LiDAR
Quality Assurance/Quality Control
Assessment Report

For

U S Army Corp of Engineers
St. Louis District

And

Maryland
Department of Natural Resources

Of

Caroline, Kent, and Queen Anne Counties, Maryland

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AERO-METRIC PROJECT NO. 1-080207

AERO-METRIC

PHOTOGRAMMETRY & GEOSPATIAL DATA SOLUTIONS

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LiDAR QA/QC of Maryland Counties of Caroline, Kent, and Queen Anne for USACE – St. Louis District

Introduction

Aero-Metric was contracted to assess the quality of LiDAR as flown and processed by Earth Data during 2006 under contract with Maryland DNR. Aero-Metric's experience and reputation for high quality LiDAR and mapping production, along with our own quality evaluation measures, gives us the ability to perform complete and accurate assessments. A deep-seated commitment to honesty and integrity allows Aero-Metric to provide unbiased quality assurance and quality control (QA/QC) reporting on any dataset.

For our assessment, 908 tiles were available for inspection; we selected 201 tiles or 21%. Of the 201 tiles, 74 tiles were selected because they contained survey checkpoints. The remaining 127 were selected randomly, but evenly distributed throughout the project area. Figure 1 shows survey checkpoint blocks in blue and random tiles in bright green.

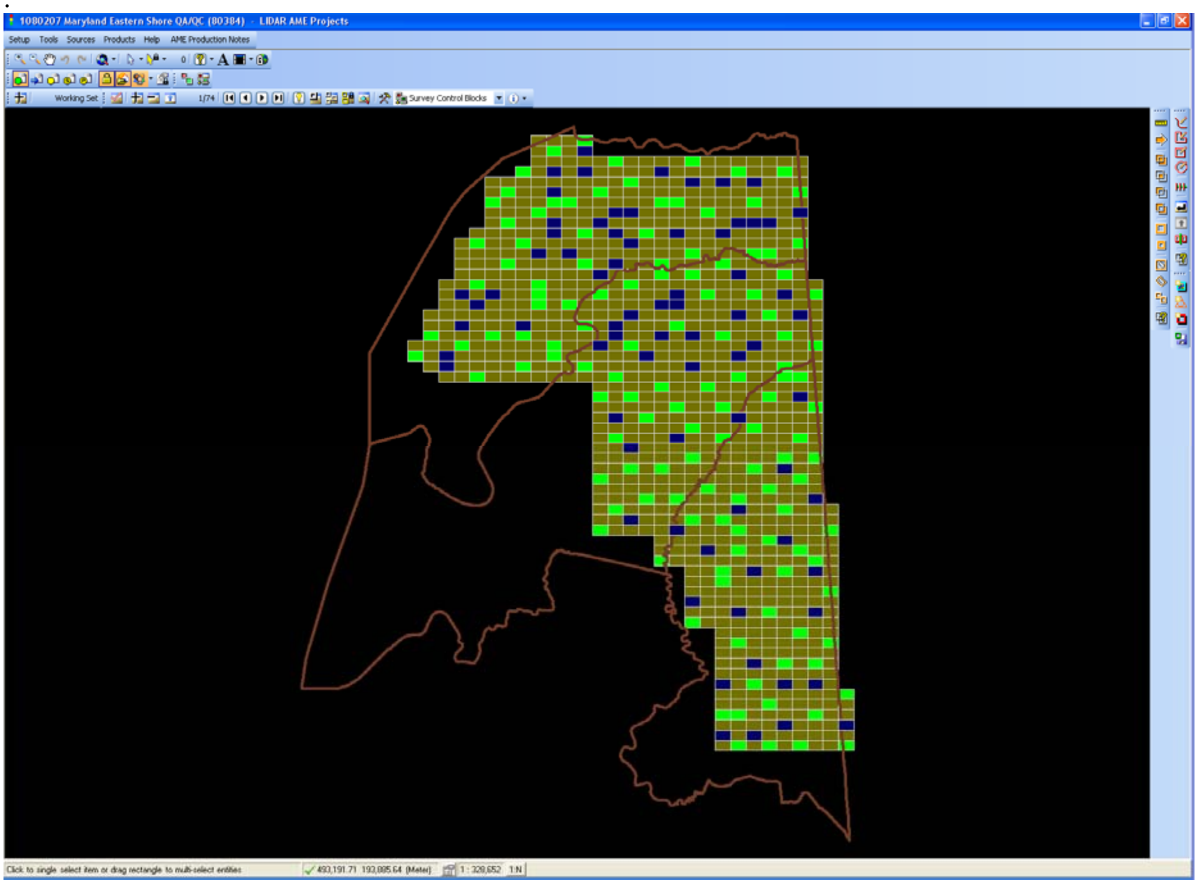


Figure 1 – 201 Inspected Tiles

We employed several software packages in order to perform the different operations necessary to determine data completeness, accuracy and usability. The following is a list of the software used and the required tasks that we performed:

- **GeoCue** is a production management system developed by GeoCue, Corp. It is designed as a framework for large volume, multiple production seat geospatial data processing. This software allows us to track our project workflow giving us the ability to record each step of the process, thereby continuously performing QA/QC procedures as production is carried out. GeoCue also contains several production tools. One of these tools is a LiDAR ortho raster generator, which creates true ortho rectified LiDAR intensity images and can fill data gaps with a specified contrasting color. The following processes were performed using GeoCue:
    - Import LAS files for project management
    - Validate file readability
    - Generate LiDAR intensity ortho raster images to scan for data voids

- **TerraScan** and **Terramodeler** are LiDAR processing software packages developed by Terrasolid, Ltd. Terrascan is used to process raw airborne laser data. Users read-in trajectories and raw data points and classify them into user-defined point classes like ground, vegetation and buildings. TerraModeler is a terrain modeling application that creates surface models (TIN) of ground, soil layers or design elements by reading in laser points, graphical design elements or XYZ text files. TerraModeler contains functions to edit TINs and display them as contours, shaded surfaces and profiles. Terrasolid products can be integrated into GeoCue. The following processes were performed using Terrascan and Terramodel:
    - Survey Control Report
        - Compare survey checkpoints against the LiDAR bare earth surface
    - Read 201 individual LAS bare earth tiles through GeoCue (21% of total)
        - Check Post Spacing
        - Inspect for Data Voids
        - Inspect for Vegetation Artifacts
        - Determine if Hydrographic Points have been removed from ground
        - Determine if Over Filtering of Ground Surface occurred

- **Quick Terrain Modeler** is LiDAR visualization software developed at the Johns Hopkins University Applied Physics Lab and distributed by Applied Imagery. The main focus of this software is to quickly read large amounts of laser points for viewing in a 3 dimensional environment. The following process were performed using Quick Terrain Modeler:
    - Import ASCII files to validate file readability
    - Create surface models to validate completeness

Quality Review

The quality of a LiDAR product is most often determined by what categories and how much of it is unacceptable, and how well it matches land surveyed checkpoints. In this assessment we addressed three areas:

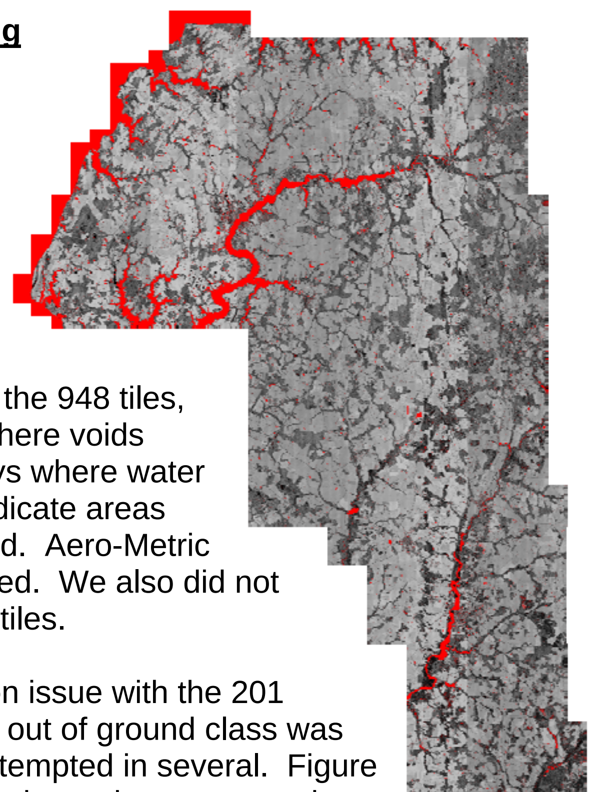
1. File validation
2. Correct and complete classification and editing
3. Accurate LiDAR system performance

File validation was determined by reading each file and creating viewable products from them. Accurate system performance was determined by comparing the LiDAR data to the required number and type of survey checkpoints as required by FEMA specifications. Correct classification was determined by editing a sampling of the blocks using our own QA/QC procedures. The following checks comprise the assessment of this report.

1. File Validation

All LAS files included in first return (948), last return (948), and bare earth (948) were imported into GeoCue. In GeoCue, we created ortho raster images and determined that all files were readable and complete. Also, all ASCII DEM files (948) were imported into Quick Terrain Modeler where we generated shaded surface models and determined that all files were readable and complete.

2. Correct and Complete Classification and Editing



A. Bare Earth Files

Point Spacing - Point spacing was randomly checked in each of the 201 blocks and was found to be within the required distance of 2.0m except in some areas of dense vegetation.

Data voids - While generating ortho images of the 948 tiles, we specified a contrasting color to be placed where voids occurred in the point data. This contrast displays where water and buildings were removed, but would also indicate areas where legitimate data might have been removed. Aero-Metric did not find data voids in the 201 blocks reviewed. We also did not notice any significant voids in the remainder of tiles.

Classification - Aero-Metric found one common issue with the 201 reviewed tiles; the classification of water points out of ground class was not completed in many water bodies and not attempted in several. Figure 2 shows an example of tile az1336mp ground points, where scattered water points were not removed from the water body throughout the tile.

This does not affect the accuracy of the ground data; however, these points do not belong in the ground class. Other minor issues included minor building and vegetation artifacts that were not removed.

Figure 2 – Water Points Not Removed from Ground Class

B. Digital Elevation Model (DEM)

Hydro - It appears that all the water has been set to an elevation of 0.0m. At the point of the land-water interface, the land has elevations between 0.0 and 0.70m lower than the water. This difference in elevations creates a "ridge" effect at the land-water interface. The difference in elevation would be plausible if the LiDAR data was acquired near the Mean Lower Low Water (MLLW) tide, which has an elevation of approximately -0.25m, as referenced to the NAVD88 datum. Profile examples from blocks au1305DM, av1303DM, and ax1323DM as shown in Figure 3 indicate differences of up to 0.70m at the land/water interface.

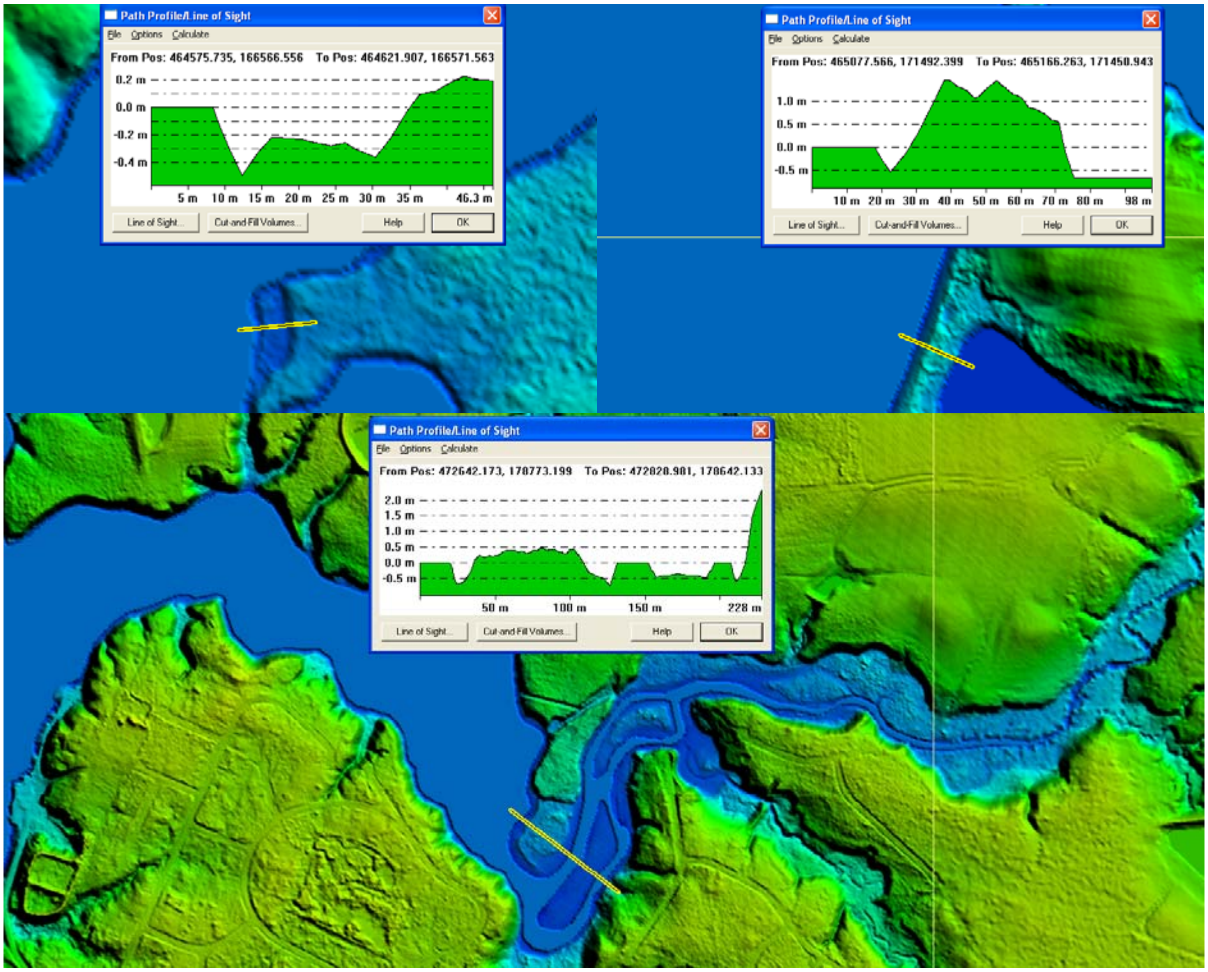


Figure 3 – Land-Water Interface Profiles

DEM Point Grid Evaluation - Although all DEM files were readable and complete, we found two issues with this dataset. First, the edges of these files do not contain common edge points. This may not be important, as long as all files are loaded and triangulated together. However, if the files are loaded and triangulated separately, such as they were in Figure 4 using Global Mapper, a 2m gap will occur between tiles. If these DEM's had been generated at cell corner rather than at cell center, then points would have been generated along the tile boundary, creating edge-matched tiles. Second, Figure 4 also shows one of the anomalies we found in the 40 tiles from Table 1. These files contain a short string of grid points that are lower in elevation than the surrounding points. These anomalies are found in the DEM files and not in the bare earth LiDAR. We can only speculate as to the cause of the problem, but it is plausible that this was a software glitch with water flattening at the time of DEM generation. Also, Aero-Metric only observed these 40 anomalies as part of a general overview of the 948 GeoTIFF's that we generated, therefore, a more in-depth analysis may reveal additional anomalies

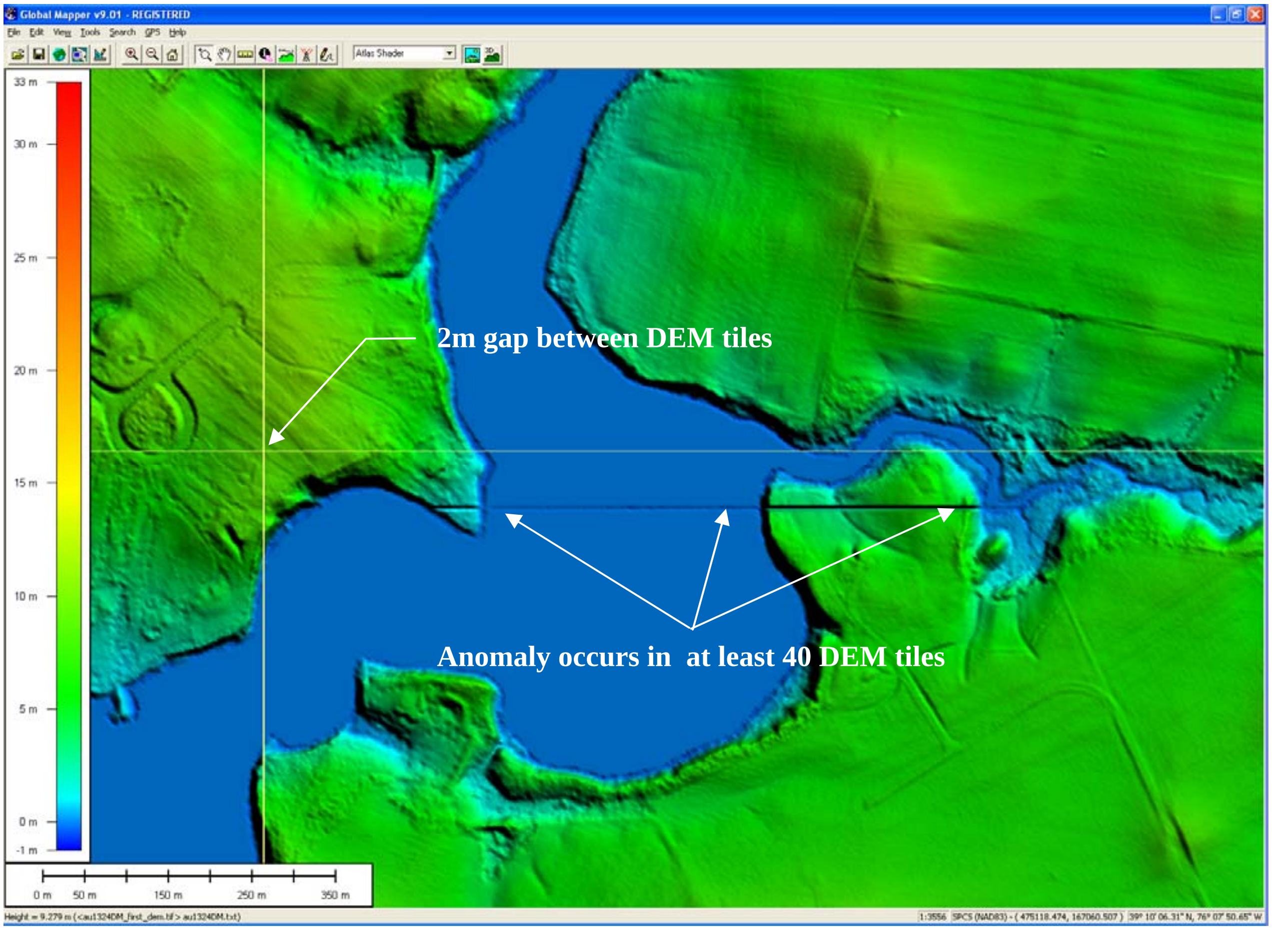


Figure 4 – 2m Gap Between Non-Edge Matched Tiles and Low Points Anomaly

Table 1 – 40 DEM Tiles Containing the Anomaly Displayed in Figure 4

at1292dm.txt	at1334dm.txt	ap1381dm.txt	au1326dm.txt	ba1355dm.txt
at1301dm.txt	at1346dm.txt	ap1413dm.txt	aw1371dm.txt	ba1344dm.txt
az1316dm.txt	ah1422dm.txt	ap1412dm.txt	aw1374dm.txt	ba1356dm.txt
at1324dm.txt	an1425dm.txt	ap1382dm.txt	aw1372dm.txt	ba1365dm.txt
au1326dm.txt	an1426dm.txt	au1342dm.txt	ay1325dm.txt	ba1366dm.txt
az1412dm.txt	aw1362dm.txt	au1335dm.txt	as1365dm.txt	ap1376dm.tx
ax1403dm.txt	aw1383dm.txt	au1356dm.txt	as1366dm.txt	ap1352dm.txt
ao1421dm.txt	am1405dm.txt	ak1396dm.txt	ak1396dm.txt	ai1422dm.txt

LiDAR Bare Earth Review Checklist

Tile	Read Tile	Inspect	Survey Tile	Random Tile	Post Space	Data Void	Vegetation	Over Filtered	**x -** indicates checked items that are o.k. = **2041**	**i -** indicates checked items that have issues = **123**
948	948	203	74	129	203	203	203	203	**Comments =**	123
AW1355	x									
AH1416	x	x		x	x	x	x	x		
AL1411	x									
AL1421	x									
AI1431	x	x		x	x	x	x	x		
AH1431	x	i	x		x	x	x	x	minor vegetation artifacts	
AI1435	x									
AH1406	x	i		x	x	x	x	x	Water on BE, BE on water in pond, minor vegetation artifacts	
AL1381	x	i	x		x	x	x	x	BE on water, Stream course definition	
AH1415	x									
AH1395	x									
AL1402	x									
AH1426	x									
AH1405	x									
AH1435	x	i		x	x	x	x	x	House/vegetation artifacts	
AH1425	x									
AL1422	x									
AI1433	x									
AL1412	x									
AL1391	x									
AH1433	x									
AL1392	x									
AL1401	x									
AL1382	x									
AH1396	x	i		x	x	x	x	x	BE pts on water layer	
AU1371	x									
AU1355	x	i	x		x	x	x	x	BE exposed at low tide or anomalous features in water	
AU1342	x	x		x	x	x	x	x		
AU1352	x	i	x		x	x	x	x	BE pts on water layer	
AO1351	x									
AS1355	x									
AU1382	x									
AO1355	x	i		x	x	x	x	x	BE pts on water layer, stream course	

AQ1395	x								
AQ1375	x	i		x	x	x	x	x	deck, BE/Trees on water layer
AU1301	x								
AU1321	x								
AU1312	x								
AQ1415	x	i	x		x	x	x	x	BE pts on water layer, stream course
AQ1353	x								
AU1332	x								
AQ1406	x								
AQ1396	x								
AU1322	x	i	x		x	x	x	x	Water on BE layer in pond, deck
AU1392	x								
AU1292	x								
AS1351	x								
AQ1386	x								
AU1361	x								
AP1351	x	i		x	x	x	x	x	Culvert- likely not a bridge, Trees on water layer
AU1401	x								
AU1351	x								
AQ1355	x								
AU1372	x	i		x	x	x	x	x	Trees on water layer
AQ1366	x								
AU1341	x								
AS1353	x	i		x	x	x	x	x	Stream course definition
AQ1425	x								
AT1353	x								
AU1391	x								
AR1351	x								
AQ1416	x								
AU1381	x								
AP1355	x								
AQ1376	x								
AV1353	x								
AP1353	x								
AV1355	x								
AR1355	x								
AT1355	x								
AU1353	x								
AT1351	x								
AQ1351	x								

AU1331	x								
AR1353	x								
AQ1365	x	x		x	x	x	x	x	
AQ1405	x	x		x	x	x	x	x	
AU1302	x	i	x		x	x	x	x	Water on BE layer
AU1412	x								
AV1351	x	i		x	x	x	x	x	BE on water layer
AO1353	x								
AU1311	x								
AQ1385	x								
AU1421	x								
AU1402	x								
AQ1356	x								
AU1411	x								
AU1362	x								
AZ1394	x								
BA1355	x								
AY1353	x								
AX1355	x								
AZ1343	x								
AZ1364	x								
AW1351	x								
AZ1355	x	x		x	x	x	x	x	
AZ1384	x								
AZ1393	x	i	x		x	x	x	x	House/deck artifacts
AY1355	x	i	x		x	x	x	x	House/deck artifacts
AZ1413	x								
AY1351	x								
AZ1414	x								
AX1353	x								
AZ1351	x								
AZ1323	x								
AZ1353	x								
AZ1363	x	i		x	x	x	x	x	Missing berm
AZ1334	x								
AZ1374	x								
AZ1373	x								
AZ1404	x								
AZ1314	x								
AZ1324	x								

AZ1344	x								
AZ1333	x								
AX1351	x								
AZ1383	x	i	x		x	x	x	x	Trees/BE on water layer
AW1353	x	i	x		x	x	x	x	Missing berm, BE on water layer
AZ1403	x	x	x		x	x	x	x	
AZ1354	x								
AI1405	x								
AI1406	x								
AI1403	x								
AI1401	x								
AI1402	x								
AJ1425	x	x	x		x	x	x	x	
AJ1423	x								
AJ1424	x								
AJ1421	x	x		x	x	x	x	x	
AJ1422	x								
AI1415	x								
AI1416	x								
AI1413	x								
AI1414	x								
AI1411	x								
AI1412	x								
AJ1395	x	i	x		x	x	x	x	BE on water layer
AJ1393	x								
AJ1394	x								
AJ1391	x								
AJ1405	x	i		x	x	x	x	x	vegetation
AJ1406	x								
AJ1403	x								
AJ1401	x	i	x		x	x	x	x	Be on water layer
AJ1402	x								
AJ1415	x	x	x		x	x	x	x	
AJ1416	x								
AJ1413	x								
AJ1414	x								
AJ1411	x	i		x	x	x	x	x	deck, Trees on water layer
AJ1412	x								
AI1425	x	x		x	x	x	x	x	
AI1426	x								

AI1423	x								
AI1424	x								
AI1421	x								
AI1422	x								
AK1395	x								
AK1396	x								
AK1393	x								
AK1391	x								
AK1392	x								
AK1405	x								
AK1403	x								
AK1404	x								
AK1401	x								
AK1415	x								
AK1416	x								
AK1413	x								
AK1414	x								
AK1411	x								
AK1412	x	i		x	x	x	x	x	deck, minor vegetation artifacts
AK1425	x								
AK1426	x								
AK1423	x								
AK1424	x	i		x	x	x	x	x	deck, building artifacts
AK1421	x								
AK1422	x								
AL1385	x	i		x	x	x	x	x	deck
AL1386	x								
AL1383	x								
AL1384	x								
AL1395	x								
AL1393	x								
AL1394	x	x	x		x	x	x	x	
AL1405	x								
AL1406	x								
AL1403	x								
AL1404	x	i		x	x	x	x	x	water on BE layer
AL1415	x								
AL1416	x								
AL1413	x								
AL1414	x								

AL1425	x								
AL1426	x								
AL1423	x	i	x		x	x	x	x	minor vegetation artifacts
AL1424	x								
AI1392	x								
AI1404	x	x		x	x	x	x	x	
AJ1426	x								
AJ1396	x								
AJ1392	x								
AJ1404	x								
AL1396	x								
AK1402	x								
AK1394	x	i		x	x	x	x	x	BE on water layer, many instances
AK1406	x								
AH1393	x	i	x		x	x	x	x	minor vegetation artifacts
AH1394	x								
AH1391	x								
AH1392	x								
AH1403	x	x	x		x	x	x	x	
AH1404	x								
AH1401	x								
AH1402	x								
AH1413	x								
AH1414	x								
AH1411	x	x	x		x	x	x	x	
AH1412	x								
AH1423	x								
AH1424	x								
AH1421	x								
AH1422	x								
AI1395	x	i		x	x	x	x	x	Water on BE layer
AI1396	x	i		x	x	x	x	x	Water on BE layer
AI1393	x								
AI1394	x								
AI1391	x								
AM1385	x								
AM1386	x								
AM1383	x								
AM1384	x								
AM1381	x								

AM1382	x								
AM1425	x								
AM1426	x	x		x	x	x	x	x	
AM1423	x								
AM1424	x								
AM1421	x	x	x		x	x	x	x	
AM1422	x								
AM1415	x								
AM1416	x								
AM1413	x								
AM1414	x								
AM1411	x	i		x	x	x	x	x	BE on water layer
AM1412	x								
AM1395	x								
AM1396	x								
AM1393	x	i		x	x	x	x	x	Ponds with water on BE layer
AM1394	x								
AM1391	x	i		x	x	x	x	x	minor vegetation artifacts
AM1392	x								
AM1405	x								
AM1406	x								
AM1403	x								
AM1404	x								
AM1401	x	i	x		x	x	x	x	BE on water layer, water on BE layer
AM1402	x								
AN1425	x	i		x	x	x	x	x	Trees/BE on water layer
AN1426	x								
AN1423	x								
AN1424	x								
AN1421	x								
AN1422	x								
AP1356	x								
AP1354	x								
AO1425	x								
AO1426	x	x		x	x	x	x	x	
AO1423	x								
AO1421	x								
AO1422	x								
AP1365	x								
AP1363	x								

AP1364	x								
AP1361	x								
AP1362	x								
AO1415	x								
AO1416	x								
AO1413	x								
AO1414	x								
AO1411	x	i		x	x	x	x	x	Vegetation on water layer
AO1412	x								
AO1356	x								
AO1354	x								
AO1352	x	x		x	x	x	x	x	
AO1365	x								
AO1363	x	x	x		x	x	x	x	
AO1364	x								
AO1361	x								
AO1362	x								
AO1375	x								
AO1376	x	i	x		x	x	x	x	BE on water layer
AO1373	x								
AO1371	x								
AO1372	x								
AO1385	x								
AO1383	x	i		x	x	x	x	x	Vegetation/deck artifacts
AO1384	x								
AO1381	x								
AO1395	x								
AO1396	x	i		x	x	x	x	x	minor vegetation artifacts
AO1393	x	x		x	x	x	x	x	
AO1394	x								
AO1391	x								
AO1392	x	x	x		x	x	x	x	
AO1405	x								
AO1406	x								
AO1403	x								
AO1404	x								
AO1401	x								
AO1402	x								
AP1375	x								
AP1376	x	x		x	x	x	x	x	

AP1373	x								
AP1371	x								
AP1372	x								
AP1385	x								
AP1383	x								
AP1384	x	i		x	x	x	x	x	Building/vegetation artifacts
AP1381	x								
AP1382	x								
AP1395	x								
AP1396	x	i		x	x	x	x	x	Dam/BE on water layer
AP1393	x								
AP1391	x								
AP1392	x								
AP1405	x								
AP1403	x								
AP1404	x	i		x	x	x	x	x	minor vegetation artifacts
AP1401	x								
AP1415	x								
AP1416	x								
AP1413	x								
AP1414	x								
AP1411	x								
AP1412	x	i		x	x	x	x	x	BE on water layer
AP1425	x	x	x		x	x	x	x	
AP1423	x								
AP1421	x								
AN1395	x								
AN1396	x								
AN1393	x								
AN1394	x	i		x	x	x	x	x	BE on water layer
AN1391	x								
AN1392	x								
AP1352	x								
AO1424	x								
AP1366	x	i		x	x	x	x	x	minor vegetation artifacts
AO1366	x								
AO1374	x								
AO1386	x								
AO1382	x								
AN1416	x								

AN1411	x	i	x		x	x	x	x	Trees/vegetation on water layer
AN1412	x								
AP1406	x								
AP1402	x								
AP1394	x								
AN1405	x								
AN1406	x								
AN1403	x								
AN1404	x								
AN1401	x								
AN1402	x	i		x	x	x	x	x	BE on water layer
AN1415	x								
AN1413	x								
AN1414	x	i		x	x	x	x	x	minor vegetation artifacts
AP1374	x								
AN1375	x	i		x	x	x	x	x	BE/riverbank on water layer
AN1376	x								
AN1373	x								
AN1374	x								
AN1371	x								
AN1372	x								
AN1385	x								
AN1386	x								
AN1383	x								
AN1384	x	i	x		x	x	x	x	water on BE layer
AN1381	x								
AN1382	x								
AP1386	x								
AU1295	x								
AU1296	x								
AU1294	x	i		x	x	x	x	x	BE on water, minor vegetation artifacts
AT1305	x								
AT1303	x	i	x		x	x	x	x	Water on BE layer, minor vegetation/deck
AT1304	x								
AT1301	x	i	x		x	x	x	x	Water on BE layer
AT1315	x	x		x	x	x	x	x	
AT1316	x								
AT1313	x								
AT1311	x								
AT1312	x								

AT1325	x								
AT1323	x								
AT1324	x	i		x	x	x	x	x	Water on BE layer
AT1321	x								
AT1335	x								
AT1336	x								
AT1333	x								
AT1331	x								
AT1332	x	i		x	x	x	x	x	Berm on 1st return, water on BE layer, trees on water layer
AT1345	x								
AT1343	x								
AT1344	x	i		x	x	x	x	x	Water on BE layer, minor vegetation
AT1341	x								
AT1342	x								
AU1305	x								
AU1306	x	i		x	x	x	x	x	noisy low vegetation
AU1303	x								
AU1304	x								
AU1315	x								
AU1316	x								
AU1313	x								
AU1314	x	i		x	x	x	x	x	BE on water layer, pond
AU1325	x								
AU1326	x								
AU1323	x								
AU1324	x	i		x	x	x	x	x	Pond, deck artifact, water on BE layer
AU1335	x								
AU1333	x								
AU1334	x								
AU1345	x								
AU1346	x								
AU1343	x								
AU1344	x								
AT1306	x								
AT1302	x								
AT1314	x								
AT1322	x								
AT1326	x								
AT1334	x								
AT1346	x								

AT1294	x								
AT1291	x	i		x	x	x	x	x	BE on water layer
AT1292	x								
AU1336	x	i		x	x	x	x	x	Ponds, BE on water layer
AS1352	x								
AS1364	x								
AU1376	x								
AS1372	x								
AQ1354	x								
AQ1352	x								
AQ1363	x								
AQ1364	x								
AQ1361	x	i	x		x	x	x	x	minor vegetation artifacts
AQ1362	x								
AQ1373	x								
AQ1374	x								
AQ1371	x								
AQ1372	x								
AQ1383	x	x		x	x	x	x	x	
AQ1384	x								
AQ1381	x								
AQ1382	x								
AQ1393	x								
AQ1394	x								
AQ1391	x								
AQ1392	x								
AQ1403	x								
AQ1404	x								
AQ1401	x								
AQ1402	x								
AQ1413	x	i		x	x	x	x	x	BE on water layer
AQ1414	x								
AQ1411	x								
AQ1412	x								
AQ1423	x	i		x	x	x	x	x	Trees on water layer, island
AQ1421	x								
AR1356	x	i		x	x	x	x	x	Deck, swimming pools
AR1354	x								
AR1352	x	i	x		x	x	x	x	minor vegetation artifacts
AR1365	x								

AR1363	x								
AR1364	x								
AR1361	x								
AR1362	x	i		x	x	x	x	x	vegetation on BE layer, BE/trees on water layer
AR1375	x								
AR1376	x	x	x		x	x	x	x	
AR1373	x								
AR1371	x								
AR1372	x								
AR1385	x								
AR1383	x	i		x	x	x	x	x	Water not removed at 493479,156952
AR1384	x	i			x	x	x	x	0.11 Flight mismatch 113-114 north tile
AR1381	x								
AR1395	x	x		x	x	x	x	x	
AR1396	x								
AR1393	x								
AR1394	x								
AR1391	x								
AR1392	x	x	x		x	x	x	x	
AR1405	x								
AR1403	x	x		x	x	x	x	x	
AR1404	x								
AR1401	x								
AR1415	x								
AR1416	x	x		x	x	x	x	x	
AR1413	x								
AR1414	x								
AR1411	x								
AR1412	x								
AR1425	x								
AR1423	x								
AR1421	x								
AS1356	x								
AS1354	x								
AS1365	x								
AS1366	x								
AS1363	x	x		x	x	x	x	x	
AS1361	x								
AS1362	x								
AS1375	x								

AS1376	x	i		x	x	x	x	x	northeast corner marshes contain noise
AS1373	x								
AS1374	x								
AS1371	x	x		x	x	x	x	x	
AS1385	x								
AS1386	x								
AS1383	x								
AS1381	x								
AS1382	x	x		x	x	x	x	x	
AS1395	x	x		x	x	x	x	x	
AS1393	x								
AS1394	x								
AS1391	x								
AS1392	x								
AS1405	x								
AS1406	x								
AS1403	x								
AS1401	x								
AS1402	x								
AS1415	x								
AS1413	x								
AS1414	x	i	x		x	x	x	x	several water holes contain brush and or water points
AS1411	x								
AS1425	x	i		x	x	x	x	x	artifacts along north-south river could have been removed
AS1423	x								
AS1421	x								
AT1356	x	x		x	x	x	x	x	
AT1354	x								
AT1352	x	x			x	x	x	x	
AT1365	x								
AT1363	x								
AT1364	x								
AT1361	x								
AT1375	x								
AT1376	x								
AT1373	x								
AT1374	x								
AT1371	x								
AT1372	x								
AT1385	x								

AT1383	x	x	x		x	x	x	x	
AT1384	x								
AT1381	x								
AT1395	x								
AT1396	x	i		x	x	x	x	x	flightline mismatch up to 0.14M xy=499821,162347
AT1393	x								
AT1391	x								
AT1392	x	x	x		x	x	x	x	
AT1405	x								
AT1406	x								
AT1403	x								
AT1404	x								
AT1401	x								
AT1415	x	i		x	x	x	x	x	low vegetation seems heavy
AT1416	x	x		x	x	x	x	x	
AT1413	x	x		x	x	x	x	x	
AT1411	x								
AT1412	x								
AT1425	x								
AT1423	x								
AT1421	x								
AU1356	x								
AU1354	x	x	x		x	x	x	x	
AU1365	x	i		x	x	x	x	x	some water points remain in river
AU1366	x								
AU1363	x								
AU1364	x								
AU1375	x								
AU1373	x	x	x		x	x	x	x	
AU1374	x								
AU1385	x								
AU1386	x								
AU1383	x	x	x		x	x	x	x	
AU1384	x								
AU1395	x								
AU1396	x								
AU1393	x	i		x	x	x	x	x	flightline mismatch 0.14M xy=498295,167895 Lines 113/114
AU1394	x								
AU1405	x	i	x		x	x	x	x	point in water body
AU1406	x								

AU1403	x								
AU1404	x								
AU1415	x								
AU1416	x								
AU1413	x	i		x	x	x	x	x	points in water bodies
AU1414	x								
AU1425	x	x		x	x	x	x	x	
AU1423	x								
AS1404	x	x		x	x	x	x	x	
AS1416	x								
AS1412	x								
AR1366	x								
AT1362	x	x	x		x	x	x	x	
AT1386	x								
AT1382	x								
AT1394	x								
AS1384	x								
AS1396	x								
AT1366	x								
AT1402	x								
AT1414	x								
AR1374	x								
AR1386	x								
AR1382	x								
AR1406	x								
AR1402	x								
AW1335	x	i		x	x	x	x	x	water body not cleared xy=475345,173211
AW1336	x								
AW1333	x								
AW1334	x								
AW1331	x								
AW1332	x								
AW1305	x								
AW1306	x								
AW1304	x								
AW1302	x								
AW1325	x								
AW1326	x								
AW1323	x								
AW1324	x								

AW1321	x	i		x	x	x	x	x	points in water body xy=471924,175584
AW1322	x								
AW1345	x								
AW1346	x								
AW1343	x								
AW1344	x								
AW1341	x								
AW1342	x	x		x	x	x	x	x	
AV1296	x								
AW1315	x	x		x	x	x	x	x	
AW1316	x								
AW1313	x								
AW1314	x								
AW1311	x								
AW1312	x								
AV1305	x								
AV1306	x								
AV1303	x								
AV1304	x								
AV1301	x								
AV1302	x	x	x		x	x	x	x	
AV1315	x								
AV1316	x								
AV1313	x	i	x		x	x	x	x	water body not cleared xy=468285,170482
AV1314	x								
AV1311	x								
AV1312	x	i	x		x	x	x	x	points not removed from water bodies
AV1325	x								
AV1326	x								
AV1323	x								
AV1324	x								
AV1321	x								
AV1322	x								
AV1335	x								
AV1336	x								
AV1333	x	i		x	x	x	x	x	points not removed from water bodies
AV1334	x								
AV1331	x	x		x	x	x	x	x	
AV1332	x								
AV1345	x								

AV1346	x								
AV1343	x	i		x	x	x	x	x	points missed in river; high points missed xy=480413,170562
AV1344	x								
AV1341	x								
AV1342	x								
AX1306	x								
AX1326	x								
AX1322	x								
AX1314	x								
AX1304	x								
AX1315	x								
AX1316	x								
AX1313	x	i		x	x	x	x	x	points not removed in large water body
AX1311	x								
AX1312	x								
AX1325	x								
AX1323	x								
AX1324	x	i		x	x	x	x	x	points not removed in water bodies
AX1321	x								
AX1335	x	x	x		x	x	x	x	
AX1336	x								
AX1333	x								
AX1334	x								
AX1331	x								
AX1332	x	i	x		x	x	x	x	water points in ground class; minor flightline mismatch
AX1345	x	i	x		x	x	x	x	points not removed from water bodies
AX1343	x								
AX1344	x								
AX1341	x								
AX1342	x	i		x	x	x	x	x	points not removed from water bodies
AY1316	x								
AY1312	x	x		x	x	x	x	x	
AY1325	x	i		x	x	x	x	x	points not removed from water body
AY1326	x								
AY1323	x								
AY1324	x								
AY1321	x								
AY1335	x								
AY1336	x	x	x		x	x	x	x	
AY1333	x	i		x	x	x	x	x	points not removed from water bodies

AY1331	x								
AY1332	x	i		x	x	x	x	x	points not removed from water bodies
AY1345	x								
AY1343	x								
AY1344	x								
AY1341	x	i		x	x	x	x	x	points not removed from water body
AY1342	x								
AZ1316	x								
AZ1325	x	x		x	x	x	x	x	
AZ1326	x								
AZ1335	x								
AZ1336	x	i	x		x	x	x	x	points not removed from water
AZ1345	x								
AZ1346	x								
AY1322	x								
AY1334	x								
AY1346	x								
AX1346	x								
AY1314	x								
AW1375	x								
AW1376	x								
AW1373	x	i		x	x	x	x	x	points not removed from water
AW1374	x								
AW1371	x	i		x	x	x	x	x	points not removed from water
AW1372	x								
AW1356	x								
AW1354	x								
AW1352	x	i	x		x	x	x	x	points not removed from water NW
AW1425	x								
AW1385	x								
AW1386	x								
AW1383	x	x		x	x	x	x	x	
AW1384	x								
AW1381	x								
AW1382	x								
AW1395	x								
AW1396	x								
AW1393	x								
AW1394	x	i	x		x	x	x	x	points not removed from river +/-9m wide
AW1391	x	i		x	x	x	x	x	points not removed from water

AW1392	x								
AW1405	x								
AW1406	x								
AW1403	x								
AW1404	x								
AW1401	x								
AW1402	x								
AW1415	x								
AW1416	x								
AW1413	x	i		x	x	x	x	x	points not removed from river +/-10m wide
AW1414	x								
AW1411	x								
AW1412	x								
AW1365	x	i		x	x	x	x	x	points not removed from water
AW1366	x								
AW1363	x								
AW1364	x								
AW1361	x								
AW1362	x								
AV1356	x								
AV1354	x								
AV1352	x								
AV1365	x	x	x		x	x	x	x	
AV1366	x								
AV1363	x								
AV1364	x								
AV1361	x								
AV1362	x								
AV1375	x								
AV1376	x								
AV1373	x	x	x		x	x	x	x	
AV1374	x	i	x		x	x	x	x	points not removed from water body
AV1371	x								
AV1372	x	x	x		x	x	x	x	
AV1385	x								
AV1386	x								
AV1383	x								
AV1384	x								
AV1381	x								
AV1382	x	i		x	x	x	x	x	points not removed from river +/9m

AV1395	x								
AV1396	x	x	x		x	x	x	x	
AV1393	x								
AV1394	x								
AV1391	x								
AV1392	x								
AV1405	x								
AV1406	x	x		x	x	x	x	x	
AV1403	x								
AV1404	x								
AV1401	x	x		x	x	x	x	x	
AV1402	x								
AV1415	x								
AV1416	x	x	x		x	x	x	x	
AV1413	x								
AV1414	x								
AV1411	x	x	x		x	x	x	x	
AV1412	x								
AV1425	x								
AV1423	x								
AV1421	x	x		x	x	x	x	x	
AX1356	x								
AX1354	x								
AX1352	x	i	x		x	x	x	x	points not removed from water NW corner
AX1365	x								
AX1366	x								
AX1363	x	x	x		x	x	x	x	
AX1364	x								
AX1361	x								
AX1375	x								
AX1376	x								
AX1373	x								
AX1371	x								
AX1372	x	x	x		x	x	x	x	
AX1385	x	i		x	x	x	x	x	points not removed from water body
AX1383	x								
AX1384	x								
AX1381	x								
AX1382	x								
AX1395	x								

AX1396	x								
AX1393	x								
AX1391	x	i	x		x	x	x	x	water points in ground class; points not remove from river
AX1392	x								
AX1405	x	i		x	x	x	x	x	points not removed from water and stream
AX1403	x								
AX1404	x								
AX1401	x								
AX1415	x								
AX1416	x								
AX1413	x								
AX1414	x	x		x	x	x	x	x	
AX1411	x								
AX1412	x								
AY1356	x								
AY1354	x	i	x		x	x	x	x	points not removed from water
AY1352	x								
AY1365	x								
AY1363	x	x	x		x	x	x	x	
AY1364	x								
AY1361	x								
AY1375	x								
AY1376	x								
AY1373	x								
AY1374	x								
AY1371	x	x		x	x	x	x	x	
AY1372	x	i		x	x	x	x	x	points not removed from water bodies
AY1385	x								
AY1383	x								
AY1384	x	i		x	x	x	x	x	water pts in ground class; island removed from water body
AY1381	x								
AY1395	x								
AY1396	x	i	x		x	x	x	x	points not removed from water bodies
AY1393	x								
AY1391	x								
AY1392	x								
AY1405	x	x	x		x	x	x	x	
AY1406	x	x	x		x	x	x	x	
AY1403	x								
AY1404	x								

AY1401	x	x		x	x	x	x	x	
AY1415	x								
AY1416	x								
AY1413	x								
AY1414	x	i	x		x	x	x	x	points not removed from water body
AY1411	x								
AY1412	x								
AZ1356	x								
AZ1365	x								
AZ1366	x								
AZ1375	x								
AZ1376	x								
AZ1385	x								
AZ1386	x								
AZ1395	x								
AZ1396	x								
AZ1405	x								
AZ1406	x								
AZ1415	x								
AZ1416	x	x		x	x	x	x	x	
AX1374	x								
AX1362	x	x		x	x	x	x	x	
AX1386	x								
AX1394	x								
AX1406	x	i		x	x	x	x	x	points not removed in water body
AX1402	x								
AY1366	x								
AY1362	x								
AY1386	x								
AY1382	x								
AY1394	x								
AY1402	x								
AZ1322	x	x		x	x	x	x	x	
AZ1331	x								
AZ1332	x	x	x		x	x	x	x	
AZ1341	x								
AZ1342	x	i	x		x	x	x	x	points not removed in water body
BA1335	x								
BA1336	x								
BA1333	x								

BA1331	x								
BA1332	x								
BA1345	x								
BA1346	x								
BA1343	x								
BA1344	x	i	x		x	x	x	x	points not removed from water
BA1341	x								
BA1342	x	i		x	x	x	x	x	points not removed from water
BA1334	x	i		x	x	x	x	x	points not removed from water
AZ1352	x								
AZ1361	x								
AZ1362	x								
AZ1371	x	x	x		x	x	x	x	
AZ1372	x								
AZ1381	x								
AZ1382	x								
AZ1391	x								
AZ1392	x	i		x	x	x	x	x	points not removed from water
AZ1401	x								
AZ1402	x								
AZ1411	x	x		x	x	x	x	x	
AZ1412	x								
BA1356	x	i		x	x	x	x	x	points not removed from water
BA1365	x								
BA1375	x								
BA1376	x								
BA1385	x	x		x	x	x	x	x	
BA1395	x								
BA1396	x								
BA1405	x								
BA1406	x								
BA1415	x								
BA1416	x								
BA1366	x								
BA1386	x								

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C. Breaklines

Breakline Data - Aero-Metric recognizes that no breaklines were required for review. However, we would like to point out in the metadata file that the vertical positional accuracy report stated the following: "The lidar data fully complies with FEMA guidance as published in Appendix A, April 2003 and National Standard for Spatial Accuracy (NSSDA)."

FEMA according to Appendix A requires breaklines. Shown below are the areas that would indicate breakline requirements according to the FEMA guidelines for full compliancy.

"A.8 Airborne Light Detection and Ranging (LIDAR) Surveys - When Mapping Partners choose to use airborne LIDAR systems for gathering the data necessary to create digital elevation data for hydraulic modeling of floodplains, digital terrain maps, and other NFIP productions, the guidelines and specifications presented herein must be used."

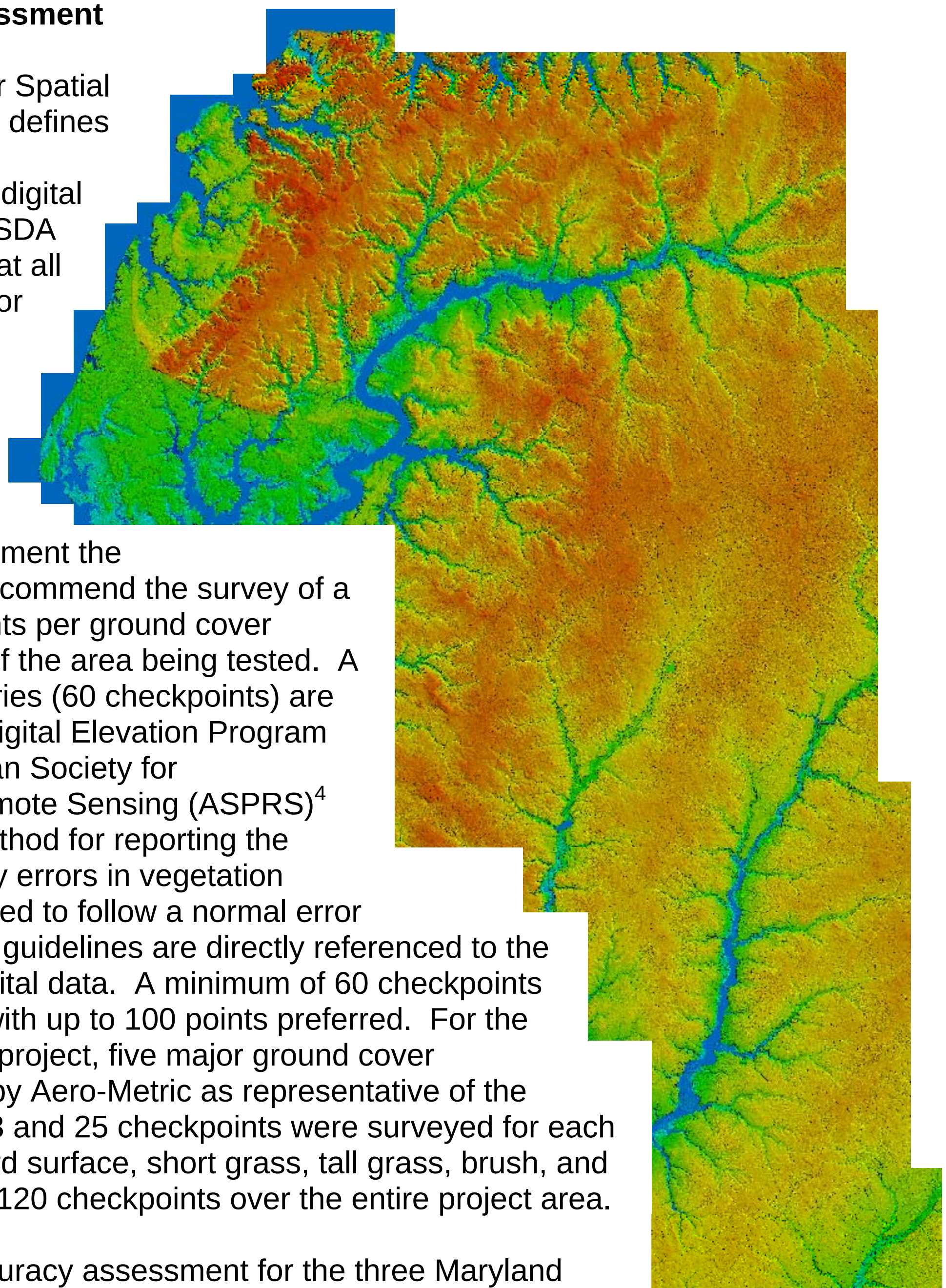
It goes on to further state the breakline requirement in Section A.8.5 – Post-Processing of Data…"Using digital orthophotos, stereo photogrammetry, or other source materials, the assigned Mapping Partner shall produce the following breaklines for the following:

- Stream centerlines;
- Drainage ditches;
- Tops and bottoms of streambanks;
- Ridge lines;
- Road crowns;
- Levees;
- Bulkheads;
- Seawalls;
- Road/highway embankments; and
- Selected manmade features that constrict or control the flow of water (e.g. curb lines)."

Aero-Metric further recognizes that the need/requirement for breaklines are not entirely required to facilitate accurate hydraulic modeling given that modern systems perform at higher density patterns and at greater degrees of accuracy, but wished to point out that the full compliancy as originally mentioned has not been met without compiling breaklines.

The contractor might wish to modify the metadata to reflect a hybrid version of the FEMA guideline to be more consistent with the data that was collected.

3. Vertical Accuracy Assessment



The National Standard for Spatial Data Accuracy (NSSDA)[1] defines guidelines for testing and reporting the accuracy of digital geospatial data. The NSSDA makes the assumption that all errors follow a normal error distribution where Root-Mean-Square-Error (RMSE) procedures apply. The Federal Emergency Management Agency (FEMA)[2] guidelines implement the NSSDA standards and recommend the survey of a minimum of 20 checkpoints per ground cover category representative of the area being tested. A minimum of three categories (60 checkpoints) are required. The National Digital Elevation Program (NDEP)[3] and the American Society for Photogrammetry and Remote Sensing (ASPRS)[4] provide an alternative method for reporting the vertical accuracy whereby errors in vegetation categories are not assumed to follow a normal error distribution. The ASPRS guidelines are directly referenced to the assessment of LiDAR digital data. A minimum of 60 checkpoints is again recommended, with up to 100 points preferred. For the three Maryland Counties project, five major ground cover categories were defined by Aero-Metric as representative of the project area. Between 23 and 25 checkpoints were surveyed for each of the five categories (hard surface, short grass, tall grass, brush, and woods) making a total of 120 checkpoints over the entire project area.

Aero-Metric's vertical accuracy assessment for the three Maryland Counties project was carried out in accordance with the two methods mentioned above. The first method (defined by NSSDA and FEMA) assumes all errors follow a normal error distribution and the newer second method (defined by NDEP and ASPRS) assumes that errors in some land cover categories may not follow a normal error distribution. Comparing the two methods helps determine the amount of systematic errors that may exist in the five ground cover categories: hard surface, short grass, tall grass, brush, and woods. The following table summarizes the criteria used to evaluate the vertical data. Criteria highlighted in yellow refer to the NSSDA and FEMA guidelines and those highlighted in orange refer to the NDEP and ASPRS guidelines.

Table 2 – DTM Acceptance Criteria

Criteria	***Acceptable Value***
$RMSE_z$= NSSDA vertical accuracy statistic at 68% confidence level (1.0 x $RMSE_z$)	0.185 meters for all ground cover categories combined
$Accuracy_z$= NSSDA vertical accuracy statistic at the 95% confidence level (1.96 x $RMSE_z$)	0.370 meters ($RMSE_z$ x 1.9600) for all ground cover categories combined
Fundamental Vertical Accuracy (FVA) in open terrain only = 95% confidence level	0.370 meters ($RMSE_z$ x 1.9600) for open terrain only
Supplemental Vertical Accuracy (SVA) in individual ground cover categories = 95% confidence level	0.370 meters (based on 95^{th} percentile per category; this is a target value only, not mandatory)
Consolidated Vertical Accuracy (CVA) in all ground cover categories combined = 95% confidence level	0.370 meters (based on combined 95^{th} percentile)

Aero-Metric tested the digital vertical data using the following steps:

1. Aero-Metric ground survey personnel collected and processed GPS data for each of the ground cover checkpoints. These points were distributed throughout ground cover category areas within the project limits.
2. The checkpoints were compared to the digital vertical data using the TerraSolid, LTD program TerraScan. The program creates a TIN surface from the digital vertical data and computes vertical differences between the surface and the surveyed checkpoints. An output file records the vertical differences and associated statistics. Files were created for each of the ground cover categories separately and one file for all categories combined.
3. The results were analyzed by AME to assess the quality of the data. Various accuracy parameters as defined by the NDEP and ASPRS guidelines were used in the review process. Also, the overall descriptive statistics of each dataset were computed to assess any tendencies or inconsistencies. The following tables, graphs, and figures illustrate the data quality.

Using the NDEP and ASPRS Guidelines for Vertical Accuracy Testing

The required Fundamental Vertical Accuracy (FVA) and the optional Supplemental Vertical Accuracy (SVA) and Consolidated Vertical Accuracy (CVA) are specified by the NDEP and ASPRS guidelines. FVA determines how well the digital data was collected in open terrain type ground cover, where all errors are presumed to be random. The SVA determines how well the digital data represents the actual ground in each of the ground cover categories, tested separately. The CVA determines the overall accuracy of all the ground categories combined as one test.

FVA for this project is calculated using only the checkpoints in the *Hard Surface* ground cover category. The digital data in this category is most likely to represent the actual ground surface, and the random errors will follow a normal error distribution. The FVA shows how well the Photogrammetric process used to produce the digital vertical data represents the actual ground. With a normal error distribution, the vertical accuracy at the 95% confidence level is computed as the vertical root mean square error ($RMSE_z$) of the checkpoints x 1.9600, as specified in Appendix 3-A of the NSSDA guidelines. As shown in Table 2, the FVA for this project (2 ft contours) is 0.370 meters.

CVA is calculated with all the checkpoints in all the ground cover categories combined. There is a possibility that the digital vertical data may yield errors that do not follow a normal distribution. CVA at the 95% confidence level equals the 95^{th} percentile error for all checkpoints in all ground cover categories combined. The CVA produces a listing of the 5% outliers that are larger than the 95^{th} percentile and that may not follow the normal error distribution.

SVA is computed for each ground cover category separately. There again is a possibility that the digital vertical data may yield errors that do not follow a normal error distribution. Systematic errors per ground cover category are identified. For each category, the SVA at the 95% confidence level equals the 95^{th} percentile error for all checkpoints in each individual ground cover category. The individual SVA statistics are used to analyze the data based on each of the ground cover categories.

Table 3 summarizes the vertical accuracy by Fundament, Consolidated, and Supplemental methods:

Table 3 – FVA, CVA, and SVA Vertical Accuracy at 95% Confidence Level

Ground Cover Category	***# of Points***	***FVA Fundamental Vertical Accuracy Spec = 0.370 m***	***CVA Consolidated Vertical Accuracy Spec = 0.370 m***	***SVA Supplemental Vertical Accuracy Target = 0.370 m***
Total Combined	101		0.272 m	
Hard Surface	20	0.345 m		0.265 m
Short Grass	21			0.202 m
Tall Grass	20			0.150 m
Brush	20			0.287 m
Woods	20			0.311 m

The digital vertical data for the three Maryland Counties project meets all mandatory and target specifications as per the following vertical accuracy tests:

Compared with the 0.370 m FVA specification, FVA tested 0.345 m at the 95% confidence level on the hard surfaces ground cover category, based on $RMSE_z$ x 1.9600. The NSSDA specifies that vertical accuracy at the 95% confidence level equals $RMSE_z$ x 1.9600; the NDEP and ASPRS stat that this method is valid only when random errors follow a normal error distribution, as in the hard surface category.

Compared with the 0.370 m CVA specification, CVA tested 0.272 m at the 95% confidence level on the hard surfaces, short grass, tall grass, brush, and woods ground cover categories combined, based on the 95^{th} Percentile. NDEP and ASPRS guidelines specify that vertical accuracy at the 95% confidence level equals the 95^{th} percentile when random errors may not follow a normal error distribution, as in vegetated or obstructed areas. Table 4 lists the 5% outliers larger than the 95^{th} percentile (0.272 m).

Table 4 – 5% Outliers Larger than 95^{th} Percentile

<table>
<tr><th>Ground Cover Category</th><th>Elev. Diff (m)</th><td rowspan="6">Four of the errors were larger than the CVA standard (0.370 m) which permits up to 5% of the checkpoints, 5 out of 101, to be larger than 0.370 m.</td></tr>
<tr><td>Hard Surface</td><td>0.407</td></tr>
<tr><td>Short Grass</td><td>0.407</td></tr>
<tr><td>Brush</td><td>0.564</td></tr>
<tr><td>Woods</td><td>0.681</td></tr>
<tr><td>Woods</td><td>0.291</td></tr>
</table>

Compared with the 0.370 m SVA target values, SVA tested 0.265 m at the 95% confidence level on hard surfaces; 0.202 m in short grass; 0.150 m in tall grass; 0.287 m in brush; and 0.311 m in woods ground cover categories, based on the 95th Percentile. These values exceed all of their target values (0.370 m).

Figure 5 illustrates the SVA by specific ground cover category. Figure 6 illustrates the magnitude of the differences between the checkpoints and the digital vertical data by specific ground cover category and sorted from lowest to highest. All but one of the checkpoints is within the 0.370 m criteria shown in figure 6. This exceeds the 95% requirement, where up to five checkpoints could be outside the 0.370 m criteria. The lone checkpoint that fell outside of the tolerance is found the woods ground cover category. Given the suitability of the GPS observation, it should be considered that process position be questioned and not the LiDAR data source.

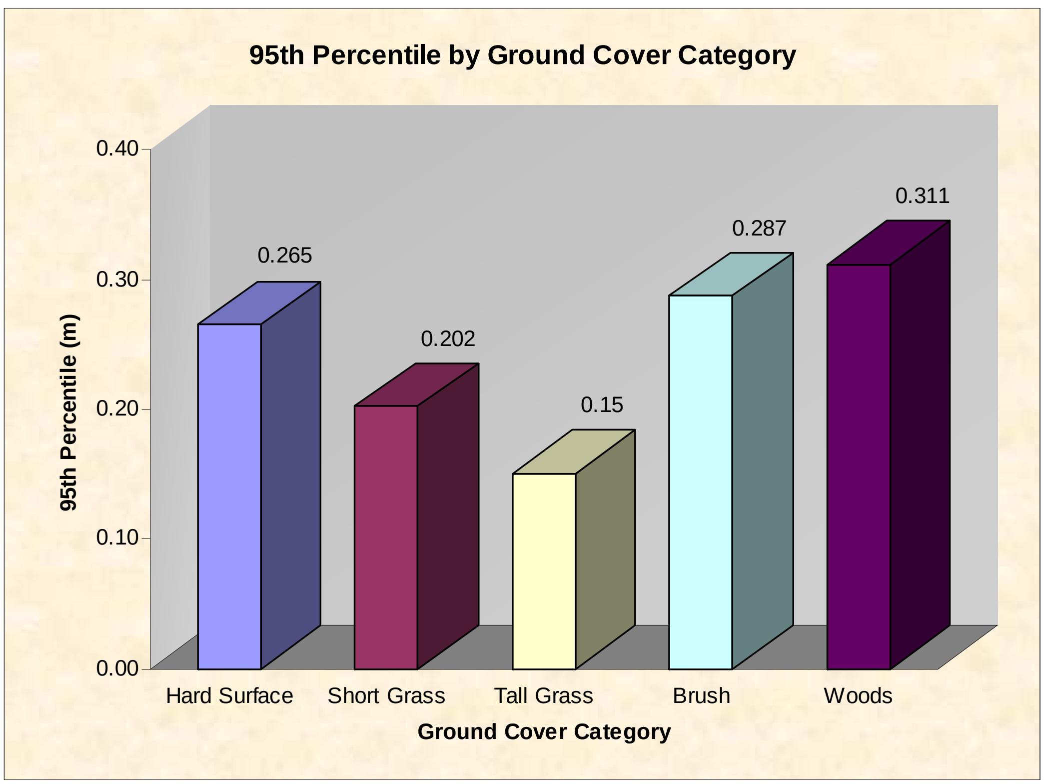


Figure 5 – Graph of SVA Values by Ground Cover Category

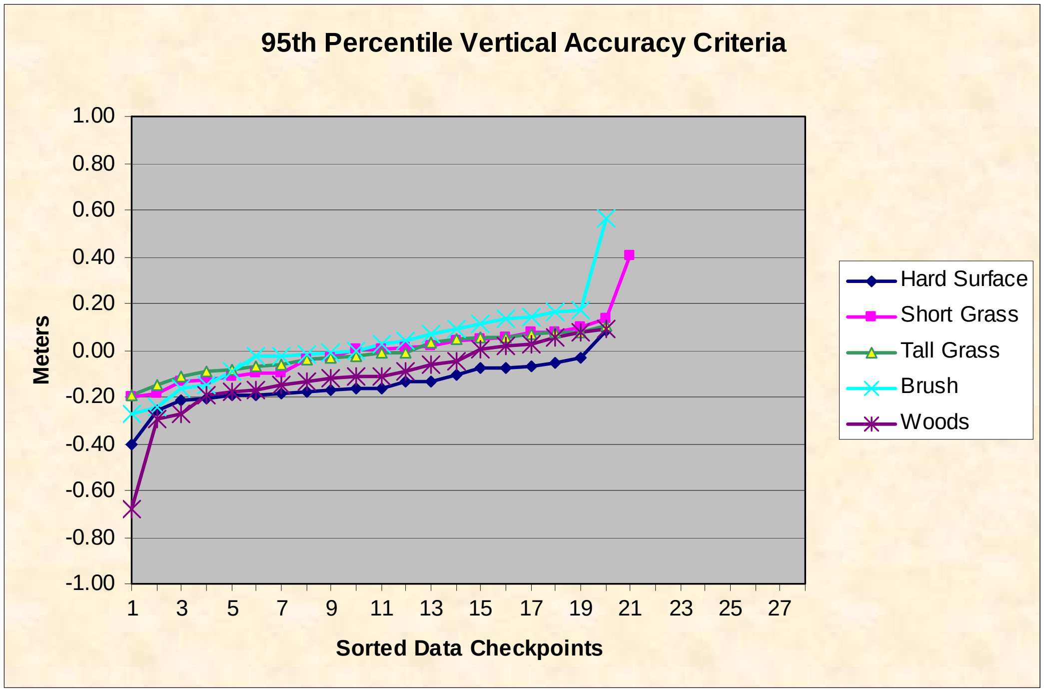


Figure 6 – Magnitude of Elevation Discrepancies, Sorted from Largest Negative to Largest Positive

Vertical Accuracy Testing in Accordance with NSSDA and FEMA Procedures

The NSSDA and FEMA guidelines were both published before it was recognized that digital data errors do not always follow a normal error distribution. Future changes to these guidelines are expected to follow those of the NDEP and ASPRS. In order to comply with FEMA's current requirements, $RMSE_z$ and other statistics were computed in all five ground cover categories, individually and combined. These statistics are shown in Figures 7 and 8 and Table 5 below.

Figure 7 shows the $RMSE_z$ values as calculated for each ground cover category separately.

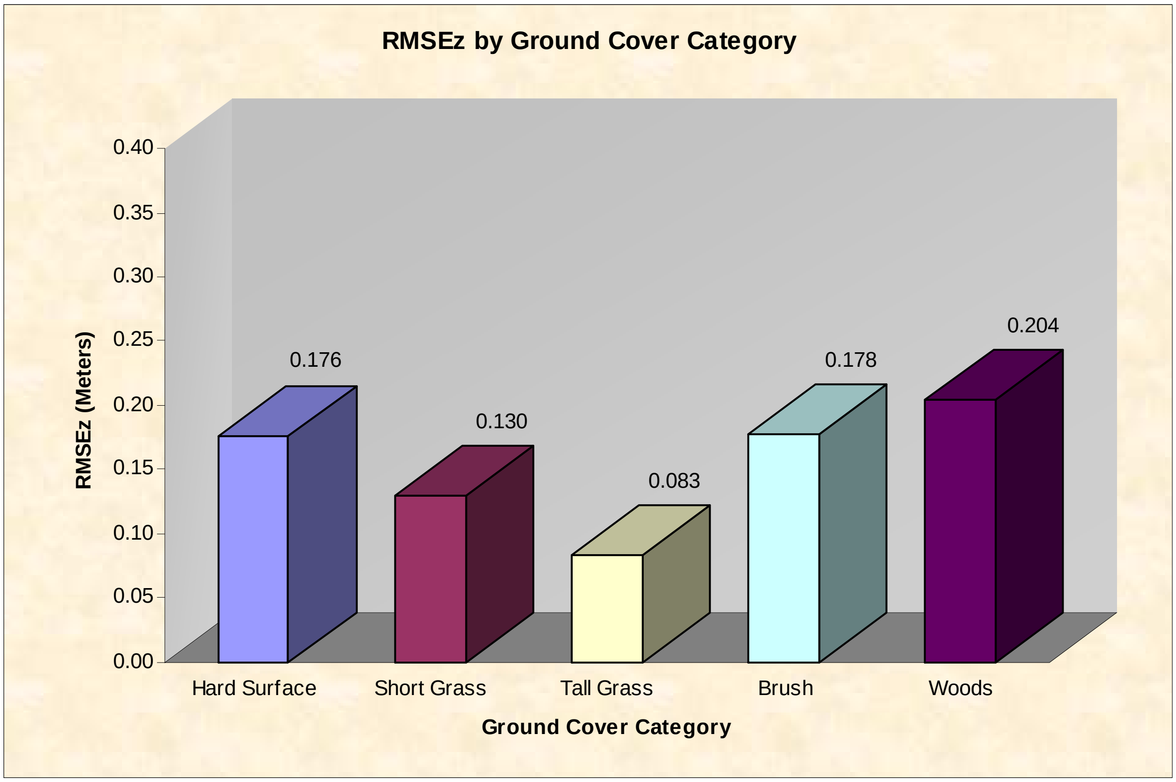


Figure 7 – $RMSE_z$ statistics by Ground Cover Category

Table 5 – Overall Descriptive Statistics by Ground Cover Category

Land Cover Category	***$RMSE_z$ (m)***	***Mean (m)***	***Median (m)***	***Skew***	***Std Dev (m)***	***# of Points***	***Min (m)***	***Max (m)***
Consolidated	0.160	-0.051	-0.049	0.067	0.152	101	-0.681	0.564
Hard Surface	0.176	-0.147	-0.165	-0.263	0.099	20	-0.407	0.082
Short Grass	0.130	-0.003	0.003	1.219	0.133	21	-0.202	0.407
Tall Grass	0.083	-0.017	-0.019	-0.396	0.083	20	-0.194	0.107
Brush	0.178	0.026	0.012	1.034	0.181	20	-0.272	0.564
Woods	0.204	-0.117	-0.116	-1.845	0.172	20	-0.681	0.093

Figure 8 shows a histogram of the elevation differences between the field surveyed checkpoints and the TIN surface computed from the digital vertical data. The histogram shows the number of occurrences (frequency) along the vertical axis that fell within the 0.20 ft ranges shown along the horizontal axis.

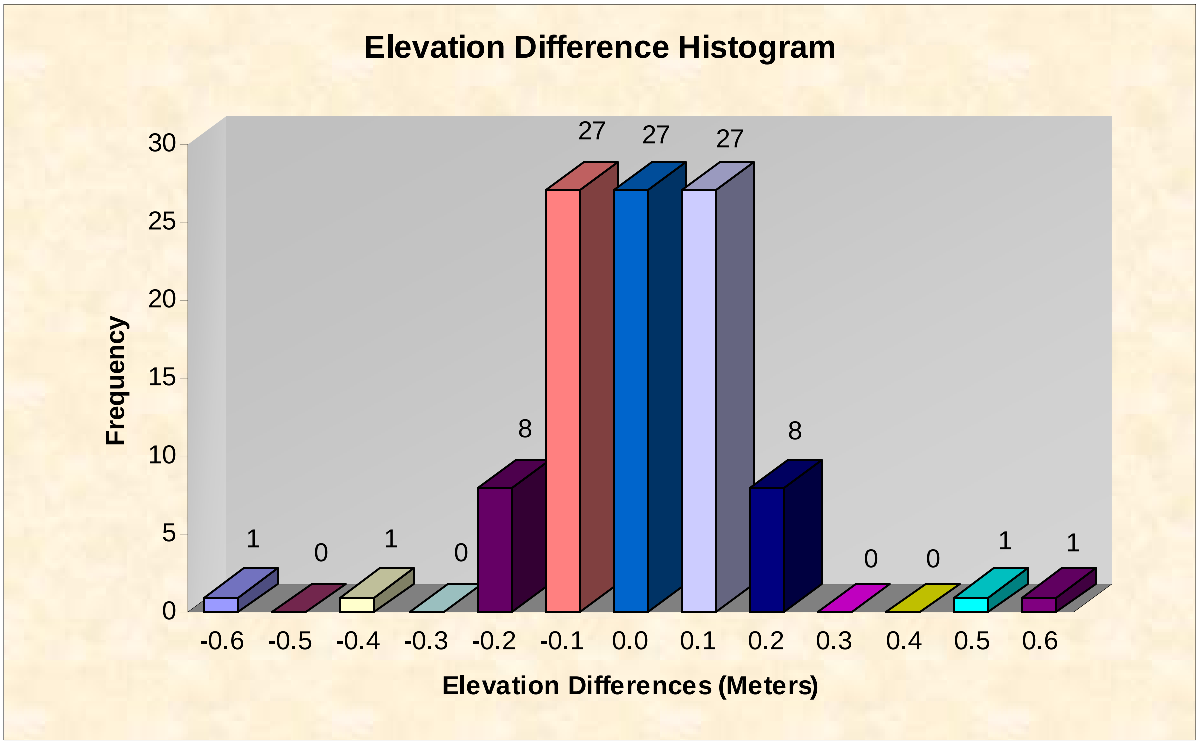


Figure 8 – Histogram of Elevation Discrepancies within 0.1 m Bands

Summary of Vertical Accuracy

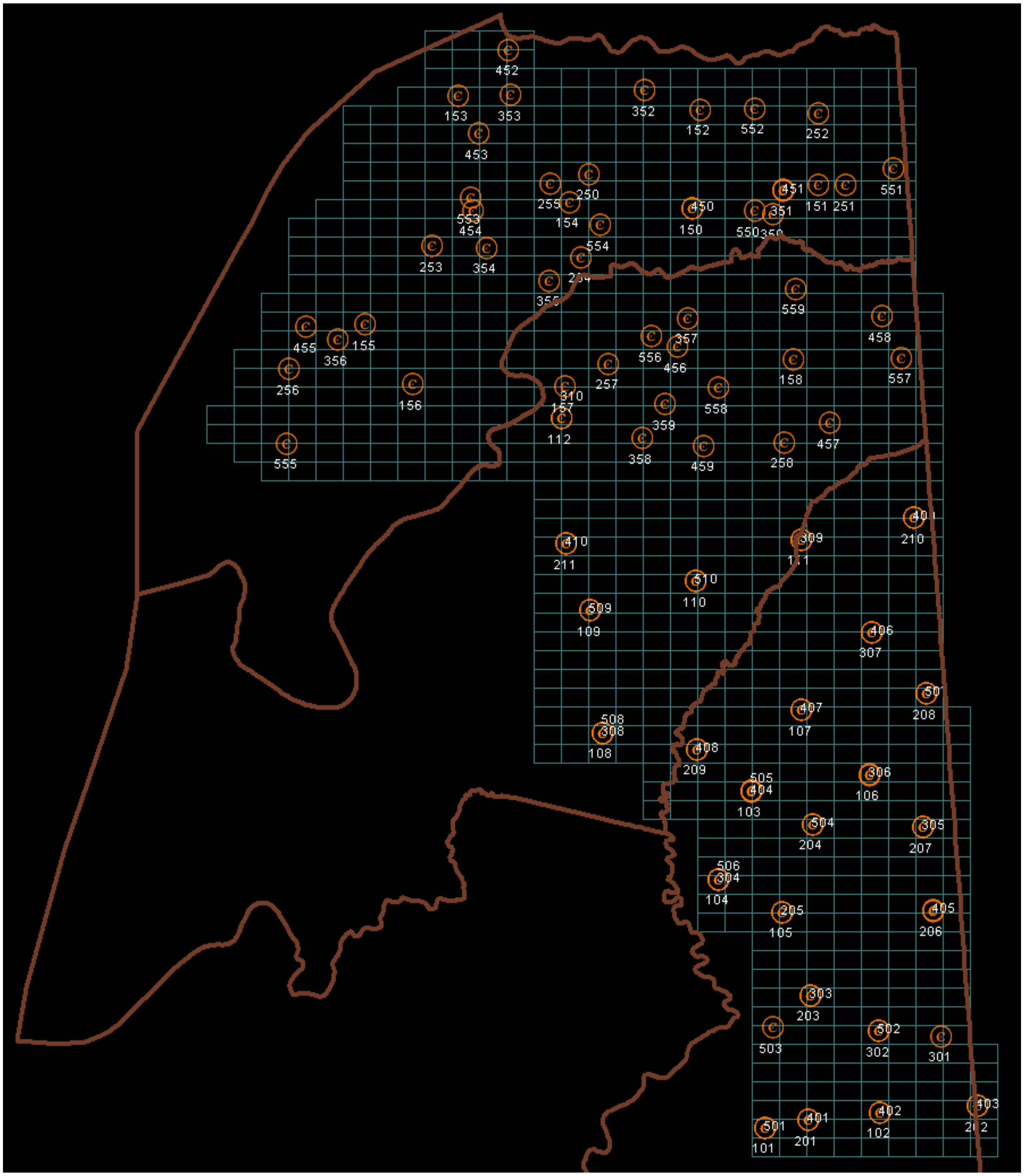
The vertical accuracy testing methods derived from the NSSDA/FEMA and NDEP/ASPRS guidelines, when applied to the three Maryland Counties project, verify that the digital vertical data provided by Aero-Metric is well suited for the production of 2 ft contours.

- Per NSSDA/FEMA guidelines: $RMSE_z$ x 1.96 = 95% confidence level
  0.160 x 1.96 = 0.314 m

- Per NDEP/ASPRS guidelines: 95th percentile (CVA) = 95% confidence level
  = 0.272 m

Both of the 95% confidence level test results exceed the required 0.370 m accuracy level to support the generation of 2 ft contours.

Survey QA/QC Checkpoints Diagram and Comparisons



All checkpoints

Point #	Easting(m)	Northing(m)	Surveyed Elevation(m)	LiDAR Elevation(m)	Elevation Difference(m)
101	497630.007	120628.479	16.569	16.670	0.101
102	505208.116	121589.068	13.865	13.740	-0.125
103	496697.508	142157.477	17.326	17.460	0.134
104	494565.520	136515.550	9.846	9.900	0.054
105	498742.683	134413.970	10.838	10.800	-0.038
106	504505.880	143185.217	16.246	16.060	-0.186
107	500043.582	147314.671	17.762	17.560	-0.202
108	486888.712	145848.672	23.213	23.180	-0.033
109	486098.791	153693.843	20.838	20.700	-0.138
110	493080.357	155558.936	21.632	21.520	-0.112
111	499993.643	158234.325	16.107	16.010	-0.097
112	484181.621	165971.103	0.703	1.110	0.407
150	492820.000	179395.979	15.487	15.490	0.003
151	501152.386	180897.565	18.262	18.280	0.018
152	493321.137	185709.961	20.502	20.580	0.078
153	477359.426	186628.176	16.532	16.580	0.048
154	484718.566	179817.747	13.717	13.790	0.073
155	471249.755	171982.750	23.559	23.600	0.041
156	474384.825	168157.372	8.326	8.230	-0.096
157	484415.113	168000.156	15.478	15.490	0.012
158	499460.976	169770.782	18.889	18.890	0.001
201	500430.091	121116.765	16.025	16.060	0.035
202	511643.769	122011.507	12.378	12.430	0.052
203	500592.826	129081.109	11.433	11.420	-0.013
204	500727.500	140006.180	11.857	11.790	-0.067
205	498744.729	134414.480	10.701	10.750	0.049
206	508683.751	134494.700	16.380	16.270	-0.110
207	507997.567	139836.066	13.682	13.620	-0.062
208	508234.988	148380.117	14.093	14.010	-0.083
209	493110.082	144822.596	15.832	15.800	-0.032
210	507444.099	159609.847	19.004	18.810	-0.194
211	484510.979	157954.580	19.578	19.570	-0.008
250	486009.454	181609.520	12.988	12.840	-0.148
251	502963.829	180888.065	19.271	19.180	-0.091
252	501173.237	185506.707	16.620	16.700	0.080
253	475696.327	176986.021	22.460	22.530	0.070
254	485484.366	176284.026	15.824	15.800	-0.024
255	483480.525	181006.363	22.110	22.190	0.080
256	466226.906	169113.310	7.793	7.900	0.107
257	487286.643	169462.302	20.966	21.020	0.054
258	498857.206	164445.610	20.352	20.310	-0.042

All checkpoints (continued)					
301	509253.835	126477.941	12.923	13.060	0.137
302	505129.727	126814.911	16.066	16.040	-0.026
303	500593.986	129083.201	11.572	11.600	0.028
304	494564.239	136515.034	9.856	10.030	0.174
305	507998.367	139837.394	13.876	13.630	-0.246
306	504509.209	143186.916	16.322	16.160	-0.162
307	504693.476	152315.000	15.482	15.210	-0.272
308	486889.042	145851.976	23.437	23.290	-0.147
309	499993.703	158235.901	15.994	15.900	-0.094
310	484179.050	165971.414	0.646	1.210	0.564
350	498151.388	179058.913	14.704	14.870	0.166
351	498850.143	180593.968	22.746	22.840	0.094
352	489693.608	186978.744	21.405	21.400	-0.005
353	480840.344	186670.638	24.278	24.420	0.142
354	479225.428	176893.468	21.109	21.150	0.041
355	483397.098	174792.522	5.669	5.780	0.111
356	469442.036	171008.346	21.382	21.450	0.068
357	492535.946	172382.586	16.598	16.590	-0.008
358	489519.011	164705.017	18.457	18.430	-0.027
359	491045.146	166888.031	17.686	17.670	-0.016
401	500430.109	121117.966	15.940	16.020	0.080
402	505208.396	121591.430	13.957	13.780	-0.177
403	511644.462	122013.229	12.519	12.470	-0.049
404	496682.091	142127.591	17.351	17.200	-0.151
405	508683.293	134498.694	16.361	16.070	-0.291
406	504691.259	152315.238	15.931	15.250	-0.681
407	500046.300	147313.228	17.697	17.580	-0.117
408	493110.298	144825.140	15.883	15.710	-0.173
409	507443.378	159609.903	18.940	18.850	-0.090
410	484511.065	157955.832	19.479	19.480	0.001
450	492810.652	179401.512	15.566	15.450	-0.116
451	498816.465	180550.619	23.073	23.100	0.027
452	480702.262	189560.158	2.361	2.380	0.019
453	478705.995	184173.573	2.114	1.980	-0.134
454	478322.601	179297.757	24.211	24.020	-0.191
455	467347.779	171814.518	9.296	9.180	-0.116
456	491836.096	170534.494	24.457	24.550	0.093
457	501916.525	165692.748	20.841	20.780	-0.061
458	505297.235	172519.466	18.762	18.490	-0.272
459	493596.338	164224.912	24.428	24.480	0.052
501	497630.892	120630.267	16.681	16.630	-0.051
502	505128.001	126812.270	16.114	15.900	-0.214
503	498133.453	127037.335	12.208	12.290	0.082
504	500726.473	140004.545	11.973	11.810	-0.163
505	496699.022	142157.646	17.345	17.210	-0.135

All checkpoints (continued)					
506	494566.995	136513.146	9.748	9.670	-0.078
507	508237.144	148380.672	14.052	13.920	-0.132
508	486889.226	145846.882	23.328	23.070	-0.258
509	486098.716	153695.558	20.788	20.610	-0.178
510	493079.685	155561.361	21.692	21.500	-0.192
550	496959.783	179250.600	15.886	15.850	-0.036
551	506113.293	181926.501	20.168	19.960	-0.208
552	496921.493	185789.315	20.807	20.730	-0.077
553	478202.562	180050.049	27.165	27.060	-0.105
554	486743.776	178358.429	13.985	13.800	-0.185
555	466095.812	164369.955	4.174	3.980	-0.194
556	490129.609	171231.315	16.967	16.800	-0.167
557	506618.379	169847.568	19.917	19.510	-0.407
558	494513.748	167913.467	22.688	22.520	-0.168
559	499612.202	174262.383	15.772	15.700	-0.072

Average dz	-0.051
Minimum dz	-0.681
Maximum dz	+0.564
Average magnitude	0.118
Root mean square	0.160
Std deviation	0.152

Short Grass					
Point #	Easting(m)	Northing(m)	Surveyed Elevation(m)	LiDAR Elevation(m)	Elevation Difference(m)
101	497630.007	120628.479	16.569	16.670	0.101
102	505208.116	121589.068	13.865	13.740	-0.125
103	496697.508	142157.477	17.326	17.460	0.134
104	494565.520	136515.550	9.846	9.900	0.054
105	498742.683	134413.970	10.838	10.800	-0.038
106	504505.880	143185.217	16.246	16.060	-0.186
107	500043.582	147314.671	17.762	17.560	-0.202
108	486888.712	145848.672	23.213	23.180	-0.033
109	486098.791	153693.843	20.838	20.700	-0.138
110	493080.357	155558.936	21.632	21.520	-0.112
111	499993.643	158234.325	16.107	16.010	-0.097
112	484181.621	165971.103	0.703	1.110	0.407
150	492820.000	179395.979	15.487	15.490	0.003
151	501152.386	180897.565	18.262	18.280	0.018
152	493321.137	185709.961	20.502	20.580	0.078
153	477359.426	186628.176	16.532	16.580	0.048
154	484718.566	179817.747	13.717	13.790	0.073
155	471249.755	171982.750	23.559	23.600	0.041
156	474384.825	168157.372	8.326	8.230	-0.096
157	484415.113	168000.156	15.478	15.490	0.012
158	499460.976	169770.782	18.889	18.890	0.001

Average dz	-0.003
Minimum dz	-0.202
Maximum dz	+0.407
Average magnitude	0.095
Root mean square	0.130
Std deviation	0.133

Tall Grass					
Point #	Easting(m)	Northing(m)	Surveyed Elevation(m)	LiDAR Elevation(m)	Elevation Difference(m)
201	500430.091	121116.765	16.025	16.060	0.035
202	511643.769	122011.507	12.378	12.430	0.052
203	500592.826	129081.109	11.433	11.420	-0.013
204	500727.500	140006.180	11.857	11.790	-0.067
205	498744.729	134414.480	10.701	10.750	0.049
206	508683.751	134494.700	16.380	16.270	-0.110
207	507997.567	139836.066	13.682	13.620	-0.062
208	508234.988	148380.117	14.093	14.010	-0.083
209	493110.082	144822.596	15.832	15.800	-0.032
210	507444.099	159609.847	19.004	18.810	-0.194
211	484510.979	157954.580	19.578	19.570	-0.008
250	486009.454	181609.520	12.988	12.840	-0.148
251	502963.829	180888.065	19.271	19.180	-0.091
252	501173.237	185506.707	16.620	16.700	0.080
253	475696.327	176986.021	22.460	22.530	0.070
254	485484.366	176284.026	15.824	15.800	-0.024
255	483480.525	181006.363	22.110	22.190	0.080
256	466226.906	169113.310	7.793	7.900	0.107
257	487286.643	169462.302	20.966	21.020	0.054
258	498857.206	164445.610	20.352	20.310	-0.042

Average dz	-0.017
Minimum dz	-0.194
Maximum dz	+0.107
Average magnitude	0.070
Root mean square	0.083
Std deviation	0.083

Brush					
Point #	Easting(m)	Northing(m)	Surveyed Elevation(m)	LiDAR Elevation(m)	Elevation Difference(m)
301	509253.835	126477.941	12.923	13.060	0.137
302	505129.727	126814.911	16.066	16.040	-0.026
303	500593.986	129083.201	11.572	11.600	0.028
304	494564.239	136515.034	9.856	10.030	0.174
305	507998.367	139837.394	13.876	13.630	-0.246
306	504509.209	143186.916	16.322	16.160	-0.162
307	504693.476	152315.000	15.482	15.210	-0.272
308	486889.042	145851.976	23.437	23.290	-0.147
309	499993.703	158235.901	15.994	15.900	-0.094
310	484179.050	165971.414	0.646	1.210	0.564
350	498151.388	179058.913	14.704	14.870	0.166
351	498850.143	180593.968	22.746	22.840	0.094
352	489693.608	186978.744	21.405	21.400	-0.005
353	480840.344	186670.638	24.278	24.420	0.142
354	479225.428	176893.468	21.109	21.150	0.041
355	483397.098	174792.522	5.669	5.780	0.111
356	469442.036	171008.346	21.382	21.450	0.068
357	492535.946	172382.586	16.598	16.590	-0.008
358	489519.011	164705.017	18.457	18.430	-0.027
359	491045.146	166888.031	17.686	17.670	-0.016
Average dz	+0.026				
Minimum dz	-0.272				
Maximum dz	+0.564				
Average magnitude	0.126				
Root mean square	0.178				
Std deviation	0.181				

Trees

Point #	Easting(m)	Northing(m)	Surveyed Elevation(m)	LiDAR Elevation(m)	Elevation Difference(m)
401	500430.109	121117.966	15.940	16.020	0.080
402	505208.396	121591.430	13.957	13.780	-0.177
403	511644.462	122013.229	12.519	12.470	-0.049
404	496682.091	142127.591	17.351	17.200	-0.151
405	508683.293	134498.694	16.361	16.070	-0.291
406	504691.259	152315.238	15.931	15.250	-0.681
407	500046.300	147313.228	17.697	17.580	-0.117
408	493110.298	144825.140	15.883	15.710	-0.173
409	507443.378	159609.903	18.940	18.850	-0.090
410	484511.065	157955.832	19.479	19.480	0.001
450	492810.652	179401.512	15.566	15.450	-0.116
451	498816.465	180550.619	23.073	23.100	0.027
452	480702.262	189560.158	2.361	2.380	0.019
453	478705.995	184173.573	2.114	1.980	-0.134
454	478322.601	179297.757	24.211	24.020	-0.191
455	467347.779	171814.518	9.296	9.180	-0.116
456	491836.096	170534.494	24.457	24.550	0.093
457	501916.525	165692.748	20.841	20.780	-0.061
458	505297.235	172519.466	18.762	18.490	-0.272
459	493596.338	164224.912	24.428	24.480	0.052

Average dz	-0.117
Minimum dz	-0.681
Maximum dz	+0.093
Average magnitude	0.145
Root mean square	0.204
Std deviation	0.172

Hard Surface

Point #	Easting(m)	Northing(m)	Surveyed Elevation(m)	LiDAR Elevation(m)	Elevation Difference(m)
501	497630.892	120630.267	16.681	16.630	-0.051
502	505128.001	126812.270	16.114	15.900	-0.214
503	498133.453	127037.335	12.208	12.290	0.082
504	500726.473	140004.545	11.973	11.810	-0.163
505	496699.022	142157.646	17.345	17.210	-0.135
506	494566.995	136513.146	9.748	9.670	-0.078
507	508237.144	148380.672	14.052	13.920	-0.132
508	486889.226	145846.882	23.328	23.070	-0.258
509	486098.716	153695.558	20.788	20.610	-0.178
510	493079.685	155561.361	21.692	21.500	-0.192
550	496959.783	179250.600	15.886	15.850	-0.036
551	506113.293	181926.501	20.168	19.960	-0.208
552	496921.493	185789.315	20.807	20.730	-0.077
553	478202.562	180050.049	27.165	27.060	-0.105
554	486743.776	178358.429	13.985	13.800	-0.185
555	466095.812	164369.955	4.174	3.980	-0.194
556	490129.609	171231.315	16.967	16.800	-0.167
557	506618.379	169847.568	19.917	19.510	-0.407
558	494513.748	167913.467	22.688	22.520	-0.168
559	499612.202	174262.383	15.772	15.700	-0.072

Average dz	-0.147
Minimum dz	-0.407
Maximum dz	+0.082
Average magnitude	0.155
Root mean square	0.176
Std deviation	0.099

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WEBSITE: www.aerometric.com
E-mail: ame@aerometric.com

Conclusion

After thorough analysis of the LiDAR data, Aero-Metric concludes that the bare earth data meets or exceeds the required accuracy of 18cm, and by all accounts it meets the FEMA guidelines of being 95% clean.

The improper classification of water points in the ground points class based on Figure 2 of this report (point class 2 in *MP.las files) does not produce an accurate representation of the bare earth. However, Aero-Metric does not believe that the inclusion of these water points will interfere with the accuracy of the ground surface to support hydraulic modeling.

Aero-Metric recommends the following corrective measures:

1. Review all DEM files to determine if any tiles contain point elevation anomalies as depicted in Figure 4 and listed in Table 1 of this report.
2. Water assigned with a zero (0) elevation in DEM files could be assigned a lower elevation based on Figure 3 of this report. This would reduce the instance of the ledge created by the zero flattening procedure.
3. Apply hydro enforcement with compiled breaklines to fully satisfy the FEMA compliancy statement, or adjust the metadata and report to reflect the current procedures employed.

With regard to the 2m gap between DEM tiles, this may be an end-user preference. As stated previously, if the user is going to load and triangulate all DEM's at once there will be no noticeable gap between tiles. However, if the user will be loading and triangulating the tiles individually, then the 2m gap will appear. The solution to the latter would be to regenerate the DEM tiles using grid corner thereby generating edge matched points on the tile perimeter.

In General this is a good data set and we believe it is not necessary to correct minor inconsistencies from manual editing on the bare earth data.

[1] Part 3: *National Standards for Spatial Data Accuracy (NSSDA)*, “Geospatial Positioning Accuracy Standards,” published by the Federal Geographic Data Committee (FGDC), 1998.

[2] Appendix A, *Guidance for Aerial Mapping and Surveying*, “Guidelines and Specifications for Flood Hazard Mapping Partners,” published by the Federal Emergency Management Agency (FEMA), April 2003.

[3] *Guidelines for Digital Elevation Data*, Version 1.0, published by the National Digital Elevation Program (NDEP), May 2004.

[4] *ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data*, published by the American Society for Photogrammetry and Remote Sensing (ASPRS), May 2004.