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U.S Geological Survey – Connecticut SANDY LiDAR

Report Produced for U.S. Geological Survey

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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 USGS Connecticut SANDY LiDAR Project Area.

The LiDAR data were processed to a bare-earth digital terrain model (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 1,974 tiles were produced for the project encompassing an area of approximately 1,526 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 Consultants LLC completed ground surveying for the project and delivered surveyed checkpoints. Their task was to acquire surveyed checkpoints for the project to use in independent testing of the vertical and horizontal accuracy of the LiDAR-derived surface model. They also verified the GPS base station coordinates used during LiDAR data acquisition to ensure that the base station coordinates were accurate. Please see Appendix A to view the separate Survey Report that was created for this portion of the project.

Leading Edge Geomatics (LEG) completed LiDAR data acquisition and data calibration for the project area.

SURVEY AREA

The project area addressed by this report falls within the Connecticut counties of Fairfield, New Haven, Litchfield, Hartford, Middlesex, and New London.

DATE OF SURVEY

The LiDAR aerial acquisition was conducted from April 27, 2014 thru May 29, 2014.

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) 2011
> **Vertical Datum:** The Vertical datum for the project is North American Vertical Datum of 1988 (NAVD88)
> **Coordinate System:** UTM Zone 18N
> **Units:** Horizontal units are in meters, Vertical units are in meters.
> **Geiod Model:** Geoid12A (Geoid 12A was used to convert ellipsoid heights to orthometricheights).

LIDAR VERTICAL ACCURACY

For the Connecticut SANDY LiDAR Project, the tested $RMSE_z$ of the classified LiDAR data for checkpoints in open terrain equaled **0.068 m** compared with the 0.0925 m specification; and the FVA of the classified LiDAR data computed using $RMSE_z$ x 1.9600 was equal to **0.133 m**, compared with the 0.181 m specification.

For the Connecticut SANDY LiDAR Project, the tested CVA of the classified LiDAR data computed using the 95^{th} percentile was equal to **0.190 m,** compared with the 0.269 m specification.

Additional accuracy information and statistics for the classified LiDAR data, raw swath data, and bare earth DEM data are found in the following sections of this report.

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. Intensity Images (8-bit gray scale, tiled, GeoTIFF format)
5. Breakline Data (File GDB and shapefiles)
6. Control & Accuracy Checkpoint Report & Points
7. Metadata
8. Project Report (Acquisition, Processing, QC)
9. Project Extents, Including a shapefile derived from the LiDAR Deliverable

PROJECT TILING FOOTPRINT

One thousand nine-hundred and seventy-four (1,974) tiles were delivered for the project. Each tile's extent is 1,500 meters by 1,500 meters (see Appendix B for a complete listing of delivered tiles).

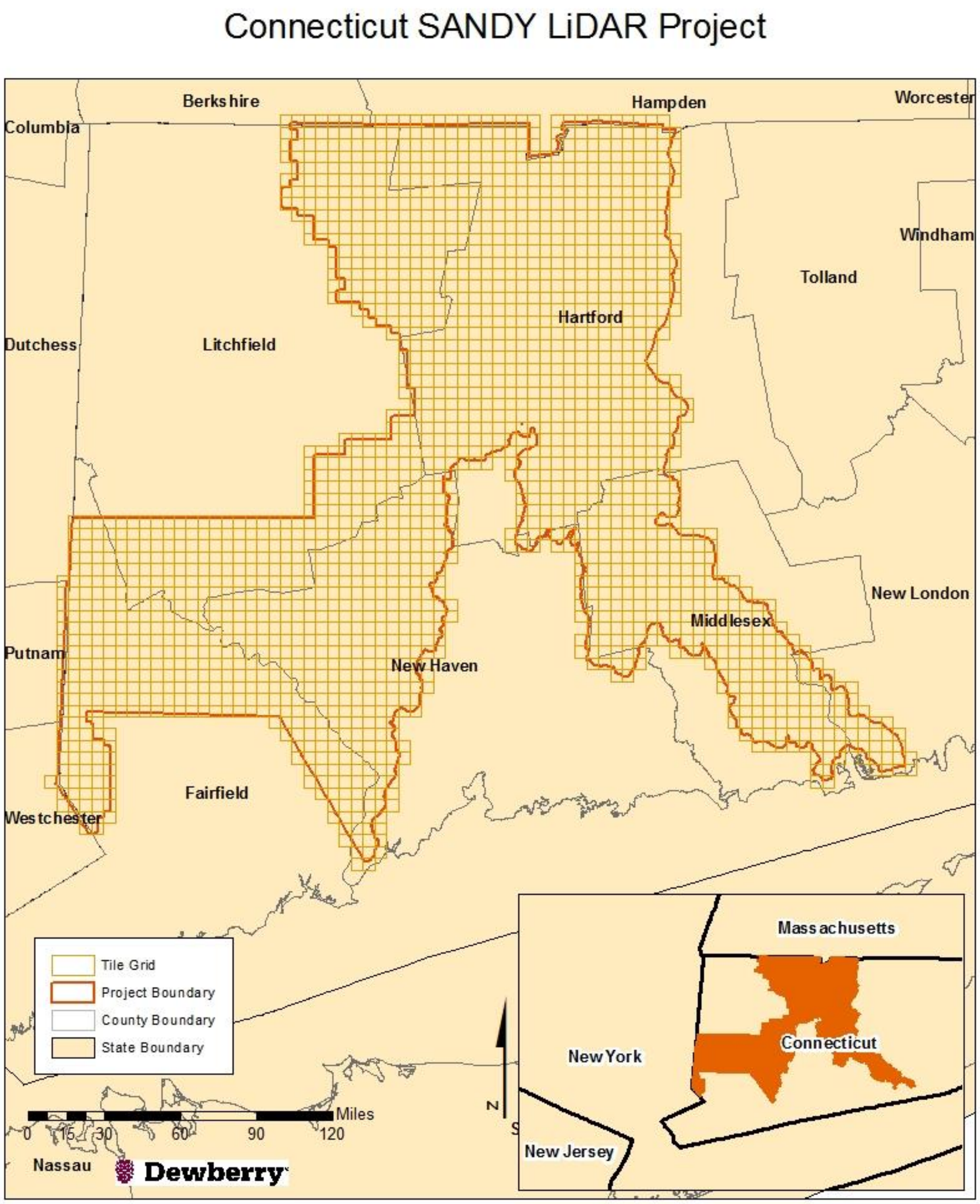


Figure 1. Project Map

LiDAR Acquisition Report

LEG provided high accuracy, calibrated multiple return LiDAR for roughly 1,526 square miles around the west-central, CT area. Data was collected and delivered in compliance with the "U.S. Geological Survey National Geospatial Program LiDAR Base Specification Version 1.0." In addition to the Specification Requirements, this task order shall meet NEEA QL2.

LIDAR ACQUISITION DETAILS

LIDAR acquisition began on April 27, 2014 (julian day 117) and was completed on May 29, 2014 (julian day 149). A total of 40 survey missions were flown to complete the project. LEG utilized a Riegl 680i (SN: 9998328) for the acquisition. The project required 428 flight lines rather than the 418 flight lines planned to complete it. There were no unusual occurrences during the acquisition and the sensor performed within specifications.

Laser Firing Rate: 50000
Altitude (mtr. AGL):1000
Swath Overlap (%): 50
Approx. Ground Speed (kts): 100
Scan Rate (Hz): 76
Scan Angle (°±): 60
Computed Along Track Spacing (mtr): 1.5
Computed Cross Track Spacing (mtr): 1.5
Computed Swath Width (mtr): 1155
Number of Lines Required: 65
Line Spacing (mtr): 0.67

LIDAR CONTROL

The project used TOPCON TOPnext active network. When it was not possible to use the active network, an NGS monument was used. The coordinates of all used base stations are provided in the table below. Before processing, all base stations were adjusted to the CORS network.

Name	Easting (m)	Northing (m)	Ellipsoid Ht (m)	Orthometric Ht (m)
CTGU - CORS	304720.2	4573504.2	-18.04	25.515
CTNE - CORS	309751.2	4616053.5	41.812	82.684
BPRT - LEG	349977	4558245.3	-20.900	20.998
DNBY - LEG	372296.1	4582356.5	115.533	155.281
E82 - LEG	305565.6	4591888	70.785	113.364
MDTN - LEG	304520.9	4604655.6	-14.621	27.156
Nail_2 - LEG	338589.6	4601794.8	109.779	150.291
Nail_3 -LEG	364674.4	4586047.1	115.097	155.082
Nail_5 - LEG	304515.6	4624219.1	-23.458	16.856
Nail_6 - LEG	332106.3	4638336.4	89.674	128.181
NHVN – LEG	322166.5	4578107.2	-17.674	24.817
OXFD – LEG	344403.6	4591943.1	168.762	209.456
PRATT – LEG	287567.3	4585243.1	38.571	82.482
PUGLISI - LEG	309691.9	4616313.9	8.931	49.705

SPFD - LEG	296484.5	4669040.8	41.708	78.679
WTFD - LEG	263039.8	4586977.2	45.837	90.431

Table 1 – Base Stations used to control LiDAR acquisition

AIRBORN GPS KINEMATIC

Airborne GPS data was processed using the POSPac 5.4 SP2 Trajectory Software. Flights were flown with a PDOP of better than 4. Distances from base station to aircraft were kept to a maximum of 40km.

GENERATION AND CALIBRATION OF LASER POINTS (RAW DATA)

The initial step of calibration is to verify availability and status of all needed GPS and Laser data against field notes and compile any data if not complete.

Subsequently the mission points are output using Riegl RiProcess. The software uses plane matching to resolve bore site differences and misalignment. Multiple planes are generated and then used to resolve the difference in the swaths in roll, pitch, and yaw. The initial point generation for each mission calibration is verified within Microstation/Terrascan for calibration errors. If a calibration error greater than specification is observed within the mission, the roll, pitch and scanner scale corrections that need to be applied are calculated. The missions with the new calibration values are regenerated and validated internally once again to ensure quality.

Data collected by the LiDAR unit is reviewed for completeness, acceptable density and to make sure all data is captured without errors or corrupted values. In addition, all GPS, aircraft trajectory, mission information, and ground control files are reviewed and logged into a database.

On a project level, a supplementary coverage check is carried out to ensure no data voids unreported by Field Operations are present.

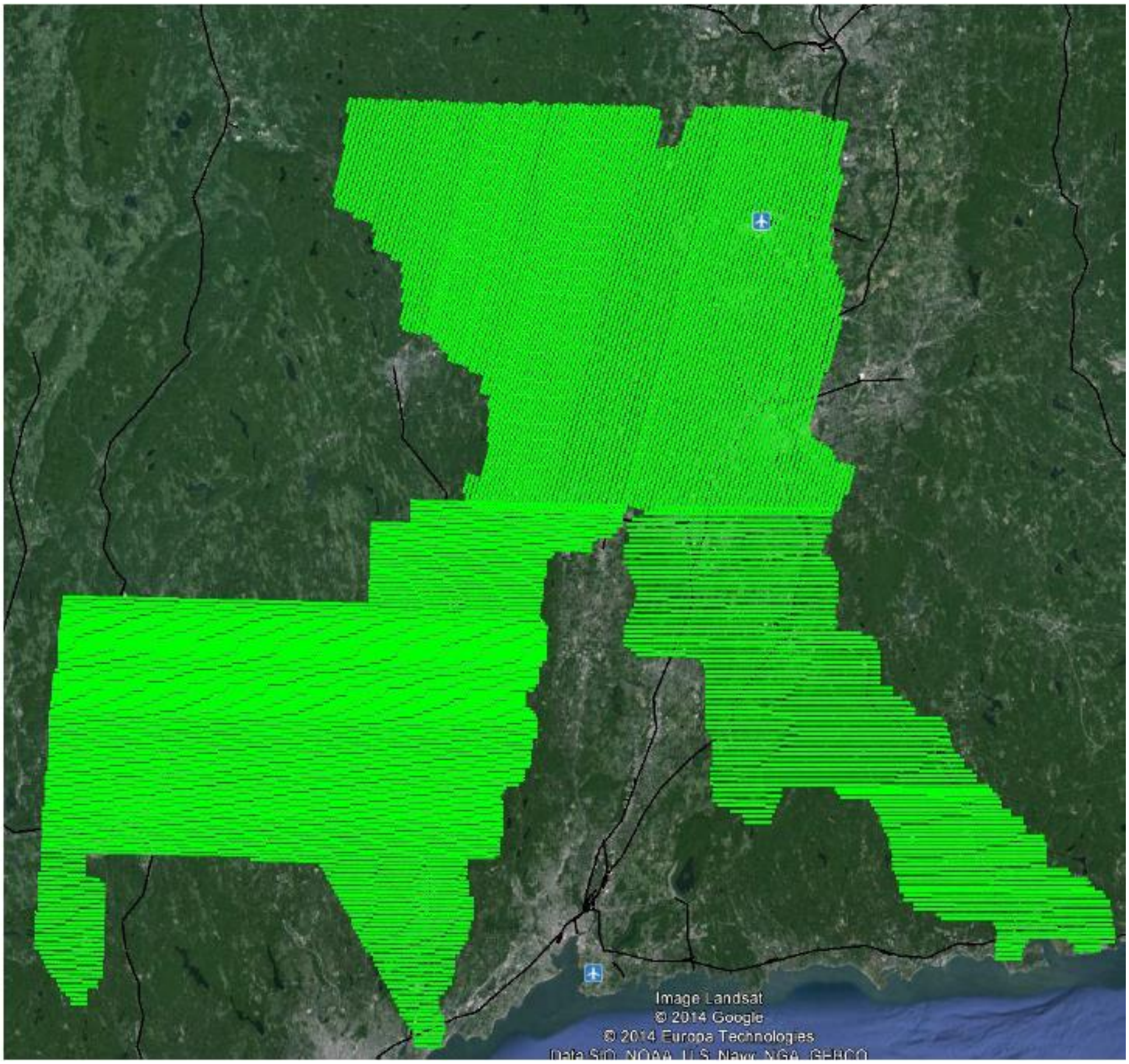


Figure 2. LiDAR Swath output showing complete coverage.

BORESIGHT AND RELATIVE ACCURACY

The initial points for each mission calibration are inspected for flight line errors, flight line overlap, slivers or gaps in the data, point data minimums, or issues with the LiDAR unit or GPS. Roll, pitch and scanner scale are optimized during the calibration process until the relative accuracy is met.

Relative accuracy and internal quality are checked. Vertical differences between ground surfaces of each line are displayed. Color scale is adjusted so that errors greater than the specifications are flagged. Cross sections are visually inspected across each block to validate point to point, flight line to flight line and mission to mission agreement.

For this project the specifications used are as follow:
Relative accuracy <= 7cm RMSEZ within individual swaths and <=10 cm RMSEZ or within swath overlap (between adjacent swaths).

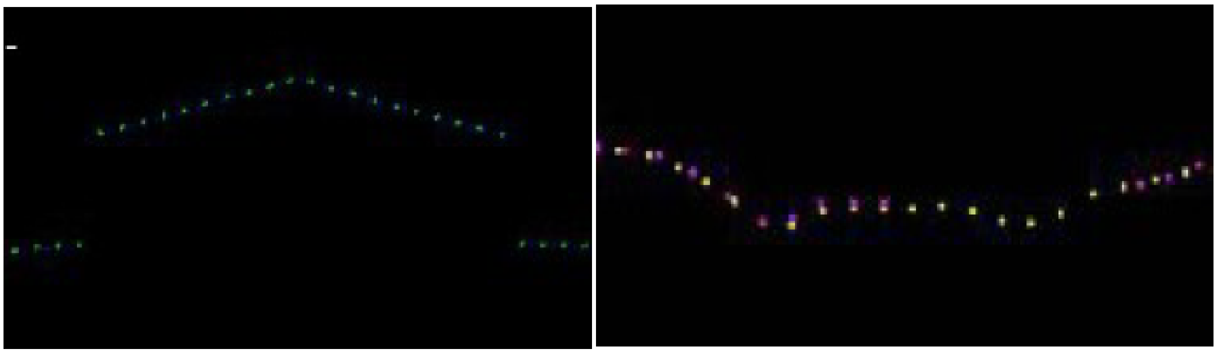


Figure 3 – Profile views showing correct roll and pitch adjustments.

FINAL SWATH VERTICAL ACCURACY ASSESSMENT

Once Dewberry received the calibrated swath data from LEG, Dewberry tested the vertical accuracy of the open terrain swath data prior to additional processing. Dewberry tested the vertical accuracy of the swath data using the twenty open terrain independent survey check points. The vertical accuracy is tested by comparing survey checkpoints in open terrain to a triangulated irregular network (TIN) that is created from the raw swath points. Only checkpoints in open terrain can be tested against raw swath data because the data has not undergone classification techniques to remove vegetation, buildings, and other artifacts from the ground surface. Checkpoints are always compared to interpolated surfaces from the LiDAR point cloud because it is unlikely that a survey checkpoint will be located at the location of a discrete LiDAR point. Project specifications require a FVA of 0.181 m based on the $RMSE_z$ (0.0925 m) x 1.96. The dataset for the Connecticut SANDY LiDAR Project satisfies this criteria. The raw LiDAR swath data tested 0.175 m vertical accuracy at 95% confidence level in open terrain, based on $RMSE_z$ (0.089m) x 1.9600. The table below shows all calculated statistics for the raw swath data.

100 % of Totals	$RMSE_z$ (m) Open Terrain Spec=0.0925m	FVA – Fundamental Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=0.181m	Mean (m)	Median (m)	Skew	Std Dev (m)	# of Points	Min (m)	Max (m)
Open Terrain	0.089	0.175	0.075	0.065	0.637	0.050	20	0.004	0.188

Table 2: FVA at 95% Confidence Level for Raw Swaths

LiDAR Processing & Qualitative Assessment

DATA CLASSIFICATION AND EDITING

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

- Class 1 = Unclassified, used for all other features that do not fit into the Classes 2, 7, 9, or 10, including vegetation, buildings, etc.
- Class 2 = Bare-Earth Ground
- 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 15 cm of each other, the pixel is colored yellow, and if the elevations of points within each pixel are greater than 15 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 Connecticut SANDY showed that several swaths in the initial data were not calibrated correctly and needed to be adjusted. LEG recalibrated these swaths and returned them to Dewberry, where a new set of DZ orthos were created. These DZ orthos demonstrated that the data was now calibrated correctly with no issues that would affect its usability. The figures below show an example of the DZ orthos before and after the swath recalibration.

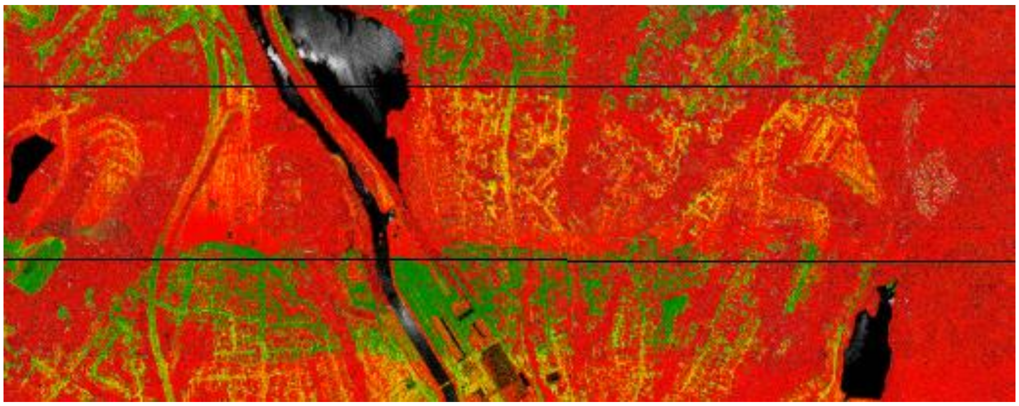


Figure 4 - DZ orthos created from the full point cloud. The swath in the center of the image has yellow and red pixels because the DZ between this swath and the surrounding swaths is greater than 10 cm. Pixels are red along embankments, sloped terrain, and in vegetated land cover, as expected.

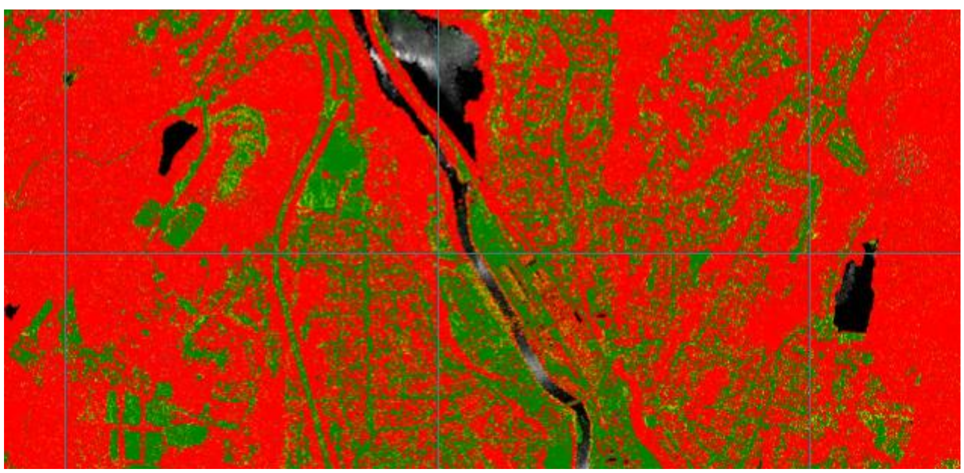


Figure 5 - DZ orthos created after the data was recalibrated by LEG. The swath in the center is now green in areas of flat, open terrain, indicating a DZ value under 10 cm. Red pixels are visible along embankments, sloped terrain, and in vegetated land cover, as expected. Open, flat areas are green indicating the calibration and relative accuracy of the data is acceptable.

Once the calibration and relative accuracy of the data was confirmed, Dewberry utilized a variety of software suites for data processing. The LAS dataset was 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.

QUALITATIVE ASSESSMENT

Dewberry's 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 0.7 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.

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 Connecticut SANDY LiDAR project incorporated the following reviews:

1. *Format:* The LAS files are verified to meet project specifications. The LAS files for the Connecticut SANDY 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 – Processed, but 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 (2011)
     - Projected Coordinate System – UTM Zone 18
     - Linear Units – Meters
     - Vertical Datum – North American Vertical Datum 1988, Geoid 12A
     - Vertical Units - Meters
   - LAS header information:
     - Class (Integer)
     - Adjusted GPS 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 Connecticut SANDY LiDAR project it is stipulated that the minimum post spacing in un-obscured areas should be 1 point per 0.7 square meters.

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. No unacceptable voids are present in Connecticut SANDY LiDAR project.

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.

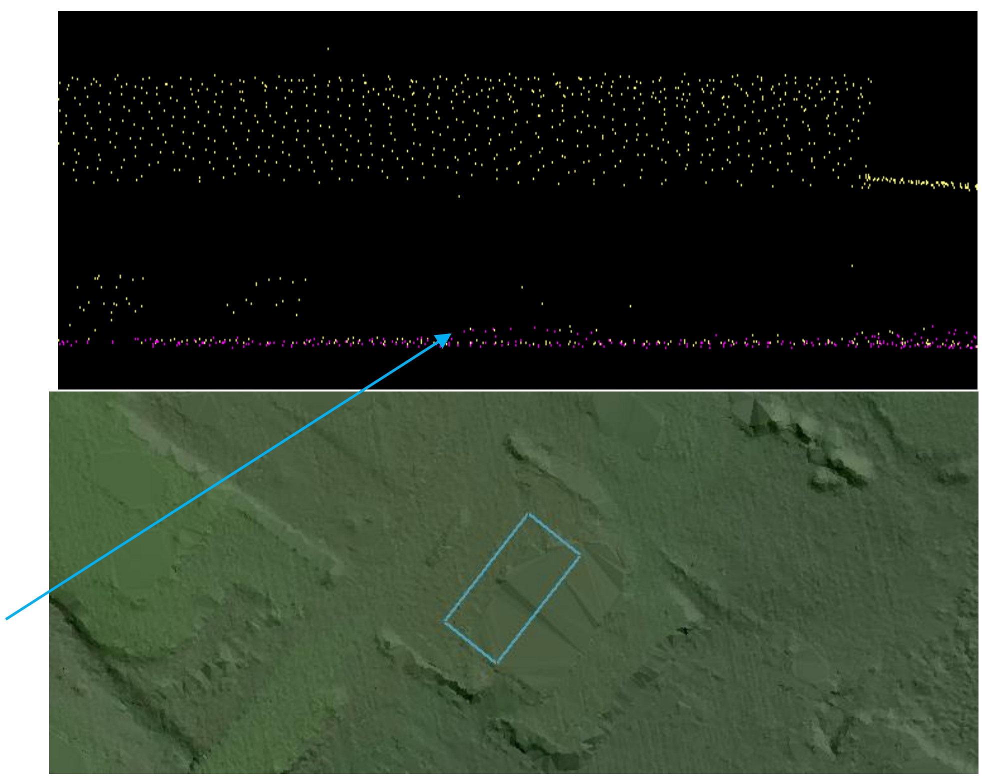


Figure 6 – Tile number 18TYL155578. Profile with points colored by class (class 1=yellow, class 2=pink) is shown in the top view and a TIN of the surface is shown in the bottom view. The arrow

identifies building or porch points. A limited number of these small features are still classified as ground but do not impact the usability of the dataset.

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 continue the surface beneath the bridge where no LiDAR data was acquired. Locations where bridges were removed will generally contain less detail in the bare-earth surface because these areas are interpolated.

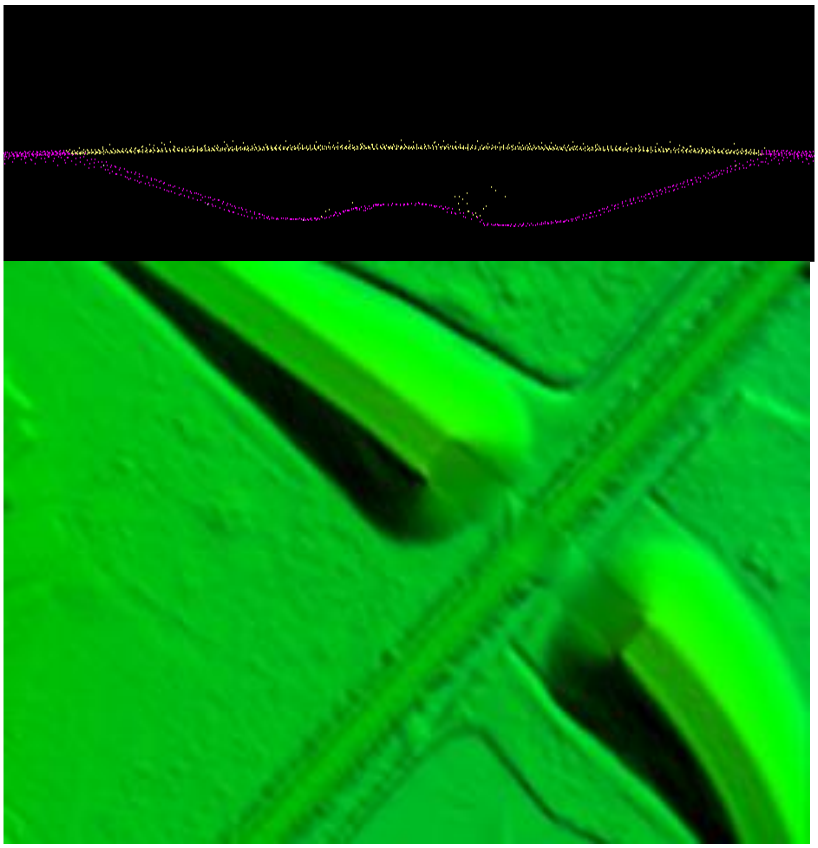


Figure 7 – Tile number 18TXM930623. The DEM in the bottom view shows an area where a bridge has been removed from ground. The surface model must make a continuous model and in order to do so, points are connected through interpolation. This results in less detail where the surface must be interpolated. 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).

c. *Bridge Saddle Mitigation:* When some bridges are removed from the ground surface, the distance from bridge abutment to bridge abutment is small enough that the DEM interpolates across the entire bridge opening, forming 'bridge saddles.' Dewberry collected 3D bridge breaklines in locations where bridge saddles were present and enforced these breaklines in the final DEM creation to help mitigate the bridge saddle artifacts. The image below on the left shows a bridge saddle while the image below on the right shows the same bridge after bridge breaklines have been enforced.

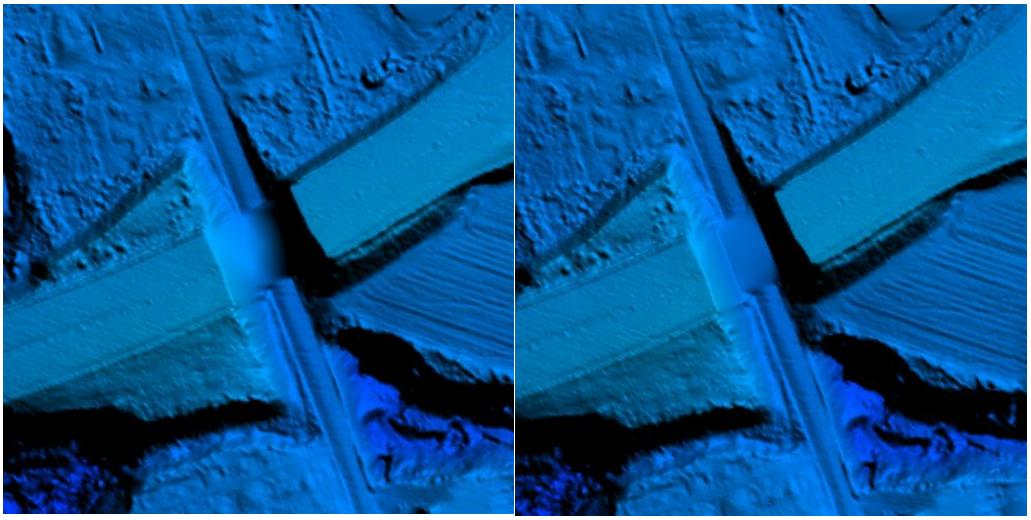


Figure 8-Tile number 18TXM975642. The DEM on the left shows a bridge saddle artifact while the DEM on the right shows the same location after bridge breaklines have been enforced.

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. Below is an example of a culvert that has been left in the ground surface.

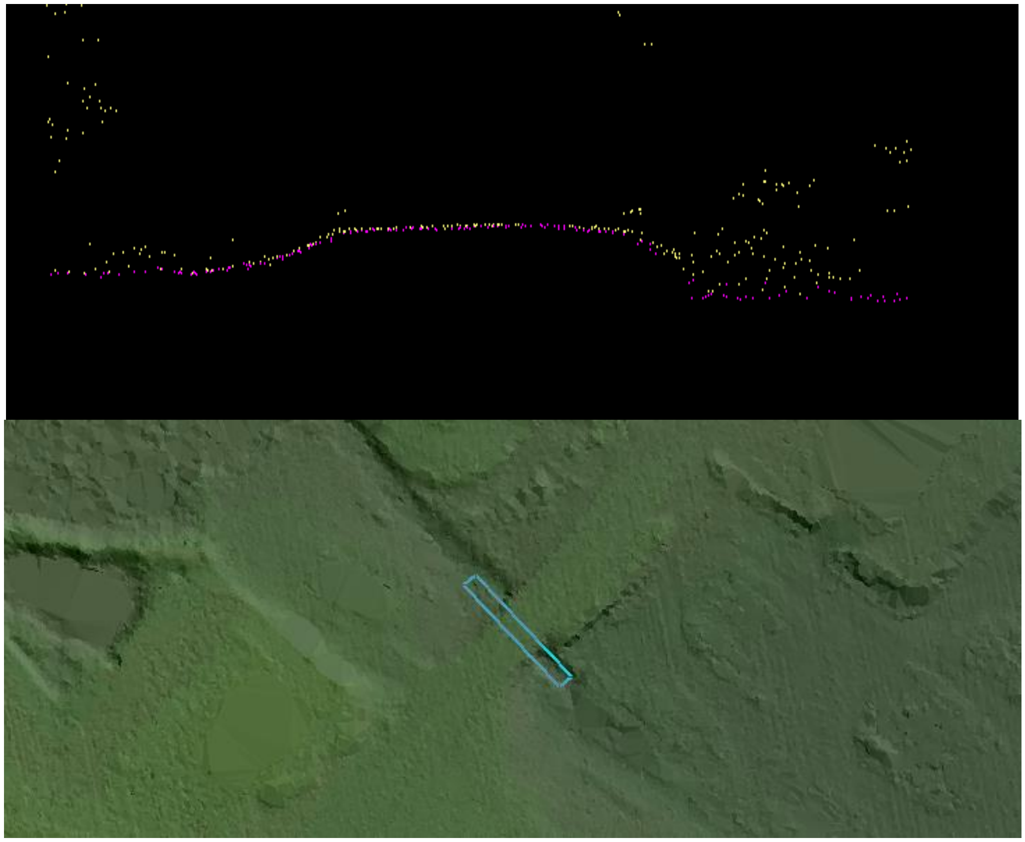


Figure9– Tile number 18TYL155578. Profile with points colored by class (class 1=yellow, class 2=pink) is shown in the top view and the DEM is shown in the bottom view. This culvert remains in the bare earth surface. Bridges have been removed from the bare earth surface and classified to class 1.

e. *Dirt Mounds*: Irregularities in the natural ground exist and may be misinterpreted as artifacts that should be removed. Small hills and dirt mounds are present throughout the project area. These features are correctly included in the ground.

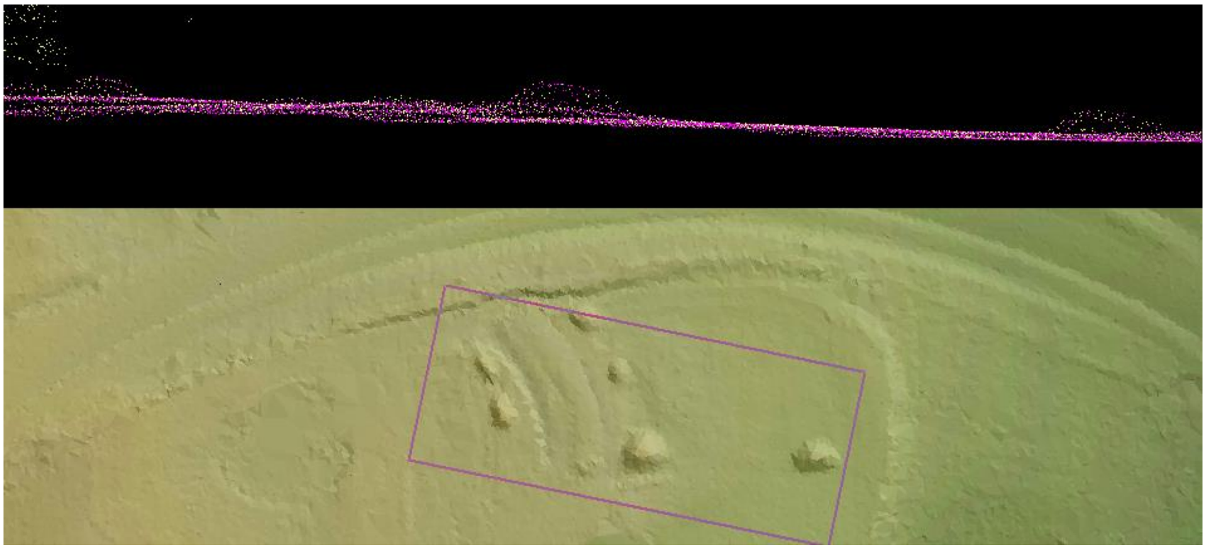


Figure 10 - Tile 18TXL540599. Profile with the points colored by class (class 1=yellow, class 2=pink) is shown in the top view and a DEM of the surface is shown in the bottom view. These features are correctly included in the ground classification.

f. *Elevation Change Within Breaklines:* While water bodies are flattened in the final DEMs, other features such as linear hydrographic features 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. Dewberry has reviewed the DEMs to ensure 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. An example is shown below.

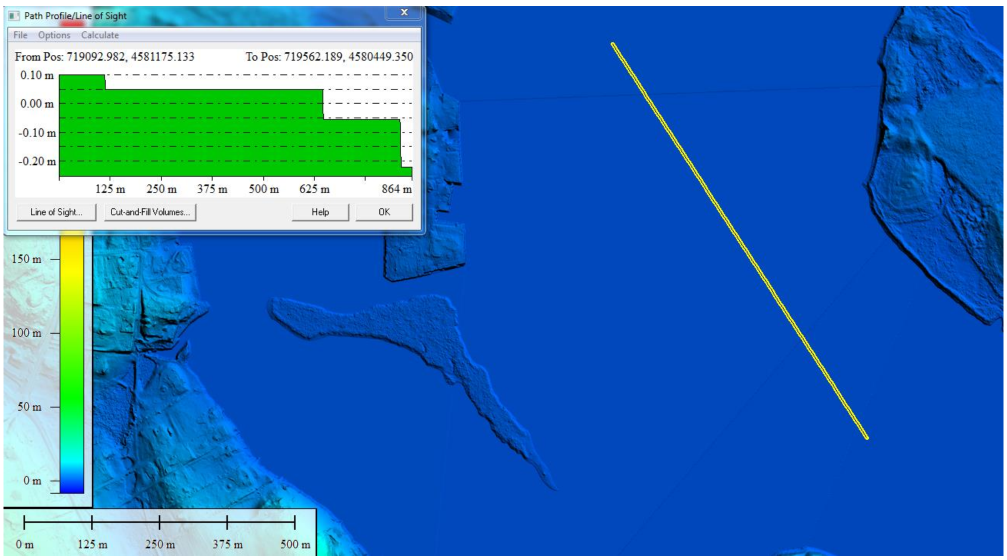


Figure 11 – Tile number 18TYL185579. Elevation change has been stair stepped. The steps are flat from bank to bank and flow consistently downhill.

g. *Flight line Ridges:* Ridges occur when there is a difference between the elevations of adjoining flight lines or swaths. Some flight line 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.

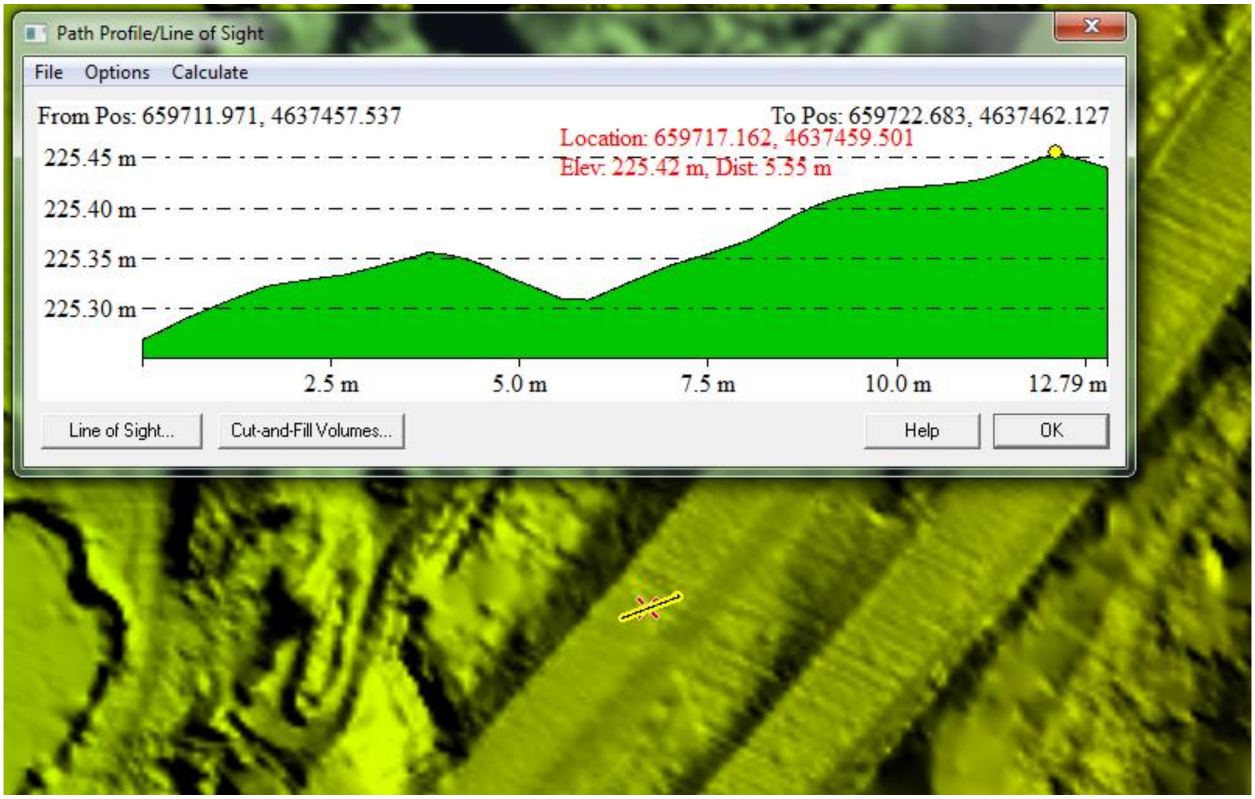


Figure 12– Tile number 18TXM585636. The flight line ridge is less than 10 cm. Overall, the Connecticut SANDY LiDAR data meets the project specifications for 10 cm RMSE relative accuracy.

Survey Vertical Accuracy Checkpoints

All checkpoints surveyed for vertical accuracy testing purposes are listed in the following table. A total of one hundred and four (104) checkpoints were surveyed for the Connecticut SANDY LiDAR Project.

Point ID	NAD83 UTM Zone 18N		NAVD88
	Easting X (m)	Northing Y (m)	Z-Survey (m)
OT-02	672618.271	4648799.471	367.501

OT-03	691109.575	4654195.459	70.506
OT-04	669456.981	4636499.092	107.434
OT-05	688620.629	4638253.268	53.489
OT-06	683810.468	4629005.03	136.368
OT-07	668529.58	4625256.056	247.485
OT-08	680963.687	4619282.443	128.57
OT-09	696501.999	4609374.897	11.952
OT-10	690365.149	4597099.522	68.856
OT-11	706399.271	4592305.703	52.672
OT-12	713390.064	4580272.751	24.442
OT-13	666052.337	4613927.52	182.934
OT-14	662750.702	4596346.139	61.326
OT-15	663379.426	4583150.468	104.365
OT-16	654935.14	4578031.399	155.627
OT-17	644895.515	4585480.195	94.708
OT-18	627258.405	4588849.438	185.89
OT-19	628821.058	4602864.123	214.061
OT-20	640490.207	4597178.923	72.204
OT-21	652300.432	4605412.023	131.955
BLT-01	625240.084	4568556.72	216.206
BLT-02	623414.216	4583032.937	161.826
BLT-03	635952.35	4584014.647	139.963
BLT-04	651756.574	4583372.976	59.012
BLT-05	656999.596	4574726.8	129.194
BLT-06	658217.507	4590472.925	219.177
BLT-07	636362.43	4596887.148	166.603
BLT-08	643508.016	4595374.752	202.664
BLT-09	642805.092	4604858.332	289.812
BLT-10	656267.285	4604116.148	195.168
BLT-11	668438.124	4605363.094	157.738
BLT-12	674852.555	4618390.972	99.733
BLT-13	683247.983	4609195.674	52.098
BLT-14	696338.012	4598053.148	96.785
BLT-15	718511.202	4583865.847	0.53
BLT-16	674026.642	4628066.527	118.169
BLT-17	694747.429	4637180.212	17.091
BLT-19	679447.559	4646168.472	106.872
BLT-18	695004.912	4652220.739	60.955
BLT-20	665614.732	4651231.284	316.187

BLT-21	659330.731	4634569.343	326.691
FO-01	622647.965	4572804.812	259.227
FO-02	624724.634	4587783.805	230.319
FO-03	625296.465	4603791.846	136.342
FO-04	645280.902	4601265.448	287.502
FO-05	637191.589	4592451.795	128.55
FO-06	640948.318	4582523.204	172.986
FO-07	648109.177	4585961.576	171.368
FO-08	662323.604	4573296.977	56.511
FO-09	650391.184	4593243.767	106.937
FO-10	655038.081	4598970.65	220.066
FO-11	666669.669	4589140.296	206.25
FO-12	663879.716	4609788.606	150.45
FO-13	682419.425	4605771.609	86.389
FO-14	690993.791	4592573.401	86.408
FO-15	702750.301	4594425.231	146.116
FO-16	680904.336	4626852.815	47.879
FO-17	668758.277	4643402.668	196.918
FO-18	687083.722	4646501.688	81.766
FO-19	673445.756	4651650.804	362.696
FO-20	664635.932	4645556.034	144.201
FO-21	657973.198	4650400.706	352.815
GWC-01	725192.098	4576710.64	6.484
GWC-02	709091.698	4585862.772	73.227
GWC-03	702632.641	4600681.1	63.903
GWC-04	692803.454	4588219.549	75.247
GWC-05	689106.758	4607743.908	74.443
GWC-06	678293.615	4621378.387	50.992
GWC-07	685747.152	4637243.808	68.889
GWC-08	685656.61	4649302.395	71.553
GWC-09	674829.863	4642945.061	303.76
GWC-10	662881.599	4648195.598	161.522
GWC-11	655257.033	4647347.551	351.326
GWC-12	662532.615	4641824.276	209.425
GWC-13	670402.542	4632251.878	150.176
GWC-14	668493.467	4608012.327	253.091
GWC-15	655635.392	4609465.948	221.467
GWC-16	637205.806	4602285.475	169.295

GWC-17	625102.243	4599452.025	219.265
GWC-18	632484.57	4596265.7	67.797
GWC-19	623392.506	4578055.461	234.985
GWC-20	639085.317	4586613.684	192.829
GWC-21	654042.179	4588798.189	98.705
UT-01	719137.663	4574911.846	4.848
UT-02	711167.133	4586203.724	44.212
UT-03	693527.8	4593996.75	53.003
UT-04	696368.196	4603217.016	9.866
UT-05	684748.481	4615610.685	53.559
UT-06	694332.718	4625088.355	5.972
UT-07	692860.141	4642959.85	47.57
UT-08	690351.433	4651414.309	60.501
UT-09	660613.314	4642529.709	214.128
UT-10	667666.829	4638384.265	116.704
UT-11	668743.923	4626267.465	264.687
UT-12	671570.889	4617043.05	120.309
UT-13	657097.54	4607513.162	148.464
UT-14	663220.934	4601580.398	78.93
UT-15	661969.606	4584668.679	54.008
UT-16	659055.594	4567960.076	15.645
UT-17	649364.986	4600543.502	82.384
UT-18	632028.475	4602211.898	89.668
UT-19	626489.933	4591560.913	190.722
UT-20	630651.566	4584343.593	117.668
UT-21	625784.958	4571969.295	197.372

Table 3: USGS – Connecticut SANDY LiDAR surveyed accuracy checkpoints

LiDAR Vertical Accuracy Statistics & Analysis

BACKGROUND

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

For quantitative assessment (i.e. vertical accuracy assessment), one hundred-four (104) check points were surveyed for the project and are located within bare earth/open terrain, urban, tall weeds/crops, brush lands/tress, and forested/fully grown land cover categories. The checkpoints were surveyed for the project using RTK survey methods. Please see appendix A to view the survey report 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.

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 ($RMSE_z$) of the checkpoints x 1.9600. For the Connecticut Sandy LiDAR project, vertical accuracy must be 0.1813 meters or less based on an $RMSE_z$ 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 Connecticut SANDY 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 Connecticut SANDY 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 Table 4.

Quantitative Criteria	Measure of Acceptability
Fundamental Vertical Accuracy (FVA) in open terrain only using $RMSE_z$ *1.9600	0.1813 meters (based on $RMSE_z$ (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 4 – Acceptance Criteria

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 every checkpoint.
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.

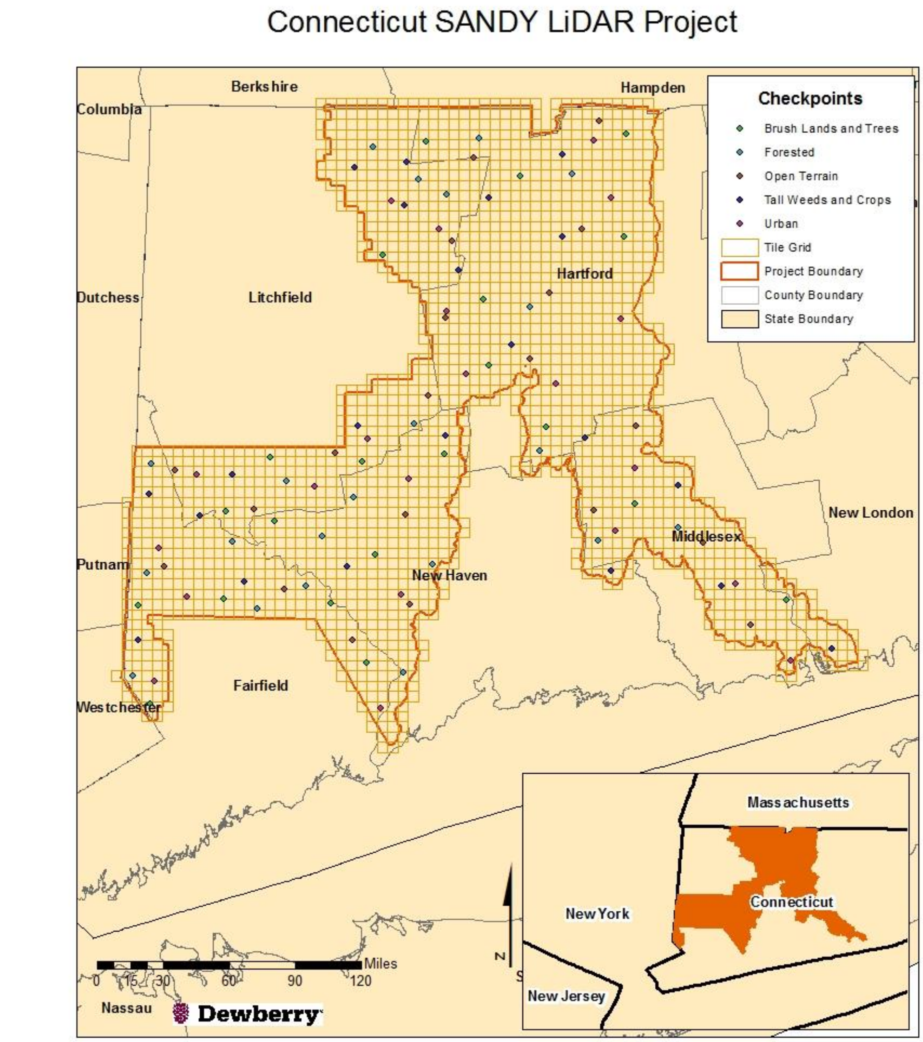


Figure 13 – Location of QA/QC Checkpoints

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 fully classified LiDAR LAS files.

Land Cover Category	# of Points	FVA — Fundamental Vertical Accuracy ($RMSE_z$ x 1.9600) Req=0.181	CVA — Consolidated Vertical Accuracy (95th Percentile) Req=0.269m	SVA — Supplemental Vertical Accuracy (95th Percentile) Target=0.269m
Consolidated	104		0.190	
Bare Earth-Open Terrain	20	0.133		
Urban	21			0.096
Tall Weeds and Crops	21			0.198
Brush Lands and Trees	21			0.198
Forested and Fully Grown	21			0.192

Table 5 — FVA, CVA, and SVA Vertical Accuracy at 95% Confidence Level

The $RMSE_z$ for checkpoints in open terrain only tested 0.068 meters, within the target criteria of 0.0925 meters. Compared with the 0.181 meters specification, the FVA tested 0.133 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 0.190 meters based on the 95^{th} percentile.

Compared with the target 0.269 meters specification, SVA for checkpoints in the urban land cover category tested 0.096 meters based on the 95^{th} percentile, checkpoints in the tall weeds and crops land cover category tested 0.198 meters based on the 95^{th} percentile, checkpoints in the forested and fully grown land cover category tested 0.192 meters based on the 95^{th} percentile, and checkpoints in the brush and small trees land cover category tested 0.198 meters based on the 95^{th} 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 + 0.15 meters of the checkpoints elevations, but there were some outliers where LiDAR and checkpoint elevations differed by up to +0.25 meters.

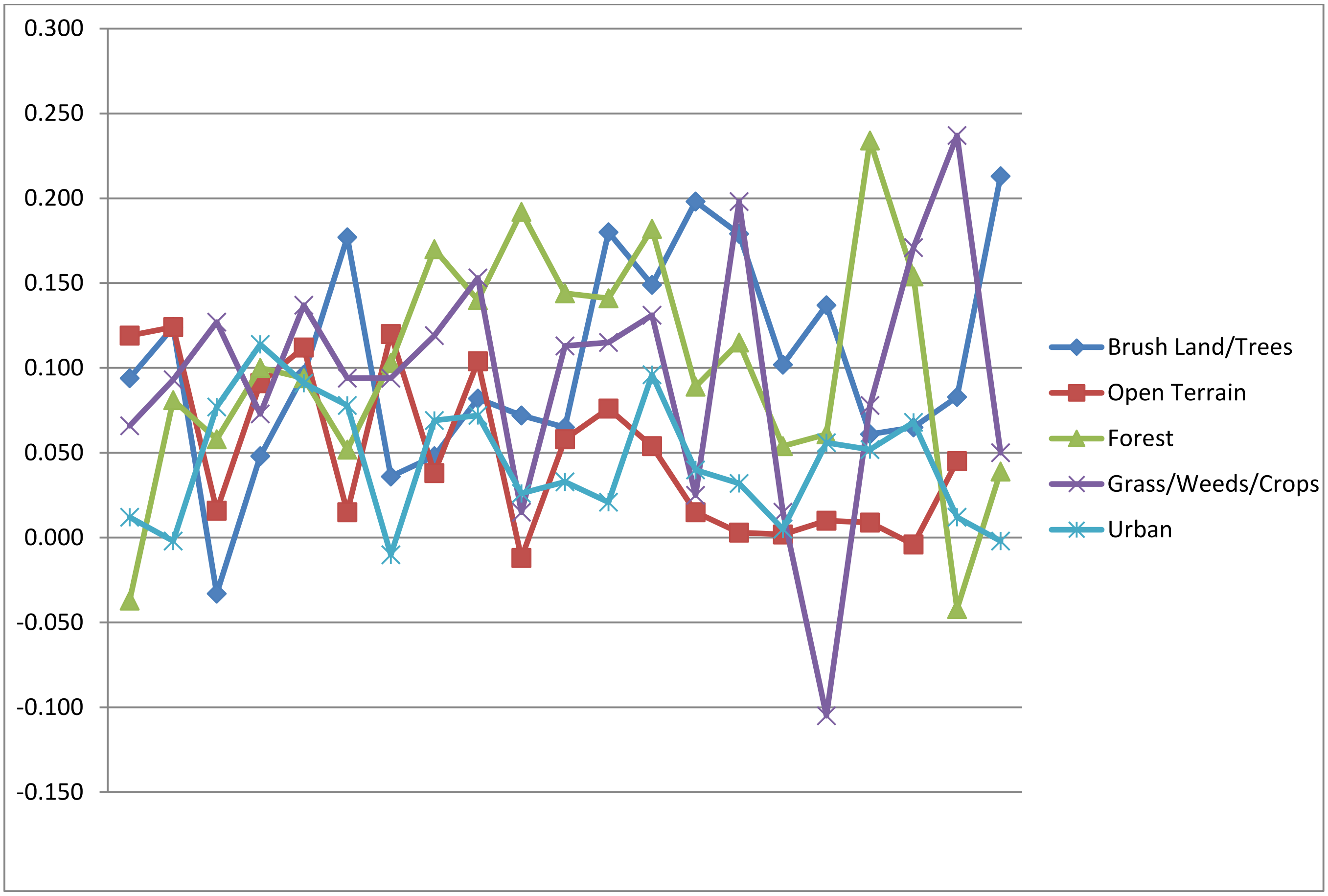


Figure 14 – Magnitude of elevation discrepancies per land cover category

Table 6 lists the 5% outliers that are larger than the 95th percentile.

Point ID	NAD83 UTM Zone 15		NAVD88	LiDAR Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
BLT-19	679447.559	4646168.472	106.872	107.07	0.198	0.198
FO-14	690993.791	4592573.401	86.408	86.6	0.192	0.192
GWC-R10	662881.599	4648195.598	161.522	161.72	0.198	0.198
GWC-R8	685656.61	4649302.395	71.553	71.79	0.237	0.237
FO-R18	687083.722	4646501.688	81.766	82	0.234	0.234
BLT-R6	658217.507	4590472.925	219.177	219.39	0.213	0.213

Table 6 — 5% Outliers

Table 7 provides overall descriptive statistics.

100 % of Totals	RMSE$_z$ (m) Open Terrain Spec=0.0925m	Mean (m)	Median (m)	Skew	Std Dev (m)	Kurtosis	Min (m)	Max (m)
Consolidated		0.079	0.076	0.164	0.064	0.067	-0.105	0.237
Open Terrain	0.068	0.050	0.041	0.397	0.047	-1.431	-0.012	0.124
Brush Lands and Trees		0.104	0.094	0.025	0.062	-0.276	-0.033	0.213
Forested and Fully Grown		0.101	0.100	-0.307	0.070	0.138	-0.042	0.234
Urban		0.045	0.040	0.186	0.036	-1.056	-0.010	0.114
Grass, Weeds, and Crops		0.095	0.094	-0.680	0.073	1.920	-0.105	0.237

Table 7 – Overall Descriptive Statistics

The figure below 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. The histogram shows that the majority of the discrepancies are skewed on the positive side. The majority of points are within the ranges of 0.0 meters to +0.15 meters.

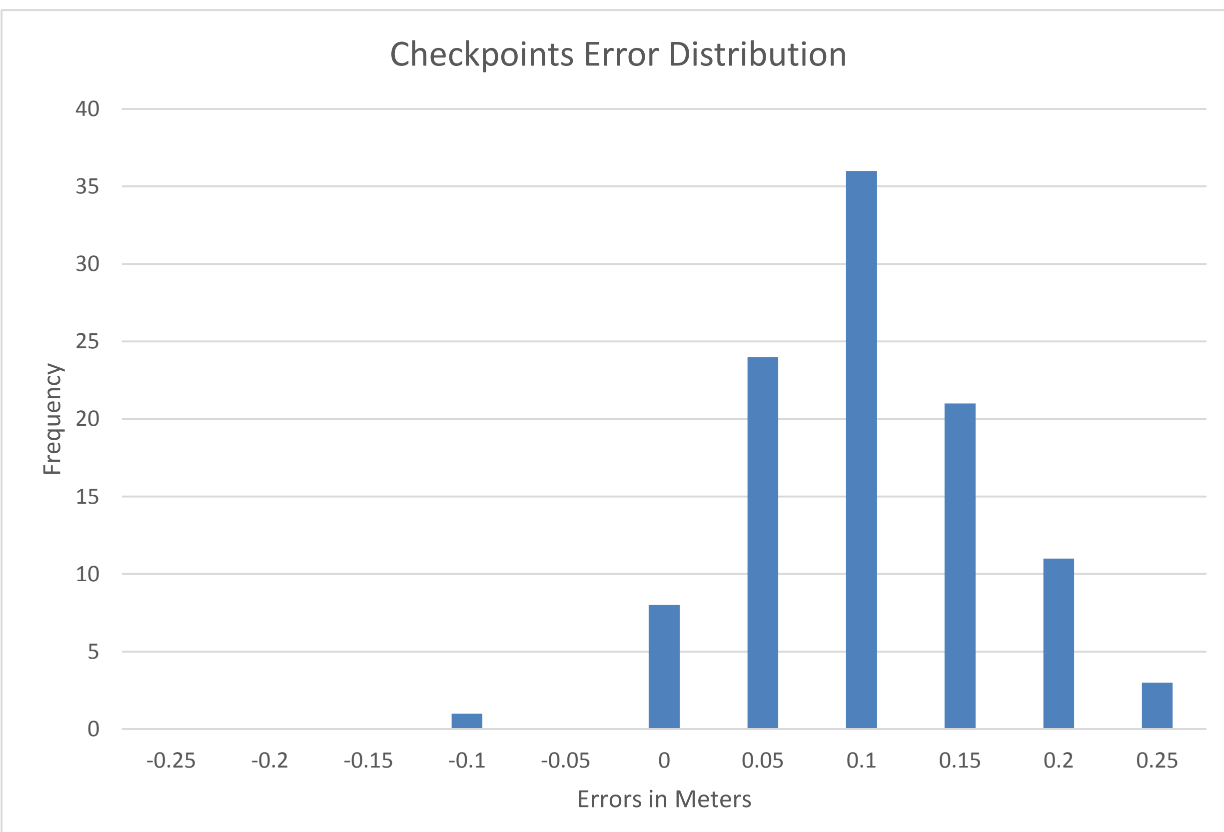


Figure 15 – Histogram of Elevation Discrepancies with errors in meters

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

Breakline Production & Qualitative Assessment Report

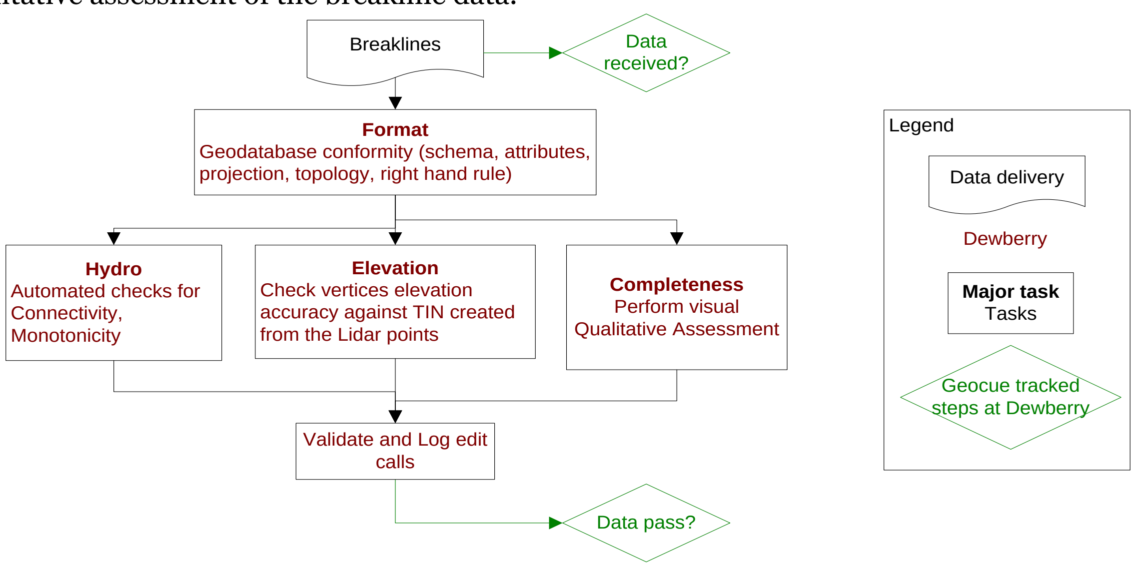
BREAKLINE PRODUCTION METHODOLOGY

Dewberry used GeoCue software to develop LiDAR stereo models of the Connecticut SANDY 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 developed by Dewberry 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 and tidal waters are reviewed in stereo and the lowest elevation is applied to the entire waterbody or tidal feature.

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.



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.

BREAKLINE QA/QC CHECKLIST

Project Number/Description: TO G14PD00241 USGS Connecticut SANDY LiDAR

Date:______ 1/26/2015____

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 ESRI's Data Reviewer

The following data checks are performed utilizing ESRI's Data Reviewer 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. Data Reviewer 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 Lakes, Tidal Waters, and Islands (if delivered as a separate feature class) feature classes. This tool is found under "Topology Checks."

☒ Perform "different Z-Value at intersection check" (Inland Streams and Rivers to Inland Streams and Rivers), (Ponds and Lakes to Ponds and Lakes), (Tidal Waters to Tidal Waters), (Streams and Rivers to Ponds and Lakes), (Streams and Rivers to Tidal Waters), (Ponds and Lakes to Tidal Waters), (Island to Inland Ponds and Lakes), (Island to Tidal Waters), (Island to Island),and (Islands to Inland Streams and Rivers) (Elevation Difference Tolerance= .01 feet Minimum, 600 feet Maximum, Touches). This tool is found under "Z Value Checks."

☒ Perform "duplicate geometry check" on (Inland Streams and Rivers to Inland Streams and Rivers), (Inland Ponds and Lakes to Inland Ponds and Lakes), (Tidal Waters to Tidal Waters), (Islands to Islands-if delivered as a separate shapefile), (Inland Streams and Rivers to Inland Ponds and Lakes), (Inland Streams and Rivers to Tidal Waters), (Inland Ponds and Lakes to Tidal Waters), (Islands to Tidal Waters), and (Islands to Inland Ponds and Lakes). Attributes do not need to be checked during this tool. This tool is found under "Duplicate Geometry Checks."

☒ Perform "geometry on geometry check" (Inland Streams and Rivers to Inland Ponds and Lakes), (Inland Streams and Rivers to Tidal Waters), (Inland Ponds and Lakes to Tidal Waters), (Inland Streams and Rivers to Inland Streams and Rivers), (Inland Ponds and Lakes to Inland Ponds and Lakes), (Tidal waters to Tidal waters), (Islands to Tidal Waters), and (Islands to Inland Ponds and Lakes), (Islands to Islands). Spatial relationship is crosses, attributes do not need to be checked. This tool is found under "Feature on Feature Checks."

☒ Perform "geometry on geometry check (Tidal Waters to Islands), and (Inland Ponds and Lakes to Islands), (Inland Streams and Rivers to Islands). Spatial relationship is contains, attributes do not need to be checked. This tool is found under "Feature on Feature Checks."

☒ Perform "geometry on geometry check" (Inland Streams and Rivers to Inland Ponds and Lakes), (Inland Streams and Rivers to Tidal Waters), (Inland Ponds and Lakes to Tidal Waters), (Inland Streams and Rivers to Inland Streams and Rivers), (Inland Ponds and Lakes to Inland Ponds and Lakes), (Tidal waters to Tidal waters), (Islands to Tidal Waters), and (Islands to Inland Ponds and Lakes), (Islands to Islands). Spatial relationship is intersect, attributes do not need to be checked. This tool is found under "Feature on Feature Checks."

☒ Perform "polygon overlap/gap is sliver check" on (Tidal Waters to Tidal Waters), (Island to Island), (Island to Inland Ponds and Lakes) and (Inland Ponds and Lakes to Inland Ponds and Lakes), (Inland Ponds and Lakes to Tidal Waters). 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 and Rivers) and (Tidal Waters to Tidal Waters if they are not a constant elevation) 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 features are ok and 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 and must be a line. If features are a polygon they will need to be converted to a line feature. Z tolerance is 0.01 meters.

☒ Perform connectivity check between (Inland Streams and Rivers to Inland Streams and Rivers), (Ponds and Lakes to Ponds and Lakes), (Tidal Waters to Tidal Waters), (Streams and Rivers to Ponds and Lakes), (Streams and Rivers to Tidal Waters), (Ponds and Lakes to Tidal Waters), (Island to Inland Ponds and Lakes), (Island to Tidal Waters), (Island to Island),and (Islands to Inland Streams and Rivers) 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.

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

Data Dictionary

HORIZONTAL AND VERTICAL DATUM

The horizontal datum shall be North American Datum of 1983 (2011), Units in Meters. The vertical datum shall be referenced to the North American Vertical Datum of 1988 (NAVD 88), Units in Meters. Geoid12A shall be used to convert ellipsoidal heights to orthometric heights.

COORDINATE SYSTEM AND PROJECTION

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

INLAND STREAMS AND RIVERS

Feature Dataset: BREAKLINES
Feature Type: Polygon
Contains Z Values: Yes
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: STREAMS_AND_RIVERS
Contains M Values: No
Annotation Subclass: None
Z Resolution: Accept Default Setting
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 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 greater than 100 feet to show as a double line. Each vertex placed should maintain vertical integrity. 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 island is greater than 1 acre. 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 Type: Polygon
Contains Z Values: Yes
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: PONDS_AND_LAKES
Contains M Values: No
Annotation Subclass: None
Z Resolution: Accept Default Setting
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 for features 2 acres in size or greater. "Donuts" will exist where there are islands within a closed water body feature.	Water bodies shall be captured as closed polygons with the water feature to the right. <u>The compiler shall take care to ensure that the z-value remains consistent for all vertices placed on the water body.</u> 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. An Island within a Closed Water Body Feature that is 1 acre in size or greater 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 Type: Polygon
Contains Z Values: Yes
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: TIDAL_WATERS
Contains M Values: No
Annotation Subclass: None
Z Resolution: Accept Default Setting
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
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Software
SHAPE_AREA	Double	Yes			0	0		Calculated by Software

Feature Definition

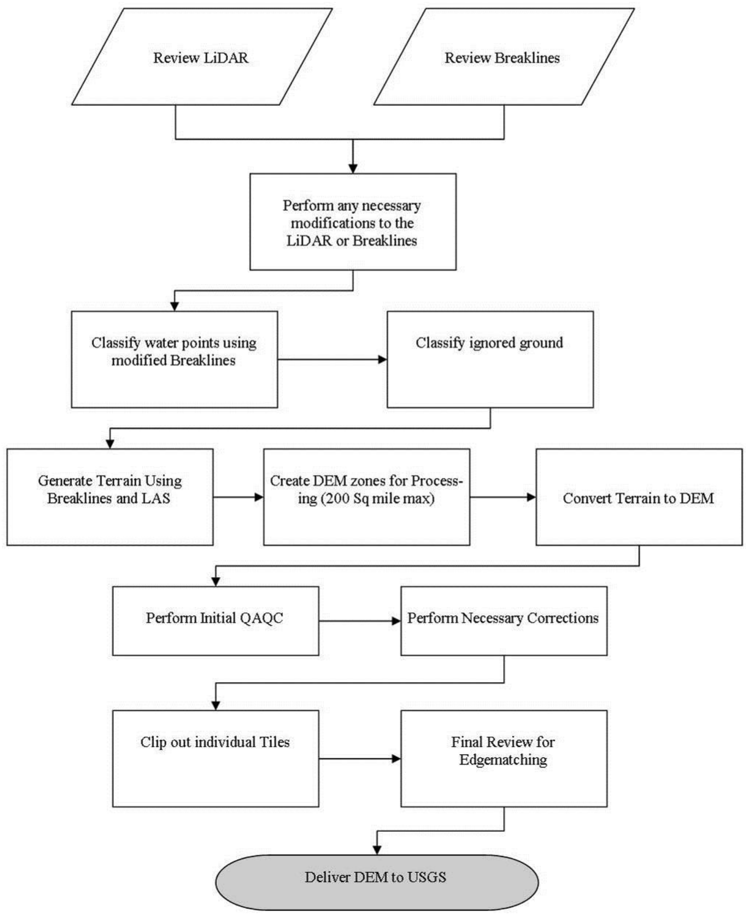
Description	Definition	Capture Rules
TIDAL_WATERS	The coastal breakline will delineate the land water interface using LiDAR data as reference. In flight line boundary areas with tidal variation the coastal shoreline may show stair stepping as no feathering is allowed. Stair stepping is allowed to show as much ground as the collected data permits.	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.

DEM Production & Qualitative Assessment

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.
3. Terrain Processing: A Terrain will be generated using the Breaklines and LAS data that has been imported into Arc as a Multipoint File.
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 4. 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 a Dewberry proprietary tool.
9. Final QA: Final QA will be performed on the dataset to ensure that tile boundaries are seamless.

DEM QUALITATIVE ASSESSMENT

Dewberry performed a comprehensive qualitative assessment of the bare earth 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. All corrections are completed using Dewberry's proprietary correction workflow. Upon completion of the corrections, the DEM data is loaded into Global Mapper for its second review and to verify corrections. Once the DEMs are tiled out, the final tiles are again loaded into Global Mapper to ensure coverage, extents, and that the final tiles are seamless.

The images below show an example of a bare earth DEM.

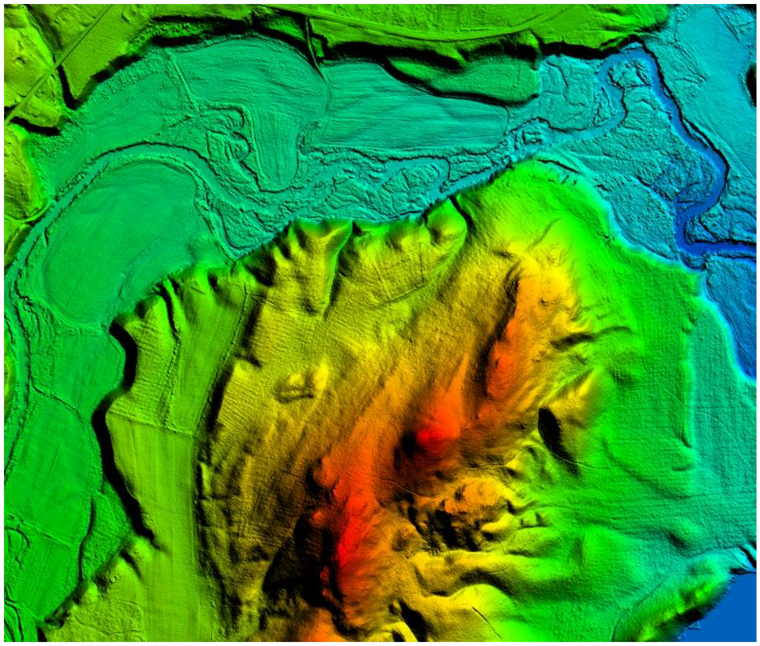


Figure 16- The bare earth DEM of Tile 18TXM810645.

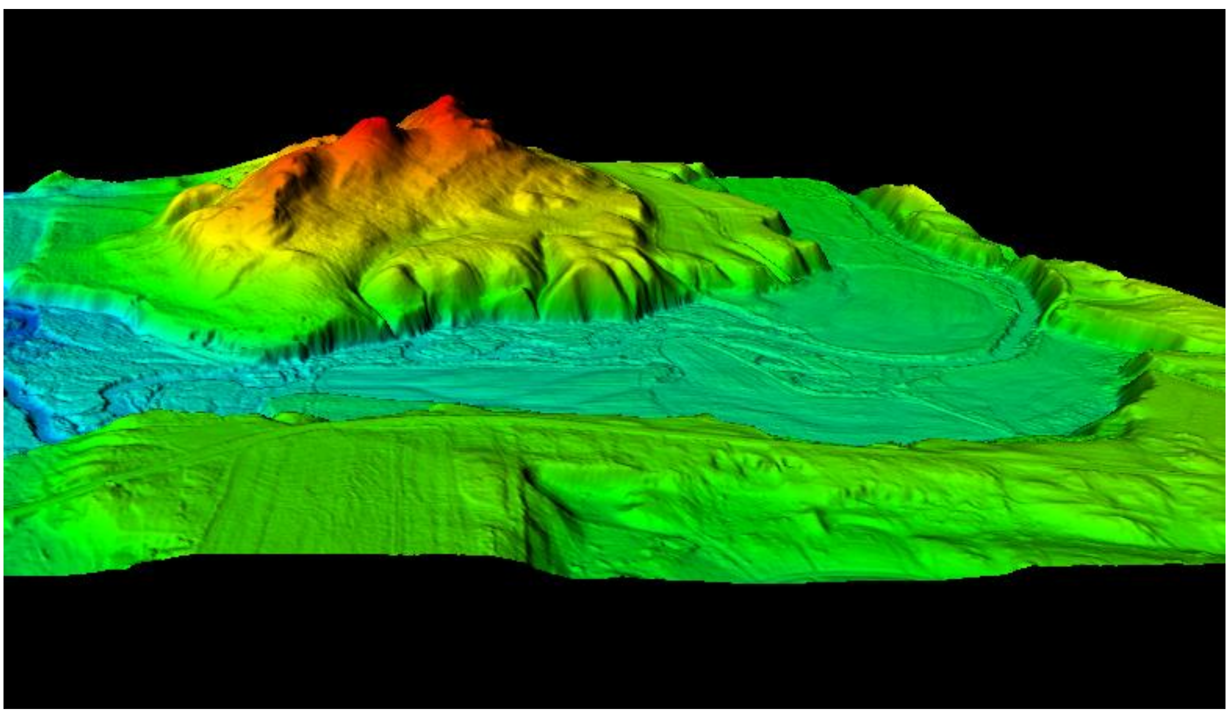


Figure 17-Tile 18TXM810645. 3D Profile view of the bare earth DEM.

DEM VERTICAL ACCURACY RESULTS

The same 104 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 8 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 ($RMSE_z$ x 1.9600) Req=0.1813m	CVA — Consolidated Vertical Accuracy (95th Percentile) Req=0.269m	SVA — Supplemental Vertical Accuracy (95th Percentile) Target=0.269m
Consolidated	104		0.201	
Bare Earth-Open Terrain	20	0.137		
Urban	21			0.098
Tall Weeds and Crops	21			0.192
Brush Lands and Trees	21			0.215
Forested and Fully Grown	21			0.203

Table 8 — FVA, CVA, and SVA Vertical Accuracy at 95% Confidence Level

The $RMSE_z$ for checkpoints in open terrain tested 0.07 meters, within the target criteria of 0.0925 meters. Compared with the 0.181 m specification, the FVA tested 0.137 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 0.201 meters based on the 95th percentile.

Compared with the target 0.269 meters specification, SVA for checkpoints in the tall weeds and crops land cover category tested 0.192 meters based on the 95th percentile, checkpoints in the forested and fully grown land cover category tested 0.203 meters based on the 95th percentile, checkpoints in the brush and small trees land cover category tested 0.215 meters based on the 95th percentile, and checkpoints in the urban land cover category tested 0.098 meters based on the 95th percentile.

Table 9 lists the 5% outliers that are larger than the 95th percentile.

Point ID	NAD83 UTM Zone 18N		NAVD88		DeltaZ	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Z-Survey (m)	Z-LiDAR (m)		
GWC-8	685656.61	4649302.395	71.553	71.793	0.240	0.240
FO-17	668758.277	4643402.668	196.918	197.121	0.203	0.203
FO-18	687083.722	4646501.688	81.766	81.995	0.229	0.229
BLT-07	636362.43	4596887.148	166.603	166.842	0.239	0.239
BLT-15	718511.202	4583865.847	0.530	0.745	0.215	0.215
BLT-19	679447.559	4646168.472	106.872	107.077	0.205	0.205

Table 9 — 5% Outliers

Table 10 provides overall descriptive statistics.

100 % of Totals	# of Points	RMSEz (m) Open Terrain Spec=0.0925 m	Mean (m)	Median (m)	Skew	Std Dev (m)	Kurtosis	Min (m)	Max (m)
Consolidated	104		0.082	0.071	0.291	0.066	-0.021	-0.099	0.240
Open Terrain	20	0.070	0.050	0.034	0.474	0.050	-1.333	-0.014	0.128
Urban	21		0.044	0.043	0.179	0.037	-0.355	-0.018	0.120
Tall Weeds and Crops	21		0.100	0.102	-0.781	0.069	2.724	-0.099	0.240
Brush Lands and Trees	21		0.105	0.089	0.371	0.068	-0.314	-0.031	0.239
Forested and Fully Grown	21		0.107	0.108	-0.209	0.071	-0.557	-0.035	0.229

Table 10 — Overall Descriptive Statistics

DEM QA/QC CHECKLIST

Project Number/Description: TO G14PD00241 USGS Connecticut SANDY LiDAR
Date:_______1/31/2015 ______

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 in Arc with a hillshade to check for issues with the hydro-flattening 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.
☒ DEM cell size is 1 meter
☒ Perform all necessary corrections in Arc using Dewberry's proprietary correction workflow.
☒ Review all corrections in Global Mapper
☒ Perform final overview on tiled data 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

Appendix A: Survey Report

1.1 Project Summary

Dewberry Consultants, LLC is under contract to the United States geological Survey to provide 105 Check Points for USGS in the State of Connecticut. Under the above referenced USGS Task Order, Dewberry is tasked to complete the quality assurance of high resolution LiDAR-derived elevation products. As part of this work Dewberry staff will complete checkpoint surveys that will be used to evaluate vertical accuracy on the bare-earth terrain derived from the LiDAR.

Existing NGS Control Points were located and surveyed to check the accuracy of the RTK/GPS survey equipment with the results shown in Section 2.4 of this Report.

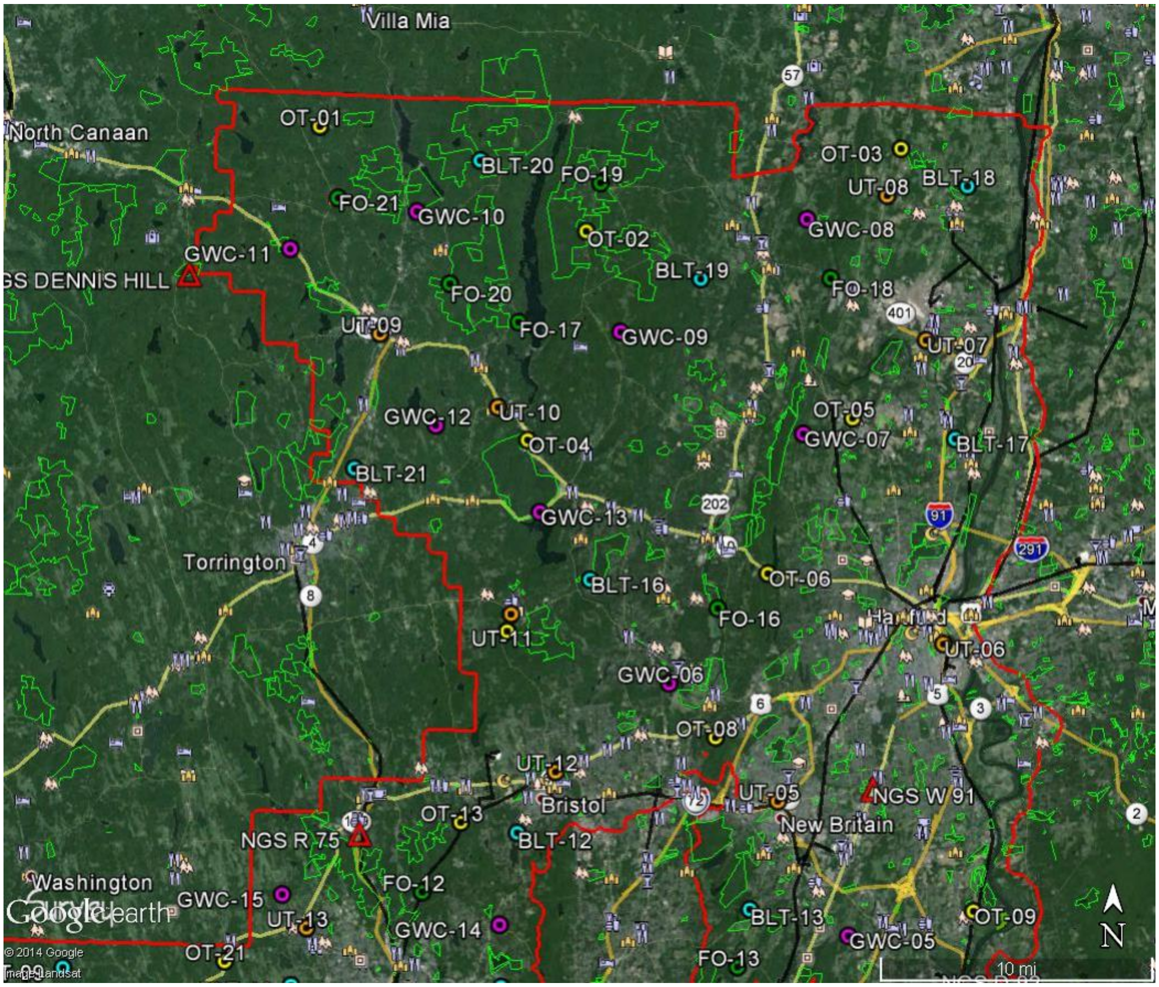
As an internal QA/QC procedure and to verify that the LiDAR Check Points meet the 95% confidence level approximately 50% of the points were re-observed and are shown in Section 5 of this report.

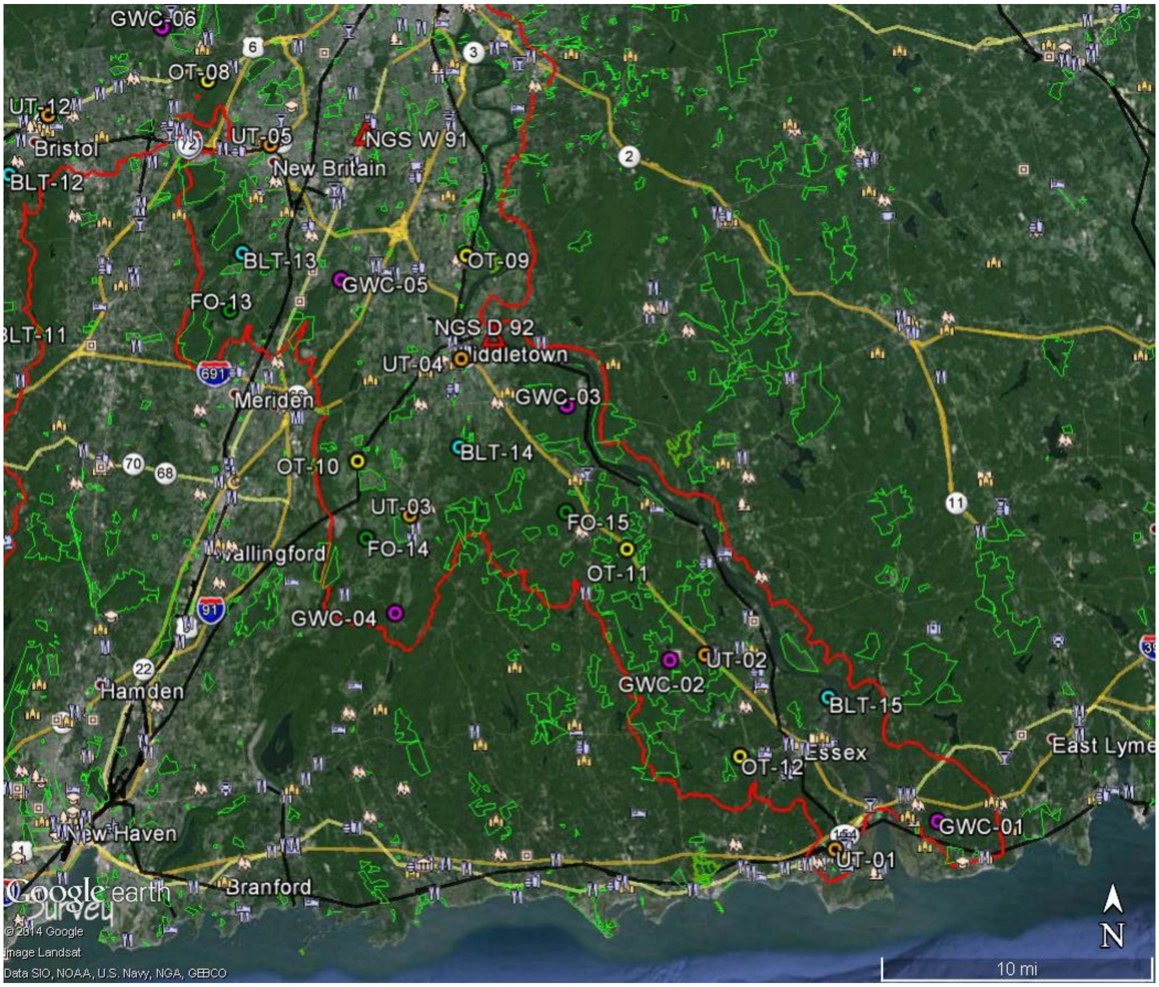
Final horizontal coordinates are referenced to UTM Zone 18, NAD83 in meters. Final Vertical elevations are referenced to NAVD88 in meters using Geoid model 2012A (Geoid12A).

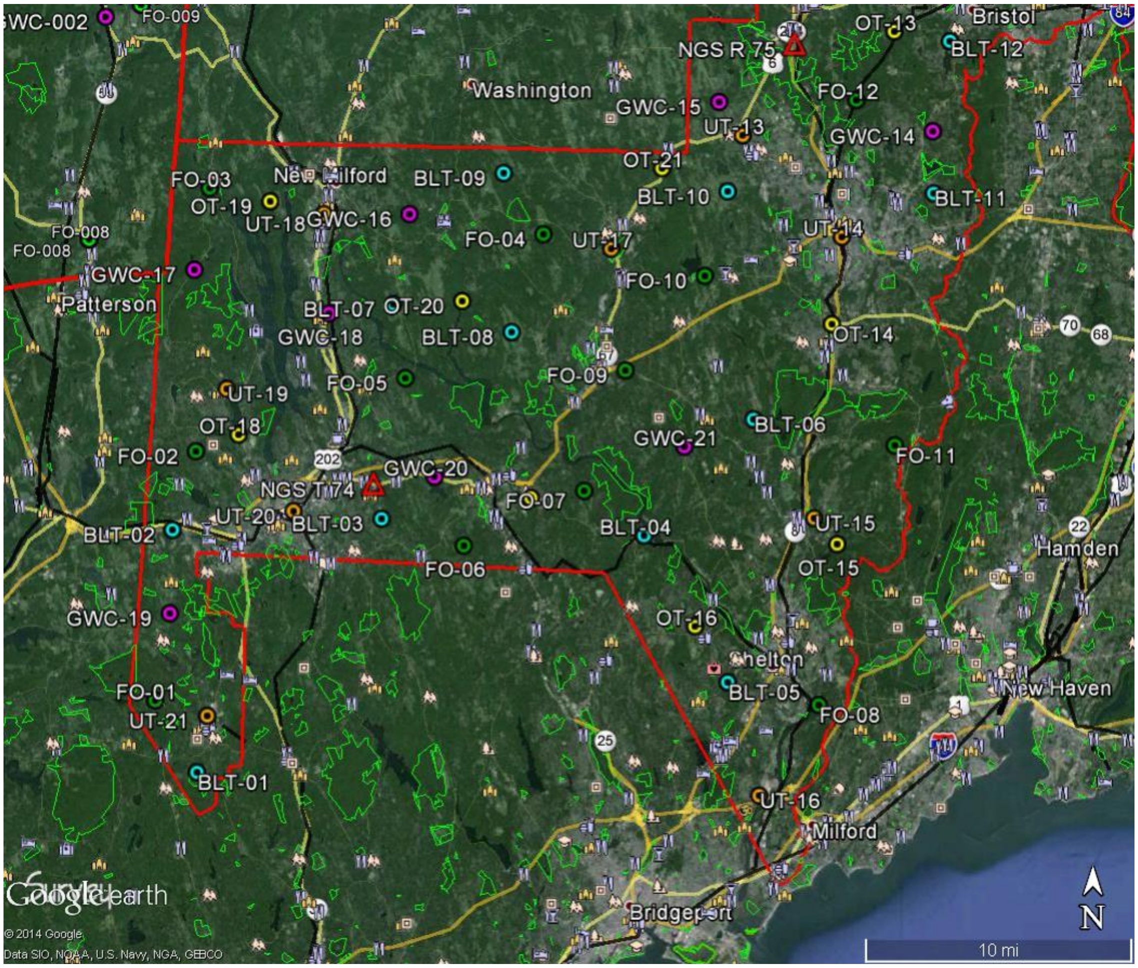
1.2 Points of Contact

Questions regarding the technical aspects of this report should be addressed to:
Dewberry Consultants LLC
Gary Simpson, L.S.
Senior Associate
10003 Derekwood Lane
Suite 204
Lanham, Maryland 20706
(301) 364-1855 direct
(301) 731-0188 fax

1.3 Project Areas


Villa Mia
North Canaan
OT-01
BLT-20
FO-19
FO-21
GWC-10
OT-02
GWC-11
NGS DENNIS HILL
BLT-19
FO-20
UT-09
FO-17
GWC-09
GWC-12
UT-10
OT-04
BLT-21
GWC-13
Torrington
BLT-16
UT-11
GWC-06
OT-08
UT-12
Bristol
OT-13
NGS R 75
BLT-12
FO-12
Washington
GWC-15
UT-13
GWC-14
OT-21
OT-03
UT-08
BLT-18
GWC-08
FO-18
UT-07
OT-05
GWC-07
BLT-17
OT-06
FO-16
Hartford
UT-06
UT-05
NGS W 91
New Britain
BLT-13
GWC-05
OT-09
FO-13
N
10 mi
© 2014 Google
Google earth


GWC-06
OT-08
UT-12
Bristol
UT-05
NGS W 91
New Britain
BLT-12
BLT-13
GWC-05
OT-09
FO-13
BLT-11
NGS D 92
UT-04
Middletown
Meriden
GWC-03
OT-10
BLT-14
UT-03
FO-15
FO-14
Wallingford
OT-11
GWC-04
GWC-02
UT-02
Hamden
BLT-15
OT-12
Essex
East Lyme
GWC-01
New Haven
UT-01
Branford
Google earth
© 2014 Google
Image Landsat
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
10 mi
N



2.1 Survey Equipment

In performing the GPS observations, Trimble R-10 GNSS receiver/antenna attached to a two meter fixed height pole with a Trimble TSC3 Data Collector to collect GPS raw data were used to perform the field surveys.

2.2 Survey Point Detail

The 104 LiDAR Check Points were well distributed throughout the project area.
A sketch was made for each location and a nail was set at the point where possible or at an identifiable point. The LiDAR Check Point locations are detailed on the “Ground Control Point Documentation Report” sheets attached to this report.

2.3 Network Design

The GPS survey performed by Dewberry Consultants, LLC office located in Lanham, MD was tied to a Real Time Network (RTN) managed by KeyNet GPS, Inc. The network is a series of “real-time” continuously operating, high precision GPS reference stations. All of the reference stations have been linked together using Trimble GPSNet software, creating a Virtual Reference Station System (VRS).

The Trimble NetR5 Reference Station is a multi-channel, multi-frequency GNSS (Global Navigation Satellite System) receiver designed for use as a stand-alone reference station or as part of a GNSS infrastructure solution. Trimble R-Track technology in the NetR5 receiver supports the modernized GPS L2C and L5 signals as well as GLONASS L1/L2 signals.

2.4 Field Survey Procedures and Analysis

Dewberry field surveyors used Trimble R-8 GNSS receivers, which is a geodetic quality dual frequency GPS receiver, to collect data at each surveyed location.
All locations were occupied once with approximately 50% of the locations being reobserved. All re-observations matched the initially derived station positions within the allowable tolerance of ± 5cm or within the 95% confidence level. Each occupation which utilized the VRS network was occupied for approximately three (3) minutes in duration and measured to 180 epochs.

Each occupation which utilized OPUS (if used) was occupied between 18 and 20 minutes.

Field GPS observations are detailed on the "Ground Control Point Documentation Reports" submitted as part of this report.

Two (4) existing NGS monument listed in the NSRS database were located as an additional QA/QC method to check the accuracy of the VRS network as well as being the primary project control monuments designated as PID LX3066, LX7346, LX2363 and LX3162. The results are as follows:

NGS PT. ID	As Surveyed (M)			Published (M)			Differences (M)		
	Northing(M)	Easting(M)	Elev.(M)	Northing(M)	Easting(M)	Elev. (M)	Δ N	Δ E	Δ Elev.
NGS-D-92	4604658.028	698169.622	9.397	4604658.026	698169.606	9.435	0.002	0.016	0.038
NGS-DENNIS HILL	4645639.340	649303.162	495.853	4645639.355	649303.167	495.9	0.015	0.005	0.047
NGST74	4586046.306	635375.010	145.954	4586046.315	635375.032	145.944	0.009	0.022	0.010
NGS-W-91	4616360.003	690299.165	37.797	4616360.006	690299.125	37.8	0.003	0.040	0.047

The above results indicate that the VRS network is providing positional values within the 5cm parameters for this survey.

2.5 Adjustment

The survey data was collected using Virtual Reference Stations (VRS) methodology within a Virtual Reference System (VRS).

The system is designed to provide a true Network RTK performance, the RTKNet software enables high-accuracy positioning in real time across a geographic region. The RTKNet software package uses real-time data streams from the GPSNet system user and generates correction models for high-accuracy RTK GPS corrections throughout the network. Therefore, corrections were applied to the points as they were being collected, thus negating the need for a post process adjustment.

2.6 Data Processing Procedures

After field data is collected the information is downloaded from the data collectors into the office software. The Software program used is called TBC or Trimble Business Center. Downloaded data is run through the TBC program to obtain the following reports; points report, point comparison report and a point detail report. The reports are reviewed for point accuracy and precision. After review of the point data an "ASCII" or "txt" file which is the industry standard is created. Point files are loaded into our CADD program (Carlson Survey 2014) to make a visual check of the point data (Pt. #, Coordinates, Elev. and Description). The data can now be imported into the final product.

Final Coordinates

POINT #	NORTHING (M)	EASTING (M)	ELEV. (M)
Open Terrain			
OT-02	4648799.471	672618.271	367.501
OT-03	4654195.459	691109.575	70.506
OT-04	4636499.092	669456.981	107.434
OT-05	4638253.268	688620.629	53.489
OT-06	4629005.030	683810.468	136.368
OT-07	4625256.056	668529.580	247.485
OT-08	4619282.443	680963.687	128.570
OT-09	4609374.897	696501.999	11.952
OT-10	4597099.522	690365.149	68.856
OT-11	4592305.703	706399.271	52.672
OT-12	4580272.751	713390.064	24.442
OT-13	4613927.520	666052.337	182.934
OT-14	4596346.139	662750.702	61.326
OT-15	4583150.468	663379.426	104.365
OT-16	4578031.399	654935.140	155.627
OT-17	4585480.195	644895.515	94.708
OT-18	4588849.438	627258.405	185.890
OT-19	4602864.123	628821.058	214.061
OT-20	4597178.923	640490.207	72.204
OT-21	4605412.023	652300.432	131.955
OT-02	4648799.471	672618.271	367.501
Brush/Low Trees Terrain			
BLT-01	4568556.720	625240.084	216.206
BLT-02	4583032.937	623414.216	161.826
BLT-03	4584014.647	635952.350	139.963
BLT-04	4583372.976	651756.574	59.012

BLT-05	4574726.800	656999.596	129.194
BLT-06	4590472.925	658217.507	219.177
BLT-07	4596887.148	636362.430	166.603
BLT-08	4595374.752	643508.016	202.664
BLT-09	4604858.332	642805.092	289.812
BLT-10	4604116.148	656267.285	195.168
BLT-11	4605363.094	668438.124	157.738
BLT-12	4618390.972	674852.555	99.733
BLT-13	4609195.674	683247.983	52.098
BLT-14	4598053.148	696338.012	96.785
BLT-15	4583865.847	718511.202	0.530
BLT-16	4628066.527	674026.642	118.169
BLT-17	4637180.212	694747.429	17.091
BLT-18	4652220.739	695004.912	60.955
BLT-19	4646168.472	679447.559	106.872
BLT-20	4651231.284	665614.732	316.187
BLT-21	4634569.343	659330.731	326.691
Forest Terrain			
FO-01	4572804.812	622647.965	259.227
FO-02	4587783.805	624724.634	230.319
FO-03	4603791.846	625296.465	136.342
FO-04	4601265.448	645280.902	287.502
FO-05	4592451.795	637191.589	128.550
FO-06	4582523.204	640948.318	172.986
FO-07	4585961.576	648109.177	171.368
FO-08	4573296.977	662323.604	56.511
FO-09	4593243.767	650391.184	106.937
FO-10	4598970.65	655038.081	220.066
FO-11	4589140.296	666669.669	206.250
FO-12	4605771.609	682419.425	86.389
FO-13	4605793.834	682602.063	76.858
FO-14	4592573.401	690993.791	86.408
FO-15	4594425.231	702750.301	146.116
FO-16	4626852.815	680904.336	47.879
FO-17	4643402.668	668758.277	196.918
FO-18	4646501.688	687083.722	81.766
FO-19	4651650.804	673445.756	362.696
FO-20	4645556.034	664635.932	144.201
FO-21	4650400.706	657973.198	352.815
Grass/Weeds/Crops Terrain			
GWC-01	4576710.640	725192.098	6.484
GWC-02	4585862.772	709091.698	73.227

GWC-03	4600681.100	702632.641	63.903
GWC-04	4588219.549	692803.454	75.247
GWC-05	4607743.908	689106.758	74.443
GWC-06	4621378.387	678293.615	50.992
GWC-07	4637243.808	685747.152	68.889
GWC-08	4649302.395	685656.61	71.553
GWC-09	4642945.061	674829.863	303.76
GWC-10	4648195.598	662881.599	161.522
GWC-11	4647347.551	655257.033	351.326
GWC-12	4641824.276	662532.615	209.425
GWC-13	4632251.878	670402.542	150.176
GWC-14	4608012.327	668493.467	253.091
GWC-15	4609465.948	655635.392	221.467
GWC-16	4602285.475	637205.806	169.295
GWC-17	4599452.025	625102.243	219.265
GWC-18	4596265.700	632484.570	67.797
GWC-19	4578055.461	623392.506	234.985
GWC-20	4586613.684	639085.317	192.829
GWC-21	4588798.189	654042.179	98.705
Urban Terrain			
UT-01	4574911.846	719137.663	4.848
UT-02	4586203.724	711167.133	44.212
UT-03	4593996.750	693527.800	53.003
UT-04	4603217.016	696368.196	9.866
UT-05	4615610.685	684748.481	53.559
UT-06	4625088.355	694332.718	5.972
UT-07	4642959.850	692860.141	47.570
UT-08	4651414.309	690351.433	60.501
UT-09	4642529.709	660613.314	214.128
UT-10	4638384.265	667666.829	116.704
UT-11	4626267.465	668743.923	264.687
UT-12	4617043.050	671570.889	120.309
UT-13	4607513.162	657097.540	148.464
UT-14	4601580.398	663220.934	78.930
UT-15	4584668.679	661969.606	54.008
UT-16	4567960.076	659055.594	15.645
UT-17	4600543.502	649364.986	82.384
UT-18	4602211.898	632028.475	89.668
UT-19	4591560.913	626489.933	190.722
UT-20	4584343.593	630651.566	117.668
UT-21	4571969.295	625784.958	197.372

GPS Observations

POINT ID	OBSERV. DATE	JULIAN DATE	TIME OF DAY	RE-OBSERV. DATE	RE-OBSERV. TIME
Open Terrain					
OT-02	6/26/2014	177	13:17	N/A	N/A
OT-03	6/25/2014	176	18:21	6/26/2014	7:13
OT-04	6/26/2014	177	11:28	N/A	N/A
OT-05	6/26/2014	177	7:05	N/A	N/A
OT-06	6/26/2014	177	7:46	N/A	N/A
OT-07	6/25/2014	176	19:31	N/A	N/A
OT-08	6/25/2014	176	20:38	N/A	N/A
OT-09	6/25/2014	176	11:16	N/A	N/A
OT-10	6/24/2014	175	15:28	6/25/2014	6:13
OT-11	6/24/2014	175	18:46	6/25/2014	8:16
OT-12	6/25/2014	176	9:42	N/A	N/A
OT-13	6/25/2014	176	18:12	N/A	N/A
OT-14	6/25/2014	176	17:27	N/A	N/A
OT-15	6/22/2014	173	14:23	6/23/2014	8:48
OT-16	6/22/2014	173	13:20	6/23/2014	7:02
OT-17	6/23/2014	174	11:39	6/24/2014	5:46
OT-18	6/24/2014	175	10:38	6/25/2014	7:29
OT-19	6/24/2014	175	16:14	6/25/2014	6:13
OT-20	6/25/2014	176	8:55	6/26/2014	5:31
OT-21	6/25/2014	176	13:09	6/26/2014	5:58
Brush/Low Trees Terrain					
BLT-01	6/23/2014	174	18:18	6/24/2014	8:30
BLT-02	6/23/2014	174	15:57	6/24/2014	7:16
BLT-03	6/23/2014	174	14:53	6/24/2014	6:32
BLT-04	6/22/2014	173	17:48	6/23/2014	6:39
BLT-05	6/22/2014	173	13:01	6/23/2014	7:23
BLT-06	1/22/2015	22	7:50		
BLT-07	6/24/2014	175	13:19	6/25/2014	9:33
BLT-08	6/25/2014	176	9:20	N/A	N/A
BLT-09	6/24/2014	175	17:39	6/25/2014	9:48
BLT-10	6/25/2014	176	12:45	N/A	N/A
BLT-11	1/22/2015	22	9:00	N/A	N/A
BLT-12	1/22/2015	22	10:40	N/A	N/A
BLT-13	6/25/2014	176	13:17	N/A	N/A

BLT-14	6/24/2014	175	17:22	6/25/2014	9:22
BLT-15	6/25/2014	176	9:19	N/A	N/A
BLT-16	1/22/2015	22	11:30	N/A	N/A
BLT-17	6/25/2014	176	3:45	6/26/2014	5:48
BLT-18	1/22/2015	22	13:30	N/A	N/A
BLT-19	6/26/2014	177	12:55	N/A	N/A
BLT-20	1/22/2015	22	14:50	N/A	N/A
BLT-21	6/26/2014	177	10:29	N/A	N/A
Forest Terrain					
FO-01	6/23/2014	174	17:11	6/24/2014	7:49
FO-02	6/24/2014	175	9:57	6/25/2014	7:48
FO-03	1/22/2015	22	17:30	N/A	N/A
FO-04	6/24/2014	175	18:09	6/25/2014	5:13
FO-05	6/24/2014	175	11:50	6/25/2014	7:59
FO-06	6/23/2014	174	12:29	6/24/2014	6:03
FO-07	6/23/2014	174	10:38	6/24/2014	5:31
FO-08	1/22/2015	22	7:00	N/A	N/A
FO-09	6/25/2014	176	10:04	N/A	N/A
FO-10	1/22/2015	22	8:20	N/A	N/A
FO-11	6/22/2014	173	15:07	6/23/2014	9:09
FO-12	6/25/2014	176	15:19	N/A	N/A
FO-13	1/22/2015	22	9:30	N/A	N/A
FO-14	6/24/2014	175	14:42	6/25/2014	6:49
FO-15	6/24/2014	175	17:55	6/25/2014	9:02
FO-16	6/26/2014	177	8:30	N/A	N/A
FO-17	6/26/2014	177	11:25	N/A	N/A
FO-18	1/22/2015	22	13:05	N/A	N/A
FO-19	1/22/2015	22	14:20	N/A	N/A
FO-20	6/26/2014	177	10:49	N/A	N/A
FO-21	6/26/2014	177	9:29	N/A	N/A
Grass/Weeds/Crops Terrain					
GWC-01	6/25/2014	176	8:46	N/A	N/A
GWC-02	6/25/2014	176	10:07	N/A	N/A
GWC-03	6/24/2014	175	16:53	6/25/2014	5:49
GWC-04	6/24/2014	175	14:00	6/25/2014	7:11
GWC-05	6/25/2014	176	12:09	N/A	N/A
GWC-06	1/22/2015	22	11:00	N/A	N/A
GWC-07	1/22/2015	22	12:10	N/A	N/A

GWC-08	1/22/2015	22	14:00	N/A	N/A
GWC-09	1/22/2015	22	12:40	N/A	N/A
GWC-10	1/22/2015	22	15:10	N/A	N/A
GWC-11	6/26/2014	177	12:17	N/A	N/A
GWC-12	1/22/2015	22	15:56	N/A	N/A
GWC-13	6/26/2014	177	9:48	N/A	N/A
GWC-14	6/25/2014	176	16:05	6/26/2014	6:26
GWC-15	6/25/2014	176	14:03	N/A	N/A
GWC-16	6/24/2014	175	17:11	6/25/2014	5:39
GWC-17	1/22/2015	22	18:00	N/A	N/A
GWC-18	6/24/2014	175	12:50	6/25/2014	9:16
GWC-19	6/23/2014	174	16:27	6/25/2014	8:23
GWC-20	6/23/2014	174	13:22	6/24/2014	6:16
GWC-21	6/22/2014	173	16:44	6/23/2014	6:13
Urban Terrain					
UT-01	6/25/2014	176	8:21	N/A	N/A
UT-02	6/24/2014	175	19:07	6/25/2014	8:35
UT-03	6/24/2014	175	15:04	6/25/2014	6:29
UT-04	6/24/2014	175	16:06	6/25/2014	5:32
UT-05	6/25/2014	176	13:52	N/A	N/A
UT-06	6/25/2014	176	15:12	N/A	N/A
UT-07	6/25/2014	176	12:24	6/26/2014	6:11
UT-08	6/25/2014	176	18:09	N/A	N/A
UT-09	6/26/2014	177	11:52	N/A	N/A
UT-10	6/26/2014	177	11:15	N/A	N/A
UT-11	6/25/2014	176	19:47	6/26/2014	6:59
UT-12	6/25/2014	176	19:01	N/A	N/A
UT-13	6/25/2014	176	13:39	N/A	N/A
UT-14	6/25/2014	176	17:09	N/A	N/A
UT-15	6/22/2014	173	13:56	6/23/2014	8:31
UT-16	6/22/2014	173	10:29	6/23/2014	7:51
UT-17	6/25/2014	176	12:11	N/A	N/A
UT-18	6/24/2014	175	16:39	6/25/2014	5:59
UT-19	6/24/2014	175	11:08	6/25/2014	7:09
UT-20	6/23/2014	174	15:27	6/24/2014	6:49
UT-21	6/23/2014	174	17:55	6/24/2014	8:13

Point Comparison

POINT ID	POINT CK	DELTA NORTH (M)	DELTA EAST (M)	VERT. DIFF (M)
Open Terrain				
OT-03	OT-03CK	0.002	0.005	0.028
OT-10	OT-10CK	0.000	0.001	0.003
OT-11	OT-11CK	0.001	0.002	0.011
OT-15	OT-15CK	0.005	0.005	0.005
OT-16	OT-16CK	0.001	0.002	0.010
OT-17	OT-17CK	0.020	0.009	0.027
OT-18	OT-18CK	0.006	0.002	0.030
OT-19	OT-19CK	0.007	0.002	0.004
OT-20	OT-20CK	0.000	0.002	0.023
OT-21	OT-21CK	0.002	0.007	0.001
Brush/Low Trees Terrain				
BLT-01	BLT-01CK	0.003	0.001	0.000
BLT-02	BLT-02CK	0.001	0.002	0.011
BLT-03	BLT-03CK	0.011	0.004	0.025
BLT-04	BLT-04CK	0.004	0.018	0.015
BLT-05	BLT-05CK	0.009	0.002	0.001
BLT-06	BLT-06CK	0.002	0.008	0.006
BLT-07	BLT-07CK	0.000	0.002	0.010
BLT-09	BLT-09CK	0.003	0.007	0.017
BLT-14	BLT-14CK	0.002	0.001	0.012
BLT-17	BLT-17CK	0.008	0.020	0.065
BLT-18	BLT-18CK	0.002	0.005	0.017
Forest Terrain				
FO-01	FO-01CK	0.007	0.005	0.014
FO-02	FO-02CK	0.001	0.003	0.003
FO-03	FO-03CK	0.011	0.004	0.005
FO-04	FO-04CK	0.002	0.005	0.017
FO-05	FO-05CK	0.020	0.001	0.004
FO-06	FO-06CK	0.009	0.013	0.031
FO-07	FO-07CK	0.002	0.004	0.015
FO-08	FO-08CK	0.011	0.004	0.005
FO-11	FO-13CK	0.001	0.009	0.002
FO-14	FO-14CK	0.023	0.012	0.006
FO-15	FO-15CK	0.016	0.004	0.028

Grass/Weeds/Crops Terrain				
GWC-03	GWC-03CK	0.020	0.001	0.004
GWC-04	GWC-04CK	0.001	0.007	0.002
GWC-08	GWC-08CK	0.006	0.016	0.006
GWC-14	GWC-14CK	0.001	0.002	0.008
GWC-16	GWC-16CK	0.012	0.005	0.019
GWC-18	GWC-18CK	0.001	0.002	0.005
GWC-19	GWC-19CK	0.002	0.004	0.018
GWC-20	GWC-20CK	0.004	0.004	0.026
GWC-21	GWC-21CK	0.005	0.002	0.039
Urban Terrain				
UT-02	UT-02CK	0.000	0.002	0.008
UT-03	UT-03CK	0.001	0.001	0.020
UT-04	UT-04CK	0.000	0.005	0.017
UT-07	UT-07CK	0.004	0.023	0.040
UT-11	UT-11CK	0.005	0.000	0.003
UT-15	UT-15CK	0.004	0.000	0.003
UT-16	UT-16CK	0.001	0.004	0.004
UT-18	UT-18CK	0.005	0.003	0.010
UT-19	UT-19CK	0.015	0.009	0.028
UT-20	UT-20CK	0.006	0.005	0.001
UT-21	UT-21CK	0.003	0.006	0.006

Appendix B: Complete List of Delivered Tiles

18TXL195572	18TXL570581	18TXM555651	18TXM735653	18TXM915606
18TXL210569	18TXL570582	18TXM555653	18TXM735654	18TXM915608
18TXL210570	18TXL570584	18TXM555654	18TXM735656	18TXM915609
18TXL210572	18TXL570585	18TXM555656	18TXM750612	18TXM915611
18TXL210573	18TXL570587	18TXM570600	18TXM750614	18TXM915612
18TXL210575	18TXL570588	18TXM570602	18TXM750615	18TXM915614
18TXL210576	18TXL570590	18TXM570603	18TXM750617	18TXM915615
18TXL210578	18TXL570591	18TXM570605	18TXM750618	18TXM915617
18TXL210579	18TXL570593	18TXM570606	18TXM750620	18TXM915618
18TXL210581	18TXL570594	18TXM570608	18TXM750621	18TXM915620
18TXL210582	18TXL570596	18TXM570609	18TXM750623	18TXM915621
18TXL210584	18TXL570597	18TXM570611	18TXM750624	18TXM915623
18TXL210585	18TXL570599	18TXM570612	18TXM750626	18TXM915624
18TXL210587	18TXL585561	18TXM570614	18TXM750627	18TXM915626
18TXL210588	18TXL585563	18TXM570615	18TXM750629	18TXM915627
18TXL210590	18TXL585564	18TXM570633	18TXM750630	18TXM915629
18TXL210591	18TXL585566	18TXM570635	18TXM750632	18TXM915630
18TXL210593	18TXL585567	18TXM570636	18TXM750633	18TXM915632
18TXL210594	18TXL585569	18TXM570638	18TXM750635	18TXM915633
18TXL210596	18TXL585570	18TXM570639	18TXM750636	18TXM915635
18TXL210597	18TXL585572	18TXM570641	18TXM750638	18TXM915636
18TXL225567	18TXL585573	18TXM570642	18TXM750639	18TXM915638
18TXL225569	18TXL585575	18TXM570644	18TXM750641	18TXM915639
18TXL225570	18TXL585576	18TXM570645	18TXM750642	18TXM915641
18TXL225572	18TXL585578	18TXM570647	18TXM750644	18TXM915642
18TXL225573	18TXL585579	18TXM570648	18TXM750645	18TXM915644
18TXL225575	18TXL585581	18TXM570650	18TXM750647	18TXM915645
18TXL225576	18TXL585582	18TXM570651	18TXM750648	18TXM915647
18TXL225578	18TXL585584	18TXM570653	18TXM750650	18TXM915648
18TXL225579	18TXL585585	18TXM570654	18TXM750651	18TXM915650
18TXL225581	18TXL585587	18TXM570656	18TXM750653	18TXM915651
18TXL225582	18TXL585588	18TXM585600	18TXM750654	18TXM915653
18TXL225584	18TXL585590	18TXM585602	18TXM750656	18TXM915654
18TXL225585	18TXL585591	18TXM585603	18TXM765614	18TXM915656
18TXL225587	18TXL585593	18TXM585605	18TXM765615	18TXM930600
18TXL225588	18TXL585594	18TXM585606	18TXM765617	18TXM930602
18TXL225590	18TXL585596	18TXM585608	18TXM765618	18TXM930603
18TXL225591	18TXL585597	18TXM585609	18TXM765620	18TXM930605

18TXL225593	18TXL585599	18TXM585611	18TXM765621	18TXM930606
18TXL225594	18TXL600561	18TXM585612	18TXM765623	18TXM930608
18TXL225596	18TXL600563	18TXM585614	18TXM765624	18TXM930609
18TXL225597	18TXL600564	18TXM585615	18TXM765626	18TXM930611
18TXL225599	18TXL600566	18TXM585632	18TXM765627	18TXM930612
18TXL240566	18TXL600567	18TXM585633	18TXM765629	18TXM930614
18TXL240567	18TXL600569	18TXM585635	18TXM765630	18TXM930615
18TXL240569	18TXL600570	18TXM585636	18TXM765632	18TXM930617
18TXL240570	18TXL600572	18TXM585638	18TXM765633	18TXM930618
18TXL240572	18TXL600573	18TXM585639	18TXM765635	18TXM930620
18TXL240573	18TXL600575	18TXM585641	18TXM765636	18TXM930621
18TXL240575	18TXL600576	18TXM585642	18TXM765638	18TXM930623
18TXL240576	18TXL600578	18TXM585644	18TXM765639	18TXM930624
18TXL240578	18TXL600579	18TXM585645	18TXM765641	18TXM930626
18TXL240579	18TXL600581	18TXM585647	18TXM765642	18TXM930627
18TXL240581	18TXL600582	18TXM585648	18TXM765644	18TXM930629
18TXL240582	18TXL600584	18TXM585650	18TXM765645	18TXM930630
18TXL240584	18TXL600585	18TXM585651	18TXM765647	18TXM930632
18TXL240585	18TXL600587	18TXM585653	18TXM765648	18TXM930633
18TXL240587	18TXL600588	18TXM585654	18TXM765650	18TXM930635
18TXL240588	18TXL600590	18TXM585656	18TXM765651	18TXM930636
18TXL240590	18TXL600591	18TXM600600	18TXM765653	18TXM930638
18TXL240591	18TXL600593	18TXM600602	18TXM765654	18TXM930639
18TXL240593	18TXL600594	18TXM600603	18TXM765656	18TXM930641
18TXL240594	18TXL600596	18TXM600605	18TXM780602	18TXM930642
18TXL240596	18TXL600597	18TXM600606	18TXM780603	18TXM930644
18TXL240597	18TXL600599	18TXM600608	18TXM780611	18TXM930645
18TXL240599	18TXL615563	18TXM600609	18TXM780612	18TXM930647
18TXL255566	18TXL615564	18TXM600611	18TXM780614	18TXM930648
18TXL255567	18TXL615566	18TXM600612	18TXM780615	18TXM930650
18TXL255569	18TXL615567	18TXM600614	18TXM780617	18TXM930651
18TXL255570	18TXL615569	18TXM600615	18TXM780618	18TXM930653
18TXL255572	18TXL615570	18TXM600630	18TXM780620	18TXM930654
18TXL255573	18TXL615572	18TXM600632	18TXM780621	18TXM930656
18TXL255575	18TXL615573	18TXM600633	18TXM780623	18TXM945600
18TXL255576	18TXL615575	18TXM600635	18TXM780624	18TXM945602
18TXL255578	18TXL615576	18TXM600636	18TXM780626	18TXM945603
18TXL255579	18TXL615578	18TXM600638	18TXM780627	18TXM945605
18TXL255581	18TXL615579	18TXM600639	18TXM780629	18TXM945606
18TXL255582	18TXL615581	18TXM600641	18TXM780630	18TXM945608

18TXL255584	18TXL615582	18TXM600642	18TXM780632	18TXM945609
18TXL255585	18TXL615584	18TXM600644	18TXM780633	18TXM945611
18TXL255587	18TXL615585	18TXM600645	18TXM780635	18TXM945612
18TXL255588	18TXL615587	18TXM600647	18TXM780636	18TXM945614
18TXL255590	18TXL615588	18TXM600648	18TXM780638	18TXM945615
18TXL255591	18TXL615590	18TXM600650	18TXM780639	18TXM945617
18TXL255593	18TXL615591	18TXM600651	18TXM780641	18TXM945618
18TXL255594	18TXL615593	18TXM600653	18TXM780642	18TXM945620
18TXL255596	18TXL615594	18TXM600654	18TXM780644	18TXM945621
18TXL255597	18TXL615596	18TXM600656	18TXM780645	18TXM945623
18TXL255599	18TXL615597	18TXM615600	18TXM780647	18TXM945624
18TXL270567	18TXL615599	18TXM615602	18TXM780648	18TXM945626
18TXL270569	18TXL630569	18TXM615603	18TXM780650	18TXM945627
18TXL270570	18TXL630570	18TXM615605	18TXM780651	18TXM945629
18TXL270572	18TXL630572	18TXM615606	18TXM780653	18TXM945630
18TXL270573	18TXL630573	18TXM615608	18TXM780654	18TXM945632
18TXL270575	18TXL630575	18TXM615609	18TXM780656	18TXM945633
18TXL270576	18TXL630576	18TXM615611	18TXM795602	18TXM945635
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18TXL570576	18TXM555650	18TXL570578	18TXL570579	

LiDAR Check Point Survey Report

"CONNECTICUT SANDY LiDAR"
USGS Contract: G10PC00013
Task Order Number: G14PD00241

Prepared for:
United States Geological Survey

Prepared By:

Dewberry Consultants LLC

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Lanham, Maryland, 20706
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TABLE OF CONTENTS

1. INTRODUCTION

1.1 *Project Summary*

Dewberry Consultants, LLC is under contract to the United States geological Survey to provide 104 Check Points for USGS in the State of Connecticut. Under the above referenced USGS Task Order, Dewberry is tasked to complete the quality assurance of high resolution LiDAR-derived elevation products. As part of this work Dewberry staff will complete checkpoint surveys that will be used to evaluate vertical accuracy on the bare-earth terrain derived from the LiDAR.

Existing NGS Control Points were located and surveyed to check the accuracy of the RTK/GPS survey equipment with the results shown in Section 2.4 of this Report.

As an internal QA/QC procedure and to verify that the LiDAR Check Points meet the 95% confidence level approximately 50% of the points were re-observed and are shown in Section 5 of this report.

Final horizontal coordinates are referenced to UTM Zone 18, NAD83 in meters. Final Vertical elevations are referenced to NAVD88 in meters using Geoid model 2012A (Geoid12A).

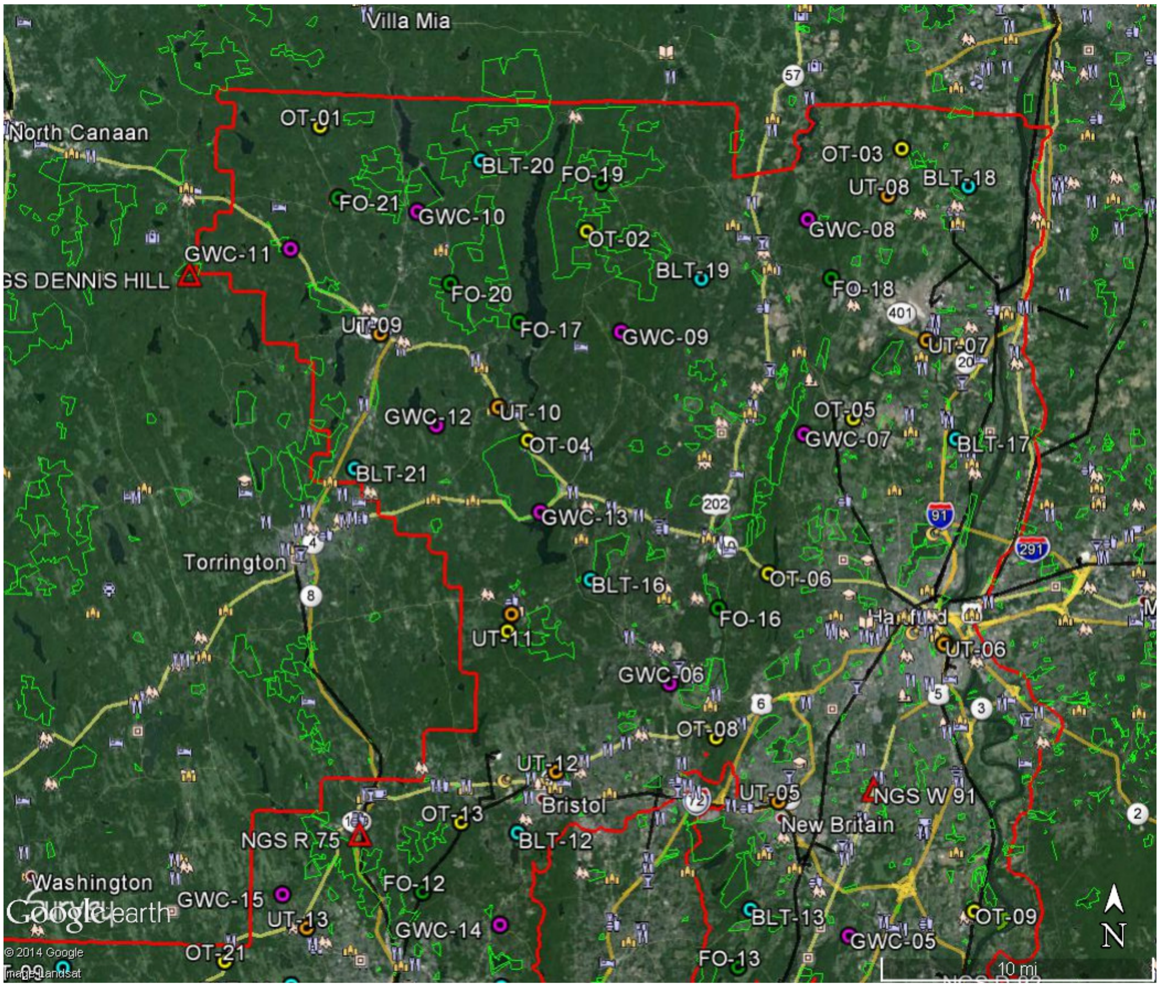
1.2 *Points of Contact*

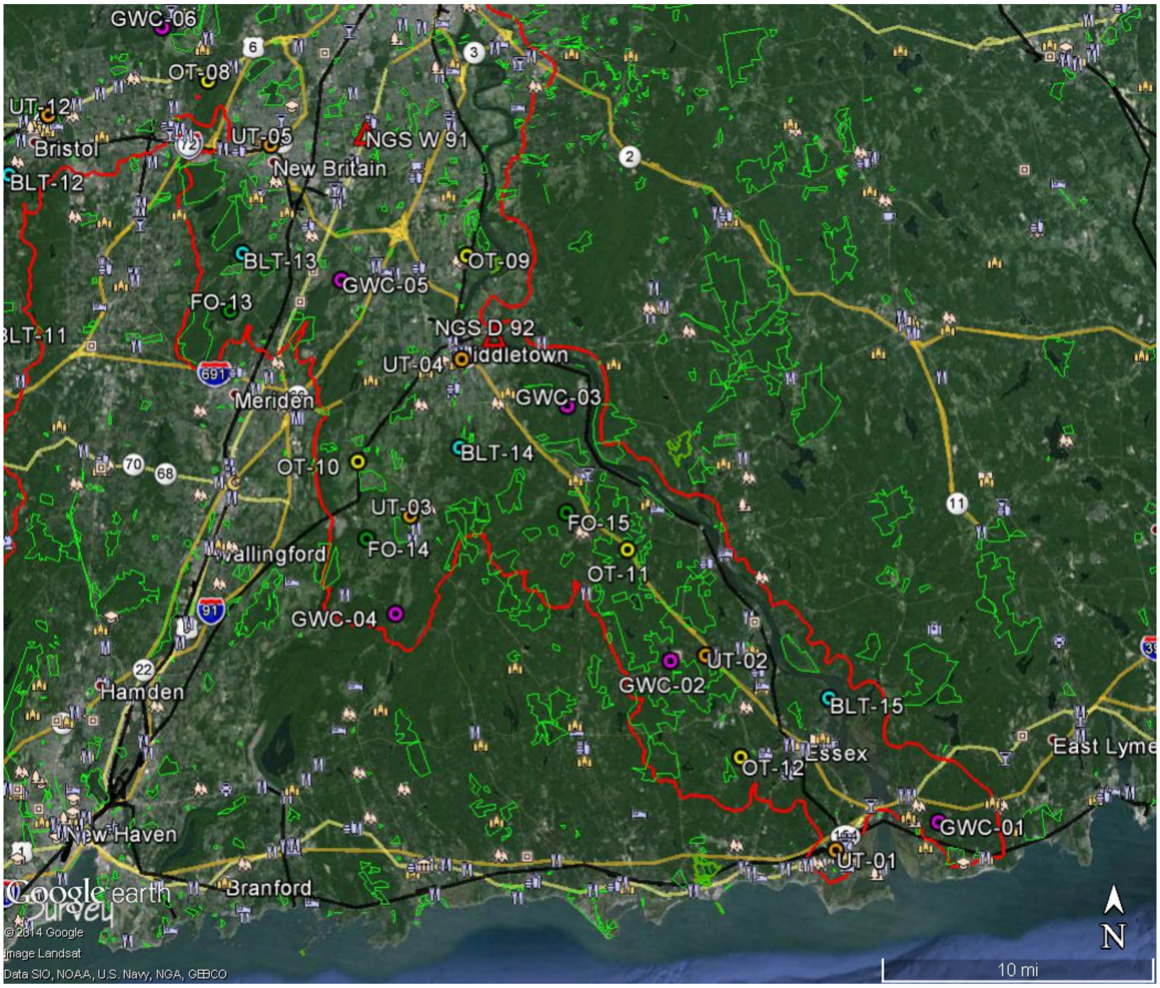
Questions regarding the technical aspects of this report should be addressed to:

Dewberry Consultants LLC

Gary Simpson, L.S.
Senior Associate
10003 Derekwood Lane
Suite 204
Lanham, Maryland 20706
(301) 364-1855 direct
(301) 731-0188 fax

1.3 *Project Areas*

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UT-12
Bristol
UT-05
NGS W 91
New Britain
BLT-12
BLT-13
OT-09
GWC-05
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NGS D 92
BLT-11
UT-04
Middletown
Meriden
GWC-03
BLT-14
OT-10
UT-03
FO-15
FO-14
Wallingford
OT-11
GWC-04
UT-02
GWC-02
Hamden
BLT-15
East Lyme
OT-12
Essex
GWC-01
New Haven
UT-01
Branford
Google earth
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Image Landsat
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
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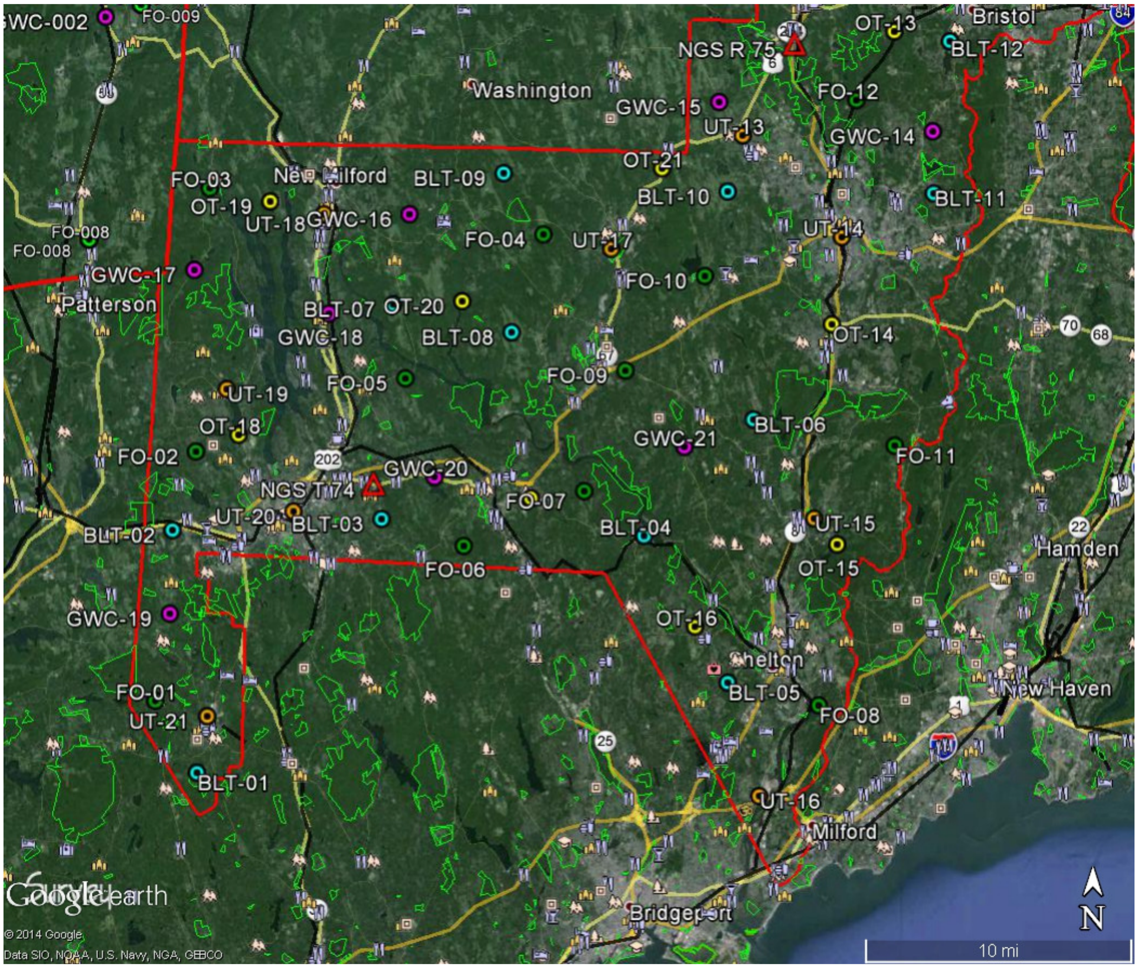

USGS – CONNECTICUT SANDY LiDAR

PROJECT DETAILS

2.1 *Survey Equipment*

In performing the GPS observations, Trimble R-10 GNSS receiver/antenna attached to a two meter fixed height pole with a Trimble TSC3 Data Collector to collect GPS raw data were used to perform the field surveys.

2.2 *Survey Point Detail*

The 104 LiDAR Check Points were well distributed throughout the project area.

A sketch was made for each location and a nail was set at the point where possible or at an identifiable point. The LiDAR Check Point locations are detailed on the "Ground Control Point Documentation Report" sheets attached to this report.

2.3 *Network Design*

The GPS survey performed by Dewberry Consultants, LLC office located in Lanham, MD was tied to a Real Time Network (RTN) managed by KeyNet GPS, Inc. The network is a series of "real-time" continuously operating, high precision GPS reference stations. All of the reference stations have been linked together using Trimble GPSNet software, creating a Virtual Reference Station System (VRS).

The Trimble NetR5 Reference Station is a multi-channel, multi-frequency GNSS (Global Navigation Satellite System) receiver designed for use as a stand-alone reference station or as part of a GNSS infrastructure solution. Trimble R-Track technology in the NetR5 receiver supports the modernized GPS L2C and L5 signals as well as GLONASS L1/L2 signals.

2.4 *Field Survey Procedures and Analysis*

Dewberry field surveyors used Trimble R-8 GNSS receivers, which is a geodetic quality dual frequency GPS receiver, to collect data at each surveyed location.

All locations were occupied once with approximately 50% of the locations being re-observed. All re-observations matched the initially derived station positions within the allowable tolerance of ± 5cm or within the 95% confidence level. Each occupation which utilized the VRS network was occupied for approximately three (3) minutes in duration and measured to 180 epochs.

Each occupation which utilized OPUS (if used) was occupied between 18 and 20 minutes.

Field GPS observations are detailed on the "Ground Control Point Documentation Reports" submitted as part of this report.

Two (4) existing NGS monument listed in the NSRS database were located as an additional QA/QC method to check the accuracy of the VRS network as well as being the primary project control monuments designated as PID LX3066, LX7346, LX2363 and LX3162. The results are as follows:

	As Surveyed (M)			Published (M)			Differences (M)		
NGS PT. ID	Northing(M)	Easting(M)	Elev.(M)	Northing(M)	Easting(M)	Elev. (M)	Δ N	Δ E	Δ Elev.
NGS-D-92	4604658.028	698169.622	9.397	4604658.026	698169.606	9.435	0.002	0.016	0.038
NGS-DENNIS HILL	4645639.340	649303.162	495.853	4645639.355	649303.167	495.9	0.015	0.005	0.047
NGST74	4586046.306	635375.010	145.954	4586046.315	635375.032	145.944	0.009	0.022	0.010
NGS-W-91	4616360.003	690299.165	37.797	4616360.006	690299.125	37.8	0.003	0.040	0.047

The above results indicate that the VRS network is providing positional values within the 5cm parameters for this survey.

2.5 *Adjustment*

The survey data was collected using Virtual Reference Stations (VRS) methodology within a Virtual Reference System (VRS).

The system is designed to provide a true Network RTK performance, the RTKNet software enables high-accuracy positioning in real time across a geographic region. The RTKNet software package uses real-time data streams from the GPSNet system user and generates correction models for high-accuracy RTK GPS corrections throughout the network. Therefore, corrections were applied to the points as they were being collected, thus negating the need for a post process adjustment.

2.6 *Data Processing Procedures*

After field data is collected the information is downloaded from the data collectors into the office software. The Software program used is called TBC or Trimble Business Center.

Downloaded data is run through the TBC program to obtain the following reports; points report, point comparison report and a point detail report. The reports are reviewed for point accuracy and precision.

After review of the point data an "ASCII" or "txt" file which is the industry standard is created. Point files are loaded into our CADD program (Carlson Survey 2014) to make a visual check of the point data (Pt. #, Coordinates, Elev. and Description). The data can now be imported into the final product.

3. *FINAL COORDINATES*

POINT #	NORTHING (M)	EASTING (M)	ELEV. (M)
Open Terrain			
OT-02	4648799.471	672618.271	367.501
OT-03	4654195.459	691109.575	70.506
OT-04	4636499.092	669456.981	107.434
OT-05	4638253.268	688620.629	53.489
OT-06	4629005.030	683810.468	136.368
OT-07	4625256.056	668529.580	247.485
OT-08	4619282.443	680963.687	128.570
OT-09	4609374.897	696501.999	11.952
OT-10	4597099.522	690365.149	68.856
OT-11	4592305.703	706399.271	52.672
OT-12	4580272.751	713390.064	24.442
OT-13	4613927.520	666052.337	182.934
OT-14	4596346.139	662750.702	61.326
OT-15	4583150.468	663379.426	104.365
OT-16	4578031.399	654935.140	155.627
OT-17	4585480.195	644895.515	94.708
OT-18	4588849.438	627258.405	185.890
OT-19	4602864.123	628821.058	214.061
OT-20	4597178.923	640490.207	72.204
OT-21	4605412.023	652300.432	131.955
Brush/Low Trees Terrain			
BLT-01	4568556.720	625240.084	216.206
BLT-02	4583032.937	623414.216	161.826

BLT-03	4584014.647	635952.350	139.963
BLT-04	4583372.976	651756.574	59.012
BLT-05	4574726.800	656999.596	129.194
BLT-06	4590472.925	658217.507	219.177
BLT-07	4596887.148	636362.430	166.603
BLT-08	4595374.752	643508.016	202.664
BLT-09	4604858.332	642805.092	289.812
BLT-10	4604116.148	656267.285	195.168
BLT-11	4605363.094	668438.124	157.738
BLT-12	4618390.972	674852.555	99.733
BLT-13	4609195.674	683247.983	52.098
BLT-14	4598053.148	696338.012	96.785
BLT-15	4583865.847	718511.202	0.530
BLT-16	4628066.527	674026.642	118.169
BLT-17	4637180.212	694747.429	17.091
BLT-18	4652220.739	695004.912	60.955
BLT-19	4646168.472	679447.559	106.872
BLT-20	4651231.284	665614.732	316.187
BLT-21	4634569.343	659330.731	326.691
Forest Terrain			
FO-01	4572804.812	622647.965	259.227
FO-02	4587783.805	624724.634	230.319
FO-03	4603791.846	625296.465	136.342
FO-04	4601265.448	645280.902	287.502
FO-05	4592451.795	637191.589	128.550
FO-06	4582523.204	640948.318	172.986
FO-07	4585961.576	648109.177	171.368

FO-08	4573296.977	662323.604	56.511
FO-09	4593243.767	650391.184	106.937
FO-10	4598970.65	655038.081	220.066
FO-11	4589140.296	666669.669	206.250
FO-12	4605771.609	682419.425	86.389
FO-13	4605793.834	682602.063	76.858
FO-14	4592573.401	690993.791	86.408
FO-15	4594425.231	702750.301	146.116
FO-16	4626852.815	680904.336	47.879
FO-17	4643402.668	668758.277	196.918
FO-18	4646501.688	687083.722	81.766
FO-19	4651650.804	673445.756	362.696
FO-20	4645556.034	664635.932	144.201
FO-21	4650400.706	657973.198	352.815
Grass/Weeds/Crops Terrain			
GWC-01	4576710.640	725192.098	6.484
GWC-02	4585862.772	709091.698	73.227
GWC-03	4600681.100	702632.641	63.903
GWC-04	4588219.549	692803.454	75.247
GWC-05	4607743.908	689106.758	74.443
GWC-06	4621378.387	678293.615	50.992
GWC-07	4637243.808	685747.152	68.889
GWC-08	4649302.395	685656.61	71.553
GWC-09	4642945.061	674829.863	303.76
GWC-10	4648195.598	662881.599	161.522
GWC-11	4647347.551	655257.033	351.326
GWC-12	4641824.276	662532.615	209.425

GWC-13	4632251.878	670402.542	150.176
GWC-14	4608012.327	668493.467	253.091
GWC-15	4609465.948	655635.392	221.467
GWC-16	4602285.475	637205.806	169.295
GWC-17	4599452.025	625102.243	219.265
GWC-18	4596265.700	632484.570	67.797
GWC-19	4578055.461	623392.506	234.985
GWC-20	4586613.684	639085.317	192.829
GWC-21	4588798.189	654042.179	98.705
Urban Terrain			
UT-01	4574911.846	719137.663	4.848
UT-02	4586203.724	711167.133	44.212
UT-03	4593996.750	693527.800	53.003
UT-04	4603217.016	696368.196	9.866
UT-05	4615610.685	684748.481	53.559
UT-06	4625088.355	694332.718	5.972
UT-07	4642959.850	692860.141	47.570
UT-08	4651414.309	690351.433	60.501
UT-09	4642529.709	660613.314	214.128
UT-10	4638384.265	667666.829	116.704
UT-11	4626267.465	668743.923	264.687
UT-12	4617043.050	671570.889	120.309
UT-13	4607513.162	657097.540	148.464
UT-14	4601580.398	663220.934	78.930
UT-15	4584668.679	661969.606	54.008
UT-16	4567960.076	659055.594	15.645
UT-17	4600543.502	649364.986	82.384

UT-18	**4602211.898**	**632028.475**	**89.668**
UT-19	**4591560.913**	**626489.933**	**190.722**
UT-20	**4584343.593**	**630651.566**	**117.668**
UT-21	**4571969.295**	**625784.958**	**197.372**

4. *GPS OBSERVATIONS*

POINT ID	OBSERV. DATE	JULIAN DATE	TIME OF DAY	RE-OBSERV. DATE	RE-OBSERV. TIME
Open Terrain					
OT-02	6/26/2014	177	13:17	N/A	N/A
OT-03	6/25/2014	176	18:21	6/26/2014	7:13
OT-04	6/26/2014	177	11:28	N/A	N/A
OT-05	6/26/2014	177	7:05	N/A	N/A
OT-06	6/26/2014	177	7:46	N/A	N/A
OT-07	6/25/2014	176	19:31	N/A	N/A
OT-08	6/25/2014	176	20:38	N/A	N/A
OT-09	6/25/2014	176	11:16	N/A	N/A
OT-10	6/24/2014	175	15:28	6/25/2014	6:13
OT-11	6/24/2014	175	18:46	6/25/2014	8:16
OT-12	6/25/2014	176	9:42	N/A	N/A
OT-13	6/25/2014	176	18:12	N/A	N/A
OT-14	6/25/2014	176	17:27	N/A	N/A
OT-15	6/22/2014	173	14:23	6/23/2014	8:48
OT-16	6/22/2014	173	13:20	6/23/2014	7:02
OT-17	6/23/2014	174	11:39	6/24/2014	5:46
OT-18	6/24/2014	175	10:38	6/25/2014	7:29
OT-19	6/24/2014	175	16:14	6/25/2014	6:13
OT-20	6/25/2014	176	8:55	6/26/2014	5:31
OT-21	6/25/2014	176	13:09	6/26/2014	5:58
Brush/Low Trees Terrain					
BLT-01	6/23/2014	174	18:18	6/24/2014	8:30
BLT-02	6/23/2014	174	15:57	6/24/2014	7:16
BLT-03	6/23/2014	174	14:53	6/24/2014	6:32
BLT-04	6/22/2014	173	17:48	6/23/2014	6:39
BLT-05	6/22/2014	173	13:01	6/23/2014	7:23
BLT-06	1/22/2015	22	7:50		
BLT-07	6/24/2014	175	13:19	6/25/2014	9:33
BLT-08	6/25/2014	176	9:20	N/A	N/A
BLT-09	6/24/2014	175	17:39	6/25/2014	9:48
BLT-10	6/25/2014	176	12:45	N/A	N/A
BLT-11	1/22/2015	22	9:00	N/A	N/A
BLT-12	1/22/2015	22	10:40	N/A	N/A
BLT-13	6/25/2014	176	13:17	N/A	N/A

BLT-14	6/24/2014	175	17:22	6/25/2014	9:22
BLT-15	6/25/2014	176	9:19	N/A	N/A
BLT-16	1/22/2015	22	11:30	N/A	N/A
BLT-17	6/25/2014	176	3:45	6/26/2014	5:48
BLT-18	1/22/2015	22	13:30	N/A	N/A
BLT-19	6/26/2014	177	12:55	N/A	N/A
BLT-20	1/22/2015	22	14:50	N/A	N/A
BLT-21	6/26/2014	177	10:29	N/A	N/A
Forest Terrain					
FO-01	6/23/2014	174	17:11	6/24/2014	7:49
FO-02	6/24/2014	175	9:57	6/25/2014	7:48
FO-03	1/22/2015	22	17:30	N/A	N/A
FO-04	6/24/2014	175	18:09	6/25/2014	5:13
FO-05	6/24/2014	175	11:50	6/25/2014	7:59
FO-06	6/23/2014	174	12:29	6/24/2014	6:03
FO-07	6/23/2014	174	10:38	6/24/2014	5:31
FO-08	1/22/2015	22	7:00	N/A	N/A
FO-09	6/25/2014	176	10:04	N/A	N/A
FO-10	1/22/2015	22	8:20	N/A	N/A
FO-11	6/22/2014	173	15:07	6/23/2014	9:09
FO-12	6/25/2014	176	15:19	N/A	N/A
FO-13	1/22/2015	22	9:30	N/A	N/A
FO-14	6/24/2014	175	14:42	6/25/2014	6:49
FO-15	6/24/2014	175	17:55	6/25/2014	9:02
FO-16	6/26/2014	177	8:30	N/A	N/A
FO-17	6/26/2014	177	11:25	N/A	N/A
FO-18	1/22/2015	22	13:05	N/A	N/A
FO-19	1/22/2015	22	14:20	N/A	N/A
FO-20	6/26/2014	177	10:49	N/A	N/A
FO-21	6/26/2014	177	9:29	N/A	N/A
Grass/Weeds/Crops Terrain					
GWC-01	6/25/2014	176	8:46	N/A	N/A
GWC-02	6/25/2014	176	10:07	N/A	N/A
GWC-03	6/24/2014	175	16:53	6/25/2014	5:49
GWC-04	6/24/2014	175	14:00	6/25/2014	7:11
GWC-05	6/25/2014	176	12:09	N/A	N/A
GWC-06	1/22/2015	22	11:00	N/A	N/A
GWC-07	1/22/2015	22	12:10	N/A	N/A
GWC-08	1/22/2015	22	14:00	N/A	N/A

GWC-09	**1/22/2015**	**22**	**12:40**	**N/A**	**N/A**
GWC-10	**1/22/2015**	**22**	**15:10**	**N/A**	**N/A**
GWC-11	**6/26/2014**	**177**	**12:17**	**N/A**	**N/A**
GWC-12	**1/22/2015**	**22**	**15:56**	**N/A**	**N/A**
GWC-13	**6/26/2014**	**177**	**9:48**	**N/A**	**N/A**
GWC-14	**6/25/2014**	**176**	**16:05**	**6/26/2014**	**6:26**
GWC-15	**6/25/2014**	**176**	**14:03**	**N/A**	**N/A**
GWC-16	**6/24/2014**	**175**	**17:11**	**6/25/2014**	**5:39**
GWC-17	**1/22/2015**	**22**	**18:00**	**N/A**	**N/A**
GWC-18	**6/24/2014**	**175**	**12:50**	**6/25/2014**	**9:16**
GWC-19	**6/23/2014**	**174**	**16:27**	**6/25/2014**	**8:23**
GWC-20	**6/23/2014**	**174**	**13:22**	**6/24/2014**	**6:16**
GWC-21	**6/22/2014**	**173**	**16:44**	**6/23/2014**	**6:13**
Urban Terrain					
UT-01	**6/25/2014**	**176**	**8:21**	**N/A**	**N/A**
UT-02	**6/24/2014**	**175**	**19:07**	**6/25/2014**	**8:35**
UT-03	**6/24/2014**	**175**	**15:04**	**6/25/2014**	**6:29**
UT-04	**6/24/2014**	**175**	**16:06**	**6/25/2014**	**5:32**
UT-05	**6/25/2014**	**176**	**13:52**	**N/A**	**N/A**
UT-06	**6/25/2014**	**176**	**15:12**	**N/A**	**N/A**
UT-07	**6/25/2014**	**176**	**12:24**	**6/26/2014**	**6:11**
UT-08	**6/25/2014**	**176**	**18:09**	**N/A**	**N/A**
UT-09	**6/26/2014**	**177**	**11:52**	**N/A**	**N/A**
UT-10	**6/26/2014**	**177**	**11:15**	**N/A**	**N/A**
UT-11	**6/25/2014**	**176**	**19:47**	**6/26/2014**	**6:59**
UT-12	**6/25/2014**	**176**	**19:01**	**N/A**	**N/A**
UT-13	**6/25/2014**	**176**	**13:39**	**N/A**	**N/A**
UT-14	**6/25/2014**	**176**	**17:09**	**N/A**	**N/A**
UT-15	**6/22/2014**	**173**	**13:56**	**6/23/2014**	**8:31**
UT-16	**6/22/2014**	**173**	**10:29**	**6/23/2014**	**7:51**
UT-17	**6/25/2014**	**176**	**12:11**	**N/A**	**N/A**
UT-18	**6/24/2014**	**175**	**16:39**	**6/25/2014**	**5:59**
UT-19	**6/24/2014**	**175**	**11:08**	**6/25/2014**	**7:09**
UT-20	**6/23/2014**	**174**	**15:27**	**6/24/2014**	**6:49**
UT-21	**6/23/2014**	**174**	**17:55**	**6/24/2014**	**8:13**

5. *POINT COMPARISON*

POINT ID	POINT CK	DELTA NORTH (M)	DELTA EAST (M)	VERT. DIFF (M)
Open Terrain				
OT-03	OT-03CK	0.002	0.005	0.028
OT-10	OT-10CK	0.000	0.001	0.003
OT-11	OT-11CK	0.001	0.002	0.011
OT-15	OT-15CK	0.005	0.005	0.005
OT-16	OT-16CK	0.001	0.002	0.010
OT-17	OT-17CK	0.020	0.009	0.027
OT-18	OT-18CK	0.006	0.002	0.030
OT-19	OT-19CK	0.007	0.002	0.004
OT-20	OT-20CK	0.000	0.002	0.023
OT-21	OT-21CK	0.002	0.007	0.001
Brush/Low Trees Terrain				
BLT-01	BLT-01CK	0.003	0.001	0.000
BLT-02	BLT-02CK	0.001	0.002	0.011
BLT-03	BLT-03CK	0.011	0.004	0.025
BLT-04	BLT-04CK	0.004	0.018	0.015
BLT-05	BLT-05CK	0.009	0.002	0.001
BLT-06	BLT-06CK	0.002	0.008	0.006
BLT-07	BLT-07CK	0.000	0.002	0.010
BLT-09	BLT-09CK	0.003	0.007	0.017
BLT-14	BLT-14CK	0.002	0.001	0.012
BLT-17	BLT-17CK	0.008	0.020	0.065
BLT-18	BLT-18CK	0.002	0.005	0.017
Forest Terrain				
FO-01	FO-01CK	0.007	0.005	0.014
FO-02	FO-02CK	0.001	0.003	0.003
FO-03	FO-03CK	0.011	0.004	0.005
FO-04	FO-04CK	0.002	0.005	0.017
FO-05	FO-05CK	0.020	0.001	0.004
FO-06	FO-06CK	0.009	0.013	0.031
FO-07	FO-07CK	0.002	0.004	0.015
FO-08	FO-08CK	0.011	0.004	0.005
FO-11	FO-13CK	0.001	0.009	0.002
FO-14	FO-14CK	0.023	0.012	0.006
FO-15	FO-15CK	0.016	0.004	0.028

Grass/Weeds/Crops Terrain				
GWC-03	GWC-03CK	0.020	0.001	0.004
GWC-04	GWC-04CK	0.001	0.007	0.002
GWC-08	GWC-08CK	0.006	0.016	0.006
GWC-14	GWC-14CK	0.001	0.002	0.008
GWC-16	GWC-16CK	0.012	0.005	0.019
GWC-18	GWC-18CK	0.001	0.002	0.005
GWC-19	GWC-19CK	0.002	0.004	0.018
GWC-20	GWC-20CK	0.004	0.004	0.026
GWC-21	GWC-21CK	0.005	0.002	0.039
Urban Terrain				
UT-02	UT-02CK	0.000	0.002	0.008
UT-03	UT-03CK	0.001	0.001	0.020
UT-04	UT-04CK	0.000	0.005	0.017
UT-07	UT-07CK	0.004	0.023	0.040
UT-11	UT-11CK	0.005	0.000	0.003
UT-15	UT-15CK	0.004	0.000	0.003
UT-16	UT-16CK	0.001	0.004	0.004
UT-18	UT-18CK	0.005	0.003	0.010
UT-19	UT-19CK	0.015	0.009	0.028
UT-20	UT-20CK	0.006	0.005	0.001
UT-21	UT-21CK	0.003	0.006	0.006

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Dewberry Response to USGS Review of the Connecticut SANDY LiDAR Project

Produced for U.S. Geological Survey

USGS Contract: G10PC00013

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Report Date: 6/5/2015

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Table of Contents

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 USGS Connecticut SANDY LiDAR Project Area.

The LiDAR data were processed to a bare-earth digital terrain models (DTM). Detailed breaklines and bare-earth digital elevation Models (DEMs) were produced for the project area.

Deliverables for this project included raw point cloud data, classified point cloud data, bare earth hydro enforced digital elevation models, intensity images, breaklines, control points, metadata, project report, and project extent shapefiles.

The USGS second review of these deliverables resulted in one call to remove building points, four calls to clean up elevation transitions at dams, six calls to modify the elevation transitions in stream and river hydro features, and two calls to modify existing hydro features.

PROJECT AREA

Data was formatted according to tiles with each tile covering an area of 1500m by 1500m. A total of 1,974 tiles were produced for the project encompassing an area of approximately 1,526 sq. miles.

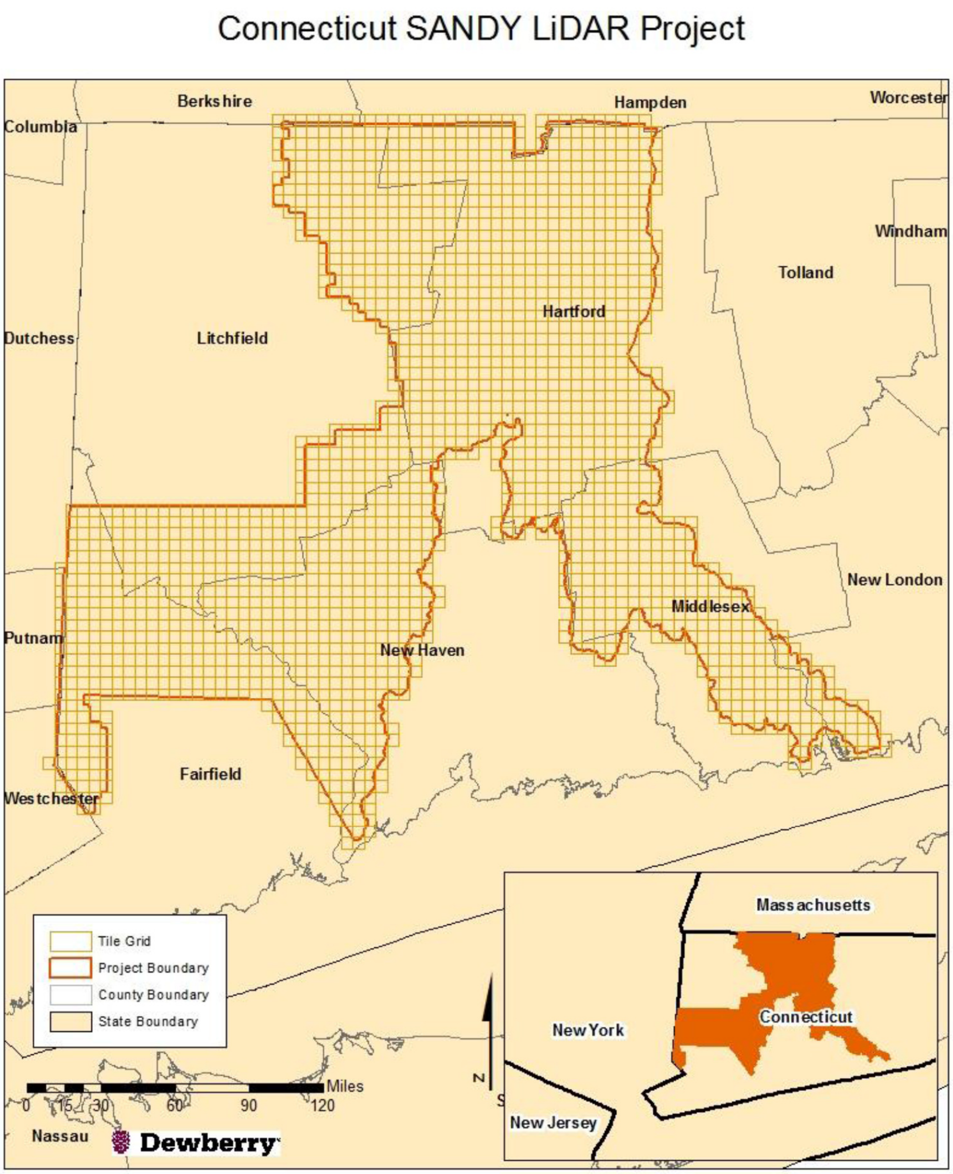

Figure 1- Project Map

Edit Calls

METADATA

The "Streams and Rivers" and "Lakes and Ponds" breakline metadata has been re-delivered with an updated feature count.

ARTIFACTS

There was one call to remove building features from the ground surface, and the feature was corrected.

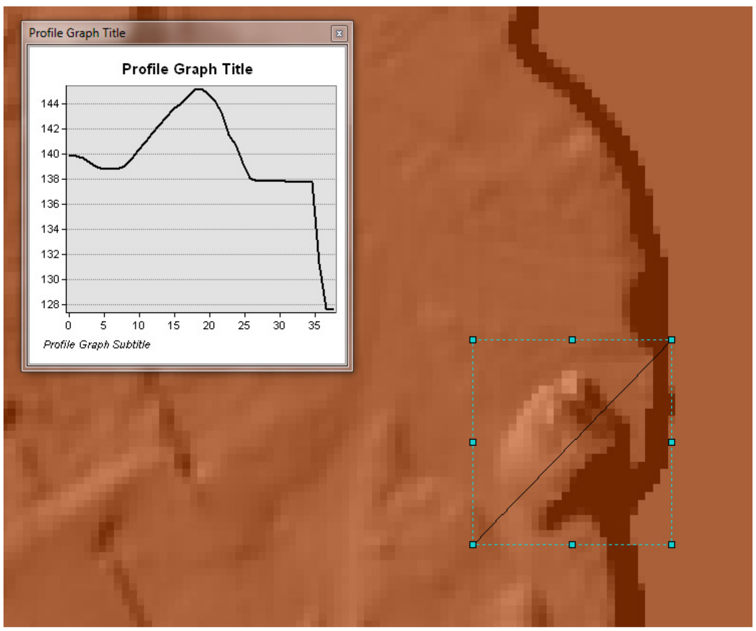

Figure 2 – Edit Call – Remove Building tile 18TXM630608

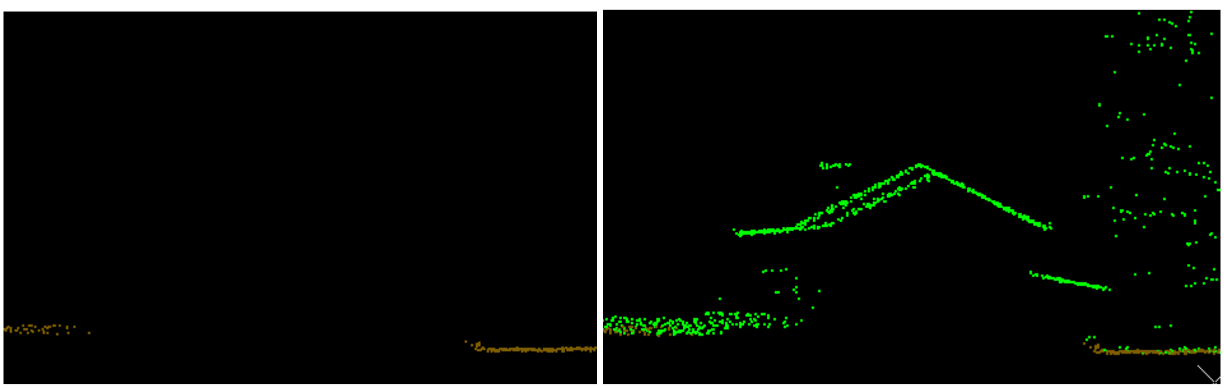

Figure 3 – Edit Call – Remove Building tile 18TXM630608. Left profile shows ground points (orange). Right profile shows ground (orange) and reclassified Class 1 (green) points.

ELEVATION TRANSITIONS AT DAMS

USGS identified several issues with elevation transitions and in four instances those issues were caused by dams. The example below shows a waterbody that was digging deeply into the surrounding ground. USGS called out two possible dams and Dewberry added these features to the breaklines.

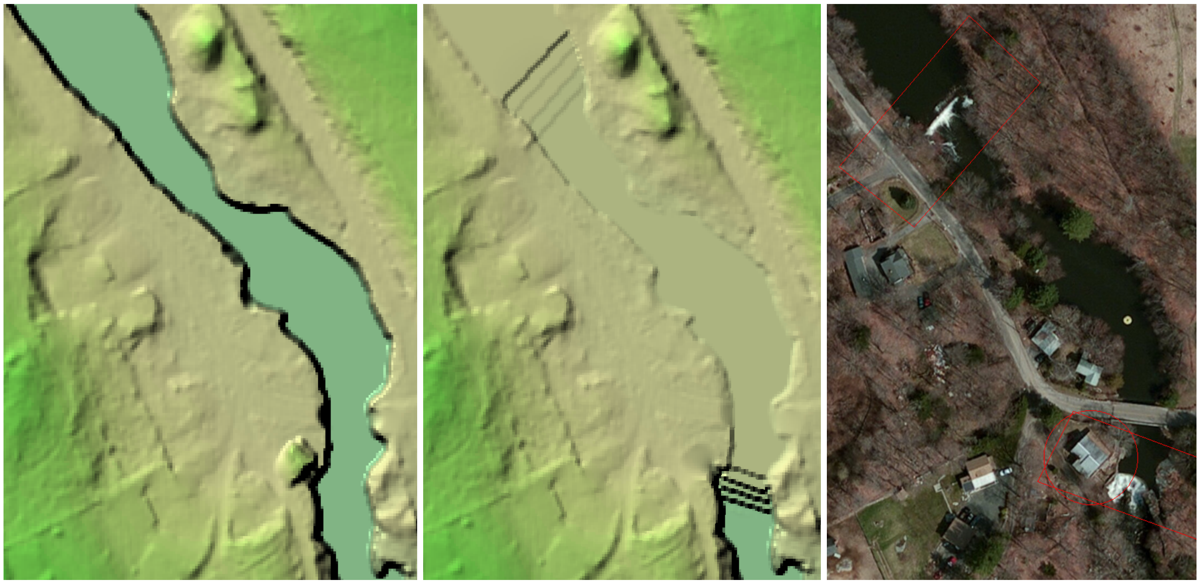

Figure 4 – Tile 18TXM630608 – The two dam features within this waterbody (now river) allow the water level to drop from over 138 meters to under 126 meters at the appropriate locations.

ELEVATION TRANSITIONS

USGS identified six areas in which the elevation transitions in streams and rivers were too abrupt. The specification for elevation transitions is that they must be no greater than 0.3 meters. Dewberry has reduced the transitions at the flagged locations to 0.15 meters.

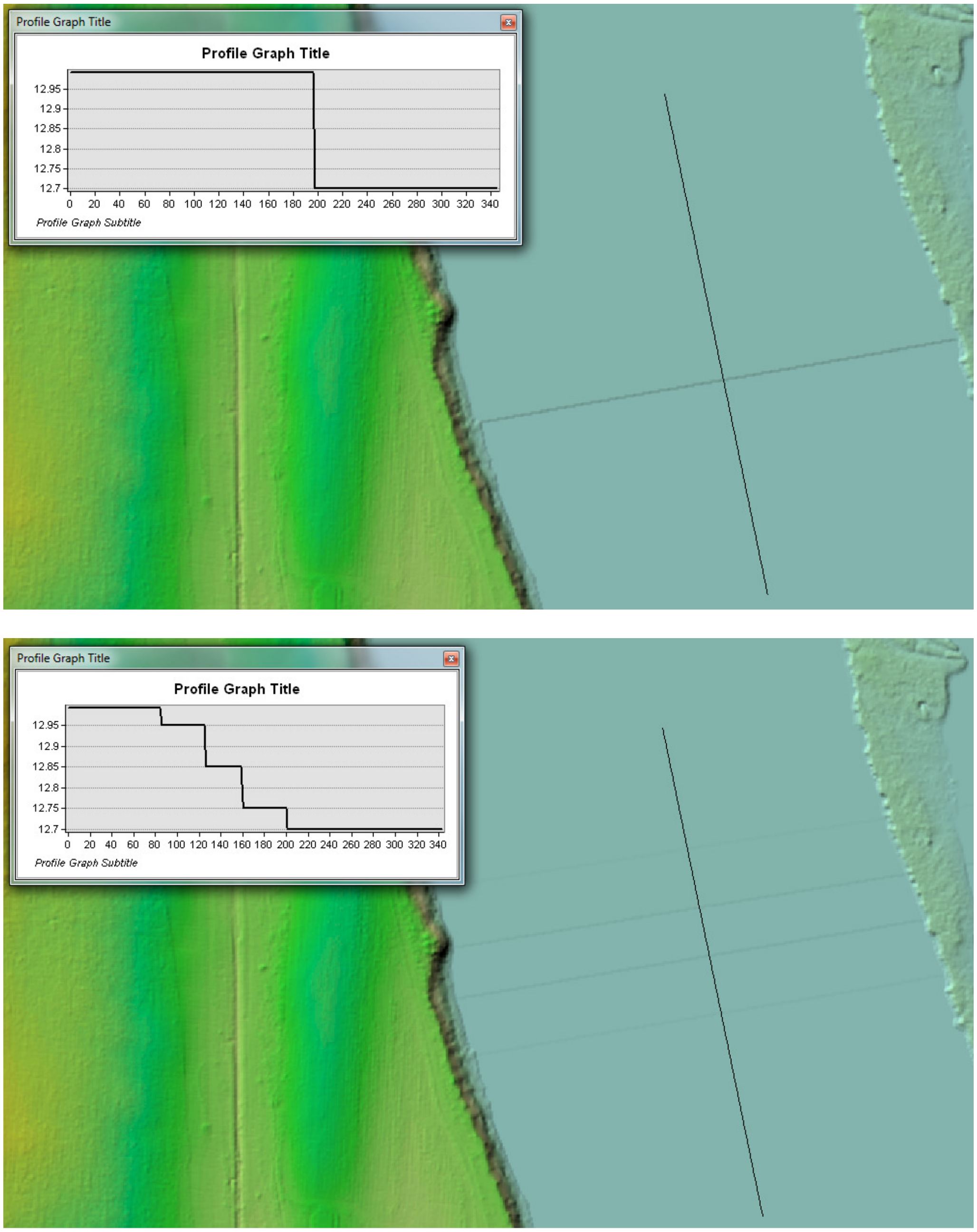

Figure 5 – Tile 18TXM975654. This elevation transition was corrected. The upper image shows the original DEM, the lower image shows the corrected DEM. The elevation transition was modified from one 25cm step to several 5 and 10 cm steps.

BREAKLINE ADJUSTMENTS

There were two locations where USGS identified areas where the breaklines should be removed. After reviewing the LiDAR, Dewberry confirmed that there were significant ground features in those areas and the breaklines were adjusted; one stream was adjusted and one pond was removed.

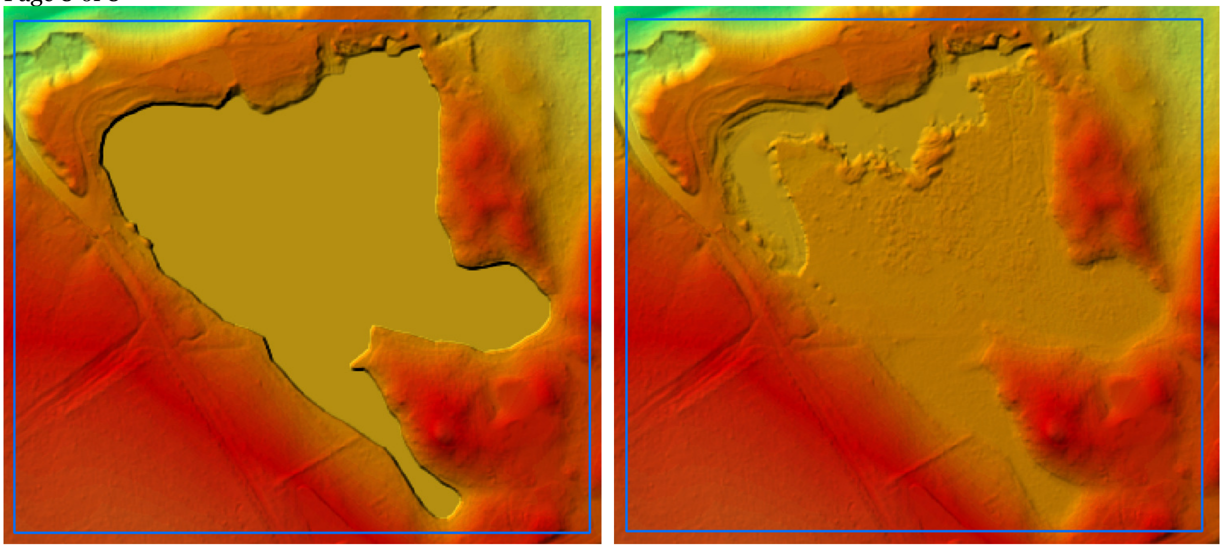

Figure 6 – Tile 18TXM555602 – A pond breakline was removed from the DEM and the LiDAR was reclassified to ground.

Summary of Edit Calls

- There were 13 calls in total. All calls were fixed.