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NY FEMA R2 CENTRAL 2018 D19- Block 02

Report Produced for U.S. Geological Survey

USGS Contract: G10PC00013

Task Order: 140G0219F0007

Report Date: 11/10/2020

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Contents

Task Order Name: USGS 140G0219F0007-NY_FEMAR2_Central_2018_D19

Date: 11/04/2020

Product: Lidar, Breaklines, DEMs, DZ Orthos, and Metadata for Lot 7: Block-2 interim deliverables

Overview

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 – New York FEMA Region 2 Central Project Area. The project includes Quality Level 2 (QL2) lidar acquisition, processing and derivative products development and data management to support the identification of flood-prone areas under Risk MAP program. The project area covers approximately 15,742 square miles over 11 full counties and 15 partial counties in New York State spanning over major geographical landforms include Hudson highlands, Hudson/Mohawk lowlands and Catskill Mountains in Southeast, Allegheny plateau in Southwest, Erie/Ontario Lowlands in Northwest and Adirondack Mountains in Northeast regions.

The project has been divided into 8 delivery blocks for interim deliveries and feedback as shown in figure-1. Data was formatted according to tiles with each tile covering an area of 1000m by 1000m (1 square kilometer). A total of 7,094 tiles were produced for the Block-2 deliverables of the project area encompassing an area of approximately 2,396 sq. miles. The lidar data were processed and classified according to project specifications. Detailed hydro breaklines, bare earth Digital Elevation Models (DEMs) and metadata were produced for the Block-2 deliverables.

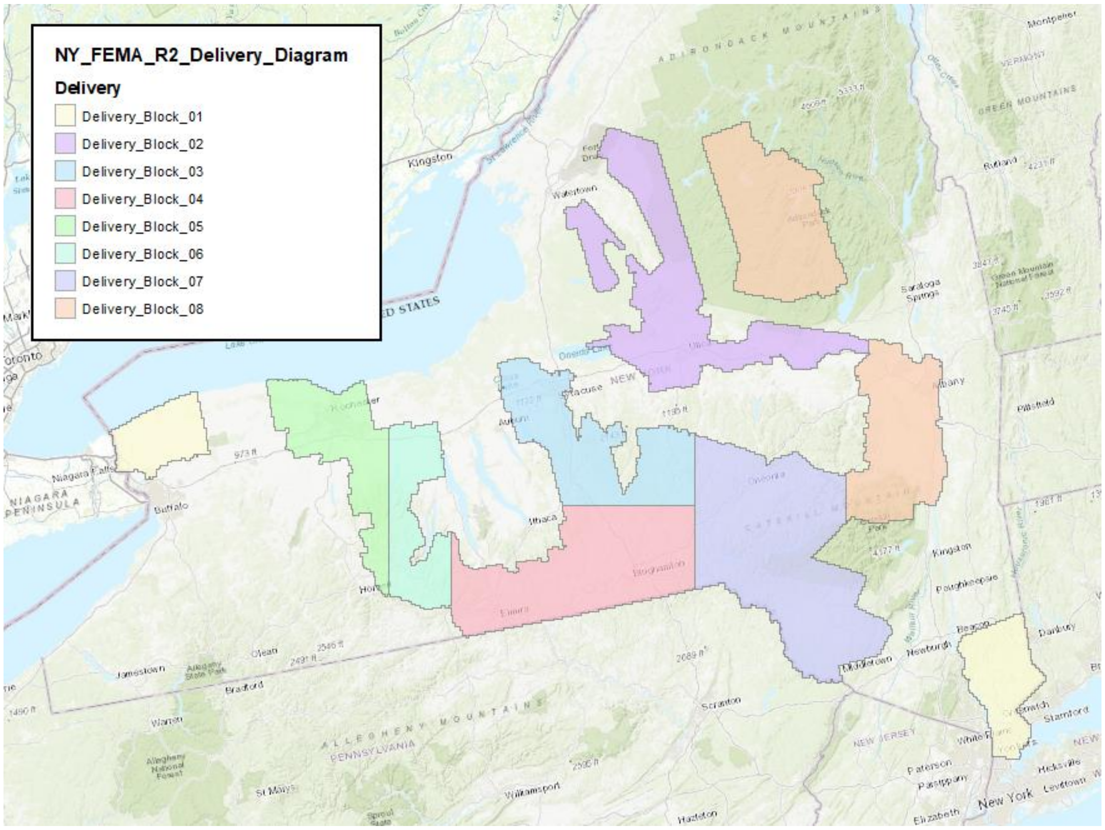


Figure 1: NY FEMA R2 2018 D19 - Delivery Blocks

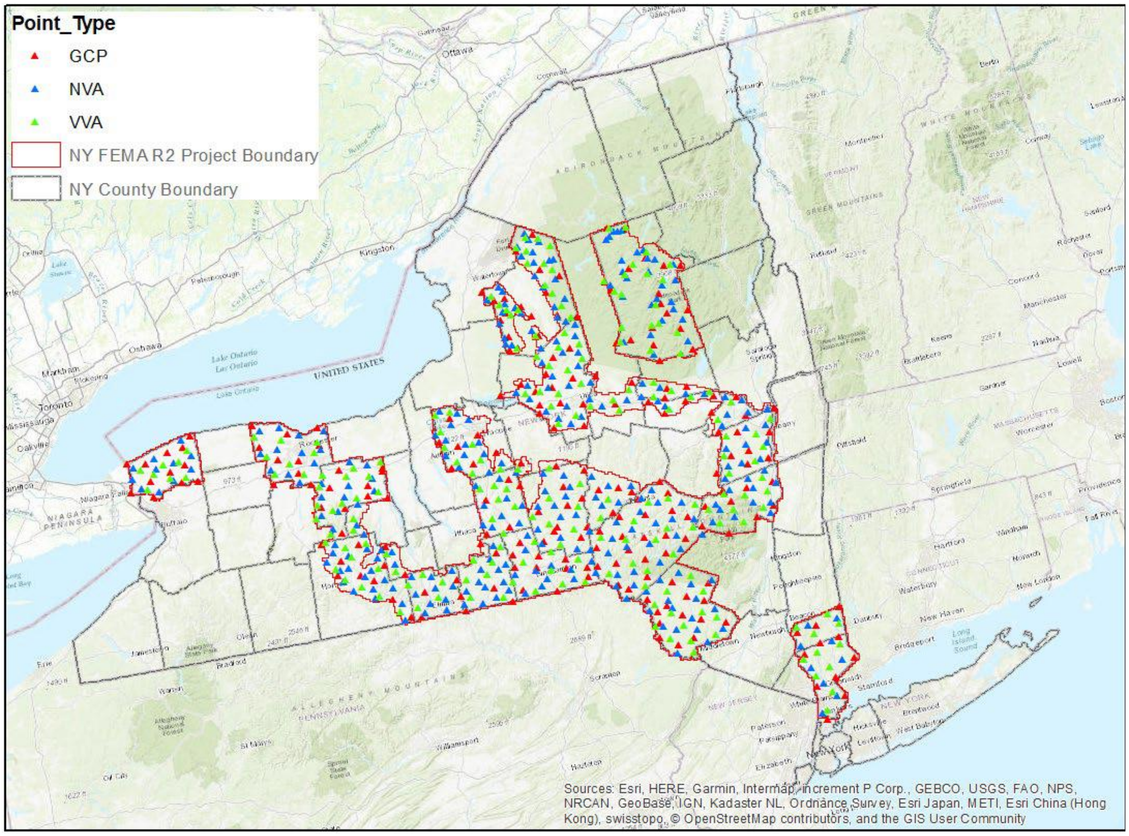
THE PROJECT TEAM

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

Dewberry's Gary D. Simpson, L.S. and team completed ground surveying for the project and delivered surveyed checkpoints. The task was to acquire surveyed calibration control and checkpoints for the project to use in independent testing of the vertical accuracy of the lidar-derived surface model. Survey team also verified the GPS base station coordinates used during lidar data acquisition to ensure that the base station coordinates were accurate.

SURVEY AREA

Dewberry Engineers Inc. is under contract to USGS United States Geological Survey to provide 509 check points in the State of New York. Under the above referenced USGS Task Order, Dewberry is tasked to complete the quality assurance of lidar mapping products. As part of this work Dewberry survey team completed Ground Control Point surveys that will be used to evaluate the mapping accuracy. The ground survey was conducted between the dates of January 28, 2019 and June 21, 2019. Detailed survey reports which include field reports, photos and surveyed control and check points for entire project area were submitted to USGS on 07/15/2019.



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Figure 2: NY FEMA R2 - GPS Survey Points (CP, NVA and VVA Points)

DATE OF SURVEY

The lidar aerial acquisition was conducted from May 18, 2019 and September 24, 2020.

COORDINATE REFERENCE SYSTEM

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 with the 2011 Adjustment (NAD 83 (2011))

Vertical Datum: The Vertical datum for the project is North American Vertical Datum of 1988 (NAVD88)

Coordinate System: Albers Equal Area

Units: Horizontal units are in meters, Vertical units are in meters.

Geiod Model: Geoid12B (Geoid 12B was used to convert ellipsoid heights to orthometric heights).

PROJECT DELIVERABLES

The deliverables for the project are listed below.

1. Classified Point Cloud Data (Tiled)
2. Bare Earth Surface (Raster DEM – IMG Format)
3. Intensity Images (8-bit gray scale, tiled, GeoTIFF format)
4. DZ Ortho Imagery (TIFF Format)
5. Intra/Interswath polygons (Shapefiles)
6. Breakline Data (File GDB)
7. Independent Survey Checkpoint Data (Report, Photos, & Points)
8. Calibration Points
9. Metadata
10. Project Report (Acquisition, Processing, QC)
11. Project Extents, including a shapefile derived from the lidar deliverable

PROJECT TILING FOOTPRINT

NY FEMA R2 2018 D19 project contains 44,764 one square kilometer tiles. Seven thousand ninety-four (7,094) tiles of Delivery Block-2 were delivered as part of this Lot-7 interim deliverable for the project. Each tile's extent is 1,000 meters by 1,000 meters.

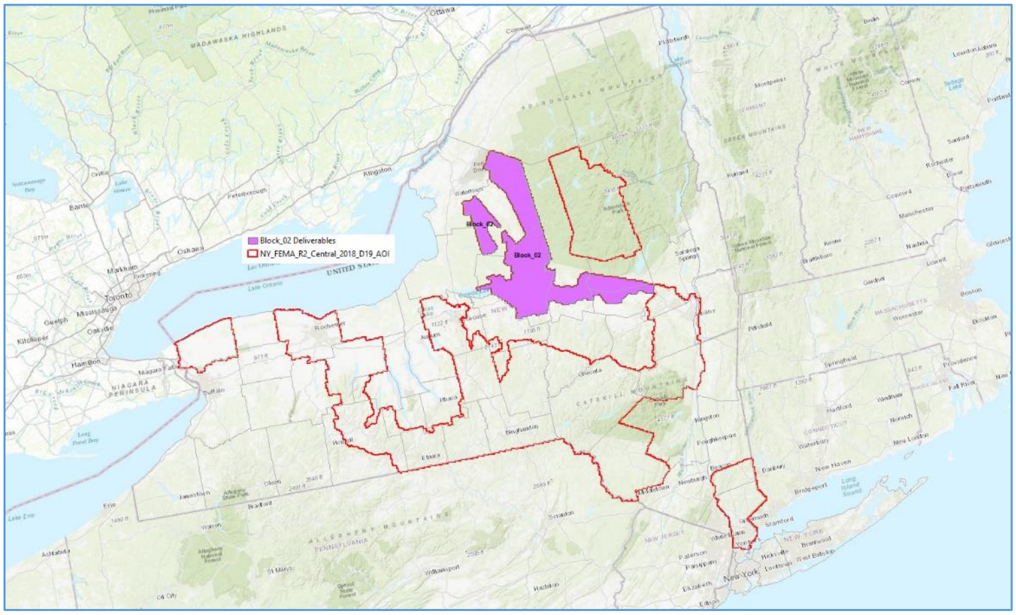


Figure 3 – Lot-7: Delivery Block-2

Lidar Acquisition Report

Dewberry elected to subcontract the lidar acquisition and calibration activities to acquisition providers Axis Geospatial (Axis), Airborne Imaging, Aerial Services (ASI) and Leading Edge Geomatics (LEG).

Dewberry allocated selective AOIs for each subcontractor based on the geographic distribution of the area and subcontractor’s capacity and availability as shown figure 4 below. Acquisition provider Leading Edge Geomatics (LEG was responsible for providing lidar acquisition, calibration and delivery of lidar data files to Dewberry for Delivery Block-2.

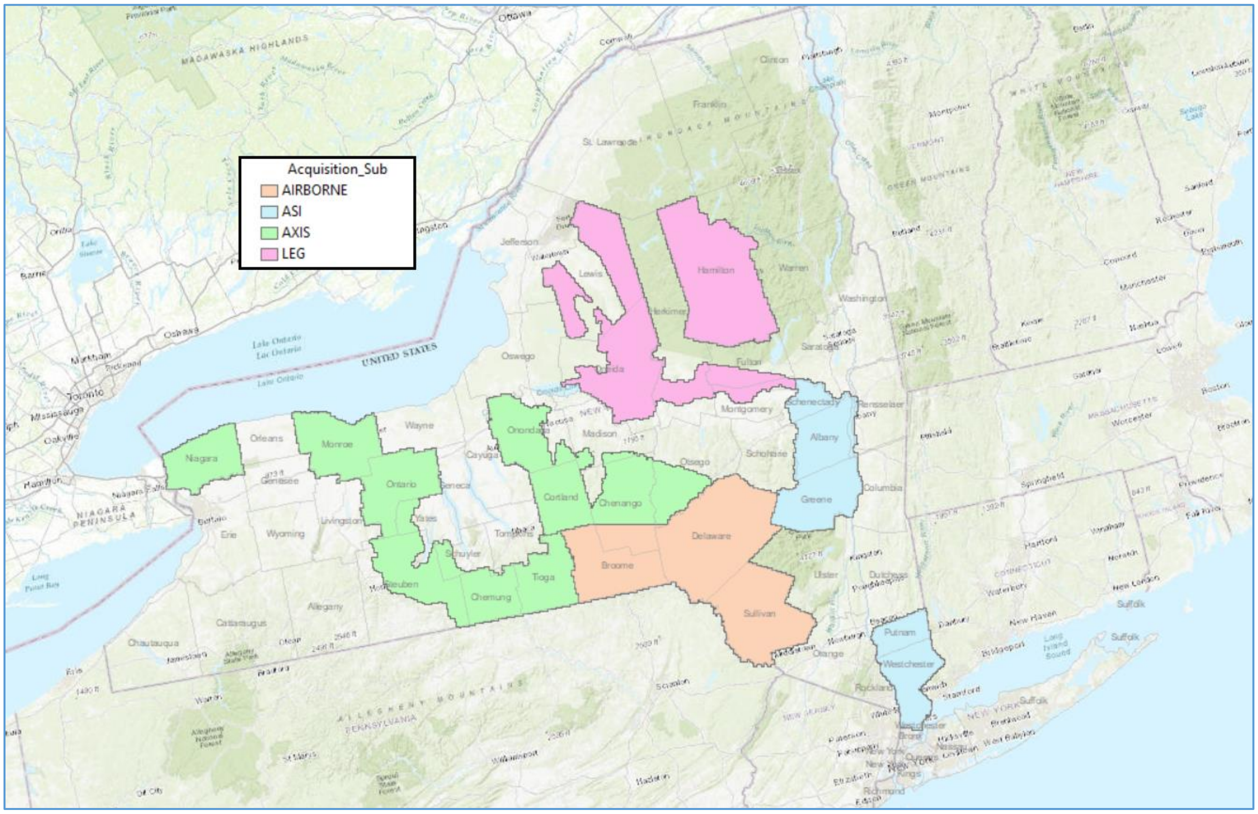


Figure 4: NY FEMA R2 Central - Lidar Acquisition Subcontractors

LIDAR ACQUISITION DETAILS

Acquisition provider LEG planned 150 passes for the delivery block-2 using Riegl VQ-1560i sensor as a series of parallel flight lines with cross flightlines for the purposes of quality control. The flight plan included zigzag flight line collection as a result of the inherent IMU drift associated with all IMU systems. In order to reduce any margin for error in the flight plan, acquisition providers followed project specifications for flight planning and, at a minimum, includes the following criteria:

- A digital flight line layout using Riegl Ri-parameter flight design software for direct integration into the aircraft flight navigation system for respective sensors used for lidar acquisition
- Planned flight lines; flight line numbers; and coverage area.
- Lidar coverage extended by a predetermined margin beyond all project borders to ensure necessary over-edge coverage appropriate for specific task order deliverables.
- Local restrictions related to air space and any controlled areas have been investigated so that required permissions can be obtained in a timely manner with respect to schedule.
- Additionally, Leading Edge Geomatics (LEG) filed our flight plans as required by local Air Traffic Control (ATC) prior to each mission.

Acquisition providers and Dewberry monitored weather and atmospheric conditions and conducted lidar missions only when no conditions exist below the sensor that will affect the collection of data. These conditions include leaf-off for hardwoods, no snow, rain, fog, smoke, mist and low clouds. Lidar systems are active sensors, not requiring light, thus missions may be conducted during night hours when weather restrictions do not prevent collection. We access reliable weather sites and indicators (webcams) to establish the highest probability for successful collection in order to position our sensor to maximize successful data acquisition.

Within 72-hours prior to the planned day(s) of acquisition, acquisition providers closely monitored the weather, checking all sources for forecasts at least twice daily. As soon as weather conditions were conducive to acquisition, our aircraft mobilized to the project site to begin data collection. Once on site, the acquisition team took responsibility for weather analysis.

LIDAR SYSTEM PARAMETERS

LEG operated a Cessna T206H (Tail # C-GPTG) and outfitted with a Riegl VQ-1560i lidar system during the collection of the respective allocated area. Table below illustrate LEG system parameters for lidar acquisition on this project.

LEG : Delivery Block-2 (Partial counties – Lewis, Herkimer, Oneida, Fulton and Montgomery)

Item	Parameter
System	VQ 1560i
Altitude (AGL meters)	1600
Approx. Flight Speed (knots)	130
Scanner Pulse Rate (kHz)	500
Scan Frequency (hz)	110
Pulse Duration of the Scanner (nanoseconds)	3
Pulse Width of the Scanner (m)	0.465
Swath width (m)	1790
Central Wavelength of the Sensor Laser (nanometers)	1064
Did the Sensor Operate with Multiple Pulses in The Air? (yes/no)	Yes
Beam Divergence (milliradians)	</= 0.5
Nominal Swath Width on the Ground (m)	1790
Swath Overlap (%)	Not less than 20%
Total Sensor Scan Angle (degree)	58
Computed Down Track spacing (m) per beam	0.61
Computed Cross Track Spacing (m) per beam	0.62
Nominal Pulse Spacing (single swath), (m)	0.70
Nominal Pulse Density (single swath) (ppsm), (m)	2

Item	Parameter
Aggregate NPS (m) (if ANPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.7
Aggregate NPD (m) (if ANPD was designed to be met through single coverage, ANPD and NPD will be equal)	2
Maximum Number of Returns per Pulse	7

Table 1: Acquisition Provider LEG lidar system parameters

ACQUISITION STATUS REPORT AND FLIGHTLINES

Upon notification to proceed, the flight crew loaded the flight plans and validated the flight parameters. The acquisition manager contacted air traffic control and coordinated flight pattern requirements. Lidar acquisition began immediately upon notification that control base stations were in place. During flight operations, the flight crew monitored weather and atmospheric conditions. Lidar missions were flown only when no condition existed below the sensor that would affect the collection of data. The pilot constantly monitored the aircraft course, position, pitch, roll, and yaw of the aircraft. The sensor operator monitored the sensor, the status of PDOPs, and performed the first Q/C review during acquisition. The flight crew constantly reviewed weather and cloud locations. Any flight lines impacted by unfavorable conditions were marked as invalid and re-flown immediately or at an optimal time.

Figure 5 shows the combined trajectory of the flight lines from acquisition provider.

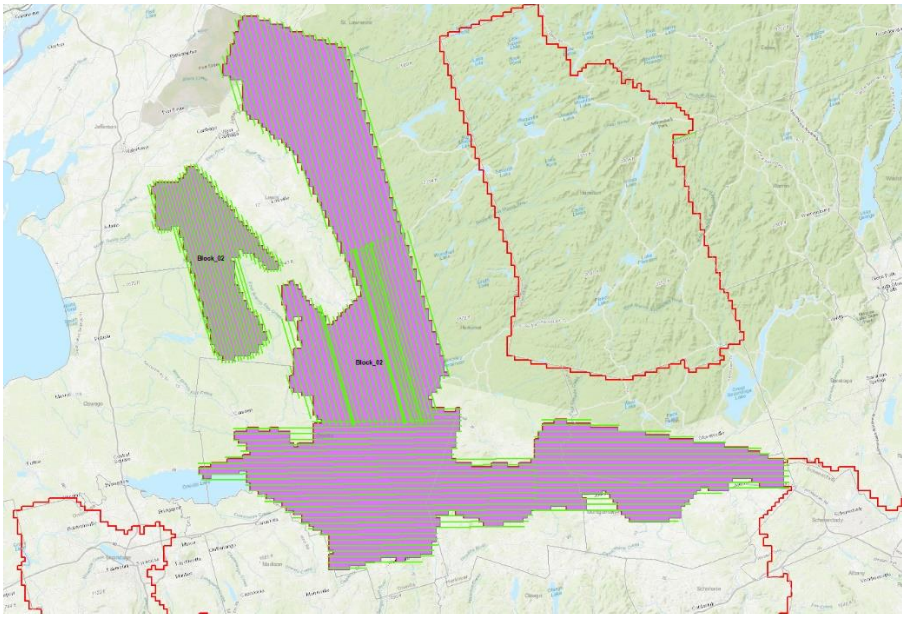


Figure 5: Trajectories as flown by Acquisition Provider LEG

LEADING EDGE GEOMATICS GPS KINEMATIC

Leading Edge Geomatics GPS data was processed using the PosPac MMS software suite. Flights were flown with a minimum of 6 satellites in view (13° above the horizon) and with a PDOP of better than 4. Distances from base station to aircraft were kept to a maximum of 40 km.

For all flights, the GPS data can be classified as excellent, with GPS residuals of 4 cm average or better but no larger than 6 cm being recorded.

GPS processing reports for each mission are included in Appendix A.

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 respective sensor software, initially with default values or the last mission calibrated for the system. 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.

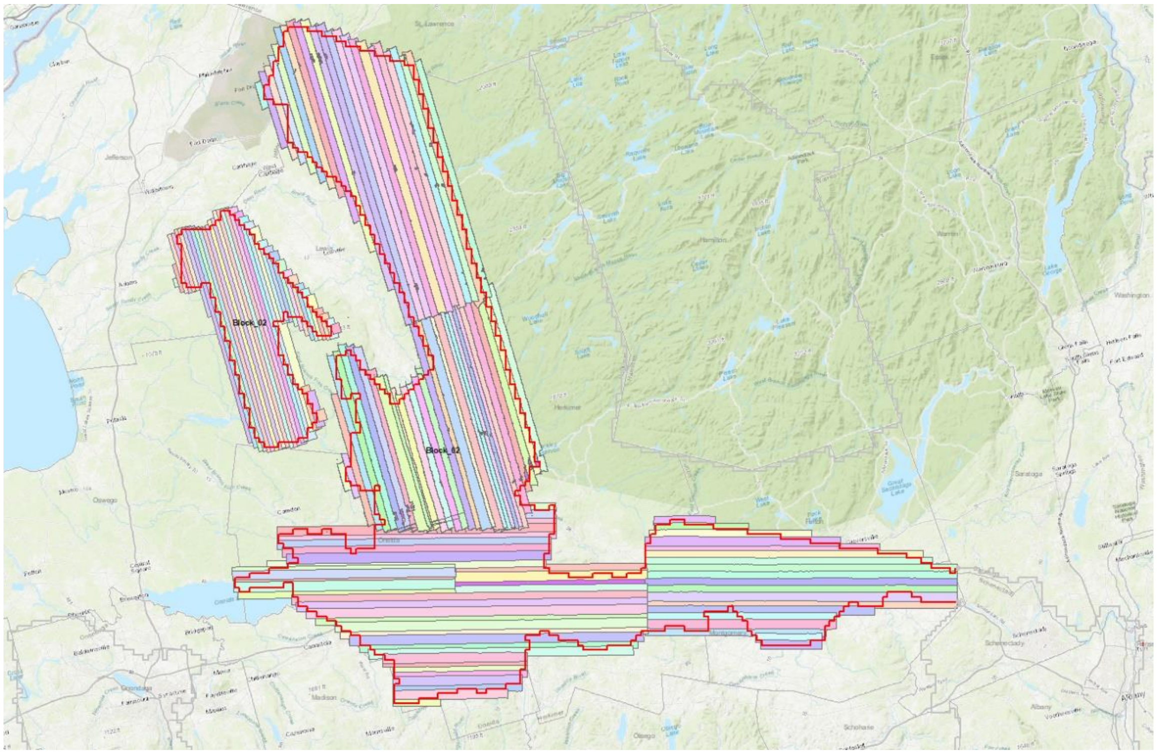


Figure 6: Lidar swath output showing complete coverage

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 using at least 3 regularly spaced QC blocks in which points from all lines are loaded and inspected. 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 <= 6 cm maximum difference within individual swaths and <=8 cm RMSDz between adjacent and overlapping swaths.

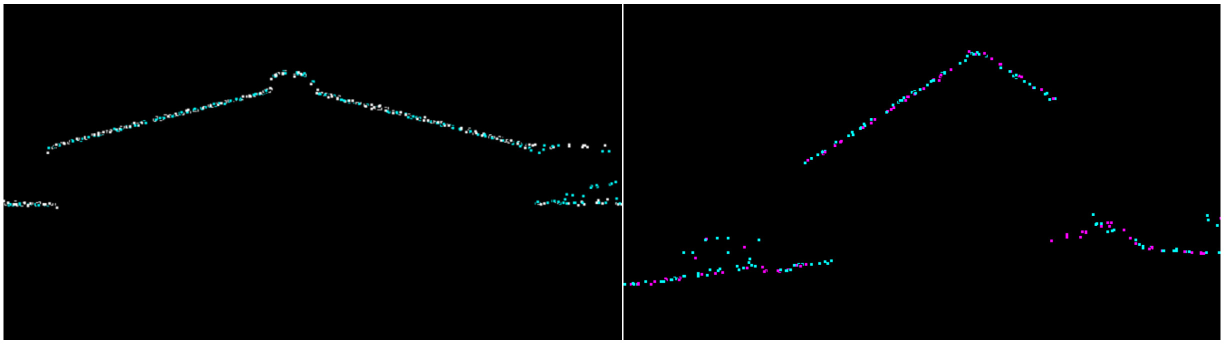


Figure 7: Profile views showing correct roll and pitch adjustments

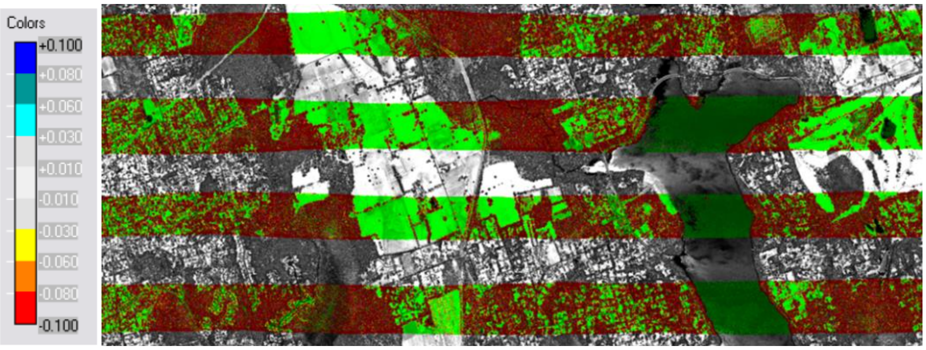


Figure 8: QC block colored by distance to ensure accuracy at swath edges

A different set of QC blocks are generated for final review after all transformations have been applied.

PRELIMINARY VERTICAL ACCURACY ASSESSMENT

A preliminary $RMSE_Z$ error check is performed by acquisition providers for their respective acquisition areas at this stage of the project life cycle in the raw lidar dataset against GPS static and kinematic data and compared to $RMSE_Z$ project specifications. The lidar data is examined in non-vegetated, flat areas away from breaks. Lidar ground points for each flight line generated by an automatic classification routine are used.

Prior to delivery to Dewberry, the elevation data was verified internally to ensure it met Nonvegetated Vertical Accuracy (NVA) requirements ($RMSE_Z$ ≤ 10 cm and $Accuracy_Z$ at the 95% confidence level ≤ 19.6 cm) when compared to static and kinematic GPS checkpoints. Below is a summary for the test:

The calibrated lidar dataset was tested to 0.020 m vertical accuracy at 95% confidence level based on RMSE2 (0.05 m x 1.9600) when compared to 40 GPS static check points.

The following are the final statistics for the GPS static checkpoints used by Acquisition Provider LEG to internally verify vertical accuracy.

Point Id	NAD83(2011) Albers		NAVD88 (Geoid 12B)		
	Easting X (m)	Northing Y (m)	Known Z (m)	Laser Z (m)	Delta Z
422	1627604.925	2427466.219	154.489	154.536	0.047
423	1613650.861	2420085.781	120.502	120.507	0.005
424	1640266.142	2407897.691	153.039	152.980	-0.059
425	1649087.709	2426046.463	139.221	139.242	0.021
426	1669862.202	2414802.915	176.950	177.000	0.050
427	1670534.192	2399482.867	380.095	380.091	-0.004
428	1702463.219	2429481.729	328.150	328.071	-0.079
429	1714048.922	2415582.076	98.486	98.561	0.075
430	1739759.924	2426739.894	252.070	252.055	-0.015
431	1738988.971	2416375.876	91.072	91.149	0.077
432	1758011.287	2419831.383	211.319	211.352	0.033
433	1725228.228	2418401.542	208.425	208.448	0.023
434	1691468.610	2414791.471	146.280	146.357	0.077
435	1649974.407	2398504.857	291.395	291.388	-0.007
436	1654432.262	2415397.291	160.168	160.180	0.012
437	1637406.837	2422709.099	131.050	131.016	-0.034
501	1601099.590	2490116.642	283.809	283.741	-0.068
502	1616842.893	2485867.601	494.985	494.976	-0.010
503	1620168.782	2450913.240	368.725	368.705	-0.020
505	1617644.155	2476268.683	567.809	567.633	-0.176
506	1609884.124	2484355.744	476.983	476.909	-0.074
507	1635671.545	2529351.502	260.936	260.954	0.018
508	1624406.301	2517959.764	249.872	249.933	0.061
509	1640424.556	2505307.477	296.106	296.076	-0.030
510	1640092.275	2460637.578	504.269	504.321	0.052
511	1644352.969	2434498.807	192.065	192.106	0.041
512	1662851.405	2431843.696	191.757	191.774	0.017
513	1678620.774	2433659.218	220.496	220.593	0.097
514	1660749.146	2452199.143	365.232	365.208	-0.024
515	1652302.203	2474673.024	374.617	374.623	0.006
516	1665827.490	2473260.747	471.287	471.369	0.082
517	1653761.583	2501189.015	477.502	477.384	-0.119

518	1644663.948	2490051.301	358.242	358.183	-0.059
536	1627598.451	2480528.640	562.012	562.002	-0.010
537	1613564.350	2471364.811	530.958	530.802	-0.157
538	1626142.729	2452040.846	391.674	391.631	-0.044
539	1619167.042	2459933.124	482.239	482.137	-0.103
540	1726519.078	2425050.890	336.442	336.371	-0.071
541	1724968.363	2408059.664	108.065	108.006	-0.059
544	1649643.177	2445676.021	224.917	224.945	0.028

Table 2 - Static GPS Points

100 % of Totals	# of Points	RMSEz (m) NVA Spec=0.1 m	NVA at 95% Spec=0.196 m	Mean (m)	Std Dev (m)	Min (m)	Max (m)
Non-Vegetated Terrain	40	0.010	0.020	-0.010	0.65	-0.176	0.097

Table 3 - Static GPS Vertical Accuracy Results

Overall the calibrated lidar data products collected by acquisition provider meets or exceeds the requirements set out in the Statement of Work. The quality control requirements of acquisition provider (LEG) quality management program were adhered to throughout the acquisition stage for this project to ensure product quality.

The tables below outline the deliverable requirements for this project and the tested positional accuracy.

Swath Lidar Formatting

Parameter	Requirement	Pass/Fail
Overlap and Withheld Points	Withheld and Overlap Bits required	Pass
Coordinate Reference System	LAS files should have the projection/datum defined.	Pass
Spatial Reference Information	Variable Length Record should be in Well Known Text (WKT) format	Pass
Point Data Format	Should be format 6	Pass
Global Encoder Bit	Should be 17 for Adjusted GPS Time	Pass
System ID	Should be recorded in the LAS header for determination of processing system	Pass
Major Version	Should be 1 (for LAS 1.4)	Pass
Minor Version	Should be 4 (for LAS 1.4)	Pass
Classes	Swath Data should be classified to Class 0	Pass
Time Stamp	Should be documented and meet the project requirement for Adjusted GPS Time	Pass

Multiple Returns	The sensor shall be able to collect multiple returns per pulse and the return numbers are recorded	Pass
Intensity	16 bit intensity values are recorded for each pulse	Pass

Lidar Processing & Qualitative Assessment

INITIAL PROCESSING

Following receipt of the calibrated swath data from the acquisition provider, Dewberry performed vertical accuracy validation of the swath data, inter-swath relative accuracy validation, intra-swath relative accuracy validation, verification of horizontal alignment between swaths, and confirmation of point density and spatial distribution. This initial assessment allowed Dewberry to determine whether the data was suitable for full-scale production. Details are provided in the table below.

Post Calibration Lidar Review Table

Requirement	Description of Deliverables	Additional Comments
The NPD/NPS (or Aggregate NPD/Aggregate NPS) meets required specification of 2 ppsm or 0.7 m NPS. The NPD (ANPD) is calculated from first return points only.	The average calculated (A)NPD of these sample swaths is 4.36 ppsm. Density raster visualization also passes specifications.	Lidar data for this block was acquired between 05/18/2019 and 06/23/2019. During this period, it was observed that the foliage conditions for some trees were fully grown causing lower ground density compared to adjacent areas but exceeds NPD required for QL2. A shapefile was included in the delivery outlining this area.
Spatial Distribution requires 90% of the project grid, calculated with cell sizes of 2*NPS, to contain at least one lidar point. This is calculated from first return points only.	98.7% of cells (2*NPS cell size) have at least 1 lidar point within the cell. A screenshot of the spatial distribution grid is included below.	None
Within swath (Intra-swath or hard surface repeatability) relative accuracy must meet ≤ 6 cm maximum difference	Within swath relative accuracy passes specification.	None
Between swath (Inter-swath or swath overlap) relative accuracy must meet 8 cm RMSDz/16 cm maximum difference. These thresholds are tested in open, flat terrain.	Between swath relative accuracy passes specification, calculated from single return lidar points.	None
Horizontal Calibration-There should not be horizontal offsets (or vertical offsets) between overlapping swaths that would negatively impact the		None

accuracy of the data or the overall usability of the data. Assessments made on rooftops or other hard planar surfaces where available.	Horizontal calibration meets project requirements.	
Ground Penetration-The missions were planned appropriately to meet project density requirements and achieve as much ground penetration beneath vegetation as possible	Ground penetration beneath vegetation is acceptable.	None
Sensor Anomalies-The sensor should perform as expected without anomalies that negatively impact the usability of the data, including issues such as excessive sensor noise and intensity gain or range-walk issues	No sensor anomalies are present.	None
Edge of Flight line bits-These fields must show a minimum value of 0 and maximum value of 1 for each swath acquired, regardless of which type of sensor is used	Edge of Flight line bits are populated correctly	None
Scan Direction bits-These fields must show a minimum value of 0 and maximum value of 1 for each swath acquired with sensors using oscillating (back-and-forth) mirror scan mechanism. These fields should show a minimum and maximum of 0 for each swath acquired with Riegl sensors as these sensors use rotating mirrors.	Scan Direction bits are populated correctly	None
Swaths are in LAS v1.4 formatting	Swaths are in LAS v1.4 as required by the project.	None
All swaths must have File Source IDs assigned (these should equal the Point Source ID or the flight line number). LAS tiles should have File Source IDs set to 0.	File Source IDs are correctly set	None
GPS timestamps must be in Adjusted GPS time format and Global Encoding field must also indicate Adjusted GPS timestamps	GPS timestamps are Adjusted GPS time and Global Encoding field is correctly set to 17	None
Intensity values must be 16-bit, with values ranging between 0-65,535	Intensity values are 16-bit	None

DATA CLASSIFICATION AND EDITING

Once the calibration, absolute swath vertical accuracy, and relative accuracy of the data were confirmed, Dewberry utilized proprietary and TerraScan software for processing. The acquired 3D laser point clouds were tiled according to the project tile grid using proprietary software. Once tiled, the laser points were classified using a proprietary routine in TerraScan. This routine classified any obvious low outliers in the dataset to class 7 and high outliers in the dataset to class 18. Points along flight line edges that were geometrically unusable were flagged as withheld and classified to a separate class so that they would be excluded from the initial ground algorithm.

After points that could negatively affect the ground were removed from class 1, the ground layer was extracted from this remaining point cloud using an iterative surface model.

This surface model was generated using four main parameters: building size, iteration angle, iteration distance, and maximum terrain angle. The initial model was based on low points being selected by a "roaming window" with the assumption that these were the ground points. The size of this roaming window was determined by the building size parameter. The low points were triangulated and the remaining points were evaluated and subsequently added to the model if they met the iteration angle and distance constraints. This process was repeated until no additional points were added within iterations. Points that did not relate to classified ground within the maximum terrain angle were not captured by the initial model.

After the initial automated ground routine, 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.

Dewberry analysts employed 3D visualization techniques to view the point cloud at multiple angles and in profile to ensure that non-ground points were removed from the ground classification. Bridge decks were classified to class 17. After the ground classification corrections were completed, the dataset was processed through a water classification routine that utilized breaklines to automatically classify hydro features. The water classification routine selected ground points within the breakline polygons and automatically classified them as class 9, water. During this water classification routine, points that were within 1 NPS distance or less of the hydrographic feature boundaries were moved to class 20, ignored ground, to avoid hydro-flattening artifacts along the edges of hydro features.

The withheld bit was set on the withheld points previously identified in TerraScan before the ground classification routine was performed.

The lidar tiles were classified to the following classification schema:

Class 1:	Unclassified, used for all other features that do not fit into the Classes 2, 7, 9, 17, 18, or 20. Includes vegetation, buildings, etc.
Class 2:	Bare-Earth Ground
Class 7:	Low Noise
Class 9:	Water, points located within collected breaklines
Class 17:	Bridge Decks
Class 18:	High Noise
Class 20:	Ignored Ground

After manual classification, the LAS tiles were peer reviewed and then underwent a final independent QA/QC. After the final QA/QC and corrections, all headers, appropriate point data records, and variable length records, including spatial reference information, were updated and verified using proprietary Dewberry software.

LIDAR QUALITATIVE ASSESSMENT

Dewberry's qualitative assessment of lidar point cloud data utilized a combination of statistical analyses and visual interpretation. Methods and products used in the assessment included profile- and map view-based point cloud review, pseudo image products (e.g., intensity orthoimages), TINs, DEMs, and point density rasters. This assessment looked for incorrect classification and other errors sourced in the LAS data. Visual Review

The following sections describe common issues identified in the lidar data for NY FEMA R2 Central 2018 D19 and how they were addressed.

Visual Review	Description of Review	Additional Comments
No Data Voids	The SOW for the project defines unacceptable data voids as voids greater than $(4 \times \text{ANPS})^2$, or 7.84 m^2, that are not related to water bodies or other areas of low near-infrared reflectivity and are not appropriately filled by data from an adjacent swath. The LAS files were used to produce density grids based on Class 2 (ground) points. No unacceptable voids were identified in this dataset.	None
Artifacts	Artifacts in the point cloud are typically caused by misclassification of points in vegetation or man-made structures as ground. Low-lying vegetation and buildings are difficult for automated grounding algorithms to differentiate and often must be manually removed from the ground class. Dewberry identified these features during lidar editing and reclassified them to Class 1 (unassigned). Artifacts up to 0.3 m above the true ground surface may have been left as Class 2 because they do not negatively impact the usability of the dataset.	None
Bridge Saddles	The DEM surface models are created from TINs or terrains. TIN and terrain models create continuous surfaces from the input points, interpolating surfaces beneath bridges where no lidar data was acquired. The surface model in these areas tend to be less detailed. Bridge saddles may be created where the surface interpolates between high and low ground points. Dewberry identified problems arising from bridge removal and resolved them by reclassifying misclassified ground points to class 1 and/or adding bridge saddle breaklines where applicable.	None
Culverts and Bridges	It is Dewberry's standard operating procedure to leave culverts in the bare earth surface model and remove bridges from the model. In instances where it was difficult to determine whether the feature was a culvert or bridge, Dewberry erred on the side of culverts, especially if the feature was on a secondary or tertiary road.	None
In-Ground Structures	In-ground structures typically occur on military bases and at facilities designed for munitions testing and storage. Dewberry identified these structures in the project and included them in the ground classification.	None

Dirt Mounds	Irregularities in the natural ground, including dirt piles and boulders, are common and may be misinterpreted as artifacts that should be removed. Small hills and dirt mounds were identified throughout the project area. To verify their inclusion in the ground class, Dewberry periodically checked the features for any points above or below the surface that might indicate vegetation or lidar penetration.	None
Elevation Change within Breaklines	While water bodies are flattened in the final DEMs, linear hydrographic features like dual line drains typically change in elevation, reflecting water flowing downhill over distance. Dewberry reviewed the DEMs to ensure that changes in water elevation were uniform from bank to bank, perpendicular to flow, and stair-stepped where appropriate with a maximum interval of 0.20 m	None
Irrigated Agricultural Areas	Per project specifications, Dewberry collected all areas of standing water greater than or equal to 2 acres. Areas of standing water that did not meet the 2 acre size criteria were not collected.	None
Marsh Areas	Marsh areas are not considered water bodies and are not hydroflattened in the final DEMs. However, it is sometimes difficult to determine true ground in low wet areas due to low reflectivity. In these areas, the lowest points available were used to represent ground, resulting in a sparse and variable ground surface.	None
Flight Line Ridges	Flight line ridges occur when there is a difference in elevation between adjacent flight lines or swaths. Some ridges are visible in the final DEMs, but Dewberry ensured that any ridges remaining after editing and QA/QC are within project relative accuracy specifications.	No flight line ridges are present in the data
Temporal Changes	If temporal differences are present in the dataset, the offsets are identified with a shapefile.	No temporal offsets are present in the data
Low NIR Reflectivity	Some materials, such as asphalt, tars, and other petroleum-based products, have low NIR reflectivity. Large-scale applications of these products, including roadways and roofing, may have diminished to absent lidar returns.	No Low NIR Reflectivity is present in the data

Laser Shadowing	Shadows in the LAS can be caused when solid features like trees or buildings obstruct the lidar pulse, preventing data collection on one or more sides of these features. First return data is typically collected on the side of the feature facing toward the incident angle of transmission (toward the sensor), while the opposite side is not collected because the feature itself blocks the incoming laser pulses. Laser shadowing typically occurs in areas of single swath coverage because data is only collected from one direction. It can be more pronounced at the outer edges of the single coverage area where higher scanning angles correspond to more area obstructed by features. Building shadow in particular can be more pronounced in urban areas where structures are taller.	No Laser Shadowing is present in the data

Formatting

After the final QA/QC is performed and all corrections have been applied to the dataset, all lidar files are updated to the final format requirements and the final formatting, header information, point data records, and variable length records are verified using Dewberry proprietary tools.

The table below lists some of the main lidar header fields that are updated and verified.

Classified Lidar Formatting		
Parameter	**Requirement**	**Pass/Fail**
LAS Version	1.4	Pass
Point Data Format	Format 6	Pass
Coordinate Reference System	NAD83 (2011) Albers Equal Area, meters and NAVD88 (Geoid 12B), meters in WKT Format	Pass
Global Encoder Bit	Should be set to 17 for Adjusted GPS Time	Pass
Time Stamp	Adjusted GPS Time (unique timestamps)	Pass
System ID	Should be set to the processing system/software and is set to the lidar sensor	Pass
Multiple Returns	The sensor shall be able to collect multiple returns per pulse and the return numbers are recorded	Pass
Intensity	16 bit intensity values are recorded for each pulse	Pass

Classification	Required Classes include: Class 1: Unclassified Class 2: Ground Class 7: Low Noise Class 9: Water Class 17: Bridge Decks Class 18: High Noise Class 20: Ignored Ground due to Breakline Proximity	Pass
Overlap and Withheld Points	Withheld points are set to the Withheld bits	Pass
Scan Angle	Recorded for each pulse	Pass
XYZ Coordinates	Unique Easting, Northing, and Elevation coordinates are recorded for each pulse	Pass

Synthetic Points

Time of flight laser measurements have their maximum unambiguous range restricted by the maximum distance the laser can travel round-trip before the next laser pulse is emitted. One solution to this problem is to limit "valid" returns to a certain window between specified elevations, or a "range gate"; however, this technique can prevent some returns from being captured if there is terrain outside of the range gate. It can also cause some late returns to be georeferenced as part subsequent pulses.

The multiple time around (MTA) capabilities of Riegl sensors enable the recording of lidar returns any distance from the laser (within detection capabilities) without forcing range gate restrictions. However, there is still a possibility that a late return will occur simultaneously with a pulse emission. The backscatter energy from the laser optics and the atmosphere directly below the aircraft during this event can effectively blind the sensor, making it unable to discern information about the laser return. Because this occurs more consistently with later returns, this blind zone is typically found in a narrow band along the edges of the sensor's range. The result is a predictable geometry of voids (typically within project specifications) in the point cloud.

During post-processing of the lidar data, Riegl software interpolates coordinates within the blind zones between last returns on each side of the gap. These are flagged as "synthetic" points and are assigned a valid time stamp, though they do not have any waveform data or pulse width information. Amplitude and reflectance are averaged from surrounding points. The assignment of synthetic points does not change the original raw point cloud data.

This dataset contains flagged synthetic points. The images below show an example from a different dataset of synthetic points applied to the ground class of the lidar point cloud.

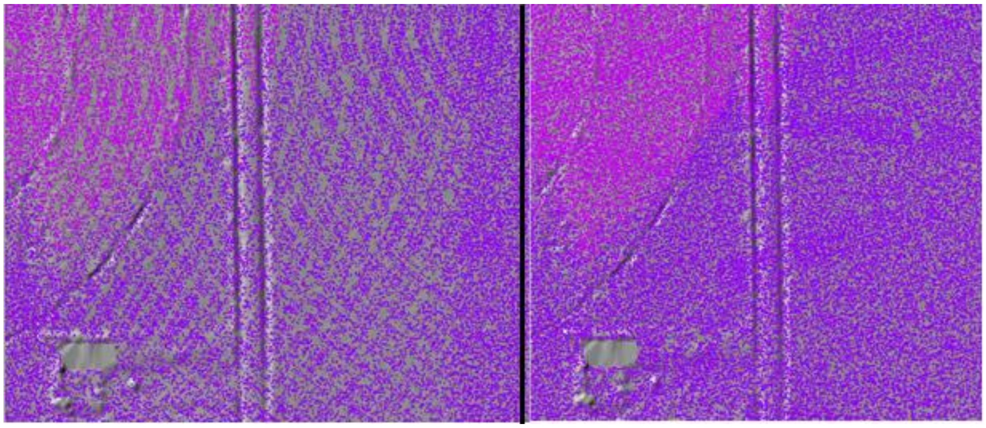


Figure 9: The left image shows ground classified without synthetic points. The right image shows ground classified with synthetic points. Both images are overlaid on a hillshade of the example area

Breakline Production & Qualitative Assessment Report

BREAKLINE SPECIFICATIONS

Parameter	Project Specification	Pass/Fail
Ponds and Lakes	Breaklines were collected in all inland ponds and lakes ~2 acres or greater. These features were flat and level water bodies at a single elevation for each vertex along the bank.	Pass
Rivers and Streams	Breaklines were collected for all streams and rivers ~100' nominal width or wider. These features are flat and level bank to bank, gradient will follow the surrounding terrain and the water surface will be at or below the surrounding terrain. Streams/river channels will break at culvert locations however not at elevated bridge locations.	Pass
Tidal	Breaklines were collected as polygon features depicting water bodies such as oceans, seas, gulfs, bays, inlets, salt marshes, very large lakes, etc. Includes any significant water body that is affected by tidal variations. Tidal variations over the course of collection, and between different collections, can result in discontinuities along shorelines. This is considered normal and should be retained. Variations in water surface elevation resulting from tidal variations during collection should not be removed or adjusted. Features should be captured as a dual line with one line on each bank. Each vertex placed shall maintain vertical integrity. Parallel points on opposite banks of the tidal waters must be captured at the same elevation to ensure flatness of the water feature. The entire water surface edge is at or below the immediate surrounding terrain.	Pass

Islands	Donuts will exist where there are islands greater than 1 acre in size within a hydro feature.	Pass
Bridge Saddle Breaklines	Bridge Saddle Breaklines were collected where bridge abutments were interpolated after bridge removal causing saddle artifacts.	Pass

BREAKLINE PRODUCTION AND QUALITATIVE ASSESSMENT

Parameter	Requirement	Pass/Fail
Collection	Collect breaklines according to project specifications using lidar-derived data, including intensity imagery, bare earth ground models, density models, slope models, and/or terrains.	Pass
Placement	Place the breakline inside or seaward of the shoreline by 1-2 x NPS in areas of heavy vegetation or where the exact shoreline is hard to delineate.	Pass
Completeness	Perform a completeness check, breakline variance check, and all automated checks on each block before designating that block complete.	Pass
Merged Dataset	Merge completed production blocks. Ensure correct horizontal and vertical snapping between all production blocks. Confirm correct horizontal placement of breaklines.	Pass
Merged Dataset Completeness Check	Check entire dataset for features that were not captured but that meet baseline specifications or other metrics for capture. Features should be collected consistently across tile boundaries.	Pass
Edge Match	Ensure breaklines are correctly edge-matched to adjoining datasets. Check completion type, attribute coding, and horizontal placement.	Pass
Vertical Consistency	Waterbodies shall maintain a constant elevation at all vertices Vertices should not have excessive min or max zvalues when compared to adjacent vertices Intersecting features should maintain connectivity in X, Y, Z planes Double stream lines shall have the same elevation at any given cross-section of the stream	Pass
Vertical Variance	Using a terrain created from lidar ground (class 2, 8, and 20 as applicable) and water points (class 9), compare breakline Z values to interpolated lidar elevations to ensure there are no unacceptable discrepancies.	Pass

Monotonicity	Double line streams shall generally maintain a consistent down-hill flow and be collected in the direction of flow – some natural exceptions will be allowed	Pass
Topology	Features must not overlap or have gaps Features must not have unnecessary dangles or boundaries	Pass
Hydro-classification	The water classification routine selected ground points within the breakline polygons and automatically classified them as class 9, water. During this water classification routine, points that were within 1 NPS distance or less of the hydrographic feature boundaries were moved to class 20, ignored ground, to avoid hydroflattening artifacts along the edges of hydro features.	Pass
Hydro-flattening	Perform hydro-flattening and hydro-enforcement checks. Tidal waters should preserve as much ground as possible and can be non-monotonic.	Pass

DEM Production & Qualitative Assessment

DEM PRODUCTION METHODOLOGY

Dewberry utilized LP360 to generate DEM products and both ArcGIS and Global Mapper for QA/QC.

The final classified lidar points in all bare earth classes were loaded into LP360 along with the final 3D breaklines and the project tile grid. A raster was generated from the lidar data with breaklines enforced and clipped to the project tile grid (or buffered boundary). The DEM was reviewed for any issues requiring corrections, including remaining lidar misclassifications, erroneous breakline elevations, incorrect or incomplete hydro-flattening or hydro-enforcement, and processing artifacts. The formatting of the DEM tiles was verified before the tiles were loaded into Global Mapper to ensure that there was no missing or corrupt data and that the DEMs matched seamlessly across tile boundaries. A final qualitative review was then conducted by an independent review department within Dewberry.

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.

Dewberry conducted the review in ArcGIS using a hillshade model of the full dataset with a partially transparent colorized elevation model overlaid. The tiled DEMs were reviewed at a scale of 1:5,000 to look for artifacts caused by the DEM generation process and to verify correct and complete hydro-flattening and hydro-enforcement. Upon correction of any outstanding issues, the DEM data was loaded into Global Mapper for its second review and to verify corrections.

Parameter	Requirement	Pass/Fail

Digital Elevation Model (DEM) of bare-earth w/ breaklines	DEM of bare-earth terrain surface (1 m) created from lidar ground points and breaklines. DEMs shall be tiled without overlaps or gaps, shall show no edge artifact or mismatch, DEM deliverables will be .img format	Pass
DEM Compression	DEMs should not be compressed	Pass
DEM NoData	Areas outside survey boundary shall be coded as NoData. Internal voids (e.g., open water areas) may be coded as NoData (-3.4E+38)	Pass
Hydro-flattening	Ensure DEMs are hydro-flattened or hydroenforced as required by project specifications	Pass
Monotonicity	Verify monotonicity of all linear hydrographic features	Pass
Breakline Elevations	Ensure adherence of breaklines to bare-earth surface elevations, i.e., no floating or digging hydrographic feature	Pass
Bridge Removal	Verify removal of bridges from bare-earth DEMs and no saddles present	Pass
DEM Artifacts	Correct any issues in the lidar classification that are visually expressed in the DEMs. Reprocess the DEMs following lidar corrections.	Pass
DEM Tiles	Split the DEMs into tiles according to the project tiling scheme	Pass
DEM Formatting	Verify all properties of the tiled DEMs, including coordinate reference system information, cell size, cell extents, and that compression has not been applied to the tiled DEMs	Pass
DEM Extents	Load all tiled DEMs into Global Mapper to verify complete coverage within the (buffered) project boundary and verify that no tiles are corrupt	Pass

Derivative Lidar Products

USGS required several derivative lidar products to be created. Each type of derived product is described below.

SWATH SEPARATION IMAGES

Swath separation images have been delivered. The images are in .TIFF format. The swath separation images are symbolized by the following ranges:

- 0-8 cm: **Green**
- 8-16 cm: **Yellow**
- 16+: **Red**

INTERSWATH AND INTRASWATH POLYGONS

Interswath Accuracy

The Interswath accuracy, or overlap consistency, measures the variation in the lidar data within the swath overlap. Interswath accuracy measures the quality of the calibration or boresight adjustment of the data in each lift. Per USGS specifications, overlap consistency was assessed at multiple locations within overlap in non-vegetated areas of only single returns. As with precision, the interswath consistency was reported by way of a polygon shapefile delineating the sample areas checked and attributed with the following and using the cells within each polygon as sample values:

- Minimum difference in the sample area (numeric)
- Maximum difference in the sample area (numeric)
- RMSDz (Root Mean Square Difference in the vertical/z direction) of the sample area (numeric)

Intraswath Accuracy

The intraswath accuracy, or the precision of lidar, measures variations on a surface expected to be flat and without variation. Precision is evaluated to confirm that the lidar system is performing properly and without gross internal error that may not be otherwise apparent. To measure the precision of a lidar dataset, level or flat surfaces were assessed. Swath data were assessed using only first returns in non-vegetated areas.

Precision was reported by way of a polygon shapefile delineating the sample areas checked and attributed with the following and using the cells within each polygon as sample values:

- Minimum slope-corrected range (numeric)
- Maximum slope-corrected range (numeric)
- RMSDz of the slope-corrected range (numeric)

REDUCED GROUND DENSITY SHAPEFILE

Lidar data for this block was acquired between 05/18/2019 and 06/23/2019. During this period, it was observed that the foliage conditions for some trees were fully grown mainly for the area marked in the red colored polygon shown in figure 10. For this area, data was acquired between 06/12/19 and 06/23/19 where the data shows lower ground density compared to adjacent areas but exceeds NPD required for QL2.

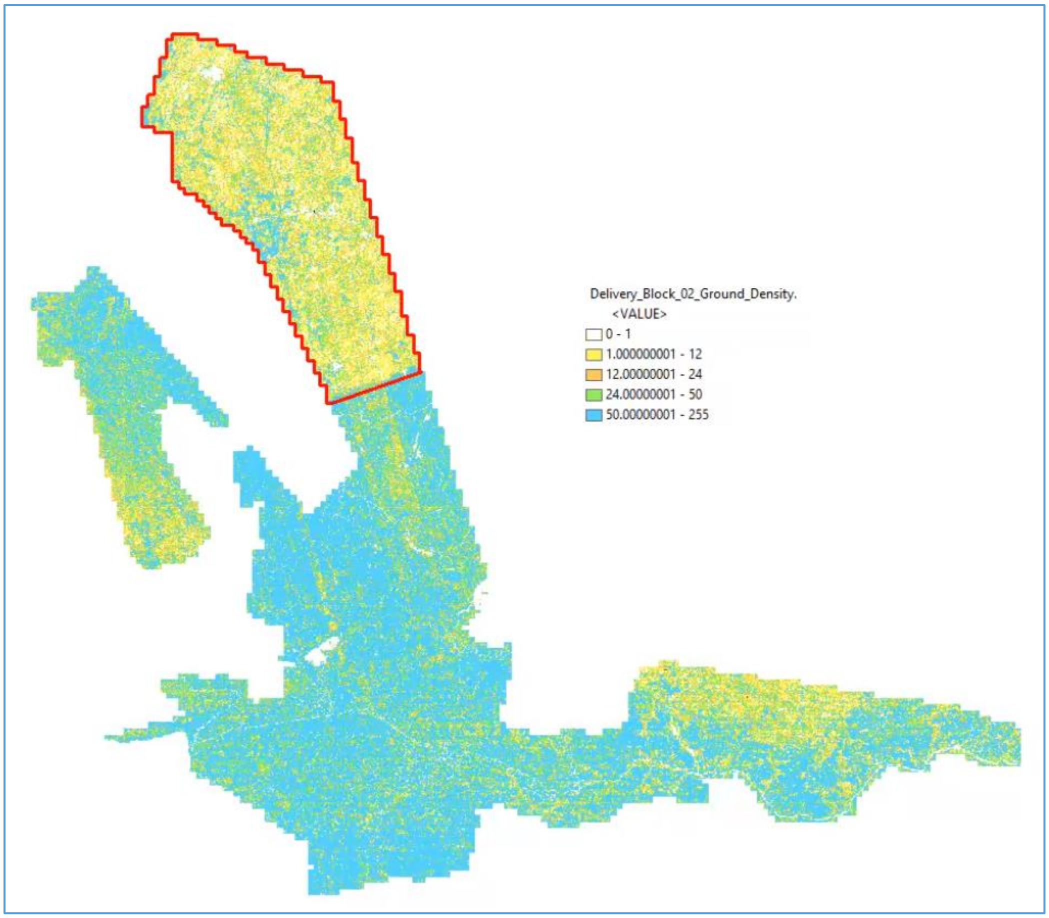


Figure 10: Lidar point cloud ground density image (values shown in points per square meter)

Appendix A-E: GPS Processing

Please refer the separate Appendix A-E documentation delivered with this project report, which include the GPS Processing information.

CONTOURS

Dewberry will create 1-foot contours, post USGS review of draft lidar, breakline, and DEM deliverables. This processing workflow allows Dewberry to incorporate any potential corrections from the draft reviews into the contour production. The contour attributes will include designation as either Index or Intermediate and an elevation value. The contours will also be 3D, storing elevation values within their internal geometry. Some algorithmic smoothing will be applied to the contours to enhance their aesthetic quality. This task order requires auto/machine generated contours so contours will be reviewed for completeness and correct attribution but will not be reviewed or edited for correct topology or correct behavior in regards to hydrographic crossings. Due to the density of the contours and their anticipated file size, the contours will be tiled to the project tiles. The contour tiles will be delivered in one file geodatabase (GDB) and will be named according to the final project tile grid.

PSID OBSERVATION

Dewberry observed that 30 PSIDs were reused between lidar acquisition and calibration blocks. The data was acquired in five acquisition blocks as shown in figure below and calibrated. During this process, PSIDs assigned for 30 of the swaths in acquisition blocks A and C were reused in acquisition block B (29 swaths) and block F (1 swath).