Project Report

FY13 Suwannee River water Management LiDAR Area 4 Florida State Plane North

Prepared For:

United States Geological Survey

Prepared By:

Digital Aerial Solutions, LLC

CONTRACT: #G10PC00093
CONTRACTOR: DIGITAL AERIAL SOLUTIONS
TASK ORDER: #G13PD00141

Project Report
LiDAR Collection, Processing, and QA/QC

2013 Suwannee Management LiDAR Task Order G13PD00141

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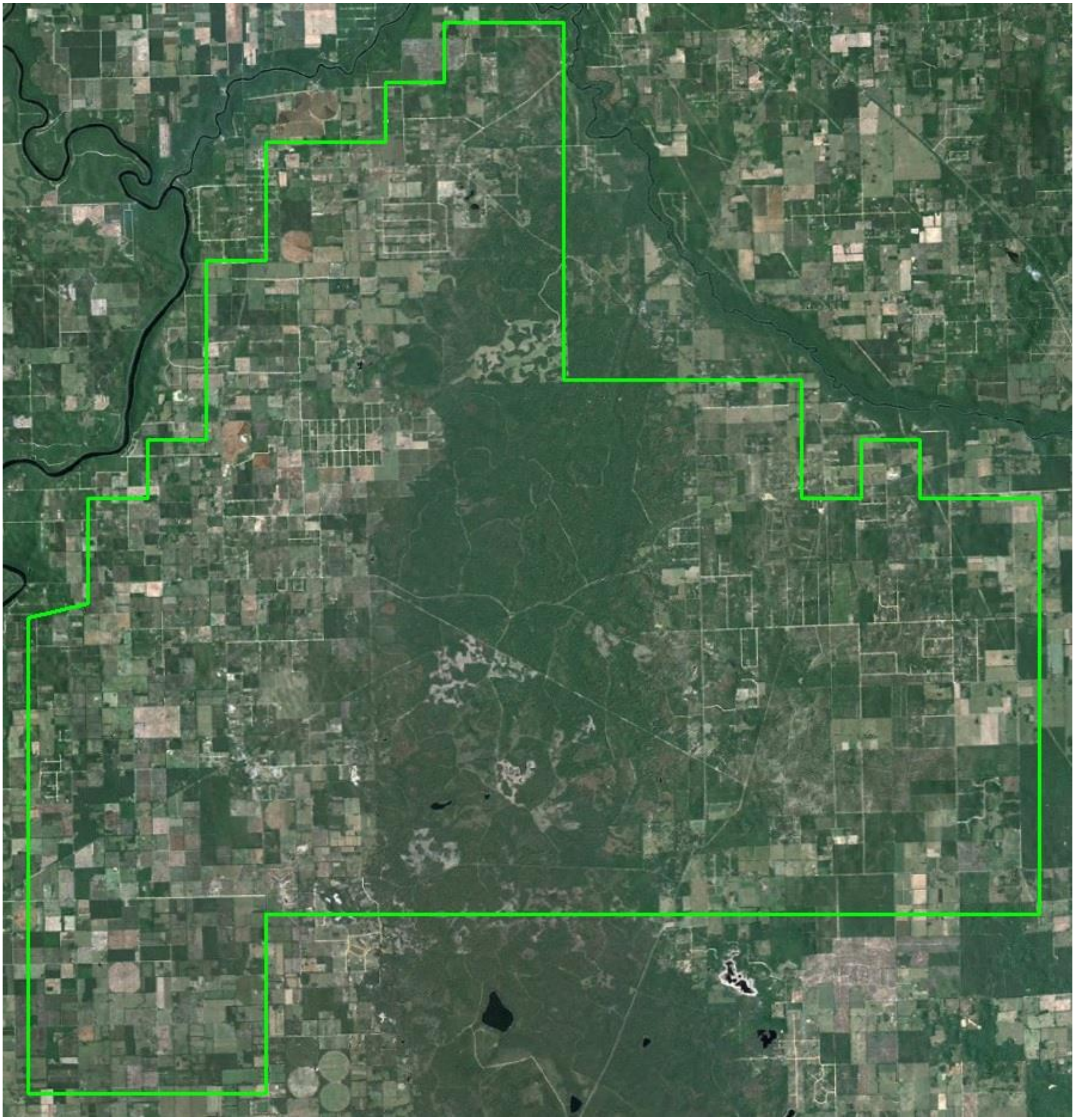

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1 Introduction and Specifications

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 area4 encompasses approximately 160 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.

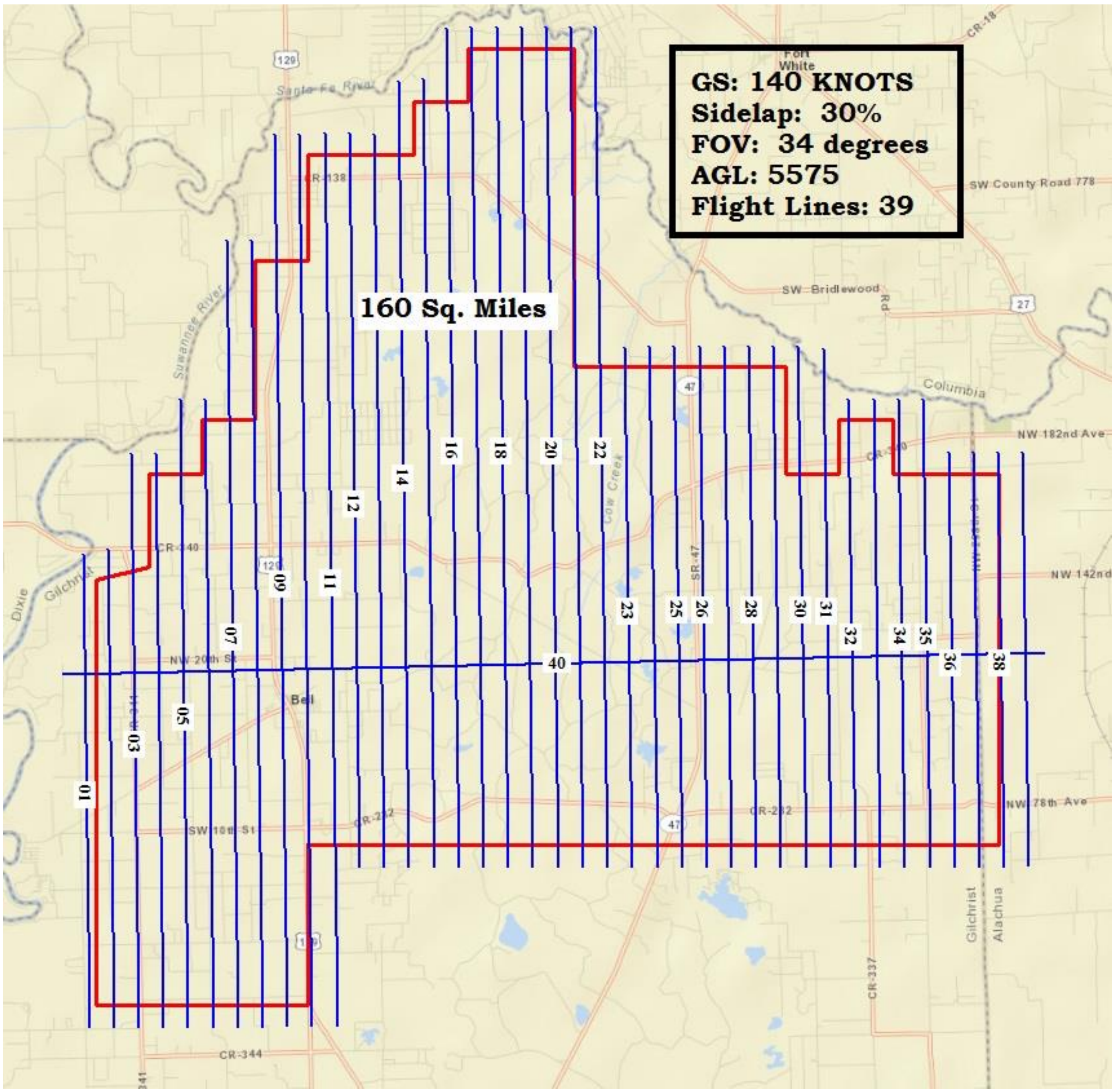
Horizontal Spatial Reference
- Datum: North American Datum of 1983 (National Spatial Reference System 2007)
- Coordinates: State Plane Florida North

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 4 survey covers approximately 160 square miles located in north central Florida. The flight plan consisted of 39 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 FY 13 Suwannee River water Management Area 4 LiDAR project are summarized below.

Parameter	Value
Flying Height Above Ground Level	5,575 feet
Nominal Sidelap	30%
Nominal Speed Over Ground	140 knots
Field of View	34°
Laser Rate	133 kHz
Scan Rate	64.3 hz
Maximum Cross Track Spacing	1.32 meters
Maximum Along Track Spacing	1.32 meters
Average Spacing	.75 meters

3.3 Acquisition Mission

The acquisition mission for the FY 13 Suwannee River water Management Area 4 LiDAR survey was coordinated to be acquired in 1 week. Collection began on February 16th 2013 and was completed on February 17th, 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 4 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 4 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 4 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 4 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 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 4 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 4 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 raw swath FVA of the TIN tested RMSEz 0.291 feet and 0.570 feet at the 95% confidence level in open terrain. Bare earth FVA of the DEM tested at an RMSEz of 0.173 and 0.344 meters at the 95% confidence level in open terrain. The full calculations for all check points can be found in Appendix B.

Raw Swath FVA of TIN

$RMSE_Z$ =	0.291	feet
NSSDA=	0.570	feet

Bare Earth FVA of DEM

$RMSE_Z$ =	0.173	feet
NSSDA=	0.344	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

DAS
Digital Aerial Solutions

ALS60 LiDAR Flight Log

Project	Suwannee 2013	ALS60	N6130_090724		Sensor Operator/s
				-	Bertin Evina-Ze
Date/Julian:	2/16/2013 Cross City	Mem Drive MM60	Int. Time: TAR AIRSPD (KNTS)	Base PID:	Pilot/s
Hobbs End	688.5	6-600110120	140	DG4685	MWAZ
Hobbs ST	684.4	LIFT A	TAR ALT AGL (ft):	Flight Plan(s): Block 4	Base Height: 1.500
Flight Time	4.1		5,575	Aircraft: 421C 112MJ	Airport Idnt: KCTY

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 4						-	-	-	62				Static Alignment
		1	130217_013928	1:39	1:42	5,570	180	134	61	19	1.2	0.6	CLEAR
		2	130217_014612	1:46	1:50	5,570	0	135	60	19	1.2	0.6	CLEAR
		3	130217_015305	1:53	1:57	5,570	180	138	59	19	1.1	0.6	CLEAR
		4	130217_020018	2:00	2:04	5,570	0	135	58	19	1.1	0.6	CLEAR
		5	130217_020744	2:07	2:12	5,570	180	142	57	19	1.1	0.6	CLEAR
		6	130217_021638	2:16	2:21	5,570	0	134	56	19	1.0	0.6	CLEAR
		7	130217_022516	2:25	2:30	5,570	180	137	55	20	1.0	0.6	CLEAR
		8	130217_023453	2:34	2:40	5,570	0	132	54	17	1.1	0.6	CLEAR
		9	130217_024358	2:43	2:50	5,570	180	140	52	16	1.2	0.7	CLEAR
		10	130217_025420	2:54	3:01	5,570	0	131	50	17	1.2	0.7	CLEAR
		11	130217_030407	3:04	3:10	5,570	180	141	49	18	1.0	0.6	CLEAR
		12	130217_031417	3:14	3:19	5,570	0	127	47	17	1.1	0.6	CLEAR
		13	130217_032251	3:22	3:27	5,570	180	138	46	18	1.1	0.6	CLEAR
		14	130217_033237	3:32	3:38	5,570	0	128	45	17	1.1	0.6	CLEAR
		15	130217_034149	3:41	3:47	5,570	180	141	43	18	1.1	0.6	CLEAR
		16	130217_035130	3:51	3:57	5,570	0	128	42	16	1.3	0.7	CLEAR
		17	130217_040039	4:00	4:06	5,570	180	138	40	17	1.2	0.6	CLEAR
		18	130217_041019	4:10	4:16	5,570	0	126	39	16	1.2	0.7	CLEAR
		19	130217_041941	4:19	4:25	5,570	180	138	38	16	1.2	0.6	CLEAR
		20	130217_042933	4:29	4:35	5,570	0	128	36	16	1.2	0.6	CLEAR
		21	130217_043816	4:38	4:44	5,570	180	143	34	15	1.2	0.7	CLEAR
		22	130217_044817	4:48	4:54	5,570	0	128	33	17	1.1	0.6	CLEAR
		40	130217_050056	5:00	5:07	5,570	270	127	31	15	1.2	0.7	X-STRIP
		40	130217_051044	5:10	5:15	5,570	90	140	30	15	1.2	0.7	X-STRIP

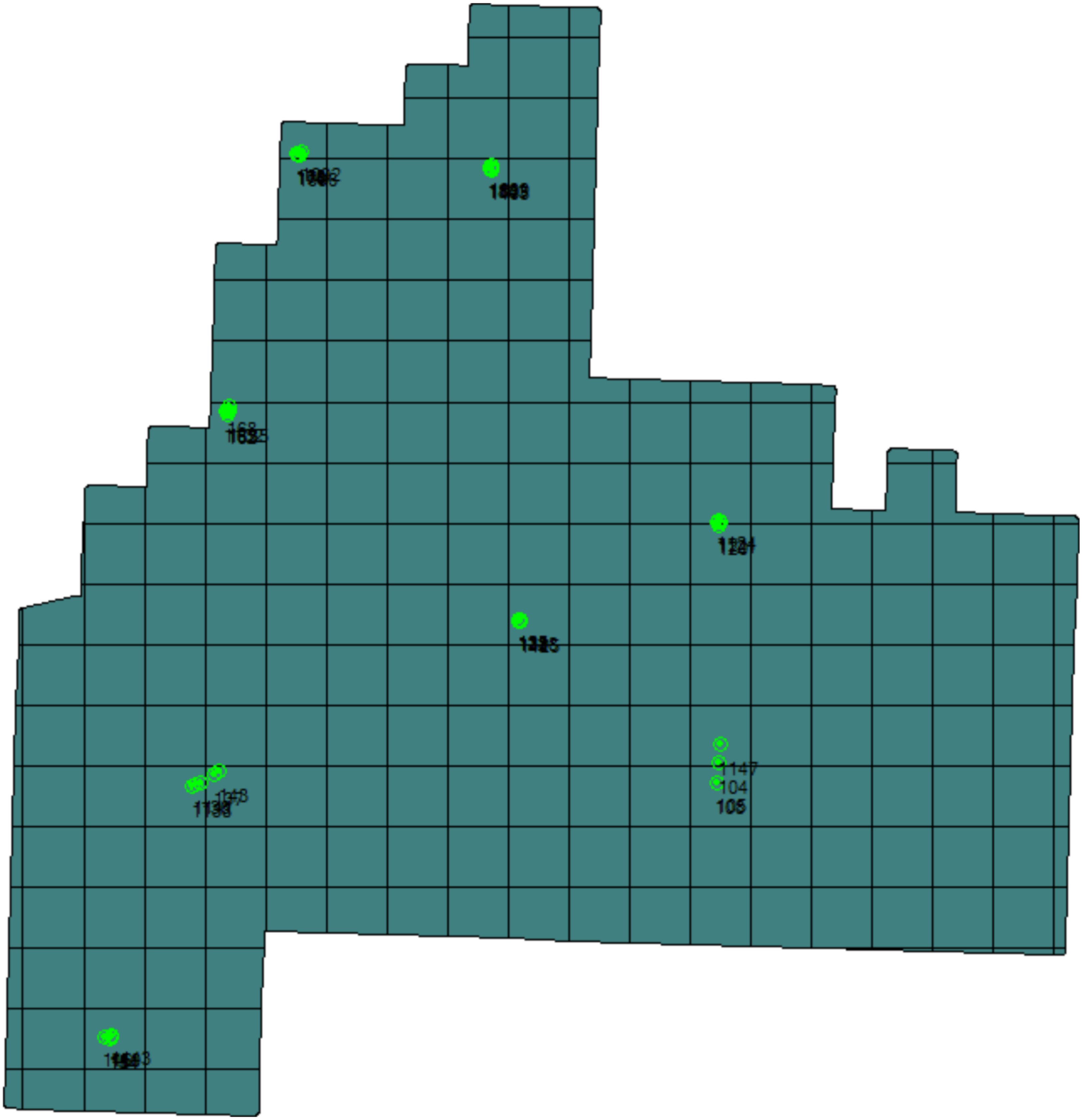
ALS60 LiDAR Flight Log

Project	Suwannee 2013	ALS60	N6130_090724			Sensor Operator/s
					-	Bertin Evina-Ze
Date/Julian:	2/17/2013 Cross City	Mem Drive MM60	Int. Time:	TAR AIRSPD (KNTS)	Base PID:	Pilot/s
Hobbs End	691.2	2-600059224		140	DG4685	MWAZ
Hobbs ST	688.5	LIFT A		TAR ALT AGL (ft):	Flight Plan(s): / Base Height:	Aircraft / Airport Idnt:
Flight Time	2.7			5,575	Block 4 / 1.500	421C 112MJ / KCTY

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 4						-	-	-	139				Static Alignment
		23	130217_150154	15:01	15:05	5,540	0	123	137	14	1.3	0.8	CLEAR
		24	130217_150947	15:09	15:13	5,540	180	139	137	15	1.3	0.7	CLEAR
		25	130217_151759	15:17	15:21	5,540	0	126	136	15	1.4	0.7	CLEAR
		26	130217_152608	15:26	15:29	5,540	180	140	135	16	1.2	0.7	CLEAR
		27	130217_153332	15:33	15:37	5,540	0	125	134	17	1.2	0.7	CLEAR
		28	130217_154105	15:41	15:44	5,540	180	138	133	17	1.2	0.7	CLEAR
		29	130217_154831	15:48	15:52	5,540	0	125	132	16	1.4	0.7	CLEAR
		30	130217_155549	15:55	15:59	5,540	180	132	131	15	1.6	0.7	CLEAR
		31	130217_160346	16:03	16:07	5,540	0	127	130	16	1.3	0.6	CLEAR
		32	130217_161017	16:10	16:13	5,540	180	133	129	16	1.3	0.6	CLEAR
		33	130217_161754	16:17	16:21	5,540	0	127	128	18	1.1	0.6	CLEAR
		34	130217_162452	16:24	16:28	5,540	180	132	127	17	1.2	0.6	CLEAR
		35	130217_163204	16:32	13:36	5,540	0	129	126	18	1.2	0.6	CLEAR
		36	130217_163817	16:38	16:41	5,540	180	136	126	18	1.1	0.6	CLEAR
		37	130217_164534	16:45	16:48	5,540	0	134	125	18	1.1	0.6	CLEAR
		38	130217_165138	16:51	16:54	5,540	180	135	124	18	1.1	0.6	CLEAR
		39	130217_165826	16:58	17:01	5,540	0	135	123	17	1.1	0.6	CLEAR
		40	130217_170533	17:05	17:09	5,540	270	139	122	17	1.1	0.6	X-STRIP
		40	130217_171257	17:12	17:17	5,540	90	133	121	15	1.3	0.7	X-STRIP

Appendix B. Vertical Accuracy Calculations

Tiled-Data Area



LiDAR Accuracy Assessment Summary

LC Type	# of Points	FVA	SVA	CVA
Classified LAS				
ALL	41			0.685
FVA	12	0.295		
Tallweeds	7		0.649	
Brushland	7		0.813	
Forested	15		0.748	
Total	41			
Bare Earth DEM				
ALL	41			0.744
FVA	12	0.344		
Tallweeds	7		0.708	
Brushland	7		0.826	
Forested	15		0.780	
Total	41			

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)	☑	104					
			331707.437	3293074.322	24.063	24.002	24.002
					-0.061	-0.061	FVA
2)	☑	120					
			331708.913	3298962.259	17.881	17.843	17.858
					-0.038	-0.023	FVA
3)	☑	121					
			331734.608	3299031.122	17.842	17.802	17.801
					-0.04	-0.041	FVA
4)	☑	131					
			326781.658	3296620.34	21.681	21.79	21.791
					0.109	0.11	FVA
5)	☑	132					
			326753.239	3296611.309	22.332	22.406	22.384
					0.074	0.052	FVA
6)	☑	136					
			318897.697	3292562.868	19.53	19.529	19.527
					-0.001	-0.003	FVA
7)	☑	146					
			316499.541	3286314.997	15.244	15.185	15.232
					-0.059	-0.012	FVA

		ID				
			Survey X	Survey Y	Z1	Z DEM	Z LAS
					ΔZ DEM	ΔZ LAS	LC Type
8)	☑	150					
			316702.046	3286307.599	15.49	15.464	15.463
					-0.026	-0.027	FVA
9)	☑	157					
			319568.321	3301756.52	14.559	14.571	14.565
					0.012	0.006	FVA
10)	☑	168					
			319596.311	3301915.184	14.784	14.771	14.762
					-0.013	-0.022	FVA
11)	☑	169					
			321296.214	3308144.044	14.615	14.676	14.647
					0.061	0.032	FVA
12)	☑	170					
			321290.207	3308120.634	13.826	13.784	13.778
					-0.042	-0.048	FVA
13)	☑	105					
			331674.361	3292593.78	19.132	19.323	19.341
					0.191	0.209	Tallweeds
14)	☑	125					
			326784.175	3296622.373	21.706	21.674	21.683
					-0.032	-0.023	Tallweeds

	ID					
		Survey X	Survey Y	Z1	Z DEM	Z LAS
				ΔZ DEM	ΔZ LAS	LC Type
15)	☑	137				
		319241.742	3292767.558	20.104	20.186	20.182
				0.082	0.078	Tallweeds
16)	☑	154				
		316650.731	3286243.955	14.726	14.953	14.899
				0.227	0.173	Tallweeds
17)	☑	165				
		319564.101	3301758.559	14.539	14.587	14.601
				0.048	0.062	Tallweeds
18)	☑	174				
		321302.129	3308095.609	12.895	12.984	12.956
				0.089	0.061	Tallweeds
19)	☑	181				
		326067.328	3307780.207	22.848	22.918	22.905
				0.07	0.057	Tallweeds
20)	☑	108				
		331655.842	3292559.226	18.639	18.92	18.925
				0.281	0.286	Brushland
21)	☑	128				
		326756.168	3296592.381	22.297	22.253	22.26
				-0.044	-0.037	Brushland

	ID					
		Survey X	Survey Y	Z1	Z DEM	Z LAS
				ΔZ DEM	ΔZ LAS	LC Type
22) ☑	143					
		319356.166	3292869.402	19.531	19.506	19.501
				-0.025	-0.03	Brushland
23) ☑	151					
		316650.663	3286256.856	14.781	14.941	14.942
				0.16	0.161	Brushland
24) ☑	162					
		319566.794	3301689.817	15.474	15.659	15.601
				0.185	0.127	Brushland
25) ☑	171					
		321268.104	3308118.825	13.418	13.3	13.308
				-0.118	-0.11	Brushland
26) ☑	184					
		326045.258	3307786.927	22.765	22.842	22.833
				0.077	0.068	Brushland
27) ☑	1092					
		321386.857	3308186.622	16.045	15.986	15.982
				-0.059	-0.063	Forested
28) ☑	1096					
		321343.788	3308094.186	14.667	14.682	14.665
				0.015	-0.002	Forested

	ID					
		Survey X	Survey Y	Z1	Z DEM	Z LAS
				ΔZ DEM	ΔZ LAS	LC Type
29) ☑	1099					
		326078.417	3307842.51	22.142	22.192	22.187
				0.05	0.045	Forested
30) ☑	1103					
		326034.735	3307772.992	22.735	22.725	22.745
				-0.01	0.01	Forested
31) ☑	1105					
		326067.135	3307733.696	22.691	22.721	22.72
				0.03	0.029	Forested
32) ☑	1121					
		331678.689	3299017.844	16.483	16.555	16.554
				0.072	0.071	Forested
33) ☑	1124					
		331692.815	3299083.072	17.932	17.919	17.947
				-0.013	0.015	Forested
34) ☑	1125					
		326805.348	3296563.303	21.91	22.066	22.077
				0.156	0.167	Forested
35) ☑	1128					
		326754.238	3296578.907	22.061	22.335	22.336
				0.274	0.275	Forested

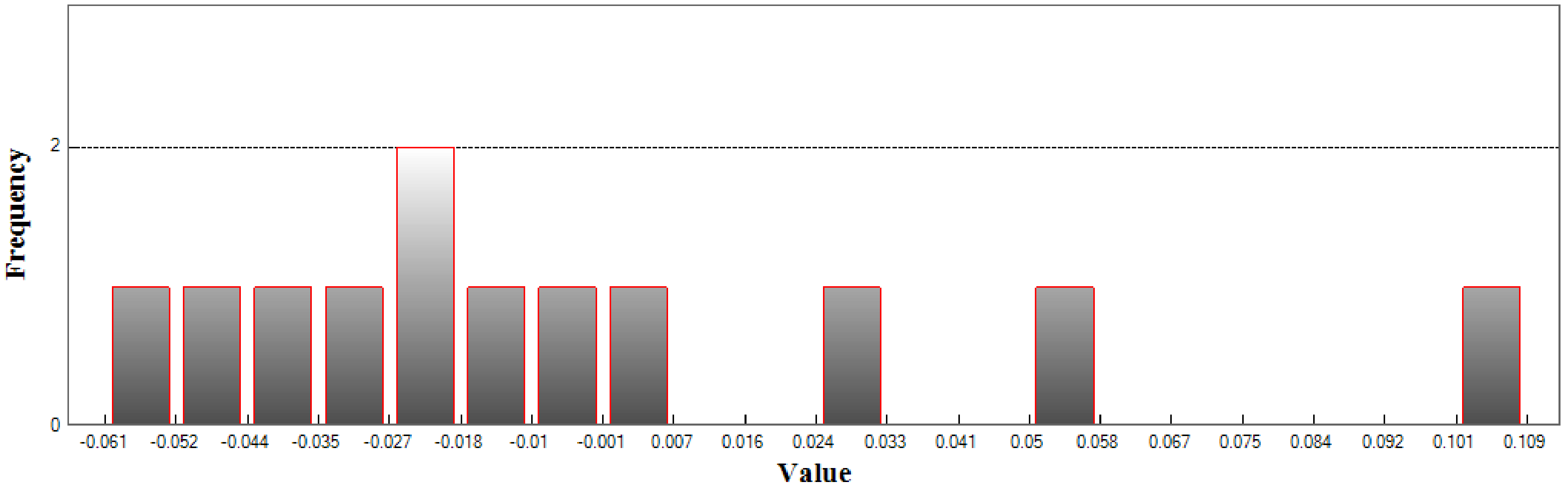
	ID					
		Survey X	Survey Y	Z1	Z DEM	Z LAS
				ΔZ DEM	ΔZ LAS	LC Type
36) ☑	1132					
		319510.689	3301756.155	14.217	14.157	14.168
				-0.06	-0.049	Forested
37) ☑	1135					
		319609.869	3301765.695	14.977	15.073	15.072
				0.096	0.095	Forested
38) ☑	1138					
		318686.214	3292491.31	19.859	19.983	19.963
				0.124	0.104	Forested
39) ☑	1141					
		318752.723	3292538.561	20.05	20.094	20.094
				0.044	0.044	Forested
40) ☑	1143					
		316688.011	3286350	15.642	15.689	15.691
				0.047	0.049	Forested
41) ☑	1147					
		331740.023	3293515.728	21.018	21.241	21.226
				0.223	0.208	Forested

Classified LAS

Fundamental Vertical Accuracy

LandCover Type: FVA
Minimum DZ: -0.200
Maximum DZ: 0.360
Mean DZ: -0.009
Mean Magnitude DZ: 0.626
Number Observations: 12
Standard Deviation DZ: 0.157
RMSE Z: 0.151
95% Confidence Level Z: 0.295
Units: Feet

Histogram

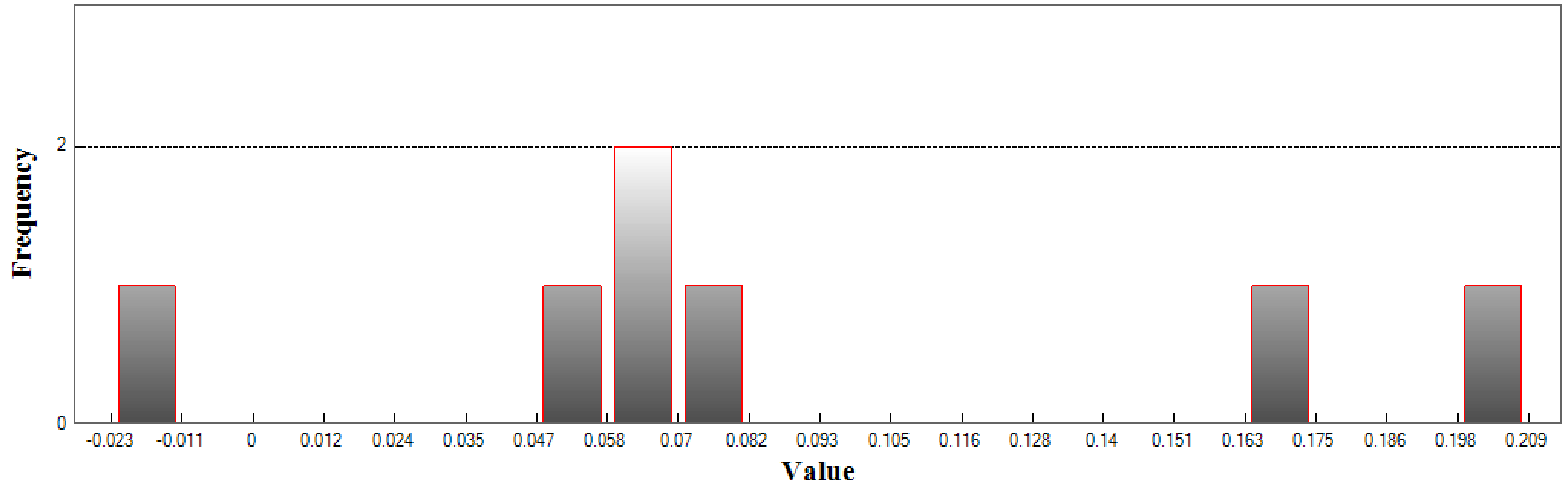


Min: -0.061
Max: 0.11
Number Of Bins: 20
Bin Interval: 0.009

Classified LAS (Continued)

Supplemental Vertical Accuracy
LandCover Type: Tallweeds
Minimum DZ: -0.075
Maximum DZ: 0.685
Mean DZ: 0.288
Mean Magnitude DZ: 1.010
Number Observations: 7
Standard Deviation DZ: 0.255
RMSE Z: 0.374
95th Percentile: 0.649
Units: Feet

Histogram

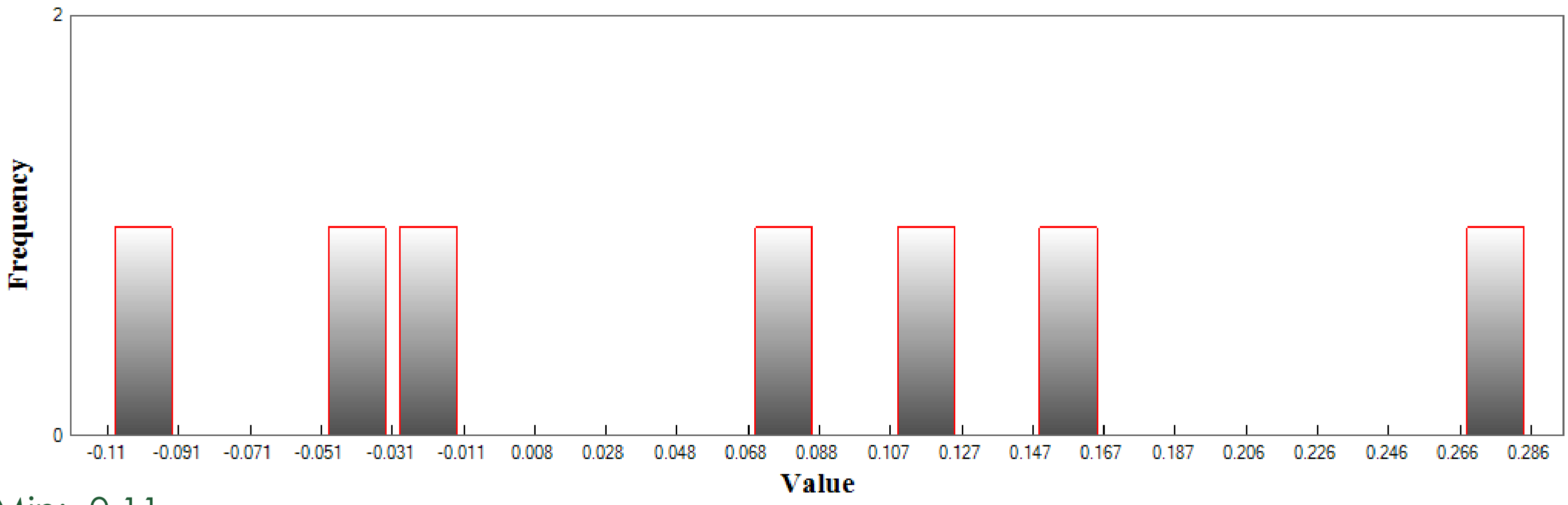


Min: -0.023
Max: 0.209
Number Of Bins: 20
Bin Interval: 0.012

Classified LAS (Continued)

Supplemental Vertical Accuracy
LandCover Type: Brushland
Minimum DZ: -0.360
Maximum DZ: 0.398
Mean DZ: 0.216
Mean Magnitude DZ: 1.122
Number Observations: 7
Standard Deviation DZ: 0.449
RMSE Z: 0.469
95th Percentile: 0.813
Units: Feet

Histogram

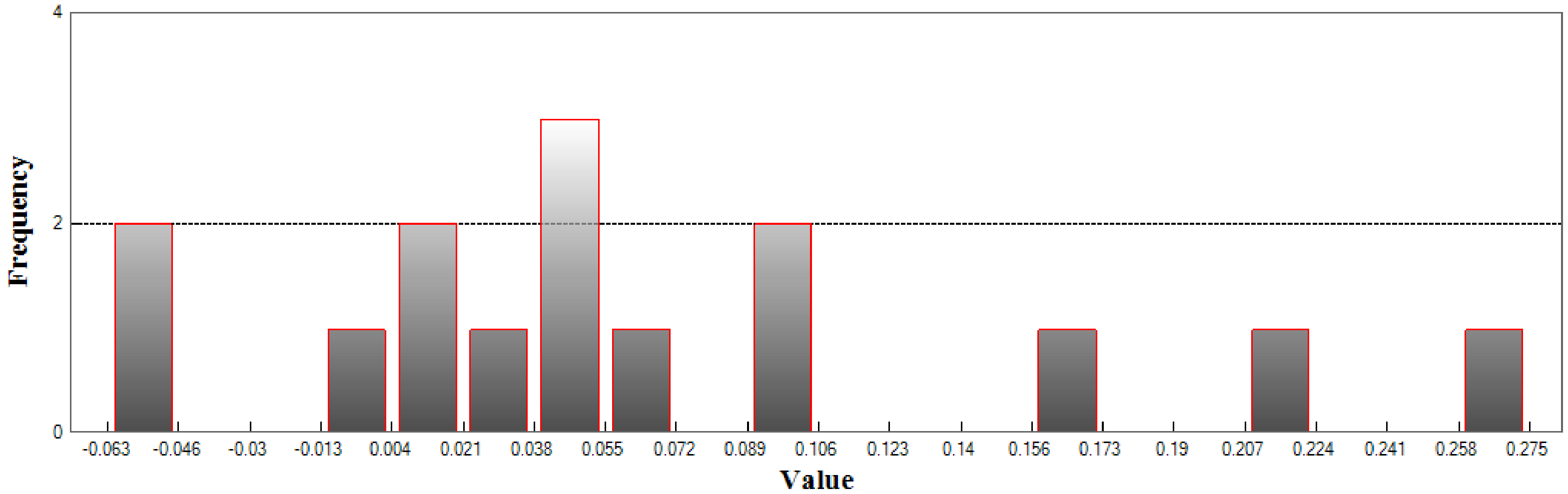


Min: -0.11
Max: 0.286
Number Of Bins: 20
Bin Interval: 0.02

Classified LAS (Continued)

Supplemental Vertical Accuracy
LandCover Type: Forested
Minimum DZ: -0.213
Maximum DZ: 0.902
Mean DZ: 0.216
Mean Magnitude DZ: 0.938
Number Observations: 15
Standard Deviation DZ: 0.301
RMSE Z: 0.364
95th Percentile: 0.748
Units: Feet

Histogram

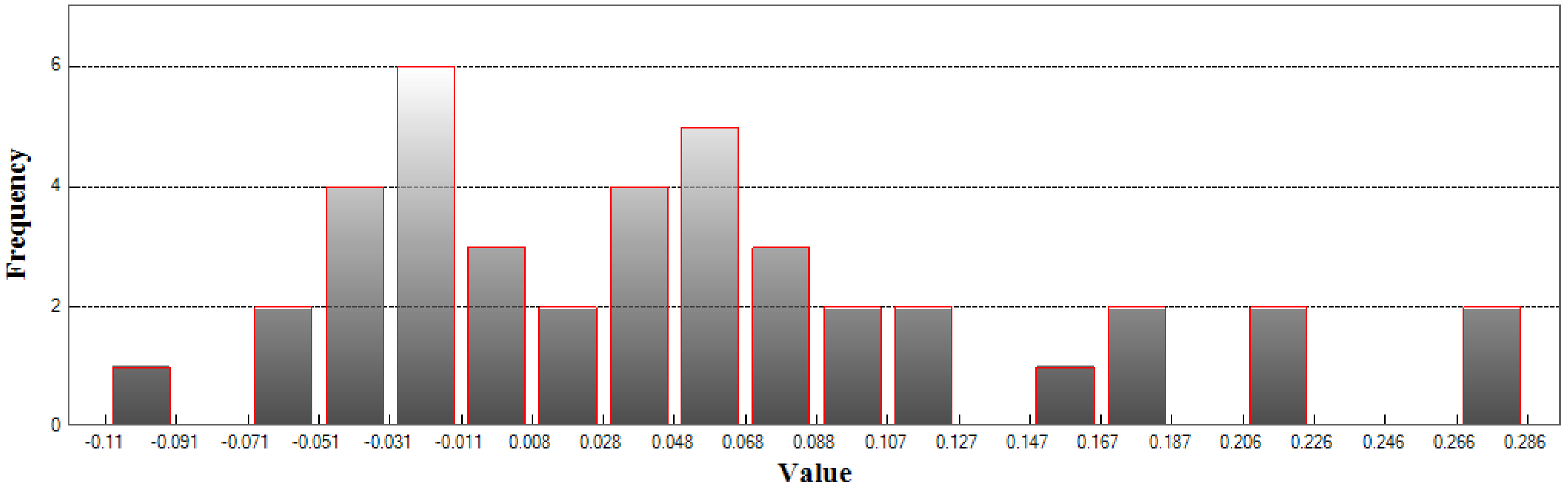


Min: -0.063
Max: 0.275
Number Of Bins: 20
Bin Interval: 0.017

Classified LAS (Continued)

Consolidated Vertical Accuracy
LandCover Type: ALL
Minimum DZ: -0.360
Maximum DZ: 0.938
Mean DZ: 0.164
Mean Magnitude DZ: 0.908
Number Observations: 41
Standard Deviation DZ: 0.305
RMSE Z: 0.341
95th Percentile: 0.685
Units: Feet

Histogram

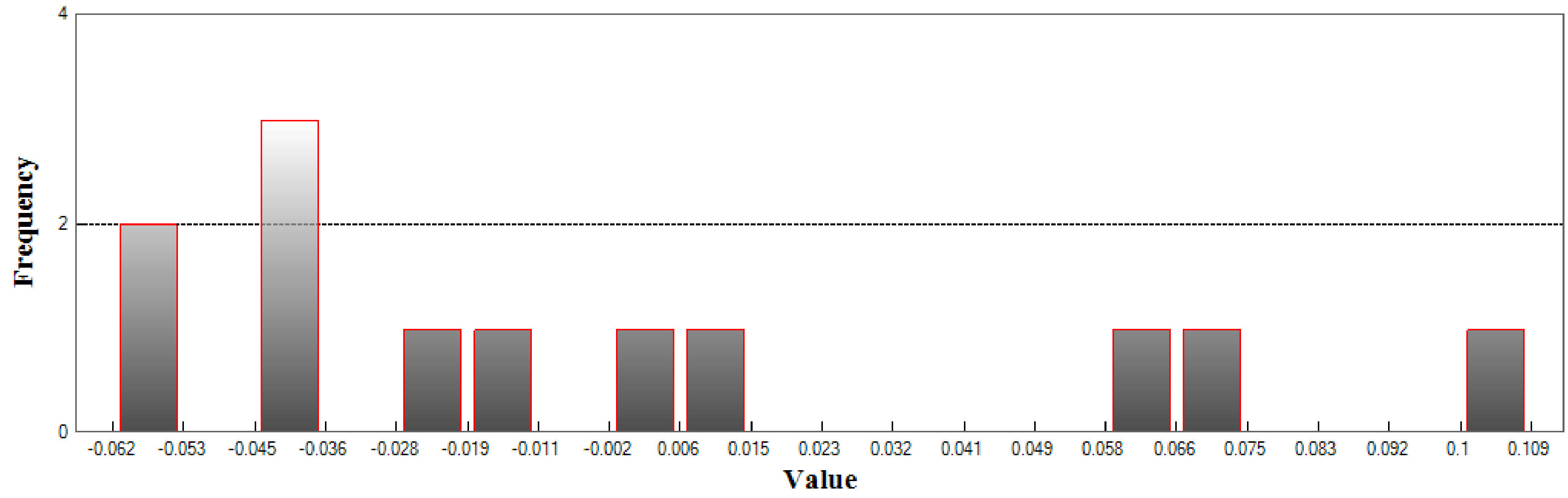


Min: -0.11
Max: 0.286
Number Of Bins: 20
Bin Interval: 0.02

Bare Earth DEM

Fundamental Vertical Accuracy
LandCover Type: FVA
Minimum DZ: -0.200
Maximum DZ: 0.357
Mean DZ: -0.006
Mean Magnitude DZ: 0.692
Number Observations: 12
Standard Deviation DZ: 0.183
RMSE Z: 0.173
95% Confidence Level Z: 0.344
Units: Feet

Histogram



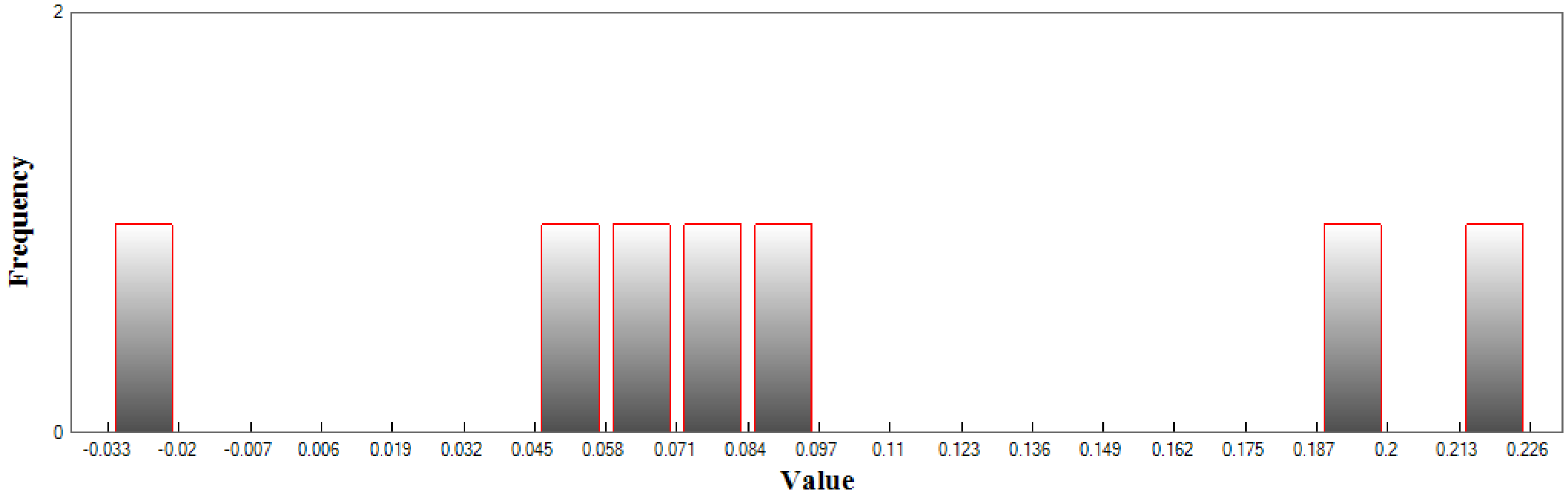
Min: -0.061
Max: 0.109
Number Of Bins: 20
Bin Interval: 0.009

Bare Earth DEM (Continued)

Supplemental Vertical Accuracy

LandCover Type: Tallweeds
Minimum DZ: -0.104
Maximum DZ: 0.744
Mean DZ: 0.314
Mean Magnitude DZ: 1.066
Number Observations: 7
Standard Deviation DZ: 0.285
RMSE Z: 0.413
95th Percentile: 0.708
Units: Feet

Histogram



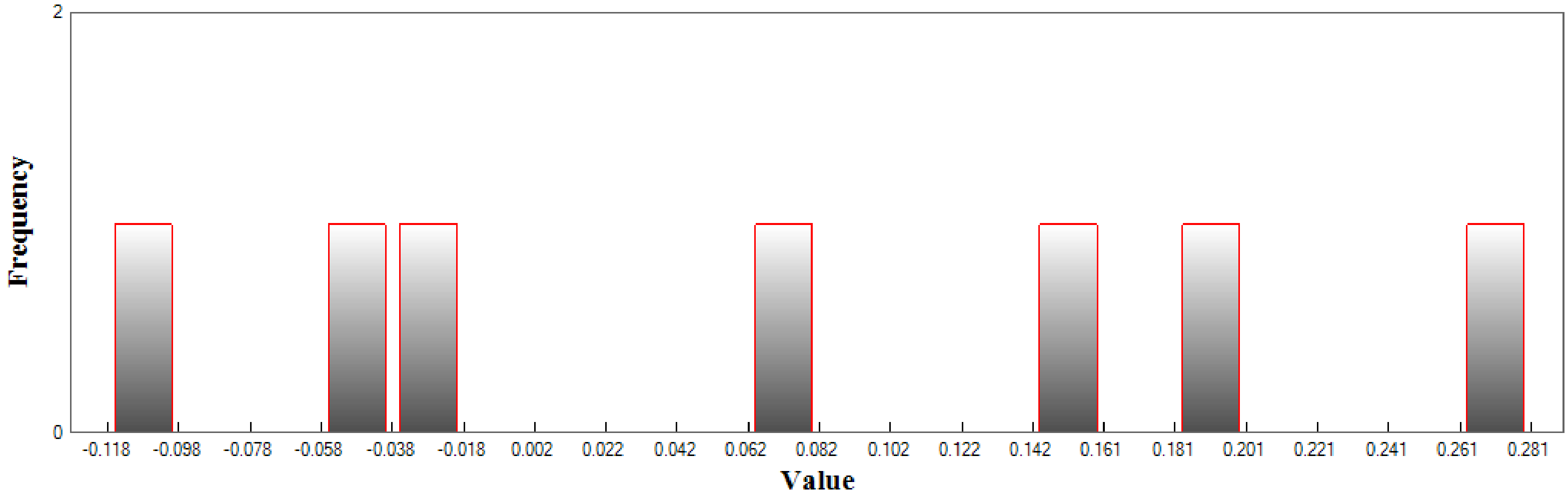
Min: -0.032
Max: 0.227
Number Of Bins: 20
Bin Interval: 0.013

Bare Earth DEM (Continued)

Supplemental Vertical Accuracy

LandCover Type: Brushland
Minimum DZ: -0.387
Maximum DZ: 0.921
Mean DZ: 0.242
Mean Magnitude DZ: 1.171
Number Observations: 7
Standard Deviation DZ: 0.469
RMSE Z: 0.498
95th Percentile: 0.826
Units: Feet

Histogram



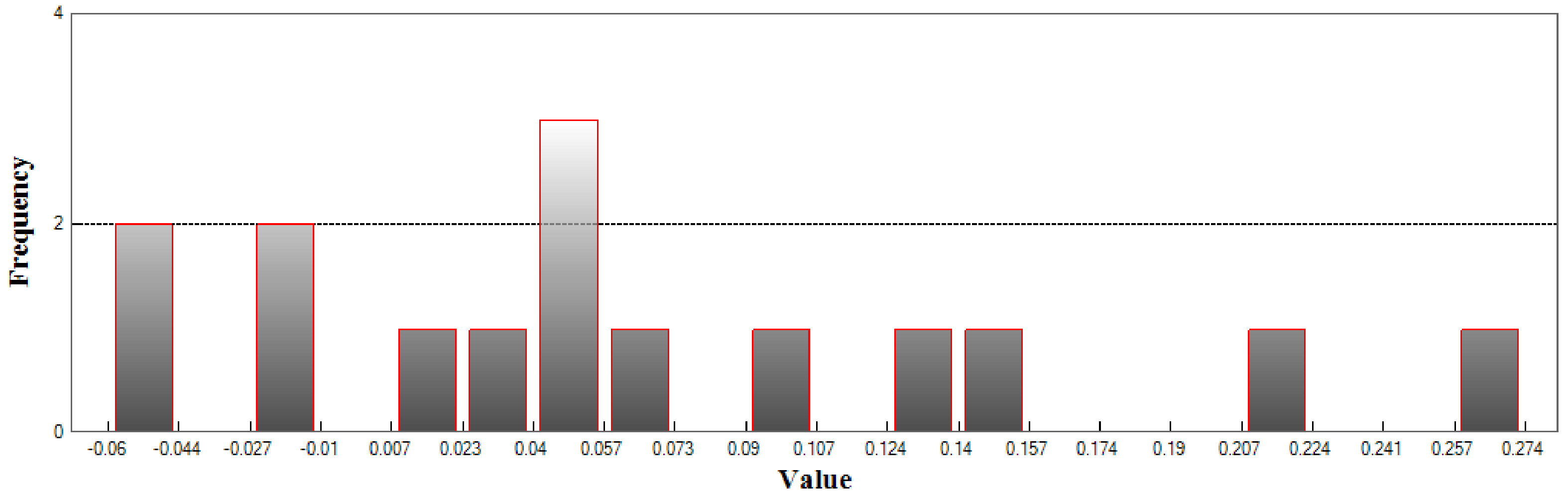
Min: -0.118
Max: 0.281
Number Of Bins: 20
Bin Interval: 0.02

Bare Earth DEM (Continued)

Supplemental Vertical Accuracy

LandCover Type: Forested
Minimum DZ: -0.196
Maximum DZ: 0.898
Mean DZ: 0.216
Mean Magnitude DZ: 0.954
Number Observations: 15
Standard Deviation DZ: 0.314
RMSE Z: 0.374
95th Percentile: 0.780
Units: Feet

Histogram



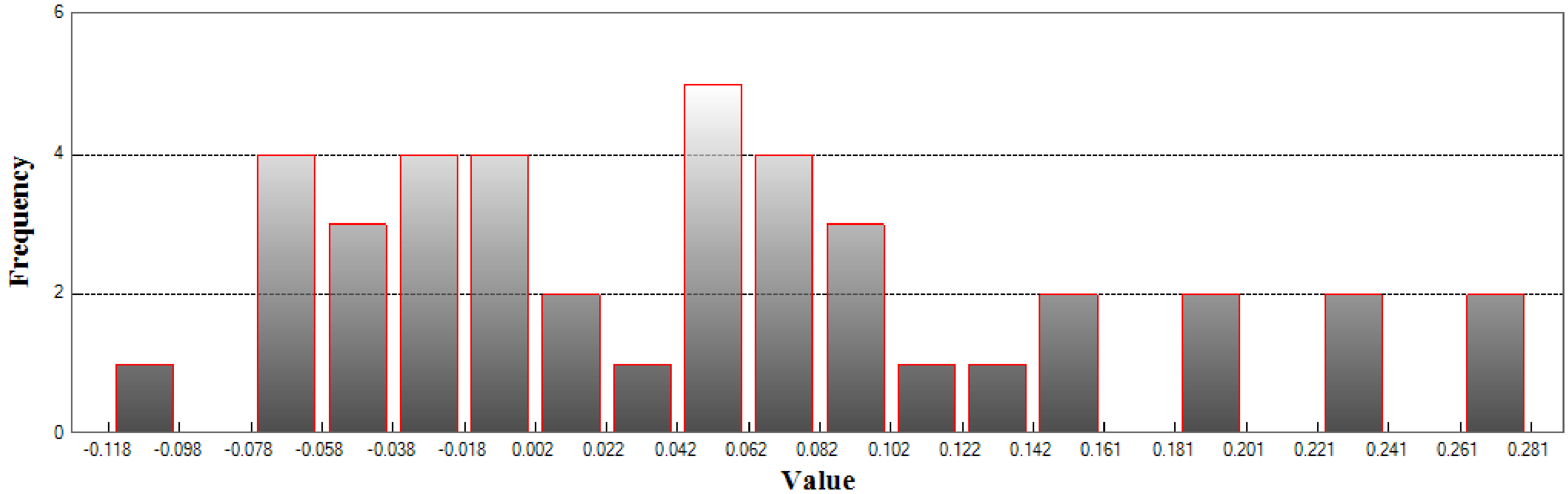
Min: -0.06
Max: 0.274
Number Of Bins: 20
Bin Interval: 0.017

Bare Earth DEM (Continued)

Consolidated Vertical Accuracy

LandCover Type: ALL
Minimum DZ: -0.387
Maximum DZ: 0.921
Mean DZ: 0.173
Mean Magnitude DZ: 0.951
Number Observations: 41
Standard Deviation DZ: 0.321
RMSE Z: 0.11
95th Percentile: 0.744
Units: Feet

Histogram



Min: -0.118
Max: 0.281
Number Of Bins: 20
Bin Interval: 0.02