Dewberry®

SPECIFIC PURPOSE LIDAR SURVEY REPORT

For the

2009 CENTRAL FLORIDA COORDINATION AREA SURFACE ELEVATION DATASET

Contract No: 25128

Work Order No: 1

Prepared for:

The St. Johns River Water Management District

Prepared by:

Dewberry
1000 Ashley Blvd., Suite 801
Tampa, Florida 33602-3718

Report Date: July 31, 2009

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2009 Central Florida Coordination Area Surface Elevation Dataset

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Prepared for:

St. Johns River Water Management District
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Prepared by:

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Report Date: July 31, 2009

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Report of Specific Purpose LiDAR Survey
2009 CENTRAL FLORIDA COORDINATION AREA SURFACE ELEVATION DATASET PROJECT

Introduction

The primary purpose of this project was to develop a consistent and accurate surface elevation dataset derived from Light Detection and Ranging (LiDAR) technology.

For this project, LiDAR data were collected and processed for a portion of the Central Florida Coordination Area (CFCA) in accordance with the Florida Department of Emergency Management (FDEM) Baseline Specifications. The CFCA defines an area that faces particularly difficult water supply issues. Three of Florida's Water Management Districts have jurisdiction in the CFCA: the South Florida Water Management District (SFWMD), the St. Johns River Water Management District (SJRWMD), and the Southwest Florida Water Management District (SWFWMD). These three water management districts are cooperating to develop and implement mutually acceptable strategies to provide adequate supplies of water to support projected growth without unacceptable impacts.

Groundwater and integrated groundwater/surface water models are important tools for developing water supply strategies, and require accurate surface elevation datasets as input. This project provided an accurate surface elevation dataset including delivery of one-foot and two-foot topographic contours delivered in a GIS-ready (Geographic Information System) format.

The LiDAR data were processed to a bare-earth digital terrain model (DTM). Detailed breaklines and contours were produced for the project area. Data was formatted according to tiles with each tile covering an area of 5000 ft by 5000 ft. A total of 355 tiles were produced for the project encompassing an area of approximately 318 sq. miles.

The Project Team

Dewberry served as the prime contractor for the project. Dewberry was responsible for the overall project including project management, scheduling, contour data production, and quality assurance. Dewberry's staff produced the contours for the project and performed rigorous quality assurance inspections on all subcontractor generated data and reports.

DeGrove Surveyors, Inc. completed ground surveying for the project. Their task was to acquire surveyed checkpoints for the project to use in independent testing of the vertical accuracy of the LiDAR-derived surface model. They also verified the GPS base station coordinates used during LiDAR data acquisition to ensure that the base station coordinates were accurate. Note that a separate Survey Report was created for this portion of the project.

Merrick and Company completed all LiDAR acquisition and post-processing tasks including data calibration, classification of points and compilation of the majority of the breaklines used to enhance the LiDAR-derived surface model.

Survey Area

The project area addressed by this report falls within the Florida counties of Seminole, Orange, and Brevard. Appendix A contains a map showing the tiling footprint and location of the project area.

Type of Survey

This report addresses the Specific Purpose Survey as defined by subsection “6G17-6.002 Definitions” of Florida’s Minimum Technical Standards (MTS).

The purpose of the survey was to generate GIS data, a digital elevation model, breaklines, and topographic contours derived from LiDAR remote sensing.

Business Entity Name

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Surveyor in Responsible Charge

Keith Patterson, PSM, GISP
Florida Professional Surveyor and Mapper (PSM) No. LS5431

Date of Survey

The LiDAR aerial acquisition was conducted from Feb. 08, 2009 thru Feb. 11, 2009 by Merrick & Company under a subcontract with Dewberry. One LiDAR aircraft, a Cessna 402C (SN35), was used to collect LiDAR Data. The Orlando Executive Airport (ORL) was used as the airfield of operations.

Monumentation

Two ground based airborne GPS Base Stations were established for the LiDAR data collection, The main airborne GPS base station (Base) was located at the Orlando Executive Airport (ORL). The auxiliary airborne GPS base station (Aux) was tied directly to the main airborne GPS base station by post processing using Trimble Geomatics Office Software version 1.63 and checked with OPUS solutions from NGS (National Geodetic Survey). A listing of these stations appears below.

Coordinate System: NAD83(NSRS2007) UTM17N
Zone: 17 North
Project Datum: NAD 1983(NSRS2007)
Vertical Datum: NAVD88
Units: Meters for Horizontal – US Feet for Vertical

	Geodetic NAD83		Ellipsoid	Ellipsoid	Description
	Latitude	Longitude	Height	Height	
	North	West	Geoid03	Geoid03	
	Deg Min Sec	Deg Min Sec	Meters	USFeet	
Base	28°32'52.60551"N	81°20'20.59643"W	3.549	11.64	Main Base
Aux	28°32'53.93266"N	81°20'22.30879"W	3.541	11.62	Aux Base

	NAD83 UTM17N		NAVD88	NAVD88	Description
	Northing	Easting	Elevation	Elevation	
	Y	X	Z	Z	
	Meters	Meters	Meters	USFeet	
Base	**3157950.481**	**466833.345**	31.254	**102.54**	Main Base
Aux	**3157991.454**	**466786.931**	31.245	**102.51**	Aux Base

Datum Reference

Horizontal Datum: The horizontal datum for the project is North American Datum of 1983 (NAD 83) NSRS2007

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

Coordinate System: Universal Transverse Mercator (UTM), Zone 17 North

Units: Horizontal units are in Meters, Vertical units are in US Survey Feet.

Geiod Model: Geoid03 (Geoid 03 was used to convert ellipsoid heights to orthometric heights).

Reference to the Map

This report is incomplete without the associated digital map data (i.e. LiDAR masspoints, breaklines, contours, geodatabase, and control) produced as a result of the survey.

The digital map associated with this survey is referenced as:

Map Title: 2009 CENTRAL FLORIDA COORDINATION AREA SURFACE ELEVATION DATASET

Digital File Name: SJRWMD_D1.gdb

Date of Digital File: July 31, 2009

Subject: LiDAR Survey

LiDAR Vertical Accuracy

Dewberry performed the LiDAR vertical accuracy assessment for the project in accordance with *ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data*, May 24, 2004, and Section 1.5 of the *Guidelines for Digital Elevation Data*, published by the National Digital Elevation Program (NDEP), May 10, 2004. These guidelines call for the mandatory determination of Fundamental Vertical Accuracy (FVA) and Consolidated Vertical Accuracy (CVA), and the optional determination of Supplemental Vertical Accuracy (SVA).

The data were compiled to meet the following Consolidated Vertical Accuracy requirements:

- **$RMSE_z$** < .61 ft (vertical accuracy at the 68% confidence level)
- **$Accuracy_z$** < 1.19 feet (vertical accuracy at the 95% confidence level)

The complete LiDAR Vertical Accuracy Report, which includes the tested $RMSE_z$ and $Accuracy_z$ for the 2009 Central Florida Coordination Area Surface Elevation Dataset Project is contained within Appendix F.

Fundamental Vertical Accuracy (FVA) is determined with QA/QC checkpoints located only in open terrain (grass, dirt, sand, and rocks) where there is a high probability that the LiDAR sensor detected the bare-earth ground surface, and where errors are expected to follow a normal error distribution. With a normal error distribution, the FVA at the 95 percent confidence level is computed as the vertical root mean square error ($RMSE_z$) of the checkpoints x 1.9600. The FVA is the same as $Accuracy_z$ at the 95% confidence level (for open terrain), as specified in Appendix 3-A of the *National Standard for Spatial Data Accuracy*, FGDC-STD-007.3-1998, see http://www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/part3/chapter3. For FDEM Baseline Specifications, the FVA standard is .60 feet at the 95% confidence level, corresponding to an $RMSE_z$ of 0.30 feet or 9.25 cm, the accuracy expected from 1-foot contours.

For the 2009 Central Florida Coordination Area Surface Elevation Dataset Project, the RMSEz in open terrain (bare earth and low grass) equaled **0.26 ft** compared with the 0.30 ft specification of FDEM; and the FVA computed using $RMSE_z$ x 1.9600 was equal to **0.51 ft**, compared with the 0.60 ft specification of FDEM.

Consolidated Vertical Accuracy (CVA) is determined with all checkpoints, representing open terrain and all other land cover categories combined. If errors follow a normal error distribution, the CVA can be computed by multiplying the consolidated $RMSE_z$ by 1.9600. However, because bare-earth elevation errors often vary based on the height and density of vegetation, a normal error distribution cannot be assumed, and $RMSE_z$ cannot necessarily be used to calculate the 95 percent confidence level. Instead, a nonparametric testing method, based on the 95th percentile, may be used to determine CVA at the 95 percent confidence level. NDEP guidelines state that errors larger than the 95th percentile should be documented in the quality control report and project metadata. For FDEM, the CVA specification for all classes combined should be less than or equal to 1.19 feet; this same CVA specification was used by NOAA.

For the 2009 Central Florida Coordination Area Surface Elevation Dataset Project, the CVA computed using $RMSE_z$ x 1.9600 was equal to **0.88 ft**, compared with the 1.19 ft specification of FDEM; and the CVA computed using the 95^{th} percentile was equal to 1**.00 ft**.

Supplemental Vertical Accuracy (SVA) is determined separately for each individual land cover category, recognizing that the LiDAR sensor and post-processing may not have mapped the bare-earth ground surface, and that errors may not follow a normal error distribution. SVA specifications are "target" values and not mandatory, recognizing that larger errors in some categories are offset by smaller errors in other land cover categories, so long as the overall mandatory CVA specification is satisfied. For each land cover category, the SVA at the 95 percent confidence level equals the 95^{th} percentile error for all checkpoints in that particular land cover category. For FDEM's specification, the SVA target is 1.19 feet for each category; this same SVA target specification was used by NOAA**.**

For the 2009 Central Florida Coordination Area Surface Elevation Dataset Project, the SVA tested as **0.52 ft** in open terrain, bare earth and low grass; **0.89 ft** in brush lands and low trees; **1.11 ft** in forested areas; and **0.47 ft** in urban, built-up areas thus passing the target specifications in all land cover categories.

LiDAR Horizontal Accuracy

The LiDAR data was compiled to meet 3.8 feet horizontal accuracy at the 95% confidence level.

Whereas FDEM Baseline Specifications call for horizontal accuracy testing, traditional horizontal accuracy testing of LiDAR data is not cost effective for the following reasons:

- Paragraphs 3.2.2 and 3.2.3 of the National Standard for Spatial Data Accuracy (NSSDA) states: "Horizontal accuracy shall be tested by comparing the planimetric coordinates of well-defined points in the dataset with coordinates of the same points from an independent source of higher accuracy … when a dataset, e.g., a gridded digital elevation dataset or elevation contour dataset does not contain well-defined points, label for vertical accuracy only." Similarly, in Appendix 3-C of the NSSDA, paragraph 1 explains well-defined points as follows: "A well-defined point represents a feature for which the horizontal position is known to a high degree of accuracy and position with respect to the geodetic datum. For the purpose of horizontal accuracy testing, well-defined points must be easily visible or recoverable on the ground, on the independent source of higher accuracy, and on the product itself. Graphic contour data and digital hypsographic data may not contain well-defined points."
- Paragraph 1.5.3.4 of the *Guidelines for Digital Elevation Data,* published in 2004 by the National Digital Elevation Program (NDEP), states: "The NDEP does not require independent testing of horizontal accuracy for elevation products. When the lack of distinct surface features makes horizontal accuracy testing of mass points, TINs, or DEMs difficult or impossible, the data producer should specify horizontal accuracy using the following statement: *Compiled to meet __ (meters, feet) horizontal accuracy at 95 percent confidence level*."
- Paragraph 1.2, Horizontal Accuracy, of *ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data*, published by the American Society for Photogrammetry and Remote Sensing (ASPRS) in 2004, further explains why it is difficult and impractical to test the horizontal accuracy of LiDAR data, and explains why ASPRS does not require horizontal accuracy testing of LiDAR-derived elevation products.
- In addition to LiDAR system factory calibration of horizontal and vertical accuracy, Merrick used valid techniques for field calibration checks used to determine if bore-sighting is accurate. Merrick's technique is explained in the LiDAR Processing Report within Appendix D.

Project Methodology and Deliverables

The specifications used for this project adhered to the Florida Baseline Specifications published by the Florida Division of Emergency Management (FDEM).

The Florida Baseline Specifications required the LiDAR data to be collected using an approved sensor with a maximum field of view (FOV) of 20˚ on either side of nadir, with GPS baseline distances limited to 20 miles, with maximum post spacing of 4 feet in unobscured areas for random point data, and with vertical root mean square error ($RMSE_z$) ≤ 0.30 ft and Fundamental Vertical Accuracy (FVA) ≤ 0.60 ft at the 95% confidence level in open terrain (bare-earth and low grass). This accuracy is equivalent to 1 ft contours in open terrain when tested in accordance with the National Map Accuracy Standard (NMAS). In other land cover categories (brush lands and low trees, forested areas fully covered by trees, and urban areas), the Florida Baseline Specifications required the LiDAR data's $RMSE_z$ to be ≤ 0.61 ft with Supplemental Vertical Accuracy (SVA) and Consolidated Vertical Accuracy (CVA) ≤ 1.19 ft at the 95% confidence level. This accuracy is equivalent to 2 ft contours when tested in accordance with the NMAS.

Low confidence areas are defined for areas where the vertical data may not meet the data accuracy requirements due to heavy vegetation.

The Florida Baseline Specifications also require the horizontal accuracy to meet or exceed 3.8 feet at the 95% confidence level, using $RMSE_r$ x 1.7308. This means that the horizontal (radial) RMSE ($RMSE_r$) must meet or exceed 2.20 ft. This is the horizontal accuracy required of maps compiled at a scale of 1:1,200 (1" = 100') in accordance with the traditional National Map Accuracy Standard.

The first deliverable is LiDAR mass points, delivered to LAS 1.1 specifications, including the following LAS classification codes:

- Class 1 = Unclassified, and used for all other features that do not fit into the Classes 2, 7, 9, or 12, including vegetation, buildings, etc.
- Class 2 = Ground, includes accurate LiDAR points in overlapping flight lines
- Class 7 = Noise, includes LiDAR points in overlapping flight lines
- Class 9 = Water, includes LiDAR points in overlapping flight lines[1]
- Class 12 = Overlap, including areas of overlapping flight lines which have been deliberately removed from Class 1 because of their reduced accuracy.

Per FDEM's Baseline Specifications, for each 500 square mile area, a total of 120 QA/QC checkpoints are surveyed and used to test accuracy. The specifications also require that each set of 120 QA/QC checkpoints contain 30 checkpoints in each of the following four land cover categories:

- Category 1 = bare-earth and low grass
- Category 2 = brush lands and low trees
- Category 3 = forested areas fully covered by trees
- Category 4 = urban areas

[1] Infrared radiation from LiDAR is partially absorbed by water, and all elevations in LAS Class 9 should be recognized as unreliable and treated accordingly.

Because the project area encompassed only 318 square miles instead of 500 square miles, only 64% of the normal 120 points were necessary to test accuracy (i.e. 76 points). However, a total of 82 QA/QC checkpoints were used for the project, as defined within Appendix F.

The following vertical accuracy guidelines were specified for the project:

- In category 1, the $RMSE_z$ must be ≤ 0.30 ft ($Accuracy_z$ ≤ 0.60 ft at the 95% confidence level); $Accuracy_z$ in Category 1 refers to Fundamental Vertical Accuracy (FVA) which defines how accurate the elevation data are when not complicated by asphalt or vegetation that may cause elevations to be either lower or higher than the bare earth terrain. This is equivalent to the accuracy expected of 1 ft contours in non-vegetated terrain.
- In category 2, the $RMSE_z$ must be ≤ 0.61 ft ($Accuracy_z$ ≤ 1.19 ft at the 95% confidence level); $Accuracy_z$ in Category 2 refers to Supplemental Vertical Accuracy (SVA) in brush lands and low trees and defines how accurate the elevation data are when complicated by such vegetation that frequently causes elevations to higher than the bare earth terrain. This is equivalent to the accuracy expected of 2 ft contours in such terrain.
- In category 3, the $RMSE_z$ must be ≤ 0.61 ft ($Accuracy_z$ ≤ 1.19 ft at the 95% confidence level); $Accuracy_z$ in Category 3 refers to Supplemental Vertical Accuracy (SVA) in forested areas fully covered by trees and defines how accurate the elevation data are when complicated by such vegetation that frequently causes elevations to be higher than the bare earth terrain. This is equivalent to the accuracy expected of 2 ft contours in such terrain.
- In category 4, the $RMSE_z$ must be ≤ 0.61 ft ($Accuracy_z$ ≤ 1.19 ft at the 95% confidence level); $Accuracy_z$ in Category 4 refers to Supplemental Vertical Accuracy (SVA) in urban areas typically paved with asphalt and defines how accurate the elevation data are when complicated by asphalt that frequently causes elevations to be lower than the bare earth terrain. This is equivalent to the accuracy expected of 2 ft contours in such terrain.
- In all land cover categories combined, the $RMSE_z$ must be ≤ 0.61 ft ($Accuracy_z$ ≤ 1.19 ft at the 95% confidence level); $Accuracy_z$ in all categories combined refers to Consolidated Vertical Accuracy (CVA).
- The terms FVA, SVA and CVA are explained in Chapter 3, *Accuracy Standards & Guidelines*, of "Digital Elevation Model Technologies and Applications: The DEM Users Manual," published by the American Society for Photogrammetry and Remote Sensing (ASPRS), January, 2007.

A second major deliverable consisted of nine types of breaklines, produced in accordance with the project's Data Dictionary at Appendix C:

1. Coastal shoreline features
2. Single-line hydrographic features
3. Dual-line hydrographic features
4. Closed water body features
5. Road edge-of-pavement features
6. Bridge and overpass features
7. Soft breakline features
8. Island features
9. Low confidence areas

Another major deliverable included both one-foot and two-foot contours, produced from the mass points and breaklines, certified to meet or exceed NSSDA standards for one-foot contours. Two-foot contours within obscured vegetated areas are not required to meet NSSDA standards. These contours were also produced in accordance with the project's Data Dictionary at Appendix C.

Table 1 is included below for ease in understanding the accuracy requirements when comparing the traditional National Map Accuracy Standard (NMAS) and the newer National Standard for Spatial Data Accuracy (NSSDA). This table is extracted from Table 13.2 of "Digital Elevation Model Technologies and Applications: The DEM Users Manual," published in January, 2007 by ASPRS. The traditional NMAS uses Vertical Map Accuracy Standard (VMAS) to define vertical accuracy at the 90% confidence level, whereas the NSSDA uses $Accuracy_z$ to define vertical accuracy at the 95% confidence level. Both the VMAS and $Accuracy_z$ are computed with different multipliers for the very same $RMSE_z$ value which represents vertical accuracy at the 68% confidence level for each equivalent contour interval specified. The term $Accuracy_z$ (vertical accuracy at the 95% confidence level) is comparable to the terms described below as Fundamental Vertical Accuracy (FVA), Consolidated Vertical Accuracy (CVA) and Supplemental Vertical Accuracy (SVA) which also define vertical accuracy at the 95% confidence level. In open (non-vegetated) terrain, $Accuracy_z$ is exactly the same as FVA (both computed as $RMSE_z$ x 1.9600) because there is no logical justification for elevation errors to depart from a normal error distribution. In vegetated areas, vertical accuracy at the 95% confidence level ($Accuracy_z$) can also be computed as $RMSE_z$ x 1.9600; however, because vertical errors do not always have a normal error distribution in vegetated terrain, alternative guidelines from the National Digital Elevation Program (NDEP) and American Society for Photogrammetry and Remote Sensing (ASPRS) allow the 95th percentile method to be used (as with the CVA and SVA) to report the vertical accuracy at the 95% confidence level in land cover categories other than open terrain.

Table 1. Comparison of NMAS/NSSDA Vertical Accuracy

NMAS Equivalent Contour Interval	**NMAS** VMAS (90 percent confidence level)	**NSSDA** $RMSE_z$ (68 percent confidence level)	**NSSDA** $Accuracy_{z,}$ (95 percent confidence level)
1 ft	0.5 ft	0.30 ft or 9.25 cm	0.60 ft or 18.2 cm
2 ft	1.0 ft	0.61 ft or 18.5 cm	1.19 ft or 36.3 cm

The next major deliverable includes metadata compliant with the Federal Geographic Data Committee's (FGDC) Content Standard for Spatial Metadata in an ArcCatalog-compatible XML format. Copies of all survey reports, including this Report of Specific Purpose LiDAR Survey, must be delivered in PDF format as attachments to the metadata.

The last major deliverable includes the Vertical Accuracy Report based on independent comparison of the LiDAR data with the QA/QC checkpoints, surveyed and tested in accordance with guidelines of the National Standard for Spatial Data Accuracy (NSSDA), American Society for Photogrammetry and Remote Sensing (ASPRS), Federal Emergency Management Agency (FEMA), and National Digital Elevation Program (NDEP), and using the QA/QC checkpoints surveyed by DeGrove and listed at Appendix E.

Appendix I to this report provides the Geodatabase structure for the project.

LiDAR Processing Methodology

A LiDAR processing report from Merrick & Company is included at Appendix D.

LiDAR Qualitative Assessments

In addition to vertical accuracy testing, Dewberry also performed the LiDAR qualitative assessment.

An assessment of the vertical accuracy alone does not yield a complete picture with regard to the usability of LiDAR data for its intended purpose. It is very possible for a given set of LiDAR data to meet the accuracy requirements, yet still contain artifacts (non-ground points) in the bare-earth surface, or a lack of ground points in some areas that may render the data, in whole or in part, unsuitable for certain applications.

Based on the extremely large volume of elevation points generated, it is neither time efficient, cost effective, nor technically practical to produce a perfectly clean (artifact-free) bare-earth terrain surface. The purpose of the LiDAR Qualitative Assessment Report (see Appendix G) is to provide a qualitative analysis of the "cleanliness" of the bare-earth terrain surface for use in supporting analysis, modeling, and mapping.

The main software programs used by Dewberry in performing the bare-earth data cleanliness review include the following:

- *GeoCue*: a geospatial data/process management system especially suited to managing large LiDAR data sets
- *QT Modeler*: used for analysis and visualization
- *TerraScan*: runs inside of MicroStation; used for point classification and points file generation
- Dewberry proprietary tools/scripts to run statistical checks

Breakline Production Methodology

The project team used a methodology that directly interacts with the LiDAR bare-earth data to collect drainage breaklines. To determine the alignment of a drainageway, the technician first views the area as a TIN of bare-earth points using a color ramp to depict varying elevations. In areas of extremely flat terrain, the technician may need to determine the direction of flow based on measuring LiDAR bare-earth points at each end of the drain. The operator will then use the color ramped TIN to digitize the drainage centerline in 2D with the elevation being attributed directly from the bare-earth .LAS data. Merrick's MARS® software has the capability of "flipping" views between the TIN and ortho imagery, as necessary, to further assist in the determination of the drainage centerline.

All drainage breaklines are collected in a downhill direction. For each point collected, the software uses a 5-ft search radius to identify the lowest point within that proximity. Within each radius, if a bare-earth point is not found that is lower than the previous point, the elevation for subsequent points remains the same as the previous point. This forces the drain to always flow in a downhill direction. Waterbodies that are embedded along a drainageway are validated to ensure consistency with the downhill direction of flow. Merrick relies on the bare-earth data to attribute breakline elevations. As a result of this methodology, there is no mismatch between LiDAR bare-earth data and breaklines that might otherwise be collected photogrammetrically in stereo 3D. This is particularly important in densely vegetated areas where breaklines collected in 3D from imagery will most likely not match (either horizontally or vertically) the more reliable LiDAR bare-earth data.

Merrick has the capability of "draping" 2D breaklines to a bare-earth elevation model to attribute the "z" as opposed to the forced downhill attribution methodology described above. However, the problem with this process in the "pooling" effect or depressions along the drainageway caused by a lack of consistent penetration in densely vegetated areas.

Water bodies are digitized from the color ramped TIN, similar to the process described above. Ortho imagery is also used, as necessary, to determine the waterbody outline. The elevation attribute is determined as a post-process using the lowest determined bare-earth point within the polygon.

All breaklines were inspected by Dewberry and conform to the data format requirements outlined by the project's Data Dictionary contained within Appendix C.

Breaklines Topology Rules

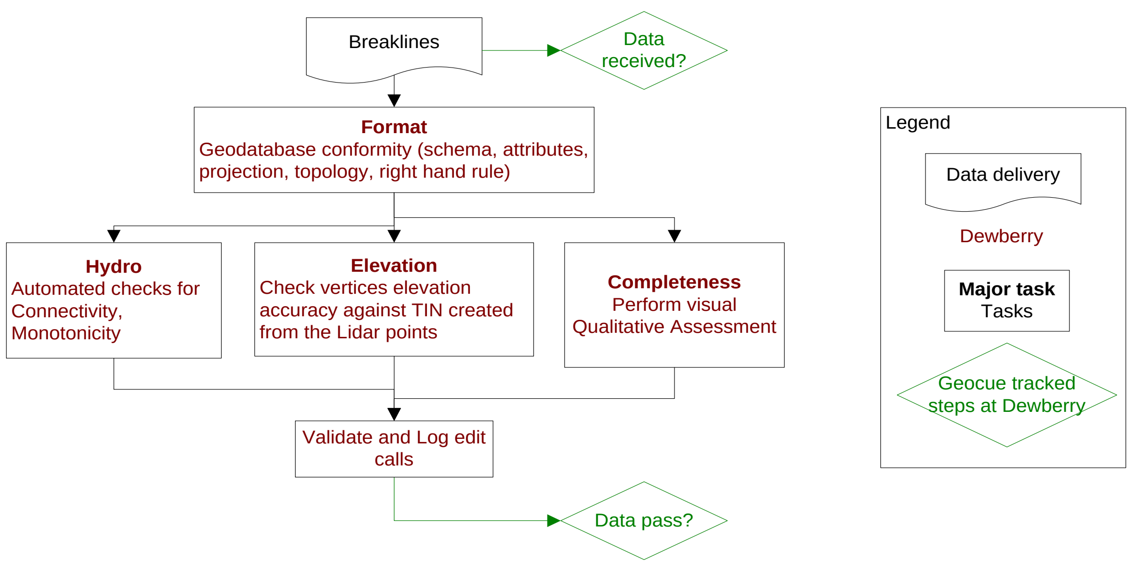
Automated checks are applied on hydro features to validate the 3D connectivity of the feature and the monotonicity of the hydrographic breaklines. Dewberry's major concern was that the hydrographic breaklines have a continuous flow downhill and that breaklines do not undulate. Error points are generated at each vertex not complying with the tested rules and these potential edit calls are then visually validated during the visual evaluation of the data. This step also helped validate that breakline vertices did not have excessive minimum or maximum elevations and that elevations are consistent with adjacent vertex elevations.

The next step is to compare the elevation of the breakline vertices against the elevation extracted from the TIN built from the LiDAR ground points, keeping in mind that a discrepancy is expected because of the hydro-enforcement applied to the breaklines and because of the interpolated imagery used to acquire the breaklines. A given tolerance is used to validate if the elevations do not differ too much from the LiDAR.

Dewberry's final check for the breaklines was to perform a full qualitative analysis. Dewberry compared the breaklines against LiDAR intensity images to ensure breaklines were captured in the required locations.

Breakline Qualitative Assessments

Dewberry performed the breakline qualitative assessments. The following workflow diagram represents the steps taken by Dewberry to provide a thorough qualitative assessment of the breakline data.



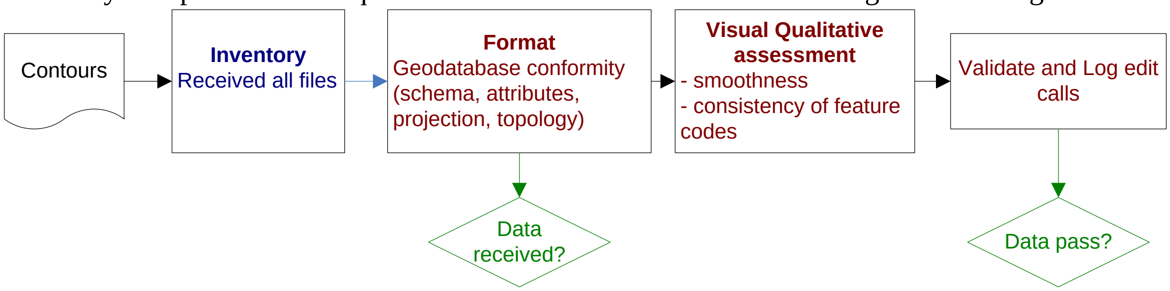
In order to ensure a correct database format, SJRWMD provided a geodatabase shell containing the required feature classes in the required format. Dewberry verified that the correct shell was used and validated the topology rules associated with it.

Contour Production Methodology

ESRI ArcGIS software was used to generate the contours at intervals of 1-foot and 2-foot in accordance with the Data Dictionary appearing within Appendix C. Prior to contour generation, breaklines are buffered to remove points within 1 foot; this enhances the aesthetics of the final contours. Topology QC checks are completed for breaklines and contours based on a script developed by Dewberry. Additional QC checks for dangles and appropriate attribution are also completed before shipment.

Contour Qualitative Assessments

Dewberry also performed the qualitative assessments of the contours using the following workflow.



The first step performed by Dewberry was a series of data topology validations. Dewberry checked for the following instances in the data:

1. Contours must not overlap
2. Contours must not intersect
3. Contours must not have dangles (except at project boundary)
4. Contours must not self-overlap
5. Contours must not self-intersect

After the topology and geodatabase format validation was complete, Dewberry checked the elevation attribute of each contour to ensure NULL values are not included. Finally, Dewberry loaded the contour data plus the Lidar intensity images into ArcGIS and performed a full qualitative review of the contour data for smoothness and consistency of feature codes.

Appendix H summarizes Dewberry's qualitative assessments of the breaklines and contours, with graphic examples of what the breaklines and contours look like.

Deliverables

The deliverables for the project are listed below.

1. LiDAR Flight Lines and Acquisition Schedule
2. Ground Control Survey Report (i.e. field survey for check points)
3. Status Reports
4. LiDAR mass points – LAS Files
5. ArcGIS Geodatabase
6. Final Report of Specific Purpose LiDAR Survey

Acronyms and Definitions

$Accuracy_r$	Horizontal (radial) accuracy at the 95% confidence level, defined by the NSSDA
$Accuracy_z$	Vertical accuracy at the 95% confidence level, defined by the NSSDA
ASFPM	Association of State Floodplain Managers
ASPRS	American Society for Photogrammetry and Remote Sensing
CFM	Certified Floodplain Manager (ASFPM)
CMAS	Circular Map Accuracy Standard, defined by the NMAS
CP	Certified Photogrammetrist (ASPRS)
CVA	Consolidated Vertical Accuracy, defined by the NDEP and ASPRS
DEM	Digital Elevation Model (gridded DTM)
DTM	Digital Terrain Model (mass points and breaklines to map the bare earth terrain)
DSM	Digital Surface Model (top reflective surface, includes treetops and rooftops)
FDEM	Florida Division of Emergency Management
FEMA	Federal Emergency Management Agency
FGDC	Federal Geographic Data Committee
FOV	Field of View
FVA	Fundamental Vertical Accuracy, defined by the NDEP and ASPRS
GS	Geodetic Surveyor
LAS	LiDAR data format as defined by ASPRS
LiDAR	Light Detection and Ranging
MHHW	Mean Higher High Water
MHW	Mean High Water, defines official shoreline in Florida
MLLW	Mean Lower Low Water
MLW	Mean Low Water
MSL	Mean Sea Level
NAD 83	North American Datum of 1983
NAVD 88	North American Vertical Datum of 1988
NDEP	National Digital Elevation Program
NMAS	National Map Accuracy Standard
NOAA	National Oceanic and Atmospheric Administration
NSSDA	National Standard for Spatial Data Accuracy
NSRS	National Spatial Reference System
PS	Photogrammetric Surveyor
PSM	Professional Surveyor and Mapper
QA/QC	Quality Assurance/Quality Control
$RMSE_h$	Vertical Root Mean Square Error (RMSE) of ellipsoid heights
$RMSE_r$	Horizontal (radial) Root Mean Square Error (RMSE) computed from $RMSE_x$ and $RMSE_y$
$RMSE_z$	Vertical Root Mean Square Error (RMSE) of orthometric heights
SVA	Supplemental Vertical Accuracy, defined by the NDEP and ASPRS
TIN	Triangulated Irregular Network
VMAS	Vertical Map Accuracy Standard, defined by the NMAS

References

ASPRS, 2007, *Digital Elevation Model Technologies and Applications: The DEM Users Manual*, 2nd edition, American Society for Photogrammetry and Remote Sensing, Bethesda, MD.

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General Notes

The digital mapping data produced for this project complies with the Federal Emergency Management Agency (FEMA) "Guidelines and Specifications for Flood Hazard Mapping Partners," Appendix A: *Guidance for Aerial Mapping and Surveying.*

The LiDAR vertical accuracy report at Appendix F conforms with the National Standard for Spatial Data Accuracy (NSSDA).

THIS REPORT IS NOT VALID WITHOUT THE SIGNATURE AND RAISED SEAL OF A FLORIDA PROFESSIONAL SURVEYOR AND MAPPER IN RESPONSIBLE CHARGE.

ADDITIONS OR DELETIONS TO THIS REPORT BY OTHER THAN THE SIGNING PARTY IS PROHIBITED WITHOUT THE WRITTEN CONSENT OF THE SURVEYOR AND MAPPER IN RESPONSIBLE CHARGE

Surveyor and Mapper in Responsible Charge:

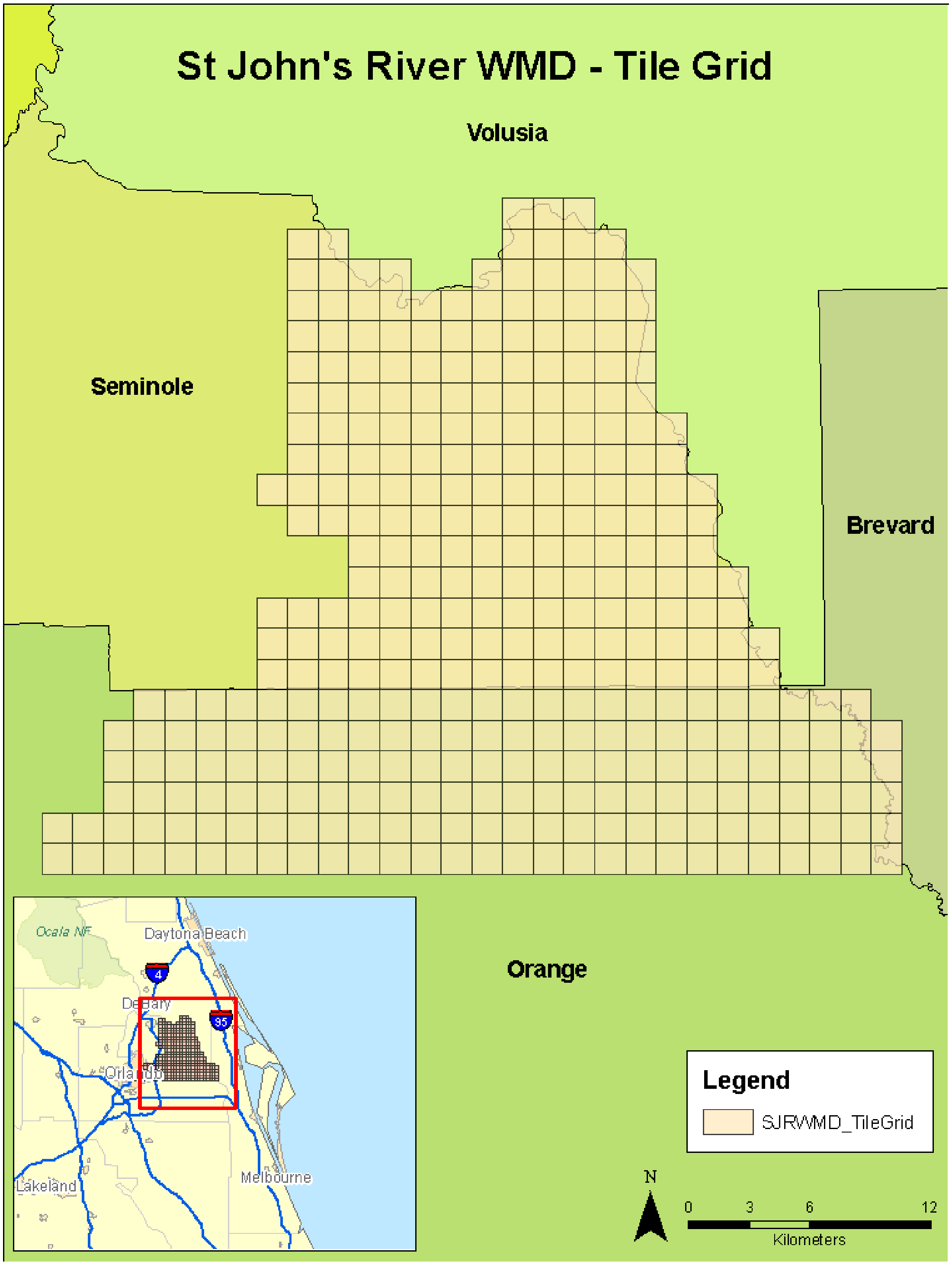
Keith Patterson, PSM, GISP
Florida Professional Surveyor and Mapper No. LS5431

Signed: ________________________________ Date: ________________

Original Copy Signed

Appendix A: Project Tiling Footprint

355 tiles delivered



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Appendix B: Geodetic Control Points

Control Point	Northing (M)	Easting(M)	Elevation (Ft)	Description
AK0453 C 188	3,156,956.498	467,717.882	108.03	Control Point used for LiDAR checkpoint Survey
AK6606 Chuluota Reset	3,166,970.280	487,335.431	54.93	Control Point used for LiDAR checkpoint Survey
AA9511 SFB C	3,182,232.438	476,987.277	41.01	Control Point used for LiDAR checkpoint Survey
AK7048 V002	3,174,951.434	498,883.234	10.78	Control Point used for LiDAR checkpoint Survey
AK0249 Gene	3,182,224.025	488,708.220	16.33	Control Point used for LiDAR checkpoint Survey
AK7334 GIS 266 Midway	3,157,436.073	506,527.817	17.35	Control Point used for LiDAR checkpoint Survey
AK6917 FLGPS 36	3,156,927.077	491,880.997	70.34	Control Point used for LiDAR checkpoint Survey
Main Base	3,157,950.481	466,833.345	102.54	Control Point used for LiDAR Acquisition
Aux Base	3,157,991.454	466,786.931	102.51	Control Point used for LiDAR Acquisition

Appendix C: Data Dictionary

LiDARgrammetry Data Dictionary
& Stereo Compilation Rules

SJRWMD (St. John's River Water Management District)

April 1, 2009

Table of Contents

HORIZONTAL AND VERTICAL DATUM

The horizontal datum shall be North American Datum of 1983/NSRS 2007 adjustment in Meters. The vertical datum shall be referenced to the North American Vertical Datum of 1988 (NAVD 88), Units in Feet. Geoid03 shall be used to convert ellipsoidal heights to orthometric heights.

Coordinate System and Projection

All data shall be projected to UTM, Zone 17 North, Horizontal Units in Meters and Vertical Units in Feet.

Contour Topology Rules

The following contour topology rules have been incorporated into each geodatabase shell provided by Dewberry. The topology must be validated by each subcontractor prior to delivery to Dewberry. Dewberry shall further validate the topology before final submittal to the SJRWMD.

Name: CONTOURS_Topology				Cluster Tolerance: 0.003 Maximum Generated Error Count: Undefined State: Analyzed without errors
Feature Class	**Weight**	**XY Rank**	**Z Rank**	**Event Notification**
CONTOUR_1FT	5	1	1	No
CONTOUR_2FT	5	1	1	No

Topology Rules

Name	Rule Type	Trigger Event	Origin (*FeatureClass::Subtype*)	Destination (*FeatureClass::Subtype*)
Must not intersect	The rule is a line-no intersection rule	No	CONTOUR_1FT::All	CONTOUR_1FT::All
Must not intersect	The rule is a line-no intersection rule	No	CONTOUR_2FT::All	CONTOUR_2FT::All
Must not self-intersect	The rule is a line-no self intersect rule	No	CONTOUR_2FT::All	CONTOUR_2FT::All
Must not self-intersect	The rule is a line-no self intersect rule	No	CONTOUR_1FT::All	CONTOUR_1FT::All

Breakline Topology Rules

The following breakline topology rules have been incorporated into each geodatabase shell provided by Dewberry. The topology must be validated by each subcontractor prior to delivery to Dewberry. Dewberry shall further validate the topology before final submittal to the SJRWMD.

Name: BREAKLINES_Topology				Cluster Tolerance: 0.003 Maximum Generated Error Count: Undefined State: Analyzed without errors
Feature Class	**Weight**	**XY Rank**	**Z Rank**	**Event Notification**
HYDROGRAPHICFEATURE	5	1	1	No
OVERPASS	5	1	1	No
ROADBREAKLINE	5	1	1	No
SOFTFEATURE	5	1	1	No

Topology Rules

Name	**Rule Type**	**Trigger Event**	**Origin** (*FeatureClass::Subtype*)	**Destination** (*FeatureClass::Subtype*)
Must not intersect	The rule is a line-no intersection rule	No	SOFTFEATURE::All	SOFTFEATURE::All
Must not intersect	The rule is a line-no intersection rule	No	OVERPASS::All	OVERPASS::All
Must not intersect	The rule is a line-no intersection rule	No	ROADBREAKLINE::All	ROADBREAKLINE::All
Must not intersect	The rule is a line-no intersection rule	No	HYDROGRAPHICFEATURE::All	HYDROGRAPHICFEATURE::All
Must not overlap	The rule is a line-no overlap line rule	No	SOFTFEATURE::All	ROADBREAKLINE::All
Must not overlap	The rule is a line-no overlap line rule	No	SOFTFEATURE::All	HYDROGRAPHICFEATURE::All
Must not overlap	The rule is a line-no overlap line rule	No	ROADBREAKLINE::All	HYDROGRAPHICFEATURE::All
Must not self-intersect	The rule is a line-no self intersect rule	No	SOFTFEATURE::All	SOFTFEATURE::All

Must not self-intersect	The rule is a line-no self intersect rule	No	OVERPASS::All	OVERPASS::All
Must not self-intersect	The rule is a line-no self intersect rule	No	ROADBREAKLINE::All	ROADBREAKLINE::All
Must not self-intersect	The rule is a line-no self intersect rule	No	HYDROGRAPHICFEATURE::All	HYDROGRAPHICFEATURE::All

Coastal Shoreline

Feature Dataset: TOPOGRAPHIC **Feature Class:** COASTALSHORELINE **Feature Type:** Polygon
Contains M Values: No **Contains Z Values:** Yes **Annotation Subclass:** None
XY Resolution: Accept Default Setting **Z Resolution:** Accept Default Setting
XY Tolerance: 0.003 **Z Tolerance:** 0.001

Description

This polygon feature class will outline the land / water interface at the time of LiDAR acquisition.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0		Assigned by Dewberry
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Dewberry
SHAPE_AREA	Double	Yes			0	0		Calculated by Dewberry

Feature Definition

Code	Description	Definition	Capture Rules
1	Coastal Shoreline	The coastal breakline will delineate the land water interface using LiDAR data as reference. In flight line boundary areas with tidal variation the coastal shoreline may require some feathering or edge matching to ensure a smooth transition.	The feature shall be extracted at the apparent land/water interface, as determined by the LiDAR intensity data, to the extent of the tile boundaries. For the polygon closure vertices and segments, null values or a value of 0 are acceptable since this is not an actual shoreline. The digital

		Orthophotography will not be used to delineate this shoreline. "Donuts" will exist where there are islands within the coastal shoreline feature.	orthophotography is not a suitable source for capturing this feature. Efforts should be taken to gradually feather the difference between tidal conditions of neighboring flights. Stair-stepping of the breakline feature will not be allowed. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water. Breaklines shall snap and merge seamlessly with linear hydrographic features.

Linear Hydrographic Features

Feature Dataset: TOPOGRAPHIC **Feature Class:** HYDROGRAPHICFEATURE **Feature Type:** Polyline

Contains M Values: No **Contains Z Values:** Yes **Annotation Subclass:** None
XY Resolution: Accept Default Setting **Z Resolution:** Accept Default Setting
XY Tolerance: 0.003 **Z Tolerance:** 0.001

Description

This polyline feature class will depict linear hydrographic features with a length of 0.5 miles or longer as breaklines.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0		Assigned by Dewberry
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Dewberry
TYPE	Short Integer	No	1	dHydroL	0	0		Assigned by Dewberry

Feature Definition

Code	Description	Definition	Capture Rules
1	Single Line Feature	Linear hydrographic features for defined streams or rivers with an average width less than or equal to 8 feet. In the case of embankments, if the feature forms a natural dual line channel, then capture it consistent with the capture rules. Other embankments fall into the soft breakline feature class.	Capture linear hydro features as single breaklines. Average width shall be 8 feet or less to show as single line. Each vertex placed should maintain vertical integrity and connectivity if adjoining to other features. The provided stream network is to be used as a guide determining which hydrographic features need to be captured, but

		Ditches and swales are not to be captured.	elevations will be derived from the LiDAR data. If significant hydrographic features not represented by provided stream network are captured, they need to be ½ mile or longer in length. If the feature is interrupted by a man-made or natural feature but both sides of the interruption equal ½ mile or longer, both segments should be captured regardless of size.

2	Dual Line Feature	Linear hydrographic features such as streams, shorelines, and embankments, etc. with an average width greater than 8 feet. In the case of embankments, if the feature forms a natural dual line channel, then capture it consistent with the capture rules. Other embankments fall into the soft breakline feature class. Ditches and swales are not to be captured.	Capture features showing dual line (one on each side of the feature). Average width shall be great than 8 feet to show as a double line. Each vertex placed should maintain vertical integrity and connectivity if adjoining to other features. Features should show "closed polygon". The provided stream network is to be used as a guide determining which hydrographic features need to be captured, but elevations will be derived from the LiDAR data. If significant hydrographic features not represented by provided stream network are captured, they need to be ½ mile or longer in length. These instructions are only for docks or piers that follow the coastline or water's edge, not for docks or piers that extend perpendicular from the land into the water. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the

			measured elevation of the water. If the feature is interrupted by a man-made or natural feature but both sides of the interruption are ½ mile or longer, both segments should be captured.

Note: Carry through bridges for all linear hydrographic features.

Closed Water Body Features

Feature Dataset: TOPOGRAPHIC **Feature Class:** WATERBODY **Feature Type:** Polygon
Contains M Values: No **Contains Z Values:** Yes **Annotation Subclass:** None
XY Resolution: Accept Default Setting **Z Resolution:** Accept Default Setting
XY Tolerance: 0.003 **Z Tolerance:** 0.001

Description
This polygon feature class will depict closed water body features and will have the associated water elevation available as an attribute.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0		Assigned by Dewberry
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Dewberry
SHAPE_AREA	Double	Yes			0	0		Calculated by Dewberry
WATERBODY_ELEVATION_MS	Double	Yes			0	0		Assigned by Dewberry

Feature Definition

Code	Description	Definition	Capture Rules
1	Water Body	Land/Water boundaries of constant elevation	Water bodies shall be captured as closed

		water bodies such as lakes, reservoirs, ponds, etc. Features shall be defined as closed polygons and contain an elevation value that reflects the best estimate of the water elevation at the time of data capture. Water body features will be captured for features one-half acres in size or greater. "Donuts" will exist where there are islands within a closed water body feature.	polygons with the water feature to the right. <u>The compiler shall ensure that the z-value maintains a single elevation for all vertices placed on the water body.</u> The field "WATERBODY_ELEVATION_MS" shall be automatically computed from the z-value of the vertices. An Island within a Closed Water Body Feature will also have a "donut polygon" compiled in addition to an Island polygon. These instructions are only for docks or piers that follow the coastline or water's edge, not for docks or piers that extend perpendicular from the land into the water. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water.

Road Features

Feature Dataset: TOPOGRAPHIC **Feature Class:** ROADBREAKLINE **Feature Type:** Polyline

Contains M Values: No **Contains Z Values:** Yes **Annotation Subclass:** None
XY Resolution: Accept Default Setting **Z Resolution:** Accept Default Setting
XY Tolerance: 0.003 **Z Tolerance:** 0.001

Description

This polyline feature class will depict apparent edge or road pavement as breaklines but will not include bridges, overpasses or box culverts.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0		Assigned by Dewberry
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Dewberry

Feature Definition

Code	Description	Definition	Capture Rules
1	Edge of Pavement	Capture edge of pavement for major paved road arteries on both sides of the road. Runways, unpaved surfaces, and residential roads are not to be included.	DO NOT INCLUDE Bridges, Overpasses or Box Culverts within this feature type. Capture apparent edge of pavement (including paved shoulders) as interpreted from the LiDAR data. Each vertex placed should maintain vertical

			integrity and data should show “closed polygon”. The provided road network is to be used as a guide for which roads need to be captured, but all elevations will be derived from LiDAR data.

Bridge and Overpass Features

Feature Dataset: TOPOGRAPHIC **Feature Class:** OVERPASS **Feature Type:** Polyline
Contains M Values: No **Contains Z Values:** Yes **Annotation Subclass:** None
XY Resolution: Accept Default Setting **Z Resolution:** Accept Default Setting
XY Tolerance: 0.003 **Z Tolerance:** 0.001

Description

This polyline feature class will depict bridges and overpasses as separate entities from the edge of pavement feature class.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0		Assigned by Dewberry
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Dewberry

Feature Definition

Code	Description	Definition	Capture Rules
1	Bridge Overpass	Feature should show edge of bridge or overpass. This feature does not include box culverts – regardless of whether or not a guardrail system is clearly in place.	Capture apparent edge of pavement on bridges or overpasses. Do not capture guard rails or non-drivable surfaces such as sidewalks. Capture edge of drivable pavement only. Each vertex placed should maintain vertical integrity and data should show “closed polygon”.

Soft Features

Feature Dataset: TOPOGRAPHIC **Feature Class:** SOFTFEATURE **Feature Type:** Polyline

Contains M Values: No **Contains Z Values:** Yes **Annotation Subclass:** None

XY Resolution: Accept Default Setting **Z Resolution:** Accept Default Setting

XY Tolerance: 0.003 **Z Tolerance:** 0.001

Description

This polyline feature class will depict soft changes in the terrain to support better hydrological modeling of the LiDAR data and sub-sequent contours.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0		Assigned by Dewberry
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Dewberry

Feature Definition

Code	Description	Definition	Capture Rules
1	Soft Breakline	Supplemental breaklines where LiDAR mass points are not sufficient to create a hydrologically correct DTM. Soft features shall include ridges, valleys, top of banks, etc.	Capture soft breaklines where additional elevation data is needed to correctly enforce DTM surfaces. Capture elevation changes not clearly visible or apparent in LiDAR data. Each vertex placed should maintain vertical integrity.

		Soft features may also include natural Embankments that act as small ponding areas. Top of Banks can also be included in the soft breakline class so long as it does not define the edge of a water feature.	

Island Features

Feature Dataset: TOPOGRAPHIC **Feature Class:** ISLAND **Feature Type:** Polygon

Contains M Values: No **Contains Z Values:** Yes **Annotation Subclass:** None
XY Resolution: Accept Default Setting **Z Resolution:** Accept Default Setting
XY Tolerance: 0.003 **Z Tolerance:** 0.001

Description

This polygon feature class will depict natural and man-made islands as closed polygons.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0		Assigned by Dewberry
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Dewberry
SHAPE_AREA	Double	Yes			0	0		Calculated by Dewberry

Feature Definition

Code	Description	Definition	Capture Rules
1	Island	Apparent boundary of natural or man-made island feature captured with a constant elevation.	Island shall take precedence over Coastal Shore Line Features. Islands shall be captured as closed polygons with the land feature to the right. The

		Island features will be captured for features one-half acres in size or greater.	compiler shall take care to ensure that the z-value remains consistent for all vertices placed around the island. These instructions are only for docks or piers that follow the coastline or water's edge, not for docks or piers that extend perpendicular from the land into the water. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water.

Low Confidence Areas

Feature Dataset: TOPOGRAPHIC **Feature Class:** LOWCONFIDENCE **Feature Type:** Polygon

Contains M Values: No **Contains Z Values:** No **Annotation Subclass:** None

XY Resolution: Accept Default Setting **Z Resolution:** Accept Default Setting

XY Tolerance: 0.003 **Z Tolerance:** 0.001

Description

This polygon feature class will depict areas where the ground is obscured by dense vegetation meaning that the resultant contours may not meet the required accuracy specifications.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0		Assigned by Dewberry
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Dewberry
SHAPE_AREA	Double	Yes			0	0		Calculated by Dewberry

Feature Definition

Code	Description	Definition	Capture Rules
1	Low Confidence Area	Apparent boundary of vegetated or marsh areas that are considered obscured to the	Capture as closed polygon with the obscured area to the right of the line. Compiler does not need to

		extent that adequate vertical data cannot be clearly determined to accurately define the DTM. These features are for reference only to indicate areas where the vertical data may not meet the data accuracy requirements due to heavy vegetation. Area must be one-half acres or larger.	worry about z-values of vertices; feature class will be 2-D only.

Note: Only outline areas where you are not sure about vegetative penetration of the LiDAR data. This is not the same as a traditional obscured area.

Masspoint

Feature Dataset: TOPOGRAPHIC **Feature Class:** MASSPOINT **Feature Type:** MultiPoint
Contains M Values: No **Contains Z Values:** Yes **Annotation Subclass:** None
XY Resolution: Accept Default Setting **Z Resolution:** Accept Default Setting
XY Tolerance: 0.003 **Z Tolerance:** 0.001

Description

This feature class depicts masspoints as determined by the LiDAR ground points (LAS Class 2).

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0		Assigned by Dewberry

Feature Definition

Code	Description	Definition	Capture Rules
1	Masspoint	Only the bare earth classification (Class 2) shall be loaded into the MASSPOINT feature class.	None. Data should be loaded from LAS Class 2 (Ground)

1 Foot Contours

Feature Dataset: TOPOGRAPHIC **Feature Class:** CONTOUR_1FT **Feature Type:** Polyline

Contains M Values: No **Contains Z Values:** No **Annotation Subclass:** None

XY Resolution: Accept Default Setting **Z Resolution:** N/A

XY Tolerance: 0.003 **Z Tolerance:** N/A

Description

This polyline feature class will depict 1’ contours modeled from the LiDAR ground points and the supplemental breaklines.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0		Assigned by Dewberry
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Dewberry
CONTOUR_TYPE_DESC	Short Integer	No	1	dCONTOURTYPE	0	0		Assigned by Dewberry
CONTOUR_ELEVATION_MS	Double	No			0	0		Calculated by Dewberry

Feature Definition

Code	Description	Definition	Capture Rules
1	Intermediate	A contour line drawn between index	They are normally continuous throughout a map,

		contours. There are four intermediate contours between the index contours.	but may be dropped or joined with an index contour where the slope is steep and where there is insufficient space to show all of the intermediate lines.
2	Supplementary	Supplementary contours are used to portray important relief features that would otherwise not be shown by the index and intermediate contours (basic contours). They are normally added only in areas of low relief, but they may also be used in rugged terrain to emphasize features. Supplementary contours are shown as screened lines so that they are distinguishable from the basic contours, yet not unduly prominent on the published map. Only the Contour_2FT feature class will have supplementary contours.	These dotted lines are placed in areas where elevation change is minimal. If there is a lot of space between Index and Intermediate Contours (as happens where the land is relatively flat), these lines are added to indicate that there *are* elevation measurements, even if they are few and far between. If the horizontal distance between two adjacent contours is larger than 1" at map scale (100'), then add appropriate supplemental contours from the 1FT_CONTOUR feature class. Supplemental contours do not have to be continuous but should have a minimum length of 200'.
3	Depression	Depression contours are closed contours that surround a basin or sink. They are shown by right-angle ticks placed on the contour lines, pointed inward (down slope). Fill contours are a special type of depression contours, used to indicate an area that has been filled to support a road or railway grade.	Use when appropriate.
4	Index	Index Contours are to be placed at every 5^{th} contour interval (1, 5, 10, etc…)	No special rules
5	Intermediate Low Confidence	Intermediate contours (Code 1) that are located in low confidence area should be cut	No special collection rules are necessary as this is a geo-processing task.

		to the low confidence boundary and should be reclassified to this code.	
6	Supplementary Low Confidence	Supplementary contours (Code 2) that are located in low confidence area should be cut to the low confidence boundary and should be reclassified to this code. Only the Contour_2FT feature class will have supplementary low confidence contours.	No special collection rules are necessary as this is a geo-processing task.
7	Depression Low Confidence	Depression contours (Code 3) that are located in low confidence area should be cut to the low confidence boundary and should be reclassified to this code.	No special collection rules are necessary as this is a geo-processing task.
8	Index Low Confidence	Index contours (Code 4) that are located in low confidence area should be cut to the low confidence boundary and should be reclassified to this code.	No special collection rules are necessary as this is a geo-processing task.

*Note: Contours should be as continuous as possible. With the exceptions of where contours are split at low confidence polygon boundaries due to required coding changes, tops of hills, and bottoms of depressions, contours should be greater than 200 feet in length.

2 Foot Contours

Feature Dataset: TOPOGRAPHIC **Feature Class:** CONTOUR_2FT **Feature Type:** Polyline

Contains M Values: No **Contains Z Values:** No **Annotation Subclass:** None
XY Resolution: Accept Default Setting **Z Resolution:** N/A
XY Tolerance: 0.003 **Z Tolerance:** N/A

Description

This polyline feature class will depict 2' contours modeled from the LiDAR ground points and the supplemental breaklines.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0		Assigned by Dewberry
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Dewberry
CONTOUR_TYPE_DESC	Short Integer	No	1	dCONTOURTYPE	0	0		Assigned by Dewberry
CONTOUR_ELEVATION_MS	Double	No			0	0		Calculated by Dewberry

Feature Definition

Code	Description	Definition	Capture Rules
1	Intermediate	A contour line drawn between index	They are normally continuous throughout a map,

		contours. There are four intermediate contours between the index contours.	but may be dropped or joined with an index contour where the slope is steep and where there is insufficient space to show all of the intermediate lines.
2	Supplementary	Supplementary contours are used to portray important relief features that would otherwise not be shown by the index and intermediate contours (basic contours). They are normally added only in areas of low relief, but they may also be used in rugged terrain to emphasize features. Supplementary contours are shown as screened lines so that they are distinguishable from the basic contours, yet not unduly prominent on the published map. Only the Contour_2FT feature class will have supplementary contours.	These dotted lines are placed in areas where elevation change is minimal. If there is a lot of space between Index and Intermediate Contours (as happens where the land is relatively flat), these lines are added to indicate that there *are* elevation measurements, even if they are few and far between. If the horizontal distance between two adjacent contours is larger than 1" at map scale (100'), then add appropriate supplemental contours from the 1FT_CONTOUR feature class. Supplemental contours do not have to be continuous but should have a minimum length of 200'.
3	Depression	Depression contours are closed contours that surround a basin or sink. They are shown by right-angle ticks placed on the contour lines, pointed inward (down slope). Fill contours are a special type of depression contours, used to indicate an area that has been filled to support a road or railway grade.	Use when appropriate.
4	Index	Index Contours are to be placed at every 5th contour interval (1, 5, 10, etc…)	No special rules
5	Intermediate Low Confidence	Intermediate contours (Code 1) that are located in low confidence area should be cut	No special collection rules are necessary as this is a geo-processing task.

		to the low confidence boundary and should be reclassified to this code.	
6	Supplementary Low Confidence	Supplementary contours (Code 2) that are located in low confidence area should be cut to the low confidence boundary and should be reclassified to this code. Only the Contour_2FT feature class will have supplementary low confidence contours.	No special collection rules are necessary as this is a geo-processing task.
7	Depression Low Confidence	Depression contours (Code 3) that are located in low confidence area should be cut to the low confidence boundary and should be reclassified to this code.	No special collection rules are necessary as this is a geo-processing task.
8	Index Low Confidence	Index contours (Code 4) that are located in low confidence area should be cut to the low confidence boundary and should be reclassified to this code.	No special collection rules are necessary as this is a geo-processing task.

*Note: Contours should be as continuous as possible and should not be segmented at tile boundaries. With the exceptions of where contours are split at low confidence polygon boundaries due to required coding changes, tops of hills, and bottoms of depressions, contours should be greater than 200 feet in length.

Ground Control

Feature Dataset: TOPOGRAPHIC **Feature Class:** GROUNDCONTROL
Feature Type: Point

Contains M Values: No **Contains Z Values:** Yes **Annotation Subclass:** None
XY Resolution: Accept Default Setting **Z Resolution:** Accept Default Setting
XY Tolerance: 0.003 **Z Tolerance:** 0.001

Description

This feature class depicts the points used in the acquisition and calibration of the LiDAR.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0		Assigned by Dewberry
POINTID	String	Yes					12	Assigned by Dewberry
X_COORD	Double	Yes			0	0		Assigned by Dewberry
Y_COORD	Double	Yes			0	0		Assigned by Dewberry
Z_COORD	Double	Yes			0	0		Assigned by Dewberry
DESCRIPTION	String	Yes					250	Assigned by Dewberry

Feature Definition

Code	Description	Definition	Capture Rules
1	Control Point	Primary or Secondary Dewberry control points used for either base station operations or in the calibration and adjustment of the control.	None.

Vertical Accuracy Test Points

Feature Dataset: TOPOGRAPHIC **Feature Class:** VERTACCTESTPTS **Feature Type:** Point

Contains M Values: No **Contains Z Values:** Yes **Annotation Subclass:** None
XY Resolution: Accept Default Setting **Z Resolution:** Accept Default Setting
XY Tolerance: 0.003 **Z Tolerance:** 0.001

Description

This feature class depicts the points used by Dewberry to test the vertical accuracy of the data produced.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0		Assigned by Dewberry
POINTID	String	Yes					12	Assigned by Dewberry
X_COORD	Double	Yes			0	0		Assigned by Dewberry
Y_COORD	Double	Yes			0	0		Assigned by Dewberry
Z_COORD	Double	Yes			0	0		Assigned by Dewberry
DESCRIPTION	String	Yes					250	Assigned by Dewberry
LANDCOVER	Short	No	1	dLANDCOVERTYPE	0	0		Assigned by

	Integer							Dewberry

Feature Definition

Code	Description	Definition	Capture Rules
1	Bare-Earth and Low Grass	Surveyed ground measurements used to test the accuracy of LiDAR data	None.
2	Brush Lands and Low Trees	Surveyed ground measurements used to test the accuracy of LiDAR data	None.
3	Forested Areas Fully Covered by Trees	Surveyed ground measurements used to test the accuracy of LiDAR data	None.
4	Urban Areas	Surveyed ground measurements used to test the accuracy of LiDAR data	None.

Footprint (Tile Boundaries)

Feature Dataset: TOPOGRAPHIC **Feature Class:** FOOTPRINT **Feature Type:** Polygon

Contains M Values: No **Contains Z Values:** No **Annotation Subclass:** None

XY Resolution: Accept Default Setting **Z Resolution:** Accept Default Setting

XY Tolerance: 0.003 **Z Tolerance:** 0.001

Description

This polygon feature class includes the Florida 5,000’ x 5,000’ tiles for each countywide geodatabase produced. These will be converted to meters for the database.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Dewberry
SHAPE_AREA	Double	Yes			0	0		Calculated by Dewberry
CELLNUM	String	No			0	0	8	Assigned by Dewberry

Contact Information

Any questions regarding this document should be addressed to:

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Appendix D: LiDAR Processing Report

St. Johns River Water Management District (SJRWMD) Florida LiDAR Mapping Report

Prepared for:

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Merrick & Company Job No. 02016203

EXECUTIVE SUMMARY

Early in the year of 2009, Merrick & Company (Merrick) was contracted by Representatives of Dewberry to execute a LiDAR (Light Detection And Ranging) survey located in portions of Seminole and Orange Counties in the greater Orlando area. The purpose of the project is to produce accurate, high-resolution data for planning, analysis, and for use with other data sets. Merrick obtained LiDAR data for approximately 318 square miles covering portions of Seminole and Orange counties. The LiDAR data has been processed to meet horizontal accuracy of 3.8 feet (2.2' radial RMSE) at the 95% confidence level using National Standards for Spatial Data Accuracy (NSSDA) methods and Fundamental Vertical Accuracy (FVA) of 0.6 feet (0.3' $RMSE_Z$) in open terrain.

CONTRACT INFORMATION

Questions regarding this report should be addressed to:

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Project Completion Report for SJRWMD

The contents of this report summarize the methods used to establish the GPS base station network, perform the LiDAR data collection and post-processing as well as the results of these methods for St. Johns River Water Management District (SJRWMD).

LiDAR FLIGHT and SYSTEM REPORT

Project Location

The project location for SJRWMD is defined by the shapefiles “ProjArea_02Feb2009”.

Duration/Time Period

One LiDAR aircraft, a Cessna 402C (SN35), was used to collect LiDAR Data. The Cessna 402C (SN35) arrived on site Feb. 07, 2009 and the LiDAR data collection was accomplished Feb. 08, 2009 thru Feb. 11, 2009. The Orlando Excecutive Airport (ORL) was used as the airfield of operations.

Flight Diagrams

See Below.

Mission Parameters for SJRWMD Cessna 402C (SN35)

LiDAR Sensor	Leica Geosystems ALS50 Phase 1
Nominal Ground Sample Distance	1.01 meters
Average Altitude	5500 Feet MSL
Average Airspeed	~140 Knots
Scan Rate	30 Hertz
Scan FOV (scan angle)	30˚
Pulse Rate	55,400 Hertz

Flight Mission Date and Times

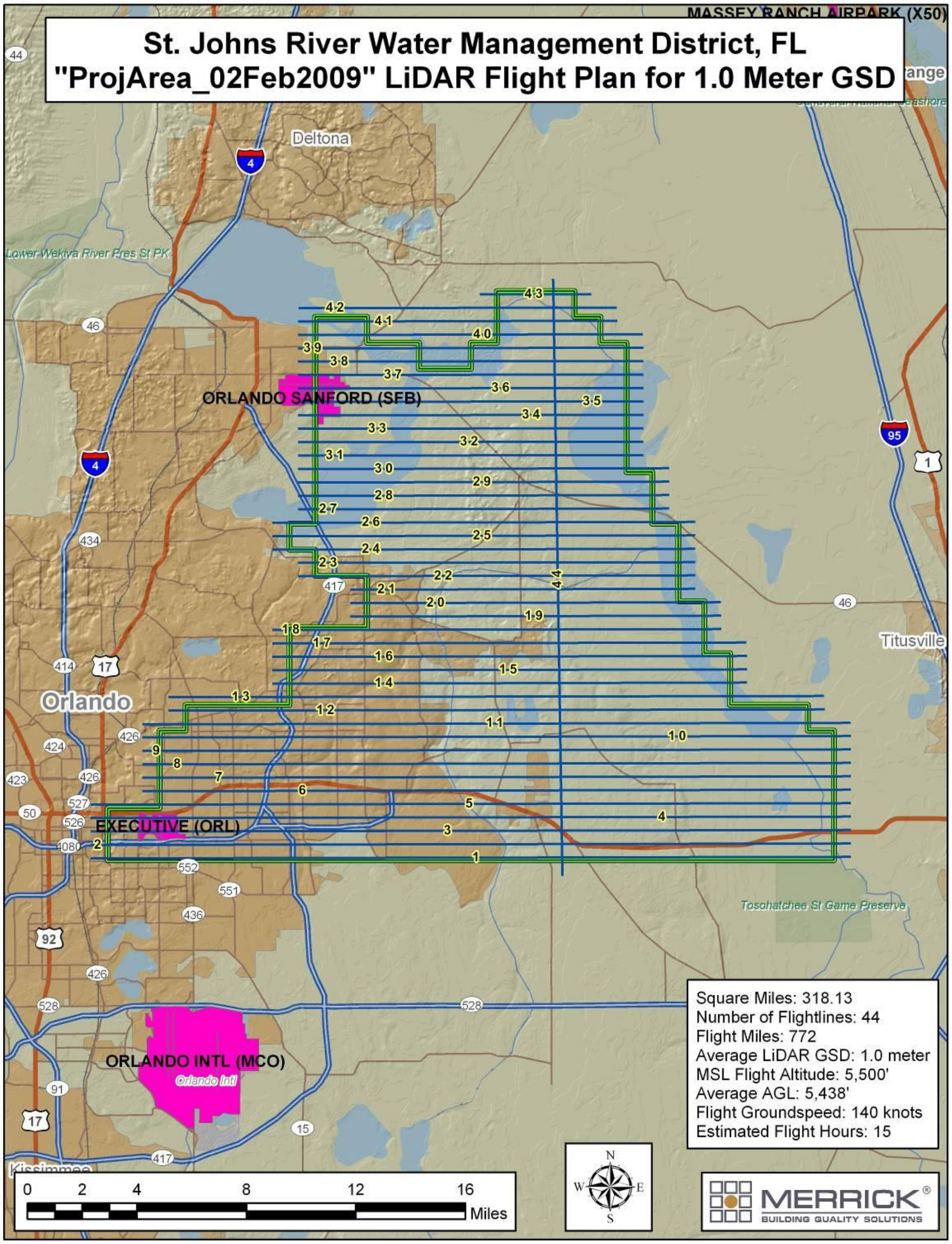
Mission	Date	Plane	Start Time	End Time	Length Time
090208_A	**Feb. 08 2009**	**SN35**	**97724 GPS sec.**	**119817 GPS sec.**	**22093 sec.**
090209_A	**Feb. 09 2009**	**SN35**	**184202 GPS sec.**	**192711 GPS sec.**	**8509 sec.**
090210_A	**Feb. 10 2009**	**SN35**	**269279 GPS sec.**	**283103 GPS sec.**	**13824 sec.**
090211_A	**Feb. 11 2009**	**SN35**	**359363 GPS sec.**	**363864 GPS sec.**	**4501 sec.**

Field Work / Procedures

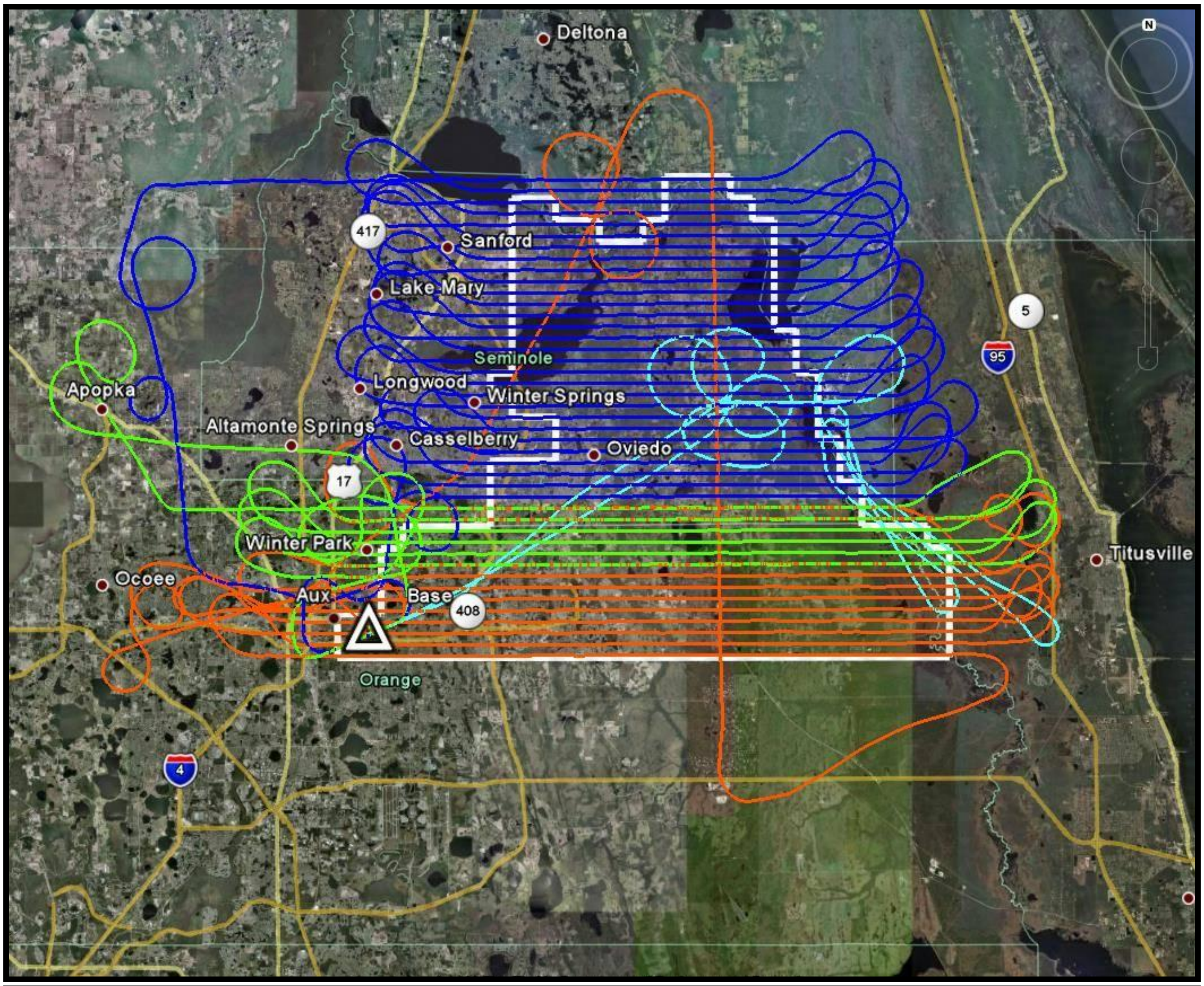
Two ground airborne GPS Base Stations, for the LiDAR data collection, were set up every mission, one main GPS receiver (Base) located at the Orlando Excecutive Airport and one auxiliary airborne GPS receiver (Aux) also located at the airport.

Pre-flight checks such as cleaning the sensor head glass are performed. A five minute INS initialization is conducted on the ground, with the aircraft engines running, prior to the flight mission. To establish fine-alignment of the INS GPS, ambiguities are resolved by flying within ten kilometers of the GPS base stations. During the data collection, the operator recorded information on log sheets which includes weather conditions, LiDAR operation parameters, and flight line statistics. Near the end of the mission, GPS ambiguities were again resolved by flying within ten kilometers of the GPS base stations to aid in post-processing. Data was sent back to the main office and preliminary data processing was performed for quality control of GPS data and to ensure sufficient overlap between flight lines. Any problematic data could then be reflown immediately as required. Final data processing was completed in the Aurora, Colorado office.

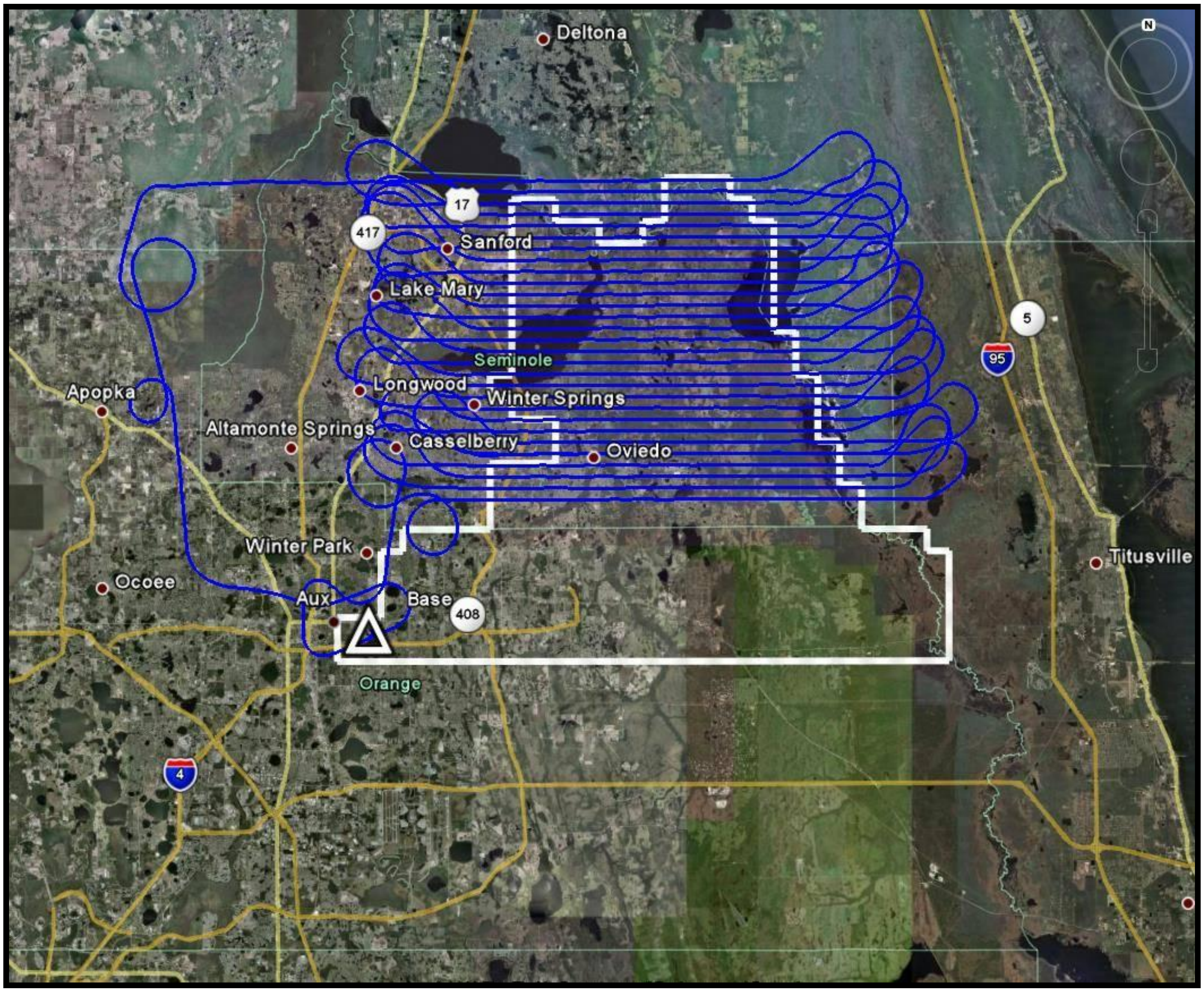
Planned Flight Line Diagram for SJRWMD



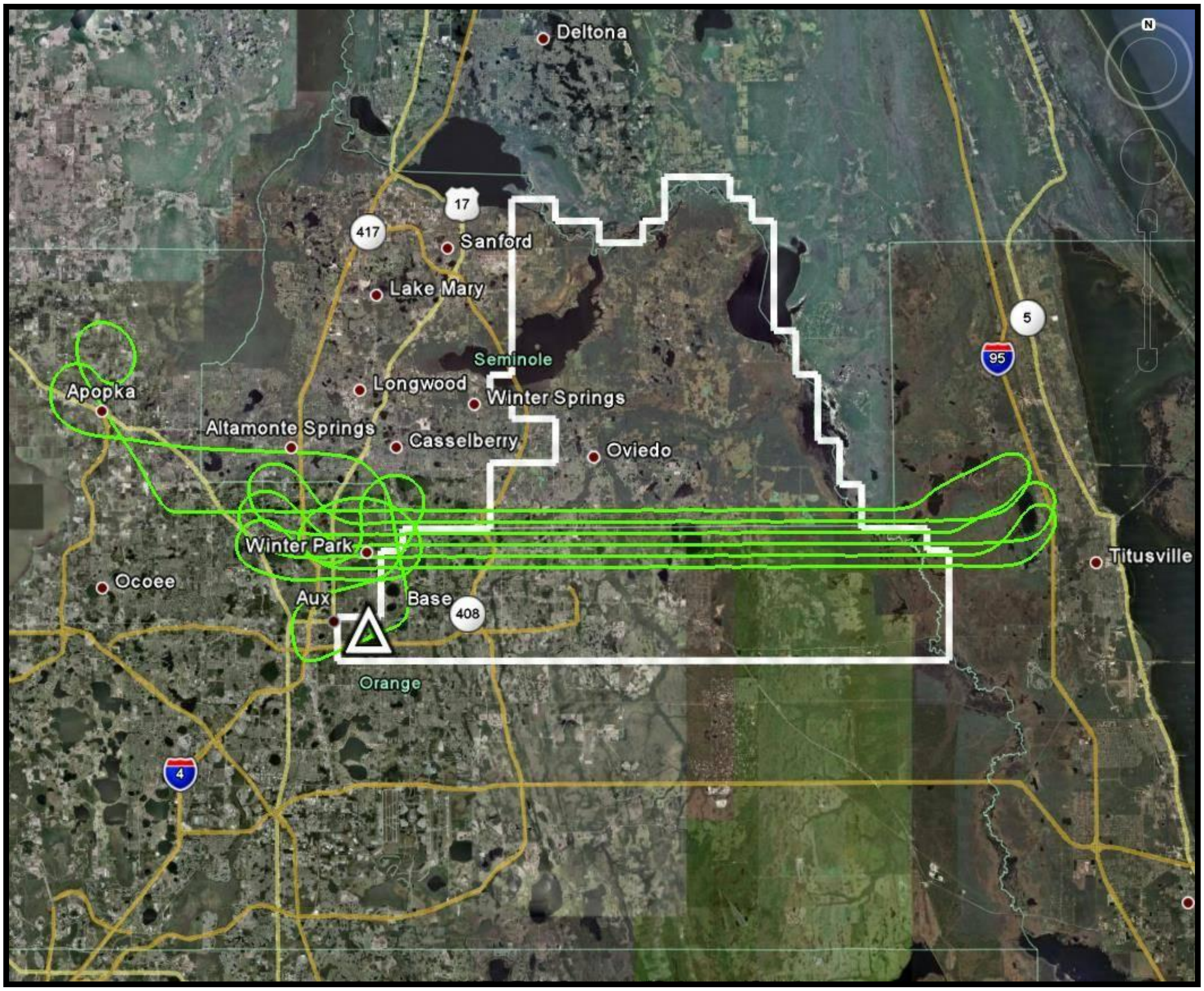
Actual Flight Lines for SJRWMD Showing Base Station Locations



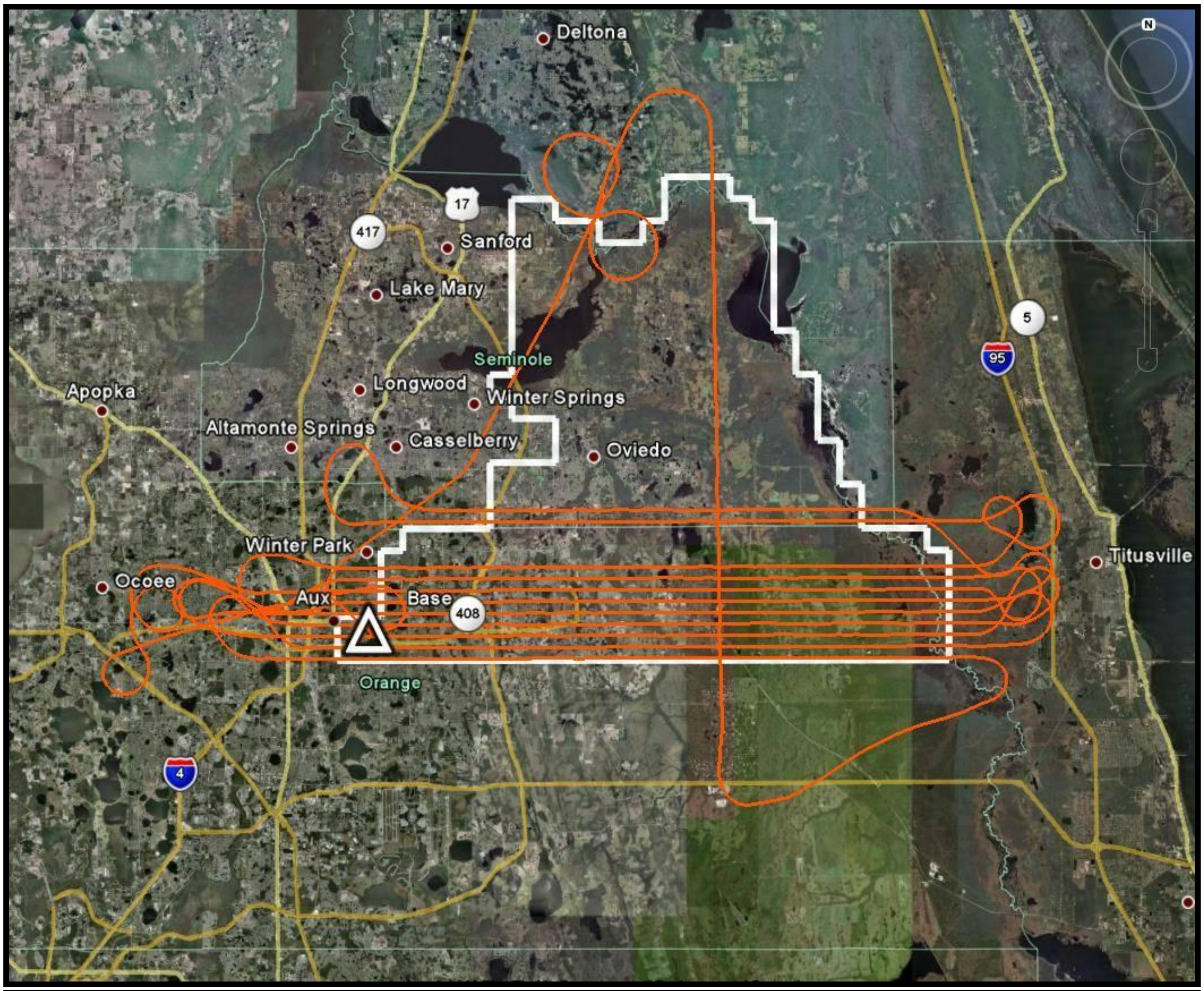
Actual Flight Lines for SJRWMD Showing Base Stations for Mission 090208_A



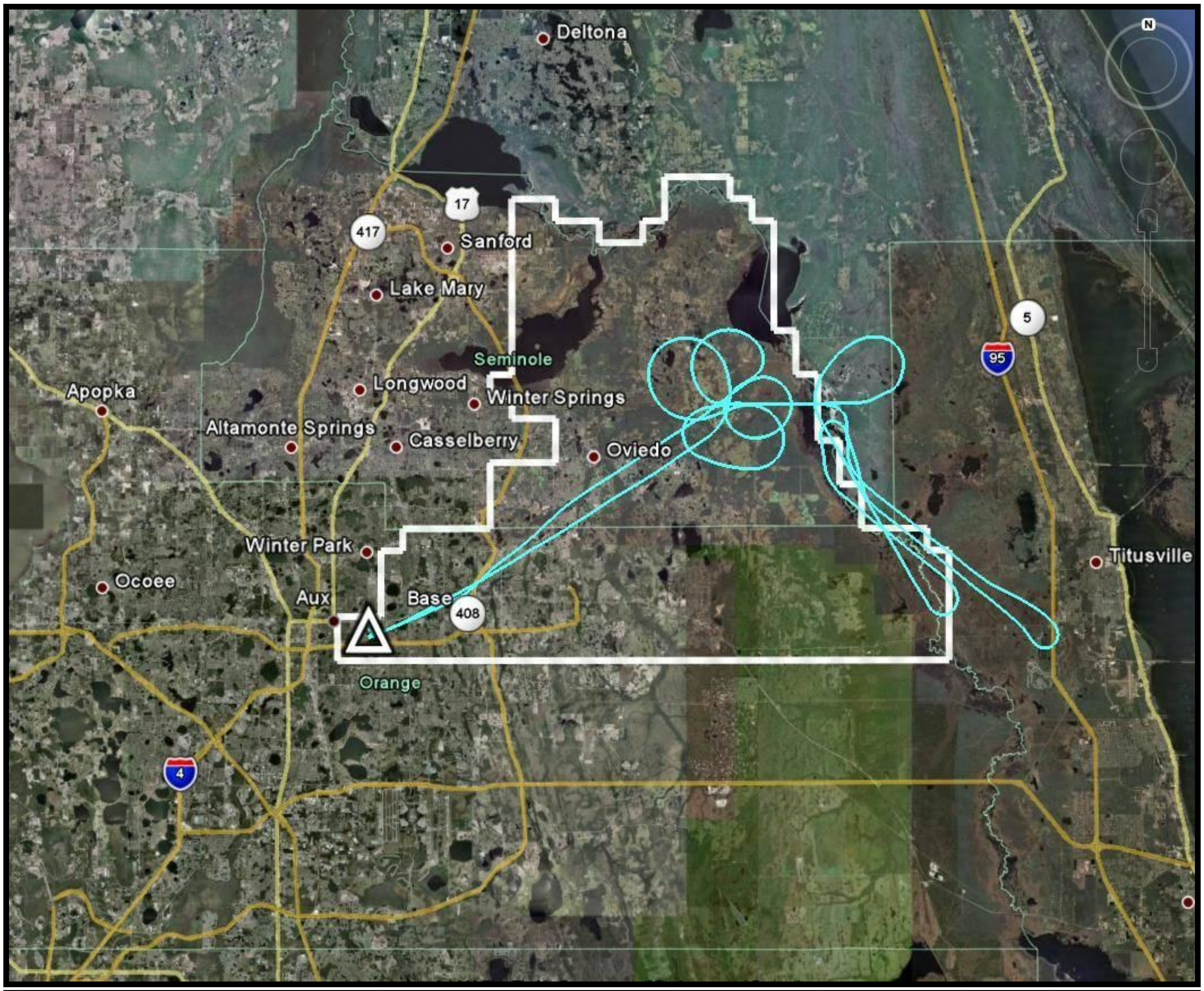
Actual Flight Lines for SJRWMD Showing Base Stations for Mission 090209_A



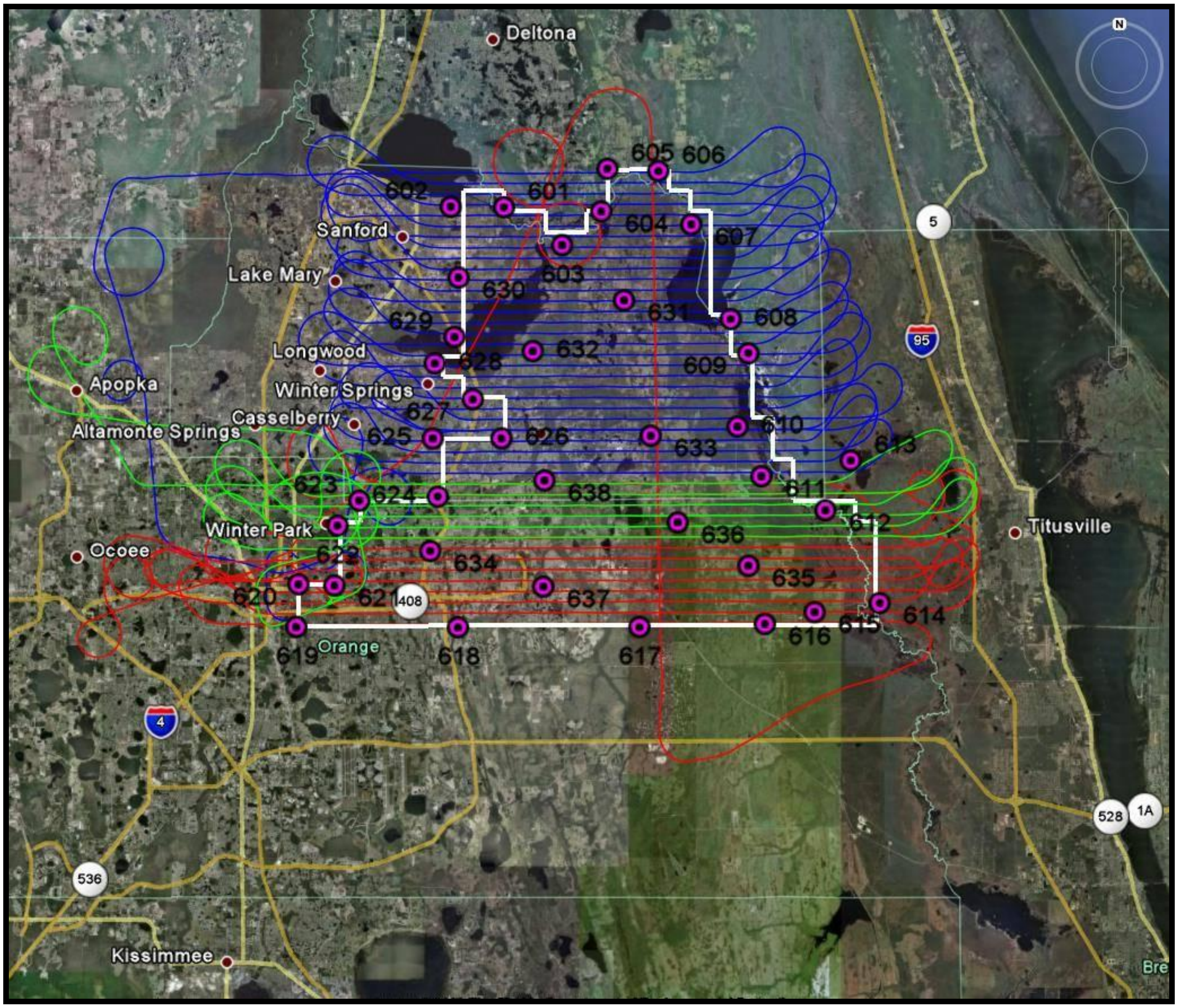
Actual Flight Lines for SJRWMD Showing Base Stations for Mission 090210_A



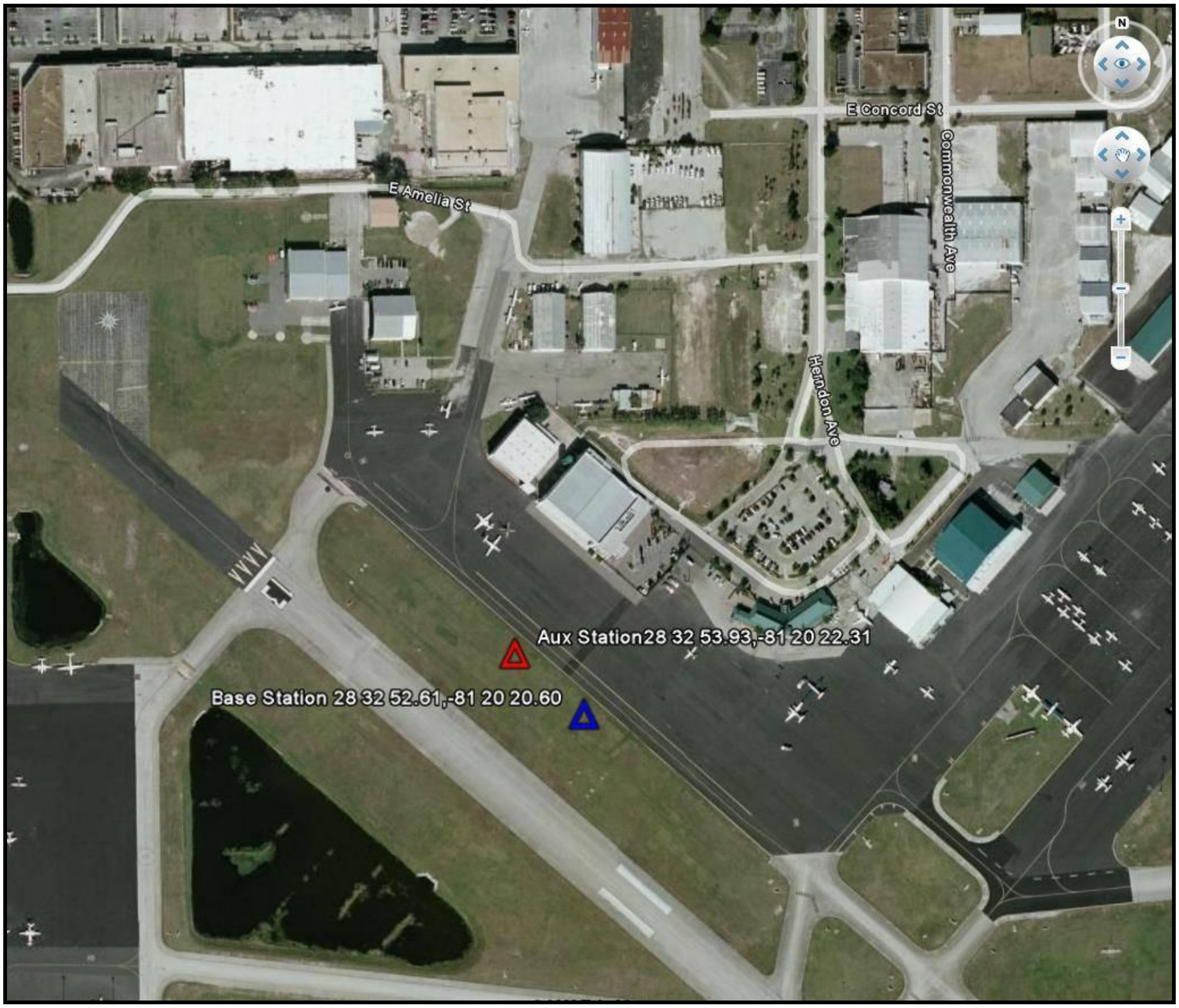
Actual Flight Lines for SJRWMD Showing Base Stations for Mission 090211_A



__Actual Flight Lines for SJRWMD Showing Ground Control__

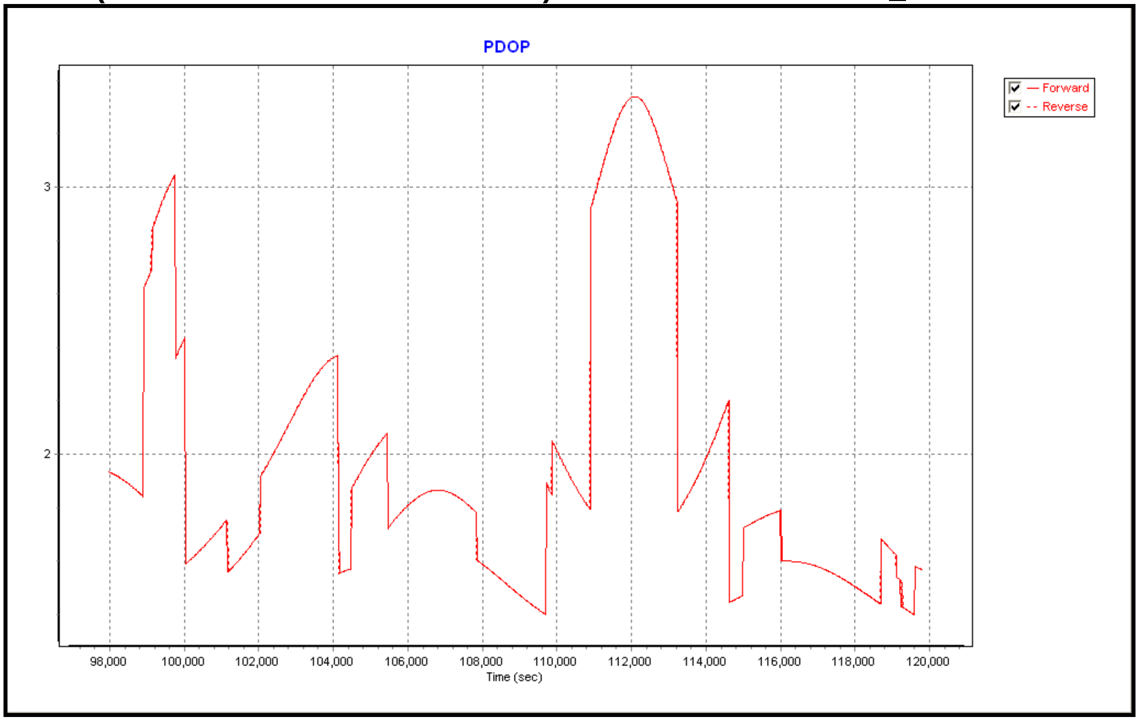


Base Station Locations

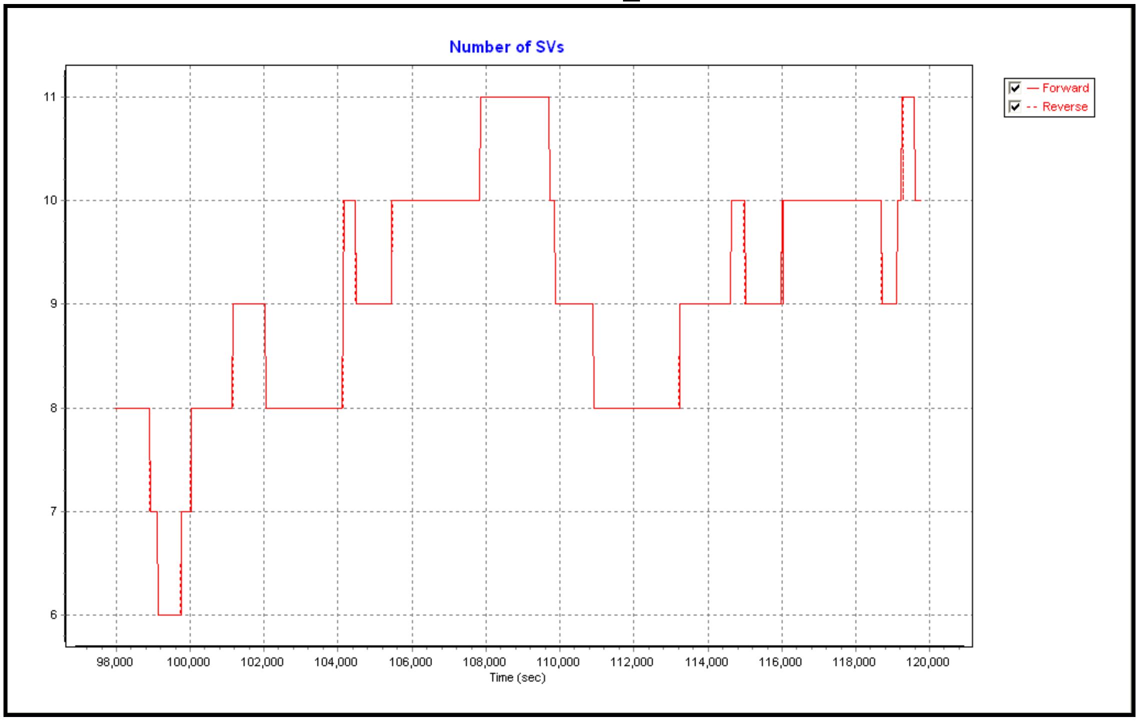


The following graphs show the mission by mission GPS PDOP (Positional Dilution Of Precision) Plots and Number of Satellites Plot.

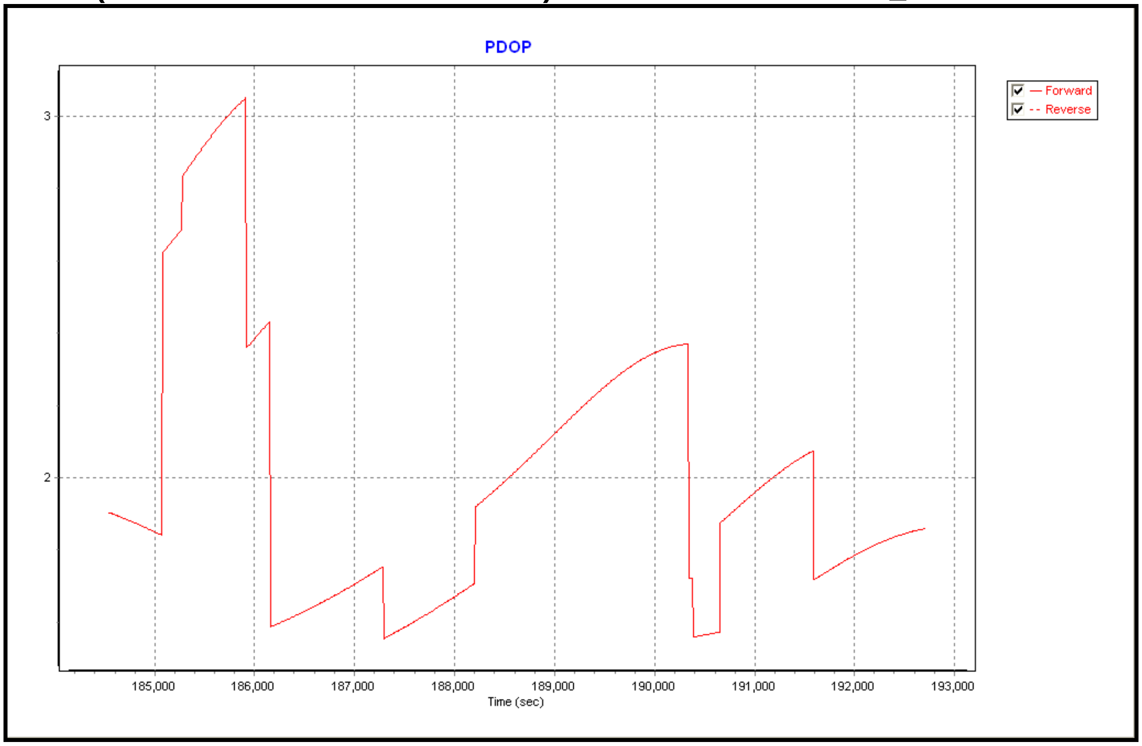
PDOP (Positional Dilution Of Precision) Plot for mission 090208_A



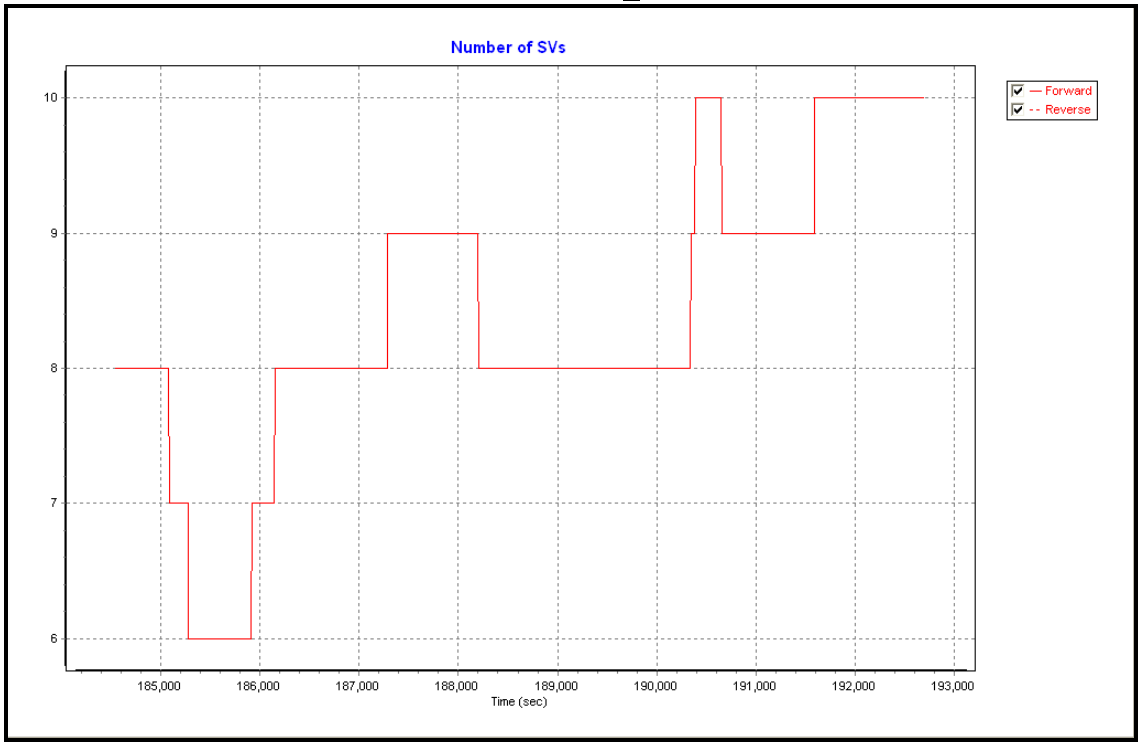
Number of Satellites Plot for mission 090208_A



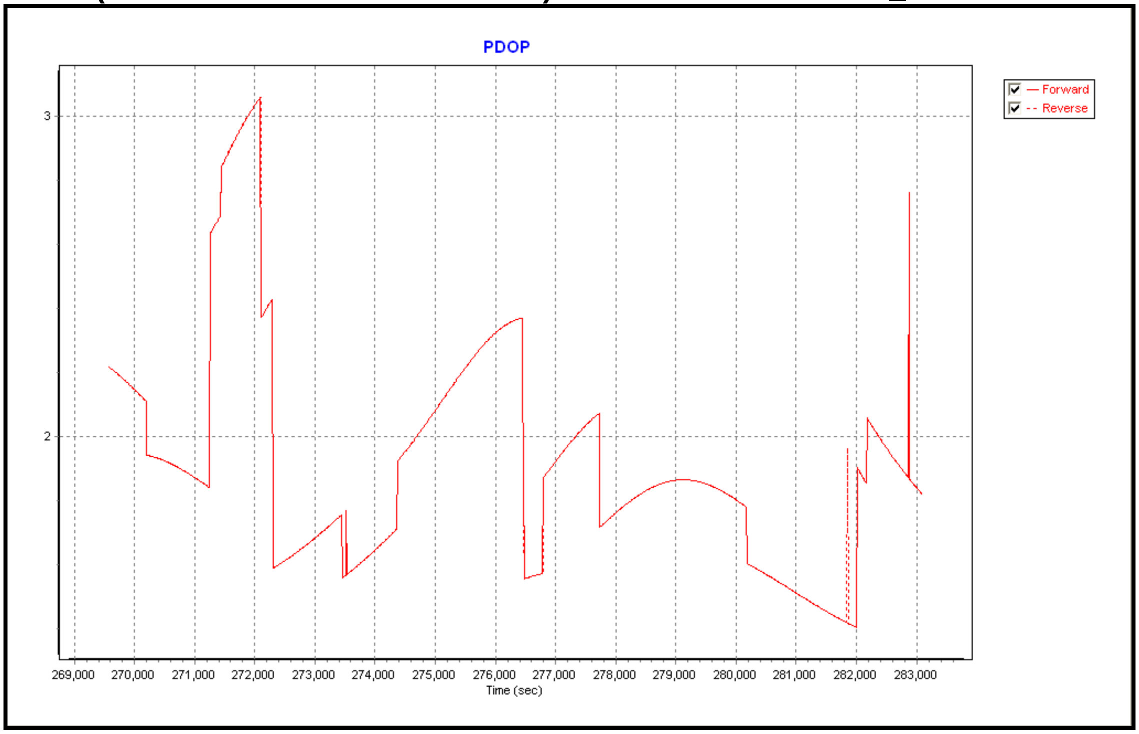
PDOP (Positional Dilution Of Precision) Plot for mission 090209_A



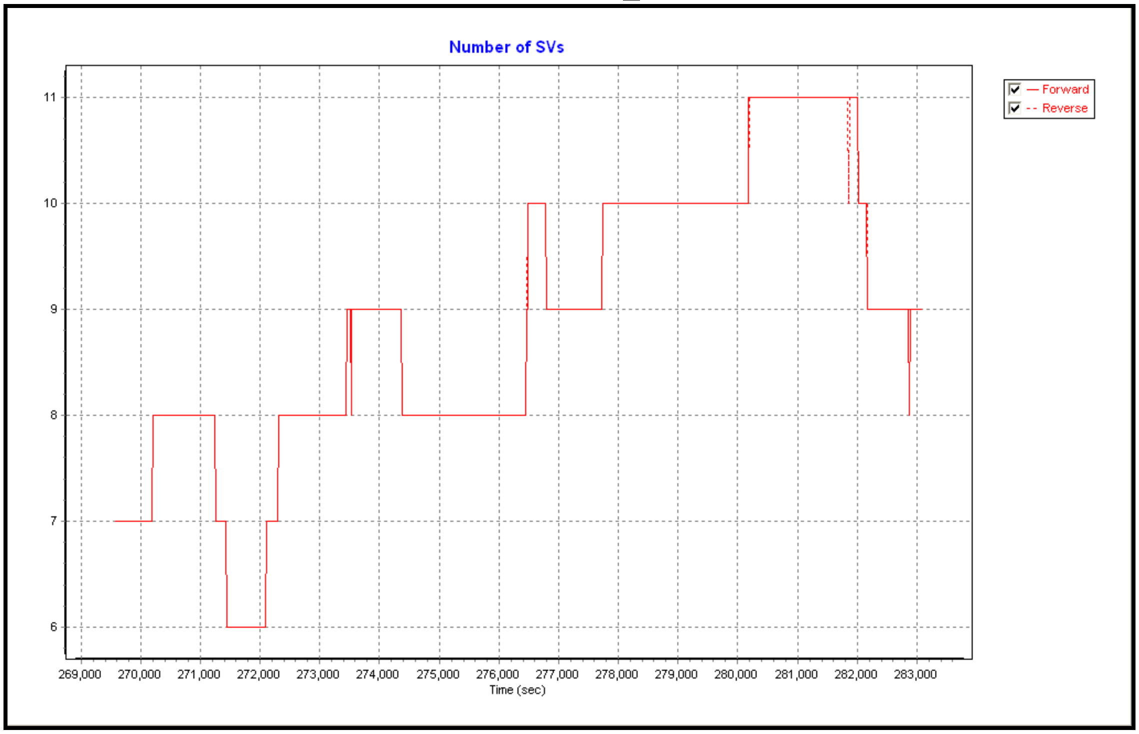
Number of Satellites Plot for mission 090209_A



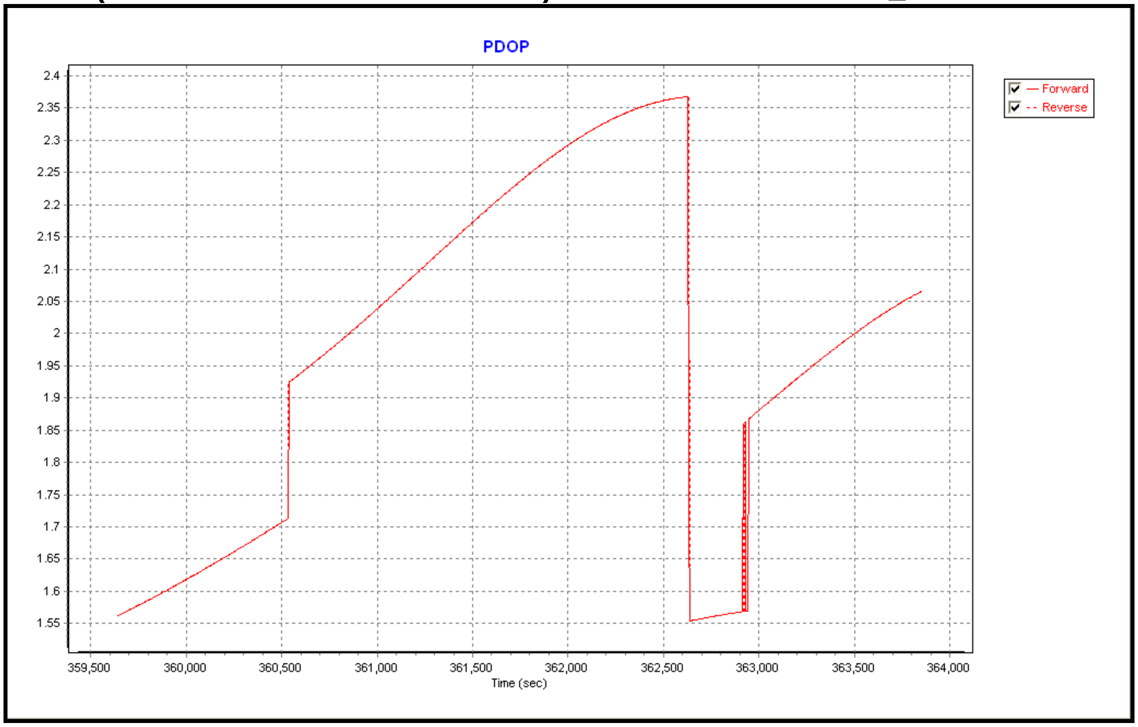
PDOP (Positional Dilution Of Precision) Plot for mission 090210_A



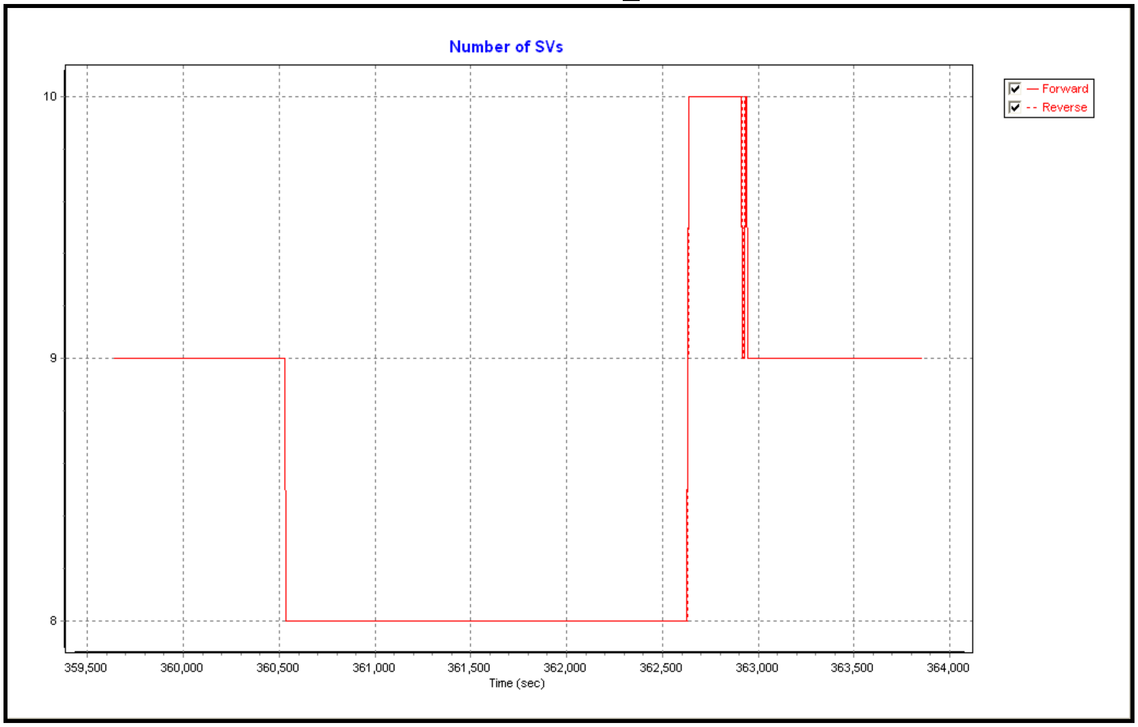
Number of Satellites Plot for mission 090210_A



PDOP (Positional Dilution Of Precision) Plot for mission 090211_A



Number of Satellites Plot for mission 090211_A



LiDAR Data Processing

The airborne GPS data was post-processed using Applanix POSPac Mobile Mapping Suite version 5.2. A fixed-bias carrier phase solution was computed in both the forward and reverse chronological directions. Whenever practical, LiDAR acquisition was limited to periods when the PDOP (Positional Dilution Of Precision) was less than 4.0. PDOP indicates satellite geometry relating to position. Generally PDOP’s of 4.0 or less result in a good solution, however PDOP’s between 4.0 and 5.0 can still yield good results most of the time. PDOP’s over 6.0 are of questionable results and PDOP’s of over 7.0 usually result in a poor solution. Usually as the number of satellites increase the PDOP decreases. Other quality control checks used for the GPS include analyzing the combined separation of the forward and reverse GPS processing from one base station and the results of the combined separation when processed from two different base stations. Basically this is the difference between the two trajectories. An analysis of the number of satellites, present during the flight and data collection times, is also performed.

The GPS trajectory was combined with the raw IMU data and post-processed using Applanix POSPac Mobile Mapping Suite version 5.2. The smoothed best estimated trajectory (SBET) and refined attitude data are then utilized in the ALS Post Processor to compute the laser point-positions – the trajectory is combined with the attitude data and laser range measurements to produce the 3-dimensional coordinates of the mass points. Up to four return values are produced within the ALS Post Processor software for each pulse which ensures the greatest chance of ground returns in a heavily forested area.

Laser point classification was completed using Merrick Advanced Remote Sensing (MARS®) LiDAR processing and modeling software. Several algorithms are used when comparing points to determine the best automatic ground solution. Each filter is built based on the projects terrain and land cover to provide a surface that is 90% free of anomalies and artifacts. After the auto filter has been completed the data sets are then reviewed by an operator utilizing MARS® to remove any other anomalies or artifacts not resolved by the automated filter process. During these final steps the operator also verifies that the datasets are consistent and complete with no data voids.

GROUND CONTROL REPORT / CHECK POINT SURVEY RESULTS

GPS Controls

Two ground airborne GPS Base Stations, for the LiDAR data collection, were set up every mission. The main airborne GPS base station (Base) was located at the Orlando Executive Airport (ORL). The auxiliary airborne GPS base station (Aux) was tied directly to the main airborne GPS base station by post processing using Trimble Geomatics Office Software version 1.63 and checked with OPUS solutions from NGS (National Geodetic Survey).

See Spreadsheet Below for Airborne GPS Base Station information.

Project: St Johns River Florida
Job#: 02016203
Date: Feb. 2009

Coordinate System: NAD83(NSRS2007) UTM17N
Zone: 17 North
Project Datum: NAD 1983(NSRS2007)
Vertical Datum: NAVD88
Units: Meters for Horizontal - USFeet for Vertical

Pt#	Geodetic NAD83		Ellipsoid	Ellipsoid	Description
Name	Latitude	Longitude	Height	Height	
	North	West	Geoid03	Geoid03	
	Deg Min Sec	Deg Min Sec	Meters	USFeet	
Base	28°32'52.60551"N	81°20'20.59643"W	3.549	11.64	Main Base
Aux	28°32'53.93266"N	81°20'22.30879"W	3.541	11.62	Aux Base

Pt#	NAD83 UTM17N		NAVD88	NAVD88	Description
Name	Northing	Easting	Elevation	Elevation	
	Y	X	Z	Z	
	Meters	Meters	Meters	USFeet	
Base	**3157950.481**	**466833.345**	31.254	**102.54**	Main Base
Aux	**3157991.454**	**466786.931**	31.245	**102.51**	Aux Base

Ground Control Parameters

Horizontal Datum: The horizontal datum for the project is North American Datum of 1983 (NAD 83) NSRS2007.

Coordinate System: Universal Transverse Mercator (UTM), Zone 17 North

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

Geiod Model: Geoid03 (Geoid 03 will be used to convert ellipsoid heights to orthometric heights).

Units: Horizontal units are in Meters, Vertical units are in US Survey Feet.

Ground Survey Control Report

The following listing shows the newly established GPS ground control, collected for LiDAR check points. The new ground control points (checkpoints) were established and surveyed by Degrove Surveyors, Inc. for Dewberry.

Point	North Meters UTM17	East Meters UTM17	Elev Meters NAVD88	North USF UTM17	East USF UTM17	Elev USF NAVD88
601	3186654.944	479912.961	0.463	10454883.762	1574514.438	1.520
602	3186699.841	475972.135	2.047	10455031.060	1561585.246	6.715
603	3183861.295	484200.992	3.787	10445718.264	1588582.754	12.426
604	3186346.580	487104.638	3.872	10453872.069	1598109.133	12.703
605	3189480.683	487560.950	7.866	10464154.539	1599606.215	25.808
606	3189316.065	491326.349	2.754	10463614.455	1611959.862	9.036
607	3185375.279	493747.214	3.773	10450685.393	1619902.316	12.380
608	3178400.469	496650.147	3.684	10427802.204	1629426.355	12.088
609	3175880.538	497950.182	1.337	10419534.730	1633691.555	4.388
610	3170494.618	497139.788	0.741	10401864.424	1631032.786	2.430
611	3166843.220	498898.931	2.263	10389884.798	1636804.243	7.426
612	3164331.194	503626.087	2.076	10381643.259	1652313.254	6.812
613	3167991.121	505504.782	2.829	10393650.868	1658476.937	9.280
614	3157499.565	507618.899	2.096	10359229.821	1665413.004	6.876
615	3156847.143	502815.158	2.496	10357089.335	1649652.731	8.189
616	3155982.812	499137.310	15.149	10354253.607	1637586.324	49.703
617	3155777.409	489877.461	19.028	10353579.716	1607206.303	62.429
618	3155777.587	476470.631	23.311	10353580.300	1563220.728	76.480
619	3155817.209	464523.414	23.446	10353710.291	1524023.899	76.923
620	3158952.289	464680.910	32.074	10363995.968	1524540.619	105.231
621	3158858.622	467344.822	35.609	10363688.661	1533280.470	116.827
622	3163259.500	467583.111	27.718	10378127.208	1534062.257	90.939
623	3165091.846	469195.349	25.344	10384138.830	1539351.741	83.149
624	3165378.079	474996.963	19.399	10385077.912	1558385.869	63.645
625	3169656.254	474628.391	17.737	10399113.893	1557176.646	58.194
626	3169654.543	479706.251	18.456	10399108.280	1573836.258	60.550
627	3172538.828	477589.375	15.526	10408571.136	1566891.139	50.939
628	3175178.517	474783.925	7.807	10417231.518	1557686.927	25.613
629	3177122.466	476239.899	0.798	10423609.289	1562463.735	2.618
630	3181493.343	476553.301	10.558	10437949.409	1563491.955	34.638
631	3179790.985	488770.621	18.650	10432364.257	1603574.944	61.189
632	3176070.419	482025.893	3.228	10420157.698	1581446.615	10.592
633	3169833.264	490726.965	13.231	10399694.634	1609993.383	43.409
634	3161381.792	474424.103	17.140	10371966.761	1556506.411	56.233
635	3160258.583	497930.216	11.691	10368281.701	1633626.050	38.356
636	3163455.711	492712.224	17.078	10378770.943	1616506.688	56.031
637	3158752.884	482774.147	19.941	10363341.752	1583901.512	65.423
638	3166552.603	482872.731	16.976	10388931.332	1584224.951	55.696

LiDAR Control Report

The following listing shows the results of the LiDAR data compared to the GPS ground survey control data. The listing is sorted by the **Z Error** column showing, in ascending order, the vertical difference between the LiDAR points and the surveyed ground control points.

Hand-filter Control Report for SJRWMD

Project File: Hand Filter QC SJRWMD Florida

Date: Apr: 2009

Vertical Accuracy Objective

Requirement Type: Accuracy(z

Accuracy(z) Objective: 1

Confidence Level: 95%

Control Points in Report: 38

Elevation Calculation Method: Interpolated from TIN

Control Points with LiDAR Coverage: 33

Control Points with Required Accuracy (+/- 1.00): 33

Percent of Control Points with Required Accuracy (+/- 1.00): 100

Average Control Error Reported: -0.03

Maximum (highest) Control Error Reported: 0.46

Median Control Error Reported: 0

Minimum (lowest) Control Error Reported: -0.47

Standard deviation (sigma) of Z for sample: 0.25

RMSE of Z for sample (RMSE(z)): 0.25: PASS

FGDC/NSSDA Vertical Accuracy (Accuracy(z)): 0.49: PASS

NSSDA Achievable Contour Interval: 0.9

ASPRS Class 1 Achievable Contour Interval: 0.8

NMAS Achievable Contour Interval: 0.9

Control	Control Pt.	Control Pt.	Coverage	Control Pt.	from LiDAR	Z Error	Min Z	Median Z	Max Z
Point Id	X(East)	Y(North)		Z(Elev)	Z(Elev)				
	USFeet	USFeet		USFeet	USFeet	USFeet	USFeet	USFeet	USFeet
627	1566891.14	10408571.14	Yes	50.94	50.47	-0.47	50.28	50.30	50.48
622	1534062.26	10378127.21	Yes	90.94	90.48	-0.46	90.37	90.55	90.55
625	1557176.65	10399113.89	Yes	58.19	57.75	-0.45	57.66	57.75	57.88
626	1573836.26	10399108.28	Yes	60.55	60.16	-0.39	60.09	60.11	60.42
637	1583901.51	10363341.75	Yes	65.42	65.13	-0.30	65.09	65.11	65.17
608	1629426.36	10427802.20	Yes	12.09	11.80	-0.29	11.57	11.65	11.88
621	1533280.47	10363688.66	Yes	116.83	116.58	-0.25	116.51	116.58	116.59
632	1581446.62	10420157.70	Yes	10.59	10.37	-0.22	10.21	10.42	10.55
620	1524540.62	10363995.97	Yes	105.23	105.02	-0.21	104.99	105.00	105.07
634	1556506.41	10371966.76	Yes	56.23	56.07	-0.17	55.92	56.02	56.20
603	1588582.75	10445718.26	Yes	12.43	12.28	-0.15	12.26	12.27	12.31

605	1599606.22	10464154.54	Yes	25.81	25.66	-0.15	25.49	25.66	25.75
638	1584224.95	10388931.33	Yes	55.70	55.58	-0.11	55.56	55.58	55.66
633	1609993.38	10399694.63	Yes	43.41	43.30	-0.11	43.28	43.29	43.33
636	1616506.69	10378770.94	Yes	56.03	55.93	-0.10	55.92	55.95	55.95
635	1633626.05	10368281.70	Yes	38.36	38.29	-0.06	38.18	38.45	38.46
616	1637586.32	10354253.61	Yes	49.70	49.70	0.00	49.64	49.75	49.77
611	1636804.24	10389884.80	Yes	7.43	7.44	0.01	7.22	7.36	7.53
628	1557686.93	10417231.52	Yes	25.61	25.67	0.06	25.57	25.61	25.79
609	1633691.55	10419534.73	Yes	4.39	4.45	0.06	4.38	4.49	4.62
607	1619902.32	10450685.39	Yes	12.38	12.46	0.08	12.33	12.45	12.48
604	1598109.13	10453872.07	Yes	12.70	12.78	0.08	12.59	12.75	12.85
612	1652313.25	10381643.26	Yes	6.81	6.90	0.09	6.79	7.02	7.09
631	1603574.94	10432364.26	Yes	61.19	61.29	0.10	60.90	61.08	61.33
617	1607206.30	10353579.72	Yes	62.43	62.59	0.16	62.40	62.50	62.65
618	1563220.73	10353580.30	Yes	76.48	76.67	0.19	76.66	76.72	77.15
623	1539351.74	10384138.83	Yes	83.15	83.37	0.22	83.34	83.36	83.43
615	1649652.73	10357089.34	Yes	8.19	8.45	0.26	8.15	8.64	8.65
619	1524023.90	10353710.29	Yes	76.92	77.21	0.29	77.15	77.30	77.47
629	1562463.74	10423609.29	Yes	2.62	2.91	0.29	2.75	3.03	3.06
610	1631032.79	10401864.42	Yes	2.43	2.74	0.31	2.73	2.77	2.81
606	1611959.86	10463614.46	Yes	9.04	9.39	0.36	9.20	9.41	9.47
601	1574514.44	10454883.76	Yes	1.52	1.98	0.46	1.93	1.96	2.00
613	1658476.94	10393650.87	No	9.28					
630	1563491.96	10437949.41	No	34.64					
624	1558385.87	10385077.91	No	63.65					
614	1665413.00	10359229.82	No	6.88					
602	1561585.25	10455031.06	No	6.71					

LiDAR CALIBRATION

Introduction

A LiDAR calibration or 'boresight' is performed on every mission to determine and eliminate systemic biases that occur within the hardware of the Leica ALS50 laser scanning system, the inertial measurement unit (IMU), and because of environmental conditions which affect the refraction of light. The systemic biases that are corrected for include roll, pitch, and heading.

Calibration Procedures

In order to correct the error in the data, misalignments of features in the overlap areas of the LiDAR flightlines must be detected and measured. At some point within the mission, a specific flight pattern must be flown which shows all the misalignments that can be present. Typically, Merrick flies a pattern of at least three opposing direction and overlapping lines, three of which provide all the information required to calibrate the system.

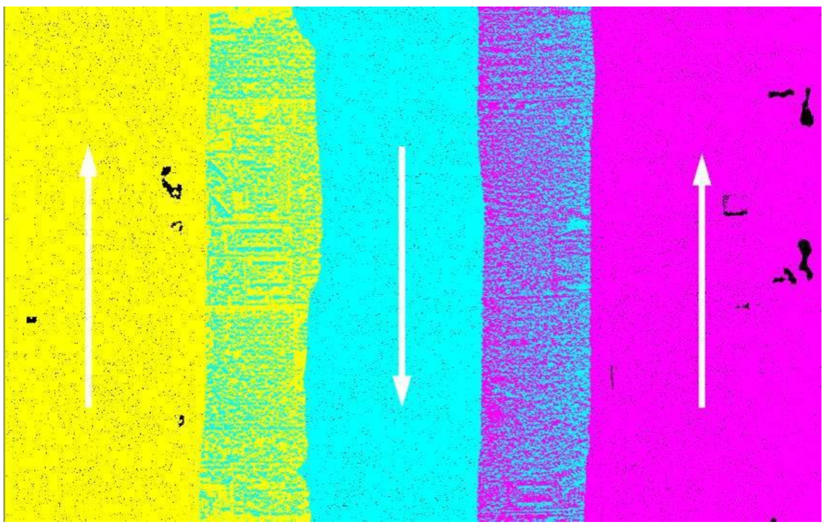


Figure 1: Flight pattern required for calibration

Correcting for Pitch and Heading Biases

There are many settings in the ALS40/50 post processor that can be used to manipulate the data; six are used for boresighting. They are roll, pitch, heading, torsion, range and atmospheric correction. The order in which each is evaluated is not very important and may be left to the discretion of the operator. For this discussion, pitch and heading will be evaluated first. It is important to remember that combinations of error can be very confusing, and this is especially true with pitch and heading. They affect the data in similar ways, so error attributed to pitch may be better blamed on heading and vice versa. To see a pitch/heading error, one must use the profile tool to cut along the flight path at a pitched roof or any elevation feature that is perpendicular to the flight path. View the data by elevation to locate these scenarios.

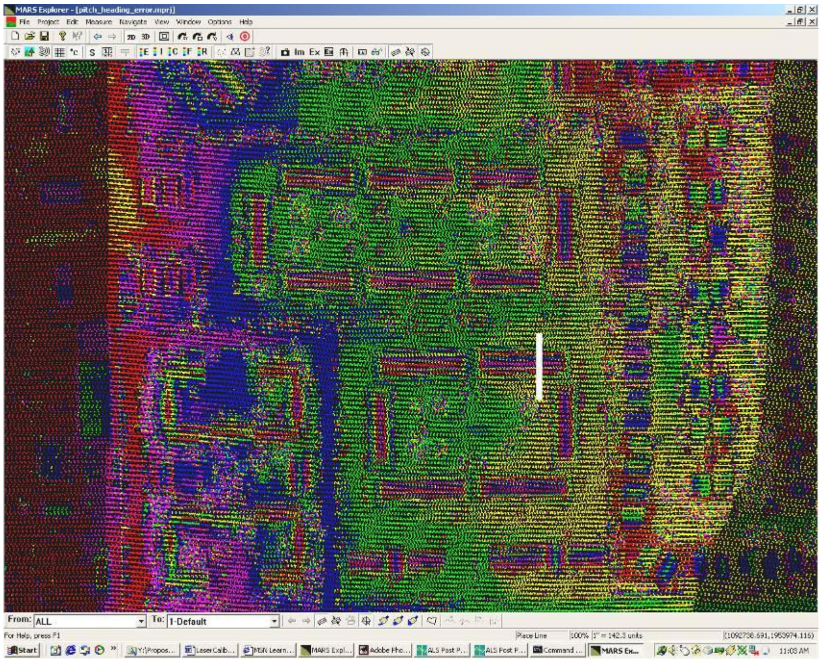


Figure 2: Orthographic view with profile line

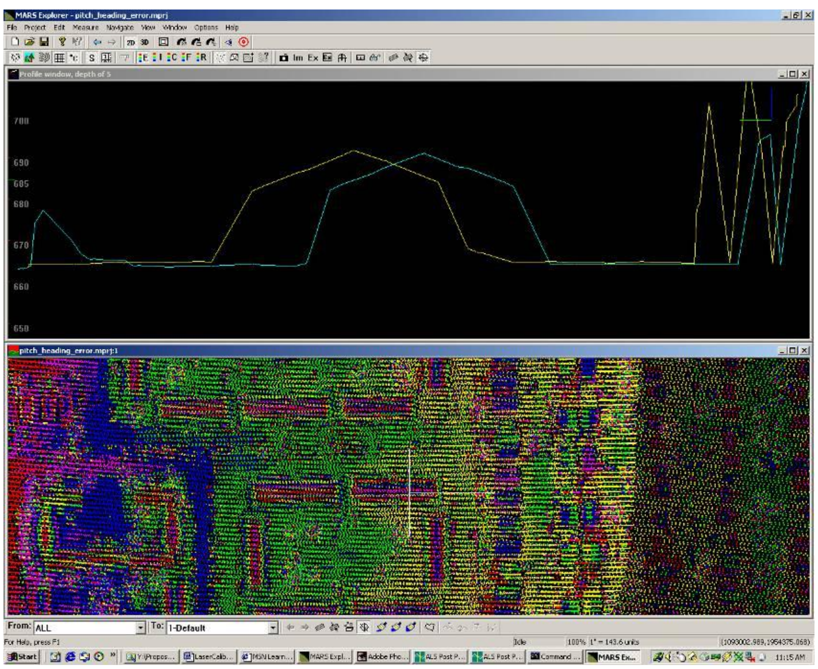


Figure 3: Profile view of misalignment

The profile line in Figures 2 and 3 has an additional thin line perpendicular to the cut that shows the direction of the view. In this case, the line is pointing to the right, or east. In the profile window, we are looking through two separate TINs, so there are two lines showing the location of the same building. The yellow line is from the flight line on the left (flown north); the light blue line is from the flight line in the middle (flown south).

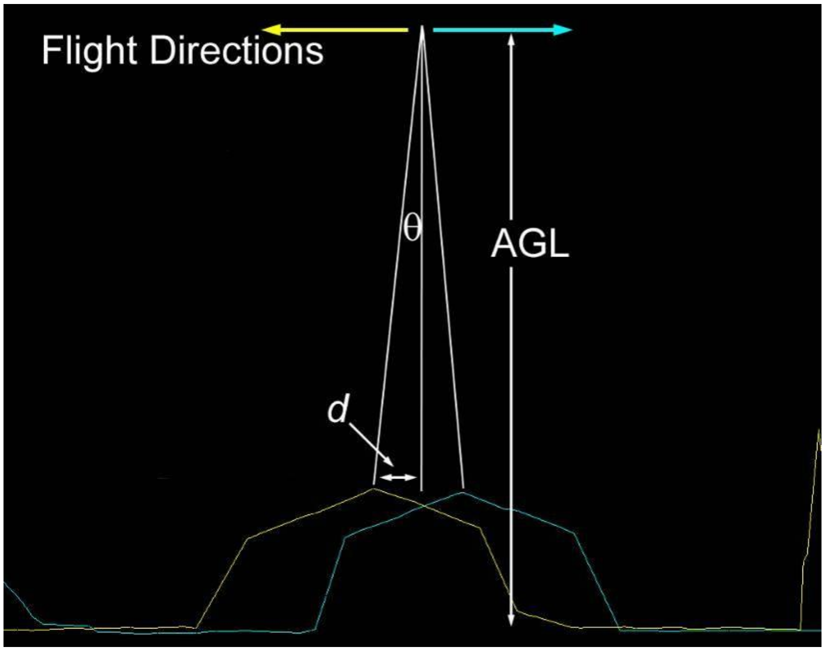


Figure 4: Adjusting pitch

The top arrows represent each respective flight direction. We are looking east, the yellow flight line was flown north, and the blue line is flown south. Adjusting pitch changes the relationship between the pitch from the IMU and the actual pitch of the plane. Increasing pitch sends the nose of the plane up and the data ahead in the flight direction. Lowering pitch does the opposite. In this example, pitch needs to decrease in order to bring these two roof lines together. The angle thetạ must be expressed in radians. The formula to arrive at this angle is…

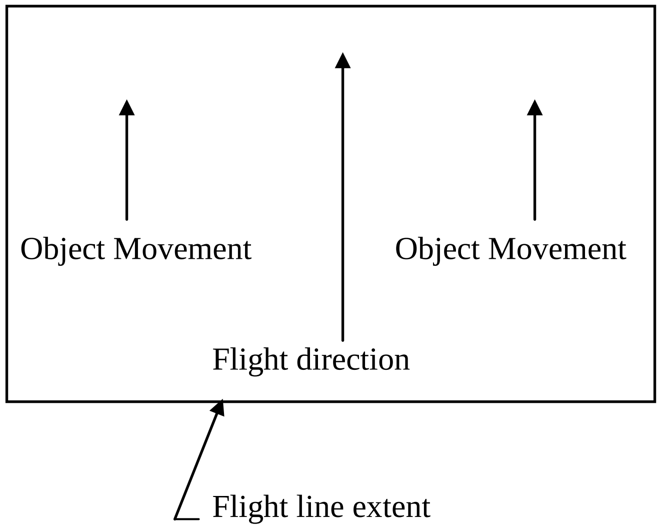
$$\theta = \frac{\arctan\left(\frac{d}{AGL}\right)}{57.2958}$$

where *d* is the distance from nadir (directly under the plane) to the peak of the roof and AGL is the 'above ground level' of the plane. The conversion from degrees to radians is one radian equals 57.2958 degrees. This number is then subtracted from the pitch value that was used to create the data.

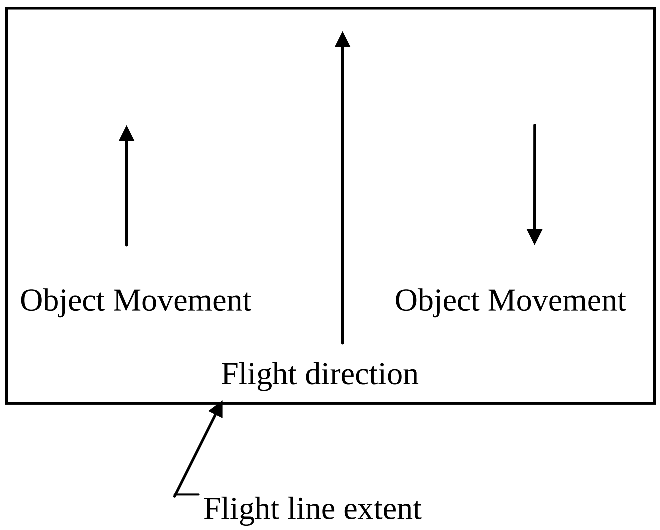
The next issue to resolve, before actually changing the pitch value, is to determine if this shift is at all due to an incorrect heading value, since heading will move data in the direction of flight also. The difference is that heading rotates the data, meaning that when heading is changed, objects on opposite sides of the swath move in opposite directions.

Figures 5 and 6: Pitch and Heading movement.

Pitch increases, objects throughout the data move forward.



Heading increases, objects move clockwise.



When heading changes, objects on the sides of the flight line move in opposite directions. If heading is increased, objects in the flight line move in a clockwise direction. If heading is decreased, objects move in a counter-clockwise direction.

To find out if heading is correct, a similar profile line must be made in the overlap area between the middle flight line and the one to the east, or right side. If the distance *d* (see Figure 4) is different on the right verses the left, then heading is partially responsible for the error. If the distance *d* is the same on both sides then heading *or* pitch is fully responsible.

Correcting for the Roll Bias

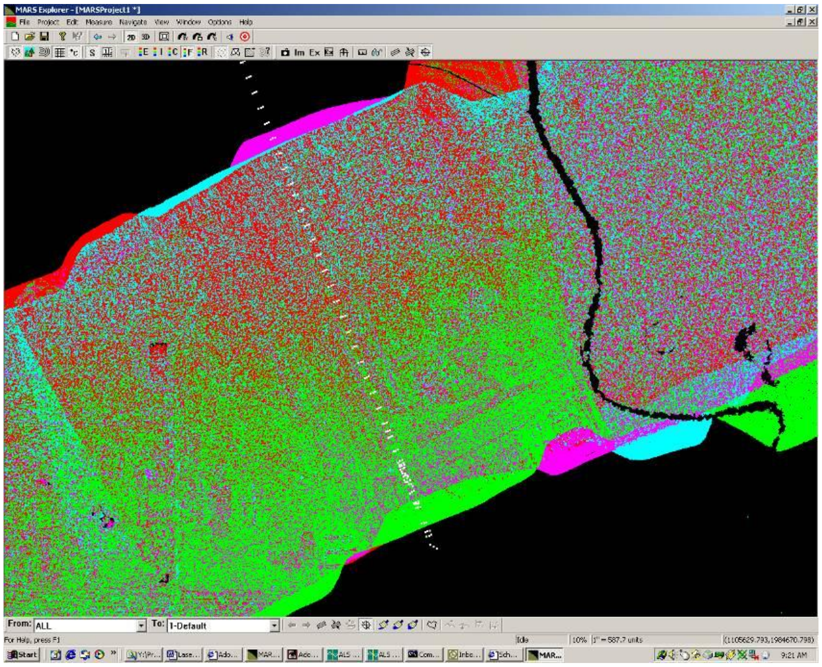


Figure 7: The truth survey

Each pair of flight lines was flown in opposite directions, and in this case the red and blue lines were flown east and the green and magenta lines were flown west. The first step is to make a profile line across the survey. Once the profile is created, exaggeration of the elevation by 100 times is necessary to see the pattern. (Figure 8)

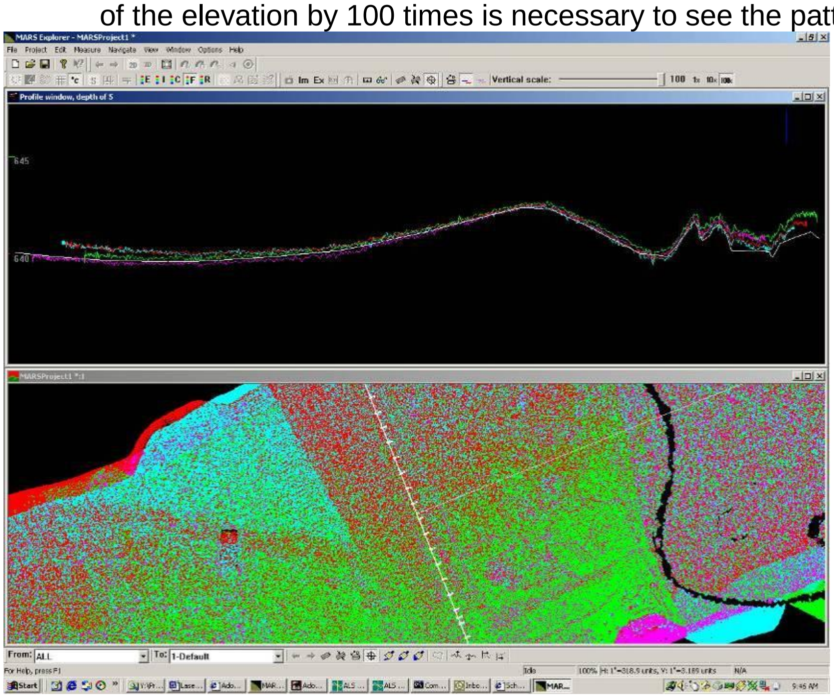


Figure 8: Profile view of calibration flight lines

Even without zooming in, a pattern is already apparent. The two east flown lines, red and blue, are high on the left compared to the west flown lines, and low on the right.

Since the profile line was created with the view eastward, it is easiest to think about what the east lines are doing. The east lines are low on the right, which means the relationship between the IMU and the right wing of the plane must be adjusted up. As in heading adjustments, sending the data in a clockwise direction is positive. If the axis of the clock is the tail/nose axis of the plane, then it is obvious this data must go in a counter clock-wise, or negative direction. The method for determining the magnitude of the adjustment is similar to determining the magnitude of the adjustment for the pitch. The only difference is how the triangles are drawn in relationship to the data. (Figures 9 and 10)

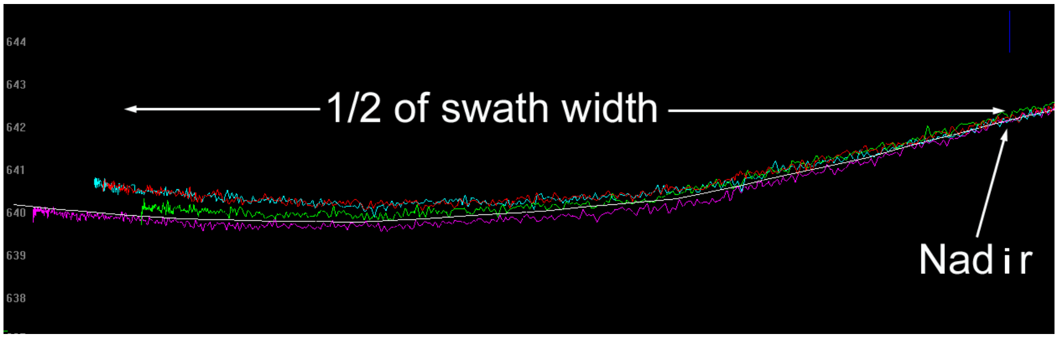


Figure 9: Half of calibration profile

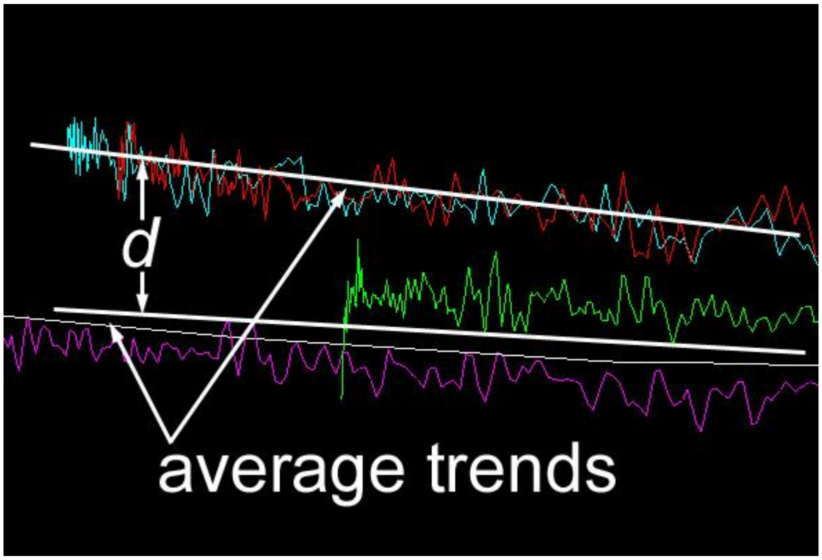


Figure 10: Differences in average roll trends

The important measurements for this formula are the distance from nadir to the edge of the swath, or ½ swath width, and d, the distance from the two average trend lines for each group. Since any adjustments made to roll effect both east and west lines, we are really interested in ½ d; this will give the value that will bring both sets of lines together. The formula is:

$$\theta = \frac{\arctan\left(\dfrac{d/2}{EdgeToNadir}\right)}{57.2958}$$

Correcting the Final Elevation

The next step is to ensure that all missions have the same vertical offset. Two techniques are used to achieve this. The first is to compare all calibration flight lines and shift the missions appropriately. The second is to fly an extra ‘cross flight’ which touches all flight lines in the project. Each mission’s vertical differences can then be analyzed and corrected. However, the result of this exercise is only proof of a high level of relative accuracy. Since many of the calibration techniques affect elevation, project wide GPS control must be utilized to place the surface in the correct location. This can be achieved by utilizing the elevation offset control in the post processor or by shifting the data appropriately in MARS®. The control network may be pre-existing or collected by a licensed surveyor. This is always the last step and is the only way to achieve the high absolute accuracy that is the overall goal.

<u>Data Collection and Contour Generation</u>

Drainage Breaklines

Merrick uses a methodology that directly interacts with the LiDAR bare-earth data to collect drainage breaklines. To determine the alignment of a drainageway, the technician first views the area as a TIN of bare-earth points using a color ramp to depict varying elevations. In areas of extremely flat terrain, the technician may need to determine the direction of flow based on measuring LiDAR bare-earth points at each end of the drain. The operator will then use the color ramped TIN to digitize the drainage centerline in 2D with the elevation being attributed directly from the bare-earth .LAS data. Merrick's proprietary MARS® software has the capability of "flipping" views between the TIN and ortho imagery, as necessary, to further assist in the determination of the drainage centerline. All drainage breaklines are collected in a downhill direction. For each point collected, the software uses a 5' search radius to identify the lowest point within that proximity. Within each radius, if a bare-earth point is not found that is lower than the previous point, the elevation for subsequent point remains the same as the previous point. This forces the drain to always flow in a downhill direction. Waterbodies that are embedded along a drainageway are validated to ensure consistency with the downhill direction of flow.

This methodology may differ from those of other vendors in that Merrick relies on the bare-earth data to attribute breakline elevations. As a result of our methodology, there is no mismatch between LiDAR bare-earth data and breaklines that might otherwise be collected in stereo 3D as a separate process. This is particularly important in densely vegetated areas where breaklines collected in 3D from imagery will most likely not match (either horizontally or vertically), the more reliable LiDAR bare-earth data.

Merrick has the capability of "draping" 2D breaklines to a bare-earth elevation model to attribute the "z" as opposed to the forced downhill attribution methodology described above. However, the problem with this process is the "pooling"effect or depressions along the drainagway caused by a lack of consistent penetration in densely vegetated areas.

Waterbodies

Waterbodies are digitized from the color ramped TIN, similar to the process described above. Ortho imagery is also used, as necessary, to determine the waterbody outline. The elevation attribute is determined as a post-process using the lowest determined bare-earth point within the polygon.

Contour Generation

Prior to contour generation, breaklines are buffered to remove points within 1 foot. This enhances the aesthetics of the final contours. Topology QC checks are completed for breaklines and contours based script provided by the Dewberry. Additional QC checks for dangles and appropriate attribution are also completed before shipment.

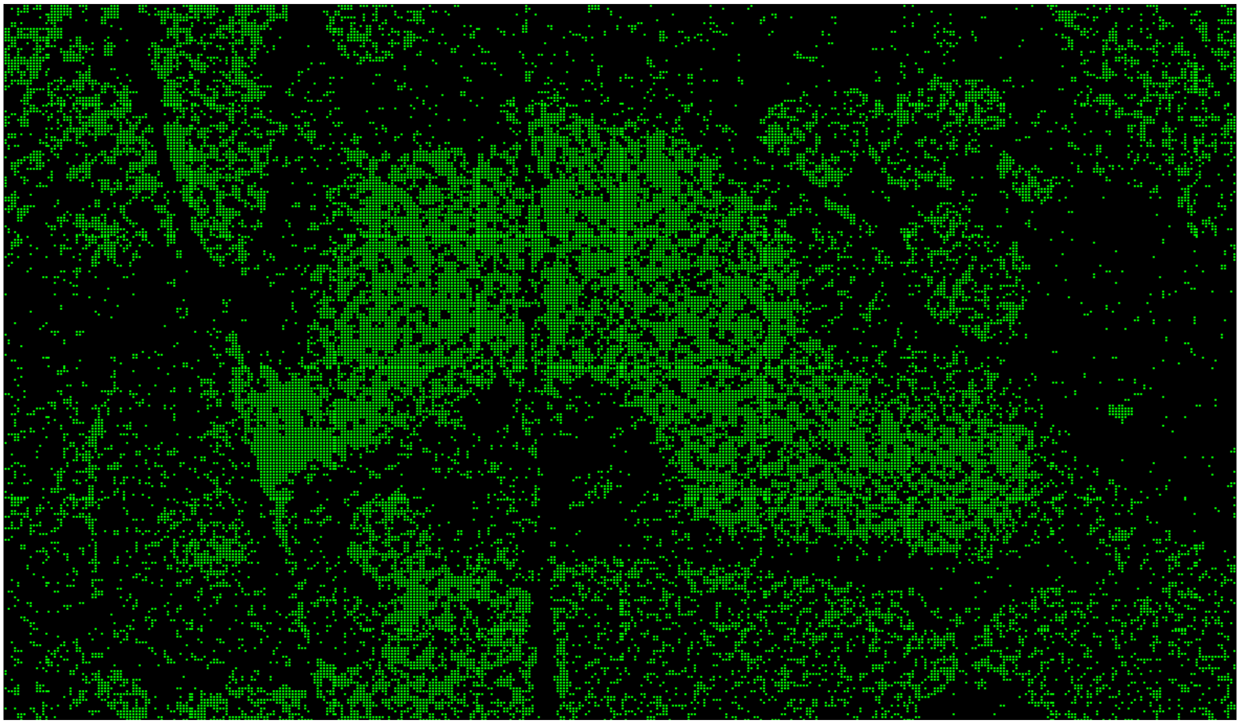
Low Confidence Area Determination

The methodology used for determining Low Confidence areas is as follows.

1. Using the ground classification, export a 4 foot LAS grid over the entire project area.
2. Combine both Ground (Class 8) and the Exported LAS Grid (Class 0) in a single MARS® window
3. A XY distance filter is used to then re-classify any grid points that fall near ground points. This will then identify areas of low or no ground penetration. (e.g., SJRWMD setting for

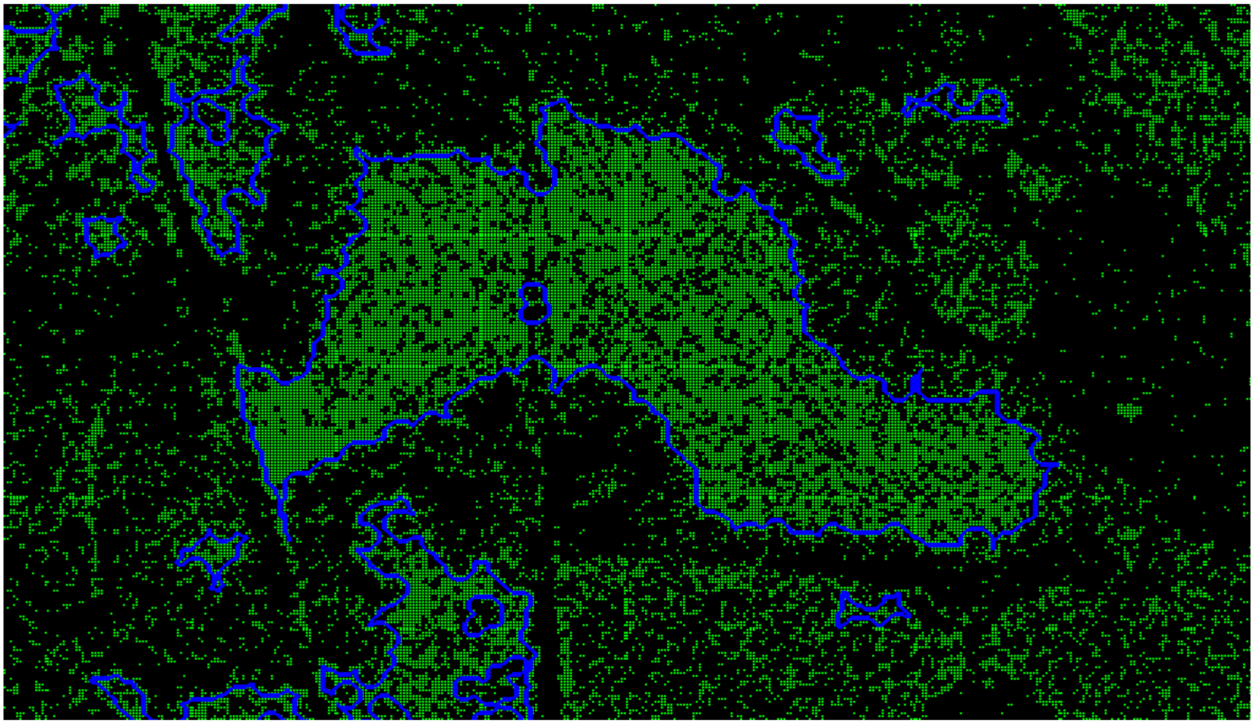
the XY distance filter was 4 foot) **Figure 1** illustrates an example of the reclassified grid points that shows an area of very little penetration.

Figure 1



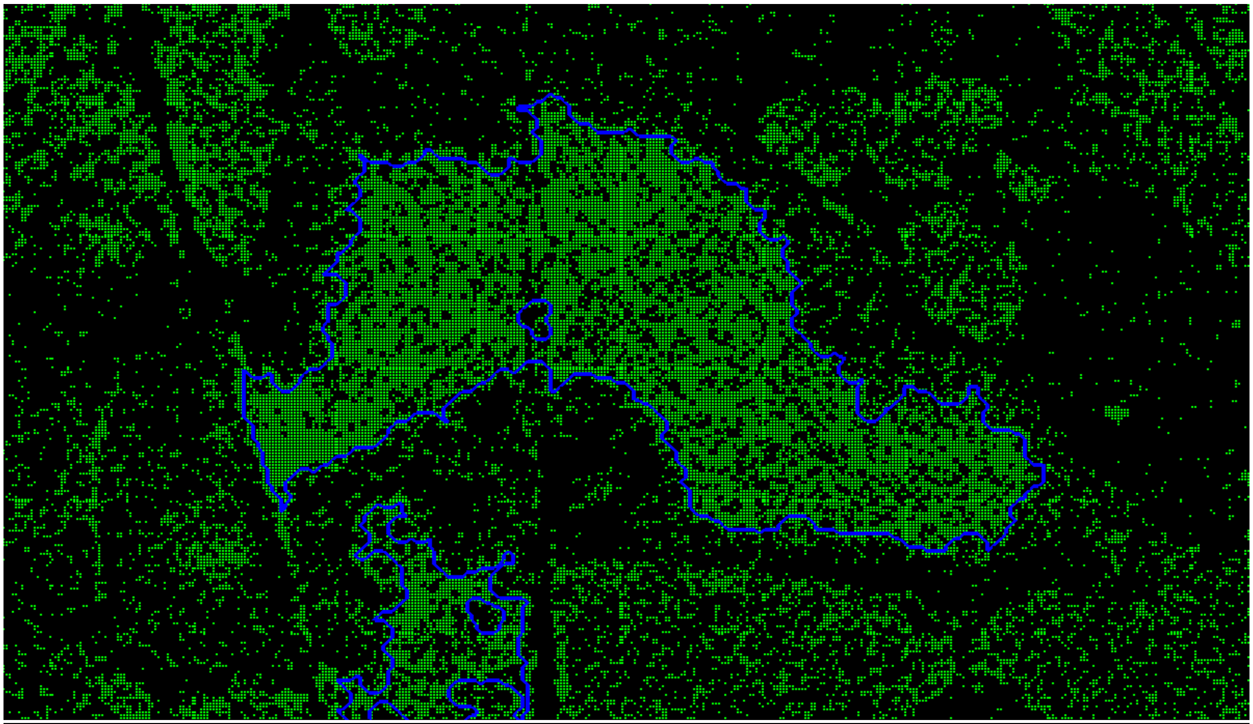
4. The Class Polygon Tool within MARS® is then used to generate the low confidence polygons around the remaining points. Settings can vary from project to project based on the GSD requirements (e.g., settings for SJRWMD are as follows: Grid size of 6, Max Span of 4, and Minimum Diameter of 3). See **Figure 2** for the results.

Figure 2



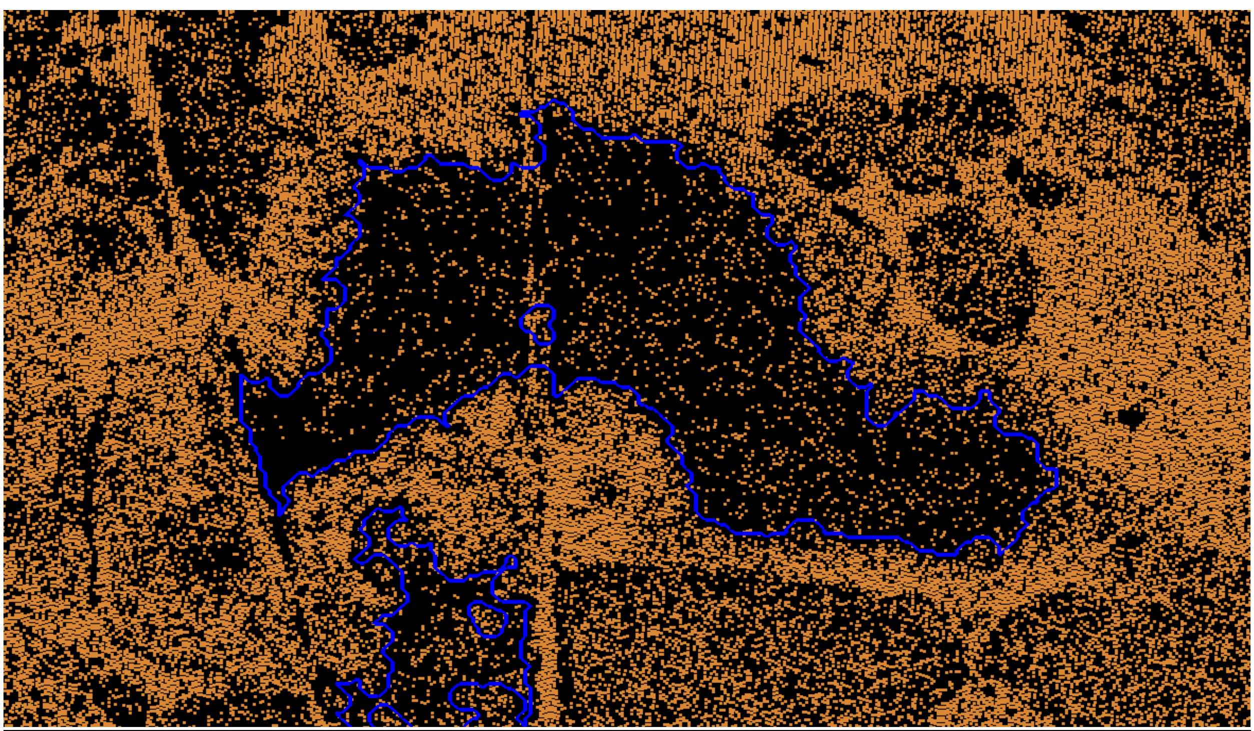
5. Intersect the Low Confidence layer with the any Hydro or Breakline features to remove non-valid Low Confidence or Obscured areas.
6. Delete any polygons less than 2,023 square meters which is equivalent to half an acre, per the project specifications.
7. Final review requires panning around with the RGB/Intensity imagery overlaid with the Low Confidence areas to look for any other features that shouldn't be classified as Low Confidence, such as buildings, bridge decks, etc. **Figure 3** represents the final results.

Figure 3



8. **Figure 4** is a screen shot of the ground with the obscured area.

Figure 4



Appendix E: QA/QC Checkpoints and Accuracy Statistics

Table 2: SJRWMD surveyed accuracy checkpoints

point No	Land Cover Class	NAD_1983_HARN_UTM_Zone_17 N		NAVD88	LiDAR - Z (feet)	Delta Z
		Easting - X (meters)	Northing - Y (meters)	Survey -Z (feet)		
o118	Open Terrain	474913.7	3158068.1	77.9	77.2	-0.7
o120	Open Terrain	478601.4	3164353.4	58.0	57.5	-0.5
o116	Open Terrain	483531.9	3160453.0	53.4	52.9	-0.5
o105	Open Terrain	496347.6	3166873.7	22.0	21.5	-0.5
o310B	Open Terrain	484093.4	3163761.9	40.8	40.4	-0.4
o637	Open Terrain	482774.1	3158752.9	65.4	65.1	-0.3
o103	Open Terrain	493391.3	3163890.2	53.0	52.7	-0.3
o632	Open Terrain	482025.9	3176070.4	10.6	10.4	-0.2
o304B	Open Terrain	496745.4	3163357.8	27.3	27.1	-0.2
o113	Open Terrain	478061.4	3169184.8	31.9	31.7	-0.2
o634	Open Terrain	474424.1	3161381.8	56.2	56.1	-0.2
o115	Open Terrain	487168.4	3166512.5	57.5	57.3	-0.2
o603	Open Terrain	484201.0	3183861.3	12.4	12.3	-0.1
o108	Open Terrain	488686.1	3173006.0	26.0	25.9	-0.1
o638	Open Terrain	482872.7	3166552.6	55.7	55.6	-0.1
o633	Open Terrain	490727.0	3169833.3	43.4	43.3	-0.1
o117	Open Terrain	481050.9	3157156.1	77.9	77.8	-0.1
o636	Open Terrain	492712.2	3163455.7	56.0	55.9	-0.1
o102	Open Terrain	494294.9	3161283.4	60.8	60.7	-0.1
o607	Open Terrain	493747.2	3185375.3	12.4	12.5	0.1
o101	Open Terrain	500397.8	3160365.4	18.5	18.6	0.1
o612	Open Terrain	503626.1	3164331.2	6.8	6.9	0.1
o631	Open Terrain	488770.6	3179791.0	61.2	61.3	0.1
o110	Open Terrain	491457.7	3187696.5	13.0	13.1	0.1
o104	Open Terrain	493336.4	3166274.0	38.2	38.3	0.1
o119	Open Terrain	472370.4	3163630.3	65.3	65.4	0.1
o112	Open Terrain	478222.9	3182714.4	24.2	24.4	0.2
o111	Open Terrain	479122.6	3185983.2	8.9	9.1	0.2
o615	Open Terrain	502815.2	3156847.1	8.2	8.4	0.3
o610	Open Terrain	497139.8	3170494.6	2.4	2.7	0.3
v208	Vegetation	486065.1	3161473.5	67.7	66.9	-0.8
v205	Vegetation	464752.8	3156728.0	76.4	75.8	-0.6

v207	Vegetation	475266.6	3163952.4	59.7	59.3	-0.4
v204	Vegetation	478401.2	3157515.0	79.0	78.6	-0.4
v209	Vegetation	490489.4	3163648.0	65.1	64.8	-0.3
v219	Vegetation	481538.3	3175693.8	12.7	12.6	-0.1
v217	Vegetation	485947.9	3178626.9	48.1	48.2	0.1
v206	Vegetation	468783.7	3160185.4	92.8	92.9	0.1
v202	Vegetation	496529.8	3157591.7	58.0	58.1	0.1
v220	Vegetation	483996.9	3169817.4	45.3	45.7	0.4
v215	Vegetation	488958.2	3187326.3	4.0	4.4	0.4
v213	Vegetation	493875.9	3176724.0	12.1	12.5	0.4
v210	Vegetation	498205.4	3163472.0	15.3	16.0	0.7
v218	Vegetation	477491.4	3180526.6	14.0	14.7	0.7
v214	Vegetation	491755.1	3182132.9	9.7	10.4	0.7
v203	Vegetation	493383.8	3156730.3	64.5	65.3	0.8
v212	Vegetation	495920.1	3171648.0	5.8	6.7	0.9
v211	Vegetation	496993.0	3170086.6	4.5	5.4	0.9
f308	Forest	475158.2	3160412.7	57.2	56.6	-0.6
f313	Forest	489755.3	3172592.5	18.6	18.4	-0.2
f318	Forest	487688.9	3181971.9	24.7	24.6	-0.1
f317	Forest	477442.3	3174609.4	4.0	4.4	0.4
f311	Forest	490368.9	3167491.6	39.0	39.4	0.4
f307	Forest	472192.6	3157557.4	86.2	86.7	0.5
f306	Forest	487464.5	3157782.8	35.0	35.6	0.6
f319	Forest	489214.6	3185738.5	12.8	13.6	0.8
f320	Forest	481498.8	3184436.5	5.8	6.7	0.9
f315	Forest	487783.0	3175689.3	34.1	35.1	1.0
f309	Forest	481188.0	3160447.2	59.1	60.1	1.0
f304	Forest	496720.3	3163377.2	29.6	30.6	1.0
f312	Forest	490690.9	3169911.6	35.4	36.5	1.1
f302	Forest	502035.1	3160238.0	11.5	12.7	1.2
u412	Urban	480038.9	3167324.1	55.5	55.1	-0.4
u408	Urban	469247.5	3157617.4	101.7	101.6	-0.1
u416	Urban	487246.4	3169210.0	58.9	58.8	-0.1
u413	Urban	481619.6	3170026.7	48.5	48.5	0.0
u418	Urban	486961.3	3180295.8	27.4	27.4	0.0
u405	Urban	483953.8	3158086.5	66.3	66.3	0.0
u404	Urban	487672.0	3163427.9	62.4	62.4	0.0
u409	Urban	468357.2	3163038.1	97.0	97.1	0.1
u407	Urban	472139.5	3160351.9	78.9	79.0	0.1
u410	Urban	476456.8	3166620.9	52.2	52.3	0.1
u415	Urban	483977.4	3173271.9	29.0	29.2	0.2

u411	Urban	480731.4	3164076.3	72.5	72.8	0.3
u402	Urban	490719.7	3156951.9	60.0	60.3	0.3
u406	Urban	478585.6	3160087.1	72.0	72.3	0.3
u403	Urban	490137.3	3160506.1	71.8	72.1	0.3
u414	Urban	480730.1	3173098.6	26.1	26.4	0.3
u420	Urban	478850.8	3184341.5	20.0	20.4	0.4
u417	Urban	490348.8	3177640.5	30.9	31.3	0.4
U401	Urban	500417.6	3156639.1	26.8	27.3	0.5
u419	Urban	492584.9	3184092.7	17.8	18.3	0.5

100 % of Totals	RMSE (ft) Open Terrain Spec=0.30ft All other Spec=0.61ft	Mean (ft)	Median (ft)	Skew	Std Dev (ft)	# of Points	Min (ft)	Max (ft)
Consolidated	0.45	0.14	0.08	0.35	0.45	82	-0.75	1.20
Open Terrain	0.26	-0.11	-0.11	-0.48	0.25	30	-0.69	0.31
Vegetation	0.56	0.20	0.23	-0.30	0.54	18	-0.75	0.90
Forest	0.78	0.57	0.71	-0.99	0.55	14	-0.64	1.20
Urban	0.28	0.16	0.16	-0.43	0.23	20	-0.35	0.51

Land Cover Category	# of Points	FVA — Fundamental Vertical Accuracy (RMSEz x 1.9600) Spec=0.60 ft	CVA — Consolidated Vertical Accuracy (95th Percentile) Spec=1.195 ft	SVA — Supplemental Vertical Accuracy (95th Percentile) Target=1.195 ft
Consolidated	82		1.004	
Open Terrain	30	0.517		0.521
Vegetation	18			0.892
Forest	14			1.105
Urban	20			0.471

Checkpoint Discrepancies

In total, eight checkpoints were removed from the final data set. Three of the checkpoints were contained in the low confidence area polygon. These checkpoints were unable to be used due of a shortage of surrounding LiDAR points which yielded an inaccurate zLiDAR value for the easting and northing provided by the survey.

Point ID	Easting	Northing	Elevation	zLidar	LandCoverType	DeltaZ	AbsDeltaZ
f310	484218.50	3163659.50	30.00	31.27	Forest	1.27	1.27
f314	491829.50	3176383.80	14.70	15.98	Forest	1.28	1.28
f316	485039.00	3175475.60	22.30	25.88	Forest	3.53	3.53

The remaining five points were removed due to poor checkpoint survey location. The checkpoints were collected within less than ideal locations resulting in invalid results. For example, v216 was removed because the checkpoint is on uneven ground with very thick impenetrable vegetation. See Figure 1. In addition, forest point 305 was removed because of excessive debris surrounding the checkpoint which would result in inaccurate elevation values. See Figure 2.

Figure 1 – V216

Figure 2 – F305

The remaining five points are shown in the table below.

Point ID	Easting	Northing	Elevation	zLidar	LandCoverType	DeltaZ	AbsDeltaZ
V201	505404.9	3157165.5	5.5	7.6162	Vegetation	2.116	2.116
V216	484585.1	3182669.7	15.4	18.9704	Vegetation	3.570	3.570
F301	502768.10	3156945.00	8.70	10.01	Forest	1.306	1.306
F303	496429.70	3160147.80	38.30	39.68	Forest	1.376	1.376
F305	488467.70	3156524.80	37.90	39.32	Forest	1.420	1.420

Appendix F: LiDAR Vertical Accuracy Report

Vertical Accuracy Assessment Report
For the
St. John's River Water Management District
2009 Central Florida Coordination Area Surface Elevation Dataset

Date: July 30, 2009

References: A — State of Florida Division of Emergency Management (FDEM) Baseline Specifications for Orthophotography and LiDAR (FDEM Baseline Specifications)
B — Part 3: *National Standard for Spatial Data Accuracy (NSSDA)*, "Geospatial Positioning Accuracy Standards," published by the Federal Geographic Data Committee (FGDC), 1998
C — Appendix A, *Guidance for Aerial Mapping and Surveying*, "Guidelines and Specifications for Flood Hazard Mapping Partners," published by the Federal Emergency Management Agency (FEMA), April 2003
D — *Guidelines for Digital Elevation Data*, Version 1.0, published by the National Digital Elevation Program (NDEP), May 10, 2004
E — *ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data*, published by the American Society for Photogrammetry and Remote Sensing (ASPRS), May 24, 2004

Background

FDEM Baseline Specifications Guidance: The St. Johns River Water Management District (SJRWMD) tasked Dewberry to validate the bare-earth LiDAR dataset of the 2009 Central Florida Coordination Area Surface Elevation Dataset project both quantitatively (for accuracy) and qualitatively (for usability). Reference A specifications were adopted for this project.

This report addresses the vertical accuracy assessment only, for which FDEM Baseline Specifications are summarized as follows:

- Vertical accuracy: $\leq$ 0.30 feet $RMSE_z$ = $\leq$ 0.60 feet vertical accuracy at 95% confidence level, tested in flat, non-vegetated terrain only, employing NSSDA procedures in Reference B.
- Validation that the data also satisfies FEMA requirements in Reference C.
- Vertical units (orthometric heights) are in US Survey Feet, NAVD88.

NSSDA Guidance: Section 3.2.2 of Reference B specifies: "A minimum of 20 check points shall be tested, distributed to reflect the geographic area of interest and the distribution of error in the dataset. When 20 points are tested, the 95% confidence level allows one point to fail the threshold given in product specifications."

FEMA Guidance: Section A.8.6 of Reference C specifies the following LiDAR testing requirement for data to be used by the National Flood Insurance Program (NFIP): "For the NFIP, TINs (and DEMs derived there from) should normally have a maximum RMSE of 18.5 centimeters, equivalent to 2-foot contours, in flat terrain; and a maximum RMSE of 37 centimeters, equivalent to 4-foot contours, in rolling to hilly terrain. The Mapping Partner shall field verify the vertical accuracy of this TIN to ensure that the 18.5- or 37.0-centimeter RMSE requirement is satisfied for all major vegetation categories that predominate within the floodplain being studied … The assigned Mapping Partner shall separately evaluate and report on the TIN accuracy for the main categories of ground cover in the study area, including the following: [followed by explanations of seven potential categories]… Ground cover

Categories 1 through 5 are fairly common everywhere. The assigned Mapping Partner shall select a minimum of 20 test points for each major vegetation category identified. Therefore, a minimum of 60 test points shall be selected for three (minimum) major land cover categories, 80 test points for four major categories, and so on."

Note: For this project, Dewberry followed the FDEM Baseline Specifications. FDEM Baseline Specifications stipulate that the vertical accuracy report will be based on a minimum of 30 ground measurements for each of four land cover categories, totaling 120 test points for each 500 square mile area of new topographic data collection. Because the SJRWMD project area encompassed only 318 square miles instead of 500 square miles, only 64% of the normal 120 points were necessary to test accuracy (i.e. 76 points). However, a total of 82 QA/QC checkpoints were used for the project.

The land cover measurements distributed through each project area were collected for each of the following land cover categories:

1. Bare-earth and low grass
2. Brush Lands and low trees
3. Forested areas fully covered by trees
4. Urban areas

<u>NDEP and ASPRS Guidance</u>: NDEP guidelines (Reference D) and ASPRS guidelines (Reference E) also recommend a minimum of 60 checkpoints, with up to 100 points preferred. (These guidelines are referenced because FEMA's next update to Appendix A will include these newer NDEP and ASPRS guidelines, now recognizing that vertical errors for LiDAR bare-earth datasets in vegetated terrain do not necessarily follow a normal error distribution as assumed by the NSSDA.)

Vertical Accuracy Test Procedures

<u>Ground Truth Surveys</u>: The Dewberry team established a primary geodetic network covering the project area to provide accurate and consistent control. The primary network was used to establish base stations to support airborne GPS data acquisition. A secondary control network was established to support the measurement of checkpoints used in the accuracy validation process.

<u>Assessment Procedures and Results</u>: The LiDAR accuracy assessment for SJRWMD was performed in accordance with References D and E which assume that LiDAR errors in some land cover categories may not follow a normal error distribution. This assessment was also performed in accordance with References B and C which assume that LiDAR bare-earth datasets errors do follow a normal error distribution. Comparisons between the two methods help determine the degree to which *systematic errors* may exist in the four major land cover categories: (1) bare-earth and low grass, (2) brush lands and low trees, (3) forested areas fully covered by trees, (4) urban areas. When a LiDAR bare-earth dataset passes testing by both methods, compared with criteria specified in Reference A, the dataset clearly passes all vertical accuracy testing criteria for a digital terrain model (DTM) suitable for FDEM and FEMA requirements.

The relevant testing criteria, as stipulated in Reference A are summarized in Table 1.

Table 1 — DTM Acceptance Criteria

Quantitative Criteria	Measure of Acceptability
Fundamental Vertical Accuracy (FVA) in open terrain only = 95% confidence level	0.60 ft (0.30 ft $RMSE_z$ x 1.96000) for open terrain only
Supplemental Vertical Accuracy (SVA) in individual land cover categories = 95% confidence level	1.19 ft (based on 95th percentile per land cover category)
Consolidated Vertical Accuracy (CVA) in all land cover categories combined = 95% confidence lever	1.19 ft (based on combined 95th percentile)

Vertical Accuracy Testing in Accordance with NDEP and ASPRS Procedures

References D and E specify the mandatory determination of Fundamental Vertical Accuracy (FVA) and the optional determination of Supplemental Vertical Accuracy (SVA) and Consolidated Vertical Accuracy (CVA). FVA determines how well the LiDAR sensor performed in category (1), open terrain, where errors are random and normally distributed; whereas SVA determines how well the vegetation classification algorithms worked in land cover categories (2) and (3) where LiDAR elevations are often higher than surveyed elevations and category (4) where LiDAR elevations are often lower.

FVA is determined with check points located only in land cover category (1), open terrain (grass, dirt, sand, and/or rocks), where there is a very high probability that the LiDAR sensor will have detected the bare-earth ground surface and where random errors are expected to follow a normal error distribution. The FVA determines how well the calibrated LiDAR sensor performed. With a normal error distribution, the vertical accuracy at the 95% confidence level is computed as the vertical root mean square error (RMSEz) of the checkpoints x 1.9600, as specified in Reference B. For the 2009 Central Florida Coordination Area Surface Elevation Dataset where floodplains are essentially flat, FDEM Baseline Specifications required the FVA to be 0.60 ft (18.29 cm) at the 95% confidence level (based on an RMSEz of 0.30 ft (9.14 cm), equivalent to 1 ft contours).

CVA is determined with all checkpoints in all land cover categories combined where there is a possibility that the LiDAR sensor and post-processing may yield elevation errors that do not follow a normal error distribution. CVA at the 95% confidence level equals the 95th percentile error for all checkpoints in all land cover categories combined. FDEM's CVA standard is 1.19 ft at the 95% confidence level. The CVA is accompanied by a listing of the 5% outliers that are larger than the 95th percentile used to compute the CVA; these are always the largest outliers that may depart from a normal error distribution. Here, $Accuracy_z$ differs from CVA because $Accuracy_z$ assumes elevation errors follow a normal error distribution where RMSE procedures are valid, whereas CVA assumes LiDAR errors may not follow a normal error distribution in vegetated categories, making the RMSE process invalid.

SVA is determined separately for each individual land cover category, again recognizing that the LiDAR sensor and post-processing may yield elevation errors that do not follow a normal error distribution, and where discrepancies can be used to identify the nature of systematic errors by land cover category. For each land cover category, the SVA at the 95% confidence level equals the 95th percentile error for all checkpoints in each individual land cover category. SVA statistics are calculated individually for bare-earth and low grass, vegetation, forested areas, and urban areas, in order to facilitate the analysis of the data based on each of these land cover categories that exist within the project. The SVA criteria in Table 1 (1.19 ft at the 95% confidence level for each category) are target values only and are not mandatory; it is common for some SVA criteria to fail individual target values, yet satisfy FEMA's mandatory CVA criterion.

QA/QC Steps: The primary QA/QC steps used by Dewberry were as follows:

1. Dewberry's team surveyed "ground truth" QA/QC vertical checkpoints in accordance with guidance in references B, C, D and E. Figure 1 shows the location of the checkpoints.
2. Next, Dewberry interpolated the bare-earth LiDAR DTM to provide the z-value for each of the 82 checkpoints.
3. Dewberry then computed the associated z-value differences between the interpolated z-value from the LiDAR data and the ground truth survey checkpoints and computed the FVA, CVA and SVA values using procedures in References D and E.
4. The data were analyzed by Dewberry to assess the accuracy of the data. The review process examined the various accuracy parameters as defined by FDEM Baseline Specifications. Also, the overall descriptive statistics of each dataset were computed to assess any trends or anomalies. The following tables, graphs and figures illustrate the data quality.

Figure 1 shows the location of the QA/QC checkpoints within the project area. The points are colored based on their land cover category.

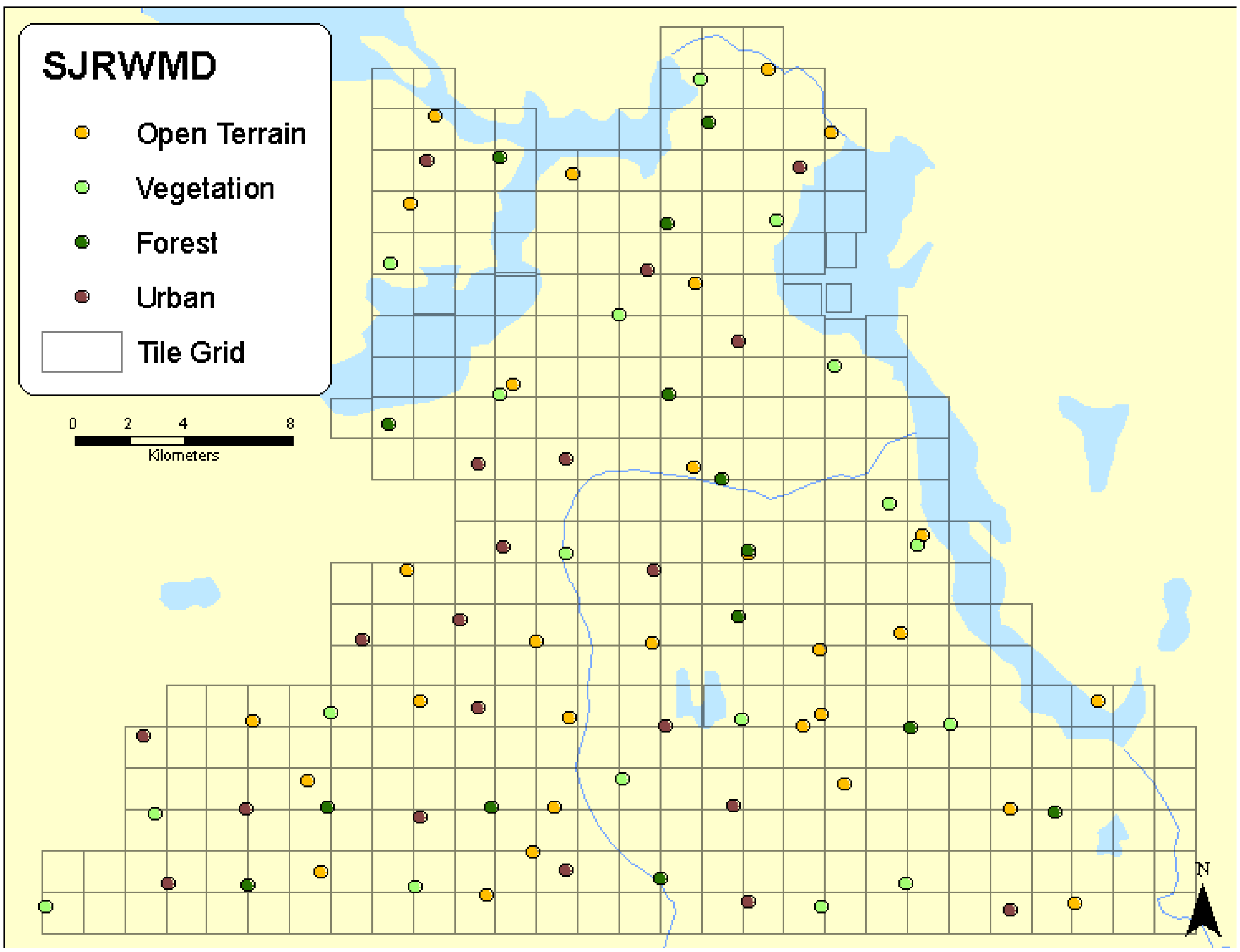


Figure 3 – Location of QA/QC Checkpoints

Table 2 summarizes the vertical accuracy by fundamental, consolidated and supplemental methods:

Table 2 — FVA, CVA and SVA Vertical Accuracy at 95% Confidence Level

Land Cover Category	# of Points	FVA — Fundamental Vertical Accuracy ($RMSE_z$ x 1.9600) Spec = 0.60 ft	CVA — Consolidated Vertical Accuracy (95th Percentile) Spec = 1.19 ft	SVA — Supplemental Vertical Accuracy (95th Percentile) Target = 1.19 ft
Consolidated	82		1.004	
Open Terrain	30	0.517		0.521
Vegetation	18			0.892
Forest	14			1.105
Urban	20			0.471

Fundamental and Consolidated Vertical Accuracy at 95% confidence level, using NDEP/ASPRS methodology:

The $RMSE_z$ in bare-earth and low grass was within the target criteria of 0.30 ft, and the FVA tested 0.41 ft at the 95% confidence level in open terrain, based on $RMSE_z$ x 1.9600.

Compared with the 1.19 ft specification, CVA tested 1.004 ft at the 95% confidence level in bare-earth and low grass, vegetation, forested, and urban areas combined, based on the 95th Percentile. Compared with the 1.19 ft SVA target values, SVA tested 0.521 ft at the 95% confidence level in bare-earth and low grass; 0.892 ft in vegetation; 1.105 ft in forested areas; and 0.471 ft in urban areas, based on the 95th Percentile. Each of the four land cover categories were within the target value of 1.19 ft.

Figure 2 illustrates the magnitude of the differences between the QA/QC checkpoints and LiDAR data by specific land cover category and sorted from lowest to highest. This shows a normal distribution of points in bare-earth and low grass.

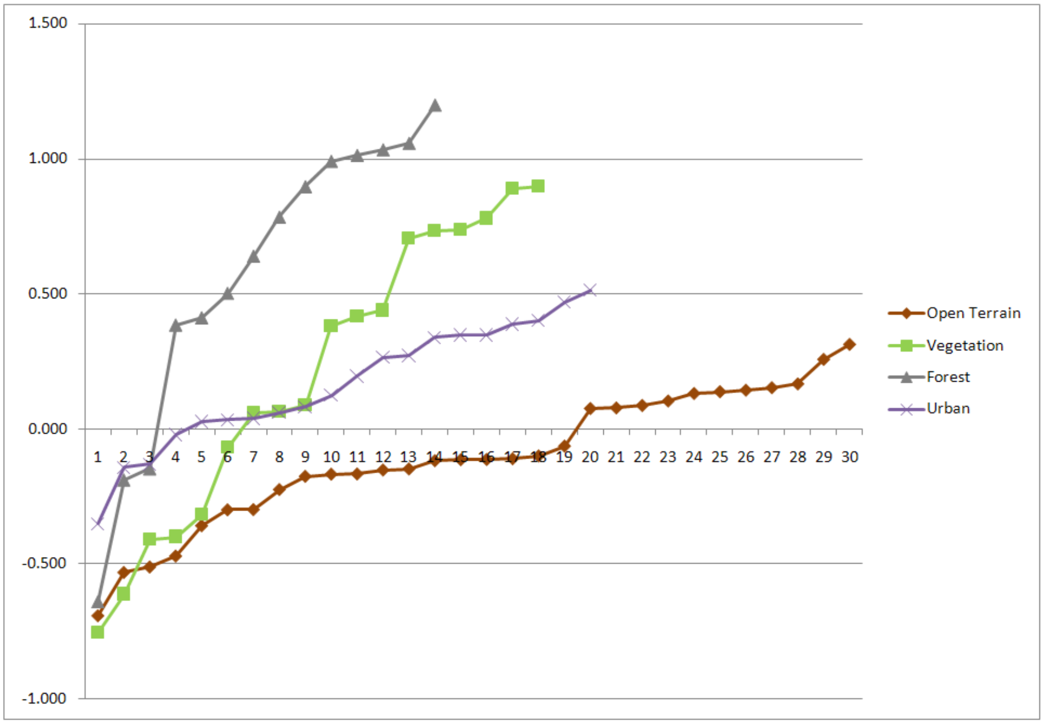


Figure 4 – Magnitude of Elevation Discrepancies, Sorted From Largest Negative to Largest Positive

The NSSDA and FEMA guidelines were both published before it was recognized that LiDAR errors do not always follow a normal error distribution. Future changes to these FGDC and FEMA documents are expected to follow the lead of the NDEP and ASPRS. Nevertheless, to comply with FEMA's current guidelines in Reference C, $RMSE_z$ statistics were computed in all four land cover categories, individually and combined, as well as other statistics that FEMA recommends to help identify any unusual characteristics in the LiDAR data. These statistics are summarized in Figures 3 and Table 3 below, consistent with Section A.8.6.3 of Reference C.

Table 4 — Overall Descriptive Statistics by Land Cover Category and Consolidated

100 % of Totals	RMSE (ft) Open Terrain Spec=0.30ft All other Spec=0.61ft	Mean (ft)	Median (ft)	Skew	Std Dev (ft)	# of Points	Min (ft)	Max (ft)
Consolidated	0.45	0.14	0.08	0.35	0.45	82	-0.75	1.20
Open Terrain	0.26	-0.11	-0.11	-0.48	0.25	30	-0.69	0.31
Vegetation	0.56	0.20	0.23	-0.30	0.54	18	-0.75	0.90
Forest	0.78	0.57	0.71	-0.99	0.55	14	-0.64	1.20
Urban	0.28	0.16	0.16	-0.43	0.23	20	-0.35	0.51

Fundamental and Consolidated Vertical Accuracy at 95% confidence level, using NSSDA/FEMA methodology:

Although the NSSDA and FEMA guidelines predated FVA and CVA terminology, vertical accuracy at the 95% confidence level (called $Accuracy_z$) is computed by the formula $RMSE_z$ x 1.9600. $Accuracy_z$ in open terrain = 0.21 ft x 1.9600 = 0.41 ft, satisfying the 0.60 ft FVA standard. $Accuracy_z$ in consolidated categories = 0.26 ft x 1.9600 = 0.51 ft, satisfying the 1.19 ft CVA standard.

Figure 5 illustrates a histogram of the associated elevation discrepancies between the QA/QC checkpoints and elevations interpolated from the LiDAR triangulated irregular network (TIN). The frequency shows the number of discrepancies within each band of elevation differences. Although the discrepancies vary between a low of -0.75 ft and a high of +1.19 ft, the histogram shows that the majority of the discrepancies are skewed on the positive side of what would be a "bell curve," with mean of zero, if the data were truly normally distributed. Typically the discrepancies tend to skew a bit more to the positive side, because discrepancies in vegetation are typically positive. The vast majority of points are within +/- 0.5 ft of 0.00 ft.

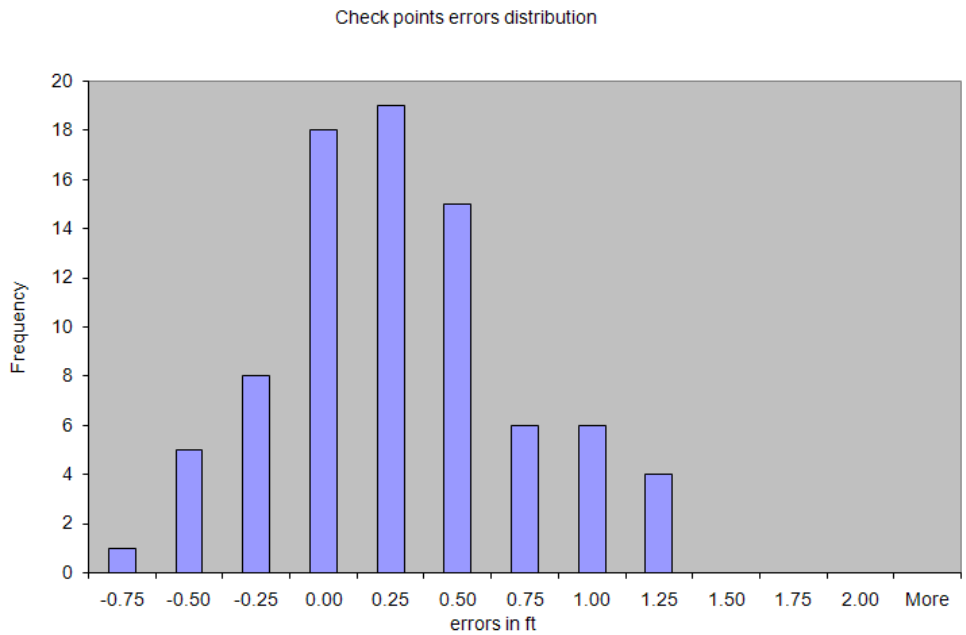


Figure 5 — Histogram of Elevation Discrepancies within 0.10 m Bands

Conclusions

Based on the vertical accuracy testing conducted by Dewberry, the LiDAR dataset for the SJRWMD satisfies the criteria established by Reference A:

- **Tested 0.517 ft fundamental vertical accuracy at 95% confidence level in Open Terrain using RMSEz x 1.9600 (FEMA/NSSDA and NDEP/ASPRS methodologies)**
- **Tested 1.004 ft consolidated vertical accuracy at 95th percentile in all land cover categories (NDEP/ASPRS methodology)**
- **Tested 0.521 ft supplemental vertical accuracy at 95th percentile in Open Terrain category (NDEP/ASPRS methodology)**
- **Tested 0.892 ft supplemental vertical accuracy at 95th percentile in Vegetation category (NDEP/ASPRS methodology)**

- **Tested 1.105 ft supplemental vertical accuracy at 95th percentile in Forest category (NDEP/ASPRS methodology)**
- **Tested 0.471 ft supplemental vertical accuracy at 95th percentile in Urban category (NDEP/ASPRS methodology)**

Appendix G: LiDAR Qualitative Assessment Report

References:

A — State of Florida Division of Emergency Management (FDEM) Baseline Specifications for Orthophotography and LiDAR (FDEM Baseline Specifications)

B – Part 3: *National Standard for Spatial Data Accuracy (NSSDA)*, “Geospatial Positioning Accuracy Standards,” published by the Federal Geographic Data Committee (FGDC), 1998

C – Appendix A, *Guidance for Aerial Mapping and Surveying*, “Guidelines and Specifications for Flood Hazard Mapping Partners,” published by the Federal Emergency Management Agency (FEMA), April 2003

D – *Guidelines for Digital Elevation Data*, Version 1.0, published by the National Digital Elevation Program (NDEP), May 10, 2004

E – *ASPRS Guidelines, Vertical Accuracy Reporting for LiDAR Data*, published by the American Society for Photogrammetry and Remote Sensing (ASPRS), May 24, 2004

Qualitative Assessment

The Dewberry qualitative assessment utilizes a combination of statistical analysis and interpretative methodology to assess the quality of the data for a bare-earth digital terrain model (DTM). This process looks for anomalies in the data and also identifies areas where man-made structures or vegetation points may not have been classified properly to produce a bare-earth model. Overall the data are of good quality and should satisfy most users for an accurate bare-earth elevation data product.

Overview

Within this review of the LiDAR data, two fundamental questions were addressed:

- Did the LiDAR system perform to specifications?
- Did the vegetation removal process yield desirable results for the intended bare-earth terrain product?

Mapping standards today address the quality of data by quantitative methods. If the data are tested and found to be within the desired accuracy standard, then the data set is typically accepted. Now with the proliferation of LiDAR, new issues arise due to the vast amount of data. Unlike photogrammetrically-derived DEMs where point spacing can be eight meters or more, LiDAR point spacing for this project is one meter or less. The end result is that millions of elevation points are measured to a level of accuracy previously unseen for traditional, elevation mapping technologies, and vegetated areas are measured that would be nearly impossible to survey by other means. The downside is that with millions of points, the data set is statistically bound to have some errors both in the measurement process and in the artifact removal process.

As previously stated, the quantitative analysis addresses the quality of the data based on absolute accuracy. This accuracy is directly tied to the comparison of the discreet measurement of the survey checkpoints and that of the interpolated value within the three closest LiDAR points that constitute the vertices of a three-dimensional triangular face of the TIN. Therefore, the end result is that only a small sample of the LiDAR data is actually tested. However 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 the next contiguous LiDAR measurement. Once the absolute and relative accuracy has been ascertained, the next stage is to address the cleanliness of the data for a bare-earth DTM.

By using survey checkpoints to compare the data, the absolute accuracy is verified, but this also allows us to understand if the artifact removal process was performed correctly. To reiterate the quantitative approach, if the LiDAR sensor operated correctly over open terrain areas, then it most likely operated correctly over the vegetated areas. This does not mean that the bare-earth was measured, but that the elevations surveyed are most likely accurate (including elevations of treetops, rooftops, etc.). In the event that the LiDAR pulse filtered through the vegetation and was able to measure the true surface (as well as measurements on the surrounding vegetation) then the level of accuracy of the vegetation removal process can be tested as a by-product.

To fully address the data for overall accuracy and quality, the level of cleanliness (or removal of above-ground artifacts) is paramount. Since there are currently no effective automated testing procedures to measure cleanliness, Dewberry employs a combination of statistical and visualization processes. This includes creating pseudo image products such as LiDAR orthos produced from the intensity returns, Triangular Irregular Network (TIN)'s, Digital Elevation Models (DEM) and 3-dimensional models. By creating multiple images and using overlay techniques, not only can potential errors be found, but Dewberry can also find where the data meets and exceeds expectations. This report will present representative examples where the LiDAR and post processing had issues as well as examples of where the LiDAR performed well.

Analysis

Process

Dewberry utilizes GeoCue software products as the primary geospatial process management system. GeoCue is a three tier, multi-user architecture that uses .NET technology from Microsoft. .NET technology provides the real-time notification system that updates users with real-time project status, regardless of who makes changes to project entities. GeoCue uses database technology for sorting project metadata. Dewberry uses Microsoft SQL Server as the database of choice.

The Dewberry qualitative assessment process flow for the Saint John's River Water Management District project incorporated the following reviews:

1. *Statistical Analysis*- A statistical analysis routine was run on the .LAS files upon receipt to verify that the .LAS files met project specifications. This routine checked for the presence of Variable Length Records, verified .LAS classifications, verified header records for min/max x,y,z, and parsed the .LAS point file to confirm that the min/max x,y,z matched the header records. These statistics were run on the all-return point data set as well as the bare-earth point data set for every deliverable tile.
    a. All LAS files contained Variable Length Records with georeferencing information.
    b. All LiDAR points in the LAS files were classified in accordance with project specifications: Class 1 - Unclassified, Class 2 - Ground, Class 7 - Noise, Class 9 – Water, and Class 12-overlap.
    c. Min/max x,y,z values matched the header files.

2. *Spatial Reference Checks*- The .LAS files were imported into the GeoCue processing environment. As part of the Dewberry process workflow the GeoCue import produced a minimum bounding polygon for each data file. This minimum bounding polygon was one of the tools used in conjunction with the statistical analysis to verify spatial reference integrity. No issues were identified with the spatial referencing of this dataset.

3. *Data Void/ Gap Checks*-The imported .LAS files were used to create LiDAR "orthos". The LiDAR orthos were one of the tools used to verify data coverage and point density, to check for data voids or gaps, and to use as reference data during checks for data anomalies and artifacts. This product is not intended to be a project deliverable. The orthos were derived from the Full Point Cloud elevations and LiDAR pulse return intensity values. The intensity values were used as delivered with no normalization applied. Due to the point density of the original collection, the orthos were produced at a 1m pixel for the entire area of interest (see Figure 5).

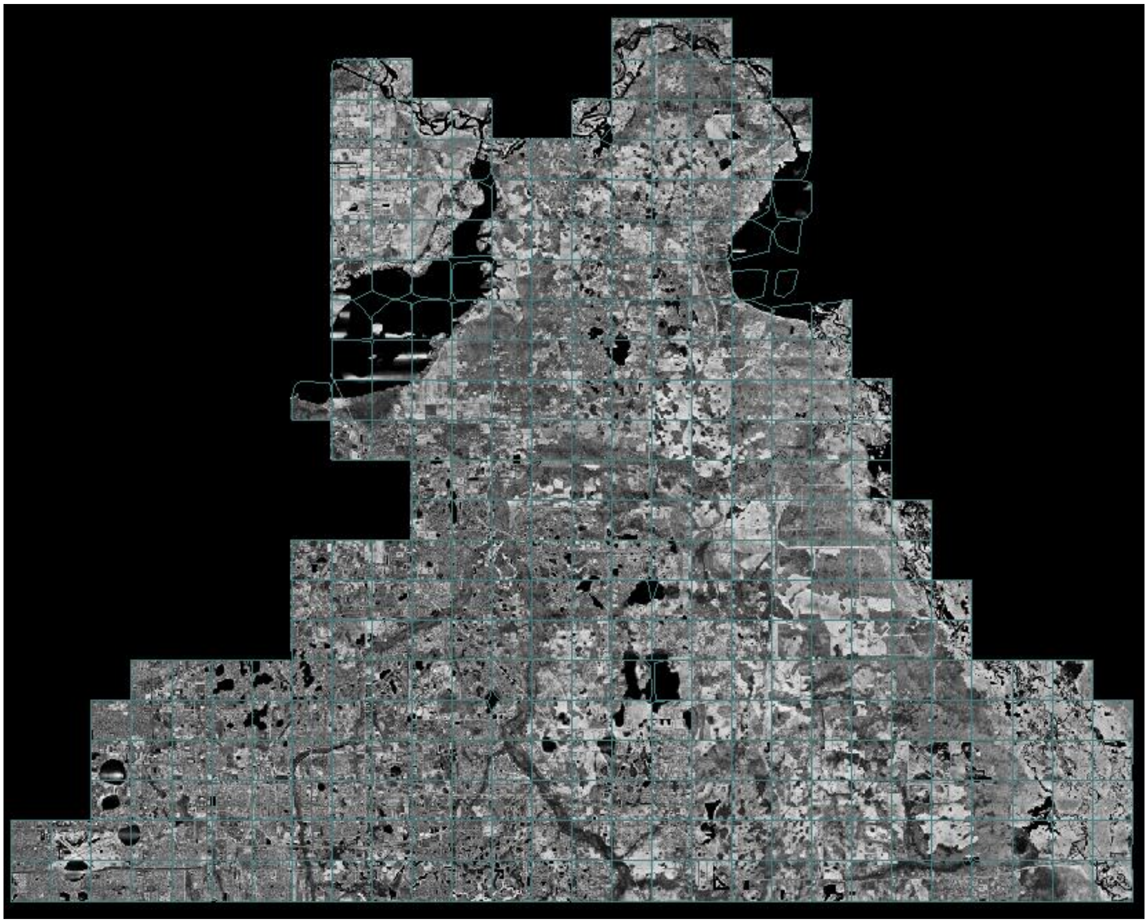


Figure 5 – SJRWMD Project LiDAR Orthos produced from Intensity Returns

Acceptable voids (areas with no LiDAR returns in the LAS files) that are present in the majority of LiDAR projects include voids caused by bodies of water. These are considered to be acceptable voids (Figure 2).

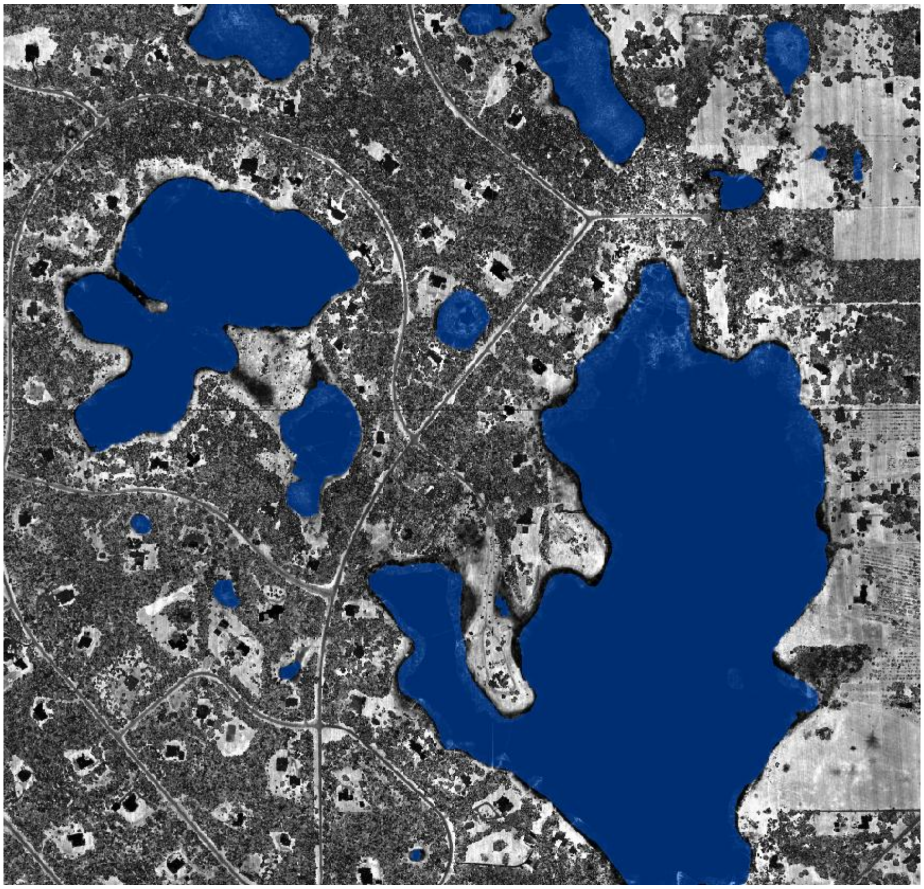


Figure 6 – Acceptable voids in data due to water bodies

4. *Initial Data Verification:* Dewberry performs an initial 10% random check of the data delivery by looking at each tile individually in great detail utilizing TIN surfaces and profiles. If the data set passes the 10 % check, the tiles continue through the remaining QC work flow where every tile is reviewed. If the data set fails the 10% check it is normally due to a systematic process error and the data set is sent back to the vendor for correction. Upon receipt of the corrected tile/s the check is performed again to ensure that any flagged errors were corrected and additional issues were not inadvertently introduced during the corrective action.

5. *Data Density/Elevation checks:* The .LAS files are used to produce Digital Elevation Models using the commercial software package "QT Modeler" which creates a 3-dimensional data model derived from Class 2(ground points) in the .LAS files. Grid spacing is based on the project density deliverable requirement for un-obscured areas. For the FDEM project it is stipulated that the maximum post spacing in un-obscured areas should not exceed 1 meter.

Model statistics were produced and characterized by density, scale, intensity, and elevation. The low confidence area polygons were overlaid onto the density grids to ensure that all low confidence areas were properly identified with a polygon. As with the LiDAR orthos, this product was produced for Quality Assessment purposes only.

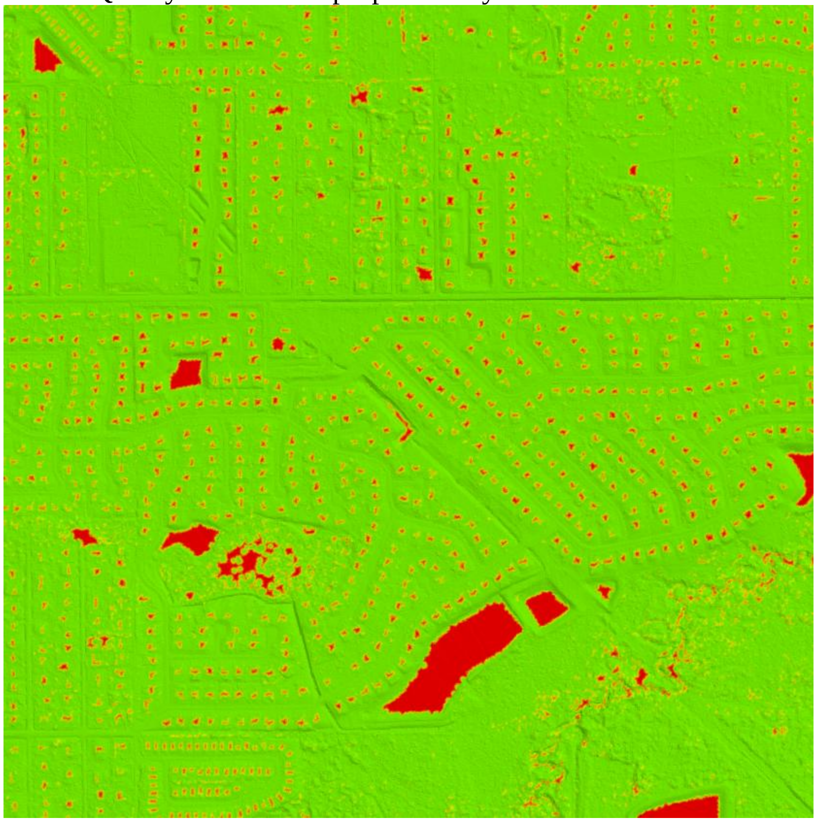


Figure 7 Density grid of SJRWMD tile 56285_E created using a green to red color ramp. The red delineates areas not meeting minimum density setting. Green areas have a higher density level. The red areas are primarily water, buildings and low-confidence areas.

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6. *Artifact Anomaly Checks.* The final step in the analysis was to review every tile for anomalies that may exist in the bare-earth terrain surface. Items that were checked include, but are not limited to: buildings, bridges, vegetation and water points classified as Class 2 points and elevation "steps" that may occur in the overlap between adjacent flight lines. Any issues found are addressed below in the "General comments and issues".

Conclusion

Overall the data meets the project specifications for general elevation use. The classification of the raw point cloud to bare ground was executed well given the low terrain relief and areas of dense vegetation. Errors that existed in the original dataset such as the flight line offset and bridge artifacts were corrected, redelivered, and have passed the qualitative assessment.

Appendix H: Breakline/Contour Qualitative Assessment Report

Linear Hydrographic Features

Linear hydrographic features are correctly captured as three-dimensional breaklines – single line features if the average width is 8 feet or less and dual line features if the average width is greater than 8 feet. Each vertex maintains vertical integrity. Figure 1 shows example breaklines and contours of linear hydrographic features.

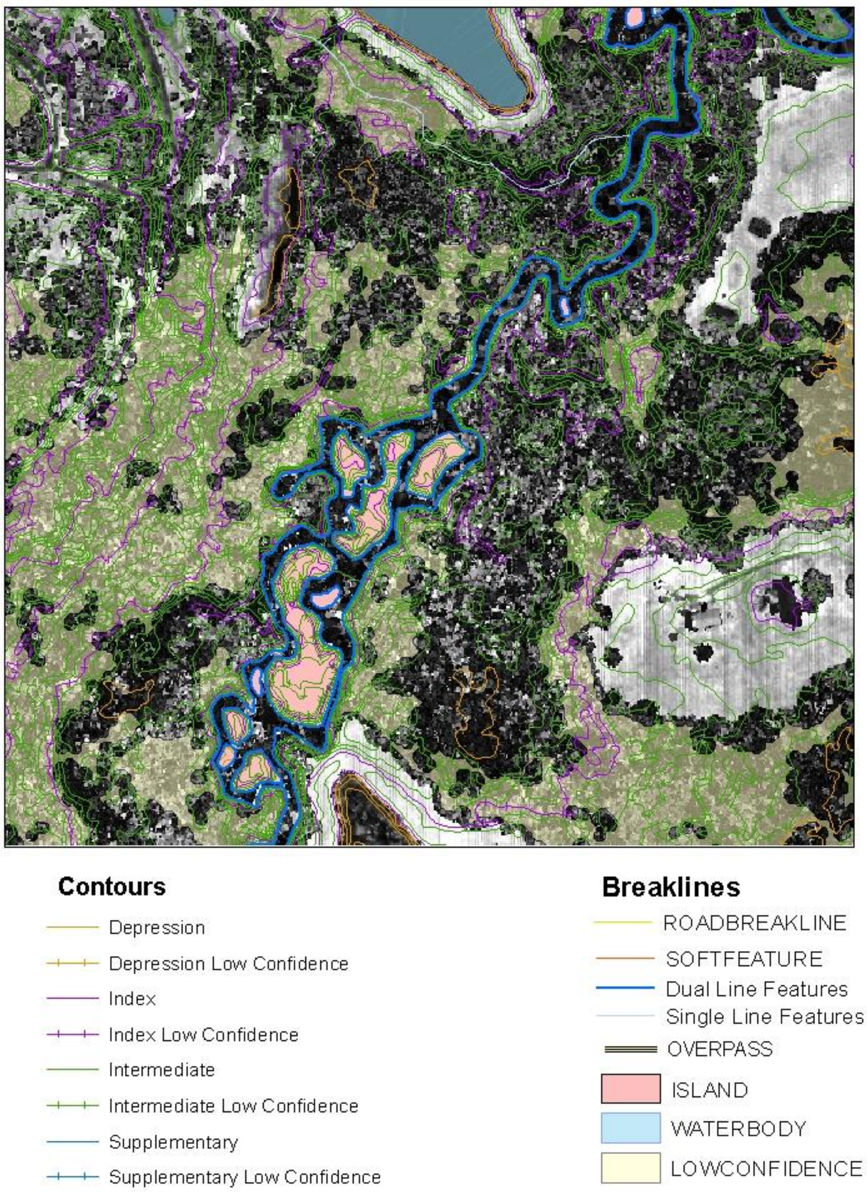

Figure 1. Example linear hydrographic feature breaklines from tile # 55986

Closed Water Body Features

Closed water body features with an area of one-half acre or greater are correctly captured as three-dimensional closed polygons with a constant elevation that reflects the best estimate of the water elevation at the time of data capture. “Donuts” exist where there are islands within a closed water body feature. Figure 2 shows example breaklines and contours of closed water body features.

Figure 2. Example closed water body feature breaklines from tile #54789

Road Features

Road edge of pavement features are correctly captured as three-dimensional breaklines on both sides of paved roads for major paved roads. Box culverts are continued as edge of pavement. Runways, unpaved surfaces, and residential roads are not captured within this feature class. Each vertex maintains vertical integrity. Figure 3 shows example breaklines and contours of road features.

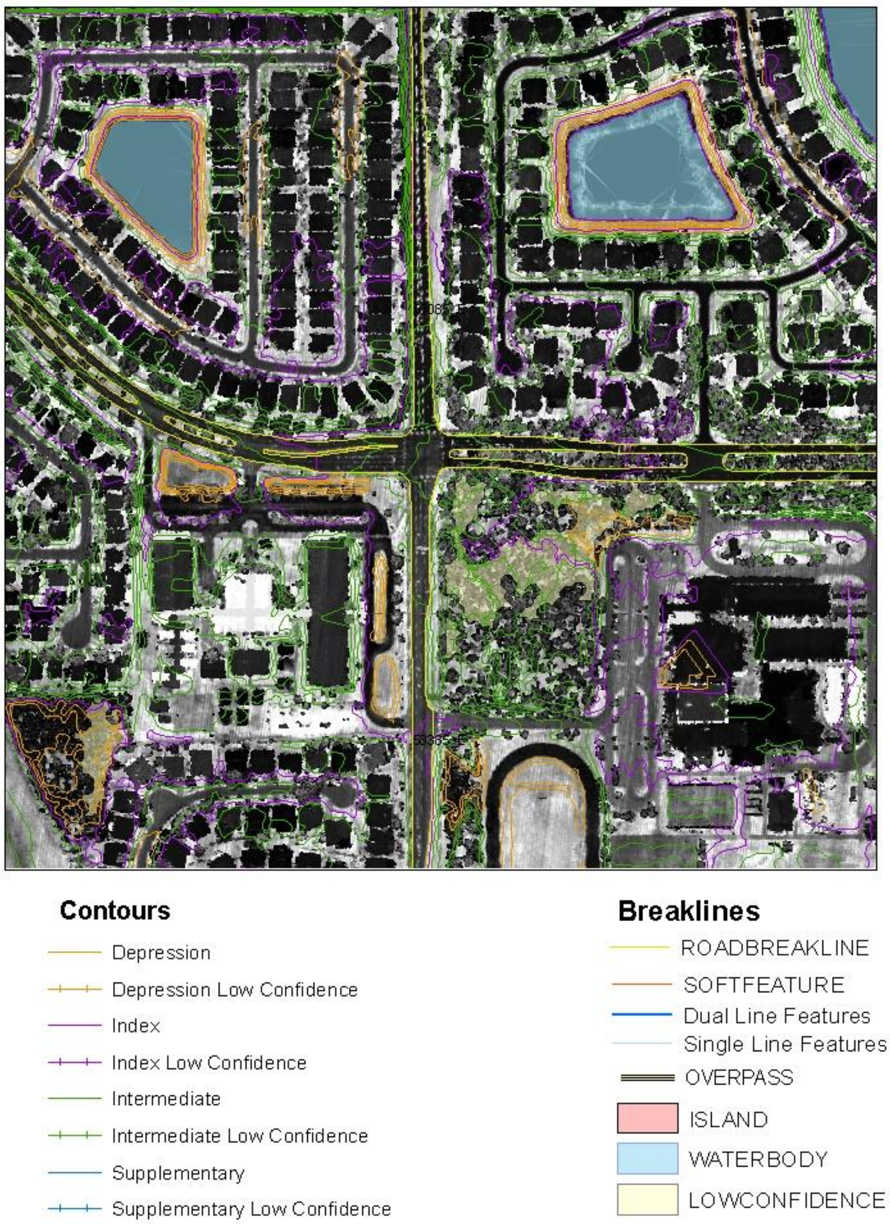

Figure 3. Example road feature breaklines and contours from tiles #58085, 58385.

Bridge and Overpass Features

Bridges and overpasses are correctly captured as three-dimensional breaklines, capturing the edge of pavement on the bridge, rather than the elevation of guard rails or other bridge surfaces. Each vertex maintains vertical integrity. Figure 4 shows example breaklines and contours of bridge and overpass features.

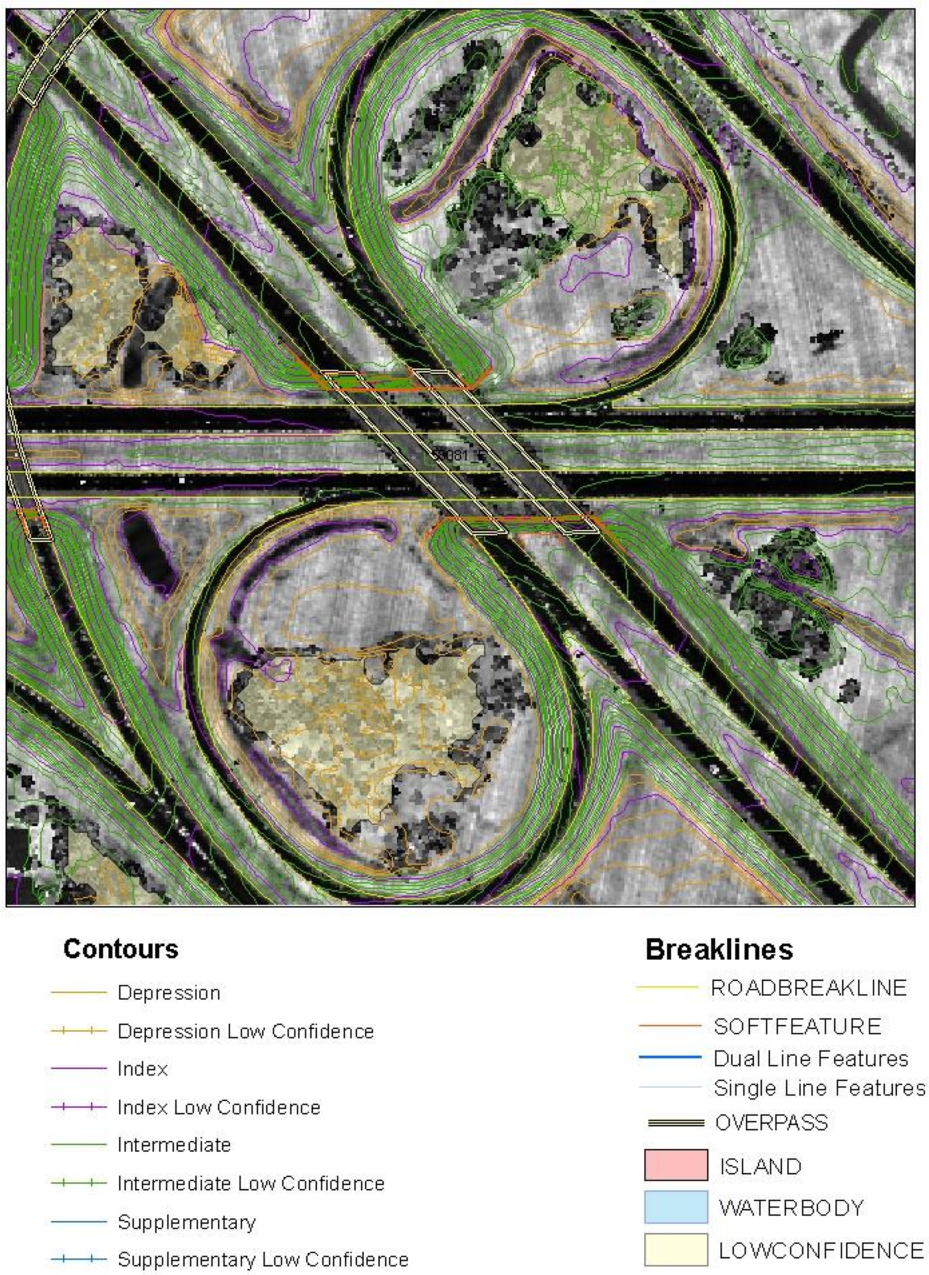

Figure 4. Example bridge and overpass feature breaklines and contours from tile # 58081

Soft Features

Soft features such as ridges, valleys, top of banks, etc. are correctly captured as three-dimensional breaklines so as to support better hydrological modeling of the LiDAR data and contours. Each vertex maintains vertical integrity. Figure 5 shows example breaklines and contours of soft features.

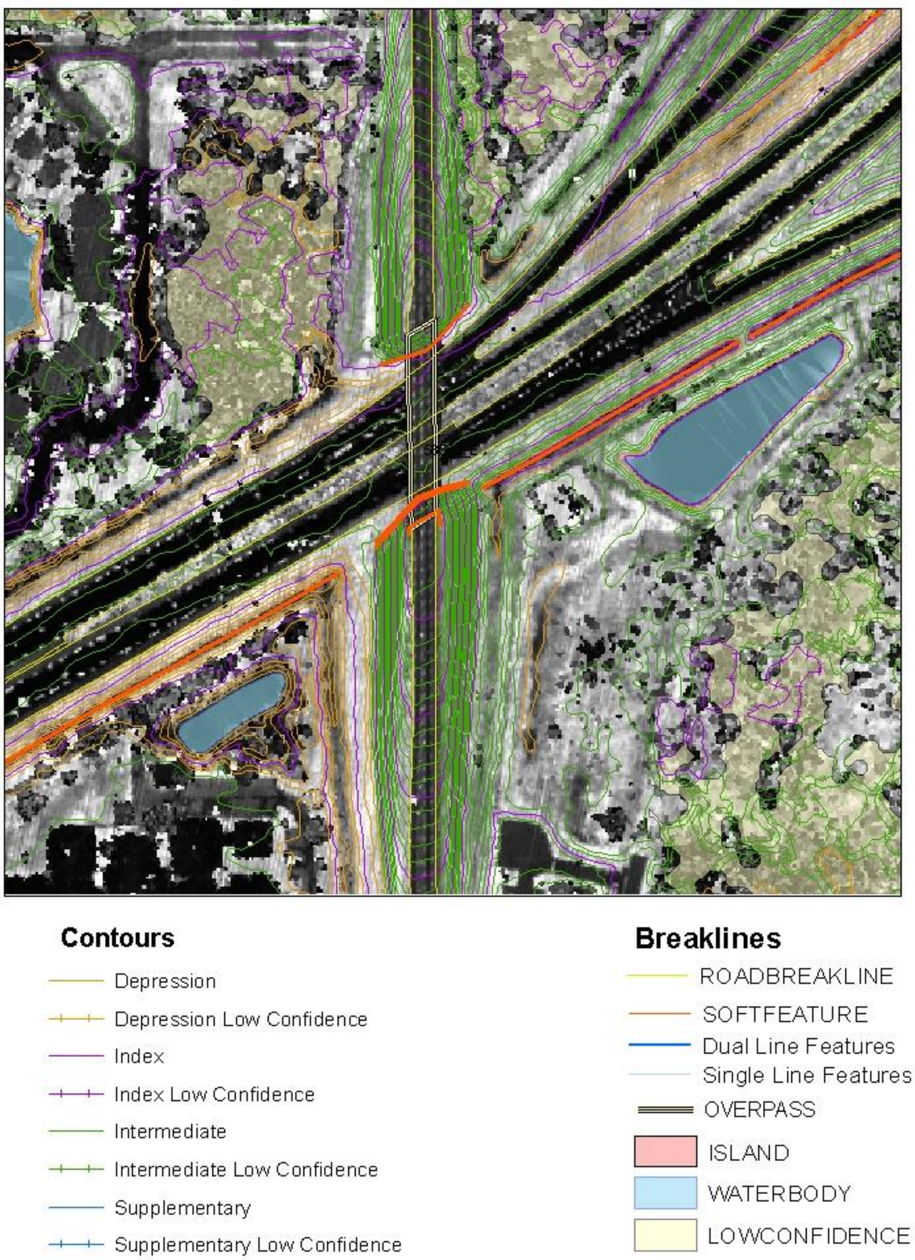

Figure 5. Example soft feature breaklines and contours from tile #58080

Island Features

The shorelines of islands are correctly captured as three-dimensional breaklines for island features one-half acre in size or greater. All natural and man-made islands are depicted as closed polygons with constant elevation. Figure 6 shows example breaklines and contours for island features.

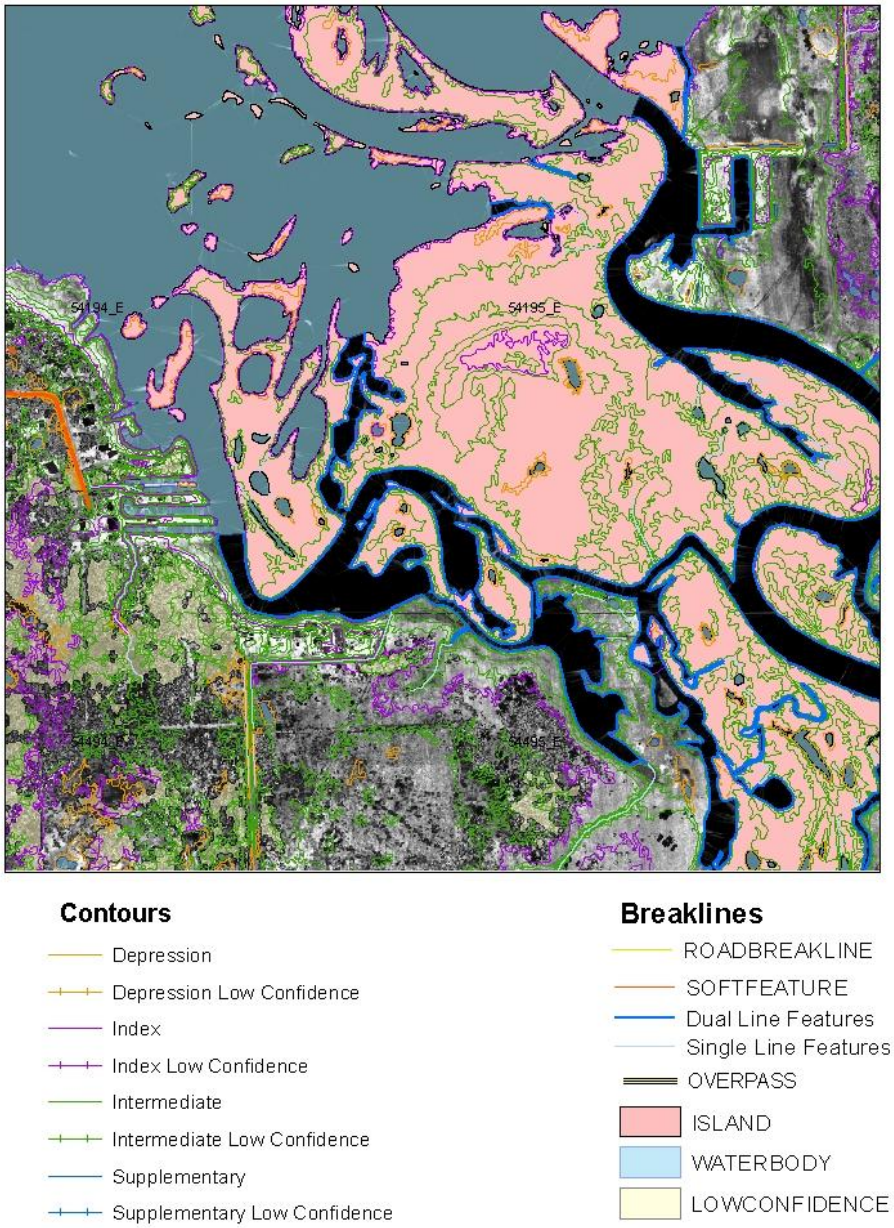

Figure 6. Example island feature breaklines and contours from tiles # 54195, 54194, 54495

Low Confidence Areas

The apparent boundary of vegetated areas (1/2 acre or larger) that are considered obscured to the extent that adequate vertical data may not be clearly determined to accurately define the DTM are correctly captured as two-dimensional features with no z-values. Figure 7 shows example breaklines and contours for low confidence areas.

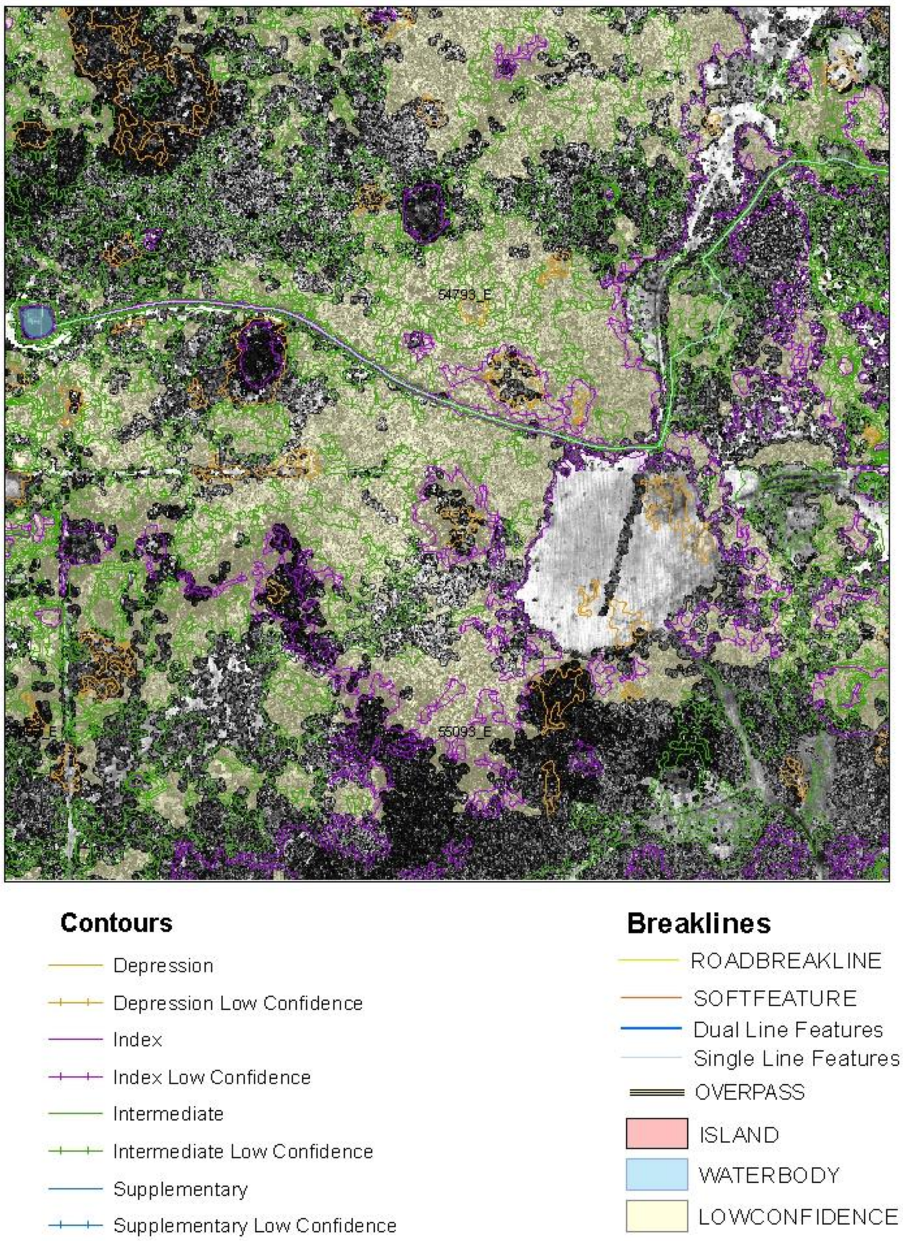

Figure 7. Example low confidence area feature breaklines from tile # 54793, 55093

Hydrographic/Waterbody Connectivity

Hydrographic features and waterbodies were connected when supported by the LiDAR data. When the LiDAR data did not fully support a connection between features, the connection was not forced as this would have the effect of "burning" breaklines in the LiDAR surface data. Merrick determined breakline collection and connectivity using MARS software, which allows the user to query and profile LiDAR surface data displayed as a TIN and create contours for the areas in question. Dewberry reviewed and checked the breaklines using profiles and surface query tools on Terrains created from the LiDAR bare earth data. Below are examples of where features were connected and where features were not connected due to conflicts with the LiDAR data.

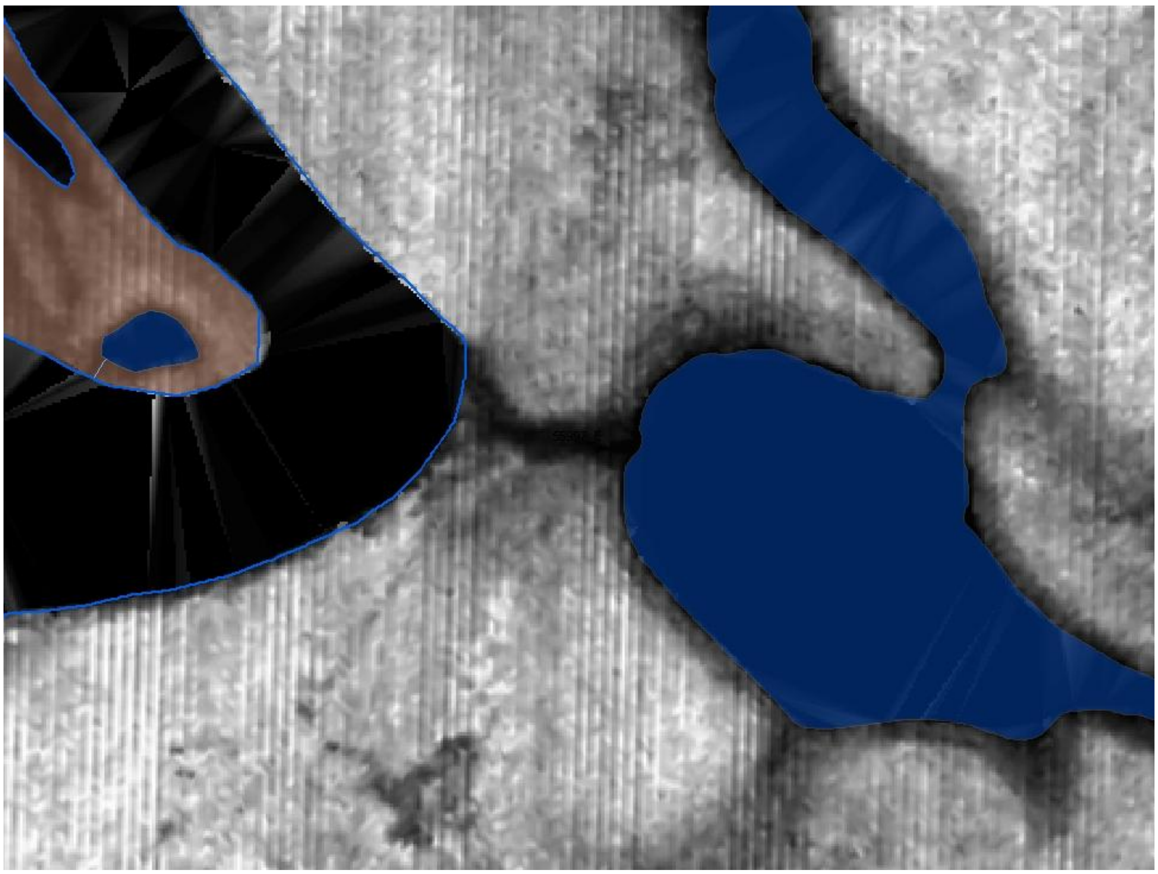

Figure 8. Intensity Imagery showing possible connection between hydrographic (blue line on left) and waterbody (blue polygon on right) features in Tile #55997.

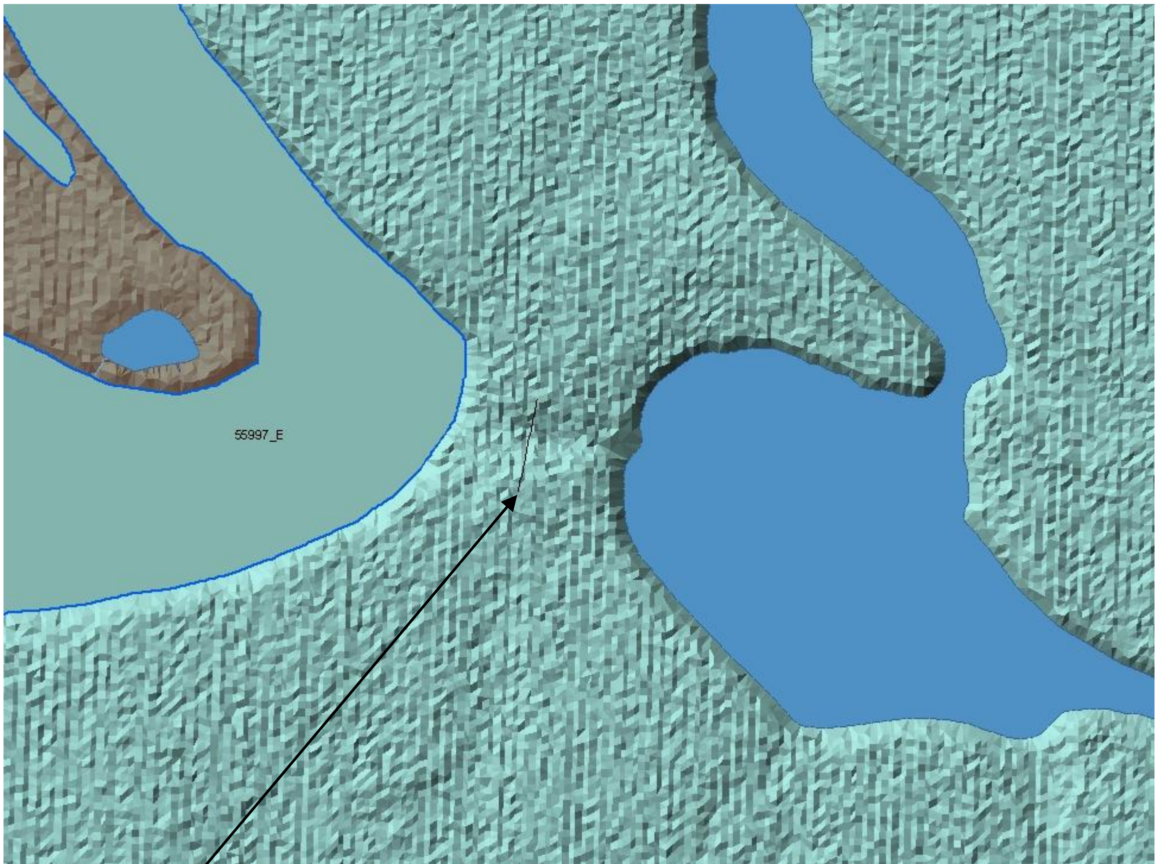

Figure 9. Terrain with hydrographic and waterbody enforced. Profile drawn across area in question.

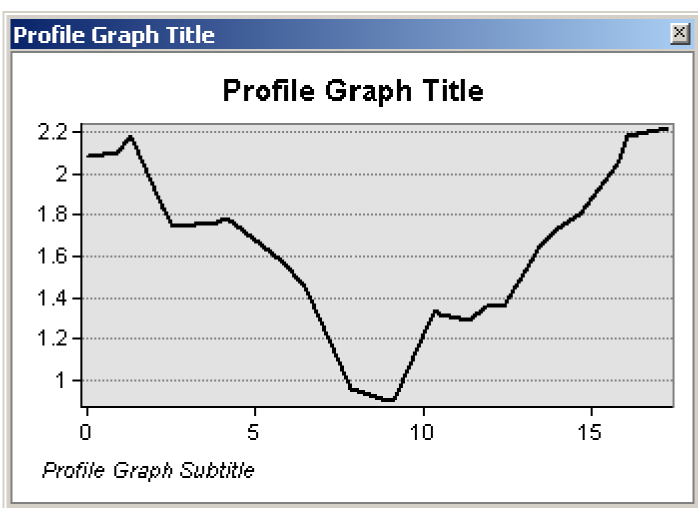

Figure 10. Profile Graph from above image.

The profile created on the terrain above does confirm there is a channel in this area. However, if a profile is drawn from hydrographic feature to waterbody (or vice versa), as the water would flow, then the profile shows that the LiDAR does not support connection between the two features as there is a high point. In order to connect the two features, the breakline would have to “burn” through the LiDAR surface by approximately 1 foot in elevation.

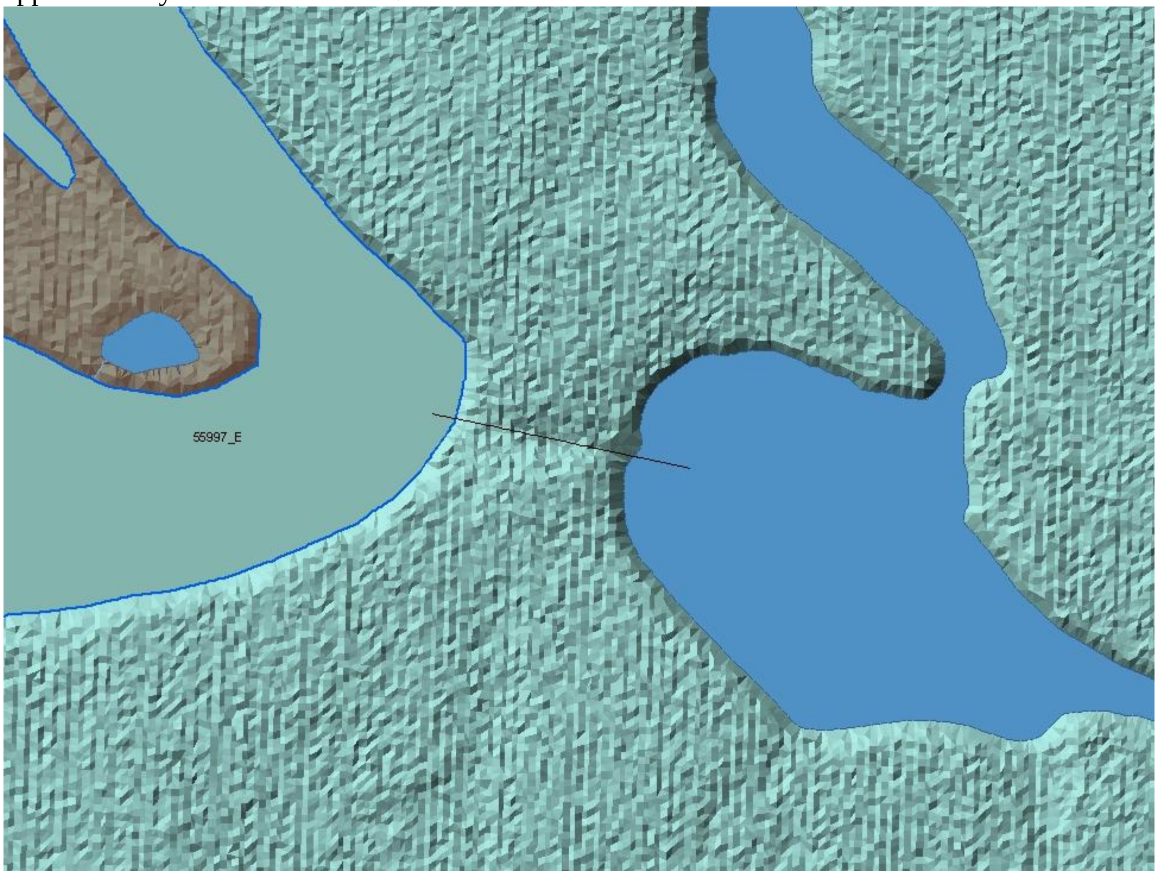

Figure 11. Terrain with hydrographic and waterbody enforced. Profile drawn between the two water features rather than across channel.

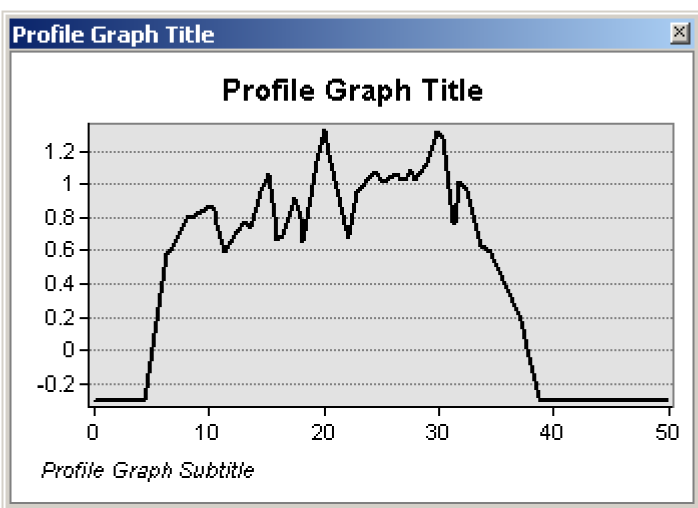

Figure 12. Profile Graph from above image showing high point between the two features.

While at some point, with a higher water level, the hydrographic and waterbody features will most likely be connected, the breaklines should maintain consistency with the LiDAR data as much as possible and not enforce potential channels, but current channels reflected in the LiDAR.

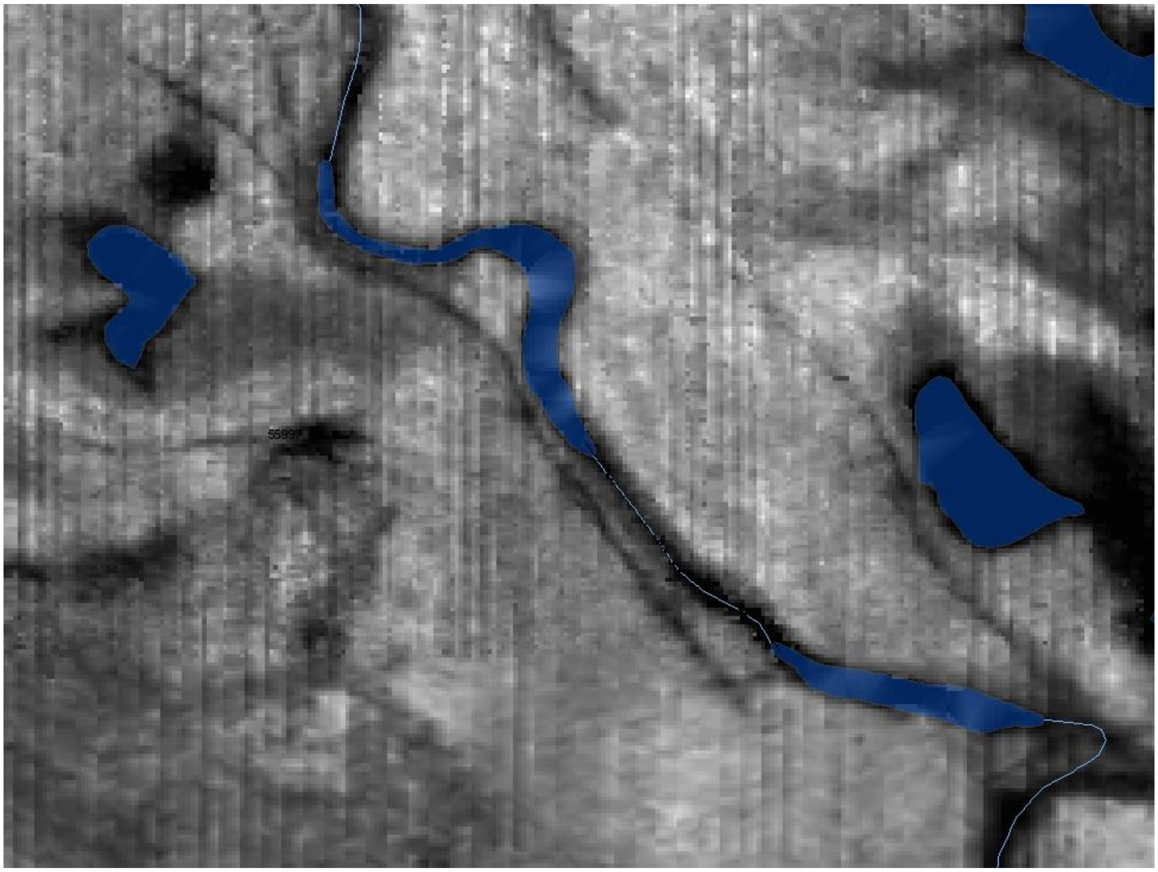

Figure 13. Intensity Imagery showing area where waterbodies (polygons in blue) were connected with single hydrographic features (polylines in light blue) in Tile #55997.

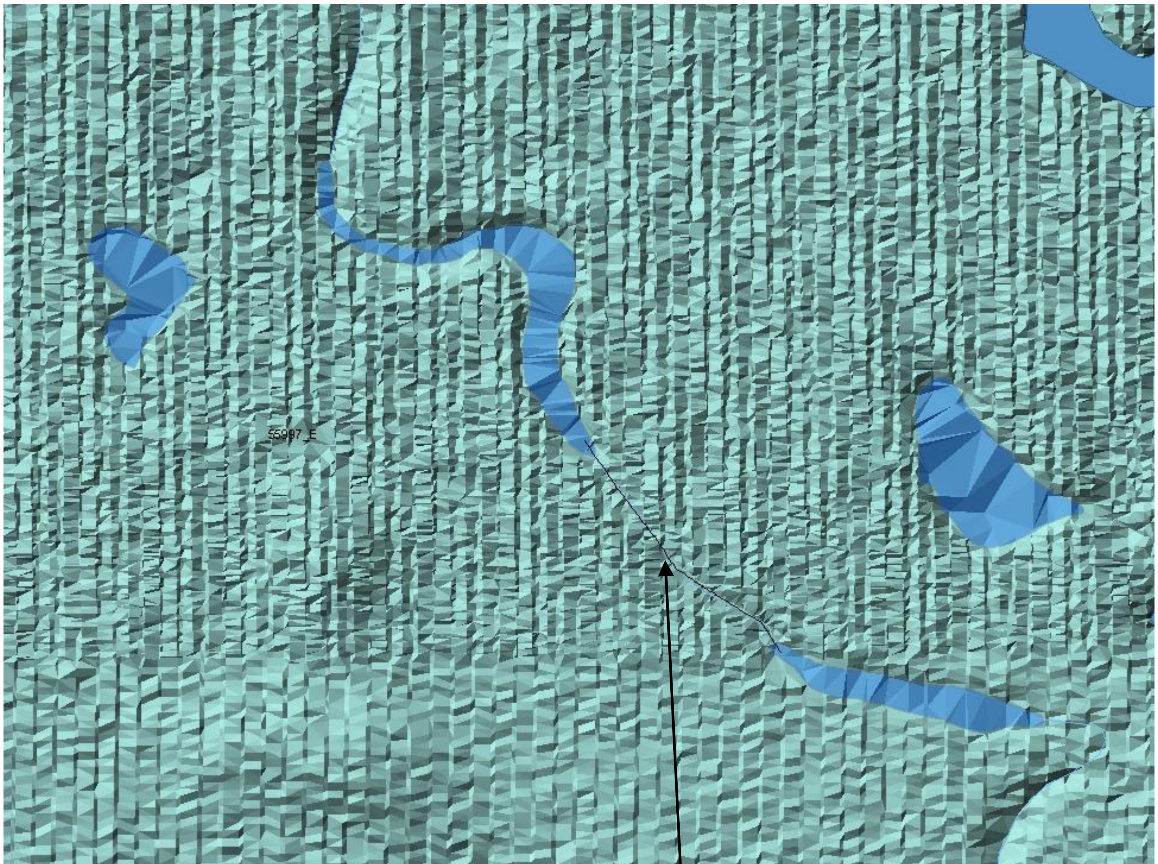

Figure 14. Terrain where breaklines have not been enforced. Profile has been drawn from waterbody to waterbody, along the stream channel.

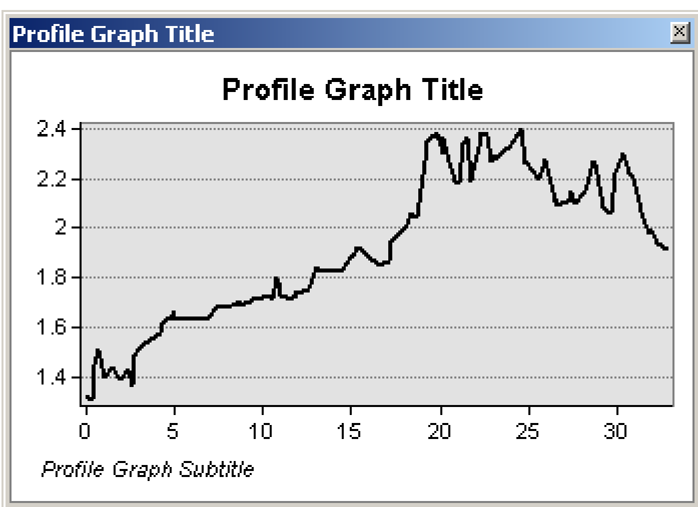

Figure 15. Profile Graph from above image showing slope of channel.

Figures 13-15 show an area where two waterbodies were connected with a single line hydrographic feature. The profile was drawn on a terrain where the breaklines were not enforced so the profile would reflect the LiDAR surface data before it is influenced by the breaklines. The profile shows a more continuous slope as it moves from the lower waterbody to the upper waterbody. Because there are no large plateaus or significant areas of data the breaklines would have to “burn” through, the two waterbodies were connected. The breakline connecting the two waterbodies will smooth out some of the “noise” that is normal for LiDAR data in order to hydro-enforce the surface and keep the breakline monotonic, but it will follow the slope of the LiDAR, maintaining consistency with the LiDAR surface.

Appendix I: Geodatabase Structure