LiDAR Quality Assurance (QA) Report
Darlington County, South Carolina
February 20, 2009

Submitted to:
USGS
Prepared by:
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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 Darlington County, SC, produced by Dewberry's subcontractor, Fugro EarthData, under the referenced USGS task order. The LiDAR data was acquired in January of 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 720 tiles (each 5000 ft x 5000 ft) were delivered covering all of Darlington 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	124	18.5 cm	7.6 cm
FVA	20	40	36.3 cm	12.3 cm
CVA	60	127	36.3 cm	11.3 cm
SVA-bare earth	20	40	36.3 cm	11.1 cm
SVA-vegetated	20	48	36.3 cm	16.4 cm
SVA-urban	20	36	36.3 cm	10.7 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 poor LiDAR penetration, small misclassifications, and flight line differences. 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 Darlington 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.

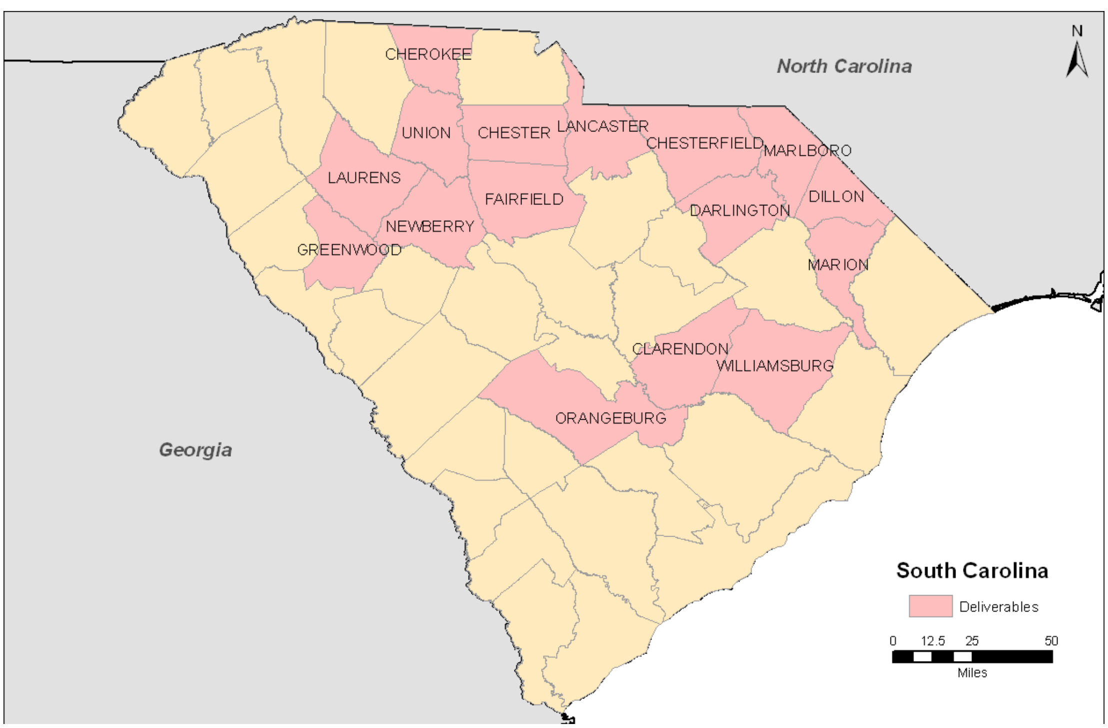

***Figure 1** – Project area; the 16 deliverable counties for the South Carolina project are shown in pink.*

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.

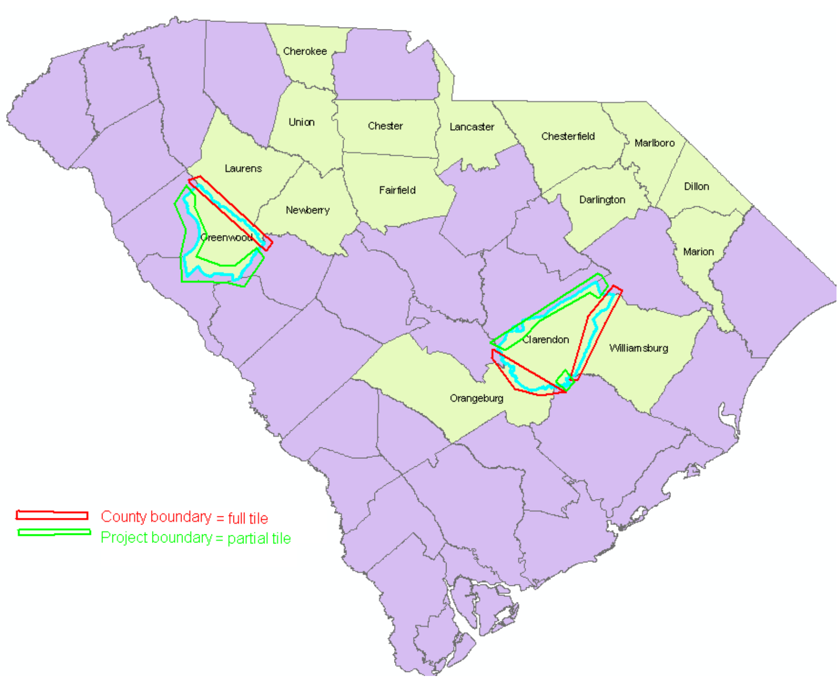

Figure 2 *– Convention used for the tile coverage: at the boundary of a county that is not part of the project, a partial tile is delivered; at the boundary of a county that is part of the project, a full tile is delivered.*

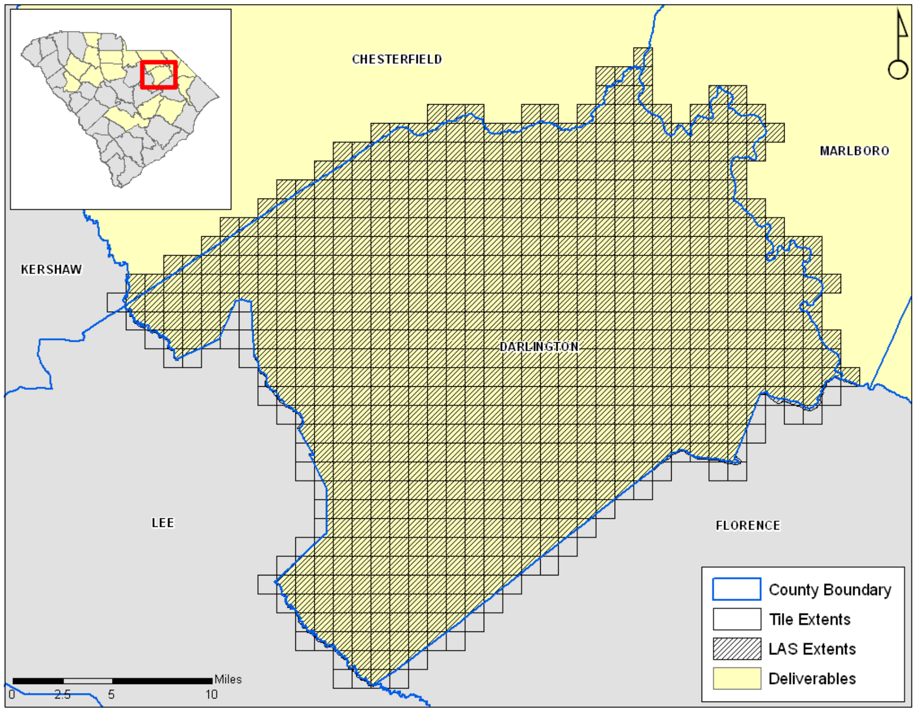

Figure 3 *– The LiDAR coverage of Darlington County. Neighboring deliverable counties are shown in yellow.*

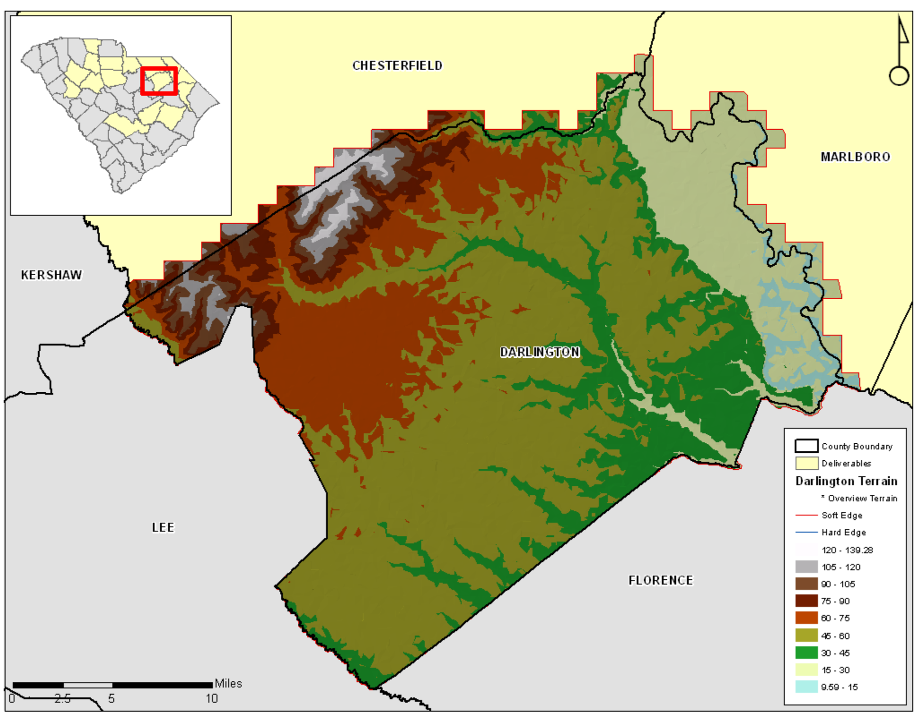

Figure 4 *– The terrain for Darlington has a 50 ft buffer outside of the project boundary.*

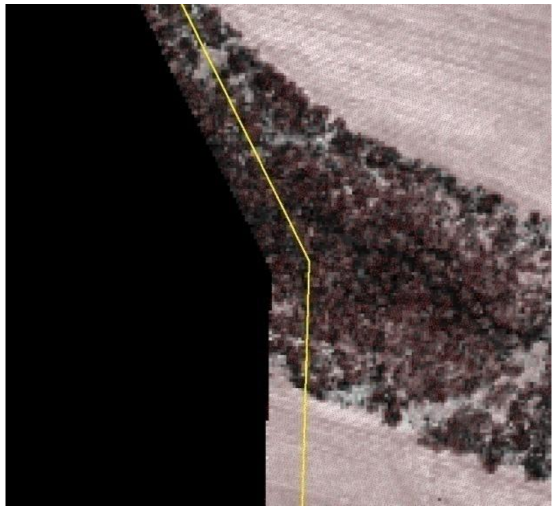

Figure 5 *- Ground masspoints (red) and intensity images extend 50 feet outside the project boundary in yellow. The LAS and terrain dataset do the same.*

3 QA of intensity images

720 intensity images in the GeoTiff format were delivered for Darlington 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 ft which is the required size of the tiles: 5000 ft by 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.

```
Output from Display Header
File Name:
Q:\DATA\SouthCarolina\SOURCE\EarthData\20081210_Darlin
gton\Intensity_Images\2854-01.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]=    2250000
 amx[ 3]=          0, amx[ 4]=         -4, amx[ 5]=     850000
      2250000 ,       850000
      2255000 ,       850000
      2255000 ,       845000
      2250000 ,       845000
Geotiff_Information:
   Version: 1
   Key_Revision: 1.0
   Tagged_Information:
     ModelTiepointTag (2,3):
       0           0           0
       2250000     850000      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 (2250000.000, 850000.000)
Lower Left (2250000.000, 845000.000)
Upper Right (2255000.000, 850000.000)
Lower Right (2255000.000, 845000.000)
Center (2252500.000, 847500.000)

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).

Two anomalies were noticed in the intensity images: white stripes over land at nadir and tonal changes within tiles (Figure 6). The white stripes occur when the intensity becomes saturated at nadir. This is expected over water but should not be observed over land. The cause of the sharp tonal transition across tiles is unknown. These intensity anomalies do not significantly affected the overall product.

Figure 6 *– Left intensity image shows white stripes at nadir. Right image shows tonal changes within a tile.*

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 720 LiDAR files covering the Darlington 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 feet;

- 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 point per tile should be around 3.9 million. The mean over Darlington County is around 4.7 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 7** - Number of points per tile. The red tiles at the border are expected to have fewer points.Figure 7 .

To first identify incorrect elevations, the z-minimum and z-maximum values for the ground class were reviewed. With maximum values between 17 m and 139 m, no noticeable anomalies were identified because this is consistent with the expected range of elevation in the county (max elevation in Darlington County: around 140 m). Figure 8 (right) shows the spatial distribution of these elevations, following the anticipated terrain topography.

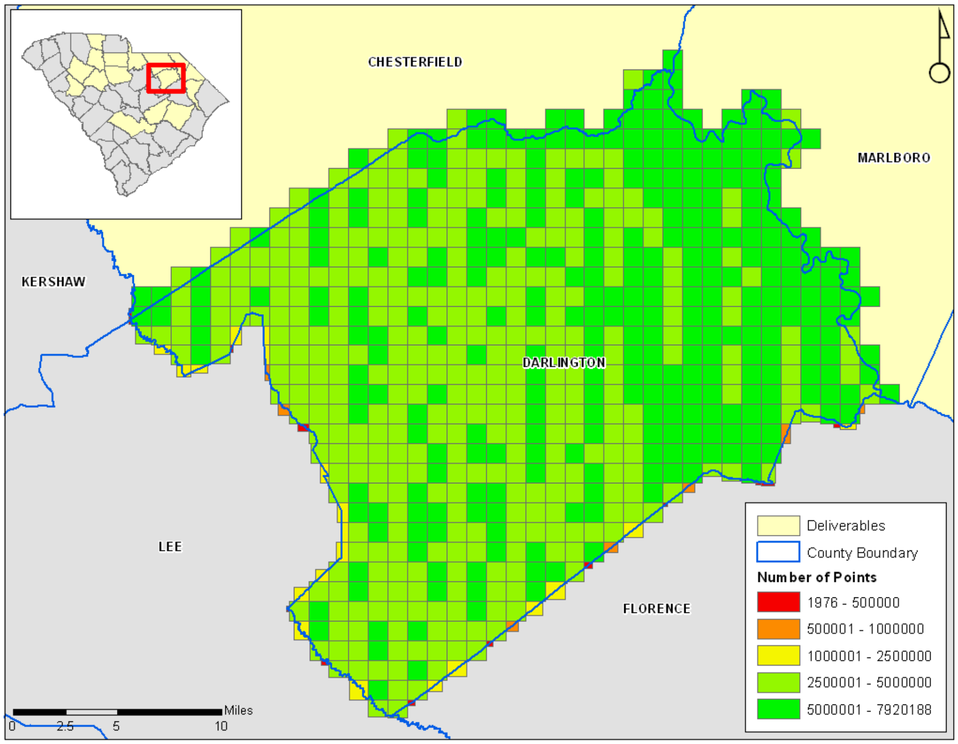

Figure 7 *- Number of points per tile. The red tiles at the border are expected to have fewer points.*

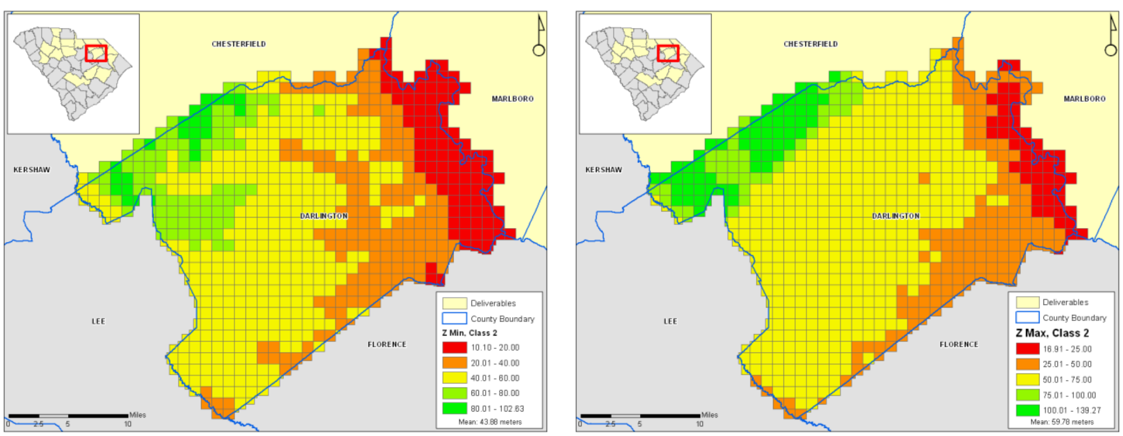

Figure 8 *- Z min and Z max elevation for ground points (class 2) per tile.*

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 127 points were collected, as presented in **Table 3**3, with 48 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 0. Figure 9 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	40
b - Bush	0	16
h - High Grass	10	15
w - Woods	10	17
u - Urban	20	39
Total	**60**	**127**

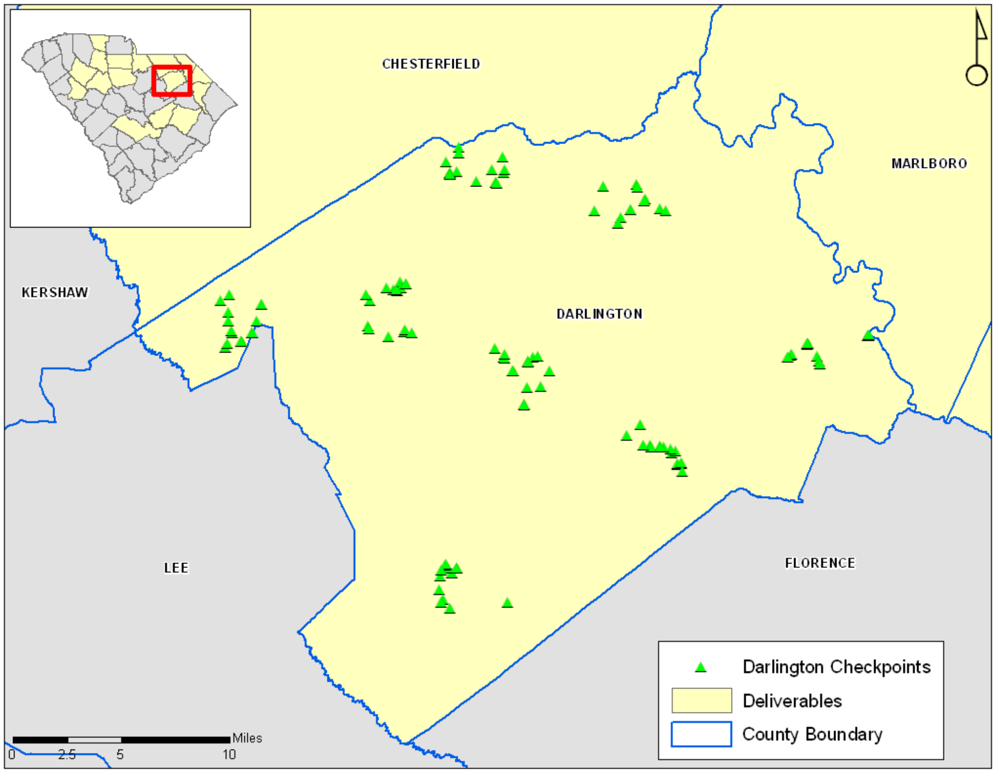

Figure 9 *- Survey checkpoints from South Carolina Geodetic Survey.*

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 checkpoint's are overlaid on the TIN and the interpolated Z value are recorded. This interpolated Z values is then compared with the survey checkpoint Z value 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 Darlington 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 (0.076 m) x 1.9600, or 0.149 m (14.9 cm).

Table 4 – Final statistics for Darlington 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	0.076	0.013	0.013	1.965	0.076	124	-0.134	0.474
Bare Earth	0.063	-0.002	-0.020	0.093	0.063	40	-0.134	0.146
Vegetated	0.097	0.034	0.023	2.537	0.091	48	-0.108	0.474
Urban	0.057	0.001	0.005	0.101	0.058	36	-0.107	0.110

Table 5 shows the complete results of the Darlington data set run through the NDEP/ASPRS process; the CVA value is 0.113 m (11.3 cm). These statistics include “outlier” points or points that are two time the standard deviation. This explains why the CVA calculated by the NDEP/ASPRS method is lower than the CVA calculated by the FEMA/NSSDA method. Even with these outliers all of the calculated statistics for Darlington County fall well below the specifications.

Table 5 – Final statistics for Darlington 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	124		11.3	
Bare Earth	40	12.3		11.1
Vegetated	48			16.4
Urban	36			10.7

Figure 10 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 positive side (LiDAR higher than the checkpoints) pointing toward a slight positive bias in the data.

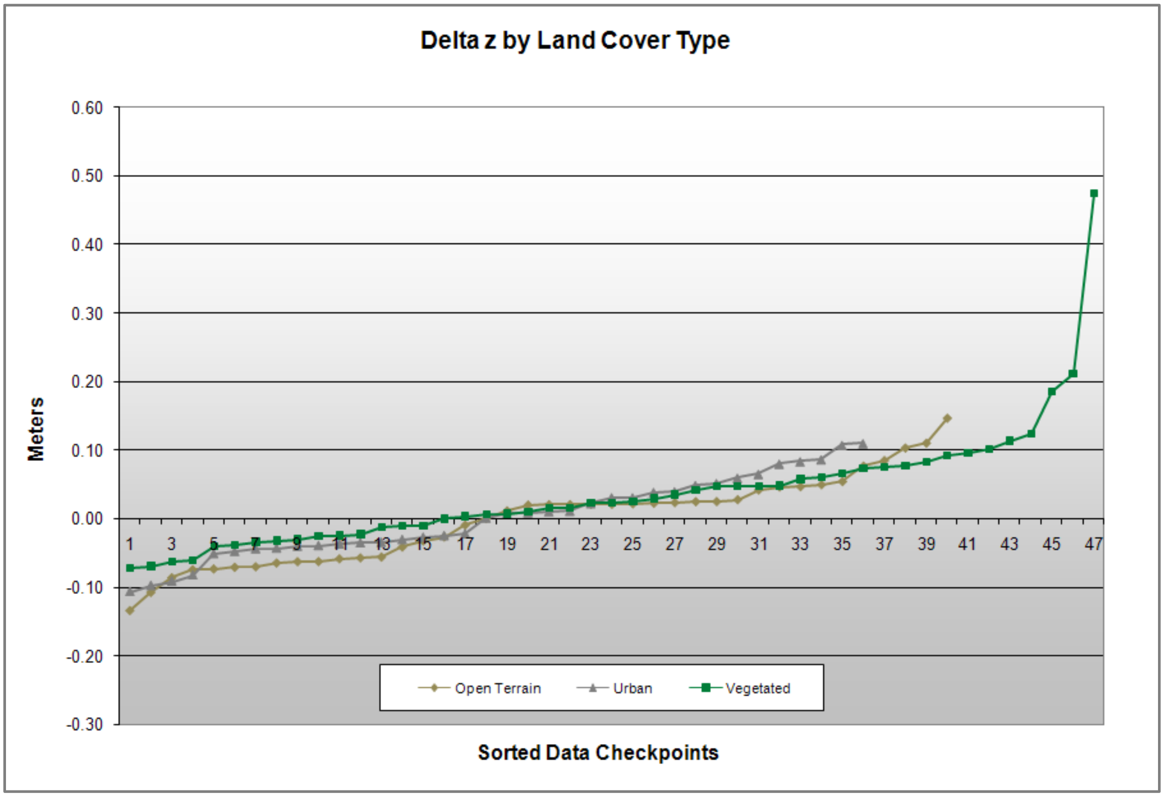

***Figure 10** – Checkpoints shown by land cover type and sorted by errors (deltaZ).*

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 12.3 cm Fundamental Vertical Accuracy at 95 % confidence level in open terrain using RMSEz x 1.9600 (FEMA/NSSDA and NDEP/ASPRS methodologies).
- Tested 14.9 cm Consolidated Vertical Accuracy at 95 % confidence level in all land cover categories combined using RMSEz x 1.9600 (FEMA/NSSDA methodology).
- Tested 11.3 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 11). 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.

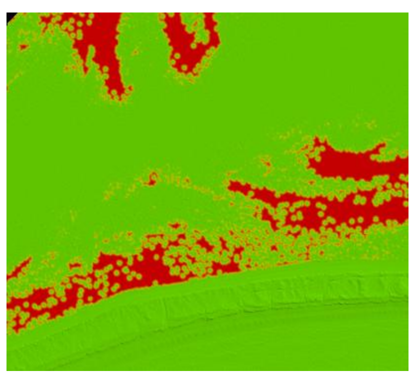

***Figure 11** – Ground model with density information (red means sparse data)*

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 12) or by class (Figure 13). 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.

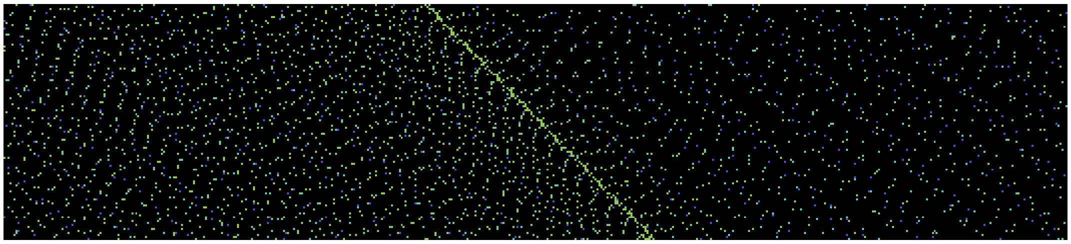

Figure 12 *– LiDAR points colored by flight line. Detail of the point distribution. Note the variations in the scan pattern.*

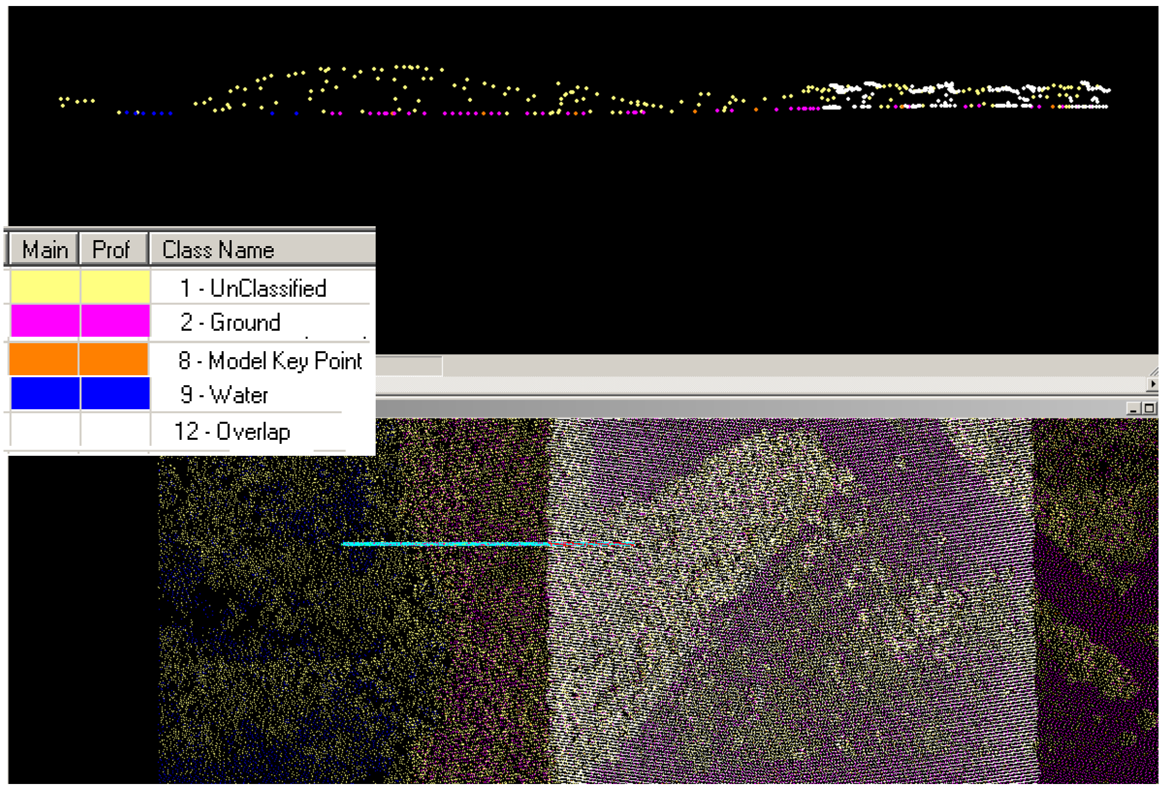

Figure 13 *- Full point cloud colored by class.*

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.

Flight Line Ridges

Small ridges at seam lines caused by a vertical mismatch between two adjacent flight lines were noticed during the QA process. Smoothing of the flight lines does not occur; therefore it is possible to find flight line ridges. Although most of the flight line ridges found within the Darlington data were below the commonly accepted threshold of 20 cm, there were a few instances where the elevation difference was larger as shown in Figure 14.

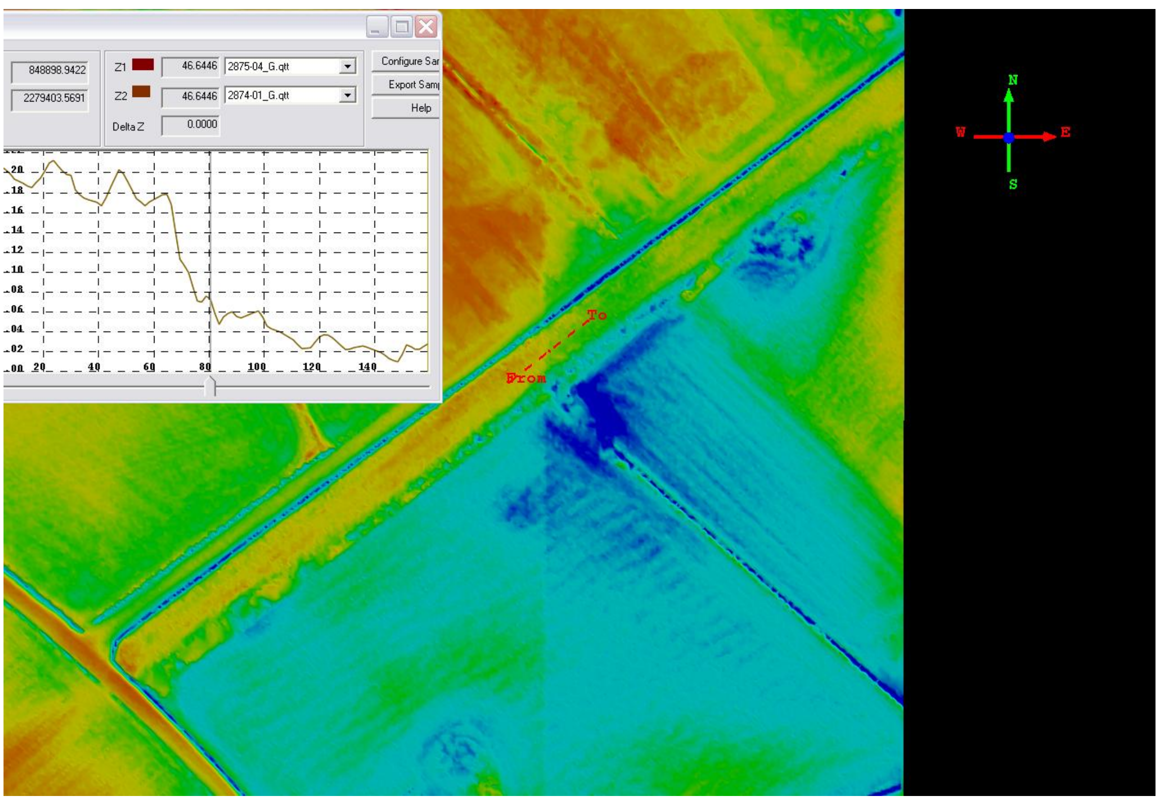

Figure 14 *– 2874-02 Flight line offset.*

Inconsistent Editing

Several instances of inconsistent editing of natural features were found in this dataset. In the case illustrated in Figure 15 it appears as though one tile was more aggressively classified than its neighbor. This type of error was not found to be very common in the dataset and has minimal impact on the quality of the data.

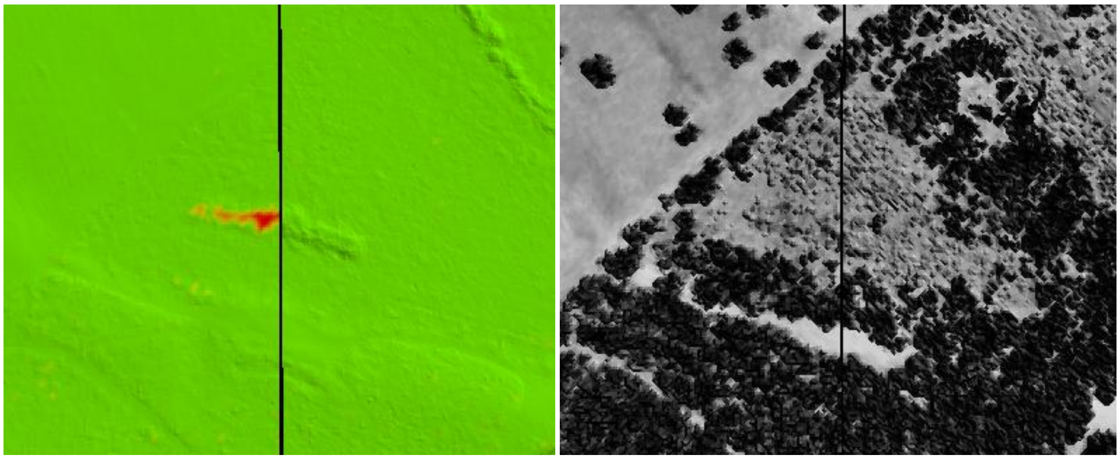

***Figure 15** – 3992-03 Inconsistent editing (L: Ground density model, R: Full point cloud intensity model).*

Figure 16 displays another example of inconsistent editing that was seen in the data within stream banks or along elevated embankments or roads. Portions of these features were removed from the ground whereas others were kept.

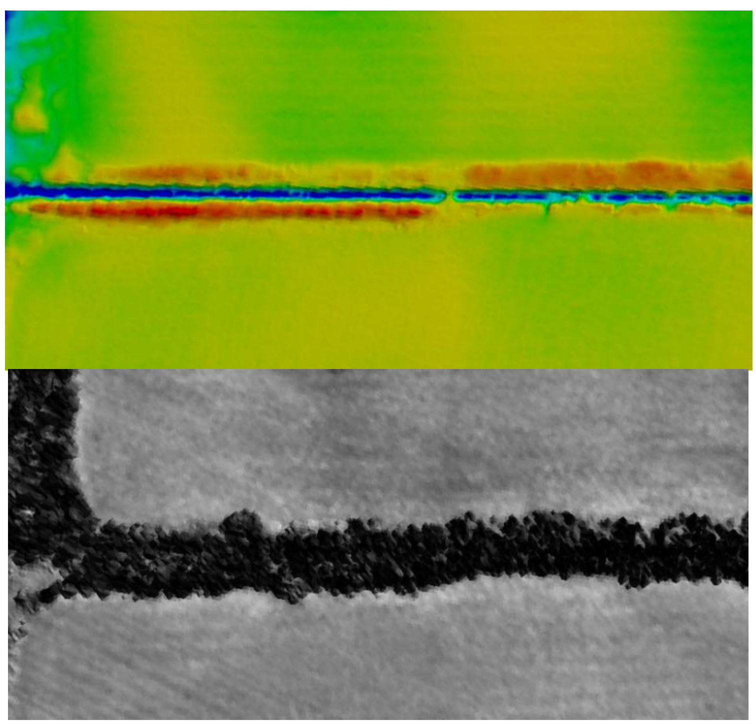

***Figure 16** - 3992-04 Inconsistent editing along canal (Top: Ground density model, Bottom: Full point cloud intensity model).*

Misclassification

One of the more common problems seen in Darlington County was the misclassification of points. There were several areas in which ground points had been classified to an incorrect class. There was a correlation in some instances between areas having a high intensity value and those lacking ground points. This problem may have been the reason for the misclassification in Figure 17. The LAS file for this area shows that some areas, which should have been classified as ground, were moved into class 1 (unclassified). See Figure 18.

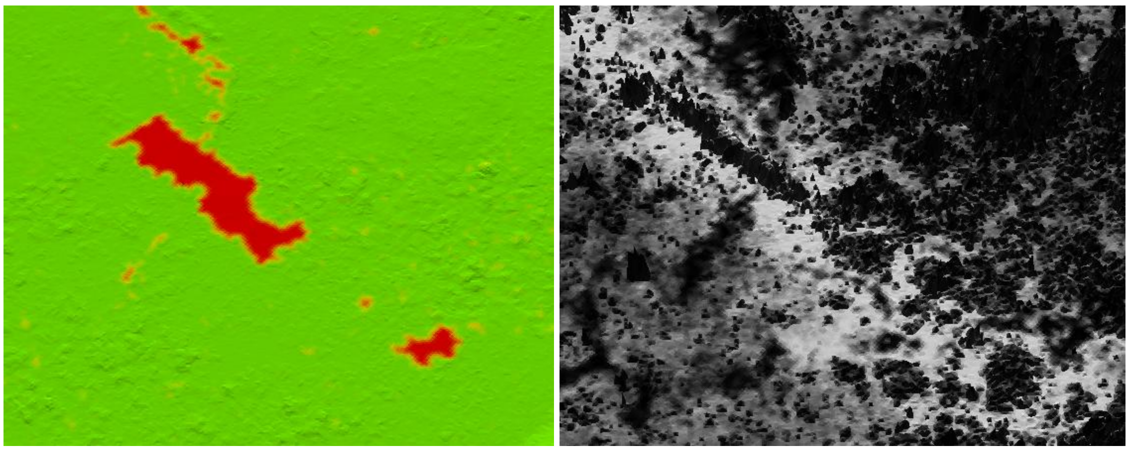

Figure 17 *– 3899-01 Misclassification due to intensity issue. (L: Ground Density Model, R: Full Point Cloud Intensity).*

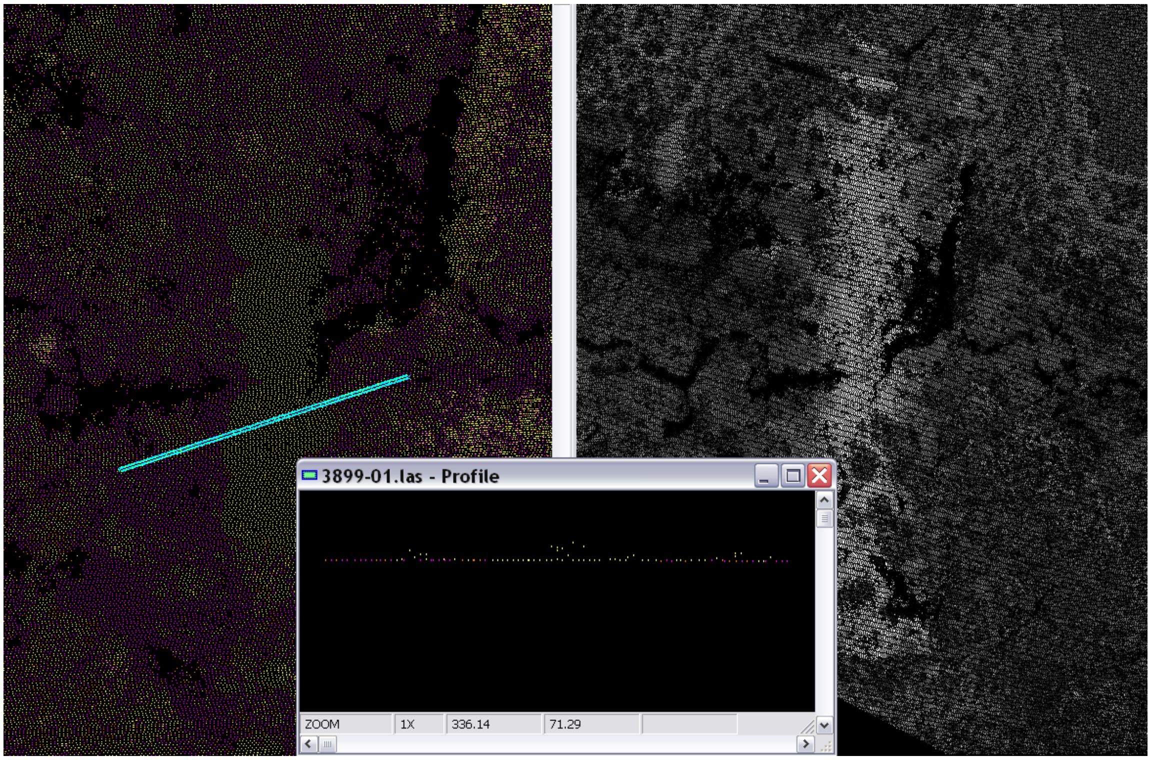

Figure 18 *– 3899-01 Misclassification due to intensity value. On the left is the LAS file with classes shown (yellow: unclassified class 1; purple: Ground class 2). On the right is the LAS file with the intensity shown. The diagram in the middle shows a cross section through one of the areas of misclassification.*

A second type of misclassification found in Darlington appears to be more editor error than systematic error. Figure 19 displays an area in a right-of-way which has been classified as unclassified class 1. This was the only instance of this type of misclassification found in Darlington.

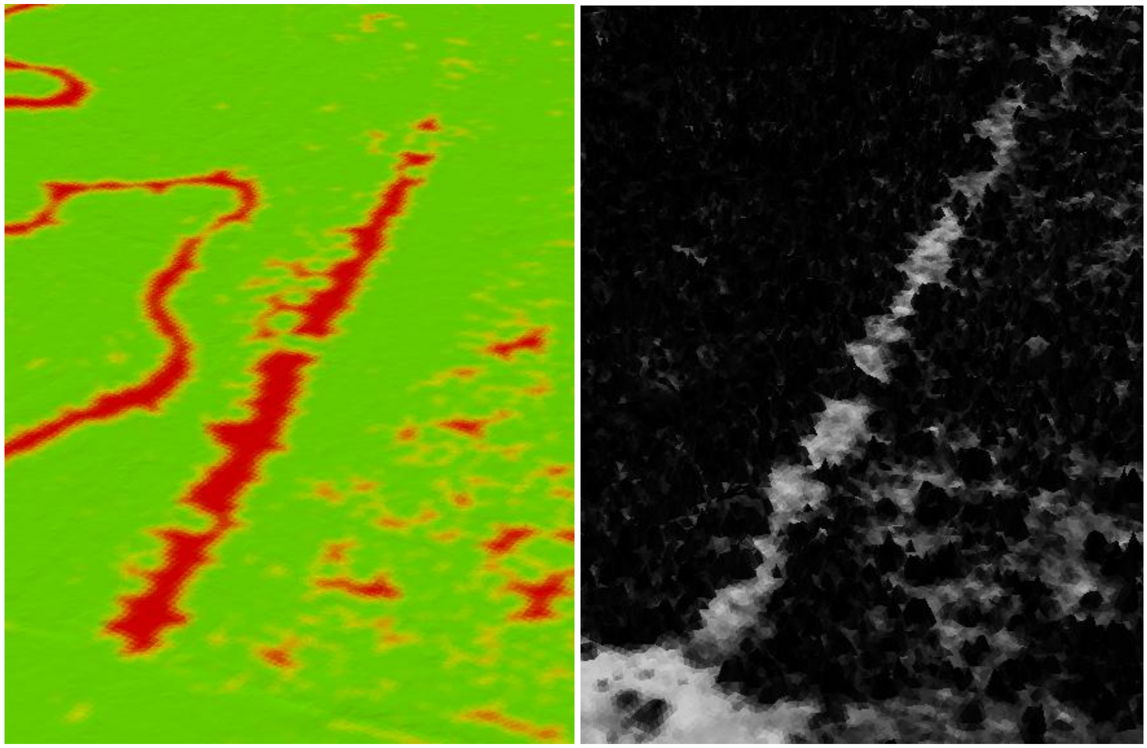

Figure 19 *– 2983-04 Misclassification of ground. (L: Ground Density Model, R: Full Point Cloud Intensity).*

Aggressive Classification

A few instances of aggressive classification of ground points were also encountered in the Darlington data. This kind of error happens when the classification process used to remove the vegetation points is too aggressive resulting in cut ridges or gaps in the bare earth surface (Figure 20 and Figure 21). There were not many examples of aggressive classification in this dataset and those that were encountered were mostly located along slopes or in hilly terrain, where this type of error is considered common.

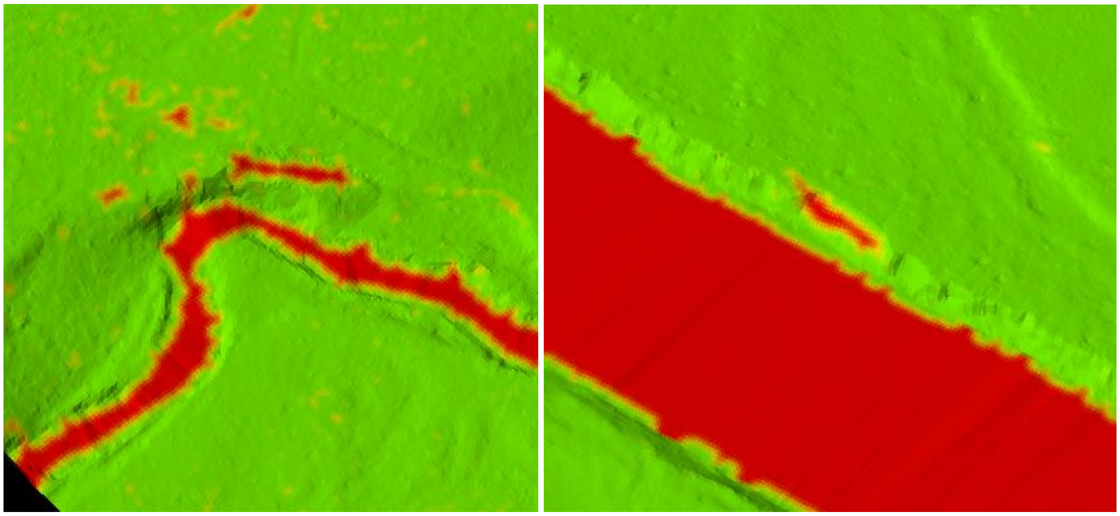

Figure 20 *- Aggressive classification. Left is ground density image of tile 3940-04. Right is ground density image of 3993-02.*

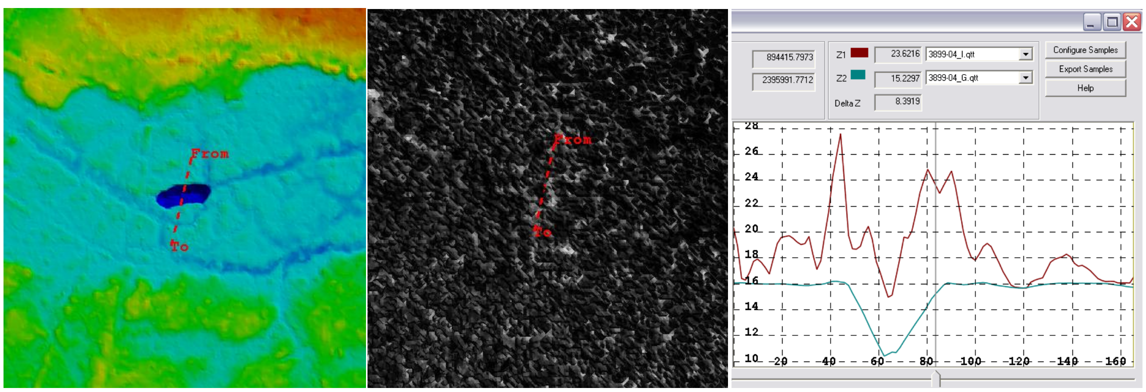

Figure 21 *- 3899-04 Left is ground elevation model, middle is full point cloud intensity, right is graph of cross-section showing gap in data.*

Poor LiDAR Penetration

Several areas were identified with patches of low density of ground points. This may be unavoidable. When the vegetation is very dense, the LiDAR may not penetrate the canopy all the way to the ground; this is illustrated in Figure 22. This type of sparse density of ground points was found throughout the dataset and causes the surface to be sometimes less accurate. Poor LiDAR penetration cannot be fixed without a re-flight, but even then, this might be inherent to the type of vegetation surveyed. While increasing the flight line overlap would provide different angles of incidence and would increase the chance of penetrating the canopy, this is more expensive, and it is possible that the density of the vegetation prevents any point to reach the ground. Regardless, the accuracy of the data is always expected to diminish in vegetated area, and when a few ground points are available an elevation model can be interpolated with acceptable precision especially in flat terrain.

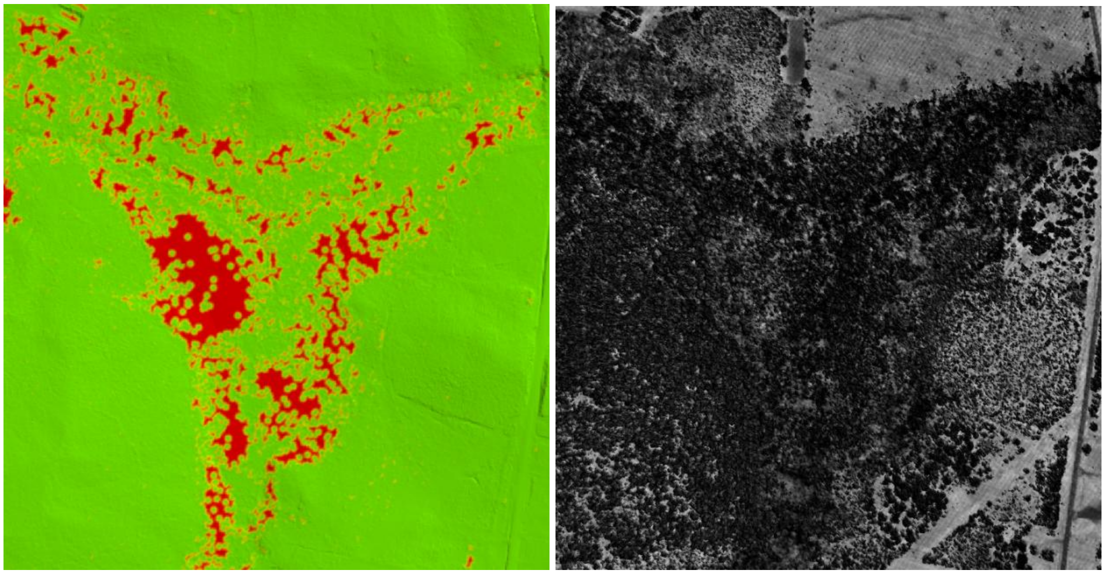

***Figure 22** – 2996-01 Poor LiDAR penetration in vegetated area.*

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	AbsDeltaZ
16-1-1	2347343.486	889120.328	44.295	44.2509	0.0441	0.0441
16-1-10	2343086.576	893618.331	45.687	45.664	0.023	0.023
16-1-11	2340591.853	893804.118	46.332	46.2584	0.0736	0.0736
16-1-12	2340770.63	893514.207	46.894	46.8117	0.0823	0.0823
16-1-13	2339024.479	893991.819	46.821	46.7881	0.0329	0.0329
16-1-14	2338136.143	898815.286	46.497	46.46	0.037	0.037
16-1-15	2334884.809	896320.18	44.312	44.2052	0.1068	0.1068
16-1-2	2347318.584	889271.072	44.354	44.401	-0.047	0.047
16-1-3	2348285.227	889350.852	44.318	44.3178	0.0002	0.0002
16-1-4	2348273.534	889636.434	44.549	44.6083	-0.0593	0.0593
16-1-5	2345960.218	891991.882	45.111	45.046	0.065	0.065
16-1-6	2346741.6	892506.404	45.034	44.9642	0.0698	0.0698
16-1-7	2345550.977	893043.044	45.091	45.0347	0.0563	0.0563
16-1-8	2343838.831	893364.836	45.346	45.2949	0.0511	0.0511
16-1-9	2343248.768	893486.537	45.578	45.5205	0.0575	0.0575
16-2-1	2337166.662	957643.681	46.879	46.8519	0.0271	0.0271
16-2-10	2326906.818	951154.765	58.513	58.5182	-0.0052	0.0052
16-2-11	2329227.662	957104.974	60.712	60.7365	-0.0245	0.0245
16-2-2	2339364.136	953988.779	55.235	55.2003	0.0347	0.0347
16-2-3	2339191.342	953502.62	54.087	54.0565	0.0305	0.0305
16-2-4	2343041.129	951684.287	51.117	51.0823	0.0347	0.0347
16-2-5	2344394.688	951026.951	53.339	53.3131	0.0259	0.0259
16-2-6	2335949.377	951446.358	56.041	56.0622	-0.0212	0.0212
16-2-7	2335902.435	951448.003	56.414	56.4361	-0.0221	0.0221
16-2-8	2333553.028	949339.268	56.472	56.5293	-0.0573	0.0573
16-2-9	2332856.033	948088.004	56.339	56.3485	-0.0095	0.0095
16-3-1	2293469.73	863777.479	51.996	51.9347	0.0613	0.0613
16-3-10	2289452.8	861860.252	50.138	50.0675	0.0705	0.0705
16-3-11	2289074.467	858551.94	48.515	48.4733	0.0417	0.0417
16-3-12	2289944.489	856334.477	50.716	50.7031	0.0129	0.0129
16-3-13	2289626.677	855391.279	49.101	49.0624	0.0386	0.0386
16-3-14	2291849.659	854128.847	47.452	47.4216	0.0304	0.0304

16-3-15	2305714.005	855538.858	48.085	48.0952	-0.0102	0.0102
16-3-2	2293472.83	863882.8	52.161	52.1218	0.0392	0.0392
16-3-3	2293291.431	863909.497	51.769	51.7982	-0.0292	0.0292
16-3-4	2292166.482	862618.553	51.722	51.6789	0.0431	0.0431
16-3-5	2292165.532	862569.174	51.742	51.6791	0.0629	0.0629
16-3-6	2291254.865	863733.909	52.162	52.1401	0.0219	0.0219
16-3-7	2290614.964	864449.845	52.613	52.635	-0.022	0.022
16-3-8	2290706.097	864866.178	52.91	52.9254	-0.0154	0.0154
16-3-9	2289624.772	863493.095	51.297	51.2222	0.0748	0.0748
16-4-1	2393879.195	920646.015	16.789	16.7411	0.0479	0.0479
16-4-10	2374850.033	915842.154	45.299	45.2352	0.0638	0.0638
16-4-11	2381322.612	915500.839	41.218	41.1102	0.1078	0.1078
16-4-12	2381915.576	914453.471	40.848	40.9224	-0.0744	0.0744
16-4-13	2382072.96	913775.601	41.418	41.3591	0.0589	0.0589
16-4-14	2382020.563	913782.67	41.579	41.5388	0.0402	0.0402
16-4-15	2378956.673	918799.876	45.058	44.9868	0.0712	0.0712
16-4-16	2375090.54	916119.264	45.739	45.6411	0.0979	0.0979
16-4-2	2393953.887	920708.807	15.678	15.6374	0.0406	0.0406
16-4-3	2394142.767	920649.026	16.617	16.6898	-0.0728	0.0728
16-4-4	2393978.657	920756.341	15.661	15.6758	-0.0148	0.0148
16-4-5	2379162.556	918716.536	44.838	44.7515	0.0865	0.0865
16-4-6	2379019.321	918481.755	44.654	44.5816	0.0724	0.0724
16-4-7	2379012.915	918718.37	44.417	44.3256	0.0914	0.0914
16-4-8	2374116.409	915316.694	45.183	45.2693	-0.0863	0.0863
16-4-9	2374232.76	915389.436	44.847	44.7128	0.1342	0.1342
16-5-1	2310766.088	914305.649	57.791	57.8116	-0.0206	0.0206
16-5-10	2311995.473	915429.606	56.986	57.0396	-0.0536	0.0536
16-5-11	2313107.728	915487.712	56.997	57.0812	-0.0842	0.0842
16-5-12	2316018.965	911919.13	54.803	54.8504	-0.0474	0.0474
16-5-13	2309810.378	903906.395	50.047	50.0117	0.0353	0.0353
16-5-14	2309913.101	903789.718	49.647	49.6955	-0.0485	0.0485
16-5-15	2310629.067	908083.191	56.979	56.9543	0.0247	0.0247
16-5-2	2310813.73	914063.903	57.579	57.5785	0.0005	0.0005
16-5-3	2313788.741	908126.941	56.097	56.173	-0.076	0.076
16-5-4	2307167.377	911968.491	56.547	56.5864	-0.0394	0.0394
16-5-5	2306920.346	912115.453	57.094	57.1212	-0.0272	0.0272
16-5-6	2302665.7	917606.4	60.89	60.8802	0.0098	0.0098
16-5-7	2304816.24	915452.145	58.336	58.3426	-0.0066	0.0066
16-5-8	2305056.425	915138.45	58.563	58.7483	-0.1853	0.1853
16-5-9	2305188.421	915965.135	59.282	59.3047	-0.0227	0.0227
16-6-1	2240836.028	919225.502	111.9	111.92	-0.02	0.02
16-6-10	2244491.637	924288.263	87.369	87.38	-0.011	0.011

16-6-11	2245599.521	928212.041	74.155	74.2645	-0.1095	0.1095
16-6-12	2245665.674	928321.377	74.661	74.7444	-0.0834	0.0834
16-6-13	2237781.097	930625.933	107.436	107.4603	-0.0243	0.0243
16-6-14	2235795.381	929145.537	107.43	107.4761	-0.0461	0.0461
16-6-15	2237572.039	926370.707	104.626	104.706	-0.08	0.08
16-6-2	2236888.982	917857.842	107.056	107.1333	-0.0773	0.0773
16-6-3	2236983.07	917834.447	106.615	106.6565	-0.0415	0.0415
16-6-4	2237289.038	918784.668	106.155	106.2559	-0.1009	0.1009
16-6-5	2238622.282	921263.861	113.406	113.4266	-0.0206	0.0206
16-6-6	2238311.674	921851.286	115.756	115.8026	-0.0466	0.0466
16-6-7	2237668.474	924216.87	116.236	116.2708	-0.0348	0.0348
16-6-8	2243420.079	921237.87	115.674	115.7658	-0.0918	0.0918
16-6-Control	2240809.839	919250.894	111.443	111.4513	-0.0083	0.0083
16-7-1	2278804.732	931537.622	61.085	61.1263	-0.0413	0.0413
16-7-10	2272227.144	929208.139	64.931	64.9534	-0.0224	0.0224
16-7-11	2271764.96	923002.332	67.361	67.3719	-0.0109	0.0109
16-7-12	2271978.171	922243.638	69.246	69.2468	-0.0008	0.0008
16-7-13	2276704.871	920283.39	67.264	67.3119	-0.0479	0.0479
16-7-14	2280585.078	921473.818	66.405	66.3727	0.0323	0.0323
16-7-15	2280830.891	921972.531	66.394	66.4762	-0.0822	0.0822
16-7-16	2282465.112	921298.578	66.241	66.3643	-0.1233	0.1233
16-7-2	2278971.217	931597.847	59.975	59.9996	-0.0246	0.0246
16-7-3	2279510.211	933675.688	65.308	65.3274	-0.0194	0.0194
16-7-4	2279835.813	932403.415	62.589	62.6196	-0.0306	0.0306
16-7-5	2281022.111	933134.559	63.003	63.0544	-0.0514	0.0514
16-7-6	2281079.58	933307.852	62.851	62.9	-0.049	0.049
16-7-7	2277927.529	931730.28	61.713	61.7779	-0.0649	0.0649
16-7-8	2276176.91	932187.467	64.56	64.5906	-0.0306	0.0306
16-7-9	2271232.58	930678.567	68.276	68.4873	-0.2113	0.2113
16-8-1	2291792.677	960121.269	88.787	88.8068	-0.0198	0.0198
16-8-10	2304850.719	960521.914	70.751	70.8584	-0.1074	0.1074
16-8-11	2302981.571	958024.03	71.188	71.2264	-0.0384	0.0384
16-8-12	2303057.971	958058.553	71.029	71.0519	-0.0229	0.0229
16-8-13	2303245.067	957915.149	71.957	72.0027	-0.0457	0.0457
16-8-14	2302018.843	961158.669	74.883	74.82	0.063	0.063
16-8-15	2298247.354	958157.33	68.761	68.8741	-0.1131	0.1131
16-8-2	2291796.058	960217.459	88.767	88.7558	0.0112	0.0112
16-8-3	2291713.674	960329.434	87.754	87.7425	0.0115	0.0115
16-8-4	2293868.047	966720.717	61.153	61.0449	0.1081	0.1081
16-8-5	2293787.834	965243.221	75.722	75.7812	-0.0592	0.0592
16-8-6	2290776.98	963036.472	94.831	94.926	-0.095	0.095
16-8-7	2293415.556	960572.539	82.524	82.499	0.025	0.025

16-8-8	2304693.009	964227.235	75.832	75.9419	-0.1099	0.1099
16-8-9	2305170.395	961103.254	72.067	72.1693	-0.1023	0.1023
16-8-ControlREO	2291741.377	960026.237	88.124	88.1326	-0.0086	0.0086
D-23-Reset	2278658.176	931877.268	61.987	62.1327	-0.1457	0.1457
DAR	2348471.414	887369.717	43.455	43.52	-0.065	0.065
LakeDarpo	2337436.978	956928.973	45.74	45.7129	0.0271	0.0271
P-29	2310830.204	914205.117	57.759	58.2333	-0.4743	0.4743
Windam-AZ-MK-2	2293457.213	863949.587	51.965	51.9678	-0.0028	0.0028