NVA	NVAH87	660611.756	3375975.404	156.179
NVA	NVAH89	663309.406	3385458.083	171.601
NVA	NVAH91	566952.626	3331585.768	410.450
NVA	NVAH94	636055.587	3401578.413	238.021
NVA	NVAH96	631082.903	3388369.000	235.233
NVA	NVAH98	650019.100	3390239.166	171.092
VVA	VVA10	614465.279	3327330.678	215.360
VVA	VVA100	640531.513	3392969.428	202.987
VVA	VVA102	618648.992	3421126.004	258.371
VVA	VVA104	619457.997	3400953.432	261.473
VVA	VVA106	665599.273	3394310.715	149.815
VVA	VVA108	649149.596	3378908.034	182.962
VVA	VVA109	597953.067	3410486.699	319.227
VVA	VVA111	602546.520	3417623.929	341.474
VVA	VVA112	632758.289	3421154.916	211.334
VVA	VVA114	596995.276	3324985.556	299.937
VVA	VVA116	590948.452	3310374.861	312.327
VVA	VVA117	572273.107	3319787.937	367.162
VVA	VVA119	630723.182	3405348.008	282.809
VVA	VVA12	619454.101	3319853.133	181.335
VVA	VVA121	642195.968	3409996.009	208.201
VVA	VVA123	629295.625	3392332.019	209.118
VVA	VVA14	596982.096	3297222.143	185.677
VVA	VVA16	606171.747	3305969.034	177.477
VVA	VVA18	609890.386	3377846.153	307.643
VVA	VVA2	629912.482	3373046.873	247.132
VVA	VVA20	610729.900	3390765.958	325.911
VVA	VVA22	618100.322	3383380.568	299.121
VVA	VVA24	622672.312	3395350.183	266.809
VVA	VVA26	651485.514	3386480.595	185.514
VVA	VVA27	571846.400	3349843.014	357.565
VVA	VVA30	651032.332	3409630.623	180.937
VVA	VVA32	622369.245	3373981.620	252.008
VVA	VVA34	586814.796	3338228.522	347.032
VVA	VVA36	582382.212	3321167.324	336.332
VVA	VVA38	607418.806	3314101.201	199.231
VVA	VVA4	635526.845	3377451.544	204.204
VVA	VVA40	608799.784	3284993.180	205.672
VVA	VVA42	597035.769	3307726.732	254.290
VVA	VVA44	575599.491	3311227.299	325.770
VVA	VVA46	595015.745	3333626.426	292.339
VVA	VVA48	584592.181	3358949.845	254.793
VVA	VVA50	615559.321	3414288.943	319.205
VVA	VVA52	591491.975	3402463.962	371.054
VVA	VVA55	607612.322	3400088.123	299.838
VVA	VVA57	621516.326	3403469.495	275.181
VVA	VVA59	648562.432	3395527.655	179.532

VVA	VVA6	640313.734	3379869.566	198.946
VVA	VVA61	654514.259	3370529.774	166.682
VVA	VVA63	671972.244	3387893.174	136.377
VVA	VVA65	672774.959	3397147.950	128.657
VVA	VVA67	659027.928	3399828.183	165.792
VVA	VVA69	595361.740	3398096.860	342.253
VVA	VVA700	640041.751	3385750.917	209.915
VVA	VVA701	635820.152	3394564.067	208.306
VVA	VVA704	613074.737	3327270.255	228.865
VVA	VVA71	588678.919	3387930.046	349.684
VVA	VVA73	592406.232	3371359.816	223.372
VVA	VVA75	586762.695	3347769.080	374.719
VVA	VVA78	597978.824	3290161.320	169.050
VVA	VVA8	596170.280	3339229.670	361.728
VVA	VVA80	604186.559	3326423.760	247.956
VVA	VVA82	669306.824	3362358.813	155.400
VVA	VVA84	677952.654	3371585.153	143.986
VVA	VVA86	672386.472	3374707.110	150.752
VVA	VVA88	660625.579	3375963.207	154.827
VVA	VVA90	662805.524	3385342.699	170.966
VVA	VVA92	566683.811	3332272.233	424.739
VVA	VVA93	575643.171	3393163.161	336.955
VVA	VVA95	635813.023	3401433.214	248.611
VVA	VVA97	632529.784	3388313.455	225.674
VVA	VVA99	649903.823	3390224.792	172.079

3. Phase II: Data Acquisition

The following QA/QC actions were performed after the aerial acquisition of the lidar data.

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 1.0 second intervals (TxGIO specification required 0.5s intervals but 1.0s was approved by TxGIO), were compared against the planned flight plans (Figure 3). A comparison of the planned flight lines and trajectories as they were flown is included below. The as-flown data aligned well with the planned datasets.

Collection Conditions Checklist

Collection Conditions Checks	
Atmospheric conditions cloud and fog free between the aircraft and ground during all collection operations.	Reporting suggests requirement achieved
Ground conditions will be snow free. Very light, undrifted snow may be acceptable with prior approval.	Reporting suggests requirement achieved
Ground conditions shall be free of extensive flooding or any other type of inundation.	Reporting suggests requirement achieved
Leaf-off vegetation conditions are preferred.	Reporting suggests requirement achieved
Penetration to the ground shall be adequate to produce an accurate and reliable bare-earth surface for the prescribed QL	Reporting suggests requirement achieved

USGS LBS 2023 Acquisition Checklist

Acquisition Summary Checks	
Lidar acquisition report in PDF format	Meets Specifications
Flight logs in PDF format	Meets Specifications
Flight logs reference base airport ID, aircraft ID, pilot, sensor operator, acquisition dates, start/stop times, flight line IDs, PDOP recordings per flight line, issues or observations worth noting as it related to data collection	Meets Specifications
Flight logs indicate leaf-off and no significant snow cover or flood conditions, no cloud, smoke, dust, and/or fog-free between the aircraft and ground	Meets Specifications
At least two (2) GPS reference stations in operation during all missions, sampling positions at 1 Hz or higher frequently	Does not apply. TxGIO approved referencing of VRS/RTK stations during flight
Differential GPS baseline lengths shall not exceed 40 km, unless otherwise approved	Does not apply. TxGIO approved baselines exceeding 40km.
Differential GPS unit in aircraft shall sample position at 2 Hz or more frequently	Fugro system limited to 1Hz
Lidar data shall only be acquired when GPS PDOP is ≤ 4 and ≥ least 6 satellites are in view	Meets Specifications
Flight report should include at a minimum the following mission parameters: sensor make and model, nominal ground sampling distance, scan angle, average groundspeed, laser pulse rate, scan rate, and average flying altitude. Network parameters with base station IDs and location should be included as well as flight PDOP.	Meets Specifications
Minimum 30% overlap on adjacent swaths	Does not apply. TxGIO approved Fugro to acquire ~20% overlap
Congested downtown areas with tall structures) planned for accordingly, if required?	Meets Specifications Additional flightlines acquired in congested downtown like areas
Sensor make(s) and model(s) referenced	Meets Specifications
Flight Trajectories in SHP point format	Meets Specifications
Trajectory attributes include recorded aircraft position (easting, northing, elevation) and attitude (heading, pitch, and roll) and Adjusted GPS time recorded at regular intervals of 1 second or less and delivered in ESRI feature class or shapefile format. May include additional attributes.	Meets Specifications
Timestamps are ~ ≤1 Hz	Meets Specifications
Actual flightlines extend 300m beyond project AOI	Meets Specifications
Actual flightlines closely mimic planned flightlines	Meets Specifications
Inter-flightline distance consistent	Meets Specifications
Data acquisition status update methodology and frequency	Meets Specifications Weekly updates via email

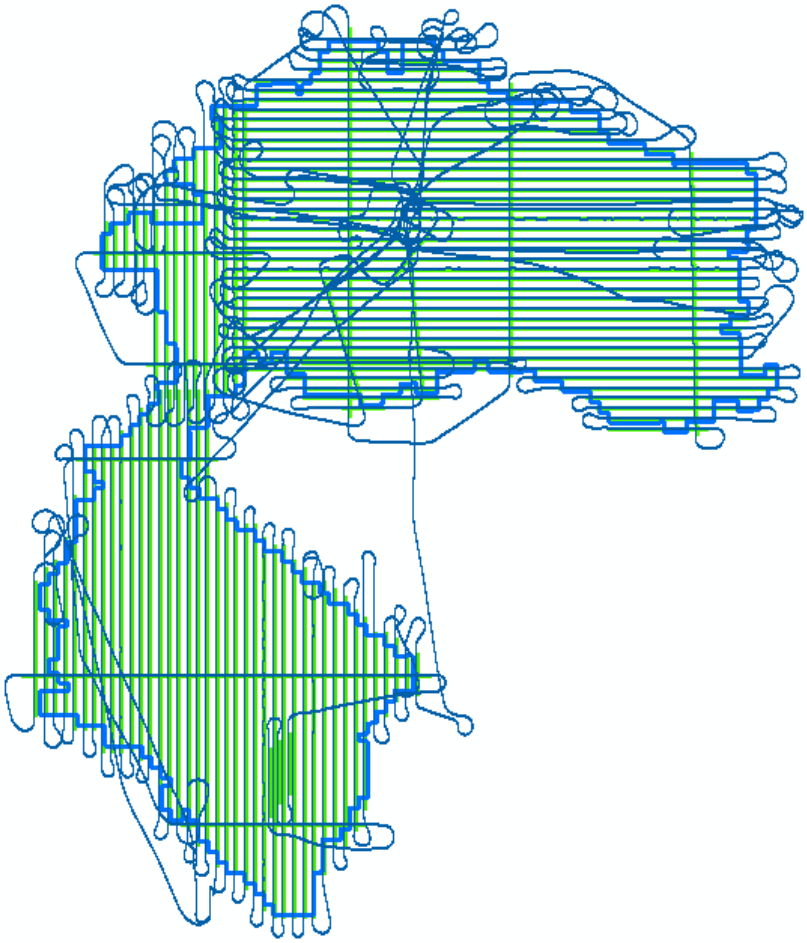


Figure 3 – Hays-Williamson AOI Lidar Flight Lines - Planned (green) and Actual (blue)

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 instantaneous/spurious noise or 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 Fugro's browser-based tracking system from acquisition commencement to completion.

Post-flight: Ground Control Review

Fugro provided a detailed survey report identifying the control network used and the spatial parameters associated with the network. The description of survey processes and methodology provided suggests the ground control data meets the horizontal and vertical accuracy specifications.

The control report included tabular data in XLS, CSV, GPKG, 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, as can be seen in Figure 4.

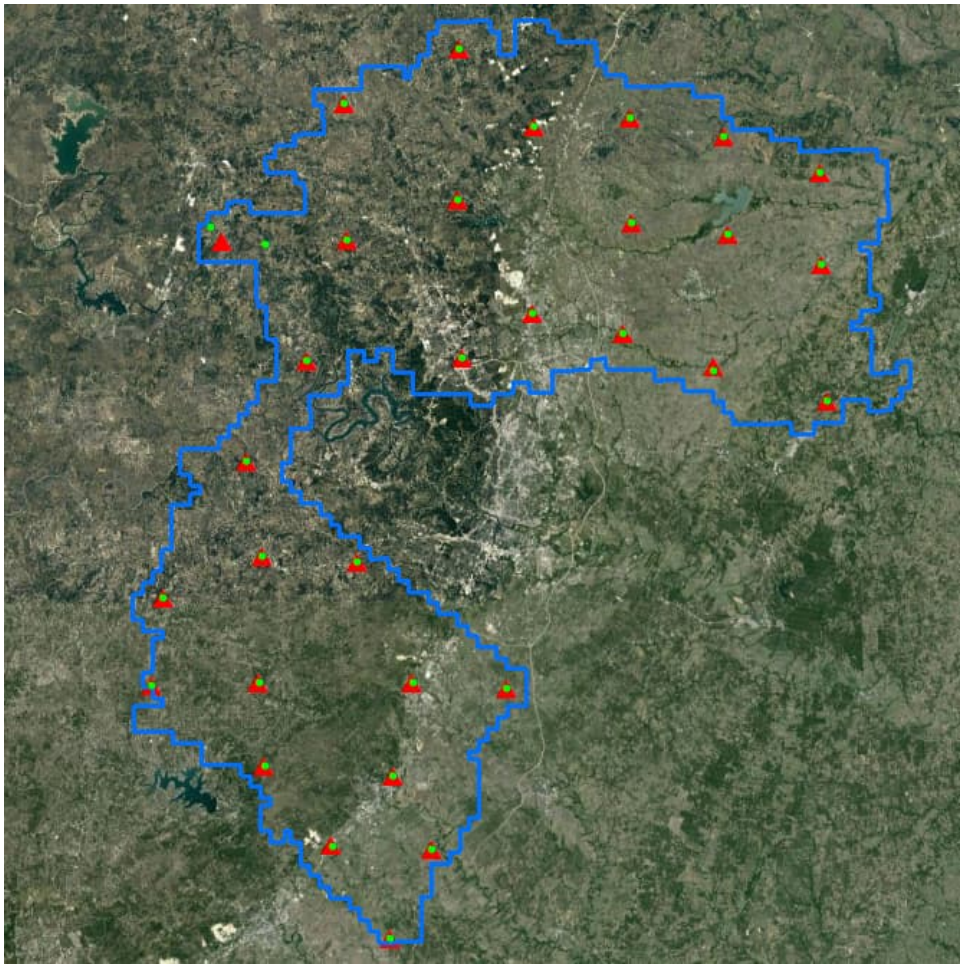


Figure 4 - Lidar Planned Control Locations (red triangle) and Actual Control Locations (green point)

Survey Point Deliverable Checklist

Survey Point Checks	
Micro Checks	
Ground survey report provided in PDF format	Meets Specifications
Ground control provided in SHP or GDB or GeoPackage format	Meets Specifications
Ground control provided in NAD83(2011), UTM Zone 14, NAVD88, Geoid 18, Meters	Meets Specifications
Ground control provided in XLS or CSV format with 3 decimal precision, point ID, and land cover type, at a minimum.	Meets Specifications
Absolute and relative accuracy of the data, both horizontal and vertical, and relative to known control, shall be verified prior to classification and subsequent product development. General survey accuracy statement (and $RMSE_{xyz}$ values) included indicating accuracy of the survey is within the project requirement where the ground control must be 4X more accurate than the delivered product	Meets Specifications
Actual ground control locations rest within 5km of planned locations	Meets Specifications
At least 3 different perspective photos of each control point location are provided in JPG format, or incorporated in the survey report PDF document	Meets Specifications

4. Phase III: Data Processing

The following QA/QC reviews were conducted during the Data Processing and Final Product Development phases.

Quality Assessment

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

Software Used

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

- *TerraSolid TerraScan & LAStools* - 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
- *GeoCue 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

Quality Assessment Process

The following systematic Macro and Micro QA/QC 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/QC processing models were run on the DEM files to isolate data voids, pits and spikes
    - QA/QC 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 TxGIO and Fugro

Macro and Micro Review Quality Assessment Results

Classified Lidar Point Cloud

Macro Checks	
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
LAS Number Variable Length Records Present	Meets specifications
Point Source ID assigned	Meets specifications
LAS Point Data Record Format - 6	Meets specifications
LAS Global Encoding Bit set to 17	Meets Specifications
UTM Zone 14, NAVD88, Geoid 18, NAD83(2011), Meters	Meets specifications
At least 3 returns per pulse	Meets specifications
Acceptable classes - 1,2,3,4,5,6,7,9,10,13,14,18,20	Meets specifications
Analysis	
No points have LAS Overlap Flag set	Meets specifications
LAS Withheld Flag - Geometrically unreliable points flagged as Withheld in Classified point clouds	Meets specifications
Horizontal Accuracy Check - RMSE ≤ 0.25 m	Meets specifications
Vertical Accuracy Check - NVA ($RMSE_z$ ≤ 0.10 m, 95% CI ≤ 0.196 m)	Meets specifications
Vertical Accuracy Check - VVA (≤ 0.30 m 95th Percentile)	Meets specifications
Inter-swath Accuracy (RMSEDz ≤ 0.08m)	Meets specifications
Intra-swath Accuracy (RMSEDz ≤ 0.06m)	Meets Specifications
ANPS ≤ 0.50 m *OR* ANPD ≥ 4.0 pts/m^2	Meets specifications
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
Duplicate Points (X, Y, Z, AND TIME)	Meets specifications
Gross Anomaly Check	
Extreme intensity values	Meets specifications
Systematic data dropouts	Meets specifications
Micro Checks	
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, 14=culverts, 17=bridges, 18=high noise, 20=ignored ground (near BL))	
Consistency in filtering	Meets specifications
Classification accuracy (misclassification)	Meets specifications
Building sides are C6 not veg	Meets specifications
Data voids/gaps ≥ 4x($ANPS^2$) = 1.0 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 Checks	
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, 8, 16, or 32bit U	Meets specifications
Resolution ≤ 1.0 m	Meets specifications
UTM Zone 14, NAVD88, Geoid 18, NAD83(2011), Meters	Meets specifications
Micro QA/QC Checks	
Uniformity/consistency across swath	Meets specifications
No over or under saturation/Extreme intensity values	Meets specifications

Hydro-flattened Breaklines

Macro Checks	
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 GeoPackage format	Meets specifications
.PRJ file present	N/A. GPKG provided
UTM Zone 14, NAVD88, Geoid 18, NAD83(2011), 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
Micro Checks	
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 8,000 m^2 collected	Meets specifications
Islands greater than 4,000 m^2 collected	Meets specifications

Vertical Accuracy Assessment

Relative Vertical Accuracy

Intraswath vertical relative accuracy was tested using 4,369, First Return, Single Swath points on a 1m grid residing on several dispersed airport tarmacs. An overall average RMSEz of 0.037 meters was measured. The specification tolerance is 0.06 meters. For the sake of brevity, a table has not be included in this report

Interswath accuracy was assessed using the USGS's DQM (Data Quality Measure) Tool. The DQM tool assesses horizontal and vertical alignment between swaths. The DQM tool is purpose built by the USGS and is a much more sophisticated tool to assess interswath alignment. For this project 1,000 well distributed assessment locations were generated for each tile. Hence ~2,681,000 swath comparison points were used to perform the interswath assessment.

Absolute Vertical Accuracy

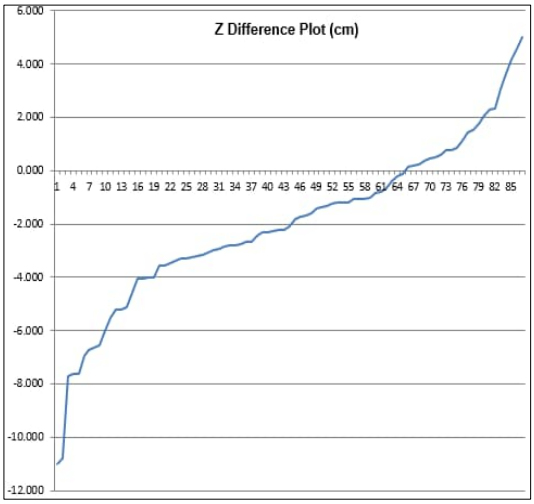
Vertical accuracy of lidar data will be achieved by comparing the elevation of Class 2 Bare Earth points against the QA/QC checkpoint elevation values. Deviations were reported as an RMSE and @95% confidence for NVA assessments and @95th Percentile for VVA assessments.

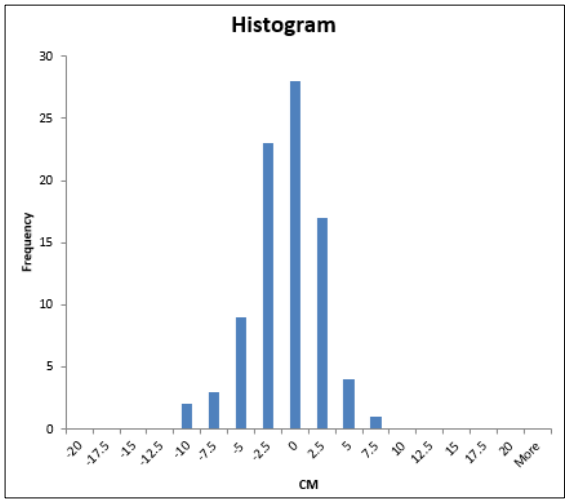
NVA Accuracy Assessment

Table 6: LAS NVA Assessment
UTM Zone 14, NAD83(2011), NAVD88 (Geoid18), Meters

GPS Point Name	Survey Elevation	Lidar Elevation	Difference
NVA11	180.990	180.963	-0.027
NVA113	303.598	303.640	0.042
NVA124	184.752	184.712	-0.040
NVA125A	161.432	161.425	-0.007
NVA127	368.430	368.402	-0.028
NVA128	267.153	267.141	-0.012
NVA13	186.432	186.380	-0.052
NVA133	317.553	317.530	-0.023
NVA137	182.853	182.842	-0.011
NVA138	179.981	180.002	0.021
NVA141	286.323	286.293	-0.030
NVA143	184.657	184.597	-0.060
NVA144A	242.288	242.284	-0.004
NVA145	239.839	239.815	-0.024
NVA17	308.351	308.315	-0.036
NVA28	357.665	357.657	-0.008
NVA29	182.925	182.915	-0.010
NVA35	330.877	330.855	-0.022
NVA37	199.474	199.463	-0.011
NVA39	148.769	148.786	0.017
NVA41	254.476	254.526	0.050
NVA45	292.168	292.135	-0.033
NVA58	176.041	176.001	-0.040
NVA66	166.186	166.201	0.015
NVA70	349.833	349.816	-0.017
NVA72	223.282	223.248	-0.034
NVA77	171.114	171.119	0.005
NVA9	214.633	214.619	-0.014
NVA91A	409.117	409.105	-0.012
NVAH1	242.626	242.586	-0.040
NVAH101	279.776	279.700	-0.076

NVAH103	263.620	263.592	-0.028
NVAH105	153.057	153.088	0.031
NVAH107	184.664	184.588	-0.076
NVAH110	342.498	342.502	0.004
NVAH115	308.342	308.365	0.023
NVAH118	280.166	280.058	-0.108
NVAH119	304.823	304.825	0.002
NVAH120	209.151	209.130	-0.021
NVAH122	267.615	267.569	-0.046
NVAH125	162.837	162.852	0.015
NVAH126	222.921	222.855	-0.066
NVAH129	272.960	272.908	-0.052
NVAH130	290.791	290.755	-0.036
NVAH131	289.981	289.911	-0.070
NVAH132	396.929	396.952	0.023
NVAH134	306.472	306.470	-0.002
NVAH135	348.323	348.290	-0.033
NVAH139	209.995	210.041	0.046
NVAH140	219.129	219.137	0.008
NVAH142	267.826	267.798	-0.028
NVAH144	247.850	247.783	-0.067
NVAH15	178.965	178.973	0.008
NVAH21	291.737	291.704	-0.033
NVAH23	208.939	208.911	-0.028
NVAH25	185.125	185.107	-0.018
NVAH3	220.350	220.327	-0.023
NVAH31	248.085	248.062	-0.023
NVAH33	347.470	347.472	0.002
NVAH36	207.672	207.662	-0.010
NVAH39	160.861	160.870	0.009
NVAH43	301.901	301.937	0.036
NVAH47	253.999	253.932	-0.067
NVAH49	319.820	319.821	0.001
NVAH5	196.090	196.013	-0.077
NVAH51	348.768	348.756	-0.012
NVAH53	312.942	312.929	-0.013
NVAH54	301.269	301.247	-0.022
NVAH56	269.531	269.517	-0.014
NVAH60	160.869	160.853	-0.016
NVAH62	138.663	138.623	-0.040
NVAH64	124.732	124.743	0.011
NVAH68	342.846	342.834	-0.012
NVAH7	368.329	368.335	0.006
NVAH74	380.261	380.230	-0.031
NVAH76	414.571	414.576	0.005
NVAH79	249.738	249.730	-0.008
NVAH79A	248.285	248.250	-0.035
NVAH81	156.302	156.273	-0.029
NVAH83	141.729	141.699	-0.030
NVAH85	150.187	150.161	-0.026
NVAH87	156.179	156.147	-0.032
NVAH89	171.601	171.600	-0.001
NVAH91	410.450	410.433	-0.017
NVAH94	238.021	237.970	-0.051
NVAH96	235.233	235.178	-0.055
NVAH98	171.092	170.982	-0.110





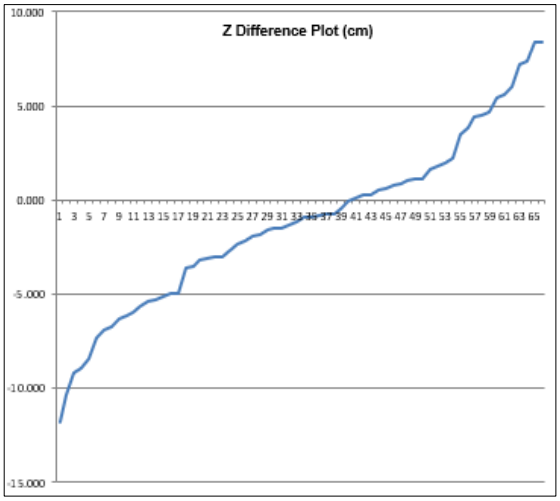
Vertical Accuracy Statistics - NSSDA									
# of Pts	RMSEz (cm)	Std Dev (cm)	Mean (cm)	Median (cm)	Skew	Min (cm)	Max (cm)	95% CI (cm) (RMSE * 1.96)	95TH (cm) Percentile
87	3.679	3.091	-2.021	2.080	-0.343	-11.025	5.002	7.210	7.419

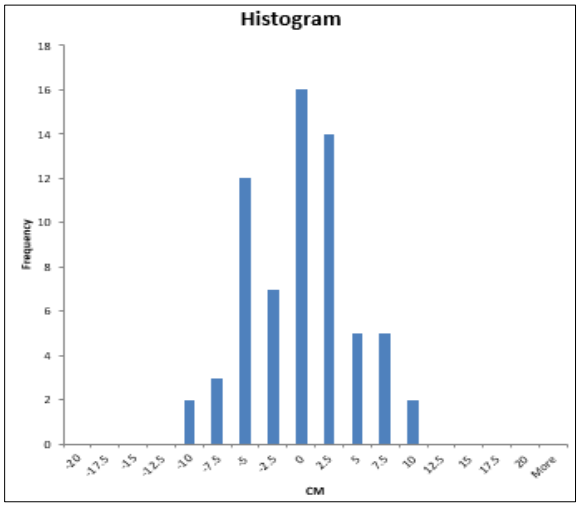
NVA Accuracy Assessment Results	
PASS	Tested 7.210 cm vertical accuracy at 95% confidence level in bare earth using RMSEz x 1.9600.

VVA Accuracy Assessment

Table 7: LAS VVA Assessment UTM Zone 14, NAD83(2011), NAVD88 (Geoid18), Meters			
GPS Point Name	Survey Elevation	Lidar Elevation	Difference
VVA10	215.360	215.306	0.054
VVA100	202.987	203.018	-0.031
VVA102	258.371	258.287	0.084
VVA104	261.473	261.546	-0.073
VVA106	149.815	149.904	-0.089
VVA108	182.962	182.953	0.009
VVA109	319.227	319.234	-0.007
VVA111	341.474	341.524	-0.050
VVA112	211.334	211.324	0.010
VVA114	299.937	300.029	-0.092
VVA116	312.327	312.411	-0.084
VVA117	367.162	367.197	-0.035
VVA119	282.809	282.791	0.018
VVA12	181.335	181.324	0.011
VVA121	208.201	208.216	-0.015
VVA123	209.118	209.127	-0.009
VVA14	185.677	185.738	-0.061
VVA16	177.477	177.528	-0.051
VVA18	307.643	307.670	-0.027
VVA2	247.132	247.144	-0.012
VVA20	325.911	325.929	-0.018
VVA22	299.121	299.083	0.038
VVA24	266.809	266.765	0.044
VVA26	185.514	185.530	-0.016

VVA27	357.565	357.580	-0.015
VVA30	180.937	180.960	-0.023
VVA32	252.008	252.002	0.006
VVA34	347.032	347.099	-0.067
VVA36	336.332	336.297	0.035
VVA38	199.231	199.349	-0.118
VVA4	204.204	204.157	0.047
VVA40	205.672	205.728	-0.056
VVA42	254.290	254.289	0.001
VVA44	325.770	325.771	-0.001
VVA46	292.339	292.352	-0.013
VVA48	254.793	254.733	0.060
VVA50	319.205	319.237	-0.032
VVA52	371.054	371.049	0.005
VVA55	299.838	299.898	-0.060
VVA57	275.181	275.190	-0.009
VVA59	179.532	179.529	0.003
VVA6	198.946	199.009	-0.063
VVA61	166.682	166.735	-0.053
VVA63	136.377	136.384	-0.007
VVA65	128.657	128.693	-0.036
VVA67	165.792	165.718	0.074
VVA69	342.253	342.283	-0.030
VVA700	209.915	210.019	-0.104
VVA701	208.306	208.328	-0.022
VVA704	228.865	228.857	0.008
VVA71	349.684	349.668	0.016
VVA73	223.372	223.352	0.020
VVA75	374.719	374.788	-0.069
VVA78	169.050	169.028	0.022
VVA8	361.728	361.747	-0.019
VVA80	247.956	248.010	-0.054
VVA82	155.400	155.389	0.011
VVA84	143.986	143.994	-0.008
VVA86	150.752	150.707	0.045
VVA88	154.827	154.755	0.072
VVA90	170.966	170.882	0.084
VVA92	424.739	424.789	-0.050
VVA93	336.955	336.952	0.003
VVA95	248.611	248.641	-0.030
VVA97	225.674	225.618	0.056
VVA99	172.079	172.084	-0.005





Vertical Accuracy Statistics - NSSDA									
# of Pts	RMSEz (cm)	Std Dev (cm)	Mean (cm)	Median (cm)	Skew	Min (cm)	Max (cm)	95% CI (cm) (RMSE * 1.96)	95TH (cm) Percentile
66	4.702	4.587	-1.179	1.050	0.028	-11.800	8.400	9.216	8.775

VVA Accuracy Assessment Results	
PASS	Tested 8.775 cm vertical accuracy at 95th percentile in vegetated areas

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. Project $RMSE_{x \text{ or } y}$ specification was not to exceed 0.25m.

Table 8: NSSDA Horizontal Accuracy Results						
UTM Zone 14, NAD83(2011), NAVD88 (Geoid18), Meters						
	Ground Control Report Values		Intensity Image Coordinates		Residuals (Errors)	
Point ID	X	Y	X	Y	Delta X	Delta Y
NVAH1	629674.445	3372630.027	629674.590	3372629.971	-0.145	0.056
NVAH101	601231.444	3382312.330	601231.508	3382312.386	-0.064	-0.056
NVAH103	619441.337	3401002.184	619441.450	3401002.176	-0.113	0.008
NVAH105	665394.067	3394401.482	665394.373	3394401.281	-0.306	0.201
NVAH107	649036.213	3378943.245	649036.294	3378943.285	-0.081	-0.040
NVAH110	602279.681	3417763.803	602280.116	3417764.037	-0.435	-0.234
NVAH115	590945.553	3310313.482	590945.698	3310313.458	-0.145	0.024
NVAH118	630773.133	3405169.371	630773.197	3405169.347	-0.064	0.024
NVAH119	609382.968	3391435.326	609383.016	3391435.511	-0.048	-0.185
NVAH120	642129.400	3410087.189	642129.883	3410087.761	-0.483	-0.572
NVAH122	622646.324	3395412.895	622646.598	3395413.145	-0.274	-0.250
NVAH125	612043.368	3295555.443	612043.432	3295555.516	-0.064	-0.073
NVAH126	608330.123	3320826.109	608330.526	3320826.053	-0.403	0.056
NVAH129	627762.476	3384640.970	627762.863	3384640.801	-0.387	0.169
NVAH130	617074.812	3367858.730	617074.828	3367858.690	-0.016	0.040
NVAH131	612452.137	3372185.201	612452.153	3372185.209	-0.016	-0.008
NVAH132	583270.490	3332734.139	583270.941	3332733.873	-0.451	0.266
NVAH134	609174.300	3384369.867	609174.381	3384370.117	-0.081	-0.250
NVAH135	590567.436	3346655.965	NOT INTERPRETABLE IN IMAGERY			
NVAH139	639799.192	3385615.925	NOT INTERPRETABLE IN IMAGERY			
NVAH140	639251.179	3395524.703	639251.195	3395524.727	-0.016	-0.024
NVAH142	633378.169	3411060.810	633378.282	3411060.931	-0.113	-0.121
NVAH144	589435.983	3362681.253	589436.370	3362681.309	-0.387	-0.056
NVAH15	606027.178	3306339.381	NOT INTERPRETABLE IN IMAGERY			
NVAH21	618122.503	3383117.787	618122.600	3383117.698	-0.097	0.089
NVAH23	629224.522	3392288.356	629224.586	3392288.429	-0.064	-0.073
NVAH25	651196.531	3385858.340	651196.692	3385858.541	-0.161	-0.201
NVAH3	635459.406	3376317.784	635459.406	3376317.744	0.000	0.040
NVAH31	622715.621	3373955.948	622715.637	3373955.956	-0.016	-0.008
NVAH33	586778.989	3338237.595	586779.166	3338237.603	-0.177	-0.008
NVAH36	608761.289	3285042.925	608761.176	3285042.965	0.113	-0.040
NVAH39	605600.007	3290772.310	605600.152	3290772.399	-0.145	-0.089
NVAH43	575579.188	3310564.762	575579.269	3310564.657	-0.081	0.105
NVAH47	584593.153	3358913.077	584593.201	3358912.859	-0.048	0.218
NVAH49	615468.163	3414267.553	615468.211	3414267.835	-0.048	-0.282
NVAH5	640424.924	3379262.154	640425.133	3379262.130	-0.209	0.024
NVAH51	593045.739	3403690.428	593045.787	3403690.533	-0.048	-0.105
NVAH53	610789.599	3408742.828	610789.631	3408742.901	-0.032	-0.073
NVAH54	607594.094	3400123.945	607594.207	3400123.969	-0.113	-0.024
NVAH56	621352.759	3403522.926	621352.759	3403522.950	0.000	-0.024
NVAH60	654480.944	3369831.748	654480.992	3369831.772	-0.048	-0.024
NVAH62	671883.694	3388475.318	671883.726	3388475.149	-0.032	0.169
NVAH64	672974.649	3397253.329	672974.762	3397253.450	-0.113	-0.121
NVAH68	595353.374	3397994.708	595353.358	3397994.797	0.016	-0.089
NVAH7	596100.816	3339171.546	596101.058	3339171.377	-0.242	0.169
NVAH74	586707.723	3347887.996	586707.916	3347887.746	-0.193	0.250
NVAH76	574582.433	3338983.353	574582.900	3338983.280	-0.467	0.073
NVAH79	604150.755	3326427.021	NOT INTERPRETABLE IN IMAGERY			

NVAH79A	604335.611	3326802.057	NOT INTERPRETABLE IN IMAGERY			
NVAH81	668743.156	3362239.163	NOT INTERPRETABLE IN IMAGERY			
NVAH83	677774.260	3372071.996	NOT INTERPRETABLE IN IMAGERY			
NVAH85	672456.422	3374749.098	NOT INTERPRETABLE IN IMAGERY			
NVAH87	660611.756	3375975.404	660611.869	3375975.541	-0.113	-0.137
NVAH89	663309.406	3385458.083	663309.390	3385458.091	0.016	-0.008
NVAH91	566952.626	3331585.768	566952.707	3331585.824	-0.081	-0.056
NVAH94	636055.587	3401578.413	636055.748	3401578.421	-0.161	-0.008
NVAH96	631082.903	3388369.000	631082.871	3388368.364	0.032	0.636
	Number of Check Points				50	50
	Mean Error (M)				-0.132	-0.012
	Standard Deviation (M)				0.145	0.175
	RMSE (M)				0.195	0.174
	RMSEr (M)				0.262	
	NSSDA Horizontal Accuracyr (ACCr) at 95% Confidence Level (M)				0.453	

Point Density and Spatial Distribution Analysis

Table 9: Aggregated Nominal Point Density (ANPD) / Aggregated Nominal Point Spacing (ANPS) Check		
Project AOI M^2	7,897,268,848.60	
Number of First Return (FR), Single Swath (SS) Points	7,897,268,849	
Specification Acceptance		
Specification Threshold	Calculated Result	Status
Number of FR, SS Points/m^2 ≥ 4.00	6.27 pts/m^2	**PASS**

ANPD = 6.27 pts/m^2 or ANPS = 0.40 m

Table 10: Spatial Distribution of Points (Uniformity Grid Analysis)		
Project AOI M^2	7,897,268,848.60	
# 1m X 1m cells in project AOI with ≥ 1 FR, SS point	7,853,565,548	
Specification Acceptance		
Specification Threshold	Calculated Result	Status
≥90% of 1m X 1m cells contain at least one single swath, FR point	99.45%	**PASS**

5. Phase IV: Product Development

DEM Macro and Micro Quality Assessment Results

AECOM evaluated 100% of the data 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/QC check. Reporting reflects the status of the final data deliverables after all revised data had been submitted for review.

DEM Rasters

Macro Checks	
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
DEM Header Check	
GeoTIFF format, 32bit U	Meets Specifications
Resolution ≤ 1.0 m	Meets Specifications
X,Y,Z 0.01 meter precision	Meets Specifications
UTM Zone 14, NAD83(2011), NAVD88 (Geoid18), Meters	Meets specifications
Analysis	
NODATA value = -999999	Meets Specifications
Vertical Accuracy Check - NVA (RMSE ≤ 0.10 m, 95% CI ≤ 0.196 m)	Meets specifications
Vertical Accuracy Check - VVA (≤ 0.30 m 95th Percentile)	Meets specifications
Micro Checks	
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 8,000m^2 (2 acres) flattened	Meets Specifications
Islands greater than 4,000 m^2 (1 acre) 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

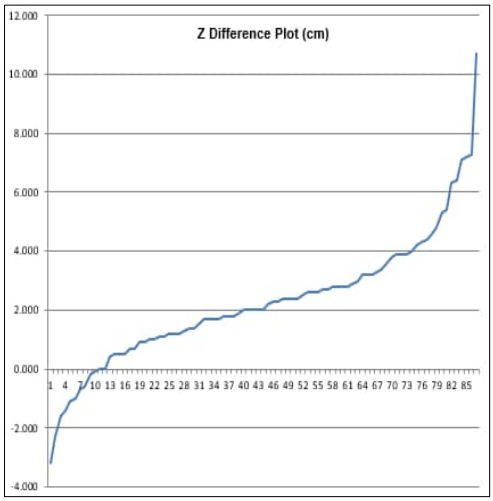
Vertical Accuracy Assessment

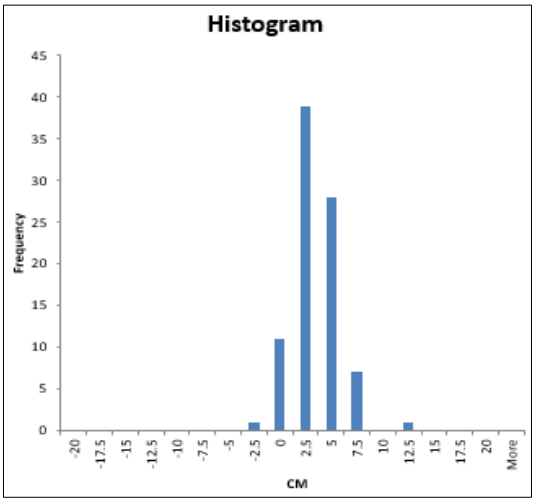
Vertical accuracy of DEM raster data will be achieved by comparing the rasterized version of Class 2 Bare Earth points against the QA checkpoint elevation values. Deviations were reported as an RMSE and @ 95% confidence for NVA assessments and @ 95th Percentile for VVA assessments.

NVA Accuracy Assessment

Table 11: DEM NVA Assessment			
UTM Zone 14, NAD83(2011), NAVD88 (Geoid18), Meters			
GPS Point Name	Survey Elevation	Lidar Elevation	Difference
NVA11	180.990	180.970	0.020
NVA113	303.598	303.608	-0.010
NVA124	184.752	184.704	0.048
NVA125A	161.432	161.406	0.026
NVA127	368.430	368.410	0.020
NVA128	267.153	267.169	-0.016
NVA13	186.432	186.386	0.046
NVA133	317.553	317.530	0.023
NVA137	182.853	182.834	0.019
NVA138	179.981	179.947	0.034
NVA141	286.323	286.280	0.043
NVA143	184.657	184.586	0.071
NVA144A	242.288	242.271	0.017
NVA145	239.839	239.807	0.032
NVA17	308.351	308.287	0.064
NVA28	357.665	357.653	0.012
NVA29	182.925	182.920	0.005
NVA35	330.877	330.850	0.027
NVA37	199.474	199.470	0.004
NVA39	148.769	148.769	0.000
NVA41	254.476	254.458	0.018
NVA45	292.168	292.129	0.039
NVA58	176.041	176.005	0.036
NVA66	166.186	166.168	0.018
NVA70	349.833	349.835	-0.002
NVA72	223.282	223.256	0.026
NVA77	171.114	171.101	0.013
NVA9	214.633	214.616	0.017
NVA91A	409.117	409.100	0.017
NVAH1	242.626	242.611	0.015
NVAH101	279.776	279.669	0.107
NVAH103	263.620	263.596	0.024
NVAH105	153.057	153.089	-0.032
NVAH107	184.664	184.592	0.072
NVAH110	342.498	342.512	-0.014
NVAH115	308.342	308.365	-0.023
NVAH118	280.166	280.134	0.032
NVAH119	304.823	304.818	0.005
NVAH120	209.151	209.141	0.010
NVAH122	267.615	267.591	0.024
NVAH125	162.837	162.832	0.005
NVAH126	222.921	222.901	0.020
NVAH129	272.960	272.930	0.030
NVAH130	290.791	290.779	0.012
NVAH131	289.981	289.928	0.053
NVAH132	396.929	396.917	0.012
NVAH134	306.472	306.452	0.020
NVAH135	348.323	348.285	0.038

NVAH139	209.995	210.001	-0.006
NVAH140	219.129	219.090	0.039
NVAH142	267.826	267.802	0.024
NVAH144	247.850	247.828	0.022
NVAH15	178.965	178.954	0.011
NVAH21	291.737	291.713	0.024
NVAH23	208.939	208.914	0.025
NVAH25	185.125	185.097	0.028
NVAH3	220.350	220.341	0.009
NVAH31	248.085	248.053	0.032
NVAH33	347.470	347.456	0.014
NVAH36	207.672	207.661	0.011
NVAH39	160.861	160.852	0.009
NVAH43	301.901	301.873	0.028
NVAH47	253.999	253.936	0.063
NVAH49	319.820	319.827	-0.007
NVAH5	196.090	196.057	0.033
NVAH51	348.768	348.761	0.007
NVAH53	312.942	312.919	0.023
NVAH54	301.269	301.24	0.029
NVAH56	269.531	269.531	0.000
NVAH60	160.869	160.83	0.039
NVAH62	138.663	138.635	0.028
NVAH64	124.732	124.705	0.027
NVAH68	342.846	342.829	0.017
NVAH7	368.329	368.33	-0.001
NVAH74	380.261	380.235	0.026
NVAH76	414.571	414.564	0.007
NVAH79	249.738	249.724	0.014
NVAH79A	248.285	248.257	0.028
NVAH81	156.302	156.26	0.042
NVAH83	141.729	141.719	0.010
NVAH85	150.187	150.167	0.020
NVAH87	156.179	156.106	0.073
NVAH89	171.601	171.612	-0.011
NVAH91	410.45	410.432	0.018
NVAH94	238.021	237.981	0.040
NVAH96	235.233	235.189	0.044
NVAH98	171.092	171.038	0.054





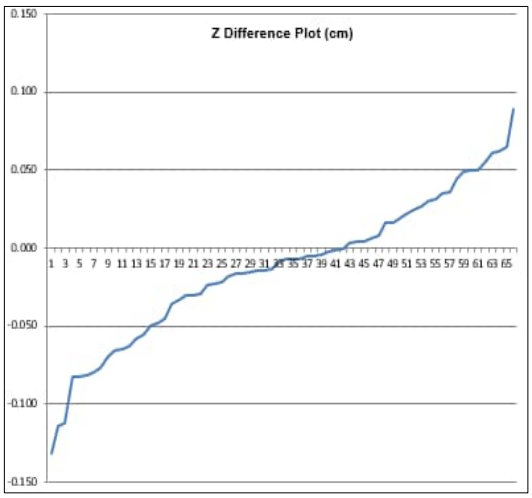
Vertical Accuracy Statistics - NSSDA									
# of Pts	RMSEz (cm)	Std Dev (cm)	Mean (cm)	Median (cm)	Skew	Min (cm)	Max (cm)	95% CI (cm) (RMSE * 1.96)	95TH (cm) Percentile
87	3.156	2.211	2.264	-2.000	0.719	-3.200	10.700	6.185	6.370

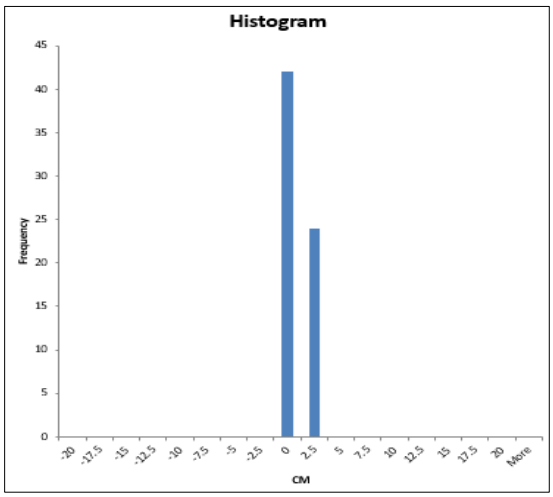
NVA Accuracy Assessment Results	
PASS	Tested 6.185cm vertical accuracy at 95% confidence level in bare earth using RMSEz x 1.9600.

VVA Accuracy Assessment

Table 12: DEM VVA Assessment UTM Zone 14, NAD83(2011), NAVD88 (Geoid18), Meters			
GPS Point Name	Survey Elevation	Lidar Elevation	Difference
VVA10	215.360	215.305	0.055
VVA100	202.987	203.017	-0.030
VVA102	258.371	258.310	0.061
VVA104	261.473	261.497	-0.024
VVA106	149.815	149.927	-0.112
VVA108	182.962	182.958	0.004
VVA109	319.227	319.242	-0.015
VVA111	341.474	341.556	-0.082
VVA112	211.334	211.341	-0.007
VVA114	299.937	300.051	-0.114
VVA116	312.327	312.407	-0.080
VVA117	367.162	367.210	-0.048
VVA119	282.809	282.801	0.008
VVA12	181.335	181.299	0.036
VVA121	208.201	208.182	0.019
VVA123	209.118	209.147	-0.029
VVA14	185.677	185.758	-0.081
VVA16	177.477	177.540	-0.063
VVA18	307.643	307.666	-0.023
VVA2	247.132	247.126	0.006
VVA20	325.911	325.944	-0.033
VVA22	299.121	299.091	0.030
VVA24	266.809	266.778	0.031
VVA26	185.514	185.532	-0.018
VVA27	357.565	357.561	0.004
VVA30	180.937	180.953	-0.016
VVA32	252.008	252.013	-0.005
VVA34	347.032	347.082	-0.050
VVA36	336.332	336.310	0.022
VVA38	199.231	199.296	-0.065
VVA4	204.204	204.226	-0.022
VVA40	205.672	205.754	-0.082
VVA42	254.290	254.274	0.016
VVA44	325.770	325.767	0.003
VVA46	292.339	292.355	-0.016
VVA48	254.793	254.777	0.016
VVA50	319.205	319.271	-0.066
VVA52	371.054	371.019	0.035
VVA55	299.838	299.811	0.027
VVA57	275.181	275.188	-0.007

VVA59	179.532	179.546	-0.014
VVA6	198.946	199.023	-0.077
VVA61	166.682	166.737	-0.055
VVA63	136.377	136.390	-0.013
VVA65	128.657	128.726	-0.069
VVA67	165.792	165.742	0.050
VVA69	342.253	342.257	-0.004
VVA700	209.915	210.047	-0.132
VVA701	208.306	208.336	-0.030
VVA704	228.865	228.874	-0.009
VVA71	349.684	349.619	0.065
VVA73	223.372	223.310	0.062
VVA75	374.719	374.755	-0.036
VVA78	169.050	169.051	-0.001
VVA8	361.728	361.735	-0.007
VVA80	247.956	248.001	-0.045
VVA82	155.400	155.405	-0.005
VVA84	143.986	143.988	-0.002
VVA86	150.752	150.702	0.050
VVA88	154.827	154.783	0.044
VVA90	170.966	170.877	0.089
VVA92	424.739	424.797	-0.058
VVA93	336.955	336.930	0.025
VVA95	248.611	248.625	-0.014
VVA97	225.674	225.625	0.049
VVA99	172.079	172.079	0.000





Vertical Accuracy Statistics - NSSDA									
# of Pts	RMSEz (cm)	Std Dev (cm)	Mean (cm)	Median (cm)	Skew	Min (cm)	Max (cm)	95% CI (cm) (RMSE * 1.96)	95TH (cm) Percentile
66	4.825	4.685	-1.291	0.800	-0.294	-13.200	8.900	9.458	8.725

VVA Accuracy Assessment Results	
PASS	Tested 8.725 cm vertical accuracy at 95th percentile in vegetated areas

Credits

Organizations involved in the procurement, acquisition, processing, and QA/QC of this project are identified below.

Table 13: Project Participants	
Project Function	Participant
LiDAR Procurement	Texas Geographic Information Office (TxGIO) Texas Water Development Board (TWDB) Hays County Williamson County Cedar Park Georgetown Round Rock Leander San Marcos
LiDAR Acquisition and Processing	Fugro
QA/QC Checkpoint Ground Surveys	CompassData & Associates, Inc. (AECOM Survey Subcontractor)
Accuracy Assessment, QA/QC Review, and Reporting	AECOM Technical Services, Inc.

6. Conclusions

By TxGIO standards the lidar data development initiative was a mid-sized project having a combination of standard TxGIO and USGS LBS 2023 rev. A Quality Level 2 deliverable requirements.

The overarching challenge associated with any geospatial data acquisition and data processing project is the narrow window within which to acquire, process, deliver, validate, and ultimately accept the data within the funding dependent project window.

QA/QC issues reported were satisfactorily addressed by Fugro or deemed insignificant and/or acceptable by TxGIO. The final data sets reviewed by AECOM met contractual expectations and will be a valuable resource for all project stakeholders.

Fugro is responsible to prepare and deliver the completed accepted datasets to TxGIO's Amazon S3 server directly.

Geospatial quality assessment conducted by:

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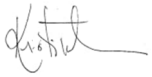
Robert T. Riley, PMP, ASPRS CP, UAS
AECOM Geospatial QA/QC Manager



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Kristi Teykl, GISP
AECOM Project Manager