Lolo Montana
LiDAR Mapping Report

Project Location
Lolo, Montana

Prepared by:

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SUMMARY

Merrick & Company (Merrick) was contracted by Sand Surveying to calibrate and classify data collected with Sand Surveying's LiDAR (**Li**ght **D**etection **A**nd **R**anging) system. The project consists of approximately 16 square miles, around Lolo, in Montana. The purpose of the project is to produce accurate high-resolution LiDAR data to support mapping.
The vertical accuracy requirements of the LiDAR data will meet or exceed the following:

- ≤10cm RMSEz

CONTACT INFORMATION

Questions regarding this report should be addressed to:

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Project Report

The contents of this report summarize the methods used to calibrate and classify as well as the results of these methods for project Lolo, Montana.

Duration/Time Period

Sand Surveying collected the project with one LiDAR helicopter, a McDonnell Douglas, tail number N520N. The airport of operation was Missoula International Airport (MSO).

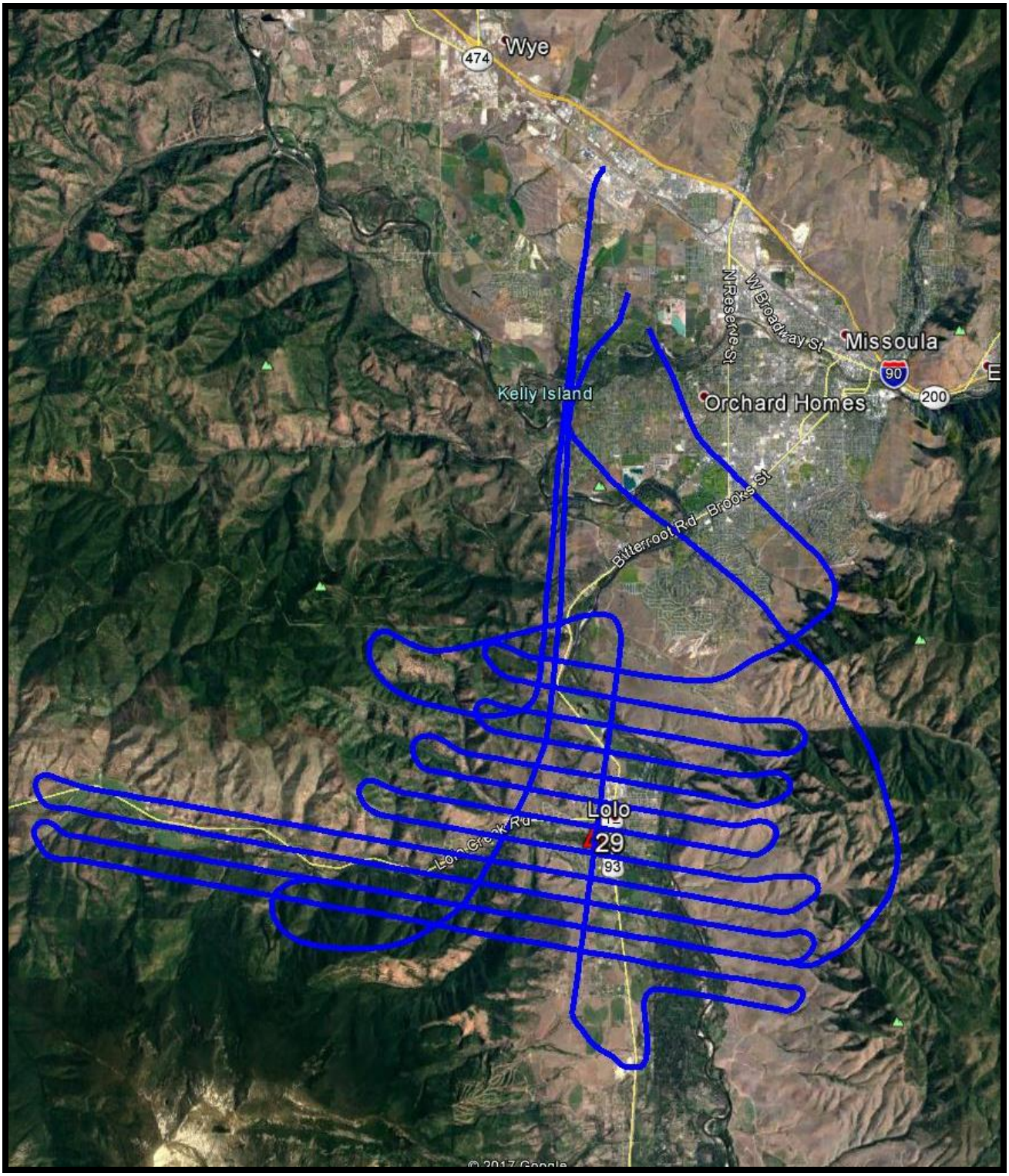
Flight Mission Date and Times

Mission	Date	Sensor S/N	Start Time GPS sec.	End Time GPS sec.	Number of GNSS Solution Records
170523_A	May 23, 2017	5060385	237669.0	243040.0	5372
170523_B	May 23, 2017	5060385	245342.0	248671.0	3330

Field Work / Procedures

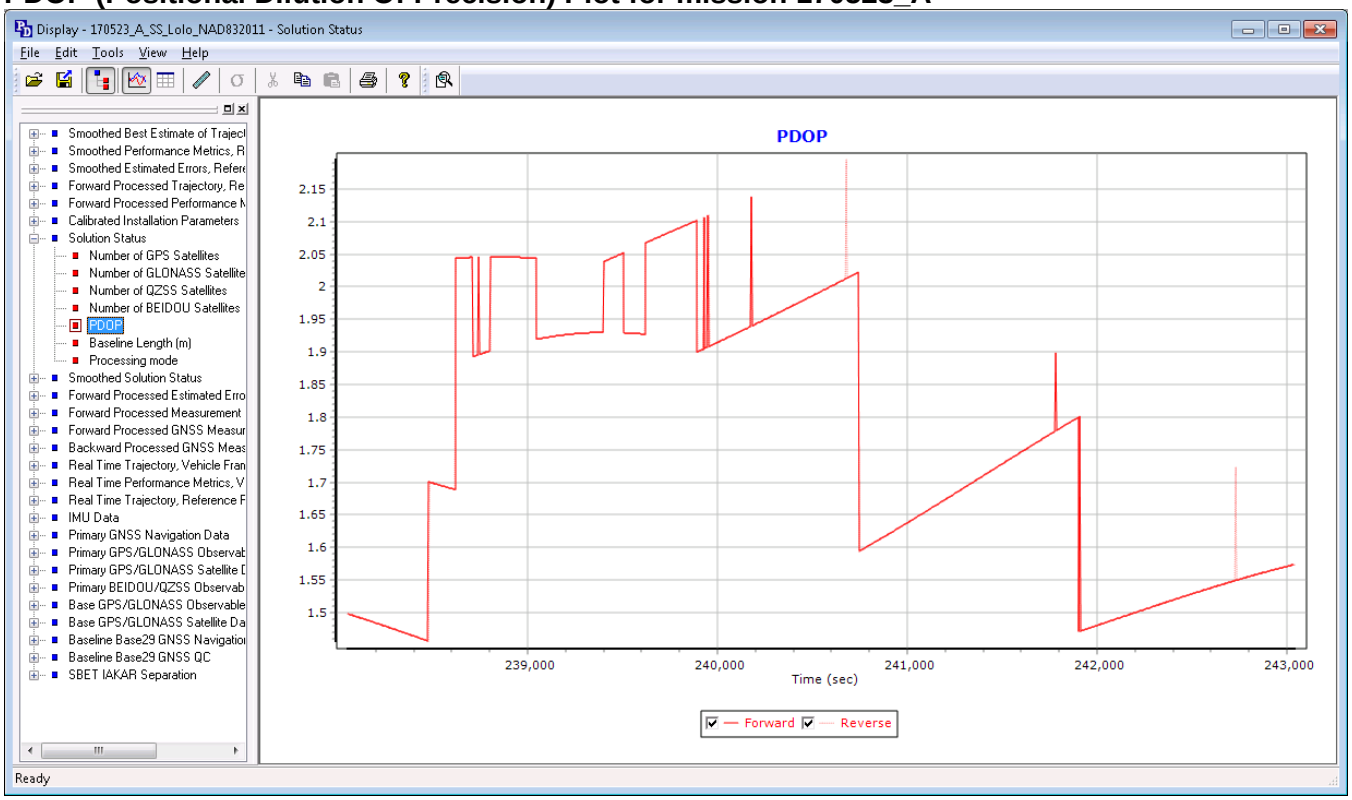
One base station, set within the project area was used to control the airborne flight lines.

Actual Flight Lines Showing Base 29

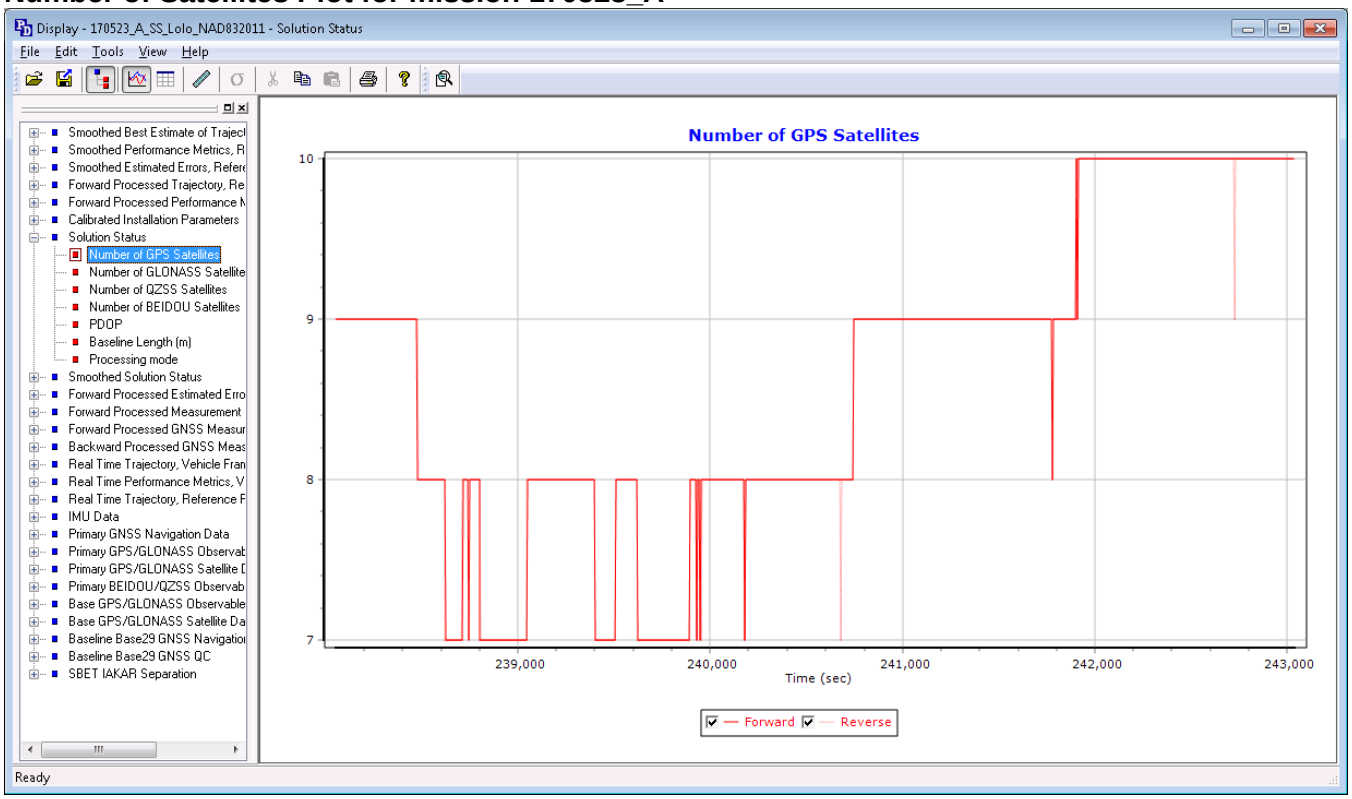


The following graphs show the GNSS PDOP (Positional Dilution Of Precision) Plot and Number of Satellites Plot

PDOP (Positional Dilution Of Precision) Plot for mission 170523_A

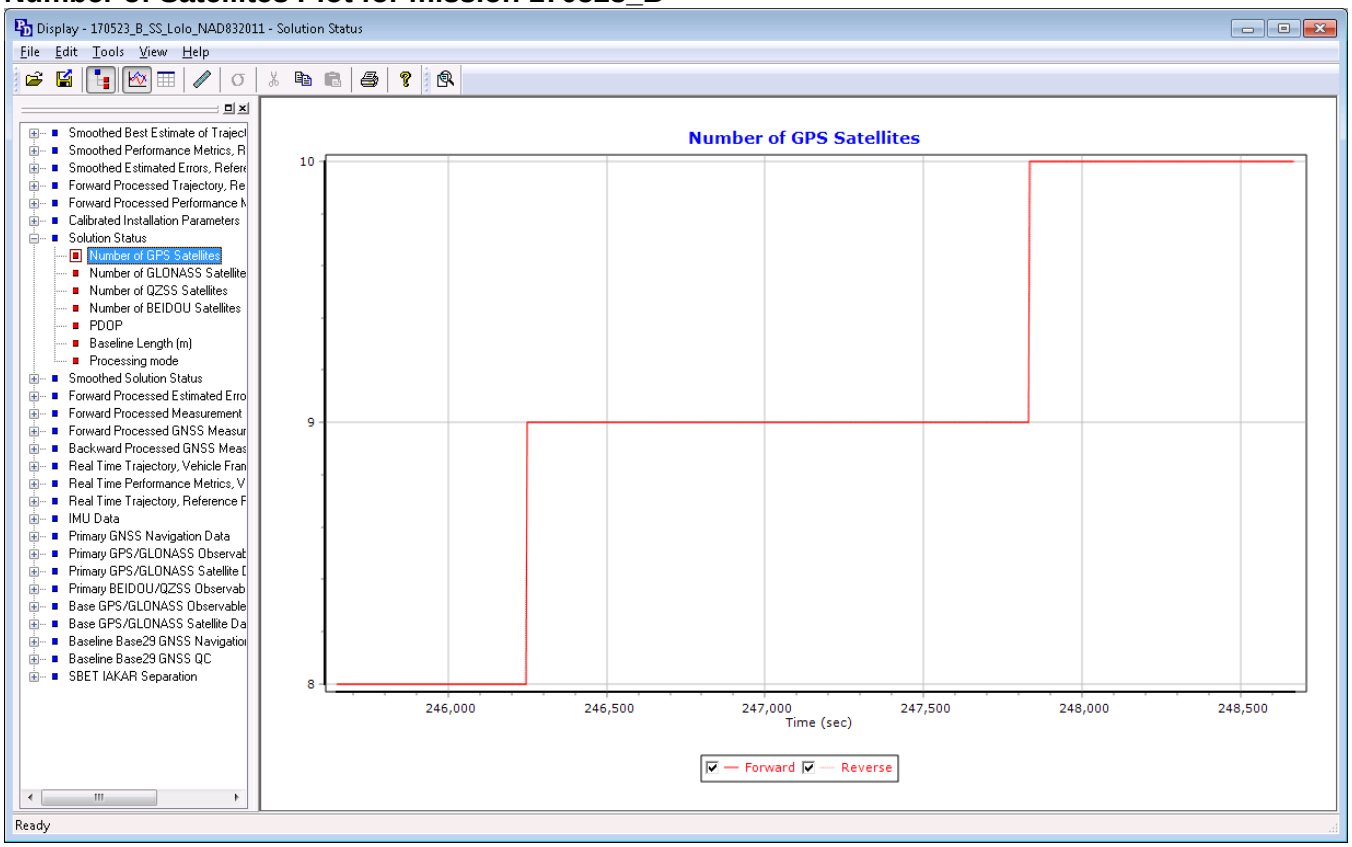


Number of Satellites Plot for mission 170523_A



PDOP (Positional Dilution Of Precision) Plot for mission 170523_B

Number of Satellites Plot for mission 170523_B



LiDAR Data Processing

The airborne GPS data was post-processed using Applanix POSPac Mobile Mapping Suite version 8.0. A fixed-bias carrier phase solution was computed in both the forward and reverse chronological directions. Whenever practical, LiDAR acquisition was limited to periods when the PDOP (**P**ositional **D**ilution **O**f **P**recision) was less than 4.0. PDOP indicates satellite geometry relating to position. Generally PDOP's of 4.0 or less result in a good quality solution, however PDOP's between 4.0 and 5.0 can still yield good results most of the time. PDOP's over 6.0 are of questionable results and PDOP's of over 7.0 usually result in a poor solution. Usually as the number of satellites increase the PDOP decreases. Other quality control checks used for the GPS include analyzing the combined separation of the forward and reverse GPS processing from one base station and the results of the combined separation when processed from two different base stations. Basically this is the difference between the two trajectories. An analysis of the number of satellites, present during the flight and data collection times, is also performed.

The GPS trajectory was combined with the raw IMU data and post-processed using POSPac Mobile Mapping Suite version 8.0. The Smoothed Best Estimated Trajectory (SBET) and refined attitude data are then utilized in the LMS Post Processor to compute the laser point-positions – the trajectory is combined with the attitude data and laser range measurements to produce the 3-dimensional coordinates of the mass points. Up to four return values are produced within the Optech LiDAR Mapping Suite (LMS) processor software for each pulse which ensures the greatest chance of ground returns in a heavily forested area.

Laser point classification was completed using Merrick Advanced Remote Sensing (MARS®) LiDAR processing and modeling software. Several algorithms are used when comparing points to determine the best automatic ground solution. Each filter is built based on the projects terrain and land cover to provide a surface that is 90% free of anomalies and artifacts. After the auto filter has been completed the data sets are then reviewed by an operator utilizing MARS® to remove any other anomalies or artifacts not resolved by the automated filter process. During these final steps the operator also verifies that the data sets are consistent and complete with no data voids.

GPS Controls

One base station was used to control the airborne flight lines.
See the following OPUS solution sheet for ground GNSS Base Station information:

FILE: 29__1430.17o OP1495831103089

NGS OPUS SOLUTION REPORT
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All computed coordinate accuracies are listed as peak-to-peak values.
For additional information: https://www.ngs.noaa.gov/OPUS/about.jsp#accuracy

USER: jamie@sandssurveying.com DATE: May 26, 2017
RINEX FILE: 29__143n.17o TIME: 20:43:00 UTC

SOFTWARE: page5 1603.24 master91.pl 160321 START: 2017/05/23 13:54:00
EPHEMERIS: igr19502.eph [rapid] STOP: 2017/05/23 21:33:00
NAV FILE: brdc1430.17n OBS USED: 19364 / 20528 : 94%
ANT NAME: LEIATX1230GG NONE # FIXED AMB: 111 / 113 : 98%
ARP HEIGHT: 1.647 OVERALL RMS: 0.015(m)

REF FRAME: NAD_83(2011)(EPOCH:2010.0000) IGS08 (EPOCH:2017.3911)

X: -1787033.847(m) 0.009(m) -1787034.761(m) 0.009(m)
Y: -3997114.809(m) 0.008(m) -3997113.592(m) 0.008(m)
Z: 4623676.655(m) 0.005(m) 4623676.630(m) 0.005(m)

LAT: 46 45 10.02416 0.004(m) 46 45 10.04101 0.004(m)
E LON: 245 54 41.36969 0.007(m) 245 54 41.30698 0.007(m)
W LON: 114 5 18.63031 0.007(m) 114 5 18.69302 0.007(m)
EL HGT: 958.576(m) 0.010(m) 958.052(m) 0.010(m)
ORTHO HGT: 973.345(m) 0.020(m) [NAVD88 (Computed using GEOID12B)]

UTM COORDINATES STATE PLANE COORDINATES
UTM (Zone 11) SPC (2500 MT)
Northing (Y) [meters] 5181809.498 288371.545
Easting (X) [meters] 722360.967 249819.722
Convergence [degrees] 2.12160811 -3.35651320
Point Scale 1.00020777 0.99940287
Combined Factor 1.00005750 0.99925272

US NATIONAL GRID DESIGNATOR: 11TQM2236081809(NAD 83)

BASE STATIONS USED
PID DESIGNATION LATITUDE LONGITUDE DISTANCE(m)
DE8232 MSOL MISSOULA CORS ARP N465545.837 W1140631.844 19698.0
DO2060 MTHC HIGHLANDS COLLEGE CORS ARP N455616.197 W1123036.108 151587.3
DN6069 LOLO LOLO CORS ARP N464546.247 W1140548.672 1296.6

NEAREST NGS PUBLISHED CONTROL POINT
DH9363 CORPS II TRAVELERS REST N464510.024 W1140518.629 0.0

This position and the above vector components were computed without any
knowledge by the National Geodetic Survey regarding the equipment or
field operating procedures used.

Ground Control Parameters

Coordinate System: Montana State Plane Coordinate System
Horizontal Datum: The horizontal datum for the project is North American Datum of 1983, adjusted to the National Spatial Reference System of 2011 (NAD83/2011)
Vertical Datum: The Vertical datum for the project is North American Vertical Datum of 1988 (NAVD88)
Geiod Model: Geoid12B (Geoid12B will be used to convert ellipsoid heights to orthometric heights)
Units: Horizontal and vertical units are in International Feet

Base29 (Location for LiDAR Data Collection)

Ground Survey

Ground Control Point GNSS Survey

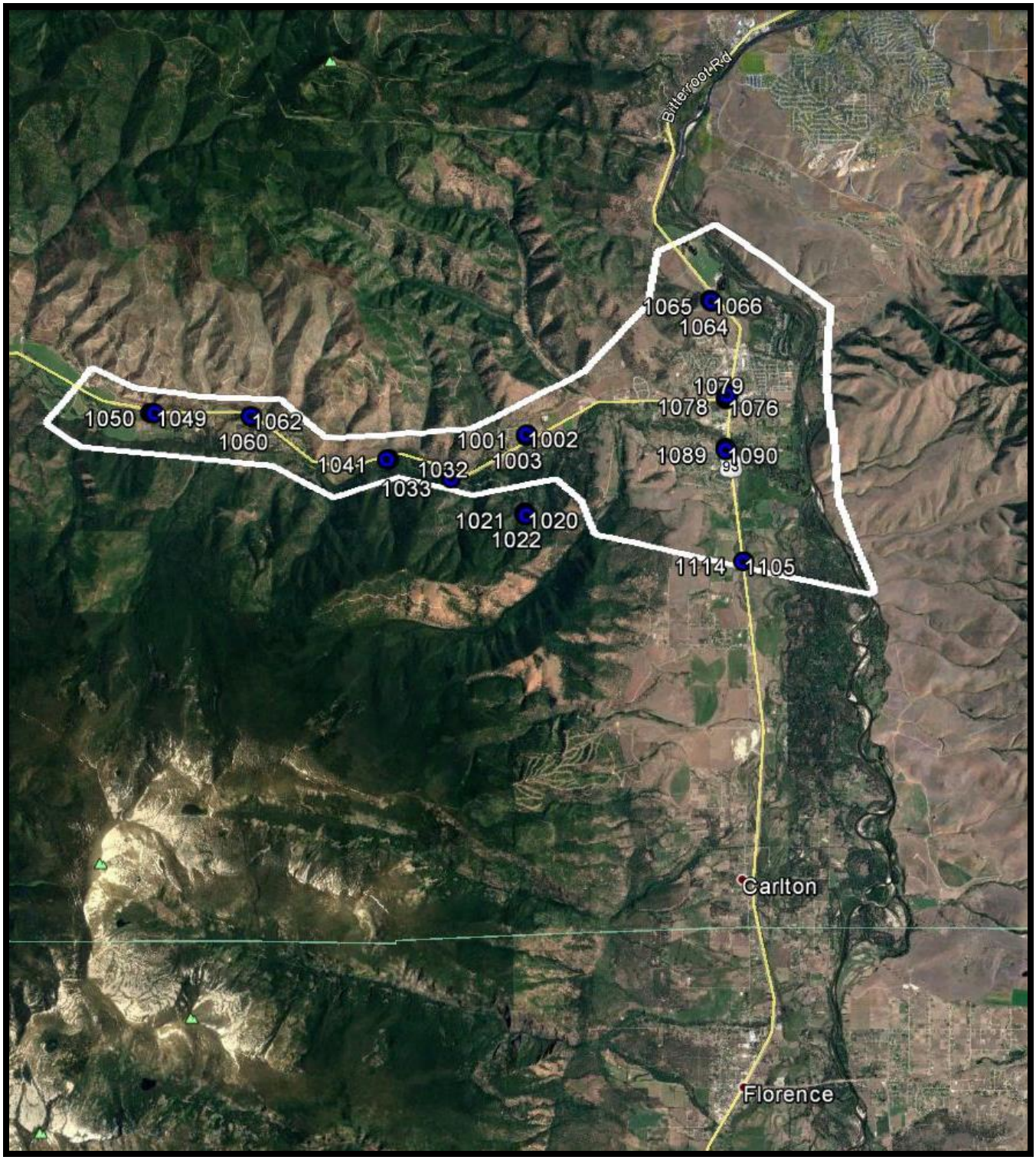
The following listing shows the ground survey points that were established as LiDAR control points. The LAS data is adjusted to the ground based on the control points. The ground survey control points were established and surveyed by Sand Surveying. Note: Description EP = shots on pavement (not edges), and EG = shots on gravel surface (not edges).

Ground Points (Control points)

Point Id	North IntlFT Montana	East IntlFT Montana	Elev IntlFT NAVD88	Desc	Code CP=Control Point
1000	945943.61	807775.63	3283.16	EP	CP_PRIMARY
1001	946007.06	807736.01	3284.13	EP	CP_PRIMARY
1002	946072.43	807701.15	3284.19	EP	CP_PRIMARY
1003	945962.05	807663.84	3283.41	EP	CP_PRIMARY
1004	946058.59	807811.60	3282.52	EP	CP_PRIMARY
1020	940675.55	807351.45	3777.59	EG	CP_PRIMARY
1021	940669.58	807279.80	3773.14	EG	CP_PRIMARY
1022	940718.61	807254.58	3770.84	EG	CP_PRIMARY
1023	940764.57	807262.04	3768.51	EG	CP_PRIMARY
1024	940827.80	807270.44	3764.58	EG	CP_PRIMARY
1025	940885.22	807268.53	3760.40	EG	CP_PRIMARY
1032	943426.96	802562.58	3325.58	EG	CP_PRIMARY
1033	943458.09	802519.81	3322.78	EG	CP_PRIMARY
1038	944961.07	798567.18	3345.77	EP	CP_PRIMARY
1039	944957.90	798502.62	3346.17	EP	CP_PRIMARY
1040	944951.46	798435.73	3346.59	EP	CP_PRIMARY
1041	944943.48	798374.08	3346.81	EP	CP_PRIMARY
1049	948901.60	783244.88	3466.69	EP	CP_PRIMARY
1050	948911.42	783168.45	3467.28	EP	CP_PRIMARY
1051	948926.79	783068.91	3468.13	EP	CP_PRIMARY
1052	948942.49	782988.23	3468.76	EP	CP_PRIMARY
1053	948954.13	782916.34	3469.20	EP	CP_PRIMARY
1059	948246.54	789684.39	3418.86	EP	CP_PRIMARY
1060	948268.84	789634.83	3419.02	EP	CP_PRIMARY
1061	948296.38	789577.39	3419.36	EP	CP_PRIMARY
1062	948331.59	789530.13	3420.17	EP	CP_PRIMARY
1064	954118.26	820552.98	3147.26	EP	CP_PRIMARY
1065	954174.39	820507.31	3146.89	EP	CP_PRIMARY
1066	954208.35	820482.28	3147.20	EP	CP_PRIMARY
1067	954254.09	820450.03	3147.44	EP	CP_PRIMARY
1068	954303.26	820415.79	3146.67	EP	CP_PRIMARY
1073	947590.24	821072.01	3200.18	EP	CP_PRIMARY

1074	947660.55	821078.43	3200.69	EP	CP_PRIMARY
1075	947717.44	821086.31	3200.30	EP	CP_PRIMARY
1076	947744.97	821122.28	3200.68	EP	CP_PRIMARY
1078	947811.53	821164.53	3201.02	EP	CP_PRIMARY
1079	947894.98	821166.50	3201.45	EP	CP_PRIMARY
1081	948005.70	821261.30	3200.66	EG	CP_PRIMARY
1082	947999.24	821295.16	3200.43	EG	CP_PRIMARY
1086	944433.34	820860.96	3194.30	EP	CP_PRIMARY
1087	944368.39	820856.14	3194.28	EP	CP_PRIMARY
1088	944320.42	820855.96	3194.12	EP	CP_PRIMARY
1089	944259.40	820859.42	3193.91	EP	CP_PRIMARY
1090	944219.38	820869.26	3193.78	EP	CP_PRIMARY
1105	936803.81	821552.79	3166.97	EP	CP_PRIMARY
1114	936823.98	821677.63	3163.03	EG	CP_PRIMARY

Ground Control Points



Ground Check Point GNSS Survey

The following listing shows the ground survey points that were established as LiDAR check points. The LAS data is verified against the ground based on the check points. The ground survey check points were established and surveyed by Sand Surveying. Note: Ground shot Checkpoints 1262 was removed due to unexplained high resisdual.

Note: Description

MAG = Survey Control (not necessarily flush with ground)
BC = Survey Control (not necessarily flush with ground)
EG = shots on gravel surface (not edges)
EP = shots on pavement (not edges)
EC = shots on edge of concrete (for horizontal check only)
BL-1 = Short Grass (lawns, short grass, bare earth)
BL-2 = Tall Grass
BL-3 = Trees
BRDGE = edge of driving/walking surface
RR = railroad rails (on rails)
BLDG-COR = Building Corner (for approximate horizontal check)
PWR-PL = Power Pole (for approximate horizontal check)
Ground Shot = ground shot - may be in short or tall grass with or without tree cover
(Horz) = horizontal check

Ground Points (Check points)

Point Id	North IntlFT Montana	East IntlFT Montana	Elev IntlFT NAVD88	Desc	Code
1201	950334.52	771846.90	3602.76	Ground Shot	NVA
1202	949668.79	780767.71	3493.17	Ground Shot	NVA
1203	948703.97	779563.64	3498.23	Ground Shot	NVA
1204	953154.61	771246.48	3566.65	Ground Shot	NVA
1205	951397.51	762535.07	3624.16	Ground Shot	NVA
1206	951957.96	713334.20	4056.02	Ground Shot	NVA
1207	951501.15	713141.20	4059.76	Ground Shot	NVA
1208	951451.29	713136.32	4060.42	Ground Shot	NVA
1209	951387.97	713067.27	4060.69	Ground Shot	NVA
1210	945777.31	820139.70	3190.83	Ground Shot	NVA
1211	946880.21	813349.23	3280.91	Ground Shot	NVA
1212	945173.48	816569.29	3225.33	Ground Shot	NVA
1213	945377.90	817314.53	3207.57	Ground Shot	NVA
1214	945175.60	818679.07	3196.51	Ground Shot	NVA
1215	944785.96	819596.70	3202.01	Ground Shot	NVA
1216	943068.04	822254.94	3179.35	Ground Shot	NVA
1217	937435.65	824511.28	3160.08	Ground Shot	NVA
1218	937568.71	824422.14	3163.13	Ground Shot	NVA
1219	944506.79	821052.58	3179.05	Ground Shot	NVA
1220	944573.99	821134.66	3181.42	Ground Shot	NVA
1221	944596.62	821101.78	3181.66	Ground Shot	NVA
1222	944820.14	821254.57	3180.54	Ground Shot	NVA

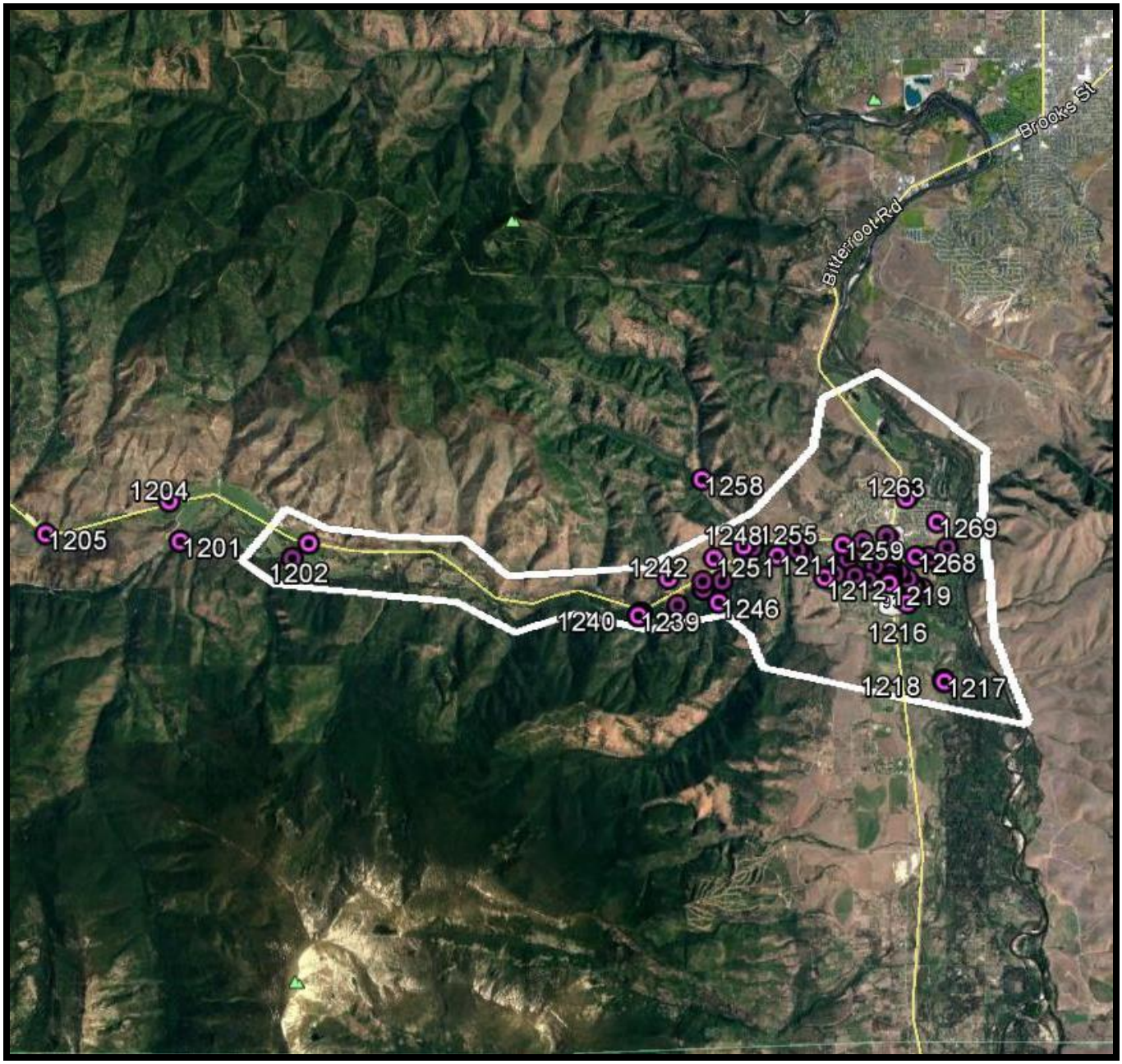
1223	945212.74	821764.72	3177.10	Ground Shot	NVA
1224	945844.43	821182.21	3184.08	Ground Shot	NVA
1225	945476.67	821255.39	3181.86	Ground Shot	NVA
1226	945336.24	821122.72	3183.54	Ground Shot	NVA
1227	944894.97	821155.97	3179.53	Ground Shot	NVA
1228	944857.44	821192.86	3178.94	Ground Shot	NVA
1229	944720.71	822375.69	3173.21	Ground Shot	NVA
1230	943985.86	823355.79	3168.22	Ground Shot	NVA
1231	944136.80	822772.93	3170.17	Ground Shot	NVA
1232	944111.52	822778.82	3170.36	Ground Shot	NVA
1233	944077.22	822739.81	3170.85	Ground Shot	NVA
1234	944106.43	822715.04	3170.76	Ground Shot	NVA
1235	946758.12	815167.91	3222.65	Ground Shot	NVA
1236	943446.58	803631.15	3303.22	Ground Shot	NVA
1237	943441.12	803620.50	3303.30	Ground Shot	NVA
1238	943335.32	803465.44	3304.77	Ground Shot	NVA
1239	943284.41	803412.28	3304.68	Ground Shot	NVA
1240	943329.50	803397.23	3304.43	Ground Shot	NVA
1241	943854.82	806207.13	3283.70	Ground Shot	NVA
1242	945762.62	805655.73	3309.15	Ground Shot	NVA
1243	944858.00	808061.21	3271.55	Ground Shot	NVA
1244	944852.12	808044.96	3271.50	Ground Shot	NVA
1245	945405.63	808048.85	3274.13	Ground Shot	NVA
1246	943876.52	809064.17	3342.31	Ground Shot	NVA
1247	947572.05	811657.19	3245.30	Ground Shot	NVA
1248	947687.93	811042.97	3249.28	Ground Shot	NVA
1249	947342.24	811005.00	3247.91	Ground Shot	NVA
1250	945356.77	809405.26	3259.35	Ground Shot	NVA
1251	946964.07	808937.41	3275.69	Ground Shot	NVA
1252	947217.65	814751.83	3225.35	Ground Shot	NVA
1253	947135.79	814842.04	3224.41	Ground Shot	NVA
1254	947248.60	814784.81	3225.63	Ground Shot	NVA
1255	947494.62	814855.63	3221.03	Ground Shot	NVA
1256	947550.11	814928.73	3220.65	Ground Shot	NVA
1257	947525.78	814876.60	3220.79	Ground Shot	NVA
1258	952456.02	808406.05	3507.76	Ground Shot	NVA
1259	947380.77	817968.48	3203.29	Ground Shot	NVA
1260	947521.97	819383.39	3194.50	Ground Shot	NVA
1261	946360.93	818249.51	3202.65	Ground Shot	NVA
1262 *	947780.49	821043.04	3201.00	Ground Shot	NVA
1263	950363.06	822601.25	3176.81	Ground Shot	NVA
1264	950613.83	822797.97	3171.17	Ground Shot	NVA
1265	946751.41	825253.43	3168.72	Ground Shot	NVA

1266	945595.57	824789.18	3160.58	Ground Shot	NVA
1267	946153.97	823930.02	3163.12	Ground Shot	NVA
1268	946246.36	823014.28	3168.95	Ground Shot	NVA
1269	948574.35	824642.91	3172.08	Ground Shot	NVA
1005	946005.57	807766.76	3283.81	EC (Horz)	VVA
1006	946006.25	807762.92	3283.86	EC (Horz)	VVA
1007	945998.59	807761.38	3283.88	EC (Horz)	VVA
1008	945997.83	807765.22	3283.79	EC (Horz)	VVA
1009	946029.40	807680.32	3282.71	BL-1	VVA
1010	946070.89	807655.03	3283.42	BL-1	VVA
1011	946095.98	807637.21	3283.55	BL-1	VVA
1012	946128.67	807614.38	3283.90	BL-1	VVA
1013	946190.84	807721.98	3281.74	BL-2	VVA
1014	946147.16	807754.74	3281.84	BL-1	VVA
1015	946108.80	807777.12	3282.36	BL-2	VVA
1016	946005.06	807839.99	3283.16	BL-2	VVA
1017	945972.20	807809.17	3283.21	BL-2	VVA
1018	945920.78	807741.83	3283.79	BL-2	VVA
1019	945920.54	807713.93	3284.02	BL-2	VVA
1026	940895.24	807234.07	3765.17	BL-1	VVA
1027	940830.23	807210.24	3777.91	BL-3	VVA
1028	940722.11	807138.49	3804.26	BL-3	VVA
1029	940584.99	807117.59	3789.39	BL-2	VVA
1030	940573.03	807086.66	3794.62	BL-3	VVA
1031	940558.62	807169.34	3787.27	BL-1	VVA
1034	943669.99	802496.80	3319.74	BRDGE (Horz)	VVA
1035	943666.99	802508.50	3319.72	BRDGE (Horz)	VVA
1036	943743.51	802527.54	3319.78	BRDGE (Horz)	VVA
1037	943746.13	802515.81	3319.58	BRDGE (Horz)	VVA
1042	944819.03	798272.84	3340.74	BL-3	VVA
1043	944918.62	798217.91	3344.86	BL-1	VVA
1044	944981.90	798289.81	3344.78	BL-3	VVA
1045	944996.21	798358.68	3346.27	BL-1	VVA
1046	945016.62	798418.30	3346.18	BL-1	VVA
1047	945073.38	798619.58	3341.52	BL-3	VVA
1048	945010.67	798613.59	3344.94	BL-1	VVA
1054	948987.29	782977.93	3464.18	BL-3	VVA
1055	948978.14	783022.07	3465.37	BL-3	VVA
1056	948886.23	783085.31	3462.52	BL-2	VVA
1057	948881.57	783128.71	3462.71	BL-2	VVA
1058	948873.44	783187.75	3464.32	BL-2	VVA
1063	948225.45	789674.65	3417.33	BL-3	VVA
1069	954139.30	820466.92	3147.45	BL-1	VVA

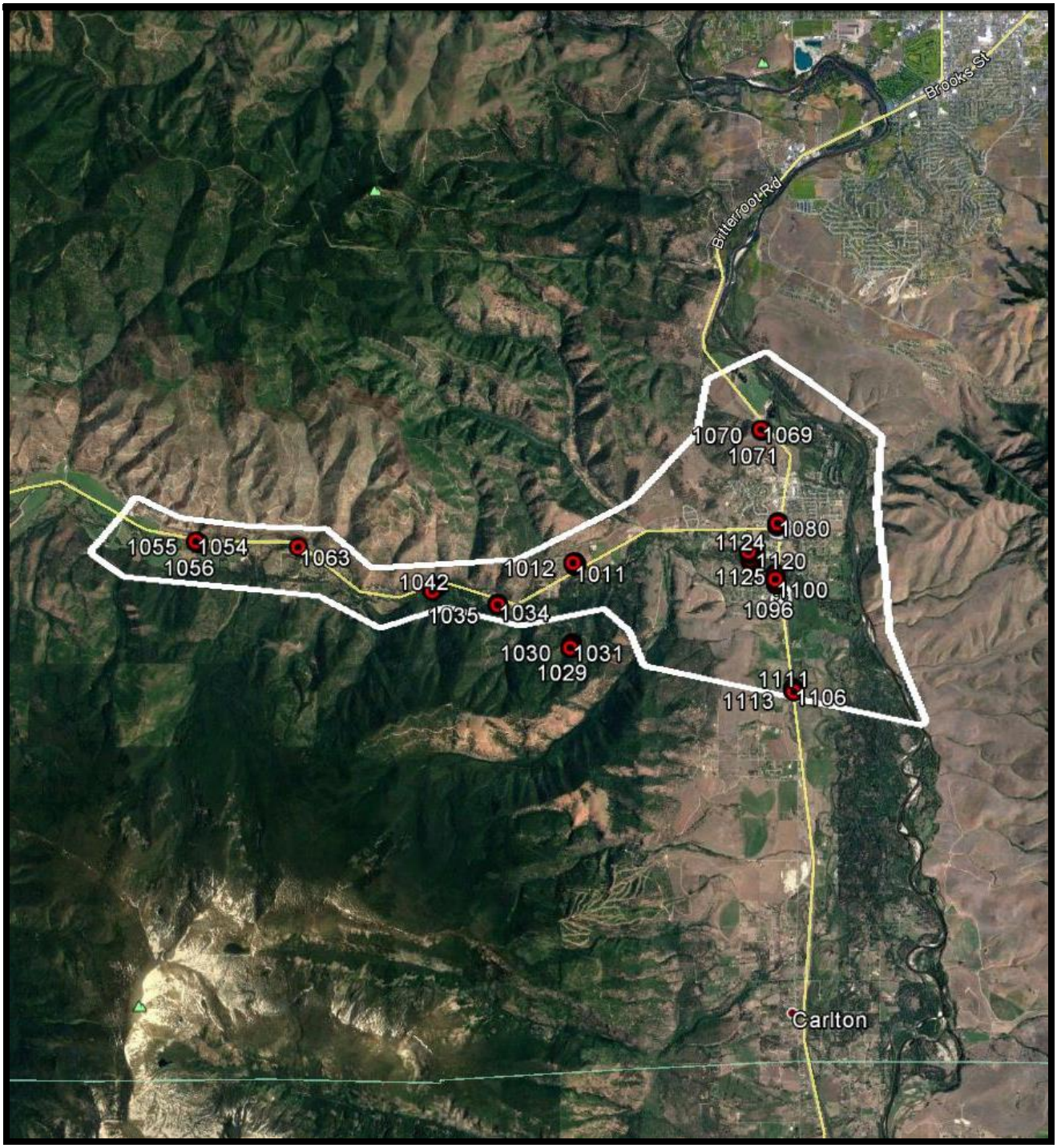
1070	954095.92	820495.69	3146.54	BL-1	VVA
1071	954045.28	820529.49	3144.45	BL-1	VVA
1072	954067.20	820583.69	3145.11	BL-1	VVA
1077	947698.54	821147.91	3200.72	BLDG-COR (Horz)	VVA
1080	947922.78	821204.06	3201.88	BLDG-COR (Horz)	VVA
1083	948033.86	821258.31	3200.40	BLDG-COR (Horz)	VVA
1084	947965.50	821172.75	3201.05	PWR-PL (Horz)	VVA
1085	947834.41	821150.23	3201.27	PWR-PL (Horz)	VVA
1091	944213.17	820882.90	3194.11	BL-2	VVA
1092	944166.47	820878.67	3193.74	BL-2	VVA
1093	944060.93	820870.70	3192.82	BL-3	VVA
1094	944023.60	820866.55	3193.41	BL-3	VVA
1095	943971.27	820897.54	3192.70	BL-3	VVA
1096	943884.51	820904.57	3191.81	BL-3	VVA
1097	943914.66	820861.50	3192.34	BL-1	VVA
1098	944136.52	820850.57	3193.47	BL-1	VVA
1099	944215.39	820843.81	3193.57	BL-1	VVA
1100	944267.51	820838.45	3193.69	BL-1	VVA
1101	944308.51	820877.12	3194.16	BL-1	VVA
1102	944390.23	820873.40	3194.45	BL-1	VVA
1103	944590.45	820862.94	3193.50	BL-2	VVA
1104	944641.66	820861.90	3193.71	BL-2	VVA
1106	936805.63	821621.56	3166.04	RR (Horz)	VVA
1107	936875.18	821617.08	3165.96	RR (Horz)	VVA
1108	936947.18	821612.33	3166.04	RR (Horz)	VVA
1109	937015.75	821607.74	3166.04	RR (Horz)	VVA
1110	937079.09	821603.59	3165.90	RR (Horz)	VVA
1111	937061.83	821564.91	3161.48	BL-2	VVA
1112	936986.52	821565.69	3162.31	BL-2	VVA
1113	936906.20	821574.91	3162.14	BL-2	VVA
1115	946057.16	819618.29	3192.81	BL-1	VVA
1116	946003.33	819622.63	3192.21	BL-1	VVA
1117	945948.16	819619.79	3191.63	BL-1	VVA
1118	945892.42	819610.84	3190.98	BL-1	VVA
1119	945866.39	819601.64	3191.37	BL-2	VVA
1120	945877.89	819542.16	3191.96	BL-2	VVA
1121	945967.19	819339.01	3191.75	BL-2	VVA
1122	945986.61	819280.03	3190.70	BL-2	VVA
1123	946006.58	819243.17	3191.10	BL-2	VVA
1124	946200.33	819178.81	3195.76	BLDG-COR (Horz)	VVA
1125	946161.79	819214.64	3195.54	BL-1	VVA
1126	946220.95	819285.72	3196.02	EC (Horz)	VVA
1127	946227.90	819285.47	3195.96	EC (Horz)	VVA

1128	946192.88	819377.59	3194.40	EC (Horz)	VVA
1129	946185.78	819377.16	3194.42	EC (Horz)	VVA
1130	945832.30	819481.53	3188.01	BL-3	VVA
1131	945828.30	819356.78	3189.34	BL-3	VVA
1132	945706.93	819253.24	3190.75	BL-3	VVA
1133	945514.56	819256.66	3187.37	BL-3	VVA
1134	945615.50	819486.21	3194.23	BRDGE (Horz)	VVA
1135	945612.23	819476.95	3194.20	BRDGE (Horz)	VVA
1136	945453.24	819534.05	3194.13	BRDGE (Horz)	VVA
1137	945456.58	819543.17	3194.16	BRDGE (Horz)	VVA
1138	945359.30	819532.51	3186.11	BL-2	VVA
1139	945404.18	819424.74	3188.19	BL-2	VVA
1140	945433.07	819341.99	3189.11	BL-3	VVA
1141	946146.33	819593.52	3192.79	EC (Horz)	VVA
1142	946134.06	819618.42	3192.81	EC (Horz)	VVA

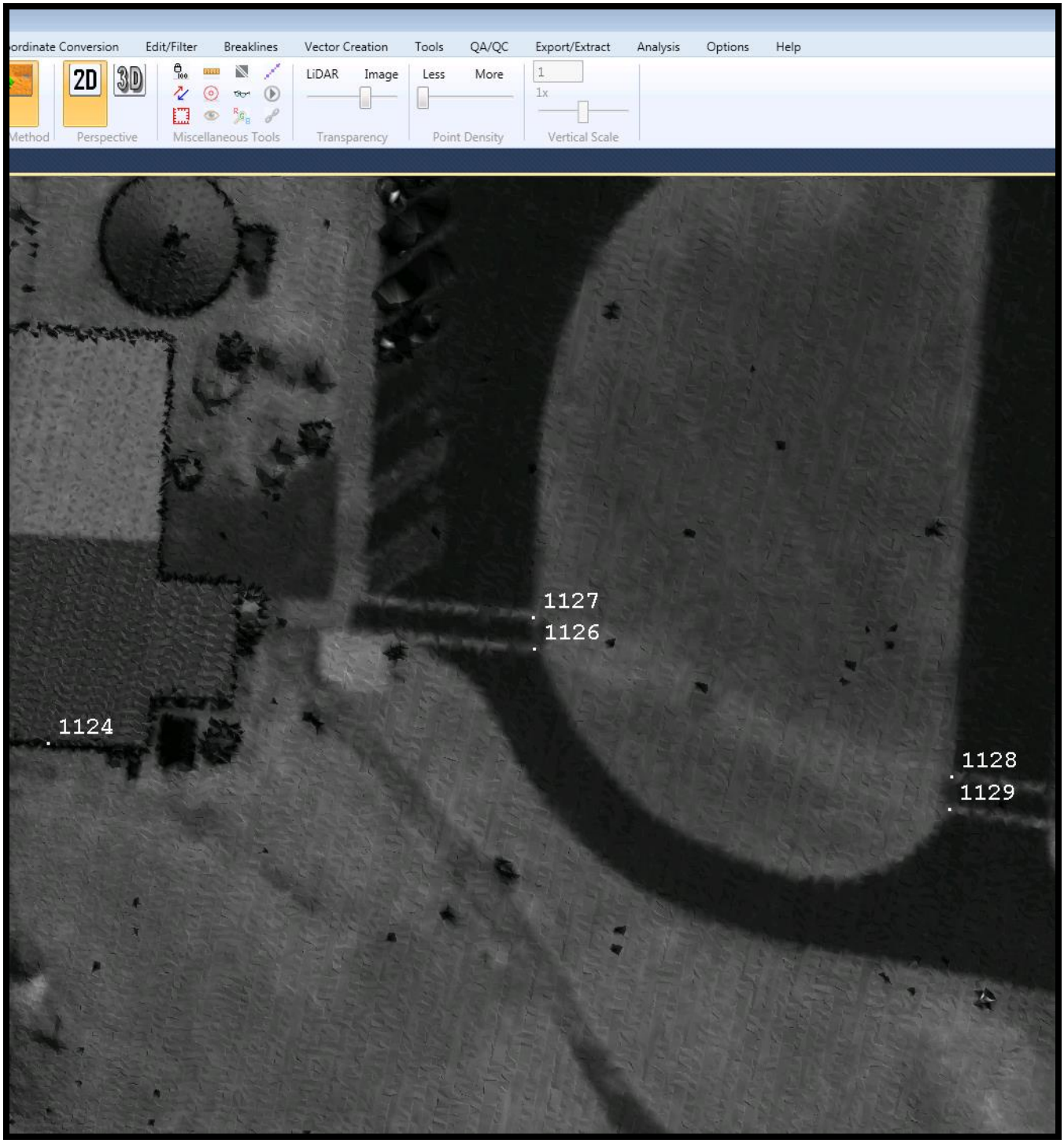
NVA Check Points



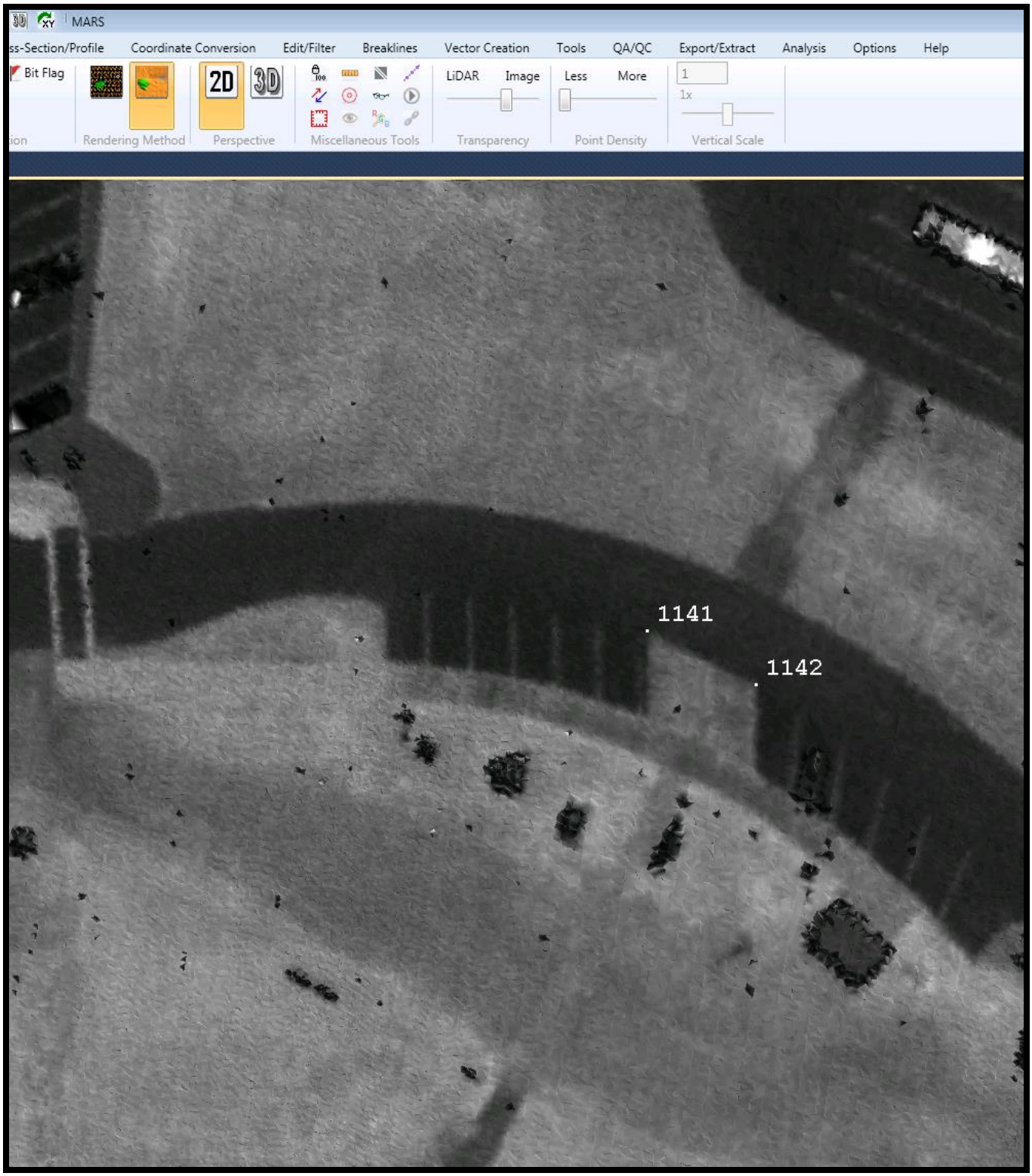
VVA Check Points



Horizontal Check for Points 1124, 1126 to 1129 matching LiDAR points for Lolo (TIN)



Horizontal Check for Points 1141 and 1142 matching LiDAR points for Lolo (TIN)



LiDAR Control point Report

Unfiltered Control point Report

The following table illustrate the results of the LiDAR data compared to the ground checkpoints (Non-vegetated). The listing is sorted by the Z Error column showing, in ascending order, the vertical difference between the LiDAR points and the surveyed ground points.

Project Data Unit: International Foot
Vertical Accuracy Class tested: 10.0-cm
Elevation Calculation Method: Interpolated from TIN
LiDAR Classifications Included: 0
Check Points in Report: 46
Check Points with LiDAR Coverage: 46
Check Points (NVA): 46
Check Points (VVA): 0
Average Vertical Error Reported: 0.000 International Foot
Maximum (highest) Vertical Error Reported: 0.239 International Foot
Median Vertical Error Reported: -0.027 International Foot
Minimum (lowest) Vertical Error Reported: -0.405 International Foot
Standard deviation of Vertical Error: 0.168 International Foot
Skewness of Vertical Error: -0.207
Kurtosis of Vertical Error: -1.073
Non-vegetated Vertical Accuracy (NVA) RMSE(z): 5.071cm PASS
Non-vegetated Vertical Accuracy (NVA) at the 95% Confidence Level +/-: 9.940cm PASS
FGDC/NSSDA Vertical Accuracy at the 95% Confidence Level +/-: 9.940cm
Non-vegetated Vertical Accuracy (NVA) RMSE(z) (DEM): 4.699cm PASS
Non-vegetated Vertical Accuracy (NVA) at the 95% Confidence Level +/- (DEM): 9.210cm PASS
This data set was tested to meet ASPRS Positional Accuracy Standard for Digital Geospatial Data (2014) for a 10.0-cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be RMSEz = 5.071cm, equating to +/- 9.940cm at the 95% confidence level.

Control Pt.	Check Pt	Check Pt	Cover	Check Pt	Z from	NVA	Z Error	Min.	Median	Max.
Point Id	X (East)	Y (North)		Z (Elev)	LiDAR	or		Z	Z	Z
	Intl.Feet	Intl.Feet		Intl.Feet	Intl.Feet	VVA	Intl.Feet	Intl.Feet	Intl.Feet	Intl.Feet
1032	802562.58	943426.96	Yes	3325.58	3325.18	NVA	**-0.41**	3325.15	3325.16	3325.20
1024	807270.44	940827.80	Yes	3764.58	3764.34	NVA	**-0.25**	3764.33	3764.34	3764.36
1021	807279.80	940669.58	Yes	3773.14	3772.91	NVA	**-0.23**	3772.82	3772.84	3772.99
1062	789530.13	948331.59	Yes	3420.17	3419.95	NVA	**-0.22**	3419.93	3420.04	3420.05
1051	783068.91	948926.79	Yes	3468.13	3467.92	NVA	**-0.21**	3467.89	3467.94	3468.01
1033	802519.81	943458.09	Yes	3322.78	3322.58	NVA	**-0.20**	3322.50	3322.59	3322.61
1041	798374.08	944943.48	Yes	3346.81	3346.62	NVA	**-0.19**	3346.60	3346.67	3346.69
1020	807351.45	940675.55	Yes	3777.59	3777.41	NVA	**-0.18**	3777.33	3777.41	3777.42
1023	807262.04	940764.57	Yes	3768.51	3768.34	NVA	**-0.17**	3768.32	3768.36	3768.44
1061	789577.39	948296.38	Yes	3419.36	3419.19	NVA	**-0.17**	3419.06	3419.20	3419.22
1040	798435.73	944951.46	Yes	3346.59	3346.42	NVA	**-0.16**	3346.37	3346.43	3346.48
1022	807254.58	940718.61	Yes	3770.84	3770.70	NVA	**-0.15**	3770.63	3770.68	3770.71

1052	782988.23	948942.49	Yes	3468.76	3468.63	NVA	**-0.13**	3468.59	3468.66	3468.70
1059	789684.39	948246.54	Yes	3418.86	3418.73	NVA	**-0.13**	3418.69	3418.77	3418.85
1039	798502.62	944957.90	Yes	3346.17	3346.05	NVA	**-0.12**	3346.03	3346.15	3346.15
1025	807268.53	940885.22	Yes	3760.40	3760.29	NVA	**-0.11**	3760.21	3760.25	3760.31
1060	789634.83	948268.84	Yes	3419.02	3418.92	NVA	**-0.10**	3418.78	3418.93	3418.94
1038	798567.18	944961.07	Yes	3345.77	3345.71	NVA	**-0.06**	3345.69	3345.73	3345.74
1050	783168.45	948911.42	Yes	3467.28	3467.22	NVA	**-0.06**	3467.21	3467.26	3467.30
1000	807775.63	945943.61	Yes	3283.16	3283.12	NVA	**-0.04**	3283.09	3283.11	3283.14
1003	807663.84	945962.05	Yes	3283.41	3283.37	NVA	**-0.04**	3283.30	3283.34	3283.40
1053	782916.34	948954.13	Yes	3469.20	3469.17	NVA	**-0.03**	3469.10	3469.20	3469.29
1049	783244.88	948901.60	Yes	3466.69	3466.66	NVA	**-0.03**	3466.63	3466.67	3466.69
1002	807701.15	946072.43	Yes	3284.19	3284.16	NVA	**-0.03**	3284.15	3284.15	3284.20
1004	807811.60	946058.59	Yes	3282.52	3282.50	NVA	**-0.02**	3282.49	3282.50	3282.52
1001	807736.01	946007.06	Yes	3284.13	3284.13	NVA	**0.00**	3284.07	3284.09	3284.14
1114	821677.63	936823.98	Yes	3163.03	3163.11	NVA	**0.09**	3163.06	3163.18	3163.20
1078	821164.53	947811.53	Yes	3201.02	3201.12	NVA	**0.10**	3201.06	3201.23	3201.26
1086	820860.96	944433.34	Yes	3194.30	3194.44	NVA	**0.13**	3194.42	3194.44	3194.46
1075	821086.31	947717.44	Yes	3200.30	3200.43	NVA	**0.13**	3200.28	3200.33	3200.53
1067	820450.03	954254.09	Yes	3147.44	3147.58	NVA	**0.14**	3147.56	3147.58	3147.58
1105	821552.79	936803.81	Yes	3166.97	3167.11	NVA	**0.14**	3167.06	3167.12	3167.14
1088	820855.96	944320.42	Yes	3194.12	3194.26	NVA	**0.14**	3194.21	3194.22	3194.27
1076	821122.28	947744.97	Yes	3200.68	3200.83	NVA	**0.15**	3200.80	3200.87	3200.90
1087	820856.14	944368.39	Yes	3194.28	3194.44	NVA	**0.16**	3194.42	3194.46	3194.49
1089	820859.42	944259.40	Yes	3193.91	3194.07	NVA	**0.17**	3194.03	3194.08	3194.14
1079	821166.50	947894.98	Yes	3201.45	3201.62	NVA	**0.17**	3201.59	3201.65	3201.66
1090	820869.26	944219.38	Yes	3193.78	3193.97	NVA	**0.19**	3193.95	3193.97	3194.02
1066	820482.28	954208.35	Yes	3147.20	3147.39	NVA	**0.19**	3147.38	3147.40	3147.41
1074	821078.43	947660.55	Yes	3200.69	3200.87	NVA	**0.19**	3200.85	3200.89	3200.91
1065	820507.31	954174.39	Yes	3146.89	3147.09	NVA	**0.19**	3147.06	3147.10	3147.11
1073	821072.01	947590.24	Yes	3200.18	3200.38	NVA	**0.20**	3200.34	3200.35	3200.43
1082	821295.16	947999.24	Yes	3200.43	3200.66	NVA	**0.23**	3200.63	3200.66	3200.67
1068	820415.79	954303.26	Yes	3146.67	3146.90	NVA	**0.23**	3146.83	3146.88	3146.91
1064	820552.98	954118.26	Yes	3147.26	3147.49	NVA	**0.23**	3147.45	3147.50	3147.56
1081	821261.30	948005.70	Yes	3200.66	3200.89	NVA	**0.24**	3200.87	3200.91	3200.91

LiDAR Checkpoint Report

Filtered Checkpoint Report

The following table illustrate the results of the LiDAR data compared to the ground checkpoints, Non-vegetated (NVA) and Vegetated (VVA). The listing is sorted by the Z Error column showing, in ascending order, the vertical difference between the LiDAR points and the surveyed ground points. Note, eleven of the control points were located outside of the LiDAR coverage, and therefore do not have statisitcs reported. The checkpoint report was run on classifications 2 (Ground) and 17 (Bridge) in order to include the control collected on bridges. There is a vertical bias of 0.285 international feet as compared to the Ground Control Points used to control the LiDAR.

Project Data Unit: International Foot
Vertical Accuracy Class tested: 10.0-cm
Elevation Calculation Method: Interpolated from TIN
LiDAR Classifications Included: 2,17/0 Ground (All)
Check Points in Report: 165
Check Points with LiDAR Coverage: 154
Check Points (NVA): 60
Check Points (VVA): 94
Average Vertical Error Reported: 0.285 International Foot
Maximum (highest) Vertical Error Reported: 0.521 International Foot
Median Vertical Error Reported: 0.272 International Foot
Minimum (lowest) Vertical Error Reported: 0.061 International Foot
Standard deviation of Vertical Error: 0.099 International Foot
Skewness of Vertical Error: 0.358
Kurtosis of Vertical Error: -0.372
Non-vegetated Vertical Accuracy (NVA) RMSE(z): 9.173cm PASS
Non-vegetated Vertical Accuracy (NVA) at the 95% Confidence Level +/-: 17.980cm PASS
Vegetated Vertical Accuracy (VVA) at the 95th Percentile +/-: 21.537cm PASS
FGDC/NSSDA Vertical Accuracy at the 95% Confidence Level +/-: 17.980cm
Non-vegetated Vertical Accuracy (NVA) RMSE(z) (DEM): 9.087cm PASS
Non-vegetated Vertical Accuracy (NVA) at the 95% Confidence Level +/- (DEM): 17.811cm PASS
Vegetated Vertical Accuracy (VVA) at the 95th Percentile +/- (DEM): 23.791cm PASS
This data set was tested to meet ASPRS Positional Accuracy Standard for Digital Geospatial Data (2014) for a 10.0-cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be RMSEz = 9.173cm, equating to +/- 17.980cm at the 95% confidence level. Actual VVA accuracy was found to be +/- 21.537cm at the 95th percentile.

Check Pt.	Check Pt	Check Pt	Cover	Check Pt	Z from	NVA	Z Error	Min.	Median	Max.
Point Id	X (East)	Y (North)		Z (Elev)	LiDAR	or		Z	Z	Z
	Intl.Feet	Intl.Feet		Intl.Feet	Intl.Feet	VVA	Intl.Feet	Intl.Feet	Intl.Feet	Intl.Feet
1135	819476.95	945612.23	Yes	3194.20	3192.76	VVA	**-1.44**	3187.44	3194.17	3194.35
1136	819534.05	945453.24	Yes	3194.13	3193.03	VVA	**-1.10**	3186.96	3194.33	3194.38
1134	819486.21	945615.50	Yes	3194.23	3193.70	VVA	**-0.53**	3187.23	3194.32	3194.39
1108	821612.33	936947.18	Yes	3166.04	3165.64	VVA	**-0.40**	3165.62	3165.64	3165.65
1107	821617.08	936875.18	Yes	3165.96	3165.59	VVA	**-0.37**	3165.52	3165.62	3165.63
1109	821607.74	937015.75	Yes	3166.04	3165.67	VVA	**-0.37**	3165.63	3165.67	3165.75
1110	821603.59	937079.09	Yes	3165.90	3165.53	VVA	**-0.37**	3165.52	3165.54	3165.56

1036	802527.54	943743.51	Yes	3319.78	3319.43	VVA	**-0.35**	3319.16	3319.49	3319.65
1008	807765.22	945997.83	Yes	3283.79	3283.47	VVA	**-0.32**	3283.38	3283.44	3283.72
1005	807766.76	946005.57	Yes	3283.81	3283.49	VVA	**-0.32**	3283.41	3283.52	3283.73
1080	821204.06	947922.78	Yes	3201.88	3201.62	VVA	**-0.26**	3201.54	3201.63	3201.66
1007	807761.38	945998.59	Yes	3283.88	3283.62	VVA	**-0.25**	3283.54	3283.61	3283.67
1006	807762.92	946006.25	Yes	3283.86	3283.63	VVA	**-0.24**	3283.45	3283.77	3283.77
1027	807210.24	940830.23	Yes	3777.91	3777.68	VVA	**-0.24**	3777.62	3777.64	3777.86
1026	807234.07	940895.24	Yes	3765.17	3764.95	VVA	**-0.22**	3764.73	3764.83	3764.99
1034	802496.80	943669.99	Yes	3319.74	3319.53	VVA	**-0.22**	3319.50	3319.57	3319.62
1046	798418.30	945016.62	Yes	3346.18	3346.00	VVA	**-0.18**	3345.95	3345.96	3346.05
1031	807169.34	940558.62	Yes	3787.27	3787.15	VVA	**-0.12**	3787.12	3787.15	3787.17
1045	798358.68	944996.21	Yes	3346.27	3346.19	VVA	**-0.09**	3346.13	3346.16	3346.20
1063	789674.65	948225.45	Yes	3417.33	3417.28	VVA	**-0.05**	3417.09	3417.36	3417.53
1010	807655.03	946070.89	Yes	3283.42	3283.40	VVA	**-0.01**	3283.38	3283.39	3283.41
1035	802508.50	943666.99	Yes	3319.72	3319.72	VVA	**0.00**	3319.51	3319.59	3319.73
1043	798217.91	944918.62	Yes	3344.86	3344.87	VVA	**0.02**	3344.84	3344.88	3344.95
1048	798613.59	945010.67	Yes	3344.94	3344.98	VVA	**0.04**	3344.92	3344.96	3345.05
1055	783022.07	948978.14	Yes	3465.37	3465.43	VVA	**0.05**	3464.51	3465.52	3467.44
1216	822254.94	943068.04	Yes	3179.35	3179.42	NVA	**0.06**	3179.34	3179.48	3179.76
1106	821621.56	936805.63	Yes	3166.04	3166.10	VVA	**0.07**	3166.06	3166.12	3166.15
1011	807637.21	946095.98	Yes	3283.55	3283.62	VVA	**0.08**	3283.56	3283.63	3283.67
1012	807614.38	946128.67	Yes	3283.90	3283.98	VVA	**0.08**	3283.89	3284.00	3284.02
1014	807754.74	946147.16	Yes	3281.84	3281.92	VVA	**0.08**	3281.92	3281.92	3281.93
1009	807680.32	946029.40	Yes	3282.71	3282.80	VVA	**0.08**	3282.79	3282.81	3282.83
1058	783187.75	948873.44	Yes	3464.32	3464.42	VVA	**0.11**	3464.34	3464.43	3464.44
1047	798619.58	945073.38	Yes	3341.52	3341.63	VVA	**0.11**	3341.52	3341.54	3341.67
1140	819341.99	945433.07	Yes	3189.11	3189.23	VVA	**0.12**	3189.04	3189.23	3189.35
1077	821147.91	947698.54	Yes	3200.72	3200.84	VVA	**0.12**	3200.80	3200.80	3200.93
1091	820882.90	944213.17	Yes	3194.11	3194.24	VVA	**0.13**	3194.17	3194.28	3194.39
1128	819377.59	946192.88	Yes	3194.40	3194.53	VVA	**0.13**	3194.52	3194.58	3194.73
1056	783085.31	948886.23	Yes	3462.52	3462.66	VVA	**0.14**	3462.62	3462.67	3462.68
1125	819214.64	946161.79	Yes	3195.54	3195.68	VVA	**0.14**	3195.66	3195.67	3195.70
1246	809064.17	943876.52	Yes	3342.31	3342.45	NVA	**0.14**	3342.37	3342.44	3342.46
1044	798289.81	944981.90	Yes	3344.78	3344.93	VVA	**0.15**	3344.91	3344.96	3344.98
1094	820866.55	944023.60	Yes	3193.41	3193.56	VVA	**0.16**	3193.34	3193.41	3193.60
1129	819377.16	946185.78	Yes	3194.42	3194.58	VVA	**0.16**	3194.57	3194.60	3194.63
1214	818679.07	945175.60	Yes	3196.51	3196.67	NVA	**0.16**	3196.63	3196.64	3196.69
1225	821255.39	945476.67	Yes	3181.86	3182.02	NVA	**0.17**	3182.00	3182.03	3182.03
1127	819285.47	946227.90	Yes	3195.96	3196.13	VVA	**0.17**	3196.02	3196.12	3196.19
1253	814842.04	947135.79	Yes	3224.41	3224.58	NVA	**0.17**	3224.57	3224.57	3224.68
1254	814784.81	947248.60	Yes	3225.63	3225.80	NVA	**0.18**	3225.76	3225.94	3225.96
1222	821254.57	944820.14	Yes	3180.54	3180.72	NVA	**0.18**	3180.68	3180.77	3180.79

1229	822375.69	944720.71	Yes	3173.21	3173.39	NVA	**0.18**	3173.31	3173.37	3173.41
1126	819285.72	946220.95	Yes	3196.02	3196.20	VVA	**0.18**	3196.14	3196.18	3196.23
1224	821182.21	945844.43	Yes	3184.08	3184.26	NVA	**0.18**	3184.22	3184.28	3184.29
1221	821101.78	944596.62	Yes	3181.66	3181.84	NVA	**0.18**	3181.83	3181.83	3181.85
1115	819618.29	946057.16	Yes	3192.81	3192.99	VVA	**0.18**	3192.90	3192.95	3193.00
1212	816569.29	945173.48	Yes	3225.33	3225.51	NVA	**0.19**	3225.51	3225.51	3225.55
1141	819593.52	946146.33	Yes	3192.79	3192.97	VVA	**0.19**	3192.95	3192.98	3192.98
1057	783128.71	948881.57	Yes	3462.71	3462.89	VVA	**0.19**	3462.87	3462.96	3462.96
1215	819596.70	944785.96	Yes	3202.01	3202.20	NVA	**0.19**	3202.19	3202.19	3202.21
1220	821134.66	944573.99	Yes	3181.42	3181.61	NVA	**0.19**	3181.57	3181.64	3181.65
1013	807721.98	946190.84	Yes	3281.74	3281.93	VVA	**0.19**	3281.89	3281.95	3282.01
1213	817314.53	945377.90	Yes	3207.57	3207.77	NVA	**0.20**	3207.72	3207.77	3207.81
1226	821122.72	945336.24	Yes	3183.54	3183.74	NVA	**0.20**	3183.70	3183.74	3183.75
1072	820583.69	954067.20	Yes	3145.11	3145.31	VVA	**0.20**	3145.27	3145.34	3145.37
1237	803620.50	943441.12	Yes	3303.30	3303.50	NVA	**0.20**	3303.49	3303.51	3303.51
1261	818249.51	946360.93	Yes	3202.65	3202.85	NVA	**0.20**	3202.81	3202.83	3202.87
1100	820838.45	944267.51	Yes	3193.69	3193.89	VVA	**0.21**	3193.85	3193.87	3194.10
1230	823355.79	943985.86	Yes	3168.22	3168.43	NVA	**0.21**	3168.42	3168.43	3168.43
1223	821764.72	945212.74	Yes	3177.10	3177.31	NVA	**0.22**	3177.25	3177.29	3177.43
1071	820529.49	954045.28	Yes	3144.45	3144.67	VVA	**0.22**	3144.55	3144.55	3144.80
1019	807713.93	945920.54	Yes	3284.02	3284.24	VVA	**0.22**	3284.21	3284.22	3284.29
1252	814751.83	947217.65	Yes	3225.35	3225.57	NVA	**0.22**	3225.55	3225.65	3225.65
1142	819618.42	946134.06	Yes	3192.81	3193.03	VVA	**0.22**	3193.01	3193.03	3193.04
1259	817968.48	947380.77	Yes	3203.29	3203.51	NVA	**0.22**	3203.46	3203.52	3203.65
1118	819610.84	945892.42	Yes	3190.98	3191.21	VVA	**0.23**	3191.16	3191.19	3191.23
1211	813349.23	946880.21	Yes	3280.91	3281.14	NVA	**0.23**	3280.84	3281.14	3281.16
1093	820870.70	944060.93	Yes	3192.82	3193.05	VVA	**0.23**	3192.89	3192.92	3193.36
1112	821565.69	936986.52	Yes	3162.31	3162.55	VVA	**0.24**	3162.54	3162.55	3162.57
1260	819383.39	947521.97	Yes	3194.50	3194.74	NVA	**0.24**	3194.55	3194.72	3194.82
1099	820843.81	944215.39	Yes	3193.57	3193.81	VVA	**0.24**	3193.80	3193.81	3193.87
1234	822715.04	944106.43	Yes	3170.76	3171.01	NVA	**0.24**	3170.99	3171.02	3171.03
1113	821574.91	936906.20	Yes	3162.14	3162.39	VVA	**0.25**	3162.35	3162.42	3162.49
1218	824422.14	937568.71	Yes	3163.13	3163.38	NVA	**0.25**	3163.33	3163.38	3163.40
1210	820139.70	945777.31	Yes	3190.83	3191.08	NVA	**0.25**	3191.01	3191.09	3191.11
1117	819619.79	945948.16	Yes	3191.63	3191.88	VVA	**0.25**	3191.84	3191.85	3191.89
1248	811042.97	947687.93	Yes	3249.28	3249.54	NVA	**0.26**	3249.38	3249.41	3249.56
1116	819622.63	946003.33	Yes	3192.21	3192.47	VVA	**0.26**	3192.45	3192.47	3192.52
1232	822778.82	944111.52	Yes	3170.36	3170.62	NVA	**0.26**	3170.59	3170.59	3170.62
1228	821192.86	944857.44	Yes	3178.94	3179.20	NVA	**0.26**	3179.16	3179.20	3179.23
1097	820861.50	943914.66	Yes	3192.34	3192.61	VVA	**0.27**	3192.52	3192.53	3192.65
1203	779563.64	948703.97	Yes	3498.23	3498.50	NVA	**0.27**	3498.47	3498.59	3498.63
1042	798272.84	944819.03	Yes	3340.74	3341.01	VVA	**0.27**	3340.96	3341.00	3341.64

1084	821172.75	947965.50	Yes	3201.05	3201.33	VVA	**0.27**	3201.31	3201.34	3201.38
1236	803631.15	943446.58	Yes	3303.22	3303.50	NVA	**0.28**	3303.49	3303.50	3303.50
1269	824642.91	948574.35	Yes	3172.08	3172.36	NVA	**0.28**	3172.29	3172.31	3172.41
1017	807809.17	945972.20	Yes	3283.21	3283.49	VVA	**0.28**	3283.45	3283.50	3283.52
1250	809405.26	945356.77	Yes	3259.35	3259.63	NVA	**0.28**	3259.57	3259.62	3259.91
1202	780767.71	949668.79	Yes	3493.17	3493.46	NVA	**0.29**	3493.41	3493.43	3493.48
1133	819256.66	945514.56	Yes	3187.37	3187.67	VVA	**0.30**	3187.41	3187.64	3187.75
1015	807777.12	946108.80	Yes	3282.36	3282.66	VVA	**0.30**	3282.58	3282.60	3282.73
1016	807839.99	946005.06	Yes	3283.16	3283.46	VVA	**0.30**	3283.38	3283.45	3283.57
1101	820877.12	944308.51	Yes	3194.16	3194.47	VVA	**0.31**	3194.44	3194.45	3194.50
1138	819532.51	945359.30	Yes	3186.11	3186.42	VVA	**0.31**	3186.37	3186.43	3186.48
1098	820850.57	944136.52	Yes	3193.47	3193.78	VVA	**0.31**	3193.72	3193.76	3193.83
1257	814876.60	947525.78	Yes	3220.79	3221.11	NVA	**0.31**	3221.07	3221.11	3221.16
1070	820495.69	954095.92	Yes	3146.54	3146.86	VVA	**0.32**	3146.85	3146.86	3146.91
1069	820466.92	954139.30	Yes	3147.45	3147.77	VVA	**0.32**	3147.74	3147.78	3147.82
1244	808044.96	944852.12	Yes	3271.50	3271.83	NVA	**0.32**	3271.79	3271.82	3271.87
1104	820861.90	944641.66	Yes	3193.71	3194.03	VVA	**0.33**	3194.02	3194.11	3194.14
1235	815167.91	946758.12	Yes	3222.65	3222.98	NVA	**0.33**	3222.94	3222.94	3222.99
1233	822739.81	944077.22	Yes	3170.85	3171.18	NVA	**0.33**	3171.15	3171.15	3171.21
1245	808048.85	945405.63	Yes	3274.13	3274.46	NVA	**0.33**	3274.42	3274.42	3274.47
1240	803397.23	943329.50	Yes	3304.43	3304.76	NVA	**0.33**	3304.73	3304.76	3304.77
1249	811005.00	947342.24	Yes	3247.91	3248.24	NVA	**0.33**	3248.21	3248.28	3248.29
1242	805655.73	945762.62	Yes	3309.15	3309.49	NVA	**0.34**	3309.45	3309.48	3309.51
1028	807138.49	940722.11	Yes	3804.26	3804.60	VVA	**0.34**	3802.74	3804.80	3805.08
1227	821155.97	944894.97	Yes	3179.53	3179.88	NVA	**0.35**	3179.87	3179.88	3179.98
1219	821052.58	944506.79	Yes	3179.05	3179.40	NVA	**0.35**	3179.39	3179.40	3179.65
1231	822772.93	944136.80	Yes	3170.17	3170.52	NVA	**0.35**	3170.51	3170.54	3170.55
1029	807117.59	940584.99	Yes	3789.39	3789.74	VVA	**0.35**	3789.33	3789.58	3791.28
1241	806207.13	943854.82	Yes	3283.70	3284.06	NVA	**0.35**	3283.99	3284.08	3284.17
1018	807741.83	945920.78	Yes	3283.79	3284.15	VVA	**0.36**	3284.04	3284.04	3284.16
1083	821258.31	948033.86	Yes	3200.40	3200.76	VVA	**0.36**	3200.73	3200.77	3200.77
1247	811657.19	947572.05	Yes	3245.30	3245.66	NVA	**0.36**	3245.64	3245.66	3245.68
1264	822797.97	950613.83	Yes	3171.17	3171.54	NVA	**0.36**	3171.54	3171.54	3171.54
1251	808937.41	946964.07	Yes	3275.69	3276.06	NVA	**0.36**	3276.04	3276.09	3276.11
1095	820897.54	943971.27	Yes	3192.70	3193.07	VVA	**0.37**	3193.05	3193.07	3193.08
1267	823930.02	946153.97	Yes	3163.12	3163.50	NVA	**0.37**	3163.44	3163.49	3163.53
1256	814928.73	947550.11	Yes	3220.65	3221.02	NVA	**0.38**	3221.00	3221.04	3221.05
1103	820862.94	944590.45	Yes	3193.50	3193.89	VVA	**0.39**	3193.82	3193.90	3193.93
1085	821150.23	947834.41	Yes	3201.27	3201.67	VVA	**0.40**	3201.66	3201.66	3201.75
1121	819339.01	945967.19	Yes	3191.75	3192.15	VVA	**0.40**	3192.14	3192.14	3192.25
1265	825253.43	946751.41	Yes	3168.72	3169.12	NVA	**0.40**	3169.07	3169.09	3169.30
1255	814855.63	947494.62	Yes	3221.03	3221.43	NVA	**0.40**	3221.38	3221.41	3221.47

1266	824789.18	945595.57	Yes	3160.58	3160.99	NVA	**0.40**	3160.92	3160.97	3161.22
1111	821564.91	937061.83	Yes	3161.48	3161.89	VVA	**0.41**	3161.80	3161.84	3161.95
1263	822601.25	950363.06	Yes	3176.81	3177.22	NVA	**0.41**	3177.21	3177.23	3177.24
1243	808061.21	944858.00	Yes	3271.55	3271.96	NVA	**0.41**	3271.83	3271.83	3272.01
1096	820904.57	943884.51	Yes	3191.81	3192.25	VVA	**0.44**	3192.10	3192.19	3192.30
1130	819481.53	945832.30	Yes	3188.01	3188.45	VVA	**0.44**	3187.94	3188.58	3188.82
1124	819178.81	946200.33	Yes	3195.76	3196.21	VVA	**0.45**	3196.15	3196.15	3196.23
1119	819601.64	945866.39	Yes	3191.37	3191.82	VVA	**0.45**	3191.44	3191.71	3191.87
1239	803412.28	943284.41	Yes	3304.68	3305.14	NVA	**0.46**	3305.11	3305.12	3305.21
1122	819280.03	945986.61	Yes	3190.70	3191.17	VVA	**0.48**	3191.14	3191.20	3191.21
1268	823014.28	946246.36	Yes	3168.95	3169.43	NVA	**0.48**	3169.41	3169.42	3169.46
1102	820873.40	944390.23	Yes	3194.45	3194.94	VVA	**0.49**	3194.93	3194.95	3194.95
1092	820878.67	944166.47	Yes	3193.74	3194.23	VVA	**0.50**	3194.07	3194.23	3194.37
1054	782977.93	948987.29	Yes	3464.18	3464.69	VVA	**0.50**	3464.58	3465.00	3465.05
1238	803465.44	943335.32	Yes	3304.77	3305.28	NVA	**0.51**	3305.16	3305.29	3305.32
1217	824511.28	937435.65	Yes	3160.08	3160.60	NVA	**0.52**	3160.56	3160.59	3160.69
1139	819424.74	945404.18	Yes	3188.19	3188.83	VVA	**0.65**	3188.52	3188.68	3189.08
1123	819243.17	946006.58	Yes	3191.10	3191.80	VVA	**0.70**	3191.54	3191.76	3191.83
1120	819542.16	945877.89	Yes	3191.96	3192.68	VVA	**0.72**	3192.64	3192.68	3192.76
1131	819356.78	945828.30	Yes	3189.34	3190.25	VVA	**0.92**	3190.25	3190.27	3190.28
1030	807086.66	940573.03	Yes	3794.62	3795.56	VVA	**0.94**	3795.42	3795.48	3796.23
1037	802515.81	943746.13	No	3319.58		VVA				
1209	713067.27	951387.97	No	4060.69		NVA				
1208	713136.32	951451.29	No	4060.42		NVA				
1207	713141.20	951501.15	No	4059.76		NVA				
1206	713334.20	951957.96	No	4056.02		NVA				
1205	762535.07	951397.51	No	3624.16		NVA				
1204	771246.48	953154.61	No	3566.65		NVA				
1137	819543.17	945456.58	No	3194.16		VVA				
1132	819253.24	945706.93	No	3190.75		VVA				
1258	808406.05	952456.02	No	3507.76		NVA				
1201	771846.90	950334.52	No	3602.76		NVA				

LiDAR CALIBRATION and BLOCK LAS OUTPUT

Note: All figures represented on the following pages are for general illustration purposes, and are not examples derived from actual Lolo, Montana Project data.

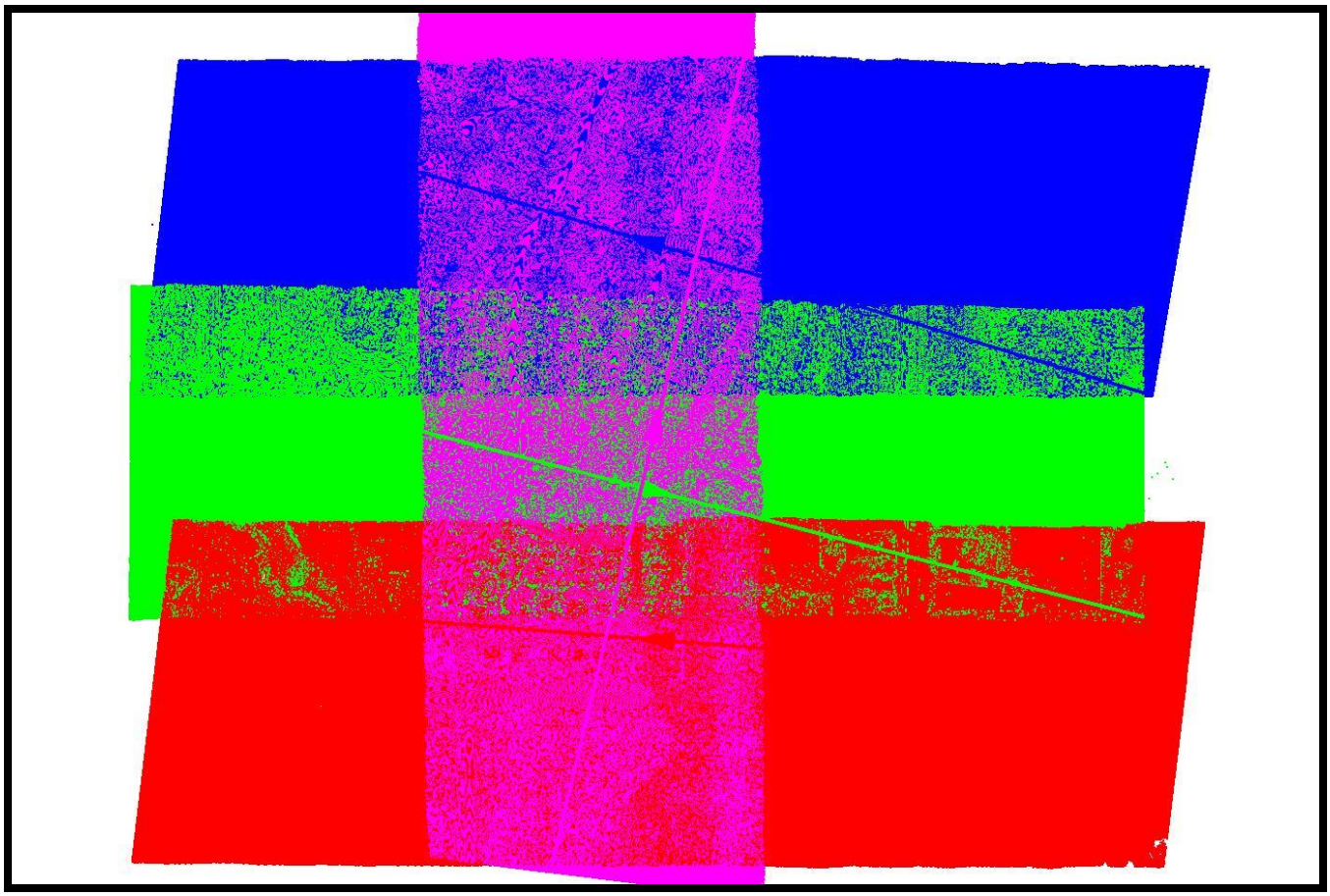
Introduction

Galaxy LiDAR data is output as LAS point data using Optech's Lidar Mapping Suite (LMS). LMS matches ground and roof planes plus roof lines to self-calibrate and correct system biases. These biases occur within the hardware of the Galaxy laser scanning systems, within the Inertial Measurement Unit (IMU) and because of environmental conditions which affect the refraction of light. The systemic biases that are corrected for include scale, roll, pitch, and heading.

In addition to the self-calibration mode LMS runs a "production" mode which applies the self-calibration parameters and then analyzes each individual flight line and applies small adjustments to each line to tie overlapping LiDAR points even more tightly together.

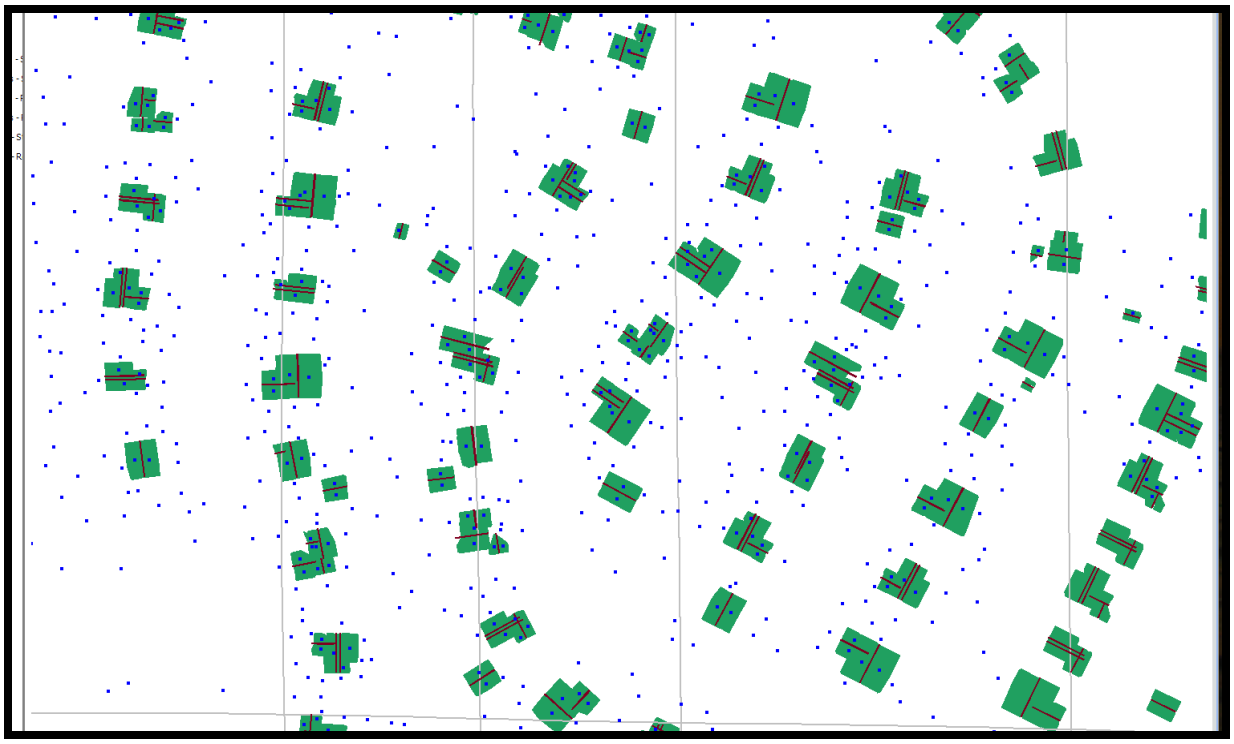
Boresight Self-Calibration Processing Procedures

An LMS boresight calibration is performed on an as-needed basis to correct scale, roll, pitch and heading biases. A minimum of three overlapping flights are flown in opposing directions with one cross flight.



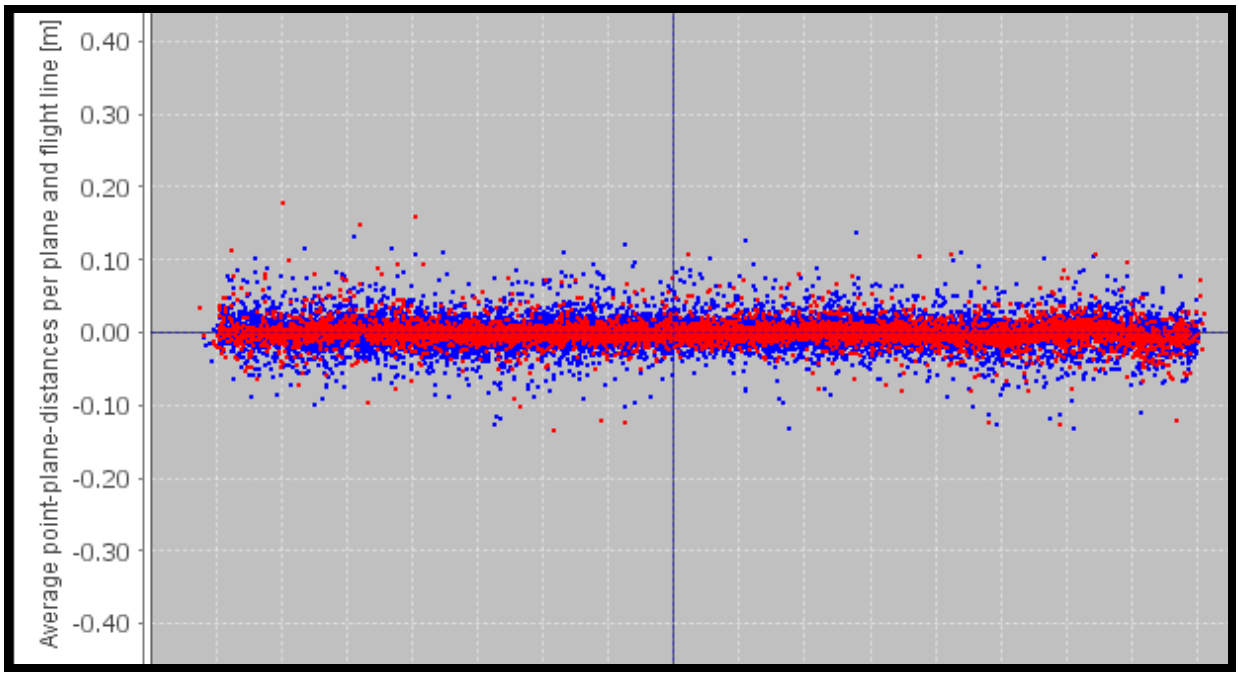
The Boresighting module frees scan angle scale, scan angle lag, XYZ boresight corrections and elevation position corrections while locking scan angle offset and XY position corrections.

The picked calibration site will have a good distribution of buildings for the self-calibration software to match ground planes, roof planes and roof lines.

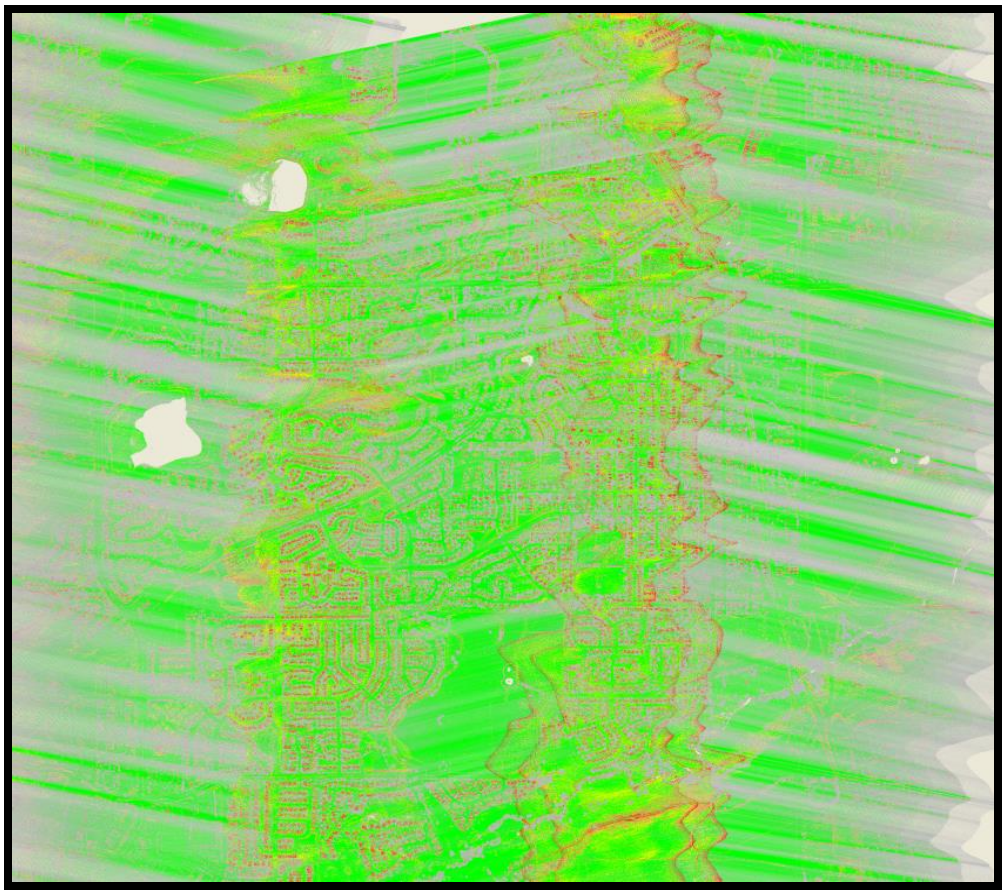


At the conclusion of the self-calibration run the data is quality checked with LMS plots

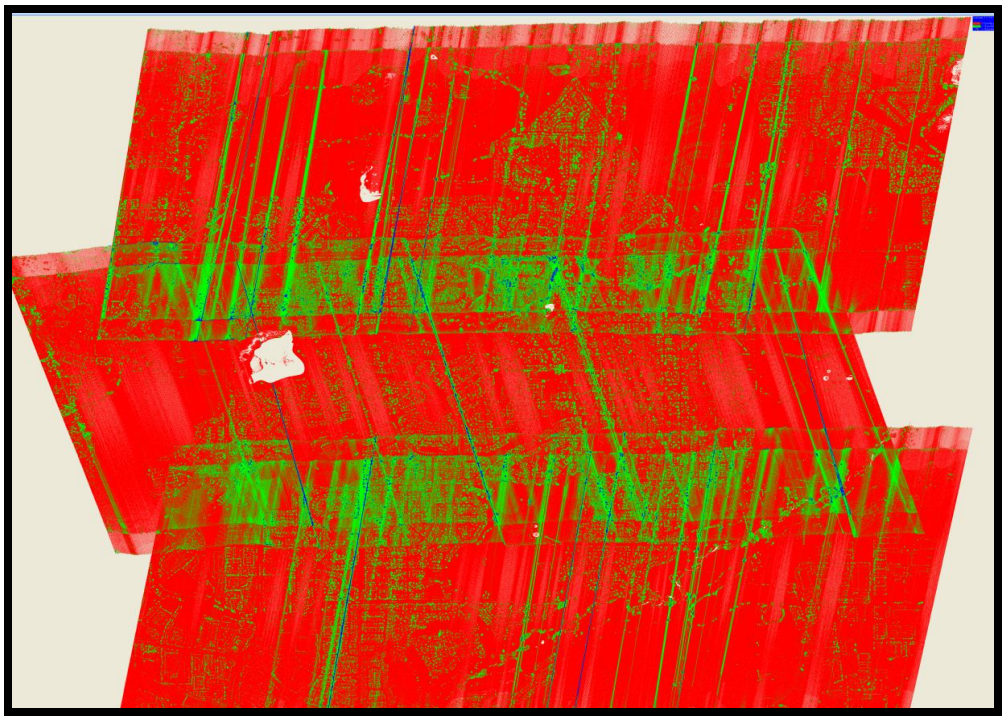
Plot of plane vertical distances from datum plane.



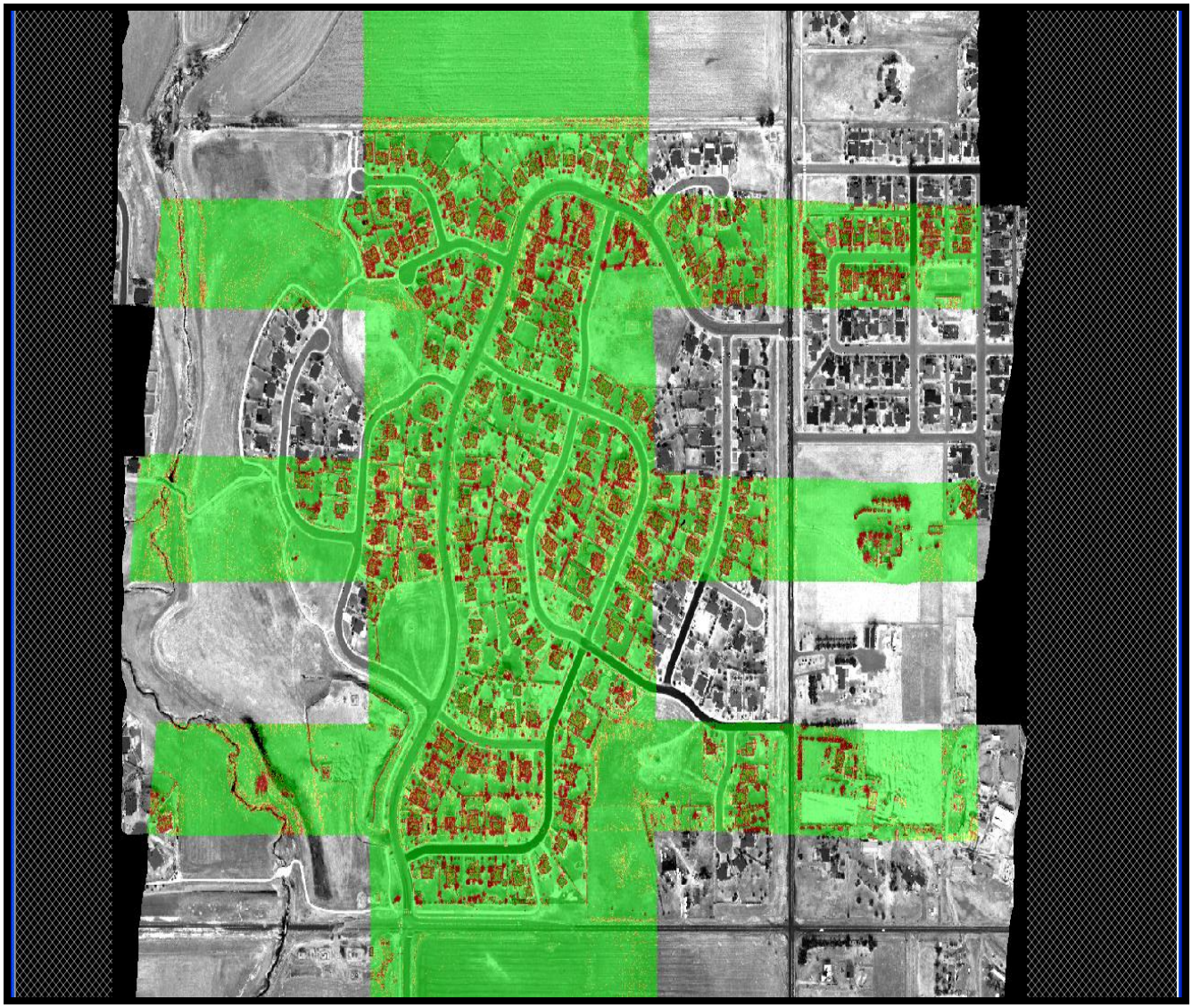
Plot of height differenced between flight lines. (Green=less than 5cm).



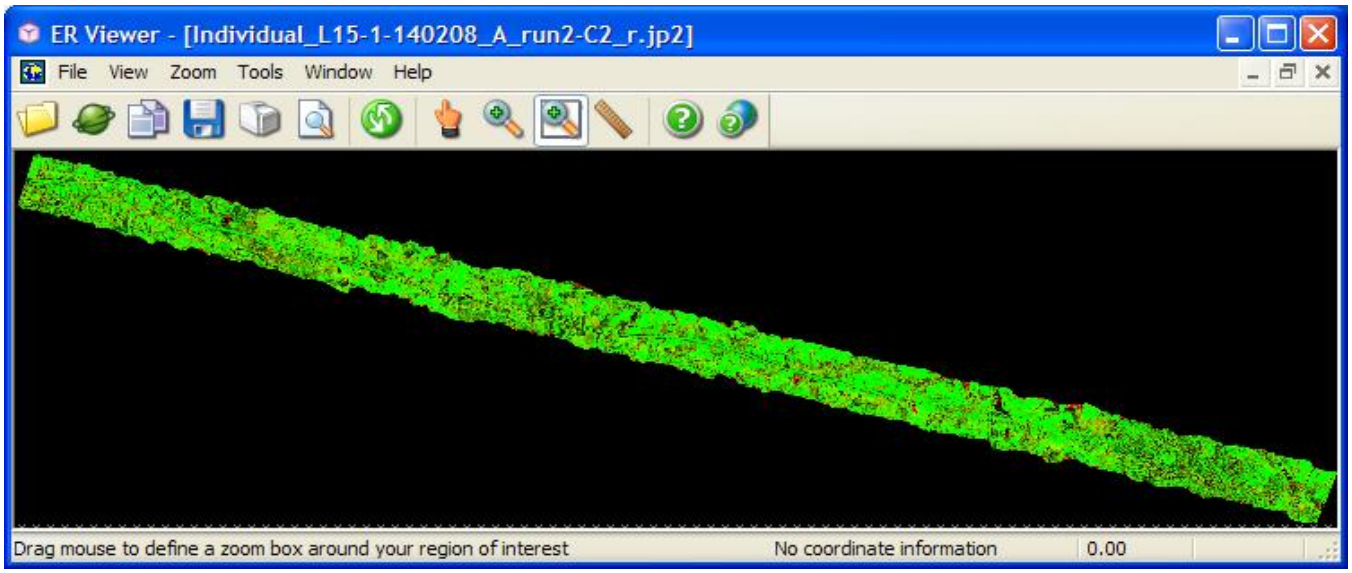
Plot of point densities. (Red=5-9 points per cell, green 10+ points per cell).



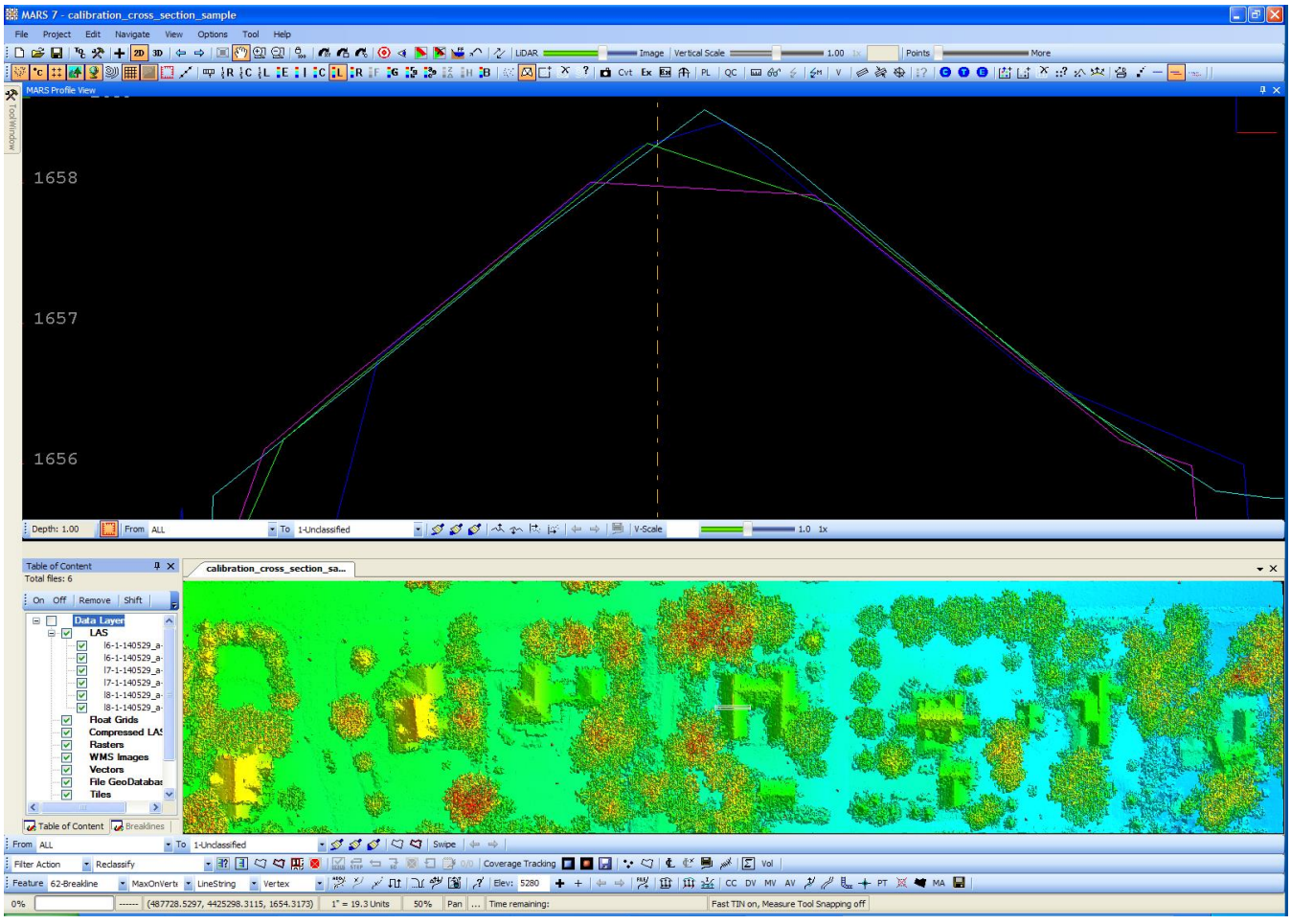
A Flight Line Separation Raster image is generated in MARS®, in this example ground returns from multiple flight lines that are fitting within 3 centimeters is colored green.



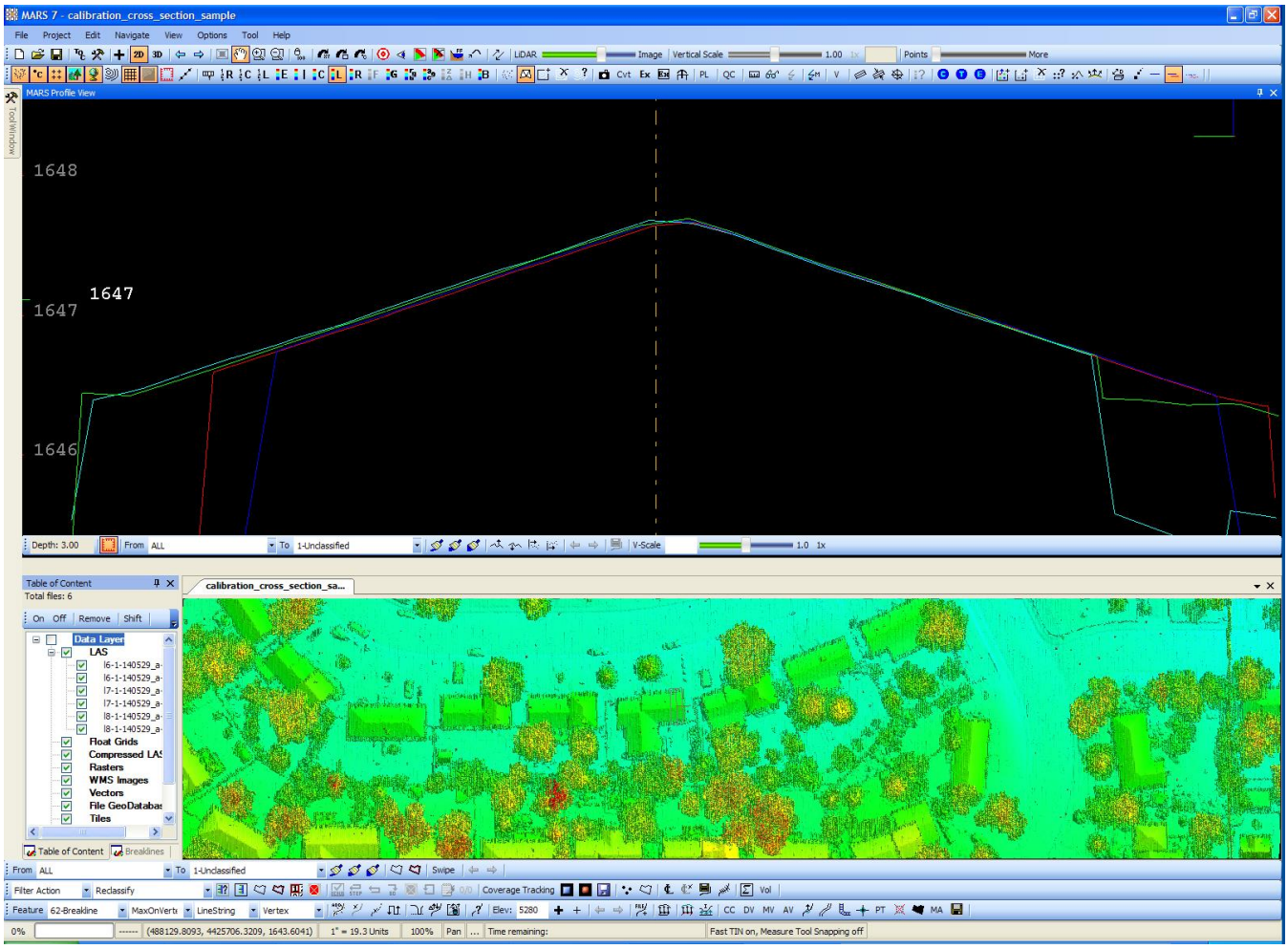
MARS® tests for internal relative vertical accuracy using inbound and outbound scan values. Again Green is showing inbound and outbound scan data fitting to 3 centimeters.



Building cross sections are checked for good alignment. Pitch and heading are checked on roof planes parallel to the flight direction.



Roll and scale are checked on roof planes perpendicular to the flight direction.

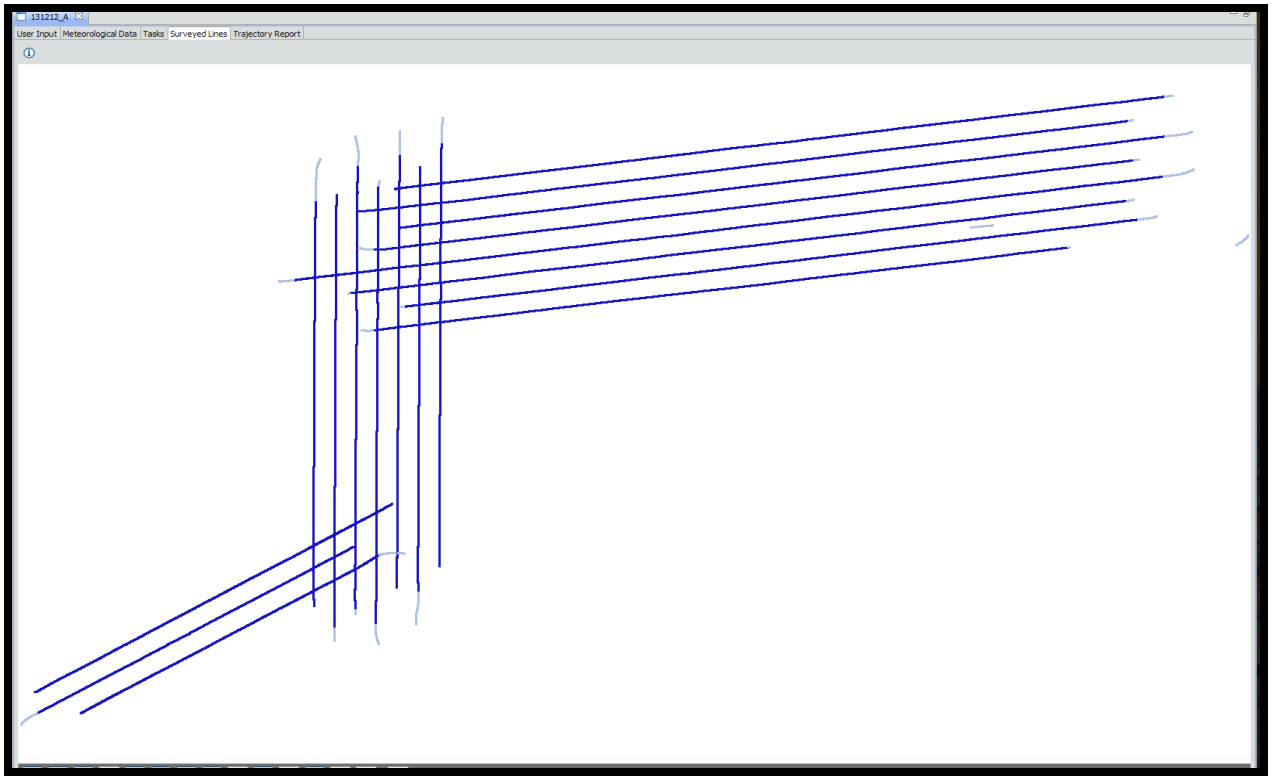


The LMS program outputs a "LCP" file with all the correction parameters. The calibration process may be run several times until the boresight adjustments are acceptable. When the boresight solution is acceptable the LCP file adjustments are saved and also applied to subsequent projects. Each new project is again analyzed and when the adjustment biases show too much drift a new boresight calibration is run. The LCP file may hold calibration tolerances for several projects.

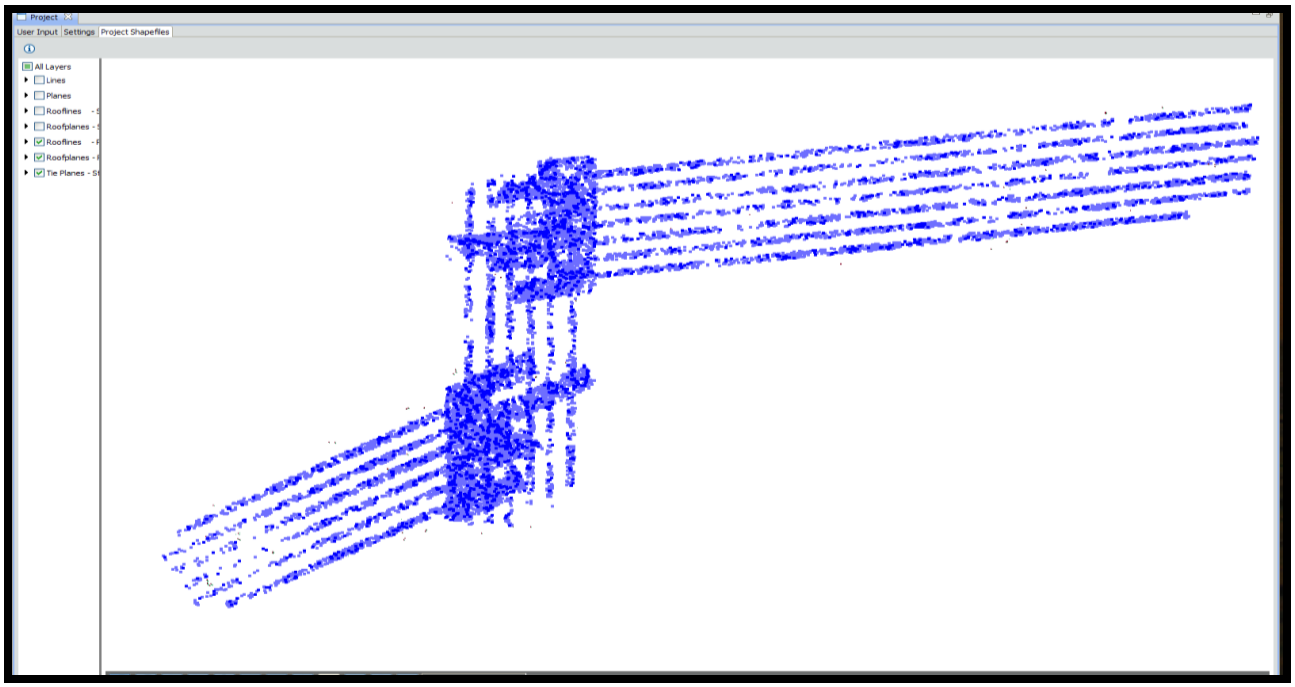
BLOCK LAS Production Processing Procedures

The LMS production mode is run on each flight line to further tie the final LiDAR LAS flight line files tightly together. Production settings allow scan angle scale, scan angle lag to float and allows elevation to move slightly during flight line to flight line comparison thus further tying flight lines together. A cross flight with locked elevation data is used for controlling flight line elevations.

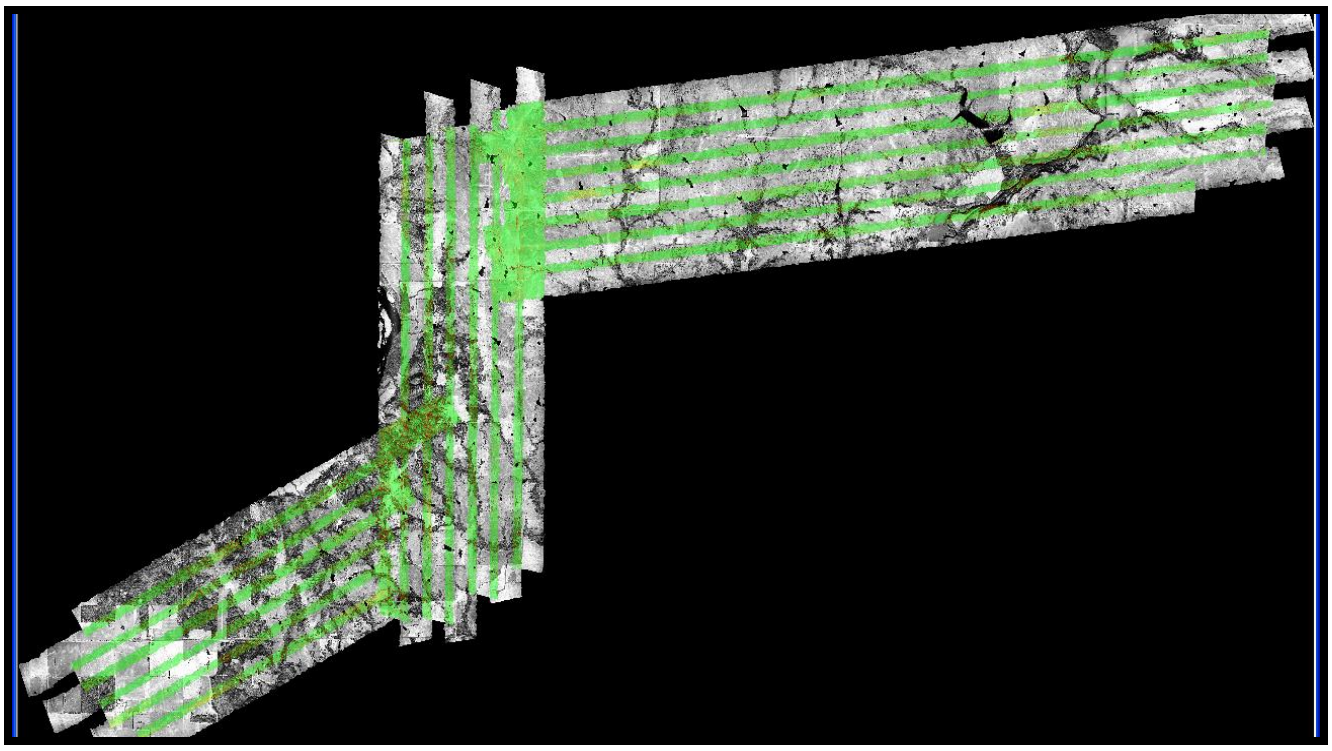
A block of data is selected to process with LMS production settings. Data collected during turns at the ends of flight lines is deselected (light blue lines).



As in self-calibration the LMS production program analyses ground, roof planes and rooflines. One cross flight is locked in elevation and all other lines are adjusted to it. Unlike the calibration site the distribution of roof planes is usually much less dense. Here matched ground tie planes are blue.

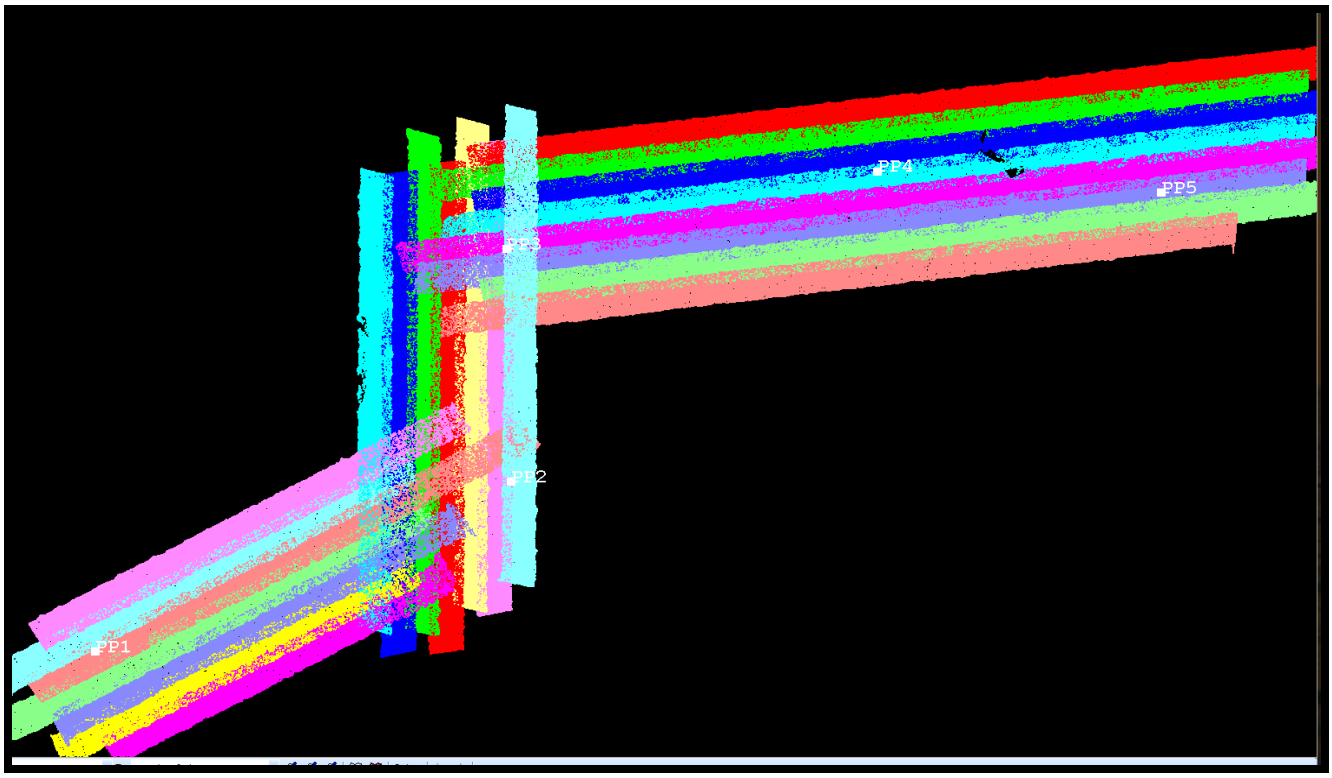


The same quality control outputs used to check self-calibrations are available to analyze the production run. Output plots are again available in LMS and cross sections plus a Flight Line Separation Raster are generated in MARS® to check coverage and quality.

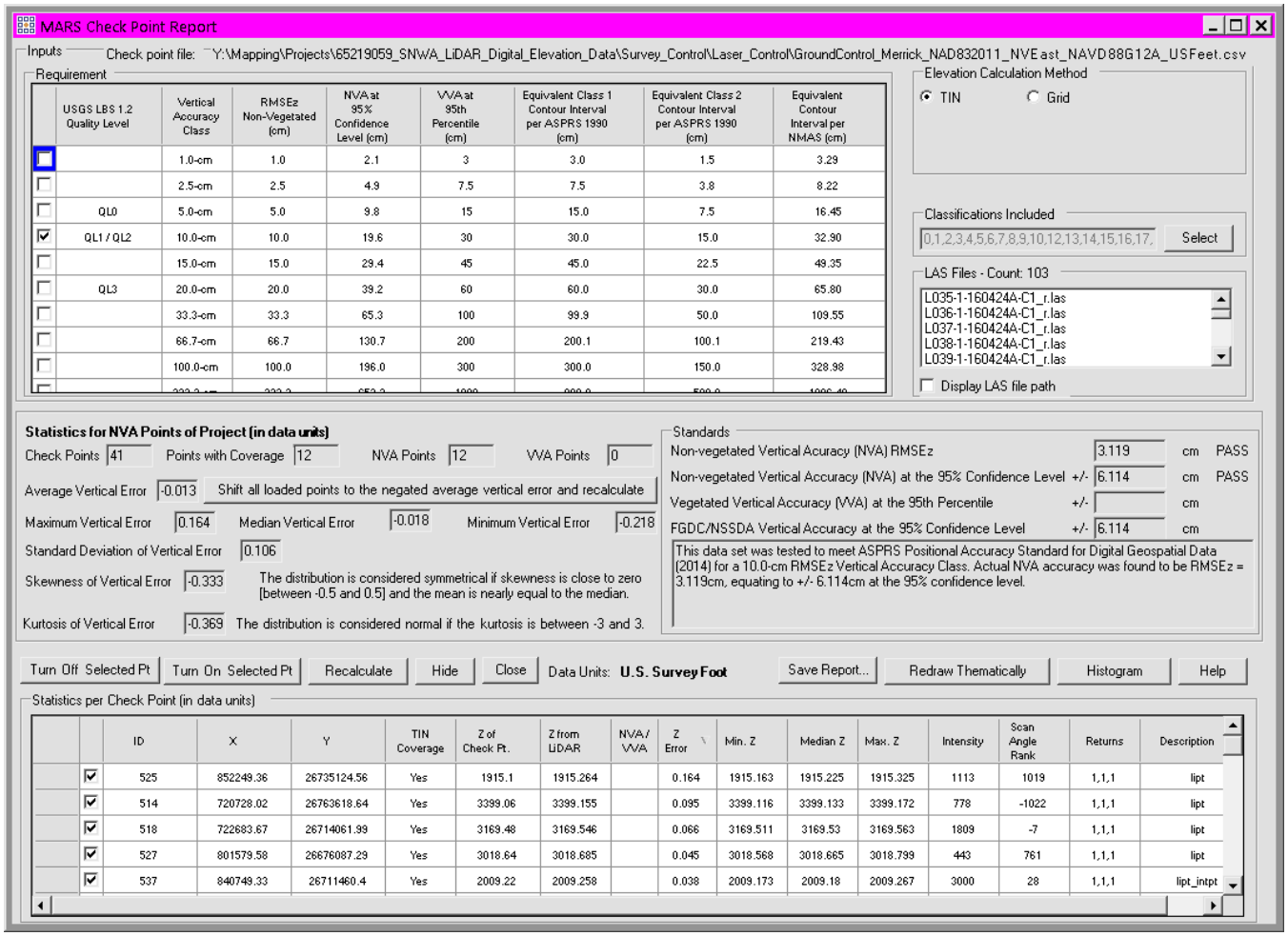


Correcting the Final Elevation

After all the lines are tied together a ground control network is imported into MARS®. The ground control network may be pre-existing or collected by a licensed surveyor.



The next step is to match the ground control elevations to the LiDAR data set. A control report is run and the data set is shifted slightly to zero out the average elevation error and points checked for quality.



The final step before boresighted, leveled LAS files are ready for filtering is to run the MARS® QC Module on the block data. The Boresighted LiDAR QC Report outputs individual reports on Point Density, Nominal Pulse Spacing, Data Voids, Spatial Distribution, Scan Angles, Control Report, Flight Line Separation, Flight Line Overlap, Buffered Boundary, LAS Formats, Datums and Coordinates. These reports are checked with the required specifications in the Project Management Plan.

LIDAR CLASSIFICATION

Auto-Filter (automated)

Merrick uses software to classify an automated bare-earth (i.e., ground / Class 2) solution from the LiDAR point cloud. The software uses several different algorithms combined in a macro to determine the ground/not ground classification for each point. Filter parameters are adjusted based on the terrain and land cover for each project to produce the best initial ground result and to minimize hand-filter cost. Merrick's automated filters typically classify ground to better than 85-percent accuracy and better than 95 percent consistency. This procedure was applied to the project area.

Hand-Filter (manual editing)

The remaining 5 to 15 percent of the points resulting from the automated filtering process are evaluated by a technician during final editing. Within Merrick's proprietary software, MARS®, there are several manual edit tools which enable quick re-classification of these features to the appropriate class. Every square mile within the project extent is reviewed by an operator to ensure all artifacts are separated from ground, and that project specifications are met. Once it is deemed to be the best Class 2 (Ground) solution, Merrick performs a re-classification process to finalize the point cloud to meet the ASPRS LAS 1.4 specifications. During this process all non-ground points are assigned to Class 1 (Unclassified), low noise points are assigned to Class 7, high noise points are assigned to Class 18. This point assignment was applied to entire project area.

Final Classifications

- Class 1 – Unclassifid
- Class 2 – Ground classification, bit flagged with model key-points 1ft spacing +/- .2
- Class 7 – Low points
- Class 9 – Water
- Class 10 – Breakline proximity (2.32 ft buffer)
- Class 17 – Bridge points
- Class 18 – Hight Points

* Note bit flags are used for Overlap to meet the LAS 1.4 specifications.

Hydro-enforcing breaklines are captured by Merrick compilers. These features are appropriately turned into polygons and are used in MARS® to reclassify ground points in water to Water (Class 9). The LiDAR points around the breaklines are reclassified to Ignored Ground (Class 10) based on predetermined buffer.

HYDRO-FLATTENING BREAKLINE COLLECTION (per the USGS National Geospatial Program Lidar Base Specification Version 1.2)

Linear hydrographic features

Merrick uses a methodology that directly interacts with the LiDAR bare-earth data to collect drainage breaklines. To determine the alignment of a drainageway, the technician first views the area as a TIN of bare-earth points using a color ramp to depict varying elevations. In areas of extremely flat terrain, the technician may need to determine the direction of flow based on measuring LiDAR bare-earth points at each end of the drain. The operator will then use the color ramped TIN to digitize the drainage in 2D with the elevation being attributed directly from the bare-earth .LAS data. Merrick's proprietary MARS® software has the capability of "flipping" views between the elevationTIN, Intensity and imagery, as necessary, to further assist in the determination of the drainage. All drainage breaklines are collected in a downhill direction. For each point collected, the software uses a five-foot (5') search radius to identify the lowest point within that proximity. Within each radius, if a bare-earth point is not

found that is lower than the previous point, the elevation for subsequent point remains the same as the previous point. This forces the drain to always flow in a downhill direction. Waterbodies that are embedded along a drainageway are validated to ensure consistency with the downhill direction of flow.

This methodology may differ from those of other vendors in that Merrick relies on the bare-earth data to attribute breakline elevations. As a result of our methodology, there is no mismatch between LiDAR bare-earth data and breaklines that might otherwise be collected in stereo 3D as a separate process. This is particularly important in densely vegetated areas where breaklines collected in 3D from imagery will most likely not match (either horizontally or vertically), the more reliable LiDAR bare-earth data.

Merrick has the capability of "draping" 2D breaklines to a bare-earth elevation model to attribute the "z" as opposed to the forced downhill attribution methodology described above. However, the problem with this process is the "pooling "effect or depressions along the drainageway caused by a lack of consistent penetration in densely vegetated areas.

Criteria of linear hydrographic breaklines are as follows:

- Linear hydrographic features (e.g., visible streams, rivers, shorelines, canals, etc.) greater than one hundred feet (100') wide will be captured as a double-lined polygon
  - linear hydrographic features must be flat and level bank-to-bank (perpendicular to the apparent flow centerline) with gradient following the immediately surrounding terrain
  - water surface edge must be at or just below the immediately surrounding terrain
  - streams should break at road crossings (e.g., culverts), and streams and rivers should not break at bridges

Waterbodies

Waterbodies are digitized from the color ramped TIN, similar to the process described above. The elevation attribute is determined as the technitian collects the hydro feature by using the lowest bare-earth point within the polygon.

Criteria of waterbody breaklines are as follows:

- Waterbodies (e.g., lakes, ponds, reservoirs) greater than two (2) acres in size are surrounded by a water breakline (i.e., closed polygon)
  - waterbodies must be flat and level with a single elevation for every bank vertex
  - water surface edge must be at or just below the immediately surrounding terrain
  - long impoundments, such as reservoirs or inlets, whose water surface elevations drop when moving downstream should be treated as rivers

DIGITAL ELEVATION MODEL (DEM)

Merrick exports the hydro-flattening breakline enforced Class 2 (ground) LiDAR points to a 2ft cell size ERDAS Imagine (IMG) format using MARS®, the DEMs are exported to the project tiling scheme. Projection information is applied that reflects the project requirements.