LiDAR Project Report

NRCS-Christian County III, 4ppsm Lidar

Prepared For:

United States Geological Survey

Prepared By:

Digital Aerial Solutions, LLC

CONTRACT: #G10PC00093

CONTRACTOR: DIGITAL AERIAL SOLUTIONS

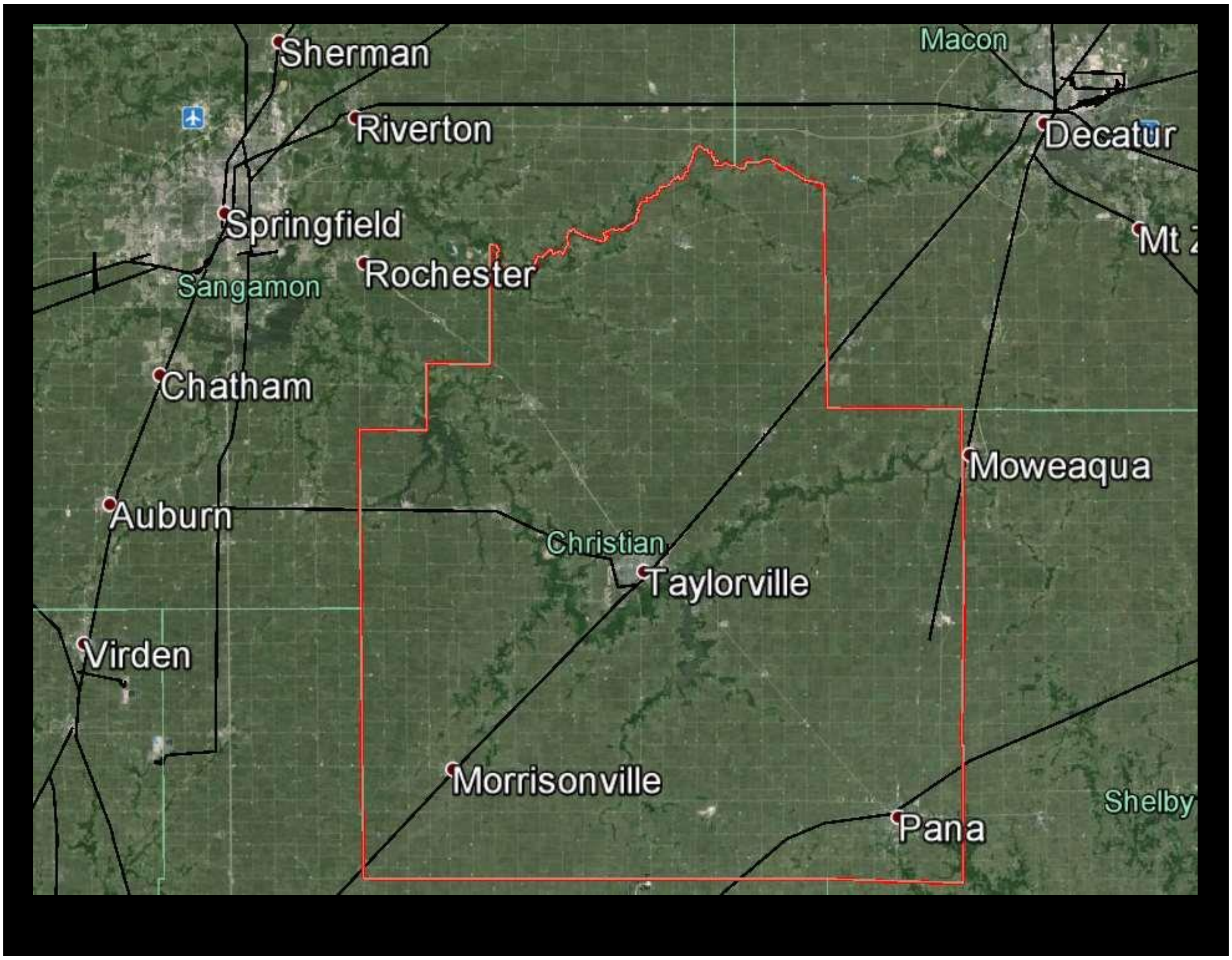
TASK ORDER: # G14PD00970

Project Report
LiDAR Collection, Processing, and QA/QC

NRCS-Christian County III, 4ppsm Lidar
Task Order G14PD00970

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


Sherman
Macon
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Springfield
Rochester
Sangamon
Chatham
Moweaqua
Auburn
Christian
Taylorville
Virden
Morrisonville
Shelby
Pana

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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 NRCS-Christian County III, 4ppsm Lidar. The area encompasses approximately 715 square miles Aerial LiDAR data was collected utilizing an ALS70 and ALS80. The ALS70 is a discrete return topographic LiDAR mapping system manufactured by Leica Geosystems. LiDAR data collected for the NRCS-Christian County III, 4ppsm Lidar survey has a nominal pulse spacing of 0.5 meters, and includes up to 5 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, intensity tiles, 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 5280 feet x 5280 feet grid. Tile number is the appropriate cell number values found in the USNG index. All deliverables were generated in conformance with the *U.S. Geological Survey National Geospatial Program Guidelines and Base Specifications, Version 1.0.*

2 Spatial Reference System

The spatial reference of the data is as follows.

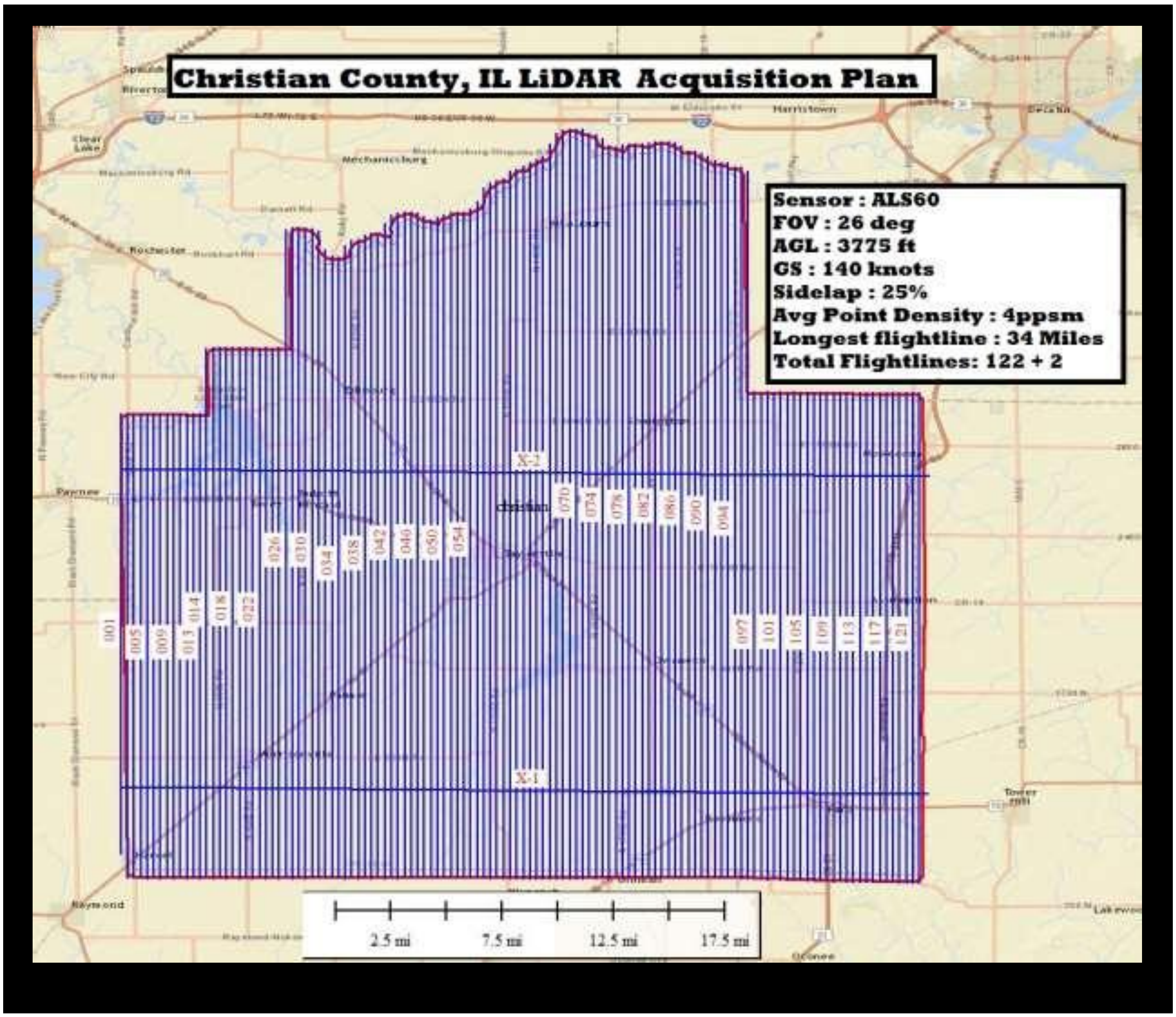
Horizontal Spatial Reference
- Datum: NAD83 HARN
- Coordinates: State Plane Coordinate System Illinois West (FIPS 1202), U.S. Survey Feet

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 (GEOID12B)

3 LiDAR Acquisition

3.1 Survey Area

The NRCS-Christian County III, 4ppsm Lidar survey covers approximately 715 square miles covering all of Christian Co. affecting Taylorville, Morrisonville, and Pana cities. The flight plan consisted of 122 survey lines and 2 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 NRCS-Christian County III, 4ppsm Lidar project are summarized below.

Parameter	Value
Flying Height Above Ground Level	3775 feet
Nominal Sidelap	25%
Nominal Speed Over Ground	140 knots
Field of View	26°
Laser Rate	132 kHz
Scan Rate	66.2 hz
Maximum Cross Track Spacing	0.78 meters
Maximum Along Track Spacing	0.82 meters
Average Spacing	0.5 meters

3.3 Acquisition Mission

The acquisition mission for the NRCS-Christian County III, 4ppsm Lidar survey was coordinated to be acquired in 2 weeks. Due to weather conditions of snow and Ice, the collection began on December 3rd 2014 and was completed on March 16th, 2015. 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	ALS70 – SN1132	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 stations were selected and placed throughout 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 Leica'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.

Swath point clouds were assigned a unique File Source ID within the LAS file format before further processing. Swath files for the NRCS-Christian County III 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 ALS70 sensor system. Terrasolid's Terramatch software was used to calculate the IMU bore-site and mirror scale parameters for the NRCS-Christian County III 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.

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 NRCS-Christian County III 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 USNG index, State Plane 5280 feet x 5280 LAS format tiles for point cloud classification and derived product creation.

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:

```
Code 1 – Processed, but unclassified
Code 2 – Bare-earth ground
Code 3 – Low Vegetation is 0-5 feet
Code 4 – Medium Vegetation is 5-20 feet
Code 5 – High Vegetation is ≥ 20 feet
Code 6 – Buildings, bridges, other manmade structures
Code 7 – Noise (low or high, manually identified, if needed)
Code 9 – Water
Code 10 – Ignored Ground (Breakline Proximity)
Code 14 – Overlap Ground
Code 15 – Overlap Unclassified
Code 17 – Bridge Decks
```

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 100-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 USNG index.

The data collected for the NRCS-Christian County III, 4ppsm Lidar 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. 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 floating point raster TIF format with a cell size of 3 feet.

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 NRCS-Christian County III, 4ppsm 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.

There is not a systematic method of testing when testing horizontal accuracy in LiDAR. The estimated Horizontal accuracy at one sigma based on the flying height for the project, is between 10cm and 20cm according to manufacturer specifications.

Absolute vertical accuracy assessments for the point cloud data are made against ground check point data. For the NRCS-Christian County III, 4ppsm Lidar, 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. The FVA of the Swath LAS tested RMSEz 0.266 feet and 0.522 feet at the 95% confidence level in open terrain. FVA of the DEM tested at an RMSEz of 0.257 feet and 0.504 feet at the 95% confidence level in open terrain. The full calculations for all check points can be found in Appendix B.

FVA of Swath LAS

$RMSE_Z$ =	0.266	feet
NSSDA=	0.522	feet

FVA of DEM

$RMSE_Z$ =	0.257	feet
NSSDA=	0.504	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. Breakline 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 Base Mapping Specification version 1.0 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 USNG index, State Plane Zone.

Appendix A. Flight Logs

0312A	Flight	ALS80	Start Time	End Time	Revised Flt
1	G0	150312_013151	1:3	1:3	20
2	1	150312_013657	1:3	1:3	20
3	82	150312_014043	1:4	1:5	82
4	82	150312_015427	1:5	2:0	82
5	82	150312_020820	2:0	2:1	82
6	82	150312_022156	2:2	2:3	82
7	82	150312_023525	2:3	2:4	82
8	82	150312_024835	2:4	2:5	82
9	82	150312_030122	3:0	3:1	82
1	82	150312_031419	3:1	3:2	82
1	82	150312_032709	3:2	3:3	82
1	82	150312_034006	3:4	3:4	82
1	81	150312_035256	3:5	4:0	81
1	81	150312_040553	4:0	4:1	81
1	81	150312_041836	4:1	4:2	81
1	X0	150312_043201	4:3	4:3	9
1	X0	150312_044216	4:4	4:4	8
1	X0	150312_045421	4:5	5:0	7
1	X0	150312_050434	5:0	5:1	6
2	X0	150312_051545	5:1	5:1	5
0312B					
1	81	150312_201237	20:12	20:21	81
2	81	150312_202506	20:25	20:34	81
3	80	150312_203857	20:39	20:45	80
4	80	150312_204859	20:49	20:55	80
5	80	150312_205853	2:0	21:05	80
6	80	150312_210848	21:08	21:15	80
7	80	150312_211833	21:18	21:25	80
8	80	150312_212821	21:28	21:30	80
9	80	150312_213805	21:38	21:45	80
1	80	150312_214852	21:48	21:56	80
1	80	150312_215946	21:59	22:06	80
1	81	150312_221031	22:10	22:18	81
1	81	150312_222112	22:21	22:28	81
1	X0	150312_223223	22:32	22:43	1
1	X0	150312_224640	22:46	22:57	1
1	81	150312_230231	23:02	23:11	81
1	81	150312_231446	23:14	23:24	81
1	81	150312_232719	23:27	23:36	81
1	X0	150312_234128	23:41	23:44	1
2	X0	150312_234924	23:49	23:58	1
2	X0	150313_000148	:	:1	1

Appendix B. Vertical Accuracy Calculations

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12353 E. Easter Ave.
Centennial, CO 80112
(303) 627-4058

Project Information

Prepared By: Kenneth L. Coffey
Project Name: NRCS-Christian County ILL
Sensor Info: Leica ALS70 & ALS60
Required Nominal Pulse Spacing: 0.5
Vendor Name: Digital Aerial Solutions, LLC
Units: US Survey Feet
Percent of Extent Tolerance: Extents Not Checked
Date of Acquisition: Start: 1/26/2015 Finish: 2/13/2015

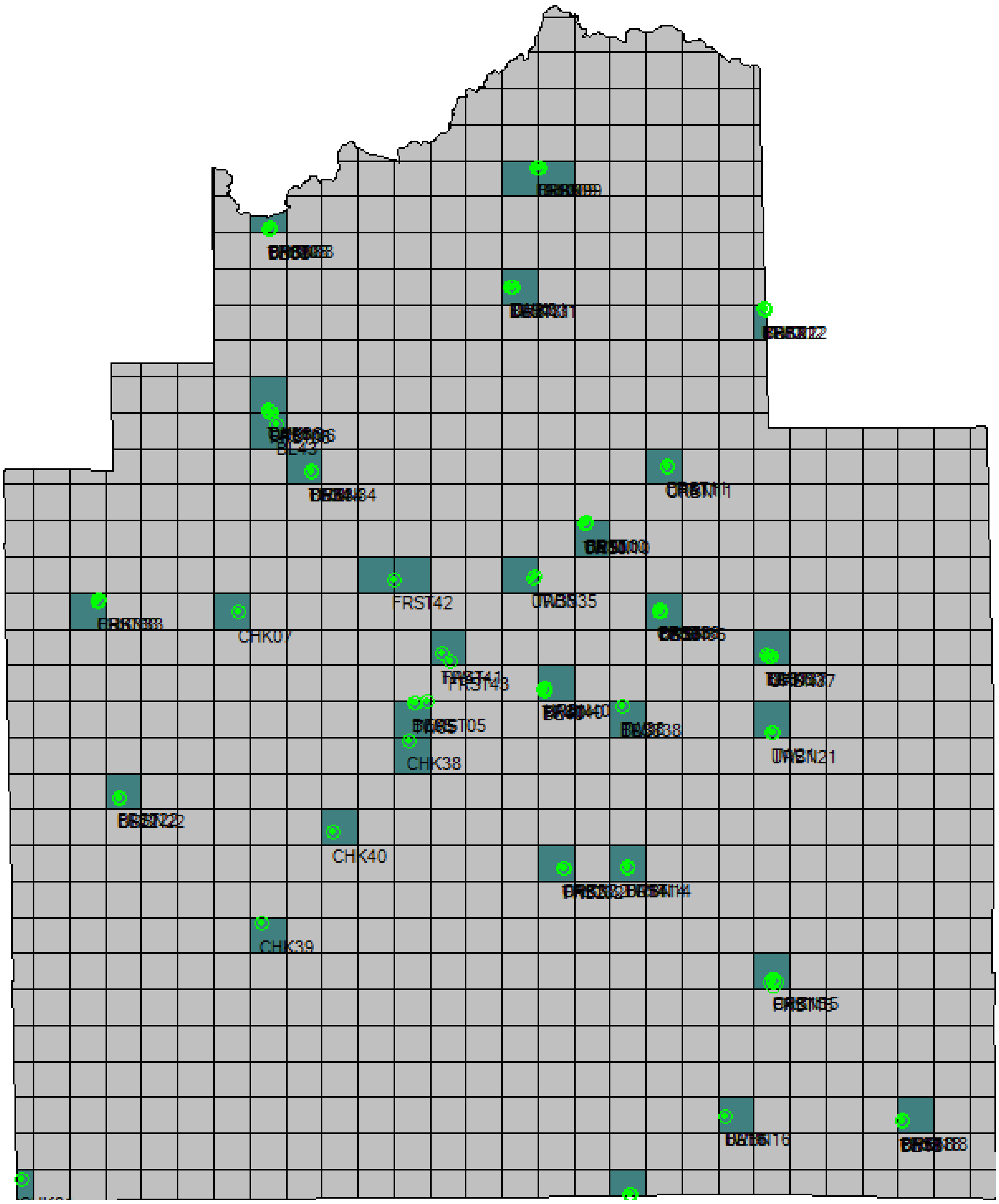
Metadata Information

Tile Index:
Path: Z:\Accuracy_Reports\LiDAR_Illinois\Index\NRCS_Christian_County_IL_TileIndex_Buffer.shp
Number of Polys: 0
Intensity:
Tile Index Attribute: Not Specified
Path to Data: Not Specified

DEM:
Tile Index Attribute: USNG
Path to Data: Z:\Accuracy_Reports\LiDAR_Illinois\DEM

LAS:
Tile Index Attribute: USNG
Path to Data: Z:\Accuracy_Reports\LiDAR_Illinois\LAS

Tiled-Data Area



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LiDAR Accuracy Assessment Summary

LC Type	# of Points	FVA	SVA	CVA
LAS				
ALL	96			7.214
Brush Land	16		4.350	
Bare Earth	20	0.522		
Forested Fully Grown	21		24.152	
Tall Weed	18		1.349	
Urban	21		0.621	
Total	96			
DEM				
ALL	96			0.690
Brush Land	16		0.685	
Bare Earth	20	0.504		
Forested Fully Grown	21		0.819	
Tall Weed	18		0.686	
Urban	21		0.653	
Total	96			

Units: US Survey Feet

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(303) 627-4058

CompassTA™

Coordinates and Offsets of Analyzed Locations

		ID					
			Survey X	Survey Y	Z1	Z DEM	Z LAS
					LC Type	ΔZ DEM	ΔZ LAS
1)	☑	BL05					
			2534235.721	1049995.12	608.668	609.259	610.731
					Brush Land	0.591	2.063
2)	☑	BL08					
			2513110.39	1119355.214	579.132	579.415	582.155
					Brush Land	0.283	3.023
3)	☑	BL09					
			2552577.838	1128464.418	610.544	610.62	613.654
					Brush Land	0.076	3.11
4)	☑	BL10					
			2559588.049	1076285.569	618.139	618.428	618.779
					Brush Land	0.289	0.64
5)	☑	BL12					
			2585646.585	1107573.754	617.598	617.587	618.844
					Brush Land	-0.011	1.246
6)	☑	BL14					
			2565509.53	1025824.361	599.191	598.225	598.362
					Brush Land	-0.966	-0.829
7)	☑	BL16					
			2579941.967	989350.157	714.195	714.581	714.891
					Brush Land	0.386	0.696

Coordinates and Offsets of Analyzed Locations (Continued)

		ID					
			Survey X	Survey Y	Z1	Z DEM	Z LAS
					LC Type	ΔZ DEM	ΔZ LAS
8)	☑	**BL18**					
			2605790.26	988497.015	682.587	682.509	686.321
					Brush Land	-0.078	3.734
9)	☑	**BL22**					
			2491060.473	1036125.465	620.781	620.215	626.98
					Brush Land	-0.566	6.199
10)	☑	**BL31**					
			2548498.481	1110821.893	584.972	585.237	585.119
					Brush Land	0.265	0.147
11)	☑	**BL34**					
			2519192.101	1083826.827	596.974	597.556	597.517
					Brush Land	0.582	0.543
12)	☑	**BL36**					
			2570298.61	1063427.474	601.211	601.458	602.373
					Brush Land	0.247	1.162
13)	☑	**BL37**					
			2586120.154	1056875.762	613.461	613.879	614.349
					Brush Land	0.418	0.888
14)	☑	**BL38**					
			2564818.56	1049411.246	614.306	614.551	614.98
					Brush Land	0.245	0.674

Coordinates and Offsets of Analyzed Locations (Continued)

		ID					
			Survey X	Survey Y	Z1	Z DEM	Z LAS
					LC Type	ΔZ DEM	ΔZ LAS
15)	☑	BL40					
			2553422.933	1051789.549	570.681	571.119	571.083
					Brush Land	0.438	0.402
16)	☑	BL43					
			2514160.676	1090668.321	574.805	574.978	574.91
					Brush Land	0.173	0.105
17)	☑	CHK01					
			2476675.171	980048.489	635.574	635.539	635.518
					Bare Earth	-0.035	-0.056
18)	☑	CHK06					
			2513013.725	1092759.848	597.86	598.105	598.113
					Bare Earth	0.245	0.253
19)	☑	CHK07					
			2508585.628	1063225.64	597.136	597.192	597.196
					Bare Earth	0.056	0.06
20)	☑	CHK08					
			2513111.589	1119413.117	581.058	581.582	581.538
					Bare Earth	0.524	0.48
21)	☑	CHK09					
			2552628.017	1128411.168	609.149	609.079	609.275
					Bare Earth	-0.07	0.126

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Centennial, CO 80112
(303) 627-4058

Coordinates and Offsets of Analyzed Locations (Continued)

		ID					
			Survey X	Survey Y	Z1	Z DEM	Z LAS
					LC Type	ΔZ DEM	ΔZ LAS
22)	☑	CHK10					
			2559394.797	1076275.624	618.298	618.488	618.503
					Bare Earth	0.19	0.205
23)	☑	CHK11					
			2571406.19	1084619.512	610.897	610.944	611.11
					Bare Earth	0.047	0.213
24)	☑	CHK12					
			2585690.529	1107590.839	616.345	616.159	616.245
					Bare Earth	-0.186	-0.1
25)	☑	CHK15					
			2587013.945	1009389.15	664.474	664.913	664.866
					Bare Earth	0.439	0.392
26)	☑	CHK17					
			2566106.303	977992.949	687.767	688.014	687.97
					Bare Earth	0.247	0.203
27)	☑	CHK18					
			2605848.153	988734.938	683.059	682.964	682.964
					Bare Earth	-0.095	-0.095
28)	☑	CHK31					
			2548847.09	1110917.486	598.973	598.806	598.902
					Bare Earth	-0.167	-0.071

Coordinates and Offsets of Analyzed Locations (Continued)

		ID					
			Survey X	Survey Y	Z1	Z DEM	Z LAS
					LC Type	ΔZ DEM	ΔZ LAS
29)	☑	CHK32					
			2556293.007	1025751.377	603.936	603.907	603.965
					Bare Earth	-0.029	0.029
30)	☑	CHK33					
			2488038.133	1064934.893	599.49	599.641	599.618
					Bare Earth	0.151	0.128
31)	☑	CHK34					
			2519228.995	1083872.327	598.199	598.299	598.288
					Bare Earth	0.1	0.089
32)	☑	CHK36					
			2570178.295	1063622.092	606.396	606.352	606.432
					Bare Earth	-0.044	0.036
33)	☑	CHK37					
			2586570.359	1056880.76	613.112	613.066	613.296
					Bare Earth	-0.046	0.184
34)	☑	CHK38					
			2533460.092	1044490.75	614.309	614.969	615.096
					Bare Earth	0.66	0.787
35)	☑	CHK39					
			2511950.986	1017658.327	621.991	622.341	622.217
					Bare Earth	0.35	0.226

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12353 E. Easter Ave.
Centennial, CO 80112
(303) 627-4058

Coordinates and Offsets of Analyzed Locations (Continued)

		ID					
			Survey X	Survey Y	Z1	Z DEM	Z LAS
					LC Type	ΔZ DEM	ΔZ LAS
36)	☑	CHK40					
			2522485.081	1030996.103	618.333	618.469	618.587
					Bare Earth	0.136	0.254
37)	☑	FRST05					
			2536183.857	1050167.16	610.448	609.868	609.881
					Forested_Fully Grown	-0.58	-0.567
38)	☑	FRST06					
			2513325.73	1092359.721	596.181	596.495	606.441
					Forested_Fully Grown	0.314	10.26
39)	☑	FRST08					
			2513045.28	1119488.135	584.624	585.001	589.022
					Forested_Fully Grown	0.377	4.398
40)	☑	FRST09					
			2552447.031	1128367.73	610.857	610.759	614.985
					Forested_Fully Grown	-0.098	4.128
41)	☑	FRST10					
			2559528.564	1076339.837	617.126	617.313	617.348
					Forested_Fully Grown	0.187	0.222
42)	☑	FRST11					
			2571485.118	1084687.307	610.495	610.513	610.957
					Forested_Fully Grown	0.018	0.462

Coordinates and Offsets of Analyzed Locations (Continued)

		ID					
			Survey X	**Survey Y**	**Z1**	**Z DEM**	**Z LAS**
					LC Type	**ΔZ DEM**	**ΔZ LAS**
43)	☑	**FRST12**					
			2585611.952	1107592.136	617.684	617.671	641.836
					Forested_Fully Grown	-0.013	24.152
44)	☑	**FRST14**					
			2565518.233	1025863.945	600.395	599.576	599.629
					Forested_Fully Grown	-0.819	-0.766
45)	☑	**FRST15**					
			2587042.11	1009090.861	663.741	664.643	702.409
					Forested_Fully Grown	0.902	38.668
46)	☑	**FRST18**					
			2605778.114	988643.219	683.151	683.092	696.057
					Forested_Fully Grown	-0.059	12.906
47)	☑	**FRST22**					
			2491081.005	1036260.741	620.62	620.851	620.804
					Forested_Fully Grown	0.231	0.184
48)	☑	**FRST31**					
			2548457.678	1110815.751	584.671	584.92	588.013
					Forested_Fully Grown	0.249	3.342
49)	☑	**FRST32**					
			2556198.721	1025641.664	611.369	611.34	611.368
					Forested_Fully Grown	-0.029	-0.001

Coordinates and Offsets of Analyzed Locations (Continued)

		ID					
			Survey X	Survey Y	Z1	Z DEM	Z LAS
					LC Type	ΔZ DEM	ΔZ LAS
50)	☑	FRST33					
			2488070.467	1065031.055	601.065	601.263	601.212
					Forested_Fully Grown	0.198	0.147
51)	☑	FRST36					
			2570335.017	1063604.896	605.589	605.807	625.539
					Forested_Fully Grown	0.218	19.95
52)	☑	FRST37					
			2586059.586	1056931.253	613.02	613.188	618.733
					Forested_Fully Grown	0.168	5.713
53)	☑	FRST38					
			2564760.413	1049465.358	615.045	614.692	614.751
					Forested_Fully Grown	-0.353	-0.294
54)	☑	FRST40					
			2553324.428	1051991.1	576.132	576.55	576.571
					Forested_Fully Grown	0.418	0.439
55)	☑	FRST41					
			2538473.342	1057157.967	609.034	609.299	609.297
					Forested_Fully Grown	0.265	0.263
56)	☑	FRST42					
			2531311.826	1068060.913	605.159	605.449	611.243
					Forested_Fully Grown	0.29	6.084

Coordinates and Offsets of Analyzed Locations (Continued)

		ID					
			Survey X	Survey Y	Z1	Z DEM	Z LAS
					LC Type	ΔZ DEM	ΔZ LAS
57)	☑	FRST43					
			2539525.141	1056156.012	612.218	612.437	616.112
					Forested_Fully Grown	0.219	3.894
58)	☑	TW05					
			2534434.087	1049988.236	608.997	609.55	609.512
					Tall Weed	0.553	0.515
59)	☑	TW06					
			2512973.857	1092862.091	596.346	596.97	597.004
					Tall Weed	0.624	0.658
60)	☑	TW08					
			2513135.353	1119344.924	578.117	578.312	578.384
					Tall Weed	0.195	0.267
61)	☑	TW10					
			2559425.046	1076153.726	618.015	618.402	618.398
					Tall Weed	0.387	0.383
62)	☑	TW12					
			2585727.986	1107639.664	615.267	615.831	615.864
					Tall Weed	0.564	0.597
63)	☑	TW14					
			2565526.881	1025893.817	600.536	601.215	601.243
					Tall Weed	0.679	0.707

Coordinates and Offsets of Analyzed Locations (Continued)

		ID					
			Survey X	Survey Y	Z1	Z DEM	Z LAS
					LC Type	ΔZ DEM	ΔZ LAS
64)	☑	TW16					
			2579975.795	989366.971	713.841	714.011	714.699
					Tall Weed	0.17	0.858
65)	☑	TW18					
			2605768.789	988551.559	683.154	682.951	687.285
					Tall Weed	-0.203	4.131
66)	☑	TW21					
			2586940.101	1045702.501	607.438	607.594	608.264
					Tall Weed	0.156	0.826
67)	☑	TW31					
			2548659.101	1110938.249	587.115	587.203	587.33
					Tall Weed	0.088	0.215
68)	☑	TW32					
			2556354.112	1025715.693	598.379	598.652	598.747
					Tall Weed	0.273	0.368
69)	☑	TW34					
			2519143.126	1083923.691	597.496	597.76	597.834
					Tall Weed	0.264	0.338
70)	☑	TW35					
			2552037.476	1068381.371	615.416	615.896	615.896
					Tall Weed	0.48	0.48

Coordinates and Offsets of Analyzed Locations (Continued)

		ID					
			Survey X	Survey Y	Z1	Z DEM	Z LAS
					LC Type	ΔZ DEM	ΔZ LAS
71)	☑	TW36					
			2570401.767	1063554.734	604.454	605.178	605.211
					Tall Weed	0.724	0.757
72)	☑	TW37					
			2586163.365	1056878.233	613.912	614.497	614.564
					Tall Weed	0.585	0.652
73)	☑	TW38					
			2564940.68	1049587.102	614.458	614.917	615.209
					Tall Weed	0.459	0.751
74)	☑	TW40					
			2553393.135	1051972.163	575.596	576.059	576.175
					Tall Weed	0.463	0.579
75)	☑	TW41					
			2538507.721	1057182.348	609.634	609.972	609.924
					Tall Weed	0.338	0.29
76)	☑	URBN06					
			2513234.993	1092559.944	596.412	596.574	596.644
					Urban	0.162	0.232
77)	☑	URBN08					
			2513068.804	1119613.712	587.993	588.306	588.309
					Urban	0.313	0.316

Coordinates and Offsets of Analyzed Locations (Continued)

		ID					
			Survey X	Survey Y	Z1	Z DEM	Z LAS
					LC Type	ΔZ DEM	ΔZ LAS
78)	☑	URBN09					
			2552288.324	1128467.848	618.695	618.609	618.623
					Urban	-0.086	-0.072
79)	☑	URBN10					
			2559381.411	1076150.853	618.402	618.692	618.667
					Urban	0.29	0.265
80)	☑	URBN11					
			2571453.571	1084399.016	611.723	611.934	611.95
					Urban	0.211	0.227
81)	☑	URBN12					
			2585439.764	1107704.031	616.253	616.251	616.337
					Urban	-0.002	0.084
82)	☑	URBN14					
			2565573.603	1025954.31	608.731	608.369	608.37
					Urban	-0.362	-0.361
83)	☑	URBN15					
			2587006.987	1009227.727	665.374	666.166	666.1
					Urban	0.792	0.726
84)	☑	URBN16					
			2579918.941	989376.422	712.491	712.597	712.705
					Urban	0.106	0.214

Coordinates and Offsets of Analyzed Locations (Continued)

		ID					
			Survey X	Survey Y	Z1	Z DEM	Z LAS
					LC Type	ΔZ DEM	ΔZ LAS
85)	☑	URBN17					
			2565943.306	977859.949	687.582	687.671	687.785
					Urban	0.089	0.203
86)	☑	URBN18					
			2605939.815	988690.567	683.56	683.776	683.834
					Urban	0.216	0.274
87)	☑	URBN21					
			2586759.171	1045535.727	611.709	611.949	611.927
					Urban	0.24	0.218
88)	☑	URBN22					
			2491155.892	1035971.411	621.817	621.164	621.196
					Urban	-0.653	-0.621
89)	☑	URBN31					
			2548750.69	1110850.91	594.009	593.888	593.906
					Urban	-0.121	-0.103
90)	☑	URBN32					
			2556307.004	1025817.252	601.679	601.802	602.014
					Urban	0.123	0.335
91)	☑	URBN33					
			2488007.019	1064805.995	600.44	600.458	600.47
					Urban	0.018	0.03

Coordinates and Offsets of Analyzed Locations (Continued)

		ID					
			Survey X	Survey Y	Z1	Z DEM	Z LAS
					LC Type	ΔZ DEM	ΔZ LAS
92)	☑	URBN34					
			2519304.982	1083873.55	599.175	599.225	599.272
					Urban	0.05	0.097
93)	☑	URBN35					
			2551652.652	1068275.605	614.607	614.899	614.89
					Urban	0.292	0.283
94)	☑	URBN36					
			2570449.731	1063444.403	605.392	605.41	605.561
					Urban	0.018	0.169
95)	☑	URBN37					
			2586586.666	1056701.204	612.748	612.899	612.891
					Urban	0.151	0.143
96)	☑	URBN40					
			2553566.066	1052282.421	586.714	586.91	586.856
					Urban	0.196	0.142

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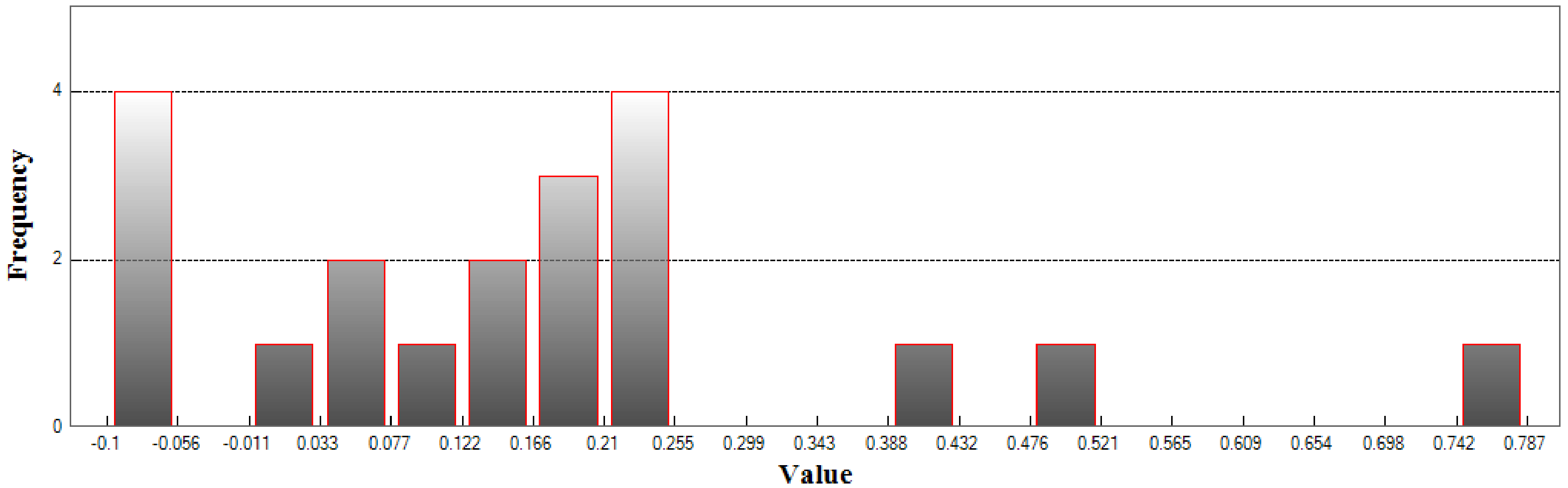
LAS

Fundamental Vertical Accuracy

Land Cover Type: Bare Earth
Minimum DZ: -0.1
Maximum DZ: 0.787
Mean DZ: 0.167
Mean Magnitude DZ: 0.446
Number Observations: 20
Standard Deviation DZ: 0.213
RMSE Z: 0.266
95% Confidence Level Z: 0.522
Units: US Survey Feet

Histogram



Min: -0.1
Max: 0.787
Number of Bins: 20
Bin Interval: 0.044

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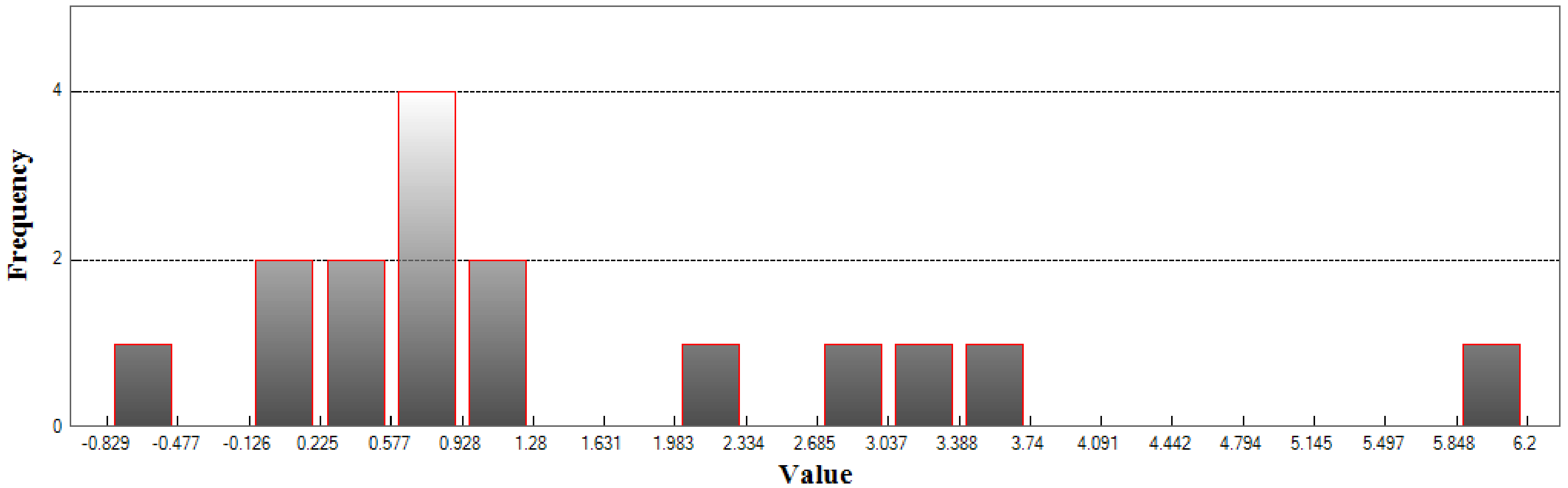
LAS (Continued)

Supplemental Vertical Accuracy

Land Cover Type: Brush Land
Minimum DZ: -0.829
Maximum DZ: 6.199
Mean DZ: 1.488
Mean Magnitude DZ: 1.261
Number Observations: 16
Standard Deviation DZ: 1.756
RMSE Z: 2.259
95th Percentile: 4.35
Units: US Survey Feet

Histogram



Min: -0.829
Max: 6.199
Number of Bins: 20
Bin Interval: 0.351

LAS (Continued)

Supplemental Vertical Accuracy

Land Cover Type: Forested Fully Grown

Minimum DZ: -0.766

Maximum DZ: 38.668

Mean DZ: 6.361

Mean Magnitude DZ: 2.553

Number Observations: 21

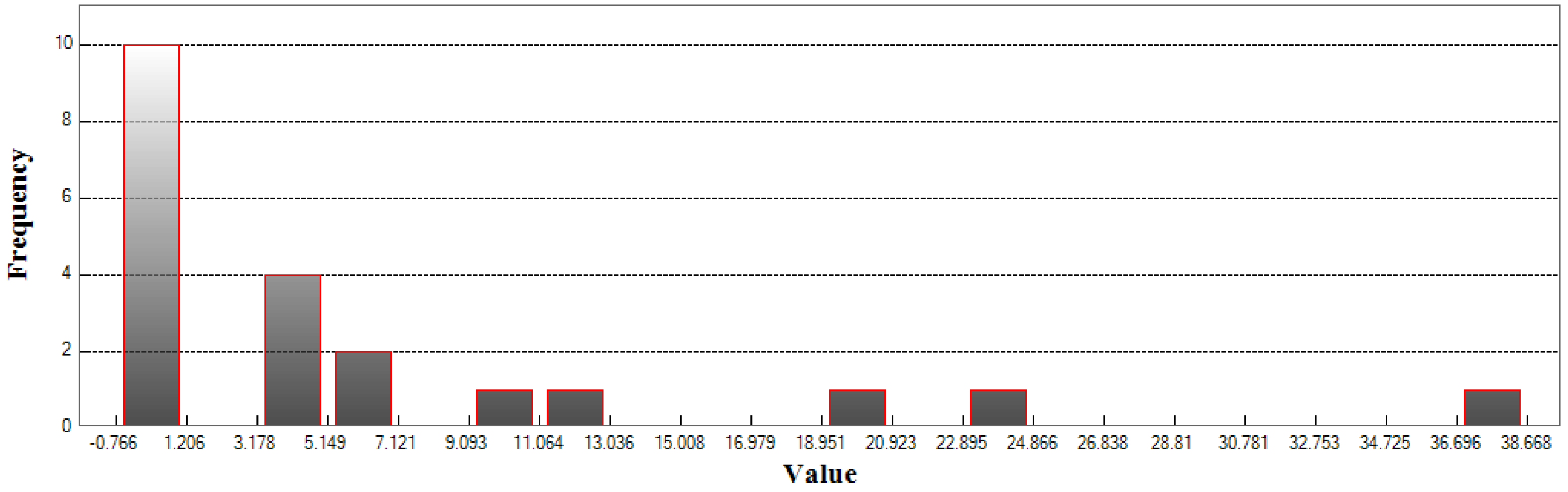
Standard Deviation DZ: 10.081

RMSE Z: 11.715

95th Percentile: 24.152

Units: US Survey Feet

Histogram



Min: -0.766

Max: 38.668

Number of Bins: 20

Bin Interval: 1.972

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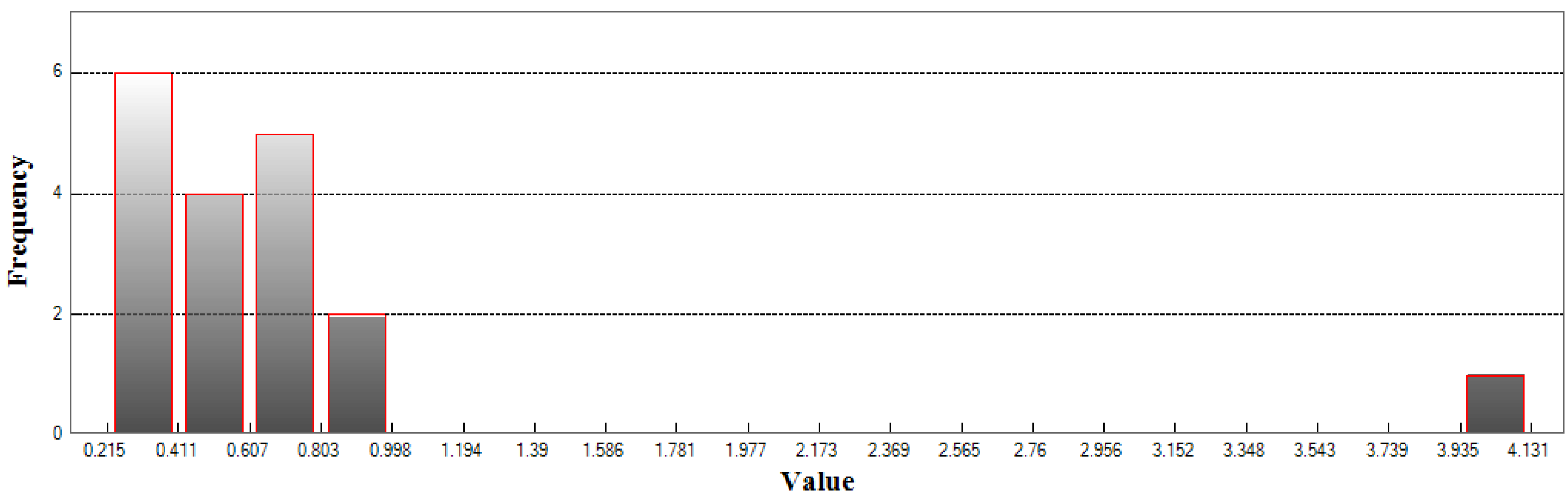
LAS (Continued)

Supplemental Vertical Accuracy

Land Cover Type: Tall Weed
Minimum DZ: 0.215
Maximum DZ: 4.131
Mean DZ: 0.743
Mean Magnitude DZ: 0.862
Number Observations: 18
Standard Deviation DZ: 0.869
RMSE Z: 1.124
95th Percentile: 1.349
Units: US Survey Feet

Histogram



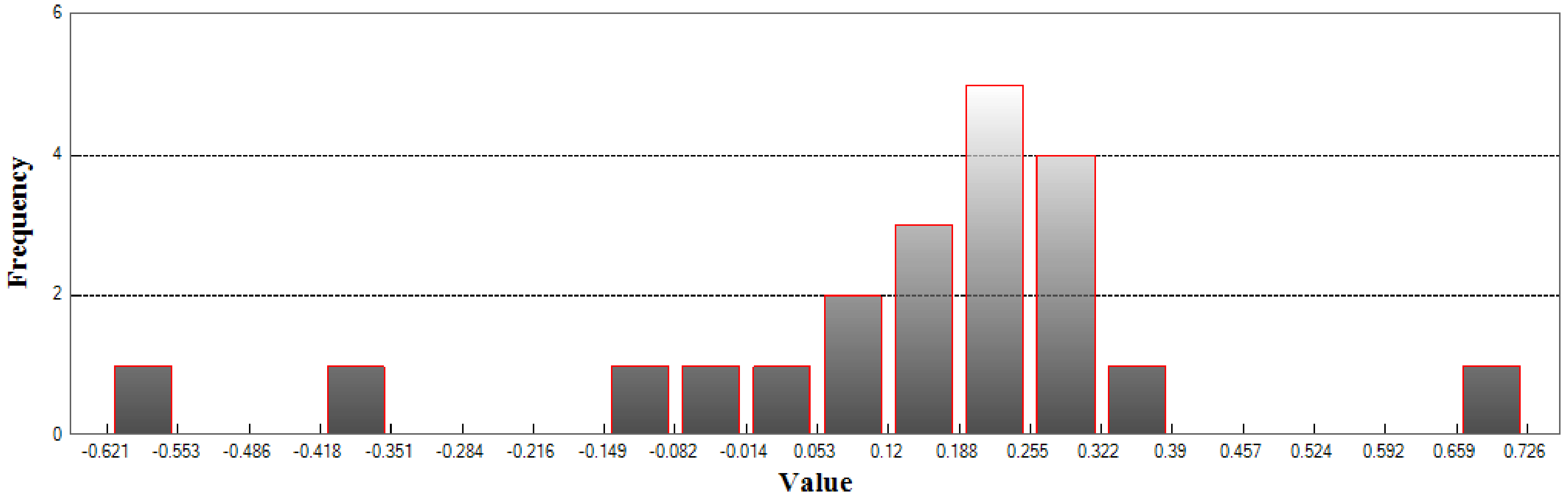
Min: 0.215
Max: 4.131
Number of Bins: 20
Bin Interval: 0.196

LAS (Continued)

Supplemental Vertical Accuracy

Land Cover Type: Urban
Minimum DZ: -0.621
Maximum DZ: 0.726
Mean DZ: 0.133
Mean Magnitude DZ: 0.494
Number Observations: 21
Standard Deviation DZ: 0.269
RMSE Z: 0.295
95th Percentile: 0.621
Units: US Survey Feet

Histogram



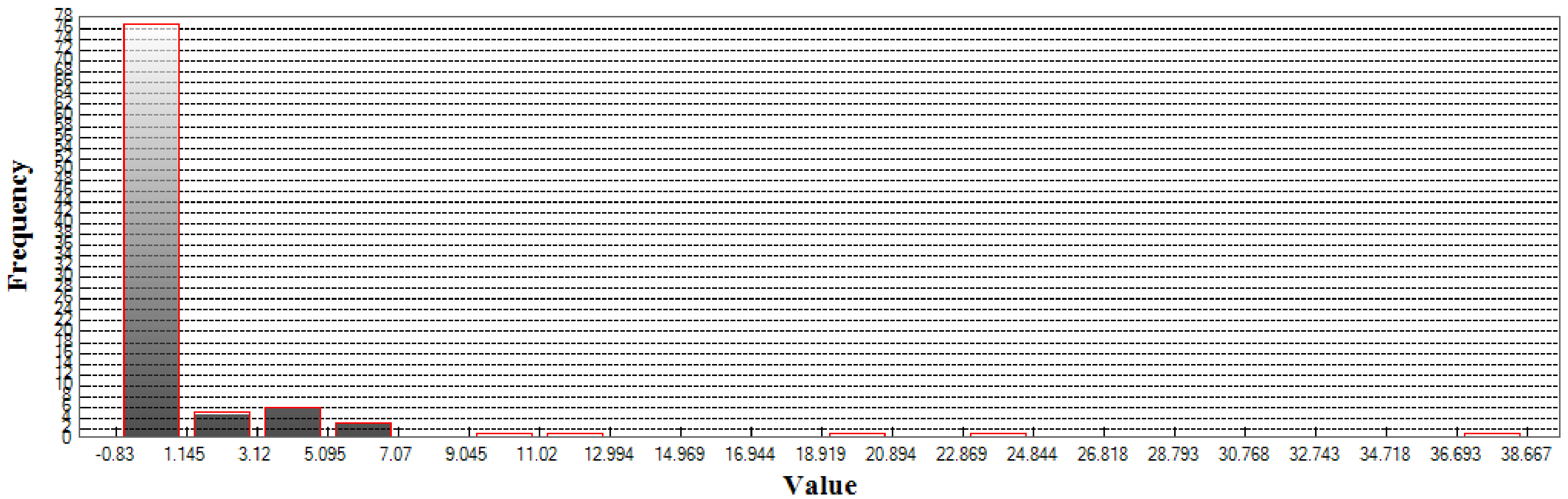
Min: -0.621
Max: 0.726
Number of Bins: 20
Bin Interval: 0.067

LAS (Continued)

Consolidated Vertical Accuracy

Land Cover Type: ALL
Minimum DZ: -0.829
Maximum DZ: 38.668
Mean DZ: 1.843
Mean Magnitude DZ: 1.387
Number Observations: 96
Standard Deviation DZ: 5.295
RMSE Z: 5.581
95th Percentile: 7.214
Units: US Survey Feet

Histogram



Min: -0.829
Max: 38.668
Number of Bins: 20
Bin Interval: 1.975

DEM

Fundamental Vertical Accuracy

Land Cover Type: Bare Earth

Minimum DZ: -0.186

Maximum DZ: 0.66

Mean DZ: 0.124

Mean Magnitude DZ: 0.437

Number Observations: 20

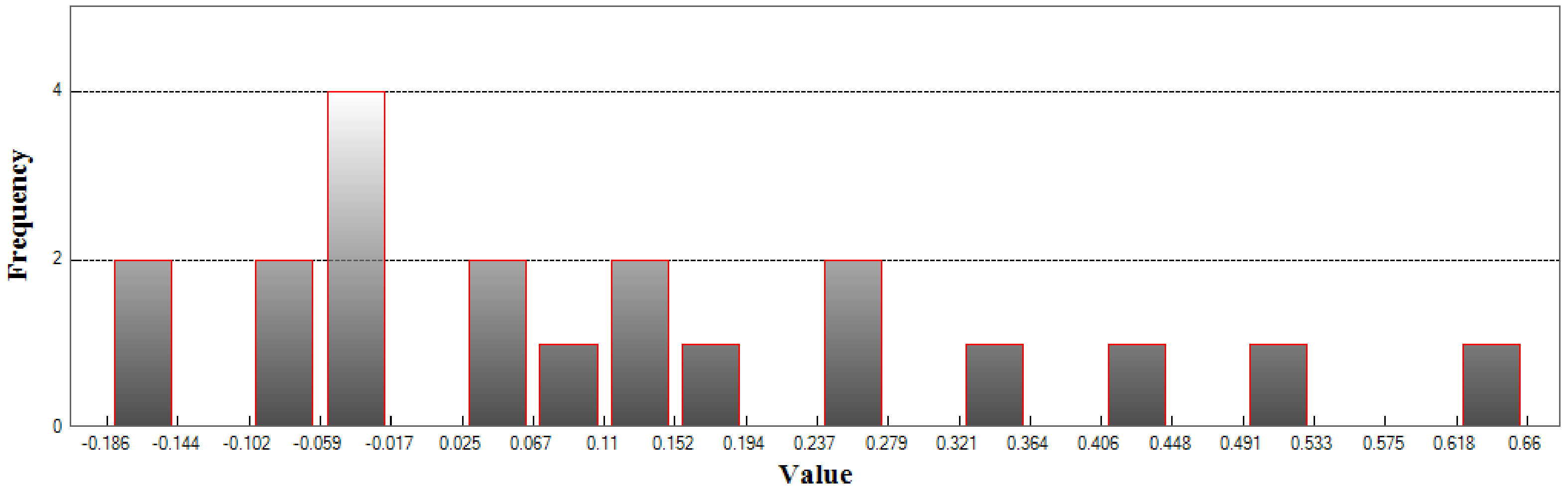
Standard Deviation DZ: 0.231

RMSE Z: 0.257

95% Confidence Level Z: 0.504

Units: US Survey Feet

Histogram



Min: -0.186

Max: 0.66

Number of Bins: 20

Bin Interval: 0.042

DEM (Continued)

Supplemental Vertical Accuracy

Land Cover Type: Brush Land

Minimum DZ: -0.966

Maximum DZ: 0.591

Mean DZ: 0.148

Mean Magnitude DZ: 0.592

Number Observations: 16

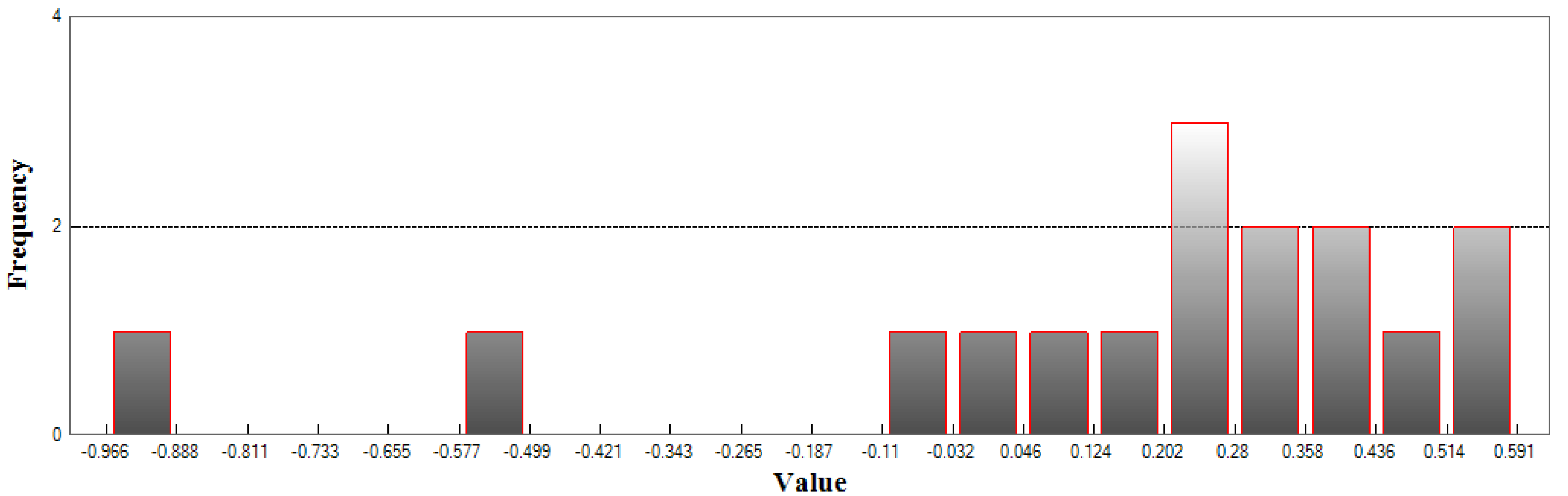
Standard Deviation DZ: 0.409

RMSE Z: 0.422

95th Percentile: 0.685

Units: US Survey Feet

Histogram



Min: -0.966

Max: 0.591

Number of Bins: 20

Bin Interval: 0.078

DEM (Continued)

Supplemental Vertical Accuracy

Land Cover Type: Forested Fully Grown

Minimum DZ: -0.819

Maximum DZ: 0.902

Mean DZ: 0.1

Mean Magnitude DZ: 0.535

Number Observations: 21

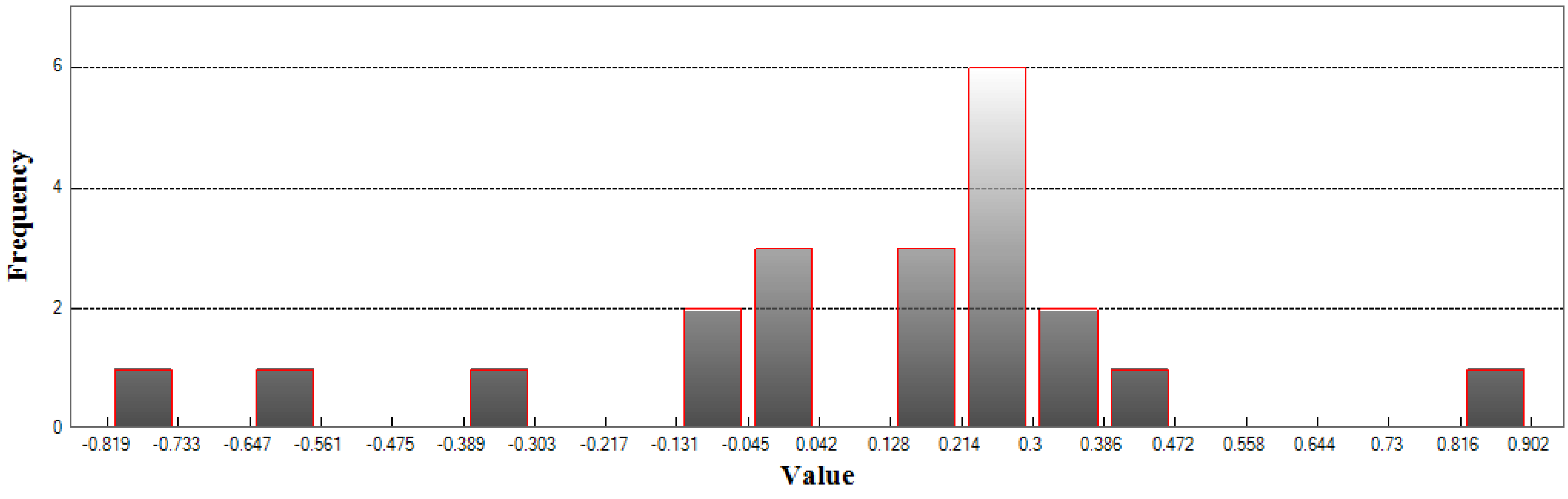
Standard Deviation DZ: 0.363

RMSE Z: 0.368

95th Percentile: 0.819

Units: US Survey Feet

Histogram



Min: -0.819

Max: 0.902

Number of Bins: 20

Bin Interval: 0.086

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DEM (Continued)

Supplemental Vertical Accuracy

Land Cover Type: Tall Weed

Minimum DZ: -0.203

Maximum DZ: 0.724

Mean DZ: 0.378

Mean Magnitude DZ: 0.633

Number Observations: 18

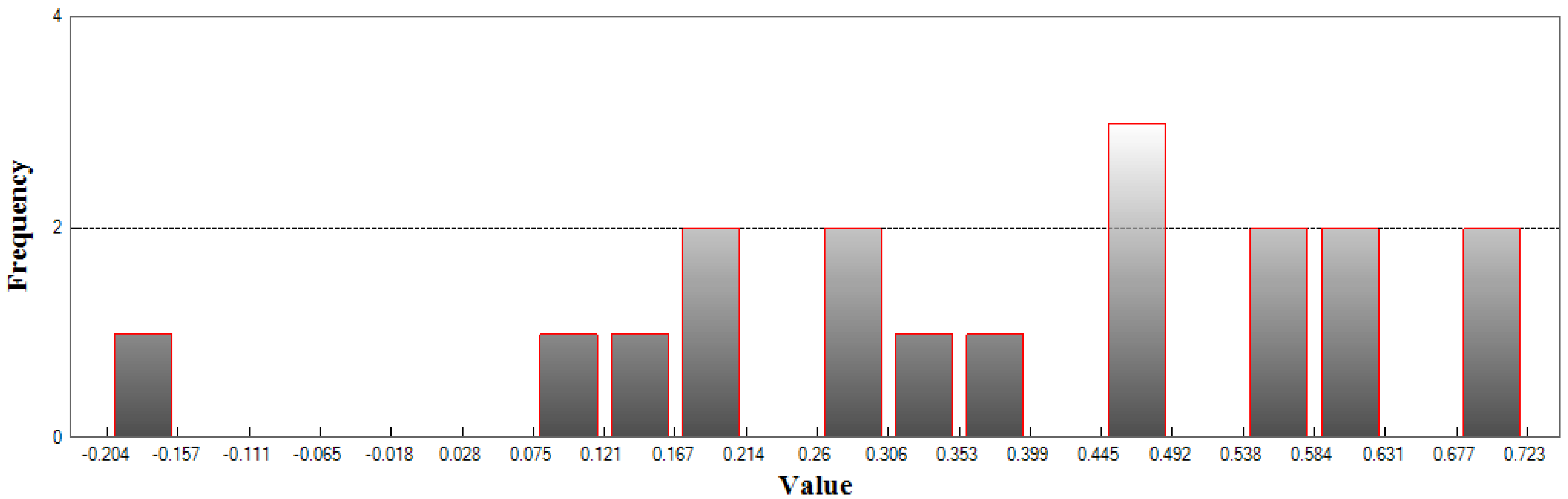
Standard Deviation DZ: 0.24

RMSE Z: 0.444

95th Percentile: 0.686

Units: US Survey Feet

Histogram



Min: -0.203

Max: 0.724

Number of Bins: 20

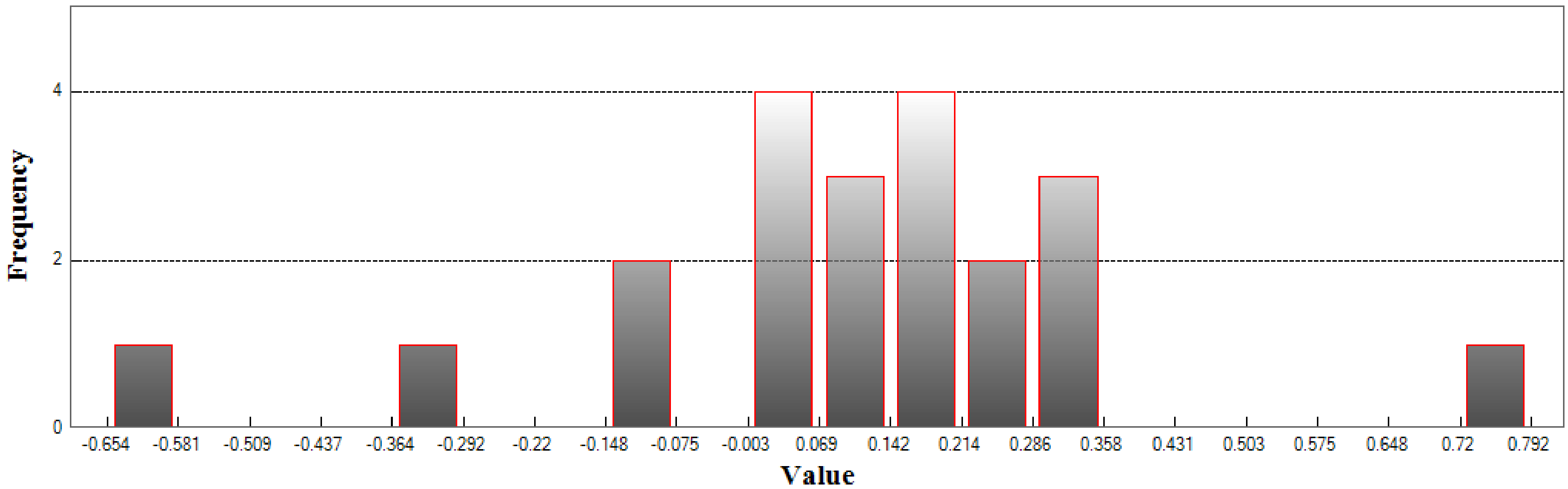
Bin Interval: 0.046

DEM (Continued)

Supplemental Vertical Accuracy

Land Cover Type: Urban
Minimum DZ: -0.653
Maximum DZ: 0.792
Mean DZ: 0.097
Mean Magnitude DZ: 0.462
Number Observations: 21
Standard Deviation DZ: 0.278
RMSE Z: 0.289
95th Percentile: 0.653
Units: US Survey Feet

Histogram



Min: -0.653
Max: 0.792
Number of Bins: 20
Bin Interval: 0.072

DEM (Continued)

Consolidated Vertical Accuracy

Land Cover Type: ALL

Minimum DZ: -0.966

Maximum DZ: 0.902

Mean DZ: 0.164

Mean Magnitude DZ: 0.532

Number Observations: 96

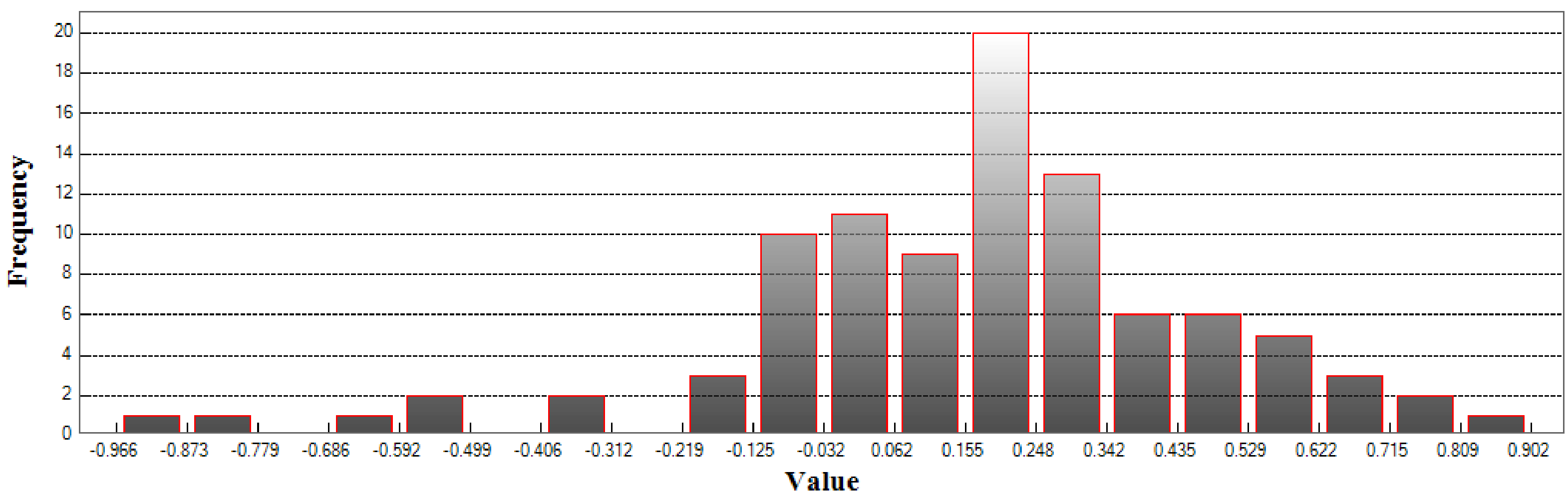
Standard Deviation DZ: 0.32

RMSE Z: 0.358

95th Percentile: 0.69

Units: US Survey Feet

Histogram



Min: -0.966

Max: 0.902

Number of Bins: 20

Bin Interval: 0.093