LiDAR Quality Assurance (QA) Report
Marlboro County, South Carolina
February 13, 2009

Submitted to:
USGS
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EXECUTIVE SUMMARY

Reference: USGS Contract 07CRCN0004, Task Order 07004C0009, South Carolina 16 County LiDAR, dated January 17, 2008.

This report documents Dewberry's actions to quality assure the LiDAR deliverables of Marlboro, County, SC, produced by Dewberry's subcontractor, Fugro EarthData, under the referenced USGS task order. The LiDAR data was acquired in January, 2008 and delivered as LiDAR LAS point cloud data in five ASPRS LAS classes (class 1 = non-ground; class 2 = ground; class 8 = intelligently-thinned model key points; class 9 = water; and class 12 = overlap points not used in other classes). The LiDAR data was determined to be of high quality.

Completeness: Dewberry verified the completeness of the classified LiDAR points, intensity images, and an ESRI geodatabase containing a terrain (triangulated irregular network) and ground masspoints. Hydrographic breaklines were delivered separately by watershed. Dewberry verified that the high density masspoint data has an average point spacing less than 1.4m, that 617 tiles (each 5000 ft x 5000 ft) were delivered covering all of Marlboro County, that all data was delivered in the correct file format and projected to the South Carolina State Plane Coordinate System in International feet, NAD83 HARN, with elevations in meters, NAVD88; and that the FGDC-complaint metadata satisfies project requirements.

Quantitative: Using checkpoints surveyed by the South Carolina Geodetic Survey, Dewberry tested the RMSEz, Fundamental Vertical Accuracy (FVA) in open terrain, Consolidated Vertical Accuracy (CVA) in all land cover categories, and Supplemental Vertical Accuracy (SVA) in each of three major land cover categories per FEMA requirements, and the accuracy easily surpassed the specified accuracy required, as shown below, when tested per FEMA, NSSDA, NDEP and ASPRS guidelines.

Criterion	Checkpoints Required	Checkpoints Used	Accuracy Specification	Results Achieved
RMSEz	60	89	18.5 cm	6.5 cm
FVA	20	27	36.3 cm	14.1 cm
CVA	60	89	36.3 cm	11.0 cm
SVA-bare earth	20	27	36.3 cm	10.4 cm
SVA-vegetated	20	34	36.3 cm	10.5 cm
SVA-urban	20	28	36.3 cm	11.0 cm

Qualitative: Dewberry visually inspected 100% of the data; no remote-sensing data voids were found and the data is free of major systematic errors. The cleanliness of the bare earth model meets expectations; minor errors were found in less than 2% of the data, including inconsistent editing and misclassification. All of the deliverables extend to the county boundaries where adjoining counties are not delivered; where adjoining counties are delivered there is no clipping of the tiles.

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QA REPORT

1 Introduction

The following definitions are provided to distinguish between steps taken by Dewberry, as prime contractor, to provide Quality Assurance (QA) of the LiDAR data produced by Fugro EarthData, and steps taken by Fugro EarthData, as data producer, to perform Quality Control (QC) of the data that it provides to Dewberry. Collectively, this QA/QC process ensures that the LiDAR data delivered to USGS and its client (South Carolina Department of Natural Resources) are accurate, usable, and in conformance with the deliverables specified in the Scope of Work. These definitions are taken from the DEM Quality Assessment chapter of the 2nd edition of “Digital Elevation Model Technologies and Applications: The DEM Users Manual,” published by the American Society for Photogrammetry and Remote Sensing (ASPRS), 2007:

> **Quality Assurance (QA)** — Steps taken: (1) to ensure the end client receives the quality products it pays for, consistent with the Scope of Work, and/or (2) to ensure an organization’s Quality Program works effectively. Quality Programs include quality control procedures for specific products as well as overall Quality Plans that typically mandate an organization’s communication procedures, document and data control procedures, quality audit procedures, and training programs necessary for delivery of quality products and services.
>
> **Quality Control (QC)** — Steps taken by data producers to ensure delivery of products that satisfy standards, guidelines and specifications identified in the Scope of Work. These steps typically include production flow charts with built-in procedures to ensure quality at each step of the work flow, in-process quality reviews, and/or final quality inspections prior to delivery of products to a client.

Dewberry’s role is to provide overall project management as well as quality management that include QA of the data, including a completeness validation of the LiDAR masspoints, vertical accuracy assessment and reporting, and a qualitative review of the derived bare earth surface. In addition, Dewberry provides an extensive review of other derived products such as 3D streamlines, TIN-terrain, and LiDAR intensity images.

First, the completeness verification is conducted at a project scale (files are considered as the entities) for all products. It consists of a file inventory and a validation of conformity to format, projection, and georeference specifications. At this point Dewberry also ensures that the data adequately covers the project area for all products. The LiDAR data review begins with the computation of general statistics over all fields per file, followed by an analysis of the results to identify anomalies, especially in the elevation fields and LAS class fields.

The quantitative analysis addresses the quality of the data based on absolute accuracy of a limited collection of discrete checkpoint survey measurements. Although only a small amount of points are actually tested through the quantitative assessment, there is an increased level of confidence with LiDAR data due to the relative accuracy. This relative accuracy in turn is based on how well one LiDAR point "fits" in comparison to surrounding LiDAR measurements as acquisition conditions remain similar from one point to the next.

To fully address the LiDAR data for overall accuracy and quality, a manual qualitative review for anomalies and artifacts is conducted on each tile. This includes creating pseudo-image products such as 3-dimensional models. The QA analyst uses multiple images and overlays to find potential errors in the data as well as areas where the data meets and exceeds expectations.

Three fundamental questions are addressed during Dewberry's QA process:

- Was the data complete?
- Did the LiDAR system perform to specifications?
- Did the ground classification process yield desirable results for the intended bare-earth terrain product?

Under the referenced task order, LiDAR data was acquired for 16 counties in South Carolina (Figure 1). This report focuses on the deliverables covering Marlboro County that are directly derived from the LiDAR. The hydrolines, derived from the LiDAR, are being delivered per watershed and thus will be discussed in a subsequent report. All quality assurance processes and results are given in the following sections.

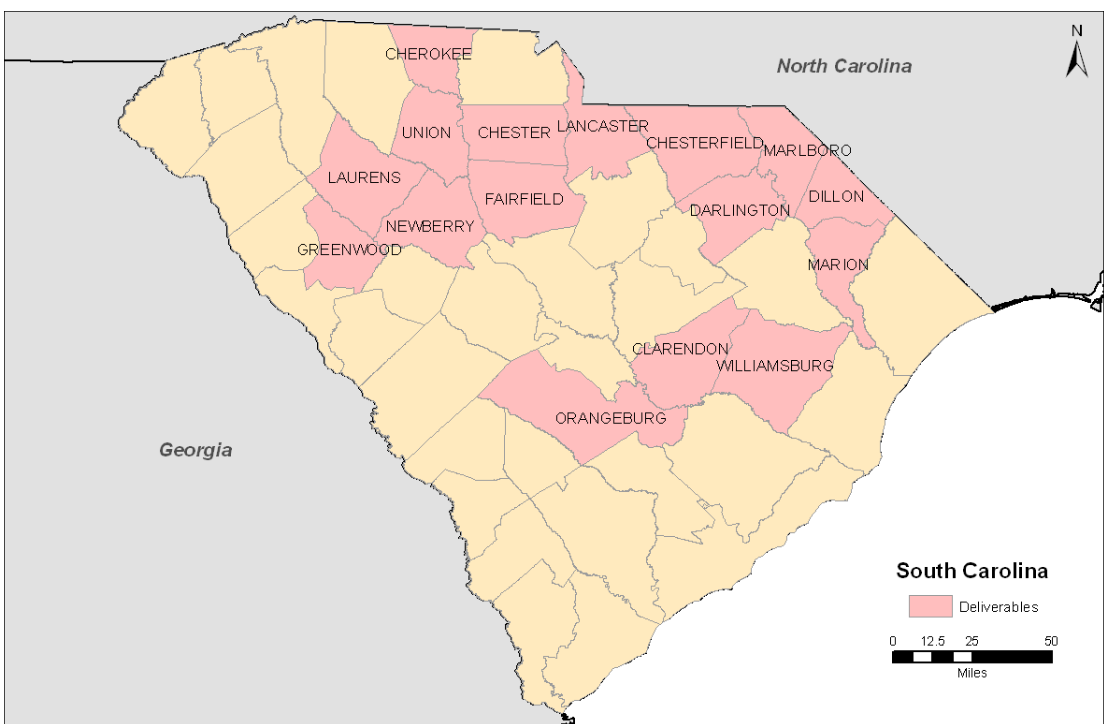

Figure 1 *– Project area; the 16 deliverable counties for the South Carolina project are shown in pink.*

2 Completeness of deliverables

Dewberry reviews the inventory of the data delivered by validating the format, projection and georeferencing. County based deliverables are listed in Table 1.

Table 1 — County deliverables.

Dataset	Format	Spatial
LiDAR	LAS	Tiled
Intensity images	GeoTiff	Tiled
Terrain (bare earth)	ESRI feature class Terrain	1 feature class
Ground masspoints	ESRI feature class multipoints	1 feature class
Boundary	ESRI feature class - polygons	3 feature classes (county/tile/LiDAR)

Clipping of the data along the county boundary was performed according to the following rules (Figure 2):

- a partial tile is delivered at the boundary with a county that is not part of the project,
- a full tile is delivered at the boundary with a county that is part of the project

LAS files and intensity images were delivered in tiles that adhere to these rules and to the State of South Carolina's 5000 ft x 5000 ft tile schema (see Figure 3). The LAS, the ground masspoint feature class, the terrain, and the intensity images extend outside the project boundary with a 50 ft buffer (Figure 4 and Figure 5) as expected.

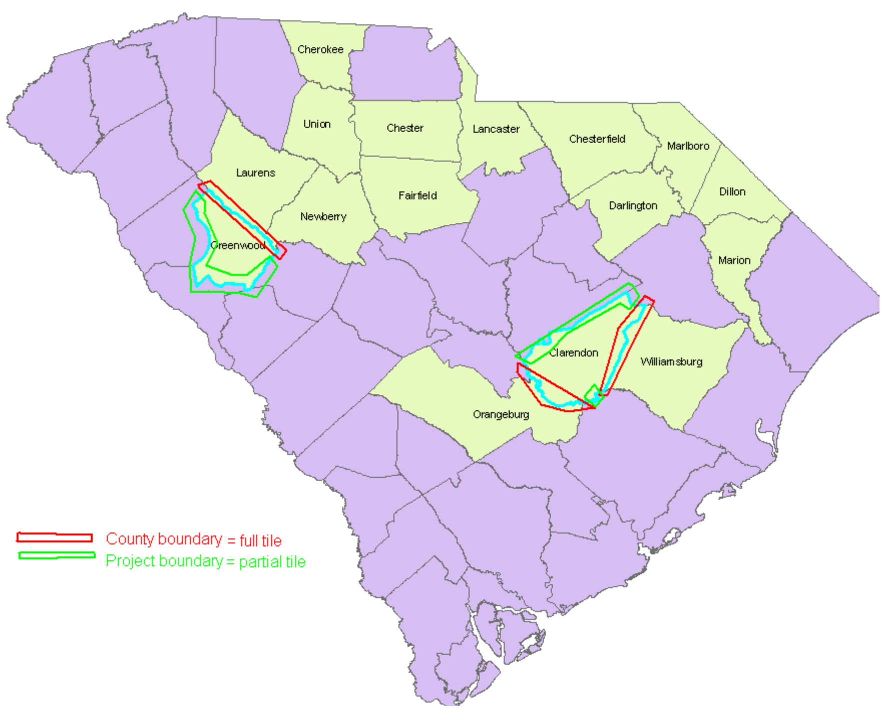

Figure 2 *– Convention used for the tile coverage: at the boundary of a county that is not part of the project, a partial tile is delivered; at the boundary of a county that is part of the project, a full tile is delivered.*

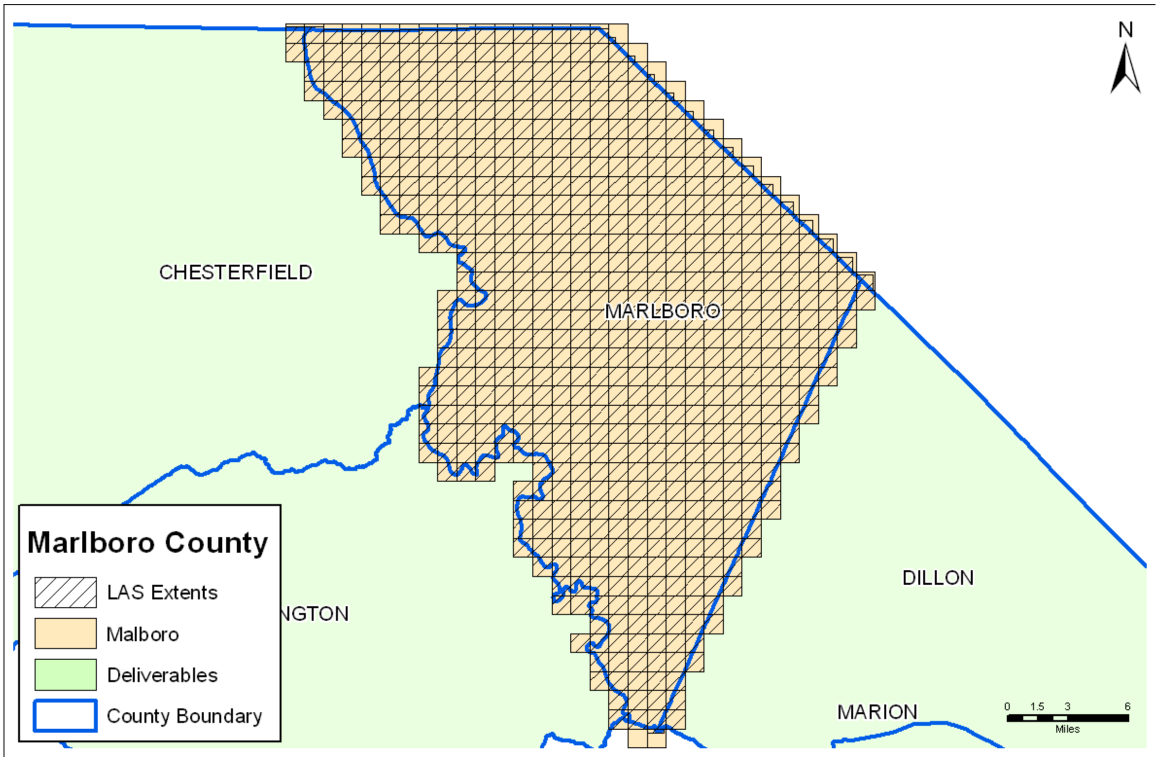

Figure 3 *– The LiDAR coverage of Marlboro County. Neighboring deliverable counties are shown in green.*

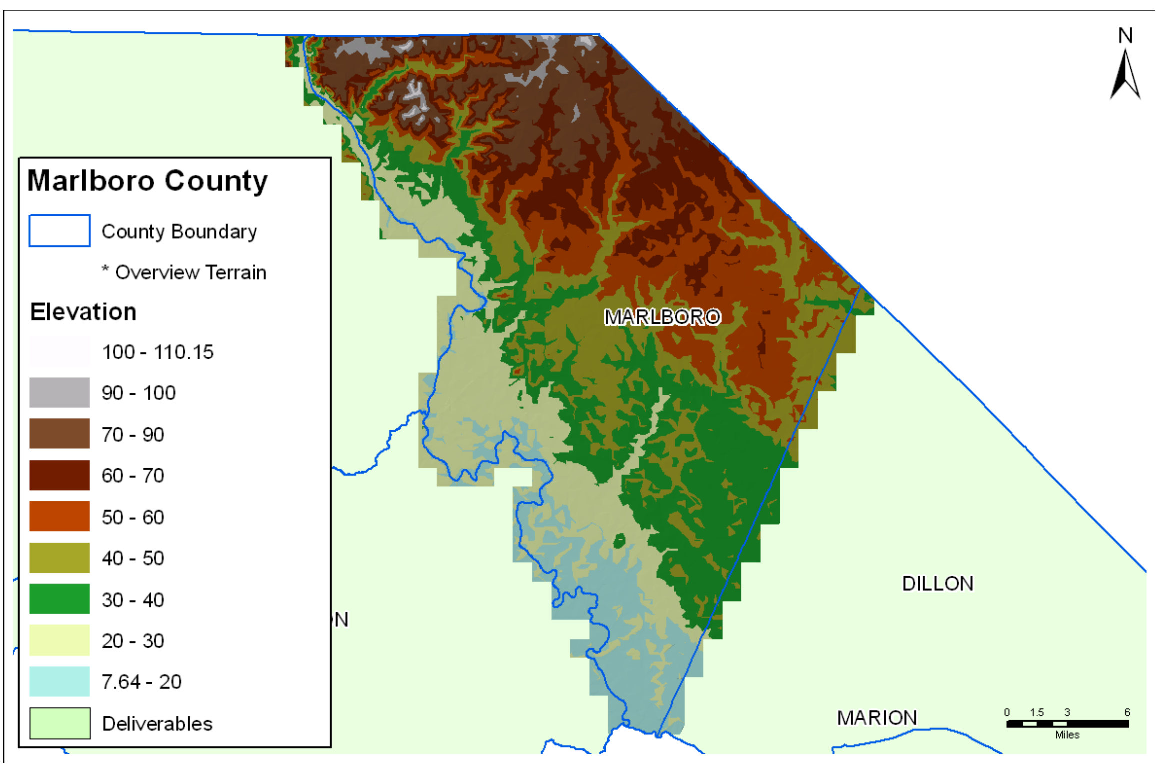

Figure 4 *– The terrain for Marlboro has a 50 ft buffer outside of the project boundary.*

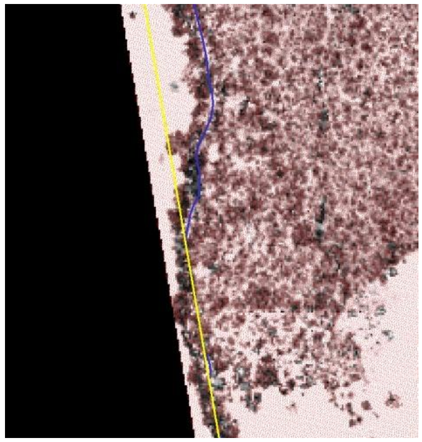

Figure 5 *- Ground masspoints (red) and intensity images extent 50 feet outside the project boundary in yellow. The LAS and terrain do the same. Hydrolines are clipped at the project boundary and the watershed boundary.*

3 QA of Intensity images

617 intensity images in GeoTiff format were delivered for Marlboro County. An automated script was used to validate that intensity values are integers ranging between 0 and 255, that the cell size is 4 ft, and that the column and row count is 1250. 1250 multiplied by 4 (the pixel size in feet) equals 5000 feet which is the required size of the tiles: 5000 ft x 5000 ft. Another automated script was used to validate the header information on all of the GeoTiffs. There were no issues with these checks. An example of the header is shown in Table .

Table 2 - Intensity header.

```
FileName:  7149-02.tif
File Information:
 Standard : : TIFF File
 Format : : Byte integers (8 bits)
 Pixels per Line :  1250
 Number of Lines :  1250
 Samples per pixel :  1
 File bits per sample : 8
 Actual bits per sample : 8
 Untiled file
 Number of overviews :  0
 Scanning device resolution :  72  : lines/inch
 Orientation :  4  : Row major order, origin at top left
 NO scan line headers : non-scannable file
 Packet size (16-bit words) : 0
 Free vlt space (16-bit words) : 2000000000
 Free packet space (16-bit words) : 2000000000
Raster to UOR matrix:
 Unspecified or All Zero Matrix
Raster to World Matrix:
 Units: Feet
 amx[ 0]=        4, amx[ 1]=        0, amx[ 2]=     1745000
 amx[ 3]=        0, amx[ 4]=       -4, amx[ 5]=     1200000
      1745000 ,     1200000
      1750000 ,     1200000
      1750000 ,     1195000
      1745000 ,     1195000
Geotiff_Information:
   Version: 1
   Key_Revision: 1.0
   Tagged_Information:
      ModelTiepointTag (2,3):
         0          0          0
         1745000    1200000    0
      ModelPixelScaleTag (1,3):
         4          4          0
      End_Of_Tags.
   Keyed_Information:
      GTModelTypeGeoKey (Short,1): ModelTypeProjected
      GTRasterTypeGeoKey (Short,1): RasterPixelIsArea
      ProjectedCSTypeGeoKey (Short,1): Unknown-3361
      ProjLinearUnitsGeoKey (Short,1): Linear_Foot
      End_Of_Keys.
   End_Of_Geotiff.
PCS = 3361 (NAD83(HARN) / South Carolina (ft))
Projection = 15355 (SPCS83 South Carolina zone (International
feet))
Projection Method: CT_LambertConfConic_2SP
   ProjFalseOriginLatGeoKey: 31.833333 ( 31d50' 0.00"N)
   ProjFalseOriginLongGeoKey: -81.000000 ( 81d 0' 0.00"W)
   ProjStdParallel1GeoKey: 34.833333 ( 34d50' 0.00"N)
   ProjStdParallel2GeoKey: 32.500000 ( 32d30' 0.00"N)
   ProjFalseEastingGeoKey: 609600.000000 m
   ProjFalseNorthingGeoKey: 0.000000 m
GCS: 4152/NAD83(HARN)
Datum: 6152/NAD83 (High Accuracy Regional Network)
Ellipsoid: 7019/GRS 1980 (6378137.00,6356752.31)
Prime Meridian: 8901/Greenwich (0.000000/  0d 0' 0.00"E)
Projection Linear Units: 9002/foot (0.304800m)
Corner Coordinates:
Upper Left    (1745000.000,1200000.000)
Lower Left    (1745000.000,1195000.000)
Upper Right   (1750000.000,1200000.000)
Lower Right   (1750000.000,1195000.000)
Center        (1747500.000,1197500.000)
```

Dewberry also visually checked the tile matching in ArcMap. Overall, the intensity is consistent between adjacent tiles. Tiles over the boundary between two delivered counties are delivered in full for each county. Tiles over the outside project boundary are partial; the section outside the buffered project area is filled with black pixels (value 0).

There were two intensity issues found in Marlboro County. These were white strips over land at nadir (Figure 6) and tonal changes within tiles (Figure 7). The white stripes occur when the intensity becomes saturated at nadir. These stripes are expected over water, but when they continue over land it may present a problem. The sharp tonal transition seems to follow the flight line boundaries, as shown in the right image in Figure 7. These intensity anomalies are notable but do not significantly impact the intensity as a whole.

Figure 6 *- 4907-02 White stripes at nadir.*

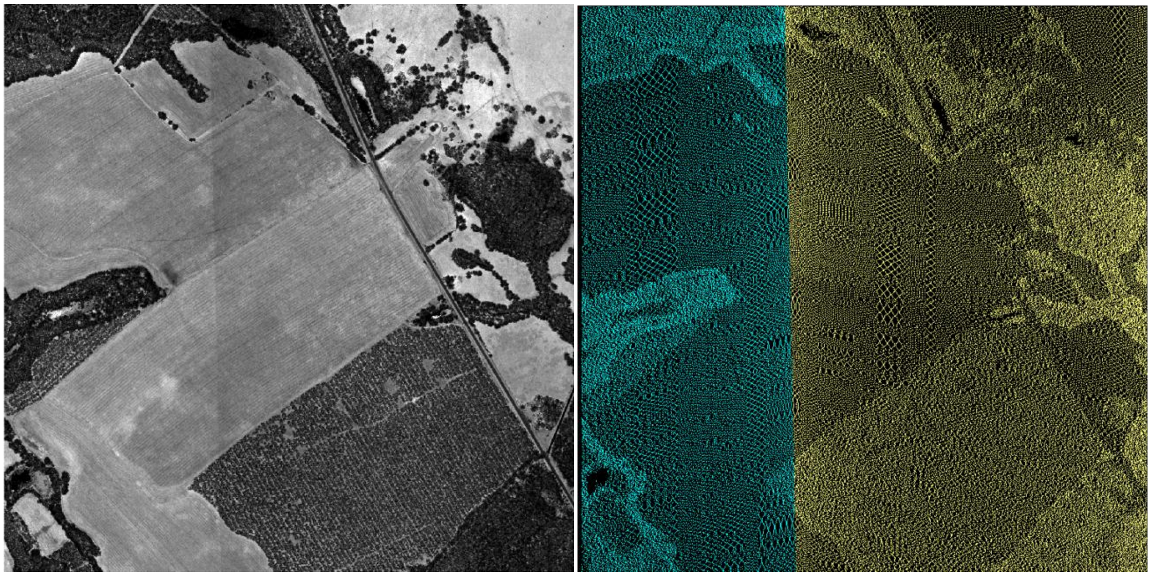

Figure 7 *- 3035-02 Tonal changes in intensity values within a tile (Left is intensity image, Right is image of LAS points colored by flight line).*

4 Metadata

Dewberry verified the metadata and all of the xml files were FGDC complaint. Metadata is delivered for the project, terrain, intensity images, and the LAS.

5 LiDAR QA

5.1 Completeness

5.1.1 LAS inventory

Dewberry received 617 LiDAR files covering the Marlboro County area. They are in the correct format and projection:

- LAS version: 1.1
- Point data format: 1
- Projection set in the header:
    - NAD_1983_HARN_StatePlane_South_Carolina_FIPS_3900_Feet_Intl;
    - Horizontal unit: linear foot;
    - NAVD88 - Geoid03;
    - Vertical unit: meters

The point spacing matches the requirement of an average point spacing of 1.4 meters.

Each record includes the following fields:

- XYZ coordinates
- Flight line
- Intensity
- Return number, number of return, scan direction, edge of a flight line and scan angle
- Classification:

- class 1 for non-ground,
- class 2 for ground (must be combined with class 8 to be complete),
- class 8 for (intelligently-thinned) model key points,
- class 9 for water,
- class 12 for overlap

• GPS time (this is expressed in second of the week; note that the date of collection will be given in the metadata file because the date contained in the LAS header is the file creation date according to LAS standard)

5.1.2 Statistical analysis of LAS tile content

To verify the content of the data and to validate the data integrity, a statistical analysis was performed on all the data. This process allows Dewberry to statistically review 100% of the data to identify any gross outliers. This statistical analysis consists of:

1. Extracting the header information
2. Reading the actual records and computing the number of points, minimum, maximum and mean elevation for each class. Minimum and maximum for other relevant variables are also evaluated.

Each tile was queried to extract the number of LiDAR points. With a nominal point spacing of 1.4m, the number of points per tile should be around 3.9 million. The mean over Marlboro County is around 5.2 million which proves that the average density is more than what is required and all tiles are within the anticipated size range except for where fewer points are expected (near the external project boundary where tiles are clipped or over large rivers and lakes) as illustrated in Figure 8.

To first identify incorrect elevations, the z-minimum and z-maximum values for the ground class were reviewed. With maximum values between 15.8m and 110.1m, no noticeable anomalies were identified because this is consistent with the expected range of elevation in the county (max elevation in Marlboro County: around 225m). Figure 9 (right) shows the spatial distribution of these elevations, following the anticipated terrain topography. Lower elevations are found near hydrographic features; see Figure 9 (left) for the Z min elevations.

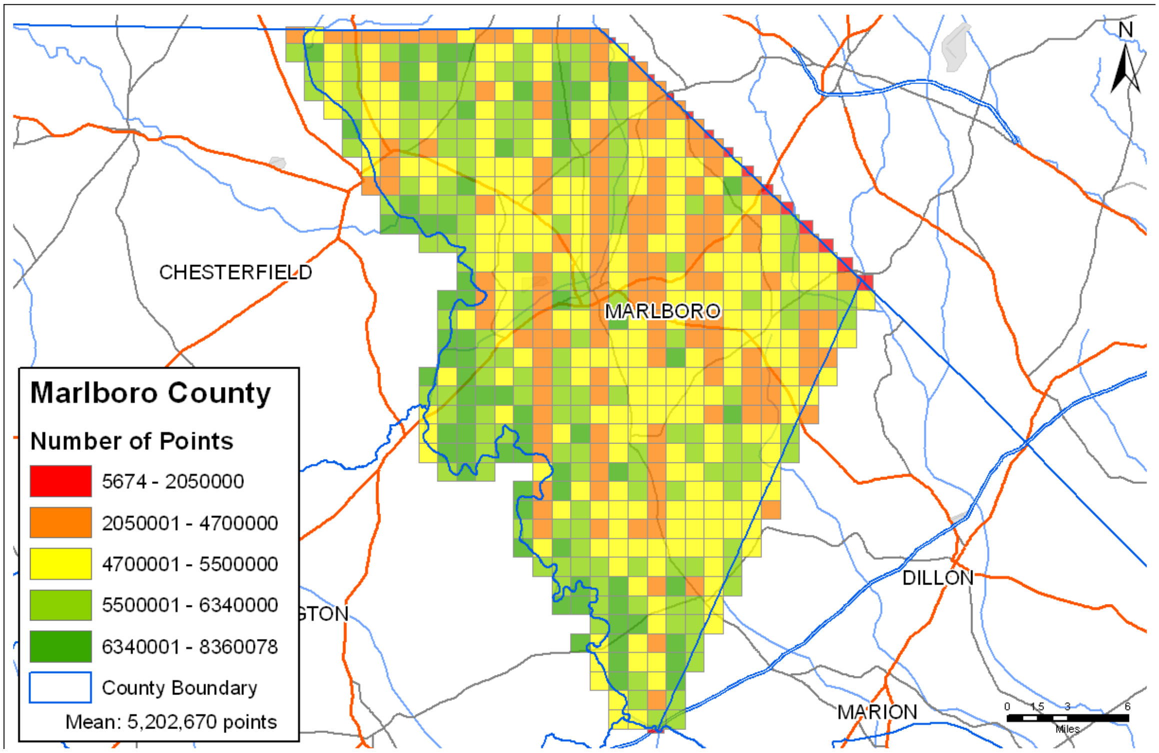

***Figure 8** – Number of points per tile. The red tiles at the border are expected to have fewer points.*

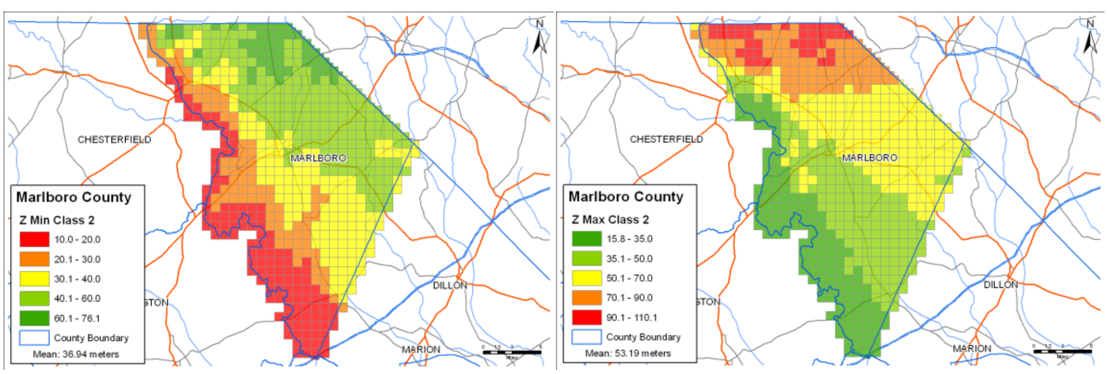

***Figure 9** – Z min and Z max elevation for ground points (class 2) per tile.*

5.2 LiDAR Quantitative Assessment

5.2.1 Checkpoint inventory

Typically for this type of data collection, a ground truth survey is conducted following the *FEMA Guidelines and Specifications for Flood Hazard Mapping Partners Appendix A: Guidance for Aerial mapping and Surveying* which is based on the NSSDA. This methodology collects a minimum of 20 points for each of the predominant land cover types (i.e. bare-earth, weeds and crop, forest, urban etc.) for a minimum of three land cover classes. By verifying the data in these different classes, the data accuracy is tested, but it also tests whether the classification of the LiDAR has been performed correctly at those test point locations. In this project the predominant land covers selected are bare-earth, mixed vegetation, and urban.

The field survey was conducted and prepared by the South Carolina Geodetic Survey in April 2008. The guidelines were to collect 60 checkpoints in 3 different land covers: 20 points in Urban Areas, 20 points in Open Terrain, and 20 points divided equally in Medium Vegetation and Forested Areas.

In reality 90 points were collected, as presented in Table 3, with 34 vegetation points instead of 20, including an additional class (bush). All the checkpoints used for the vertical assessment of the LiDAR data are available in Appendix A. Figure 10 shows the distribution of the checkpoints throughout the area. The points are grouped together in clusters. In some cases the checkpoints within a cluster are less than 100 ft apart which is not ideal but still acceptable.

Table 3 – Number of points required and acquired.

Class	Guidelines	Acquired
o - Open Terrain	20	27
b - Bush	0	12
h - High Grass	10	11
w - Woods	10	12
u - Urban	20	28
Total	**60**	**90**

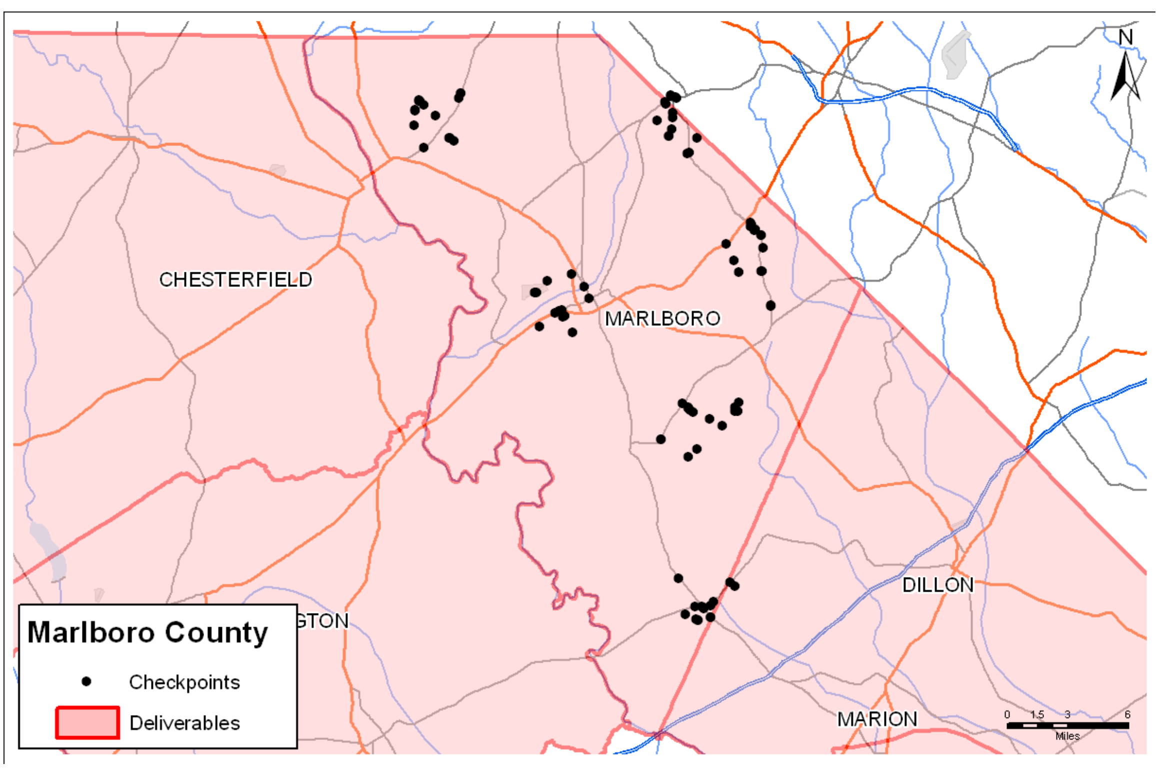

***Figure 10** – Survey checkpoints from South Carolina Geodetic Survey.*

5.2.2 Vertical Accuracy Assessment Methodologies

The first method of testing vertical accuracy used the FEMA specifications which follows the National Standard for Spatial Data Accuracy (NSSDA) procedures. The accuracy is reported at the 95% confidence level using the Root Mean Square Error (RMSE) which is valid when errors follow a normal distribution. By this method, vertical accuracy at the 95% confidence level equals RMSEz x 1.9600. This methodology measures the square root of the average of the set of squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy for identical points. The vertical accuracy assessment compares the measured survey checkpoint elevations with those of the TIN as generated from the bare-earth LiDAR. The X/Y locations of the survey checkpoints are overlaid on the TIN and the interpolated Z values are recorded. This interpolated Z values are then compared with the survey checkpoint Z values and this difference represents the amount of error between the measurements.

The second method of testing vertical accuracy, endorsed by the National Digital Elevation Program (NDEP) and American Society for Photogrammetry and Remote Sensing (ASPRS) uses the same (RMSE) method in open terrain only; an alternative method uses the 95^{th} percentile to report vertical accuracy in each of the other land cover categories (defined as Supplemental Vertical Accuracy – SVA) and all land cover categories combined (defined as Consolidated Vertical Accuracy – CVA). The 95^{th} percentile method is used when vertical errors may not follow a normal error distribution, as in vegetated terrain.

The Fundamental Vertical Accuracy (FVA) is the same for both methods; both methods utilize RMSE x 1.9600 in open terrain where there is no reason for LiDAR errors to depart from a normal error distribution.

The following tables and graphs outline the vertical accuracy and the statistics of the associated errors as computed by the different methods.

Table 4 shows the complete results of the Marlboro County data set run through the FEMA/NSSDA process; vertical accuracy at the 95% confidence level equals the RMSE x 1.9600. By this method, the consolidated vertical accuracy equals the RMSE (0.065 m) x 1.9600, or 0.127 m (12.7 cm).

Table 4 – Final statistics for Marlboro County using FEMA/NSSDA processes.

100 % of Totals	RMSE (m) Spec=0.185m	Mean (m)	Median (m)	Skew	Std Dev (m)	# of Points	Min (m)	Max (m)
Consolidated	0.065	-0.043	-0.051	0.511	0.049	89	-0.151	0.092
Open Terrain	0.072	-0.059	-0.061	0.167	0.041	27	-0.151	0.023
Vegetated	0.061	-0.028	-0.040	0.411	0.055	34	-0.118	0.092
Urban	0.063	-0.046	-0.049	0.363	0.043	28	-0.114	0.054

Table 5 shows the complete results of the Marlboro data set run through the NDEP/ASPRS process; the CVA value 0.110 m (11.0 cm). The similar results between the two methods (12.7 cm and 11.0 cm) demonstrate that the errors did approximate a normal error distribution, even in vegetation. All of the calculated statistics for Marlboro County fall well below the specifications.

Table 5 – Final statistics for Marlboro County using NDEP/ASPRS processes.

Land Cover Category	# of Points	FVA — Fundamental Vertical Accuracy (RMSEz x 1.9600) Spec=36.3 cm	CVA — Consolidated Vertical Accuracy (95th Percentile) Spec=36.3 cm	SVA — Supplemental Vertical Accuracy (95th Percentile) Target=36.3 cm
Consolidated	89		11.0	
Bare Earth	27	14.1		10.4
Vegetated	34			10.5
Urban	28			11.0

Figure 11 illustrates the distribution of the elevation differences between the LiDAR data and the surveyed checkpoints. The majority of delta Z values are concentrated on the negative side (LiDAR lower than the checkpoints) pointing toward a slight negative bias in the data.

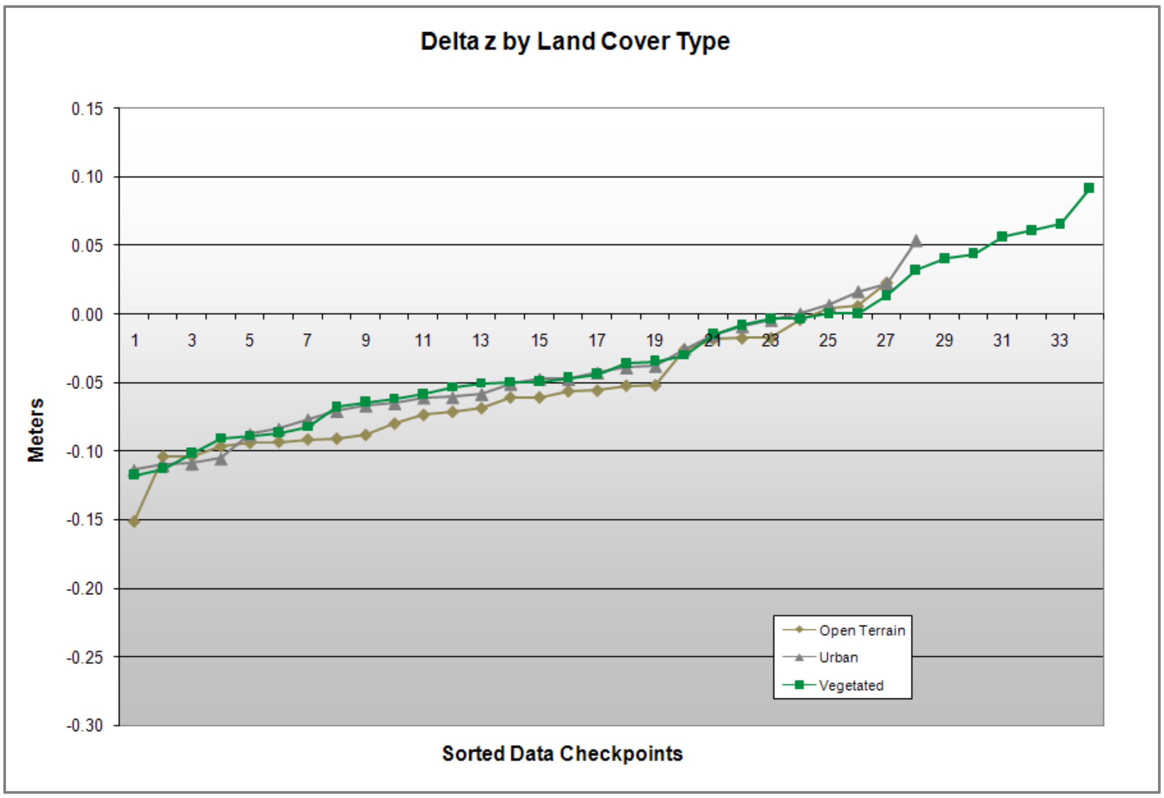

Figure 11 - *Checkpoints by land cover type and sorted by errors (DeltaZ).*

Given the good results and the high number of checkpoints used, Dewberry is confident that the data meets the accuracy requirement despite the less ideal spatial dispersion of the checkpoints.

Compared with the 36.3 cm specification for vertical accuracy at the 95% confidence level, equivalent to 2-foot contours, the dataset passes by all methods of accuracy assessment:

- Tested 14.1 cm Fundamental Vertical Accuracy at 95% confidence level in open terrain using RMSEz x 1.9600 (FEMA/NSSDA and NDEP/ASPRS methodologies).
- Tested 12.7 cm Consolidated Vertical Accuracy at 95% confidence level in all land cover categories combined using RMSEz x 1.9600 (FEMA/NSSDA methodology).
- Tested 11.0 cm Consolidated Vertical Accuracy at 95th percentile in all land cover categories combined (NDEP/ASPRS methodology).

5.3 LiDAR Qualitative Assessment

5.3.1 Protocol

The goal of Dewberry's qualitative review is to assess the continuity and the level of cleanliness of the bare earth product. Each LiDAR tile is expected to meet the following acceptance criteria:

- The point density is homogeneous and sufficient to meet the user needs;
- The ground points have been correctly classified (no manmade structures and vegetation remains, no gap except over water bodies);
- The ground surface model exhibits a correct definition (no aggressive classification, no over-smoothing, no inconsistency in the post-processing);
- No obvious anomalies due to sensor malfunction or systematic processing artifact is present (data holidays, spikes, divots, ridges between tiles, cornrows…);
- 90% or more of the artifacts have been removed, 95% of the outliers, 95% of the vegetation, and 98% of the buildings.

Dewberry analysts, experienced in evaluating LIDAR data, performed a visual inspection of the bare-earth digital elevation model (bare-earth DEM). LiDAR masspoints were first gridded with a grid distance of 2x the full point cloud resolution. Then, a triangulated irregular network (TIN) was built based on this gridded DEM and displayed as a 3D surface. A shaded relief effect was applied which enhances 3D rendering. The software used for visualization allows the user to navigate, zoom and rotate models and to display elevation information with an adaptive color coding in order to better identify anomalies.

One of the variables established when creating the models is the threshold for missing data. For each individual triangle, the point density information is stored; if it meets the threshold, the corresponding surface will be displayed in green, if not it will be displayed in red (see Figure 12). It should also be noted that if this density model is created with the ground points only, it is expected to have void areas where buildings exist or in water; vegetation can also reduce the number of points hitting the ground, resulting in more distanced points.

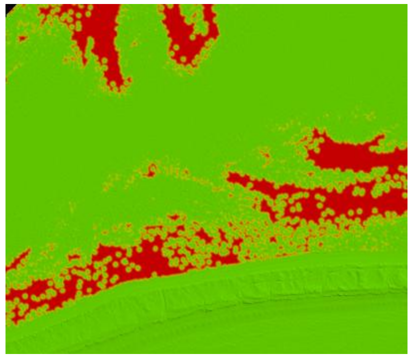

Figure 12 *– Ground model with density information (red means sparse data).*

The first step of Dewberry's qualitative workflow was to verify the point distribution by systematically loading a percentage of the tiles as masspoints colored by flight line (Figure 13) or by class (Figure 14). This particular type of display helps us visualize and better understand the scan pattern, the flight line orientation, flight coverage, and gives additional confirmation that all classes are present and logically represent the terrain.

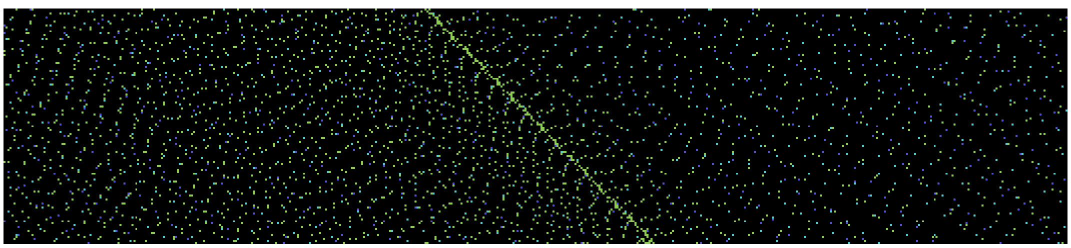

Figure 13 *– LiDAR points colored by flight line. Note the variations in the scan pattern.*

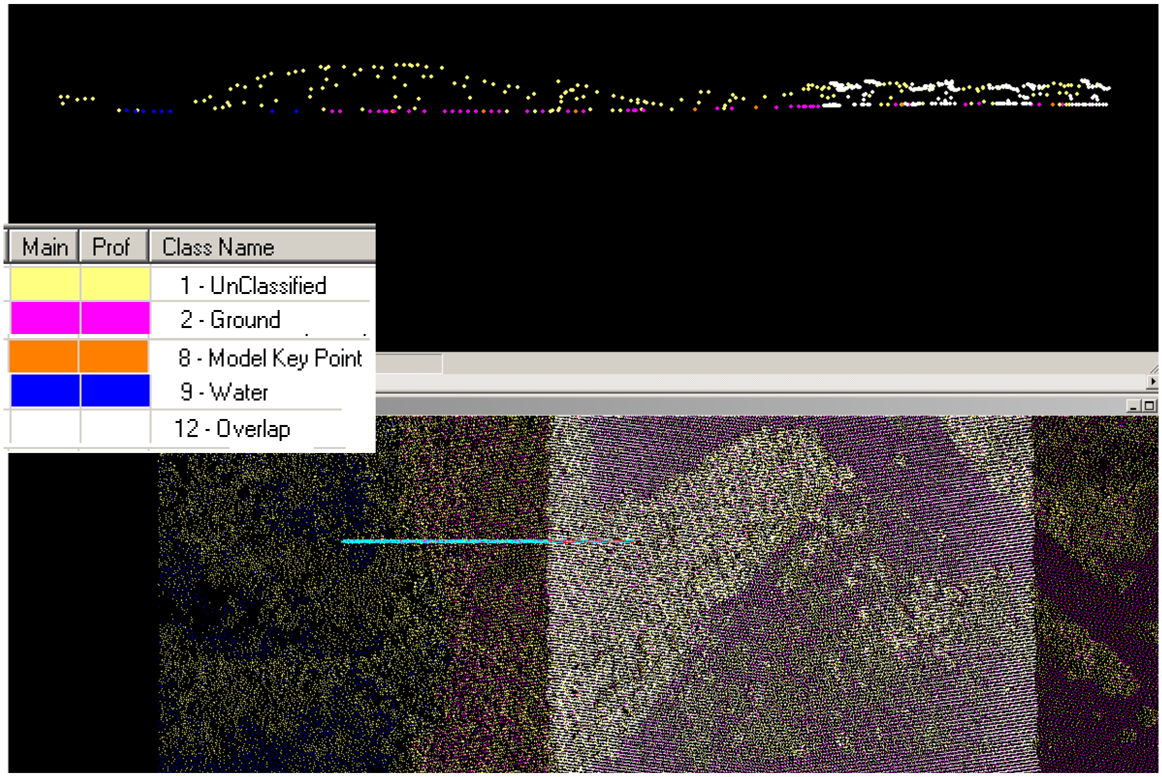

Figure 14 *- Full point cloud colored by classification.*

The second step was to verify data completeness and continuity using the bare-earth DEM with density information, displayed at a macro level. If, during this macro review of the ground models, potential artifacts or large voids are found, the digital surface model (DSM) based on the full point cloud including vegetation and buildings will be used to pinpoint the extent and the cause of the issue. Moreover, the intensity information stored in the LiDAR data can be visualized over this surface model, helping in interpretation of the terrain. Finally, if the analyst suspects a systematic error relating to data collection, a visualization of the 3D raw masspoints is performed, rather than visualizing as a surface.

Dewberry's micro-level qualitative review is the process of importing, comparing and analyzing these two later types of models (DSM with intensity and raw masspoints), along with cross section extraction, surface measurements, and density evaluation.

5.3.2 Quality report

Dewberry's qualitative review consists of a micro visual inspection of all the tiles. There is no automated toolset more effective than the manual inspection by a GIS analyst to find errors in automated processing of LiDAR data. The analyst will inspect the data for processing anomalies, classification errors, and full point cloud artifacts remaining in the ground surface models.

After closely examining the dataset, the bare earth model is determined to be of high quality. The data set is very clean with nearly zero artifacts. Dewberry found very few errors in the data as outlined in the text and images below. The majority of the calls are due to inconsistent editing and minor misclassifications. However, these issues are not serious enough to render the data unusable.

Inconsistent Editing

Several instances of inconsistent editing of natural features were found in this dataset. In the example illustrated in Figure 15, it is apparent that different parameters were used to classify the bordering tiles, resulting in an abrupt and unnatural change in classification. This type of error does not have a significant effect on the usability of the data.

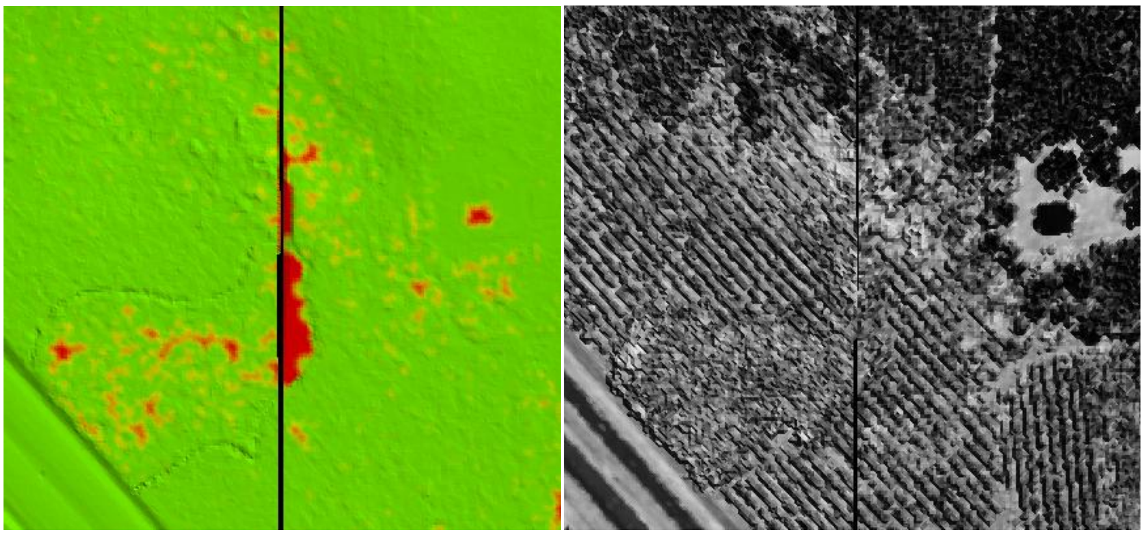

***Figure 15** – 4914-01 Inconsistent editing (L: Ground density model, R: Full point cloud intensity)*

Misclassification

One of the more common problems seen in Marlboro County was misclassification of ground points. During the classification process, it appears that a hydroline dataset was used to classify water points. However, at the time of acquisition many of these retention areas were fully or partially dry and the LiDAR sensor was able to return ground points resulting in good representation of the ground surface. In the left image of Figure 16, the red area signifies an absence of ground points. The full point cloud intensity image in the middle shows that the LiDAR sensor actually returned points as the retention area was partially dry at the time. The image on the right illustrates that these points were classified as water (colored blue).

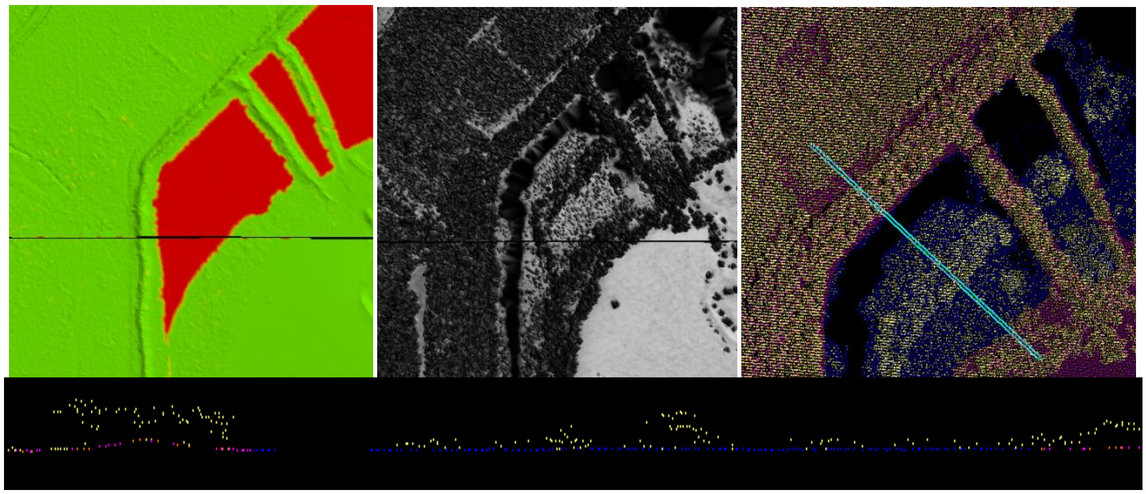

Figure 16 *– 4905-03 Misclassification of ground points. Left image is ground density model and middle is full point cloud with intensity. Right image is full point cloud colored by classification, yellow is unclassified (class 1), purple is ground (class 2), and blue is water (class 9). Bottom image is profile of cross-section.*

A second type of misclassification found in Marlboro County appears to be more editor error than systematic error. Figure 17 displays areas of points that have been accidentally placed into class 1 (unclassified).

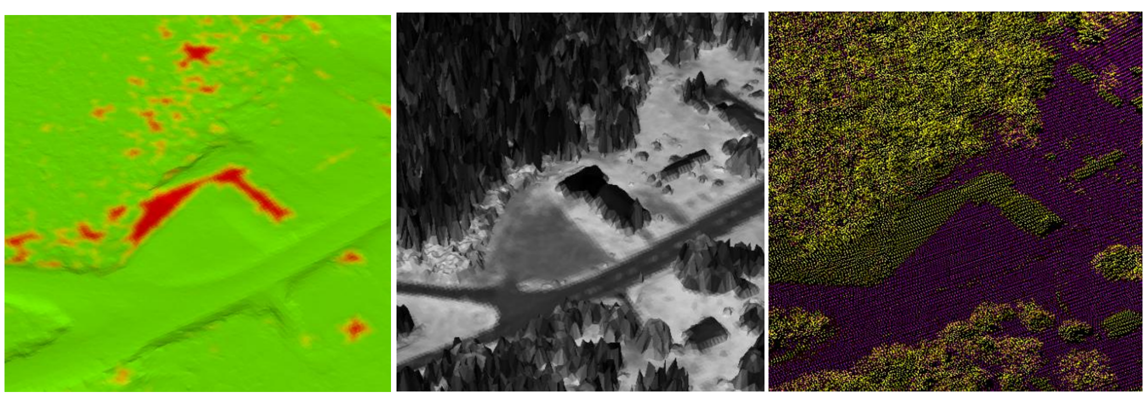

Figure 17 *– 4907-02 Misclassification of ground points. Left image is ground density model and middle is full point cloud with intensity. Right image is full point cloud colored by classification, yellow is unclassified (Class 1), and purple is ground (Class 2).*

Dewberry believes that one particular area of misclassification was caused by the previously mentioned intensity issue. A small subset of tiles displayed high intensity values at nadir. This problem may have been the reason for the misclassification in Figure 18. The LAS file for this area shows that some areas, which should have been classified as ground, were moved into class 1 (unclassified). This misclassification sometimes results in a strip of elevated ground points that resembles a small berm. As shown in the cross-section in Figure 18, some of these elevated areas can be up to 40 cm higher than the surrounding area. Although this is considered a relatively significant change, it is easily fixable and will not render the data unusable.

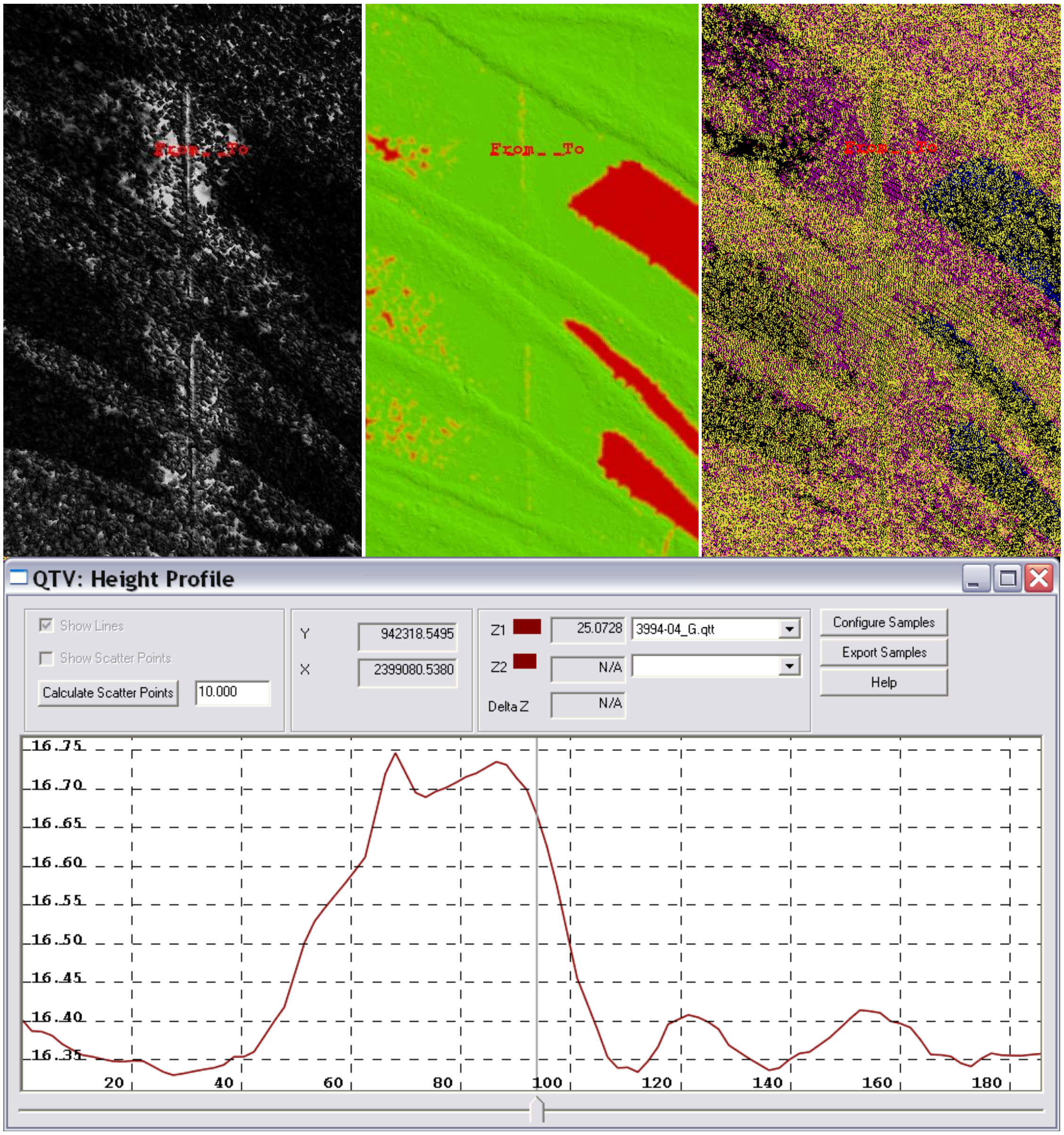

Figure 18 *- 3994-04 Misclassification due to saturation of intensity at nadir. Left is full point cloud with intensity, middle is ground density model, right is full point cloud colored by classification (yellow is unclassified, purple is ground, and blue is water). Bottom is cross-section showing the "false berm".*

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Negligible Flight Line Ridges

A few tiles within the dataset included small ridges at seam lines caused by a vertical mismatch between two adjacent flight lines. Since the overlap is stored in a different class, no real blending of flight lines is done and a seam line is used to cut the data from one line to the next. The result is two flight lines that do not precisely match vertically. Although they are easily visible in the shaded ground model with vertical exaggeration, these ridges are below the commonly accepted threshold of 20 cm and are therefore minor. See Figure 19.

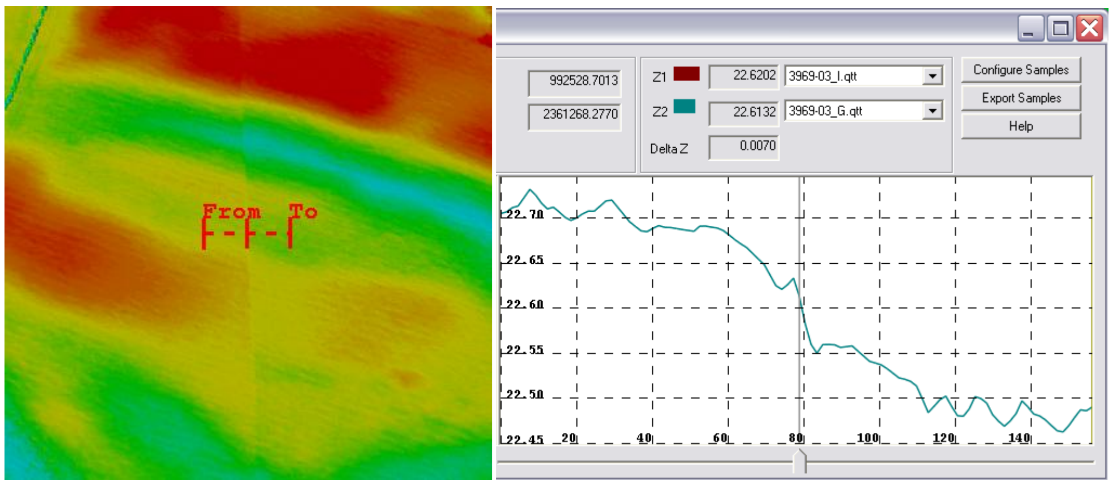

Figure 19 *- 3968-03 Negligible flight line offset.*

Conclusions

Overall the LiDAR data meets the minimum standards for absolute and relative accuracy. The level of cleanliness for the bare-earth terrain easily meets the specifications and no major anomalies were found. The user should be aware of the minor misclassification when focusing on portions of the data, but the data set as a whole is of high quality. The processing performed exceptionally well given the low relief terrain. The figures highlighted above are a sample of the minor issues that were encountered and are not representative of the majority of the data, which is of high quality. The intensity images meet specifications and the terrain and multipoint entities are correctly derived from the classified bare earth LiDAR points.

Appendix A Checkpoints

The horizontal coordinate system is South Carolina State Plane **International feet,** horizontal datum NAD83 **HARN** with **elevation in meters** (NAVD88).

The point numbering scheme uses a three digit sequence starting with the county number (SC numbers its counties in alphabetical order), a dash, followed by zone number, a dash and then a sequence number corresponding to order of collection within the zone, the land cover code was concatenated in front of the number.

PointNo	Easting	Northing	Elevation	zLidar	DeltaZ
b35-1-2	2351642.67	1065712.587	85.712	85.6776	-0.034
b35-1-8	2349016.232	1060320.474	85.627	85.6881	0.061
b35-2-2	2415260.494	1065968.421	75.069	75.113	0.044
b35-2-7	2416954.059	1062294.539	72.421	72.4176	-0.003
b35-3-3	2423560.673	930309.478	36.586	36.4951	-0.091
b35-3-9	2426900.796	934068.512	38.428	38.3813	-0.047
b35-4-4	2388048.256	1009954.187	42.376	42.3266	-0.049
b35-4-8	2386202.099	1011030.959	42.738	42.6738	-0.064
b35-5-2	2433163.372	1024742.344	58.423	58.4793	0.056
b35-5-3	2434278.829	1021729.89	57.513	57.5097	-0.003
b35-6-2	2421104.286	986172.475	38.075	38.0216	-0.053
b35-6-5	2422281.382	984930.74	39.203	39.1524	-0.051
h35-1-9	2351675.911	1054481.468	49.805	49.7035	-0.102
h35-2-3	2412835.111	1061530.433	73.132	73.1644	0.032
h35-2-5	2415894.875	1057564.297	69.436	69.4061	-0.030
h35-3-2	2423101.219	930445.977	36.7	36.6503	-0.050
h35-4-1	2387137.033	1011622.815	43.683	43.594	-0.089
h35-4-5	2390799.594	1005836.465	41.376	41.3682	-0.008
h35-5-1	2431120.098	1029140.268	58.643	58.5607	-0.082
h35-5-8	2440683.929	1028065.157	55.322	55.3876	0.066
h35-6-8	2423502.937	975371.545	39.872	39.8281	-0.044
hCP1	2419548.929	987207.954	38.936	38.8777	-0.058
hKOLLOCKRM4	2354581.232	1062859.141	85.052	85.0654	0.013
o35015	2387245.912	1011646.178	43.445	43.341	-0.104
o35-1-11	2358449.176	1056991.977	58.843	58.8484	0.005
o35-1-14	2361446.422	1068769.842	82.119	82.058	-0.061
o35-1-15	2360917.294	1067323.544	72	71.9821	-0.018
o35125	2431150.743	1029186.426	58.833	58.7397	-0.093
o35-1-4	2350270.447	1066782.149	91.962	91.9356	-0.026
o35-1-7	2349275.589	1064348.185	102.297	102.3195	0.023
o35-2-13	2420953.806	1053013.95	68.439	68.4427	0.004
o35-2-4	2415926.204	1057479.183	69.654	69.5599	-0.094

o35-3-11	2433480.631	939156.1	42.237	42.1655	-0.072
o35-3-12	2432044.564	940362.136	40.81	40.7576	-0.052
o35-3-15	2422836.908	933916.953	39.132	39.028	-0.104
o35-3-6	2426959.891	931107.957	40.714	40.6618	-0.052
o35-3-7	2425146.454	933486.138	40.881	40.8122	-0.069
o35-4-10	2380672.513	1016255.836	42.903	42.8293	-0.074
o35-4-3	2387783.78	1011637.164	43.347	43.256	-0.091
o35-4-6	2388625.154	1010159.509	43.027	42.8756	-0.151
o35-4-9	2382075.859	1007361.451	42.206	42.1496	-0.056
o35-5-12	2438786.6	1033018.571	58.696	58.6773	-0.019
o35-5-14	2437643.297	1033830.423	58.882	58.821	-0.061
o35-5-15	2437387.234	1034809.528	55.932	55.9141	-0.018
o35-5-5	2442771.674	1012896.874	58.242	58.2377	-0.004
o35-6-10	2413945.156	977817.851	41.826	41.7377	-0.088
o35-6-12	2433400.151	986132.271	40.178	40.098	-0.080
o35-6-14	2434058.824	985314.424	39.843	39.787	-0.056
o35-6-15	2434421.566	987622.228	40.598	40.5014	-0.097
o35-6-4	2421697.657	985583.381	39.526	39.4344	-0.092
u35-1-10	2358402.673	1056976.819	58.825	58.8252	0.000
u35-1-12	2359591.723	1056128.93	54.381	54.403	0.022
u35-1-13	2361403.755	1068769.357	81.878	81.84	-0.038
u35-1-3	2350418.238	1066879.216	93.317	93.3334	0.016
u35-1-5	2350686.292	1066627.766	93.625	93.564	-0.061
u35-2-1	2415045.541	1066455.798	75.692	75.653	-0.039
u35-2-14	2421315.65	1053052.027	68.274	68.2805	0.007
u35-2-15	2423394.755	1056989.184	69.702	69.6867	-0.015
u35-3-10	2427627.117	935263.471	38.972	38.8583	-0.114
u35-3-13	2418624.767	941250.599	38.557	38.5096	-0.047
u35-3-14	2424647.873	933887.613	40.367	40.2793	-0.088
u35-3-5	2427000.899	931158.31	40.739	40.6622	-0.077
u35-3-8	2425065.827	933548.648	40.658	40.5913	-0.067
u35-4-11	2381277.764	1016391.325	43.402	43.2965	-0.105
u35-4-13	2390569.701	1021256.733	56.276	56.2052	-0.071
u35-4-14	2393839.984	1018004.684	41.024	40.9633	-0.061
u35-4-15	2395079.88	1014742.098	46.778	46.6689	-0.109
u35-4-2	2387797.388	1011801.832	43.721	43.6701	-0.051
u35-5-11	2438471.224	1032820.8	58.789	58.78	-0.009
u35-5-13	2437563.586	1033833.681	58.706	58.7015	-0.005
u35-5-16	2437708.717	1034183.445	57.735	57.7886	0.054
u35-5-4	2442749.334	1012946.777	58.123	58.0801	-0.043
u35-5-7	2440333.03	1021929.475	56.15	56.0849	-0.065
u35-6-1	2419468.906	987196.098	39.181	39.1226	-0.058

u35-6-11	2413952.43	977789.775	41.754	41.6437	-0.110
u35-6-13	2433344.013	985153.061	39.836	39.8105	-0.026
u35-6-7	2430099.045	981322.778	37.547	37.4995	-0.047
u35-6-9	2421096.686	973155.113	40.143	40.0593	-0.084
w35-1-1	2354578.486	1062934.709	85.914	85.8781	-0.036
w35-1-6	2349333.325	1064252.32	101.961	102.0531	0.092
w35-2-6	2416743.827	1059154.404	67.705	67.7053	0.000
w35-2-8	2416965.011	1063571.268	73.079	73.0641	-0.015
w35-3-1	2420304.416	931951.676	32.739	32.7795	0.041
w35-3-4	2423592.96	930270.365	36.886	36.7993	-0.087
w35-4-12	2384076.774	1019503.84	44.124	44.0623	-0.062
w35-4-7	2388422.187	1010132.037	42.902	42.7891	-0.113
w35-5-10	2440222.845	1031487.392	54.502	54.4344	-0.068
w35-5-6	2440420.727	1021876.24	55.775	55.7756	0.001
w35-6-6	2426722.169	983075.215	37.496	37.3784	-0.118