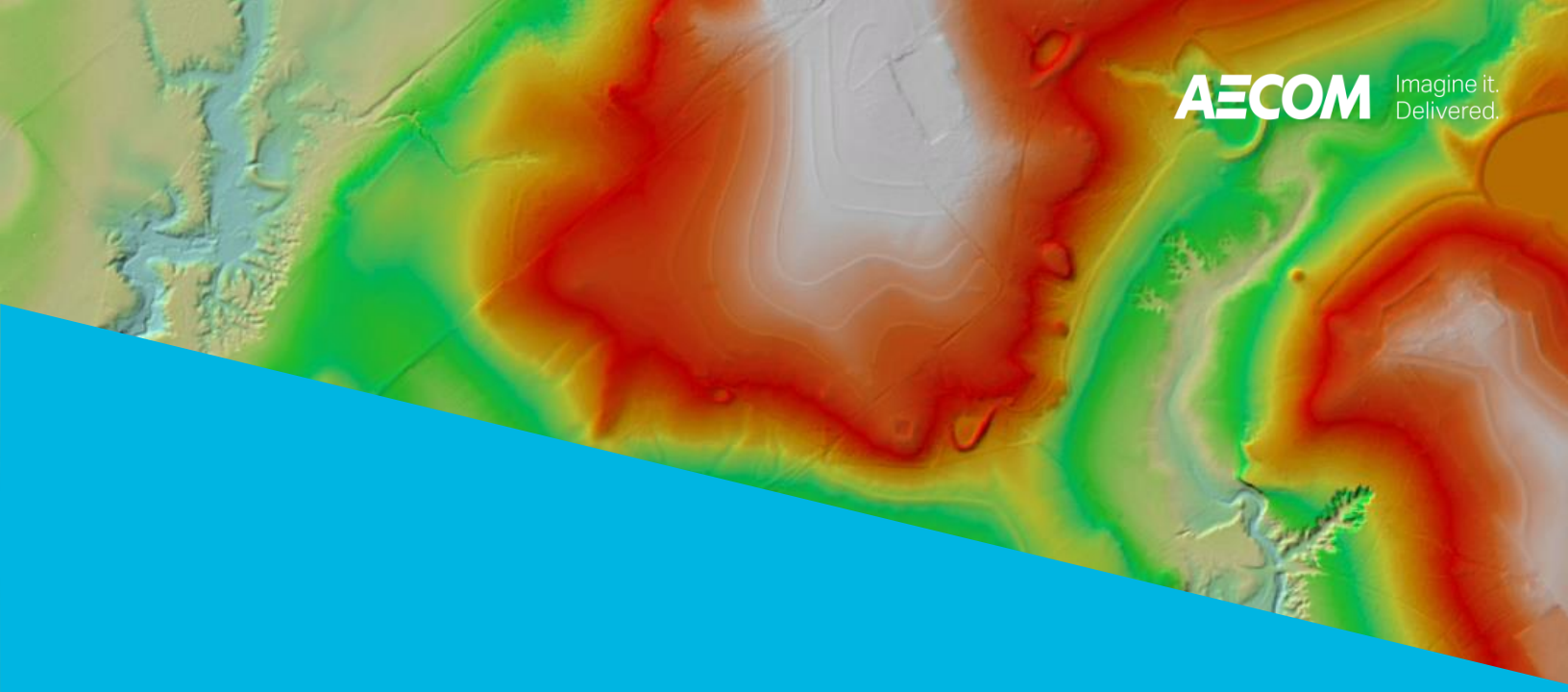


AECOM Imagine it. Delivered.

Final QA/QC Report

2017 LIDAR QA/QC FOR COASTALTEXAS
STATEMENT OF WORK #580170040

TEXAS WATER DEVELOPMENT BOARD

April 4, 2018

Prepared for:
TEXAS WATER DEVELOPMENT BOARD

Prepared by:
AECOM

Table of Contents

1. Overview

Independent quality checks for Texas Water Development Board (TWDB) project 580170040 (Quality Assurance / Quality Control of the Acquisition and Production of Lidar Elevation Data for 2017 Coastal Texas) were performed by AECOM to validate the LiDAR data and various derivative products meet project specifications, expectations, and quality standards.

Project stakeholders included the Texas Natural Resources Information System (TNRIS), a part of the Texas Water Development Board (TWDB), and the Trinity River Authority (TRA).

> *"The project area of interest (AOI) of ~977 square miles is on the Texas coast consisting of much of Jefferson County and the north eastern tip of Trinity Bay at the mouth of the Trinity River. This region is strongly dominated by coastal ecology.*
>
> *The data acquired will be used for floodplain management and planning, feature extraction, water quality modeling, stream restoration potential analysis and change detection.*
>
> *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."* - TWDB Project Solicitation # 580-17-SOW0040.

Additional areas were added to the fundamental AOI resulting in a final project area of ~1,140.2 mi^2.

The larger Eastern AOI was required to meet USGS QL2 specifications (≥ 4 pts/m^2 having an RMSE vertical accuracy ≤ 10 cm in Non Vegetated Areas) while the smaller Western AOI was to meet USGS QL0 specifications (≥ 8 pts/m^2 having an RMSE vertical accuracy ≤ 5 cm in Non Vegetated Areas). Through testing the Western AOI data did not meet the QL0 accuracy requirements. TNRIS, consulting with TRA, assigned QL1 accuracy requirements (≥ 8 pts/m^2 having an RMSE vertical accuracy ≤ 10 cm in Non Vegetated Areas) to the Western AOI dataset.

Derivative LiDAR products included Hydro Breaklines, Hydro-flattened DEM Rasters, Intensity Rasters, and Metadata.

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

LiDAR data products were acquired and processed by Sanborn.

This report references data deliverables received from December 2016 to April 2018.

Listed below are the QA/QC review 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 assurance and 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.

Independent Quality Assurance and Control Scope of Work

The following scope of work (SOW) as highlighted in Table 1 was completed during the project:

Table 1: AECOM – Independent Quality Assurance and Control Tasks

Phase	Tasks
Phase I Pre-flight Planning	1. Participate in Project Kickoff Meeting 2. Review timeline and projected milestones 3. Review Sanborn's LiDAR flight plans and 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 Sanborn'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. Hydro-flattened breaklines c. Intensity rasters d. 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 3. Prepare and submit Final QA/QC report

Project Area and Deliverables Received

The 2017 Coastal Texas project area consisted of two AOI's covering ~1,140.2 mi^2.

Western AOI - 291.67 mi^2
Eastern AOI – 843.53 mi^2

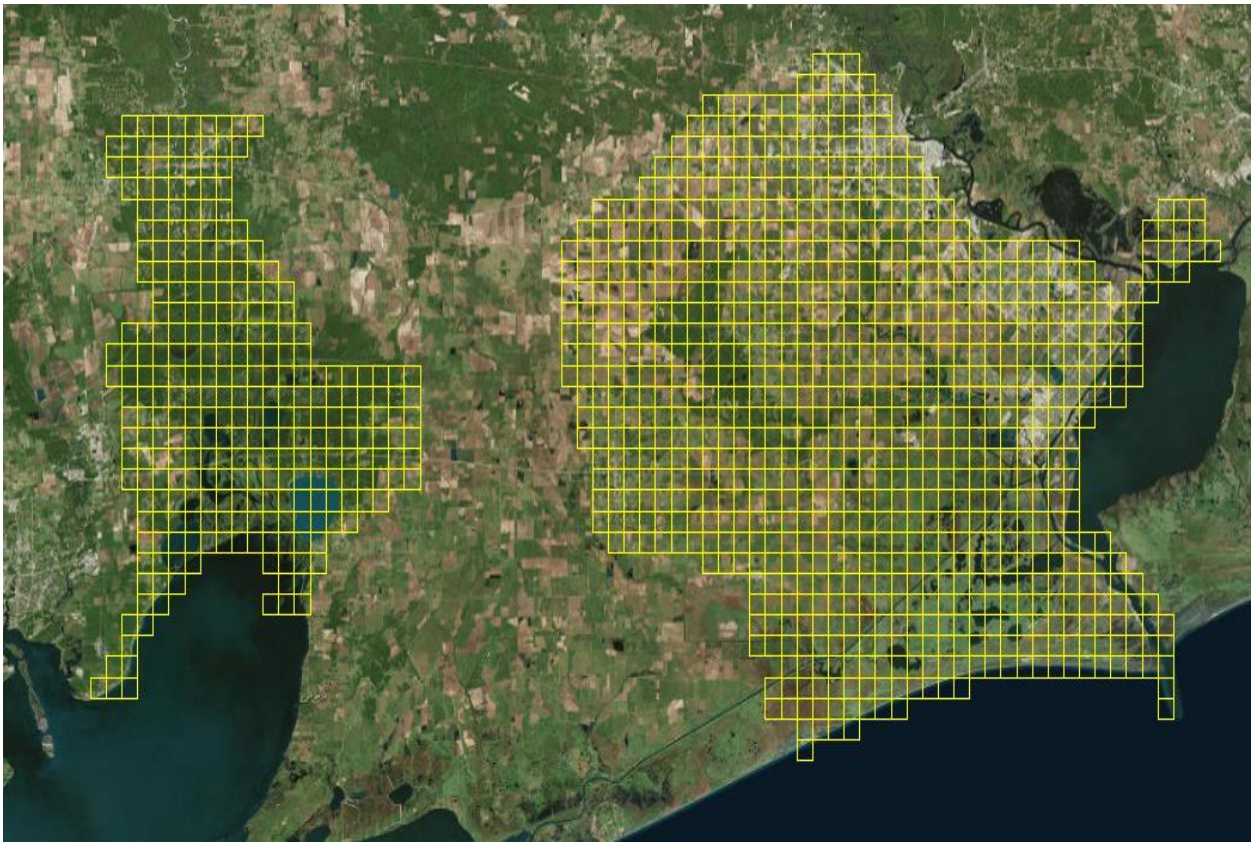


Figure 1 – TNRIS 2017 Coastal Texas Areas of Interest

Deliverables were received in the following formats in UTM Zone 15, NAD83 (2011), NAVD88 (Geoid 12B), Meters.

Table 2: Data Deliverables Received

Deliverable	Western AOI	Eastern AOI
LiDAR files in .LAS v1.4 format	Y	Y
Hydro-flattened 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

Applicable Specifications and Guidelines

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

A. TWDB/TNRIS SOW - SM_58017SOW0040_QAQC_Coastal_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 project kickoff meeting project stakeholders reviewed the QA/QC specifications that would be employed. Subsequent to the project kickoff meeting AECOM utilized previous established Phase I review procedures to provide reporting on quality assurance and control tasks.

For Phase I (Pre-Flight Planning), AECOM conducted a review of the proposed flight operations and plan files submitted by Sanborn 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 acquisition and processing tasks of the project.

Aerial Acquisition Pre-flight Planning Review

For the purpose of this review, Sanborn 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 the Project 580170040 SOW. AECOM sent clarifying questions to Sanborn, 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.

The following table details 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)	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

QA/QC Checkpoint Survey Plan Review

The ground survey layout for the QA/QC 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 selected locations conformed to project specifications and guidelines.

Gorrondona & Associates, Inc. (Gorrondona), working as a subcontractor to AECOM, executed the field survey.

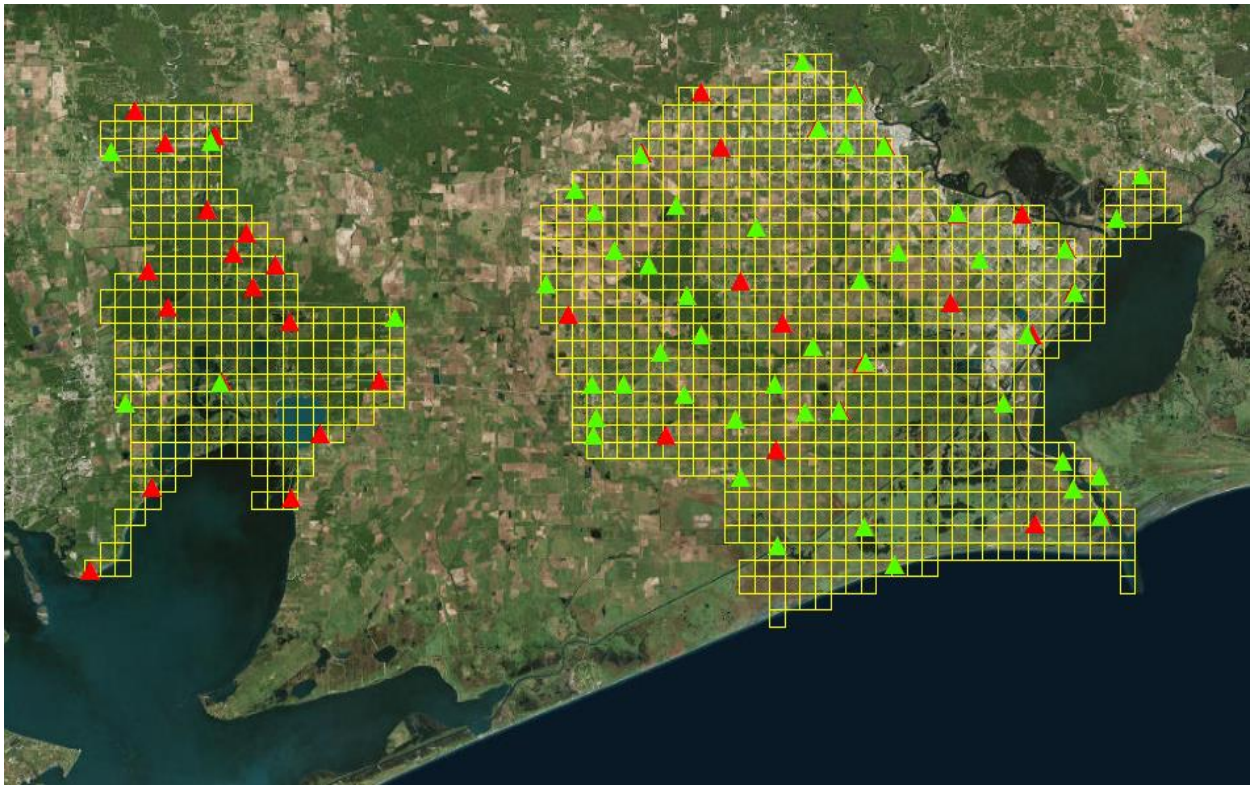


Figure 2 – AECOM QA/QC Checkpoint Survey Plan

A total of 75 NVA and 30 VVA checkpoints were established across both AOIs.

- NVA and VVA checkpoints supported the vertical accuracy assessments of the LiDAR and DEM datasets.

3. Phase II: Data Acquisition Review

The following quality assurance and control actions were performed after aerial acquisition of the LiDAR data was complete.

Post-flight Aerial Acquisition Review

Following the aerial acquisition of the LiDAR data Sanborn 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 0.5 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.

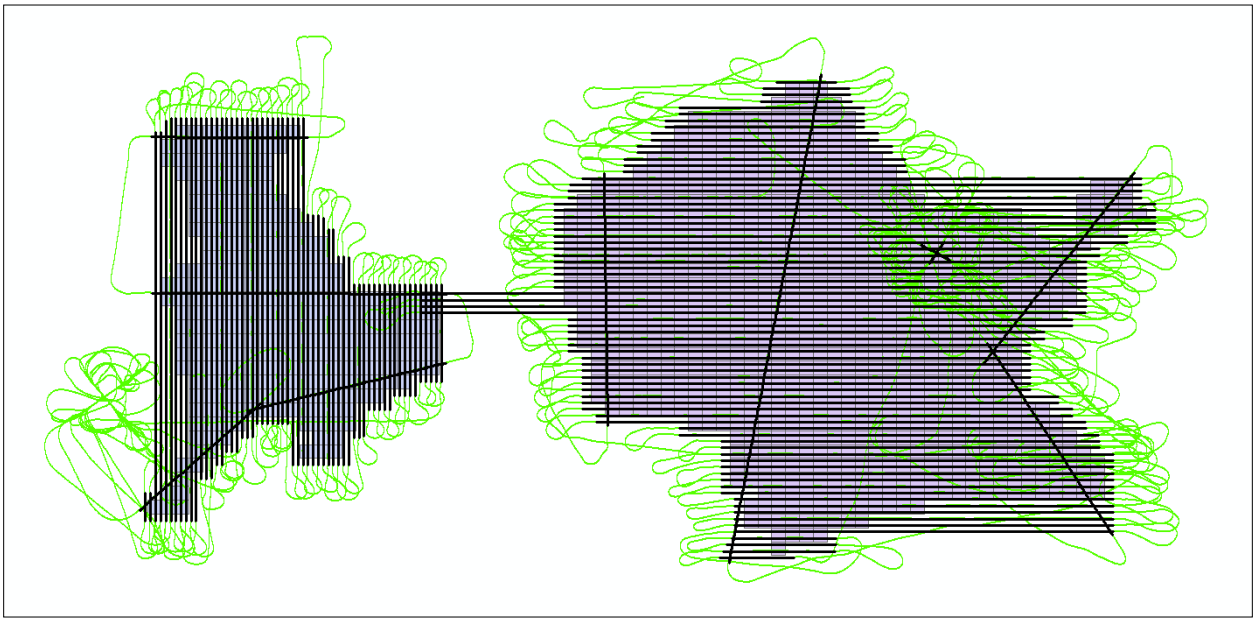


Figure 3 – LiDAR Planned Flight lines (Black) overlaid As-Flown Trajectories (Green)

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 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

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

Post-flight Ground Control Review

Sanborn 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, 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 for the most part closely mimic the planned control point locations, as can be seen in the graphic below. Two control points in the East AOI are shifted ~5 miles from their planned positions.

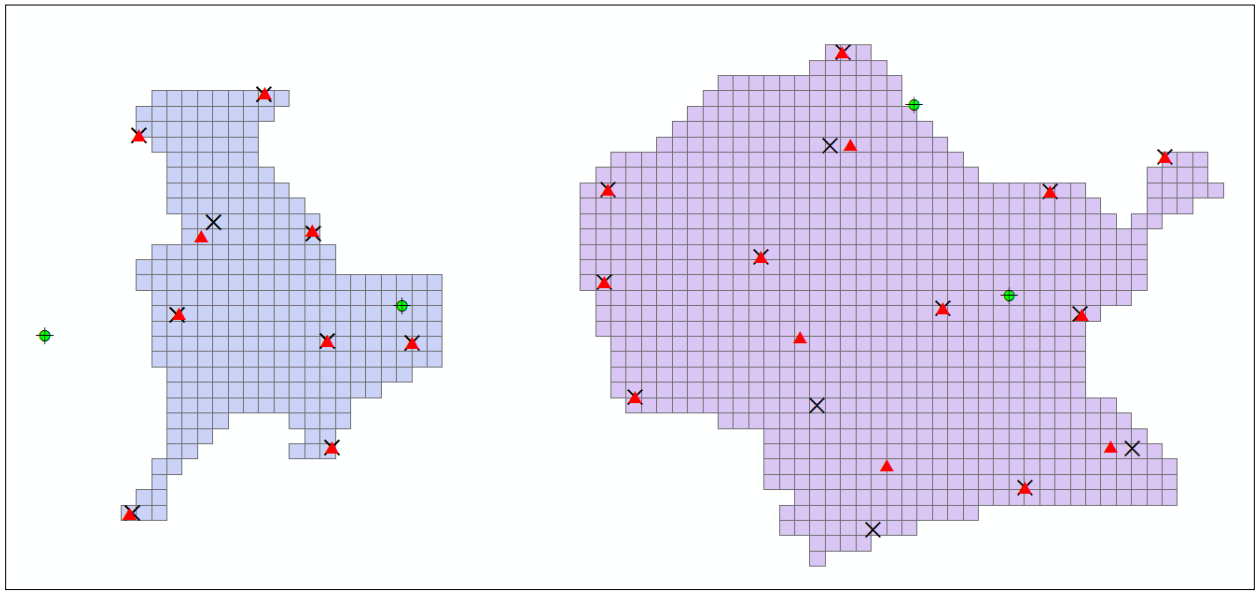


Figure 4 - Sanborn LiDAR Planned Control Locations (X) and Actual Control Locations (▲)

Review and Delivery of QA/QC Checkpoint Survey

During the planning and establishment of QA/QC checkpoints, AECOM and Gorrondona frequently coordinated regarding status. Gorrondona completed the field survey work in March 2017.

A total of 75 NVA and 30 VVA checkpoints were established across both AOIs.

NVA and VVA checkpoints supported the vertical accuracy assessments of the LiDAR and DEM datasets.

AECOM reviewed all pertinent documentation submitted by Gorrondona at the conclusion of the QA/QC checkpoint field 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 point locations were verified against project specifications and control plan layouts. All survey related documentation was then delivered to TNRIS in April 2017.

Table 4: Vertical Checkpoint Types and Coordinates
UTM Z15N, NAVD88 (Geoid12B), NAD83(2011), Meters

AOI	Check Point Type	Point ID	X	Y	Z
East	NVA	1001	387455.962	3334159.907	10.557
East	NVA	1002	395498.225	3325438.372	6.503
East	NVA	1003	402727.542	3318439.327	5.176
East	NVA	1004	413368.924	3314736.467	1.853
East	NVA	1005	420862.387	3322259.448	3.089
East	NVA	1006	414063.081	3310172.571	1.463
East	NVA	1007	410019.607	3305850.740	0.504
East	NVA	1008	407079.975	3298938.078	0.892
East	NVA	1009	413823.808	3290078.071	0.678
East	NVA	1010	416708.630	3287206.284	0.891
East	NVA	1011	392967.522	3311706.639	2.091
East	NVA	1012	380868.662	3291477.098	2.635
East	NVA	1013	366614.378	3297865.270	6.331
East	NVA	1014	371458.708	3324917.373	11.590
East	NVA	1015	377364.532	3331215.028	12.573
East	NVA	1016	382750.991	3317172.562	6.322
East	NVA	1017	388880.145	3327302.094	5.101
East	NVA	1018	379368.433	3325535.178	9.650
East	NVA	1019	375780.042	3310212.219	4.362
East	NVA	1020	377086.203	3306202.751	3.475
East	NVA	1021	393168.445	3303141.008	1.240
East	NVA	1022	390811.402	3298282.123	1.063
East	NVA	1023	384384.134	3301045.850	1.581
East	NVA	1024	369437.032	3301151.024	5.165
East	NVA	1025	404828.889	3313766.435	1.344
East	NVA	1026	418409.608	3317767.231	0.499
East	NVA	1027	416505.138	3291321.125	2.963
East	NVA	1028	410131.629	3286485.774	1.746
East	NVA	1029	391602.722	3325607.536	4.015
East	NVA	1030	366336.759	3296070.730	6.159
East	NVA	1031	401873.369	3309295.304	0.580
East	NVA	1032	381146.653	3311734.490	6.714
East	NVA	1033	364771.133	3321251.868	10.395
East	NVA	1034	392770.416	3330930.864	8.635
East	NVA	1035	409026.799	3318316.593	5.218
East	NVA	1036	396717.074	3314561.720	4.222

East	NVA	1037	387389.025	3298167.684	1.945
East	NVA	1038	388142.436	3304917.597	4.167
East	NVA	1039	373141.875	3304403.694	4.850
East	NVA	1040	366303.549	3301299.500	8.502
East	NVA	1041	393058.778	3286287.041	0.093
East	NVA	1042	396092.736	3282452.176	1.592
East	NVA	1043	384465.648	3284421.947	2.133
East	NVA	1044	374758.505	3319527.604	7.553
East	NVA	1045	371991.506	3313510.406	7.058
East	NVA	1046	361823.143	3311650.243	12.414
East	NVA	1047	366760.437	3318974.627	9.473
East	NVA	1048	368703.128	3314923.078	7.793
East	NVA	1049	384495.559	3294281.764	1.890
East	NVA	1050	380495.414	3297544.699	2.696
East	NVA	1051	373465.057	3295943.945	2.419
East	NVA	1052	375388.321	3300134.087	3.018
East	NVA	1053	385174.788	3307289.050	4.064
East	NVA	1054	364062.639	3308439.363	10.153
East	NVA	1055	412922.279	3292873.515	3.709
East	VVA	1056	414103.758	3310203.775	0.682
East	VVA	1057	409405.933	3305831.131	0.348
East	VVA	1058	407078.954	3298959.075	0.461
East	VVA	1059	413883.549	3290051.610	0.675
East	VVA	1060	416647.670	3287206.432	0.786
East	VVA	1061	392957.142	3311699.534	1.727
East	VVA	1062	380830.513	3291492.829	2.182
East	VVA	1063	366599.562	3297877.216	6.461
East	VVA	1064	371367.625	3324858.854	12.406
East	VVA	1065	382723.066	3317172.306	5.329
East	VVA	1066	388886.299	3327266.862	4.877
East	VVA	1067	375774.969	3310231.109	4.086
East	VVA	1068	377100.004	3306237.067	3.178
East	VVA	1069	393185.948	3303163.341	0.901
East	VVA	1070	390799.038	3298294.091	0.815
East	VVA	1071	369416.216	3301152.231	5.076
East	VVA	1072	404842.684	3313753.491	1.678
East	VVA	1073	418437.076	3317818.009	0.237
East	VVA	1074	416559.666	3291286.317	2.283
East	VVA	1075	391599.717	3325595.727	4.222
East	VVA	1076	366331.739	3296042.281	5.879
East	VVA	1077	396701.843	3314561.943	4.045
East	VVA	1078	387414.174	3298204.704	2.043
East	VVA	1079	388144.474	3304935.555	3.979
East	VVA	1080	373128.018	3304416.997	4.575
East	VVA	1081	396080.470	3282466.786	1.685
East	VVA	1082	384500.077	3284425.801	1.082
East	VVA	1083	374775.263	3319545.505	7.742
East	VVA	1084	366775.154	3319002.249	9.298
East	VVA	1085	368687.731	3314928.484	7.700
East	VVA	1086	375375.941	3300137.649	2.893
East	VVA	1087	412916.155	3292831.584	3.693
East	VVA	1088	387427.904	3334172.612	10.574
East	VVA	1089	395479.834	3325455.467	6.472
East	VVA	1090	402701.072	3318450.688	5.753

East	VVA	1091	413232.643	3314748.304	1.742
East	VVA	1092	420910.858	3322259.700	2.226
East	VVA	1093	384373.068	3301049.161	1.503
East	VVA	1094	364758.501	3321237.880	9.811
East	VVA	1095	392676.464	3330852.757	8.990
East	VVA	1096	366261.313	3301297.199	8.272
East	VVA	1097	393043.078	3286294.659	-0.143
East	VVA	1098	371962.050	3313503.727	6.140
East	VVA	1099	361854.063	3311688.505	11.978
East	VVA	1100	380477.914	3297549.411	2.540
West	NVA	1101	3282861.832	316220.656	8.129
West	NVA	1102	3291308.336	322384.945	7.336
West	NVA	1103	3290035.219	336243.393	5.192
West	NVA	1104	3308366.022	346779.036	10.376
West	NVA	1105	3313983.393	335055.211	9.814
West	NVA	1106	3319767.106	328316.553	6.525
West	NVA	1107	3327269.757	329246.007	13.711
West	NVA	1108	3326644.458	324324.575	8.700
West	NVA	1109	3325801.081	318906.071	8.542
West	NVA	1110	3313532.844	322405.364	14.357
West	NVA	1111	3309719.666	324339.748	12.007
West	NVA	1112	3299948.688	320003.754	9.415
West	NVA	1113	3301990.653	329469.279	1.752
West	NVA	1114	3311748.860	332765.748	8.690
West	NVA	1115	3315144.356	330881.224	5.392
West	NVA	1116	3329987.371	321363.178	22.968
West	NVA	1117	3301911.823	345139.653	8.204
West	NVA	1118	3317254.576	332240.792	5.458
West	NVA	1119	3308103.342	336428.144	12.038
West	NVA	1120	3296517.741	339248.457	6.917
West	VVA	1121	3325798.654	318914.938	7.821
West	VVA	1122	3300029.801	320021.031	8.643
West	VVA	1123	3326740.598	328849.253	11.632
West	VVA	1124	3308390.987	346804.681	10.027
West	VVA	1125	3301976.441	329360.099	1.643

Horizontal Checkpoints – Given the project area terrain and challenging opportunities to collect horizontal checkpoints no checkpoints were specifically assigned to support the horizontal accuracy assessment of check of LiDAR data. As a solution AECOM proposed the utilization of existing TNRIS orthophotography data to assess the LiDAR horizontal accuracy.

4. Phase III: Data Processing

The following quality assurance and control 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 for the project deliverables.

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
- *FugronViewer* – 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 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 Sanborn

Western AOI 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/QC 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/QC Checks		
	Review Status	**Comments to Sanborn & TNRIS**
Inventory Assessment		
Conduct file inventory	Meets project specifications	
Verify readability of media	Meets project specifications	
Coverage/Gap check	Meets project specifications	
No tile/data overlap	Meets project specifications	
Tile Naming Convention		
Tile name match index	Meets project specifications	
Metadata Review		
Project Level metadata - Content check	Meets project specifications	
USGS metadata parser check	Meets project specifications	
USGS LiDAR tags present	Meets project specifications	
Tile Level metadata - Content check	Meets project specifications	
USGS metadata parser check	Meets project specifications	
USGS Lidar tags present	Meets project specifications	
LAS Header Check		
LAS format (LAS 1.4)	Meets project specifications	
GPS Times is Adjusted GPS time	Meets project specifications	
GPS times (0.01 m)	Meets project specifications	
LAS X,Y,Z scale factors 0.01 precision	Meets project specifications	
File source ID assigned	Meets project specifications	
LAS Number Variable Length Records Present	Meets project specifications	
Point Source ID equal to the File Source ID	Meets project specifications	
LAS Point Data Record Format - 6	Meets project specifications	
NAVD88, Geoid 12B, NAD83(2011), UTM Z15 meters	Meets project specifications	
At least 3 returns per pulse	Meets project specifications	
Acceptable classes - 1,2,3,4,5,6,7,9,10,13,14	Meets project specifications	
Analysis		
LAS Overlap Flag - Overage points flagged as Overlap in Classified point clouds. Class 12 should NOT be used	Meets project specifications	1,635,004,777 points are tagged as Overlap
LAS Withheld Flag - Geometrically unreliable points flagged as Withheld in Classified point clouds	Meets project specifications	No points tagged as Withheld
Horizontal Accuracy Check - RMSE ≤ 0.20 m	Meets project specifications	Highest accuracy orthoimagery available was downloaded from TNRIS data repository.
Vertical Accuracy Check - NVA (RMSE ≤ 0.1 m, 95% CI ≤ 0.194 m)	Meets project specifications	RMSEz = 0.082 m 18 checkpoints used, 2 checkpoints ignored (1120 & 1109).
Vertical Accuracy Check - VVA (≤ 0.196 m @ 95th Percentile)	Meets project specifications	95th Percentile = 0.125 m using 4 points after ignoring checkpoint 1121.
Intra-swath Accuracy (≤ 0.06 m)	Meets project specifications	1,749 points tested on 2 dispersed airport tarmacs. All but 5 points (0.2%) have Z difference of less than 6 cm and are deemed ignored.
Inter-swath Accuracy (≤ 0.08 m, MAX +/- 0.16m)	Meets project specifications	Measuring 169,094 interswath points, and excluding an additional 2,463 points that exceeded 0.16 m that resided in vegetated or steep areas, an RMSEz = 0.03 m was calculated.
ANPS ≤ 0.35 m *OR* ANPD ≥ 8.0 pts/m^2	Meets project specifications	ANPD = 9.21 pts/m^2 or ANPS = 0.33 m
Spatial Distribution and Uniformity (At least 90	Meets project specifications	95% of 0.7 m grid of pixels contain at least

percent of the cells in a 0.7 m grid contain at least one single swath, FR lidar point)		1 SS, FR point
Duplicate Points (X, Y, Z, AND TIME)	Meets project specifications	Observation – 18,199,874 points have repeating XYZ values. Random sampling suggests time is unique. Vast majority of duplicate points located at swath edge. Class 1 points comprised greatest percentage of these points.
Gross Anomaly Check		
Extreme intensity values	Meets project specifications	
Systematic data dropouts	Meets project specifications	
Micro QA/QC Checks		
	Review Status	**Comments to Sanborn & 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 (near BL), 13=bridges, 14=culverts)		
Consistency in filtering	Meets project specifications	
Classification accuracy (misclassification)	Meets project specifications	
Building sides are C6 not veg	Meets project specifications	
Data voids/gaps ≥ $(4x\ ANPS)^2 = 1.96\ m^2$	Meets project specifications	
Ridges/steps	Meets project specifications	
Cornrows	Meets project specifications	
Spikes/Divots (noise)	Meets project specifications	
No LiDAR shadowing (sliver gaps) around taller structures	Meets project specifications	

Intensity Rasters

Macro QA/QC Checks		
	Review Status	**Comments to Sanborn & TNRIS**
Inventory Assessment		
Conduct file inventory	Meets project specifications	
Verify readability of media	Meets project specifications	
Coverage/Gap check	Meets project specifications	
50 meter tile overlap with 90 degree corners	Meets project specifications	
Tile Naming Convention		
Tile name match index	Meets project specifications	
Metadata Review		
Project Level metadata - Content check	Meets project specifications	
USGS metadata parser check	Meets project specifications	
Tile Level metadata - Content check	Meets project specifications	
USGS metadata parser check	Meets project specifications	
INTENSITY Header Check		
GeoTIFF format, 8, 16, or 32bit U	Meets project specifications	
Resolution ≤ 0.5 m	Meets project specifications	
NAVD88, Geoid 12B, NAD83(2011), UTM Z15 meters	Meets project specifications	
Analysis		
NODATA set to 256	Meets project specifications	
Micro QA/QC Checks		
	Review Status	**Comments to Sanborn & TNRIS**
Micro Review		
Uniformity/consistency across swath	Meets project specifications	
No over or under saturation/Extreme intensity values	Meets project specifications	

Hydro-flattened Breaklines

Macro QA/QC Checks		
	Review Status	**Comments to Sanborn & TNRIS**
Inventory Assessment		
Conduct file inventory	Meets project specifications	
Verify readability of media	Meets project specifications	
Coverage/Gap check	Meets project specifications	
Breaklines can extend just beyond AOI limits	Meets project specifications	
Metadata Review		
Project Level metadata - Content check	Meets project specifications	
USGS metadata parser check	Meets project specifications	
Tile Level metadata - Content check	Meets project specifications	
USGS metadata parser check	Meets project specifications	
Breakline Header Checks		
Seamless or Tile based PolylineZ or PolygonZ GDB format v10.3	Meets project specifications	
.PRJ file present	N/A. GDB provided	
NAVD88, Geoid 12B, NAD83(2011), UTM Z15 meters	Meets project specifications	
Analysis		
No duplicate features	Meets project specifications	
No topology issues (overlapping features, snapping issues, or open polygons)	Meets project specifications	
Expresses monotonicity	Meets project specifications	
Relative Vertical Accuracy Check	Meets project specifications	
Micro QA/QC Checks		
	Review Status	**Comments to Sanborn & TNRIS**
Micro Review		
Streams/Rivers break at culverts	Meets project specifications	
Streams/Rivers continuous at bridges	Meets project specifications	
All inland streams and rivers should have been captured and flattened that have a 15.25 m nominal width	Meets project specifications	
Water bodies greater than 10,000 m^2 collected	Meets project specifications	
Islands greater than 5,000 m^2 collected	Meets project specifications	

Vertical Accuracy Assessments

Relative Vertical Accuracy

Intraswath Relative Accuracy – Intraswath vertical relative accuracy was tested using 1,749 points on a 1m grid residing on two dispersed airport tarmacs. All but 5 First Return, Single Swath points (0.2%) have Z difference of less than 6 cm and are deemed ignored. For the sake of brevity a table has not be included in this report.

Interswath Relative Accuracy - Measuring 169,094 interswath points, and excluding 2,463 points that exceeded 0.16 m that resided in vegetation areas, an RMSEz = 0.03m was calculated. For the sake of brevity a table has not be included in this report.

Absolute Vertical Accuracy

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.

NVA Accuracy Assessment

Table 5: Western AOI LiDAR NVA Assessment
UTM Z15N, NAVD88 (Geoid12B), NAD83(2011), Meters

GPS Point Name	Survey Elevation	LiDAR Elevation	Difference
1120	6.917	6.629	-0.288
1104	10.376	10.152	-0.224
1107	13.711	13.543	-0.168
1106	6.525	6.410	-0.115
1113	1.752	1.706	-0.046
1115	5.392	5.376	-0.016
1110	14.357	14.372	0.015
1103	5.192	5.209	0.017
1108	8.700	8.728	0.028
1112	9.415	9.444	0.029
1117	8.204	8.236	0.032
1111	12.007	12.043	0.036
1116	22.968	23.010	0.042
1114	8.690	8.733	0.043
1105	9.814	9.857	0.043
1119	12.038	12.083	0.045
1118	5.458	5.514	0.056
1101	8.129	8.200	0.071
1102	7.336	7.428	0.092
1109	8.542	8.848	0.306

20 NVA checkpoints were run against the data as part of the initial accuracy check. The results identified two checkpoints with deltas larger than expected which warranted further review (points 1109 and 1120). As reported as part of the initial Phase III report, excerpt below, these points were determined to be blunders and excused from the overall accuracy calculation.

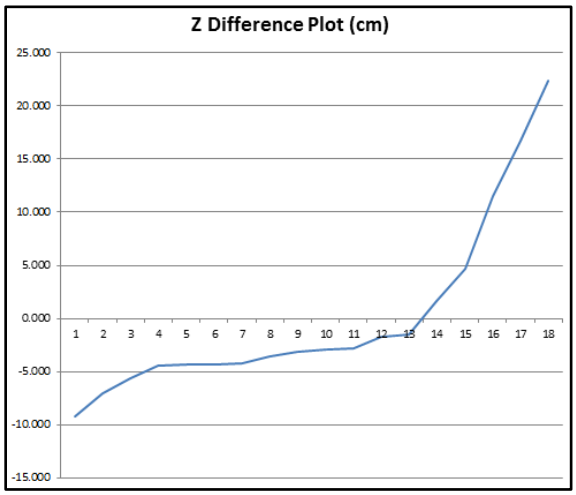
NVA Assessment

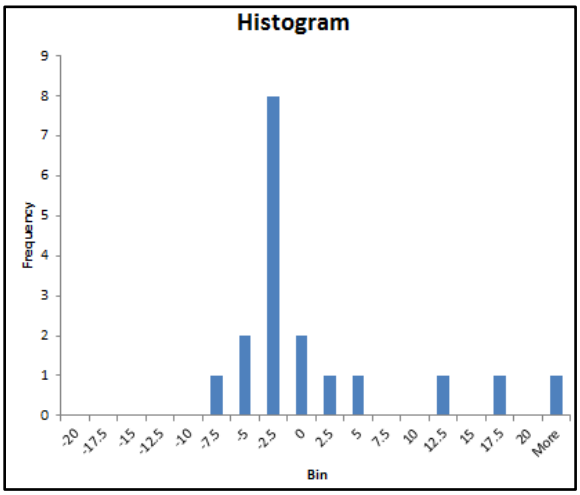
- *Point 1120 proximity of surveyed point to culvert may impact vertical results*
- *Point 1109 appears to rest on a sloping and what may be an actively eroding surface which may impact vertical results*

Survey crew photos of these points are provided below.

Figure 5 CP 1109 excused (left)
Figure 6 CP 1120 excused (right)

Removal of points 1120 and 1109 resulted in an RMSEz of 8.252 cm using 18 checkpoints. This result is within the USGS QL1 ≥8 PPSM absolute accuracy requirements.





NVA Vertical Accuracy Statistics - NSSDA									
# of Pts	RMSEz (cm)	Std Dev (cm)	Mean (cm)	Median (cm)	Skew	Min (cm)	Max (cm)	95% CI (RMSE * 1.96) (cm)	95TH Percentile (cm)
18	8.246	8.485	0.109	3.029	1.666	-9.200	22.370	16.163	17.619

NVA Accuracy Assessment Results	
PASS	Tested 16.16 cm vertical accuracy at 95% confidence level in bare earth using RMSEz x 1.9600.

VVA Accuracy Assessment

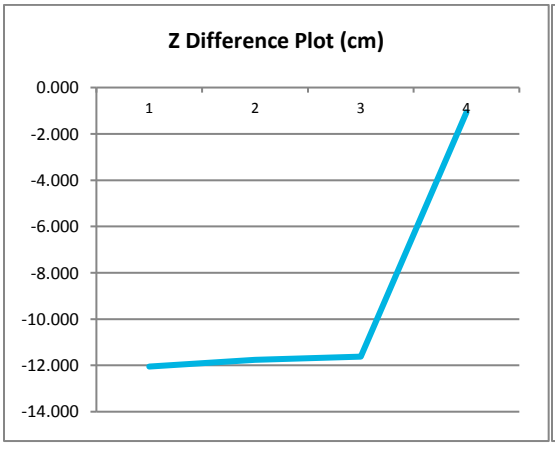
Table 6: Western AOI LiDAR VVA Assessment UTM Z15N, NAVD88 (Geoid12B), NAD83(2011), Meters			
GPS Point Name	Survey Elevation	LiDAR Elevation	Difference
1121	7.821	8.1929	0.3719
1122	8.643	8.7607	-0.1177
1123	11.632	11.643	-0.0107
1125	1.643	1.759	-0.1162
1124	10.027	10.148	-0.1205

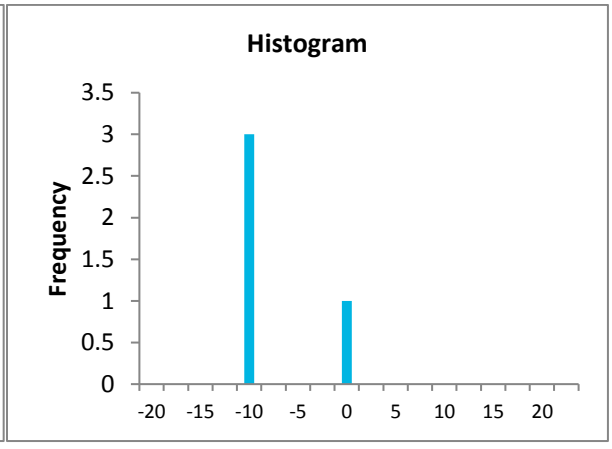
Similar to the NVA assessment above, and as reported as part of the initial Phase III report, excerpt below, checkpoint 1121 was excused from the overall accuracy calculation.

VVA Assessment

- Point 1121 appears to rest on sloping terrain which may impact vertical results

Figure 7 CP 1121 excused





VVA Vertical Accuracy Statistics - NSSDA

# of Pts	RMSEz (cm)	Std Dev (cm)	Mean (cm)	Median (cm)	Skew	Min (cm)	Max (cm)	95% CI (RMSE * 1.96) (cm)	95TH Percentile (cm)
4	10.256	5.366	-9.143	11.685	1.991	-12.100	-1.100	20.101	12.051

VVA Accuracy Assessment Results	
PASS	Tested 12.05 cm vertical accuracy at 95th percentile in vegetated areas.

Point Density and Spatial Distribution Analysis

Table 7: Aggregated Nominal Point Density (ANPD) / Aggregated Nominal Point Spacing (ANPS) Check		
Project AOI M^2	755,421,800	
Number of First Return(FR), Single Swath(SS) Points	6,953,803,181	
Specification Acceptance		
Specification Threshold	Calculated Result	Status
Number of FR, SS Points/m^2 ≥ 8.00	9.21 pts/m^2	**PASS**

ANPD = 9.21 pts/m^2 or ANPS = 0.33 m

Table 8: Spatial Distribution of Points (Uniformity Grid Analysis)		
Project AOI M^2	755,421,800	
# 1m X 1m cells in project AOI with ≥ 1 FR, SS point	1,467,255,160	
Specification Acceptance		
Specification Threshold	Calculated Result	Status
≥90% of 1m X 1m cells contain at least one single swath, FR point	95.0%	**PASS**

LiDAR Horizontal Accuracy Assessment

AECOM downloaded the most recent and highest accuracy orthoimagery available from the TNRIS data repository. The accuracy of the reference orthoimagery is 2.45 meters at 95% confidence level. Given the stated horizontal accuracy of the reference orthos and the project specification AECOM could not perform and report an accuracy assessment. AECOM did however perform a check of 20 locations to assess the horizontal alignment of the Intensity rasters and the orthoimagery. AECOM did not encounter any locations where the alignment of the two datasets was concerning.

Eastern AOI 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/QC 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/QC Checks		
	Review Status	**Comments to Sanborn & TNRIS**
Inventory Assessment		
Conduct file inventory	Meets project specifications	
Verify readability of media	Meets project specifications	
Coverage/Gap check	Meets project specifications	
No tile/data overlap	Meets project specifications	
Tile Naming Convention		
Tile name match index	Meets project specifications	
Metadata Review		
Project Level metadata - Content check	Meets project specifications	
USGS metadata parser check	Meets project specifications	
USGS Lidar tags present	Meets project specifications	
Tile Level metadata - Content check	Meets project specifications	
USGS metadata parser check	Meets project specifications	
USGS Lidar tags present	Meets project specifications	
LAS Header Check		
LAS format (LAS 1.4)	Meets project specifications	
GPS Times is Adjusted GPS time	Meets project specifications	
GPS times (0.01 m)	Meets project specifications	
LAS X,Y,Z scale factors 0.01 precision	Meets project specifications	
File source ID assigned	Meets project specifications	
LAS Number Variable Length Records Present	Meets project specifications	
Point Source ID equal to the File Source ID	Meets project specifications	
LAS Point Data Record Format - 6	Meets project specifications	
NAVD88, Geoid 12B, NAD83(2011), UTM Z15 meters	Meets project specifications	
At least 3 returns per pulse	Meets project specifications	
Acceptable classes - 1,2,3,4,5,6,7,9,10,13,14	Meets project specifications	
Analysis		
LAS Overlap Flag - Overage points flagged as Overlap in Classified point clouds Class 12 should NOT be used	Meets project specifications	1,653,974,880 points tagged as Overlap
LAS Withheld Flag - Geometrically unreliable points flagged as Withheld in Classified point clouds	Meets project specifications	No points tagged as Withheld
Horizontal Accuracy Check - RMSE ≤ 0.25 m	Meets project specifications	Highest accuracy orthoimagery available was downloaded from TNRIS data repository.
Vertical Accuracy Check - NVA (RMSE ≤ 0.1 m, 95% CI ≤ 0.196 m)	Meets project specifications	RMSEz = 0.10 m using 55 points
Vertical Accuracy Check - VVA (≤ 0.294 m 95th Percentile)	Meets project specifications	0.29 m at 95th Percentile using 43 points after ignoring checkpoints 1080 and 1073.
Intra-swath Accuracy (≤ 0.06 m)	Meets project specifications	9,860 points tested on 2 dispersed airport tarmacs. Less than 7% of points tested have Z difference ≥ 6 cm and are deemed ignored.
Inter-swath Accuracy (≤ 0.08m, MAX +/- 0.16m)	Meets project specifications	Measuring 296,454 interswath points, and excluding 3,077 points that exceeded 0.16 m that resided in vegetated or steep areas, an RMSEz = 0.03 m was calculated.
ANPS ≤ 0.5 m ***OR*** ANPD ≥ 4.0 pts/m^2	Meets project specifications	ANPD = 4.29 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 project specifications	97% of 1.0 m grid of pixels contain at least 1 SS, FR point
Duplicate Points (X, Y, Z, AND TIME)	Meets project specifications	6,714,292 points have repeating XYZ values. Random sampling suggests time is unique with these points and the vast majority of duplicate points located at swath edge. Class 1 points comprised greatest percentage of these points.
Gross Anomaly Check		

Extreme intensity values	Meets project specifications	
Systematic data dropouts	Meets project specifications	
Micro QA/QC Checks		
	Review Status	**Comments to Sanborn & 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 (near BL), 13=bridges, 14=culverts)		
Consistency in filtering	Meets project specifications	
Classification accuracy (misclassification)	Meets project specifications	
Building sides are C6 not veg	Meets project specifications	
Data voids/gaps ≥ (4x ANPS)^2 = 4.0 m^2	Meets project specifications	
Ridges/steps	Meets project specifications	
Cornrows	Meets project specifications	
Spikes/Divots (noise)	Meets project specifications	
No LiDAR shadowing (sliver gaps) around taller structures	Meets project specifications	

Intensity Rasters

Macro QA/QC Checks		
	Review Status	**Comments to Sanborn & TNRIS**
Inventory Assessment		
Conduct file inventory	Meets project specifications	
Verify readability of media	Meets project specifications	
Coverage/Gap check	Meets project specifications	
50 meter tile overlap with 90 degree corners	Meets project specifications	
Tile Naming Convention		
Tile name match index	Meets project specifications	
Metadata Review		
Project Level metadata - Content check	Meets project specifications	
USGS metadata parser check	Meets project specifications	
Tile Level metadata - Content check	Meets project specifications	
USGS metadata parser check	Meets project specifications	
INTENSITY Header Check		
GeoTIFF format, 8, 16, or 32bit U	Meets project specifications	
Resolution ≤ 0.5 m	Meets project specifications	
NAVD88, Geoid 12B, NAD83(2011), UTM Z15 meters	Meets project specifications	
Analysis		
NODATA set to 255	Meets project specifications	
Micro QA/QC Checks		
	Review Status	**Comments to Sanborn & TNRIS**
Micro Review		
Uniformity/consistency across swath	Meets project specifications	
No over or under saturation/Extreme intensity values	Meets project specifications	

Hydro-flattened Breaklines

Macro QA/QC Checks		
	Review Status	**Comments to Sanborn & TNRIS**
Inventory Assessment		
Conduct file inventory	Meets project specifications	

Verify readability of media	Meets project specifications	
Coverage/Gap check	Meets project specifications	
Breaklines can extend just beyond AOI limits	Meets project specifications	
Metadata Review		
Project Level metadata - Content check	Meets project specifications	
USGS metadata parser check	Meets project specifications	
Tile Level metadata - Content check	Meets project specifications	
USGS metadata parser check	Meets project specifications	
Breakline Header Checks		
Seamless or Tile based PolylineZ or PolygonZ GDB format v10.3	Meets project specifications	
.PRJ file present	Meets project specifications	
NAVD88, Geoid 12B, NAD83(2011), UTM Z15 meters	Meets project specifications	
Analysis		
No duplicate features	Meets project specifications	
No topology issues (overlapping features, snapping issues, or open polygons)	Meets project specifications	
Expresses monotonicity	Meets project specifications	
Relative Vertical Accuracy Check	Meets project specifications	
Micro QA/QC Checks		
	Review Status	**Comments to Sanborn & TNRIS**
Micro Review		
Streams/Rivers break at culverts	Meets project specifications	
Streams/Rivers continuous at bridges	Meets project specifications	
All inland streams and rivers should have been captured and flattened that have a 15.25 m nominal width	Meets project specifications	
Water bodies greater than 10,000 m^2 collected	Meets project specifications	
Islands greater than 5,000 m^2 collected	Meets project specifications	

Vertical Accuracy Assessments

Relative Vertical Accuracy

Intraswath Relative Accuracy – Intraswath vertical relative accuracy was tested using 9,860 points on a 1m grid residing in 2 dispersed airport tarmacs. Less than 7% of the First Return, Single Swath points tested ≤ 6 cm and are deemed ignored. For the sake of brevity a table has not be included in this report.

Interswath Relative Accuracy – Measuring 296,454 interswath points, and excluding 3,077 points that exceeded 16 cm that resided in vegetation areas, an RMSEz = 3 cm was calculated. For the sake of brevity a table has not be included in this report.

Absolute Vertical Accuracy

NVA Vertical Accuracy

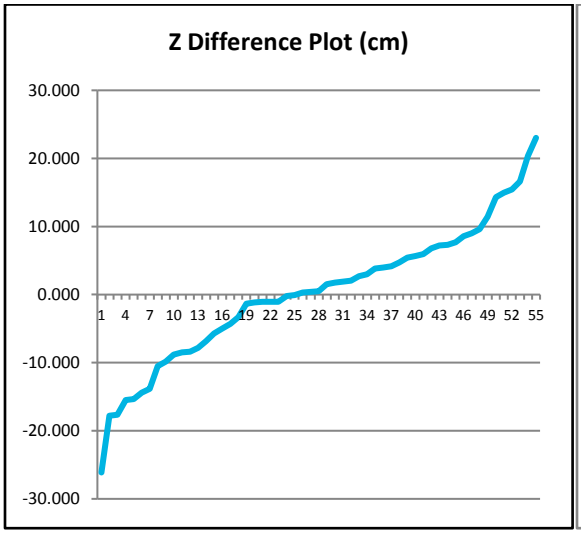
Vertical accuracy of LiDAR data will be achieved by comparing the elevation of Class 2 Bare Earth points against the QA checkpoint elevation values. Deviations were reported as an RMSE and @95% confidence for NVA assessments and @95th Percentile for VVA assessments.

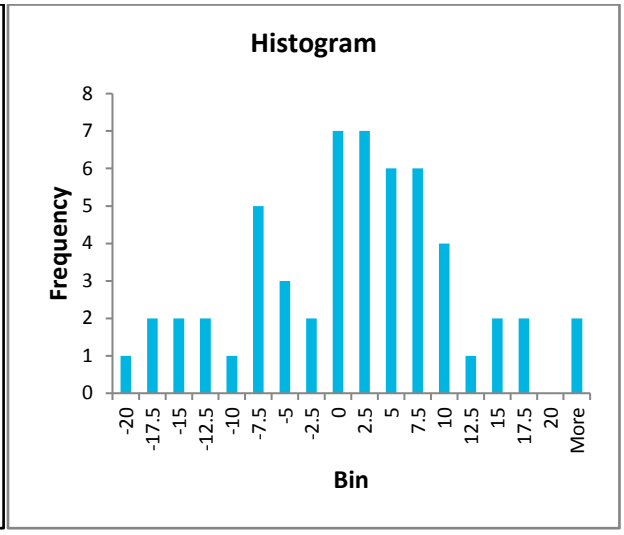
Fifty-five (55) evenly distributed checkpoints were utilized to report NVA RMSEz.

Table 9: Eastern AOI LiDAR NVA Assessment
UTM Z15N, NAVD88 (Geoid12B), NAD83(2011), Meters

GPS Point Name	Survey Elevation	LiDAR Elevation	Difference
1039	4.850	4.646	0.204
1045	7.058	6.828	0.230
1042	1.592	1.426	0.166
1025	1.344	1.190	0.154
1036	4.222	4.072	0.150
1048	7.793	7.650	0.143
1028	1.746	1.631	0.115
1044	7.553	7.457	0.096
1001	10.557	10.467	0.090
1046	12.414	12.328	0.086
1018	9.650	9.573	0.077
1043	2.133	2.060	0.073
1017	5.101	5.029	0.072
1033	10.395	10.327	0.068
1010	0.891	0.832	0.059
1015	12.573	12.517	0.056
1004	1.853	1.799	0.054
1011	2.091	2.044	0.047
1021	1.240	1.198	0.042
1022	1.063	1.023	0.040
1027	2.963	2.925	0.038
1002	6.503	6.473	0.030
1038	4.167	4.140	0.027
1055	3.709	3.688	0.021
1035	5.218	5.199	0.019
1052	3.018	3.000	0.018
1034	8.635	8.620	0.015
1029	4.015	4.010	0.005
1049	1.890	1.886	0.004
1041	0.093	0.090	0.003
1013	6.331	6.332	-0.001
1014	11.590	11.592	-0.002
1006	1.463	1.473	-0.010
1032	6.714	6.725	-0.011
1019	4.362	4.373	-0.011
1009	0.678	0.689	-0.011
1024	5.165	5.178	-0.013
1047	9.473	9.506	-0.033
1008	0.892	0.935	-0.043
1023	1.581	1.631	-0.050
1037	1.945	2.002	-0.057
1003	5.176	5.244	-0.068
1050	2.696	2.774	-0.078
1040	8.502	8.586	-0.084
1031	0.580	0.665	-0.085
1007	0.504	0.592	-0.088
1012	2.635	2.733	-0.098
1005	3.089	3.194	-0.105

1053	4.064	4.203	-0.139
1054	10.153	10.297	-0.144
1030	6.159	6.313	-0.154
1020	3.475	3.630	-0.155
1026	0.499	0.675	-0.176
1016	6.322	6.500	-0.178
1051	2.419	2.680	-0.261





NVA Vertical Accuracy Statistics - NSSDA									
# of Pts	RMSEz (cm)	Std Dev (cm)	Mean (cm)	Median (cm)	Skew	Min (cm)	Max (cm)	95% CI (RMSE * 1.96) (cm)	95TH Percentile (cm)
55	9.992	10.080	0.268	-0.513	-0.190	-26.129	23.022	19.584	18.568

NVA Accuracy Assessment Results	
PASS	Tested 19.584 cm vertical accuracy at 95% confidence level in bare earth using RMSEz x 1.9600.

VVA Vertical Accuracy

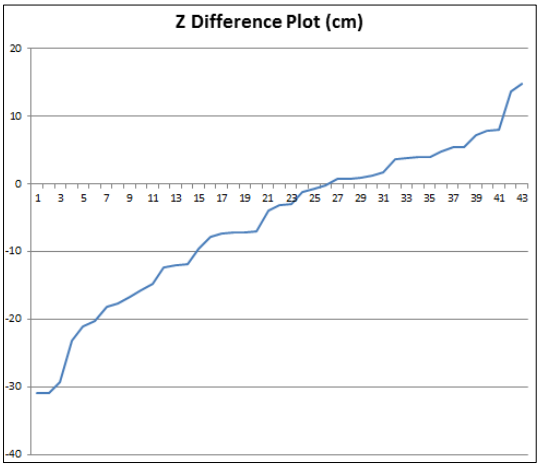
Forty-three (43) distributed checkpoints were utilized to report VVA RMSEz. Elevation deltas observed for the following points were ignored due to unreasonably high delta returns. These include the checkpoints presented below:

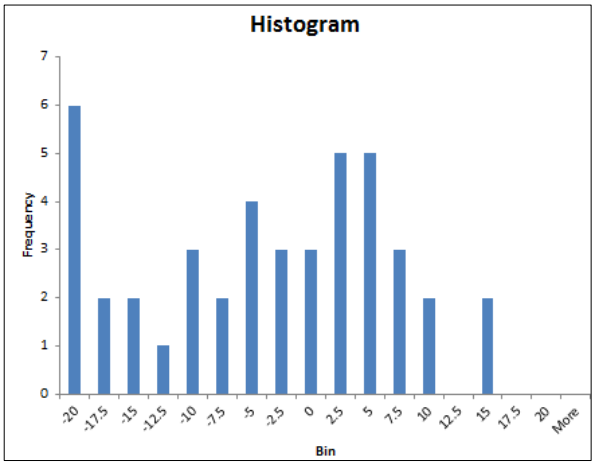
VVA Assessment

- Point 1080 – short grass that may have grown since the data was flown compared to ground survey
- Point 1073 – tall grass that may have been cut/flattened/compressed since the data was flown compared to ground survey

Table 10: Eastern AOI LiDAR VVA Assessment
UTM Z15N, NAVD88 (Geoid12B), NAD83(2011), Meters

GPS Point Name	Survey Elevation	DEM Elevation	Difference
1081	1.685	1.537	0.148
1072	1.678	1.541	0.137
1061	1.727	1.647	0.080
1091	1.742	1.664	0.078
1100	2.540	2.469	0.071
1098	6.140	6.085	0.055
1088	10.574	10.520	0.054
1094	9.811	9.763	0.048
1089	6.472	6.432	0.040
1075	4.222	4.182	0.040
1077	4.045	4.007	0.038
1085	7.700	7.663	0.037
1056	0.682	0.664	0.018
1066	4.877	4.864	0.013
1087	3.693	3.684	0.009
1084	9.298	9.290	0.008
1082	1.082	1.074	0.008
1096	8.272	8.275	-0.003
1095	8.990	8.998	-0.008
1064	12.406	12.418	-0.012
1058	0.461	0.490	-0.029
1093	1.503	1.535	-0.032
1099	11.978	12.017	-0.039
1074	2.283	2.353	-0.070
1079	3.979	4.050	-0.071
1063	6.461	6.533	-0.072
1083	7.742	7.815	-0.073
1090	5.753	5.831	-0.078
1086	2.893	2.989	-0.096
1060	0.786	0.904	-0.118
1078	2.043	2.163	-0.120
1069	0.901	1.024	-0.123
1092	2.226	2.373	-0.147
1059	0.675	0.832	-0.157
1067	4.086	4.253	-0.167
1070	0.815	0.992	-0.177
1097	-0.143	0.039	-0.182
1071	5.076	5.278	-0.202
1065	5.329	5.540	-0.211
1057	0.348	0.580	-0.232
1076	5.879	6.172	-0.293
1062	2.182	2.491	-0.309
1068	3.178	3.488	-0.310





VVA Vertical Accuracy Statistics - NSSDA									
# of Pts	RMSEz (cm)	Std Dev (cm)	Mean (cm)	Median (cm)	Skew	Min (cm)	Max (cm)	95% CI (RMSE * 1.96) (cm)	95TH Percentile (cm)
43	12.853	11.664	-5.684	3.157	-0.511	-30.983	14.839	25.192	28.648

VVA Accuracy Assessment Results	
PASS	Tested 28.648 cm vertical accuracy at 95th percentile in vegetated areas.

Point Density and Spatial Distribution Analysis

Table 11: Aggregated Nominal Point Density (ANPD) / Aggregated Nominal Point Spacing (ANPS) Check		
Project AOI M^2	2,197,682,518	
Number of First Return(FR), Single Swath(SS) Points	9,430,916,834	
Specification Acceptance		
Specification Threshold	Calculated Result	Status
Number of FR, SS Points/m^2 ≥ 4.00	4.29 pts/m^2	**PASS**

ANPD = 4.29 pts/m^2 or ANPS = 0.48 m

Table 12: Spatial Distribution of Points (Uniformity Grid Analysis)		
Project AOI M^2	2,197,682,518	
# 1m X 1m cells in project AOI with ≥ 1 FR, SS point	2,132,048,091	
Specification Acceptance		
Specification Threshold	Calculated Result	Status
≥90% of 1m X 1m cells contain at least one single swath, FR point	97.0%	**PASS**

LiDAR Horizontal Accuracy Assessment

AECOM downloaded the most recent and highest accuracy orthoimagery available from the TNRIS data repository. The accuracy of the reference orthoimagery is 2.45 meters at 95% confidence level. Given the stated horizontal accuracy of the reference orthos and the project specification AECOM could not perform and report an accuracy assessment. AECOM did however perform a check of 20 locations to assess the horizontal alignment of the Intensity

rasters and the orthoimagery. AECOM did not encounter any locations where the alignment of the two datasets was concerning.

5. Phase IV: Product Development

Western AOI 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/QC check. Reporting reflects the status of the final data deliverables after all revised data had been submitted for review.

Macro QA/QC Checks		
	Review Status	**Comments to Sanborn & 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 = 0.5 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 (RMSEz ≤ 0.10 m, 95% CI ≤ 0.196 m)	Meets Specifications	RMSEz = 0.084 m using 18 checkpoints
Vertical Accuracy Check - VVA (≤ 0.294 m 95th Percentile)	Meets Specifications	95th Percentile = 0.161 m using 4 checkpoints
Micro QA/QC Checks		
	Review Status	**Comments to Sanborn & 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 m2 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 Assessments

Absolute Vertical Accuracy

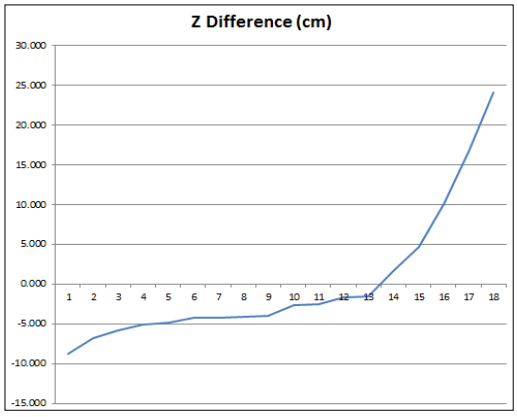
Vertical accuracy of DEM raster data will be achieved by comparing the rasterized version of Class 2 Bare Earth points against the QA checkpoint elevation values. Deviations were reported as an RMSE and @ 95% confidence for NVA assessments and @ 95th Percentile for VVA assessments.

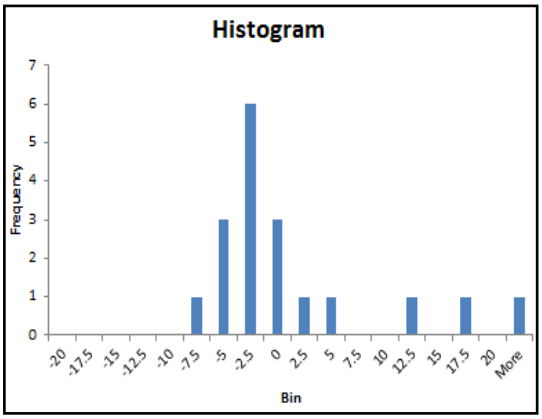
NVA Accuracy Assessment

Mimicking the checkpoints used as part of the LiDAR NVA checks 18 evenly distributed checkpoints were utilized to calculate the NVA RMSEz.

Table 13: Western AOI DEM NVA Assessment
UTM Z15N, NAVD88, Geoid 12B, NAD83(2011), Meters

GPS Point Name	Survey Elevation	DEM Elevation	Difference
101	8.129	8.197	-0.068
102	7.336	7.423	-0.087
103	5.192	5.207	-0.015
104	10.376	10.134	0.242
105	9.814	9.862	-0.048
106	6.525	6.424	0.101
107	13.711	13.544	0.167
108	8.700	8.725	-0.025
110	14.357	14.373	-0.016
111	12.007	12.046	-0.039
112	9.415	9.457	-0.042
113	1.752	1.706	0.046
114	8.690	8.732	-0.042
115	5.392	5.376	0.016
116	22.968	23.009	-0.041
117	8.204	8.230	-0.026
118	5.458	5.517	-0.059
119	12.038	12.089	-0.051





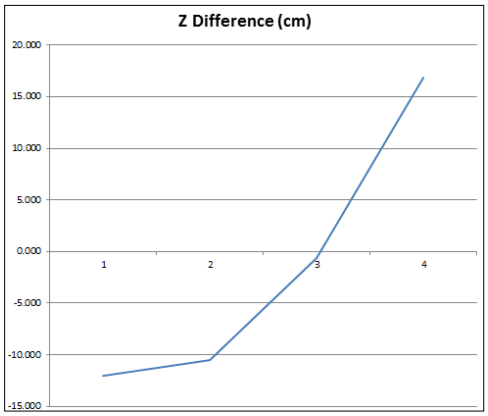
NVA Vertical Accuracy Statistics - NSSDA									
# of Pts	RMSEz (cm)	Std Dev (cm)	Mean (cm)	Median (cm)	Skew	Min (cm)	Max (cm)	95% CI (RMSE * 1.96) (cm)	95TH Percentile (cm)
18	8.432	8.676	0.076	3.258	1.813	-8.709	24.172	16.526	17.817

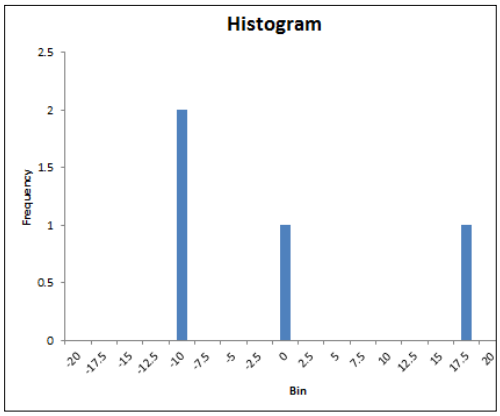
NVA Accuracy Assessment Results	
PASS	Tested 16.53 cm vertical accuracy at 95% confidence level in bare earth using RMSEz x 1.9600

VVA Accuracy Assessment

Mimicking the checkpoints used as part of the LiDAR VVA checks 4 evenly distributed checkpoints were utilized to report VVA RMSEz.

Table 14: Western AOI DEM VVA Assessment UTM Z15N, NAVD88 (Geoid12B), NAD83(2011), Meters			
GPS Point Name	Survey Elevation	DEM Elevation	Difference
122	8.643	8.763	-0.120
123	11.632	11.638	-0.006
124	10.027	9.859	0.168
125	1.643	1.748	-0.105





VVA Vertical Accuracy Statistics - NSSDA									
# of Pts	RMSEz (cm)	Std Dev (cm)	Mean (cm)	Median (cm)	Skew	Min (cm)	Max (cm)	95% CI (RMSE * 1.96) (cm)	95TH Percentile (cm)
4	11.602	13.272	-1.581	5.552	1.248	-12.038	16.818	22.740	16.101

VVA Accuracy Assessment Results	
PASS	Tested 16.10 cm vertical accuracy at 95th percentile in vegetated areas

Eastern AOI 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/QC check. Reporting reflects the status of the final data deliverables after all revised data had been submitted for review.

Macro QA/QC Checks

	Review Status	Comments to Sanborn & 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 (RMSEz ≤ 0.10 m, 95% CI ≤ 0.196 m)	Meets Specifications	RMSEz = 0.103 m using 55 checkpoints
Vertical Accuracy Check - VVA (≤ 0.294 m 95th Percentile)	Meets Specifications	95th Percentile = 0.289 m using 43 checkpoints
Micro QA/QC Checks		
	Review Status	**Comments to Sanborn & 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 m2 collected	Meets Specifications	
Data voids/gaps	Meets Specifications	
Ridges/steps between tiles	Meets Specifications	
Over or Under aggressive filtering anomolies	Meets Specifications	
Spikes/Divots (noise)	Meets Specifications	

Vertical Accuracy Assessments

Absolute Vertical Accuracy

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.

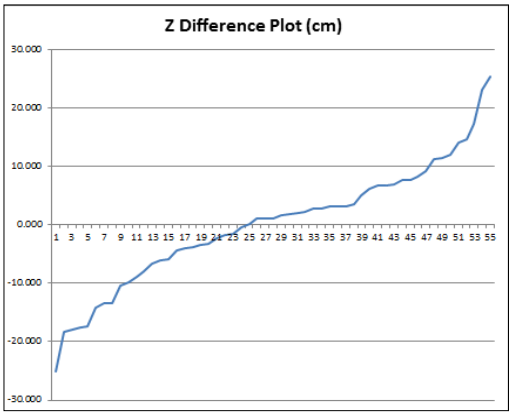
NVA Accuracy Assessment

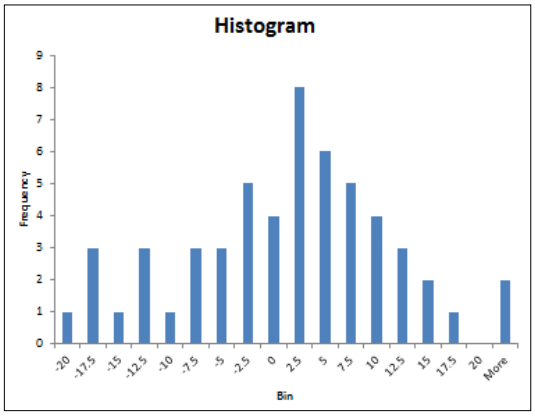
Mimicking the checkpoints used as part of the LiDAR NVA checks 55 evenly distributed checkpoints were utilized to calculate the NVA RMSEz.

Table 15: Eastern AOI DEM NVA Assessment
UTM Z15N, NAVD88 (Geoid12B), NAD83(2011), Meters

GPS Point Name	Survey Elevation	DEM Elevation	Difference
1	10.557	10.495	0.062
15	12.573	12.522	0.051
34	8.635	8.625	0.010
17	5.101	5.024	0.077
29	4.015	4.005	0.010
2	6.503	6.472	0.031
18	9.650	9.568	0.082
14	11.590	11.558	0.032
5	3.089	3.188	-0.099
33	10.395	10.329	0.066
44	7.553	7.462	0.091
47	9.473	9.506	-0.033
3	5.176	5.215	-0.039
35	5.218	5.198	0.020
26	0.499	0.683	-0.184
16	6.322	6.497	-0.175
48	7.793	7.652	0.141
4	1.853	1.784	0.069
36	4.222	4.102	0.120
25	1.344	1.172	0.172
45	7.058	6.827	0.231
32	6.714	6.731	-0.017
11	2.091	2.059	0.032
46	12.414	12.347	0.067
19	4.362	4.366	-0.004
6	1.463	1.498	-0.035
31	0.580	0.668	-0.088
54	10.153	10.287	-0.134
53	4.064	4.243	-0.179
20	3.475	3.609	-0.134
7	0.504	0.609	-0.105
38	4.167	4.140	0.027
39	4.850	4.597	0.253
21	1.240	1.164	0.076
40	8.502	8.582	-0.080
23	1.581	1.624	-0.043
24	5.165	5.206	-0.041
52	3.018	3.002	0.016
8	0.892	0.951	-0.059
22	1.063	1.040	0.023
37	1.945	2.007	-0.062
13	6.331	6.354	-0.023
50	2.696	2.762	-0.066
30	6.159	6.333	-0.174
51	2.419	2.670	-0.251
49	1.890	1.880	0.010
55	3.709	3.691	0.018
12	2.635	2.776	-0.141
27	2.963	2.928	0.035
9	0.678	0.693	-0.015
10	0.891	0.863	0.028

28	1.746	1.634	0.112
41	0.093	0.091	0.002
43	2.133	2.020	0.113
42	1.592	1.446	0.146





NVA Vertical Accuracy Statistics - NSSDA									
# of Pts	RMSEz (cm)	Std Dev (cm)	Mean (cm)	Median (cm)	Skew	Min (cm)	Max (cm)	95% CI (RMSE * 1.96) (cm)	95TH Percentile (cm)
55	10.297	10.392	0.081	-1.045	-0.066	-25.059	25.345	20.182	20.713

TNRIS indicated that the 3mm RMSEz overage is acceptable.

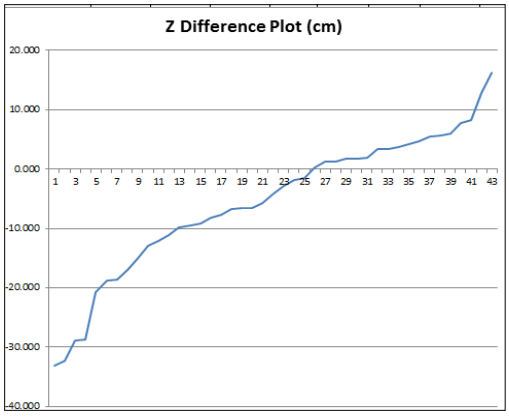
NVA Accuracy Assessment Results	
PASS	Tested 20.18 cm vertical accuracy at 95% confidence level in bare earth using RMSEz x 1.9600

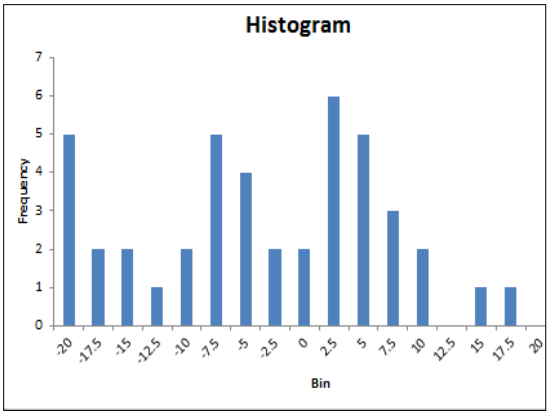
VVA Accuracy Assessment

Mimicking the checkpoints used as part of the LiDAR VVA checks 43 evenly distributed checkpoints were utilized to report VVA RMSEz.

Table 16: Eastern AOI DEM VVA Assessment UTM Z15N, NAVD88 (Geoid12B), NAD83(2011), Meters			
GPS Point Name	Survey Elevation	DEM Elevation	Difference
56	0.682	0.665	0.017

57	0.348	0.555	-0.207
58	0.461	0.555	-0.094
59	0.675	0.825	-0.150
60	0.786	0.897	-0.111
61	1.727	1.671	0.056
62	2.182	2.505	-0.323
63	6.461	6.527	-0.066
64	12.406	12.393	0.013
65	5.329	5.617	-0.288
66	4.877	4.822	0.055
67	4.086	4.207	-0.121
68	3.178	3.509	-0.331
69	0.901	0.978	-0.077
70	0.815	0.945	-0.130
71	5.076	5.263	-0.187
72	1.678	1.550	0.128
74	2.283	2.340	-0.057
75	4.222	4.188	0.034
76	5.879	6.168	-0.289
77	4.045	3.998	0.047
78	2.043	2.135	-0.092
79	3.979	4.046	-0.067
81	1.685	1.522	0.163
82	1.082	1.070	0.012
83	7.742	7.771	-0.029
84	9.298	9.296	0.002
85	7.700	7.617	0.083
86	2.893	2.991	-0.098
87	3.693	3.675	0.018
88	10.574	10.537	0.037
89	6.472	6.490	-0.018
90	5.753	5.835	-0.082
91	1.742	1.682	0.060
92	2.226	2.396	-0.170
93	1.503	1.568	-0.065
94	9.811	9.769	0.042
95	8.990	8.973	0.017
96	8.272	8.287	-0.015
97	-0.143	0.045	-0.188
98	6.140	6.107	0.033
99	11.978	12.020	-0.042
100	2.540	2.462	0.078





VVA Vertical Accuracy Statistics - NSSDA									
# of Pts	RMSEz (cm)	Std Dev (cm)	Mean (cm)	Median (cm)	Skew	Min (cm)	Max (cm)	95% CI (RMSE * 1.96) (cm)	95TH Percentile (cm)
43	12.965	11.837	-5.589	4.186	-0.662	-33.121	16.302	25.412	28.903

VVA Accuracy Assessment Results	
PASS	Tested 28.90 cm vertical accuracy at 95th percentile in vegetated areas

Credits

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

Table 17: Project Stakeholders	
Project Function	Participant
LiDAR procurement	Texas Natural Resources Information System (TNRIS) Texas Water Development Board (TWDB) Trinity River Authority (TRA)
LiDAR acquisition and processing	Sanborn Mapping Company
QA checkpoint ground surveys	AECOM subcontractor - Gorrondona & Associates, Inc.
Accuracy assessment, QA review, and reporting	AECOM Technical Services, Inc.

6. Conclusions

By TNRIS standards the 2017 Coastal Texas project was a small to medium size project appyling standard TNRIS and USGS specifications and deliverable requirements.

The overarching challenge associated with any geospatial data acquisition and data processing project is the narrow window within which to acquire, process, quality assure, and ultimately accept the data within the funding dependent project window. An additional challenge was the requirement to collect the Western AOI at QL0 specifications (≥8ppsm at an RMSEz of ≤ 5cm in Non Vegetated Areas). The Eastern AOI was scoped to be captured at the more common QL2 specifications (≥8ppsm at an RMSEz of ≤ 10cm in Non Vegetated Areas).

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

- As part of the initial Phase III submittal report it was noted that the classification structure relative to the swath overlap needed to be altered to align with the USGS LBS v1.2 specifications. The structure issue had a secondary impact by overstating ANPS and ANPD. The classification structure was eventually addressed by Sanborn and ANPS and ANPD accurately reported for each AOI.
- The project concluded 5 months after the most recent published completion date of November 6, 2017. The overage was primarily due to three Phase III rounds of the backcheck reviews and two Phase IV rounds of backcheck reviews.
- AECOM had issues with 5 of the 105 QA check points where the Z Deltas we unexpectedly high. After careful review AECOM elected to categorize these points as blunders and excuse these checkpoints. None of the results associated with these checkpoints were included in any of the reported vertical accuracy calculations.
- The Western AOI was originally required to meet USGS QL0 specifications. Through the results of vertical testing it was determined that the Western AOI did not meet QL0 specifications, but did meet QL1 specifications. TNRIS conferred with TRA and it was decided that meeting QL1 specifications were acceptable.

Despite the laborious flight planning steps utilizing the LiDAR manufacturer's planning software, and the numerous subsequent internal checks performed by Sanborn and AECOM, unanticipated 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/QC issues reported were satisfactorily addressed by Sanborn or deemed insignificant and acceptable by TNRIS. Sanborn was responsible for preparing and delivering the finalized and accepted datasets to TNRIS via mobile drive directly.

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

Geospatial Quality Assessment Conducted by:

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