Project Report

Suwannee River water Management Area 2 LiDAR Florida State Plane North

Prepared For:

United States Geological Survey

Prepared By:

Digital Aerial Solutions, LLC

CONTRACT: #G10PC00093
CONTRACTOR: DIGITAL AERIAL SOLUTIONS
TASK ORDER: #G12PD00242

Project Report
LiDAR Collection, Processing, and QA/QC

2012 Suwannee Management LiDAR Task Order

Prepared For:
US Geological Survey
1400 Independence Road
Rolla, MO 65401
Phone: (573) 308-3587

Prepared By:
Digital Aerial Solutions, LLC
8409 Laurel Fair Circle, Suite 100
Tampa, FL 33610
Phone: (813) 628-0788

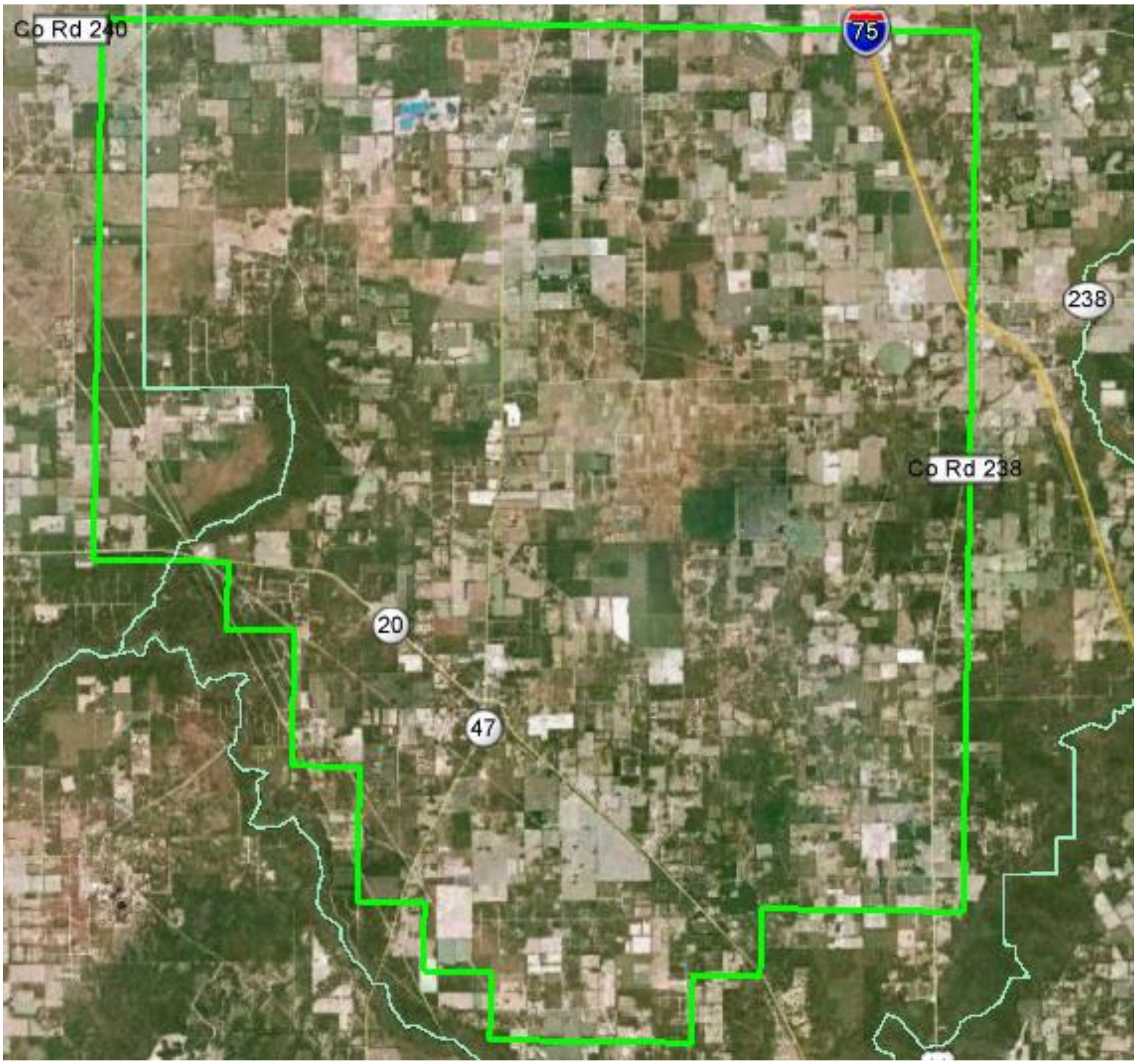

Co Rd 240
75
238
Co Rd 238
20
47

Table of Contents

1 Introduction and Specifications

Digital Aerial Solutions, LLC (DAS) was tasked to collect and process a Light Detection And Ranging (LiDAR) derived elevation dataset for the Suwannee Management, FL. The Suwannee Management survey area encompasses approximately 145 square miles. Aerial LiDAR data was collected utilizing an ALS60. The ALS60 is a discrete return topographic LiDAR mapping system manufactured by Leica Geosystems. LiDAR data collected for the Suwannee Management survey has a nominal pulse spacing of 0.9 meters, and includes up to 4 discrete returns per pulse, along with intensity values for each return.

LiDAR datasets were post processed to generate elevation point cloud swaths for each flight line. Deliverables include the point cloud swaths, tiled point clouds classified by land cover type, breaklines to support hydro-flattening of digital elevation models (DEM)s, and bare-earth DEM tiles. Point cloud deliverables are stored in the LAS version 1.2 format, point data record format 1. The tiling scheme for tiled deliverables is a 4900 feet x 4900 feet grid. All deliverables were generated in conformance with the *U.S. Geological Survey National Geospatial Program Guidelines and Base Specifications, Version 1.*

2 Spatial Reference System

The spatial reference of the data is as follows.

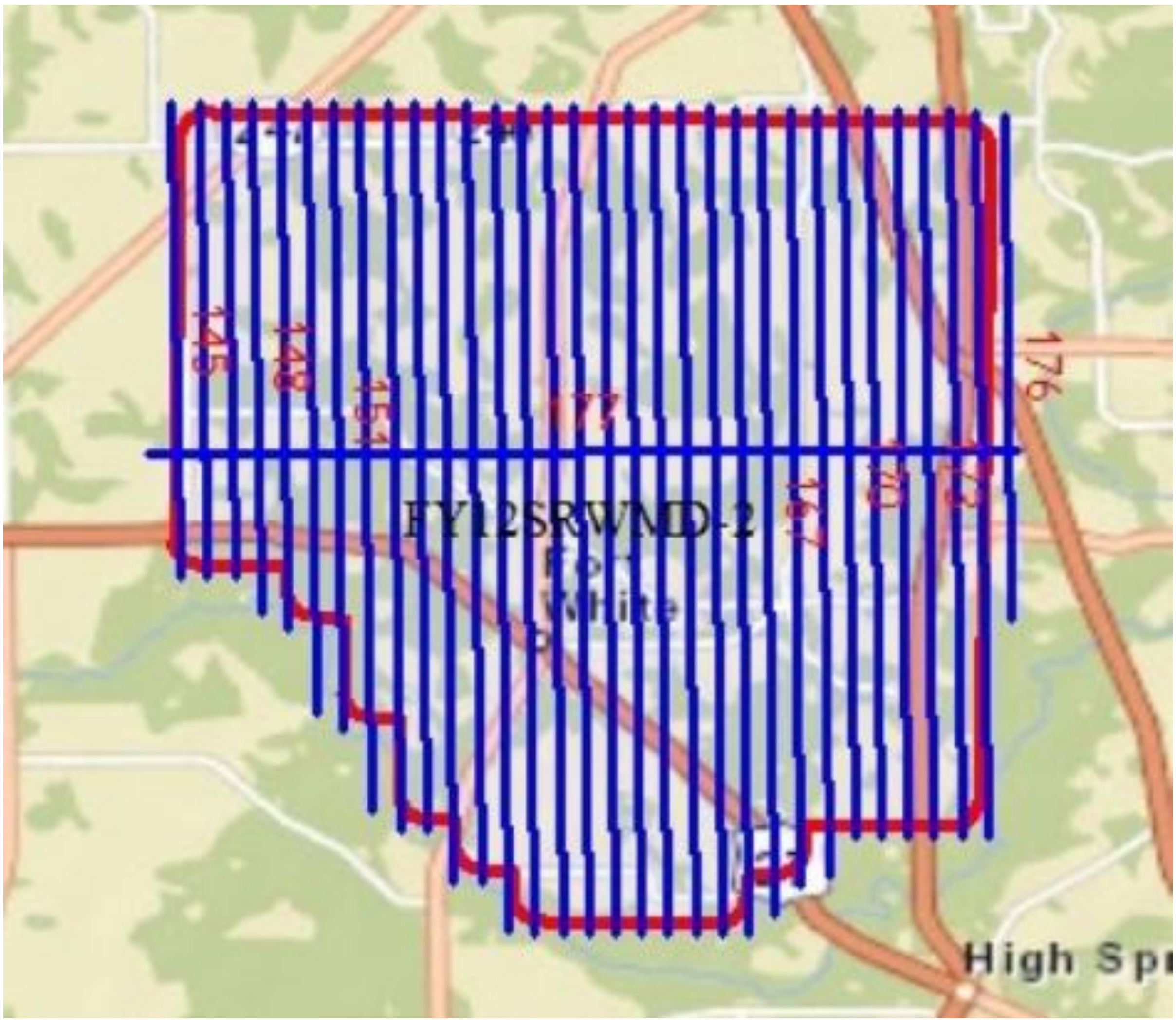
Horizontal Spatial Reference
- Datum: North American Datum of 1983 (National Spatial Reference System 2007)
- Coordinates: Florida State Plane North

Vertical Spatial Reference
All datasets are available with orthometric elevation; point cloud datasets are also available with ellipsoid heights
- Datum: North American Vertical Datum of 1988 (GEOID09)

3 LiDAR Acquisition

3.1 Survey Area

The Suwannee Management Area 2 survey covers approximately 145 square miles located in north central Florida. The flight plan consisted of 32 survey lines and
1 control lines.



3.2 Acquisition Parameters

Acquisition parameters include the sensor configuration and the flight plan characteristics, and are selected based on a number of project specific criteria. Criteria reviewed include the required accuracies for the final dataset, the land cover types within the project survey area, and the required nominal pulse spacing. Acquisition parameters selected for the Suwannee River water Management Area 2 LiDAR project are summarized below.

Parameter	Value
Flying Height Above Ground Level	3,775 feet
Nominal Sidelap	30%
Nominal Speed Over Ground	130 knots
Field of View	30°
Laser Rate	200 kHz
Scan Rate	68.4 hz
Maximum Cross Track Spacing	0.98 meters
Maximum Along Track Spacing	0.98 meters
Average Spacing	1 meters

3.3 Acquisition Mission

The acquisition mission for the Suwannee Management area 2 LiDAR survey was coordinated to be acquired in 1 week. Collection began on January 18th 2013 and was completed on January 19th, 2013, A complete flight log for the acquisition mission may be found in Appendix A.

3.4 Airborne GPS/IMU

Airborne global positioning system (GPS) and inertial measurement unit (IMU) data was collected on the aircraft during the acquisition mission, providing sensor position and orientation information for geo-referencing the LiDAR data. Airborne GPS observations were collected at a frequency of 2Hz, and IMU observations are collected at a frequency of 200Hz.

Aircraft	Sensor	GPS Lever Arm (m)	IMU Lever Arm (m)
C421 – N112MJ	ALS60 – SN6130	x: -0.210, y: -0.060, z: -1.370	x: -0.450, y: -0.159, z: -0.169

In addition, GPS data was collected with ground base stations during the acquisition mission, providing corrections to support differential post-processing of the airborne GPS. One ground base station was setup at an NGS Benchmark (Keyport) as the base of operation. The additional ground base station were selected and place threw the project to ensure complete coverage. Ground GPS observations were collected at a frequency of 2Hz.

4 LiDAR Processing

4.1 Acquisition Post-Processing

Once the acquisition was completed, initial post-processing was performed to generate geo-referenced LiDAR elevation point clouds.

The airborne GPS dataset was differentially corrected using the ground base station GPS datasets collected by DAS in Lecia's IPAS software. IPAS computes the GPS dataset corrections in both forward and reverse chronological sequence, obtaining two solutions for the GPS trajectory. The differences between these two solutions were reviewed to ensure a consistent result, and agree within +/- 3cm. The forward and reverse solutions also show good fit between the two different base stations used in the post-processing.

Differentially corrected airborne GPS data was merged with the airborne IMU dataset in Leica's IPAS software through Kalman filtering techniques. IPAS applies the reference lever arms for the GPS and IMU measurement systems during processing to determine the trajectory (position and orientation) of the LiDAR sensor during the acquisition mission. Estimated lever arm values reported posteriori validate the measurements made during sensor installation in the aircraft.

Raw LiDAR sensor ranging data and the final sensor trajectory from IPAS were processed in Leica's ALSPP software to produce the LiDAR elevation point cloud swaths for each flightline, stored in LAS version 1.2 file format. Quality control of the swath point clouds was performed to validate proper function of the sensor systems, full coverage of the project AOI, and point density consistent with the planned nominal pulse spacing. The LiDAR data collected for the Suwannee Management survey area2 passed these quality control checks.

Swath point clouds were assigned a unique File Source ID within the LAS file format before further processing. Swath files for the Suwannee Management area 2 LiDAR project were numbered in chronological order of acquisition.

4.2 Geometric Calibration

Geometric and positional accuracy of the LiDAR swath point clouds is highly dependent on accurate calibration of the various subsystems within the LiDAR sensor system. Sensor calibration parameters fall into two categories, one being those parameters proprietary to the manufacturer's sensor design, and the other being parameters common to most commercial airborne LiDAR sensors, the IMU to laser reference system alignment angles (bore-site), and mirror deformation constants (scaling).

The manufacturer specific calibration parameters are applied in Leica's ALSPP software for the ALS60 sensor system. Terrasolid's Terramatch software was used to calculate the IMU bore-site and mirror scale parameters for the Suwannee Management's area 2 LiDAR data. Within the TerraMatch software, the Tie-line workflow was used to solve for the parameters. The Tie-line workflow involves automated selection of numerous 'tie-lines', which represent a linear segment fit to the data that should have the same slope, azimuth, position and elevation, within the overlap sections of the survey lines and control lines. The tie- lines provide observations for algorithms within TerraMatch to solve for the bore-site and mirror scale parameters for the lift.

The Tie-line workflow is dependent upon well distributed tie-lines throughout the swath point clouds to effectively solve for bore-site and mirror scale parameters with the automated algorithms. The Suwannee Management survey area did not support this requirement, due to the large water area within the survey and control lines. Manual estimation of the bore-site and mirror scale parameters was performed using the observed tie-lines in overlap areas.

The final step of geometric calibration is to determine elevation (z) offset corrections to be applied to the swath point clouds. Z values calculated during the course of the acquisition mission can vary at the centimeter level as the GPS satellite constellation observed in the survey area changes with satellites moving through their orbits over the course of the mission. Baseline length from the ground base station GPS to the airborne GPS can also impact the z values calculated for the swath point clouds. Z offset corrections are calculated in two steps; a relative step, where individual lines are corrected one to another using the adjusted tie-lines from the bore-site and mirror scale calculation step; and an absolute step, where groups of lines are leveled to project ground control.

For the Suwannee Management area 2 LiDAR project, the control lines were used to determine relative z offset corrections in areas of discernible ground. The base station operated by DAS in the survey area provided for minimal baseline lengths, resulting in generally good z agreement between the survey lines and control lines.

The final geometrically calibrated swath point clouds were compared to the bare-earth profile survey data. The data fit the profile surveys within the vertical accuracy tolerance specified for the project. Full documentation of the vertical accuracy checks maybe found in section 5.1.

4.3 Point Cloud Classification

Georeference information was applied to the swath point could LAS files. Geometrically calibrated swath point clouds were cut into 4900 feet x 4900 feet LAS format tiles for point cloud classification and derived product creation. It is important to note that US National Grid tiles are non- orthogonal when stored and displayed in a geographic coordinate system. As a result, tiled vector data does not have overlap, but tiled raster data does have overlap to permit seamless display of the data products.

Tiled point cloud data was processed in Terrasolid's Terrascan software to assign initial classification values. The Terrascan software provides a number of routines to algorithmically detect and assign points to their appropriate class. Points left unclassified by the algorithmic routine remain as Class 1 – Processed, but unclassified. Automated classification routines assigned points to one of the following classes:

- Class 1 – Processed, but unclassified
- Class 2 – Bare-earth ground
- Class 7 – Noise
- Class 9 – Water
- Class 10 – Ignored Ground
- Class 11 – Withheld
- Class 17 – Reserve
- Class 18 – Reserve

Automated classification results were reviewed for each tiled point cloud, and manual edits made where necessary to correct for misclassified points. Points remaining in Class 1 after the automated classification routines were run were left in Class 1. Points falling outside of a 105 meter buffer of the project AOI polygon were excluded from the tiled point clouds.

4.4 Breakline Collection

Manual breakline collection was performed to support the hydro-flattening requirements of the project's DEM deliverables. Breaklines were collected directly from the classified point clouds and from triangulated irregular network (TIN) surface models built from the classified point clouds, in Terrasolids's Terrascan and Terramodeler software. Breakline features were collected as design file elements in Bentley's Microstation software. Breaklines were converted to ESRI 3D shapefile format for the breakline deliverable, and tiled to the project US National Grid index.

The data collected for the Suwannee Management LiDAR area 2 survey maintained significant point density in the water, marsh, and swamp, limiting the usefulness of point density as guiding factor in breakline placement.

Points classified as Class 2 – Bare-earth ground, falling within a one meter buffer of the collected breaklines, were reassigned to Class 10 – Ignored Ground. These points are excluded from the surface model during DEM generation to preserve the hydro-flattening characteristics of the breaklines.

4.5 DEM Generation

The final classified point clouds and collected breaklines were reviewed for completeness and conformance to the task order scope of work and the NGP version 13 guidelines. Within the Terramodeler software, points in Class 2 – Bare-earth ground and the breaklines were combined to generate TIN elevation models for each tile, from which the bare-earth DEM tiles were interpolated and exported as 32 bit float Arc Grid.

5 Quality Control

5.1 Point Clouds

Accuracy and completeness of the LiDAR point clouds directly impacts the quality of all other derived LiDAR derived products. Ensuring a quality LiDAR dataset begins with proper mission planning and execution. Ground GPS base stations are located such that GPS baselines between the ground and airborne receivers do not exceed 30km. For the Suwannee Management LiDAR project, two base stations were run to meet this requirement, one at the field operations airport and one within the survey area. Static alignment is performed both before take-off and after landing to allow for GPS integer ambiguity resolution. Sensor operators carefully monitor the LiDAR unit and its various subsystems during the acquisition mission to ensure proper function. Airborne GPS positional dilution of precision (PDOP) estimates are monitored to ensure they remain less than 3.The optical system is monitored to ensure there are no ranging errors encountered during the flight lines.

During acquisition post-processing estimates of the trajectory data accuracy are reviewed to ensure they will support the required accuracies of the point cloud data. The trajectory accuracy is a function of the differentially corrected GPS data and the IMU data.

The raw swath point clouds generated from ALSPP are reviewed as another check for proper sensor function. The point clouds are reviewed for full coverage of the AOI, required point density and nominal pulse spacing, clustering, proper intensity values, full swath coverage within the planned field of view, and planned survey line overlap.

Geometric calibration quality control validates that the positional accuracy requirements of the project are met, and includes relative accuracy assessments for intra-swath (within) and inter-swath (between) accuracy, along with absolute accuracy assessments against project ground control.

Relative vertical accuracy assessments are normally made using the tie-lines generated in the Terramatch software, as these lines provide positional observations throughout the extent of individual swaths, and between neighboring swaths.

Horizontal accuracy assessments of LiDAR data require the presence of vertical targets such as buildings within in the survey area. Field check points are surveyed at the corners of the building roofs, and the surveyed locations compared to the estimated corner locations in the LiDAR point cloud. The Suwannee Management survey area did not present any accessible buildings for use as vertical targets. From the manufacturer's specifications, the estimated horizontal accuracy at one sigma, based on flying height for the project, is between 10cm and 20cm.

Absolute vertical accuracy assessments for the point cloud data are made against ground check point data. For the Suwannee Management area 2 survey, ground check point data consisted of the ground GPS base station, and real-time kinematic (RTK) GPS techniques.

Check point locations were collected at 1 – second intervals during the RTK survey. Points collected during the static pre-initialization and post-initialization were removed from the assessment so as not to bias the assessment.

Local TIN models of the elevation points are built around each ground check points. The tin model elevation is sampled at the horizontal position of the ground check point. The TIN model elevation and ground check point survey elevation values were used to calculate the fundamental vertical accuracy (FVA) of the swath point clouds as described in NDEP Elevation Guidelines Version 1. The FVA of the TIN tested RMSEz 0.144 feet and 0.285 feet at the 95% confidence level in open terrain. FVA of the DEM tested at an RMSEz of 0.118 feet and 0.232 feet at the 95% confidence level in open terrain. The full calculations for all check points can be found in Appendix B.

FVA of TIN

$RMSE_Z$ =	0.144	Feet
NSSDA=	0.285	Feet

FVA of DEM

$RMSE_Z$ =	0.118	Feet
NSSDA=	0.232	Feet

The tiled point cloud products were reviewed for full coverage of the AOI and proper classification. As part of the QC process, TINs are built in the Terramodeler software for each tile using the ground class and the hydro-flattening breaklines. The TINs are reviewed for non-ground features, and edited where necessary to remove any remaining non-ground features. Points were also reviewed for absolute elevation, and points falling below the selected orthometric elevation for water were removed from the ground class.

5.2 Breaklines

The final breaklines in ESRI 3D shapefile format were reviewed for topological consistency and correct elevation. Breaklines features are continuous and do not have overlaps or dangles.

5.3 Digital Elevation Models

Digital elevation models (DEMs) were reviewed for conformance with the SOW and the NGP version 1 guidelines. DEM files were loaded in the Global Mapper software and inspected visually for edge matching between tiles, void areas within the project AOI, and proper coding of the NODATA values. DEM file naming was verified for consistency with the US National Grid tile index.

Appendix A. Flight Logs

ALS60 LiDAR Flight Log

Project	Suwannee 2013		ALS60	N6130 090724				Senior Operator/s
						-		Meagan McCall
Date/Julian	1/18/2013	Lake City	Mem Drive MM60	Int. Time:	TARAIRSPD(KNTS)		Base PID:	Pilot/s
Hobbs End	649.1		6-600110120		140		BD2712	MWAZ
Hobbs ST	644.9		LIFT A		TARALT AGL (ft):	Flight Plan(s):	Base Height:	Aircraft / Airport Idnt:
Flight Time	4.2				5,575	Block 2	1,500	421C 112MU / LCQ

Lift		Flight Line	Mission Line	UTC time: B:	E:	GPS Altitude: ASL:	Direction	Speed: kts:	Memory	S/Vs:	Position Acc. PDOP	HDOP		Comments and Conditions:
						-	-	-	135					Static Alignment
		145	130119_011354	1:13	1:17	5,645	0	139	134	17	1.1	0.6		CLEAR
		146	130119_012142	1:21	1:25	5,700	180	143	133	15	1.2	0.7		CLEAR
		147	130119_012911	1:29	1:32	5,600	0	139	132	17	1.2	0.7		CLEAR
		148	130119_013633	1:36	1:40	5,600	180	138	131	18	1	0.6		CLEAR
		149	130119_014402	1:44	1:47	5,595	0	139	130	17	1.1	0.6		CLEAR
		150	130119_015111	1:51	1:55	5,600	180	138	129	17	1.2	0.7		CLEAR
		151	130119_015928	1:59	2:03	5,591	0	142	128	17	1.3	0.7		CLEAR
		152	130119_020755	2:07	2:13	5,614	180	131	127	18	1.1	0.6		CLEAR
		153	130119_021654	2:16	2:21	5,621	0	144	125	18	1.2	0.6		CLEAR
		154	130119_022542	2:25	2:30	5,621	180	135	124	18	1.2	0.6		CLEAR
		155	130119_023441	2:34	2:39	5,630	0	149	123	18	1.3	0.6		CLEAR
		156	130119_024657	2:46	2:52	5,639	180	133	121	18	1.3	0.6		CLEAR
		157	130119_025708	2:57	3:02	5,630	0	149	120	18	1.3	0.6		CLEAR
		158	130119_030651	3:06	3:12	5,636	180	129	118	18	1.3	0.6		CLEAR
		159	130119_031624	3:16	3:22	5,630	0	145	117	20	1.1	0.6		CLEAR
		160	130119_032616	3:26	3:32	5,638	180	130	115	19	1.2	0.6		CLEAR
		161	130119_033556	3:35	3:41	5,629	0	145	114	19	1.2	0.6		CLEAR
		162	130119_034558	3:45	3:52	5,642	180	130	112	20	1.1	0.6		CLEAR
		163	130119_035603	3:56	4:01	5,638	0	146	111	20	1.1	0.6		CLEAR
		164	130119_040603	4:06	4:12	5,657	180	125	109	20	1.1	0.6		CLEAR
		165	130119_041553	4:15	4:21	5,642	0	144	108	21	1.0	0.5		CLEAR
		166	130119_042534	4:25	4:32	5,647	180	128	106	21	1.0	0.5		CLEAR
		167	130119_043543	4:35	4:42	5,644	0	146	105	18	1.1	0.6		CLEAR
		177	130119_044817	4:48	4:53	5671	270	140	103	17	1.2	0.6		X STRIP
		177	130119_045835	4:58	5:03	5667	90	131	102	18	1.1	0.6		X STRIP

ALS60 LiDAR Flight Log

Project	Suwannee 2013		ALS60	N6130 090724				Senior Operator/s
						-		Berth Bulla-Ze
Date/Julian	1/19/13	Lake City	Mem Drive MM60	Int. Time:	TARAIRSPD(KNTS)		Base PID:	Pilot/s
Hobbs End	651.3		6-600110120		140		BD2712	MWAZ
Hobbs ST	649.1		LIFT A		TARALT AGL (ft):	Flight Plan(s):	Base Height:	Aircraft / Airport Idnt:
Flight Time	2.2				5,575	Block 2	1,500	421C 112MU / LCQ

Lift		Flight Line	Mission Line	UTC time: B:	E:	GPS Altitude: ASL:	Direction	Speed: kts:	Memory	S/Vs:	Position Acc. PDOP	HDOP	Comments and Conditions:
						-	-	-	102				Static Alignment
		168	130119_154113	15:41	15:46	5,578	0	136	100	15	1.1	0.7	CLEAR
		169	130119_155120	15:51	15:56	5,594	180	143	99	14	1.2	0.7	CLEAR
		170	130119_160112	16:01	16:06	5,584	0	141	98	15	1.2	0.7	CLEAR
		171	130119_161049	16:10	16:16	5,570	180	142	96	14	1.5	0.9	CLEAR
		172	130119_162021	16:20	16:25	5,594	0	141	95	14	1.5	0.9	CLEAR
		173	130119_163017	16:30	16:35	5,598	180	141	94	14	1.3	0.8	CLEAR
		174	130119_164007	16:40	16:45	5,584	0	140	92	15	1.3	0.8	CLEAR
		175	130119_164956	16:49	16:55	5,596	180	141	91	15	1.3	0.8	CLEAR
		176	130119_170644	17:06	17:10	5,602	0	141	90	16	1.2	0.7	CLEAR
		177	130119_171545	17:15	17:18	5,606	270	134	89	16	1.3	0.7	X STRIP
		177	130119_172225	17:22	17:26	5,600	90	145	88	17	1.1	0.6	X STRIP

Appendix B. Vertical Accuracy Calculations

DEM FVA Report

LandCover Type: Bare Earth
Minimum DZ: -0.101
Maximum DZ: 0.206
Mean DZ: 0
Mean Magnitude DZ: 0.600
Number Observations: 6
Standard Deviation DZ: 0.13
RMSE Z: 0.154
95% Confidence Level Z: 0.301
Units: Feet

TIN FVA Report

LandCover Type: Bare Earth
Minimum DZ: -0.147
Maximum DZ: 0.249
Mean DZ: 0.026
Mean Magnitude DZ: 0.629
Number Observations: 6
Standard Deviation DZ: 0.157
RMSE Z: 0.177
95% Confidence Level Z: 0.347
Units: Feet

DEM Urban SVA Report

LandCover Type: Urban SVA
Minimum DZ: -0.141
Maximum DZ: 0.157
Mean DZ: 0.045
Mean Magnitude DZ: 0.574
Number Observations: 5
Standard Deviation DZ: 0.114
RMSE Z: 0.111
95th Percentile: 0.154
Units: Feet

TIN Urban SVA Report

LandCover Type: Urban SVA
Minimum DZ: -0.137
Maximum DZ: 0.160
Mean DZ: 0.049
Mean Magnitude DZ: 0.59
Number Observations: 5
Standard Deviation DZ: 0.121
RMSE Z: 0.118
95th Percentile: 0.154
Units: Feet

DEM Tallweeds SVA Report

LandCover Type: Tallweeds SVA
Minimum DZ: 0.049
Maximum DZ: 0.308
Mean DZ: 0.226
Mean Magnitude DZ: 0.859
Number Observations: 6
Standard Deviation DZ: 0.108
RMSE Z: 0.246
95th Percentile: 0.308
Units: Feet

TIN Tallweeds SVA Report

LandCover Type: Tallweeds SVA
Minimum DZ: 0.118
Maximum DZ: 0.314
Mean DZ: 0.219
Mean Magnitude DZ: 0.849
Number Observations: 6
Standard Deviation DZ: 0.088
RMSE Z: 0.236
95th Percentile: 0.314
Units: Feet

DEM Brushland SVA Report

LandCover Type: Brushland SVA
Minimum DZ: -0.095
Maximum DZ: 0.416
Mean DZ: 0.164
Mean Magnitude DZ: 0.807
Number Observations: 6
Standard Deviation DZ: 0.206
RMSE Z: 0.252
95th Percentile: 0.413
Units: Feet

TIN Brushland SVA Report

LandCover Type: Brushland SVA
Minimum DZ: -0.059
Maximum DZ: 0.364
Mean DZ: 0.150
Mean Magnitude DZ: 0.748
Number Observations: 6
Standard Deviation DZ: 0.170
RMSE Z: 0.216
95th Percentile: 0.357
Units: Feet

DEM Forested SVA Report

LandCover Type: Forested SVA
Minimum DZ: -0.042
Maximum DZ: 0.925
Mean DZ: 0.380
Mean Magnitude DZ: 1.13
Number Observations: 6
Standard Deviation DZ: 0.331
RMSE Z: 0.488
95th Percentile: 0.823
Units: Feet

TIN Forested SVA Report

LandCover Type: Forested SVA
Minimum DZ: 0.101
Maximum DZ: 0.948
Mean DZ: 0.423
Mean Magnitude DZ: 1.177
Number Observations: 6
Standard Deviation DZ: 0.301
RMSE Z: 0.505
95th Percentile: 0.853
Units: Feet

DEM CVA Report

LandCover Type: ALL
Minimum DZ: -0.141
Maximum DZ: 0.925
Mean DZ: 0.183
Mean Magnitude DZ: 0.820
Number Observations: 30
Standard Deviation DZ: 0.216
RMSE Z: 0.282
95th Percentile: 0.488
Units: Feet

TIN CVA Report

LandCover Type: ALL
Minimum DZ: -0.137
Maximum DZ: 0.948
Mean DZ: 0.193
Mean Magnitude DZ: 0.830
Number Observations: 30
Standard Deviation DZ: 0.209
RMSE Z: 0.285
95th Percentile: 0.501
Units: Feet