

Virginia– FEMA R3 Southwest Lidar – 2016 Final Vertical Accuracy Report

Report Produced for U.S. Geological Survey

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Final Swath Vertical Accuracy Assessment

Once Dewberry received the calibrated swath data from LEG, Dewberry tested the vertical accuracy of the non-vegetated terrain swath data prior to additional processing. Dewberry tested the vertical accuracy of the swath data using the 115 non-vegetated (open terrain and urban) independent survey check points. The vertical accuracy is tested by comparing survey checkpoints in non-vegetated terrain to a triangulated irregular network (TIN) that is created from the raw swath points. Only checkpoints in non-vegetated terrain can be tested against raw swath data because the data has not undergone classification techniques to remove vegetation, buildings, and other artifacts from the ground surface. Checkpoints are always compared to interpolated surfaces from the lidar point cloud because it is unlikely that a survey checkpoint will be located at the location of a discrete lidar point. Dewberry typically uses LP360 software to test the swath lidar vertical accuracy, Terrascan software to test the classified lidar vertical accuracy, and Esri ArcMap to test the DEM vertical accuracy so that three different software programs are used to validate the vertical accuracy for each project. Project specifications require a NVA of 19.6 cm based on the $RMSE_z$ (10 cm) x 1.96. The dataset for the Virginia Southwest AOI satisfies this criteria. This raw lidar swath data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm $RMSE_z$ Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z = 6.4$ cm, equating to +/- 12.4 cm at 95% confidence level. The table below shows all calculated statistics for the raw swath data.

100 % of Totals	# of Points	$RMSE_z$ NVA Spec=0.10 m	NVA –Non-vegetated Vertical Accuracy ($RMSE_z \times 1.9600$) Spec=0.196 m	Mean (m)	Median (m)	Skew	Std Dev (m)	Min (m)	Max (m)	Kurtosis
Non-Vegetated Terrain	179	0.063	0.124	0.002	-0.001	0.190	0.063	-0.179	0.202	0.349

Table 1: NVA at 95% Confidence Level for Raw Swaths

One (1) checkpoint (NVA-136) was removed from the raw swath vertical accuracy testing due to its location underneath parked vehicle. Only non-vegetated terrain checkpoints are used to test the raw swath data because the raw swath data has not been classified to remove vegetation, structures, and other above ground features from the ground classification. While NVA-136 is located in open terrain, the car is modeled by the lidar point cloud. These high points caused erroneous high values during the swath vertical accuracy testing so this point was removed from the final calculations. Once the data underwent the classification process, the vehicle was removed from the final ground classification and this point could be used in the final vertical accuracy testing for the fully classified lidar data. Table 4, below, provides the coordinates for this checkpoint and the vertical accuracy results from the raw swath data. Table 5, below, provides the usable vertical accuracy results of this checkpoint from the fully classified lidar. The differences in the tables show how above ground features can cause erroneous vertical accuracy results in the raw swath data. Figure 4, below, shows a 3D model of the lidar point cloud and the location of the checkpoint beneath a power line.

Point ID	NAD83 UTM 17N		NAVD88 (Geoid 12B)	Lidar Z (ft)	Delta Z	AbsDeltaZ
	Easting X (ft)	Northing Y (ft)	Survey Z (ft)			
NVA-136	409807.916	4061488.872	642.649	643.409	0.760	0.760

Table 2: Checkpoint removed from raw swath vertical accuracy testing

Point ID	NAD83 State Plane VA		NAVD88 (Geoid 12A)	Lidar Z (ft)	Delta Z	AbsDeltaZ
	Easting X (ft)	Northing Y (ft)	Survey Z (ft)			
NVA-136	409807.916	4061488.872	642.649	642.684	0.035	0.035

Table 3: Final tested vertical accuracy for NVA- 136 post ground classification

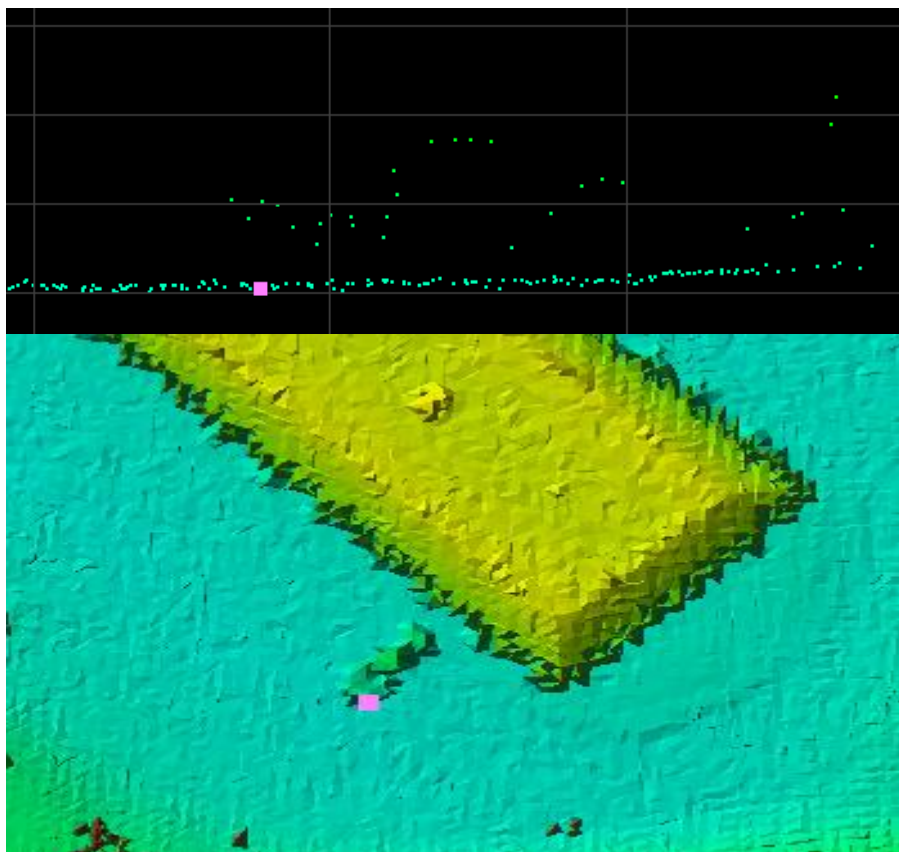


Figure 1 – NVA- 136, shown as the Pink Square, is located underneath a vehicle. This point was removed from raw swath vertical accuracy testing because above ground features, including vehicles, have not been separated from the ground classification yet.

SURVEY VERTICAL ACCURACY CHECKPOINTS

For the vertical accuracy assessment, Three hundred eight (308) check points were surveyed for the project and are located within bare earth/open terrain, grass/weeds/crops, and forested/fully grown land cover categories. Please see appendix A to view the survey report which details and validates how the survey was completed for this project.

Checkpoints were evenly distributed throughout the project area so as to cover as many flight lines as possible using the “dispersed method” of placement.

All checkpoints surveyed for vertical accuracy testing purposes are listed in the following table.

Point ID	NAD83 (2011) UTM Zone 17		NAVD88 (Geoid 12B)
	Easting X (m)	Northing Y (m)	Elevation (m)
NVA-065	568717.177	4138058.716	457.226
NVA-001	692710.070	4385322.529	202.000
NVA-002	703286.184	4376801.591	181.167
NVA-003	721813.647	4369841.440	191.714
NVA-004	721327.362	4352833.915	248.726
NVA-005	707217.698	4363958.846	249.554
NVA-006	698346.304	4369240.587	225.017
NVA-007	691460.816	4374659.813	183.823
NVA-008	677761.663	4365052.296	259.076
NVA-009	697544.831	4356062.278	439.016
NVA-010	706828.614	4352508.053	320.315
NVA-011	720454.565	4347137.510	271.186
NVA-012	719483.139	4337463.880	414.954
NVA-013	707618.371	4342539.110	290.892
NVA-014	694695.375	4345264.771	600.926
NVA-015	684277.725	4353717.711	239.375
NVA-016	673030.777	4357454.493	318.548
NVA-017	671035.698	4365638.032	341.668
NVA-018	665477.177	4360983.785	942.975
NVA-019	669383.111	4350872.749	319.026
NVA-020	685393.837	4344173.031	227.088
NVA-021	698413.881	4340125.171	501.066
NVA-022	708115.684	4327963.002	308.401
NVA-023	696679.359	4325684.159	390.099
NVA-024	686638.286	4330214.652	656.746
NVA-025	676467.904	4339914.759	334.851
NVA-026	668444.157	4341173.598	355.347
NVA-027	661227.021	4354323.679	831.602
NVA-028	651623.334	4349094.519	867.182
NVA-029	651776.965	4343490.361	869.097
NVA-030	661240.304	4335312.806	426.512
NVA-031	675084.610	4324392.827	249.455
NVA-032	688826.579	4323617.089	510.195

NVA-033	702599.495	4317662.690	521.036
NVA-034	695990.183	4314282.043	582.551
NVA-035	679430.939	4318150.640	509.180
NVA-036	661955.782	4326946.815	339.338
NVA-037	648868.444	4341148.560	1011.580
NVA-038	652910.893	4327503.347	511.782
NVA-039	663186.728	4317846.026	283.245
NVA-040	673128.658	4312933.227	299.422
NVA-041	685090.547	4305340.580	466.535
NVA-042	680838.485	4299905.960	521.509
NVA-043	667165.980	4300898.558	346.372
NVA-044	660244.045	4303135.162	381.887
NVA-045	657884.436	4309919.602	321.112
NVA-046	648432.387	4314465.272	356.498
NVA-047	646532.808	4308119.311	406.989
NVA-048	652088.242	4300195.456	389.781
NVA-049	662745.500	4291354.082	438.985
NVA-050	659539.777	4284315.529	486.985
NVA-051	648815.865	4291052.248	454.664
NVA-052	640921.062	4299309.489	479.877
NVA-053	632909.148	4302315.918	619.193
NVA-054	633917.008	4286541.183	592.050
NVA-055	645474.014	4278422.910	514.724
NVA-056	652865.208	4276986.659	481.080
NVA-057	650683.787	4268417.906	562.212
NVA-058	643446.154	4272472.295	566.039
NVA-059	639515.038	4275340.889	632.725
NVA-060	635773.150	4289602.254	543.191
NVA-061	631115.337	4281589.889	632.067
NVA-062	636764.329	4269330.788	615.603
NVA-063	642781.252	4264302.522	673.928
NVA-064	642506.098	4255692.445	646.458
NVA-066	562962.158	4148854.224	568.663
NVA-067	555367.920	4137304.653	748.514
NVA-068	542874.069	4143629.396	818.402
NVA-069	542873.221	4129041.525	575.861
NVA-070	529434.256	4136880.719	541.363
NVA-071	533709.789	4126876.067	521.828
NVA-072	523334.083	4131521.874	543.432
NVA-073	513141.441	4136765.222	509.032
NVA-074	512990.630	4128640.921	491.673
NVA-075	519408.396	4121462.002	736.688
NVA-076	510250.062	4114172.240	638.351
NVA-077	504111.690	4120160.338	682.190
NVA-078	490189.021	4121832.992	616.962
NVA-079	501639.443	4114941.019	645.946
NVA-080	501164.063	4102174.524	685.450

NVA-081	505132.986	4088823.665	632.624
NVA-082	512417.839	4078252.321	622.880
NVA-083	497680.937	4081373.274	707.431
NVA-084	493821.618	4090276.589	720.067
NVA-085	489895.984	4106402.651	760.412
NVA-086	486533.924	4111625.760	668.457
NVA-087	475031.795	4108336.315	961.623
NVA-088	478724.134	4124321.204	772.937
NVA-089	470187.202	4119626.269	758.660
NVA-090	469669.561	4128755.382	707.737
NVA-091	455906.039	4109829.525	739.582
NVA-092	470176.404	4105127.099	942.595
NVA-093	474587.088	4100420.550	829.465
NVA-094	475420.541	4083323.266	776.120
NVA-095	484409.390	4074420.727	702.023
NVA-096	485236.222	4065026.025	796.176
NVA-097	507092.570	4056662.830	718.010
NVA-098	486526.771	4052895.357	821.126
NVA-099	475459.117	4064197.372	932.763
NVA-100	474503.616	4077278.068	800.089
NVA-101	469717.797	4083372.373	758.354
NVA-102	452532.448	4096419.559	643.187
NVA-103	451198.671	4103596.823	841.419
NVA-104	444634.235	4115921.626	521.352
NVA-105	430481.116	4116886.165	910.264
NVA-106	418863.744	4122168.128	479.602
NVA-107	410841.482	4129907.039	404.940
NVA-108	409841.557	4141956.475	295.313
NVA-109	416444.738	4114544.692	499.363
NVA-110	428818.366	4105628.752	591.358
NVA-111	441638.568	4095988.958	715.281
NVA-112	429524.183	4096113.726	689.402
NVA-113	443232.591	4083680.008	625.496
NVA-114	462082.029	4080169.221	700.502
NVA-115	438884.876	4073057.560	624.088
NVA-116	462826.449	4069903.363	791.573
NVA-117	452191.398	4066769.065	748.936
NVA-118	460254.078	4062150.360	939.957
NVA-119	469843.728	4049412.805	763.730
NVA-120	463752.483	4056325.448	857.732
NVA-121	451930.758	4050418.168	969.122
NVA-122	443944.817	4050657.181	1090.464
NVA-123	436499.908	4062376.609	696.735
NVA-124	430339.350	4070672.909	664.573
NVA-125	431730.525	4081446.947	520.226
NVA-126	413238.216	4087924.129	684.256
NVA-127	407024.358	4102817.777	634.655

NVA-128	399439.052	4114042.378	572.580
NVA-129	397657.525	4120928.700	654.829
NVA-130	394458.038	4134889.886	282.676
NVA-131	380795.110	4121969.337	378.348
NVA-132	385436.799	4105591.146	478.286
NVA-133	395114.556	4091191.331	473.598
NVA-134	403214.801	4084282.433	631.874
NVA-135	408919.890	4072117.409	459.663
NVA-136	409807.916	4061488.872	642.649
NVA-137	429331.129	4053630.932	599.277
NVA-138	399188.495	4054984.005	560.752
NVA-139	391545.571	4050745.521	523.602
NVA-140	393210.231	4073905.064	634.847
NVA-141	380894.327	4074083.045	669.020
NVA-142	383111.890	4085022.299	452.876
NVA-143	368879.192	4089332.368	606.412
NVA-144	384751.214	4097070.145	545.681
NVA-145	363233.028	4096255.318	774.164
NVA-146	377009.463	4102406.850	737.299
NVA-147	376378.800	4111085.867	659.471
NVA-148	369126.019	4119602.558	556.619
NVA-149	364198.182	4113245.210	467.278
NVA-150	367542.635	4105290.032	459.195
NVA-151	358077.446	4110144.323	482.472
NVA-152	351508.880	4103225.216	718.825
NVA-153	355181.889	4088904.570	649.481
NVA-154	364198.345	4081280.111	847.883
NVA-155	369323.886	4077164.363	412.552
NVA-156	376846.949	4063827.767	531.996
NVA-157	372897.362	4055911.905	401.734
NVA-158	367203.022	4061569.306	485.022
NVA-159	359015.362	4070783.449	386.478
NVA-160	350881.297	4078976.961	973.622
NVA-161	341267.483	4081693.295	448.021
NVA-162	341425.324	4091299.424	574.873
NVA-163	331006.254	4081553.102	644.971
NVA-164	340775.506	4075636.996	586.149
NVA-165	348788.593	4066602.492	466.339
NVA-166	359675.921	4056413.225	411.919
NVA-167	344479.680	4056439.996	410.062
NVA-168	339164.737	4066108.768	414.728
NVA-169	331385.325	4071630.521	457.401
NVA-170	318647.577	4078363.317	527.179
NVA-171	316861.867	4068891.524	434.473
NVA-172	329233.494	4065415.938	565.724
NVA-173	333058.613	4057125.263	372.976
NVA-174	317373.089	4055160.189	383.603

NVA-175	309981.018	4062076.597	437.183
NVA-176	307412.202	4054105.343	426.736
NVA-177	295379.546	4063137.755	433.421
NVA-178	291528.562	4057169.507	427.725
NVA-179	280309.880	4056685.962	419.628
NVA-180	265092.667	4053722.300	369.857
VVA-001	688471.667	4379446.246	278.348
VVA-002	705646.852	4368288.794	328.808
VVA-003	715552.117	4372029.472	332.859
VVA-004	722193.075	4364649.736	210.782
VVA-005	715607.949	4356892.522	257.403
VVA-006	703904.886	4359487.750	290.528
VVA-007	689981.477	4363018.836	417.447
VVA-008	680784.642	4370365.277	276.043
VVA-009	670535.004	4363040.788	305.434
VVA-010	679701.019	4356341.875	224.018
VVA-011	689372.670	4351317.143	227.623
VVA-012	704664.538	4348127.687	401.123
VVA-013	714719.487	4346153.247	325.472
VVA-014	714428.171	4339433.723	267.567
VVA-015	696419.186	4343313.892	561.283
VVA-016	679223.619	4345771.701	283.431
VVA-017	670034.174	4353278.989	349.196
VVA-018	658281.794	4350550.985	857.634
VVA-019	670411.094	4343379.062	271.846
VVA-020	682791.881	4337789.425	311.624
VVA-021	693062.064	4331364.382	556.150
VVA-022	705167.780	4327096.498	319.498
VVA-023	696791.816	4316805.581	507.374
VVA-024	685976.278	4316930.058	492.786
VVA-025	670431.805	4328285.969	422.780
VVA-026	657384.295	4335571.733	601.337
VVA-028	649567.948	4325156.784	766.789
VVA-029	652793.226	4314632.829	506.938
VVA-030	669872.374	4315992.321	300.116
VVA-031	679392.373	4307726.577	638.641
VVA-032	683707.121	4298425.024	531.858
VVA-033	664158.362	4295347.427	385.143
VVA-034	656082.457	4306624.335	336.583
VVA-035	646447.986	4310113.397	393.916
VVA-036	638297.276	4305052.814	664.159
VVA-037	645689.244	4292258.760	536.365
VVA-038	654155.307	4288947.029	795.638
VVA-039	656545.514	4274151.025	579.265
VVA-040	643093.923	4283668.388	693.327
VVA-041	631870.192	4287558.429	906.086
VVA-042	625106.943	4278887.338	990.316

VVA-043	626437.431	4271935.294	728.238
VVA-044	644726.786	4269266.987	736.494
VVA-045	641044.043	4261711.584	742.531
VVA-046	647618.604	4262367.190	594.341
VVA-047	559722.582	4145196.383	535.466
VVA-048	562526.101	4139778.119	757.912
VVA-049	547561.065	4138416.566	620.999
VVA-050	533863.502	4135901.310	1265.326
VVA-051	546050.066	4133799.811	701.632
VVA-052	528766.225	4122026.598	579.295
VVA-053	513618.984	4140680.248	453.721
VVA-054	515717.498	4117185.122	597.731
VVA-055	506617.632	4125877.015	523.123
VVA-056	506564.424	4114319.702	631.437
VVA-057	489361.285	4120885.347	620.818
VVA-058	467313.082	4127246.521	769.508
VVA-059	474755.974	4118862.825	1103.243
VVA-060	485064.145	4108551.118	952.839
VVA-061	503890.297	4096370.620	679.881
VVA-062	483068.790	4096035.863	713.778
VVA-063	490183.019	4080664.506	812.320
VVA-064	510881.080	4086140.571	642.634
VVA-065	501853.721	4049571.930	763.605
VVA-066	484818.997	4061124.979	815.913
VVA-067	472350.459	4072074.545	812.797
VVA-068	465169.154	4090992.417	809.788
VVA-069	465611.797	4098419.714	721.218
VVA-070	456175.314	4121148.017	657.252
VVA-071	448613.911	4116354.663	704.733
VVA-072	437396.857	4115134.246	689.928
VVA-073	428162.477	4122212.941	803.257
VVA-074	413555.206	4131832.810	511.454
VVA-075	406311.279	4145029.345	280.220
VVA-076	402179.108	4135702.732	397.679
VVA-077	422176.273	4114001.186	831.570
VVA-078	437445.421	4108008.835	639.441
VVA-079	435347.070	4089336.491	1224.106
VVA-080	448575.316	4089741.627	593.395
VVA-081	466399.994	4079863.692	812.672
VVA-082	437990.797	4078620.462	722.178
VVA-083	455110.555	4067420.910	781.847
VVA-084	471691.039	4060107.408	862.972
VVA-085	458798.697	4052386.347	972.077
VVA-086	438318.545	4056831.477	925.678
VVA-087	427744.113	4077130.672	608.511
VVA-088	419110.733	4091631.002	723.175
VVA-089	410195.307	4100037.688	666.585

VVA-090	404285.020	4115509.421	450.448
VVA-091	390682.009	4127089.424	635.545
VVA-092	377204.271	4122077.661	534.848
VVA-093	390687.933	4109586.643	406.776
VVA-094	402490.703	4092756.688	475.169
VVA-095	414175.500	4076306.477	523.468
VVA-096	420777.039	4058226.561	574.556
VVA-097	408479.202	4051134.642	534.205
VVA-098	397854.470	4068152.071	438.218
VVA-099	392650.368	4084436.088	542.875
VVA-100	377864.543	4100478.650	500.829
VVA-101	373278.527	4115108.464	535.241
VVA-102	356287.066	4113426.923	629.649
VVA-103	362287.555	4102358.735	495.363
VVA-104	369624.258	4095685.828	797.243
VVA-105	378719.774	4091104.613	857.703
VVA-106	373343.985	4083220.198	585.846
VVA-107	383838.465	4070872.097	540.918
VVA-108	386639.000	4064277.116	423.854
VVA-109	390801.451	4055089.543	616.383
VVA-110	374066.176	4051673.347	493.282
VVA-111	371065.067	4065352.449	602.410
VVA-112	364929.278	4076947.154	436.772
VVA-113	354588.996	4086712.841	968.501
VVA-114	346254.781	4097526.676	653.673
VVA-115	350531.856	4106855.071	505.494
VVA-116	336762.438	4092098.582	599.090
VVA-117	347875.019	4080791.564	503.674
VVA-118	354448.511	4064645.276	460.088
VVA-119	348748.204	4056114.960	491.610
VVA-120	339553.642	4067855.477	429.186
VVA-122	316401.019	4075174.568	466.998
VVA-123	323065.397	4065644.052	477.637
VVA-124	325628.985	4056086.160	445.872
VVA-125	315079.079	4055662.729	431.951
VVA-126	306408.004	4067054.799	486.725
VVA-127	298953.317	4063315.896	500.715
VVA-128	295682.925	4054509.531	404.660
VVA-129	282638.475	4054483.093	467.836
VVA-130	271750.810	4057340.982	444.156

Table 4- Virginia South West AOI surveyed accuracy checkpoints

The figure below shows the location of the QA/QC checkpoints used to test the positional accuracy of the dataset.

One checkpoint (VVA-027) was removed from the vertical accuracy testing for the classified lidar because it is outside of the AOI. The coordinates of the checkpoint are provided in the table below and a visual showing the checkpoint outside the AOI is provided in the figure below.

Point ID	NAD83 (2011) UTM Zone 17		NAVD88 (Geoid 12B)
	Easting X (m)	Northing Y (m)	Survey Z (m)
VVA-027	638514.287	4346303.065	777.810

Table 5: Checkpoint removed from vertical accuracy testing due to its location outside of the project AOI.

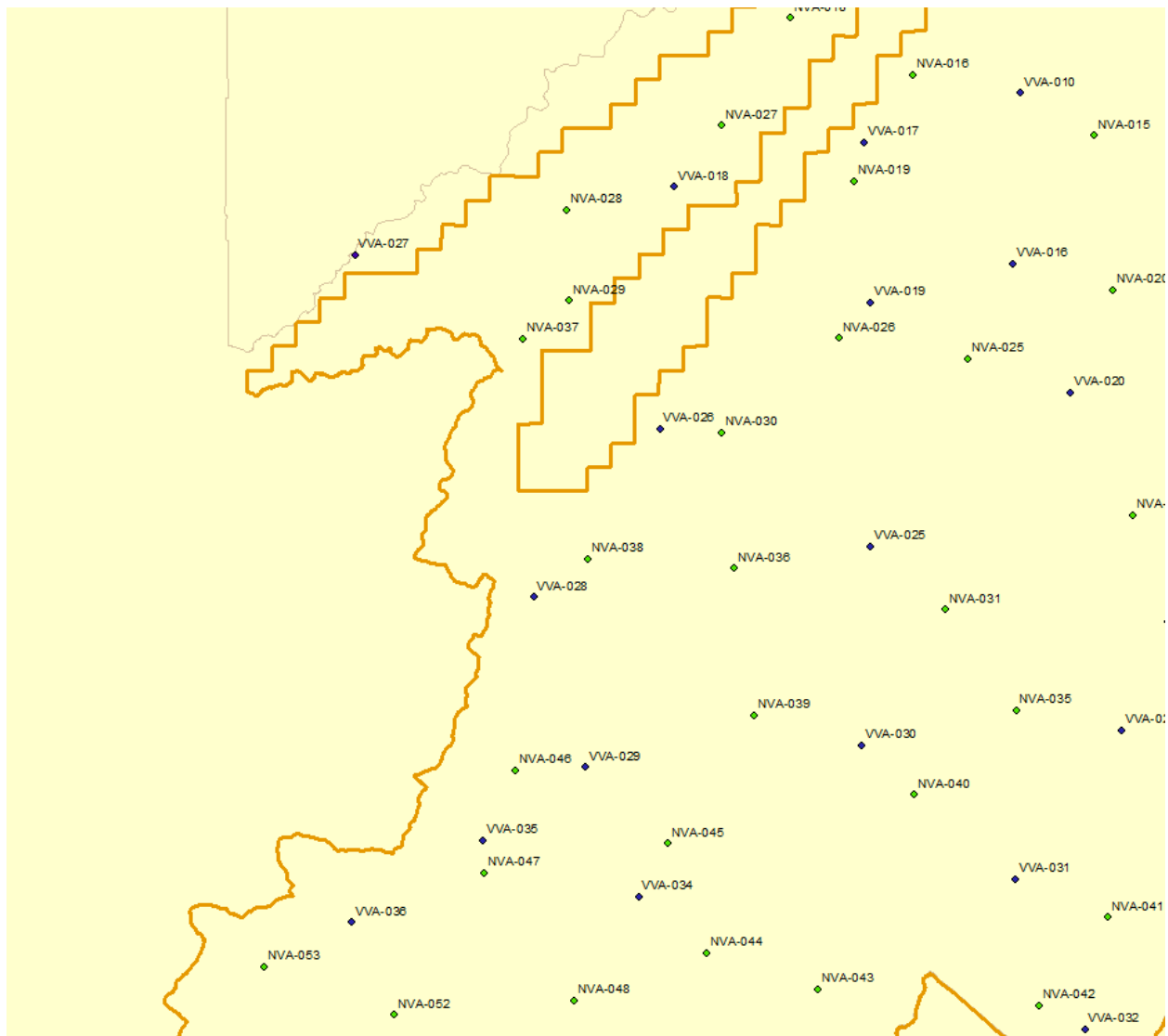


Figure 2 – VVA-027, shown as blue point outside of the AOI

Virginia FEMA R3 SW Lidar - Checkpoint Locations

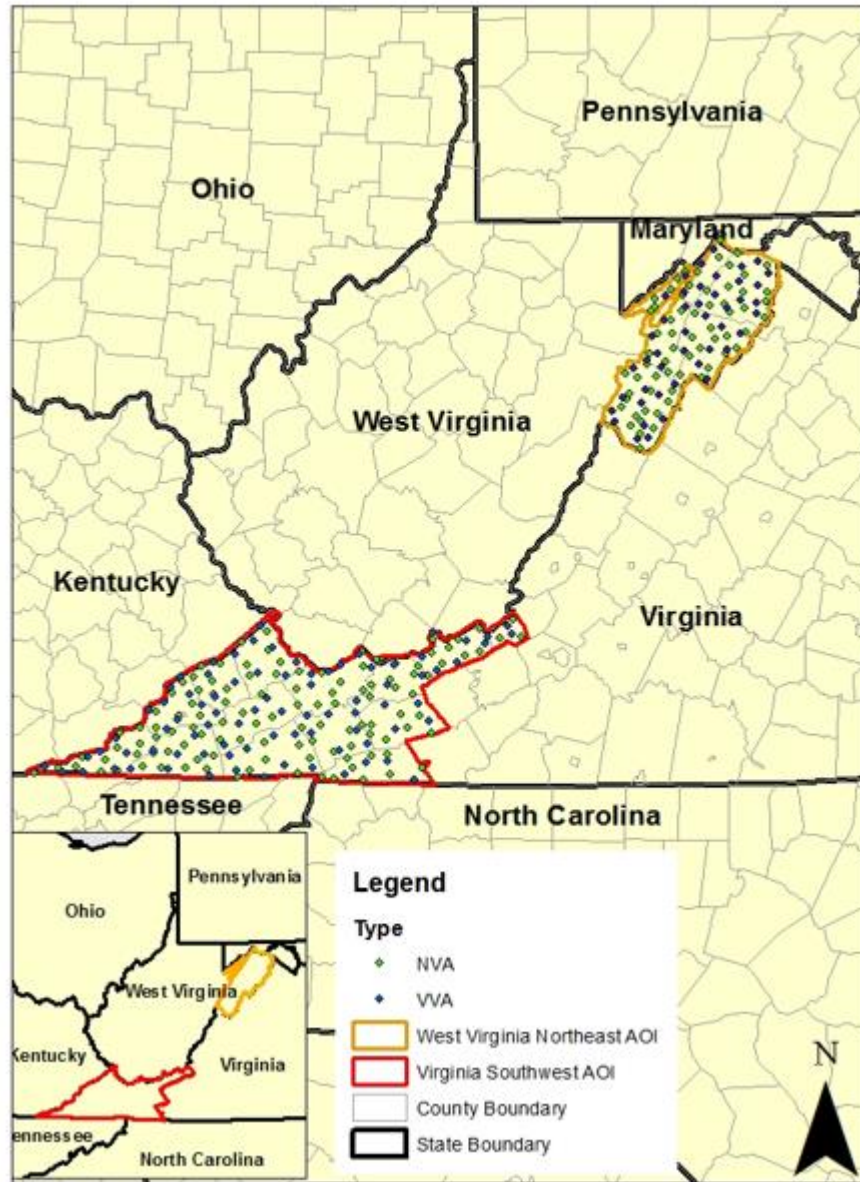


Figure 3 – Location of QA/QC Checkpoints

VERTICAL ACCURACY TEST PROCEDURES

NVA (Non-vegetated Vertical Accuracy) is determined with check points located only in non-vegetated terrain, including open terrain (grass, dirt, sand, and/or rocks) and urban areas, where there is a very high probability that the lidar sensor will have detected the bare-earth ground surface and where random errors are expected to follow a normal error distribution. The NVA

determines how well the calibrated lidar sensor performed. With a normal error distribution, the vertical accuracy at the 95% confidence level is computed as the vertical root mean square error (RMSE_z) of the checkpoints x 1.9600. For the Virginia Southwest AOI, vertical accuracy must be 19.6 cm or less based on an RMSE_z of 10 cm x 1.9600.

VVA (Vegetated Vertical Accuracy) is determined with all checkpoints in vegetated land cover categories, including tall grass, weeds, crops, brush and low trees, and fully forested areas, where there is a possibility that the lidar sensor and post-processing may yield elevation errors that do not follow a normal error distribution. VVA at the 95% confidence level equals the 95th percentile error for all checkpoints in all vegetated land cover categories combined. The Virginia Southwest AOI VVA standard is 29.4 cm based on the 95th percentile. The VVA is accompanied by a listing of the 5% outliers that are larger than the 95th percentile used to compute the VVA; these are always the largest outliers that may depart from a normal error distribution. Here, Accuracy_z differs from VVA because Accuracy_z assumes elevation errors follow a normal error distribution where RMSE procedures are valid, whereas VVA assumes lidar errors may not follow a normal error distribution in vegetated categories, making the RMSE process invalid.

The relevant testing criteria are summarized in Table 6.

Quantitative Criteria	Measure of Acceptability
Non-Vegetated Vertical Accuracy (NVA) in open terrain and urban land cover categories using RMSE _z *1.9600	19.6 cm (based on RMSE _z (10 cm) * 1.9600)
Vegetated Vertical Accuracy (VVA) in all vegetated land cover categories combined at the 95% confidence level	29.4 cm (based on combined 95 th percentile)

Table 6 – Acceptance Criteria

The primary QA/QC vertical accuracy testing steps used by Dewberry are summarized as follows:

1. Dewberry’s team surveyed QA/QC vertical checkpoints in accordance with the project’s specifications.
2. Next, Dewberry interpolated the bare-earth lidar DTM to provide the z-value for every checkpoint.
3. Dewberry then computed the associated z-value differences between the interpolated z-value from the lidar data and the ground truth survey checkpoints and computed NVA, VVA, and other statistics.
4. The data were analyzed by Dewberry to assess the accuracy of the data. The review process examined the various accuracy parameters as defined by the scope of work. The overall descriptive statistics of each dataset were computed to assess any trends or anomalies. This report provides tables, graphs and figures to summarize and illustrate data quality.

VERTICAL ACCURACY RESULTS

The table below summarizes the tested vertical accuracy resulting from a comparison of the surveyed checkpoints to the elevation values present within the fully classified lidar LAS files.

Land Cover Category	# of Points	NVA – Non-vegetated Vertical Accuracy	VVA – Vegetated Vertical Accuracy (95th Percentile) Spec=29.4 cm
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		(RMSE _z x 1.9600) Spec=19.6 cm	
NVA	180	0.122	
VVA	128		0.192

Table 7 – Tested NVA and VVA

This lidar dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm RMSE_z Vertical Accuracy Class. Actual NVA accuracy was found to be RMSE_z = 6.2 cm, equating to +/- 12.2 cm at 95% confidence level. Actual VVA accuracy was found to be +/- 19.2 cm at the 95th percentile.

The figure below illustrates the magnitude of the differences between the QA/QC checkpoints and lidar data. This shows that the majority of lidar elevations were within +/- 20 cm of the checkpoints elevations, but there were some outliers where lidar and checkpoint elevations differed by up to +70 cm.

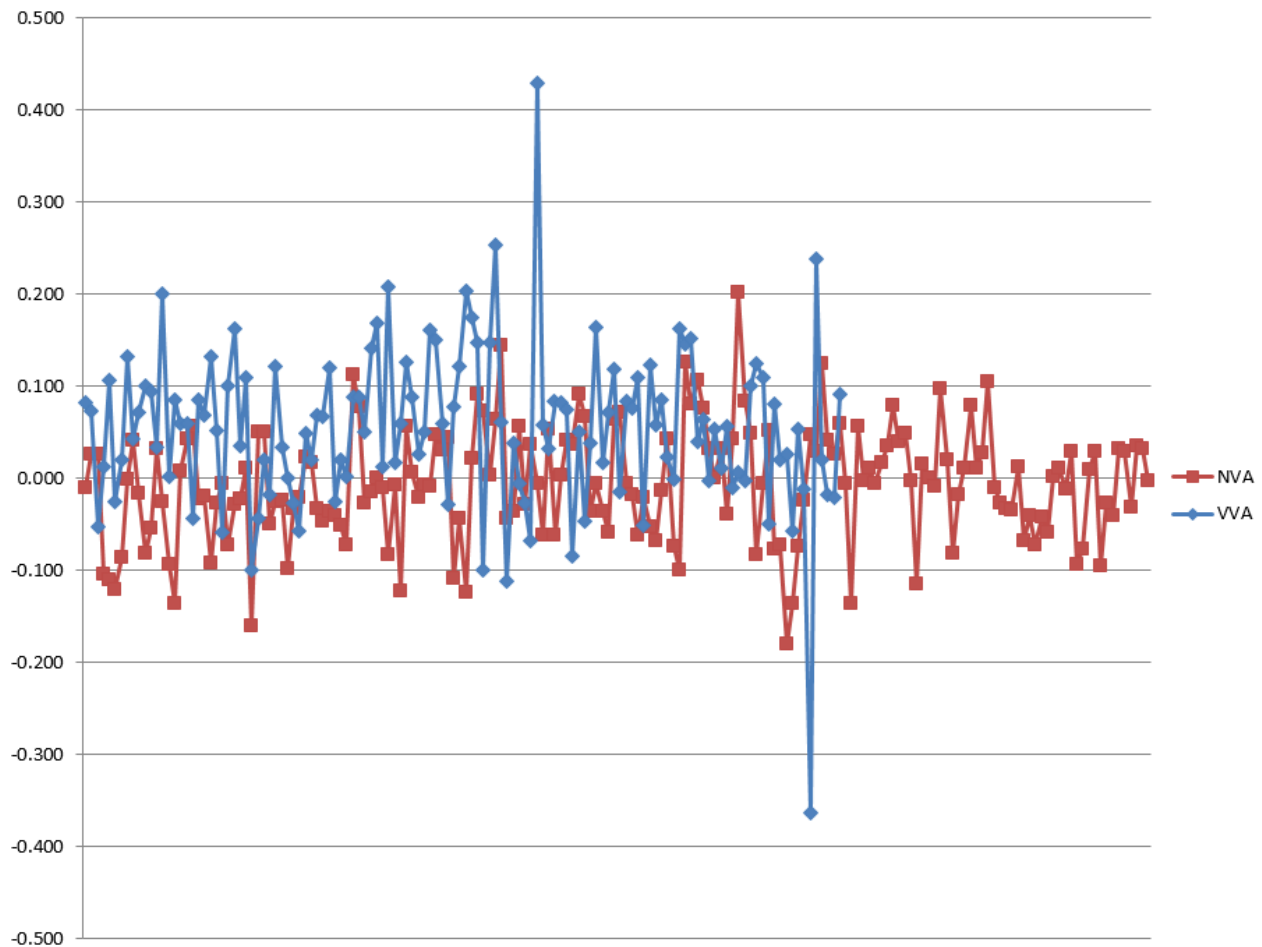


Figure 4 – Magnitude of elevation discrepancies per land cover category

Table 8 lists the 5% outliers that are larger than the VVA 95th percentile.

Point ID	NAD83 UTM Zone 15		NAVD88 (Geoid 12A)	Lidar Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
VVA-014	714428.171	4339433.723	267.567	267.768	0.201	0.201
VVA-066	484818.997	4061124.979	815.913	816.117	0.204	0.204
VVA-053	513618.984	4140680.248	453.721	453.929	0.208	0.208
VVA-126	306408.004	4067054.799	486.725	486.964	0.239	0.239
VVA-071	448613.911	4116354.663	704.733	704.987	0.254	0.254
VVA-125	315079.079	4055662.729	431.951	431.588	-0.363	0.363
VVA-078	437445.421	4108008.835	639.441	639.871	0.430	0.430

Table 8 – 5% Outliers

Table 9 provides overall descriptive statistics.

100 % of Totals	# of Points	RMSEz (m) NVA Spec=0.1 m	Mean (m)	Median (m)	Skew	Std Dev (m)	Kurtosis	Min (m)	Max (m)
NVA	180	0.062	-0.006	-0.006	0.001	0.062	0.297	-0.179	0.202
VVA	128	N/A	0.055	0.058	-0.145	0.088	5.330	-0.363	0.430

Table 9 – Overall Descriptive Statistics

The figure below illustrates a histogram of the associated elevation discrepancies between the QA/QC checkpoints and elevations interpolated from the lidar triangulated irregular network (TIN). The frequency shows the number of discrepancies within each band of elevation differences. Although the discrepancies vary between a low of -0.36 meters and a high of +0.43 meters, the histogram shows that the majority of the discrepancies are skewed on the positive side. The vast majority of points are within the ranges of -0.05 meters to +0.05 meters.

Checkpoints Error Distribution

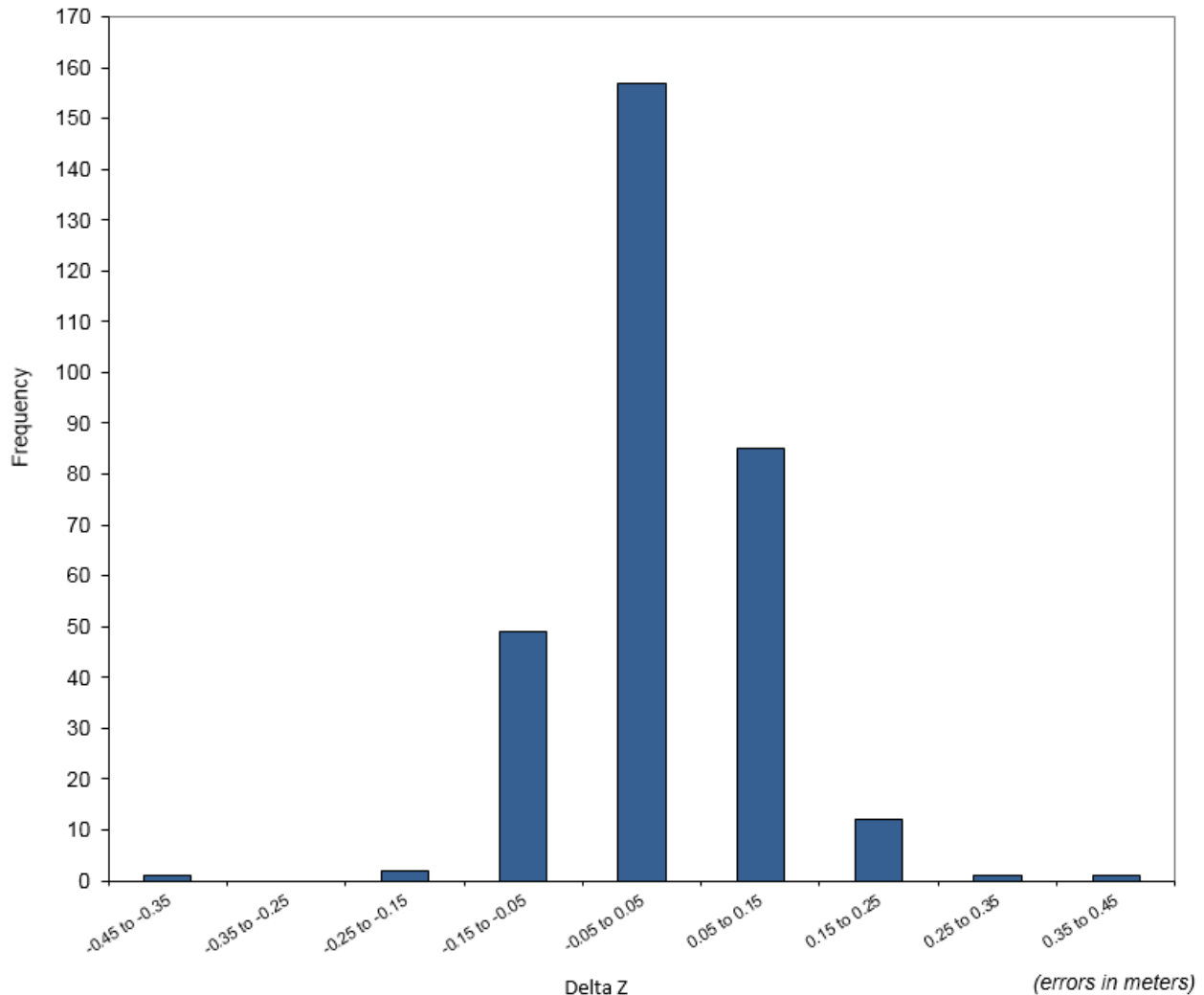


Figure 5 – Histogram of Elevation Discrepancies with errors in meters

Based on the vertical accuracy testing conducted by Dewberry, the lidar dataset for the Virginia FEMA R3 SW Lidar satisfies the project’s pre-defined vertical accuracy criteria.

HORIZONTAL ACCURACY TEST PROCEDURES

Horizontal accuracy testing requires well-defined checkpoints that can be identified in the dataset. Elevation datasets, including lidar datasets, do not always contain well-defined checkpoints suitable for horizontal accuracy assessment. However, the ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) recommends at least half of the NVA vertical check points should be located at the ends of paint stripes or other point features visible on the lidar intensity image, allowing them to double as horizontal check points.

Dewberry reviews all NVA checkpoints to determine which, if any, of these checkpoints are located on photo-identifiable features in the intensity imagery. This subset of checkpoints are then used for horizontal accuracy testing.

The primary QA/QC horizontal accuracy testing steps used by Dewberry are summarized as follows:

1. Dewberry’s team surveyed QA/QC vertical checkpoints in accordance with the project’s specifications and tried to locate half of the NVA checkpoints on features photo-identifiable in the intensity imagery.
2. Next, Dewberry identified the well-defined features in the intensity imagery.
3. Dewberry then computed the associated xy-value differences between the coordinates of the well-defined feature in the lidar intensity imagery and the ground truth survey checkpoints.
4. The data were analyzed by Dewberry to assess the accuracy of the data. Horizontal accuracy was assessed using NSSDA methodology where horizontal accuracy is calculated at the 95% confidence level. This report provides the results of the horizontal accuracy testing.

HORIZONTAL ACCURACY RESULTS

Sixty checkpoints were determined to be photo-identifiable in the intensity imagery and were used to test the horizontal accuracy of the lidar dataset.

Using NSSDA methodology (endorsed by the ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014)), horizontal accuracy at the 95% confidence level (called ACCURACY_r) is computed by the formula $RMSE_r * 1.7308$ or $RMSE_x * 2.448$.

No horizontal accuracy requirements or thresholds were provided for this project. However, lidar datasets are generally calibrated by methods designed to ensure a horizontal accuracy of 1 meter or less at the 95% confidence level.

# of Points	RMSE _x (Target=41 cm)	RMSE _y (Target=41 cm)	RMSE _r (Target=58 cm)	ACCURACY _r (RMSE _r x 1.7308) Target=100 cm
63	0.283	0.188	0.339	0.588

Table 10-Tested horizontal accuracy at the 95% confidence level

This data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 41 cm RMSE_x/RMSE_y Horizontal Accuracy Class which equates to Positional Horizontal Accuracy = +/- 1 meter at a 95% confidence level. Using this sample set of photo-identifiable checkpoints, positional accuracy of this dataset was found to be RMSE_x = 28.3 cm and RMSE_y = 18.8 cm which equates to +/- 58.8 cm at 95% confidence level.

DEM VERTICAL ACCURACY RESULTS

The same 308 checkpoints that were used to test the vertical accuracy of the lidar were used to validate the vertical accuracy of the final DEM products as well. Accuracy results may vary between the source lidar and final DEM deliverable. DEMs are created by averaging several lidar points within each pixel which may result in slightly different elevation values at each survey checkpoint when compared to the source LAS, which does not average several lidar points together but may interpolate (linearly) between two or three points to derive an elevation value. The vertical accuracy of the DEM is tested by extracting the elevation of the pixel that contains the x/y coordinates of the checkpoint and comparing these DEM elevations to the surveyed elevations. Dewberry typically uses LP360 software to test the swath lidar vertical accuracy, Terrascan software to test the classified lidar vertical accuracy, and Esri ArcMap to test the DEM vertical accuracy so that three different software programs are used to validate the vertical accuracy for each project.

Table 11 summarizes the tested vertical accuracy results from a comparison of the surveyed checkpoints to the elevation values present within the final DEM dataset.

Land Cover Category	# of Points	NVA – Non-vegetated Vertical Accuracy (RMSE _z x 1.9600) Spec=19.6 cm	VVA – Vegetated Vertical Accuracy (95th Percentile) Spec=29.4 cm
NVA	180	0.119	
VVA	128		0.201

Table 11 – DEM tested NVA and VVA

This DEM dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm RMSE_z Vertical Accuracy Class. Actual NVA accuracy was found to be RMSE_z =6.1 cm, equating to +/- 11.9 cm at 95% confidence level. Actual VVA accuracy was found to be +/- 20.1 cm at the 95th percentile.

Table 12 lists the 5% outliers that are larger than the VVA 95th percentile.

Point ID	NAD83 UTM Zone 17		NAVD88 (Geoid 12B)	DEM Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
VVA-102	356287.066	4113426.923	629.649	629.852	0.203	0.203
VVA-014	714428.171	4339433.723	267.567	267.774	0.207	0.207
VVA-053	513618.984	4140680.248	453.721	453.931	0.210	0.210
VVA-071	448613.911	4116354.663	704.733	704.972	0.239	0.239
VVA-126	306408.004	4067054.799	486.725	486.981	0.256	0.256
VVA-125	315079.079	4055662.729	431.951	431.618	-0.333	0.333
VVA-078	437445.421	4108008.835	639.441	639.863	0.422	0.422

Table 12 – 5% Outliers

Table 13 provides overall descriptive statistics.

100 % of Totals	# of Points	RMSEz (m) NVA Spec=0.1 m	Mean (m)	Median (m)	Skew	Std Dev (m)	Kurtosis	Min (m)	Max (m)
NVA	180	0.061	-0.008	-0.008	0.072	0.061	0.658	-0.166	0.217
VVA	128	N/A	0.061	0.058	-0.120	0.089	3.963	-0.333	0.422

Table 13 – Overall Descriptive Statistics

Based on the vertical accuracy testing conducted by Dewberry, the DEM dataset for the Virginia FEMA R3 SW Lidar Project satisfies the project’s pre-defined vertical accuracy criteria.