Dewberry®

PROJECT REPORT

For the

NRCS Maryland LiDAR Project

USGS Contract:

G10PC00013

Task Order Number:

G12PD00092

Prepared for:
USGS

Prepared by:
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Report Date: September 20, 2012

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Executive Summary

The primary purpose of this project was to develop a consistent and accurate surface elevation dataset derived from high-accuracy Light Detection and Ranging (LiDAR) technology for the NRCS Maryland LiDAR Project Area.

The LiDAR data were processed to digital surface models (DSM) and bare-earth digital terrain models (DTM). Detailed breaklines and bare-earth Digital Elevation Models (DEMs) were produced for the project area. Data was formatted according to tiles with each tile covering an area of 1500m by 1500m. A total of 833 tiles were produced for the project encompassing an area of approximately 681 sq. miles.

The Project Team

Dewberry served as the prime contractor for the project. In addition to project management, Dewberry was responsible for LAS classification, all LiDAR products, breakline production, Digital Elevation Model (DEM) production, and quality assurance.

Dewberry's Gary Simpson completed ground surveying for the project and delivered surveyed checkpoints. His task was to acquire surveyed checkpoints for the project to use in independent testing of the vertical accuracy of the LiDAR-derived surface model. He also verified the GPS base station coordinates used during LiDAR data acquisition to ensure that the base station coordinates were accurate. Note that a separate Survey Report was created for this portion of the project.

Aerial Cartographics of America, Inc completed LiDAR data acquisition and data calibration for the project area.

Survey Area

The project area addressed by this report falls within the Maryland counties of Dorchester, Wicomico, Worchester, and Somerset.

Date of Survey

The LiDAR aerial acquisition was conducted from February 14, 2012 thru March 13, 2012.

Datum Reference

Data produced for the project were delivered in the following reference system.

Horizontal Datum: The horizontal datum for the project is North American Datum of 1983 (NAD 83) National Spatial Reference System 2007 (NSRS2007)
Vertical Datum: The Vertical datum for the project is North American Vertical Datum of 1988 (NAVD88)
Coordinate System: UTM Zone 18
Units: Horizontal units are in meters, Vertical units are in meters.
Geoid Model: Geoid09 (Geoid 09 was used to convert ellipsoid heights to orthometric heights).

LiDAR Vertical Accuracy

For the NRCS Maryland LiDAR Project, the tested $RMSE_z$ for checkpoints in open terrain equaled **0.08 m** compared with the 0.0925 m specification; and the FVA computed using $RMSE_z$ x 1.9600 was equal to **0.157 m**, compared with the 0.182 m specification.

For the NRCS Maryland LiDAR Project, the tested CVA computed using the 95th percentile was equal to **0.267 m,** compared with the 0.269 m specification.

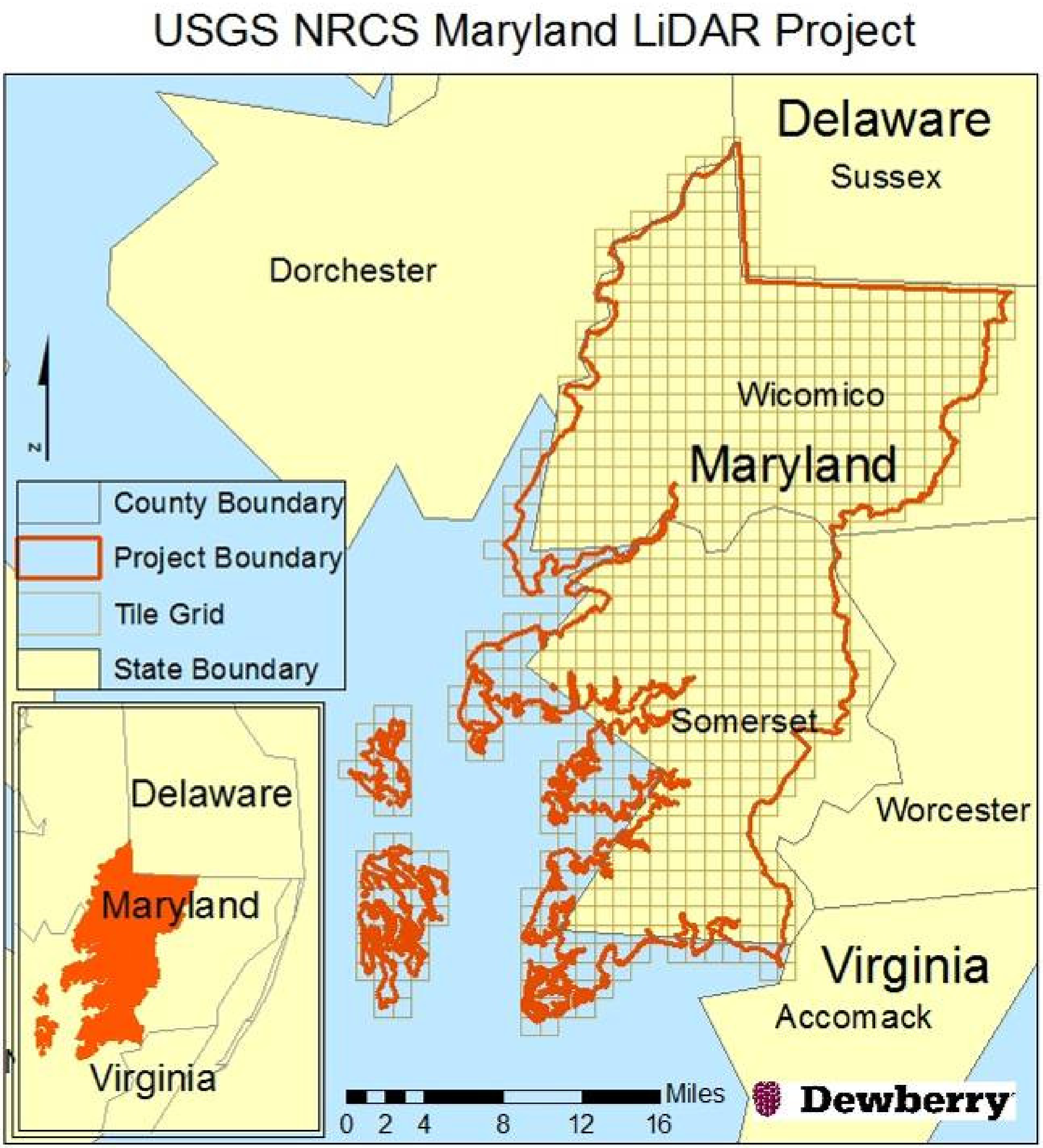
Project Deliverables

The deliverables for the project are listed below.

1. Raw Point Cloud Data (Swaths)
2. Classified Point Cloud Data (Tiled)
3. Bare Earth Surface (Raster DEM – IMG Format)
4. Digital Terrain Model (Raster DTM – IMG Format)
5. Digital Surface Model (Raster DSM – IMG Format)
6. Intensity Images (8-bit gray scale, tiled, GeoTIFF format)
7. Breakline Data (File GDB)
8. Control & Accuracy Checkpoint Report & Points
9. Metadata
10. Project Report (Acquisition, Processing, QC)
11. Project Extents, Including a shapefile derived from the LiDAR Deliverable

1 Project Tiling Footprint

Eight hundred thirty three (833) tiles were delivered for the project. Each tile's extent is 1,500 meters by 1,500 meters.



Project Map

1.1 List of delivered tiles (833):

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2 LiDAR Acquisition Report

2.1 Overview

The purpose of the LiDAR Topographic Survey is to provide LiDAR acquisition, calibration and delivery of LiDAR data. The project is comprised of portions of Somerset and Wicomico counties in Maryland. The total size of the project is approximately 564 square miles, plus the required buffer. The LiDAR data was acquired by Aerial Cartographics of America, Inc. (ACA). This report covers the acquisition activities for the entire project. This report covers the mission parameters, QA/QC steps, control information and other pertinent details of the LiDAR acquisition task. ACA was responsible for providing LiDAR acquisition, calibration and delivery of unclassified LiDAR data files to Dewberry for their assigned areas.

2.2 Project Area

The project map in Figure 1 illustrates project extents. The total project area is approximately 564 square miles plus the required 100 meter buffer.

Figure 1: Project Boundary 4

2.3 *Acquisition Equipment*

A Riegl LMS-Q680i Full Waveform LiDAR sensor was used to collect the data. Table 1 represents a list of the features and characteristics for the Riegl LMS-Q680i LiDAR system:

CHARACTERISTIC	LMS-Q680I
Manufacturer	Riegl
Platform	Fixed-wing/Helicopter
Scan principle/pattern	Parallel scan lines
Wavelength(s) (μm)	1.550
Scan angle θ (°)	60º
Pulse rate (kHz)	0 – 400
Scan rate (Hz)	10-200
Flying height *h* minimum-maximum (m)	30 – 5000
Swath width (m)	1.15 x altitude (m)
Beam divergence (mrad)	0.5
Laser footprint (m)	0.5 @ 1000 m *h* (typical)
Across track point spacing (m)	Variable
Along track point spacing (m)	Variable
Point density (points/ sq m)	Variable
Flying speed typical (km/h)	200
Area/h (sq km/h)	Varies
Net flying time max/typical (h)	Typical at 5 hours
No. of echoes per pulse	Full waveform - limited only be time
Intensity recording	Yes
Cameras	None used on this project
Ground GPS receivers (dual–frequency)	Any geodetic grade
Airborne GPS receiver (dual–frequency)	Geodetic grade dual frequency
IMU Manufacturer	Litton
IMU Frequency (Hz)	200
Attitude precision roll, pitch/heading (°)	0.005 / 0.008
Laser classification	Class 3R
Eyesafe range (m)	N.O.H.D. >1.5
Power requirements	18-32 VDC
Operating temperature (°C)	0º to +40º
Humidity (%)	0 to 95 non-condensing
Sensor dimensions (cm)	48 (l) x 21.2 (w) x 23 (h)
Sensor weight (kg)	17.5
Sensor mount	Shock isolated mounting plates
Data storage/acquisition duration	DR560-RD Recorder/ 5 hours

Table 1: LiDAR Sensor Characteristic

2.4 *LiDAR System Project Parameters*

Table 2 illustrates the system parameters for LiDAR acquisition on this project.

Item	Parameter	Units
Aircraft Speed	120	knots
Data Acquisition Height	1000	m AGL
Swath Width	1160	m
Distance Between Flight Lines	813	m
Overlap	30	%
Scanner Field Of View	30	+/- degrees
Scan Cutoff	0	Degrees
Pulse Repetition Rate	220	KHz
Scan Frequency	93	Hz
Number of Returns Per Pulse	unlimited	Full Waveform (discrete point delivery)
Beam Divergence	.5	m
Flight Line Length	50	<X km
Base Station Distance	40	<X km
Resultant Raw Point Density	0.7	pt/m2 without overlap

Table 2: LiDAR System Parameter

2.5 *Acquisition Dates and Flight Lines*

Table 3 shows the flight missions to acquire the laser data including flight dates, daily missions, number of lines, tidal information, and comments for each flight.

Date	Missions Completed	Number of Lines Flown	Tide gauge / Tide level	Comments (Weather, system delays)
02/14/12	N/A	N/A	N/A	Mobilized to Salisbury, MD
02/15/12	N/A	N/A	N/A	Boresight Calibration
02/16/12	N/A	N/A	N/A	0.1" of rain at SBY (No Flight)
02/17/12	2	65	-0.1'-0.5'	Night Flights - Good Conditions
02/18/12	1	27	0.0-0.5'	Night Flight - Good Conditions
02/19/12	0	0	N/A	0.5 – 0.75" rain and snow at SBY
02/20/12	0	0	N/A	3 day wait due to rainfall
02/21/12	0	0	N/A	3 day wait due to rainfall
02/22/12	0	0	N/A	3 day wait due to rainfall
02/23/12	1	18	-0.25'-0.75'	Good Conditions
02/24/12	1	5	0.4'-1.0'	Good Conditions
02/25/12	1	7	0.0'-1.0'	Rainfall previous night
02/26/12	0	0	N/A	Return to Kissimmee, FL
03/11/12	0	0	N/A	Mobilize to Salisbury, MD
03/12/12	1	7	-0.25'-0.0'	Reflight of Lines 29-35
03/13/12	0	0	N/A	Return to Kissimmee, FL
TOTAL	7	121	N/A	Project 100% Complete

Table 3: Flight Lines and Acquisition Dates

Figure 2 shows the combined trajectory of the flightlines.

Figure 2: Flight Lines Combined Trajectories

2.6 Acquisition

Collections (Lifts): 6
Collection Dates: 2012 February 17,18,23,24 and March 12
Field of View (FOV): 60 degrees
Average Point Density (planned): 0.7 m
Flight Level(s): 1000 / 3280 m/ft
Sensor Type: Riegl LMS-Q680i **Sensor Serial Number(s):** 9997848

The LiDAR data was collected using the specifications outlined in the "U.S. Geological Survey National Geospatial Program Base LiDAR Specification, Version 13 (ILMF)".
A calibration flight was flown on February 15, 2012 to obtain current boresight misalignment angles defining the relationship between the scanner and the Inertial Measurement Unit (IMU). A site was selected in Salisbury, Maryland. The 1320' X 1320' site was surveyed to provide twelve (12) horizontal and vertical control locations for assessing the calibration. The area was flown at 1,600 feet AGL at 400 kHz with 50 percent sidelap in the recommended configuration of four (4) north south lines flown in alternating directions and four (4) east west lines flown in alternating directions. Refer to document NCRS Maryland Riegl Calibration.docx for additional information.

The project laser data were collected on February 17, 18, 23, 24 and March 12, 2012 utilizing a Riegl LMS-Q680i full waveform laser scanner (Serial Number 9997848) mounted in a Cessna 208 Grand Caravan aircraft at an approximate altitude of 3,300 feet above ground level (AGL) with a ground speed of 120 knots per hour, 30% sidelap, a pulse rate repetition (PRR) of 320 kHz, a scan half angle of 30 degrees resulting in a point spacing of 0.64 meters. The data were collected under cloud-, fog-, and snow-free conditions with no unusual flooding. No data were collected within 72 hours of rainfall that measured more than 0.25 inches. All data were acquired within 2 hours of low tide as predicted by tidal stations located on the bay and inland rivers.
Tidal Stations used to determine tidal activity are Sharptown, Vienna, Salisbury, Roaring Point, Whitehaven, Great Shoals Light, Chance, Teague Creek, Long Point, Ewell, Crisfield, Ape Hole, and Shelltown as shown in Figure 3.

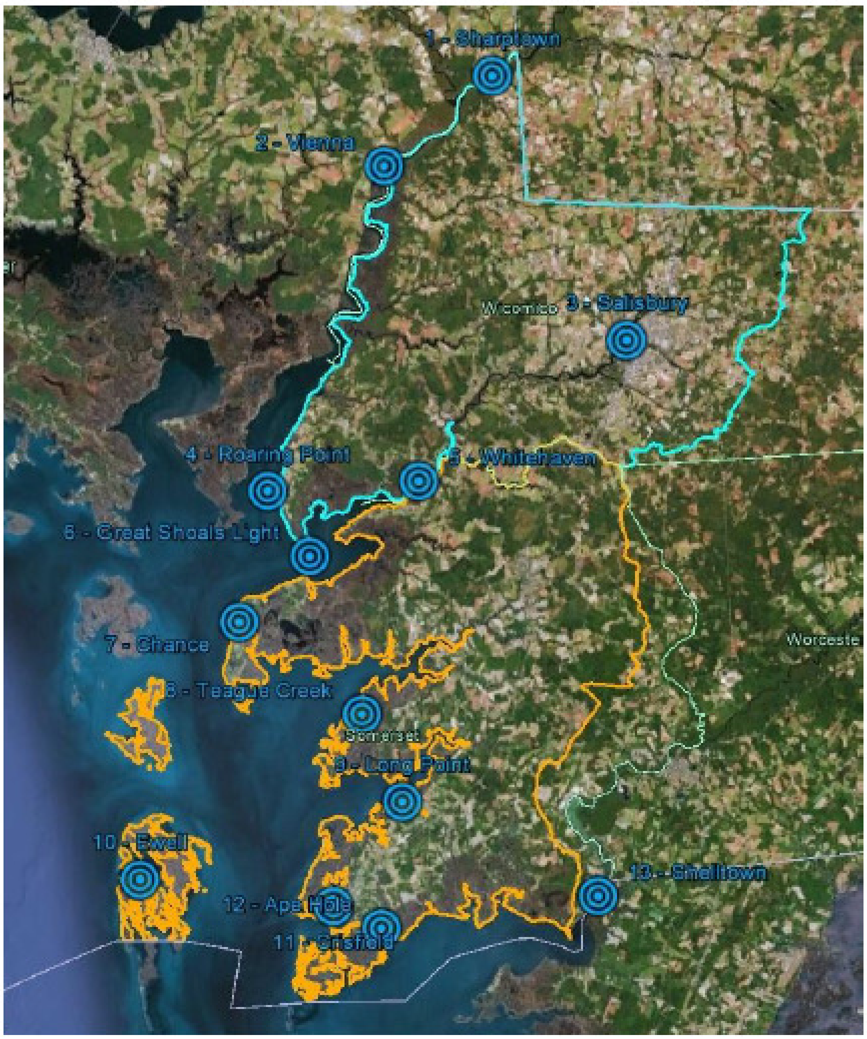


Figure 3: Tidal Station Locations

2.7 Airborne GPS Positioning

The GPS data from the ground base stations and the airborne platform were processed using Applanix POSPac 4.4 software module POSGPS. The Inertial Measurement Unit (IMU) solution was processed to provide information regarding the attitude of the sensor platform using the Applanix POSPac 4.4 software module POSProc. This solution was integrated with the Airborne GPS and adjusted using a Kalman filter in a forward/reverse solution to provide a Smoothed Best Estimate of Trajectory (SBET). The ground base stations were set up at the Salisbury-Ocean City Wicomico Regional Airport (ACA001) and on control point 111 enabling the aircraft to be within 25 miles of ground base station at all times.

Receivers for base station during Airborne Data Capture:

Make	Model	Serial #	Description
Leica	GX1230	464483	Duel frequency GPS Receiver
Leica	AX1220GG	0632001	Duel frequency GPS Antenna
Leica	GX1230	464495	Duel frequency GPS Receiver
Leica	AX1220GG	0632002	Duel frequency GPS Antenna

Table 4

Two base stations locations were used for the ABGPS processing 111 and ACA001, located at the Salisbury Municipal airport.

Station	Easting	Northing	Height
111	426121.404	4216147.508	0.627
ACA001	343022.014	4185037.17	38.948

Table 5

2.8 Ground Survey

Coordinate information for 13 aerial targets distributed throughout the project site was provided by Greenman Pedersen Incorporated, Annapolis Junction, MD for ground validation. The validation is for the acquisition portion of this project only. The control points were taken in flat, open areas to determine a fundamental vertical accuracy.

Horizontal and vertical was established at the calibration site in Salisbury, Maryland and throughout Somerset and Wicomico Counties on the Eastern Shore of Maryland.

The horizontal datum for the project is referenced to NAD 83 (2007), Maryland State Plane Coordinate System, U.S. survey feet and UTM Zone 18, meters. The vertical datum for the project is referenced to NAVD 88, U.S. survey feet and meters. Geoid 2009 was used as the reference model for all GPS computations.

2.9 Salisbury Calibration Site

The calibration site is located in a residential area of Salisbury and consists of twelve (12) pre-determined calibration locations selected by Aerial Cartographics of America (ACA). All field observations and measurements were obtained between February 7, 2012 and February 13, 2012. Survey instruments used for Salisbury Calibration Site:

Make	Model	Serial #	Description
Leica	TCRP 1201 R300	224744	1" Robotic Total Station
Leica	DNA03	340789	Digital Level

Table 6

Calibration Site Control Points:

Name	Northing	Easting	Elevation
1	4245019.458	447861.762	8.561
2	4245020.897	448097.263	9.056
3	4244975.066	448286.584	9.428
4	4244887.191	447882.324	8.552
5	4244897.39	448064.707	8.681
6	4244894.471	448236.89	9.199
7	4244700.849	447863.356	8.405
8	4244714.903	448039.091	8.73
9	4244729.383	448269.639	9.301
10	4244602.684	447843.091	8.806
11	4244594.581	448065.923	9.274
12	4244593.078	448247.212	9.689

Table 7

2.10 LiDAR Network Control

LiDAR targets were set in locations selected by ACA throughout Somerset and Wicomico Counties on the Eastern Shore of Maryland. Solid square targets were painted on existing asphalt roads and measured 36” x 36”, and a Mag nail was set in the center of each target. All GPS observations were performed between February 14, 2012 and March 7, 2012. Receivers used for Network Observations:

Make	Model	Serial #	Description
Leica	GX1230GG	468655	Duel frequency GPS/Glonas Receiver
Leica	AX1220GG	007420012	Duel frequency GPS/Glonas Antenna
Leica	GX1230GG	468657	Duel frequency GPS/Glonas Receiver
Leica	AX1220GG	07430032	Duel frequency GPS/Glonas Antenna
Leica	GX1230GG	468665	Duel frequency GPS/Glonas Receiver
Leica	AX1220GG	07430037	Duel frequency GPS/Glonas Antenna

Table 8

Project Control Points:

Name	Northing	Easting	Elevation
101	4257340.613	434142.363	6.798
102	4253898.658	450092.669	12.623
103	4240186.216	426366.672	2.177
104	4246916.109	441135.75	6.538
105	4241546.831	448980.035	11.771
106	4237524.798	437194.635	5.015
107	4230878.253	442977.035	7.174
108	4226723.831	422155.971	0.868
109	4230310.963	434396.355	3.352
110	4223999.305	439657.801	4.482
111	4216147.508	426121.404	0.627
112	4210446.149	436377.452	2.204
113	4205051.146	427241	0.808

Table 9

The following NGS Geodetic Control Monuments were held fixed for the final adjustment:

PID	NAME	ORDER
HU0431	EAST SCHOOL	1st Order -Vertical
HU0458	SALISBURY	1st Order -Vertical
HU0490	Q105	1st Order -Vertical
HU2364	Z 183	2nd Order -Vertical
HU2579	WESTOVER	2nd Order -Vertical
AJ7996	DEAL	2nd Order -Vertical
AJ7997	PRINCE	2nd Order -Vertical
AJ7999	LUKE	2nd Order -Vertical
AJ8000	TULLS	2nd Order -Vertical
AJ8011	PORTER	2nd Order -Vertical
HU2247	X 186	2nd Order -Vertical

Table 10

2.11 Boresight Calibration

On February 15, 2012 between 1912 and 2010 hrs (UTC), ACA, Inc. collected airborne LiDAR data over the calibration site located in Salisbury, Maryland with the Riegl LMS-Q680i mounted in a Cessna Grand Caravan 208 fixed wing aircraft for the NRCS Maryland LiDAR project. The altitude for the flight was 1600 feet Above Ground Level (AGL) at a ground speed of approximately 90 knots and a Pulse Rate Repetition (PRR) of 400 kHz and a scan angle of 60 degrees (30 degree half angle). Eight flight lines were flown in a traditional crossing pattern with four lines in alternating north and south directions and four lines in alternating east and west directions.

The GPS data from the ground base station and the airborne platform were processed using Applanix POSPac 4.4 software module POSGPS. The Inertial Measurement Unit (IMU) solution was processed to provide information regarding the attitude of the sensor platform using the Applanix POSPac 4.4 software module POSProc. This solution was integrated with the Airborne GPS and adjusted using a Kalman filter in a forward/reverse solution to provide a Smoothed Best Estimate of Trajectory (SBET). The ground base station was set up at the Salisbury-Ocean City Wicomico Regional Airport enabling the aircraft to always be within 6 miles of the ground base station.

Using Riegl processing software RiAnalyze, RiProcess, and RiWorld, the system calibration was performed. The Scan Data Adjustment module is the principal tool for determining the boresight misalignment angles. The planar surfaces of overlapping laser scans are used to obtain the best results. Corresponding surfaces are determined by resolution, angle (degree), and direction (north-south). Threshold values in the form of standard deviation are established to determine if the surface meets an angle or height tolerance to be considered in the adjustment. When the surfaces meet the criteria, they are considered to be corresponding.

Visual confirmation of the calibration is undertaken by analyzing the height differences between adjacent flight strips. Each overlapping flight can be assessed for quality assurance. Differences are displayed by color according to an assigned scale making it simple to identify any problem areas.

2.12 Laser Processing

The laser data was processed using Riegl proprietary software RiAnalyze, RiWorld and RiProcess. RiAnalyze was used to extract discrete point data from the digitized echo signals and perform a geometric transformation to put the target data into the scanner's own coordinate system with additional descriptors for every point (range, scan angle, xyz coordinates, time stamp, intensity, first, second, last target indication). RiWorld transformed the data into the coordinate position of the trajectory providing the laser data within a geocentered coordinate system for further processing in RiProcess. The project oriented RiProcess tool geo-references the laser data by merging it with the SBET obtained from the GPS/IMU processing along with mounting information and calibration data and digitized echo signals. Quality analysis was performed on the laser data through visualization in 2D and 3D modes for data density, height differences and scan data matching. Data matching was performed using a scan data adjustment feature based on matching data on planar objects, such as rooftops, to ensure meeting the 0.10 meter RMSE relative accuracy between adjacent flight swaths. Data was output to LAS 1.2 format in NAD83 UTM Zone 18 Meters. Waveform packets were output to LAS 1.3 format. Flight lines longer than 2 GB were separated into two parts. The first part retained the original naming and the second part had an "A" added to the name.

2.13 Flight Planning QC

ACA Flight Operations Manager imported project information into Track'Air Flight Planning and Management software to place and number the flight lines according to altitude, sidelap, Pulse Rate Repetition, speed, point density, MTA (Multiple Time Around) zones. The project was reviewed for best location of base stations to ensure aircraft was operating within a 25 mile radius. Flight data were reviewed by project manager to verify there was no error in planning parameters and locations. Additional data necessary for the project were researched and provided to the flight crew such as ATC and flight maps, prime acquisition times based on tide charts (within two hours of mean low tide) from stations on the bay and inland rivers, and PDOP predictors for windows of flight opportunity. A kick-off meeting was held with flight personnel (Project Manager, Flight Operations Manager, pilot, and system operator). Project details were reviewed, maps and charts supplied to the crew members. The geodetic locations of the base stations were supplied to flight crew for in air alignments along with contact information of ground field survey support for discussion of anticipated flight dates and times. Weather reports, PDOP and GDOP (with weekly almanac) were checked daily to stay abreast of changes to planned flight windows of opportunity.

2.14 System Health Checks QC

The system operator confirms all systems are go by checking indicators in the hardware and software that monitor the component's health and functionality.

2.15 Real Time Acquisition Checks QC

Daily coordination with ground field support personnel was made to coordinate location, date and time of their mission responsibilities. Field crews were contacted prior to flight by the flight system operator to ensure base station data collection was started 30 minutes prior to take off.
Verification is made of the correct altitude. The number and percentage of returns are monitored ensuring they are within expected project limits. Laser sensor data are monitored to verify flight lines are correct and that there is proper sidelap having no data voids. Any observed problems deviating from project specifications are noted on the flight reports by flight line number and the line is flown again.

2.16 Post Acquisition Data Check QC

The sensor data is downloaded immediately following mission. The download of laser, POS, and GPS base station data is monitored for any suspicious differences in file sizes and other anomalies that might indicate a problem. Any issues are reported and corrective measures are taken including reflights.

2.17 Data Backup with Redundancy QC

Two copies of the data are made. One was delivered to the office for immediate processing and the other retained as a flight department archive until notified that the office had successfully copied data to their system.

2.18 ABGPS Data Processing QC

A kickoff meeting for all personnel scheduled to work on the laser portion of the project was held to review project specifications. When data was uploaded from the drives, checks were made to look for differences in file sizes and other anomalies that might indicate a problem. The data was inspected for completeness noting any POS or GPS irregularities. A full Investigation was made contacting flight department for any incomplete or missing data. Trajectories were processed using Applanix software noting any discrepancies detrimental to acceptable solutions. Techniques were used to achieve a GPS combined separation solution that met the 5 cm project requirement. Solutions not meeting the criteria were rejected and the flight department was notified to fly the line again. When the solution reached the 5 cm criteria, the ABGPS solution was sent to client for review and acceptance. Upon word of acceptance, the Smoothed Best Estimate of Trajectory (SBET) was exported for laser processing in Riegl software.

2.19 Boresight Calibration and Laser Data Processing QC

The SBET was imported. Required parameters for laser processing were input. The data was analyzed visually in 2D and 3D environments for point density, sidelap, holidays, data voids, MTA zone violations, clouds and other anomalies. Problems were reported to the project manager for determination of corrective measures. Boresight misalignment angles were calculated. Iterations were run as necessary to arrive at a satisfactory solution with contract standard deviations. Data was compared against ground survey data and any necessary adjustments were made. A calibration report was developed for file and client.
Project site data was processed confirming that boresight misalignment angles from the calibration flight were correct. Iterations were run as necessary to arrive at a satisfactory solution with contract standard deviations to meet a 0.10 meter RMSEz between flight lines. Data was compared against ground survey data and any necessary adjustments were made. A protocol report summarizing results was produced.
An Output Control Report was produced showing differences between laser and ground control values. A statistical analysis report was produced along with a histogram documenting the fundamental vertical accuracy prior to classification for file and client.

2.20 Accuracy Statement

Using TerraSolid Ltd. software, an output control report was produced by comparing a triangulated irregular network of the laser points at the horizontal location of the known ground control points and measuring the vertical difference. The Vertical Root Mean Square Error (RMSEz) is 0.0246 meters. Accuracyz (RMSEz*1.96) is calculated at 0.048meters at 95% confidence level with no outliers.

2.21 Conclusion

The LiDAR data products collected for the project meet or exceed the requirements set out in the task order statement of work and specifications. All work was accomplished under the supervision of a Certified Photogrammetrist as recognized by the American Society for Photogrammetry and Remote Sensing.

3 LiDAR Processing & Qualitative Assessment

3.1 Data Classification and Editing

LiDAR mass points were produced to LAS 1.2 specifications, including the following LAS classification codes:

- Class 1 = Unclassified, and used for all other features that do not fit into the Classes 2, 7, 9, or 10, including vegetation, buildings, etc.
- Class 2 = Ground, includes accurate LiDAR points in overlapping flight lines
- Class 7 = Noise, low and high points
- Class 9 = Water, points located within collected breaklines
- Class 10 = Ignored Ground due to breakline proximity.

The data was processed using GeoCue and TerraScan software. The initial step is the setup of the GeoCue project, which is done by importing a project defined tile boundary index encompassing the entire project area. The acquired 3D laser point clouds, in LAS binary format, were imported into the GeoCue project and tiled according to the project tile grid. Once tiled, the laser points were classified using a proprietary routine in TerraScan. This routine classifies any obvious outliers in the dataset to class 7. After points that could negatively affect the ground are removed from class 1, the ground layer is extracted from this remaining point cloud. The ground extraction process encompassed in this routine takes place by building an iterative surface model.

This surface model is generated using three main parameters: building size, iteration angle and iteration distance. The initial model is based on low points being selected by a "roaming window" with the assumption that these are the ground points. The size of this roaming window is determined by the building size parameter. The low points are triangulated and the remaining points are evaluated and subsequently added to the model if they meet the iteration angle and distance constraints. This process is repeated until no additional points are added within iterations. A second critical parameter is the maximum terrain angle constraint, which determines the maximum terrain angle allowed within the classification model.

The following fields within the LAS files are populated to the following precision: GPS Time (0.000001 second precision), Easting (0.003 meter precision), Northing (0.003 meter precision), Elevation (0.003 meter precision), Intensity (integer value - 12 bit dynamic range), Number of Returns (integer - range of 1-4), Return number (integer range of 1-4), Scan Direction Flag (integer - range 0-1), Classification (integer), Scan Angle Rank (integer), Edge of flight line (integer, range 0-1), User bit field (integer - flight line information encoded). The LAS file also contains a Variable length record in the file header that defines the projection, datums, and units.

Once the initial ground routine has been performed on the data, Dewberry creates Delta Z (DZ) orthos to check the relative accuracy of the LiDAR data. These orthos compare the elevations of LiDAR points from overlapping flight lines on a 1 meter pixel cell size basis. If the elevations of points within each pixel are within 10 cm of each other, the pixel is colored green. If the elevations of points within each pixel are between 10 cm and 20 cm of each other, the pixel is colored yellow, and if the elevations of points within each pixel are greater than 20 cm in difference, the pixel is colored red. Pixels that do not contain points from overlapping flight lines are colored according to their intensity values. DZ orthos can be created using the full point cloud or ground only points and are used to review and verify the calibration of the data is acceptable. Some areas are expected to show sections or portions of red, including terrain variations, slope changes, and vegetated areas or buildings if the full point cloud is used. However, large or continuous sections of yellow or red pixels can indicate the data was not calibrated correctly or that there were issues during acquisition that could affect the usability of the data. The DZ orthos for NRCS Maryland showed that the data was calibrated correctly with no issues that would affect its usability. The figure below shows an example of the DZ orthos.

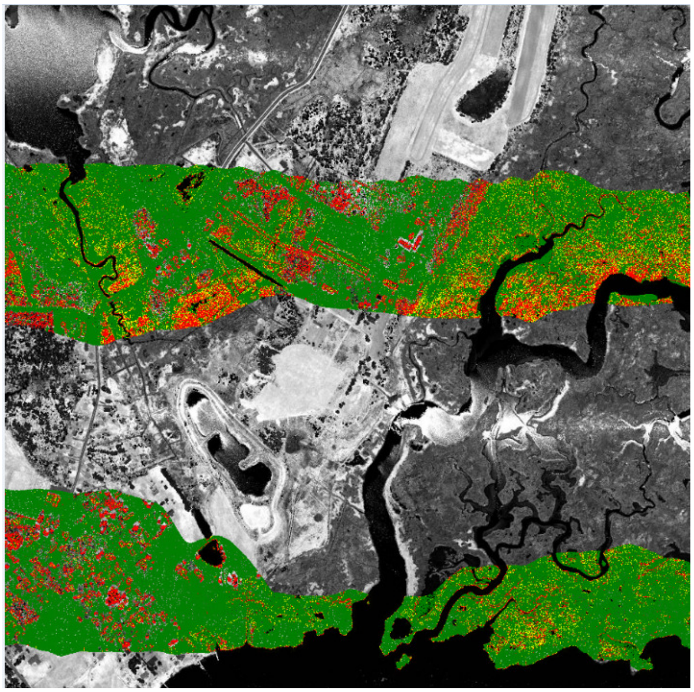


Figure 4: DZ orthos created from the full point cloud. Some red pixels are visible along embankments, sloped terrain, and in vegetated land cover, as expected. Open, flat areas are green indicating the calibration and relative accuracy of the data is acceptable.

Dewberry utilized a variety of software suites for data processing. The LAS dataset was received and imported into GeoCue task management software for processing in Terrascan. Each tile was imported into Terrascan and a surface model was created to examine the ground classification. Dewberry analysts visually reviewed the ground surface model and corrected errors in the ground classification such as vegetation, buildings, and bridges that were present following the initial processing conducted by Dewberry. Dewberry analysts employ 3D visualization techniques to view the point cloud at multiple angles and in profile to ensure that non-ground points are removed from the ground classification. After the ground classification corrections were completed, the dataset was processed through a water classification routine that utilizes breaklines compiled by dewberry to automatically classify hydro features. The water classification routine selects ground points within the breakline polygons and automatically classifies them as class 9, water. The final classification routine applied to the dataset selects ground points within a specified distance of the water breaklines and classifies them as class 10, ignored ground due to breakline proximity.

3.2 Qualitative Assessment

Dewberry qualitative assessment utilizes a combination of statistical analysis and interpretative methodology to assess the quality of the data for a bare-earth digital terrain model (DTM). This process looks for anomalies in the data and also identifies areas where man-made structures or vegetation points may not have been classified properly to produce a bare-earth model.

Within this review of the LiDAR data, two fundamental questions were addressed:

- Did the LiDAR system perform to specifications?
- Did the vegetation removal process yield desirable results for the intended bare-earth terrain product?

Mapping standards today address the quality of data by quantitative methods. If the data are tested and found to be within the desired accuracy standard, then the data set is typically accepted. Now with the proliferation of LiDAR, new issues arise due to the vast amount of data. Unlike photogrammetrically-derived DEMs where point spacing can be eight meters or more, LiDAR nominal point spacing for this project is 1 point per 1 square meters. The end result is that millions of elevation points are measured to a level of accuracy previously unseen for traditional elevation mapping technologies and vegetated areas are measured that would be nearly impossible to survey by other means. The downside is that with millions of points, the dataset is statistically bound to have some errors both in the measurement process and in the artifact removal process.

As previously stated, the quantitative analysis addresses the quality of the data based on absolute accuracy. This accuracy is directly tied to the comparison of the discreet measurement of the survey checkpoints and that of the interpolated value within the three closest LiDAR points that constitute the vertices of a three-dimensional triangular face of the TIN. Therefore, the end result is that only a small sample of the LiDAR data is actually tested. However there is an increased level of confidence with LiDAR data due to the relative accuracy. This relative accuracy in turn is based on how well one LiDAR point "fits" in comparison to the next contiguous LiDAR measurement, and is verified with DZ orthos. Once the absolute and relative accuracy has been ascertained, the next stage is to address the cleanliness of the data for a bare-earth DTM.

By using survey checkpoints to compare the data, the absolute accuracy is verified, but this also allows us to understand if the artifact removal process was performed correctly. To reiterate the quantitative approach, if the LiDAR sensor operated correctly over open terrain areas, then it most likely operated correctly over the vegetated areas. This does not mean that the entire bare-earth was measured; only that the elevations surveyed are most likely accurate (including elevations of treetops, rooftops, etc.). In the event that the LiDAR pulse filtered through the vegetation and was able to measure the true surface (as well as measurements on the surrounding vegetation) then the level of accuracy of the vegetation removal process can be tested as a by-product.

To fully address the data for overall accuracy and quality, the level of cleanliness (or removal of above-ground artifacts) is paramount. Since there are currently no effective automated testing procedures to measure cleanliness, Dewberry employs a combination of statistical and visualization processes. This includes creating pseudo image products such as LiDAR orthos produced from the intensity returns, Triangular Irregular Network (TIN)'s, Digital Elevation Models (DEM) and 3-dimensional models. By creating multiple images and using overlay techniques, not only can potential errors be found, but Dewberry can also find where the data meets and exceeds expectations. This report will present representative examples where the LiDAR and post processing had issues as well as examples of where the LiDAR performed well.

3.3 Analysis

Dewberry utilizes GeoCue software as the primary geospatial process management system. GeoCue is a three tier, multi-user architecture that uses .NET technology from Microsoft. .NET technology provides the real-time notification system that updates users with real-time project status, regardless of who makes changes to project entities. GeoCue uses database technology for sorting project metadata. Dewberry uses Microsoft SQL Server as the database of choice. Specific analysis is conducted in Terrascan and QT Modeler environments.

Following the completion of LiDAR point classification, the Dewberry qualitative assessment process flow for the USGS NRCS Maryland LiDAR project incorporated the following reviews:

1. *Format:* The LAS files are verified to meet project specifications. The LAS files for the USGS NRCS Maryland LiDAR project conform to the specifications outlined below.

- Format, Echos, Intensity
    - LAS format 1.2
    - Point data record format 1
    - Multiple returns (echos) per pulse
    - Intensity values populated for each point
- ASPRS classification scheme
    - Class 1 – unclassified
    - Class 2 – Bare-earth ground
    - Class 7 – Noise
    - Class 9 – Water
    - Class 10 – Ignored Ground due to breakline proximity
- Projection
    - Datum – North American Datum 1983 (NAD83) National Spatial Reference System 2007 (NSRS 2007)
    - Projected Coordinate System – UTM Zone 18
    - Units – Meters
    - Vertical Datum – North American Vertical Datum 1988, Geoid 09
    - Vertical Units - Meters
- LAS header information:
    - Class (Integer)
    - GPS Week Time (0.0001 seconds)
    - Easting (0.003 meters)
    - Northing (0.003 meters)
    - Elevation (0.003 meters)
    - Echo Number (Integer 1 to 4)
    - Echo (Integer 1 to 4)
    - Intensity (8 bit integer)
    - Flight Line (Integer)
    - Scan Angle (Integer degree)

2. *Data density, data voids:* The LAS files are used to produce Digital Elevation Models using the commercial software package "QT Modeler" which creates a 3-dimensional data model derived from Class 2 (ground points) in the LAS files. Grid spacing is based on the project density deliverable requirement for un-obscured areas. For the USGS NRCS Maryland LiDAR project it is stipulated that the minimum post spacing in un-obscured areas should be 1 point per 1 square meter.

   a. Acceptable voids (areas with no LiDAR returns in the LAS files) that are present in the majority of LiDAR projects include voids caused by bodies of water. These are considered to be acceptable voids.

3. *Bare earth quality:* Dewberry reviewed the cleanliness of the bare earth to ensure the ground has correct definition, meets the project requirements, there is correct classification of points, and there are less than 5% residual artifacts.

   a. *Artifacts:* Artifacts are caused by the misclassification of ground points and usually represent vegetation and/or man-made structures. The artifacts identified are usually low lying structures, such as porches or low vegetation used as landscaping in neighborhoods and other developed areas. These low lying features are extremely difficult for the automated algorithms to detect as non-ground and must be removed manually. The vast majority of these features have been removed but a small number of these features are still in the ground classification. The limited numbers of features remaining in the ground are usually 0.3 meters or less above the actual ground surface, and should not negatively impact the usability of the dataset.

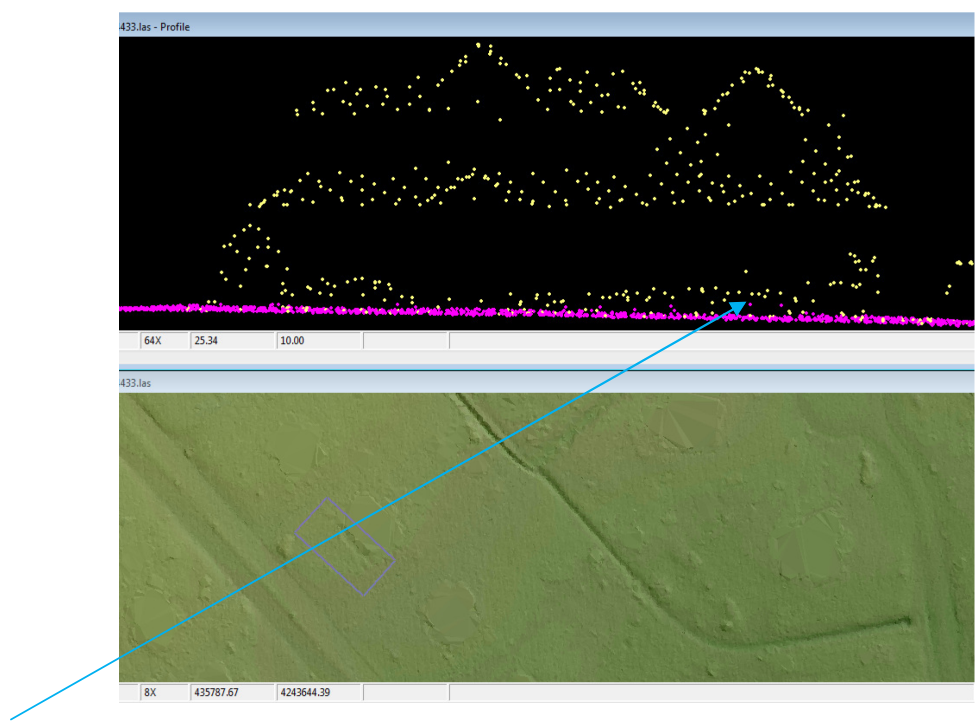


Figure 5 – Tile number 18SVH344433. Profile with points colored by class (class 1=yellow, class 2=pink) is shown in the top view and a TIN of the surface is shown in the bottom view. The arrow identifies low vegetation points. A limited number of these small features are still classified as ground.

b. *Bridge Removal Artifacts:* The DEM surface models are created from TINs or Terrains. TIN and Terrain models create continuous surfaces from the inputs. Because a continuous surface is being created, the TIN or Terrain will use interpolation to triangulate across a bridge opening from legitimate ground points on either side of the actual bridge. This can cause visual artifacts or "saddles." These "artifacts" are only visual and do not exist in the LiDAR points or breaklines.

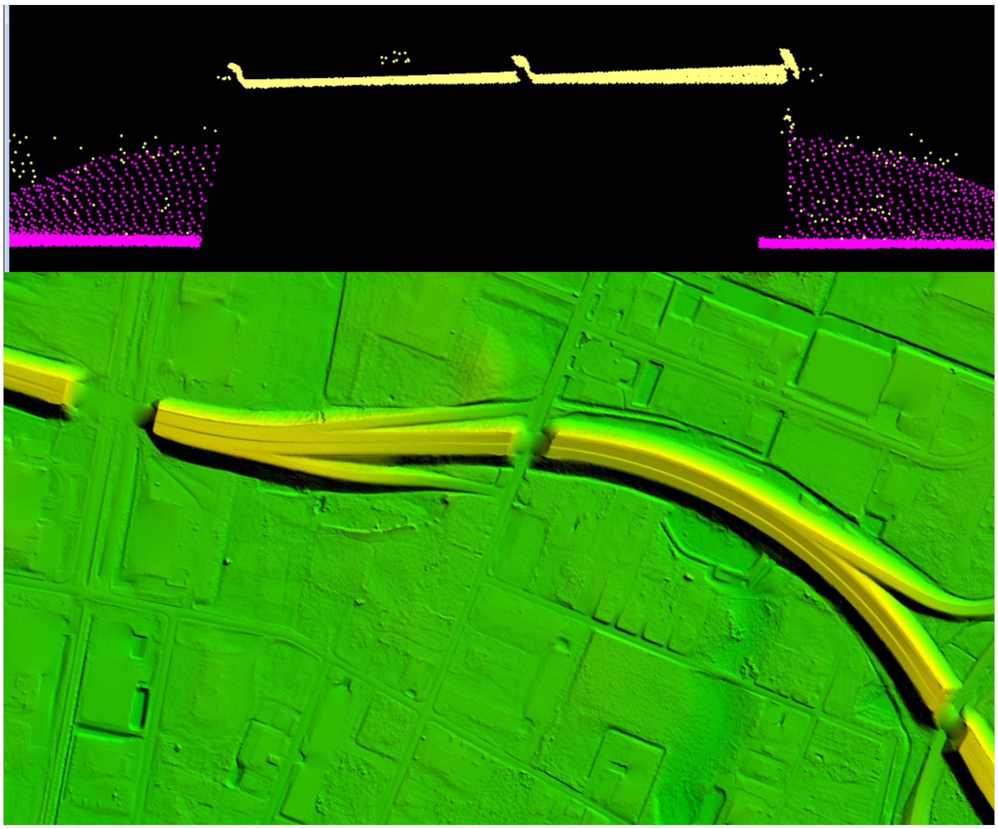


Figure 6 – Tile number 18SVH479493. The DEM artifacts shown in the bottom view are due to the surface model interpolating from the slope leading to the bridge, to the lower ground points on either side of where the bridge points were removed. The surface model must make a continuous model and in order to do so, points are connected through interpolation. This can cause visual artifacts when there are features with large elevation differences. The profile in the top view shows the LiDAR points of this particular feature colored by class. All bridge points have been removed from ground (pink) and are unclassified (yellow). There are no ground points that can be modified to correct this visual artifact.

c. *Building Removal Artifacts:* Large buildings, unique construction, and buildings built on sloped terrain or built into the ground can make a noticeable impact on the bare earth DEM once they have been removed, often in the form of large void areas with obvious triangulation or interpolation across the area and general lack of detail in the ground where the structure stood. In a few areas, this interpolation has resulted in visual artifacts within building footprints. These “artifacts” are only visual and do not exist in the LiDAR points.

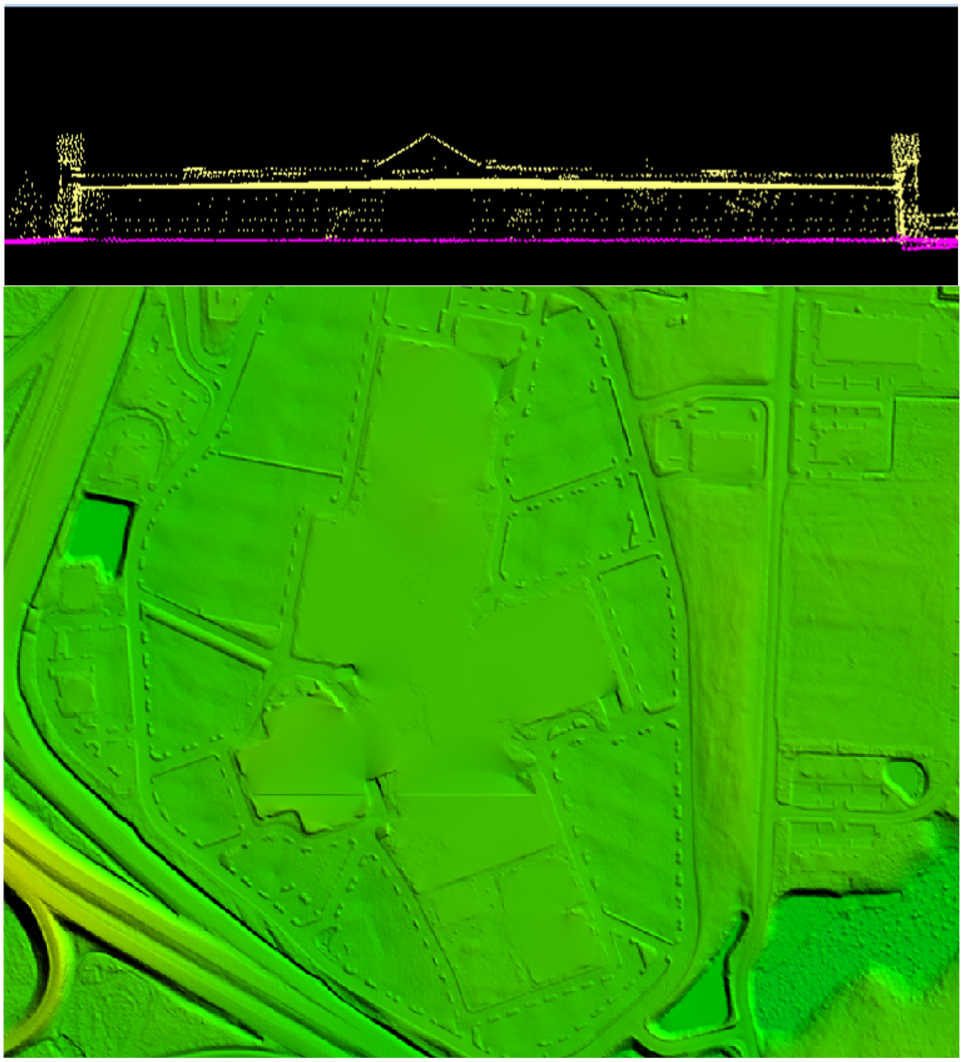


Figure 7 – Tile number 18SVH494493. The DEM in the bottom view shows a visual artifact because the surface model is interpolating between the available ground points on either side of the building points that were removed. The surface model must make a continuous model and in order to do so, points are connected through interpolation. This can cause visual artifacts in areas where the ground elevation is slightly lower on one side of building than the other. The profile in the top view shows the LiDAR points of this particular feature colored by class. All building points have been removed from ground (pink) and are unclassified (yellow). There are no ground points that can be modified to correct this visual artifact.

d. Culverts and Bridges: Bridges have been removed from the bare earth surface while culverts remain in the bare earth surface. In instances where it is difficult to determine if the feature is a culvert or bridge, such as with some small bridges, Dewberry erred on assuming they would be culverts especially if they are on secondary or tertiary roads. There were also several large structures throughout the project area that Dewberry determined to be box culverts. Below is an example of a culvert that has been left in the ground surface.

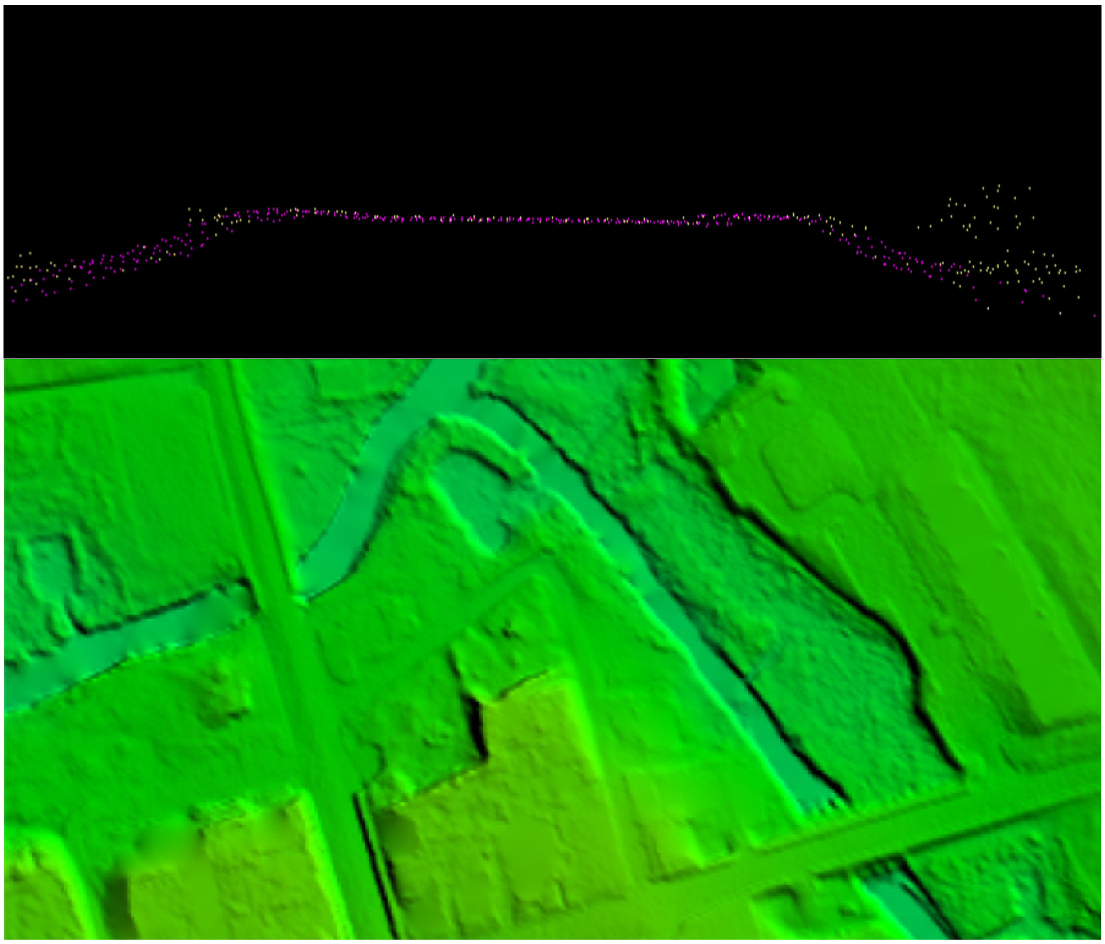


Figure 8– Tile number 18SVH389283. Profile with points colored by class (class 1=yellow, class 2=pink) is shown in the top view and the DEM is shown in the bottom view. This culvert remains in the bare earth surface. Bridges have been removed from the bare earth surface and classified to class 1.

e. Low marsh areas: It is sometimes difficult to determine true ground in low wet areas. The area shown below has many low mounds that at first glance may be considered vegetation. As the profile shows, the vegetation has been removed and the small mounds have are correctly left in the ground.

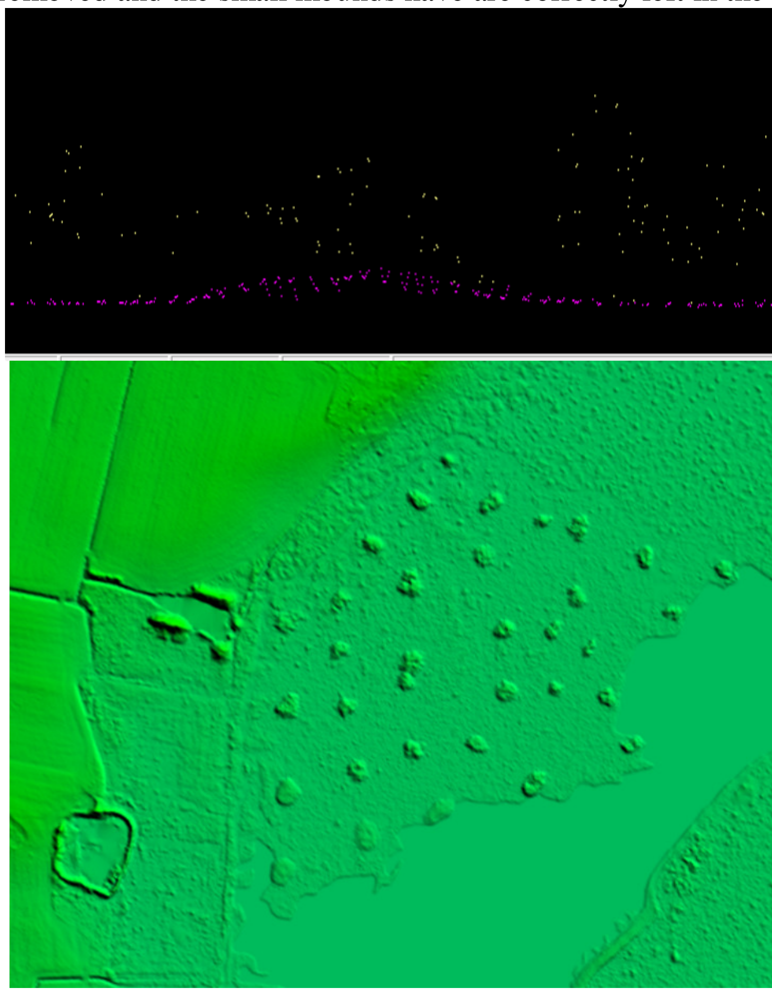


Figure 9– Tile number 18SVH224388. Profile with points colored by class (class 1=yellow, class 2=pink) is shown in the top view and the DEM is shown in the bottom view. The mounds shown in the above DEM remain in the bare earth surface.

f. *In Ground Structures:* In ground structures exist within the project area. These features are correctly included in the ground classification.

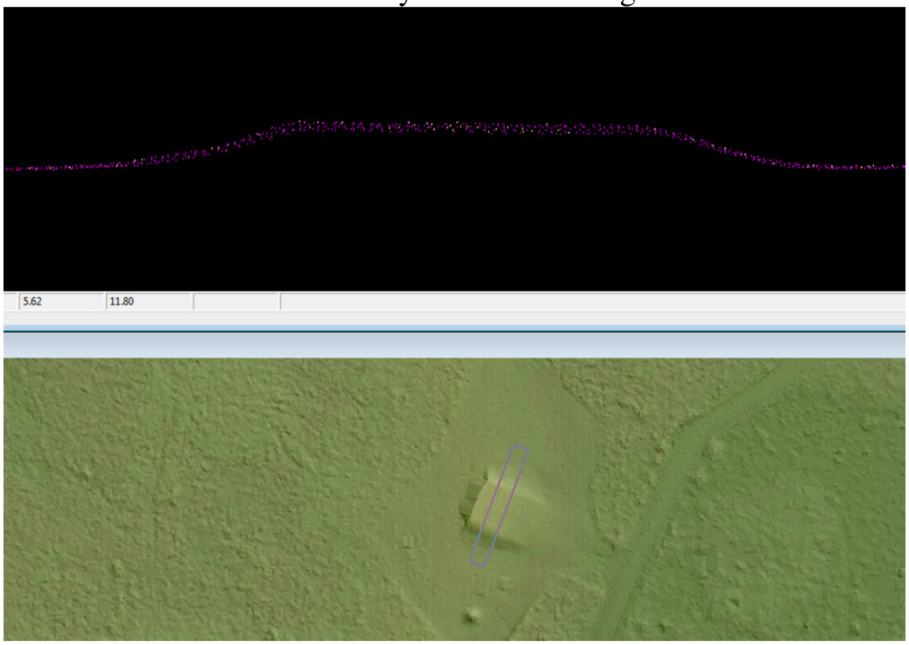


Figure 10 – Tile number 18SVH359388. Profile with points colored by class (class 1=yellow, class 2=pink) is shown in the top view and a TIN of the surface is shown in the bottom view. In ground structures have been included in the ground classification.

g. *Elevation Change within Breaklines:* While water bodies are flattened in the final DEMs, other features such as linear hydrographic features and tidal waters can have significant changes in elevation within a small distance. In linear hydrographic features, this is often due to the presence of a structure that affects flow such as a dam or spillway. Sudden changes in elevation occur naturally in tidally influenced areas which are present within the project area. Dewberry has gone through the DEMs making sure that changes in elevation are shown from bank to bank. These changes are often shown as steps to reduce the presence of artifacts while ensuring consistent downhill flow. Examples of elevation change due to a structure and within a tidally influenced area are shown below.

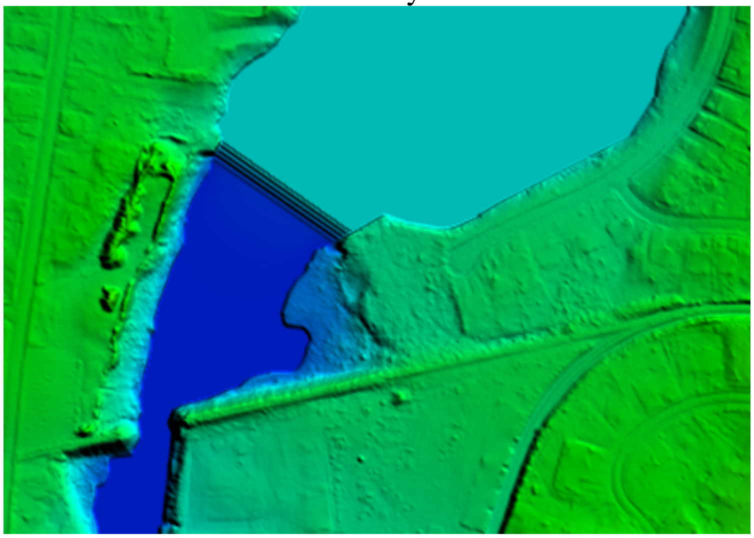


Figure 11 – Tile number 18SVH464463. Elevation change due to the structure has been stair stepped. The steps are straight across from bank to bank and flow consistently downhill.

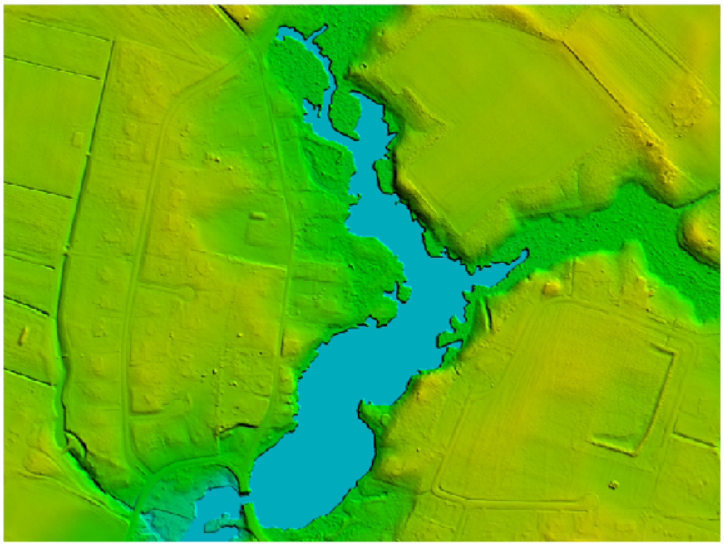


Figure 12 – Tile number 18SVH389373. Tidal water elevation is noticeably lower than the surrounding terrain in some areas.

h. *Flightline Ridges:* Ridges occur when there is a difference between the elevations of adjoining flightlines or swaths. Some flightline ridges are visible in the final DEMs but they do not exceed the project specifications and the overall relative accuracy requirements for the project area have been met. An example of a visible ridge that is within tolerance is shown below.

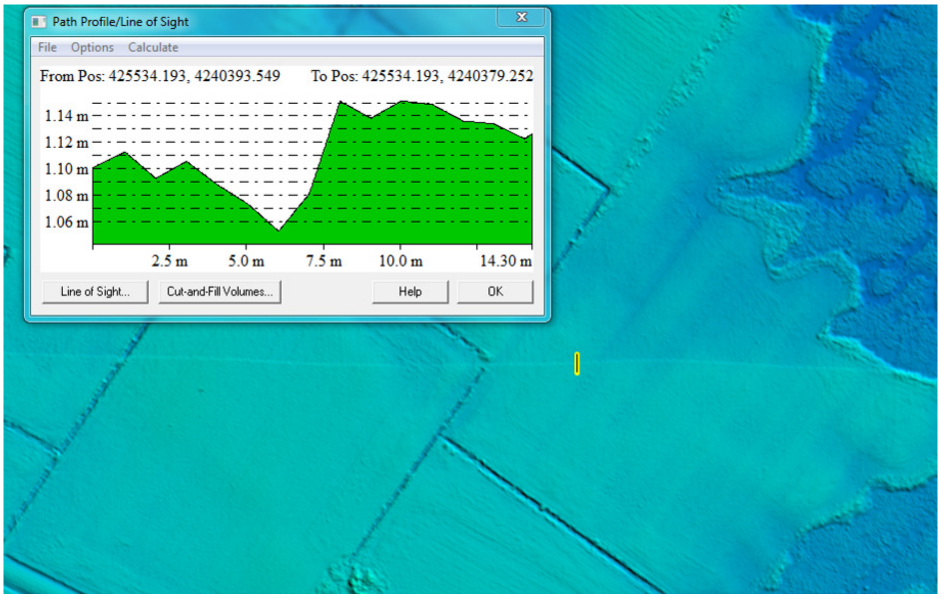


Figure 13 – Tile number 18SVH254403. The flight line ridge is 10cm or less. Overall, the NRCS Maryland LiDAR data meets the project specifications for 10 cm RMSE relative accuracy.

3.4 Conclusion

The dataset conforms to project specifications for format and header values. The spatial projection information and classification of points is correct. Minor artifacts and small areas of misclassification are isolated and have minimal impact on the usability of the dataset.

4 Survey Vertical Accuracy Checkpoints

NRCS Maryland LiDAR QA			
UTM ZONE 18 COORDINATE SYSTEM			
	NAD83 (m)		NAVD88 (m)
POINT ID	NORTHING (m)	EASTING (m)	ORTHO HEIGHT (m)
OPEN TERRAIN POINTS			
OT-1	4265239.636	437608.503	6.675
OT-2	4258283.876	431696.234	7.724
OT-3	4254029.559	439949.957	12.530
OT-4	4253807.230	449884.029	13.912
OT-5	4246618.841	449167.687	9.118
OT-6	4244508.837	439233.252	7.151
OT-7	4240875.488	423734.111	4.551
OT-8	4238614.178	435225.389	3.242
OT-9	4238294.436	444088.664	9.694
OT-10	4234065.268	443420.533	8.703
OT-11	4232526.013	433036.604	3.565
OT-12	4225328.778	430154.355	1.570
OT-13	4227122.182	421340.367	0.789
OT-14	4221248.153	416616.219	1.700
OT-15	4224346.602	443271.202	5.396
OT-16	4219867.810	436526.328	2.510
OT-17	4217771.450	429517.100	1.352
OT-18	4214337.350	436144.156	2.468
OT-19	4206045.966	436547.686	0.839
OT-20	4204487.439	424929.592	0.641
OT-21	4202729.745	410034.625	0.437
OT-22	4205867.688	409306.401	0.735
GRASS, WEEDS, CROPS POINTS			
GWC-1	4205222.307	428959.396	0.915
GWC-2	4211468.936	431475.041	1.225
GWC-3	4216965.955	441013.728	4.949
GWC-4	4218937.116	434320.815	1.927
GWC-5	4223114.852	438993.235	4.380
GWC-6	4227899.842	444029.033	8.886
GWC-7	4229541.347	437188.554	4.743
GWC-8	4226711.167	427313.987	0.767

GWC-9	4233573.912	440899.313	6.177
GWC-10	4235098.336	445208.515	13.280
GWC-11	4237790.272	430436.476	0.867
GWC-12	4235987.024	421078.190	2.506
GWC-13	4245126.807	426459.383	3.768
GWC-14	4244416.309	435190.370	5.216
GWC-15	4241448.349	440732.196	8.225
GWC-16	4241506.681	451980.339	13.875
GWC-17	4247850.332	455061.409	14.522
GWC-18	4250110.153	442967.775	12.940
GWC-19	4251457.375	430751.956	5.806
GWC-20	4255863.182	434150.765	7.273
GWC-21	4260883.764	437384.762	10.412
FOREST POINTS			
FO-1	4260524.286	434421.372	4.974
FO-2	4254059.998	431416.914	4.557
FO-3	4248998.986	436300.553	6.610
FO-4	4254243.287	445267.061	13.276
FO-5	4253573.899	457520.283	17.868
FO-6	4246323.113	453384.661	12.983
FO-7	4245173.070	431785.025	3.320
FO-8	4243517.698	444815.451	5.086
FO-9	4239132.453	450299.297	12.943
FO-10	4240289.921	426405.870	2.006
FO-11	4232463.171	436661.726	4.199
FO-12	4231113.231	443275.887	7.556
FO-13	4228505.642	431728.238	1.961
FO-14	POINT	FAILED	
FO-15	4225489.898	418195.724	1.535
FO-16	4221602.334	446819.264	5.876
FO-17	4219292.411	438870.808	4.159
FO-18	4215735.051	427533.470	0.533
FO-19	4210624.801	436497.551	2.138
FO-20	4207146.595	439994.302	0.970
FO-21	4208312.956	429750.090	1.926

Table 11: USGS NRCS Maryland LiDAR surveyed accuracy checkpoints

5 LiDAR Vertical Accuracy Statistics & Analysis

5.1 Background

Dewberry tests and reviews project data both quantitatively (for accuracy) and qualitatively (for usability).

For qualitative assessment (i.e. vertical accuracy assessment), Sixty four (64) check points were surveyed for the project and are located within open terrain, grass/weeds/crops, and forest cover categories. The checkpoints were surveyed for the project using RTK survey methods. A survey report was produced which details and validates how the survey was completed for this project.

Checkpoints were evenly distributed throughout the project area so as to cover as many flight lines as possible using the "dispersed method" of placement.

Out of the sixty four checkpoints received from the surveyor, one was determined to be unusable by the surveyor. Five were not used in the final vertical accuracy testing due to the presence of dense organic debris at the survey site. The surveyor's antenna rod was able to penetrate the debris at these sites while the LiDAR was not. The resulting difference in elevation, though only a few centimeters, was significant enough to justify the omission of these points. Fifty eight surveyed checkpoints were used for the final qualitative assessment. The checkpoints that were not included in the accuracy testing are listed below accompanied by the photos of each location.

Open terrain point number OT-2 shown below was not used.

Grass, weed, crop point number GWC-20 shown below was not used.

Grass, weed, crop point number GWC-21 shown below was not used.

Forest point number FO-1 shown below was not used.

Forest point number FO-10 shown below was not used.

5.2 *Vertical Accuracy Test Procedures*

FVA (Fundamental Vertical Accuracy) is determined with check points located only in the open terrain (grass, dirt, sand, and/or rocks) land cover category, where there is a very high probability that the LiDAR sensor will have detected the bare-earth ground surface and where random errors are expected to follow a normal error distribution. The FVA determines how well the calibrated LiDAR sensor performed. With a normal error distribution, the vertical accuracy at the 95% confidence level is computed as the vertical root mean square error (RMSEz) of the checkpoints x 1.9600. For the USGS NRCS Maryland LiDAR project, vertical accuracy must be 0.182 meters or less based on an RMSEz of 0.0925 meters x 1.9600.

CVA (Consolidated Vertical Accuracy) is determined with all checkpoints in all land cover categories combined where there is a possibility that the LiDAR sensor and post-processing may yield elevation errors that do not follow a normal error distribution. CVA at the 95% confidence level equals the 95th percentile error for all checkpoints in all land cover categories combined. The USGS NRCS Maryland LiDAR Project CVA standard is 0.269 meters based on the 95th percentile. The CVA is accompanied by a listing of the 5% outliers that are larger than the 95th percentile used to compute the CVA; these are always the largest outliers that may depart from a normal error distribution. Here, $Accuracy_z$ differs from CVA because $Accuracy_z$ assumes elevation errors follow a normal error distribution where RMSE procedures are valid, whereas CVA assumes LiDAR errors may not follow a normal error distribution in vegetated categories, making the RMSE process invalid.

SVA (Supplemental Vertical Accuracy) is determined for each land cover category other than open terrain. SVA at the 95% confidence level equals the 95th percentile error for all checkpoints in each land cover category. The USGS NRCS Maryland LiDAR Project SVA target is 0.269 meters based on the 95th percentile. Target specifications are given for SVA's as one individual land cover category may exceed this target value as long as the overall CVA is within specified tolerances. Again, $Accuracy_z$ differs from SVA because $Accuracy_z$ assumes elevation errors follow a normal error distribution where RMSE procedures are valid, whereas SVA assumes LiDAR errors may not follow a normal error distribution in vegetated categories, making the RMSE process invalid.

The relevant testing criteria are summarized in the table below.

Quantitative Criteria	Measure of Acceptability
Fundamental Vertical Accuracy (FVA) in open terrain only using RMSEz *1.9600	0.182 meters (based on RMSEz (0.0925 meters) * 1.9600)
Consolidated Vertical Accuracy (CVA) in all land cover categories combined at the 95% confidence level	0.269 meters (based on combined 95th percentile)
Supplemental Vertical Accuracy (SVA) in each land cover category separately at the 95% confidence level	0.269 meters (based on 95th percentile for each land cover category)

Table 12 — Acceptance Criteria

5.3 *Vertical Accuracy Testing Steps*

The primary QA/QC vertical accuracy testing steps used by Dewberry are summarized as follows:

1. Dewberry's team surveyed QA/QC vertical checkpoints in accordance with the project's specifications.
2. Next, Dewberry interpolated the bare-earth LiDAR DTM to provide the z-value for each of the 58 checkpoints.

3. Dewberry then computed the associated z-value differences between the interpolated z-value from the LiDAR data and the ground truth survey checkpoints and computed FVA, CVA, and SVA values.
4. The data were analyzed by Dewberry to assess the accuracy of the data. The review process examined the various accuracy parameters as defined by the scope of work. The overall descriptive statistics of each dataset were computed to assess any trends or anomalies. This report provides tables, graphs and figures to summarize and illustrate data quality.

The figure below shows the location of the QA/QC checkpoints within the project area.

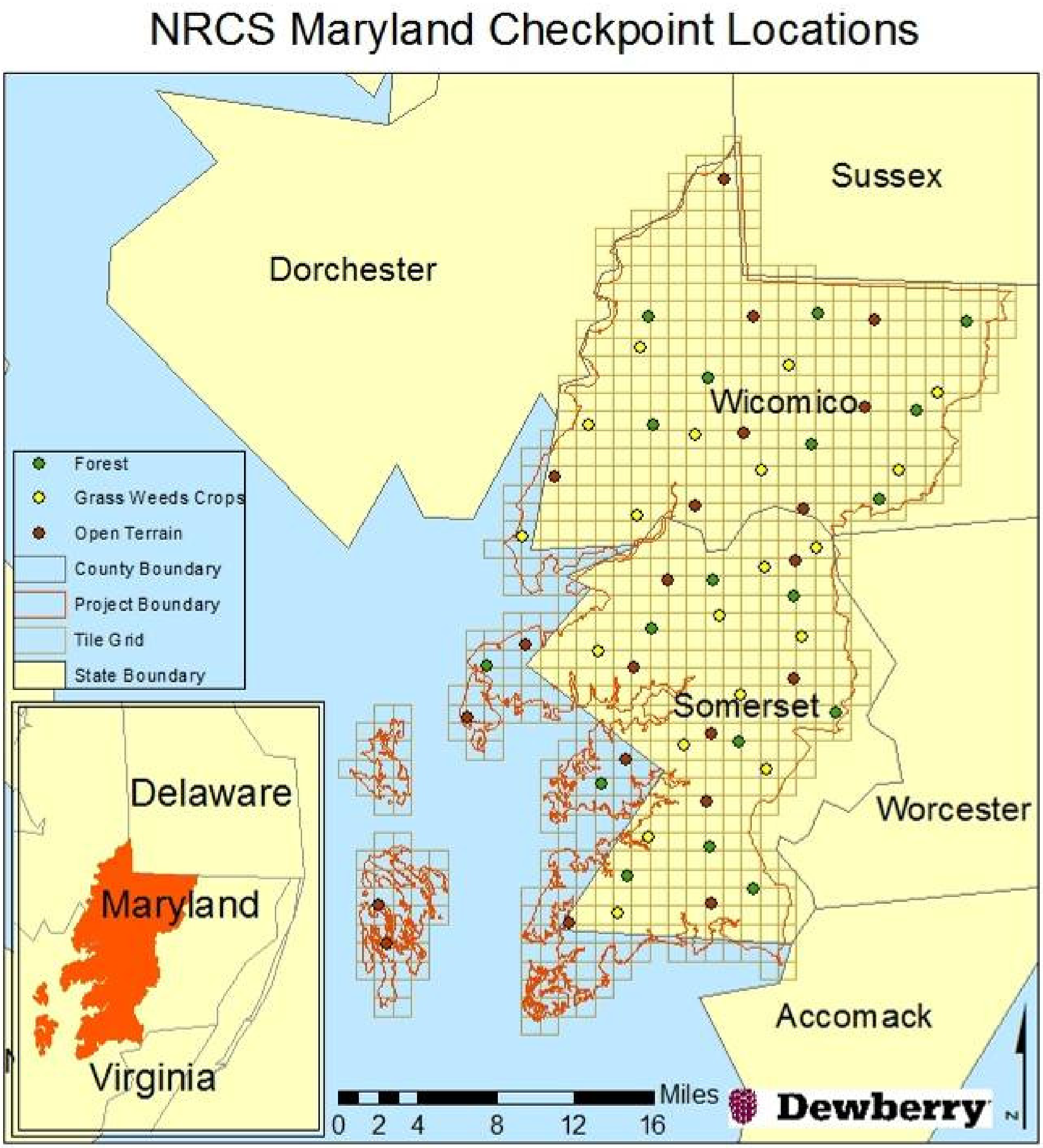


Figure 14 – Location of QA/QC Checkpoints

5.4 Vertical Accuracy Results

The table below summarizes the tested vertical accuracy resulting from a comparison of the surveyed checkpoints to the elevation values present within the LiDAR LAS files.

Land Cover Category	**# of Points**	**FVA — Fundamental Vertical Accuracy (RMSEz x 1.9600) Spec=0.182 m**	**CVA — Consolidated Vertical Accuracy (95th Percentile) Spec=0.269 m**	**SVA — Supplemental Vertical Accuracy (95th Percentile) Target=0.269 m**
Consolidated	58		0.267	
Open Terrain	21	0.157		
Grass Weeds Crops	19			0.275
Forest	18			0.215

Table 13 — FVA Vertical Accuracy at 95% Confidence Level. CVA, and SVA Vertical Accuracy based on the 95th percentile.

The $RMSE_z$ for checkpoints in open terrain only tested 0.08 meters, within the target criteria of 0.0925 meters. Compared with the 0.182 meters specification, the FVA tested 0.157 meters at the 95% confidence level based on $RMSE_z$ x 1.9600.

Compared with the 0.269 meters specification, CVA for all checkpoints in all land cover categories combined tested 0.267 meters based on the 95th percentile.

Compared with target 0.269 specification, SVA for checkpoints in the grass weeds and crops land cover category tested 0.215 meters and checkpoints in the forest land cover category tested 0.275 meters at the based on the 95th percentile.

The figure below illustrates the magnitude of the differences between the QA/QC checkpoints and LiDAR data. This shows that the majority of LiDAR elevations were within +/- 0.20 meters of the checkpoints elevations, but there were some outliers where LiDAR and checkpoint elevations differed by up to +/- 0.30 meters.

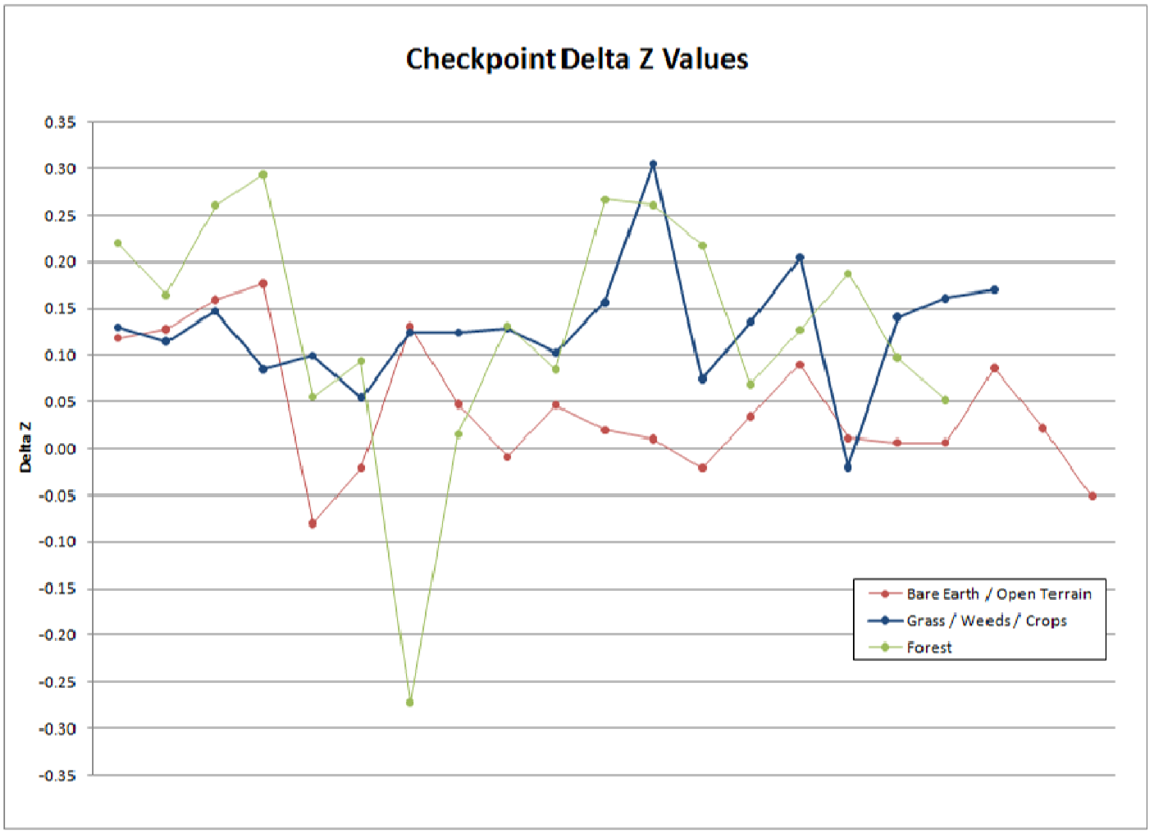


Figure 15 – Magnitude of Elevation Discrepancies

Table 14 lists the 5% outliers that are larger than the 95th percentile.

Point ID	NAD83 UTM North Zone 18		NAVD88	LiDAR - Z (m)	Delta Z	AbsDelta Z
	Easting - X (m)	Northing - Y (m)	Survey -Z (m)			
FO-5	457520.283	4253573.90	17.87	18.1619	0.29	0.29
FO-8	444815.451	4243517.70	5.09	4.8138	-0.27	0.27
FO-13	431728.238	4228505.64	1.96	2.2275	0.27	0.27
GWC-12	421078.19	4235987.02	2.51	2.8108	0.30	0.30

Table 14 — 5% Outliers

Table 15 provides overall descriptive statistics.

100 % of Totals	RMSE (m) Open Terrain Spec=0.125m	Mean (m)	Mean Absolute (m)	Median (m)	Skew	Std Dev (m)	# of Points	Min (m)	Max (m)
Consolidated		0.10	0.11	0.10	-0.62	0.10	58	-0.27	0.30
Open Terrain	0.08	0.04	0.06	0.02	0.36	0.07	21	-0.08	0.18
Forest		0.13	0.16	0.13	-1.57	0.13	18	-0.27	0.29
Grass Weeds and Crops		0.13	0.13	0.13	0.49	0.06	19	-0.02	0.30

Table 15 — Overall Descriptive Statistics

Figure 16 illustrates a histogram of the associated elevation discrepancies between the QA/QC checkpoints and elevations interpolated from the LiDAR triangulated irregular network (TIN). The frequency shows the number of discrepancies within each band of elevation differences. Although the discrepancies vary between a low of -0.27 meters and a high of +0.30 meters, the histogram shows that the majority of the discrepancies are skewed on the positive side. The majority of points are within the ranges of -0.025 meters to +0.175 meters.

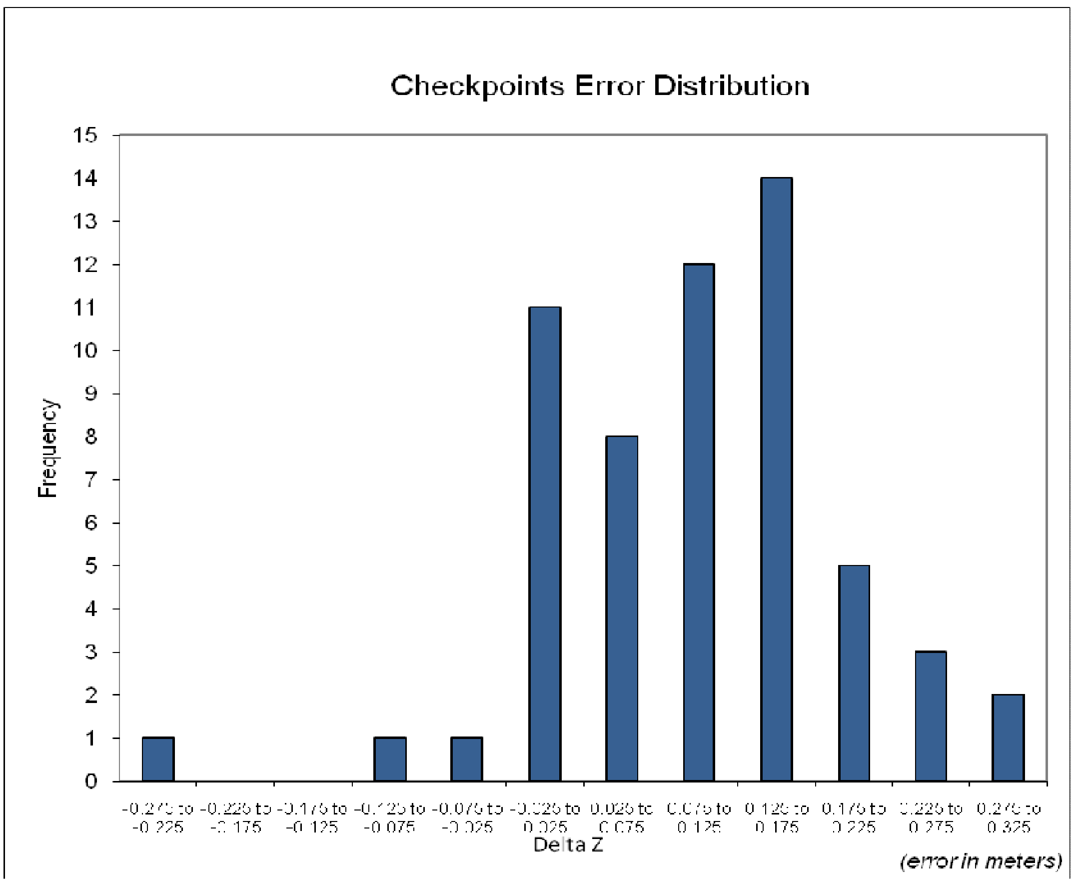


Figure 16 — Histogram of Elevation Discrepancies within errors in feet

5.5 *Conclusion*

Based on the vertical accuracy testing conducted by Dewberry, the LiDAR dataset for the USGS NRCS Maryland LiDAR Project satisfies the project's pre-defined vertical accuracy criteria.

6 Breakline Production & Qualitative Assessment Report

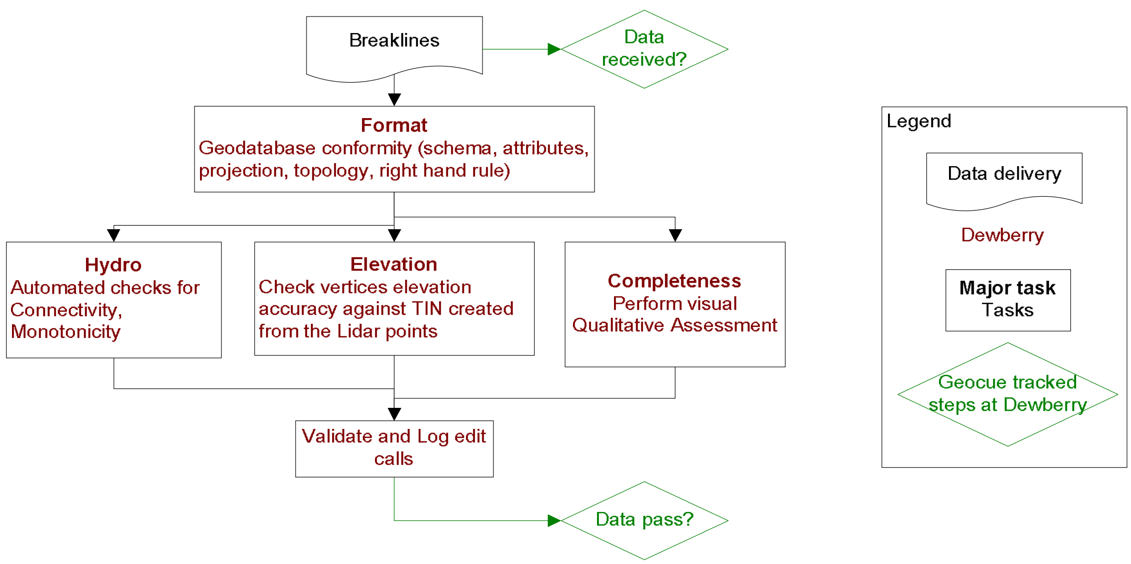
6.1 *Breakline Production Methodology*

Dewberry used GeoCue software to develop LiDAR stereo models of the USGS NRCS Maryland LiDAR Project area so the LiDAR derived data could be viewed in 3-D stereo using Socet Set softcopy photogrammetric software. Using LiDARgrammetry procedures with LiDAR intensity imagery, Dewberry used the stereo models to stereo-compile the three types of hard breaklines in accordance with the project's Data Dictionary.

All drainage breaklines are monotonically enforced to show downhill flow. Water bodies are reviewed in stereo and the lowest elevation is applied to the entire waterbody.

6.2 *Breakline Qualitative Assessment*

Dewberry completed breakline qualitative assessments according to a defined workflow. The following workflow diagram represents the steps taken by Dewberry to provide a thorough qualitative assessment of the breakline data.



6.3 *Breakline Topology Rules*

Automated checks are applied on hydro features to validate the 3D connectivity of the feature and the monotonicity of the hydrographic breaklines. Dewberry's major concern was that the hydrographic breaklines have a continuous flow downhill and that breaklines do not undulate. Error points are generated at each vertex not complying with the tested rules and these potential edit calls are then visually validated during the visual evaluation of the data. This step also helped validate that breakline vertices did not have excessive minimum or maximum elevations and that elevations are consistent with adjacent vertex elevations.

The next step is to compare the elevation of the breakline vertices against the elevation extracted from the ESRI Terrain built from the LiDAR ground points, keeping in mind that a discrepancy is expected because of the hydro-enforcement applied to the breaklines and because of the interpolated imagery used to acquire the breaklines. A given tolerance is used to validate if the elevations differ too much from the LiDAR.

Dewberry's final check for the breaklines was to perform a full qualitative analysis. Dewberry compared the breaklines against LiDAR intensity images to ensure breaklines were captured in the required locations. The quality control steps taken by Dewberry are outlined in the QA Checklist below.

6.4 Breakline QA/QC Checklist

Project Number/Description: TO G12PD00092 NRCS Maryland LiDAR

Date:______09/20/2012____

Overview

☒ All Feature Classes are present in GDB

☒ All features have been loaded into the geodatabase correctly. Ensure feature classes with subtypes are domained correctly.

☒ The breakline topology inside of the geodatabase has been validated. See Data Dictionary for specific rules

☒ Projection/coordinate system of GDB is accurate with project specifications

Perform Completeness check on breaklines using either intensity or ortho imagery

☒ Check entire dataset for missing features that were not captured, but should be to meet baseline specifications or for consistency (See Data Dictionary for specific collection rules). Features should be collected consistently across tile bounds within a dataset as well as be collected consistently between datasets.

☒ Check to make sure breaklines are compiled to correct tile grid boundary and there is full coverage without overlap

☒ Check to make sure breaklines are correctly edge-matched to adjoining datasets if applicable. Ensure breaklines from one dataset join breaklines from another dataset that are coded the same and all connecting vertices between the two datasets match in X,Y, and Z (elevation). There should be no breaklines abruptly ending at dataset boundaries and no discrepancies of Z-elevation in overlapping vertices between datasets.

Compare Breakline Z elevations to LiDAR elevations

☒ Using a terrain created from LiDAR ground points and water points, drape breaklines on terrain to compare Z values. Breakline elevations should be at or below the elevations of the immediately surrounding terrain. This should be performed before other breakline checks are completed.

Perform automated data checks using PLTS

The following data checks are performed utilizing ESRI's PLTS extension. These checks allow automated validation of 100% of the data. Error records can either be written to a table for future correction, or browsed for immediate correction. PLTS checks should always be performed on the full dataset.

☒ Perform "adjacent vertex elevation change check" on the Inland Ponds feature class (Elevation Difference Tolerance=.001 meters). This check will return Waterbodies whose vertices are not all identical. This tool is found under "Z Value Checks."

☒ Perform "unnecessary polygon boundaries check" on Inland Ponds and Inland Streams feature classes. This tool is found under "Topology Checks."

☒ Perform "duplicate geometry check" on (inland streams to inland streams), (inland ponds to inland ponds), (inland ponds to inland streams). Attributes do not need to be checked during this tool. This tool is found under "Duplicate Geometry Checks."

☒ Perform "geometry on geometry check" on (inland ponds to inland streams). Spatial relationship is contains, attributes do not need to be checked. This tool is found under "Feature on Feature Checks."

☒ Perform "polygon overlap/gap is sliver check" (inland streams to inland streams), (inland ponds to inland ponds), (inland ponds to inland streams). Maximum Polygon Area is not required. This tool is found under "Feature on Feature Checks."

Perform Dewberry Proprietary Tool Checks

☒ Perform monotonicity check on inland streams features using "A3_checkMonotonicityStreamLines." This tool looks at line direction as well as elevation. Features in the output shapefile attributed with a "d" are correct monotonically, but were compiled from low elevation to high elevation. These errors can be ignored. Features in the output shapefile attributed with an "m" are not correct monotonically and need elevations to be corrected. Input features for this tool need to be in a geodatabase. Z tolerance is .01 meters. Polygons need to be exported as lines for the monotonicity tool.

☒ Perform connectivity check between (inland ponds to inland streams) using the tool "07_CheckConnectivityForHydro." The input for this tool needs to be in a geodatabase. The output is a shapefile showing the location of overlapping vertices from the polygon features and polyline features that are at different Z-elevation. The unnecessary polygon boundary check must be run and all errors fixed prior to performing connectivity check. If there are exceptions to the polygon boundary rule then that feature class must be checked against itself, i.e. inland streams to inland streams.

Metadata

☒ Each XML file (1 per feature class) is error free as determined by the USGS MP tool

☒ Metadata content contains sufficient detail and all pertinent information regarding source materials, projections, datums, processing steps, etc. Content should be consistent across all feature classes.

Completion Comments: Complete – Approved

6.5 LiDARgrammetry Data Dictionary & Stereo Compilation Rules

HORIZONTAL AND VERTICAL DATUM

The horizontal datum shall be North American Datum of 1983, Units in Meters. The vertical datum shall be referenced to the North American Vertical Datum of 1988 (NAVD88) National Spatial Reference System 2007 (NSRS2007), Units in Meters. Geoid09 shall be used to convert ellipsoidal heights to orthometric heights.

Coordinate System and Projection

All data shall be projected to UTM Zone 18, Horizontal Units in Meters and Vertical Units in Meters.

Inland Streams and Rivers

Feature Dataset: BREAKLINES

Feature Class: STREAMS_AND_RIVERS

Feature Type: Polygon

Contains M Values: No

Contains Z Values: Yes

Annotation Subclass: None

XY Resolution: Accept Default Setting

Z Resolution: Accept Default Setting

XY Tolerance: 0.003

Z Tolerance: 0.001

Description

This polygon feature class will depict linear hydrographic features with a width greater than 100 feet.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Software
SHAPE_AREA	Double	Yes			0	0		Calculated by Software

Feature Definition

Description	Definition	Capture Rules
Streams and Rivers	Linear hydrographic features such as streams, rivers, canals, etc. with an average width greater than 100 feet in length. In the case of embankments, if the feature forms a natural dual line channel, then capture it consistent with the capture rules. Other natural or manmade embankments will not qualify for this project.	Capture features showing dual line (one on each side of the feature). Average width shall be great than 100 feet to show as a double line. Each vertex placed should maintain vertical integrity and data is required to show “closed polygon”. Generally both banks shall be collected to show consistent downhill flow. There are exceptions to this rule where a small branch or offshoot of the stream or river is present. The banks of the stream must be captured at the same elevation to ensure flatness of the water feature. If the elevation of the banks appears to be different see the task manager or PM for further guidance. Breaklines must be captured at or just below the elevations of the immediately surrounding terrain. Under no circumstances should a feature be elevated above the surrounding LiDAR points. Acceptable variance in the negative direction will be defined for each project individually. These instructions are only for docks or piers that follow the coastline or water’s edge, not for docks or piers that extend perpendicular from the land into the water. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water’s edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured

		elevation of the water. Every effort should be made to avoid breaking a stream or river into segments. Dual line features shall break at road crossings (culverts). In areas where a bridge is present the dual line feature shall continue through the bridge. Islands: The double line stream shall be captured around an island if the features on either side of the island meet the criteria for capture. In this case a segmented polygon shall be used around the island in order to allow for the island feature to remain as a "hole" in the feature.

Inland Ponds and Lakes

Feature Dataset: BREAKLINES
Feature Class: PONDS_AND_LAKES
Feature Type: Polygon
Contains M Values: No
Contains Z Values: Yes
Annotation Subclass: None
XY Resolution: Accept Default Setting
Z Resolution: Accept Default Setting

XY Tolerance: 0.003
Z Tolerance: 0.001

Description

This polygon feature class will depict closed water body features that are at a constant elevation.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Software
SHAPE_AREA	Double	Yes			0	0		Calculated by Software

Feature Definition

Description	Definition	Capture Rules
Ponds and Lakes	Land/Water boundaries of constant elevation water bodies such as lakes, reservoirs, ponds, etc. Features shall be defined as closed polygons and contain an elevation value that reflects the best estimate of the water elevation at the time of data capture. Water body features will be captured	Water bodies shall be captured as closed polygons with the water feature to the right. The compiler shall take care to ensure that the z-value remains consistent for all vertices placed on the water body. Breaklines must be captured at or just below the elevations of the immediately surrounding terrain. Under no circumstances should a feature be elevated above the

	for features 2 acres in size or greater. "Donuts" will exist where there are islands within a closed water body feature greater than ½ acre in size.	surrounding LiDAR points. Acceptable variance in the negative direction will be defined for each project individually. An Island within a Closed Water Body Feature will also have a "donut polygon" compiled. These instructions are only for docks or piers that follow the coastline or water's edge, not for docks or piers that extend perpendicular from the land into the water. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water.

Tidal Waters

Feature Dataset: BREAKLINES **Feature Class: TIDAL_WATERS**
Feature Type: Polygon
Contains M Values: No **Contains Z Values: Yes**
Annotation Subclass: None
XY Resolution: Accept Default Setting **Z Resolution: Accept Default Setting**

XY Tolerance: 0.003 **Z Tolerance: 0.001**

Description
This polygon feature class will outline the land / water interface at the time of LiDAR acquisition.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by Dewberry
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Dewberry
SHAPE_AREA	Double	Yes			0	0		Calculated by Dewberry

Feature Definition

Description	Definition	Capture Rules
TIDAL_WATERS	The coastal breakline will delineate the land water interface using LiDAR data as reference. In flight line boundary areas with tidal variation the coastal shoreline may require some feathering or edge matching to ensure a smooth transition.	The feature shall be extracted at the apparent land/water interface, as determined by the LiDAR intensity data, to the extent of the tile boundaries. Differences caused by tidal variation are acceptable and breaklines delineated should reflect that change with no feathering. Breaklines must be captured at or just below the elevations of the immediately surrounding terrain. Under no circumstances should a feature be elevated above the surrounding LiDAR points. Acceptable variance in the negative direction will be defined for each project individually. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water. Breaklines shall snap and merge seamlessly with linear hydrographic features.

Contact Information

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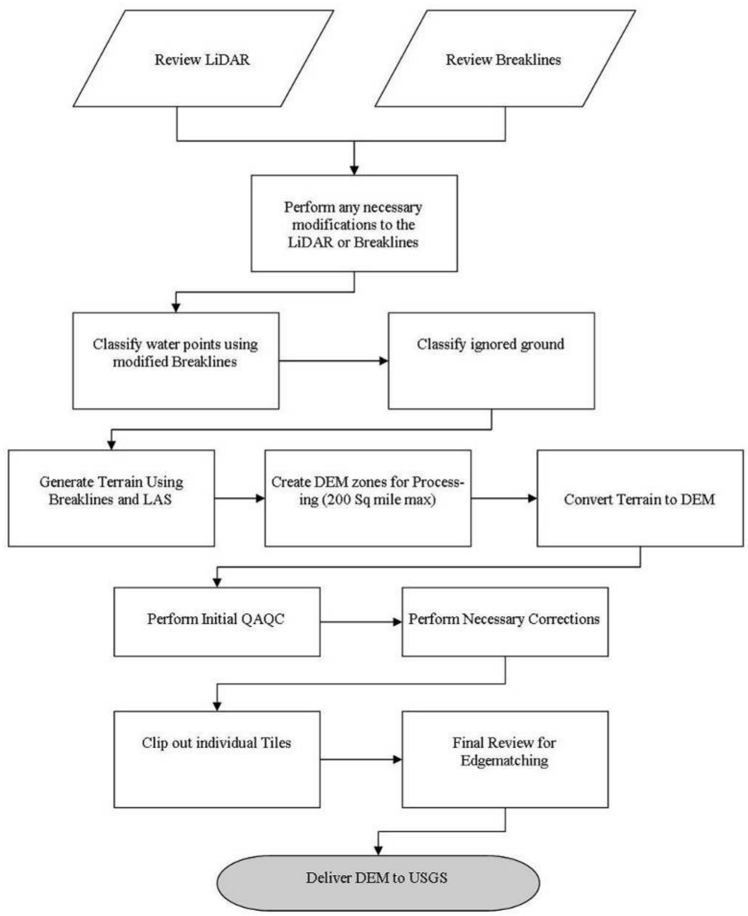
7 DEM Production & Qualitative Assessment

7.1 DEM Production Methodology

Dewberry utilized ESRI software and Global Mapper for the DEM production and QC process. ArcGIS software is used to generate the products and the QC is performed in both ArcGIS and Global Mapper.

Dewberry Hydro-Flattening Workflow



1. Classify Water Points: LAS point falling within hydrographic breaklines shall be classified to ASPRS class 9 using TerraScan. Breaklines must be prepared correctly prior to performing this task.
2. Classify Ignored Ground Points: Classify points in close proximity to the breaklines from Ground to class 10 (Ignored Ground). Close proximity will be defined as no more than 1x the nominal point spacing on the landward side of the breakline. Breaklines will be buffered using this specification and the subsequent file will need to be prepared in the same manner as the water breaklines for classification. This process will be performed after the water points have been classified and only run on remaining ground points.

3. Terrain Processing: A Terrain will be generated using the Breaklines and LAS data that has been imported into Arc as a Multipoint File. If the final DEMs are to be clipped to a project boundary that boundary will be used during the generation of the Terrain.
4. Create DEM Zones for Processing: Create DEM Zones that are buffered around the edges. Zones should be created in a logical manner to minimize the number of zones without creating zones too large for processing. Dewberry will make zones no larger than 200 square miles (taking into account that a DEM will fill in the entire extent not just where LiDAR is present). Once the first zone is created it must be verified against the tile grid to ensure that the cells line up perfectly with the tile grid edge.
5. Convert Terrain to Raster: Convert Terrain to raster using the DEM Zones created in step 6. In the environmental properties set the extents of the raster to the buffered Zone. For each subsequent zone, the first DEM will be utilized as the snap raster to ensure that zones consistently snap to one another.
6. Perform Initial QAQC on Zones: During the initial QA process anomalies will be identified and corrective polygons will be created.
7. Correct Issues on Zones: Dewberry will perform corrections on zones following Dewberry's correction process.
8. Extract Individual Tiles: Dewberry will extract individual tiles from the zones utilizing the Dewberry created tool.
9. Final QA: Final QA will be performed on the dataset to ensure that tile boundaries are seamless.

7.2 DEM Qualitative Assessment

Dewberry performed a comprehensive qualitative assessment of the DEM deliverables to ensure that all tiled DEM products were delivered with the proper extents, were free of processing artifacts, and contained the proper referencing information. This process was performed in ArcGIS software with the use of a tool set Dewberry has developed to verify that the raster extents match those of the tile grid and contain the correct projection information. The DEM data was reviewed at a scale of 1:5000 to review for artifacts caused by the DEM generation process and to review the hydro-flattened features. To perform this review Dewberry creates HillShade models and overlays a partially transparent colorized elevation model to review for these issues. Upon completion of this review the DEM data is loaded into Global Mapper to ensure that all files are readable and that no artifacts exist between tiles.

7.3 DEM Vertical Accuracy Results

The same 58 checkpoints that were used to test the vertical accuracy of the LiDAR were used to validate the vertical accuracy of the final DEM products as well. Accuracy results may vary between the source LiDAR and final DEM deliverable. DEMs are created by averaging several LiDAR points within each pixel which may result in slightly different elevation values at each survey checkpoint when compared to the source LAS, which does not average several LiDAR points together but may interpolate (linearly) between two or three points to derive an elevation value.

Table 16 summarizes the tested vertical accuracy results from a comparison of the surveyed checkpoints to the elevation values present within the final DEM dataset.

Land Cover Category	# of Points	FVA — Fundamental Vertical Accuracy (RMSEz x 1.9600) Spec=0.182 m	CVA — Consolidated Vertical Accuracy (95th Percentile) Spec=0.269 m	SVA — Supplemental Vertical Accuracy (95th Percentile) Target=0.269 m
Consolidated	58		0.260	
Open Terrain	21	0.157		
Grass Weeds Crops	19			0.264
Forest	18			0.252

Table 16— FVA Vertical Accuracy at 95% Confidence Level. CVA, and SVA Vertical Accuracy based on the 95th percentile.

The $RMSE_z$ for checkpoints in open terrain only tested 0.08 meters, within the target criteria of 0.0925 meters. Compared with the 0.182 meters specification, the FVA tested 0.157 meters at the 95% confidence level based on $RMSE_z$ x 1.9600.

Compared with the 0.269 meters specification, CVA for all checkpoints in all land cover categories combined tested 0.260 meters based on the 95th percentile.

Compared with target 0.269 specification, SVA for checkpoints in the grass weeds crops land cover category tested 0.252 meters and checkpoints in the forest land cover category tested 0.264 meters based on the 95th percentile.

Table 17 lists the 5% outliers that are larger than the 95th percentile.

Point ID	NAD83 UTM North Zone 11		NAVD88	DEM - Z (m)	Delta Z	AbsDelta Z
	Easting - X (m)	Northing - Y (m)	Survey -Z (m)			
FO-5	457520.283	4253573.90	17.87	18.125151	0.26	0.26
FO-8	444815.451	4243517.70	5.09	4.824843	-0.26	0.26
FO-15	418195.724	4225489.90	1.54	1.815234	0.28	0.28
FO-16	446819.264	4221602.33	5.88	6.135294	0.26	0.26
GWC-12	421078.19	4235987.02	2.51	2.853479	0.35	0.35

Table 17 — 5% Outliers

Table 18 provides overall descriptive statistics.

100 % of Totals	RMSE (m) Open Terrain Spec=0.125m	Mean (m)	Mean Absolute (m)	Median (m)	Skew	Std Dev (m)	# of Points	Min (m)	Max (m)
Consolidated		0.10	0.12	0.11	-0.47	0.10	58	-0.26	0.35
Open Terrain	0.08	0.04	0.06	0.02	0.43	0.07	21	-0.07	0.20
Forest		0.14	0.17	0.15	-1.77	0.13	18	-0.26	0.28
Grass Weeds Crops		0.13	0.14	0.12	0.88	0.08	19	-0.03	0.35

Table 18 — Overall Descriptive Statistics

7.3 DEM QA/QC Checklist

Project Number/Description: TO G12PD00092 NRCS Maryland LiDAR
Date:______09/20/2012_____
Overview

☒ Correct number of files is delivered and all files are in ERDAS IMG format
☒ Verify Raster Extents
☒ Verify Projection/Coordinate System

Review

☒ Manually review bare-earth DEMs with a hillshade to check for issues with hydro-enforcement process or any general anomalies that may be present. Specifically, water should be flowing downhill, water features should NOT be floating above surrounding terrain and bridges should NOT be present in bare-earth DEM. Hydrologic breaklines should be overlaid during review of DEMs.
☒ Overlap points (in the event they are supplied to fill in gaps between adjacent flightlines) are not to be used to create the bare-earth DEMs
☒ DEM cell size is 1 meter
☒ Perform final overview in Global Mapper to ensure seamless product.

Metadata

☒ Project level DEM metadata XML file is error free as determined by the USGS MP tool

☒ Metadata content contains sufficient detail and all pertinent information regarding source materials, projections, datums, processing steps, etc.

Completion Comments: Complete - Approved