FINAL REPORT OF SPECIFIC PURPOSE LIDAR SURVEY

LiDAR, Breaklines and Contours for

Levy County, Florida

State of Florida

Division of Emergency Management

Contract 07-HS-34-14-00-22-469

Task Order 20070525-492718a

PDS Task Order B

October 30, 2009

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Report of Specific Purpose LiDAR Survey, LiDAR-Generated Breaklines and Contours Levy County, Florida

Type of Survey: Specific Purpose Survey

This report pertains to a Specific Purpose LiDAR Survey of Levy County, Florida, conducted in the summer of 2007, and breaklines and contours generated in 2007 and 2008, for the Florida Division of Emergency Management (FDEM).

The LiDAR dataset, breaklines and contours were prepared by the Program and Data Solutions (PDS) team under FDEM contract 07-HS-34-14-00-22-469, Task Order 20070525-492718a (PDS Task Order B). The LiDAR dataset of Levy County was acquired by The Sanborn Map Company (Sanborn) in the summer of 2007 and processed to a bare-earth digital terrain model (DTM); it was produced to FDEM vertical accuracy specifications that differ from NOAA specifications in other LiDAR datasets of the Florida Panhandle, as summarized in Table 1.

Table 1. Comparison of FDEM and NOAA Vertical Accuracy Criteria

Vertical Accuracy Criteria	FDEM Specifications	NOAA Specifications
Fundamental Vertical Accuracy (FVA) at the 95% confidence level, in open terrain (non-vegetated) land cover only	≤ **18.2-cm** (0.60-ft) (based on $RMSE_z$ of 9.25-cm x 1.9600)	≤ **29.4-cm** (0.96-ft) (based on $RMSE_z$ of 15-cm x 1.9600)
Consolidated Vertical Accuracy (CVA) at the 95% confidence level, in all land cover categories combined	≤ **36.3-cm** (1.19-ft) (based on 95th percentile) or $RMSE_z$ of 18.5-cm x 1.9600	≤ **36.3-cm** (1.19-ft) (based on 95th percentile) or $RMSE_z$ of 18.5-cm x 1.9600

Under Task Order B, this is one of 12 similar county reports prepared by the PDS team of coastal areas along the Florida Panhandle, from Escambia County through Levy County, considered by FDEM to be vulnerable to hurricane tidal surges. Of these 12 reports, those for coastal Escambia, Santa Rosa, Walton and northern Bay County are based on LiDAR data previously acquired in support of the Northwest Florida Water Management District (NWFWMD) and produced to different accuracy specifications as indicated in Table 1 and to different point densities. The LiDAR datasets produced for Escambia, Santa Rosa and Walton counties were produced by three different NOAA contractors, but with independent QA/QC by Dewberry.

The reports for coastal areas of Levy County, as well as Okaloosa, Bay, Gulf, Franklin, Wakulla, Jefferson, Taylor and Dixie Levy counties are based on LiDAR data acquired in 2007 by the PDS team under the referenced FDEM contract, produced to the more-rigorous FDEM specifications. Detailed breaklines and contours were produced by the PDS team for areas to be mapped/improved as identified by a tile index provided by FDEM to PDS. Each tile covers an area of 5000 ft by 5000 ft. The map at Appendix A displays the 732 tiles of Levy County for which LiDAR DTMs and LiDAR-derived breaklines and contours were produced by the PDS team under Task Order B. To avoid double counting, tiles on the county border with Dixie County were delivered only in one county dataset — normally whichever county included the majority of the area of each 5000 ft by 5000 ft tile.

Rather than describe only the data provided of Levy County in isolation, this report also explains the differences between LiDAR datasets acquired of Escambia, Santa Rosa and Walton counties and those of other counties in the Florida Panhandle produced to different specifications. In addition to the differences in vertical accuracy criteria, summarized in Table 1, there are also differences in the geodetic control used for the different contracts, and there are different point densities between the data acquired to NOAA specifications and data acquired to FDEM Baseline Specifications:

- For the nine new counties mapped by the PDS team for FDEM in the Florida Panhandle under Task Order B, a rigorous geodetic control network was established by the PDS team for all coastal counties between Okaloosa and Levy counties, but excluding Walton County which had been previously mapped by NOAA. Thus, the survey control used for Escambia, Santa Rosa, and Walton counties may differ from the geodetic control network established for the nine other counties in the Panhandle. Primarily because a rigorous geodetic control network was surveyed by the PDS team for the nine new counties, it is expected that there will be differences in the elevations of topographic surfaces between counties, primarily around the boundaries of Escambia, Santa Rosa and Walton counties where the 2006 LiDAR datasets, controlled to older survey control, merge with the 2007 LiDAR datasets controlled to the new geodetic control network established by the PDS team.
- For the nine new counties, including Levy County, the FDEM Baseline Specifications require a maximum post spacing of 4 feet, i.e., an average point density of less than 1 point per square meter. However, the PDS team required a much higher point density of its subcontractors in order to increase the probability of penetrating dense foliage during the mandated summer acquisition; with nominal post spacing of 0.7 meters per flight line and 50% sidelap between flight lines, the average point density is 4 points per square meter. The NOAA specifications for Escambia County, Santa Rosa County, Walton County, and northern Bay County, required a nominal post spacing of 2 meters, yielding an average point density of 0.25 points per square meter. The significance of this difference is that the nine new counties acquired for FDEM, including Levy County, have LiDAR point densities approximately 16 times higher than the LiDAR point densities in Escambia County, Santa Rosa County, Walton County, and northern Bay County. With higher point density there is a greater probability of penetrating dense vegetation and minimizing areas defined as "low confidence areas."

The PDS Team

PDS is a Joint Venture consisting of PBS&J, Dewberry, and URS Corp:

- PBS&J provided local client liaison in Tallahassee. PBS&J was also responsible for the overall ground survey effort including management of field survey subcontractors – Allen Nobles & Associates, Inc. (ANA) and Diversified Design & Drafting Services, Inc. (3DS) – which performed the geodetic control surveys and quality assurance/quality control (QA/QC) checkpoint surveys used for independent accuracy testing by Dewberry and URS. These surveyors executed a network adjustment of control points used throughout the Florida Panhandle. It was important to execute this network adjustment because of widely-held concerns that the survey control was deficient in the Florida Panhandle counties. Mr. Glenn Bryan, PSM, of PBS&J, and Mr. Brett Wood, PSM, of 3DS, were the technical leads for the control surveys and QA/QC surveys.

- Dewberry was responsible for the overall Work Plan and aerial survey effort for the nine new counties, including management of LiDAR subcontractors that performed the LiDAR data acquisition and post-processing and produced LAS classified data. A staff of QA/QC specialists at Dewberry's Fairfax (VA) office performed quality assessments of the breaklines and contours. Dewberry served as the single point of contact with FDEM. Dr. David Maune, PSM, was Dewberry's technical lead for the digital orthophoto and LiDAR surveys and derived products. Under separate contract with NOAA, Dr. Maune had previously served as Dewberry's Quality Manager for its independent QA/QC of LiDAR data produced by NOAA for the NWFWMD of Escambia, Santa Rosa, and Walton counties.

- URS Corp. was responsible for data management and information management. URS developed the GeoCue Distributed Production Management System (DPMS), managed and tracked the flow of data, performed independent accuracy testing and quality assessments of FDEM's new LiDAR data acquired in 2007, tracked and reported the status of individual tiles during production, and produced all final deliverables for FDEM. Mr. Robert Ryan, CP, of URS, was the technical lead for this effort.

Name of Company in Responsible Charge

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Name of Responsible Surveyor

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Survey Area

The project area for this report encompasses approximately 656 square miles within Levy County and small adjoining areas of Dixie County.

Map Reference

There are no hardcopy map sheets for this project. The map at Appendix A provides graphical reference to the 5000-ft x 5000-ft tiles covered by this report.

Summary of FDEM Baseline Specifications

All new data produced for FDEM under the referenced contract are required to satisfy the Florida Baseline Specifications, included as appendices to PDS's Task Order B, dated May 23, 2007, from FDEM. To expedite production, the Florida Baseline Specifications were modified by FDEM to require new LiDAR data acquisition during the summer of 2007 (leaf-on) as opposed to the normal leaf-off.

Task Order B presented demanding technical challenges for the PDS team because the existing geodetic control monuments in the Florida Panhandle are believed to be the most inaccurate in Florida, with elevation discrepancies as much as several feet; and some areas in the Panhandle are subject to subsidence. LiDAR elevations produced relative to some survey control monuments are believed to differ by as much as several feet from LiDAR elevations produced relative to other control monuments in the Panhandle. This caused a new geodetic control network to be established by the PDS team for the counties to be newly surveyed, but without adjusting the geodetic control monuments used for Escambia

County, Santa Rosa County, Walton County, and northern Bay County for which existing LiDAR data was used "as is."

The official State Plane Coordinate System tiling scheme was provided by FDEM to the PDS team on July 10, 2007 for Florida's North Zone and West Zone. The Levy County tiling footprint graphics are shown at Appendix A for tiles delivered in the West zone.

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*, originally called *obscured vegetated 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 required 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.

To meet and exceed these specifications for the nine new county LiDAR datasets, the PDS team established the following more-rigorous specifications for its LiDAR subcontractors:

- Instead of a 20˚ FOV on either side of nadir, the PDS team limited the FOV to 18˚
- Instead of GPS baselines ≤ 20 miles, the PDS team limited baseline lengths to ≤ 20 km, except in one small isolated area where the baseline length was approximately 23 km (14 miles).
- Instead of 4 foot post spacing which yields an average of 0.67 points per m^2, the PDS team chose 0.7 m point spacing and 50% sidelap that yields an average of more than 4 points per m^2. Thus, the PDS team's average point density is nearly 6 times higher than required by FDEM, greatly increasing the probability of LiDAR points penetrating through dense vegetation so as to minimize areas defined as *low confidence areas*. The PDS team defines *low confidence areas* as vegetated areas of ½ acre or larger that are considered obscured to the extent that adequate vertical data cannot be clearly determined to accurately define the DTM. Such areas indicate where the vertical data may not meet the data accuracy requirements due to heavy vegetation.

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

- Class 12 = Overlap, including areas of overlapping flight lines which have been deliberately removed from Class 1 because of their reduced accuracy.

Table 2 compares the LiDAR LAS classes specified by the FDEM and NOAA specifications.

Table 2. Comparison of FDEM and NOAA LAS Classes

FDEM LAS Classes	NOAA LAS Classes
Class 1 – Unclassified, including vegetation, buildings, bridges, piers Class 2 – Ground points (used for contours) Class 7 – Noise Class 9 – Water[1] Class 12 – Overlap points deliberately removed	Class 1 – Unclassified Class 2 – Ground points (used for contours) Class 9 – Water

For each 500 square mile area within the nine new county datasets, a total of 120 "blind" QA/QC checkpoints were surveyed, totally unknown to (i.e., "blind" from) the LiDAR subcontractors. Each set of 120 QA/QC checkpoints had the goal to include 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

In a few cases, there were insufficient dispersed areas to acquire 30 QA/QC checkpoints for one or more land cover categories; when this occurred, Dewberry advised the surveyors to select additional QA/QC checkpoints for land cover categories that were predominant in the area and therefore more representative of the area being tested.

The following vertical accuracy guidelines were specified by the Florida Baseline Specifications:

- In category 1, the $RMSE_z$ must be ≤ 0.30 ft ($Accuracy_z \leq 0.60$ 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 ($Accuracy_z \leq 1.19$ 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 be lower or higher than the bare earth terrain. This is equivalent to the accuracy expected of 2 ft contours in such terrain.

[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.

- 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 lower or 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 consists of nine types of breaklines, produced in accordance with the PDS team'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 includes 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 PDS team's Data Dictionary at Appendix C.

Table 3 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 3. 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 of Levy County, 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 the PDS team and listed at Appendix E.

Instead of delivering one vertical accuracy report, using 120 QA/QC checkpoints for each 500 square miles of the project area, separate reports are delivered for each county. Therefore, individual county vertical accuracy reports may be based on fewer than or more than 120 QA/QC checkpoints, depending on whether the area mapped in each county is smaller than or larger than 500 square miles. Regardless, the average density of QA/QC checkpoints remains the same on average for each countywide report.

Datums and Coordinates: North American Datum of 1983 (NAD 83)/HARN for horizontal coordinates and North American Vertical Datum of 1988 (NAVD 88) for vertical coordinates. All coordinates are Florida State Plane Coordinate System (SPCS) in U.S. Survey Feet. All counties listed are in the Florida SPCS North Zone, except for Levy County which is delivered in both Florida SPCS North and West Zones. Levy County is normally in the West Zone but the LiDAR data are also delivered in the North Zone for ease in merger with all Panhandle counties for SLOSH modeling of all counties from Escambia through Levy.

Appendix I to this report provides the Geodatabase structure for all digital vector deliverables in Levy County.

Acronyms and Definitions

3DS	Diversified Design & Drafting Services, Inc.
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
ANA	Allen Nobles & Associates, Inc.
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
GIS	Geographic Information System Surveyor
LAS	LiDAR data format as defined by ASPRS
LiDAR	Light Detection and Ranging
LMSI	Laser Mapping Specialists Inc.
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
NWFWMD	Northwest Florida Water Management District
PDS	Program & Data Solutions, joint venture between PBS&J, Dewberry and URS Corp
PS	Photogrammetric Surveyor
PSM	Professional Surveyor and Mapper (Florida)
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
SLOSH	Sea, Lake, and Overland Surges from Hurricanes
SRWMD	Suwannee River Water Management District
SVA	Supplemental Vertical Accuracy, defined by the NDEP and ASPRS

TIN	Triangulated Irregular Network
VMAS	Vertical Map Accuracy Standard, defined by the NMAS

Ground Surveys and Dates

Past experience with control in the Florida Panhandle area indicated a need to improve the accuracy of the existing survey monuments. For the nine newly-mapped counties in the Florida Panhandle, including Levy County, the PDS team established a geodetic control network to provide accurate and consistent horizontal and vertical control for LiDAR and photogrammetric mapping using GPS technology. The project consisted of a Primary and two Secondary control networks supporting the mapping of approximately 6,113 square miles located in Northwest Florida. PBS&J managed the overall ground survey effort including management of field survey subcontractors, Allen Nobles & Associates, Inc. (ANA) and Diversified Design & Drafting Services, Inc. (3DS), which performed control surveys and QA/QC checkpoint surveys used for independent accuracy testing, and executed a network adjustment of control points used throughout the Florida panhandle.

The Primary network stations (see Figure 1) were used as base stations supporting the airborne GPS data acquisition, and as a consistent control framework for the more densely spaced Secondary control networks, and all subsequent control surveying activity on the project. They were setup at 40 kilometer spacing per the 2 centimeter requirements for Primary Control stated in the NOS NGS-58. The Primary Control network consisted of 55 stations, including 10 Continuously Operating Reference Stations (CORS), 27 existing monuments from the National Spatial Reference System (NSRS) and 18 new monuments set so as to limit LiDAR GPS baseline lengths to 20 Km relative to GPS base stations on either side of stations spaced ≈40 Km apart. Third order differential leveling was used to establish elevations on 20 Primary network stations in specific areas where published vertical stations could not be occupied directly with GPS. A minimally constrained (free) Least Squares adjustment was run to verify the internal accuracy of the Primary network. After evaluating and removing any outliers, a final free adjustment was generated, consisting of 191 independent vectors. The input error estimates were scaled by a factor of 14.90 which resulted in a properly weighted adjustment with a variance factor of 1.0154, with no flagged residuals. A constrained (fixed) 3-D horizontal adjustment was run using the same input error estimates as were used in the free adjustment; the variance factor was 1.3712 and there were no flagged residuals. A constrained (fixed) 1-D vertical adjustment was run using the same input error estimates as were used in the free adjustment; Station BE3991 was fixed in latitude, longitude and orthometric height; the variance factor was 1.2866 and there were no flagged residuals.

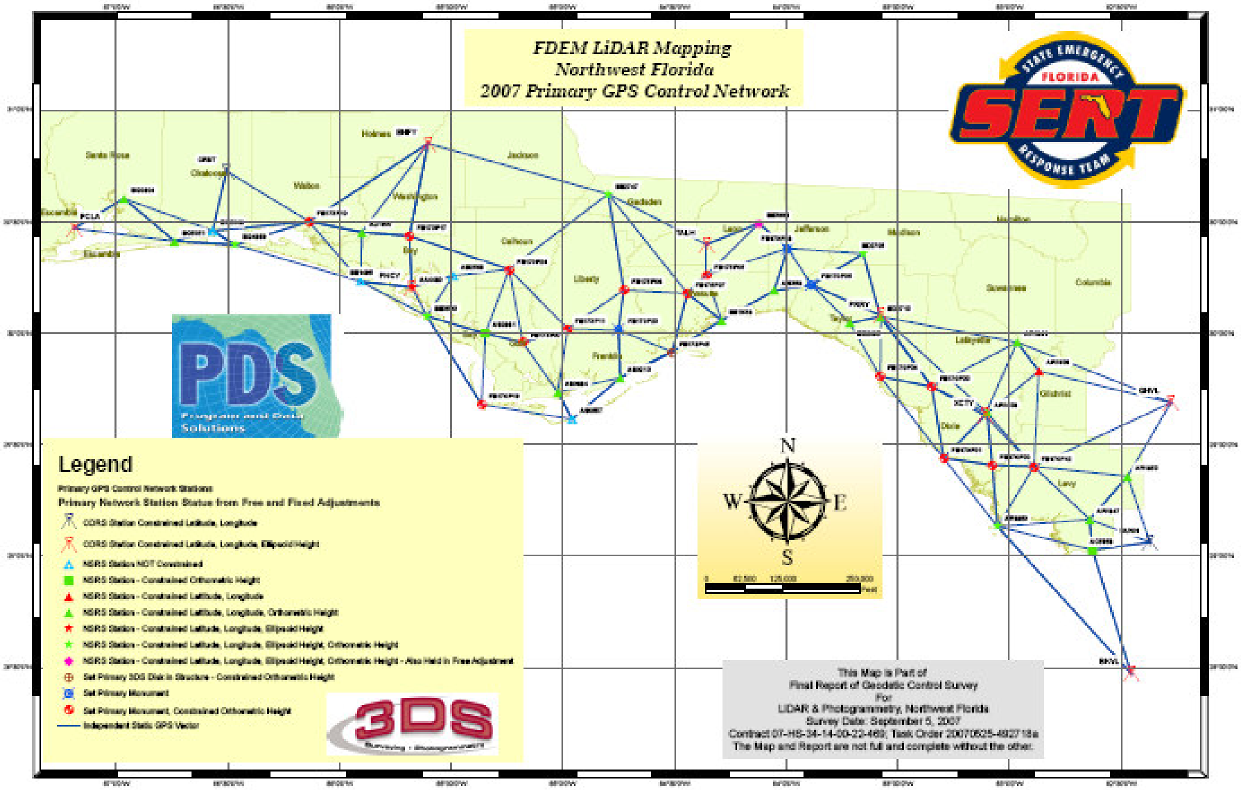


Figure 1. Primary Control Network

The Secondary network stations (see Figure 2) were used to support the measurement of both LiDAR and orthophoto QA/QC checkpoint sites. They were setup at 15 kilometer spacing per the 2 centimeter requirements for Secondary Control stated in NOS NGS-58.

The first Secondary Control network consisted of 4 stations in the Okaloosa County area. The second Secondary Control network consisted of all remaining mapping areas in the Florida Panhandle. The Secondary Control networks included a total of 80 control points, including 16 recovered NSRS monuments, 2 recovered DNR monuments, and 62 new monuments set for this network. A minimally constrained (free) Least Squares adjustment was run to verify the internal accuracy of the Secondary networks. After evaluating and removing any outliers, a final free adjustment was generated. This final free adjustment consisted of 254 independent vectors. The input error estimates were scaled by a factor of 6.234, which resulted in a properly weighted adjustment with a variance factor of 1.000; there were no flagged residuals. A constrained (fixed) 3-D horizontal adjustment was run using the same input error estimates as were used in the free adjustment; the variance factor was 1.6339 and there were six flagged residuals. A constrained (fixed) 1-D vertical adjustment was run using the same input error estimates as were used in the free adjustment; Station BE3991 was fixed in latitude, longitude and orthometric height; the variance factor was 1.2136 and there were no flagged residuals.

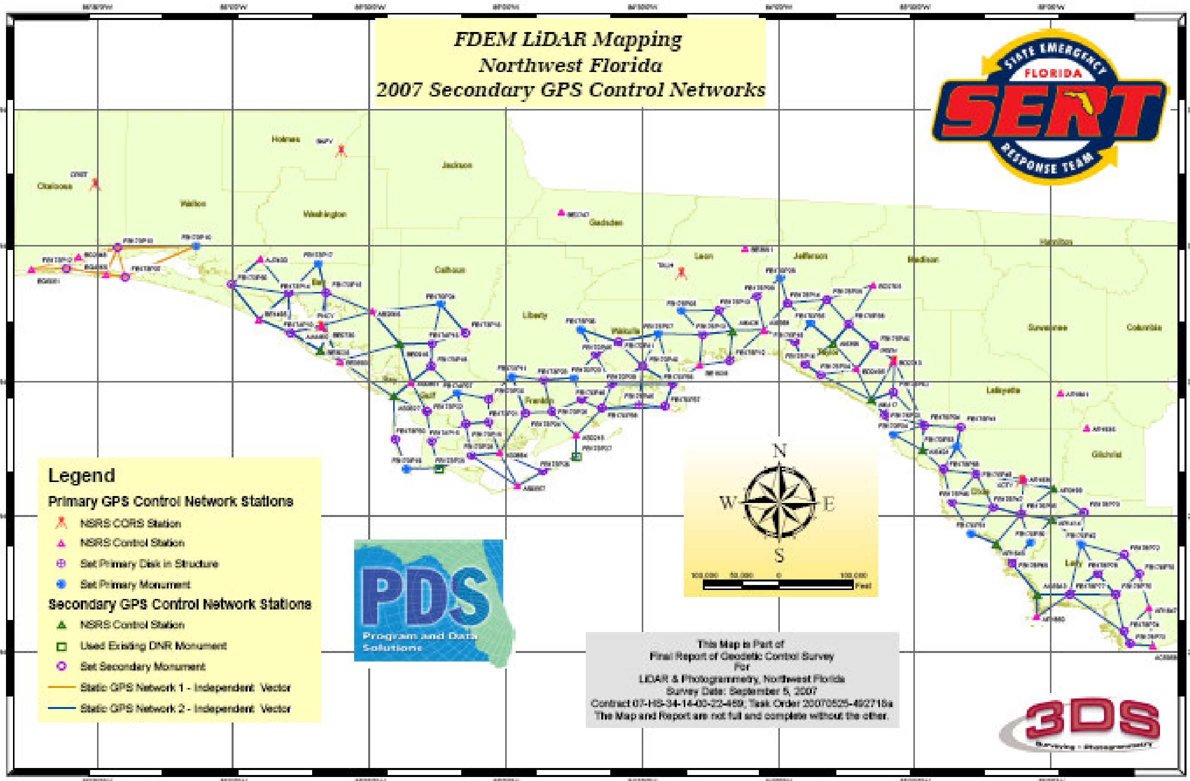


Figure 2. Secondary Control Networks

These GPS ground surveys were executed between May and September 2007. Full details are documented in 3DS's "Final Report of Geodetic Control Survey for LiDAR and Photogrammetry, Northwest Florida," dated March 13, 2008.

The QA/QC checkpoints used for this county are listed at Appendix E.

LiDAR Aerial Survey Areas and Dates

Sanborn collected the LiDAR data for Levy County during the summer of 2007.

LiDAR Processing Methodology

A LiDAR processing report from Sanborn is included at Appendix D.

LiDAR Vertical Accuracy Testing

URS performed the LiDAR vertical accuracy assessment for Levy County 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). NOAA's accuracy specifications are compared with FDEM's accuracy specifications at Table 1. NOAA's checkpoint requirements are compared with FDEM's checkpoint requirements at Table 4.

Table 4. Comparison of FDEM and NOAA Checkpoint Requirements

	FDEM Specifications	**NOAA Specifications**
Land cover categories tested by QA/QC checkpoints	Four land cover categories tested: 1. Open terrain; bare-earth, low grass 2. Brush lands and low trees 3. Forested areas 4. Urban, built-up areas	Five land cover categories tested: 1. Open terrain; bare-earth, low grass 2. Weeds and crops 3. Scrub 4. Forested areas 5. Urban, built-up areas
Number of checkpoints per category	20 checkpoints, per category, for each 500 square mile area	20 checkpoints, per category, for each countywide dataset

The LiDAR dataset of Levy County, delivered in May of 2008, passed the accuracy testing by URS as documented at Appendices E and 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, including Levy County, the FVA standard is .60 feet, corresponding to an $RMSE_z$ of 0.30 feet or 9.25 cm, the accuracy expected from 1-foot contours. ***In Levy County, the $RMSE_z$ in bare earth and low grass equaled 0.30 ft compared with the 0.30 ft specification of FDEM; and the FVA computed using $RMSE_z$ x 1.9600 was equal to 0.58 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. ***In Levy County, the CVA computed using $RMSE_z$ x 1.9600 was equal to 0.86 ft, compared with the 1.19 ft specification of FDEM; and the CVA computed using the 95^{th} percentile was equal to 0.85 ft. URS determined that the dataset passed the CVA standard.***

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. ***In Levy County, the SVA tested as 0.50 ft in bare earth and low grass, 0.93 ft in brush and low trees, 0.97 ft in forested areas, and 0.59 ft in urban terrain. All of these four land cover categories met theirs target value of 1.19 ft or less.***

The complete LiDAR Vertical Accuracy Report for Levy County is at Appendix F.

LiDAR Horizontal Accuracy Testing

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 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.
- ASPRS has been actively seeking to develop cost-effective techniques to use LiDAR intensity imagery to test the horizontal accuracy of LiDAR data. As recently as May 1, 2008, at the annual conference of ASPRS, the most relevant technique for doing so was in a paper entitled "New

Horizontal Accuracy Assessment Tools and Techniques for Lidar Data," presented by the Ohio DOT. Whereas the technique had research value, it was neither practical nor affordable for use in horizontal accuracy testing of FDEM data.

- Appendix A of FDEM's Baseline Specifications require 20 horizontal test points for every 500 square mile area of digital orthophotos to be produced, and Appendix B of FDEM's Baseline Specifications requires 120 vertical test points for each 500 square mile area of LiDAR data to be produced. The PDS task orders included no funding for the more-expensive horizontal checkpoints that would be certain to appear on LiDAR intensity images as clearly-defined point features.
- In addition to LiDAR system factory calibration of horizontal and vertical accuracy, each of the PDS team's LiDAR subcontractors have different techniques for field calibration checks used to determine if bore-sighting is still accurate. Sanborn's technique, used for Levy County, is explained at Appendix D. Sanborn's field calibration tests indicated the horizontal accuracy tested 2.274 feet at the 95 percent confidence level, well within FDEM's 3.8 foot specification.

LiDAR Qualitative Assessments

URS 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 riverine and coastal analysis, modeling, and mapping.

The main software programs used by URS 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
- *TerraModeler*: used for analysis and visualization
- *TerraScan*: runs inside of MicroStation; used for point classification and points file generation
- *GeoCue LAS EQC:* is also used for data analysis and edit

The following systematic approach was followed by URS in performing the cleanliness review and analysis:

- Uploaded data to the GeoCue data warehouse (enhanced data management)
    - LiDAR: cut the data into uniform tiles measuring 5,000 feet by 5,000 feet – using the State Plane tile index provided by FDEM
    - Imagery: Best available orthophotography was used to facilitate the data review. Additional LiDAR Orthos were created from the LiDAR intensity data and used for review purposes.
- Performed coverage/gap check to ensure proper coverage of the project area

    - Created a large post grid (~30 meters) from the bare-earth points, which was used to identify any holes or gaps in the data coverage.
- Performed tile-by-tile analyses
    - Using TerraScan and LAS EQC, checked for gross errors in profile mode (noise, high and low points)
    - Reviewed each tile for anomalies; identified problem areas with a polygon, annotated comment, and screenshot as needed for clarification and illustration. Used ortho imagery when necessary to aid in making final determinations with regards to:
        - Buildings left in the bare-earth points file
        - Vegetation left in the bare-earth points file
        - Water points left in the bare-earth points file
        - Proper definition of roads
        - Bridges and large box culverts removed from the bare-earth points file
        - Areas that may have been "shaved off" or "over-smoothed" during the auto-filtering process
- Prepared and sent the error reports to LiDAR firm for correction
- Reviewed revisions and comments from the LiDAR firm
- Prepared and submitted final reports to FDEM

The LiDAR data of Levy County was processed to a bare-earth terrain surface by Sanborn, as explained at Appendix D. The LiDAR dataset provided to URS for accuracy and qualitative assessment passed, as explained at Appendix E, Appendix F and Appendix G.

Breakline Production Methodology

Sanborn used GeoCue software to develop LiDAR stereo models for Levy County. Using 3-D softcopy photogrammetric LiDARgrammetry procedures, and the LiDAR intensity imagery (stereo models), Sanborn stereo-compiled the eight types of *hard breaklines* in accordance with the Data Dictionary at Appendix C. The breaklines conform to data format requirements outlined by the FDEM Baseline Specifications.

For the *soft hydro breaklines*, Dewberry used 2.5-D techniques to digitize soft, linear hydrographic features first in 2-D and then used its GeoFIRM toolkit to drape the soft breaklines over the ESRI Terrain to derive the Z-values (elevations), also consistent with the Data Dictionary at Appendix C. All breakline compilation was performed under the direct supervision of an ASPRS Certified Photogrammetrist and Florida Professional Surveyor and Mapper (PSM). The breaklines conform with data format requirements outlined by the FDEM Baseline Specifications.

Whereas flowing rivers and streams are "hydro-enforced" to depict the downward flow of water, dry drainage features are not "hydro-enforced" but deliberately include undulations that more-accurately represent the true topography. This is, in fact, the ideal situation for topographic mapping.

The five figures below demonstrate how the PDS team's high LiDAR point density (4 points per square meter) are used to penetrate dense vegetation and accurately map the dry drainage feature not visible from a normal digital orthophoto (Figure 1); the total density of the LiDAR point cloud (Figure 2); the density of LAS Class 2 points that penetrated to the ground (Figure 3); the color-coded Terrain to help in visualizing the variable elevations (Figure 4); and the soft hydro breakline that approximates the potential flow line of the dry drainage feature and the contours that clearly show the undulations in the Terrain (Figure 5). At Figure 5, the 9-foot contour lines are *depression contours* that surround elevation points that are lower than 9-feet. Although the undulations, by definition, are not "hydro-enforced," the PDS Team's PSM in responsible charge of this project considers it a violation of professional standards if one were to deliberately degrade the accurate Terrain, soft hydro breakline and contours in a dry drainage feature in order to "hydro-enforce" that feature by filling the depressions and falsely scalping off the higher undulations in order to make an idealized monotonic dry streambed out of the true undulating streambed. To "hydro-enforce" such a dry streambed would be to falsify the true topography of naturally undulating terrain. The soft hydro breaklines are part of the hydrographic feature class, but have a separate sub-class code, 3. This enables hydro-enforced hydrographic features, sub-class codes 1 and 2 for single and dual lines, to be distinguished from these non-hydro-enforced soft hydrographic features representing dry drainage features.

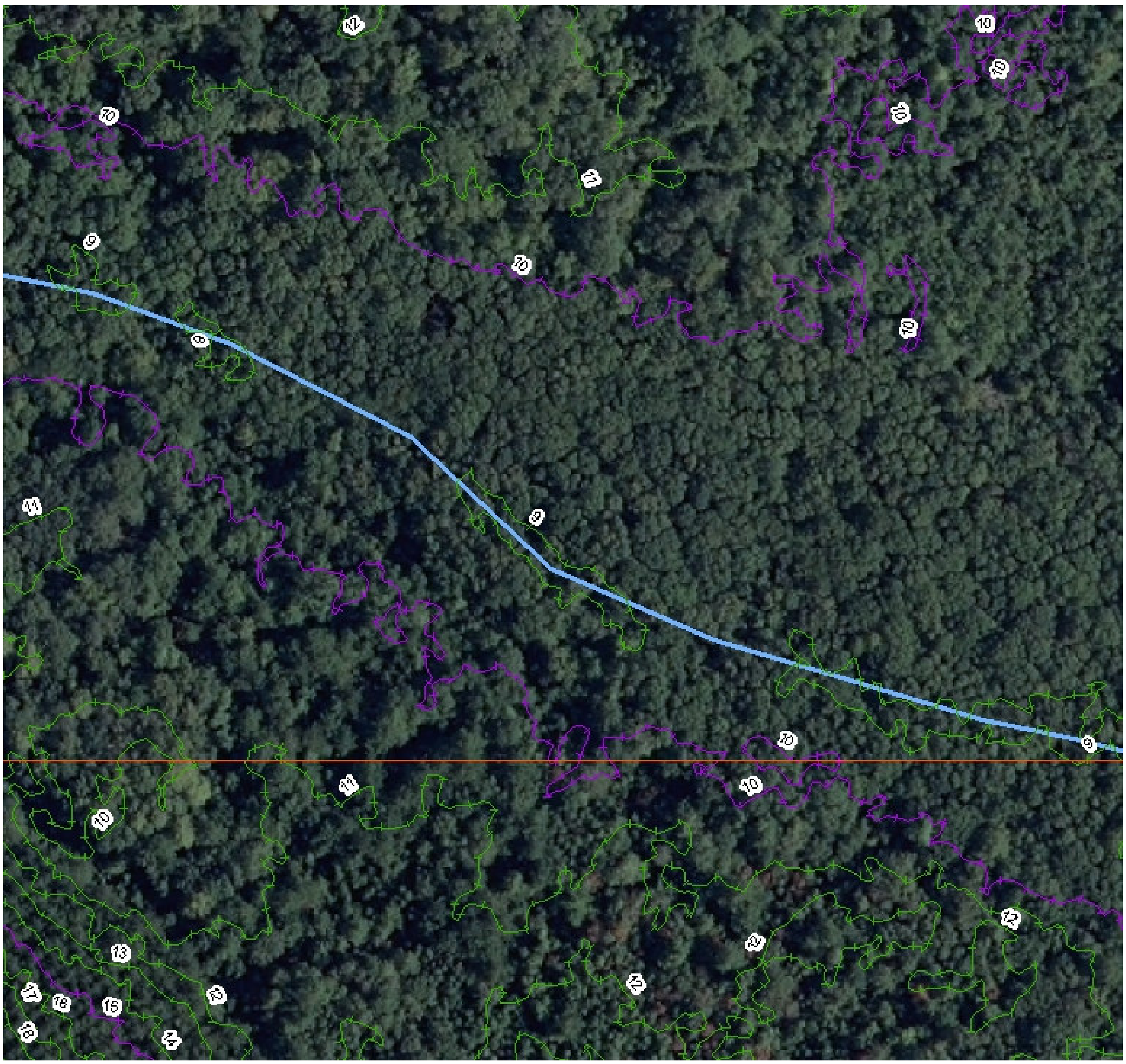


Figure 3. Even in very dense vegetation, the PDS team's high LiDAR point density (4 points per square meter) enabled the detection of dry drainage features beneath the vegetation.

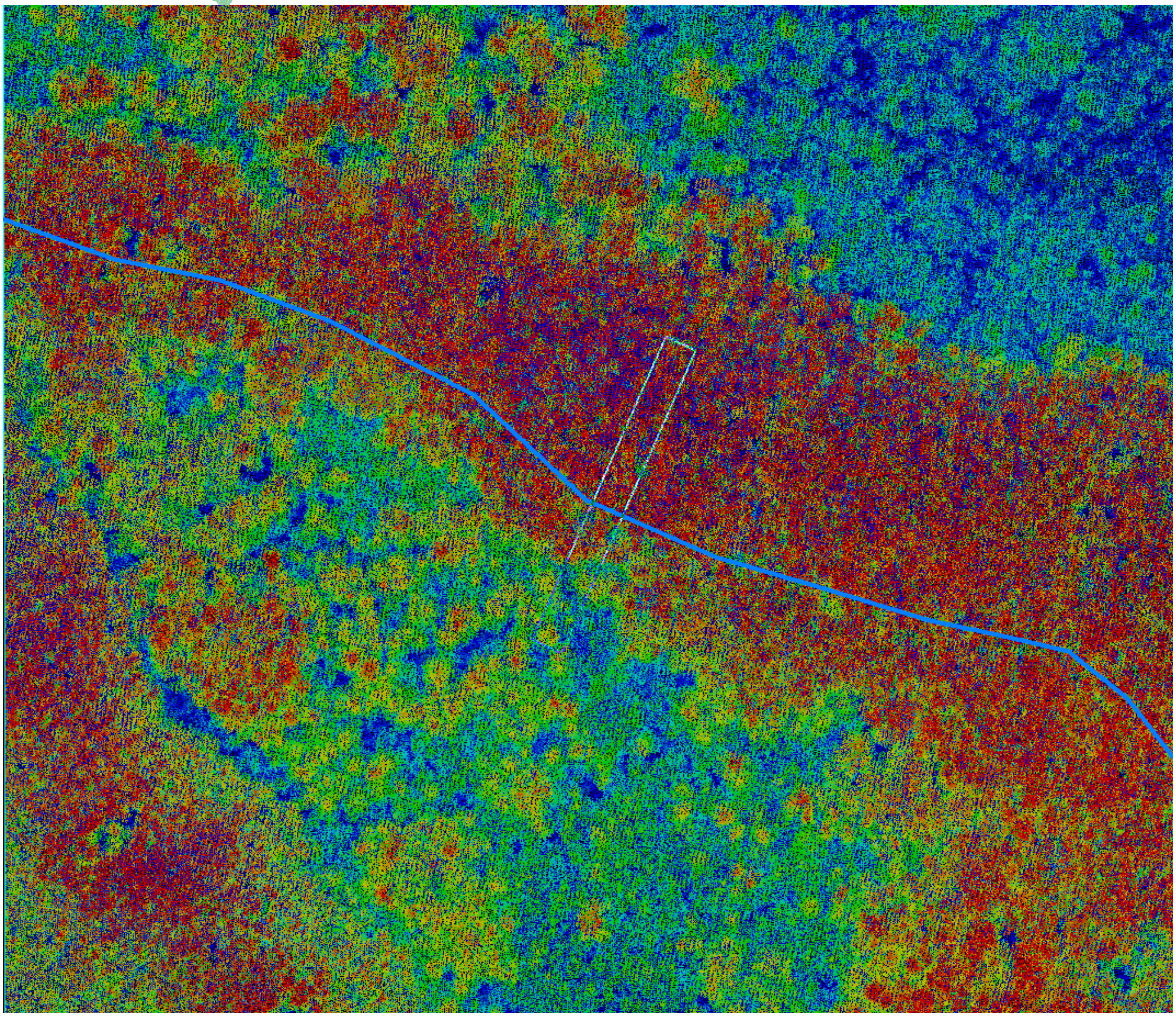
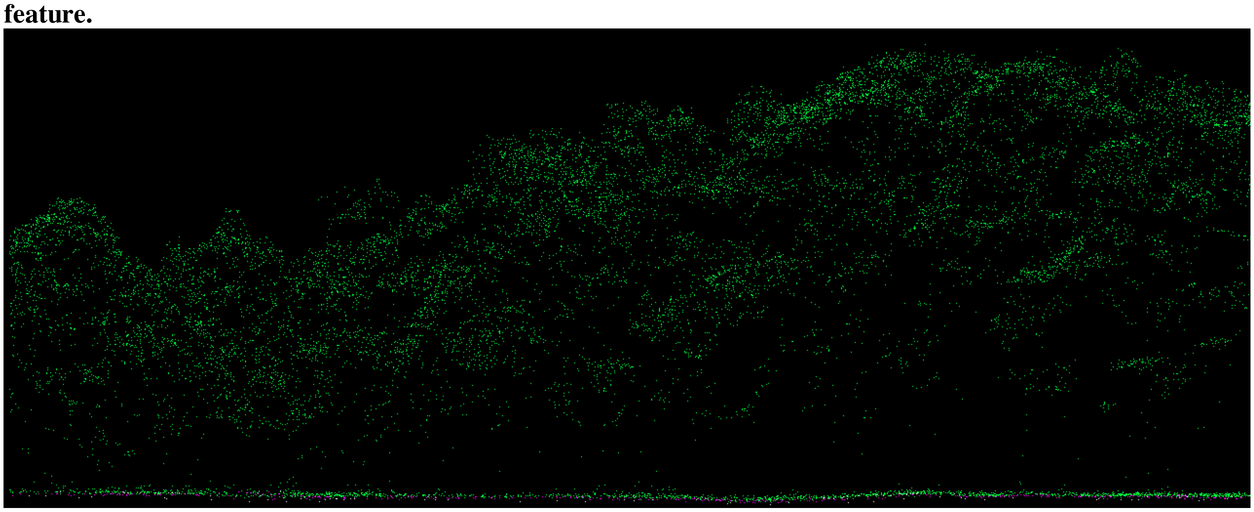


Figure 4. Full point cloud with profile (below) showing density of vegetation in the area of the dry drainage feature.



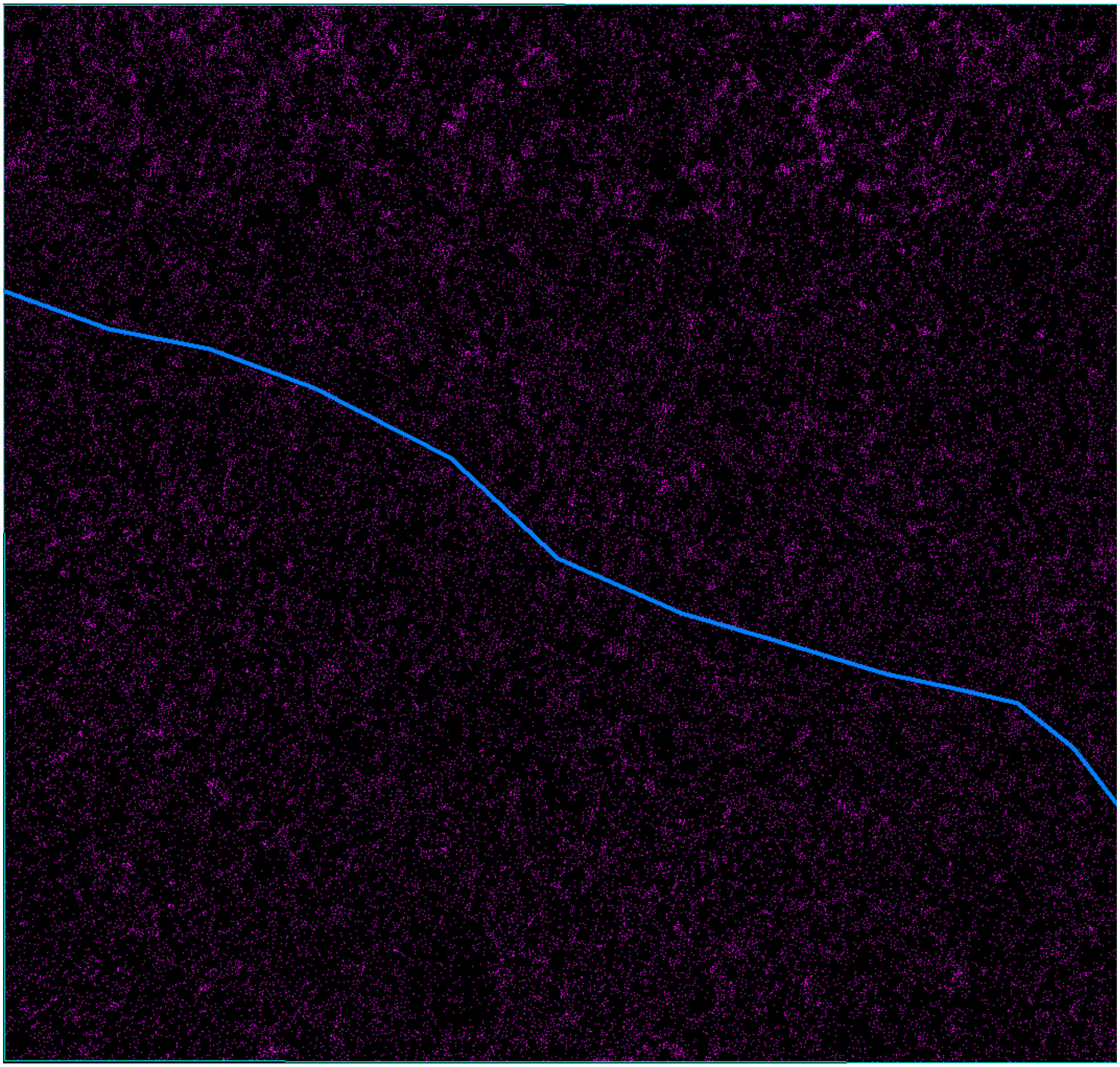


Figure 5. LAS Class 2 (ground) points showing the high density of points that penetrated the vegetation.

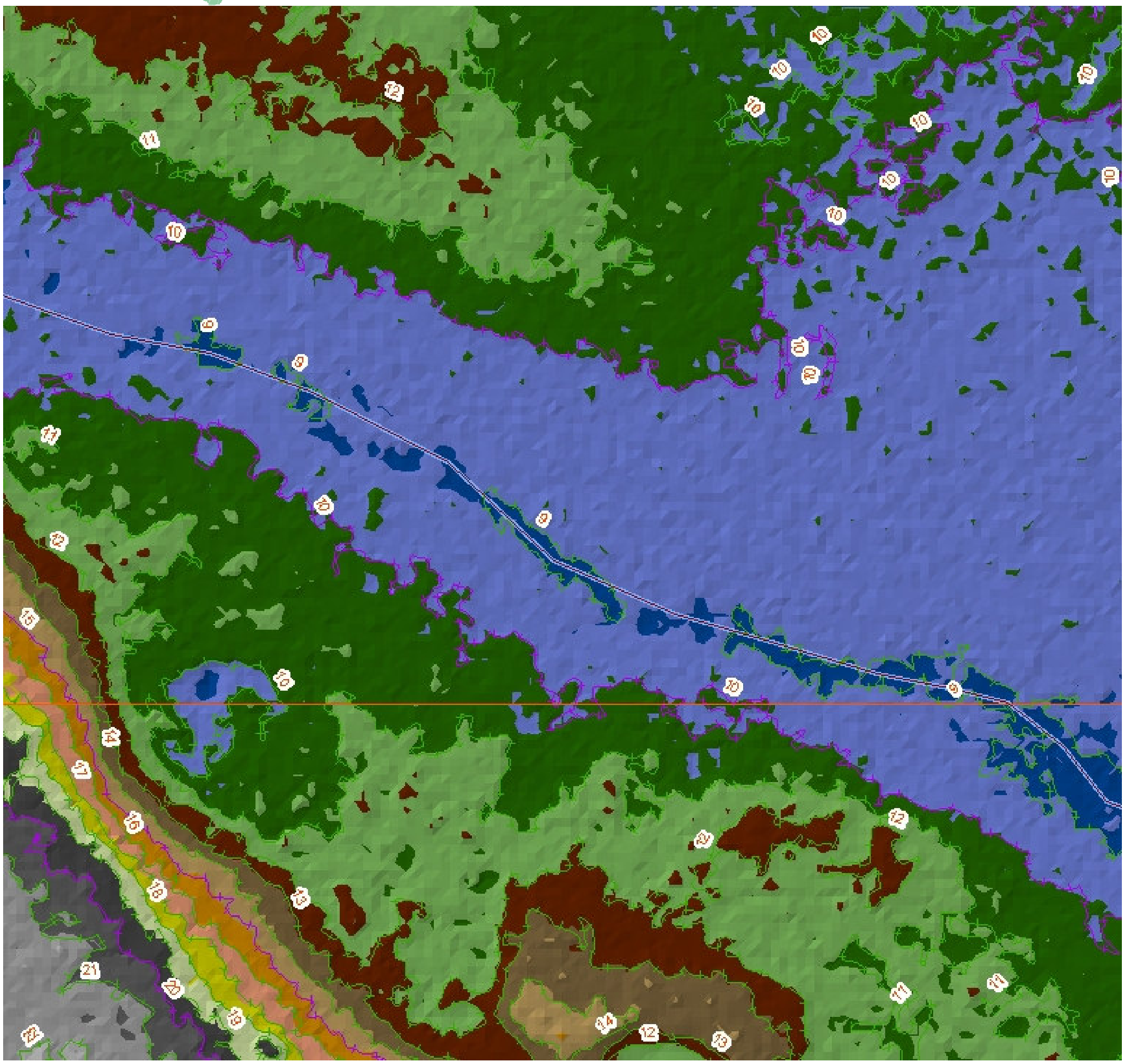


Figure 6. The ESRI Terrain is color-coded to depict the variable elevation bands. This clearly shows the lower, undulating elevations in the dry drainage feature.

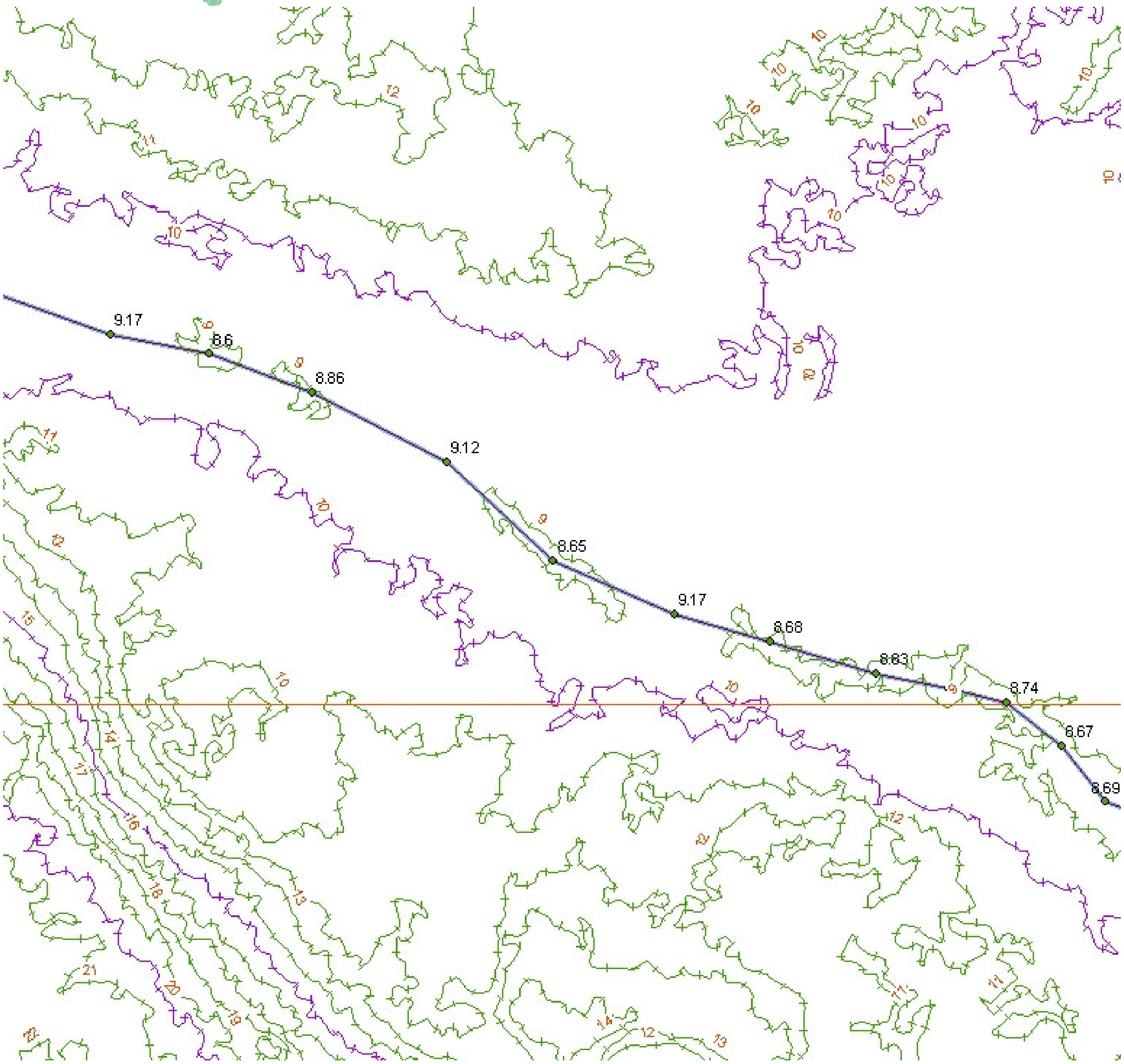


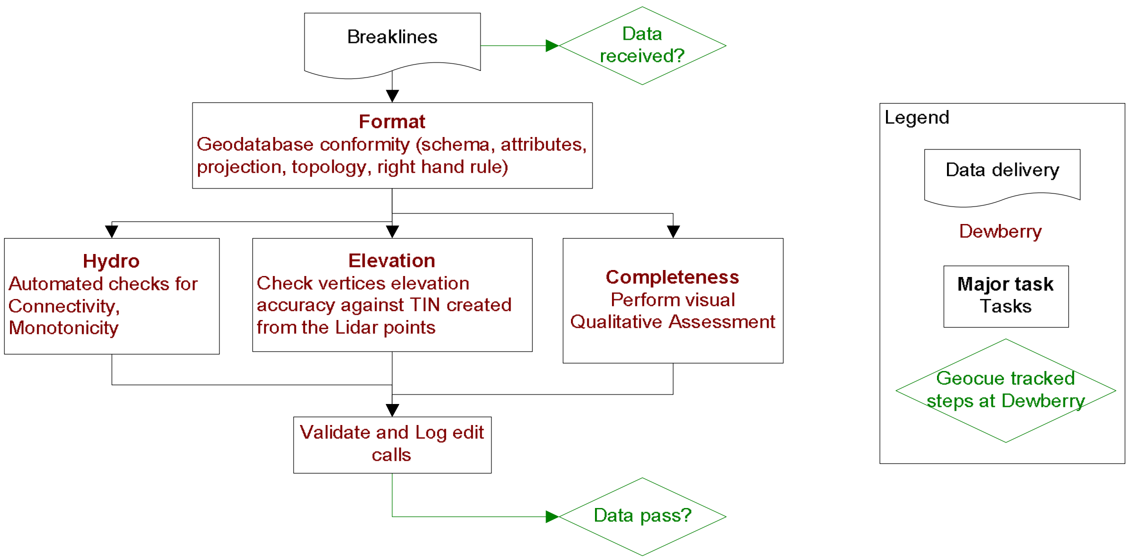
Figure 7. This figure shows variable "invert elevations" along the soft hydro breakline. It also shows "depression contours" where water would normally puddle if the drainage feature was only half dry. The soft hydro breakline passing through the "depression contours" clearly depict elevations lower than the 9-foot contour lines.

Contour Production Methodology

Sanborn used proprietary procedures to generate accurate contours from the LiDAR and breakline data. Using the LiDAR, a digital elevation model is filtered and further interpolated as a triangulated irregular network (TIN) of points. The TIN is rasterized to an ESRI GRID format and with the compiled breaklines, the 2-foot and 1-foot contours are generated and in accordance with the Data Dictionary at Appendix C. The contours conform to data format Requirements outlined by the FDEM Baseline Specifications.

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, Dewberry provided all subcontractors with geodatabase shells containing the required feature classes in the required format. Upon receipt of the data, Dewberry verified that the correct shell was used and validated the topology rules associated with it.

Feature Class	Rule	Feature Class
SOFTFEATURE	Must Not Intersect	
OVERPASS	Must Not Intersect	
ROADBREAKLINE	Must Not Intersect	
HYDROGRAPHIC...	Must Not Intersect	
SOFTFEATURE	Must Not Overlap With	ROADBREAKLINE
SOFTFEATURE	Must Not Overlap With	HYDROGRAPHICF
ROADBREAKLINE	Must Not Overlap With	HYDROGRAPHICF
SOFTFEATURE	Must Not Self-Intersect	
OVERPASS	Must Not Self-Intersect	
ROADBREAKLINE	Must Not Self-Intersect	
HYDROGRAPHIC...	Must Not Self-Intersect	

Figure 8. Breaklines topology rules

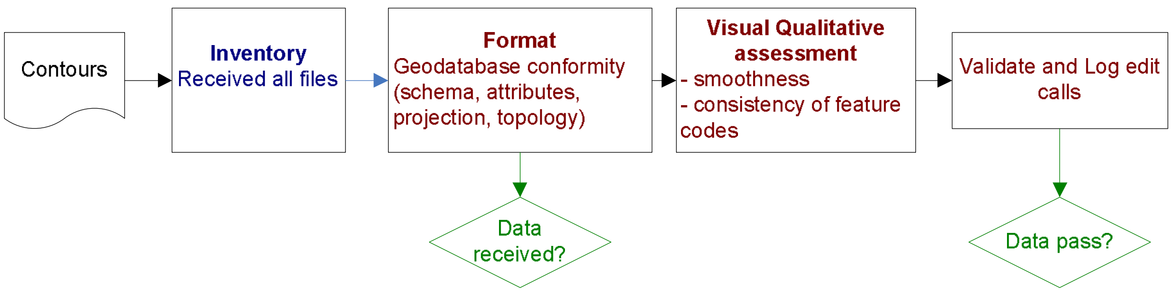
Then automated checks are applied on hydrofeatures to validate the 3D connectivity of the feature and the monotonicity of the hydrographic breaklines. Dewberry's major concern was that the hydrographic breaklines have a continuous flow downhill and that breaklines do not undulate. Error points are generated 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 of the breaklines. Dewberry compared the breaklines against LiDAR intensity images to ensure breaklines were captured in the required locations.

Contour Qualitative Assessments

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



Upon receipt of each delivery area, 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

Except for the Report of Geodetic Control Survey for LiDAR and Photogrammetry, dated March 13, 2008, which was delivered separately and pertains to all deliverables in the Florida Panhandle, the deliverables listed at Table 5 are included on the external hard drive that accompanies this report.

Table 5. Summary of Deliverables

Copies	Deliverable Description	Format	Location
2	Report of Geodetic Control Survey for LiDAR and Photogrammetry, Northwest Florida, dated 3/13/2008	Hardcopy and pdf	Submitted separately
1	Data Dictionary	pdf	Appendix C
3	LiDAR Processing Report	Hardcopy and pdf	Appendix D

3	LiDAR Vertical Accuracy Report	Hardcopy and pdf	Appendix F
1	LiDAR Qualitative Assessment Report	pdf	Appendix G
1	Breakline/Contour Qualitative Assessment Report	pdf	Appendix H
1	Breaklines, Contours, Network-Adjusted Control Points, Vertical accuracy checkpoints, Tiling Footprint, Lidar ground masspoints	Geodatabase	Submitted separately

References

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NDEP, 2004, *Guidelines for Digital Elevation Data*, Version 1.0, National Digital Elevation Program, May 10, 2004, http://www.ndep.gov/

NOAA, 1997, *Guidelines for Establishing GPS-Derived Ellipsoid Heights (Standards: 2 cm and 5 cm),* NOAA Technical Memorandum NOS NGS-58, November, 1997.

General Notes

This report is incomplete without the external hard drives of the LiDAR masspoints, breaklines, contours, and control. See the Geodatabase structure at Appendix I.

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

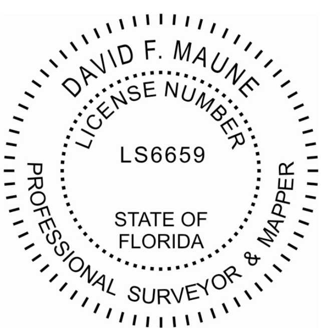
The LiDAR vertical accuracy report at Appendix F conforms with the National Standard for Spatial Data Accuracy (NSSDA).

The digital mapping data is certified to conform to Appendix B, *Terrestrial LiDAR Specifications*, of the "Florida Baseline Specifications for Orthophotography and LiDAR." This report is certified to conform with Chapter 61G17-6, Minimum Technical Standards, of the Florida Administrative Code, as pertains to a Specific Purpose LiDAR Survey.

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

Surveyor and Mapper in Responsible Charge:
David F. Maune, PhD, PSM, PS, GS, CP, CFM
Professional Surveyor and Mapper
License #LS6659

Signed: ________________________________ Date: ________________



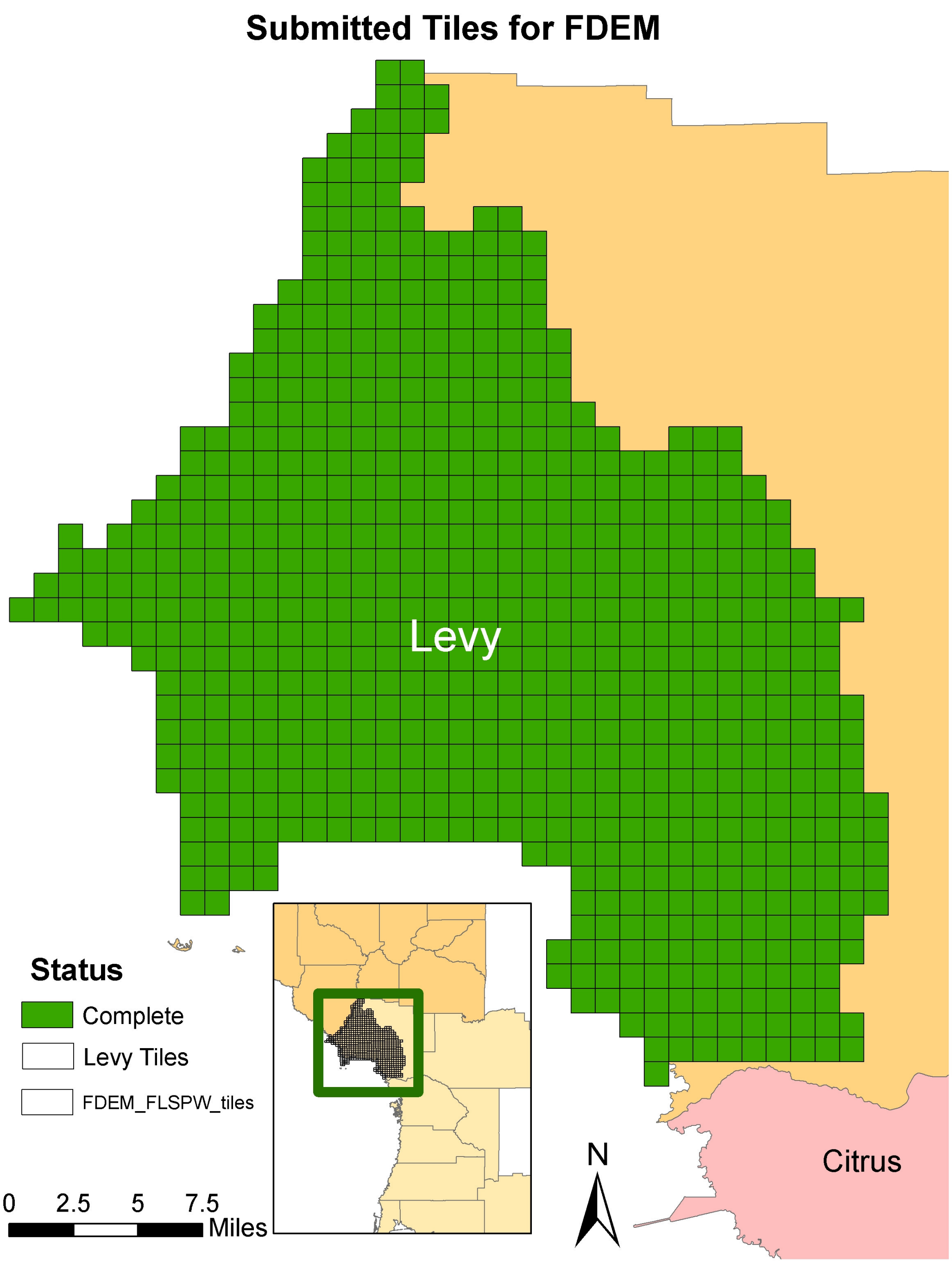
PDS Program and Data Solutions

List of Appendices

A. County Project Tiling Footprint
B. County Geodetic Control Points
C. Data Dictionary
D. LiDAR Processing Report
E. QA/QC Checkpoints and Associated Discrepancies
F. LiDAR Vertical Accuracy Report
G. LiDAR Qualitative Assessment Report
H. Breakline/Contour Qualitative Assessment Report
I. Geodatabase Structure

Appendix A: County Project Tiling Footprint: Levy

732 tiles delivered



List of delivered complete tiles (732):

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037277_W	037278_W	041159_W	041160_W	041161_W	042362_W
042363_W	042364_W	042369_W	042370_W	041162_W	041163_W
041164_W	041165_W	041166_W	041167_W	041168_W	041169_W
041170_W	039964_W	036969_W	036369_W	036370_W	035772_W
035771_W	036070_W	037868_W	037869_W	039366_W	041760_W
041761_W	041762_W	041763_W	041764_W	041765_W	041766_W
041767_W	041768_W	041769_W	041770_W	041771_W	041772_W
041777_W	041778_W	041779_W	041780_W	041781_W	041782_W
041783_W	041784_W	041785_W	041786_W	041787_W	041788_W
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040586_W	040587_W	040588_W	040859_W	040861_W	040867_W
040868_W	040869_W	040870_W	040871_W	040872_W	040873_W

040874_W	040875_W	040876_W	040877_W	040878_W	040884_W
040885_W	040886_W	040887_W	040888_W	041171_W	041176_W
041177_W	041178_W	041179_W	041180_W	041181_W	041182_W
041183_W	041184_W	041185_W	041186_W	041187_W	041188_W
041460_W	041465_W	041466_W	041467_W	041468_W	041469_W
041470_W	041471_W	041472_W	041473_W	041474_W	041475_W
041476_W	041482_W	041483_W	041484_W	041485_W	041486_W
041487_W	041488_W	041489_W	042060_W	042061_W	042062_W
042063_W	042064_W	042065_W	042070_W	042071_W	042072_W
042073_W	042074_W	042075_W	042076_W	042077_W	042078_W
042079_W	042080_W	042081_W	042087_W	042088_W	042089_W
042090_W	042663_W	042668_W	042669_W	042670_W	042671_W
042672_W	042673_W	042674_W	042675_W	042676_W	042677_W
042678_W	042679_W	042680_W	042685_W	042686_W	042687_W
042688_W	042689_W	042690_W	042963_W	042964_W	042965_W
042966_W	042967_W	042968_W	042969_W	042970_W	042971_W
042972_W	042973_W	042974_W	042365_W	042366_W	042367_W
042368_W	039066_W	038167_W	038168_W	037569_W	038767_W
041757_W	041758_W	041759_W	041773_W	041774_W	041775_W
041776_W	041789_W	041790_W	041791_W	037570_W	037571_W
039368_W	039369_W	039370_W	039371_W	042371_W	042372_W
042373_W	042374_W	042388_W	042389_W	042390_W	043563_W
043564_W	043565_W	043578_W	043579_W	043580_W	043581_W
043582_W	045064_W	045080_W	045081_W	037877_W	037878_W
038470_W	038471_W	038472_W	038473_W	038768_W	038769_W
038770_W	039067_W	040272_W	039664_W	039665_W	039666_W
040563_W	040564_W	039679_W	039680_W	039681_W	039975_W
039976_W	039977_W	039978_W	040273_W	040274_W	040275_W
040276_W	040562_W	040565_W	040579_W	040580_W	040581_W
040582_W	040863_W	040864_W	040865_W	040866_W	040879_W
040880_W	040881_W	040882_W	040883_W	041172_W	041173_W
041174_W	041175_W	041189_W	041461_W	041462_W	041463_W
041464_W	041477_W	041478_W	041479_W	041480_W	041481_W
042066_W	042067_W	042068_W	042069_W	042082_W	042083_W
042084_W	042085_W	042086_W	042664_W	042665_W	042666_W
042667_W	042681_W	042682_W	042683_W	042684_W	042975_W
042976_W	042977_W	044491_W	044492_W	044481_W	044482_W
044483_W	044484_W	044489_W	044490_W	045364_W	045365_W
045380_W	045381_W	045382_W	045383_W	045388_W	045389_W
044485_W	044486_W	044487_W	044488_W	045384_W	045385_W
045386_W	045387_W	044474_W	044475_W	044476_W	044477_W
044478_W	044479_W	044480_W	042979_W	042980_W	042982_W
042984_W	042985_W	042986_W	042987_W	042989_W	042991_W
043269_W	043271_W	043278_W	043280_W	043879_W	043880_W
043881_W	043882_W	043883_W	043888_W	045689_W	045690_W
045691_W	046580_W	046581_W	046582_W	042981_W	042983_W
042988_W	042990_W	043263_W	043264_W	043265_W	043266_W
043267_W	043268_W	043270_W	043272_W	043277_W	043279_W
043281_W	043282_W	043283_W	043284_W	043285_W	043286_W
043287_W	043288_W	044766_W	044767_W	044782_W	044783_W
044784_W	044785_W	044786_W	044791_W	044792_W	046588_W
046589_W	043867_W	043868_W	043869_W	043870_W	043871_W
043872_W	043873_W	043874_W	043875_W	043876_W	043877_W

043878_W	043889_W	044167_W	044168_W	044169_W	044170_W
044175_W	044176_W	044177_W	044178_W	044183_W	044184_W
044185_W	044186_W	044192_W	044471_W	044472_W	044473_W
044787_W	044788_W	044789_W	044790_W	044164_W	044165_W
044166_W	044179_W	044180_W	044181_W	044182_W	044464_W
044465_W	044466_W	044467_W	044468_W	044469_W	044470_W
045680_W	045681_W	045682_W	045683_W	045684_W	045685_W
045686_W	045687_W	045688_W	045390_W	045391_W	045392_W
045980_W	045981_W	045982_W	045983_W	045984_W	045985_W
045986_W	045991_W	046279_W	046280_W	046281_W	046282_W
046283_W	046288_W	046289_W	046290_W	046587_W	046883_W
046884_W	046885_W	046886_W	046887_W	046888_W	046889_W
046890_W	046891_W	047186_W	047187_W	047188_W	047189_W
047190_W	047191_W	047483_W	042978_W	043273_W	043274_W
043275_W	043276_W	043289_W	043290_W	043291_W	043863_W
043864_W	043865_W	043866_W	043884_W	043885_W	043886_W
043887_W	043890_W	043891_W	044171_W	044172_W	044173_W
044174_W	044187_W	044188_W	044189_W	044190_W	044191_W
044764_W	044765_W	044778_W	044779_W	044780_W	044781_W
045979_W	045987_W	045988_W	046590_W	045989_W	045990_W
046284_W	046285_W	046286_W	046287_W	046583_W	046584_W
046585_W	046586_W	046882_W	047183_W	047184_W	047185_W

Appendix B: Levy County Geodetic Control Points

Station	County	Longitude (DMS)	Latitude (DMS)	Ortho Height (meters)	Ellipsoid Height (meters)	Description
AC5958	Levy	82 37 37.43481	29 1 36.66374	8.868	-18.564	RECOVERED NSRS STATION (SEE DATASHEET PID# AC5958)
AR1847	Levy	82 38 24.33771	29 9 51.32010	10.746	-16.79	RECOVERED NSRS STATION (SEE DATASHEET PID# AR1847)
AR1850	Levy	83 3 10.36498	29 7 55.76453	1.344	-26.127	RECOVERED NSRS STATION (SEE DATASHEET PID# AR1850)
AC5943	Levy	83 3 1.16754	29 12 49.95660	1.38	-26.186	RECOVERED NSRS STATION (SEE DATASHEET PID# AC5943)
FB170P42	Levy	82 53 24.63376	29 24 6.95643	8.656	-18.908	SET ALUMINUM ROD MONUMENT
FB178P70	Levy	82 52 48.03042	29 31 3.00089	9.58	-18.085	SET SECONDARY MONUMENT
FB178P72	Levy	82 43 57.55819	29 21 31.57033	9.319	-18.247	SET SECONDARY MONUMENT
FB178P73	Levy	82 42 43.06433	29 1 53.38788	1.108	-26.253	SET SECONDARY MONUMENT
FB178P74	Levy	82 44 0.28570	29 4 34.87668	0.463	-26.935	SET SECONDARY MONUMENT
FB178P75	Levy	82 45 48.14858	29 12 48.15501	1.001	-26.497	SET SECONDARY MONUMENT
FB178P76	Levy	82 40 38.69897	29 17 22.78855	10.096	-17.461	SET SECONDARY MONUMENT
FB178P77	Levy	82 55 57.12756	29 12 55.60347	1.729	-25.782	SET SECONDARY MONUMENT
FB178P78	Levy	82 49 44.83951	29 17 31.59225	5.105	-22.414	SET SECONDARY MONUMENT
FB170P42	Levy	82 53 24.63376	29 24 6.95643	8.656	18.908	SET PRIMARY MONUMENT

Appendix C: Data Dictionary

LiDARgrammetry Data Dictionary & Stereo Compilation Rules

FINAL

FDEM (Florida Department of Emergency Management)

January 25, 2008

Table of Contents

Horizontal and Vertical Datum

Horizontal datum shall be referenced to the appropriate Florida State Plane Coordinate System. The horizontal datum shall be North American Datum of 1983/HARN adjustment in US Survey Feet. The vertical datum shall be referenced to the North American Vertical Datum of 1988 (NAVD 88). Geoid03 shall be used to convert ellipsoidal heights to orthometric heights.

Coordinate System and Projection

All data shall be projected to the appropriate Florida State Plane Coordinate System Zone, Units in US Survey Feet.

Contour Topology Rules

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

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 PDS. The topology must be validated by each subcontractor prior to delivery to PDS. PDS shall further validate the topology before final submittal to FDEM.

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**
COASTALSHORELINE	5	1	1	No
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 intersect	The rule is a line-no intersection rule	No	COASTALSHORELINE::All	COASTALSHORELINE::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	SOFTFEATURE::All	COASTALSHORELINE::All
Must not overlap	The rule is a line-no overlap line rule	No	ROADBREAKLINE::All	HYDROGRAPHICFEATURE::All
Must not overlap	The rule is a line-no overlap line rule	No	ROADBREAKLINE::All	COASTALSHORELINE::All
Must not overlap	The rule is a line-no overlap line rule	No	HYDROGRAPHICFEATURE::All	COASTALSHORELINE::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
Must not	The rule is a line-no	No	COASTALSHORELINE::All	COASTALSHORELINE::All

self-intersect	self intersect rule

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	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
SHAPE_AREA	Double	Yes			0	0		Calculated by PDS
TYPE	Long Integer	No	1	Coast	0	0		Assigned by PDS

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. Orthophotography will not be use to delineate this shoreline.	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 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	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
TYPE	Long Integer	No	1	HydroL	0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Single Line Feature	Linear hydrographic features such as streams, shorelines, canals, swales, embankments, etc. 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.
2	Dual Line Feature	Linear hydrographic features such as streams, shorelines, canals, swales, 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.	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 data is not required to show "closed 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.
3	Soft Hydro Single Line Feature	Linear hydro features with an average width less than 8 feet that compilation staff originally coded as soft features due to unclear definition of hydro feature, but that have been determined to be hydro features by FDEM. Connectivity and monotonicity are not enforced on these features.	Capture linear hydro features as single breaklines. Average width shall be 8 feet or less to show as single line.
4	Soft Hydro Dual Line Feature	Linear hydro features with an average width greater than 8 feet that compilation staff originally coded as soft features due to unclear definition of hydro feature, but that have been determined to be hydro features by FDEM. Connectivity and monotonicity are not enforced on these features.	Capture features showing dual line (one on each side of the feature). Average width shall be greater than 8 feet to show as a double line. Data is not required to show "closed polygon".

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	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
SHAPE_AREA	Double	Yes			0	0		Calculated by PDS
WATERBODY_ELEVATION_MS	Double	Yes			0	0		Assigned by PDS
TYPE	Long Integer	No	1	HydroP	0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Water Body	Land/Water boundaries of constant elevation 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.	Water bodies shall be captured as closed polygons with the water feature to the right. The compiler shall take care to ensure that the z-value remains consistent for all vertices placed on the water body. 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.

		"Donuts" will exist where there are islands within a closed water body feature.	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 or overpasses.

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	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
TYPE	Long Integer	No	1	Road	0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Edge of Pavement	Capture edge of pavement (non-paved or compact surfaces as open to compiler interpretability) on both sides of the road. Runways are not to be included.	DO NOT INCLUDE Bridges or Overpasses within this feature type. Capture apparent edge of pavement (including paved shoulders). Each vertex placed should maintain vertical integrity and data is not required to show "closed polygon". Box culverts should be continued as edge of pavement unless a clear guardrail system is in place; in that case, feature should be shown as bridge / overpass.

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	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
TYPE	Long Integer	No	1	Bridge	0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Bridge Overpass	Feature should show edge of bridge or overpass.	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 is not required to show “closed polygon”. Box culverts should be captured in this feature class if a clear guardrail system is in place; otherwise, show as edge-of-pavement.

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	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
TYPE	Long Integer	No	1	Soft	0	0		Assigned by PDS

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. 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.	Capture breaklines to depict soft changes in the elevation. If the elevation changes are easily visible, go light on the breakline capture. Each vertex placed should maintain vertical integrity.

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	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
SHAPE_AREA	Double	Yes			0	0		Calculated by PDS
TYPE	Long Integer	No	1	Island	0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Island	Apparent boundary of natural or man-made island feature captured with a constant elevation. Island features will be captured for features one-half acres in size or greater.	Island shall take precedence over Coastal Shore Line Features. Islands shall be captured as closed polygons with the land feature to the right. The 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: CONFIDENCE
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	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
SHAPE_AREA	Double	Yes			0	0		Calculated by PDS
TYPE	Long Integer	No	1	Obscure	0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Low Confidence Area	Apparent boundary of vegetated areas that are considered obscured to the 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.	Capture as closed polygon with the obscured area to the right of the line. Compiler does not need to worry about z-values of vertices; feature class will be 2-D only.

Note: Area must be ½ acre or larger. 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.

Masspoints

Feature Dataset: TOPOGRAPHIC

Feature Class: MASSPOINT

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 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	8	Assigned by PDS
TYPE	Long Integer	No	1	Masspoint	0	0		Assigned by PDS

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 Type: Polyline

Contains M Values: No

Annotation Subclass: None

XY Resolution: Accept Default Setting

XY Tolerance: 0.003

Feature Class: CONTOUR_1FT

Contains Z Values: No

Z Resolution: N/A

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	Lengt
OBJECTID	Object ID						
SHAPE	Geometry						
DATESTAMP_DT	Date	Yes			0	0	8
SHAPE_LENGTH	Double	Yes			0	0	
CONTOUR_TYPE_DESC	Long Integer	No		dCONTOURTYPE	0	0	50
CONTOUR_ELEVATION_MS	Double	No			0	0	

Feature Definition

Code	Description	Definition	Capture Rules
1	Intermediate	A contour line drawn between index contours. Depending on the contour interval there are three or four intermediate contours between the index contours.	They are normally continuous throughout a map, 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.	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 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.
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.	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.

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 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	Lengt
OBJECTID	Object ID						
SHAPE	Geometry						
DATESTAMP_DT	Date	Yes			0	0	8
SHAPE_LENGTH	Double	Yes			0	0	
CONTOUR_TYPE_DESC	Long Integer	No		dCONTOURTYPE	0	0	50
CONTOUR_ELEVATION_MS	Double	No			0	0	

Feature Definition

Code	Description	Definition	Capture Rules
1	Intermediate	A contour line drawn between index contours. Depending on the contour interval there are three or four intermediate contours between the index contours.	They are normally continuous throughout a map, 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.	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 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.
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.	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.

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 and aerial photography collected by Aero-Metric, Sanborn and Terrapoint.

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	8	Assigned by PDS
TYPE	Long Integer	No	1	Control	0	0		Assigned by PDS
POINTID	String	Yes					12	Assigned by PDS
X_COORD	Double	Yes			0	0		Assigned by PDS
Y_COORD	Double	Yes			0	0		Assigned by PDS
Z_COORD	Double	Yes			0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Control Point	Primary or Secondary PDS 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 PDS 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	8	Assigned by PDS
POINTID	String	Yes					12	Assigned by PDS
X_COORD	Double	Yes			0	0		Assigned by PDS
Y_COORD	Double	Yes			0	0		Assigned by PDS
Z_COORD	Double	Yes			0	0		Assigned by PDS
LANDCOVER	Long Integer	No	1	dLANDCOVERTYPE	0	0		Assigned by PDS

Feature Definition

Code	Description	Definition	Capture Rules
1	Bare-Earth and Low Grass	None.	None.
2	Brush Lands and Low Trees	None.	None.
3	Forested Areas Fully Covered by Trees	None.	None.
4	Urban Areas	None.	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.

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	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
SHAPE_AREA	Double	Yes			0	0		Calculated by PDS
CELLNUM	String	No			0	0	8	Assigned by PDS

Contact Information

Any questions regarding this document should be addressed to:

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Appendix D: LiDAR Processing Report

Dewberry
LiDAR Campaign
Final Report
For
FDEM – Levy County
March 2008

Prepared by:

Sanborn

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EXECUTIVE SUMMARY

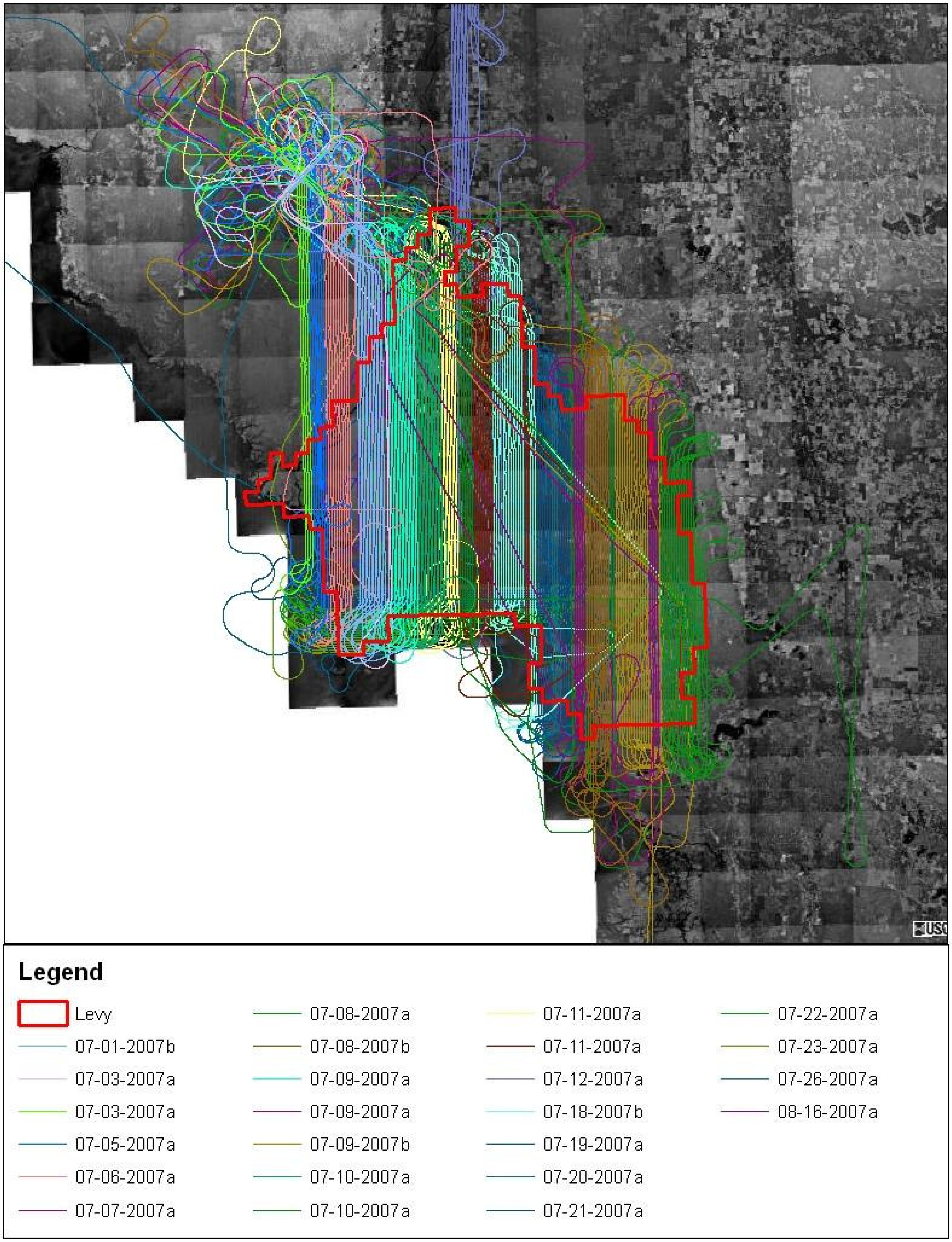
In the spring of 2007, Sanborn was contracted by Dewberry to execute a LiDAR (Light Detection and Ranging) survey campaign in the state of Florida. LiDAR data in the form of 3-dimensional positions of a dense set of mass points was collected for the 713 square miles of Levy County. This data was used in the development of the bare-earth-classified elevation point data sets.

The flight lines used for data acquisition and bore-sighting are shown in the graphic on the next page.

The Leica ALS-50 LiDAR system and the Optech ALTM 2050 LiDAR system was used to collect data for the survey campaign. The LiDAR system is calibrated by conducting flight passes over a known ground surface before and after each LiDAR mission. During final data processing, the calibration parameters are inserted into post-processing software.

The acquired LiDAR data was processed to obtain first and last return point data. The last return data was further filtered to yield a LiDAR surface representing the bare earth.

The contents of this report summarize the methods used to establish the base station coordinate check, perform the LiDAR data collection and post-processing as well as the results of these methods.


Legend
Levy
07-01-2007b
07-03-2007a
07-03-2007a
07-05-2007a
07-06-2007a
07-07-2007a
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07-08-2007b
07-09-2007a
07-09-2007a
07-09-2007b
07-10-2007a
07-10-2007a
07-11-2007a
07-11-2007a
07-12-2007a
07-18-2007b
07-19-2007a
07-20-2007a
07-21-2007a
07-22-2007a
07-23-2007a
07-26-2007a
08-16-2007a

INTRODUCTION

This report contains the technical write-up of the Dewberry LiDAR campaign, including system calibration techniques, the establishment of base stations by a differential GPS network survey, and the collection and post-processing of the LiDAR data.

1.1 Contact Information

Questions regarding the technical aspects of this report should be addressed to:

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------- Jamie Young (General Manager)
Telephone: ------ 1–719-264-5602
FAX: ------------- 1–719-264-5637
email: ------------- jyoung@sanborn.com

1.2 Purpose of the LiDAR Acquisition

This LiDAR operation was designed to provide a highly detailed ground surface dataset to be used for the development of topographic, contour mapping and hydraulic modeling

1.3 Project Location

Levy County, Florida

1.4 Project Scope, Specifications and Time Line

The summer of 2007 LiDAR Flight Acquisition required the collection of 713 square miles of Levy County collected at a nominal point spacing of 0.7 meters and based on the Sanborn FEMA compliant LiDAR product specification.

Table 1: Project Specifications and Deliverable Coordinate and Datum Systems

Area (sq. mi)	713	**Product type**	Fema(F)	**Projection**	Florida State Plane
Vertical RMSE (CM)	Bare Earth 9.25cm	**Check Points required**	Yes	**Horizontal Datum Vertical Datum**	NAD83/Harn NAVD88
Horizontal RMSE (CM)	50cm	**Number Collected**	60	**Units**	US Survey Ft

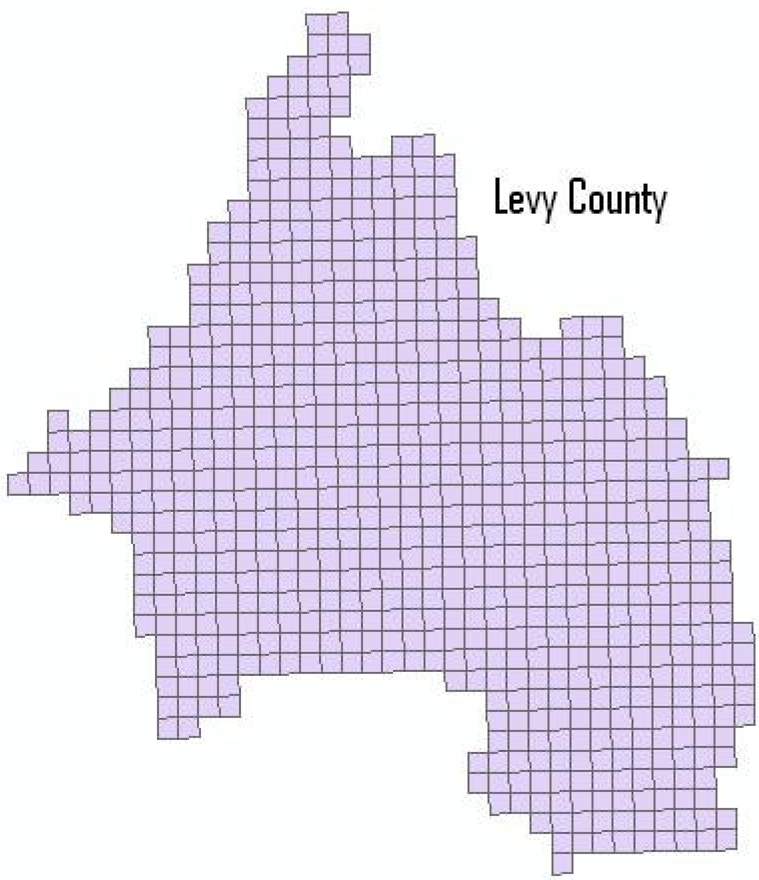


Figure 1: Area of Collection

LiDAR CALIBRATION

2.1 Introduction

LiDAR calibrations are performed to determine and therefore eliminate systematic biases that occur within the hardware of the Leica ALS-50 system and the Optech ALTM 2050 system. Once the biases are determined they can be modeled out. The systematic biases are corrected for include scale, roll, and pitch.

The following procedures are intended to prevent operational errors in the field and office work, and are designed to detect inconsistencies. The emphasis is not only on the quality control (QC) aspects, but also on the documentation, i.e., on the quality assurance (QA).

2.2 Calibration Procedures

Sanborn performs two types of calibrations on its LiDAR system. The first is a building calibration, and it is done any time the LiDAR system has been moved from one plane to another. New calibration parameters are computed and compared with previous calibration runs. If there is any change, the new values are updated internally or during the LiDAR post-processing. These values are applied to all data collected with the plane/ALS-50/ALTM 2050 system configurations.

Once final processing calibration parameters are established from the building data, a precisely-surveyed surface is observed with the LiDAR system to check for stability in the system. This is done several times during each mission. An average of the systematic biases are applied on a per mission basis.

2.3 Building Calibration

Whenever the ALS-50 or ALTM 2050 is moved to a new aircraft, a building calibration is performed. The rooftop of a large, flat, rectangular building is surveyed on the ground using conventional survey methods, and used as the LiDAR calibration target. The aircraft flies several specified passes over the building with the ALS-50 system and the ALTM 2050 system set first in scan mode, then in profile mode, and finally in both scan and profile modes with the scan angle set to zero degrees.

Figure 2 shows a pass over the center of the building. The purpose of this pass is to identify a systematic bias in the scale of the system.

Figure 3 demonstrates a pass along a distinct edge of the building to verify the roll compensation performed by the Inertial Navigation System, INS.

Additionally, a pass is made in profile mode across the middle of the building to compensate for any bias in pitch.

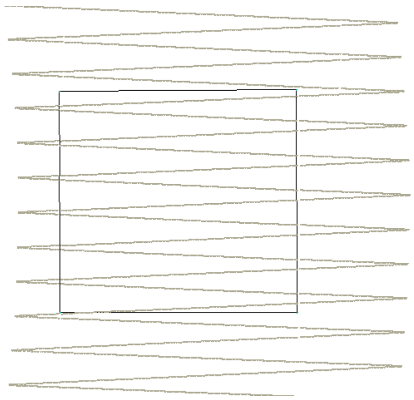


Figure 2: Calibration Pass 1

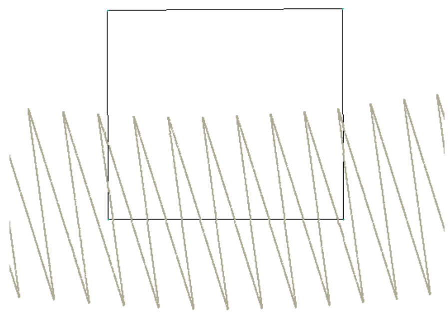


Figure 3: Calibration Pass 2

2.4 Runway Calibration, System Performance Validation

An active asphalt runway was precisely-surveyed at the Cross City Airport for Levy County using kinematic GPS survey techniques (accuracy: ±3cm at 1σ, along each coordinate axis) to establish an accurate digital terrain model of the runway surface. The LiDAR system is flown at right angles over the runway several times and residuals are generated from the processed data. Figure 4 shows a typical pass over the runway surface.

Approximately 25,000 LiDAR points are observed with each pass. A Triangulated Irregular Network (TIN) surface is created from these passes. The ground control x,y,z points are then compared with the z of the LiDAR surface to compute vertical residuals of the LiDAR data. After careful analysis of noise associated with non-runway returns, any system bias is documented and removed from the process.

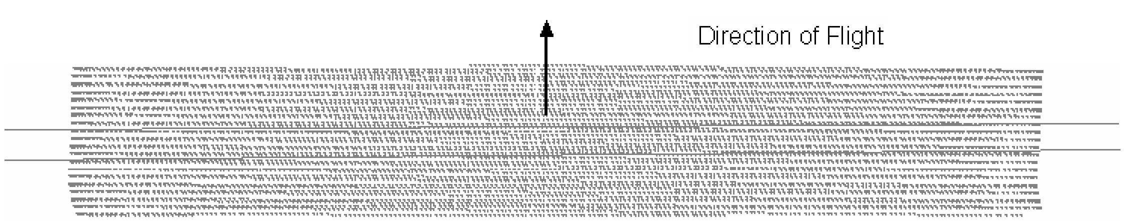


Figure 4: Runway Calibration

3 RUNWAY CALIBRATION, SYSTEM PERFORMANCE VALIDATION

3.1 Calibration Results

“Bore-sighting” and “runway calibration” are essentially the same thing, i.e., they determine if the LiDAR sensor has maintained its factory calibration and is still sensing the correct position on the ground, both vertically and horizontally. The LiDAR data captured over the building is used to determine whether there have been any changes to the alignment of the Inertial Measurement Unit, IMU, with respect to the laser system. The parameters are designed to eliminate systematic biases within certain system parameters.

The runway over-flights are intended to be a quality check on the calibration and to identify any system irregularities and the overall noise. IMU misalignments and internal system calibration parameters are verified by comparing the collected LiDAR points with the runway surface.

Figure 5 shows the typical results of a runway over-flight analysis. The X-axis represents the position along the runway. The overall statistics from this analysis provides evidence of the overall random noise in the data (typically, 7 cm standard deviation – an unbiased estimator, and 8 cm RMS which includes any biases) and indicates that the system is performing within specifications. As described in later sections of this report, this analysis will identify any peculiarities within the data along with mirror-angle scale errors (identified as a “smile” or “frown” in the data band) or roll biases.

> The calibration is done based on a kinematic survey on the runway. Given that the Kinematic survey RMSE is no better than 4 centimeters as a result of none exact height of the antenna and weight of the aircraft. Sanborn was required to do additional check points in the project area to meet the 9.25 centimeter vertical accuracy requirement knowing that the calibration site is only good to 4 centimeters RMSE. A z bump adjustment was made to the entire data set based on the survey points in the project area and the relative accuracy of the data to itself and in all areas.

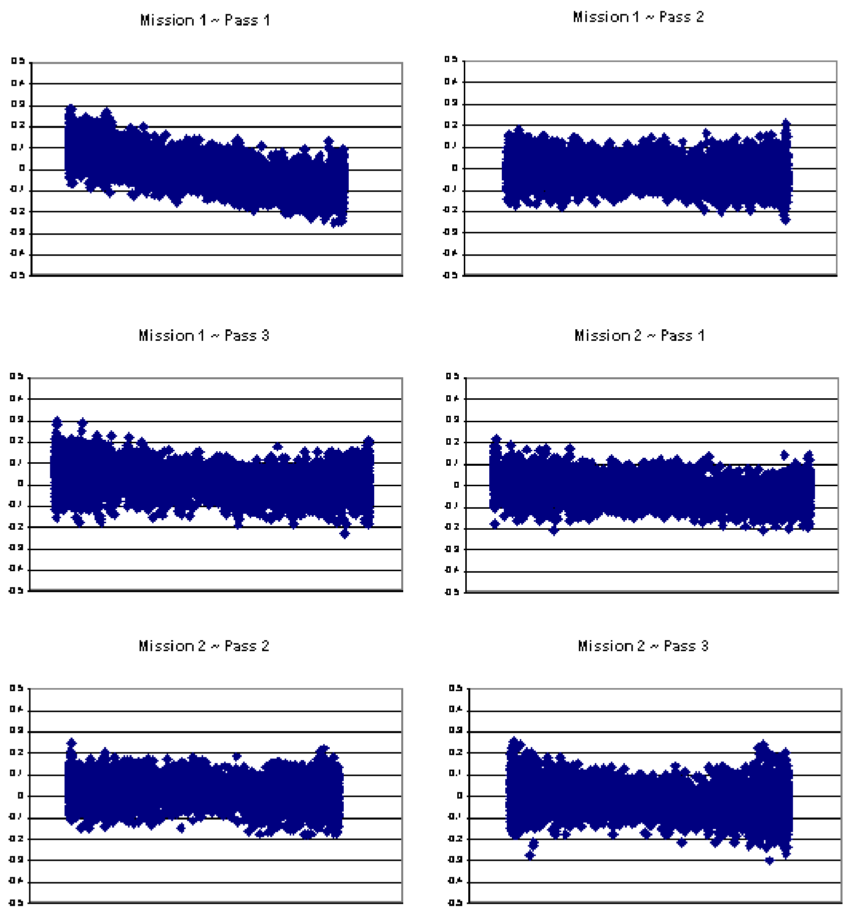


Figure 5: Runway Calibration Results

3.2 Daily Runway Performance/Data Validation Tests

Performance flights over the runway test field were performed before and after each mission. Table 2 shows the standard deviation and RMS values of the residuals between the test flights and the known surface of the test ranges for each pass. The maximum RMS value is 0.087 meters and the maximum standard deviation is 0.087 meters. The average RMS among all test flights is 0.062 meters.

Table 2: Runway Validation Results for Levy County (Meters)

Mission	Passes	Standard Deviation	RMS
178a_Leica	4	0.034	0.038
179a_Leica	4	0.040	0.040
179a_Optech	2	0.040	0.060
182a_Optech	4	0.040	0.068
182b_Optech	4	0.043	0.054
183a_Optech	4	0.040	0.040
184a_Leica	4	0.041	0.041
184a_Optech	4	0.046	0.050
186a_Leica	4	0.067	0.067
187a_Leica	4	0.061	0.061
188a_Leica	4	0.069	0.069
189a_Leica	4	0.046	0.047
189b_Leica	4	0.067	0.067
190a_Leica	4	0.039	0.049
190a_Optech	4	0.080	0.081
190b_Leica	4	0.069	0.069
191a_Leica	4	0.069	0.069
191a_Optech	4	0.065	0.076
192a_Leica	4	0.054	0.054
192a_Optech	4	0.082	0.082
193a_Optech	4	0.078	0.084
197a_Leica	4	0.086	0.086
197a_Optech	4	0.071	0.072
199b_Leica	4	0.075	0.075
200a_Leica	4	0.087	0.087
200a_Optech	4	0.087	0.087
201a_Leica	4	0.060	0.061
201a_Optech	4	0.069	0.077
202a_Leica	4	0.056	0.056
203a_Leica	4	0.038	0.038
204a_Leica	4	0.042	0.042
207a_Leica	4	0.041	0.079
228a_Leica	4	0.036	0.037
229a_Leica	4	0.040	0.040

3.3 Horizontal Validation

The horizontal accuracy was checked within the calibration site and the project area. Five random tiles within each county were selected and five calibrations within each county were selected for the different missions. The horizontal accuracy was checked at both center and edge of the flight line swath in the calibration lines. In the project area the horizontal accuracy was check in the over lapping areas of these tiles. Locations for each check was randomly selected based on like features in a single flightline overlap or corresponding calibration lines. For example building corner locations were identified and differences where measured in reference to each other. Given that the calibration lines were flown in opposing directions and an additional line was flown perpendicular to these opposing lines, this would indicate a valid horizontal position to the absolute location of the position. If there was an error greater than stated in the specifications, the location directional miss-alignment would be greater than the specified RMSE in either northing or easting. The difference was check and the RMSE of all differences were computed and reported in Tables 3 & 4 below. Based on the results of Table 3 & 4 it has been determined that the horizontal accuracy has been met.

Table 3: Horizontal Validation Results for Levy County (Centimeters)

Levy County			
Tile	**Northing Offset (cm)**	**Easting Offset (cm)**	**Center/Edge**
82404	24.2	15.93	E
84026	23.74	16.33	E
85108	22.98	14.79	E
86189	27.74	22.21	C
95363	23.56	22.96	C
RMSE	**24.444**	**18.444**	
Calibration Mission	**Northing Offset (cm)**	**Easting Offset (cm)**	**Center/Edge**
Day179	16.31	23.02	E
Day191	30.49	20.14	E
Day199b	26.24	26.05	E
Day200	26.72	40.94	E
Day229a	18.53	10.04	E
RMSE	**23.658**	**24.038**	

Table 4: Combined Horizontal Validation Results for Levy County (Centimeters)

Tile/Mission	Northing (cm)	Easting (cm)	Center/Edge
82404	24.2	15.93	E
84026	23.74	16.33	E
85108	22.98	14.79	E
86189	27.74	22.21	C
95363	23.56	22.96	C
Day179	16.31	23.02	E
Day191	30.49	20.14	E
Day199b	26.24	26.05	E
Day200	26.72	40.94	E
Day229a	18.53	10.04	E
RMSE	**24.051**	**21.241**	

4 LiDAR FLIGHT AND SYSTEM REPORT

4.1 Introduction

This section addresses LiDAR system, flight reporting and data acquisition methodology used during the collection of the Levy County campaign. Although Sanborn conducts all LiDAR with the same rigorous and strict procedures and processes, all LiDAR collections are unique.

4.2 Field Work Procedures

A minimum of two GPS base stations were set up, with one receiver located at the airport set up on AR1838, and the secondary GPS receiver placed at survey control point BD2495, which is within the project area or within the required baseline specifications of the project.

Pre-flight checks such as cleaning the sensor head glass are performed. A four minute INS initialization is conducted on the ground, with the engines running, prior to flight, to establish fine-alignment of the INS. GPS ambiguities are resolved by flying within ten kilometers of the base stations.

The flight missions were typically four or five hours in duration including runway calibration flights flown at the beginning and the end of each mission. 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 are again resolved by flying within ten kilometers of the base stations, to aid in post-processing.

Table 5 and 6 shows the planned LiDAR acquisition parameters with a flying height of 800 meters above ground level (AGL) for both Leica and Optech on a mission to mission basis.

Table 5: LiDAR Leica Acquisition Parameters

Average Altitude	800 Meters AGL
Airspeed	~120 Knots
Scan Frequency	36 Hertz
Scan Width Half Angle	20 Degrees
Pulse Rate	50,000 Hertz

Table 6: LiDAR Optech Acquisition Parameters

Average Altitude	800 Meters AGL
Airspeed	~120 Knots
Scan Frequency	40 Hertz
Scan Width Half Angle	16 Degrees
Pulse Rate	50,000 Hertz

Preliminary data processing was performed in the field immediately following the missions for quality control of GPS data and to ensure sufficient overlap between flight lines. Any problematic data could then be re-flown immediately as required. Final data processing was completed in the Colorado Springs office.

Table 7: Collection Dates, Times, Average Per Flight Collection Parameters and PDOP

Mission	Date	Sensor	Start Time	End Time	Altitude (m)	Airspeed (Knots)	Scan Angle	Scan Rate	Pulse Rate	PDOP
178a	Jun27	Leica	00:47	05:36	800	120	40˚	36	50000	1.0
179a	Jun 28	Optech	2:01	2:44	800	120	32˚	40	50000	1.8
179a	Jun 28	Leica	3:47	7:28	800	120	40˚	36	50000	1.3
182a	Jul 1	Optech	20:20	1:52	800	120	32˚	40	50000	1.7
182b	Jul 1	Optech	15:58	19:39	800	120	32˚	40	50000	1.9
183a	Jul 2	Optech	15:14	16:08	800	120	32˚	40	50000	2.1
184a	Jul 3	Leica	2:07	3:55	800	120	40˚	36	50000	1.2
184a	Jul 3	Optech	2:21	3:05	800	120	32˚	40	50000	1.7
186a	Jul 5	Leica	6:10	10:09	800	120	40˚	36	50000	1.1
187a	Jul 6	Leica	18:56	23:30	800	120	40˚	36	50000	1.3
188a	Jul 7	Leica	18:41	20:57	800	120	40˚	36	50000	1.3
189a	Jul 8	Leica	0:39	5:27	800	120	40˚	36	50000	1.2
189b	Jul 8	Leica	20:19	1:01	800	120	40˚	36	50000	1.0
190a	Jul 9	Leica	3:54	6:29	800	120	40˚	36	50000	1.3
190a	Jul 9	Optech	21:51	2:28	800	120	32˚	40	50000	1.8
190b	Jul 9	Leica	21:38	3:12	800	120	40˚	36	50000	1.0
191a	Jul 10	Optech	19:45	23:36	800	120	32˚	40	50000	1.8
191a	Jul 10	Leica	21:15	2:17	800	120	40˚	36	50000	1.2
192a	Jul 11	Leica	19:02	22:53	800	120	40˚	36	50000	1.0
192a	Jul 11	Optech	19:10	22:37	800	120	32˚	40	50000	1.7
193a	Jul 12	Optech	21:57	1:44	800	120	32˚	40	50000	1.8
197a	Jul 16	Leica	19:38	00:09	800	120	40˚	36	50000	0.9
197a	Jul 16	Optech	22:42	00:22	800	120	32˚	40	50000	1.7
199b	Jul 18	Leica	00:16	5:40	800	120	40˚	36	50000	1.7
200a	Jul 19	Leica	6:28	10:25	800	120	40˚	36	50000	1.7
200a	Jul 19	Leica	22:54	1:23	800	120	40˚	36	50000	1.5
200a	Jul 19	Optech	23:26	2:42	800	120	32˚	40	50000	1.8
200b	Jul 19	Optech	18:43	21:43	800	120	32˚	40	50000	1.6

201a	Jul 20	Leica	06:01	11:01	800	120	40˚	36	50000	1.7
201a	Jul 20	Leica	23:48	1:44	800	120	40˚	36	50000	1.1
202a	Jul 21	Leica	17:56	23:10	800	120	40˚	36	50000	1.5
203a	Jul 22	Leica	23:24	2:15	800	120	40˚	36	50000	1.3
204a	Jul 23	Leica	17:26	19:27	800	120	40˚	36	50000	1.5
207a	Jul 26	Leica	1:03	3:30	800	120	40˚	36	50000	1.4
228a	Aug 16	Leica	13:56	15:07	800	120	40˚	36	50000	1.2
229a	Aug 17	Leica	13:07	14:15	800	120	40˚	36	50000	1.5

4.3 Final LiDAR Processing

Final post-processing of LiDAR data involves several steps. The airborne GPS data was post-processed using Waypoint's GravNAV™ software (version 7.5). A fixed-bias carrier phase solution was computed in both the forward and reverse chronological directions. The data was processed for both base stations and combined. In the event that the solution worsened as a result of the combination of both solutions the best of both solutions was used to yield more accurate data. LiDAR acquisition was limited to periods when the PDOP was less than 3.2.

The GPS trajectory was combined with the raw IMU data and post-processed using Applanix Inc.'s POSPROC (version 4.3) Kalman Filtering software. This results in a two-fold improvement in the attitude accuracies over the real-time INS data. The best estimated trajectory (BET) and refined attitude data are then re-introduced into the LEICA ALS post processor for the Leica system and the REALM Survey Suite OPTECH for the Optech system to compute the laser point-positions. The trajectory is then combined with the attitude data and laser range measurements to produce the 3-dimensional coordinates of the mass points.

All return values are produced within ALS Post processing software for the Leica system and within REALM Survey Suite OPTECH software for the Optech system. The multi-return information is processed to obtain the "Bare Earth Dataset" as a deliverable. All LiDAR data is processed using the binary LAS format 1.1 file format.

LiDAR filtering was accomplished using TerraSolid, TerraScan LiDAR processing and modeling software. The filtering process reclassifies all the data into classes with in the LAS formatted file based scheme set using the LAS format 1.1 specifications or by the client. For FDEM the classification specifications are ground, default, noise, water and overlap. (Classes: 1, 2, 7, 9 and 12) Once the data is classified, the entire data set is reviewed and manually edited for anomalies that are outside the required guidelines of the product specification or contract guidelines, whichever apply. Table 8 indicates the required product specifications.

The coordinate and datum transformations are then applied to the data set to reflect the required deliverable projection, coordinate and datum systems as provided in the contract.

The client required deliverables are then generated. At this time, a final QC process is undertaken to validate all deliverables for the project. Prior to release of data for delivery, Sanborn's Quality control/ quality assurance department reviews the data and then releases it for delivery.

Table 8: Processing Accuracies and Requirements

Accuracy of LiDAR Data (H)	50 cm RMSE
Accuracy of LiDAR data in bare areas	9.25 cm RMSE
Accuracy of LiDAR data in vegetated areas	18.5 cm RMSE
Percent of artifacts removed (terrain and vegetation dependent)	95%
Percent of all outliers removed	95%
Percent of all vegetation removed	95%
Percent of all buildings removed	98%

5 GEODETIC BASE NETWORK

5.1 Network Scope

During the LiDAR campaign, the geodetic control survey and final coordinates were provided to Sanborn by the PDS team. For Levy County the Sanborn crew set up on NGS points BD2495 and AR1838. These two points were tied into the fully constrained network that was provided.

5.2 Final LiDAR Verification

Figure 6 shows a diagram of the checkpoints collected for Levy County. For the Levy County area the standard deviation is 0.291 and the root mean squared is 0.288. The LiDAR data was compared to each of these classes yielding much better result than was required for the project. Points indicating removed are points outside the statistical variance in the data. Points indicating outside indicate points taken in areas where LiDAR data is not present or the TIN used to generate the analysis could not compute a value as a result of data void as a result of the filtering process. Table 9 indicates the results for Levy County and each point including the overall results as it compares to the LiDAR data set.

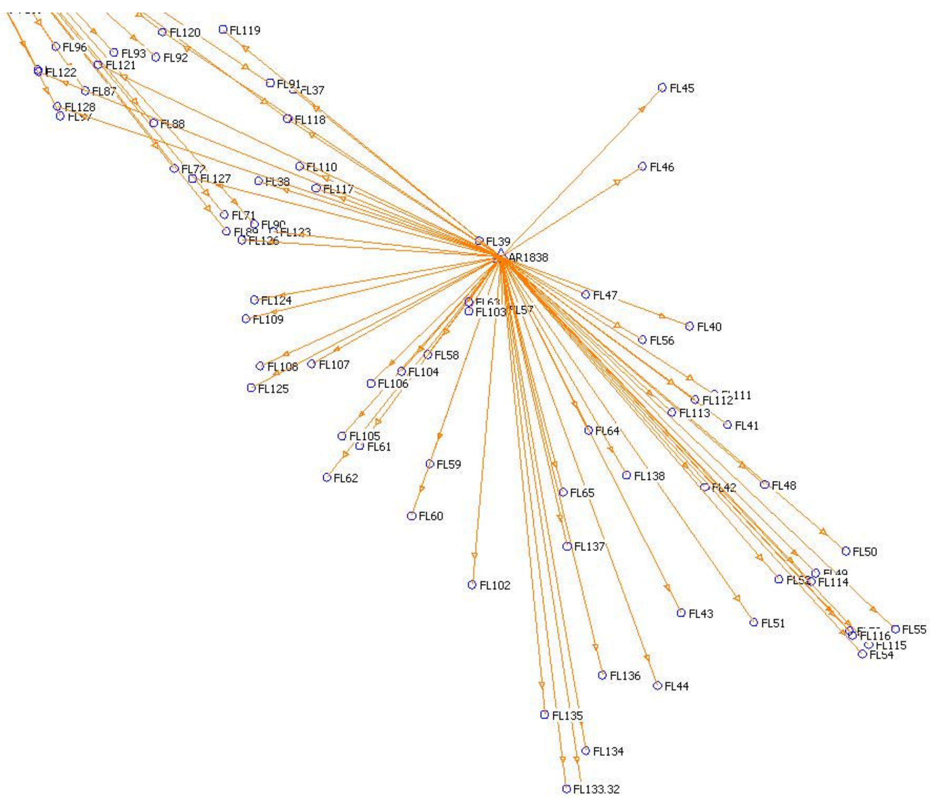


Figure 6: FDEM Survey Checkpoint Diagram

Table 9: FDEM Levy County Checkpoint Results (US Survey Feet)

Number	Easting	Northing	Known Z	Laser Z	Dz
18	388446.312	1801700.691	17.618	18.290	+0.672
20	394193.008	1848861.701	33.904	34.460	+0.556
106	408685.372	1814767.144	27.513	27.970	+0.457
103	378209.035	1880634.263	33.087	33.450	+0.363
134	325386.226	1830528.685	7.133	7.420	+0.287
23	425247.905	1789207.810	13.383	13.640	+0.257
25	354380.541	1900359.207	13.232	13.440	+0.208
22	421216.862	1797392.593	19.859	20.030	+0.171
108	422135.116	1795662.937	17.631	17.660	+0.029
107	427590.101	1792228.440	12.293	12.320	+0.027
11	373585.866	1848775.735	28.448	28.470	+0.022
17	421118.112	1824867.617	28.504	28.500	-0.004
13	354413.383	1781426.777	10.358	10.330	-0.028
104	371510.162	1878969.377	34.970	34.940	-0.030
21	410398.826	1817611.036	25.013	24.970	-0.043
131	328831.348	1760033.554	4.892	4.810	-0.082
129	326879.339	1747134.911	4.987	4.860	-0.127
24	436956.049	1797211.776	20.702	20.570	-0.132
130	321624.935	1747145.816	4.482	4.340	-0.142
105	363416.429	1874992.660	29.888	29.730	-0.158
19	397718.278	1816131.189	29.344	29.180	-0.164
135	346857.521	1854158.878	15.696	15.500	-0.196
12	363630.457	1806039.834	22.224	21.850	-0.374
133	335638.066	1785758.342	9.406	8.800	-0.606

Average dz	+0.040
Minimum dz	-0.606
Maximum dz	+0.672
Average magnitude	0.214
Root mean square	0.288
Std deviation	0.291

6 GROUND CONTROL REPORT

6.1 Introduction

This section addresses Ground Control reporting in the Ellipsoid model used as part of the collection and the Geoid model used to compute orthometric heights.

6.2 Horizontal Datum

The horizontal datum associated with the LiDAR data is NAD83 (1993)/HARN, as realized by the physical NGS control monuments used to constrain the survey control network.

6.3 Vertical Datum

The vertical datum associated with the LiDAR data is the NAVD88, as realized by the physical NGS benchmarks used to constrain the survey control network.

Appendix E: QA/QC Checkpoints and Accuracy Spreadsheet

Point Number		Land Cover Class	SPCS NAD83/99 West Zone Easting-X (Ft)	Northing-Y (FT)	NAVD88 Survey Z	LIDAR-Z	ΔZ
LV001M7	1	BE & Low Grass	362,175.150	1,912,508.620	29.780	29.587	-0.193
LV002M4	1	BE & Low Grass	357,509.550	1,876,973.670	25.410	24.873	-0.537
LV002M8	1	BE & Low Grass	357,412.260	1,877,081.550	25.640	25.197	-0.443
LV003M6	1	BE & Low Grass	367,777.710	1,878,190.180	33.090	32.906	-0.184
LV003M7	1	BE & Low Grass	367,774.830	1,878,214.770	33.450	33.167	-0.283
LV004M8	1	BE & Low Grass	384,278.520	1,867,172.810	28.570	28.948	0.378
LV005M7	1	BE & Low Grass	331,559.940	1,842,366.740	9.460	9.650	0.190
LV006M1	1	BE & Low Grass	342,806.440	1,854,161.460	13.850	13.978	0.128
LV006M3	1	BE & Low Grass	342,908.430	1,854,178.610	14.570	14.613	0.043
LV006M7	1	BE & Low Grass	343,056.270	1,854,224.420	16.050	15.980	-0.070
LV007M3	1	BE & Low Grass	352,000.800	1,854,292.110	19.850	19.567	-0.283
LV007M6	1	BE & Low Grass	352,066.570	1,854,318.270	20.820	20.875	0.055
LV008M3	1	BE & Low Grass	373,227.310	1,854,187.420	29.800	29.872	0.072
LV009M4	1	BE & Low Grass	394,194.900	1,848,772.470	31.840	32.228	0.388
LV010M3	1	BE & Low Grass	362,537.470	1,838,224.260	27.090	26.704	-0.386
LV011M6	1	BE & Low Grass	375,267.740	1,830,332.850	30.490	30.373	-0.117
LV011M7	1	BE & Low Grass	375,064.440	1,830,325.850	31.820	31.420	-0.400
LV012M3	1	BE & Low Grass	390,659.810	1,824,396.970	28.610	28.903	0.293
LV013M1	1	BE & Low Grass	404,889.990	1,828,372.960	31.890	31.486	-0.404
LV015M4	1	BE & Low Grass	359,966.140	1,799,397.620	18.810	18.461	-0.349
LV017M3	1	BE & Low Grass	319,739.190	1,775,098.520	8.910	8.871	-0.039
LV018M8	1	BE & Low Grass	333,914.730	1,775,757.990	9.930	9.457	-0.473
LV019M1	1	BE & Low Grass	324,885.940	1,749,044.250	3.870	3.591	-0.279
LV020M4	1	BE & Low Grass	347,201.060	1,776,278.210	7.530	7.548	0.018
LV020M7	1	BE & Low Grass	347,485.790	1,776,369.360	9.960	9.905	-0.055
LV021M2	1	BE & Low Grass	357,604.170	1,783,694.960	17.720	17.228	-0.492
LV021M3	1	BE & Low Grass	357,711.800	1,783,761.310	15.880	15.383	-0.497
LV022M2	1	BE & Low Grass	370,319.830	1,790,331.010	13.320	13.097	-0.223
LV023M1	1	BE & Low Grass	379,388.630	1,795,966.270	15.670	15.657	-0.013
LV024M6	1	BE & Low Grass	390,051.370	1,802,707.330	15.820	16.022	0.202
LV025M3	1	BE & Low Grass	402,914.160	1,810,925.430	24.580	24.351	-0.229
LV025M5	1	BE & Low Grass	402,778.500	1,811,091.980	24.350	24.167	-0.183
LV026M3	1	BE & Low Grass	417,047.600	1,819,889.200	29.480	29.239	-0.241
LV027M6	1	BE & Low Grass	426,470.560	1,831,478.230	37.570	37.477	-0.093
LV027M7	1	BE & Low Grass	426,497.570	1,831,550.910	36.780	36.842	0.062
LV028M1	1	BE & Low Grass	423,381.390	1,793,277.660	15.710	15.985	0.275
LV029M5	1	BE & Low Grass	446,591.870	1,798,111.140	34.400	34.156	-0.244
LV029M7	1	BE & Low Grass	446,687.450	1,798,129.050	35.350	34.921	-0.429
LV030M7	1	BE & Low Grass	433,230.340	1,774,631.210	13.680	13.964	0.284
LV031M5	1	BE & Low Grass	441,080.410	1,763,292.110	17.990	18.006	0.016
LV032M2	1	BE & Low Grass	458,184.380	1,753,301.500	37.080	36.854	-0.226
LV033M4	1	BE & Low Grass	453,041.520	1,732,144.100	40.220	39.845	-0.375
LV033M7	1	BE & Low Grass	452,983.110	1,732,073.270	37.890	37.497	-0.393
LV034M7	1	BE & Low Grass	436,654.330	1,712,004.350	8.930	9.508	0.578
LV005M2	2	Brush & Low Trees	331,688.360	1,842,478.160	11.050	11.861	0.811
LV008M1	2	Brush & Low Trees	373,278.010	1,854,243.670	30.370	30.222	-0.148
LV009M7	2	Brush & Low Trees	394,103.420	1,848,921.710	31.680	32.226	0.546
LV010M7	2	Brush & Low Trees	362,696.780	1,838,247.760	27.860	27.615	-0.245
LV012M6	2	Brush & Low Trees	390,746.400	1,824,242.030	29.270	29.468	0.198
LV013M3	2	Brush & Low Trees	404,896.890	1,828,461.890	27.860	27.873	0.013
LV014M7	2	Brush & Low Trees	365,208.340	1,809,246.840	21.400	20.209	-1.191
LV015M7	2	Brush & Low Trees	359,956.990	1,799,488.000	18.080	18.207	0.127
LV016M5	2	Brush & Low Trees	324,887.950	1,819,962.560	3.250	2.544	-0.706
LV017M4	2	Brush & Low Trees	319,772.090	1,775,039.490	10.940	11.131	0.191
LV018M4	2	Brush & Low Trees	333,799.320	1,775,506.480	13.220	12.628	-0.592
LV019M3	2	Brush & Low Trees	324,931.100	1,749,003.110	2.580	2.356	-0.224
LV022M8	2	Brush & Low Trees	370,240.670	1,790,421.120	12.280	12.145	-0.135
LV023M4	2	Brush & Low Trees	379,355.940	1,796,085.750	13.760	13.904	0.144

LV024M5	2	Brush & Low Trees	389,990.090	1,802,677.780	16.030	16.476	0.446
LV025M7	2	Brush & Low Trees	402,721.610	1,811,012.440	24.280	24.175	-0.105
LV026M4	2	Brush & Low Trees	417,076.260	1,819,939.840	28.090	27.978	-0.112
LV027M4	2	Brush & Low Trees	426,421.840	1,831,486.710	36.120	36.788	0.668
LV028M7	2	Brush & Low Trees	423,439.480	1,793,240.230	12.490	12.639	0.149
LV030M1	2	Brush & Low Trees	433,339.800	1,774,501.770	10.770	11.329	0.559
LV031M6	2	Brush & Low Trees	441,132.110	1,763,308.910	13.060	13.742	0.682
LV032M7	2	Brush & Low Trees	458,278.110	1,753,196.340	37.020	36.670	-0.350
LV014M2	2	Brush & Low Trees	365,084.030	1,809,081.850	19.770	18.827	-0.943
LV016M2	2	Brush & Low Trees	324,921.050	1,819,824.540	5.960	5.126	-0.834
LV001M2	3	Forested	362,256.610	1,912,259.290	30.070	29.833	-0.237
LV002M2	3	Forested	357,518.290	1,876,839.490	24.810	24.089	-0.721
LV003M4	3	Forested	367,818.720	1,878,161.010	32.750	31.486	-1.264
LV004M1	3	Forested	384,402.210	1,866,990.030	28.970	28.595	-0.375
LV004M2	3	Forested	384,371.870	1,867,030.880	28.540	29.598	1.058
LV005M6	3	Forested	331,561.490	1,842,395.960	11.030	10.982	-0.048
LV007M5	3	Forested	352,073.410	1,854,377.600	19.740	19.715	-0.025
LV008M7	3	Forested	373,017.890	1,854,120.100	29.530	29.215	-0.315
LV009M2	3	Forested	394,245.950	1,848,820.790	32.240	33.158	0.918
LV010M1	3	Forested	362,467.820	1,838,240.930	26.500	25.630	-0.870
LV011M5	3	Forested	375,115.410	1,830,382.660	30.830	30.609	-0.221
LV012M2	3	Forested	390,654.550	1,824,441.190	28.650	28.280	-0.370
LV013M5	3	Forested	404,856.080	1,828,568.150	27.300	27.274	-0.026
* LV014M3	3	Forested	365,162.330	1,809,122.300	21.650	20.254	-1.396
LV015M2	3	Forested	359,882.880	1,799,310.140	17.410	16.602	-0.808
LV016M6	3	Forested	324,764.350	1,820,008.300	2.980	2.321	-0.659
LV017M7	3	Forested	319,661.250	1,774,937.640	8.700	8.617	-0.083
LV018M9	3	Forested	333,706.580	1,775,279.500	8.460	9.179	0.719
LV019M7	3	Forested	325,190.840	1,749,091.320	3.730	3.308	-0.422
LV020M1	3	Forested	347,037.540	1,776,161.490	6.810	6.154	-0.656
LV021M8	3	Forested	357,834.890	1,783,959.500	16.570	15.987	-0.583
LV022M1	3	Forested	370,381.900	1,790,377.340	10.590	9.809	-0.781
LV023M7	3	Forested	379,320.890	1,795,934.060	14.390	14.355	-0.035
LV024M3	3	Forested	389,992.330	1,802,562.600	17.650	17.265	-0.385
LV024M4	3	Forested	390,038.300	1,802,614.510	16.420	16.006	-0.414
LV025M5	3	Forested	417,088.560	1,819,965.600	11.55	11.130	-0.420
LV027M3	3	Forested	426,401.610	1,831,463.160	36.090	36.777	0.687
LV028M5	3	Forested	423,320.370	1,793,159.420	11.550	12.363	0.813
LV029M1	3	Forested	446,483.010	1,798,210.430	33.490	33.072	-0.418
LV030M9	3	Forested	433,089.650	1,774,476.310	10.260	10.782	0.522
LV031M7	3	Forested	441,179.800	1,763,135.440	13.570	12.910	-0.660
LV032M6	3	Forested	458,240.630	1,753,233.100	36.520	36.387	-0.133
LV033M2	3	Forested	452,905.570	1,732,213.750	31.820	31.498	-0.322
LV034M3	3	Forested	436,513.290	1,712,032.820	9.470	10.047	0.577
LV034M4	3	Forested	436,590.710	1,712,026.640	9.360	9.966	0.606
LV001M1	4	Urban	362,176.260	1,912,280.310	29.870	29.854	-0.016
LV002M5	4	Urban	357,450.400	1,876,974.870	25.940	25.363	-0.577
LV003M5	4	Urban	367,801.160	1,878,177.580	33.160	32.791	-0.369
LV004M5	4	Urban	384,279.390	1,867,096.320	30.810	31.096	0.286
LV005M8	4	Urban	331,500.770	1,842,293.940	9.530	9.669	0.139
LV006M8	4	Urban	343,066.710	1,854,179.820	17.200	17.163	-0.037
LV007M8	4	Urban	352,120.390	1,854,231.430	20.710	20.276	-0.434
LV008M5	4	Urban	373,189.440	1,854,114.220	30.770	30.498	-0.272
LV009M6	4	Urban	394,034.630	1,848,811.820	36.660	37.063	0.403
LV010M8	4	Urban	362,794.720	1,838,259.180	28.550	28.202	-0.348
LV011M1	4	Urban	374,882.240	1,830,277.770	31.440	31.084	-0.356
LV012M8	4	Urban	390,765.560	1,824,109.650	29.890	29.989	0.099
LV013M8	4	Urban	404,754.320	1,828,495.590	33.280	32.956	-0.324
LV014M1	4	Urban	365,098.880	1,809,034.810	23.270	22.367	-0.903
LV015M1	4	Urban	359,852.960	1,799,341.240	19.870	19.389	-0.481
LV016M1	4	Urban	324,949.370	1,819,807.250	6.770	6.264	-0.506
LV017M1	4	Urban	319,811.680	1,775,147.750	9.340	9.140	-0.200
LV018M1	4	Urban	333,634.580	1,775,328.330	11.800	11.500	-0.300
LV019M6	4	Urban	325,145.730	1,749,089.910	3.790	3.407	-0.383
LV020M5	4	Urban	347,259.960	1,776,357.170	7.570	7.395	-0.175

LV021M1	4	Urban	357,573.190	1,783,731.990	18.220	17.877	-0.343
LV022M5	4	Urban	370,194.550	1,790,324.110	14.890	14.274	-0.616
LV023M2	4	Urban	379,386.040	1,796,010.290	17.340	17.141	-0.199
LV025M1	4	Urban	402,884.470	1,811,090.200	25.220	24.788	-0.432
LV026M1	4	Urban	417,129.630	1,819,903.530	29.880	29.716	-0.164
LV028M2	4	Urban	423,344.320	1,793,260.830	16.690	16.907	0.217
LV029M2	4	Urban	446,480.770	1,798,166.660	35.570	35.323	-0.247
LV030M4	4	Urban	433,200.500	1,774,578.350	14.310	14.518	0.208
LV031M3	4	Urban	441,119.500	1,763,213.220	19.240	19.449	0.209
LV032M8	4	Urban	458,272.780	1,753,283.920	37.770	37.416	-0.354
LV033M6	4	Urban	453,055.830	1,732,052.840	40.300	39.927	-0.373
LV034M5	4	Urban	436,591.320	1,712,068.460	11.180	11.540	0.360

* LV014M3: This checkpoint was located at the base of a tree (~18 inch diameter), in a low confidence area and was not used in the vertical accuracy assessment

100 % of Totals	# of Points	RMSE (ft) Spec = 0.61 (BE = 0.30)	Mean (ft)	Median (ft)	Min (ft)	Max (ft)
Consolidated	134	0.44	-0.13	-0.20	-1.26	1.06
BE & Low Grass	44	0.30	-0.12	-0.18	-0.54	-0.59
Brush & Low Trees	24	0.53	-0.04	-0.05	-1.19	0.81
Forested	34	0.58	-0.14	-0.28	-1.26	1.06
Urban	32	0.37	-0.20	-0.29	-0.90	0.40

Land Cover Category	# of Points	FVA — Fundamental Vertical Accuracy (RMSEz x 1.9600) Spec = 0.60 ft	CVA — Consolidated Vertical Accuracy (95th Percentile) Spec = 1.19 ft	SVA — Supplemental Vertical Accuracy (95th Percentile) Target = 1.19 ft
Consolidated	134		0.85	
BE & Low Grass	44	0.58		0.50
Brush & Low Trees	24			0.93
Forested	34			0.97
Urban	32			0.59

Levy County - Vertical Accuracy Assessment for Category 1 Points						
Point No	Land Cover Class	LiDAR TIN - Z	Survey - Z	ΔZ	ΔZ^2	ABS ΔZ
LV001M7	1	29.59	29.78	-0.19	0.04	0.19
LV002M4	1	24.87	25.41	-0.54	0.29	0.54
LV002M8	1	25.20	25.64	-0.44	0.20	0.44
LV003M6	1	32.91	33.09	-0.18	0.03	0.18
LV003M7	1	33.17	33.45	-0.28	0.08	0.28
LV004M8	1	28.95	28.57	0.38	0.14	0.38
LV005M7	1	9.65	9.46	0.19	0.04	0.19
LV006M1	1	13.98	13.85	0.13	0.02	0.13
LV006M3	1	14.61	14.57	0.04	0.00	0.04
LV006M7	1	15.98	16.05	-0.07	0.00	0.07
LV007M3	1	19.57	19.85	-0.28	0.08	0.28
LV007M6	1	20.88	20.82	0.05	0.00	0.05
LV008M3	1	29.87	29.80	0.07	0.01	0.07
LV009M4	1	32.23	31.84	0.39	0.15	0.39
LV010M3	1	26.70	27.09	-0.39	0.15	0.39
LV011M6	1	30.37	30.49	-0.12	0.01	0.12
LV011M7	1	31.42	31.82	-0.40	0.16	0.40
LV012M3	1	28.90	28.61	0.29	0.09	0.29
LV013M1	1	31.49	31.89	-0.40	0.16	0.40
LV015M4	1	18.46	18.81	-0.35	0.12	0.35
LV017M3	1	8.87	8.91	-0.04	0.00	0.04
LV018M8	1	9.46	9.93	-0.47	0.22	0.47
LV019M1	1	3.59	3.87	-0.28	0.08	0.28
LV020M4	1	7.55	7.53	0.02	0.00	0.02
LV020M7	1	9.91	9.96	-0.06	0.00	0.06
LV021M2	1	17.23	17.72	-0.49	0.24	0.49
LV021M3	1	15.38	15.88	-0.50	0.25	0.50
LV022M2	1	13.10	13.32	-0.22	0.05	0.22
LV023M1	1	15.66	15.67	-0.01	0.00	0.01
LV024M6	1	16.02	15.82	0.20	0.04	0.20
LV025M3	1	24.35	24.58	-0.23	0.05	0.23
LV025M5	1	24.17	24.35	-0.18	0.03	0.18
LV026M3	1	29.24	29.48	-0.24	0.06	0.24
LV027M6	1	37.48	37.57	-0.09	0.01	0.09
LV027M7	1	36.84	36.78	0.06	0.00	0.06
LV028M1	1	15.99	15.71	0.28	0.08	0.28
LV029M5	1	34.16	34.40	-0.24	0.06	0.24
LV029M7	1	34.92	35.35	-0.43	0.18	0.43
LV030M7	1	13.96	13.68	0.28	0.08	0.28
LV031M5	1	18.01	17.99	0.02	0.00	0.02
LV032M2	1	36.85	37.08	-0.23	0.05	0.23
LV033M4	1	39.85	40.22	-0.38	0.14	0.38
LV033M7	1	37.50	37.89	-0.39	0.15	0.39
LV034M7	1	9.51	8.93	0.58	0.33	0.58

	Geo-Referencing			sum of dz²	3.89	
	Horiz	NAD83(1992) WZ		count	44.00	
	Vert.	NAVD88 (Geoid99)		sum dz2/count	0.09	
	Units	US Survey Feet		RMSE	0.30	
				1.96 * RMSE	0.58	
	RMSE Calculation			mean	-0.12	
	Square Root of $\sum(Zn\text{-}Z'n)^2/N$			median	-0.18	
	Zn = LiDAR Dem Heights			skew	0.52	
	Z'n = Checkpoint Heights			std dev	0.28	
	N = The number of check points			**95th percentile**	**0.50**	
Ground Cover CAT	**CAT Description**	**Survey CAT**	**Surv. CAT Ground Cover Equivalent**		**DZ MIN**	**DZ MAX**
CAT 1	BE & Low Grass	GND 1, DRD, MGF	GND 1 = Ground - BE & Low Grass		-0.54	0.58
CAT 2	Brush & Low Trees	GND 2	GND 2 = Ground - Brush & Low Trees			
CAT 3	Forested	GND 3	GND 3 = Ground - Forested			
CAT 4	Urban	PVM 4	DRD = Ground - Dirt/Clay Road			
			PVM = Pavement (Asphalt/Concrete)			
			MGF= Well Maintained Ground Feature			
Land Cover Categories and Accuracy Criteria			**Computed Accuracies**			
Ground Cover CAT	**RMSEz (Ft) ≤**	**ACCURACYz (Ft) ≤**	**Actual RMSEz**	**95% Acc Z**	**95th Percentile**	
CAT 1	0.30	0.60	0.30	0.58	0.50	
CAT 2	0.61	1.19				
CAT 3	0.61	1.19				
CAT 4	0.61	1.19				
COMBINED	0.61	1.19				
The following check points did not meet location criteria for CAT 1 points and were changed to the CAT 2 classification						
Point No	**Land Cover Class**		**Survey - Z**	**ΔZ**	**ΔZ^2**	**ABS ΔZ**
LV014M2	CAT 1	18.83	19.77	-0.94	0.89	0.94
LV016M	CAT 1	5.13	5.96	-0.83	0.70	0.83

Levy County - Vertical Accuracy Assessment for Category 2 Points						
PID	Land Cover Cat.	LiDAR TIN - Z	Survey Height	DELTA Z	DZ*2	ABS DZ
LV005M2	2	11.86	11.05	0.81	0.66	0.81
LV008M1	2	30.22	30.37	-0.15	0.02	0.15
LV009M7	2	32.23	31.68	0.55	0.30	0.55
LV010M7	2	27.62	27.86	-0.24	0.06	0.24
LV012M6	2	29.47	29.27	0.20	0.04	0.20
LV013M3	2	27.87	27.86	0.01	0.00	0.01
LV014M7	2	20.21	21.40	-1.19	1.42	1.19
LV015M7	2	18.21	18.08	0.13	0.02	0.13
LV016M5	2	2.54	3.25	-0.71	0.50	0.71
LV017M4	2	11.13	10.94	0.19	0.04	0.19
LV018M4	2	12.63	13.22	-0.59	0.35	0.59
LV019M3	2	2.36	2.58	-0.22	0.05	0.22
LV022M8	2	12.15	12.28	-0.14	0.02	0.14
LV023M4	2	13.90	13.76	0.14	0.02	0.14
LV024M5	2	16.48	16.03	0.45	0.20	0.45
LV025M7	2	24.18	24.28	-0.11	0.01	0.11
LV026M4	2	27.98	28.09	-0.11	0.01	0.11
LV027M4	2	36.79	36.12	0.67	0.45	0.67
LV028M7	2	12.64	12.49	0.15	0.02	0.15
LV030M1	2	11.33	10.77	0.56	0.31	0.56
LV031M6	2	13.74	13.06	0.68	0.47	0.68
LV032M7	2	36.67	37.02	-0.35	0.12	0.35
LV014M2	2	18.83	19.77	-0.94	0.89	0.94
LV016M2	2	5.13	5.96	-0.83	0.70	0.83
	Geo-Referencing			sum of dz²	6.66	
	Horiz	NAD83(1992) WZ		count	24.00	
	Vert.	NAVD88 (Geoid99)		sum dz2/count	0.28	
	Units	US Survey Feet		RMSE	0.53	
				1.96 * RMSE	1.03	
	RMSE Calculation			mean	-0.04	
	Square Root of $\sum(Zn-Z'n)^2/N$			median	-0.05	
	Zn = LiDAR Dem Heights			skew	-0.39	
	Z'n = Checkpoint Heights			std dev	0.54	
	N = The number of check points			**95th percentile**	**0.93**	
Ground Cover CAT	**CAT Description**	**Survey CAT**	**Surv. CAT Ground Cover Equivalent**		**DZ MIN**	**DZ MAX**
CAT 1	BE & Low Grass	GND 1, DRD, MGF	GND 1 = Ground - BE & Low Grass		-1.19	0.81
CAT 2	Brush & Low Trees	GND 2	GND 2 = Ground - Brush & Low Trees			
CAT 3	Forested	GND 3	GND 3 = Ground - Forested			
CAT 4	Urban	PVM 4	DRD = Ground - Dirt/Clay Road			

			PVM = Pavement (Asphalt/Concrete)			
			MGF= Well Maintained Ground Feature			
Land Cover Categories and Accuracy Criteria			**Computed Accuracies**			
Ground Cover CAT	**RMSEz (Ft) ≤**	**ACCURACYz (Ft) ≤**	**Actual RMSEz**	**95% Acc Z**	**95th Percentile**	
CAT 1	0.30	0.60				
CAT 2	0.61	1.19	0.53	1.03	0.93	
CAT 3	0.61	1.19				
CAT 4	0.61	1.19				
COMBINED	0.61	1.19				

Levy County - Vertical Accuracy Assessment for Category 3 Points						
PID	Land Cover Cat.	LiDAR TIN - Z	Survey - Z	DELTA Z	DZ^2	ABS DZ
LV001M2	3	29.83	30.07	-0.24	0.06	0.24
LV002M2	3	24.09	24.81	-0.72	0.52	0.72
LV003M4	3	31.49	32.75	-1.26	1.60	1.26
LV004M1	3	28.60	28.97	-0.38	0.14	0.38
LV004M2	3	29.60	28.54	1.06	1.12	1.06
LV005M6	3	10.98	11.03	-0.05	0.00	0.05
LV007M5	3	19.72	19.74	-0.02	0.00	0.02
LV008M7	3	29.22	29.53	-0.32	0.10	0.32
LV009M2	3	33.16	32.24	0.92	0.84	0.92
LV010M1	3	25.63	26.50	-0.87	0.76	0.87
LV011M5	3	30.61	30.83	-0.22	0.05	0.22
LV012M2	3	28.28	28.65	-0.37	0.14	0.37
LV013M5	3	27.27	27.30	-0.03	0.00	0.03
LV015M2	3	16.60	17.41	-0.81	0.65	0.81
LV016M6	3	2.32	2.98	-0.66	0.43	0.66
LV017M7	3	8.62	8.70	-0.08	0.01	0.08
LV018M9	3	9.18	8.46	0.72	0.52	0.72
LV019M7	3	3.31	3.73	-0.42	0.18	0.42
LV020M1	3	6.15	6.81	-0.66	0.43	0.66
LV021M8	3	15.99	16.57	-0.58	0.34	0.58
LV022M1	3	9.81	10.59	-0.78	0.61	0.78
LV023M7	3	14.36	14.39	-0.04	0.00	0.04
LV024M3	3	17.27	17.65	-0.38	0.15	0.38
LV024M4	3	16.01	16.42	-0.41	0.17	0.41
LV026M5	3	11.13	11.55	-0.42	0.18	0.42
LV027M3	3	36.78	36.09	0.69	0.47	0.69
LV028M5	3	12.31	11.50	0.81	0.66	0.81
LV029M1	3	33.07	33.49	-0.42	0.17	0.42
LV030M9	3	10.78	10.26	0.52	0.27	0.52
LV031M7	3	13.50	13.57	-0.07	0.00	0.07
LV032M6	3	36.39	36.52	-0.13	0.02	0.13
LV033M2	3	31.50	31.82	-0.32	0.10	0.32
LV034M3	3	10.05	9.47	0.58	0.33	0.58
LV034M4	3	9.97	9.36	0.61	0.37	0.61
	Geo-Referencing			sum of dz²	11.39	
	Horiz	NAD83(1992) WZ		count	34.00	
	Vert.	NAVD88 (Geoid99)		sum dz2/count	0.34	
	Units	US Survey Feet		RMSE	0.58	
				1.96 * RMSE	1.13	
	RMSE Calculation			mean	-0.14	
	Square Root of $\sum(Zn-Z'n)^2/N$			median	-0.28	
	Zn = LiDAR Dem Heights			skew	0.52	

	Z'n = Checkpoint Heights			std dev	0.57	
	N = The number of check points			**95th percentile**	**0.97**	
Ground Cover CAT	**CAT Description**	**Survey CAT**	**Surv. CAT Ground Cover Equivalent**		**DZ MIN**	**DZ MAX**
CAT 1	BE & Low Grass	GND 1, DRD, MGF	GND 1 = Ground - BE & Low Grass		-1.26	1.06
CAT 2	Brush & Low Trees	GND 2	GND 2 = Ground - Brush & Low Trees			
CAT 3	Forested	GND 3	GND 3 = Ground - Forested			
CAT 4	Urban	PVM 4	DRD = Ground - Dirt/Clay Road			
			PVM = Pavement (Asphalt/Concrete)			
			MGF= Well Maintained Ground Feature			
Land Cover Categories and Accuracy Criteria			**Computed Accuracies**			
Ground Cover CAT	**RMSEz (Ft) ≤**	**ACCURACYz (Ft) ≤**	**Actual RMSEz**	**95% Acc Z**	**95th Percentile**	
CAT 1	0.30	0.60				
CAT 2	0.61	1.19				
CAT 3	0.61	1.19	0.58	1.13	0.97	
CAT 4	0.61	1.19				
COMBINED	0.61	1.19				
The following check point was located in a low conficence area and was not used in the vertical accuracy assessment						
Point No	**Land Cover Class**	**LiDAR TIN - Z**	**Survey - Z**	**ΔZ**	**ΔZ*2**	**ABS ΔZ**
LV014M3	3	20.25	21.65	-1.40	1.95	1.40

Levy County - Vertical Accuracy Assessment for Category 4 Points						
PID	Land Cover Cat.	LiDAR TIN - Z	Survey - Z	DELTA Z	DZ^2	ABS DZ
LV001M1	4	29.85	29.87	-0.02	0.00	0.02
LV002M5	4	25.36	25.94	-0.58	0.33	0.58
LV003M5	4	32.79	33.16	-0.37	0.14	0.37
LV004M5	4	31.10	30.81	0.29	0.08	0.29
LV005M8	4	9.67	9.53	0.14	0.02	0.14
LV006M8	4	17.16	17.20	-0.04	0.00	0.04
LV007M8	4	20.28	20.71	-0.43	0.19	0.43
LV008M5	4	30.50	30.77	-0.27	0.07	0.27
LV009M6	4	37.06	36.66	0.40	0.16	0.40
LV010M8	4	28.20	28.55	-0.35	0.12	0.35
LV011M1	4	31.08	31.44	-0.36	0.13	0.36
LV012M8	4	29.99	29.89	0.10	0.01	0.10
LV013M8	4	32.96	33.28	-0.32	0.10	0.32
LV014M1	4	22.37	23.27	-0.90	0.82	0.90
LV015M1	4	19.39	19.87	-0.48	0.23	0.48
LV016M1	4	6.26	6.77	-0.51	0.26	0.51
LV017M1	4	9.14	9.34	-0.20	0.04	0.20
LV018M1	4	11.50	11.80	-0.30	0.09	0.30
LV019M6	4	3.41	3.79	-0.38	0.15	0.38
LV020M5	4	7.40	7.57	-0.18	0.03	0.18
LV021M1	4	17.88	18.22	-0.34	0.12	0.34
LV022M5	4	14.27	14.89	-0.62	0.38	0.62
LV023M2	4	17.14	17.34	-0.20	0.04	0.20
LV025M1	4	24.79	25.22	-0.43	0.19	0.43
LV026M1	4	29.72	29.88	-0.16	0.03	0.16
LV028M2	4	16.91	16.69	0.22	0.05	0.22
LV029M2	4	35.32	35.57	-0.25	0.06	0.25
LV030M4	4	14.52	14.31	0.21	0.04	0.21
LV031M3	4	19.45	19.24	0.21	0.04	0.21
LV032M8	4	37.42	37.77	-0.35	0.13	0.35
LV033M6	4	39.93	40.30	-0.37	0.14	0.37
LV034M5	4	11.54	11.18	0.36	0.13	0.36
	Geo-Referencing			sum of dz²	4.31	
	Horiz	NAD83(1992) WZ		count	32.00	
	Vert.	NAVD88 (Geoid99)		sum dz2/count	0.13	
	Units	US Survey Feet		RMSE	0.37	
				1.96 * RMSE	0.72	
	RMSE Calculation			mean	-0.20	
	Square Root of $\sum(Zn-Z'n)^2/N$			median	-0.29	
	Zn = LiDAR Dem Heights			skew	0.27	
	Z'n = Checkpoint Heights			std dev	0.31	
	N = The number of check points			**95th percentile**	**0.59**	

Ground Cover CAT	CAT Description	Survey CAT	Surv. CAT Ground Cover Equivalent	DZ MIN	DZ MAX
CAT 1	BE & Low Grass	GND 1, DRD, MGF	GND 1 = Ground - BE & Low Grass	-0.90	0.40
CAT 2	Brush & Low Trees	GND 2	GND 2 = Ground - Brush & Low Trees		
CAT 3	Forested	GND 3	GND 3 = Ground - Forested		
CAT 4	Urban	PVM 4	DRD = Ground - Dirt/Clay Road		
			PVM = Pavement (Asphalt/Concrete)		
			MGF= Well Maintained Ground Feature		

Land Cover Categories and Accuracy Criteria			Computed Accuracies			
Ground Cover CAT	**RMSEz (Ft) ≤**	**ACCURACYz (Ft) ≤**	**Actual RMSEz**	**95% Acc Z**	**95th Percentile**	
CAT 1	0.30	0.60				
CAT 2	0.61	1.19				
CAT 3	0.61	1.19				
CAT 4	0.61	1.19	0.37	0.72	0.59	
COMBINED	0.61	1.19				

Levy County - Vertical Accuracy Assessment for All Categories Combined						
PID	Land Cover Cat.	LiDAR TIN - Z	Survey - Z	DELTA Z	DZ*2	ABS DZ
LV001M7	1	29.59	29.78	-0.19	0.04	0.19
LV002M4	1	24.87	25.41	-0.54	0.29	0.54
LV002M8	1	25.20	25.64	-0.44	0.20	0.44
LV003M6	1	32.91	33.09	-0.18	0.03	0.18
LV003M7	1	33.17	33.45	-0.28	0.08	0.28
LV004M8	1	28.95	28.57	0.38	0.14	0.38
LV005M7	1	9.65	9.46	0.19	0.04	0.19
LV006M1	1	13.98	13.85	0.13	0.02	0.13
LV006M3	1	14.61	14.57	0.04	0.00	0.04
LV006M7	1	15.98	16.05	-0.07	0.00	0.07
LV007M3	1	19.57	19.85	-0.28	0.08	0.28
LV007M6	1	20.88	20.82	0.05	0.00	0.05
LV008M3	1	29.87	29.80	0.07	0.01	0.07
LV009M4	1	32.23	31.84	0.39	0.15	0.39
LV010M3	1	26.70	27.09	-0.39	0.15	0.39
LV011M6	1	30.37	30.49	-0.12	0.01	0.12
LV011M7	1	31.42	31.82	-0.40	0.16	0.40
LV012M3	1	28.90	28.61	0.29	0.09	0.29
LV013M1	1	31.49	31.89	-0.40	0.16	0.40
LV015M4	1	18.46	18.81	-0.35	0.12	0.35
LV017M3	1	8.87	8.91	-0.04	0.00	0.04
LV018M8	1	9.46	9.93	-0.47	0.22	0.47
LV019M1	1	3.59	3.87	-0.28	0.08	0.28
LV020M4	1	7.55	7.53	0.02	0.00	0.02
LV020M7	1	9.91	9.96	-0.06	0.00	0.06
LV021M2	1	17.23	17.72	-0.49	0.24	0.49
LV021M3	1	15.38	15.88	-0.50	0.25	0.50
LV022M2	1	13.10	13.32	-0.22	0.05	0.22
LV023M1	1	15.66	15.67	-0.01	0.00	0.01
LV024M6	1	16.02	15.82	0.20	0.04	0.20
LV025M3	1	24.35	24.58	-0.23	0.05	0.23
LV025M5	1	24.17	24.35	-0.18	0.03	0.18
LV026M3	1	29.24	29.48	-0.24	0.06	0.24
LV027M6	1	37.48	37.57	-0.09	0.01	0.09
LV027M7	1	36.84	36.78	0.06	0.00	0.06
LV028M1	1	15.99	15.71	0.28	0.08	0.28
LV029M5	1	34.16	34.40	-0.24	0.06	0.24
LV029M7	1	34.92	35.35	-0.43	0.18	0.43
LV030M7	1	13.96	13.68	0.28	0.08	0.28
LV031M5	1	18.01	17.99	0.02	0.00	0.02
LV032M2	1	36.85	37.08	-0.23	0.05	0.23
LV033M4	1	39.85	40.22	-0.38	0.14	0.38
LV033M7	1	37.50	37.89	-0.39	0.15	0.39
LV034M7	1	9.51	8.93	0.58	0.33	0.58

LV005M2	2	11.86	11.05	0.81	0.66	0.81
LV008M1	2	30.22	30.37	-0.15	0.02	0.15
LV009M7	2	32.23	31.68	0.55	0.30	0.55
LV010M7	2	27.62	27.86	-0.24	0.06	0.24
LV012M6	2	29.47	29.27	0.20	0.04	0.20
LV013M3	2	27.87	27.86	0.01	0.00	0.01
LV014M7	2	20.21	21.40	-1.19	1.42	1.19
LV015M7	2	18.21	18.08	0.13	0.02	0.13
LV016M5	2	2.54	3.25	-0.71	0.50	0.71
LV017M4	2	11.13	10.94	0.19	0.04	0.19
LV018M4	2	12.63	13.22	-0.59	0.35	0.59
LV019M3	2	2.36	2.58	-0.22	0.05	0.22
LV022M8	2	12.15	12.28	-0.14	0.02	0.14
LV023M4	2	13.90	13.76	0.14	0.02	0.14
LV024M5	2	16.48	16.03	0.45	0.20	0.45
LV025M7	2	24.18	24.28	-0.11	0.01	0.11
LV026M4	2	27.98	28.09	-0.11	0.01	0.11
LV027M4	2	36.79	36.12	0.67	0.45	0.67
LV028M7	2	12.64	12.49	0.15	0.02	0.15
LV030M1	2	11.33	10.77	0.56	0.31	0.56
LV031M6	2	13.74	13.06	0.68	0.47	0.68
LV032M7	2	36.67	37.02	-0.35	0.12	0.35
LV014M2	2	18.83	19.77	-0.94	0.89	0.94
LV016M2	2	5.13	5.96	-0.83	0.70	0.83
LV001M2	3	29.83	30.07	-0.24	0.06	0.24
LV002M2	3	24.09	24.81	-0.72	0.52	0.72
LV003M4	3	31.49	32.75	-1.26	1.60	1.26
LV004M1	3	28.60	28.97	-0.38	0.14	0.38
LV004M2	3	29.60	28.54	1.06	1.12	1.06
LV005M6	3	10.98	11.03	-0.05	0.00	0.05
LV007M5	3	19.72	19.74	-0.02	0.00	0.02
LV008M7	3	29.22	29.53	-0.32	0.10	0.32
LV009M2	3	33.16	32.24	0.92	0.84	0.92
LV010M1	3	25.63	26.50	-0.87	0.76	0.87
LV011M5	3	30.61	30.83	-0.22	0.05	0.22
LV012M2	3	28.28	28.65	-0.37	0.14	0.37
LV013M5	3	27.27	27.30	-0.03	0.00	0.03
LV015M2	3	16.60	17.41	-0.81	0.65	0.81
LV016M6	3	2.32	2.98	-0.66	0.43	0.66
LV017M7	3	8.62	8.70	-0.08	0.01	0.08
LV018M9	3	9.18	8.46	0.72	0.52	0.72
LV019M7	3	3.31	3.73	-0.42	0.18	0.42
LV020M1	3	6.15	6.81	-0.66	0.43	0.66
LV021M8	3	15.99	16.57	-0.58	0.34	0.58
LV022M1	3	9.81	10.59	-0.78	0.61	0.78
LV023M7	3	14.36	14.39	-0.04	0.00	0.04
LV024M3	3	17.27	17.65	-0.38	0.15	0.38

LV024M4	3	16.01	16.42	-0.41	0.17	0.41
LV026M5	3	11.13	11.55	-0.42	0.18	0.42
LV027M3	3	36.78	36.09	0.69	0.47	0.69
LV028M5	3	12.31	11.50	0.81	0.66	0.81
LV029M1	3	33.07	33.49	-0.42	0.17	0.42
LV030M9	3	10.78	10.26	0.52	0.27	0.52
LV031M7	3	13.50	13.57	-0.07	0.00	0.07
LV032M6	3	36.39	36.52	-0.13	0.02	0.13
LV033M2	3	31.50	31.82	-0.32	0.10	0.32
LV034M3	3	10.05	9.47	0.58	0.33	0.58
LV034M4	3	9.97	9.36	0.61	0.37	0.61
LV001M1	4	29.85	29.87	-0.02	0.00	0.02
LV002M5	4	25.36	25.94	-0.58	0.33	0.58
LV003M5	4	32.79	33.16	-0.37	0.14	0.37
LV004M5	4	31.10	30.81	0.29	0.08	0.29
LV005M8	4	9.67	9.53	0.14	0.02	0.14
LV006M8	4	17.16	17.20	-0.04	0.00	0.04
LV007M8	4	20.28	20.71	-0.43	0.19	0.43
LV008M5	4	30.50	30.77	-0.27	0.07	0.27
LV009M6	4	37.06	36.66	0.40	0.16	0.40
LV010M8	4	28.20	28.55	-0.35	0.12	0.35
LV011M1	4	31.08	31.44	-0.36	0.13	0.36
LV012M8	4	29.99	29.89	0.10	0.01	0.10
LV013M8	4	32.96	33.28	-0.32	0.10	0.32
LV014M1	4	22.37	23.27	-0.90	0.82	0.90
LV015M1	4	19.39	19.87	-0.48	0.23	0.48
LV016M1	4	6.26	6.77	-0.51	0.26	0.51
LV017M1	4	9.14	9.34	-0.20	0.04	0.20
LV018M1	4	11.50	11.80	-0.30	0.09	0.30
LV019M6	4	3.41	3.79	-0.38	0.15	0.38
LV020M5	4	7.40	7.57	-0.18	0.03	0.18
LV021M1	4	17.88	18.22	-0.34	0.12	0.34
LV022M5	4	14.27	14.89	-0.62	0.38	0.62
LV023M2	4	17.14	17.34	-0.20	0.04	0.20
LV025M1	4	24.79	25.22	-0.43	0.19	0.43
LV026M1	4	29.72	29.88	-0.16	0.03	0.16
LV028M2	4	16.91	16.69	0.22	0.05	0.22
LV029M2	4	35.32	35.57	-0.25	0.06	0.25
LV030M4	4	14.52	14.31	0.21	0.04	0.21
LV031M3	4	19.45	19.24	0.21	0.04	0.21
LV032M8	4	37.42	37.77	-0.35	0.13	0.35
LV033M6	4	39.93	40.30	-0.37	0.14	0.37
LV034M5	4	11.54	11.18	0.36	0.13	0.36
	Geo-Referencing			sum of dz^2	26.26	
	Horiz	NAD83(1992) WZ		count	134.00	

	Vert.	NAVD88 (Geoid99)		sum dz2/count	0.20		
	Units	US Survey Feet		RMSE	0.44		
				1.96 * RMSE	0.87		
	RMSE Calculation			mean	-0.13		
	Square Root of $\sum(Zn-Z'n)^2/N$			median	-0.20		
	Zn = LiDAR Dem Heights			skew	0.33		
	Z'n = Checkpoint Heights			std dev	0.42		
	N = The number of check points			**95th percentile**	**0.85**		
Ground Cover CAT	**CAT Description**	**Survey CAT**	**Surv. CAT Ground Cover Equivalent**		**DZ MIN**	**DZ MAX**	
CAT 1	BE & Low Grass	GND 1, DRD, MGF	GND 1 = Ground - BE & Low Grass		-1.26	1.06	
CAT 2	Brush & Low Trees	GND 2	GND 2 = Ground - Brush & Low Trees				
CAT 3	Forested	GND 3	GND 3 = Ground - Forested				
CAT 4	Urban	PVM 4	DRD = Ground - Dirt/Clay Road				
			PVM = Pavement (Asphalt/Concrete)				
			MGF= Well Maintained Ground Feature				
Land Cover Categories and Accuracy Criteria			**Computed Accuracies**				
Ground Cover CAT	**RMSEz (Ft) ≤**	**ACCURACYz (Ft) ≤**	**RMSEz**	**95% Acc Z**	**95th Percentile**		
CAT 1	0.30	0.60	0.30	0.58	0.50		
CAT 2	0.61	1.19	0.53	1.03	0.93		
CAT 3	0.61	1.19	0.58	1.13	0.97		
CAT 4	0.61	1.19	0.37	0.72	0.59		
COMBINED	0.61	1.19	0.44	0.87	0.85		
Calculation of Estimated and Actual Number of Check Points and Clusters for This County Area							
Total Number of Tiles This County Area	**Square Miles Per 5K Tile**	**Total Square Miles This County Area**	**Number of Check Points per Sq. Mi.**	**Estimated Number of Check Points**	**Estimated Number of Point Clusters**	**Actual No. Points and Clusters**	
*532	0.897	477	4.17	114	29	136 / 34	
The following check points did not meet location criteria for CAT 1 points and were changed to the CAT 2 classification							
Point No	**Land Cover Class**	**LiDAR TIN - Z**	**Survey - Z**	**ΔZ**	**ΔZ^2**	**ABS ΔZ**	
LV014M2	CAT 1	18.83	19.77	-0.94	0.89	0.94	
LV016M	CAT 1	5.13	5.96	-0.83	0.70	0.83	
The following check point was located in a low conficence area and was not used in the vertical accuracy assessment							
Point No	**Land Cover Class**	**LiDAR TIN - Z**	**Survey - Z**	**ΔZ**	**ΔZ^2**	**ABS ΔZ**	
LV014M3	3	20.25	21.65	-1.40	1.95	1.40	

* Note there are actually 727 tiles in the Levy County area, but ~195 tiles are located in marsh where check points cannot be established. Therefore, the calculation to determine the number of check points to be established was based on 532 tiles comprising 477 square miles.

Appendix F: LiDAR Vertical Accuracy Report

Vertical Accuracy Assessment Report 2007 LiDAR Bare-Earth Dataset for Levy County, Florida

Date: April 23, 2008

References: A — State of Florida Division of Emergency Management (FDEM), Contract Number 07-HS-34-14-00-22-469, Task Order Number 20070525-492718a
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 Guidance: Reference A tasked PDS to validate the bare-earth LiDAR dataset of Levy County, FL, both quantitatively (for accuracy) and qualitatively (for usability). This report addresses the vertical accuracy assessment only, for which FDEM's major 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 PDS followed the FDEM guidelines in Reference A, which stipulates 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. The land cover measurements distributed through each project area will be 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 PDS team established a primary geodetic network covering approximately 6,000 square miles along the panhandle area of Northwest Florida to provide accurate and consistent control throughout the project area, which includes Levy County. The Primary Network was used to establish base stations to support airborne GPS data acquisition. Two Secondary control networks were established to support the measurement of checkpoints used in the accuracy validation process for newly generated LiDAR and Orthophotography.

<u>Assessment Procedures and Results</u>: The LiDAR accuracy assessment for Levy County 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 Levy County's 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 for Levy County

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 95^{th} percentile per land cover category)
Consolidated Vertical Accuracy (CVA) in all land cover categories combined = 95% confidence lever	1.19 ft (based on combined 95^{th} 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 ($RMSE_z$) of the checkpoints x 1.9600, as specified in Reference B. For Levy County, for which floodplains are essentially flat, FDEM required the FVA to be 0.60 ft (18.29 cm) at the 95% confidence level (based on an $RMSE_z$ 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 95^{th} 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 95^{th} 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 95^{th} percentile error for all checkpoints in each individual land cover category. SVA statistics are calculated individually for bare-earth and low grass, brush lands and low trees, 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 Levy County. 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 PDS were as follows:

1. PDS surveyed "ground truth" QA/QC vertical checkpoints in accordance with guidance in references B, C, D and E. Figure 1 shows the location of "cluster areas" where PDS attempted to survey a minimum of 30 QA/QC checkpoints in each of the four land cover categories. Some cluster areas did not include all land cover categories. The final totals were 44 checkpoints in bare-earth and low grass; 24 checkpoints in brush and low trees; 34 checkpoints in forested areas; and 32checkpoints in urban areas, for a total of 134 checkpoints.
2. Next, PDS interpolated the bare-earth LiDAR DTM to provide the z-value for each of the 134 checkpoints.
3. PDS 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 PDS to assess the accuracy of the data. The review process examined the various accuracy parameters as defined by FDEM guidelines. 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 checkpoint clusters within Levy County. Each point represents a checkpoint cluster and. There are nominally four checkpoints in each cluster, one per land cover category.

Figure 1 — Location of QA/QC Checkpoint Clusters for Levy County

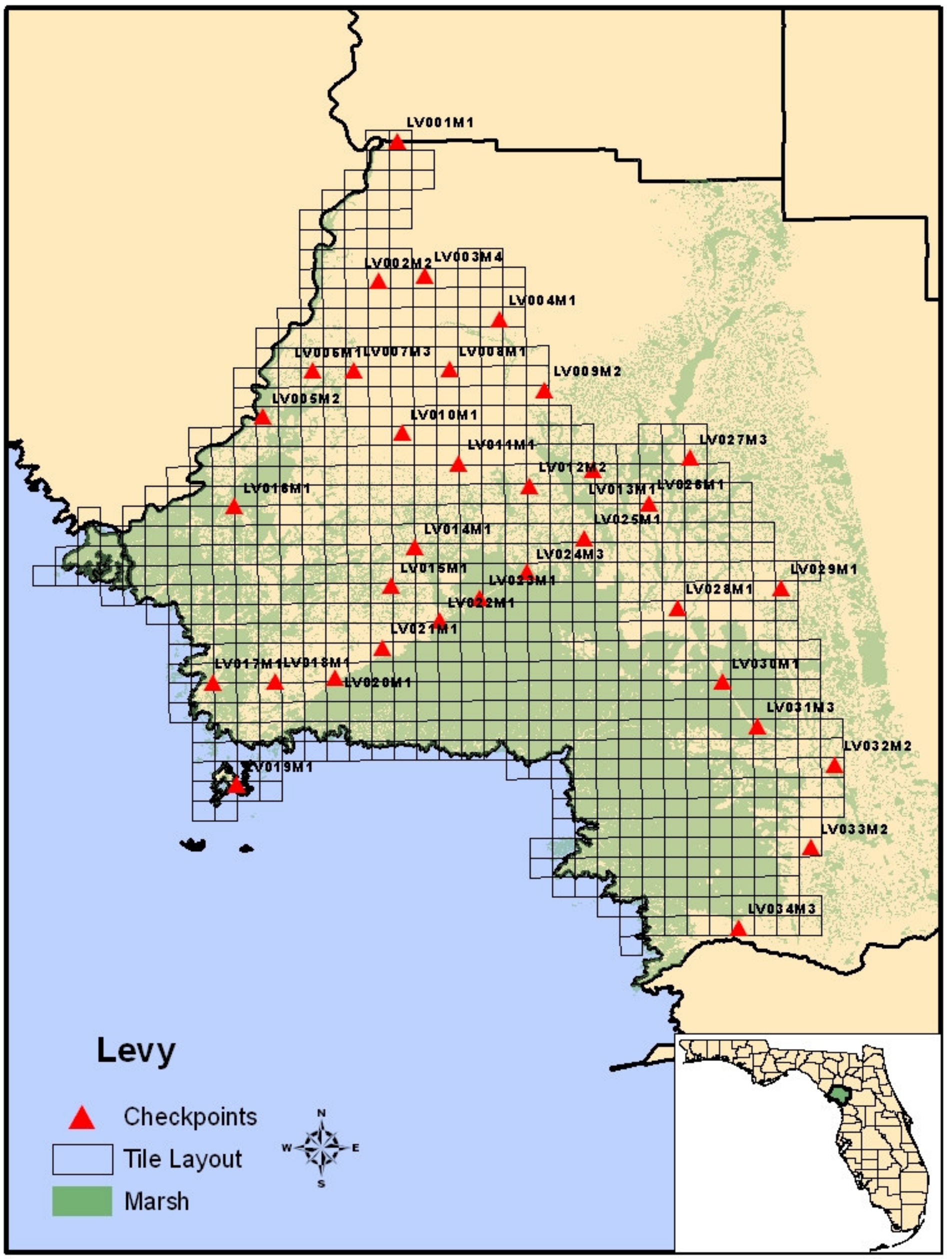


Table 2

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 (95^{th} Percentile) Spec = 1.19 ft	SVA — Supplemental Vertical Accuracy (95^{th} Percentile) Target = 1.19 ft
Total Combined	134		0.85	
BE & Low Grass	44	0.58		0.50
Brush & Low Trees	24			0.93
Forested	34			0.97
Urban	32			0.59

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 0.58 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 0.85 ft at the 95% confidence level in bare-earth and low grass, brush and low trees, forested, and urban areas combined, based on the 95th Percentile. Table 3 lists the 5% outliers larger than the 95^{th} percentile error. There was only one category 3 (forested area) point that exceeded the 1.19 ft criterion.

Table 3 — 5% Outliers Larger than 95th Percentile

Errors Exceeding 95th Percentile		
Land Cover Category	**Elevation Difference**	**Explanation**
	(feet)	
Forested (LV003M4)	-1.26	This is an anomaly – all other point is this cluster were well within the accuracy criteria

Compared with the 1.19 ft SVA target values, SVA tested 0.50 ft at the 95% confidence level in bare-earth and low grass; 0.93 ft in brush and low trees; 0.97 ft in forested areas; and 0.59 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 SVA by specific land cover category.

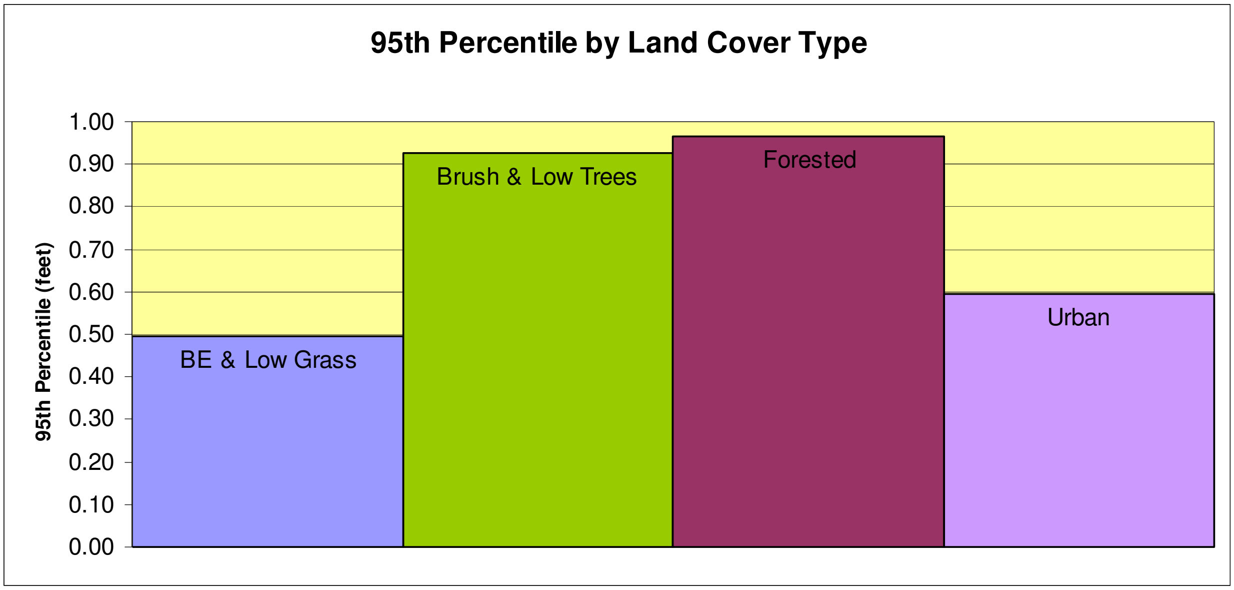


Figure 2 — Graph of SVA Values by Land Cover

Figure 3 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 all categories. One category 2 checkpoint in the brush and low grass exceed the 1.19 ft SVA accuracy criteria by 0.31 ft.

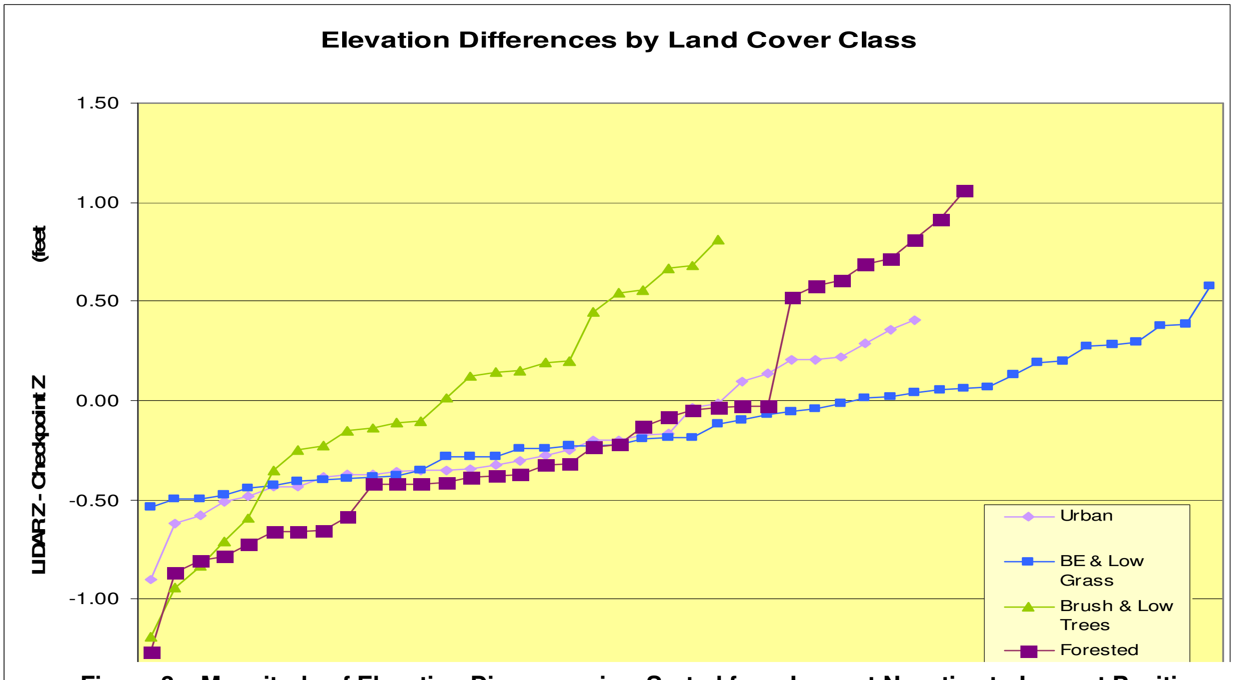


Figure 3 – Magnitude of Elevation Discrepancies, Sorted from Largest Negative to Largest Positive

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 4 and 5 and Table 4 below, consistent with Section A.8.6.3 of Reference C.

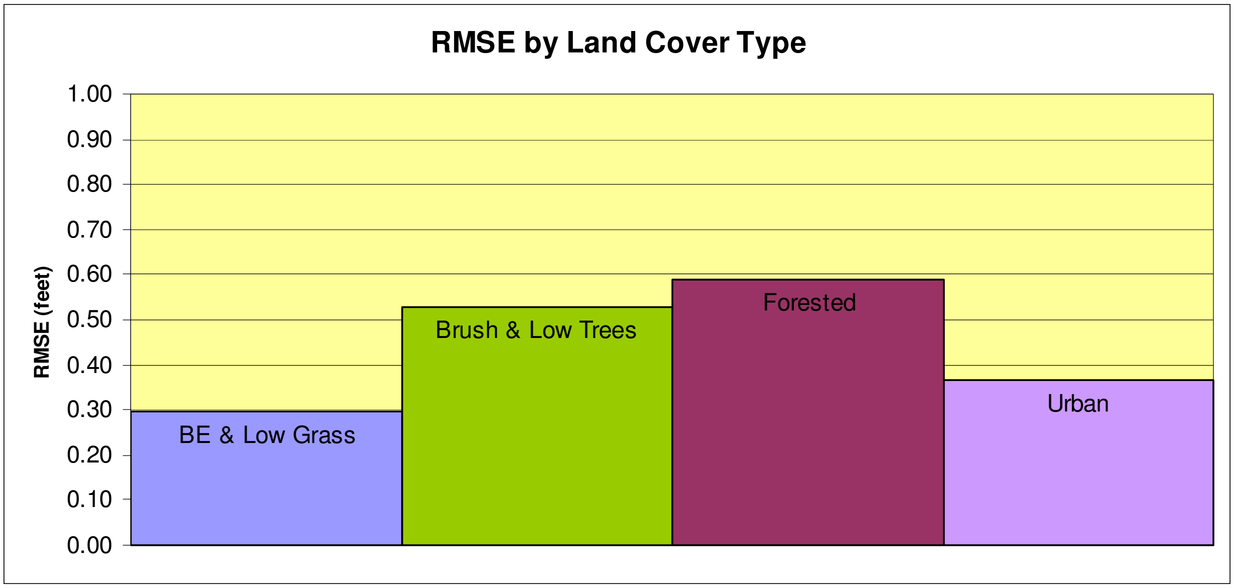


Figure 4 — $RMSE_z$ statistics by Land Cover Category

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

Descriptive Statistics							
Land Cover Category	**Points**	**RMSE (feet)**	**Mean Error (feet)**	**Median Error (feet)**	**SKEW**	**STDEV (feet)**	**95th Percentile (feet)**
Consolidated	134	0.00	-0.13	-0.20	0.34	0.43	0.85
BE & Low Grass	44	0.30	-0.12	-0.18	0.52	0.28	0.50
Brush & Low Trees	24	0.53	-0.04	-0.05	-0.39	0.54	0.93
Forested	34	0.59	-0.16	-0.32	0.57	0.58	0.97
Urban	32	0.37	-0.20	-0.29	0.27	0.31	0.59

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 = 0.30 ft x 1.9600 = 0.58 ft, satisfying the 0.60 ft FVA standard. $Accuracy_z$ in consolidated categories = 0.44 ft x 1.9600 = 0.87ft, 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 -1.26 ft and a high of +1.06 ft, the histogram shows that the discrepancies are skewed very slightly on the negative 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.

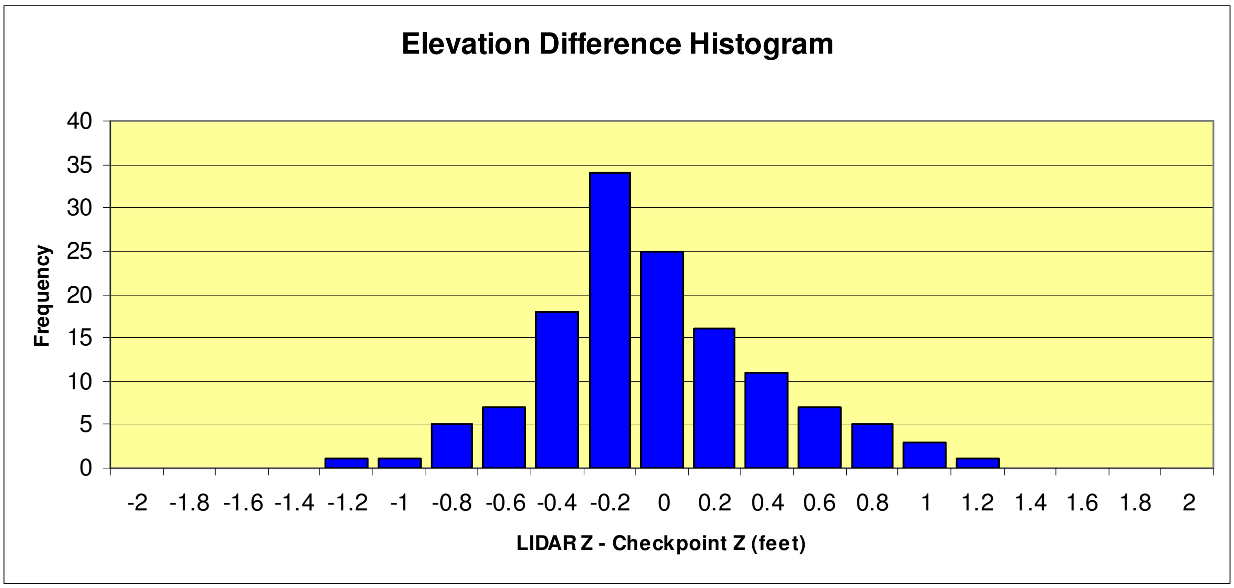
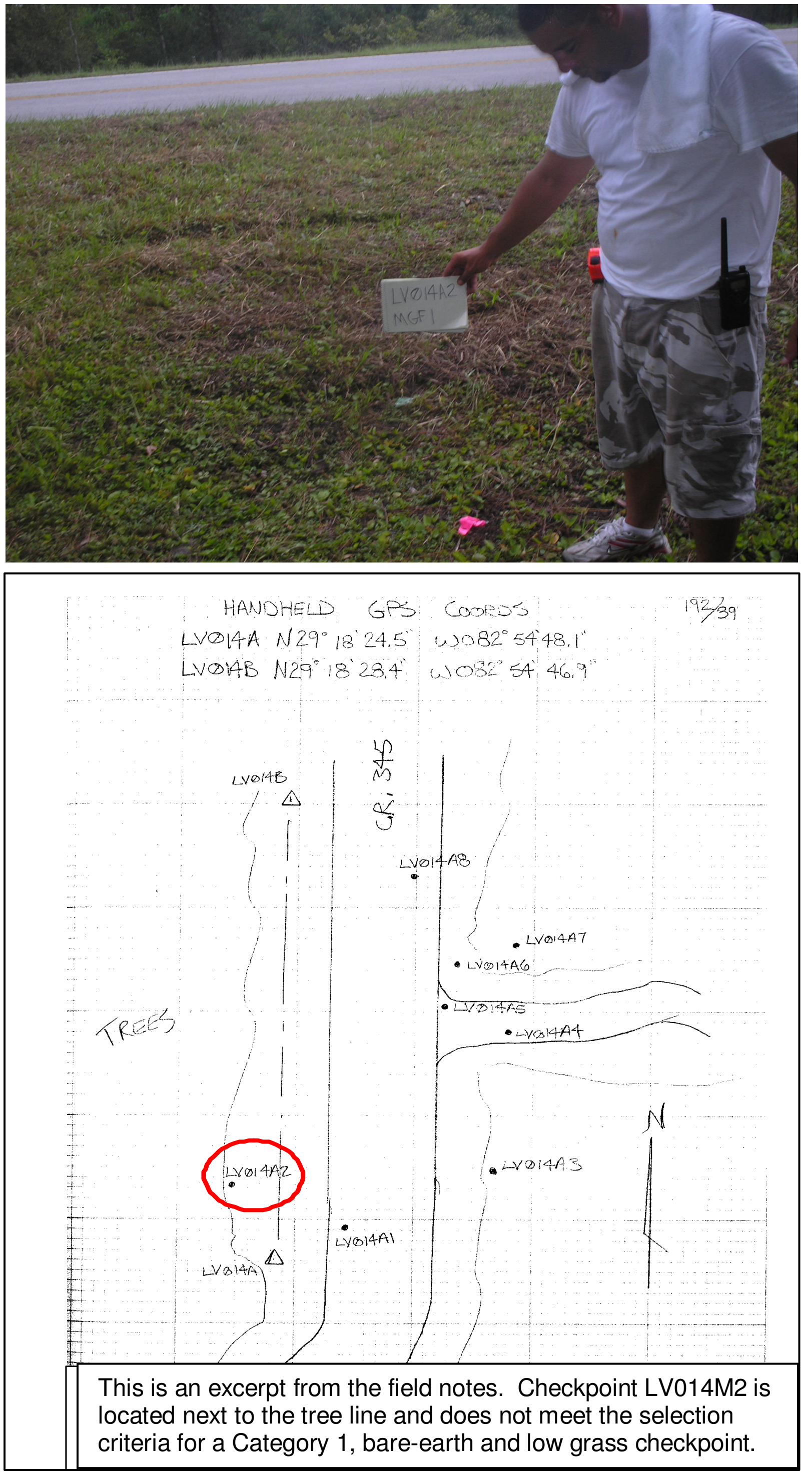


Figure 5 — Histogram of Elevation Discrepancies within 0.02 ft Bands

Reclassified Checkpoints

Category 1 bare-earth and low grass checkpoints LV014M2 and LV016M2 did not fit the specified criteria for Category 1; these points were reclassified as Category 2, brush and low trees. Checkpoint LV014M3 was located at the base of a large tree and was not used in the vertical accuracy assessment. The digital pictures taken in the field, which show each checkpoint location, as well as the field notes, were among the tools used to performing analysis of all checkpoints that had large delta-z values.

Figure 6 shows the field picture location of checkpoint LV014M2, which is at the edge of the tree line depicted in the field sketch (point is circled in red). This point was reclassified as a category 2 point, as it did not meet the selection criteria for a Category 1 checkpoint.



This is an excerpt from the field notes. Checkpoint LV014M2 is located next to the tree line and does not meet the selection criteria for a Category 1, bare-earth and low grass checkpoint.

Figure 6 — Checkpoint LV014M2 Field Picture and Page from Field Notes

Figure 7 shows the field picture captured for Category 1, bare-earth and low grass checkpoint LV016M2 and screen shot showing bare-earth contours (0.5m CI) reference with all returns. Although it is not evident by looking at the field picture, the contours show that the checkpoint is located on an 8-foot slope, which does not meet the selection criteria for a Category 1 point. This point was reclassified to Category 2.

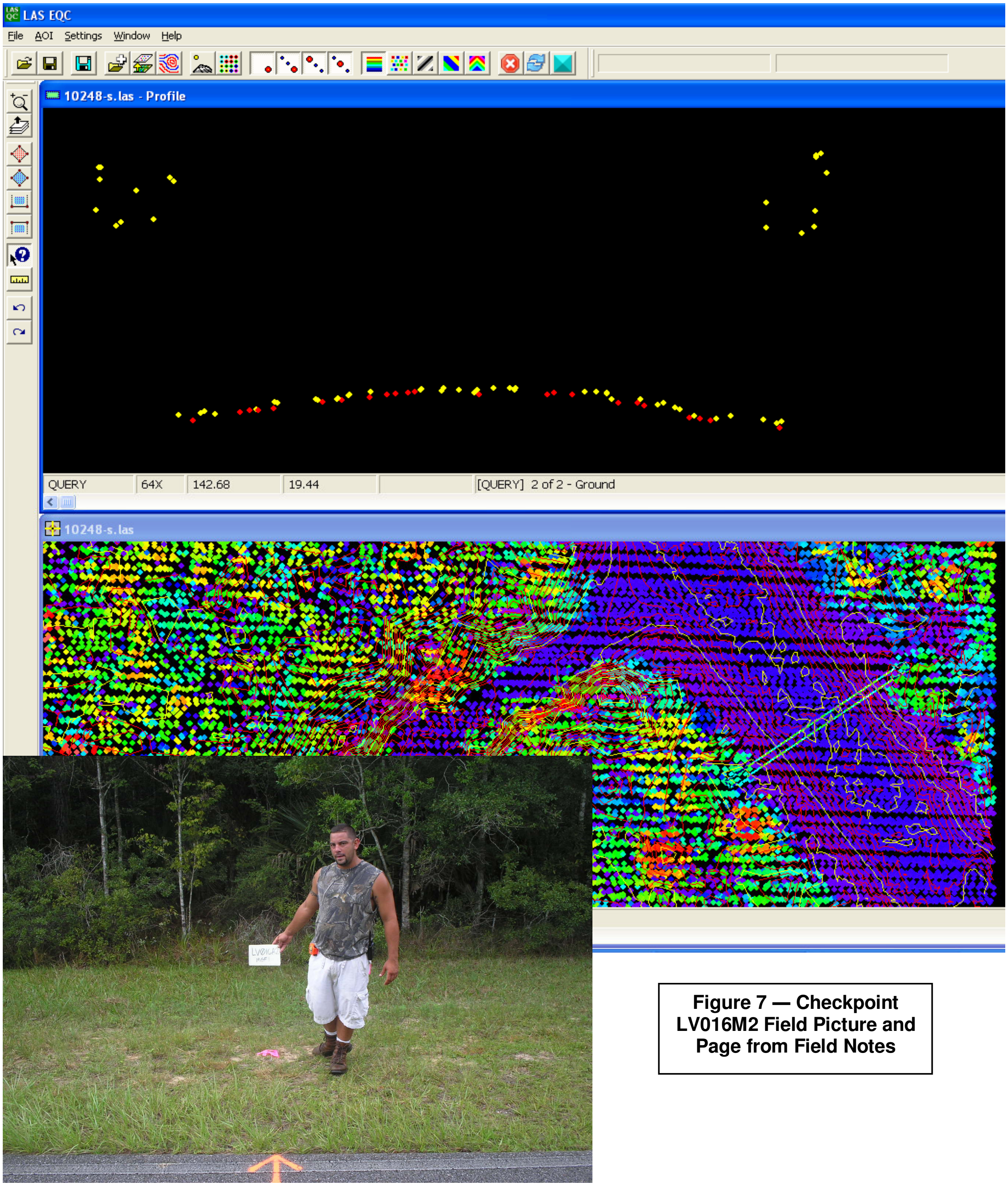


Figure 7 — Checkpoint LV016M2 Field Picture and Page from Field Notes

Figure 8 shows the field picture captured for Category 3, forested area checkpoint LV014M3. The colored survey marking tape on the ground near the base of the tree (~18” diameter) indicates the point location. This point was deemed a low confidence point due to the proximity to the base of the tree and it was not used in the vertical accuracy assessment.

Figure 8 — Field Picture of Checkpoint LV014M3

Conclusions

Based on the vertical accuracy testing conducted by PDS, the undersigned certifies that the LiDAR dataset for Levy County, Florida satisfies the criteria established by Reference A:

- **Based on NSSDA, FEMA, NDEP and ASPRS methodology: Tested 0.58' vertical accuracy at 95% confidence level in open terrain.**

- **Based on NSSDA and FEMA methodology: Tested 0.85' vertical accuracy at 95% confidence level in all land cover categories combined.**

David F. Maune, Ph.D., PSM, PS, GS, CP
QA/QC Manager

Appendix G: LiDAR Qualitative Assessment Report

References:

A — State of Florida Division of Emergency Management (FDEM), Contract Number 07-HS-34-14-00-22-469, Task Order Number 20070525-492718a

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 PDS 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, the nominal LiDAR point spacing for this project was 0.7 meters, and with the PDS team's 50% sidelap between flightlines, the nominal overall point density was designed to be approximately 4 points per square meter. 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, PDS 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 the PDS team 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

PDS 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. PDS uses Microsoft SQL Server as the database of choice.

The PDS qualitative assessment process flow for Levy County, FL 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, and Class 9 - Water. No records were present in Class 12 - Overlap as Sanborn utilized all points in the overlap areas in the terrain files.
    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 URS 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 Florida Baseline Specifications, the orthos were produced at a 1.2m pixel for the entire area of interest (see Figure 1).

Figure 9 Screenshot of Levy County LiDAR Orthos produced from Intensity Returns

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).

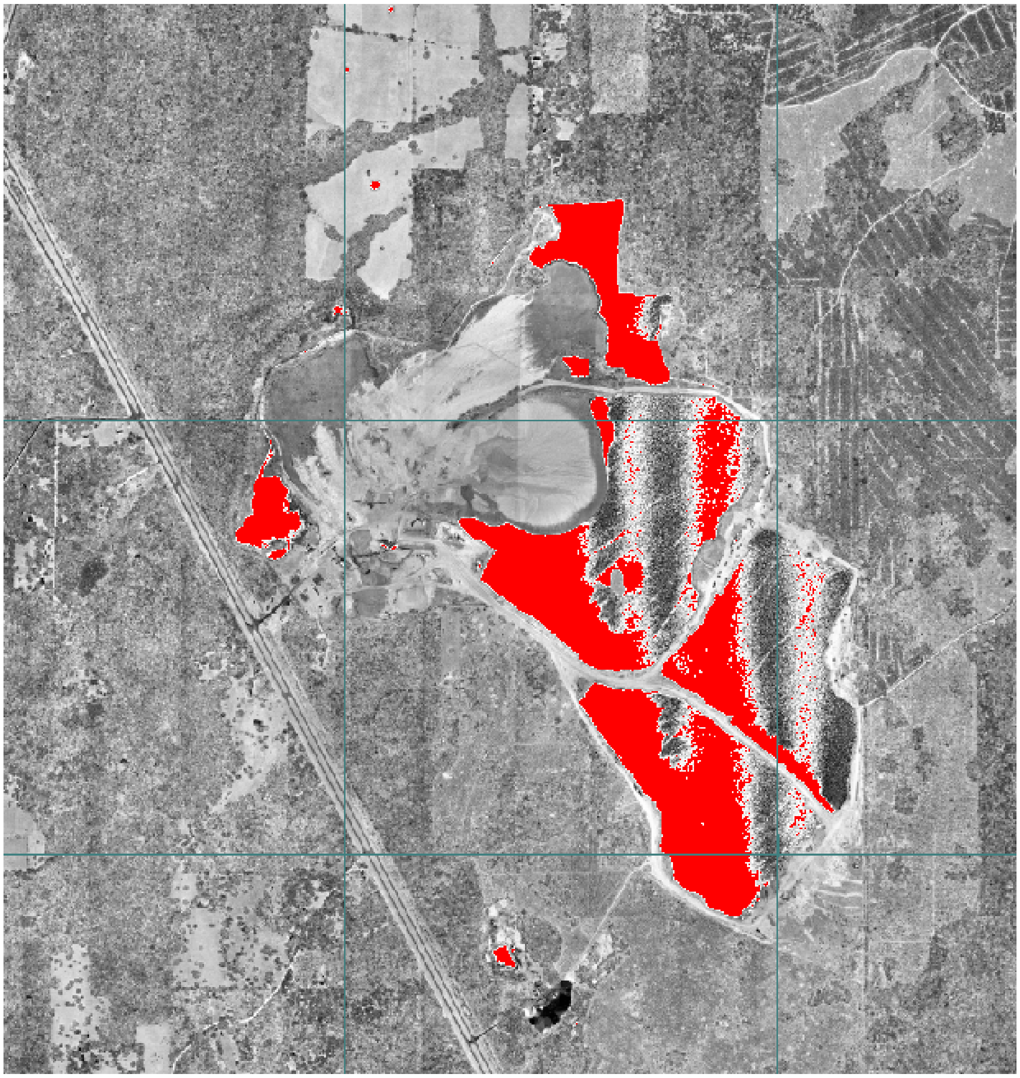


Figure 10 Acceptable voids in data due to water bodies

4. *Initial Data Verification:* PDS 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 1.2m.

Model statistics were produced and characterized by density, scale, intensity, and elevation. (Figure 5) 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.

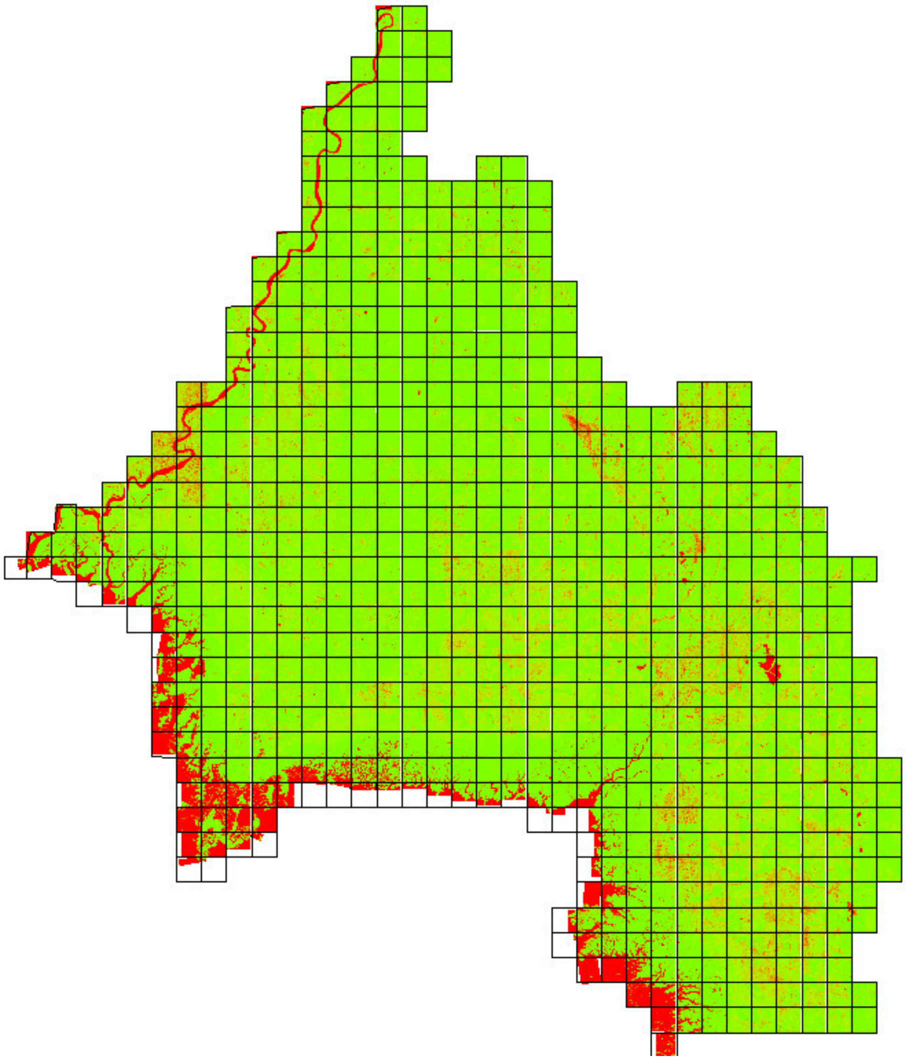


Figure 11 Density grid of Levy County, created using a green to red color ramp. Green areas meet project specifications; red delineates areas not meeting minimum density requirements (primarily water and low-confidence areas)

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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 in the below "General comments and issues".

General comments and issues

The project area in Levy County, Florida is predominantly a rural area, with extensive farm lands in the upper portion of the county. There are several national and state forests and parks. (Figure 6).

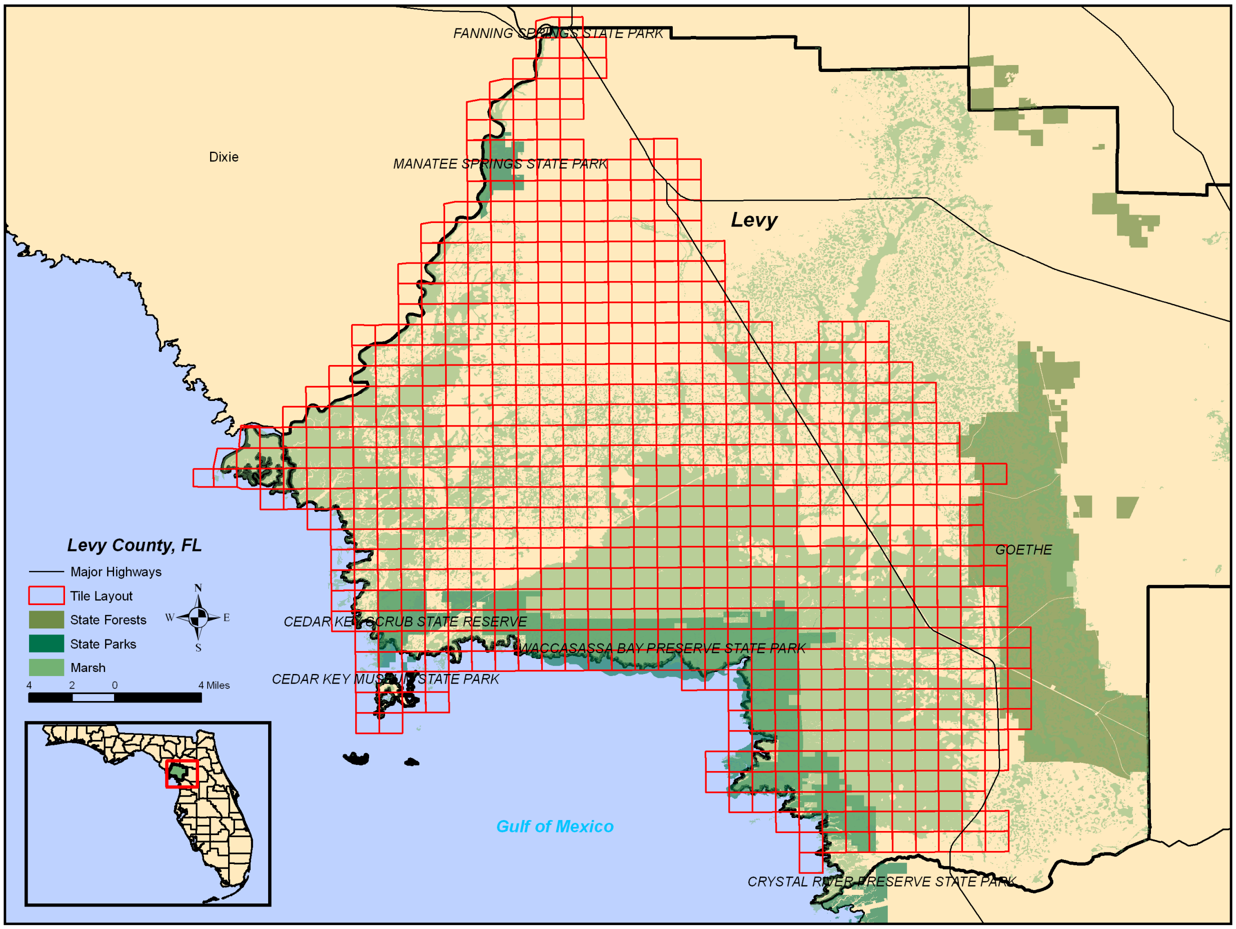

Figure 12 Map of Levy County Florida with Marsh areas from Florida Geographic Data Library (FGDL)

The initial data acquisition was very dense. Overall the acquired point spacing was around 0.45m (more than 4 points per square meter). In general, the bare earth ground surface was clear of artifacts and very clean. The algorithms used to classify the above-ground ground points were very stringent; given the overall physical characteristics of the county this does not seem inappropriate. There is a fine line in the decision-making process of which points to classify as ground. By removing points from the ground classification due to heavy vegetation there is risk of over-smoothing or “flattening” the ground surface which can have a greater impact than leaving points to maintain the ground surface model. In addition, due to the lack of significant elevation changes in the physical terrain there are places where there is no visible break in the terrain between the ground surface and what in traditional mapping would be considered a hard breakline feature, for example roads.

Because the project includes the collection of breaklines, this will be compensated for in the hard breakline collection. The LiDAR data contained sporadic issues such as artifacts or small anomalies which is typical of any LiDAR dataset. Due to the presence of dense vegetation throughout the county, the low confidence area polygons and breaklines are important deliverables for this particular county.

The bare earth terrain model was checked for consistency in bare earth processing, tile edge-match with neighboring tiles, flight line edge match, correct water classification and bridge, building and vegetation removal. There were some issues noted in the qualitative assessment but these were minor and repaired by the contractor. Of the 732 tiles LAS files reviewed, some tiles were flagged for improper classification in areas where ground points were found in water bodies or, in one case, a canal or large ditch was mistaken for a road. The redelivery of the data was checked thoroughly and passed. The following table and associated screenshots is representative of the issues found in water bodies:

Points		
Tile	**Issue**	**Code**
LID 010842	Water classified as ground	Corrected
LID 010935	Water classified as ground	Corrected
LID 010842	Canal or ditch mistaken for road/ground	Corrected
LID 010849	Culverts removed from highway	Corrected

In several areas ground points were found in the .LAS files that should have been classified as water (see Figures 7 - 9). This was likely due to an automated filter confusing the points with ground points, based on elevation. In addition, two culverts were inadvertently removed from a major highway feature (see Figure 10). These tiles were rejected and subsequently corrected by The Sanborn Map Company.

In addition, several tiles were found to contain noise points below and above the ground surface (see figures 11-12).

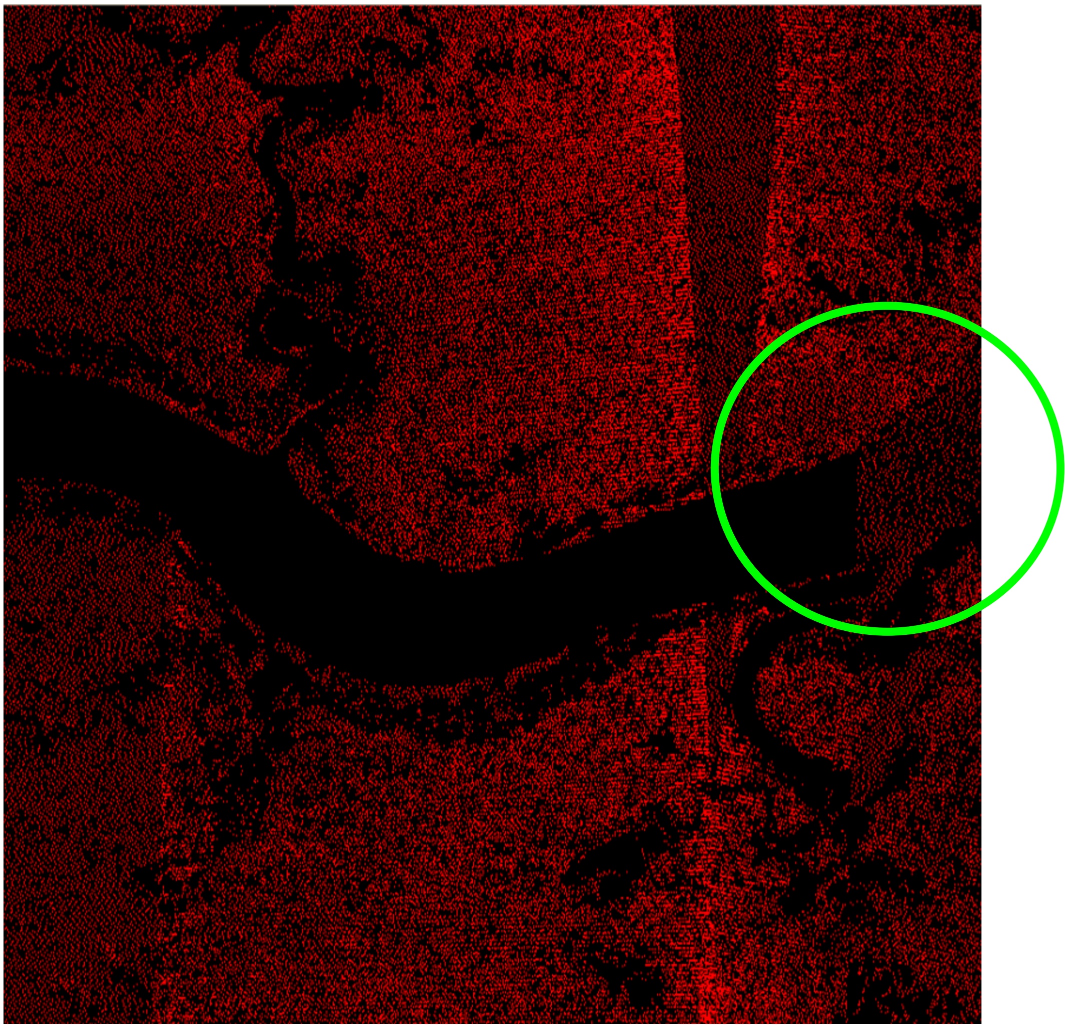

Figure 13 Tile 010842 – example of points classified as Class 2- ground points in a water body.

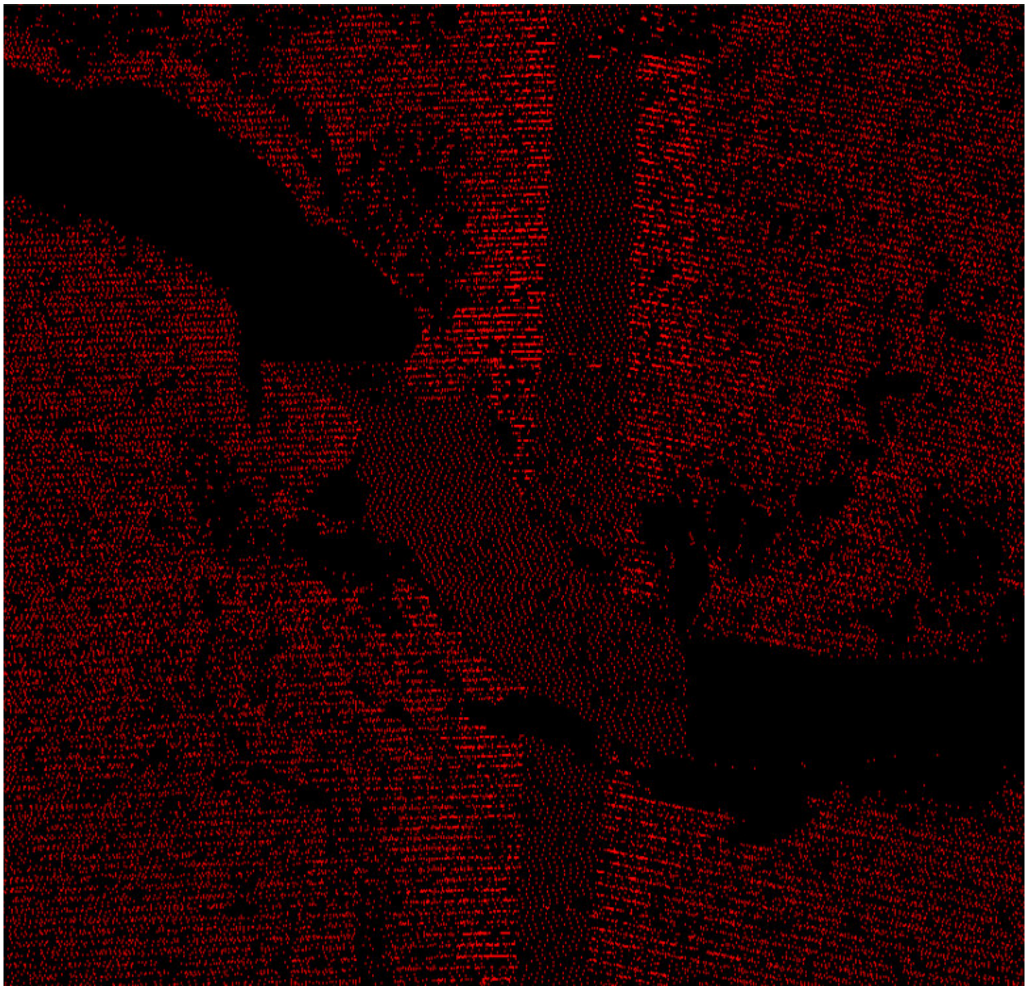

Figure 14 Tile 0109350 – example of points classified as Class 2- ground points in a water body.

Figure 9 Tile 0100842 – Canal or water-filled ditch classified as Class 2- ground points.

Figure 10 Tile 0100849 – Culverts removed from bare earth classification

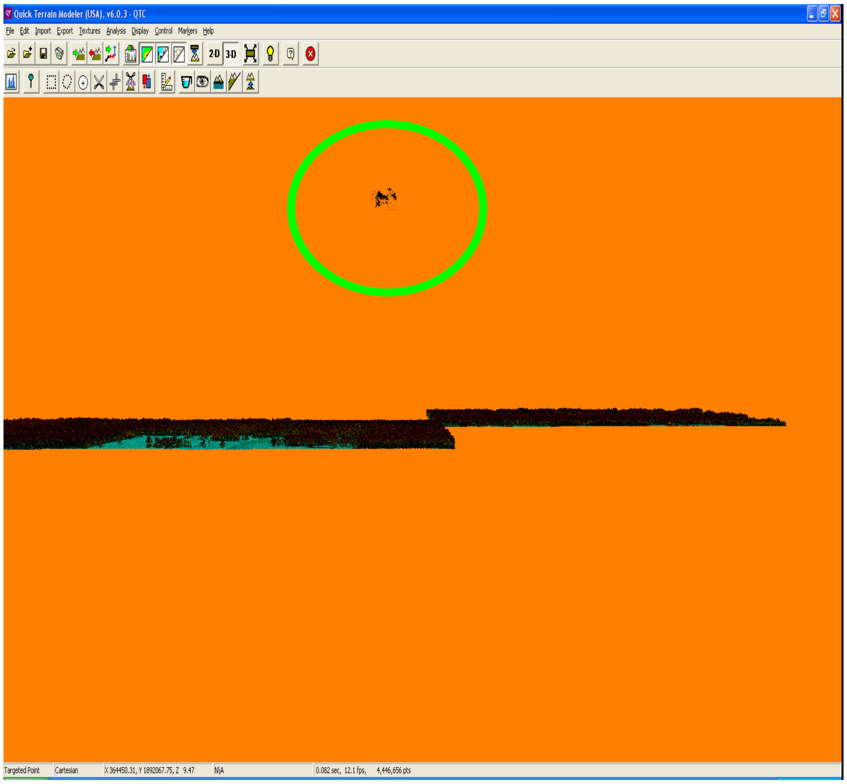

Figure 11: "Noise" approximately 3,000 ft above ground

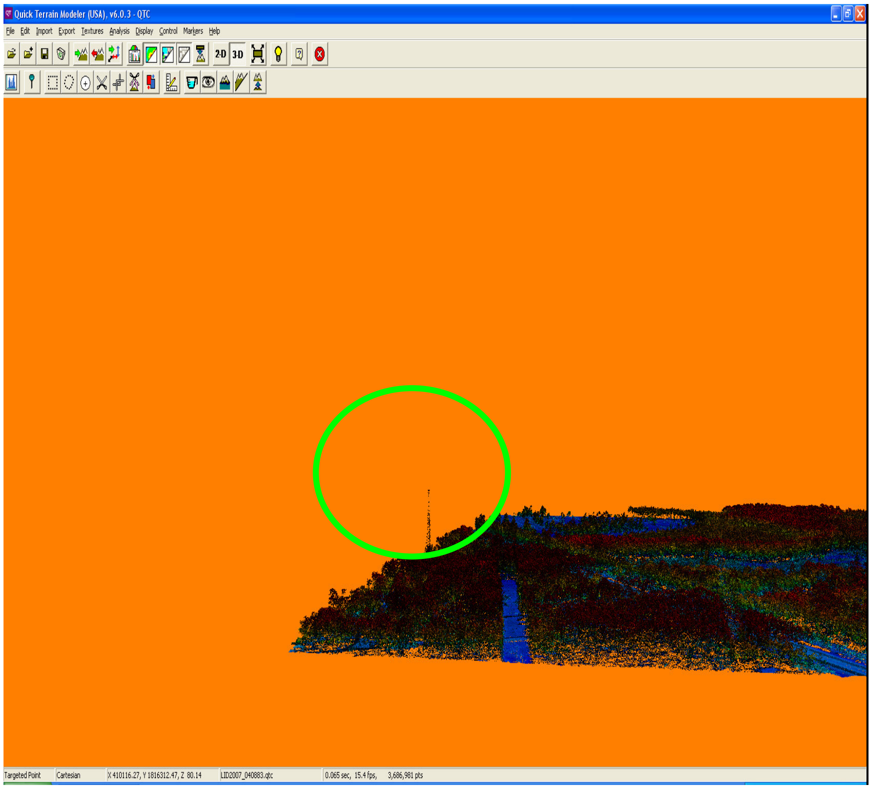

Figure 12: Radio tower left in ground points

Conclusion

Overall the data meets the project specifications. The classification of the raw point cloud to bare ground was executed well given the low terrain relief and areas of dense vegetation. The data did contain areas of improperly classified water points and isolated instances of noise points; however these issues were corrected by The Sanborn Map Company and were not present in the redelivered data. As commonly occurs elsewhere, the Levy County dataset contained random voids on features such as paved surfaces in parking lots and on roads where the LiDAR laser energy can be absorbed by hot asphalt.

Appendix H: Breakline/Contour Qualitative Assessment Report

Coastal Shorelines

Coastal shorelines are correctly captured as two-dimensional polygon features, extracted from the LiDAR data and not from digital orthophotos, except for manmade features with varying heights such as seawalls which are captured as three-dimensional breaklines. Coastal breaklines merge seamlessly with linear hydrographic features. Shorelines continue beneath docks and piers. There is no “stair-stepping” of coastal shorelines. Figure 1 shows example coastal breaklines and contours.

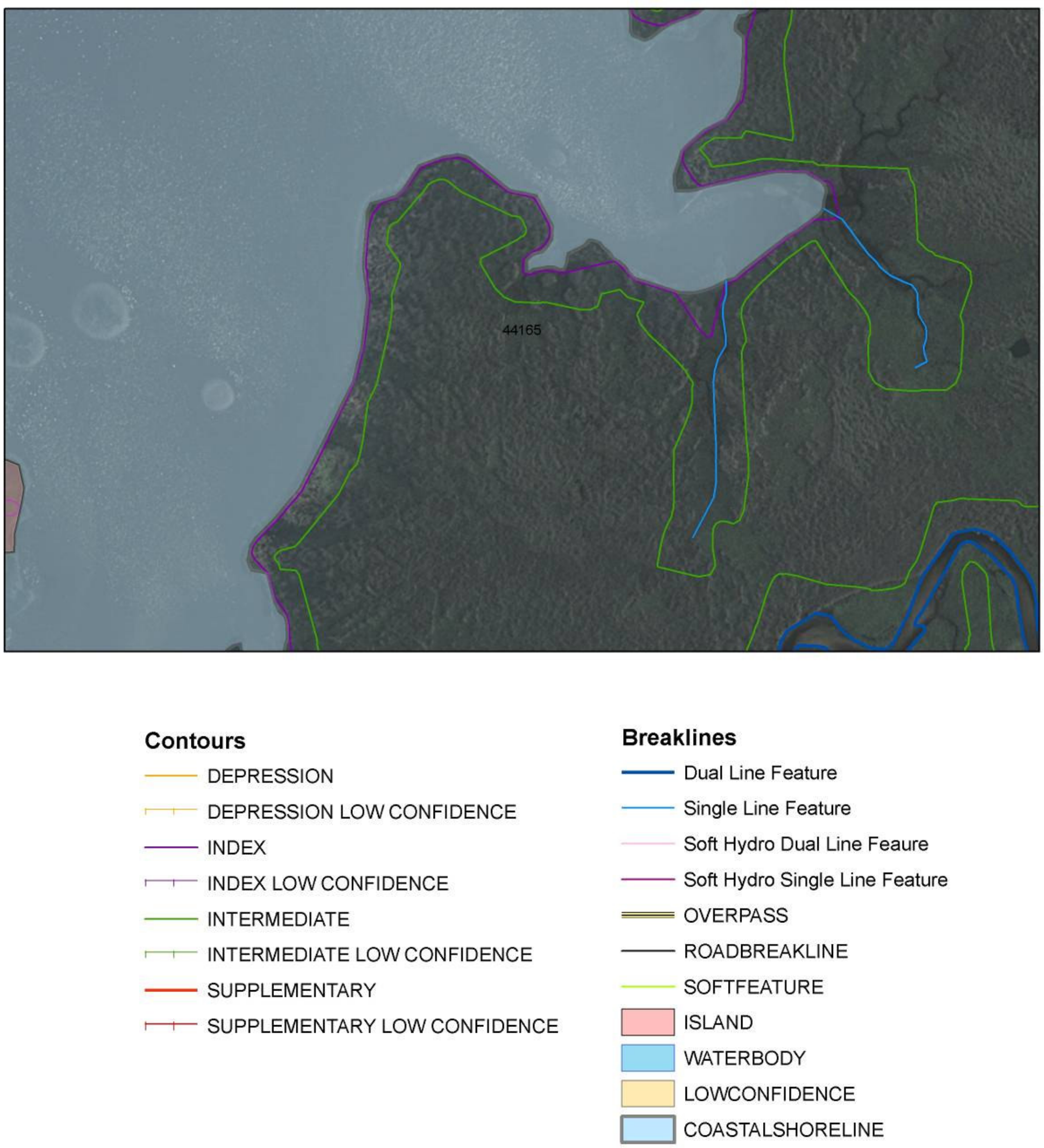

Figure 1. Example coastal breaklines and contours from tile #44165

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 2 shows example breaklines and contours of linear hydrographic features.

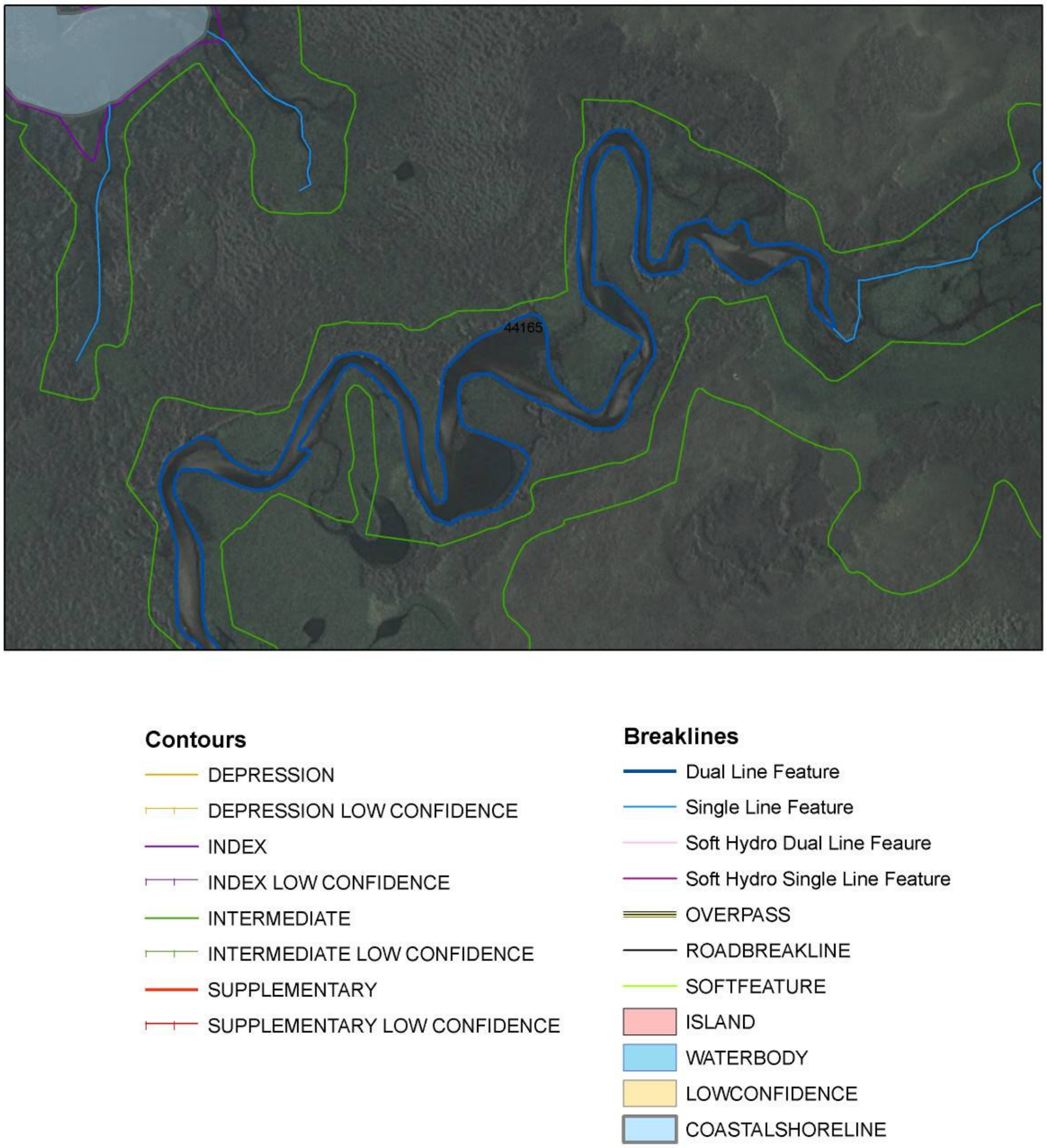

Figure 2. Example linear hydrographic feature breaklines and contours from tile # 44165

Closed Water Body Features

Closed water body features with an area of one-half acre or greater are correctly captured as two-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 3 shows example breaklines and contours of closed water body features.

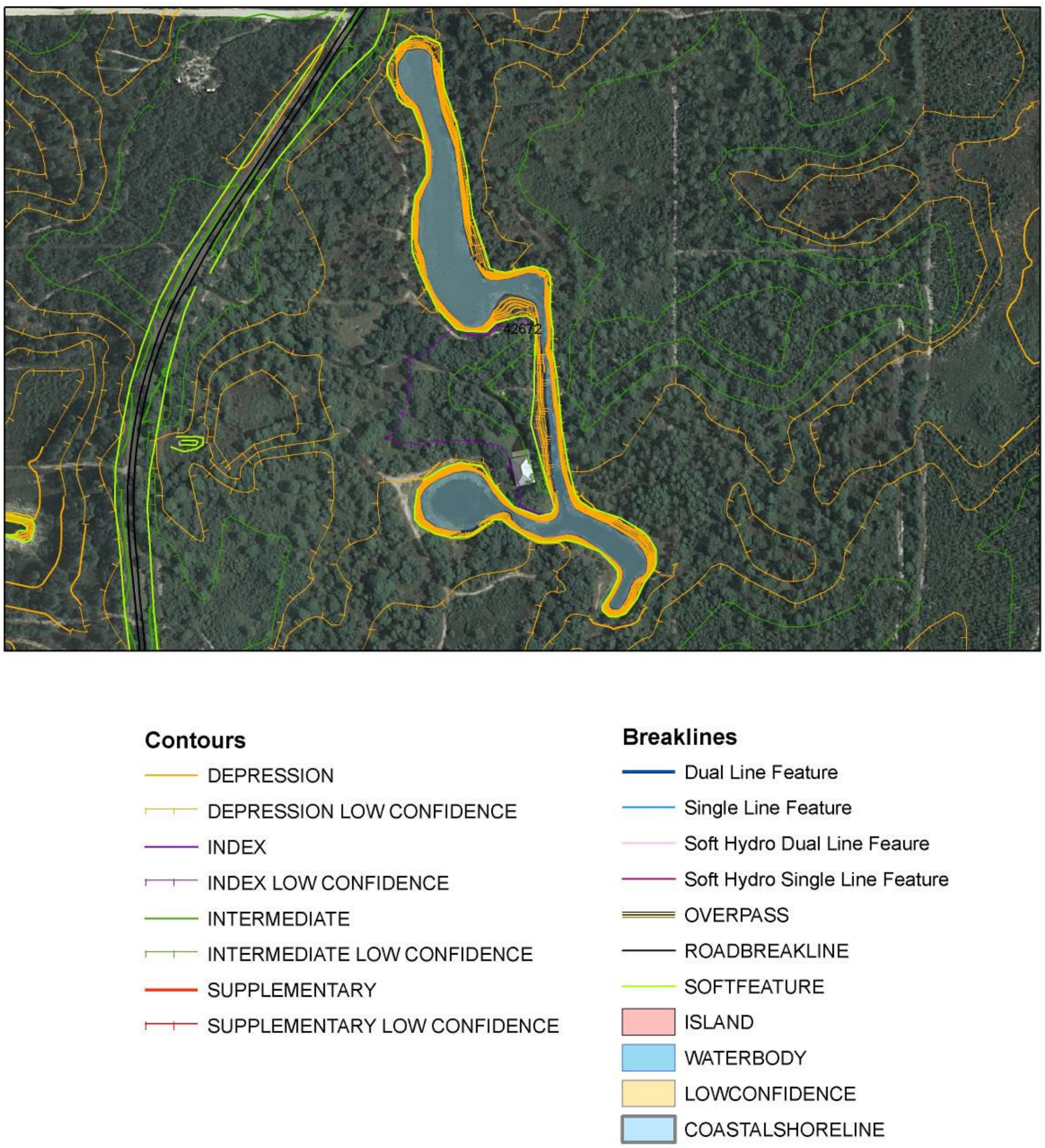

Figure 3. Example closed water body feature breaklines and contours from tile #42672

Road Features

Road edge of pavement features are correctly captured as three-dimensional breaklines on both sides of paved roads. Box culverts are continued as edge of pavement unless a clear guardrail system is in place; in that case, culverts are captured as a bridge or overpass feature. Each vertex maintains vertical integrity. Figure 4 shows example breaklines and contours of road features.

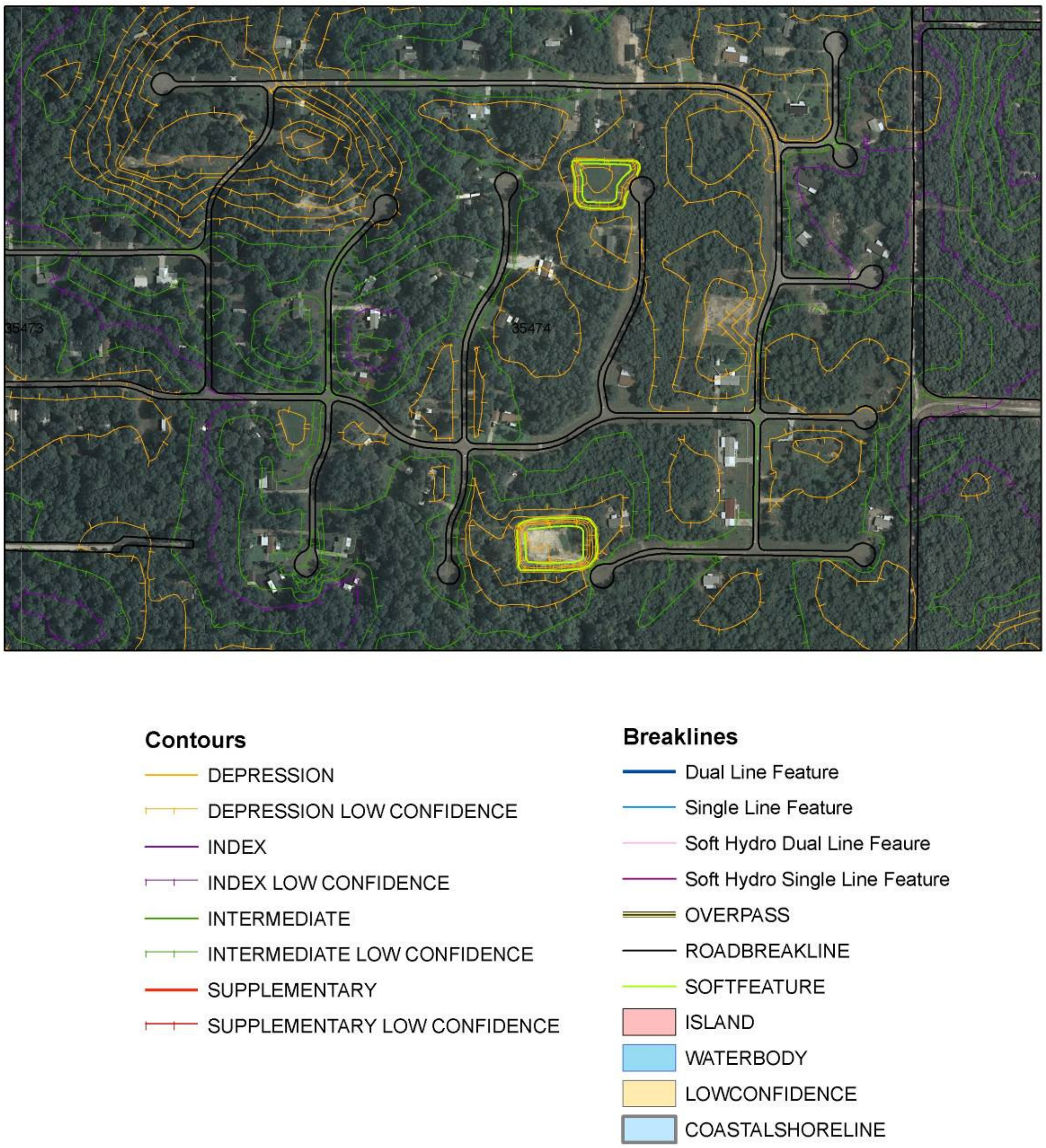

Figure 4. Example road feature breaklines and contours from tiles #35474

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 5 shows example breaklines and contours of bridge and overpass features.

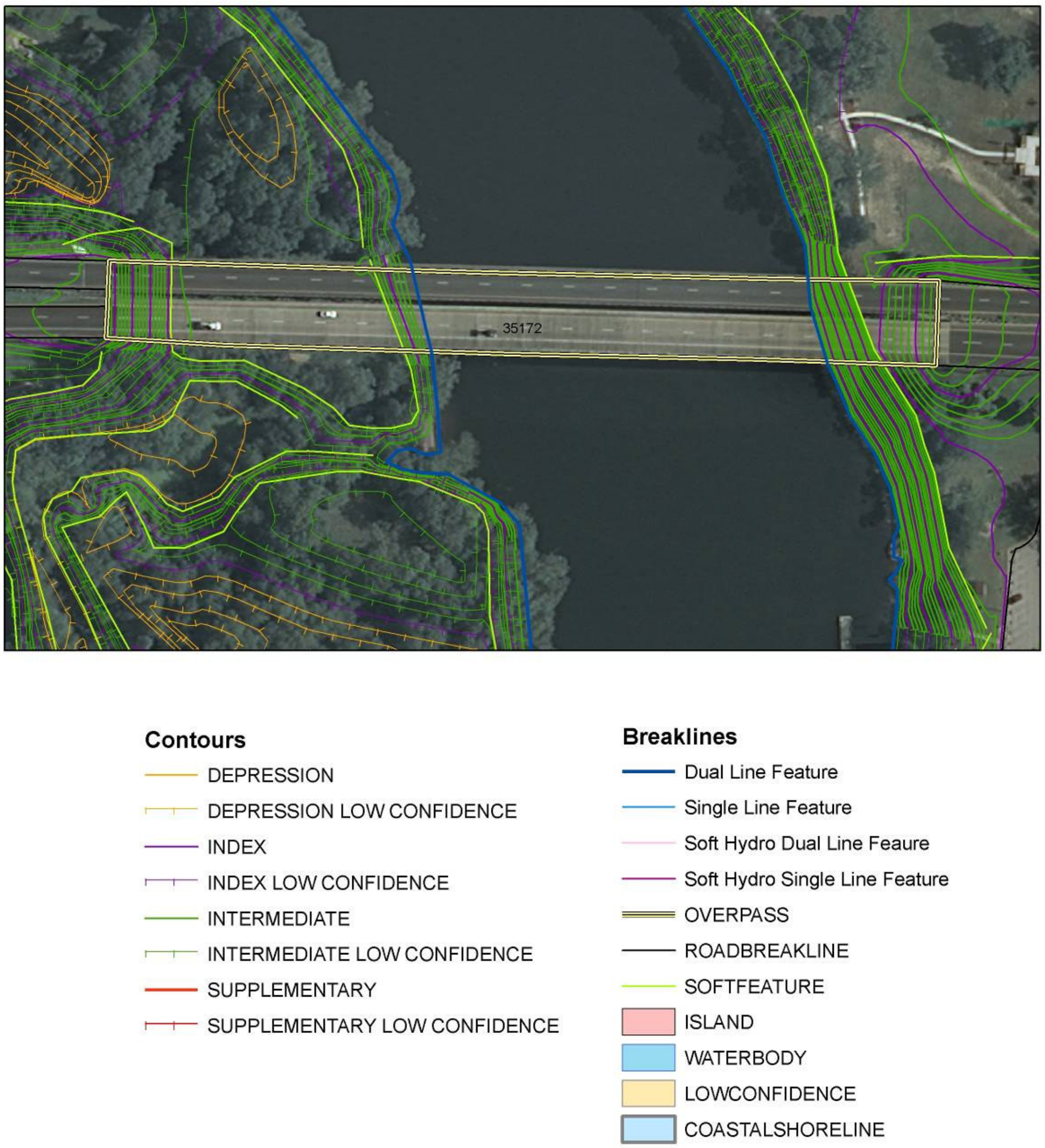

Figure 5. Example bridge and overpass feature breaklines and contours from tile # 35172

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 6 shows example breaklines and contours of soft features.

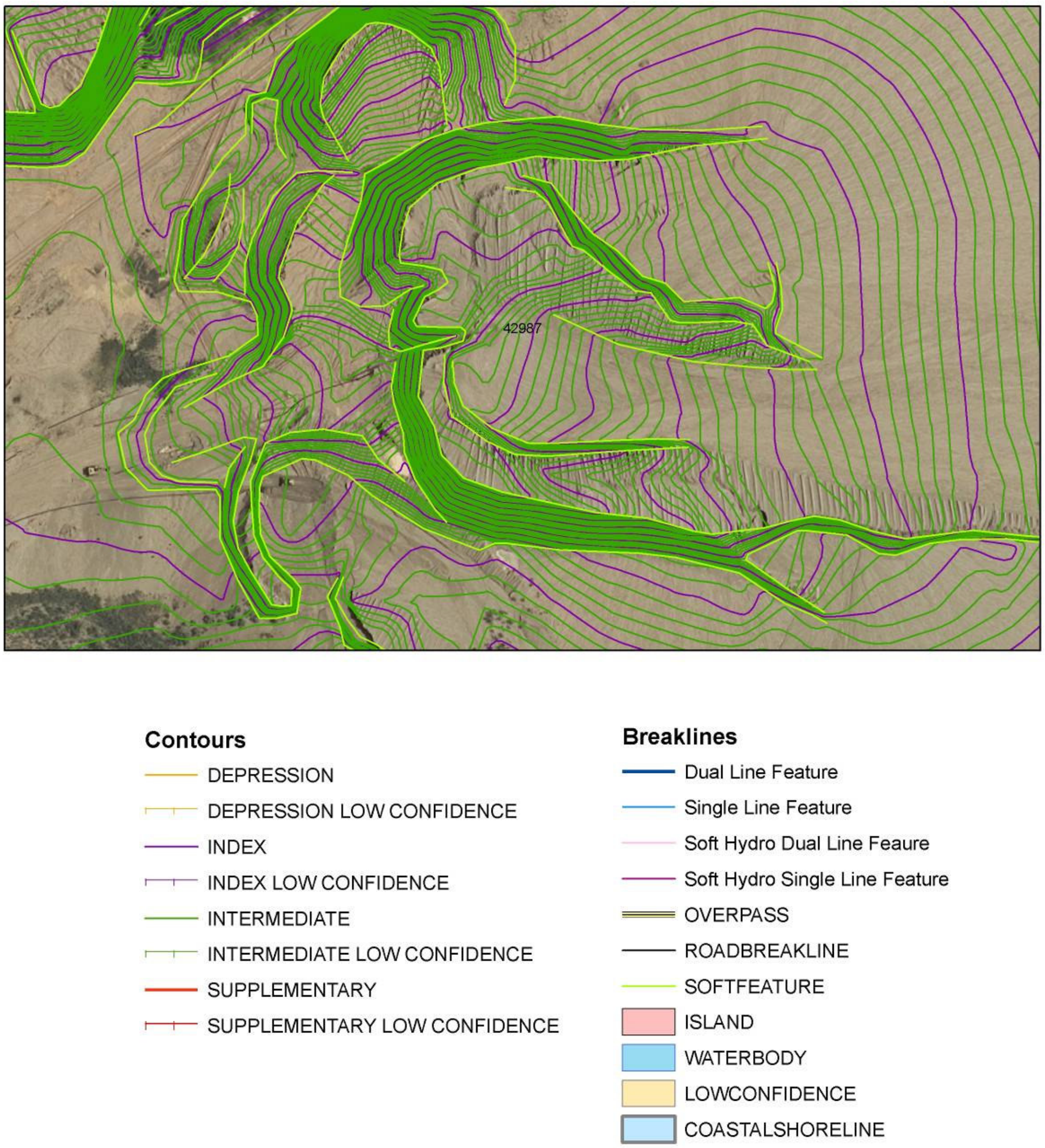

Figure 6. Example soft feature breaklines and contours from tile #42987

Island Features

The shoreline of islands within water bodies are correctly captured as two-dimensional breaklines in coastal and/or tidally influenced areas and as three-dimensional breaklines in non-tidally influenced areas 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 7 shows example breaklines and contours for island features.

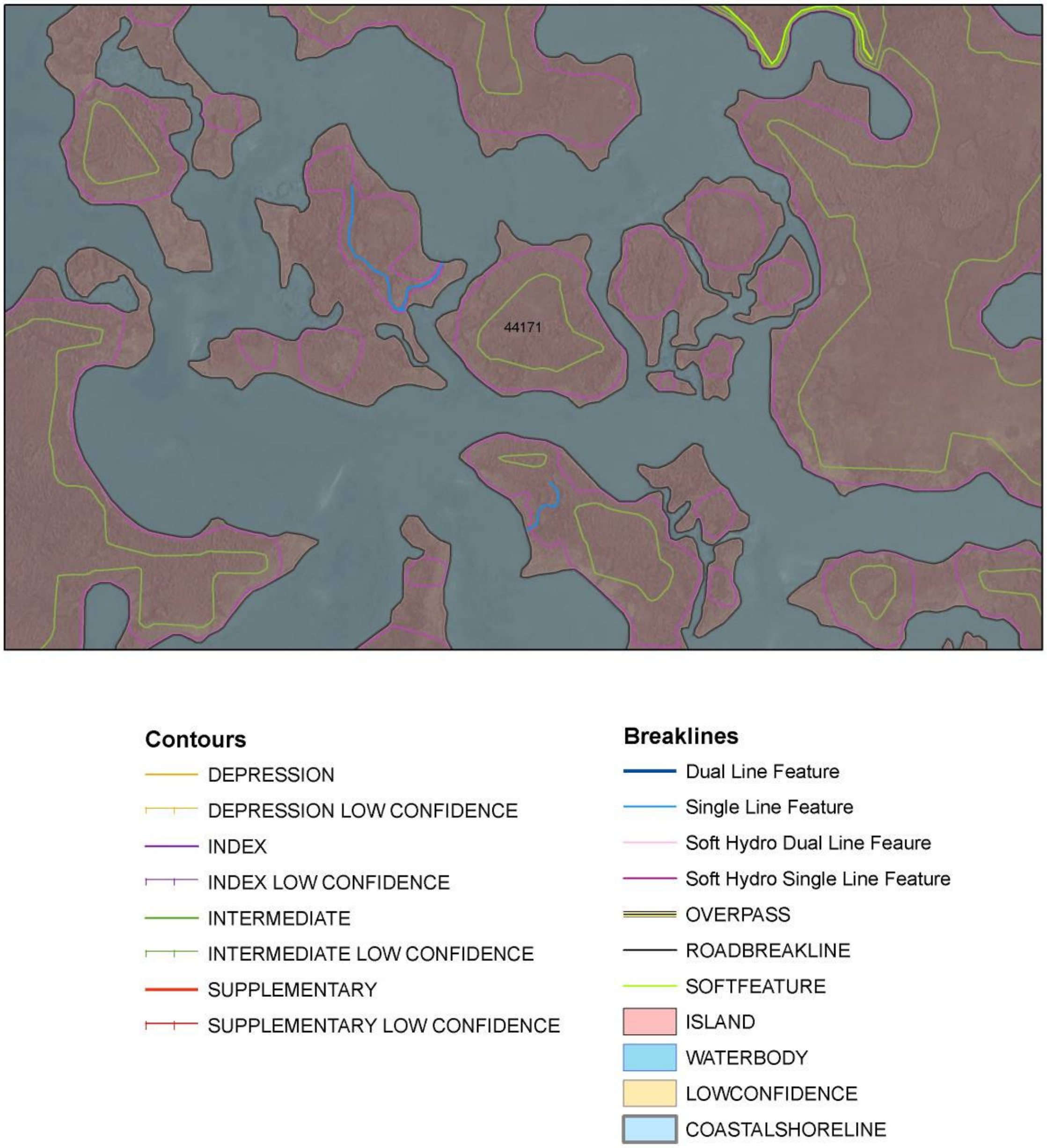

Figure 7. Example island feature breaklines and contours from tiles # 44171

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 cannot be clearly determined to accurately define the DTM are correctly captured as two-dimensional features with no z-values. Figure 8 shows example breaklines and contours for low confidence areas.

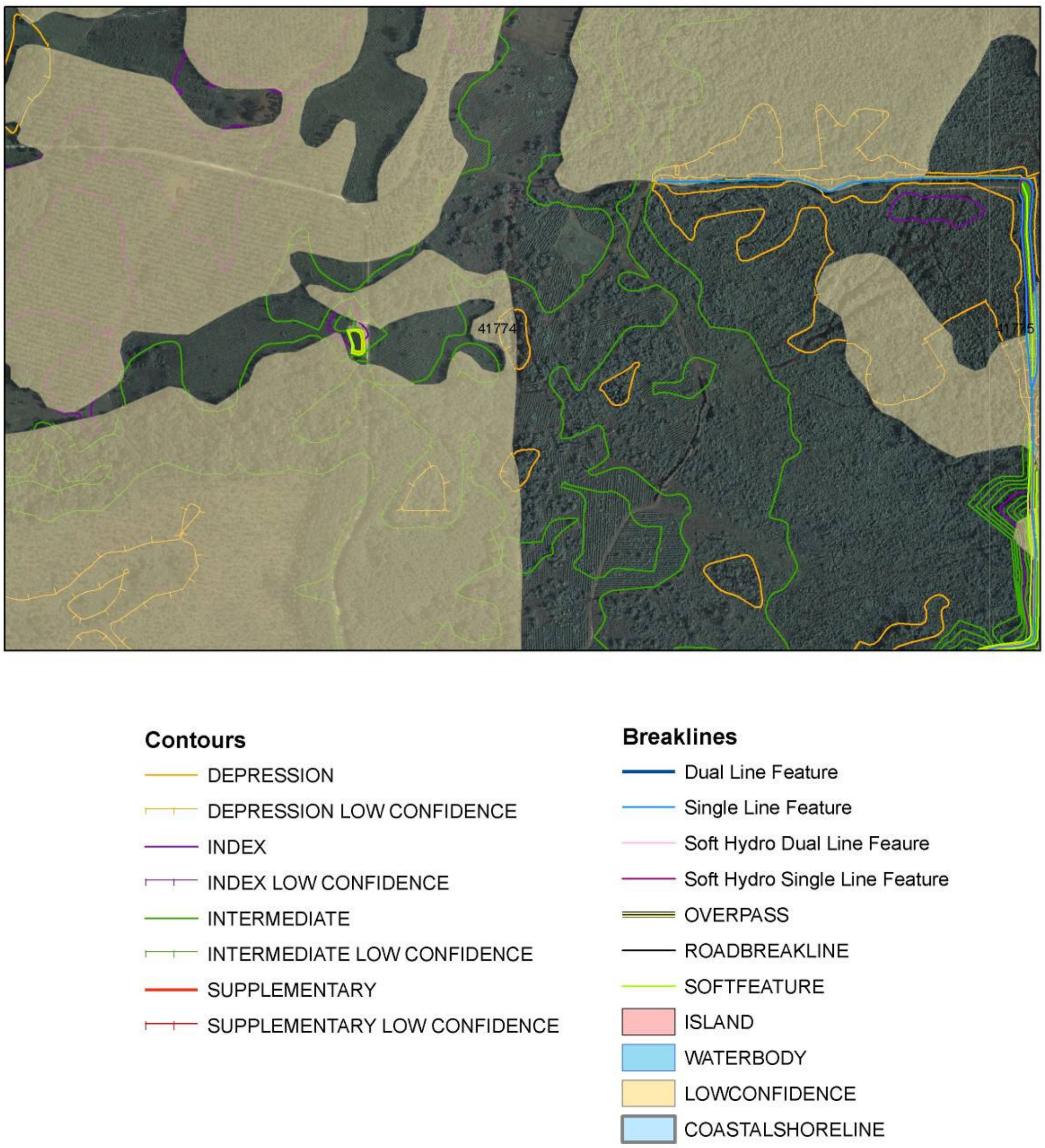

Figure 8. Example low confidence area feature breaklines and contours from tile # 41774

Appendix I: Geodatabase Structure