Data Post-Processing Report

2020 Lidar and Derivative Products for Cherokee, Chester, Fairfield, Lancaster, and Union Counties

Data Processing Report for 2020 Lidar: Flood Map Modernization Initiative Contract

December 15, 2022

Prepared for:

South Carolina Floodplain Mitigation Program
South Carolina Department of Natural Resources

Prepared by:

ESP Associates, Inc.

Overview

This Data Processing Report provides a comprehensive accounting of lidar processing and the production of derivative products such as intensity images, Digital Elevation Models (DEMs), hydro-breakline layers, and a classified lidar point cloud. The data will support flood modeling, contour generation and other uses as needed by the South Carolina Department of Natural Resources (SCDNR). Tasks for this project were performed under the “Flood Map Modernization Initiative” Contract (Contract) between ESP Associates, Inc. (formerly ESP Associates, P.A.) and the SCDNR Flood Mitigation Program, dated December 2015.

The 2020 SCDNR Lidar project area was comprised of 5 Counties in South Carolina with an aerial acquisition extent of 3,021 square miles that included a 1,000 ft buffer from the county boundaries. The project area of interest (AOI) encompassed the required 5,000 ft X 5,000 ft deliverable tiles, including the tiles that intersect with the 1,000 ft buffer. The South Carolina counties included in this project were: Cherokee, Chester, Fairfield, Lancaster, and Union. All products were processed between January 16 and October 30, 2022.

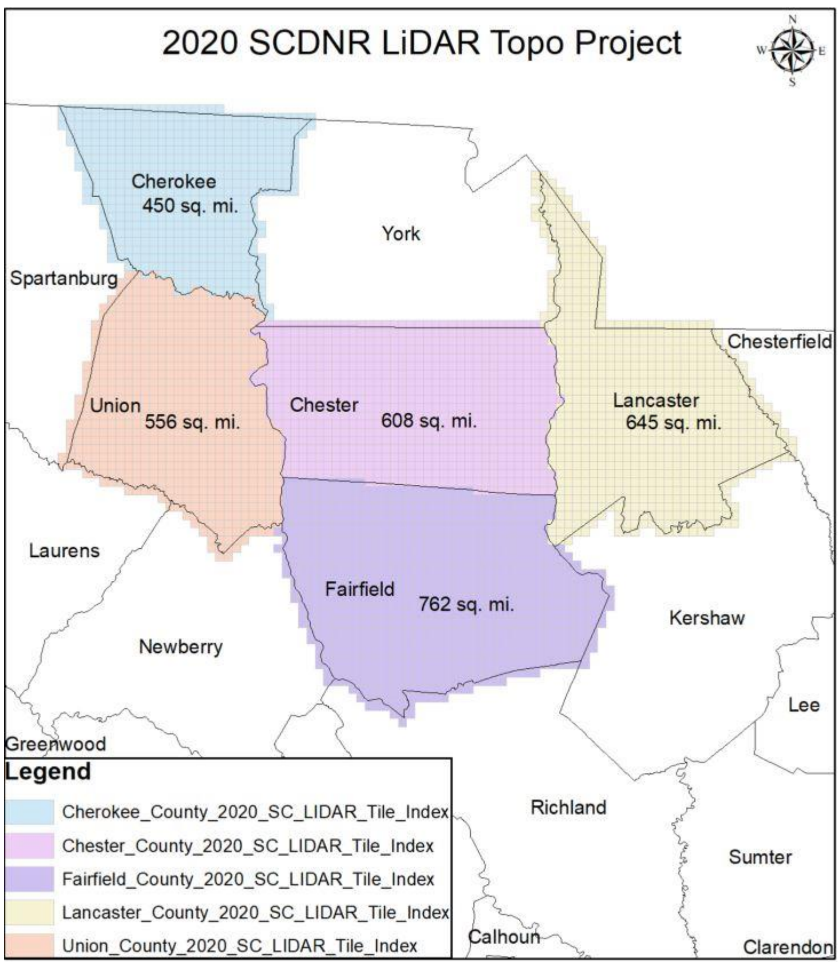

Figure 1. Project AOI

Aerial lidar data collection and ground survey support tasks have been documented separately in the following reports submitted to SCDNR:

- **Aerial Data Acquisition Report –** reports on the data collection efforts for aerial lidar collection and Airborne GPS (ABGPS) quality and as-flown line information
- **Report of Survey –** reports on the ground survey support component of the project, including collection and processing of survey control points in support of lidar calibration tasks and survey checkpoints in support of independent accuracy checks of the data

Internal checkpoint results, as assessed against the classified lidar point cloud, are provided at the end of this report.

Scope of Work

The processing tasks reported on are organized in the order of workflow, and coincide with the contractual project task numbers, beginning with the calibration of the lidar data. All work complied with the specifications outlined in the SCDNR Scope of Services. The base specifications for this project were derived primarily from the USGS National Geospatial Program Base Lidar Specifications, Version 2.1, dated September, 2019 (BLS V2.1) and supplemented as appropriate by FEMA's Guidelines and Specifications for Flood Hazard Mapping Partners, dated April 2003 and the American Society for Photogrammetry and Remote Sensing (ASPRS) Positional Accuracy Standards for Digital Geospatial Data, Edition 1, Version 1.0.0.

Geodesy

For all geospatial deliverables, horizontal coordinates were in International Feet to two decimal places, State Plane Coordinate System, South Carolina zone, NAD83 (2011). Elevations will be in U.S. Survey foot units to two decimal places, North American Vertical Datum of 1988 (NAVD88) and processed with the Geoid12B for all products

Task 4: Calibrate the Aerial Data

The lidar calibration process was conducive to postprocessing an accurate data set. Significant attention was given to GPS baseline distances and GPS satellite constellation geometry and outages during the trajectory processing. Verification that proper ABGPS surveying techniques were followed including: pre and post mission static initializations and review of In-air Inertial Measurement Unit (IMU) alignments, if performed, both before and after on-site collection activities to ensure proper self-calibration of the IMU accelerometers and gyros were achieved.

Relative Accuracy Calibration

Cross flights were planned throughout each project block area across all flight lines and over roadways where possible. The cross-flight provided a common control surface used to remove any vertical discrepancies in the Lidar data between flight lines and aided in the bundle adjustment process with review of the roll, pitch, heading (omega, phi, kappa). The cross-flight design is critical to ensure flight line ties across the sub-blocks and the entire project area. The areas of overlap between flight lines were used to calibrate (aka boresight) the lidar point cloud to achieve proper flight line to flight line alignment in all 6 degrees of freedom. This included adjustment of IMU and scanner-related variables such as roll, x, y, z, pitch, heading, and timing interval (calibration range bias by return) Each lidar mission flown was independently reviewed, bundle adjusted (bore-sighted), and/if necessary, improved by a hands-on boresight refinement in the office.

A final quality control step was conducted by running elevation difference rasters (DZ rasters) which give the quality control technician a graphical representation of any elevation difference between flight lines in the overlap areas between parallel lines and between cross-flight lines that are perpendicular to the main lines. Figure 2 depicts a DZ raster mosaic of the entire, 5-county project area showing green where overlapping data matches (open terrain) and areas of above-ground features (primarily vegetation) where it is expected to show variance.

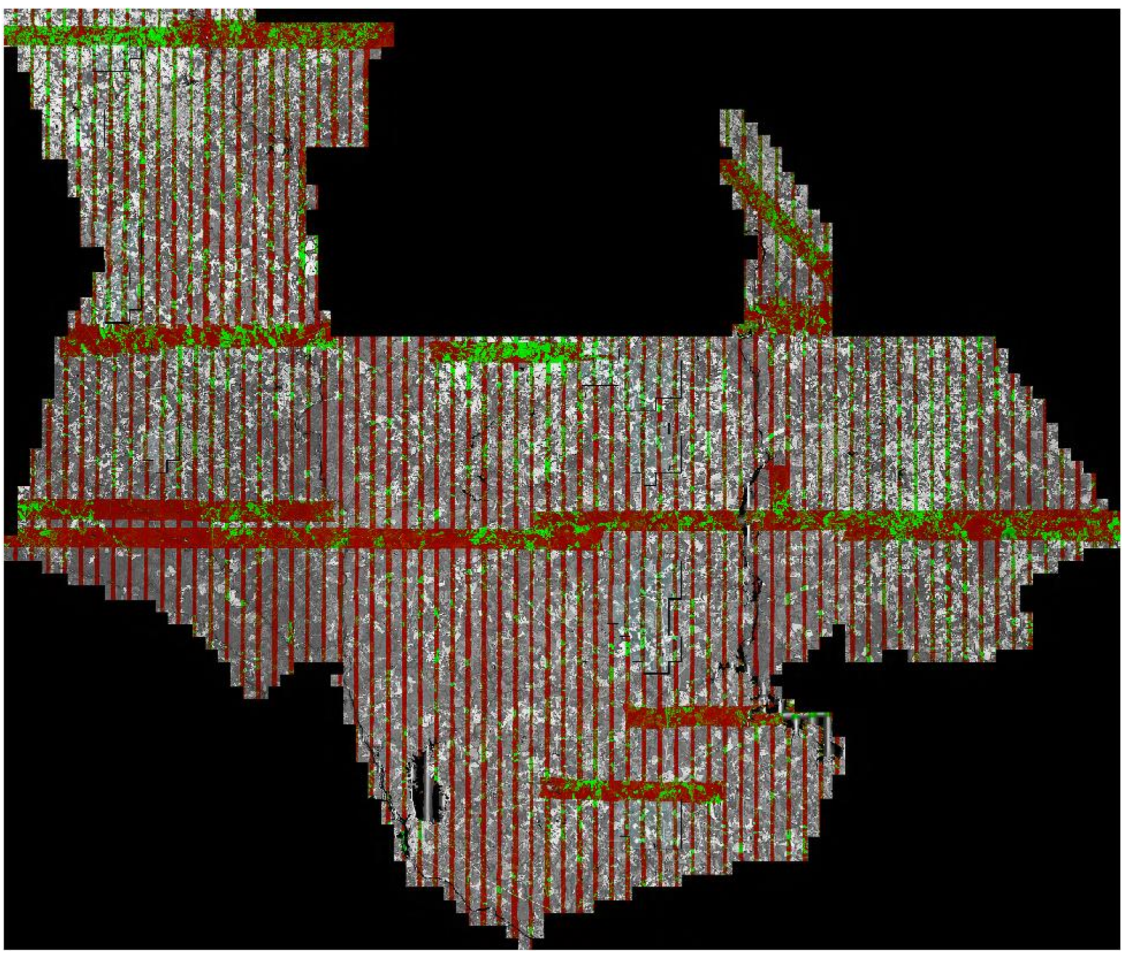

Figure 2: Elevation difference (DZ) rasters for visual check of calibration

Figure 3 is a closeup showing an area with multiple cross-flights and parallel lines. As expected with a good calibration, ground features are green showing that the relative difference between strips is within specifications while above-ground features show variance as expected.

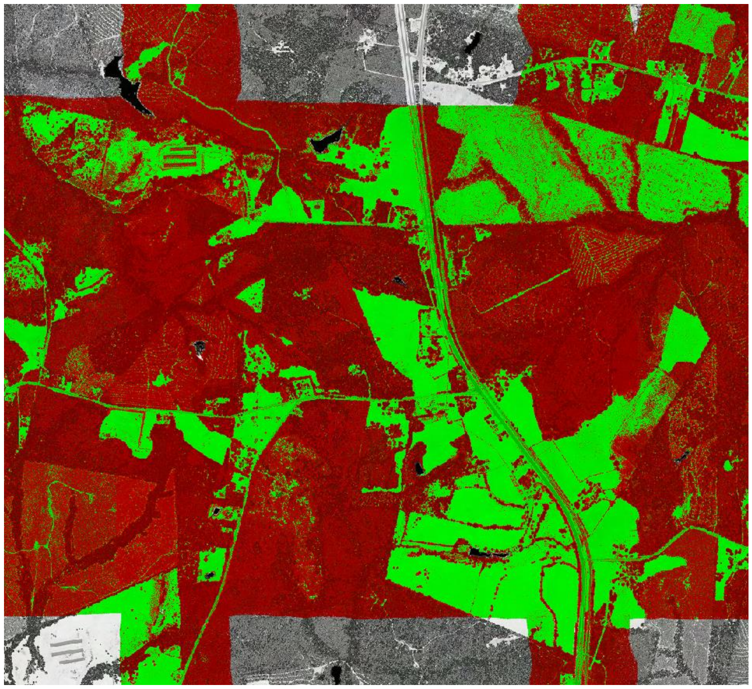

Figure 3: Closeup of DZ image showing good relative accuracy results between lines

Fundamental Accuracy Verifications (Absolute Accuracy)

Once the relative accuracy adjustment was complete, the data was adjusted to the high order GPS calibration control to achieve a zero-mean bias for fundamental accuracy computation, verification, and reporting. Internal accuracy testing procedures and methods were compliant with USGS specifications.

Horizontal Accuracy

The flying height was designed to be at ~2,105m above ground level (AGL) for the entire project. Based on this height, the recommended horizontal accuracy threshold for this project (based on the ASPRS standards) was 29cm $RMSE_r$.

Altitude (AGL, m)	Positional $RMSE_r$ (cm)	Altitude (AGL, m)	Positional $RMSE_r$ (cm)
500	13.1	3,000	41.6
1,000	17.5	3,500	48.0
1,500	23.0	4,000	54.5
2,000	29.0	4,500	61.1
2,500	35.2	5,000	67.6

Table 1. ASPRS expected horizontal errors for lidar

Standards

Post calibration, the data were verified by ESP independently of Quantum's calibration process. ESP verified that the aggregate nominal pulse density (ANPD) of >4 points per square meter (PPSM) at an aggregate nominal post spacing (ANPS) of <0.7 meters was met. Though the data was not cleaned of artifacts at this point in the workflow, internal survey checkpoints were used in open terrain areas to verify that an RMSE of 10.0 cm or better for Non-vegetated Accuracy (NVA) based on current USGS specifications was met. Addition checkpoints for various, other land cover categories were used to validate the data after the manual classification task was completed.

Though an independently-verified accuracy check was not commissioned by SCDNR for this project, ESP conducted checkpoint collection and verification independent of the calibrations process and withheld the checkpoint from the calibration team at Quantum in order to verify internally that the data met specifications.

NVA Accuracy Results

The results of ESP's independent checkpoint verification of NVA are presented in Table 2, as a consolidated calculation for the entire project area. Calculations by county are provided in Attachment A: Digital Attachments, of this report. A total of 67 bare earth and 21 urban checkpoints were used to compute NVA.

Name	Z (ft)	Z TIN (ft)	Delta (ft)	Delta^2 (ft)	Name	Z (ft)	Z TIN (ft)	Delta (ft)	Delta^2 (ft)
BE01	788.260	788.340	0.079	0.006	**BE47**	471.980	471.930	-0.049	0.002
BE02	695.280	695.190	-0.091	0.008	**BE48**	446.550	446.610	0.061	0.004
BE03	824.140	824.130	-0.008	0.000	**BE49**	417.970	418.010	0.042	0.002
BE04	702.640	702.630	-0.010	0.000	**BE50**	488.830	488.820	-0.016	0.000
BE05	739.340	739.280	-0.060	0.004	**BE51**	385.060	385.060	-0.005	0.000
BE06	822.000	822.160	0.160	0.026	**BE52**	537.090	537.120	0.026	0.001
BE07	797.310	797.370	0.061	0.004	**BE53**	558.740	558.810	0.067	0.005
BE08	746.490	746.550	0.062	0.004	**BE54**	532.120	532.290	0.168	0.028
BE09	617.550	617.460	-0.093	0.009	**BE55**	441.200	441.600	0.402	0.161
BE10	549.850	550.030	0.176	0.031	**BE56**	420.720	420.820	0.091	0.008
BE11	576.830	576.910	0.079	0.006	**BE57**	360.570	360.470	-0.099	0.010
BE12	615.070	615.220	0.155	0.024	**BE58**	325.010	325.190	0.183	0.034
BE13	591.240	590.960	-0.275	0.076	**BE59**	857.260	857.340	0.077	0.006
BE14	627.430	627.390	-0.044	0.002	**BE60**	652.630	652.760	0.131	0.017
BE15	609.970	609.960	-0.008	0.000	**BE61**	480.170	480.320	0.151	0.023
BE16	617.970	617.990	0.020	0.000	**BE62**	576.950	577.070	0.116	0.013
BE17	573.760	573.810	0.046	0.002	**BE63**	549.820	549.940	0.120	0.014
BE18	586.410	586.600	0.189	0.036	**BE64**	436.820	436.870	0.055	0.003
BE19	609.500	609.540	0.039	0.002	**BE65**	575.780	575.760	-0.022	0.001
BE20	553.900	553.950	0.047	0.002	**BE66**	228.670	228.780	0.108	0.012
BE21	658.720	658.670	-0.056	0.003	**BE67**	596.270	596.480	0.213	0.045
BE22	597.300	597.440	0.140	0.020	**UA01**	787.350	787.420	0.062	0.004
BE23	588.010	588.120	0.112	0.013	**UA02**	911.900	911.990	0.093	0.009
BE24	630.840	630.920	0.079	0.006	**UA03**	828.020	828.090	0.072	0.005
BE25	634.010	634.050	0.042	0.002	**UA04**	555.710	555.750	0.037	0.001
BE26	558.640	558.750	0.109	0.012	**UA05**	841.080	841.100	0.016	0.000
BE27	515.050	515.120	0.069	0.005	**UA06**	600.070	600.230	0.169	0.028
BE28	600.970	601.080	0.119	0.014	**UA07**	574.280	574.370	0.084	0.007
BE29	550.940	551.130	0.197	0.039	**UA08**	669.950	669.960	0.008	0.000
BE30	420.060	420.080	0.022	0.000	**UA09**	636.230	636.230	-0.005	0.000
BE31	557.370	557.460	0.093	0.009	**UA10**	573.520	573.630	0.108	0.012
BE32	553.850	553.850	0.003	0.000	**UA11**	632.790	632.840	0.055	0.003
BE33	593.610	593.730	0.118	0.014	**UA12**	582.860	582.940	0.084	0.007
BE34	392.260	392.240	-0.019	0.000	**UA13**	634.520	634.540	0.021	0.000
BE35	462.370	462.420	0.055	0.003	**UA14**	553.360	553.530	0.167	0.028
BE36	613.960	613.950	-0.006	0.000	**UA15**	487.930	487.870	-0.062	0.004
BE37	536.010	536.150	0.141	0.020	**UA16**	419.700	419.760	0.058	0.003
BE38	525.960	526.080	0.116	0.013	**UA17**	490.000	490.030	0.031	0.001
BE39	465.280	465.290	0.011	0.000	**UA18**	229.920	230.030	0.109	0.012
BE40	572.280	572.230	-0.045	0.002	**UA20**	461.590	461.870	0.280	0.078
BE41	608.920	608.990	0.065	0.004	**UA21**	544.020	544.130	0.107	0.012

BE42	491.930	492.040	0.110	0.012	**UA22**	534.120	534.200	0.083	0.007
BE43	489.060	489.220	0.168	0.028	**UA23**	436.340	436.500	0.157	0.025
BE44	340.450	340.450	-0.004	0.000	**UA24**	552.570	552.670	0.105	0.011
BE45	516.760	516.850	0.093	0.009	**UA25**	547.370	547.490	0.115	0.013
BE46	525.760	525.760	0.003	0.000	**UA26**	574.380	574.480	0.103	0.011

Sum	6.134	1.139
Min	-0.275	0.000
Max	0.402	0.161
Average	0.067	0.012
Std. Dev.	0.090	0.021
Skew	-0.032	4.615
RMSEz		**0.089**
RMSEz (95% Confidence)		**0.175**

Table 2: NVA results, project wide. Values are in Feet.

VVA Accuracy Results

The results of ESP's independent checkpoint verification of VVA are presented in Table 3, as a consolidated calculation for the entire project area. Calculations by county are provided in Attachment A: Digital Attachments, of this report. A total of 68 vegetated area checkpoints were used to compute VVA.

A single VVA checkpoint, FO07, was discarded due to the lack of surrounding ground points under the vegetation. Figure 4 illustrates the lack of ground where the lidar did not penetrate canopy.

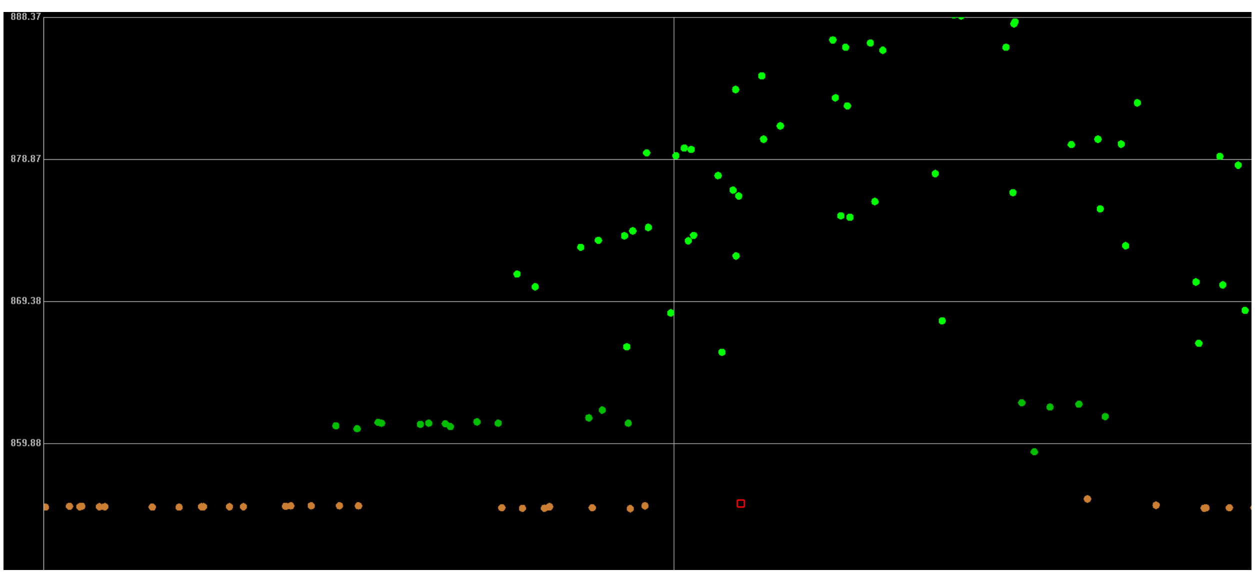

Figure 4: VVA Checkpoint FO07 (red square) discarded due to lack of ground points under dense vegetation

Name	Z (ft)	Z TIN (ft)	Delta (ft)	Delta^2 (ft)	Name	Z (ft)	Z TIN (ft)	Delta (ft)	Delta^2 (ft)
FO01	790.490	790.360	-0.129	0.017	FO36	444.950	445.110	0.153	0.023
FO02	680.810	681.140	0.330	0.109	FO37	469.110	469.380	0.274	0.075
FO03	823.840	823.680	-0.165	0.027	FO38	511.380	511.630	0.250	0.062
FO04	695.960	696.030	0.072	0.005	FO39	340.260	340.610	0.344	0.118
FO05	740.080	740.170	0.095	0.009	FO40	229.070	229.290	0.218	0.047
FO06	822.810	822.810	0.000	0.000	FO41	534.930	535.130	0.203	0.041
FO08	916.020	915.700	-0.320	0.103	FO42	557.640	557.760	0.117	0.014
FO09	746.590	746.810	0.224	0.050	FO43	546.890	547.220	0.334	0.111
FO10	565.810	565.990	0.182	0.033	FO44	539.200	539.460	0.267	0.071
FO11	606.690	606.610	-0.084	0.007	FO45	455.240	455.880	0.642	0.413
FO12	589.940	590.390	0.446	0.199	FO46	416.790	417.010	0.220	0.049
FO13	567.060	567.170	0.118	0.014	FO47	478.450	478.590	0.143	0.021
FO14	616.690	616.910	0.221	0.049	FO48	530.280	530.660	0.379	0.143
FO15	502.390	502.650	0.259	0.067	FO49	545.740	546.120	0.374	0.140
Fo16	625.180	625.300	0.116	0.013	FO50	440.130	440.230	0.093	0.009
FO17	644.030	644.290	0.258	0.066	FO51	320.900	321.330	0.427	0.183
FO18	581.410	581.200	-0.206	0.042	FO52	352.550	353.220	0.678	0.460
FO19	479.480	479.390	-0.086	0.007	FO53	384.780	384.880	0.099	0.010
FO20	569.650	569.770	0.117	0.014	SH01	595.690	596.010	0.324	0.105
FO21	426.040	426.130	0.089	0.008	SH02	493.770	493.940	0.170	0.029
FO22	557.560	557.780	0.225	0.051	TW01	914.550	914.630	0.076	0.006
FO23	523.630	523.780	0.151	0.023	TW02	751.230	751.270	0.040	0.002
FO24	565.060	565.240	0.179	0.032	TW03	548.910	548.990	0.082	0.007
FO25	632.160	632.440	0.277	0.077	TW04	596.230	596.350	0.124	0.015
FO26	584.050	584.340	0.290	0.084	TW05	616.880	617.020	0.140	0.020
FO27	598.720	599.130	0.410	0.168	TW06	668.670	668.770	0.102	0.010
FO28	485.870	486.220	0.350	0.122	TW07	612.080	612.210	0.127	0.016
FO29	463.440	463.750	0.310	0.096	TW08	638.590	638.610	0.014	0.000
FO30	543.500	543.640	0.143	0.020	TW09	616.260	616.330	0.068	0.005
FO31	522.450	522.550	0.098	0.010	TW10	657.030	657.020	-0.009	0.000
FO32	601.770	601.960	0.189	0.036	TW11	630.910	631.030	0.117	0.014
FO33	463.630	463.780	0.148	0.022	TW12	575.190	575.310	0.119	0.014
FO34	392.230	392.440	0.210	0.044	TW14	592.290	592.340	0.041	0.002
FO35	404.120	404.340	0.221	0.049	TW15	518.560	518.740	0.180	0.033

Sum	11.672	3.941
Min	-0.320	0.000
Max	0.678	0.460
Average	0.172	0.058
Std. Dev.	0.170	0.082
Skew	0.112	3.227
RMSEz		**0.169**
RMSEz (95th Percentile)		**0.507**

Task 5: Perform Lidar Data Classification

The lidar classification process encompassed a series of automated and manual steps to classify the calibrated point cloud dataset. Each project represents unique characteristics in terms of cultural features (urbanized vs. rural areas), terrain type, and vegetation coverage. These characteristics were thoroughly evaluated at the onset of the project to ensure that the appropriate automated filters were applied and that subsequent manual filtering yielded correctly classified data.

Lidar Classification Schema

ESP classified the lidar point cloud in accordance with the following classifications as shown in table 3, for this task. Tasks 9 and 10 for this project contain additional classifications as well.

Task 5 Lidar Classifications	
Class 1 - Unclassified (non-ground)	Class 20 - Ignored Ground (Breakline Proximity)
Class 2 - Ground (bare-earth)	Class 11 - Withheld Points (exceed scan angle limit)
Class 7 - Low Noise	Class 21 - Culverts
Class 8 - Model Key Points	Class 17 - Bridge Decks
Class 9 - Water	Class 18 – High Noise
Task 9 Lidar Classifications	
Class 6 – Building (≥500 sq. ft.)	Class 4 – Medium Vegetation
Class 3 – Low Vegetation	Class 5 – High Vegetation
Task 10 Lidar Classifications	
Class 13 - Roads	

Table 3. Lidar point classification schema by project task

The team recommended that the Ignored Breakline Proximity classification be moved from Class 10 to Class 20 per the latest USGS specification which ensures that it does not conflict with the ASPRS Rail classification (Class 10) and that culverts be moved to Class 21 as to not conflict with the ASPRS Road classification (Class 13). SCDNR agreed with these project specification changes. Classes 3, 4 and 5 for vegetation strata were classified using the following heights above ground:

- Class 3 Low Vegetation 0.5 – 3ft

- Class 4 Medium Vegetation 3 – 10ft
- Class 5 High Vegetation 10 – 220ft

Auto Filter (Classification)

Filtering macro(s), which may contain one or more filtering algorithms, were developed and executed to derive lidar points in the point cloud separated into the different classification groups as defined in the classification table. The macros were tested in several portions of the project area to verify the appropriateness of the filters. Often, there is a combination of several filter macros that optimize the filtering based on the unique characteristics of the project. Automatic filtering generally yields a ground surface that is 85-90% valid, so additional editing (hand filtering) is required to produce a more robust ground surface.

Re-classification Editing

The next task associated with Lidar classification was to manually re-classify (or hand-filter) "noise" and other features that may remain in the ground classification after the auto filtering. Cross-sections of the post-auto-filtered surface were viewed to assist in the reclassification of non-ground data artifacts. Certain features such as berms, hilltops, cliffs, and other features that may have been aggressively auto-filtered and points were re-classified into the ground classification. Conversely, above-ground artifacts such as decks, bushes, and other subtle features that remained in the ground classification after automated filtering were classified manually out of the layer.

Standards

All lidar point classification work was performed in accordance with the standards specified in Section 5 – Standards of the FY18 MAS.

Contractor Deliverables

The deliverable for this task was cut to the SC 5,000 X 5,000ft tile layout, delivered by county and consisted of:

- Lidar point cloud files, classified to the project classification schema, in LAS 1.4 format

Task 6: Perform Hydro-breakline Collection

Hydro-flattening breaklines were collected and compiled using Lidargrammetry techniques for drainage features that drain approximately ½ sq. mi. or more.

Hydrographic Feature Attributes

A minimum of four feature attributes, outlined in table 3, were included in the linework.

Feature	Attribute Type
Single Line Stream	Polyline Z
Stream Centerline/Connector	Polyline Z
Stream Banks (as polygons)	Polygon Z
Waterbodies (as polygons)	Polygon Z

Table 4: Minimum hydrographic feature attributes

Hydrographic Feature Data Capture

The feature data capture for hydrographic features was conducted in the following manner:

- Hydro breaklines were captured for drainage features that drain approximately 1/2 square mile or more:
    - Centerlines were captured for all streams that were ≤ 20 feet in width
    - Banks AND centerlines/connectors were captured for streams that were ≥20 feet in width
    - All closed water bodies were captured that exceeded 1 acre in surface area
- For lakes and ponds located along these stream reaches, both edge of water polygons AND a centerline through the feature were captured
- Stream banks greater than 20 feet in width were mapped as closed polygons
- Dangles only exist at upstream headwater end of streams and at the downstream outfalls
- Line intersections were located at nodes
- Adjoining counties were edge-matched (x-y-z values)

ESP's Minimum Map Unit Tool

ESP utilized a minimum map unit (MMU) tool to assist the technicians in determining whether island, ponds and other closed water bodies needed to be collected based on the project minimum map units of ≥1 acre for permanent island and ≥1 acre for closed water bodies. This tool introduces greater efficiency to the hydro collection process and doubles as a quality control tool. Figure 5 is an example of this tool in use. Grid displayed is a 1-acre grid. The smaller pond would not be required in the hydro layer but the larger pond would.

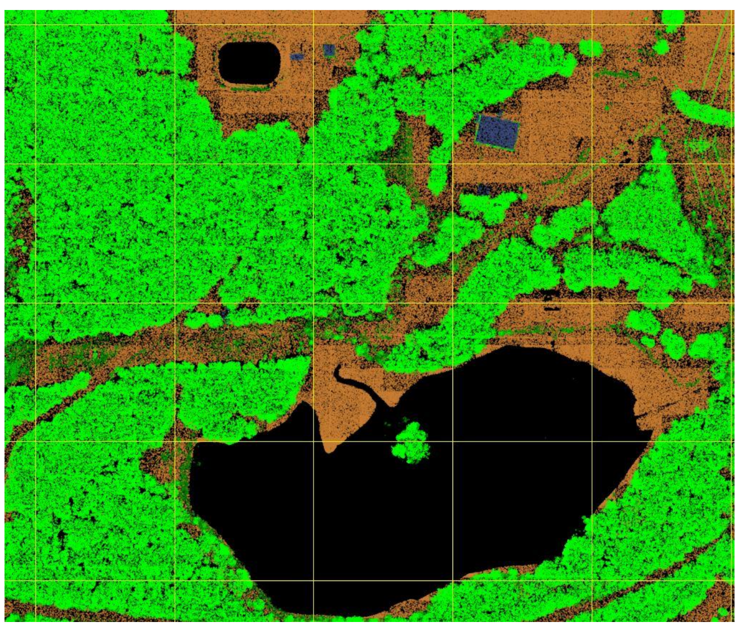

Figure 5. MMU tool displaying a 1-acre grid over lidar

Standards

All breaklines collected met or exceeded the specifications described in "Breaklines" section of the USGS BLS V2.1. and the SCDNR scope of services.

Contractor Deliverables

The completed Hydro breaklines were delivered in in ESRI File Geodatabase format, by county.

Task 7: Develop Hydro-flattened DEM

Hydro-flattening breaklines were reviewed and adjusted, if needed, to conduct hydro-flattening processes in order to ensure that the DEMs produced under this task met hydro-flattening requirements. These requirements applied to any streams, rivers, ponds, or lakes that met the minimum map unit (MMU) threshold for collection.

Inland Streams and Rivers

The following requirements were applied to the mapping of inland streams and rivers:

- Features were made flat and level bank-to-bank (perpendicular to the apparent flow centerline) with gradient following the adjacent terrain
- Entire water surface edges were located at or just below the immediately surrounding terrain
- Streams were broken at road crossings (culvert locations). Streams and rivers were not broken at bridges. When identification of a feature as a bridge or culvert could not be made reliably, the features were regarded as culverts
- Stream connectors were used to show flow between interconnecting rivers and streams at culvert, aqueduct, and similar feature type locations
- Stream channels were broken at road crossings with a connecter used to continue the feature
- Only connectors were used to introduce cuts into the terrain surface at road crossings (culverts), dams, or other such features.

Requirements for Inland Ponds and Lakes

The following requirements were applied for the mapping of inland ponds and lakes:

- Flat and level water bodies were attributed with a single elevation for every bank vertex
- Water surface edges were mapped at or just below the adjacent terrain
- Long impoundments, such as reservoirs or inlets, whose water surface elevations drop when moving downstream, were treated as rivers
- Stream Connectors were used to show flow between interconnecting water bodies at culvert, aqueduct, and similar feature type locations.

Bridge Structure Treatment

Per the latest USGS specifications, ESP included a separate set of breaklines that were used to enforce the TIN properly around bridge abutments when generating the DEMs. To enforce a logical terrain surface below a bridge, the following requirements from the USGS BLS V2.1 were applied:

- All instructions and requirements regarding the use of breaklines were also applied to non-hydrographic terrain generation below bridges
- Any breaklines used to enforce a logical terrain surface below a bridge were considered as required deliverables
- The bare-earth surface below the bridge represented a continuous, logical interpolation of the apparent terrain lateral to the bridge deck.
- Where abutments were clearly visible, the bare-earth interpolation began at the junction of the bridge deck and approach structure. Where this junction was not clear, the technicians used their best judgement to delineate the separation of below-bridge terrain from elevated bridge surface
- Streams, rivers, and water bodies meeting the criteria for hydro-flattening were monotonically continuous where bridge decks were removed
- Bridges, as defined in the glossary, will be removed from the bare-earth surface

Bare-earth Digital Elevation Model (DEM)

The bare-earth lidar points, bridge breaklines, and the hydro-flattened water body linework were used to generate DEMs for the project. The DEMs meet the following requirements:

- DEM point/post spacing is a 5-foot gridded elevation surface for the hydro flattened Geodatabase Terrain.
- Grid output consisted of a "Floating Point" for all output cell values and Natural Neighbors for an interpolation method.
- Any voids and NoData cells encountered within the project rasters were corrected
- Horizontal coordinates were in international feet for at least three decimal places, State Plane Coordinate System, South Carolina zone, NAD83 (2011).
- Elevations were in U.S. Survey foot units to at least three decimal places, North American Vertical Datum of 1988 (NAVD88) for bare-earth surface, breaklines, and Geodatabase Terrain.
- Elevation data points represent the topographic surface (i.e., for last-return bare- earth) and were reported to the nearest two decimal places for U.S. Survey foot units of measure.

Standards

The DEMs and hydro-flattened properties of the hydro breaklines meet USGS BLS V2.1 standard.

Contractor Deliverables

ESP provided the following deliverables as part of this task:

- Bare-earth DEMs at a 5ft resolution in ESRI Grid format

- Bridge breaklines in ESRI Shapefile format

Task 8: Generate Lidar Intensity Images

Once the lidar point cloud was calibrated and passed internal quality control, lidar intensity images were generated using ESP's proprietary software. Each of the images were generated using the lidar point clouds and their associated intensity returns, except for any noise or overlap classifications. The intensity images were exported in grayscale, 8-bit, GeoTIFF format using the same tile scheme as the other lidar deliverables. The 8-bit format was an unsigned 8-bit depth with 256 available unique values from 0 to 255. The GeoTIFF intensity images were produced with a raster cell size of 5 feet.

Every attempt was made to achieve homogeneity across the project area in image appearance. There will, however, be some variance in the appearance, especially over water bodies and other features where the reflected signal was either absorbed or reflected to a degree greater than normal. Figure 6 illustrates an area where the bright reflectance off the river surface gives intensity values outside of what is expected, affecting an otherwise homogenous scene.

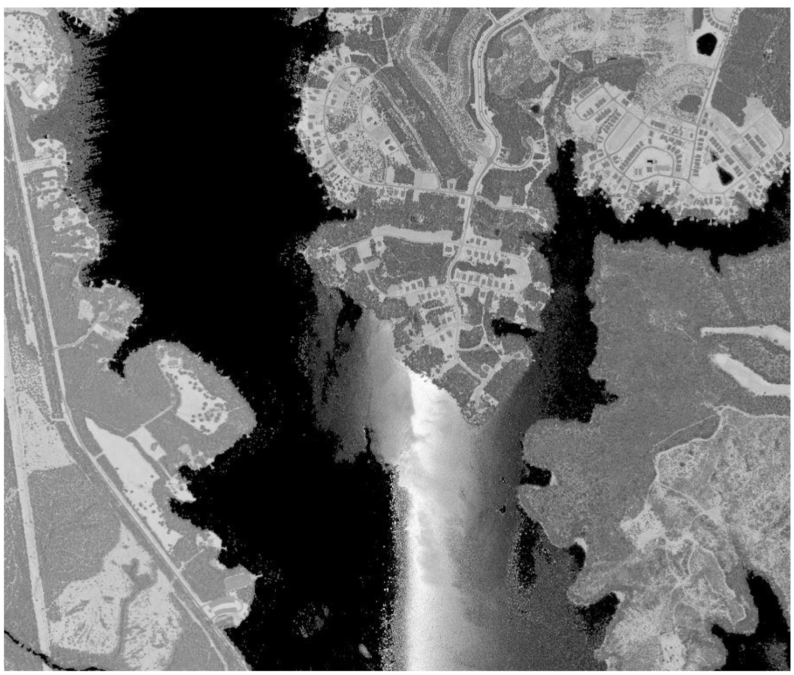

Figure 6. Intensity example showing high reflectance values over water

Contractor Deliverables

ESP provided the following deliverable as part of this task:

- 8-bit, GeoTIFF intensity image tiles corresponding to the project LAS tile layout

Task 9: Classification Upgrade – Buildings and Vegetation

ESP incorporated a building macro as part of the automated filtering routine along with a vegetation macro to determine the initial Class 6 and Classes 3,4, and 5 attributes. The elevations determining the vegetation strata are described under Task 5 of this report.

Re-classification Editing

Automated processes for these classes achieved reasonable confidence however manual editing is always required to correct instances where the automated macro did not correctly classify a building or vegetation; especially in cases where vegetation obscured or directly adjoined structures. Building features such as skylights, highly-reflective or absorbent surfaces, and rounded edges may also cause erroneous classifications that would have been corrected.

The following is an example of re-classification of the non-ground points (elevated features) that would typically need to be excluded from the true ground surface. Figure 7 illustrates a small building that was incorrectly auto-filtered. Data in the colorized TIN orthographic and point profile view displays vegetation in green (High, Medium, Low, classes 3, 4, and 5) and building in blue (Class 6) which needs to be manually re-classified. Figure 8, shows the result of the re-classification using manual filtering.

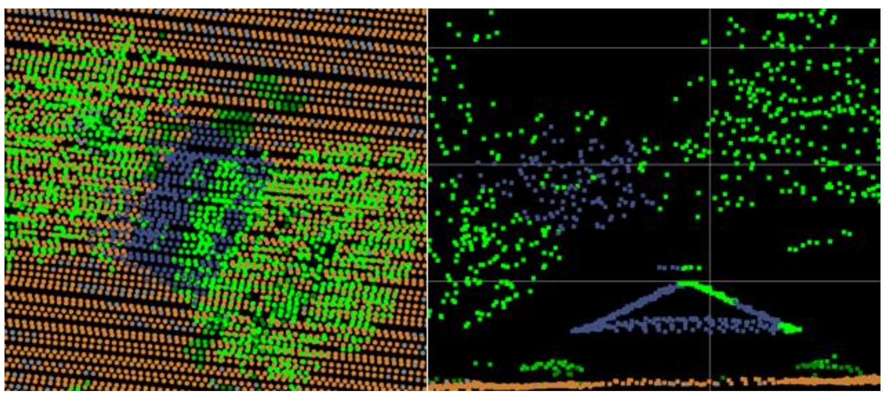

Figure 7. Erroneous classifications remaining after automated filter

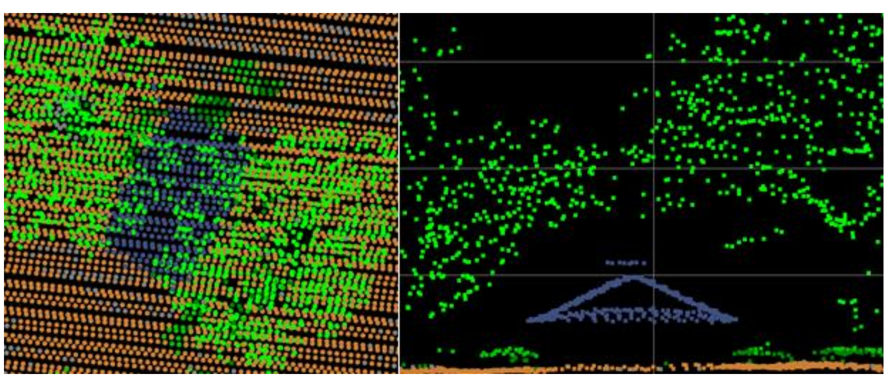

Figure 8. Point classifications corrected via manual edits

The ESP used a combination of automated and semi-automated routines to classify buildings and vegetation. We classified buildings will typically meet a filtering criterion in the range of 95-98%.

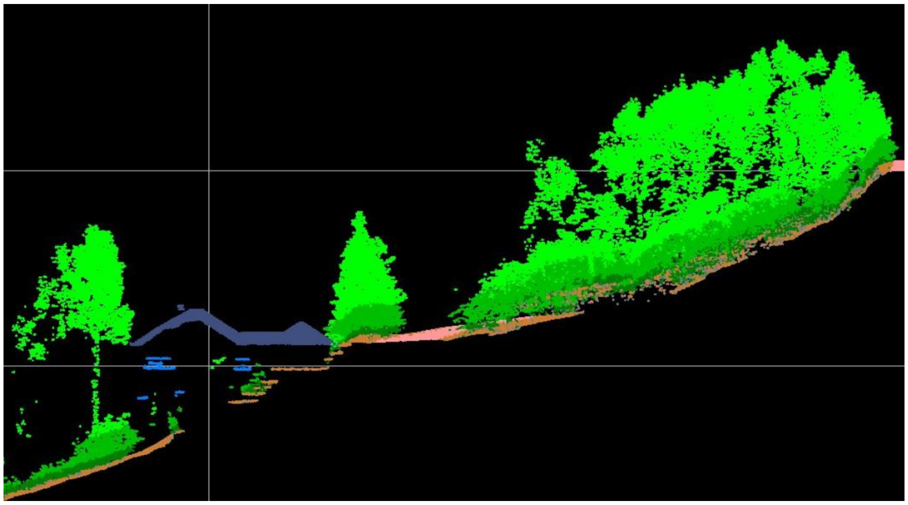

Figure 9. Example of fully classified lidar with vegetation strata and man-made features

Standards

Enhanced lidar classifications met the same standards as outlined in task 5.

Contractor Deliverables

The enhanced classifications were part of the task 5 deliverable

Task 10: Road and Bridge Polygons and Classification

ESP conducted a highly detailed road and bridge classification in the Lidar point cloud. This was completed for only state and federal-maintained roads included in ancillary information provided by SCDNR. The following is an outline of the technical approach and scope of services used for Task 10.

Process Overview

ESP classified the road points in the lidar by using a comprehensive collection process for mapping road edges, bridge decks, and road islands. Using the collected lidar data as well as ancillary reference files such as the latest-available orthophotos, technicians collected road edge polygons delineating the edge of pavement. The process utilized the planimetric tool within ESP's proprietary software. This allowed the technician to edit polygons and lines while mapping if need be and close the polygon correctly upon completion of the drawing. The technician was able to view the lidar, orthophoto, and other ancillary GIS data simultaneously. A transparency slider bar allowed the technician to adjust how visible the Lidar was through the other layers. Figures 10 through 12 depict the steps of the process used.

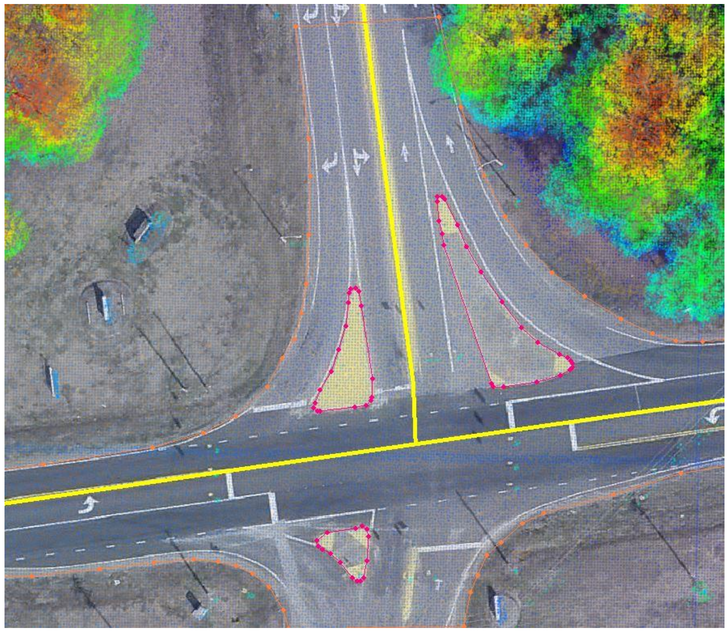

Figure 10. Lidar, orthophoto, and GIS road centerline displayed simultaneously

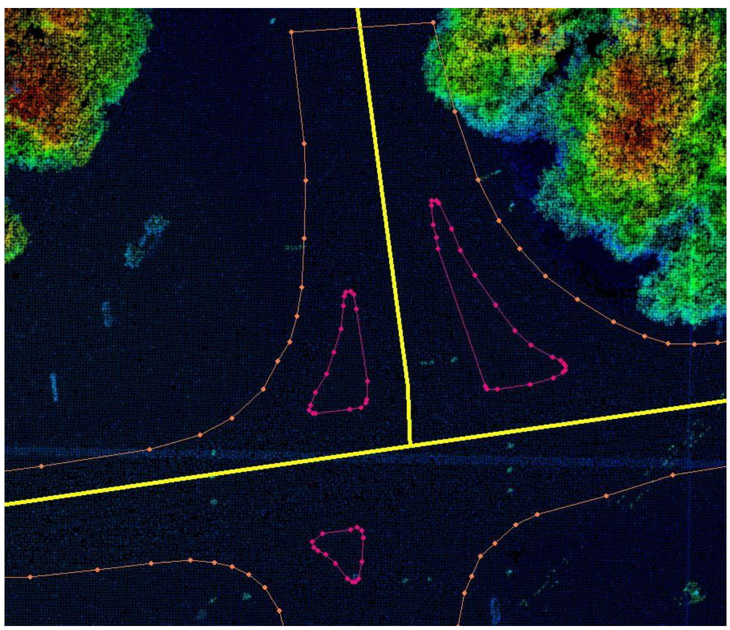

Figure 11. Road and road island polygons captured as separate layers

Figure 12. Completed classifications with road islands retained in Class 2 Ground and road surfaces in Class 13

Bridge Polygons and Classification

Bridges were classified as found during the road collection phase. Supplementing the identification of bridges was the SCDNR-provided GIS files of know bridge locations. This provided the technicians with a quick check to ensure that none were missed, and served as a QA file at the end of the classification process.

Recommended Guidelines Utilized

ESP recommended and incorporated the following guidelines in order to ensure that all project stakeholders understood the minimum acceptable criteria for the road classifications:

- It was understood that reference imagery and the lidar have their own error budgets which can affect the placement of the road polygons. It is reasonable that the horizontal accuracy of road polygons would within ~0.5 meters of the position within the lidar. Other factors, such as the technician’s interpretation of where the edge of pavement was and lidar resolution could affect line placement accuracy.
- Bridge polygon extents were mapped where the bridge seam was visible. At times, the bridge seam may not be evident in the imagery or lidar. The bridge classification was manually reviewed/edited to fix any issues where the bridge points were short or overextended where the deck met the ground or road. When a bridge classification was corrected in the point cloud, could result in the original bridge deck not matching the fixed classification perfectly. Re-adjusting the bridge deck polygons was not included under this task or as part of the project scope.
- Stakeholders allowed for road and bridge classifications to fall within reasonable error parameters. ESP recommended about a 2% threshold of classification error which is like a 98% level of confidence in classification accuracy for bridge decks. Note that this does not include the editing of above-deck features such as passing vehicles or light poles.

Standards

Road polygons are generally be within 0.5 meters of true position overall but may have areas not meeting this criterion in obscured regions, areas of construction, or areas of poor ancillary data availability (such as imagery with significant temporal differences as compared with the lidar).

Contractor Deliverables

ESP provided the following deliverables as a product of the process used.

- All road and bridge polygons collected, as separate layers, in ESRI Shapefile format

Task 11: Building Polygon Update and Upgrade

Utilizing the Class 6 Building points in the lidar data, ESP generated new building polygons to update the existing building layer provided by SCDNR. Because the existing layer was digitized off of orthophotography, the new polygons generated from lidar are closer to the true horizontal position of each structure.

Process Overview

ESP created new lidar files from the point clouds containing only the classified building points (Class 6). The LAS files were then converted to ESRI multipoint files to ingest them into an ArcGIS environment. These multipoint files were then used to create rasters of the buildings. The rasters were converted to polygons, holes filled, and then the polygons were simplified. A final step was run in ArcMap to normalize the building footprint which removed artifacts from the geometry of each footprint. Once the footprints were created, they were attributed with the mean elevation of the roof as well as whether the polygon was a new or existing structure as compared to the State’s building layer.

The data were reviewed thoroughly using a manual, QA/QC process to identify erroneously positions or polygons and correct them if necessary. In the below example (Figure 13), the green polygons are the State-provided Microsoft building polygons and the purple polygons are the new polygons. This example shows new buildings that are not in the current Microsoft layer as well as the spatial displacement that is common to polygons that have been derived from orthophotography (green polygons).

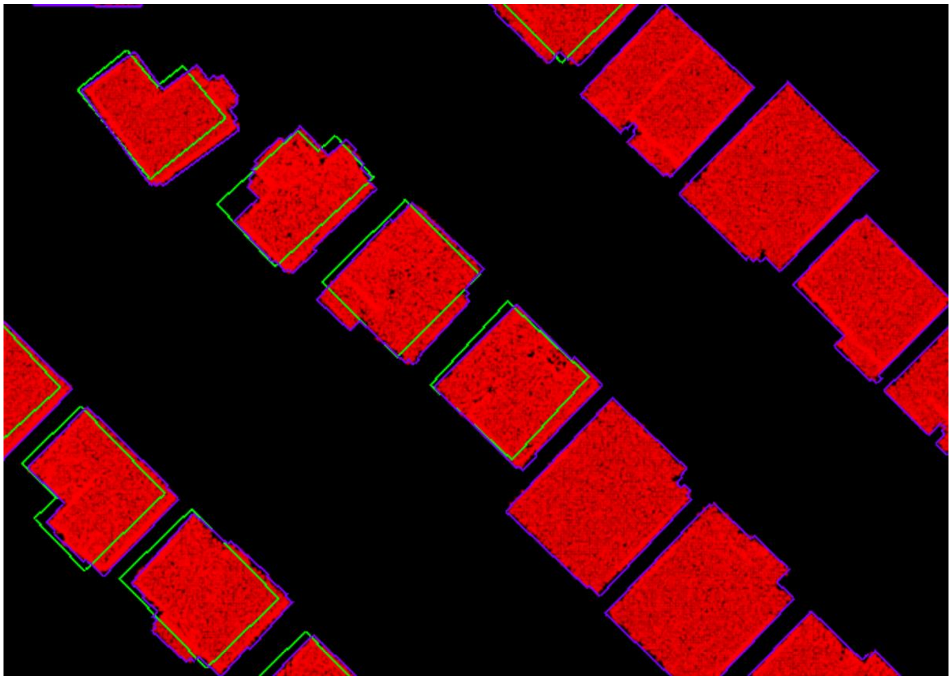

Figure 13. Update example, green polys are buildings from orthophotography and purple are from the lidar

Contractor Deliverables

ESP delivered the following product from the task:

- ESRI Shapefile containing lidar-derived building polygons attributed with the mean roof elevation and whether the structure is new.

Task 12: 1ft Contours Derived from Lidar Surface

ESP generated 1ft contours from the lidar bare earth points using proprietary software, with a contour index of 5ft. The contours were delivered "as is" with no express statement as to the accuracy.

Classified ground points from the lidar files were converted to an even, 5ft grid (such as a 5ft grid). This helped to remove the jagged contours common to lidar-derived contour data and smooth the lines. The grid was then used to generate a surface that supported the generations of the contours. No new breaklines will be created or used for the process, however the approved hydro-flattening layers were used for closed water bodies and rivers to help enforce the contours.

The contours will be labeled and checked manually for isolations and other anomalies that need to be removed.

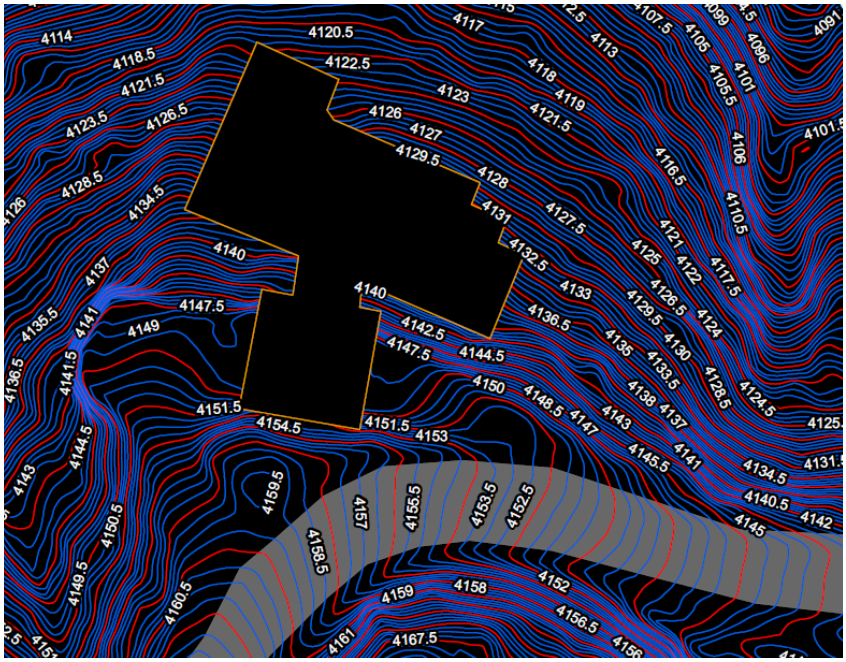

Figure 14. Example of 0.5 contours generated from lidar

Contractor Deliverables

ESP delivered the following product from this task:

- ESRI geodatabase or shapefile (to be determined at kick off meeting)

Issues Encountered

The following issues were encountered during the project. A description of each issue and their solutions are documented for informational purposes.

Flooding at Lake Wateree

During the data collection flight the energy utility released water upstream. This was not known as a potential event during the flight nor during planning for this project. During post-processing and client QA/QC it was noted that a significant temporal difference existed between the legacy lidar data for the area and the data collected for this project. The differences in the hydro boundary lines between the new and legacy datasets are illustrated in Figures 14 - 16.

Figure 15: Flooding in the lake resulted in the hydro breakline being inset significantly along the shoreline

Figure 16: Blue line is hydro breakline from current dataset

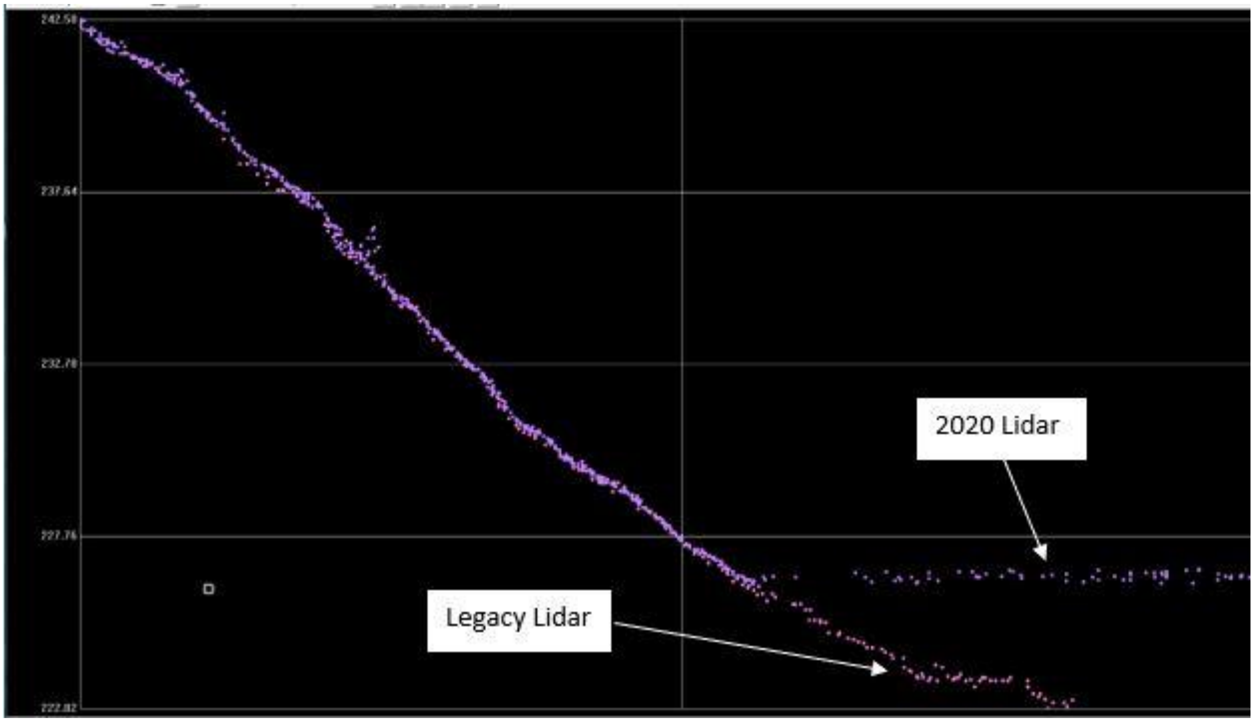

Figure 17: Profile of legacy and new lidar showing the temporal difference

ESP proposed the following solution to address these temporal differences and to allow for a more complete model of the shoreline for flood mapping purposes:

- Reference in the legacy lidar lake polygon breakline
- Spatially overlay the legacy and new polygons to identify areas to use either the legacy or new lidar, keeping the data that best covered ground to the shoreline
- Merge and edge-match the two lidar data sets in areas needing correction, allowing legacy lidar to fill in where the new lidar has gaps in coverage
- Recreate DEMs/contours/etc. using the merged lidar points and breaklines

By utilizing the legacy lidar in flooded areas, ESP created a seamless product suitable for modeling up to the shoreline of Lake Wateree.

Recommendations for Future Projects

The following recommendations are being made for the benefit of future lidar acquisition tasks commissioned by the SCDNR:

1. Conduct a post-project stakeholder meeting to discuss:
    a. The deliverables and determine if any lessons learned should be incorporated into similar products in the future
    b. Effectiveness of the independent QA/QC process
2. Conduct a review of the latest 3DEP Lidar Base Specification 2022 rev. and adaption of current SCDNR specifications to the latest USGS guidelines if appropriate.

Lidar Accuracy Statement

Data accuracy for the lidar dataset meets or exceed USGS specifications for QL1 data, which has been aligned with ASPRS standards as of USGS BLS V2.1. Reported accuracy conforms to the ASPRS Positional Accuracy Standards for Digital Geospatial Data, Edition 1, Version 1.0.0 using the Accuracy Classes defined in the document.

The absolute vertical accuracy requirements for this project meets ASPRS Vertical Accuracy Class 10-cm (or <10-cm RMSEz) after correction for systematic errors and discarding no more than 5% of check points and the root mean square error (RMSE) calculations to account for un-cleaned artifacts.

The vegetated vertical accuracy requirement for this project was 30.0 cm or better at the 95th percentile i.e., 3.00 x RMSEz.

Accuracy Statement

This data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 (cm) RMSEz Vertical Accuracy Class. Actual NVA accuracy was
found to be RMSEz = 2.71 cm, equating to +/- 5.33 cm at 95% confidence level. Actual VVA accuracy was found to be +/- 15.45 cm at the 95th percentile.

Report Prepared by:

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(ASPRS) No. R1418
Exp. 2/21/2024

12/15/2022

Post-Processing Report

Appendixes

Appendix A – Digital Attachments

The following digital attachments have been provided as part of this report:

- Elevation Accuracy Control Reports: control checkpoint results independent of the calibration control in (.xlxs Excel format)
    - Consolidated reports for entire project by NVA and VVA results
    - Reports by county by NVA and VVA results