

Technical Memorandum

To: HDR

From: Wood Environment & Infrastructure Solutions, Inc.

Date: September 24, 2019 (Revised from August 15, 2019)

Re: Monroe County Mobile LiDAR Vertical Accuracy Assessment – Road Elevation Data and Finished Floor Elevations (FFE)

Introduction

A vertical accuracy assessment of recently-captured mobile LiDAR data was requested by Monroe County, prior to commencement of the Roads Vulnerability Study. This assessment includes evaluation of elevation data captured on county roads as well as finished floor elevations (FFE) at county buildings and facilities. The results of the road elevation data and FFEs are presented herein.

Methods

Road Data

Using the Michael Baker International (MBI) project website, each area .DGN file was downloaded. The files contain breaklines, contours and points generally on a 3' grid. Surfaces were initially created using Trimble Business Center (TBC) v 5.0 to define project area boundaries. Digital Globe satellite imagery was used as a background in TBC, along with Google Earth, to select checkpoint locations for the field team. Surface boundaries were then created and exported as both Google Earth .KML files and .DXF files. These boundary files were used by the field team members to navigate to each area using the .KML files, then more precisely locate checkpoint locations using the .DXF files on their Trimble Survey Controllers.

The office-selected checkpoint locations were intended to be general locations, and field staff used independent judgement in setting and surveying actual checkpoints based on local conditions. Real-Time Kinematic (RTK) GPS Surveying was used to collect Northing, Easting and Elevation at each checkpoint. A permanent point (MAG Nail in pavement or spike nail in sand) was set and occupied at least two times for redundancy at each checkpoint. Each occupation collected satellite data for 3 minutes.

RTK Surveying methods yield vertical accuracies on the same order of that collected by mobile LiDAR (0.05' to 0.10'). This survey method was chosen to rapidly and cost effectively capture elevation data for the assessment.

RTK Surveying relies on radio link to a base station receiver, which occupies a known control point. Control points were benchmarks set by the National Geodetic Survey (NGS), having vertical First Order, Class II or Second Order Class I elevations. In a few cases, a reliable control point and/or radio link was unobtainable. In which case, a base station point was established using the Online Positioning User Service (OPUS), as operated by NGS or the Florida Permanent Reference Network (FPRN), as operated by the Florida Department of Transportation (FDOT), was used.

Finished Floor Elevations (FFE's)

In most cases, conventional surveying methods using a total station, were used to collect Finished Floor Elevations. This was necessary because buildings obstruct direct observations via GPS. When conventional methods were used, a pair of control points were observed via RTK Surveying, to obtain coordinates and elevation on each point. Then one control point was occupied by the total station, backsighting the second point and observing angle and distance to the FFE to obtain coordinates and elevation for checking against the County's GIS layer of FFEs.

Analysis

For comparing surveyed checkpoints to the mobile LiDAR road dataset, a raster surface was created by converting raw LAS point files prepared by MBI for each area, into a LAS dataset feature class in ArcGIS 10.4. This data was then quality assured by running the Add Surface Information geoprocessing tool on the original elevation points in 3D Analyst. This tool takes the elevation of a topographic surface at each point's location throughout the surface. These results were then checked against the elevation point values for accuracy.

When comparing surveyed FFEs to the County's GIS layer the two datasets were first joined based on spatial proximity. To facilitate this, the spatial join geoprocessing command was used in ArcGIS 10.4. After spatially joining the points the data was analyzed for accuracy to assure only points from the two datasets that were within the same buildings were associated with each other. The elevations of the surveyed FFE's were then compared to the County's GIS layer for accuracy.

To evaluate the datasets, the Root Mean Square Error (RMSE) was computed. First, the differences (discrepancies) were computed between each surveyed checkpoint and the associated surface created from the MBI mobile LiDAR LAS files, or County GIS layer of FFEs. The differences were then squared, and results summed. Finally, the sum was divided by the total number of checkpoints. Deriving the square root of this value yields the RMSE of the dataset as follows:

$$RMSE_{Errors} = \sqrt{\frac{\sum_{i=1}^n (\hat{y}_i - y_i)^2}{n}}$$

The Wood survey of checkpoints compared to the surface derived by MBI mobile LiDAR of collected road surfaces and adjacent sand areas yields a RMSE of 0.09'. The RMSE of all observed FFEs is 0.15'.

On the attached file, each checkpoint identifies the corresponding MBI area it was collected in, as well as the base station point used (NOTE: RTCM0604 is a FPRN base station). All surveys from each RTK base station checked into another known control point for quality control daily. FFEs comparisons are shown separately.

Summary

Surveying checkpoints for Road Data was conducted from June 25, 2019 to July 2, 2019. Approximately 10% - 20% of the checkpoints were placed in sand and checkpoints were distributed randomly and evenly throughout the project area. Nearly 250 occupations were made on nearly 115 checkpoints. In total, 108 checkpoints were used to compute the final RMSE.

Surveying of FFEs was conducted from September 9, 2019 to September 12, 2009 and yielded a slightly higher RMSE value.

Overall, the vertical accuracy of the mobile LiDAR dataset is acceptable for the assessing flood inundation vulnerability and sea level rise impacts. For further evaluation, additional surveying may be conducted using traditional leveling methods, to acquire more accurate elevation data, after recommendations are made and during the design phase of adopted improvements.

COMPARISONS OF SURVEYED VS MOBILE LIDAR CAPTURED ROAD ELEVATIONS

Checkpoint				Checkpoint	LAS Surface	Δ Elevation		
		Northing	Eastings	Elevation	Elevation	(US survey foot)		
	Area	(US survey foot)	(US survey foot)	(US survey foot)	(US survey foot)	Discrepancy	Discrepancy Squared	Base Station
10001 CK	Key West 1	82036.666	389104.510	7.13	7.18	-0.05	0.0029594	AA1629
10002 CK	Key West 1	83687.973	391523.626	1.36	1.25	0.11	0.0118592	AA1629
10003 CK	Key West 1	83228.768	395538.341	2.58	2.60	-0.01	0.0001960	AA1629
10004 CK	Key West 1	81269.227	396967.669	2.53	2.52	0.00	0.0000185	AA1629
10005 CK	Key West 1	79585.146	398099.717	2.74	2.70	0.04	0.0013032	AA1629
10006 CK	Key West 1	85112.564	406245.633	3.55	3.53	0.01	0.0001020	AA1629
10006CK1	Key West 1	85212.446	406534.662	3.07	3.02	0.04	0.0019360	AA1629
10007 CK	Stock Island	85982.087	412632.351	2.00	1.95	0.05	0.0024701	AA1629
10009 CK	Stock Island	87628.494	411482.968	3.07	3.08	-0.01	0.0000846	AA1629
10010CK	Stock Island	84872.135	408535.149	2.99	2.98	0.00	0.0000130	AA1629
10011CK1	Key Haven	92003.644	410192.830	2.73	2.79	-0.06	0.0038564	AA1629
10012CK	Key Haven	92867.525	411211.449	2.68	2.77	-0.09	0.0085933	AA1629
10013CK	Key Haven	90507.395	411710.126	3.44	3.43	0.00	0.0000102	AA1629
10014 CK1	Key Haven	89599.540	413197.380	2.44	2.52	-0.08	0.0064000	AA1629
10015CK	Boca Chica Key	85232.739	432576.628	5.01	5.03	-0.03	0.0007076	933
10016CK	Boca Chica Key	86058.488	433315.072	2.40	2.28	0.11	0.0127690	933
10017CK	Geiger Key	88931.800	436399.256	1.54	1.52	0.02	0.0003686	933
10018CK	Geiger Key	89390.296	438347.273	3.83	3.77	0.06	0.0034457	933
10019CK	Geiger Key	90546.032	438146.889	3.23	3.13	0.10	0.0091776	933
10020CK	Geiger Key	90524.826	439671.833	1.73	1.77	-0.04	0.0014440	933
10021CK	Geiger Key	92979.118	440603.943	2.44	2.40	0.04	0.0015602	933
10022CK	Geiger Key	92990.879	440570.803	1.89	1.96	-0.07	0.0049280	933
10023 CK	East Rock Island Key SOUTH	92122.504	431271.052	3.15	2.98	0.17	0.0302760	AA1629
10024 CK1	East Rock Island Key SOUTH	91971.021	432711.260	1.97	1.89	0.08	0.0072080	AA1629
10025CK1	East Rock Island Key SOUTH	93623.430	432418.622	6.25	6.16	0.09	0.0076213	AA1629
10026 CK	East Rock Island Key SOUTH	96078.213	433474.095	3.27	3.33	-0.07	0.0047472	AA1629
10027 CK	East Rock Island Key SOUTH	94382.905	433237.519	2.97	2.93	0.04	0.0020070	AA1629
10028CK	Big Coppitt Key	97892.191	434465.968	2.52	2.48	0.03	0.0012110	933
10029CK	Big Coppitt Key	96195.343	437503.555	2.10	2.24	-0.14	0.0205923	933
10030CK	Big Coppitt Key	97969.502	439353.660	4.12	4.21	-0.10	0.0094868	933
10031 CK1	Saddlebunch Key WEST	105904.934	456462.914	2.15	2.05	0.09	0.0082992	933
10032 CK1	Saddlebunch Key EAST	104022.865	459527.362	1.91	1.98	-0.07	0.0049000	933
10033 CK	Saddlebunch Key EAST	107121.898	459497.910	2.76	2.81	-0.05	0.0023426	933
10034 CK	Lower Sugarloaf	98660.651	466741.055	3.33	3.28	0.05	0.0025806	933
10035 CK	Lower Sugarloaf	104198.080	478057.444	2.53	2.51	0.03	0.0006760	933
10036 CK1	Lower Sugarloaf	110969.427	468059.762	2.21	2.36	-0.15	0.0234090	933
10037 CK	Upper Sugarloaf WEST	122162.967	479926.596	2.27	2.42	-0.16	0.0243360	764
10039 CK1	Upper Sugarloaf EAST	117236.474	484623.472	2.30	2.51	-0.21	0.0457960	764
10040CK1	Cudjoe EAST	115148.447	498386.109	2.74	2.76	-0.02	0.0003460	764
10041CK1	Cudjoe EAST	119003.570	497063.777	2.25	2.45	-0.20	0.0388090	764
10042 CK	Cudjoe WEST	118518.989	488555.693	3.47	3.60	-0.13	0.0159264	764
10043 CK	Cudjoe WEST	123606.131	490249.012	2.42	2.65	-0.22	0.0501760	764
10044 CK	Cudjoe WEST	131127.428	490266.459	2.45	2.43	0.02	0.0005476	764

10045CK	Summerland	115204.638	508463.657	2.84	2.68	0.16	0.0252492	764
10046CK	Summerland	118141.404	509188.270	3.05	3.03	0.01	0.0001988	764
10047CK	Summerland	119447.317	503469.846	2.19	2.08	0.11	0.0120341	764
10048CK	Summerland	119971.845	508960.337	1.44	1.55	-0.11	0.0110250	764
10049CK	Ramrod	115814.236	521808.101	2.31	2.40	-0.10	0.0093509	764
10049CK1	Ramrod	115814.319	521808.106	2.44	2.40	0.04	0.0015682	764
10050CK1	Ramrod	119616.876	521287.134	2.14	1.92	0.22	0.0468290	764
10052CK	Big MiddleTorch	123542.647	522058.388	1.81	1.88	-0.06	0.0039188	764
10053CK	Big MiddleTorch	123860.726	522009.826	0.53	0.32	0.21	0.0420250	764
10054CK2	Big MiddleTorch	128565.045	520665.595	2.92	2.88	0.04	0.0019981	641
10055 CK1	Big MiddleTorch	133100.013	519334.888	3.03	2.82	0.20	0.0409253	764
10056 CK1	Big MiddleTorch	133098.961	514300.661	2.13	2.02	0.12	0.0140660	764
10057CK	Little Torch	118650.886	527676.308	2.75	2.84	-0.09	0.0073788	641
10058CK	Little Torch	124751.054	526697.211	1.49	1.52	-0.03	0.0009120	641
10059CK	Little Torch	128955.802	524845.634	2.21	2.24	-0.03	0.0009672	641
10060CK	Little Torch	120704.307	526023.816	0.85	0.89	-0.04	0.0014977	641
10061CK	Big Pine A1	117292.019	533380.076	2.81	2.93	-0.12	0.0139240	641
10062CK	Big Pine A1	120532.575	533712.508	2.91	2.96	-0.05	0.0023232	641
10063CK1	Big Pine A1	120655.022	533707.158	2.40	2.35	0.05	0.0028409	641
10065CK	Big Pine A2	123168.550	532528.706	2.79	2.84	-0.05	0.0030250	641
10066CK	Big Pine A2	124659.828	535136.747	1.77	1.70	0.08	0.0059753	641
10067CK	Big Pine A2	122526.669	536185.355	2.54	2.62	-0.08	0.0060373	641
10068CK	Big Pine A3	122007.774	540613.221	4.71	4.78	-0.07	0.0051266	641
10069 CK	Big Pine A3	126130.191	540354.245	2.12	2.15	-0.02	0.0005198	641
10070CK	Big Pine A3	124229.159	542583.179	1.85	1.79	0.06	0.0032948	641
10071 CK	Big Pine A4	132595.913	546247.021	2.50	2.50	0.00	0.0000008	641
10072 CK	Big Pine A4	133945.471	538429.439	2.09	2.12	-0.03	0.0009734	641
10073 CK	Big Pine A4	129128.863	537929.771	1.53	1.67	-0.14	0.0194882	641
10074 CK	Big Pine A4	122555.098	537826.802	3.43	3.49	-0.06	0.0030250	641
10074CK1	Big Pine A4	122570.093	537825.910	3.00	3.13	-0.13	0.0174240	641
10076 CK	Big Pine A5	132812.642	531691.401	4.91	4.95	-0.04	0.0013322	641
10076 CK2	Big Pine A5	132812.631	531691.454	4.89	4.95	-0.07	0.0044890	641
10077 CK	Big Pine A5	130038.550	530691.158	2.49	2.58	-0.08	0.0070560	641
10078 CK	Big Pine A5	127816.601	531147.863	2.80	2.83	-0.03	0.0010498	641
10079 CK1	Big Pine A6	140787.379	524375.180	2.68	2.81	-0.14	0.0184145	641
10080 CK	Big Pine A6	142698.661	527451.407	2.42	2.44	-0.02	0.0004580	641
10081 CK	Big Pine A6	135548.842	530064.247	4.09	4.13	-0.04	0.0016646	641
10082 CK1	Big Pine A6	138733.479	531910.596	1.85	1.88	-0.03	0.0008762	641
10083 CK	Big Pine A7	110129.900	539083.739	2.68	2.68	-0.01	0.0000640	641
10084 CK	Big Pine A7	114412.520	545950.385	2.75	2.69	0.05	0.0026112	641
10085CK	Duck Key	158019.183	682880.210	2.95	2.97	-0.02	0.0003063	106
10086CK	Duck Key	158062.325	686457.759	3.89	3.94	-0.05	0.0020976	106
10087CK1	Duck Key	161037.607	684814.445	3.38	3.50	-0.11	0.0129277	106
10088 CK1	Conch Key	165860.893	693058.667	4.35	4.48	-0.13	0.0167962	106
10089 CK	Conch Key	166444.617	692404.534	0.69	0.61	0.08	0.0068228	106
10090 CK	Key Largo South SOUTH	243927.654	816183.779	2.94	3.02	-0.08	0.0059290	109
10091 CK	Key Largo South SOUTH	246572.155	816495.769	7.75	7.56	0.19	0.0349690	RTCM0604
10092 CK1	Key Largo South SOUTH	248782.623	820450.304	3.59	3.37	0.22	0.0479610	109
10093 CK	Key Largo South SOUTH	254805.529	821668.934	4.55	4.57	-0.02	0.0004410	109
10096CK	Key Largo Middle SOUTH	269675.490	835025.214	2.31	2.35	-0.04	0.0016000	109
10097CK1	Key Largo Middle SOUTH	272781.019	836215.310	6.05	6.02	0.03	0.0009000	109
10099CK	Key Largo Middle MID	280981.727	843625.130	5.81	5.75	0.06	0.0034810	109

<u>10100</u> CK	Key Largo Middle MID	284350.343	846181.472	2.16	2.15	0.01	0.0001440	109
<u>10101</u> CK	Key Largo Middle NORTH	285172.250	850961.854	2.34	2.40	-0.06	0.0038440	RTCM0604
<u>10105</u> CK	Key Largo North SOUTH	292530.742	852509.992	2.19	2.29	-0.10	0.0098010	191
<u>10106</u> CK	Key Largo North SOUTH	290479.717	853256.423	6.48	6.52	-0.04	0.0016000	191
<u>10107</u> CK	Key Largo North SOUTH	294590.332	856675.841	3.84	3.75	0.09	0.0081000	191
<u>10107</u> CK2	Key Largo North SOUTH	294590.322	856675.800	3.74	3.75	-0.01	0.0000360	191
<u>10108</u> CK	Key Largo North MID	297754.633	858037.597	9.29	9.22	0.07	0.0050410	191
<u>10109</u> CK	Key Largo North MID	300552.785	858028.531	0.10	0.03	0.07	0.0053290	191
<u>10111</u> CK	Key Largo North NORTH	304940.792	865334.575	2.40	2.42	-0.01	0.0001690	191
<u>10113</u> CK	RT 905_905A	312630.574	869266.748	6.41	6.40	0.01	0.0001562	191
<u>10114</u> CK	RT 905_905A	317812.502	873339.358	8.32	8.43	-0.11	0.0116208	191
<u>10116</u> CK	RT 905_905A	346834.808	886094.749	3.34	3.29	0.05	0.0023717	RTCM0604
<u>10117</u> CK3	RT 905_905A	346030.448	867883.635	2.80	2.87	-0.07	0.0051409	RTCM0604
TOTAL OBS						108	0.9050196	SUM
							0.0083798	
							0.09	RMSE

COMPARISONS OF SURVEYED VS MOBILE LIDAR CAPTURED FINISHED FLOOR ELEVATIONS (FFE_s)

Checkpoint			Surveyed FFE	County FFE	Δ Elevation				
	Northing	Easting	Elevation	Elevation	(US survey foot)				
	(US survey foot)	(US survey foot)	(US survey foot)	(US survey foot)	Discrepancy	Discrepancy Squared	Wood Description	Comments	County Facility
5001	81632.985	393358.080	10.42	10.36	0.06	0.0037210	SIDE DOOR 1	Side Door	Harvey Government Center (HGC)
5003	79745.266	391206.690	8.97	8.75	0.22	0.0488410	FFE GATO	Door	Gato Building
5004	79641.223	391018.478	8.64	8.57	0.07	0.0050410	FFE GATO GEN.	Door	Gato Generator Building
5005	78377.374	394009.243	4.00	3.95	0.05	0.0021160	HIGGS PIER @ DESIGN LOC	Front of Pier	Higgs Beach Pier
5007	78647.890	394121.866	3.06	2.98	0.08	0.0065610	HIGGS TENNIS COURT @ DESIGN LOC	Tennis Courts	Higgs Beach Tennis Court
5008	89074.521	406428.545	3.12	3.25	-0.13	0.0169000	DET. CENTER PARKING LOT@ DESIGN LOC	Parking Garage	MCSO Detention Center
5009	89343.786	406204.694	2.51	2.62	-0.11	0.0123210	FFE MCSO ADMIN PARKING @ DESIGN LOC	Parking Garage	MCSO Administrative Building
5011	136835.167	624339.801	10.08	10.04	0.04	0.0015210	FFE CORRECTIONS	Door	Marathon
5012	136868.314	624346.346	7.75	7.72	0.03	0.0006250	FFE CORRECTIONS GEN. BLDG	Door	Marathon
5013	136944.073	624455.588	8.46	8.45	0.01	0.0001210	FFE MONROE CO LIB BACK DOOR	Door	Marathon
5015	137050.298	624239.781	7.74	7.41	0.33	0.1075840	FFE MCSO	Porch	Marathon
5016	137038.518	624199.662	7.67	7.42	0.25	0.0630010	FFE TAX COLLECTOR	Door	Marathon
5019	124151.245	536719.546	6.81	6.92	-0.10	0.0106090	FFE	Door	Fire Station #13
5020	124137.216	536598.565	6.65	6.79	-0.15	0.0213160	FFE SENIOR CENTER	Door	Senior Center
5021	123223.217	537723.227	6.82	6.95	-0.14	0.0187690	FFE TAX COLLECTOR	Door	Tax Collector's Office
5023	123341.004	537724.997	6.86	7.12	-0.26	0.0665640	FFE LIBRARY	Door	Public Library
5025	246476.736	815980.632	8.46	8.34	0.12	0.0151290	FFE TAVERNIER FD #22	Dor	Tavernier Fire Station
5026	246356.302	815840.097	12.68	12.57	0.11	0.0118810	FFE HISTORIC SCHOOL	Door	Historic Tavernier School
5028	276591.307	842352.339	4.94	4.87	0.06	0.0040960	FFE MCMUA BLDG	Door	Key Largo Park PW Service Bldg
5029	278897.370	843949.118	7.82	7.96	-0.14	0.0184960	FFE MCPW BLDG	Door	Public Works
			TOTAL OBS	20		0.4352130	SUM		
						0.0217607			
						0.15	RMSE		