Project Report

FY13 Suwannee River water Management LiDAR Area 1 Florida State Plane North

Prepared For:

United States Geological Survey

Prepared By:

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Project Report
LiDAR Collection, Processing, and QA/QC

2013 Suwannee Management LiDAR Task
Order G13PD00141

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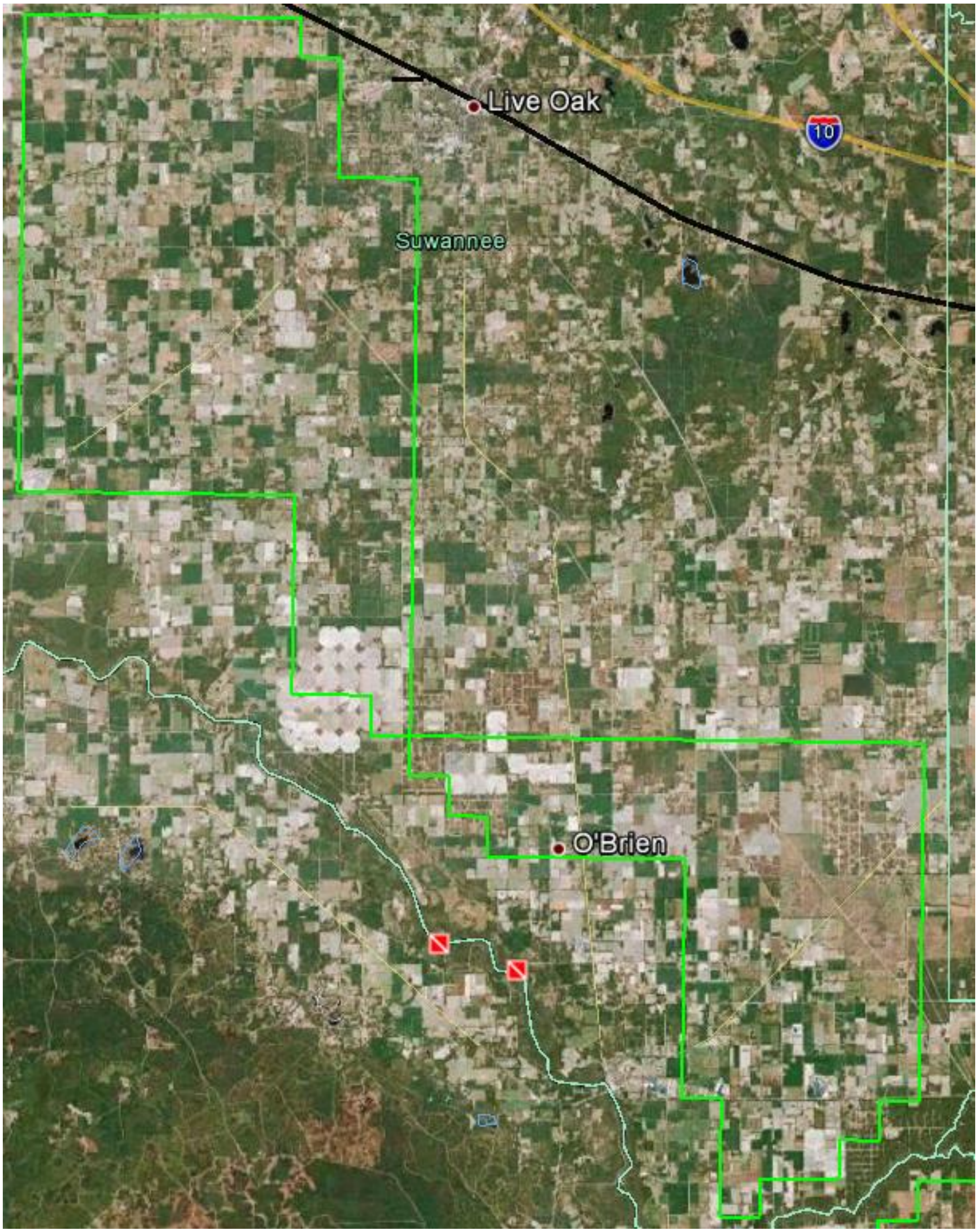
Live Oak
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1 Introduction and Specifications

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 FY13 Suwannee Management survey area1 encompasses approximately 186 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.

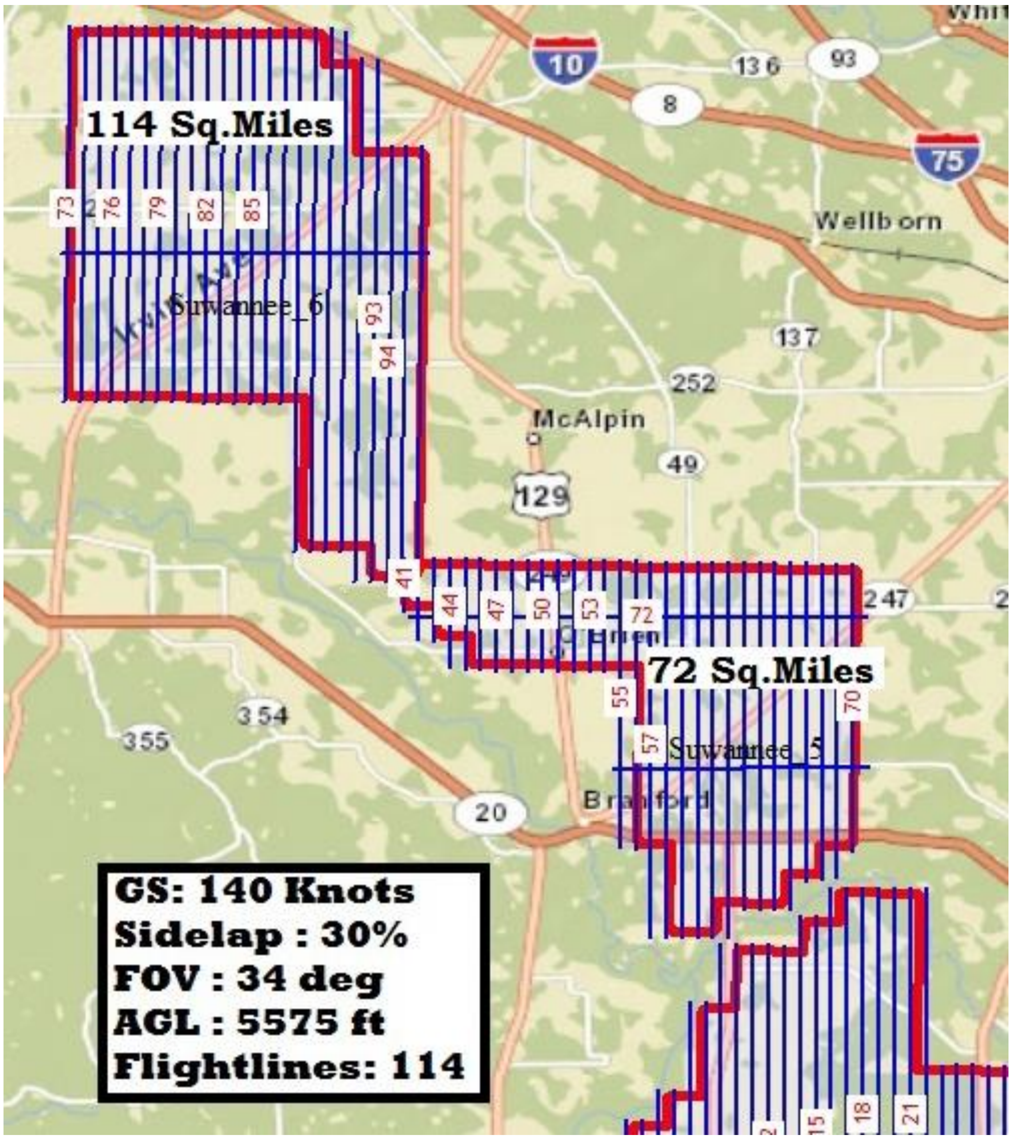
Horizontal Spatial Reference
- Datum: North American Datum of 1983 (National Spatial Reference System 2007)
- Coordinates: State Plane Florida North

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 FY13 Suwannee Management Area 1 survey covers approximately 186 square miles located in north central Florida. The flight plan consisted of 54 survey lines and 3 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 FY 13 Suwannee River water Management Area 1 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 FY 13 Suwannee River water Management Area 1 LiDARsurvey was coordinated to be acquired in 1 week. Collection began on February 4th 2013 and was completed on February 15th, 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 FY 13 Suwannee River water Management Area 1 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 FY13 Suwannee Management's area 1 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 FY13 Suwannee Management survey area 1 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 FY 13 Suwannee River water Management Area 1 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 FY 13 Suwannee Management survey area 1 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 FY13 Suwannee Management area 1 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 0.279 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=	0.279	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
Date/Julian:	2/4/2013	Lake City	
Hobbs End	671.7	Mem Drive MM60	3-600093051
Hobbs ST	667.5		LIFT A
Flight Time	4.2		
Int. Time:			
TAR AIRSPD(KNTS)	140	TAR ALT AGL (ft):	5,575
Flight Plan(s):	Block 7 AND Block 5		
Base PID:	BD2712	Base Height:	1.500
Senior Operator/s	Berth Bulia-Ze	Pilot/s	MWAZ
Aircraft	421C 112MU	Airport Idnt:	LCQ

Lift		Flight Line	Mission Line	UTC time: B:	UTC time: E:	GPS Altitude: ASL:	Direction	Speed: kts:	Memory	S/Vs:	Position Acc. PDOP	Position Acc. HDOP	Comments and Conditions:
Block 7						-	-	-	138				Static Alignment
		105		18:24	18:28	5,690	271	130	137	18	1.3	0.6	
		106		18:31	18:35	5,690	91	143	136	18	1.2	0.6	
		107		18:39	18:43	5,712	271	130	135	17	1.4	0.7	
		108		18:47	18:50	5,701	91	140	134	17	1.4	0.7	
		109		18:54	18:57	5,701	271	128	133	17	1.3	0.7	
		110		18:59	19:03	5,740	91	141	132	18	1.4	0.6	
		111		19:07	19:09	5,718	271	130	131	18	1.1	0.6	
		112		19:13	19:15	5,721	91	141	131	18	1.1	0.6	
		113		19:19	19:22	5,726	271	128	130	17	1.2	0.7	
		114		19:27	19:29	5,718	1.4	137	130	18	1.0	0.6	X-STRIP
		114		19:31	19:33	5,754	181.4	123	129	18	1.0	0.6	X-STRIP
Block 5		70		19:44	19:47	5,690	180	137	129	17	1.1	0.6	
		69		19:50	19:54	5,680	0	136	128	17	1.1	0.6	
		68		19:58	20:02	5,676	180	135	127	17	1.1	0.6	
		67		20:25	20:09	5,676	0	132	126	15	1.5	0.8	
		66		20:12	20:16	5,648	180	136	125	15	1.5	0.8	
		65		20:19	20:23	5,648	0	139	123	14	1.5	0.7	
		64		20:26	20:31	5,666	180	138	122	15	1.2	0.6	
		63		20:33	20:38	5,658	0	136	121	15	1.2	0.6	
		62		20:41	20:46	5,562	180	139	120	17	1.1	0.6	
		61		20:49	20:54	5,558	0	139	119	17	1.1	0.6	
		60		20:57	21:02	5,558	180	137	118	15	1.2	0.6	
		59		21:04	21:09	5,563	0	135	117	14	1.2	0.7	
		58		21:12	21:17	5551	180	139	115	14	1.2	0.7	
		57		21:20	21:24	5,570	0	137	114	14	1.6	0.8	
		56		21:28	21:31	5,562	180	138	113	14	1.5	0.8	
		55		21:34	21:38	5,560	0	133	112	16	1.1	0.6	
		54		21:41	21:41	5,565	180	137	112	16	1.1	0.6	
		71		21:47	21:50	5,572	89.1	140	111	15	1.2	0.6	X-STRIP
		71		21:53	21:56	5,550	269.1	130	111	15	1.2	0.6	X-STRIP
		72		21:59	22:03	5,560	90.3	140	110	15	1.2	0.6	X-STRIP
		72		22:09	22:13	5,558	270.3	134	109	15	1.2	0.6	X-STRIP

ALS60 LiDAR Flight Log

Project		Suwannee 2013		ALS60	N6130_090724								Senior Operator/s
										-			Berth Bulla-Ze
Date/Julian:		2/5/2013	Suwannee	Mem Drive MM60			Int. Time:	TAR AIRSPD(KNTS)				Base PID:	Pilot/s
Hobbs End		673.6		5-600106700				140				BD2735	MMAZ
Hobbs ST		671.9		LIFT A				TAR ALT AGL (ft):		Flight Plan(s):		Base Height:	Aircraft / Airport Ident:
Flight Time		1.7						5,575		Block 5		1,500	421C 112NU / 24J
Lift		Flight Line	Mission Line	UTC time: B:	UTC time: E:	GPS Altitude: ASL:	Direction	Speed: kts:	Memory	S/Vs:	Position Acc. PDOP	Position Acc. HDOP	Comments and Conditions:
B						-	-	-					Static Alignment
Block 5		41		13:12	13:13	5,590	180	133	108	15	1.2	0.7	
		42		13:17	13:18	5,544	0	125	108	14	1.3	0.7	
		43		13:20	13:21	5,560	180	130	108	14	1.3	0.7	
		44		13:24	13:25	5,563	0	131	107	14	1.3	0.7	
		45		13:29	13:30	5,565	180	136	107	16	1.2	0.7	
		46		13:33	13:35	5,574	0	128	107	15	1.3	0.7	
		47		13:38	13:39	5,570	180	138	106	15	1.3	0.7	
		48		13:42	13:44	5,580	0	137	106	15	1.3	0.7	
		49		13:47	13:48	5,589	180	136	106	15	1.3	0.7	
		50		13:52	13:53	5,587	0	131	105	15	1.4	0.7	
		51		13:57	13:58	5,581	180	135	105	15	1.4	0.7	
		52		14:02	14:03	5,589	0	131	104	15	1.4	0.7	
		53		14:06	14:07	5,579	180	139	104	15	1.4	0.7	
		72		14:15	14:18	5,615	90	136	103	15	1.4	0.7	X-STRIP
		72		14:21	14:25	5,615	270	120	102	15	1.4	0.7	X-STRIP

ALS60 LiDAR Flight Log

Project		Suwannee 2013		ALS60	N6130_090724								Senior Operator/s
										-			Berth Bulla-Ze
Date/Julian:		2/15/2013	Suwannee	Mem Drive MM60			Int. Time:	TAR AIRSPD(KNTS)				Base PID:	Pilot/s
Hobbs End		681.2		3-600093051				140				BD2735	MMAZ
Hobbs ST		677.1		LIFT A				TAR ALT AGL (ft):		Flight Plan(s):		Base Height:	Aircraft / Airport Ident:
Flight Time		4.1						5,575		Block 6		1,500	421C 112NU / 24J
Lift		Flight Line	Mission Line	UTC time: B:	UTC time: E:	GPS Altitude: ASL:	Direction	Speed: kts:	Memory	S/Vs:	Position Acc. PDOP	Position Acc. HDOP	Comments and Conditions:
Block 6						-	-	-	79				Static Alignment
		73	130215_185558	18:55	19:01	5,642	180	138	78	18	1.0	0.6	CLEAR
		74	130215_190425	19:04	19:09	5,635	0	138	76	19	1.0	0.6	CLEAR
		75	130215_191213	19:12	19:16	5,635	180	134	75	17	1.1	0.6	CLEAR
		76	130215_192006	19:20	19:24	5,570	0	135	74	17	1.1	0.6	CLEAR
		77	130215_192811	19:28	19:32	5,570	180	139	73	16	1.1	0.6	CLEAR
		78	130215_193618	19:36	19:41	5,570	0	135	72	15	1.2	0.7	CLEAR
		79	130215_194426	19:44	19:49	5,570	180	139	71	15	1.2	0.7	CLEAR
		80	130215_195200	19:52	19:56	5,570	0	131	69	16	1.1	0.6	CLEAR
		81	130215_200018	20:00	20:05	5,570	180	138	68	15	1.2	0.7	CLEAR
		82	130215_200815	20:08	20:13	5,570	0	131	67	13	1.3	0.8	SMALL FIRE
		83	130215_201642	20:16	20:21	5,570	180	132	66	13	1.2	0.8	CLEAR
		84	130215_202449	20:24	20:29	5,570	0	132	65	13	1.2	0.2	CLEAR
		85	130215_203253	20:32	20:37	5,570	180	134	63	12	1.5	0.9	CLEAR
		86	130215_204141	20:41	20:46	5,570	0	136	62	13	1.5	0.9	CLEAR
		87	130215_204938	20:49	20:54	5,570	180	136	61	15	1.1	0.7	CLEAR
		88	130215_205901	20:59	21:05	5,570	0	134	59	15	1.1	0.7	CLEAR
		89	130215_210920	21:09	21:15	5,570	180	135	58	14	1.3	0.7	CLEAR
		90	130215_211921	21:19	21:25	5,570	0	138	57	14	1.3	0.7	CLEAR
		91	130215_212859	21:28	21:35	5,570	180	138	54	14	1.3	0.7	CLEAR
		92	130215_213856	21:38	21:45	5,570	0	136	53	14	1.3	0.7	CLEAR
		93	130215_214828	21:48	21:55	5,570	180	137	51	16	1.1	0.6	CLEAR
		94	130215_215829	21:58	22:03	5,570	0	138	50	16	1.1	0.6	CLEAR
		95	130215_220729	22:07	22:12	5,570	180	139	48	15	1.2	0.7	CLEAR
		96	130215_221633	22:16	22:21	5,570	0	139	47	13	1.5	0.7	CLEAR
		82	130215_222701	22:27	22:31	5,570	180	141	46	14	1.3	0.7	REFLT DUE TO SMOKE
		97	130215_223722	22:37	22:41	5,570	270	131	45	14	1.3	0.7	X-STRIP
		97	130215_224435	22:44	22:48	5,570	90	142	44	15	1.2	0.7	X-STRIP

Appendix B. Vertical Accuracy Calculations

Tiled-Data Area

LiDAR Accuracy Assessment Summary

LC Type	# of Points	FVA	SVA	CVA
LAS				
ALL	95			0.692
FVA	34	0.534		
TallWeeds	18		0.757	
BrushLand	18		0.757	
Forested	25		0.488	
Total	95			
DEM				
ALL	95			0.659
FVA	34	0.544		
TallWeeds	18		0.734	
BrushLand	18		0.679	
Forested	25		0.469	
Total	95			

Units: Feet

Coordinates and Offsets of Analyzed Locations

		ID					
			Survey X	Survey Y	Z1	Z DEM	Z LAS
					ΔZ DEM	ΔZ LAS	LC Type
1)	☑	201_FVA					
			320427.193	3312335.833	14.33	14.306	14.292
					-0.024	-0.038	FVA
2)	☑	202_FVA					
			320421.727	3312187.242	15.977	15.94	15.918
					-0.037	-0.059	FVA
3)	☑	203_FVA					
			323714.537	3316595.393	17.715	17.379	17.385
					-0.336	-0.33	FVA
4)	☑	204_FVA					
			323701.183	3316594.023	17.633	17.567	17.609
					-0.066	-0.024	FVA
5)	☑	214_FVA					
			316287.201	3317028.926	12.622	12.551	12.579
					-0.071	-0.043	FVA
6)	☑	224_FVA					
			316366.731	3317033.146	13.808	13.793	13.779
					-0.015	-0.029	FVA
7)	☑	225_FVA					
			321238.975	3318634.434	18.168	18.154	18.142
					-0.014	-0.026	FVA

Coordinates and Offsets of Analyzed Locations (Continued)

		ID					
			Survey X	Survey Y	Z1	Z DEM	Z LAS
					ΔZ DEM	ΔZ LAS	LC Type
8)	☑	226_FVA					
			321304.466	3318647.341	18.023	18.015	18.013
					-0.008	-0.01	FVA
9)	☑	236_FVA					
			321786.627	3323598.833	24.256	24.251	24.243
					-0.005	-0.013	FVA
10)	☑	237_FVA					
			321849.633	3323593.252	21.858	21.902	21.866
					0.044	0.008	FVA
11)	☑	247_FVA					
			311641.269	3324751.25	15.37	15.392	15.383
					0.022	0.013	FVA
12)	☑	251_FVA					
			325392.589	3326775.174	29.609	29.597	29.604
					-0.012	-0.005	FVA
13)	☑	255_FVA					
			325323.306	3326724.969	29.3	29.252	29.315
					-0.048	0.015	FVA
14)	☑	262_FVA					
			320122.249	3326737.629	23.091	23.215	23.205
					0.124	0.114	FVA

Coordinates and Offsets of Analyzed Locations (Continued)

		ID					
			Survey X	Survey Y	Z1	Z DEM	Z LAS
					ΔZ DEM	ΔZ LAS	LC Type
15)	☑	272_FVA					
			320181.735	3326736.846	24.024	24.112	24.129
					0.088	0.105	FVA
16)	☑	273_FVA					
			311681.31	3324733.461	15.094	15.133	15.142
					0.039	0.048	FVA
17)	☑	280_FVA					
			309193.422	3328416.251	17.933	18.133	18.107
					0.2	0.174	FVA
18)	☑	282_FVA					
			309057.843	3328420.836	17.83	17.912	17.946
					0.082	0.116	FVA
19)	☑	292_FVA					
			306076.734	3331724.937	24.085	24.103	24.113
					0.018	0.028	FVA
20)	☑	293_FVA					
			306076.598	3331792.628	24.304	24.284	24.285
					-0.02	-0.019	FVA
21)	☑	305_FVA					
			303532.639	3339810.826	27.408	27.472	27.482
					0.064	0.074	FVA

Coordinates and Offsets of Analyzed Locations (Continued)

	ID					
		Survey X	Survey Y	Z1	Z DEM	Z LAS
				ΔZ DEM	ΔZ LAS	LC Type
22) ☑	315_FVA					
		303390.759	3339815.632	25.945	26.093	26.1
				0.148	0.155	FVA
23) ☑	316_FVA					
		294828.831	3339927.407	23.086	23.056	23.07
				-0.03	-0.016	FVA
24) ☑	326_FVA					
		294976.543	3339920.513	21.318	21.311	21.312
				-0.007	-0.006	FVA
25) ☑	327_FVA					
		299841.981	3344625.941	26.66	26.71	26.674
				0.05	0.014	FVA
26) ☑	337_FVA					
		299752.309	3344640.775	24.816	24.773	24.787
				-0.043	-0.029	FVA
27) ☑	338_FVA					
		303753.51	3349453.068	29.29	29.26	29.244
				-0.03	-0.046	FVA
28) ☑	348_FVA					
		303861.318	3349451.343	28.797	28.731	28.732
				-0.066	-0.065	FVA

Coordinates and Offsets of Analyzed Locations (Continued)

		ID					
			Survey X	Survey Y	Z1	Z DEM	Z LAS
					ΔZ DEM	ΔZ LAS	LC Type
29)	☑	349_FVA					
			294561.505	3349627.059	27.163	27.163	27.152
					0	-0.011	FVA
30)	☑	359_FVA					
			294712.826	3349609.727	26.317	26.305	26.315
					-0.012	-0.002	FVA
31)	☑	360_FVA					
			295028.798	3354477.996	26.104	26.05	26.056
					-0.054	-0.048	FVA
32)	☑	479_FVA					
			306172.125	3337185.111	28.364	28.335	28.346
					-0.029	-0.018	FVA
33)	☑	480_FVA					
			306240.151	3337165.382	27.487	27.441	27.425
					-0.046	-0.062	FVA
34)	☑	516_FVA					
			323832.858	3316620.618	17.504	17.483	17.478
					-0.021	-0.026	FVA
35)	☑	195_TallWeeds					
			320358.415	3312911.405	16.091	16.154	16.151
					0.063	0.06	TallWeeds

Coordinates and Offsets of Analyzed Locations (Continued)

		ID					
			Survey X	**Survey Y**	**Z1**	**Z DEM**	**Z LAS**
					ΔZ DEM	**ΔZ LAS**	**LC Type**
36)	☑	**208_TallWeeds**					
			323711.643	3316588.307	17.668	17.612	17.63
					-0.056	-0.038	TallWeeds
37)	☑	**221_TallWeeds**					
			316314.986	3316881.52	13.494	13.585	13.575
					0.091	0.081	TallWeeds
38)	☑	**233_TallWeeds**					
			321237.911	3318617.864	17.899	17.929	17.925
					0.03	0.026	TallWeeds
39)	☑	**241_TallWeeds**					
			321882.055	3323582.476	21.281	21.355	21.373
					0.074	0.092	TallWeeds
40)	☑	**259_TallWeeds**					
			325403.237	3326777.697	29.824	29.878	29.883
					0.054	0.059	TallWeeds
41)	☑	**266_TallWeeds**					
			320148.649	3326738.926	23.425	23.523	23.514
					0.098	0.089	TallWeeds
42)	☑	**277_TallWeeds**					
			311784.899	3324755.165	14.921	15.139	15.145
					0.218	0.224	TallWeeds

Coordinates and Offsets of Analyzed Locations (Continued)

		ID				
			Survey X	Survey Y	Z1	Z DEM	Z LAS
					ΔZ DEM	ΔZ LAS	LC Type
43)	☑	289_TallWeeds					
			309204.541	3328351.267	17.903	18.095	18.092
					0.192	0.189	TallWeeds
44)	☑	299_TallWeeds					
			306055.458	3331716.211	24.023	24.155	24.131
					0.132	0.108	TallWeeds
45)	☑	309_TallWeeds					
			303562.233	3339777.74	27.263	27.522	27.532
					0.259	0.269	TallWeeds
46)	☑	320_TallWeeds					
			294814.383	3339921.77	23.28	23.405	23.394
					0.125	0.114	TallWeeds
47)	☑	331_TallWeeds					
			299867.131	3344592.967	25.585	25.572	25.597
					-0.013	0.012	TallWeeds
48)	☑	342_TallWeeds					
			303761.701	3349456.096	28.977	29.012	29.015
					0.035	0.038	TallWeeds
49)	☑	353_TallWeeds					
			294578.844	3349639.254	26.691	26.78	26.769
					0.089	0.078	TallWeeds

Coordinates and Offsets of Analyzed Locations (Continued)

		ID					
			Survey X	Survey Y	Z1	Z DEM	Z LAS
					ΔZ DEM	ΔZ LAS	LC Type
50)	☑	**364_TallWeeds**					
			294999.608	3354471.136	25.542	25.576	25.624
					0.034	0.082	TallWeeds
51)	☑	**376_TallWeeds**					
			301090.131	3355186.128	28.821	28.842	28.82
					0.021	-0.001	TallWeeds
52)	☑	**484_TallWeeds**					
			306194.523	3337193.26	27.557	27.583	27.583
					0.026	0.026	TallWeeds
53)	☑	**198_BrushLand**					
			320334.247	3312897.778	15.875	15.979	15.975
					0.104	0.1	BrushLand
54)	☑	**211_BrushLand**					
			323699.501	3316593.797	17.571	17.737	17.728
					0.166	0.157	BrushLand
55)	☑	**218_BrushLand**					
			316278.222	3316976.859	12.648	12.711	12.713
					0.063	0.065	BrushLand
56)	☑	**230_BrushLand**					
			321292.289	3318688.949	17.795	17.999	18.025
					0.204	0.23	BrushLand

Coordinates and Offsets of Analyzed Locations (Continued)

		ID					
			Survey X	Survey Y	Z1	Z DEM	Z LAS
					ΔZ DEM	ΔZ LAS	LC Type
57)	☑	244_BrushLand					
			321834.059	3323562.886	22.268	22.282	22.307
					0.014	0.039	BrushLand
58)	☑	248_BrushLand					
			311660.62	3324771.41	15.473	15.582	15.586
					0.109	0.113	BrushLand
59)	☑	256_BrushLand					
			325381.258	3326794.151	29.442	29.461	29.454
					0.019	0.012	BrushLand
60)	☑	269_BrushLand					
			320180.57	3326718.122	23.998	24.034	24.02
					0.036	0.022	BrushLand
61)	☑	286_BrushLand					
			309221.875	3328356.67	17.731	17.954	17.964
					0.223	0.233	BrushLand
62)	☑	302_BrushLand					
			306053.405	3331729.931	24.422	24.539	24.543
					0.117	0.121	BrushLand
63)	☑	312_BrushLand					
			303578.522	3339779.762	26.981	27.17	27.186
					0.189	0.205	BrushLand

Coordinates and Offsets of Analyzed Locations (Continued)

		ID				
			Survey X	Survey Y	Z1	Z DEM	Z LAS
					ΔZ DEM	ΔZ LAS	LC Type
64)	☑	323_BrushLand					
			294858.485	3339917.32	23.449	23.457	23.459
					0.008	0.01	BrushLand
65)	☑	334_BrushLand					
			299922.742	3344561.332	25.848	25.787	25.805
					-0.061	-0.043	BrushLand
66)	☑	345_BrushLand					
			303747.543	3349460.247	29.264	29.366	29.368
					0.102	0.104	BrushLand
67)	☑	356_BrushLand					
			294584.682	3349665.327	26.761	26.938	26.933
					0.177	0.172	BrushLand
68)	☑	367_BrushLand					
			295020.837	3354508.385	26.128	26.187	26.182
					0.059	0.054	BrushLand
69)	☑	379_BrushLand					
			301000.571	3355215.637	28.4	28.355	28.343
					-0.045	-0.057	BrushLand
70)	☑	487_BrushLand					
			306134.95	3337427.833	25.42	25.45	25.436
					0.03	0.016	BrushLand

Coordinates and Offsets of Analyzed Locations (Continued)

		ID					
			Survey X	Survey Y	Z1	Z DEM	Z LAS
					ΔZ DEM	ΔZ LAS	LC Type
71)	☑	1016_Forested					
			295060.371	3354428.026	25.249	25.25	25.253
					0.001	0.004	Forested
72)	☑	1018_Forested					
			295056.474	3354503.817	25.887	25.739	25.745
					-0.148	-0.142	Forested
73)	☑	1020_Forested					
			300865.976	3355233.447	26.808	26.841	26.847
					0.033	0.039	Forested
74)	☑	1022_Forested					
			300930.161	3355239.822	27.528	27.408	27.42
					-0.12	-0.108	Forested
75)	☑	1024_Forested					
			294528.966	3349592.635	26.547	26.504	26.493
					-0.043	-0.054	Forested
76)	☑	1027_Forested					
			303760.719	3349414.86	29.572	29.456	29.464
					-0.116	-0.108	Forested
77)	☑	1030_Forested					
			299829.688	3344681.747	26.613	26.523	26.533
					-0.09	-0.08	Forested

Coordinates and Offsets of Analyzed Locations (Continued)

		ID					
			Survey X	Survey Y	Z1	Z DEM	Z LAS
					ΔZ DEM	ΔZ LAS	LC Type
78)	☑	1033_Forested					
			294787.15	3339962.2	23.289	23.322	23.317
					0.033	0.028	Forested
79)	☑	1036_Forested					
			294860.965	3339961.801	24.018	24.023	24.012
					0.005	-0.006	Forested
80)	☑	1039_Forested					
			303402.718	3339781.002	26.462	26.587	26.613
					0.125	0.151	Forested
81)	☑	1042_Forested					
			306037.152	3331809.711	24.371	24.446	24.438
					0.075	0.067	Forested
82)	☑	1046_Forested					
			306137.674	3337135.289	29.154	29.157	29.163
					0.003	0.009	Forested
83)	☑	1049_Forested					
			309001.752	3328453.249	17.642	17.752	17.741
					0.11	0.099	Forested
84)	☑	1051_Forested					
			309091.219	3328464.164	17.697	17.682	17.69
					-0.015	-0.007	Forested

Coordinates and Offsets of Analyzed Locations (Continued)

		ID					
			Survey X	**Survey Y**	**Z1**	**Z DEM**	**Z LAS**
					ΔZ DEM	**ΔZ LAS**	**LC Type**
85)	☑	**1053_Forested**					
			311631.193	3324715.189	15.048	15.159	15.163
					0.111	0.115	Forested
86)	☑	**1056_Forested**					
			320124.93	3326695.793	23.575	23.614	23.624
					0.039	0.049	Forested
87)	☑	**1059_Forested**					
			325293.717	3326694.561	29.658	29.606	29.607
					-0.052	-0.051	Forested
88)	☑	**1063_Forested**					
			321846.4	3323632.302	22.58	22.559	22.56
					-0.021	-0.02	Forested
89)	☑	**1068_Forested**					
			321353.789	3318581.283	17.411	17.585	17.586
					0.174	0.175	Forested
90)	☑	**1073_Forested**					
			321348.728	3318719.839	17.694	17.769	17.784
					0.075	0.09	Forested
91)	☑	**1076_Forested**					
			316267.515	3317068.598	13.047	13.014	13.016
					-0.033	-0.031	Forested

Coordinates and Offsets of Analyzed Locations (Continued)

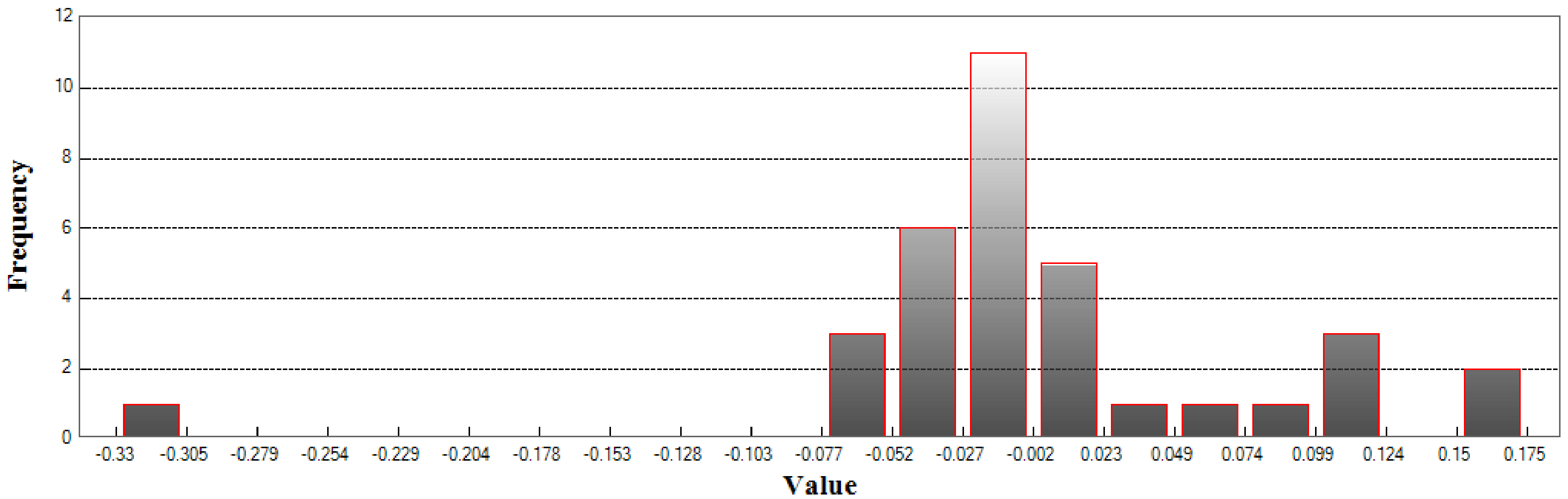
		ID					
			Survey X	Survey Y	Z1	Z DEM	Z LAS
					ΔZ DEM	ΔZ LAS	LC Type
92)	☑	1079_Forested					
			316207.125	3317023.61	13.276	13.219	13.22
					-0.057	-0.056	Forested
93)	☑	1081_Forested					
			323643.259	3316617.971	17.528	17.615	17.63
					0.087	0.102	Forested
94)	☑	1085_Forested					
			323728.951	3316629.957	17.381	17.316	17.305
					-0.065	-0.076	Forested
95)	☑	1087_Forested					
			320480.305	3312209.341	15.342	15.37	15.366
					0.028	0.024	Forested

LAS

Fundamental Vertical Accuracy

LandCover Type: FVA
Minimum DZ: -1.082
Maximum DZ: 0.570
Mean DZ: -0.006
Mean Magnitude DZ: 0.754
Number Observations: 34
Standard Deviation DZ: 0.275
RMSE Z: 0.272
95% Confidence Level Z: 0.534
Units: Feet

Histogram



Min: -0.33
Max: 0.174
Number Of Bins: 20
Bin Interval: 0.025

LAS (Continued)

Supplemental Vertical Accuracy
LandCover Type: TallWeeds

Minimum DZ: -0.124

Maximum DZ: 0.882

Mean DZ: 0.275

Mean Magnitude DZ: 0.974

Number Observations: 18

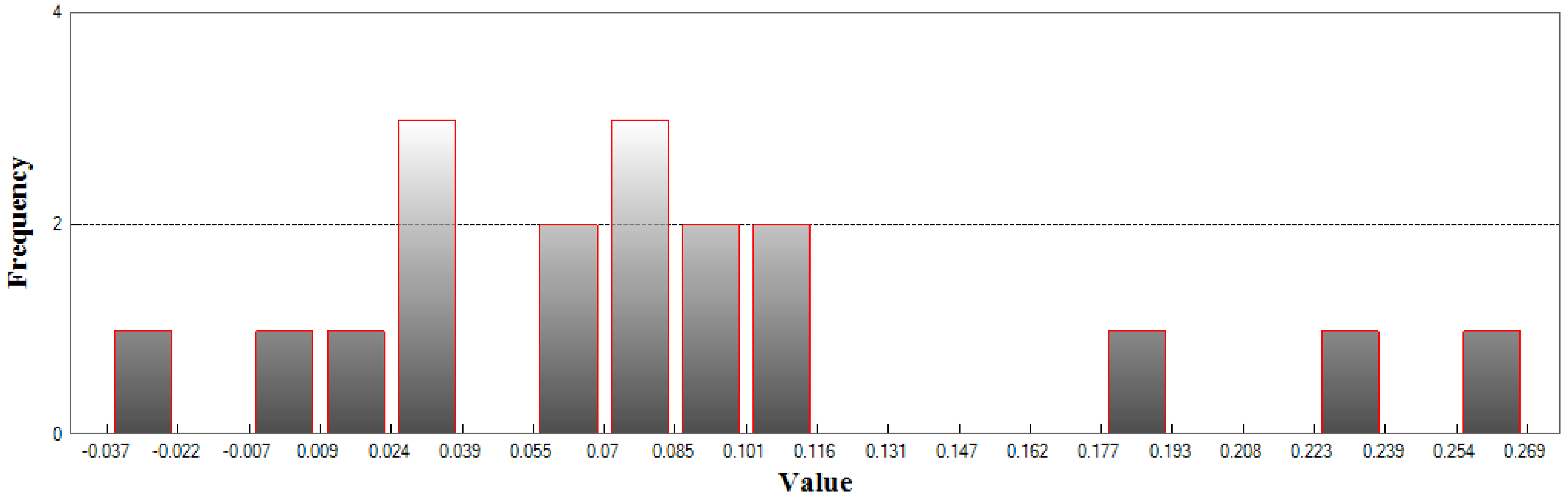
Standard Deviation DZ: 0.255

RMSE Z: 0.370

95th Percentile: 0.757

Units: Feet

Histogram



Min: -0.038

Max: 0.269

Number Of Bins: 20

Bin Interval: 0.015

LAS (Continued)

Supplemental Vertical Accuracy
LandCover Type: BrushLand

Minimum DZ: -0.187

Maximum DZ: 0.764

Mean DZ: 0.282

Mean Magnitude DZ: 1.023

Number Observations: 18

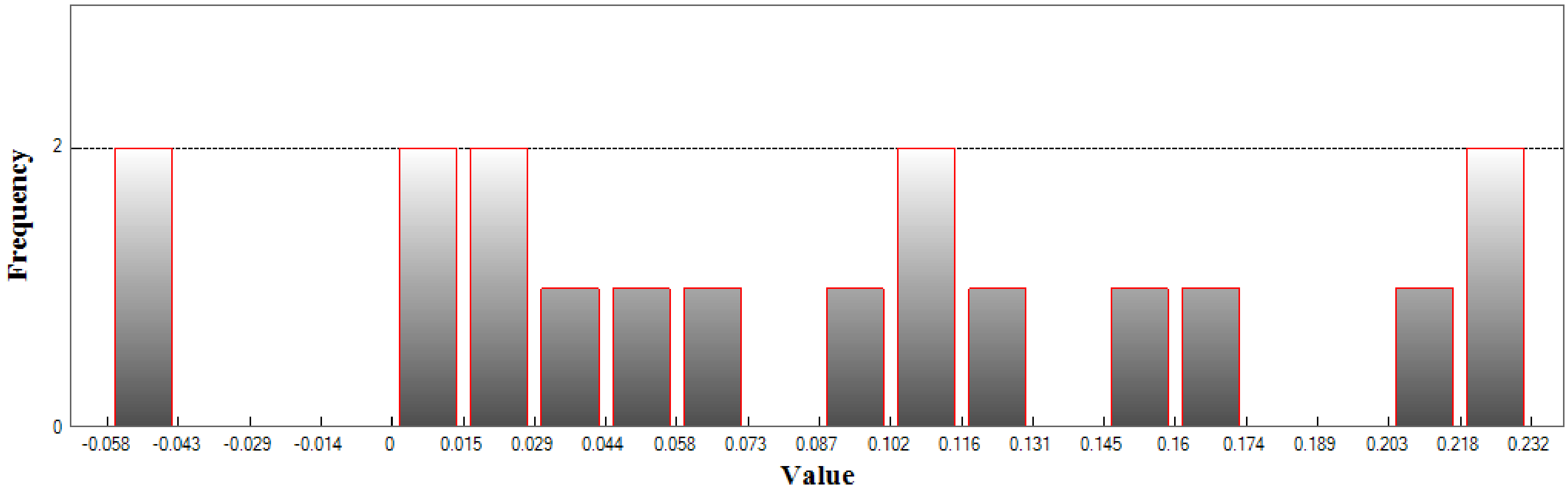
Standard Deviation DZ: 0.288

RMSE Z: 0.400

95th Percentile: 0.757

Units: Feet

Histogram



Min: -0.057

Max: 0.233

Number Of Bins: 20

Bin Interval: 0.015

LAS (Continued)

Supplemental Vertical Accuracy
LandCover Type: Forested

Minimum DZ: -0.465

Maximum DZ: 0.574

Mean DZ: 0.029

Mean Magnitude DZ: 0.853

Number Observations: 25

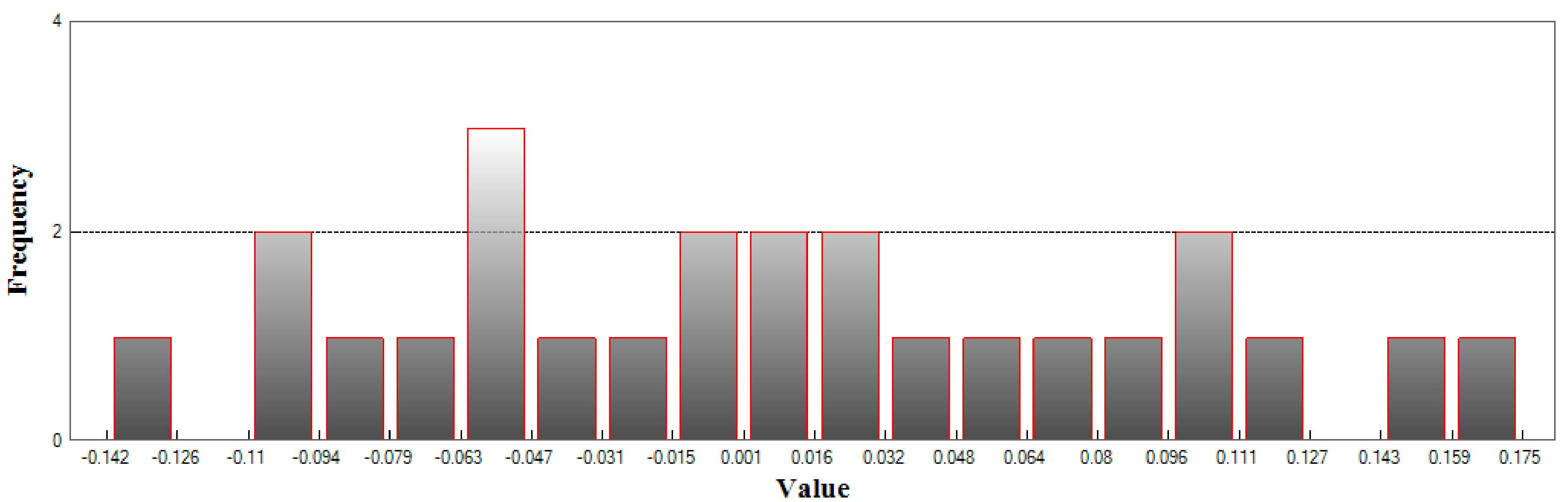
Standard Deviation DZ: 0.275

RMSE Z: 0.272

95th Percentile: 0.488

Units: Feet

Histogram



Min: -0.142

Max: 0.175

Number Of Bins: 20

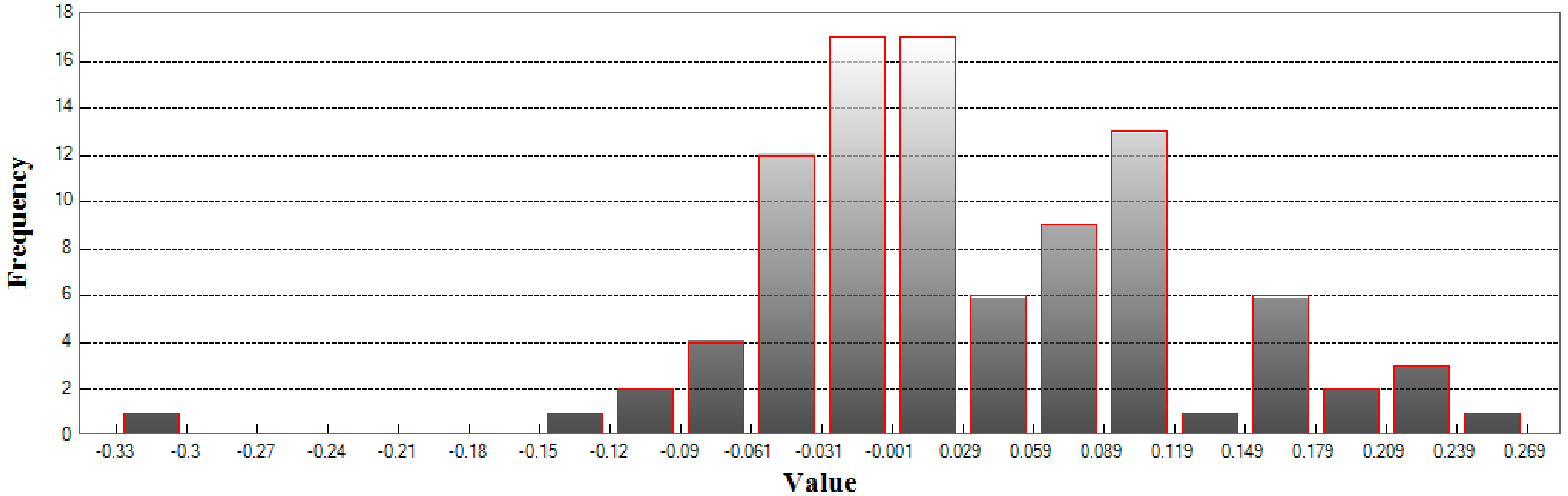
Bin Interval: 0.016

LAS (Continued)

Consolidated Vertical Accuracy

LandCover Type: ALL
Minimum DZ: -1.082
Maximum DZ: 0.882
Mean DZ: 0.111
Mean Magnitude DZ: 0.879
Number Observations: 95
Standard Deviation DZ: 0.301
RMSE Z: 0.318
95th Percentile: 0.692
Units: Feet

Histogram



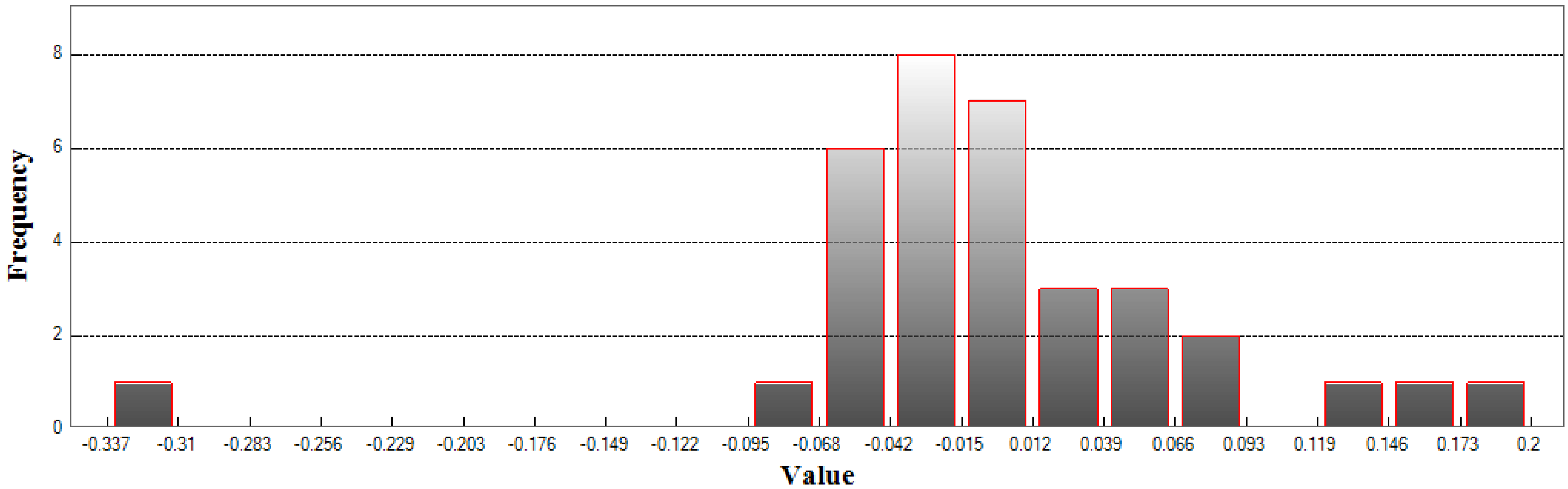
Min: -0.33
Max: 0.269
Number Of Bins: 20
Bin Interval: 0.03

DEM

Fundamental Vertical Accuracy

LandCover Type: FVA
Minimum DZ: -1.102
Maximum DZ: 0.656
Mean DZ: -0.009
Mean Magnitude DZ: 0.770
Number Observations: 34
Standard Deviation DZ: 0.282
RMSE Z: 0.278
95% Confidence Level Z: 0.544
Units: Feet

Histogram



Min: -0.336
Max: 0.2
Number Of Bins: 20
Bin Interval: 0.027

DEM (Continued)

Supplemental Vertical Accuracy
LandCover Type: TallWeeds

Minimum DZ: -0.183

Maximum DZ: 0.849

Mean DZ: 0.269

Mean Magnitude DZ: 0.980

Number Observations: 18

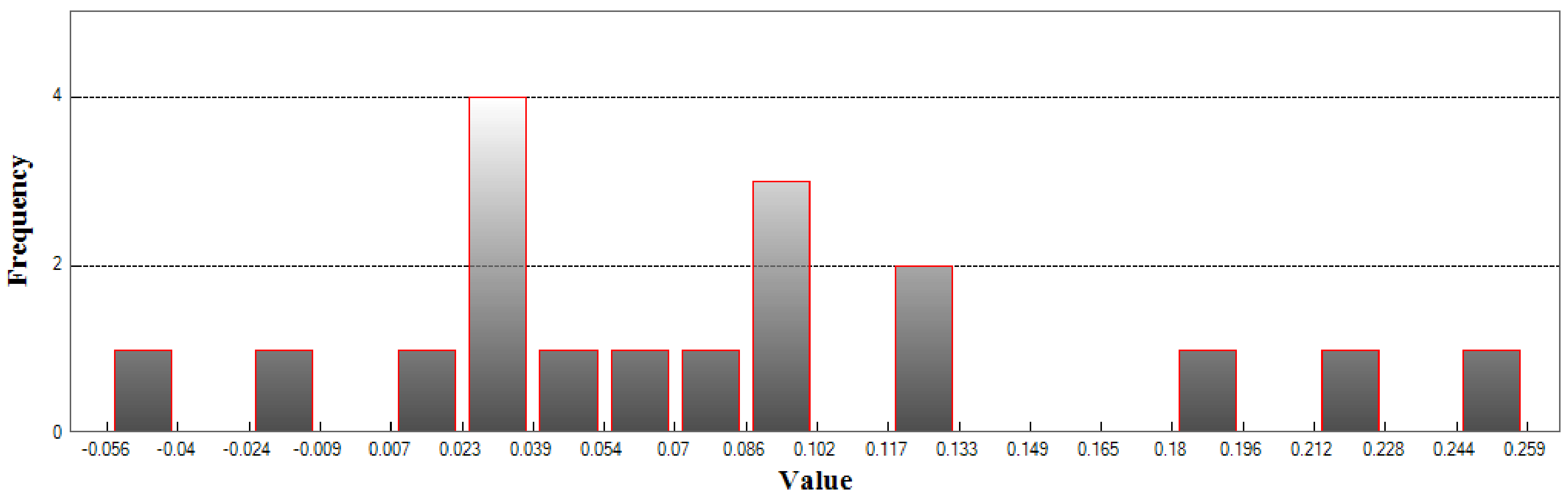
Standard Deviation DZ: 0.265

RMSE Z: 0.370

95th Percentile: 0.734

Units: Feet

Histogram



Min: -0.056

Max: 0.259

Number Of Bins: 20

Bin Interval: 0.016

DEM (Continued)

Supplemental Vertical Accuracy
LandCover Type: BrushLand

Minimum DZ: -0.200

Maximum DZ: 0.731

Mean DZ: 0.275

Mean Magnitude DZ: 1.017

Number Observations: 18

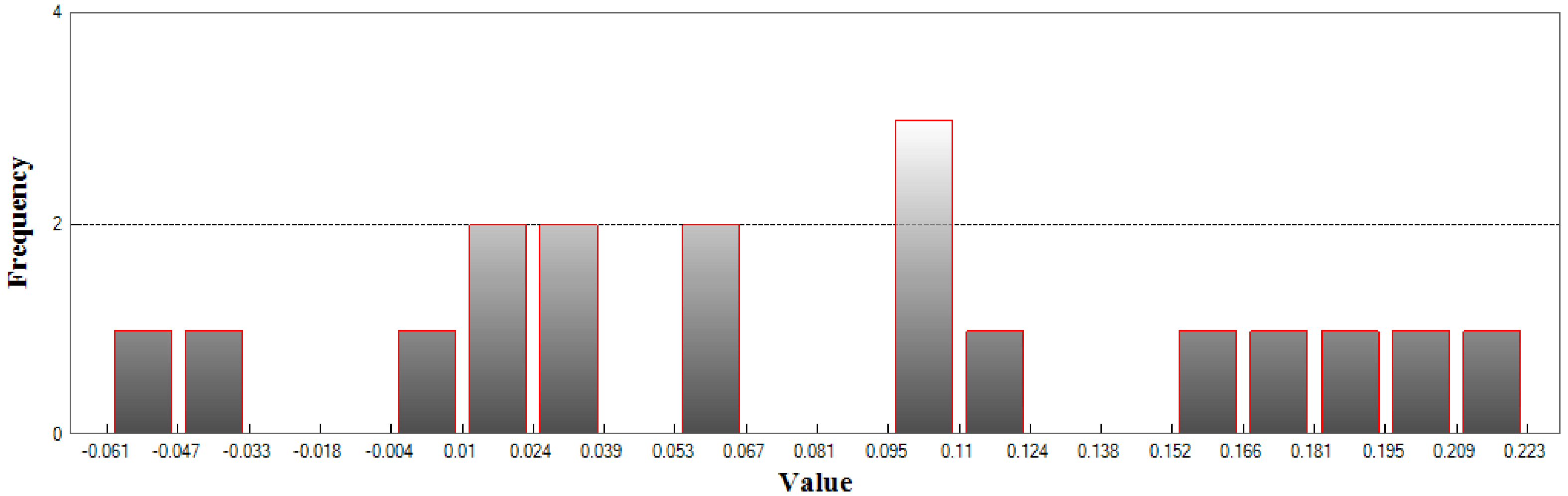
Standard Deviation DZ: 0.278

RMSE Z: 0.387

95th Percentile: 0.679

Units: Feet

Histogram



Min: -0.061

Max: 0.223

Number Of Bins: 20

Bin Interval: 0.014

DEM (Continued)

Supplemental Vertical Accuracy
LandCover Type: Forested

Minimum DZ: -0.495

Maximum DZ: 0.570

Mean DZ: 0.019

Mean Magnitude DZ: 0.843

Number Observations: 25

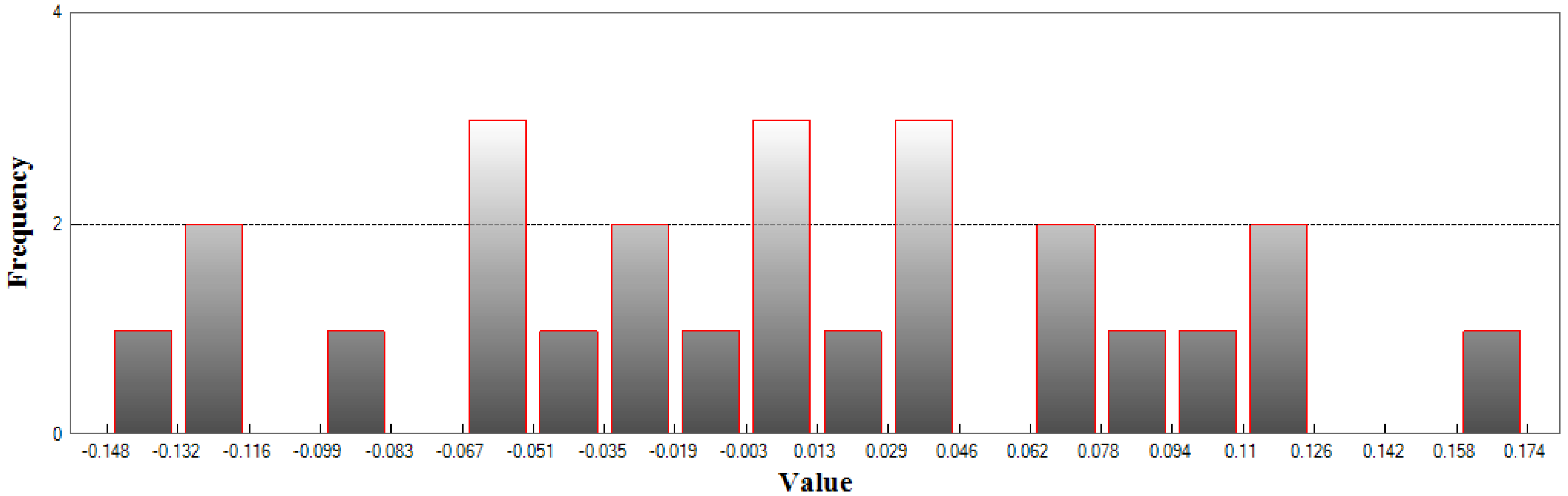
Standard Deviation DZ: 0.272

RMSE Z: 0.265

95th Percentile: 0.469

Units: Feet

Histogram



Min: -0.148

Max: 0.174

Number Of Bins: 20

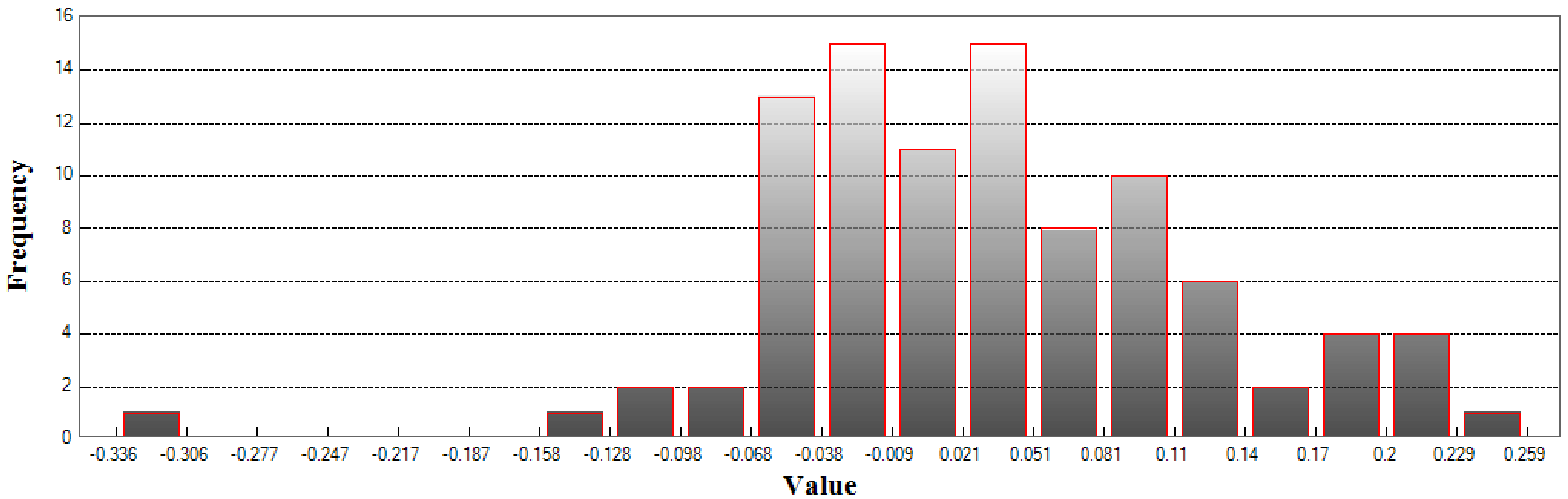
Bin Interval: 0.016

DEM (Continued)

Consolidated Vertical Accuracy

LandCover Type: ALL
Minimum DZ: -1.102
Maximum DZ: 0.849
Mean DZ: 0.104
Mean Magnitude DZ: 0.882
Number Observations: 95
Standard Deviation DZ: 0.301
RMSE Z: 0.318
95th Percentile: 0.659
Units: Feet

Histogram



Min: -0.336
Max: 0.259
Number Of Bins: 20
Bin Interval: 0.03