FINAL REPORT OF SPECIFIC PURPOSE LIDAR SURVEY
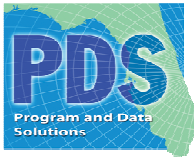
STATE EMERGENCY
FLORIDA
SERT
RESPONSE TEAM

LiDAR, Breaklines and Contours for

Dixie 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

Prepared by:

Dewberry
8401 Arlington Blvd.
Fairfax, VA 22031-4666
for
Program & Data Solutions (PDS)
1625 Summit Lake Drive, Suite 200
Tallahassee, FL 32317

Final Report of Specific Purpose LiDAR Survey, including

LiDAR-Generated Breaklines and Contours for Dixie County, Florida

Contract 07-HS-34-14-00-22-469; T.O. No. 20070525-492718a, Task Order B

For:
State of Florida
Division of Emergency Management
2555 Shumard Oak Blvd.
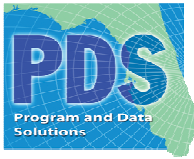Tallahassee, FL 32399

By:
Program & Data Solutions (PDS)
1625 Summit Lake Drive, Suite 200
Tallahassee, FL 32317

Prepared by:
David F. Maune, PhD, PSM, PS, GS, CP, CFM
Florida Professional Surveyor and Mapper No. LS6659
Dewberry
8401 Arlington Blvd.
Fairfax, VA 22031

Table of Contents

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

Type of Survey: Specific Purpose Survey

This report pertains to a Specific Purpose LiDAR Survey of Dixie 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 Dixie 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 the adjoining LiDAR datasets of Walton County and Santa Rosa County, 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 Dixie County, as well as Okaloosa, Bay, Gulf, Franklin, Wakulla, Jefferson, Taylor, and 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 622 tiles of Dixie 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 Taylor County and Levy 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.
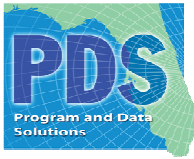
Rather than describe only the data provided of Dixie County in isolation, this report also explains the differences between LiDAR datasets acquired of Escambia, Santa Rosa and Walton counties and those of other counties in the Florida Panhandle produced to different specifications. In addition to the 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 Dixie 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 Dixie 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
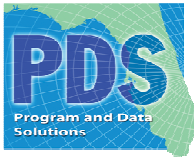
acquisition and post-processing and produced LAS classified data. A staff of QA/QC specialists at Dewberry's Fairfax (VA) office performed quality assessments of the breaklines and contours. Dewberry served as the single point of contact with FDEM. Dr. David Maune, PSM, was Dewberry's technical lead 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

Dewberry
8401 Arlington Blvd.
Fairfax, VA 22031-4666

Name of Responsible Surveyor

David F. Maune, PhD, PSM, PS, GS, CP, CFM
Florida Professional Surveyor and Mapper (PSM) No. LS6659

Survey Area

The project area for this report encompasses approximately 558 square miles within Dixie County and small adjoining areas of Taylor County and Levy 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 Dixie County tiling footprint graphic is shown at Appendix A.

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
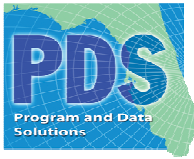
- Class 7 = Noise, includes LiDAR points in overlapping flight lines
- Class 9 = Water, includes LiDAR points in overlapping flight lines[1]
- Class 12 = Overlap, including areas of overlapping flight lines which have been deliberately removed from Class 1 because of their reduced accuracy.

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 1 – Unclassified
Class 2 – Ground points (used for contours)	Class 2 – Ground points (used for contours)
Class 7 – Noise	Class 9 – Water
Class 9 – Water	
Class 12 – Overlap points deliberately removed	

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

---

[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.
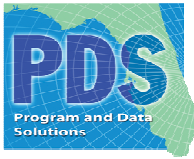
frequently causes elevations to be lower or higher than the bare earth terrain. This is equivalent to the accuracy expected of 2 ft contours in such terrain.

- In category 3, the $RMSE_z$ must be ≤ 0.61 ft ($Accuracy_z \leq 1.19$ 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 ($Accuracy_z \leq 1.19$ 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 ($Accuracy_z \leq 1.19$ 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.
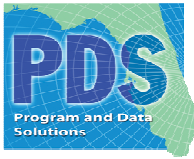
The term Accuracy$_z$ (vertical accuracy at the 95% confidence level) is comparable to the terms described below as Fundamental Vertical Accuracy (FVA), Consolidated Vertical Accuracy (CVA) and Supplemental Vertical Accuracy (SVA) which also define vertical accuracy at the 95% confidence level. In open (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 Dixie 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 Dewberry 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 Dixie 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
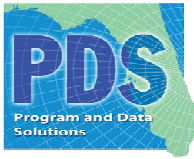
Ground Surveys and Dates

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 Dixie 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.
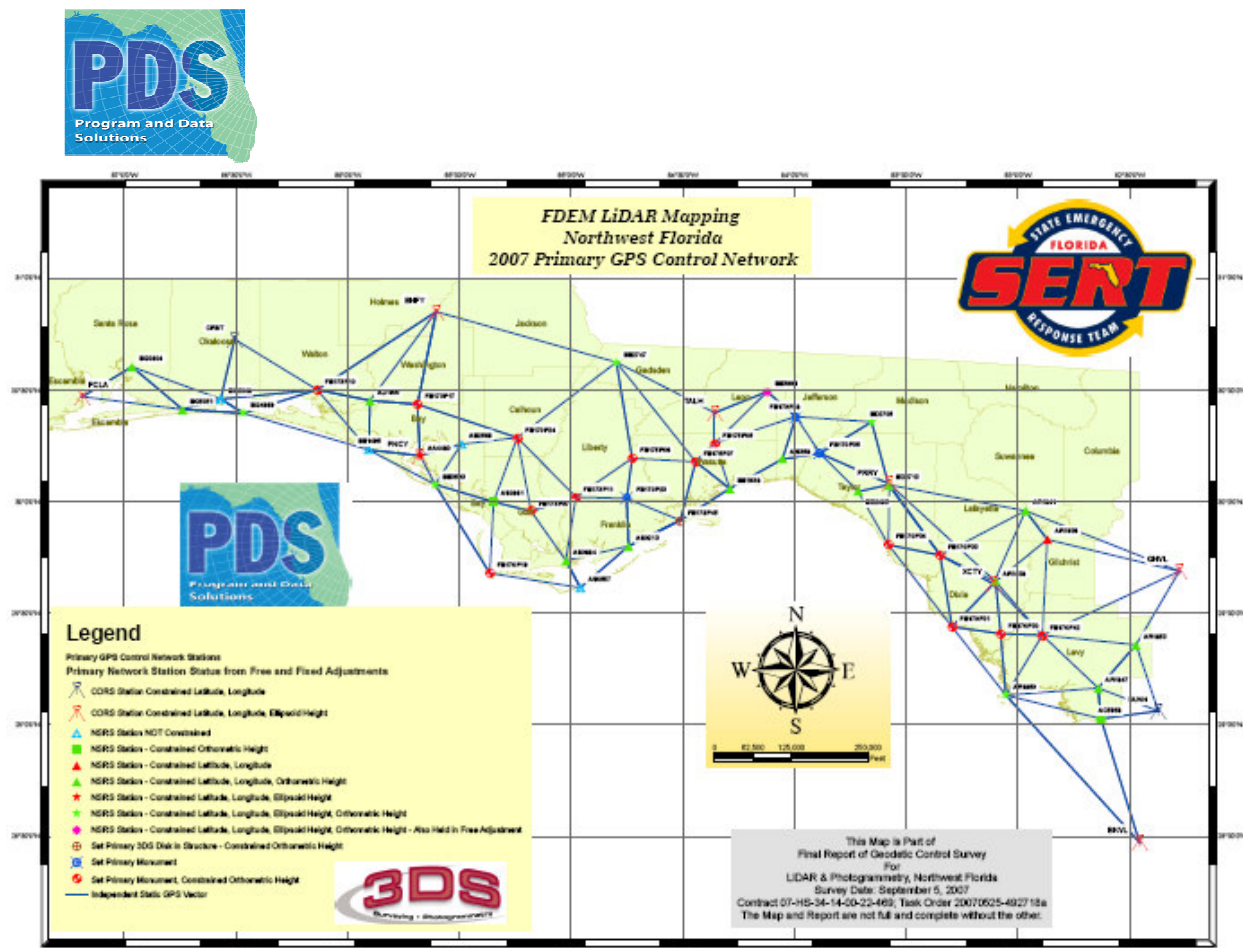
Figure 1. Primary Control Network

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.
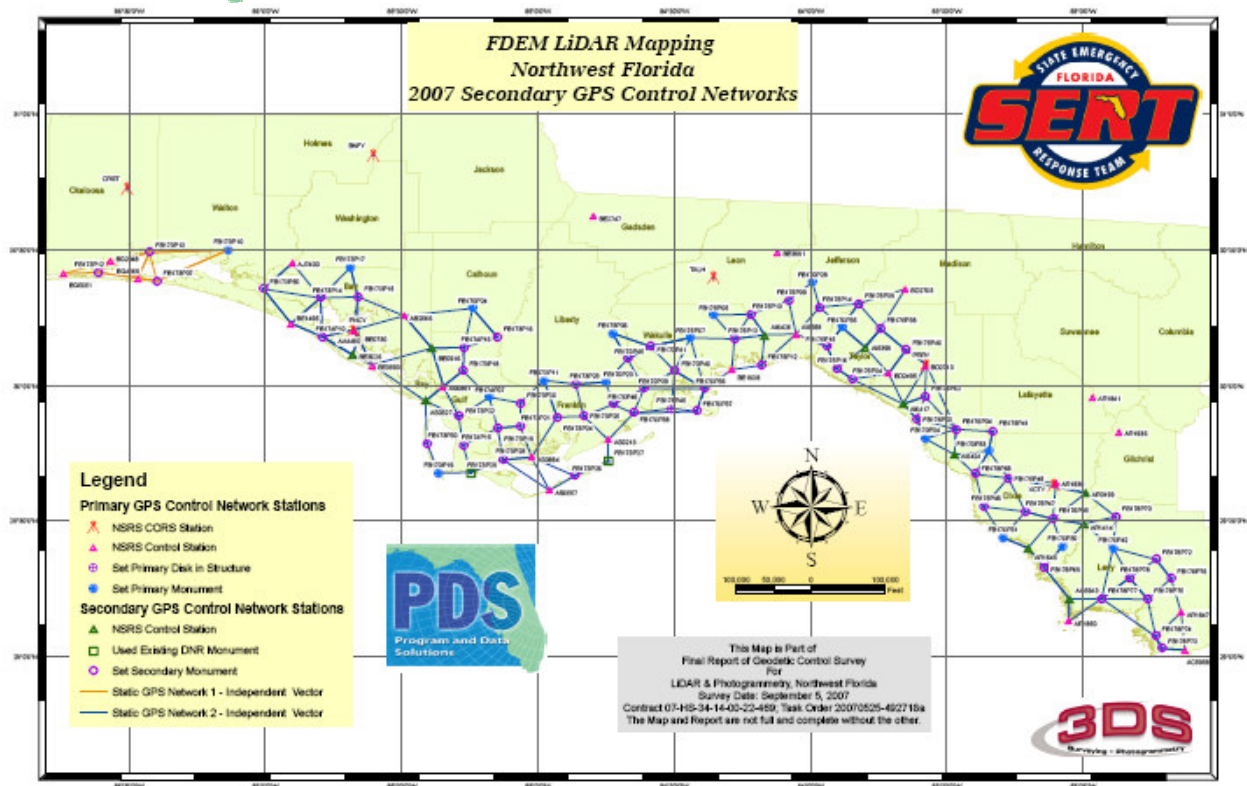
Figure 2. Secondary Control Networks

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 Dixie 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 Dixie 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 Dixie County, delivered in March 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 Dixie 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 Dixie County, the $RMSE_z$ in bare earth and low grass equaled 0.29 ft compared with the 0.30 ft specification of FDEM; and the FVA computed using $RMSE_z$ x 1.9600 was equal to 0.57 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
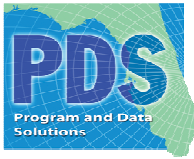
NOAA. *In Dixie County, the CVA computed using RMSE$_z$ x 1.9600 was equal to 0.73 ft, compared with the 1.19 ft specification of FDEM; and the CVA computed using the 95th percentile was also equal to 0.73 ft. URS determined that the dataset passed the CVA standard.*

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 95th 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 Dixie County, the SVA tested as 0.57 ft in bare earth and low grass, 0.79 ft in brush and low trees, 0.88 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 Dixie 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
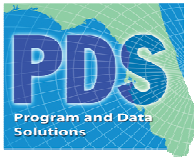
horizontal accuracy of LiDAR data, and explains why ASPRS does not require horizontal accuracy testing of LiDAR-derived elevation products.

- 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 Dixie County, is explained at Appendix D. Sanborn's field calibration tests indicated the horizontal accuracy tested 1.962 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
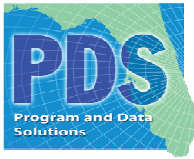
The following systematic approach was followed by URS in performing the cleanliness review and analysis:

- 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 Dixie County was processed to a bare-earth terrain surface by Sanborn. The initial LiDAR dataset provided to URS for accuracy and qualitative assessment failed for three reasons: (1) systematic errors in vertical accuracy, (2) elevation offsets between flight lines and "cornrows" that exceeded the 20-cm criteria used by the LiDAR industry, and (3) excessive noise, artifacts and anomalies. The data was reprocessed and the revised dataset passed URS's qualitative assessment as reported at Appendix G.

Breakline Production Methodology

For the *hard breaklines*, Sanborn used GeoCue software to develop LiDAR stereo models of Dixie County so the LiDAR derived data could be viewed in 3-D stereo using Socet Set softcopy photogrammetric software. Using LiDARgrammetry procedures with LiDAR intensity imagery, Sanborn stereo-compiled the eight types of *hard breaklines* in accordance with the Data Dictionary at Appendix C.

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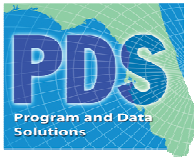
Whereas flowing rivers and streams are "hydro-enforced" to depict the downward flow of water, dry drainage features are not "hydro-enforced" but deliberately include undulations that more-accurately represent the true topography. This is, in fact, the ideal situation for topographic mapping.

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.
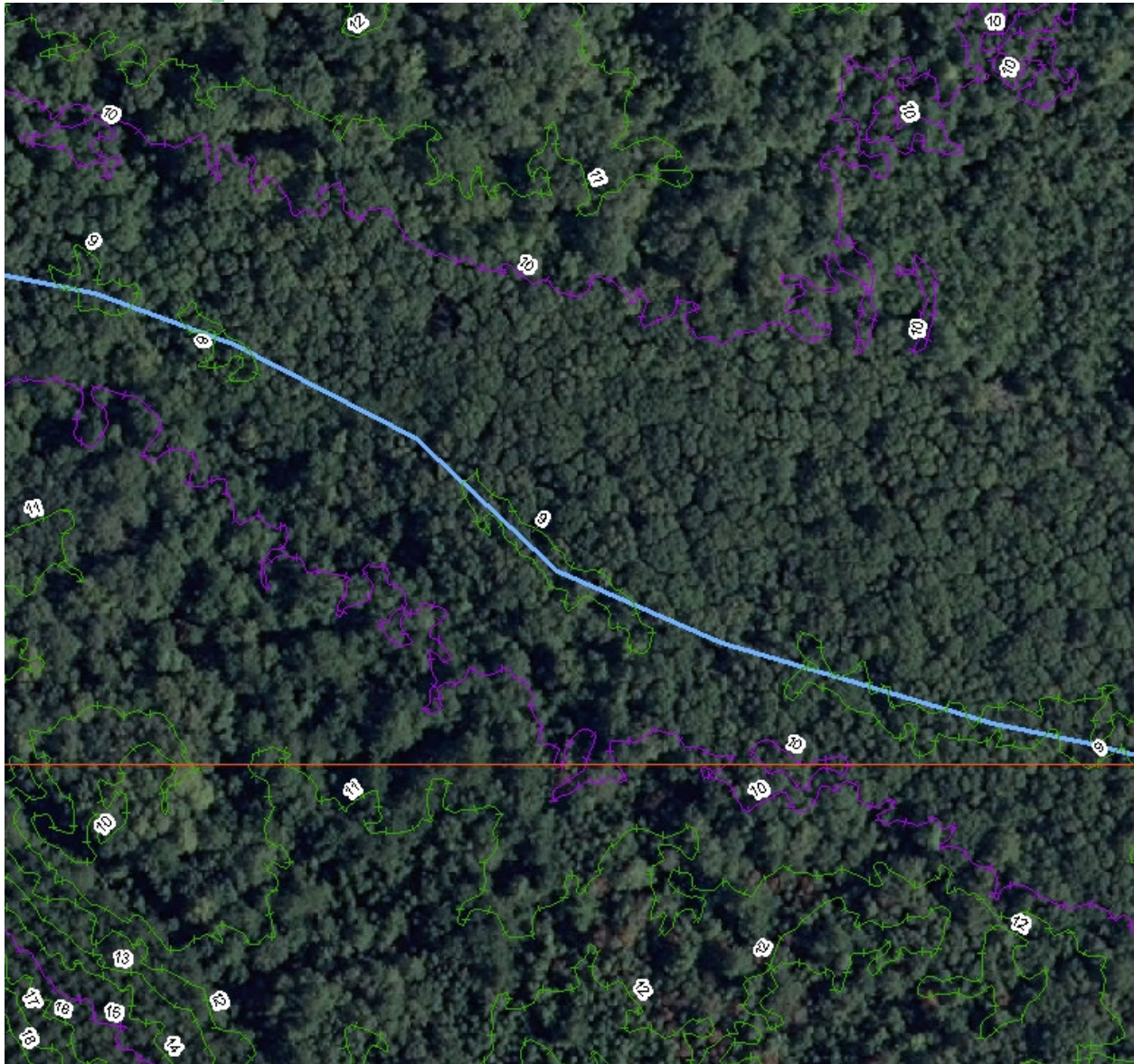
Figure 3. Even in very dense vegetation, the PDS team's high LiDAR point density (4 points per square meter) enabled the detection of dry drainage features beneath the vegetation.
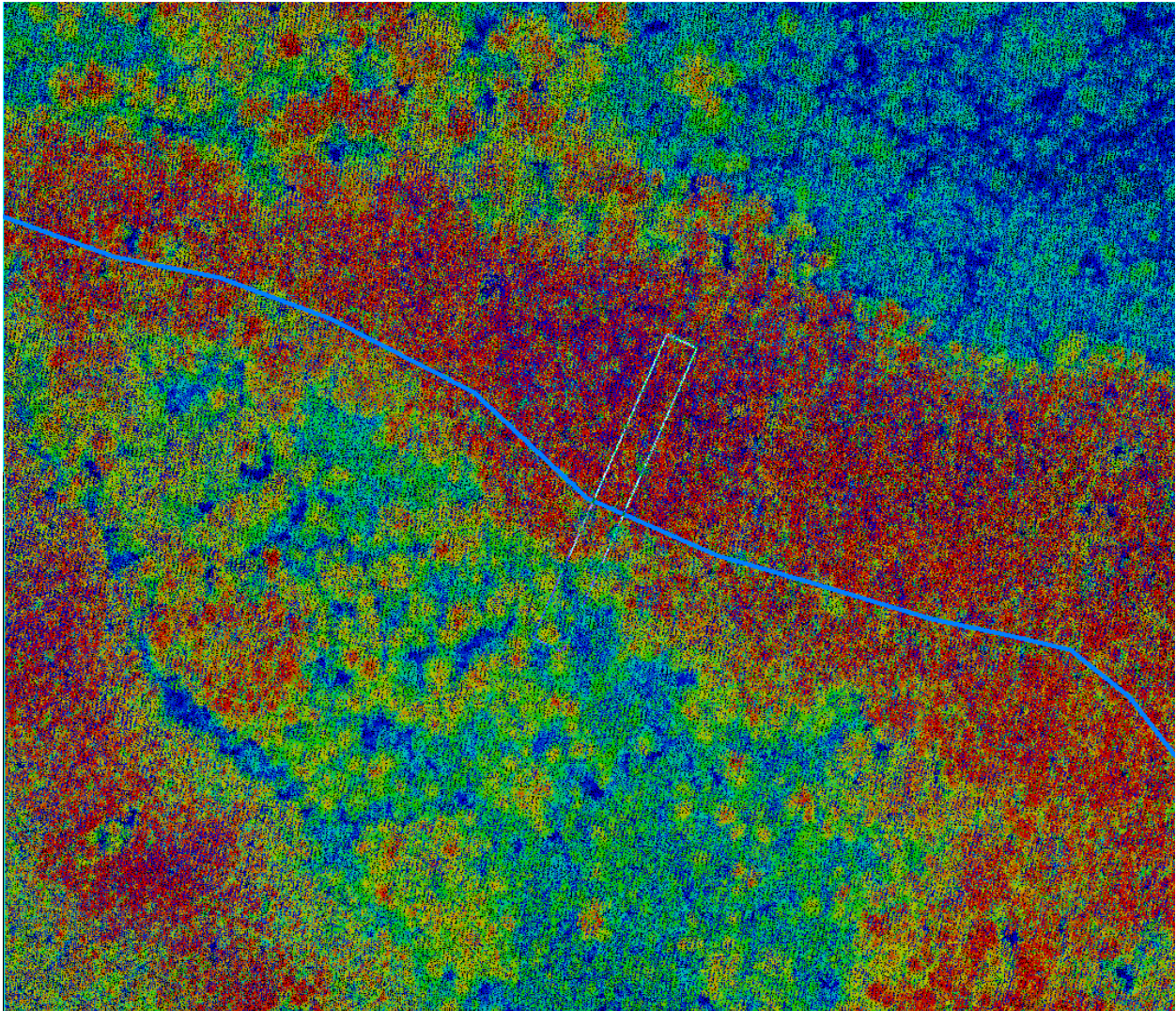
Figure 4. Full point cloud with profile (below) showing density of vegetation in the area of the dry drainage feature.
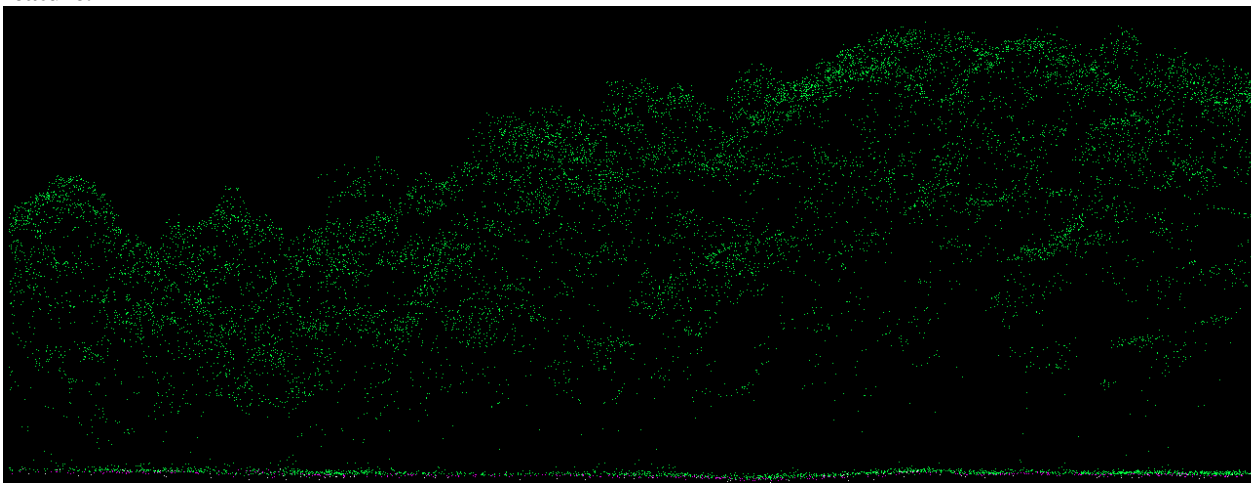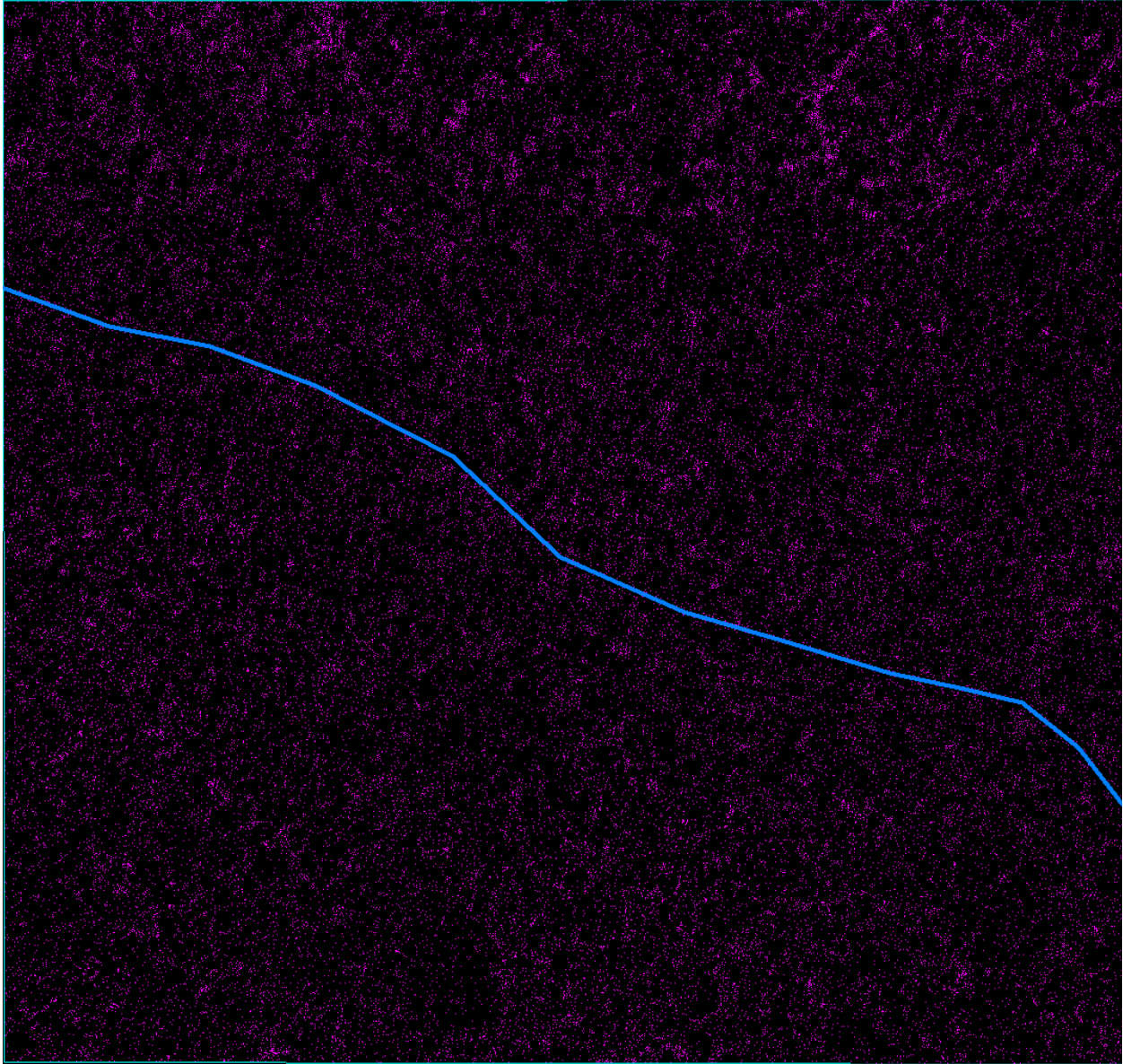
Figure 5. LAS Class 2 (ground) points showing the high density of points that penetrated the vegetation.
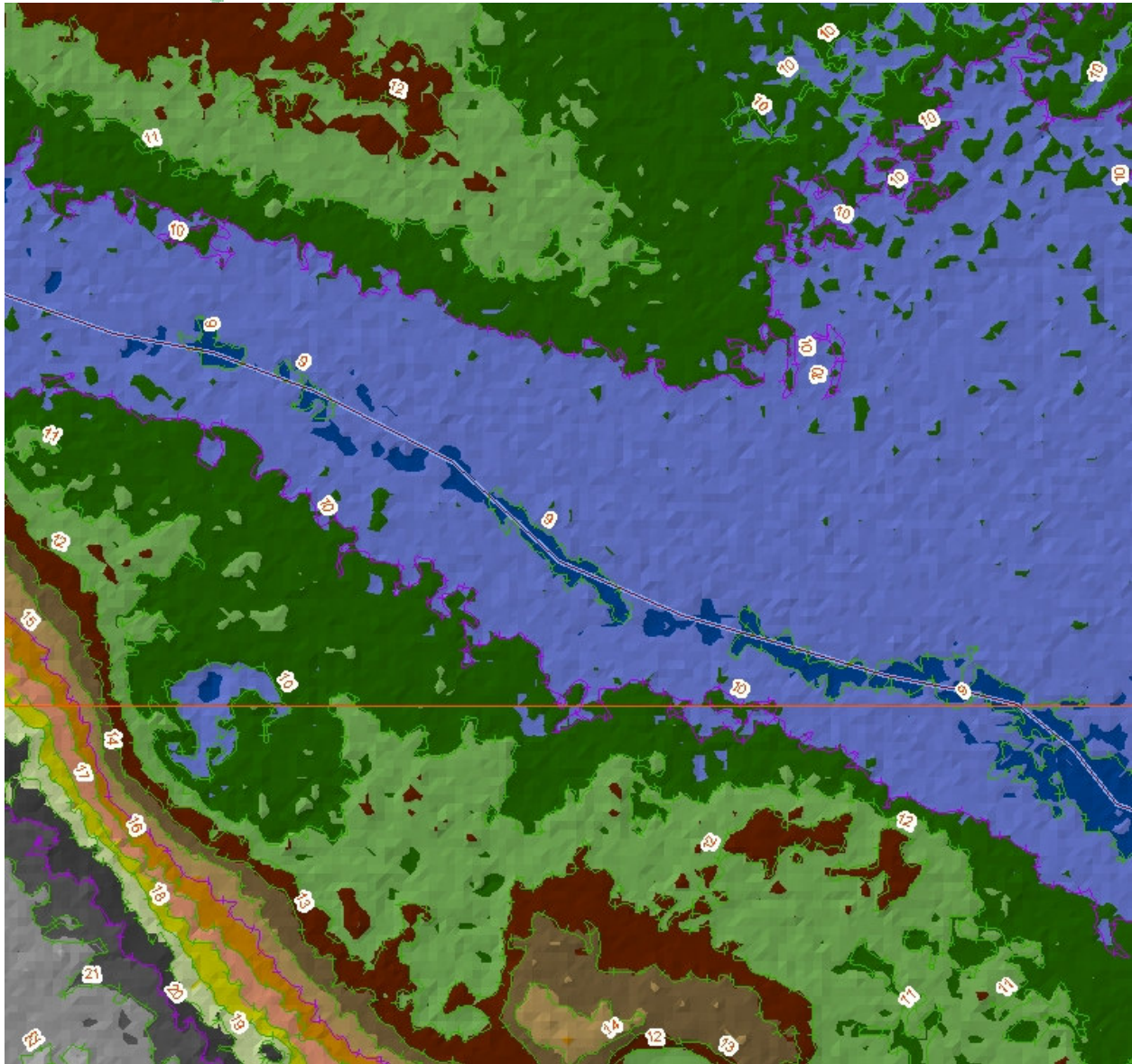
Figure 6. The ESRI Terrain is color-coded to depict the variable elevation bands. This clearly shows the lower, undulating elevations in the dry drainage feature.
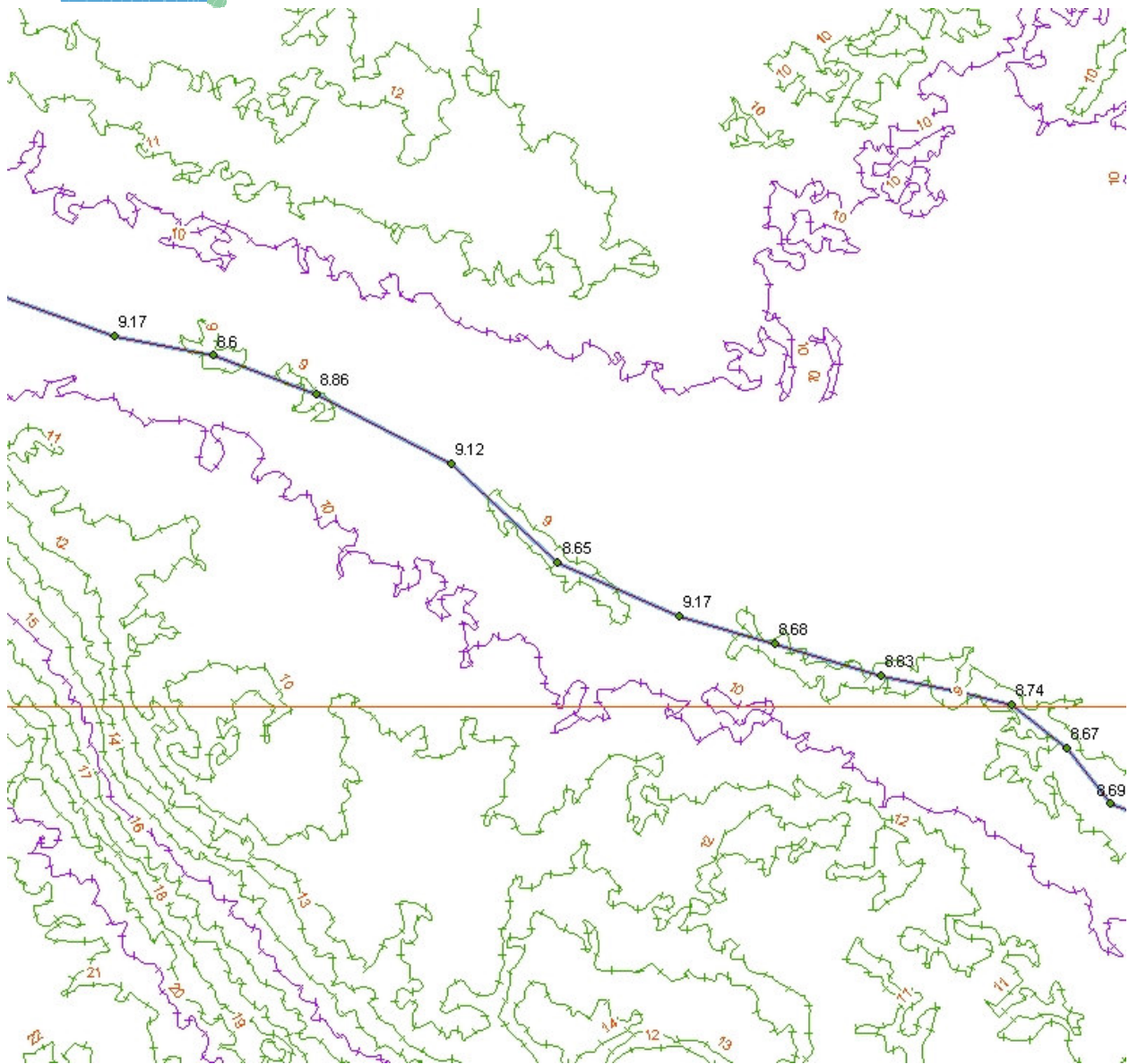
Figure 7. This figure shows variable "invert elevations" along the soft hydro breakline. It also shows "depression contours" where water would normally puddle if the drainage feature was only half dry. The soft hydro breakline passing through the "depression contours" clearly depict elevations lower 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.
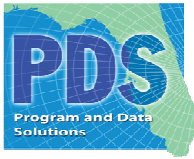
Breakline Qualitative Assessments

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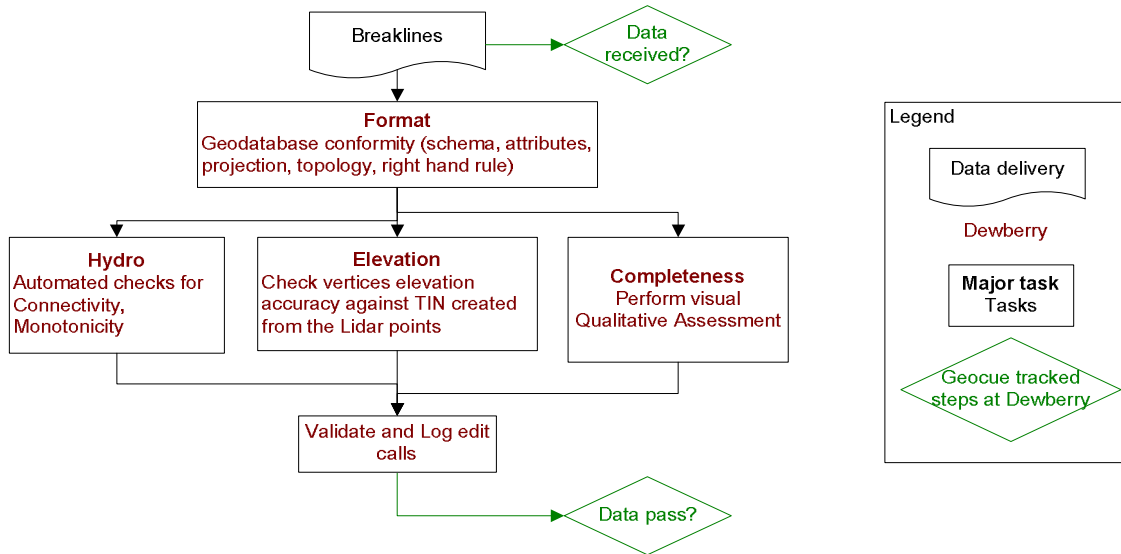
In order to ensure a correct database format, Dewberry provided all subcontractors with geodatabase shells containing the required feature classes in the required format. Upon receipt of the data, Dewberry verified that the correct shell was used and validated the topology rules associated with it.

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
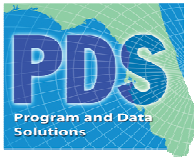
hydro-enforcement applied to the breaklines and because of the interpolated imagery used to acquire the breaklines. A given tolerance is used to validate if the elevations do not differ too much from the LiDAR.

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.
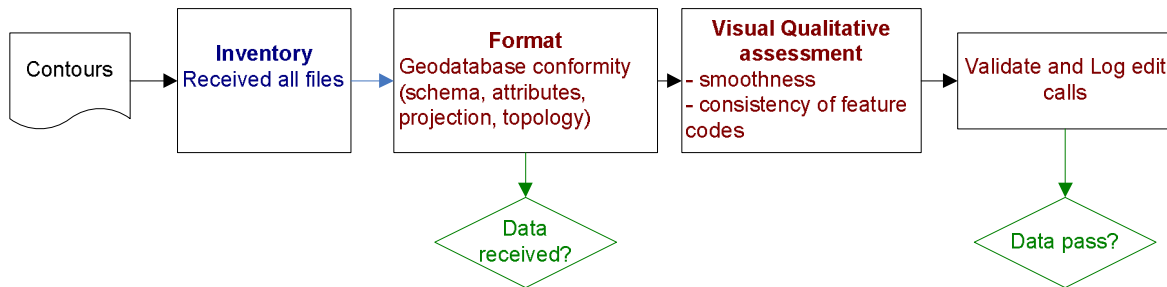
Upon receipt of each delivery area, the first step performed by Dewberry was a series of data topology validations. Dewberry checked for the following instances in the data:

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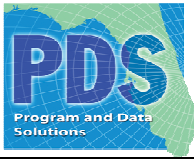
3	LiDAR Processing Report	Hardcopy and pdf	Appendix D
3	LiDAR Vertical Accuracy Report	Hardcopy and pdf	Appendix F
1	LiDAR Qualitative Assessment Report	pdf	Appendix G
1	Breakline/Contour Qualitative Assessment Report	pdf	Appendix H
1	Breaklines, Contours, Network-Adjusted Control Points, Vertical accuracy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

References

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

ASPRS, 2004, *ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data*, American Society for Photogrammetry and Remote Sensing, Bethesda, MD, May 24, 2004, http://www.asprs.org/society/committees/lidar/downloads/Vertical_Accuracy_Reporting_for_Lidar_Data.pdf.

Bureau of the Budget, 1947, *National Map Accuracy Standards*, Office of Management and Budget, Washington, D.C.

FDEM, 2006, Florida GIS, *Baseline Specifications for Orthophotography and LiDAR*, Appendix B, *Terrestrial LiDAR Specifications*, Florida Division of Emergency Management, Tallahassee, FL, October, 2006.

FEMA, 2004, Appendix A, *Guidance for Aerial Mapping and Surveying*, to "Guidelines and Specifications for Flood Hazard Mapping Partners," Federal Emergency Management Agency, Washington, D.C.

FGCC, 1984, *Standards and Specifications for Geodetic Control Networks*, Federal Geodetic Control Committee, Silver Spring, ,MD, reprinted August 1993.

FGCC, 1988, *Geometric Geodetic Accuracy Standards and Specifications for Using GPS Relative Positioning Techniques*, Federal Geodetic Control Committee, Silver Spring, MD, reprinted with corrections, August, 1989.

FGDC, 1998a, *Geospatial Positioning Accuracy Standards, Part I: Reporting Methodology*, Federal Geographic Data Committee, c/o USGS, Reston, VA, http://www.fgdc.gov/standards/standards_publications/.

FGDC, 1998b, *Geospatial Positioning Accuracy Standards, Part 2, Standards for Geodetic Networks*, Federal Geographic Data Committee, c/o USGS, Reston, VA, http://www.fgdc.gov/standards/standards_publications/

FGDC, 1998b, *Geospatial Positioning Accuracy Standards, Part 3, National Standard for Spatial Data Accuracy*, Federal Geographic Data Committee, c/o USGS, Reston, VA, http://www.fgdc.gov/standards/standards_publications/

FGDC, 1998d, Content Standard for Digital Geospatial Metadata (CSDGM), Federal Geographic Data Committee, c/o USGS, Reston, VA, www.fgdc.gov/metadata/contstan.html.
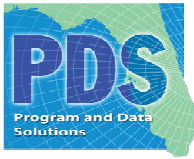
NDEP, 2004, *Guidelines for Digital Elevation Data*, Version 1.0, National Digital Elevation Program, May 10, 2004, http://www.ndep.gov/

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: _____
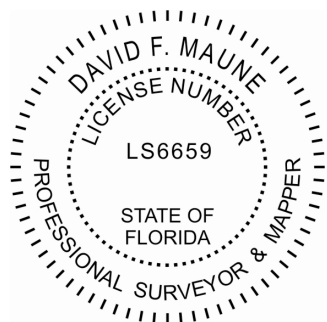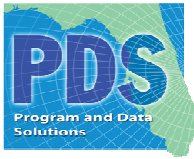
List of Appendices

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
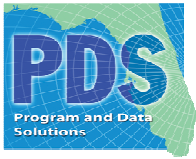
Appendix A: County Project Tiling Footprint

622 Tiles Delivered

Submitted Tiles for FDEM

Taylor

Dixie

Levy

Status

☐ Dixie Tiles
■ Complete Tiles
☐ FDEM FLSPN Tile Grid

N

0 2 4 6 8 Miles
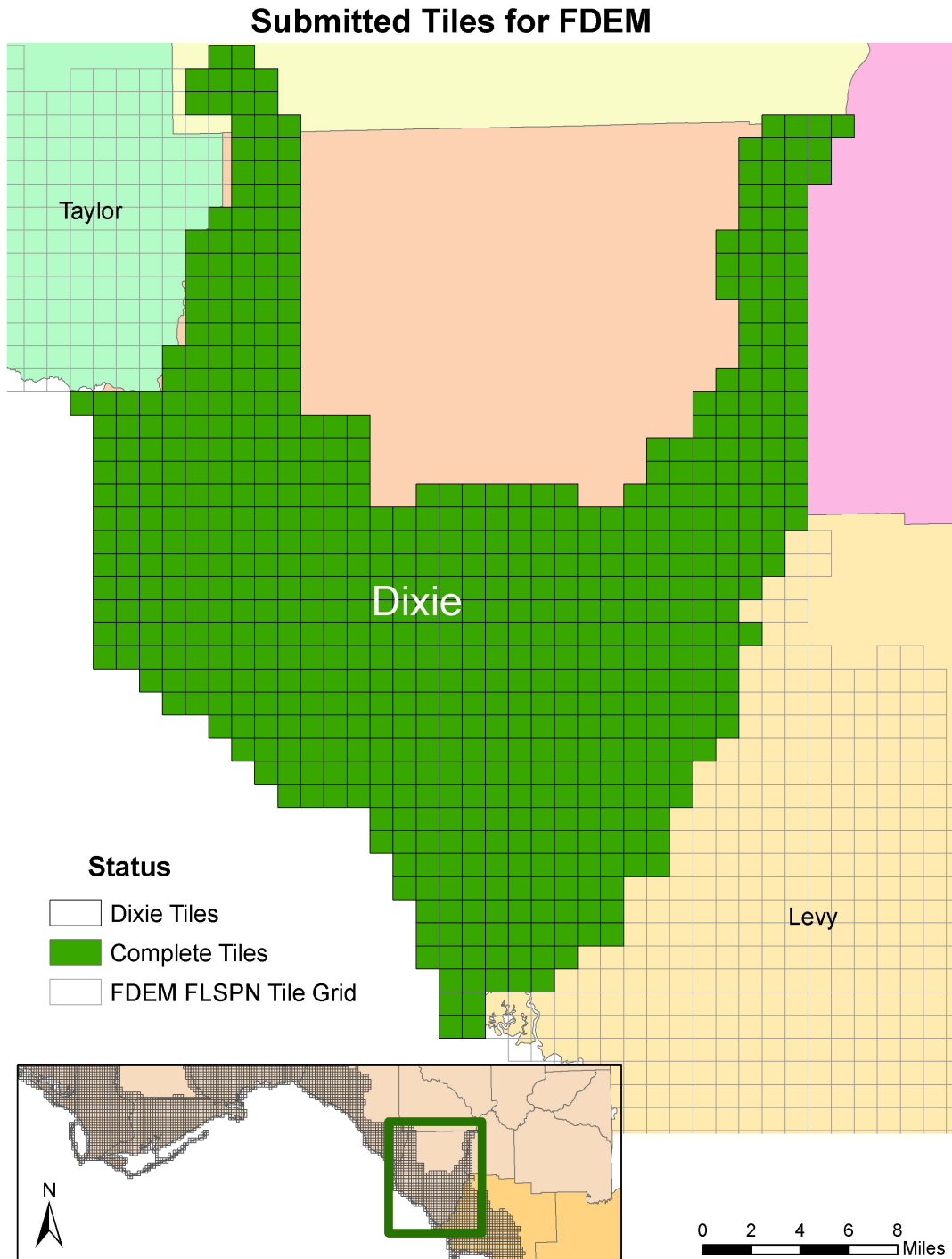
List of Delivered Tiles (622):

079134_N	081836_N	078084_N	080220_N	079675_N
079135_N	081837_N	087241_N	080221_N	079677_N
079136_N	081838_N	087242_N	080222_N	079682_N
079137_N	081839_N	087243_N	080223_N	079684_N
079138_N	081840_N	087244_N	080224_N	079700_N
079139_N	081841_N	087245_N	080225_N	079702_N
079140_N	081842_N	087246_N	076438_N	083458_N
079141_N	081843_N	087251_N	076440_N	083459_N
079142_N	081848_N	087252_N	078620_N	083460_N
079143_N	081849_N	087253_N	078622_N	083461_N
079160_N	081850_N	087254_N	076439_N	083467_N
086159_N	081851_N	087255_N	076441_N	083468_N
086164_N	081852_N	072682_N	077519_N	083469_N
086165_N	081853_N	072120_N	078621_N	083470_N
086166_N	081854_N	072121_N	081304_N	083475_N
086167_N	081855_N	072122_N	081306_N	083476_N
086168_N	081856_N	072660_N	083454_N	083477_N
086169_N	081857_N	072661_N	083455_N	083478_N
086170_N	070499_N	072662_N	077518_N	080781_N
086171_N	070500_N	072683_N	080238_N	080783_N
084561_N	073222_N	073740_N	080239_N	080784_N
079144_N	073223_N	073741_N	080240_N	077544_N
079145_N	073224_N	073742_N	081305_N	078593_N
079161_N	073225_N	074302_N	075362_N	078594_N
079162_N	071040_N	074841_N	077520_N	078595_N
079163_N	071041_N	074842_N	077522_N	078597_N
079164_N	081844_N	074304_N	079674_N	079683_N
086160_N	081845_N	081861_N	079676_N	079685_N
086161_N	081846_N	081862_N	080780_N	079698_N
086162_N	081847_N	081863_N	080782_N	079699_N
086163_N	074818_N	078060_N	075361_N	079701_N
086172_N	074819_N	078061_N	075381_N	079703_N
072146_N	074820_N	078062_N	075382_N	083462_N
073201_N	074821_N	087256_N	075383_N	083463_N
073202_N	074822_N	087257_N	075384_N	083464_N
072143_N	074843_N	087258_N	075921_N	083465_N
072144_N	074844_N	087247_N	075922_N	083466_N
072145_N	073762_N	087248_N	075923_N	083479_N
073200_N	073763_N	087249_N	075924_N	083480_N
076462_N	073764_N	087250_N	076978_N	080214_N
071038_N	074303_N	072684_N	076979_N	080215_N
071039_N	081858_N	072685_N	076980_N	080216_N
076463_N	081859_N	087259_N	077002_N	080217_N
076464_N	081860_N	074279_N	077003_N	080218_N
071578_N	078057_N	074280_N	077004_N	080241_N
071579_N	078058_N	074281_N	077521_N	080754_N
071580_N	078059_N	074282_N	077542_N	080755_N
071581_N	078081_N	085101_N	077543_N	080756_N
081834_N	078082_N	083456_N	078596_N	080757_N
081835_N	078083_N	080219_N	078598_N	080758_N

		084549_N	082378_N	086181_N
080759_N	082388_N	084550_N	082379_N	091036_N
080764_N	082389_N	081323_N	082380_N	084551_N
080765_N	082390_N	081324_N	082394_N	084552_N
080768_N	082391_N	081315_N	082395_N	084553_N
080769_N	082392_N	081316_N	082396_N	084554_N
080770_N	082393_N	081317_N	082397_N	084559_N
080771_N	082398_N	081318_N	082922_N	084560_N
080772_N	082399_N	081319_N	082923_N	084009_N
080773_N	082400_N	081320_N	082924_N	084010_N
080774_N	082401_N	081321_N	082925_N	084014_N
085077_N	082402_N	081322_N	082926_N	084015_N
085082_N	082914_N	075358_N	082940_N	084016_N
085084_N	082915_N	075359_N	082941_N	084017_N
085091_N	082916_N	075360_N	083997_N	084018_N
085093_N	082917_N	076981_N	083998_N	084019_N
085100_N	082919_N	076982_N	083999_N	085617_N
081298_N	082921_N	078599_N	084001_N	085618_N
081300_N	082928_N	078600_N	084002_N	085619_N
083481_N	082930_N	078601_N	084003_N	085620_N
076442_N	082931_N	078602_N	084004_N	085626_N
078623_N	082932_N	079678_N	084538_N	085627_N
078624_N	082933_N	079679_N	084539_N	085628_N
085086_N	082934_N	079680_N	084540_N	085629_N
085087_N	082935_N	079681_N	084541_N	085630_N
085088_N	083994_N	079704_N	082942_N	085631_N
085089_N	083995_N	083457_N	075899_N	085632_N
081294_N	083996_N	083471_N	075900_N	085633_N
081295_N	082403_N	083472_N	075901_N	085634_N
081296_N	082918_N	083473_N	075902_N	085635_N
077517_N	082920_N	083474_N	081310_N	085636_N
085076_N	082927_N	080242_N	081311_N	085637_N
085083_N	082929_N	080243_N	081312_N	086175_N
085085_N	082936_N	080244_N	081313_N	086177_N
085090_N	082937_N	080760_N	081314_N	086700_N
085092_N	082938_N	080761_N	075898_N	086701_N
085099_N	082939_N	080762_N	084020_N	086702_N
081297_N	084000_N	080763_N	084021_N	086703_N
081299_N	084005_N	080777_N	084022_N	086704_N
081301_N	084006_N	080778_N	086717_N	086705_N
081307_N	084007_N	080779_N	086718_N	086706_N
081308_N	084008_N	085078_N	086719_N	086707_N
081309_N	084534_N	085079_N	086720_N	086708_N
082374_N	084535_N	085080_N	086715_N	086709_N
082375_N	084536_N	085081_N	086716_N	086714_N
082376_N	084537_N	085094_N	086176_N	087786_N
082381_N	084542_N	085095_N	086178_N	087788_N
082382_N	084543_N	085096_N	086179_N	087793_N
082383_N	084544_N	085097_N	086180_N	087795_N
082384_N	084545_N	085098_N	091028_N	088868_N
082385_N	084546_N	081302_N	091029_N	088870_N
082386_N	084547_N	081303_N	091034_N	090496_N
082387_N	084548_N	082377_N	091035_N	092650_N

087782_N	089417_N	087799_N	091573_N	088873_N
087783_N	089947_N	089418_N	084557_N	088874_N
087784_N	089948_N	089956_N	084558_N	088875_N
087785_N	089949_N	092111_N	084011_N	089407_N
087787_N	089950_N	092113_N	084012_N	089408_N
087794_N	089951_N	084555_N	084013_N	089409_N
087796_N	089952_N	084556_N	085621_N	090489_N
087797_N	089953_N	086173_N	085622_N	090490_N
087798_N	089954_N	086174_N	085623_N	090491_N
088866_N	089955_N	091030_N	085624_N	090492_N
088867_N	090488_N	091031_N	085625_N	090493_N
088869_N	090494_N	091032_N	085638_N	092649_N
088871_N	090495_N	091033_N	085639_N	093189_N
088876_N	091568_N	088338_N	085640_N	085641_N
088877_N	091569_N	088326_N	086710_N	093190_N
089410_N	091570_N	088327_N	086711_N	088331_N
089411_N	091571_N	088328_N	086712_N	088332_N
089412_N	091572_N	088329_N	086713_N	088333_N
089413_N	092109_N	088330_N	087789_N	088334_N
089414_N	092110_N	088335_N	087790_N	
089415_N	092112_N	088336_N	087791_N	
089416_N	088878_N	088337_N	087792_N	
		091574_N	088872_N	
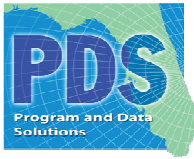
Appendix B: Dixie County Geodetic Control Points

STATION NAME	COUNTY	LATITUDE (Deg, Min, Sec)	LONGITUDE (Deg, Min, Sec	ELLIPSOID HEIGHT (meters)	NAVD88 HEIGHT (meters)	DESCRIPTION
AR0199	DIXIE	29 36 12.37847	82 59 25.98802	-21.043	6.778	RECOVERED NSRS STATION (SEE DATASHEET PID# AR0199)
AR1414	DIXIE	29 29 27.65232	82 59 50.22688	-22.148	5.563	RECOVERED NSRS STATION (SEE DATASHEET PID# AR1414)
AR1645	DIXIE	29 24 5.25391	83 12 6.79242	-25.19	2.563	RECOVERED NSRS STATION (SEE DATASHEET PID# AR1645)
AR1838	DIXIE	29 38 27.32413	83 5 57.64871	-15.767	12.002	RECOVERED NSRS STATION (SEE DATASHEET PID# AR1838)
AR1841	LAFAYETTE	29 57 29.01491	82 57 55.44440	-14.304	13.633	RECOVERED NSRS STATION (SEE DATASHEET PID# AR1841)
AR1936	GILCHRIST	29 49 47.56753	82 52 2.97586	-12.467	15.384	RECOVERED NSRS STATION (SEE DATASHEET PID# AR1936)
FB170P30	DIXIE	29 24 28.35743	83 4 35.43119	-23.66	4.035	SET PRIMARY MONUMENT
FB170P31	DIXIE	29 26 23.20971	83 17 37.19391	-26.336	1.384	SET PRIMARY MONUMENT
XCTY	DIXIE	29 37 51.61310	83 6 29.33781	-13.811	13.959	NSRS CORS STATION (SEE DATASHEET PID# DG4685)
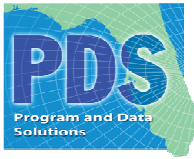
Appendix C: Data Dictionary
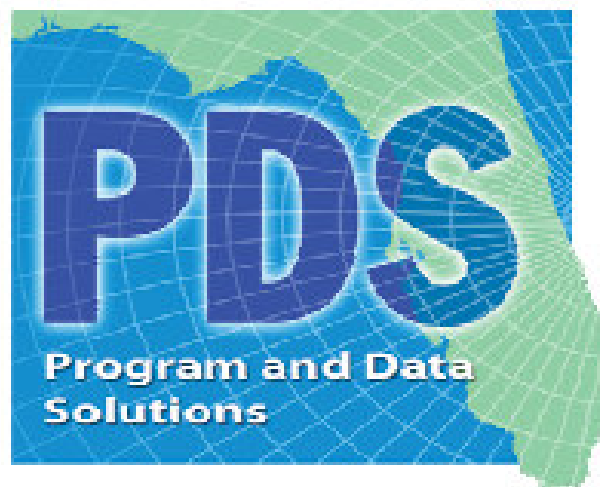
**LiDARgrammetry Data Dictionary
& Stereo Compilation Rules**

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 self-intersect	The rule is a line-no self intersect rule	No	COASTALSHORELINE::All	COASTALSHORELINE::All

Coastal Shoreline

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: COASTALSHORELINE
Contains Z Values: Yes
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Polygon
Annotation Subclass: None

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

32

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

38

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.

41

Masspoints

Feature Dataset: TOPOGRAPHIC
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: MASSPOINT
Contains Z Values: Yes
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Point
Annotation Subclass: None

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 Class:** CONTOUR_1FT   **Feature Type:** Polyline
Contains M Values: No   **Contains Z Values:** No   **Annotation Subclass:** None
XY Resolution: Accept Default Setting   **Z Resolution:** N/A
XY Tolerance: 0.003   **Z Tolerance:** N/A

Description

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

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by PDS
SHAPE_LENGTH	Double	Yes			0	0		Calculated by PDS
CONTOUR_TYPE_DESC	Long Integer	No		dCONTOURTYPE	0	0	50	Assigned by PDS
CONTOUR_ELEVATION_MS	Double	No			0	0		Calculated by PDS

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	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

		unduly prominent on the published map.	larger than 1" at map scale (100'), then add appropriate supplemental contours from the 1FT_CONTOUR feature class. Supplemental contours do not have to be continuous but should have a minimum length of 200'.
3	Depression	Depression contours are closed contours that surround a basin or sink. They are shown by right-angle ticks placed on the contour lines, pointed inward (down slope). Fill contours are a special type of depression contours, used to indicate an area that has been filled to support a road or railway grade.	Use when appropriate.
4	Index	Index Contours are to be placed at every 5th contour interval (1, 5, 10, etc…)	No special rules
5	Intermediate Low Confidence	Intermediate contours (Code 1) that are located in low confidence area should be cut 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	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
CONTOUR_TYPE_DESC	Long Integer	No		dCONTOURTYPE	0	0	50	Assigned by PDS
CONTOUR_ELEVATION_MS	Double	No			0	0		Calculated by PDS

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	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.

		shown as screened lines so that they are distinguishable from the basic contours, yet not unduly prominent on the published map.	If the horizontal distance between two adjacent contours is larger than 1" at map scale (100'), then add appropriate supplemental contours from the 1FT_CONTOUR feature class. Supplemental contours do not have to be continuous but should have a minimum length of 200'.
3	Depression	Depression contours are closed contours that surround a basin or sink. They are shown by right-angle ticks placed on the contour lines, pointed inward (down slope). Fill contours are a special type of depression contours, used to indicate an area that has been filled to support a road or railway grade.	Use when appropriate.
4	Index	Index Contours are to be placed at every 5th contour interval (1, 5, 10, etc...)	No special rules
5	Intermediate Low Confidence	Intermediate contours (Code 1) that are located in low confidence area should be cut 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
Contains M Values: No
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: GROUNDCONTROL
Contains Z Values: Yes
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Feature Type: Point
Annotation Subclass: None

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:

Brian Mayfield, C.P., GISP, G.L.S.
Associate / Sr. Project Manager
Dewberry
8401 Arlington Blvd.
Fairfax, VA 22031
(703) 849-0254 – voice
(703) 340-4141 – cell
bmayfield@dewberry.com

Appendix D: LiDAR Processing Report

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

Prepared by:

Sanborn

1935 Jamboree Dr., Suite 100

Colorado Springs, CO, 80920

Phone: (719) 593-0093

Fax: (719) 528-5093

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 470 square miles of Dixie 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 Dixie County 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

▭ Dixie	—— 07-01-2007b	—— 07-12-2007a	—— 07-21-2007a
—— 06-24-2007a	—— 07-02-2007a	—— 07-13-2007a	—— 07-22-2007a
—— 06-25-2007a	—— 07-03-2007a	—— 07-16-2007a	—— 07-23-2007b
—— 06-27-2007a	—— 07-03-2007a	—— 07-16-2007a	—— 07-27-2007a
—— 06-28-2007a	—— 07-05-2007a	—— 07-18-2007a	—— 08-08-2007a
—— 06-28-2007a	—— 07-06-2007a	—— 07-19-2007a	—— 08-16-2007a
—— 07-01-2007a	—— 07-09-2007a	—— 07-19-2007b	—— 08-17-2007b

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:

Sanborn
1935 Jamboree Drive, Suite 100
Colorado Springs, CO 80920

Attention: ---------- Andy Lucero (Project Manager)
------- James 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

Dixie County, Florida

1.4 Project Scope, Specifications and Time Line

The summer of 2007 LiDAR Flight Acquisition required the collection of 470 square miles of Dixie 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

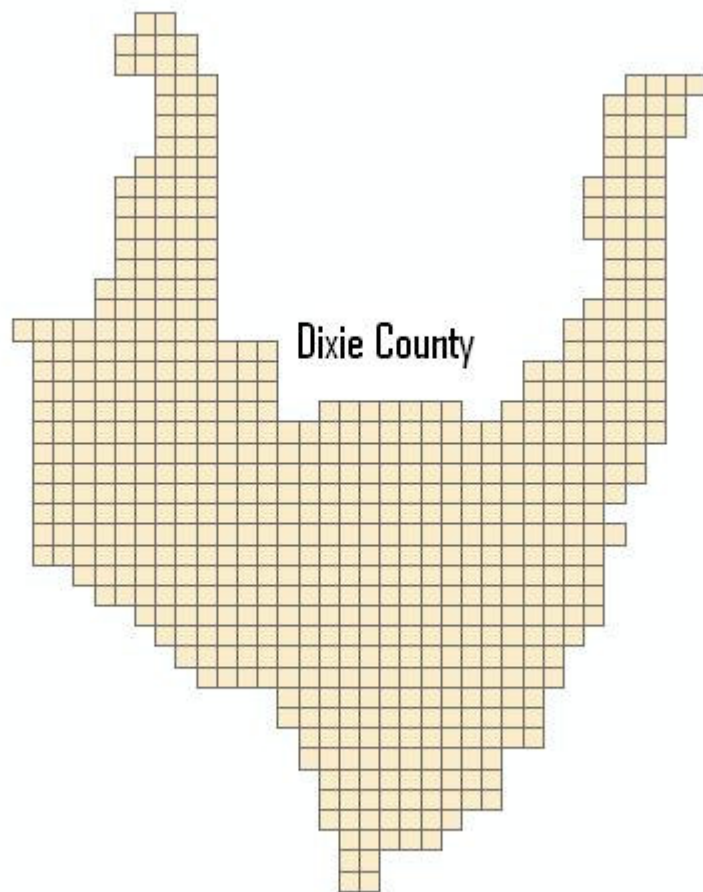| Area (sq. mi)	470	Product type	Fema(F)	Projection	Florida State Plane
Vertical RMSE (cm)	Bare Earth 9.25cm	Check Points required	Yes	Horizontal Datum Vertical Datum	NAD83/Harn NAVD88
Horizontal RMSE (cm)	50cm	Number Collected	60	Units	US Survey Ft

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.
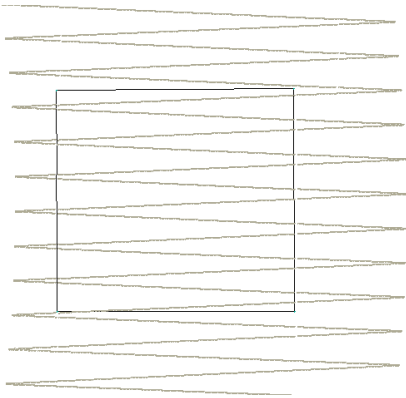
Figure 2: Calibration Pass 1   **Figure 3: Calibration Pass 2**
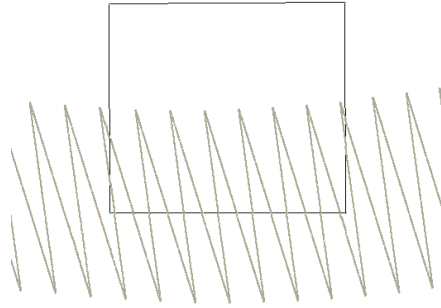
2.4 Runway Calibration, System Performance Validation

An active asphalt runway was precisely-surveyed at the Cross City Airport for Dixie 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.

Direction of Flight
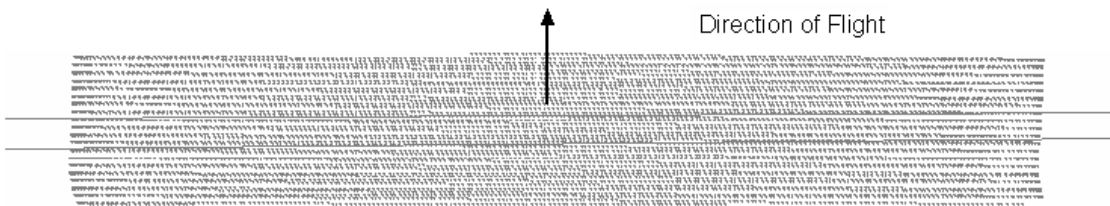
Figure 4: Runway Calibration

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.
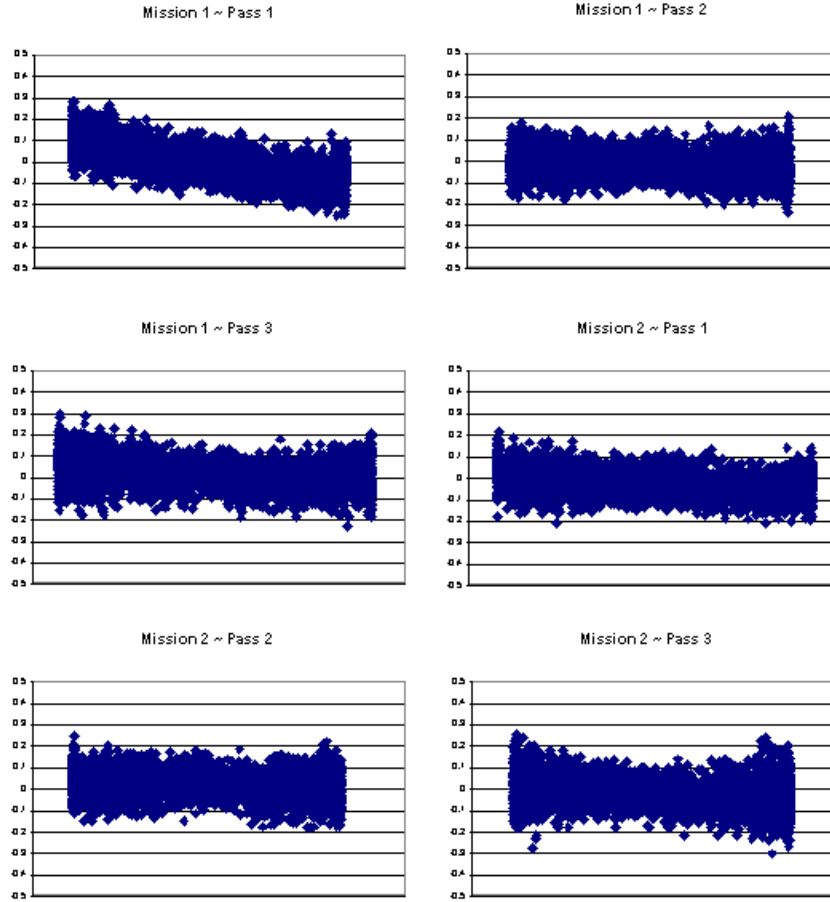
Figure 5: Runway Calibration Results

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 0.088 meters and the maximum standard deviation is 0.088 meters. The average RMS among all test flights is 0.065 meters.

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

Mission	Passes	Standard Deviation	RMS
175a_Leica_40	4	0.042	0.056
176a_Leica_40	3	0.041	0.053
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
190a_Optech	4	0.080	0.081
190b_Leica	4	0.069	0.069
192a_Leica	4	0.054	0.054
193a_Optech	4	0.078	0.084
194a_Optech	4	0.067	0.069
197a_Leica	4	0.086	0.086
199a_Leica_40	4	0.058	0.058
200a_Optech	4	0.087	0.087
201a_Leica	4	0.060	0.061
201a_Optech	4	0.069	0.077
203a_Optech	4	0.088	0.088
204a_Optech	4	0.087	0.087
204b_Optech	5	0.078	0.087
208a_Leica_49	4	0.065	0.078
216a_Leica_40	4	0.062	0.088
228a_Leica	4	0.036	0.037

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. $RMSE_r = SQRT (RMSE_x^2 + RMSE_y^2) = 34.548$ cm = 1.133 ft. Horizontal accuracy at the 95% confidence level = $RMSE_r$ x 1.7308 = 1.962 ft, well within the 3.8 ft horizontal accuracy specification.

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

Dixie County			
Tile	**Northing Offset (cm)**	**Easting Offset (cm)**	**Center/Edge**
91571	25.38	21.58	C
91031	33.85	21.45	C
81321	33.73	35.79	C
80781	27.37	21.57	C
80241	29.25	22.37	E
RMSE	**29.916**	**24.552**	
Calibration Mission	**Northing Offset (cm)**	**Easting Offset (cm)**	**Center/Edge**
Day176	22.14	20.82	E
Day178	9.66	11.88	E
Day186	25.22	27.12	E
Day188	12.91	25.11	E
Day228	48.24	10.63	E
RMSE	**23.634**	**19.112**	

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

Tile/Mission	Northing (cm)	Easting (cm)	Center/Edge
91571	25.38	21.58	C
91031	33.85	21.45	C
81321	33.73	35.79	C
80781	27.37	21.57	C
80241	29.25	22.37	E
Day176	22.14	20.82	E
Day178	9.66	11.88	E
Day186	25.22	27.12	E
Day188	12.91	25.11	E
Day228	48.24	10.63	E
RMSE	26.775	21.832	

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 Dixie 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
175a	Jun 24	Leica	13:09	14:16	800	120	40˚	36	50000	0.9
176a	Jun 25	Leica	19:37	20:29	800	120	40˚	36	50000	1.0
178a	Jun 27	Leica	00:47	5:37	800	120	40˚	36	50000	1.1
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
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
192a	Jul 11	Leica	19:02	22:53	800	120	40˚	36	50000	1.0
193a	Jul 12	Optech	21:57	1:44	800	120	32˚	40	50000	1.8
194a	Jul 13	Optech	19:17	22:23	800	120	32˚	40	50000	1.9
197a	Jul 16	Leica	19:38	00:09	800	120	40˚	36	50000	0.9
199a	Jul 18	Leica	7:15	12:53	800	120	40˚	36	50000	1.3
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	23:48	1:44	800	120	40˚	36	50000	1.1
202a	Jul 21	Optech	18:19	21:21	800	120	32˚	40	50000	1.9
203a	Jul 22	Optech	17:20	2:03	800	120	32˚	40	50000	1.7
204a	Jul 23	Optech	16:02	19:51	800	120	32˚	40	50000	1.8
204b	Jul 23	Optech	21:49	23:28	800	120	32˚	40	50000	2.0
208a	Jul 27	Leica	1:14	6:18	800	120	40˚	36	50000	1.6
216a	Aug 4	Leica	20:56	23:46	800	120	40˚	36	50000	1.3
228a	Aug 16	Leica	13:56	15:07	800	120	40˚	36	50000	1.2

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^{TM} 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 Dixie 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 Dixie County. For the Dixie County area the standard deviation is 0.295 feet and the root mean squared is 0.288 feet. 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. Table 9 indicates the results for Dixie County and each point including the overall results as it compares to the LiDAR data set.
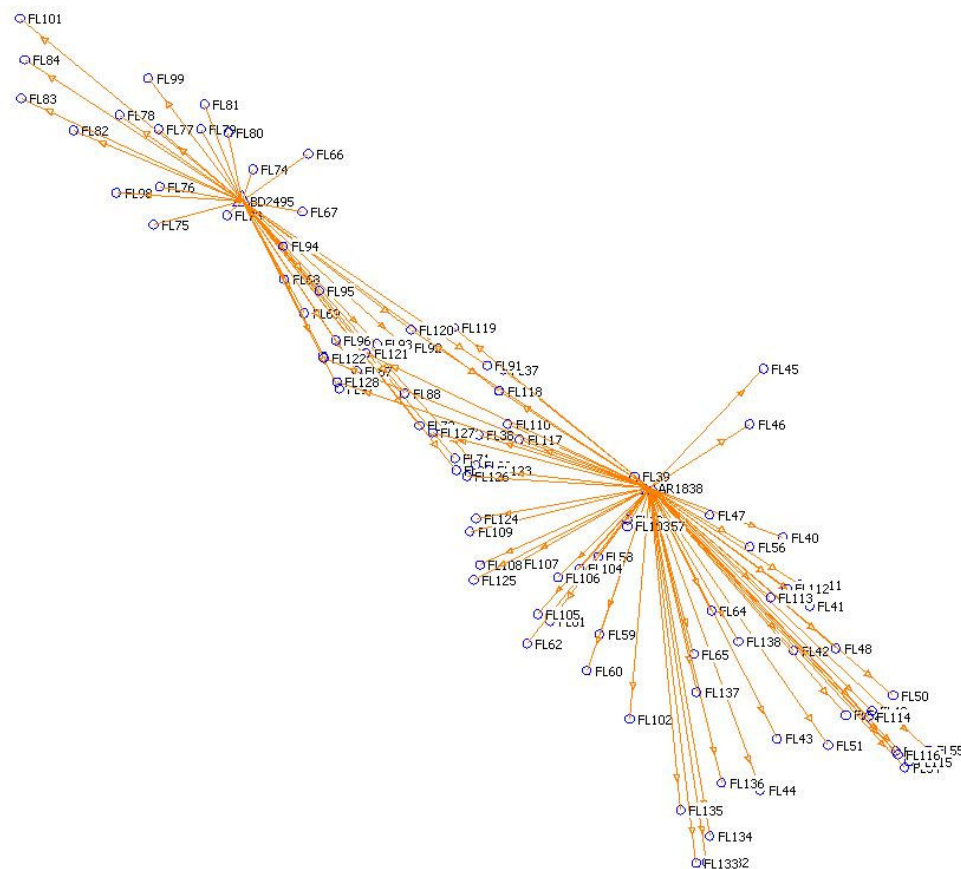

Figure 6: FDEM Survey Checkpoint Diagram

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

Number	Easting	Northing	Known Z	Laser Z	Dz
23	2341006.470	284919.330	22.870	23.320	+0.450
12	2442295.690	175451.200	16.040	16.470	+0.430
24	2335231.670	246138.480	7.190	7.600	+0.410
13	2341074.630	284927.560	22.870	23.250	+0.380
6	2387563.750	202747.820	24.480	24.840	+0.360
14	2335322.230	297342.400	29.000	29.250	+0.250
19	2367752.560	193248.560	17.520	17.750	+0.230
3	2462793.750	265934.600	13.160	13.270	+0.110
22	2350342.510	260810.740	32.780	32.870	+0.090
11	2402057.350	220543.810	30.480	30.550	+0.070
21	2344775.930	268443.160	28.150	28.180	+0.030
20	2347535.710	200314.240	11.350	11.370	+0.020
9	2363446.470	171938.110	8.860	8.870	+0.010
15	2401176.950	123359.480	4.330	4.230	-0.100
10	2351890.840	161139.870	5.680	5.560	-0.120
7	2387387.520	165125.880	5.250	5.130	-0.120
1	2343223.020	295009.530	24.870	24.690	-0.180
17	2378388.860	197244.190	21.590	21.390	-0.200
2	2470187.580	292821.410	32.380	32.110	-0.270
16	2401992.980	217414.000	28.380	28.050	-0.330
18	2357461.940	175372.290	10.790	10.350	-0.440
5	2413245.920	217674.250	30.050	29.590	-0.460
4	2442350.480	222196.940	24.610	24.120	-0.490

Average dz   +0.006
Minimum dz   -0.490
Maximum dz   +0.450
Average magnitude   0.241
Root mean square   0.288
Std deviation   0.295

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 Associated Discrepancies

Point Number	Land Cover Class		SPCS NAD83/99 North Zone Easting-X (Ft)	Northing-Y (Ft)	NAVD88 Survey-Z (Ft)	LIDAR-Z (Feet)	ΔZ (Feet)
DX001M4	1	BE & Low Grass	2,324,029.270	201,114.870	5.280	5.2740	-0.006
DX001M7	1	BE & Low Grass	2,324,007.090	201,139.980	5.670	5.7520	0.082
DX002M6	1	BE & Low Grass	2,351,544.590	259,820.570	31.120	31.5110	0.391
DX003M8	1	BE & Low Grass	2,359,992.120	251,715.580	36.110	36.4610	0.351
DX004M6	1	BE & Low Grass	2,356,490.900	168,527.700	8.440	8.3990	-0.041
DX005M2	1	BE & Low Grass	2,325,089.680	218,292.450	4.940	4.8700	-0.070
DX005M7	1	BE & Low Grass	2,325,110.560	218,429.920	6.250	6.0170	-0.233
DX006M5	1	BE & Low Grass	2,380,870.070	147,338.950	7.150	7.4140	0.264
DX006M7	1	BE & Low Grass	2,380,823.420	147,379.770	5.690	6.0980	0.408
DX007M2	1	BE & Low Grass	2,361,664.370	182,949.270	12.250	12.2970	0.047
DX008M1	1	BE & Low Grass	2,367,855.190	193,210.700	17.090	17.0180	-0.072
DX009M6	1	BE & Low Grass	2,372,053.290	195,126.230	19.450	19.1960	-0.254
DX010M3	1	BE & Low Grass	2,353,009.690	200,595.880	13.980	13.3000	-0.680
DX010M5	1	BE & Low Grass	2,353,104.670	200,598.940	13.860	13.5770	-0.283
DX011M4	1	BE & Low Grass	2,382,909.900	199,189.120	24.640	24.7890	0.149
DX012M8	1	BE & Low Grass	2,386,161.080	162,633.690	6.100	6.0960	-0.004
DX013M4	1	BE & Low Grass	2,392,682.770	206,518.530	25.340	25.4050	0.065
DX013M6	1	BE & Low Grass	2,392,740.240	206,454.830	24.850	24.9430	0.093
DX014M6	1	BE & Low Grass	2,402,082.590	220,543.580	29.190	29.0800	-0.110
DX015M4	1	BE & Low Grass	2,401,045.570	123,175.340	3.680	3.5200	-0.160
DX016M7	1	BE & Low Grass	2,406,716.140	128,862.710	7.250	6.9100	-0.340
DX017M6	1	BE & Low Grass	2,416,964.850	137,506.650	8.670	8.3840	-0.286
DX021M4	1	BE & Low Grass	2,431,738.550	152,903.020	10.360	10.0610	-0.299
DX022M3	1	BE & Low Grass	2,464,731.870	247,499.830	20.350	20.1100	-0.240
DX022M5	1	BE & Low Grass	2,464,841.270	247,500.140	21.880	21.8120	-0.068
DX022M7	1	BE & Low Grass	2,464,822.360	247,554.180	22.020	21.5400	-0.480
DX023M6	1	BE & Low Grass	2,438,294.890	168,065.410	13.700	13.7910	0.091
DX023M7	1	BE & Low Grass	2,438,371.140	168,016.440	12.900	13.2980	0.398
DX024M6	1	BE & Low Grass	2,447,405.430	196,537.160	21.570	20.9990	-0.571
DX025M2	1	BE & Low Grass	2,444,973.050	179,299.800	18.890	18.7910	-0.099
DX026M5	1	BE & Low Grass	2,451,490.810	207,411.520	23.030	22.9140	-0.116
DX026M6	1	BE & Low Grass	2,451,433.140	207,435.370	23.880	23.8260	-0.054
DX027M1	1	BE & Low Grass	2,457,796.820	255,139.870	21.860	21.4820	-0.378
DX027M2	1	BE & Low Grass	2,457,770.050	255,138.190	22.070	22.0310	-0.039
DX028M3	1	BE & Low Grass	2,470,719.670	292,835.300	31.570	30.9900	-0.580
DX028M6	1	BE & Low Grass	2,470,648.190	292,798.780	32.100	31.6770	-0.423
DX029M2	1	BE & Low Grass	2,340,196.600	200,141.100	6.790	6.9420	0.152
DX029M6	1	BE & Low Grass	2,340,529.240	200,178.970	9.350	9.5690	0.219
DX030M1	1	BE & Low Grass	2,456,857.620	218,302.210	20.470	20.6400	0.170
DX031M1	1	BE & Low Grass	2,395,532.620	194,503.330	18.910	19.1030	0.193
DX031M2	1	BE & Low Grass	2,395,536.170	194,450.890	17.900	18.2460	0.346
DX032M6	1	BE & Low Grass	2,382,982.760	156,883.510	5.250	4.9270	-0.323
DX033M2	1	BE & Low Grass	2,436,400.940	184,699.840	23.980	23.8680	-0.112
DX034M2	1	BE & Low Grass	2,420,053.820	184,199.210	16.740	17.1060	0.366
DX034M5	1	BE & Low Grass	2,420,130.460	184,211.130	17.590	18.0320	0.442
DX035M7	1	BE & Low Grass	2,442,629.870	218,083.710	21.160	20.6010	-0.559
DX036M2	1	BE & Low Grass	2,413,936.510	178,179.000	14.140	14.2050	0.065
DX036M3	1	BE & Low Grass	2,413,965.630	178,144.320	16.060	15.7420	-0.318
*DX018M7	2	Brush & Low Trees	2,418,523.510	224,448.550	38.770	38.0910	-0.679
*DX019M5	2	Brush & Low Trees	2,422,381.580	145,005.430	10.380	9.7450	-0.635
*DX033M1	2	Brush & Low Trees	2,436,368.820	184,659.340	24.210	23.5020	-0.708
DX001M2	2	Brush & Low Trees	2,324,027.220	201,034.540	2.880	3.2010	0.321
DX002M8	2	Brush & Low Trees	2,351,590.810	259,796.730	31.700	32.1310	0.431
DX004M1	2	Brush & Low Trees	2,356,422.080	168,334.960	7.050	7.0060	-0.044
DX008M8	2	Brush & Low Trees	2,367,636.070	193,208.790	17.710	18.2140	0.504
DX009M1	2	Brush & Low Trees	2,371,712.180	194,991.660	18.650	18.8750	0.225
DX010M4	2	Brush & Low Trees	2,353,145.870	200,596.310	14.500	13.5880	-0.912

DX011M7	2	Brush & Low Trees	2,382,827.720	199,279.930	24.650	25.1040	0.454
DX012M5	2	Brush & Low Trees	2,386,166.180	162,819.050	5.140	5.3110	0.171
DX013M5	2	Brush & Low Trees	2,392,711.330	206,479.570	25.310	25.5070	0.197
DX014M2	2	Brush & Low Trees	2,402,100.120	220,389.630	29.820	29.8620	0.042
DX015M3	2	Brush & Low Trees	2,401,097.980	123,122.990	1.390	1.6400	0.250
DX016M4	2	Brush & Low Trees	2,406,661.870	128,760.160	3.970	3.8260	-0.144
DX017M5	2	Brush & Low Trees	2,417,060.530	137,530.220	8.500	8.4710	-0.029
DX018M4	2	Brush & Low Trees	2,418,497.770	224,247.930	35.480	34.8180	-0.662
DX019M8	2	Brush & Low Trees	2,422,456.500	145,091.640	8.830	8.7710	-0.059
DX020M8	2	Brush & Low Trees	2,427,085.630	217,820.960	31.270	31.1670	-0.103
DX021M3	2	Brush & Low Trees	2,431,690.810	152,888.510	6.670	6.7450	0.075
DX024M5	2	Brush & Low Trees	2,447,336.160	196,597.860	22.570	22.2750	-0.295
DX025M7	2	Brush & Low Trees	2,445,071.890	179,632.640	17.620	17.7170	0.097
DX027M5	2	Brush & Low Trees	2,457,637.210	255,231.930	20.830	20.9510	0.121
DX027M6	2	Brush & Low Trees	2,457,634.970	255,267.250	20.820	20.8450	0.025
DX029M4	2	Brush & Low Trees	2,340,340.060	200,159.410	8.220	8.2830	0.063
DX030M7	2	Brush & Low Trees	2,457,101.790	218,311.720	17.850	17.4930	-0.357
DX032M7	2	Brush & Low Trees	2,383,057.860	157,039.510	8.760	9.5100	0.750
DX033M3	2	Brush & Low Trees	2,436,417.740	184,686.150	23.320	23.6270	0.307
DX034M4	2	Brush & Low Trees	2,420,083.730	184,222.400	17.030	16.9350	-0.095
DX036M5	2	Brush & Low Trees	2,413,981.130	178,197.230	14.290	14.5140	0.224
*DX008M4	2	Brush & Low Trees	2,367,785.650	193,289.650	17.520	16.8160	-0.704
*DX012M2	2	Brush & Low Trees	2,386,318.180	163,074.310	5.410	4.5790	-0.831
DX002M7	3	Forested	2,351,572.720	259,839.050	31.890	31.9150	0.025
DX003M1	3	Forested	2,359,828.970	251,671.470	31.320	31.4520	0.132
DX004M7	3	Forested	2,356,482.440	168,561.860	8.270	8.2510	-0.019
DX005M5	3	Forested	2,325,010.660	218,375.200	4.770	4.5350	-0.235
DX006M3	3	Forested	2,380,998.190	147,308.380	8.950	8.6310	-0.319
DX007M4	3	Forested	2,361,747.220	182,820.970	10.030	10.3680	0.338
DX007M8	3	Forested	2,361,750.020	182,728.070	10.630	10.6920	0.062
DX009M8	3	Forested	2,372,088.700	195,183.670	20.200	21.0140	0.814
DX011M3	3	Forested	2,382,885.950	199,161.050	24.670	23.8120	-0.858
DX014M4	3	Forested	2,402,138.590	220,475.900	28.610	28.7500	0.140
DX016M3	3	Forested	2,406,638.820	128,727.960	3.840	4.0470	0.207
DX017M3	3	Forested	2,417,107.440	137,657.970	4.600	4.1970	-0.403
DX018M9	3	Forested	2,418,387.170	224,260.200	36.300	36.1090	-0.191
DX019M6	3	Forested	2,422,482.730	144,974.880	7.220	7.1830	-0.037
DX020M2	3	Forested	2,426,811.250	217,947.250	31.560	31.0870	-0.473
DX020M3	3	Forested	2,426,844.390	217,927.590	31.570	31.0420	-0.528
DX021M5	3	Forested	2,431,728.950	152,950.810	8.220	9.2070	0.987
DX023M3	3	Forested	2,438,449.760	168,102.040	12.200	12.3260	0.126
DX024M4	3	Forested	2,447,327.790	196,647.680	22.700	22.4630	-0.237
DX025M4	3	Forested	2,445,058.030	179,414.200	18.330	17.9610	-0.369
DX026M3	3	Forested	2,451,514.750	207,497.410	24.250	23.7540	-0.496
DX027M4	3	Forested	2,457,659.010	255,167.990	20.350	20.2180	-0.132
DX027M7	3	Forested	2,457,686.770	255,276.970	19.950	19.3300	-0.620
DX028M7	3	Forested	2,470,572.790	292,796.490	32.480	31.5760	-0.904
DX029M5	3	Forested	2,340,395.590	200,152.570	8.810	8.3960	-0.414
DX030M8	3	Forested	2,457,180.350	218,201.050	18.650	18.5590	-0.091
DX031M4	3	Forested	2,395,486.160	194,586.840	19.280	19.7730	0.493
DX032M8	3	Forested	2,383,032.710	156,991.290	7.090	6.9990	-0.091
DX033M7	3	Forested	2,436,488.860	184,707.800	24.150	24.3090	0.159
DX034M7	3	Forested	2,420,246.690	184,251.510	17.570	18.1990	0.629
DX035M4	3	Forested	2,442,771.350	217,975.270	20.200	19.4660	-0.734
DX035M5	3	Forested	2,442,838.430	217,974.630	20.080	19.5810	-0.499
DX036M4	3	Forested	2,414,039.310	178,060.010	15.200	14.9450	-0.255
DX001M8	4	Urban	2,323,992.040	201,183.540	6.410	6.3800	-0.030
DX002M5	4	Urban	2,351,430.020	259,796.600	33.560	33.5430	-0.017
DX003M4	4	Urban	2,359,916.690	251,747.420	37.410	37.6630	0.253
DX004M3	4	Urban	2,356,505.910	168,428.060	7.480	7.3180	-0.162
DX005M8	4	Urban	2,325,150.540	218,374.210	7.820	7.6070	-0.213
DX006M1	4	Urban	2,381,092.510	147,298.540	7.080	7.4130	0.333
DX007M5	4	Urban	2,361,676.840	182,806.200	11.780	11.5710	-0.209
DX008M7	4	Urban	2,367,717.770	193,207.980	18.400	18.2510	-0.149
DX009M2	4	Urban	2,371,767.970	195,067.420	20.180	20.4390	0.259

DX011M1	4	Urban	2,382,812.390	199,177.490	25.940	26.0420	0.102
DX012M1	4	Urban	2,386,343.980	162,965.010	6.070	5.8990	-0.171
DX013M7	4	Urban	2,392,670.930	206,541.780	26.510	26.5220	0.012
DX014M1	4	Urban	2,402,035.950	220,393.600	32.180	31.9570	-0.223
DX015M5	4	Urban	2,401,126.550	123,241.580	5.400	4.8210	-0.579
DX016M6	4	Urban	2,406,717.190	128,814.000	5.390	5.0480	-0.342
DX017M4	4	Urban	2,417,026.730	137,538.330	9.610	9.0730	-0.537
DX018M3	4	Urban	2,418,425.140	224,256.870	37.130	36.4350	-0.695
DX019M7	4	Urban	2,422,446.100	145,033.570	11.040	10.8040	-0.236
DX020M6	4	Urban	2,426,924.260	217,878.290	33.020	32.7400	-0.280
DX021M2	4	Urban	2,431,653.540	152,792.650	10.960	10.6240	-0.336
DX022M1	4	Urban	2,464,696.320	247,563.550	20.450	20.0040	-0.446
DX023M5	4	Urban	2,438,360.480	168,074.730	15.240	15.2360	-0.004
DX024M7	4	Urban	2,447,350.850	196,483.160	22.450	22.0530	-0.397
DX025M6	4	Urban	2,445,107.320	179,571.380	19.030	18.8440	-0.186
DX026M7	4	Urban	2,451,361.500	207,460.190	24.550	24.4360	-0.114
DX027M3	4	Urban	2,457,753.470	255,190.400	22.210	22.0040	-0.206
DX027M8	4	Urban	2,457,742.650	255,281.400	21.680	21.6410	-0.039
DX028M2	4	Urban	2,470,784.270	292,862.000	31.750	31.1460	-0.604
DX030M4	4	Urban	2,457,057.410	218,102.240	22.050	21.9630	-0.087
DX032M4	4	Urban	2,383,083.920	156,961.870	8.880	8.8480	-0.032
DX035M2	4	Urban	2,442,863.470	218,044.770	22.870	22.4080	-0.462

* The following CAT 1 points were reclassified to CAT 2 points because they either did not meet the CAT 1 criteria, or they were located on dirt/sand roads that are subject to elevation fluctuations as a result of grading and or unusually high LiDAR intensity values: DX008M4, DX012M2, DX018M7, DX019M5 and DX033M1

100 % of Totals	# of Points	RMSE (ft) Spec = 0.61 (BE = 0.30)	Mean (ft)	Median (ft)	Min (ft)	Max (ft)
Consolidated	144	0.37	-0.10	-0.09	-0.91	0.99
BE & Low Grass	48	0.29	-0.06	-0.06	-0.68	0.44
Brush & Low Trees	32	0.42	-0.06	0.06	-0.91	0.75
Forested	33	0.45	-0.11	-0.13	-0.90	0.99
Urban	31	0.31	-0.19	-0.19	-0.69	0.33

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	144		0.73	
BE & Low Grass	48	0.58		0.57
Brush & Low Trees	32			0.79
Forested	33			0.88
Urban	31			0.59

Appendix F: LiDAR Vertical Accuracy Report

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

Date: April 14, 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 Dixie 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: ≤ 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

NDEP and ASPRS Guidance: 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

Ground Truth Surveys: 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 Dixie 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.

Assessment Procedures and Results: The LiDAR accuracy assessment for Dixie 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 Dixie 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 Dixie 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 95th percentile per land cover category)
Consolidated Vertical Accuracy (CVA) in all land cover categories combined = 95% confidence lever	1.19 ft (based on combined 95th percentile)

Vertical Accuracy Testing in Accordance with NDEP and ASPRS Procedures

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

FVA is determined with check points located only in land cover category (1), open terrain (grass, dirt, sand, and/or rocks), where there is a very high probability that the LiDAR sensor will have detected the bare-earth ground surface and where random errors are expected to follow a normal error distribution. The FVA determines how well the calibrated LiDAR sensor performed. With a normal error distribution, the vertical accuracy at the 95% confidence level is computed as the vertical root mean square error ($RMSE_z$) of the checkpoints x 1.9600, as specified in Reference B. For Dixie 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 95th percentile error for all checkpoints in all land cover categories combined. FDEM's CVA standard is 1.19 ft at the 95% confidence level. The CVA is accompanied by a listing of the 5% outliers that are larger than the 95th percentile used to compute the CVA; these are always the largest outliers that may depart from a normal error distribution. Here, $Accuracy_z$ differs from CVA because $Accuracy_z$ assumes elevation errors follow a normal error distribution where RMSE procedures are valid, whereas CVA assumes LiDAR errors may not follow a normal error distribution in vegetated categories, making the RMSE process invalid.

SVA is determined separately for each individual land cover category, again recognizing that the LiDAR sensor and post-processing may yield elevation errors that do not follow a normal error distribution, and where discrepancies can be used to identify the nature of systematic errors by land cover category. For each land cover category, the SVA at the 95% confidence level equals the 95th percentile error for all checkpoints in each individual land cover category. SVA statistics are calculated individually for bare-earth and low grass, 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 Dixie 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 48 checkpoints in bare-earth and low grass; 32 checkpoints in brush and low trees; 33 checkpoints in forested areas; and 31checkpoints in urban areas, for a total of 144 checkpoints.
2. Next, PDS interpolated the bare-earth LiDAR DTM to provide the z-value for each of the 144 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 Dixie County. Each point represents a checkpoint cluster. There are nominally four checkpoints in each cluster, one per land cover category.

Figure 1 — Location of QA/QC Checkpoint Clusters for Dixie County
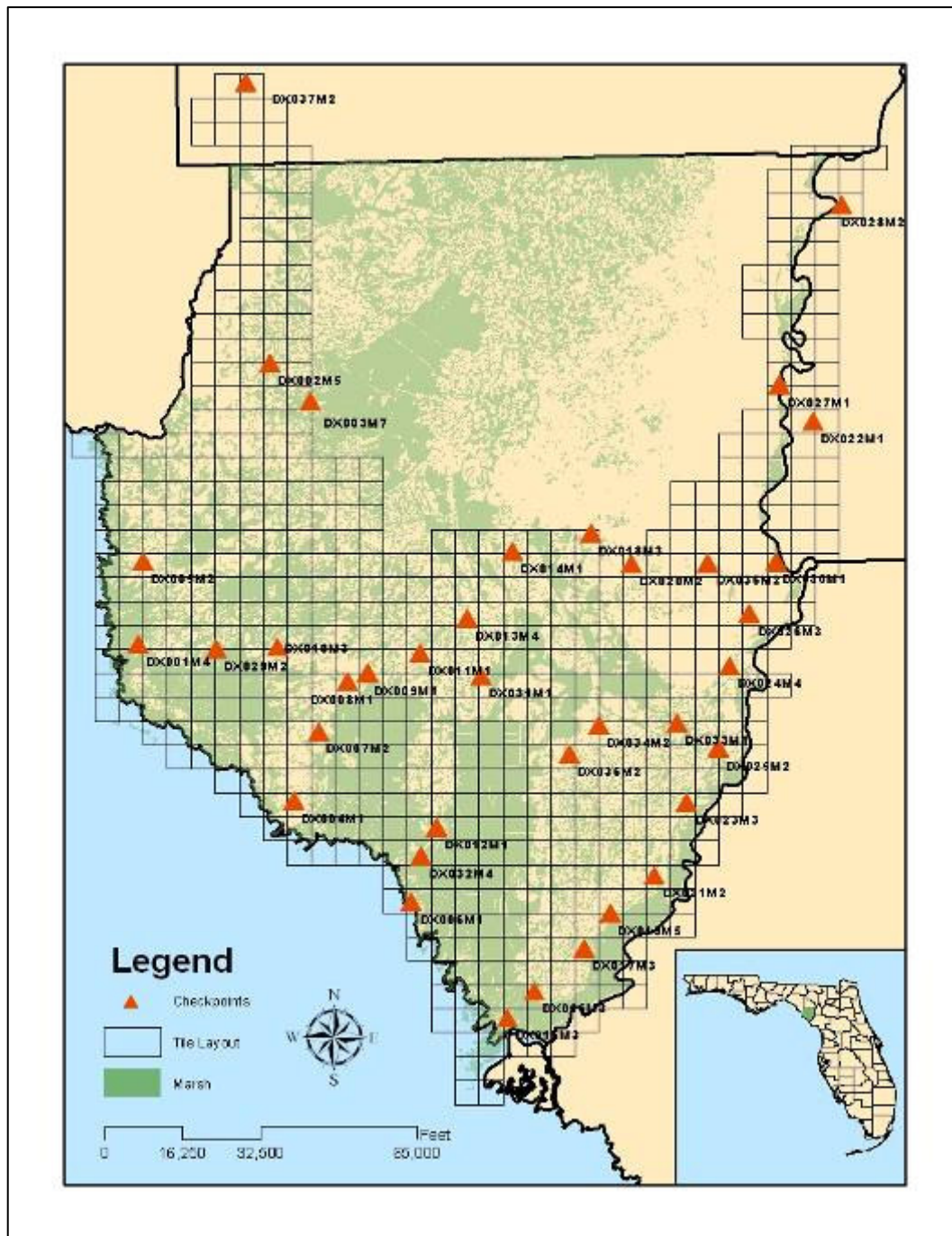
Table   2

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 (95th Percentile) Spec = 1.19 ft	SVA — Supplemental Vertical Accuracy (95th Percentile) Target = 1.19 ft
Total Combined	144		0.73	
BE & Low Grass	48	0.58		0.57
Brush & Low Trees	32			0.79
Forested	33			0.88
Urban	31			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 0.73 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 95th percentile error; whereas 5% of the points could have exceeded the 1.19 ft criterion, no points actually exceeded this criterion.

Table 3 — 5% Outliers Larger than 95th Percentile

Land Cover Category	Elevation Diff. (ft)	
		No points exceeded the 1.19 ft 95th percentile criteria

Compared with the 1.19 ft SVA target values, SVA tested 0.57 ft at the 95% confidence level in bare-earth and low grass; 0.79 ft in brush and low trees; 0.88 ft in forested areas; and 0.59 ft in urban areas, based on the 95th Percentile. Each of the four land cover categories were well within the target value of 1.19 ft.

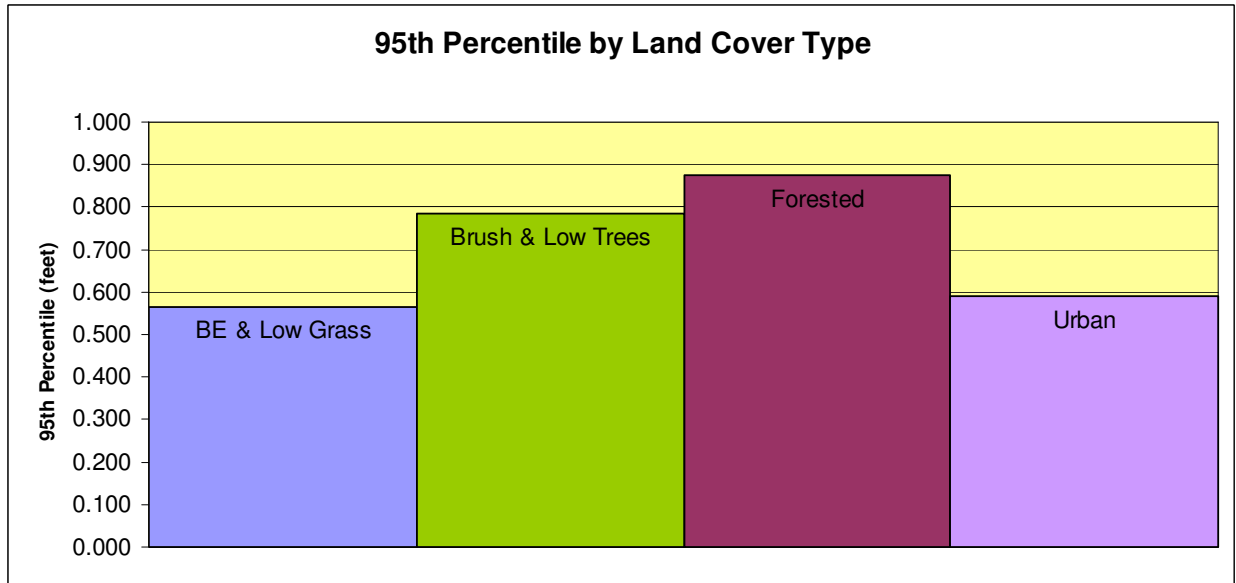Figure 2 illustrates the SVA by specific land cover category.

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. Also, of significant note is the fact that there were no checkpoints in any of the four land cover classifications that exceed the 1.19 ft SVA accuracy criteria.
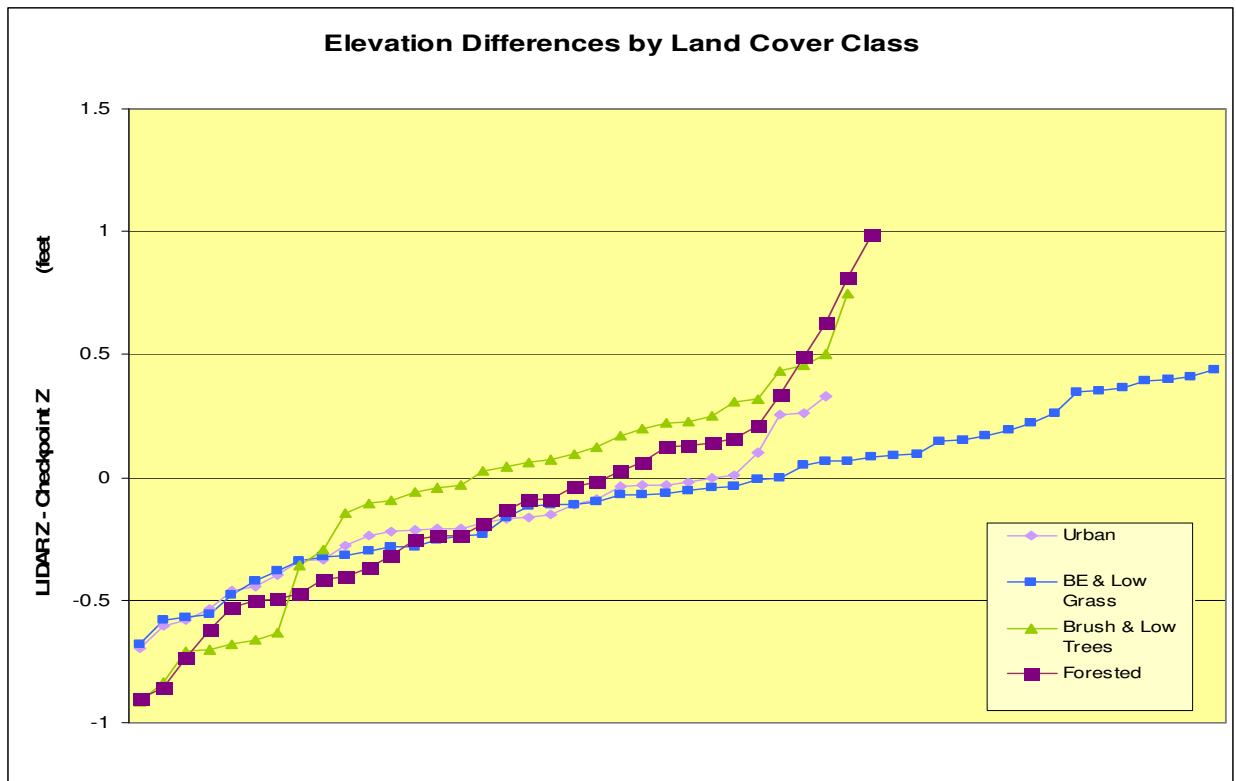

Figure 3 – Magnitude of Elevation Discrepancies, Sorted from Largest Negative to Largest Positive

Vertical Accuracy Testing in Accordance with NSSDA and FEMA Procedures

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.
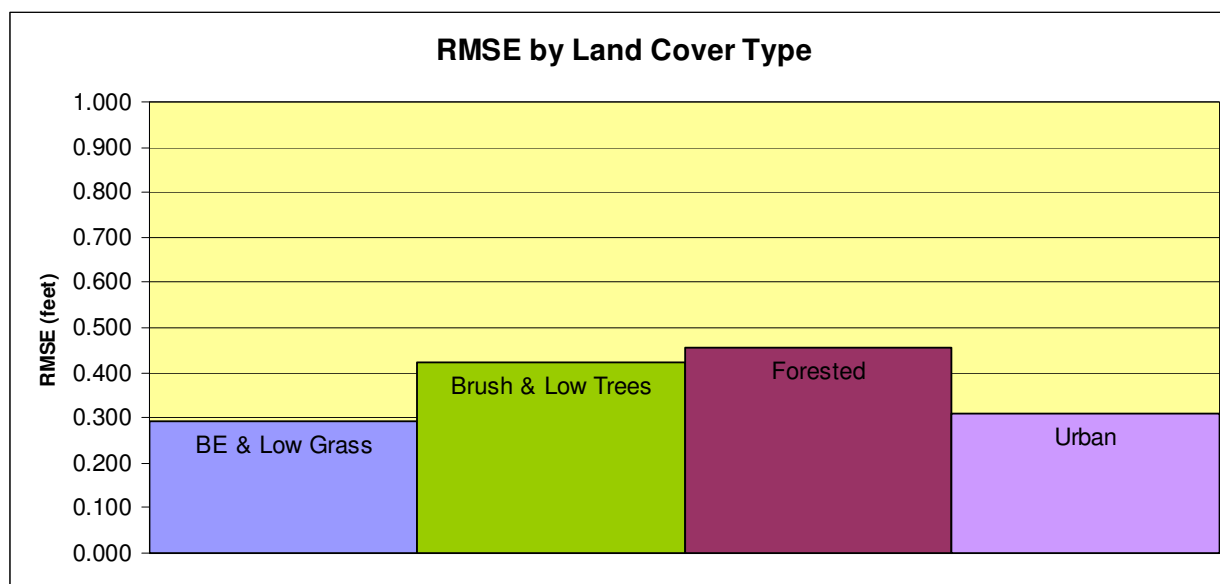
Figure 4 — RMSE$_z$ statistics by Land Cover Category

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	144	0.37	-0.10	-0.09	0.08	0.36	0.73
BE & Low Grass	48	0.29	-0.06	-0.06	-0.13	0.29	0.57
Brush & Low Trees	32	0.42	-0.06	0.06	-0.47	0.43	0.79
Forested	33	0.45	-0.11	-0.13	0.52	0.45	0.88
Urban	31	0.31	-0.19	-0.19	0.02	0.25	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 = 0.29 ft x 1.9600 = 0.57 ft, satisfying the 0.60 ft FVA standard. Accuracy$_z$ in consolidated categories = 0.37 ft x 1.9600 = 0.72 ft, satisfying the 1.19 ft CVA standard.

Figure 5 illustrates a histogram of the associated elevation discrepancies between the QA/QC checkpoints and elevations interpolated from the LiDAR triangulated irregular network (TIN). The frequency shows the number of discrepancies within each band of elevation differences. Although the discrepancies vary between a low of -0.91 ft and a high of +0.99 ft, the histogram shows that slightly more of the discrepancies are skewed 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. However, the skew difference in this case is very minor, does not indicate any systematic error, and is of no concern.
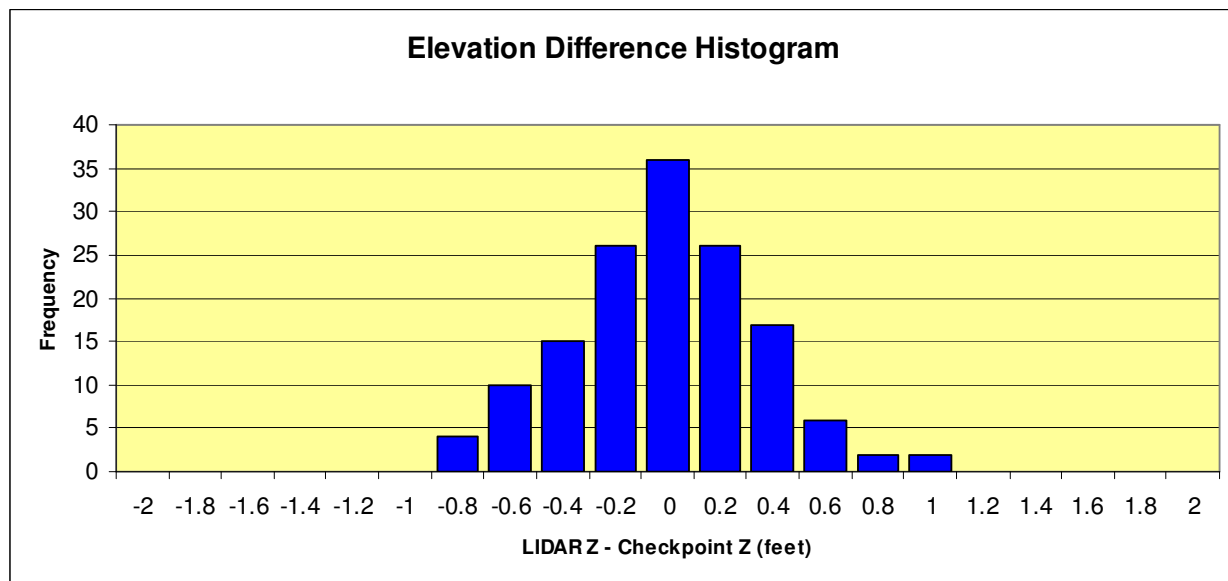
Figure 5 — Histogram of Elevation Discrepancies within 0.10 m Bands

Reclassified Checkpoints

The following points did not fit the specified criteria for Category 1, bare-earth and low grass: DX018M7, DX019M5. These points were reclassified as Category 2, brush and low trees, because the grass was longer than 6" tall, the norm for low grass. The digital pictures taken in the field, which show each checkpoint location, are an invaluable tool in the proper analysis of discrepancies that may occur between the LiDAR terrain surface elevations and the field surveyed checkpoint elevations.

Figure 6 shows the digital pictures captured in the field for Category 1 checkpoints DX018M7 and DX033M1. These point location actually fit the criteria for Category 2 checkpoints, brush and low trees. These points were reclassified to Category 2 for the final vertical accuracy calculations.

Figure 6 — Pictures showing locations for checkpoints DX018M7 and DX033M1

Figure 7 show the digital pictures captured in the field for Category 1 checkpoints DX008M4, DX012M2 and D[DX008M4] e points were changed to Category 2 checkpoints because they were located on dirt/sand roads that are subject to elevation fluctuations as a result of grading and or unusually high LiDAR intensity values.
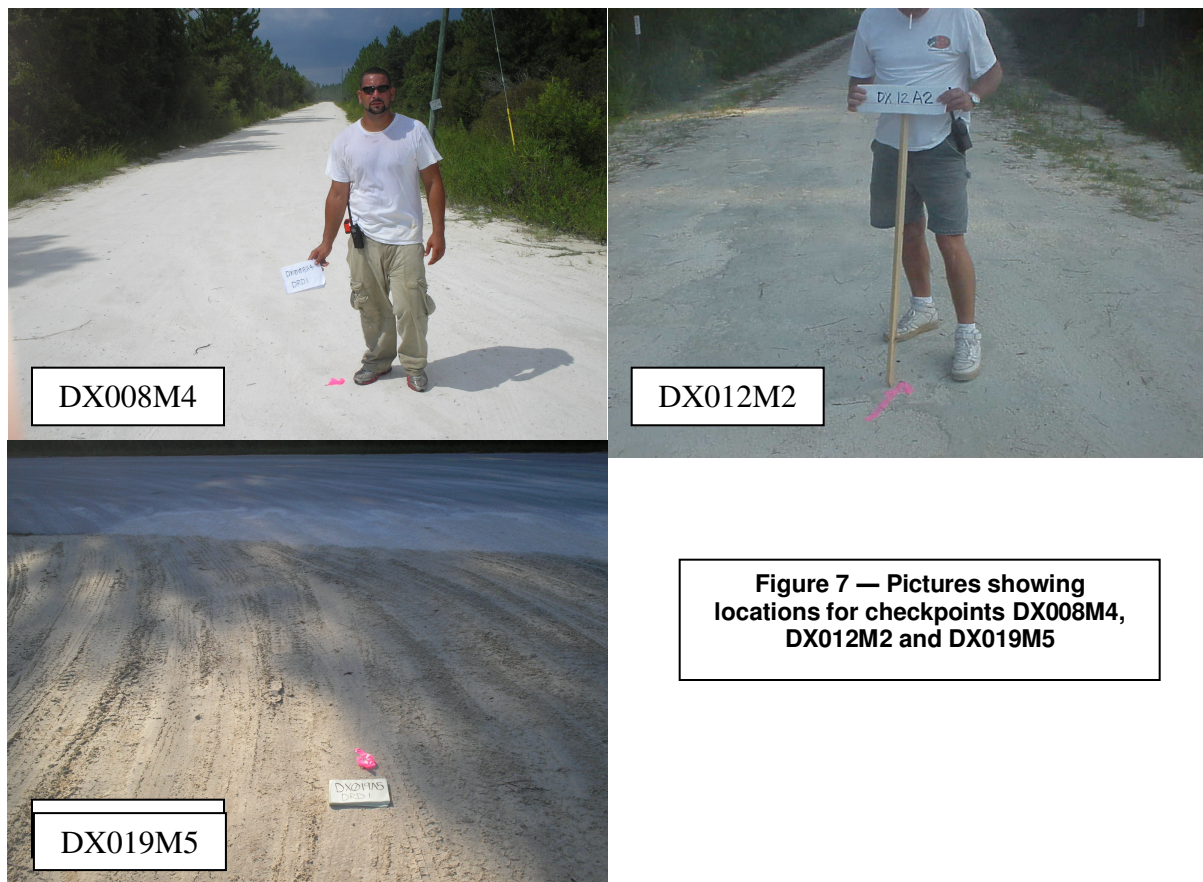
Figure 7 — Pictures showing locations for checkpoints DX008M4, DX012M2 and DX019M5

Conclusions

Based on the vertical accuracy testing conducted by PDS, the undersigned certifies that the LiDAR dataset for Dixie 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 0.73' 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 Dixie 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 foot pixel resolution for the entire area of interest (see Figure 1).

Figure 9 Screenshot of Dixie 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).
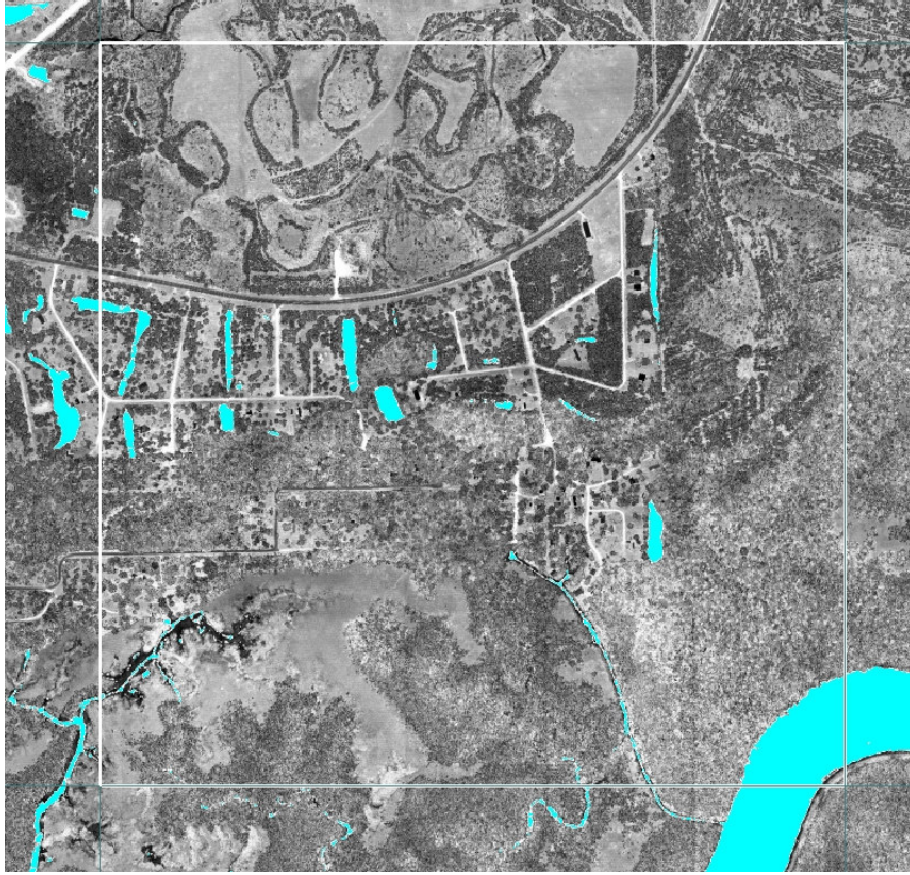
Figure 10 Acceptable voids in data due to water bodies

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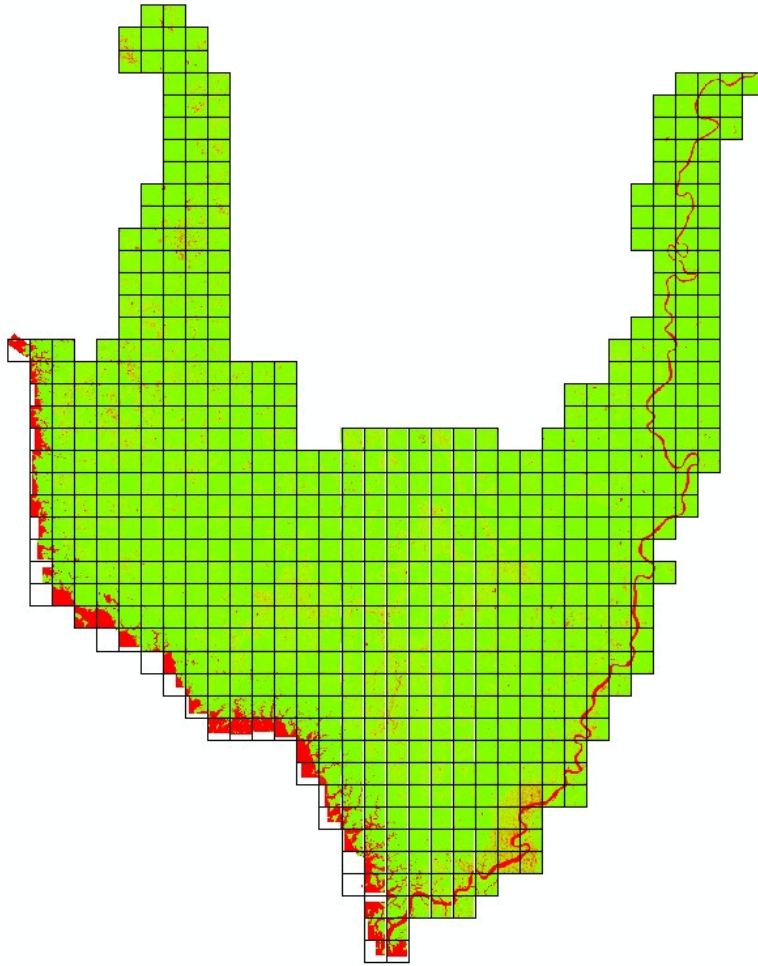
Figure 11 Density grid of Dixie County, created using a green to red color ramp. Green areas meet project specifications; red delineates areas not meeting minimum density requirements (primarily water and low-confidence areas)

.

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 Dixie County, Florida is predominantly rural. There is one significant Metropolitan incorporated area, Cross City. There is one State Park (Figure 6).
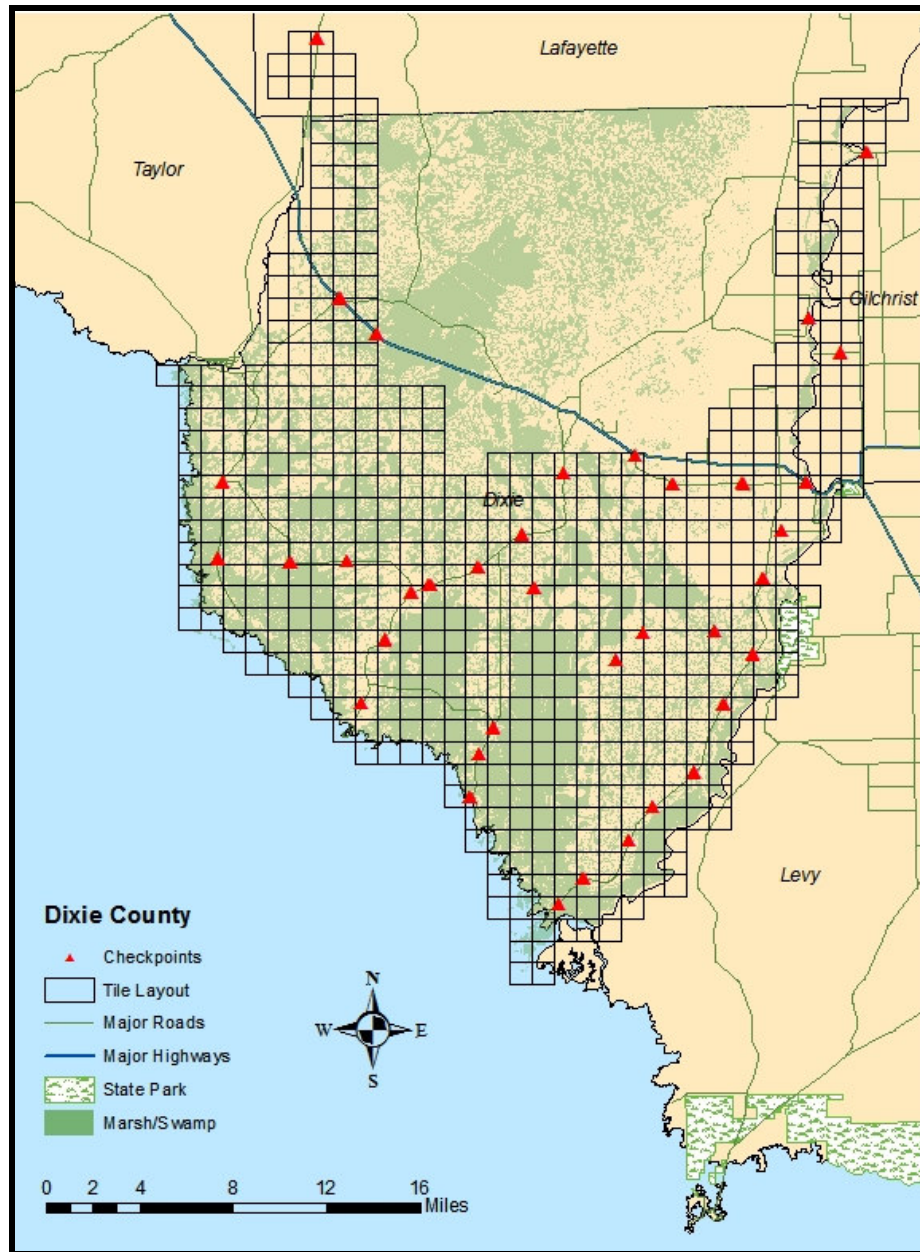

Figure 12 Map of Dixie County Florida with Marsh areas from Florida Geographic Data Library (FGDL)

The initial data acquisition was very dense. Overall the calculated average maximum point density of all the Dixie County all return LAS tiles was .54 ft. 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 616 LAS files reviewed, some tiles were flagged for containing noise points or artifacts, visible seamlines between adjacent flight lines, gaps on open road surfaces, removal of culverts, and for the improper classification of points in water bodies to the ground classification. The redelivery of the data was checked thoroughly and passed. The following table and associated screenshots is representative of the issues found:

Points		
Tile	**Issue**	**Code**
LID 086706	Artifacts in ground points	Corrected
LID 077522	Lack of points on open road surface	Noted
LID 081310	Visible flight line seamlines	Noted
LID 080777	Box culverts removed	Noted

Several tiles were found to contain ground points in water bodies, which was an issue that was more prevalent in areas of dense vegetation cover. This problem required that the dataset be reprocessed and corrected by The Sanborn Map Company.
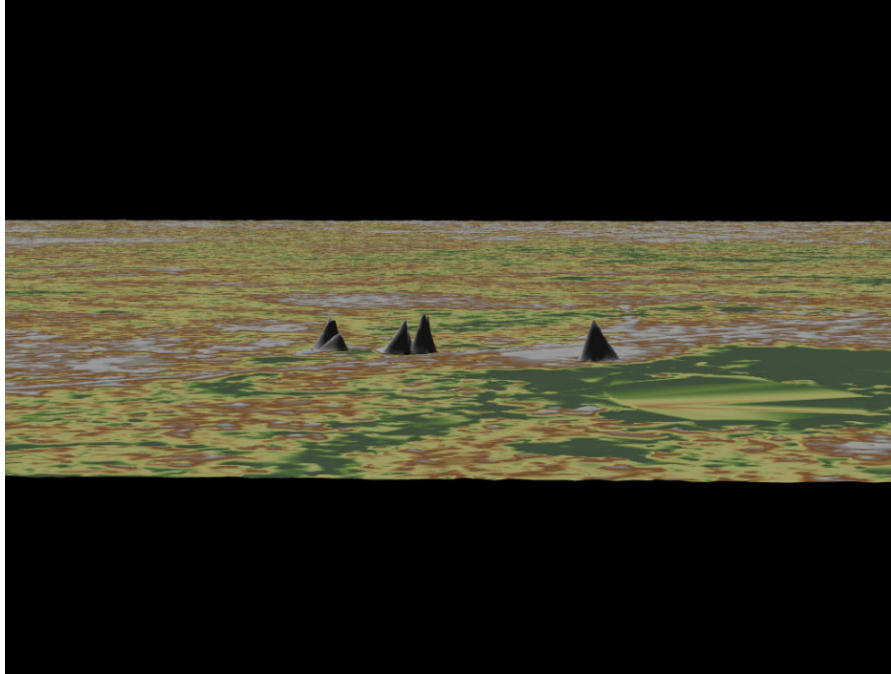
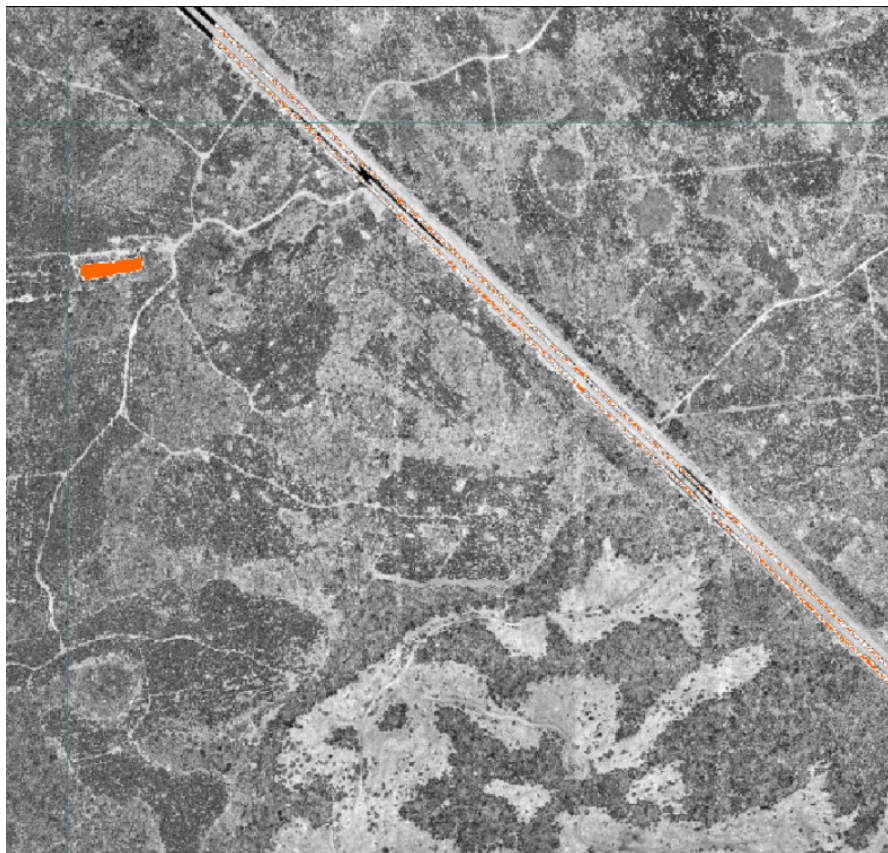**Figure 13 Tile 086706 – artifacts in ground points.**
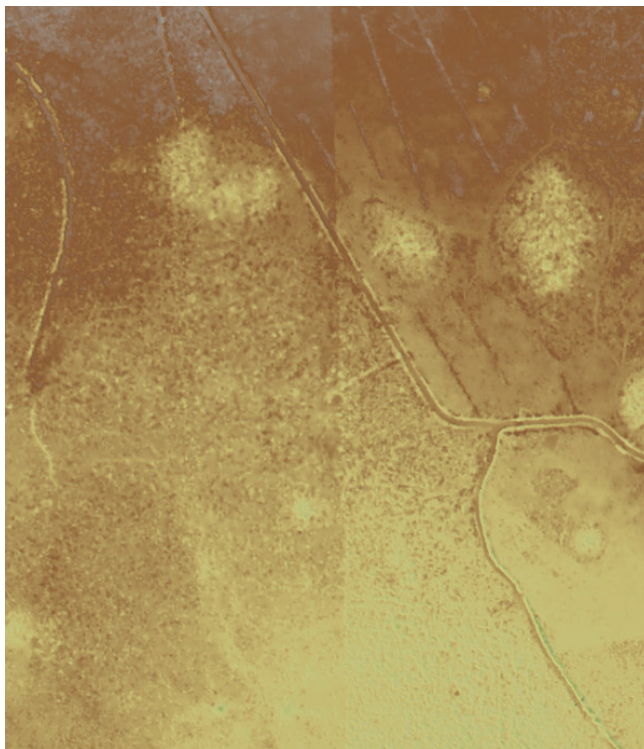

Figure 14 Tile 077522 – lack of points on highway surface.

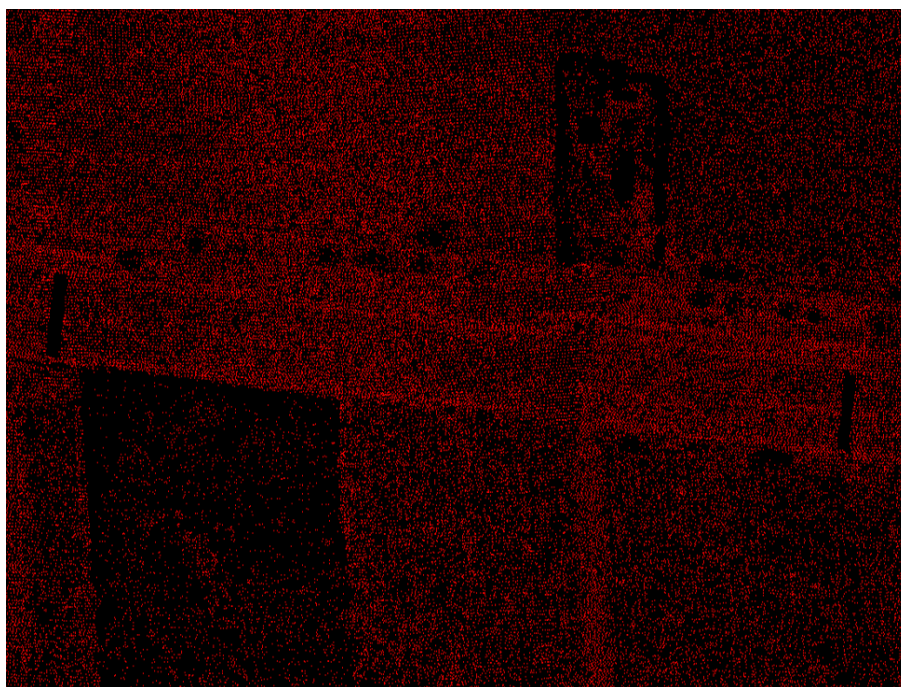**Figure 9 Tile 081310 – Visible seamline between flight lines.**

Figure 10 Tile 080777 – Culverts removed from bare earth classification

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 removed culverts; however these issues were corrected by The Sanborn Map Company and were not present in the redelivered data. There were areas noted as containing visible seamlines from flight line to flight line however the filtering in these areas does meet project specifications.

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.
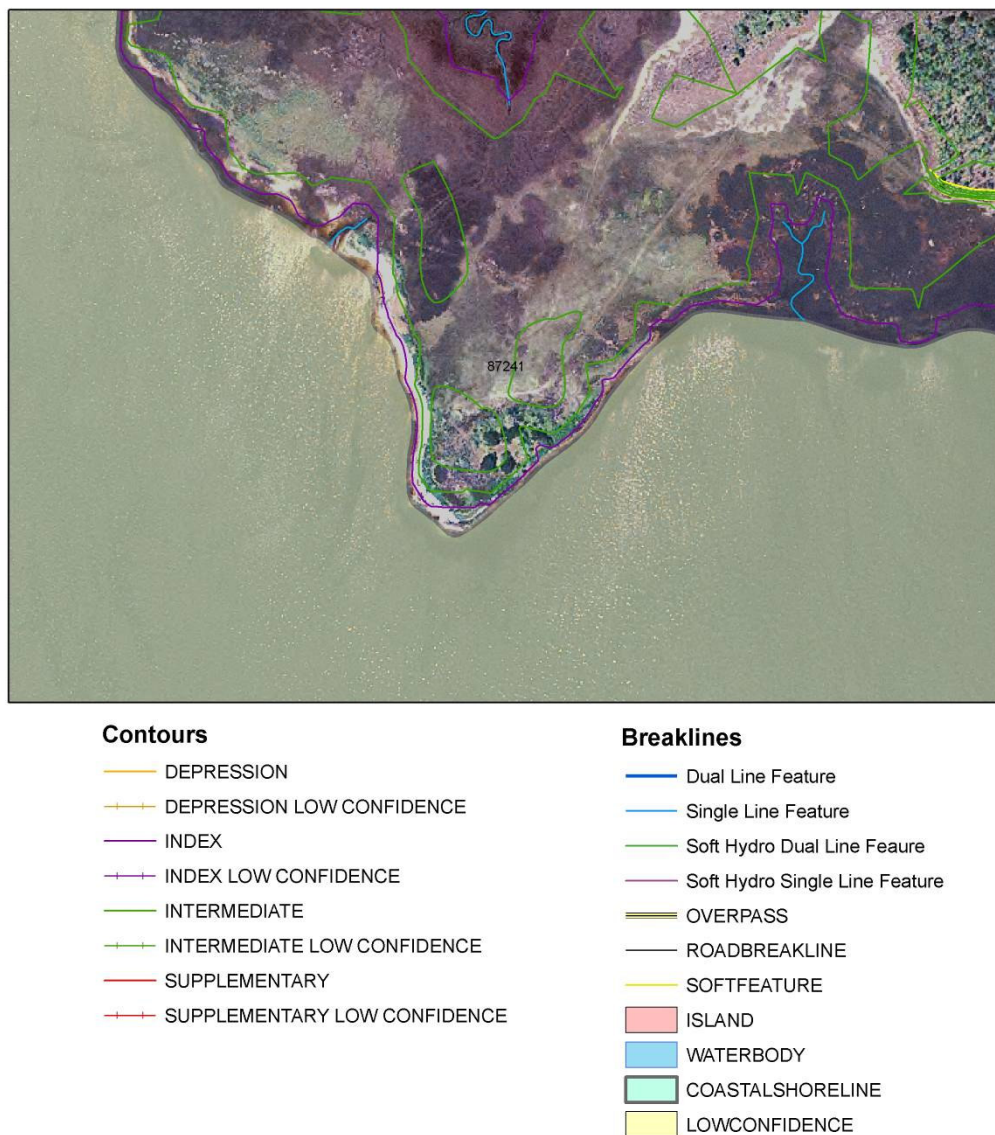

Contours

— DEPRESSION
—+— DEPRESSION LOW CONFIDENCE
— INDEX
—+— INDEX LOW CONFIDENCE
— INTERMEDIATE
—+— INTERMEDIATE LOW CONFIDENCE
— SUPPLEMENTARY
—+— SUPPLEMENTARY LOW CONFIDENCE

Breaklines

— Dual Line Feature
— Single Line Feature
— Soft Hydro Dual Line Feaure
— Soft Hydro Single Line Feature
— OVERPASS
— ROADBREAKLINE
— SOFTFEATURE
▢ ISLAND
▢ WATERBODY
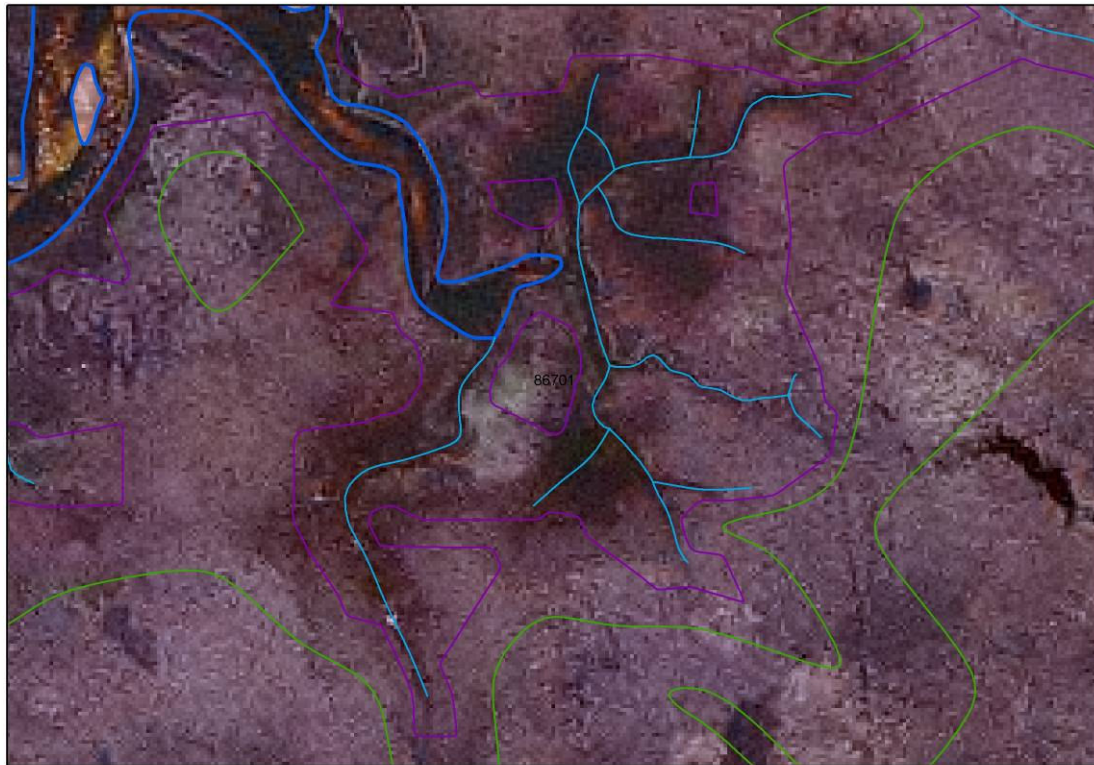▢ COASTALSHORELINE
▢ LOWCONFIDENCE

Figure 1. Example coastal breaklines and contours from tile #87241

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.

Contours

— DEPRESSION
—+— DEPRESSION LOW CONFIDENCE
— INDEX
—+— INDEX LOW CONFIDENCE
— INTERMEDIATE
—+— INTERMEDIATE LOW CONFIDENCE
— SUPPLEMENTARY
—+— SUPPLEMENTARY LOW CONFIDENCE

Breaklines

— Dual Line Feature
— Single Line Feature
— Soft Hydro Dual Line Feaure
— Soft Hydro Single Line Feature
= OVERPASS
— ROADBREAKLINE
— SOFTFEATURE
▮ ISLAND
▮ WATERBODY
▮ COASTALSHORELINE
▮ LOWCONFIDENCE

Figure 2. Example linear hydrographic feature breaklines and contours from tile # 86701

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.
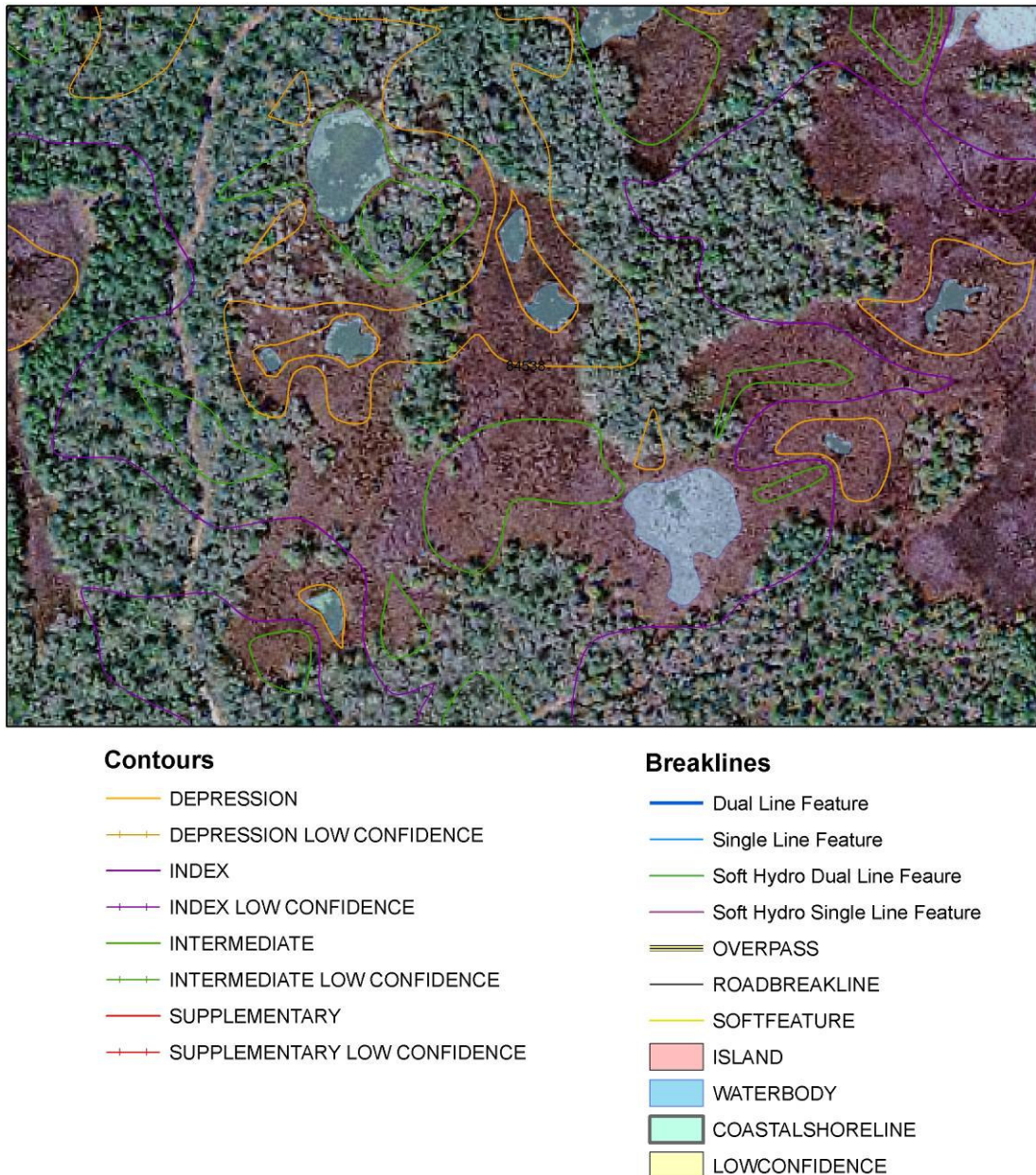

Contours

— DEPRESSION
—+— DEPRESSION LOW CONFIDENCE
— INDEX
—+— INDEX LOW CONFIDENCE
— INTERMEDIATE
—+— INTERMEDIATE LOW CONFIDENCE
— SUPPLEMENTARY
—+— SUPPLEMENTARY LOW CONFIDENCE

Breaklines

— Dual Line Feature
— Single Line Feature
— Soft Hydro Dual Line Feaure
— Soft Hydro Single Line Feature
═ OVERPASS
— ROADBREAKLINE
— SOFTFEATURE
▮ ISLAND
▮ WATERBODY
▮ COASTALSHORELINE
▮ LOWCONFIDENCE

Figure 3. Example closed water body feature breaklines and contours from tile #84538

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.
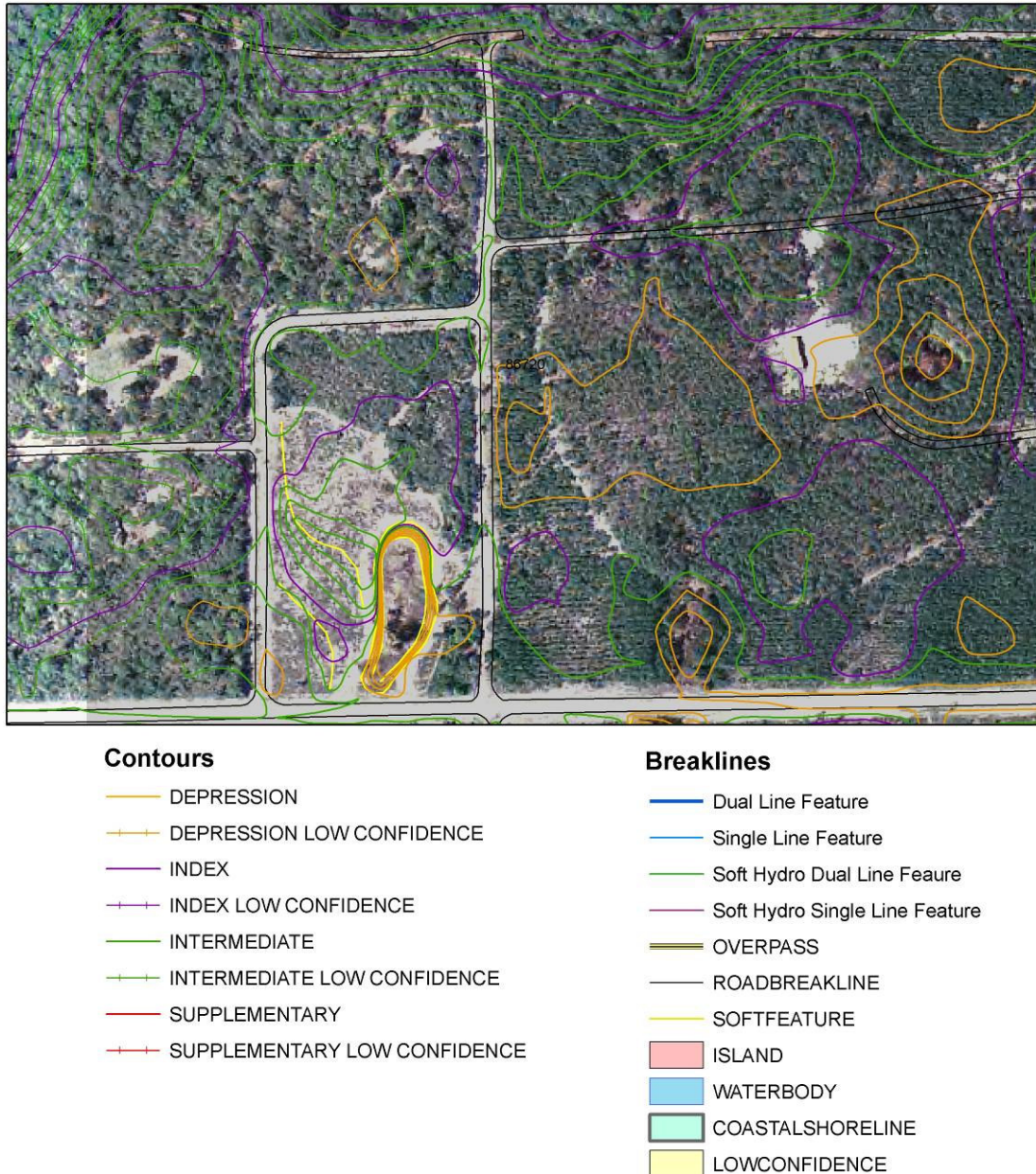

Contours

—— DEPRESSION
+—+— DEPRESSION LOW CONFIDENCE
—— INDEX
+—+— INDEX LOW CONFIDENCE
—— INTERMEDIATE
+—+— INTERMEDIATE LOW CONFIDENCE
—— SUPPLEMENTARY
+—+— SUPPLEMENTARY LOW CONFIDENCE

Breaklines

—— Dual Line Feature
—— Single Line Feature
—— Soft Hydro Dual Line Feaure
—— Soft Hydro Single Line Feature
═══ OVERPASS
—— ROADBREAKLINE
—— SOFTFEATURE
▧ ISLAND
▧ WATERBODY
▧ COASTALSHORELINE
▧ LOWCONFIDENCE

Figure 4. Example road feature breaklines and contours from tiles #86720

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.
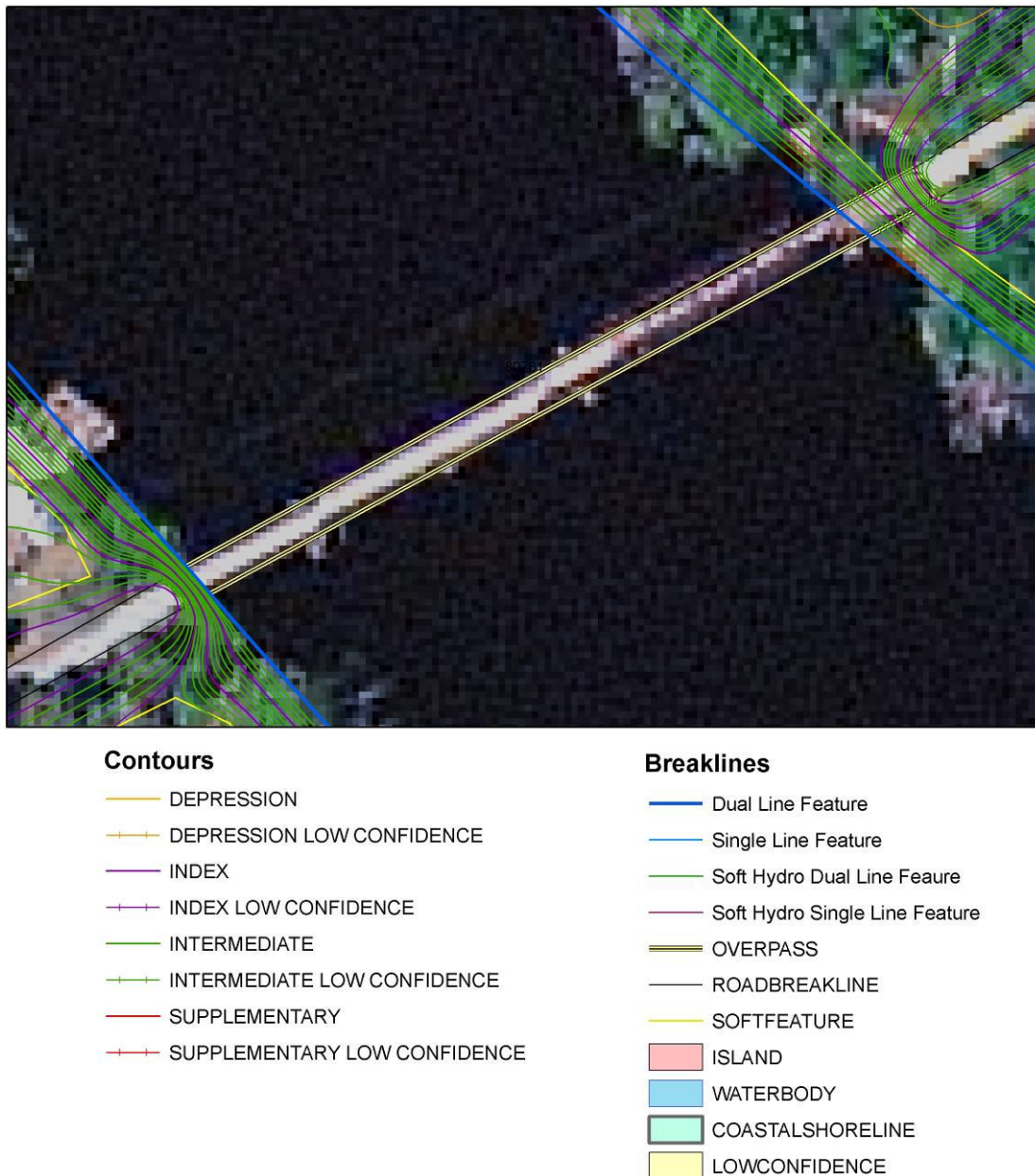

Figure 5. Example bridge and overpass feature breaklines and contours from tile # 80781

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 #81860

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.
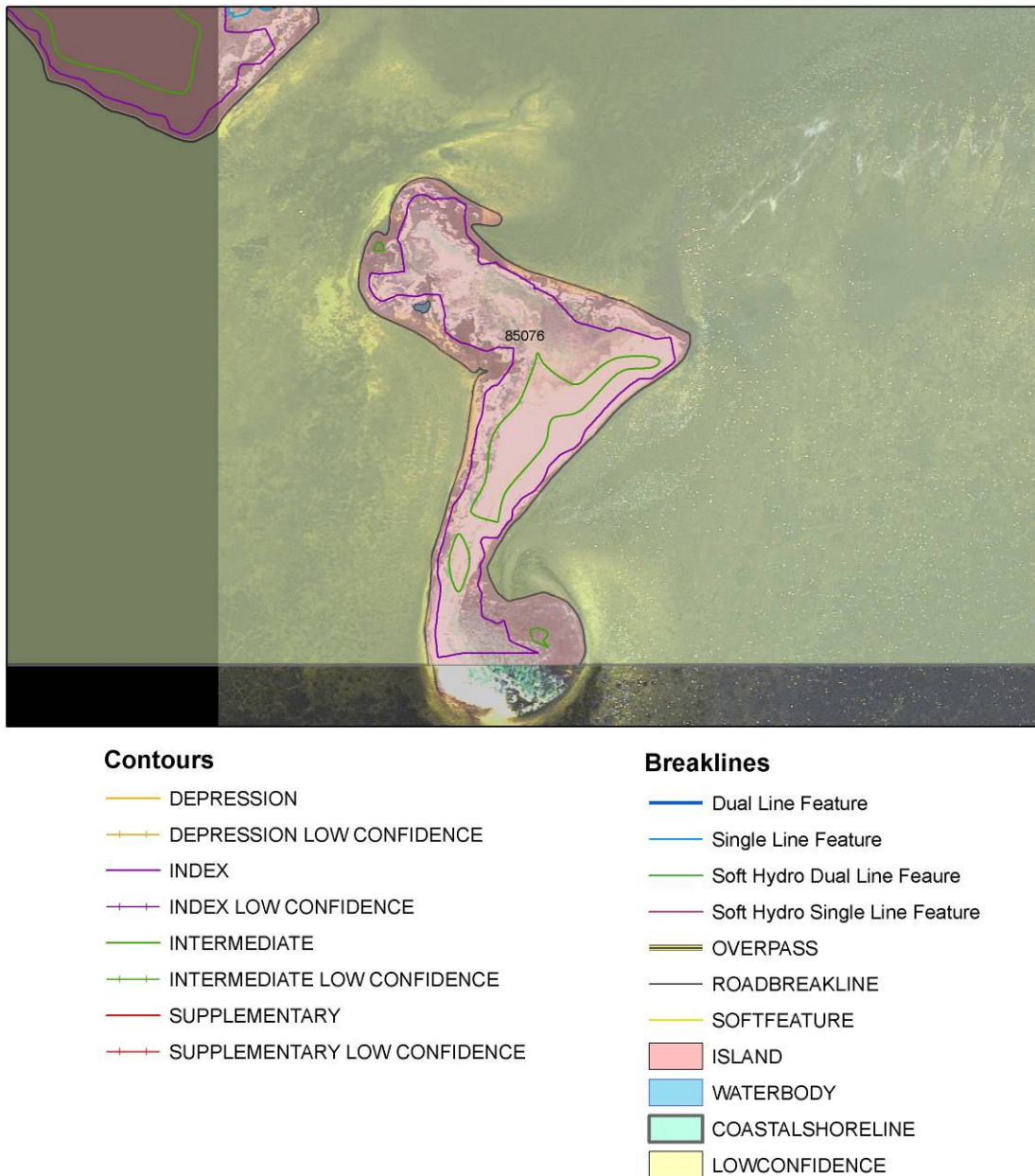

Contours

— DEPRESSION
+—+—+ DEPRESSION LOW CONFIDENCE
— INDEX
+—+—+ INDEX LOW CONFIDENCE
— INTERMEDIATE
+—+—+ INTERMEDIATE LOW CONFIDENCE
— SUPPLEMENTARY
+—+—+ SUPPLEMENTARY LOW CONFIDENCE

Breaklines

— Dual Line Feature
— Single Line Feature
— Soft Hydro Dual Line Feaure
— Soft Hydro Single Line Feature
═══ OVERPASS
— ROADBREAKLINE
— SOFTFEATURE
▨ ISLAND
▨ WATERBODY
▨ COASTALSHORELINE
▨ LOWCONFIDENCE

Figure 7. Example island feature breaklines and contours from tile #85076

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.
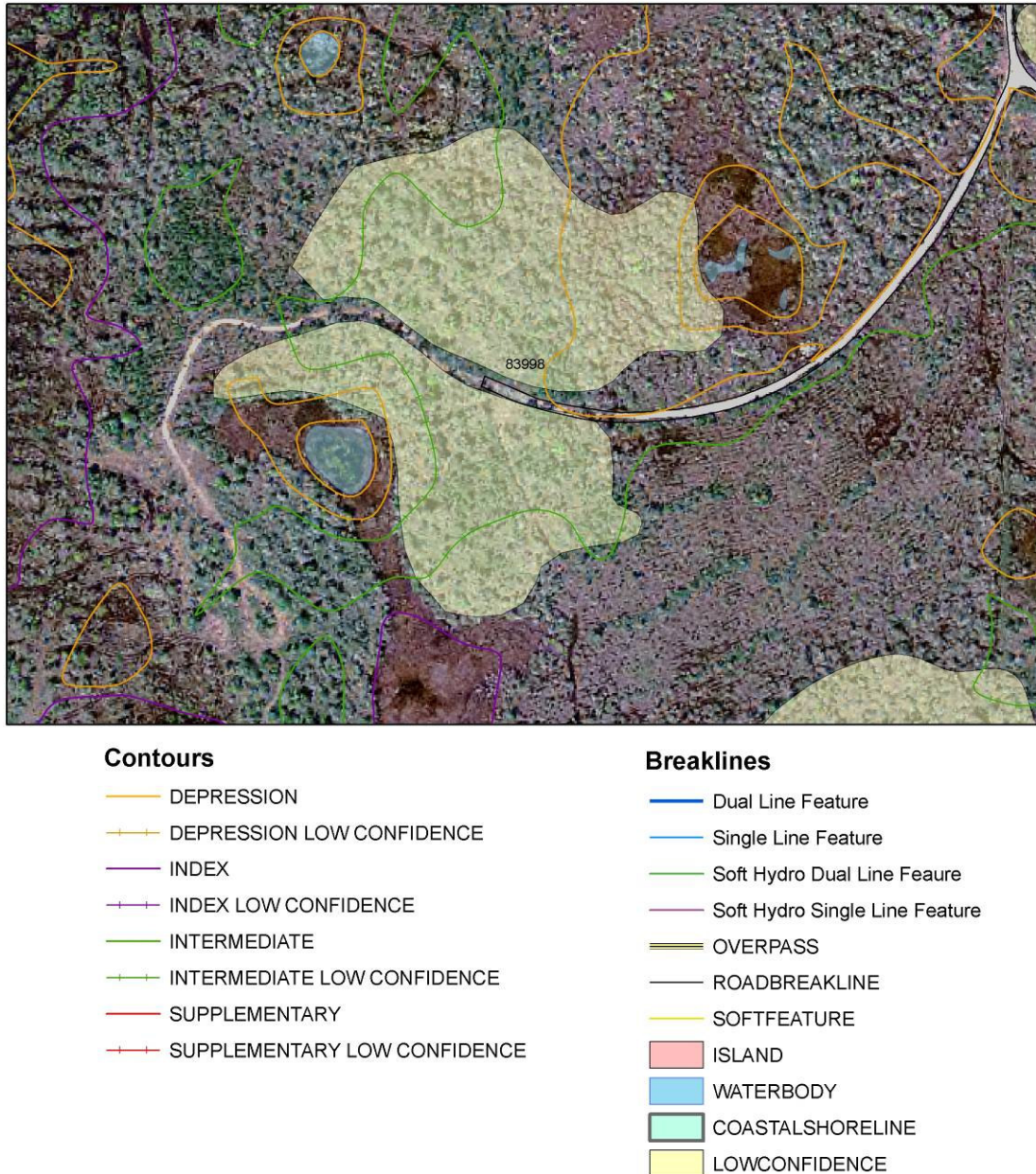

Contours

— DEPRESSION
+—+ DEPRESSION LOW CONFIDENCE
— INDEX
+—+ INDEX LOW CONFIDENCE
— INTERMEDIATE
+—+ INTERMEDIATE LOW CONFIDENCE
— SUPPLEMENTARY
+—+ SUPPLEMENTARY LOW CONFIDENCE

Breaklines

— Dual Line Feature
— Single Line Feature
— Soft Hydro Dual Line Feaure
— Soft Hydro Single Line Feature
≡ OVERPASS
— ROADBREAKLINE
— SOFTFEATURE
▮ ISLAND
▮ WATERBODY
▮ COASTALSHORELINE
▮ LOWCONFIDENCE

Figure 8. Example low confidence area feature breaklines and contours from tile #83998

100

Appendix I: Geodatabase Structure