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NY FEMA R2 CENTRAL 2018 D19- WUID#214093

Report Produced for U.S. Geological Survey

USGS Contract: G10PC00013

Task Order: 140G0219F0007

Report Date: 02/17/2022

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U.S. Geological Survey

Contents

Task Order Name: USGS 140G0219F0007-NY_FEMAR2_Central_2018_D19

Date: 02/17/2022

Product: Lidar, Breaklines, DEMs, Intensity, Relative Accuracy, DZ Orthos, and Metadata for Lot 7: WUID# 214093 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 1,000m by 1,000m (1 square kilometer). A total of 7,968 tiles were produced for WUID 214093 deliverables of the project area encompassing an area of approximately 2,806 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 WUID 214093 deliverables.

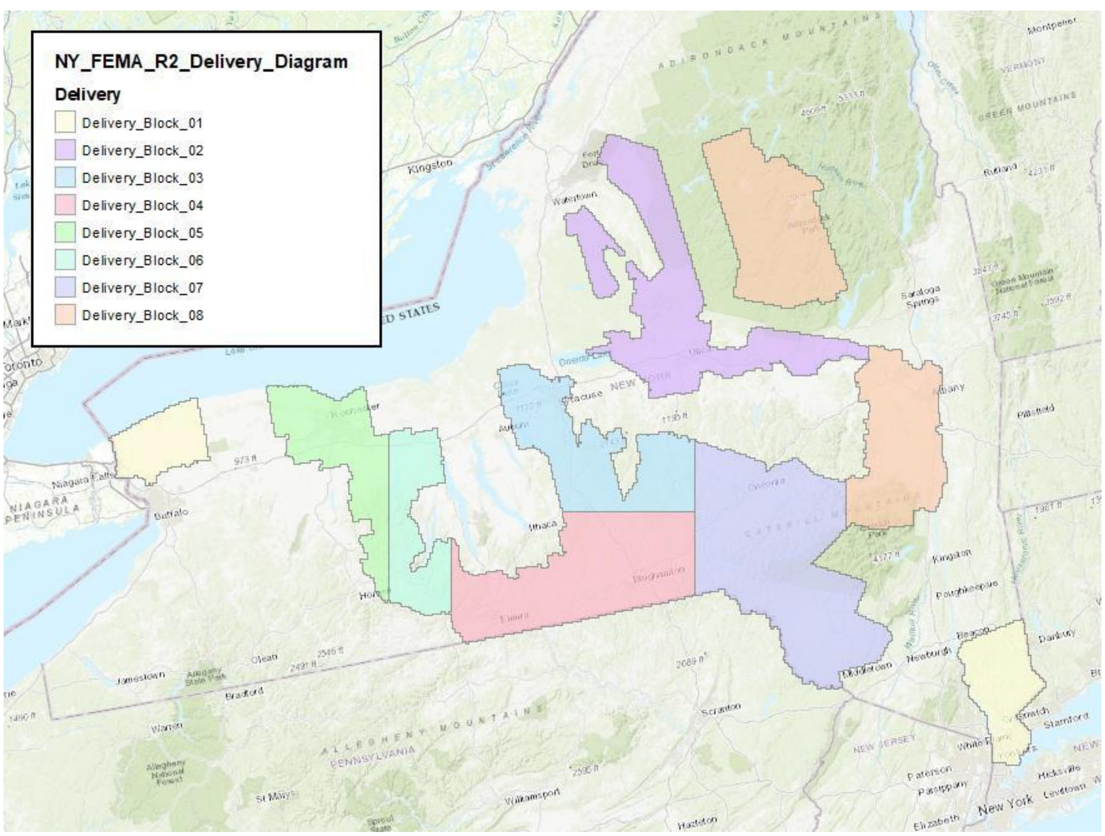

Figure 1: NY FEMA R2 2018 D19 - Delivery Blocks

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.

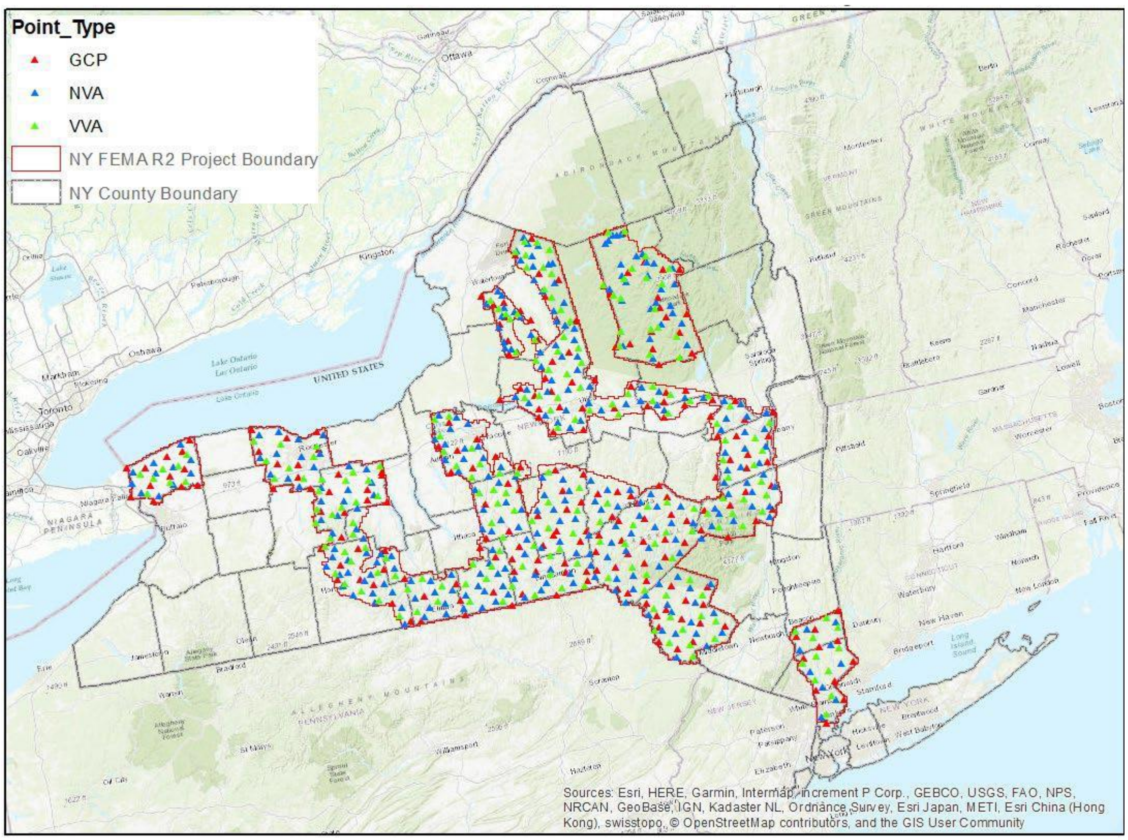

Figure 2: NY FEMA R2 - GPS Survey Points (CP, NVA and VVA Points)

DATE OF SURVEY

The lidar aerial acquisition was conducted from April 16, 2019 and May 18, 2019.

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 – GeoTIFF 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 44,861 one square kilometer tiles. Seven thousand nine hundred sixty-eight (7,968) tiles of WUID#214093 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.

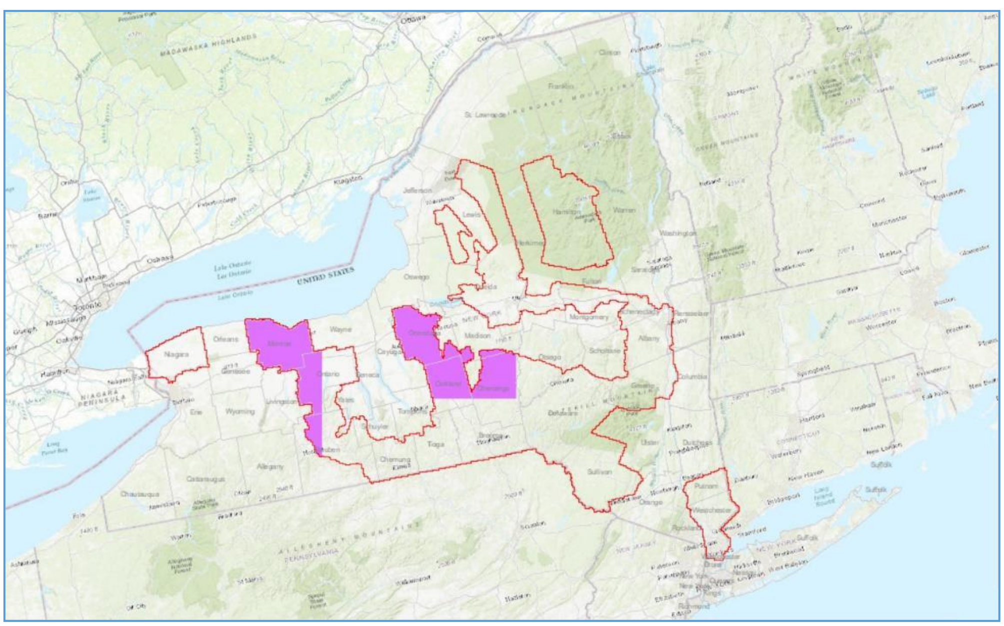

Figure 3 – Lot-7: Delivery WUID#214093

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 Axis Geospatial (Axis) was responsible for providing lidar acquisition, calibration and delivery of lidar data files to Dewberry for this work unit.

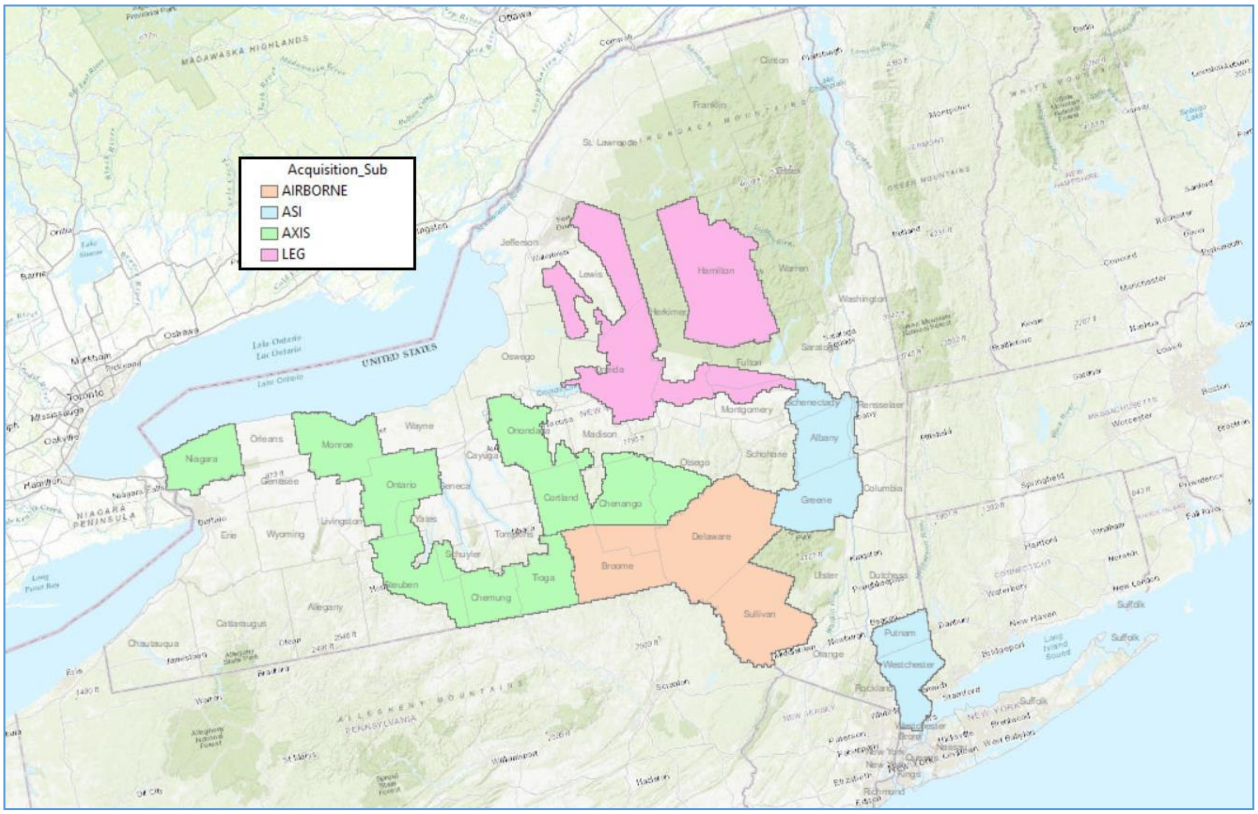

Figure 4: NY FEMA R2 Central - Lidar Acquisition Subcontractors

LIDAR ACQUISITION DETAILS

Acquisition provider Axis planned 251 passes for their assigned acquisition area which covers 11 counties as shown in figure 4 using two Riegl VQ-1560i sensors and one LMS 1560 sensor as a series of parallel flight lines with cross flight lines 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 beeninvestigated so

that required permissions can be obtained in a timely manner with respect to schedule.

- Additionally, Axis filed our flight plans as required by local Air Traffic Control (ATC) prior to each mission.

Acquisition provider 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

Axis operated a Cessna T206H (Tail # N223TC) with a LMS 1560 system, as well as a Piper Navajo (Tail # N359RX) and a Vulcan Air P68C (Tail#N89LT) with Riegl VQ-1560i lidar systems during the collection of the respective allocated area. Table below illustrate Axis system parameters for lidar acquisition on this project.

Axis: Lidar acquisition block includes full /partial counties – Monroe, Ontario, Yates, Steuben, Schuyler, Chemung, Tioga, Cortland, Onondaga, and Madison)

Item	Parameter	Parameter	Parameter
System	VQ-1560i	VQ-1560i	LMS 1560
Serial Number	S2222593	S2223544	S2221262
Aircraft and Tail Number	Vulcan Air P68C-N89LT	Navajo-N359RX	Cessna 206H-N223TC
Maximum Number of Returns per Pulse	7	7	7
Nominal Pulse Spacing (single swath), (m)	.680	.700	.700
Nominal Pulse Density (single swath) (ppsm), (m)	*2.16*	*2.63*	*2.31*
Aggregate NPS (m) (if ANPS was designed to be met through single coverage, ANPS and NPS will be equal)	.680	.700	.700
Aggregate NPD (m) (if ANPD was designed to be met through single coverage, ANPD and NPD will be equal)	2.16	2.63	2.31
Altitude (AGL meters)	1828	1001	2134
Approx. Flight Speed (knots)	130	150	170
Total Sensor Scan Angle (degree)	58.52	58.52	58.52

Item	Parameter	Parameter	Parameter
Scan Frequency (hz)	2 x 500	2x500	2x400
Scanner Pulse Rate (kHz)	2 x 103	2x125	Xx88.9
Pulse Duration of the Scanner (nanoseconds)	3 ns	3 ns	3 ns
Pulse Width of the Scanner (m)	.457	.25	.535
Central Wavelength of the Sensor Laser (nanometers)	1064 nm	1064 nm	1064 nm
Did the Sensor Operate with Multiple Pulses in The Air? (yes/no)	Yes	Yes	Yes
Beam Divergence (milliradians)	≤ 0.25 mrad	≤ 0.25 mrad	≤ 0.25 mrad
Nominal Swath Width on the Ground (m)	1985	1902	2285
Swath Overlap (%)	40	20	20
Computed Down Track spacing (m) per beam	.680	.700	.700
Computed Cross Track Spacing (m) per beam	.680	.700	.700
GNSS positional error (radial, in cm) *	0.05	0.05	.05
IMU error (in decimal degrees) *	0.005	0.005	.005
Line Spacing (m)	1356	990	1340

Table 1: Acquisition Provider Axis 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.

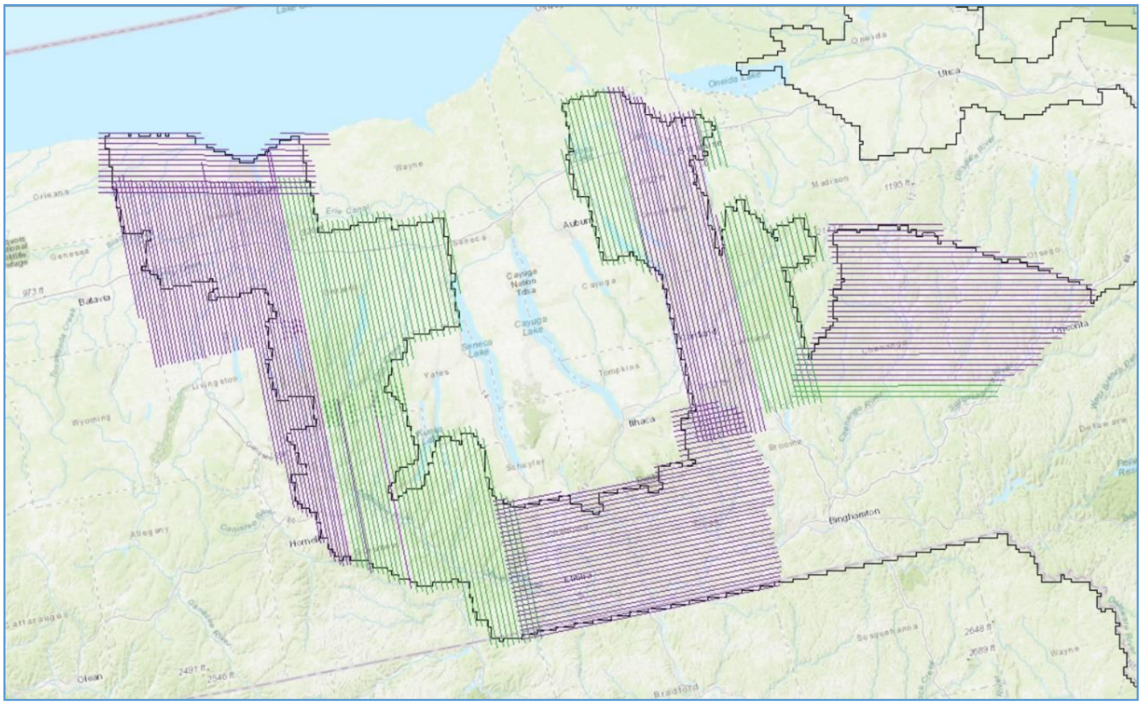

Figure 5: Trajectories as flown by Acquisition Provider Axis Geospatial

AXIS GEOSPATIAL GPS KINEMATIC

Axis 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.

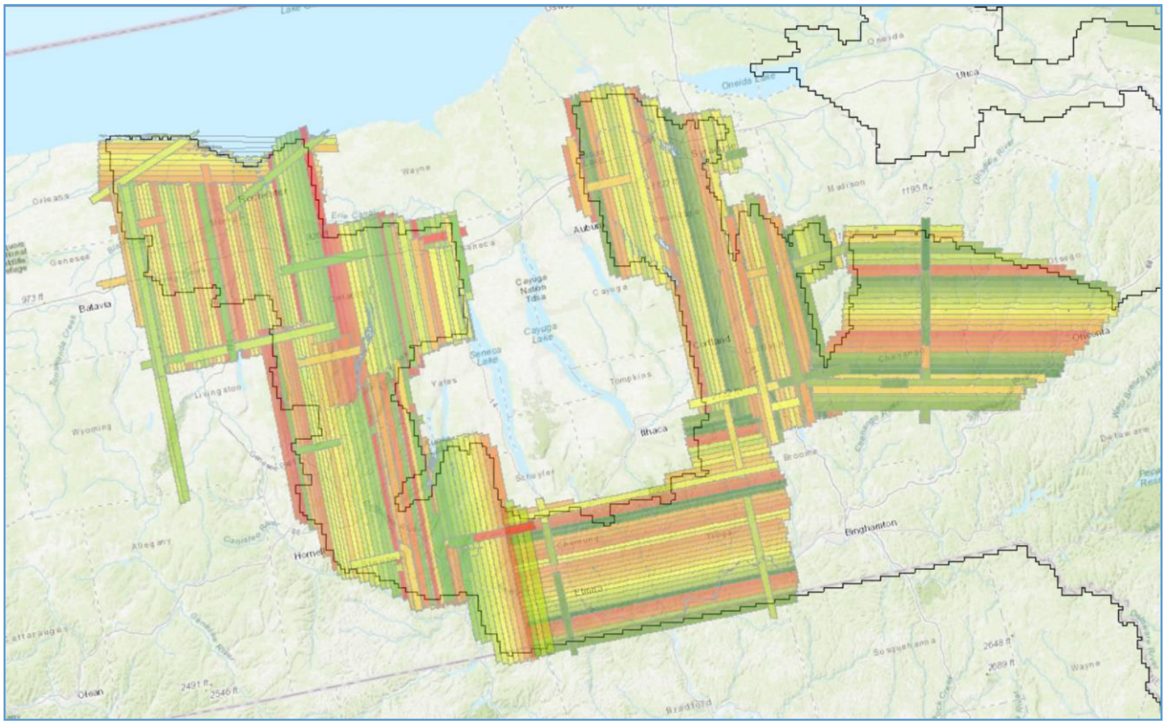

Figure 6: Lidar swath output showing complete coverage

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.

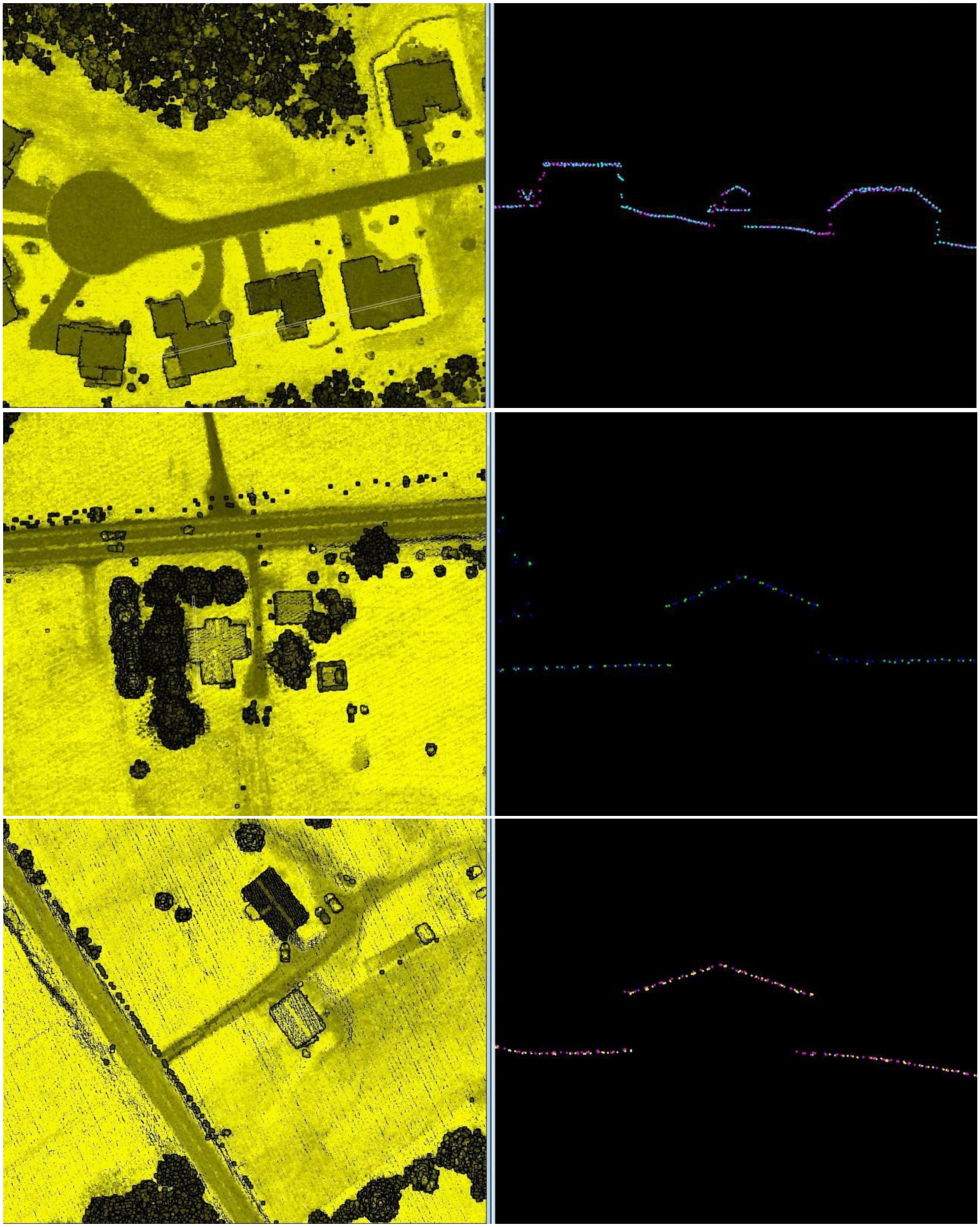

Figure 7: Profile views showing correct roll and pitch adjustments

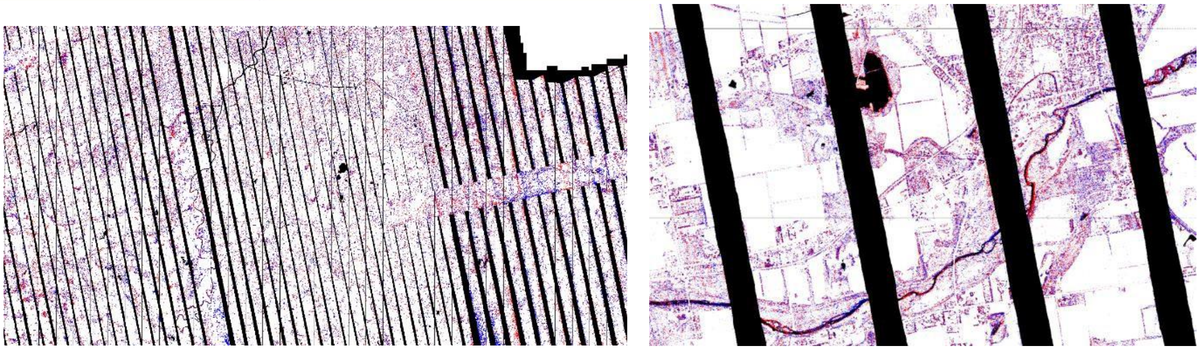

Figure 8: QC block colored by distance to ensure accuracy at swath edges

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 Non-vegetated Vertical Accuracy (NVA) requirements ($RMSE_z \leq 10$ cm and $Accuracy_z$ at the 95% confidence level ≤ 19.6 cm) when compared to static and kinematic GPS checkpoints. Below isa summary for the test:

The calibrated lidar dataset was tested to 0.060 m vertical accuracy at 95% confidence level based on RMSE2 (0.05 m x 1.9600) when compared to 62 GPS static check points.

The following are the final statistics for the GPS static checkpoints used by Acquisition Provider Axis 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
GCP-006	1446283.125	2399481.765	90.544	90.420	-0.041
GCP-009	1460965.068	2360072.696	215.118	214.950	-0.085
GCP-010	1477604.847	2375877.134	160.227	160.110	-0.034
GCP-012	1533808.546	2368869.754	148.410	148.190	-0.137
GCP-013	1537477.769	2351033.031	142.947	142.740	-0.124
GCP-014	1536339.101	2318118.155	397.175	397.220	0.128
GCP-015	1554012.954	2270297.020	396.791	396.780	0.072
GCP-016	1492663.942	2319378.704	418.349	418.180	-0.086
GCP-017	1509058.872	2343962.233	327.951	327.830	-0.038
GCP-018	1519582.750	2298268.647	336.627	336.560	0.016
GCP-019	1549480.111	2299007.593	383.483	383.430	0.030

Point ID	NAD83(2011) Albers		NAVD88 (Geoid 12B)		
	Easting X (m)	Northing Y (m)	Known Z (m)	Laser Z (m)	Delta Z
GCP-020	1600737.957	2319772.327	388.947	388.890	0.026
GCP-021	1622250.345	2280823.124	310.026	310.030	0.087
GCP-022	1560764.689	2270106.447	316.499	316.520	0.104
GCP-023	1563050.502	2286847.712	271.708	271.650	0.025
GCP-024	1609599.308	2290225.203	248.766	248.750	0.067
GCP-025	1584329.726	2295583.314	319.196	319.090	-0.023
GCP-026	1524659.439	2359037.709	257.237	257.020	-0.134
GCP-027	1498293.277	2358175.107	303.399	303.340	0.024
GCP-028	1517753.084	2319543.373	457.128	457.030	-0.015
GCP-029	1535600.703	2305498.664	342.450	342.470	0.103
GCP-030	1540821.545	2281934.300	286.720	286.690	0.053
GCP-031	1451156.107	2385023.804	158.982	158.910	0.011
GCP-032	1504701.238	2369675.831	187.817	187.710	-0.024
GCP-040	1469418.444	2394412.873	82.545	82.490	0.028
GCP-041	1590845.275	2274787.481	243.836	243.810	0.057
GCP-042	1611164.098	2313795.057	321.306	321.190	-0.033
GCP-043	1528575.334	2294831.173	320.814	320.720	-0.011
GCP-044	1503743.574	2298404.523	502.644	502.560	-0.001
GCP-045	1506619.433	2327055.821	246.106	246.070	0.047
GCP-046	1492710.042	2344603.068	286.480	286.370	-0.027
GCP-047	1491532.676	2386780.563	161.033	160.960	0.010
GCP-048	1524031.039	2351972.933	272.755	272.540	-0.132
GCP-049	1463790.916	2376644.735	177.554	177.460	-0.011
GCP-050	1505901.009	2308240.681	378.551	378.460	-0.008
GCP-051	1477266.346	2367620.497	207.422	207.220	-0.119
GCP-052	1587091.148	2284256.075	272.867	272.840	0.056
GCP-401	1579763.956	2404452.185	116.065	115.920	-0.062
GCP-402	1572276.441	2388457.028	175.251	175.140	-0.028
GCP-403	1598294.173	2393264.732	142.654	142.560	-0.011
GCP-404	1603773.797	2349682.980	345.491	345.390	-0.018
GCP-405	1605051.902	2326125.397	366.588	366.440	-0.065
GCP-406	1595758.044	2373886.926	451.296	451.150	-0.063
GCP-407	1610877.196	2381568.642	510.186	510.040	-0.063
GCP-408	1627888.141	2374928.617	432.395	432.310	-0.002
GCP-409	1651918.182	2372542.500	333.867	333.790	0.006

Point ID	NAD83(2011) Albers		NAVD88 (Geoid 12B)		
	Easting X (m)	Northing Y (m)	Known Z (m)	Laser Z (m)	Delta Z
GCP-410	1670694.208	2369863.390	352.285	352.220	0.018
GCP-411	1702914.364	2355055.446	348.062	347.960	-0.019
GCP-412	1620288.464	2330978.443	308.797	308.640	-0.074
GCP-413	1673024.464	2331053.824	310.906	310.860	0.037
GCP-414	1652529.024	2331085.660	299.955	299.900	0.028
GCP-415	1656584.439	2358451.120	314.444	314.360	-0.001
GCP-416	1693387.268	2357561.319	339.668	339.610	0.025
GCP-417	1680172.816	2356124.617	353.947	353.820	-0.044
GCP-418	1627202.396	2359443.000	362.464	362.270	-0.111
GCP-419	1640138.489	2341628.616	428.966	428.840	-0.043
GCP-420	1689993.795	2341274.805	328.924	328.850	0.009
GCP-421	1669269.489	2350730.656	325.056	324.970	-0.003
GCP-439	1659178.309	2345838.756	309.758	309.650	-0.025
GCP-440	1619255.697	2363654.580	362.890	362.760	-0.047
GCP-441	1585045.606	2385592.307	292.034	291.920	-0.031
GCP-442	1580926.719	2371255.843	270.314	270.180	-0.051

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	62	0.060	0.010	-0.013	0.059	-0.137	0.128

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 (Axis) 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.	None
Spatial Distribution requires 90% of		None

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.	
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 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.	None
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

Due to re-flights and significant noise in portions of the WUID, Dewberry had to manually review and parse flightlines for suitability. This was done to ensure consistent ground density and noise classification throughout the WUID.

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 datasetto 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, 20 or 32. Includes vegetation, buildings, etc.
Class 2:	Bare-Earth Ground
Class 7:	Low Noise
Class 9:	Water, points located within collected breaklines Bridge
Class 17:	Decks
Class 18:	High Noise Ignored
Class 20:	Ground
Class 32:	Lake Erie Temporal

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 $(4 \times ANPS)^2$, 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 GPSTime	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 Class 32: lake Erie Temporal	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.

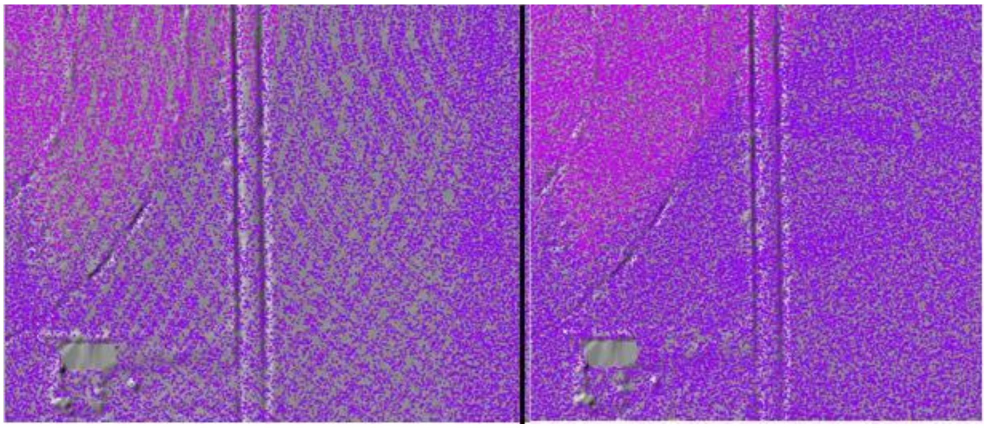

Figure 9: The left image shows ground classified without synthetic points. The right image shows ground classified with synthetic points. Both images are overlaid on a hillshade of the example area

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	Pass

	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.	
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 z values 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 properextents, 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 productis 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)

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.

Appendix A: GPS Processing

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

Appendix B: Erie Canal Elevation

Please refer the separate Appendix B documentation delivered with this project report, which describes the methodology used to hydroflatten the Erie Canal/Genesee River intersection.