‘WV FEMA R3 South Central’ LiDAR Acquisition and Calibration Report

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SUBMITTED BY:

Eagle Mapping Inc.
114 W. Magnolia Street
Suite 400-140
Bellingham, WA, 98225
503.501.7278

SUBMITTED TO:
U.S. Geological Survey
1400 Independence Road
Rolla, MO 65401
573.308.3810

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Overview

Dewberry elected to subcontract LiDAR acquisition and calibration activities to Eagle Mapping Inc. Eagle Mapping was responsible for providing LiDAR acquisition, calibration and delivery of LiDAR data files to Dewberry.

Dewberry received calibrated swath data from Eagle Mapping on May 27, 2019.

Project Area

This report addresses the collection and calibration of 4741 square miles located near Charleston, WV as shown in the map below.

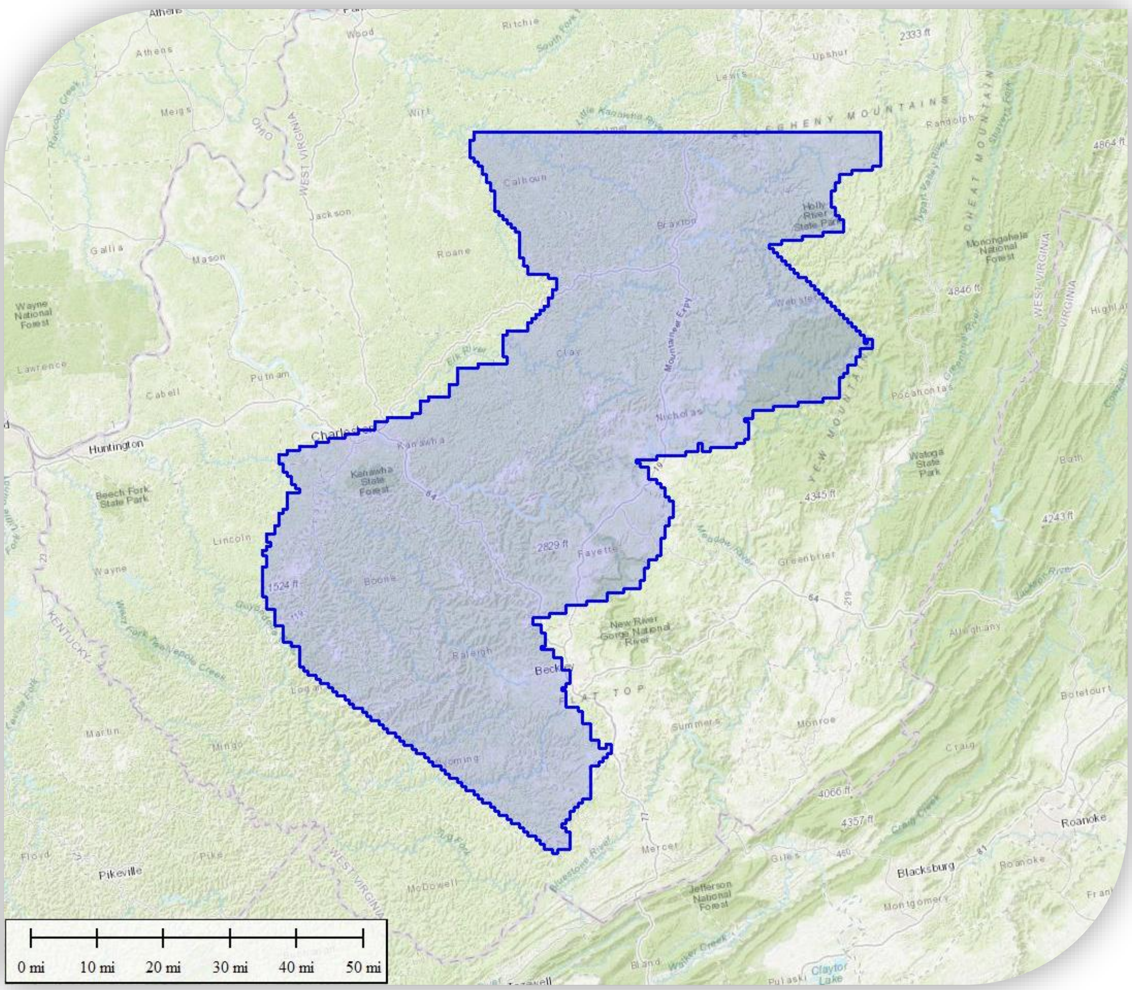

Figure 1 – Area of Interest

Project names & Areas (sq. miles)	
WV South Central	4741

Acquisition Dates

LiDAR was collected over one mobilization and consisted of nine missions.

AOI	Date of Mission	Missions Required
WV South Central	March 27-April 16, 2019	10

Datum Reference

Data produced for the project was delivered in the following reference system

Map Projection Information	
Projection	Conus Albers
Horizontal Datum	NAD83 (2011) Epoch 2010
Vertical Datum	NAVD88
Geoid	GEOID12B
Units	Meters
EPSG Code	6350

LiDAR Acquisition Details

Eagle Mapping planned 178 passes to complete coverage of the WV South Central project area. Flight lines were planned as a series of parallel passes flown in opposing directions to aid in the calibration process. In order to reduce any margin for error in the flight plan, Eagle Mapping followed FEMA's Appendix A "guidelines" for flight planning and, at a minimum, include the following criteria:

- A digital flight line layout using Track' Air Flight management software for direct integration into the aircraft flight navigation system.
- Planned flight lines; flight line numbers; and coverage area.
- LiDAR coverage extended by a predetermined margin beyond all project borders to ensure necessary over-edge coverage appropriate for specific task order deliverables.
- Local restrictions related to air space and any controlled areas were investigated so that required permissions could be obtained in a timely manner with respect to the schedule. Additionally, Eagle Mapping filed flight plans as required by local Air Traffic Control (ATC) prior to each mission.

Eagle Mapping monitored weather and atmospheric conditions and conducted LiDAR missions only when no conditions existed below the sensor that would affect the collection of data. These conditions included leaf-off for hardwoods, no snow, rain, fog, smoke, mist and low clouds.

LiDAR systems are active sensors, not requiring light, thus missions may be conducted during night hours when weather restrictions do not prevent collection. Eagle Mapping accessed reliable weather sites and indicators (webcams) to establish the highest probability for successful collection in order to position the sensor to maximize successful data acquisition.

Within 72-hours prior to the planned day(s) of acquisition, Eagle Mapping closely monitored the weather, checking all sources for forecasts at least twice daily. As soon as weather conditions were conducive to acquisition, the aircraft mobilized to the project site to begin data collection. Once on site, the acquisition team took responsibility for weather analysis.

Eagle Mapping's LiDAR sensors are calibrated at a designated site located at the Chilliwack Regional Airport in Chilliwack BC, Canada and are periodically checked and adjusted to minimize corrections at project sites.

LiDAR System parameters

A Riegl LMS-Q1560 dual-channel LiDAR system was used for acquisition of the LiDAR data. This system was installed in a Piper Navajo aircraft operated by Peregrine Aerial Surveys out of Abbotsford, BC. Table 1 illustrates Eagle Mapping's system parameters for LiDAR acquisition on this project.

Item	Parameter
System	Riegl LMS-Q1560
Maximum Number of Returns per Pulse	Unlimited
Nominal Pulse Spacing (single swath), (m)	0.40
Nominal Pulse Density (single swath) (ppsm), (m)	3.2
Aggregate NPS (m) (if ANPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.40
Aggregate NPD (m) (if ANPD was designed to be met through single coverage, ANPD and NPD will be equal)	3.2
Altitude (AGL meters)	2000
Approx. Flight Speed (knots)	140
Total Sensor Scan Angle (degree)	58
Scan Frequency (hz)	176
Scanner Pulse Rate (kHz)	800
Pulse Duration of the Scanner (nanoseconds)	3
Pulse Width of the Scanner (m)	0.9
Central Wavelength of the Sensor Laser (nanometers)	1064
Did the Sensor Operate with Multiple Pulses in The Air? (yes/no)	Yes
Beam Divergence (milliradians)	<0.25
Nominal Swath Width on the Ground (m)	2240
Swath Overlap (%)	>20
Computed Down Track spacing (m) per beam	0.40
Computed Cross Track Spacing (m) per beam	0.41

Table 1: Eagle Mapping LiDAR System Parameters

Acquisition Status Report and Flight-lines

Upon notification to proceed, the flight crew loaded the flight plans and validated the flight parameters. The Acquisition Manager contacted air traffic control and coordinated flight pattern requirements. LiDAR acquisition began immediately upon notification that control base stations were in place. During flight operations, the flight crew monitored weather and atmospheric conditions. LiDAR missions were flown only when no condition existed below the sensor that would affect the collection of data. The pilot constantly monitored the aircraft course, position, pitch, roll, and yaw of the aircraft. The sensor operator monitored the sensor, the status of PDOPs, and performed the first Q/C review during acquisition. The flight crew constantly reviewed weather and cloud locations. Any flight lines impacted by unfavorable conditions were marked as invalid and re-flown immediately or at an optimal time.

Figure 2 shows the combined trajectory of the flight lines for the March 27, 2019 mission of the WV South Central project area.

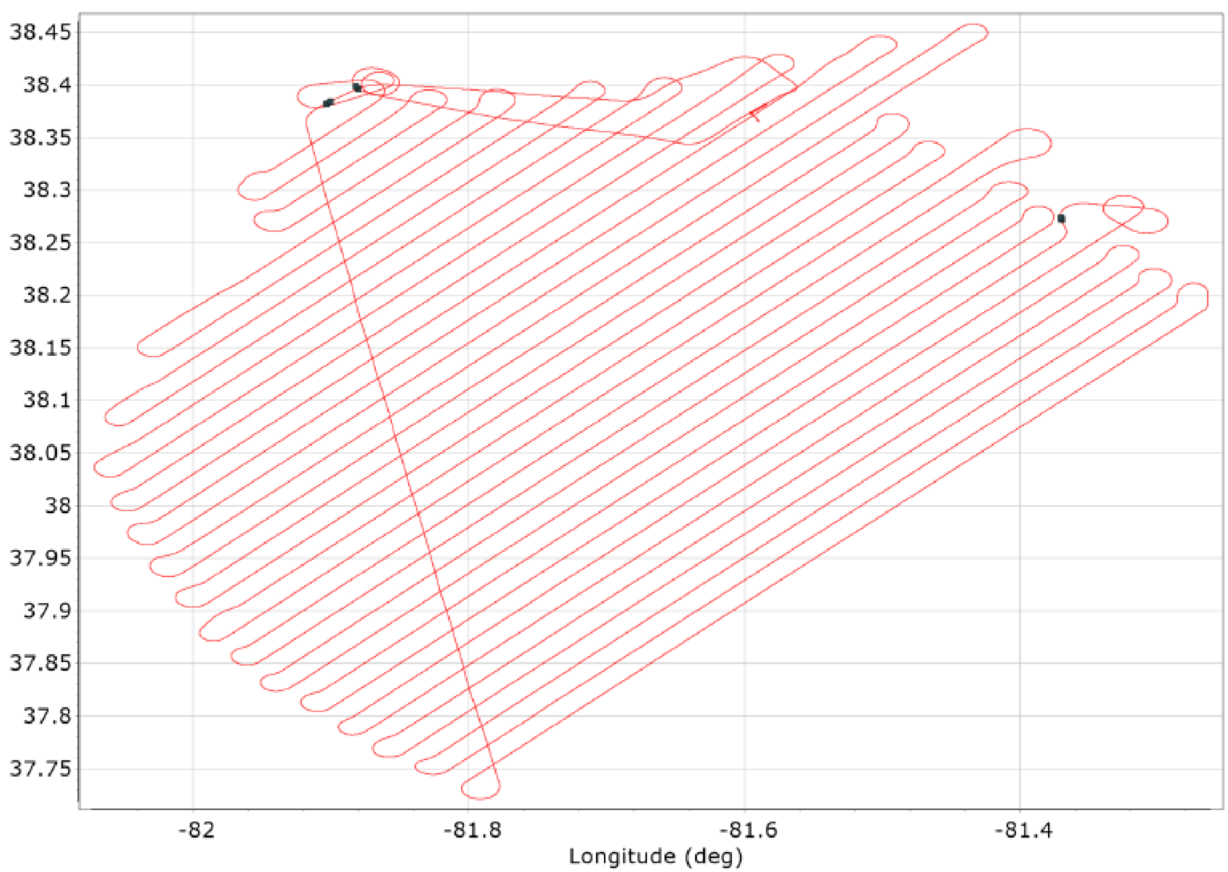

Figure 2: March 27, 2019 trajectory as flown by Eagle Mapping

Acquisition Static Control

Eagle Mapping used the widely-available 1 Hz CORS stations in the area to create an Applanix SmartBase for post-processing. Coordinates of nearby CORS base stations are provided in the table below.

CONUS Albers - NAD83 (2011) epoch 2010.0 NAVD88 – Geoid12B				
Date Rate	Name	Latitude (N) (DDMMSS.SSSSS)	Longitude (W) (DDMMSS.SSSSS)	Ellipsoidal height (m)
1 sec (CORS)	WVAT	37.42851	-81.06788	705.980
	WVGB	38.43012	-79.81703	812.469
	WVMZ	38.83890	-81.10877	296.833
	WVOH	37.99826	-81.13216	597.484
	WVRA	38.94135	-81.75135	149.245
	KYGB	38.48061	-82.87333	184.297
	LS08	38.98034	-80.21973	407.318
	WVHA	39.24785	-81.04385	290.141
	KYTL	37.48338	-82.53547	186.977
	WVLE	37.82228	-80.42182	656.501
	WVNR	38.89570	-79.85841	582.775

Table 2 – Base station used for trajectory processing

Airborne GPS Kinematic

Airborne GPS data was processed using the Applanix PosPAC MMS v8.3 software suite and utilized a SmartBase trajectory solution. Flights were flown with a minimum of 7 satellites in view (12° above the horizon) and with a PDOP of better than 3.

Trimble RTX was also used for real-time corrected positioning of the aircraft, to assist with satellite coverage.

For all flights, the GPS data can be classified as excellent, with GPS residuals of 3 cm average or better but no larger than 10 cm being recorded during acquisition.

GPS processing reports for each mission are included in Appendix A.

Generation and Calibration of Laser Points (raw data)

The initial step of calibration is to verify availability and status of all necessary GPS and laser data against field notes and compile any data if not complete.

Subsequently the mission points are output using Riegl's RiProcess software, with default values from Riegl or the last mission calibrated for the system. Data is then output in the proper projection and orthometric height and calibrated using BayesMap StripAlign software. This software uses a rigorous time-dependent approach to address effect such as IMU drifts and oscillations to correct both relative and absolute geometric errors. The missions with the new calibration values are regenerated and validated internally once again to ensure quality requirements are met.

Data collected by the LiDAR sensor is reviewed for completeness, acceptable density and to ensure all data is captured without errors or corrupted values. In addition, all GPS, aircraft trajectory, mission information, and ground control files are reviewed.

On a project level, a supplementary coverage check is carried out to ensure no data voids unreported by Field Operations are present.

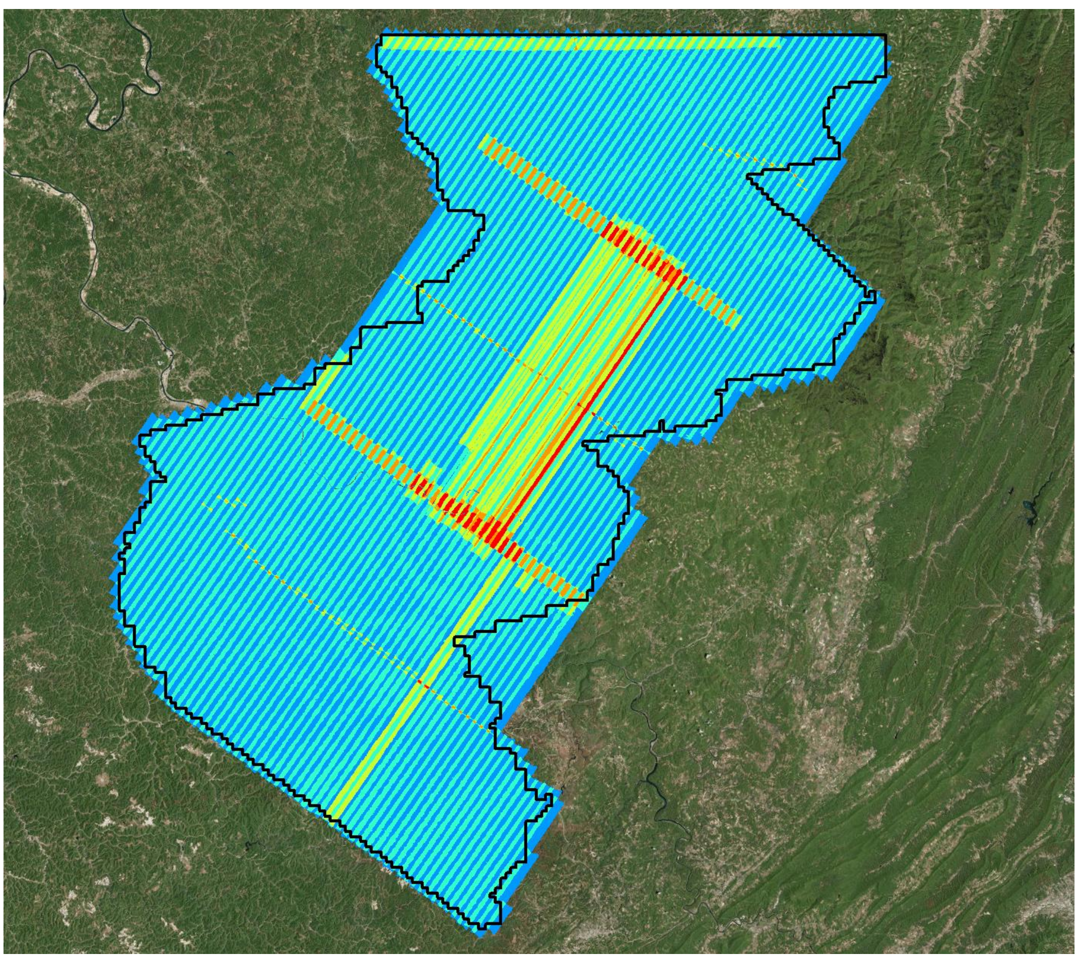

Figure 3 – LiDAR overlap output showing complete coverage of WV South Central AOI

Boresight and Relative accuracy

The initial strips calibrated for each mission are inspected for flight line errors, flight line overlap, slivers or gaps in the data, point data minimums, or issues with the LiDAR unit or GPS. Roll, pitch and scanner scale are optimized during the calibration process until the relative accuracy is met.

Relative accuracy and internal quality are checked using at least 2 regularly spaced QC blocks in which points from all lines are loaded and inspected. Vertical differences between ground surfaces of each line are displayed. Color scale is adjusted so that errors greater than the specifications are flagged. Cross sections are visually inspected across each block to validate point to point, flight line to flight line and mission to mission agreement.

For this project the specifications used are as follow:
Relative accuracy ≤6 cm maximum differences within individual swaths and ≤8 cm RMSDz between adjacent and overlapping swaths with maximum difference of ±16 cm.

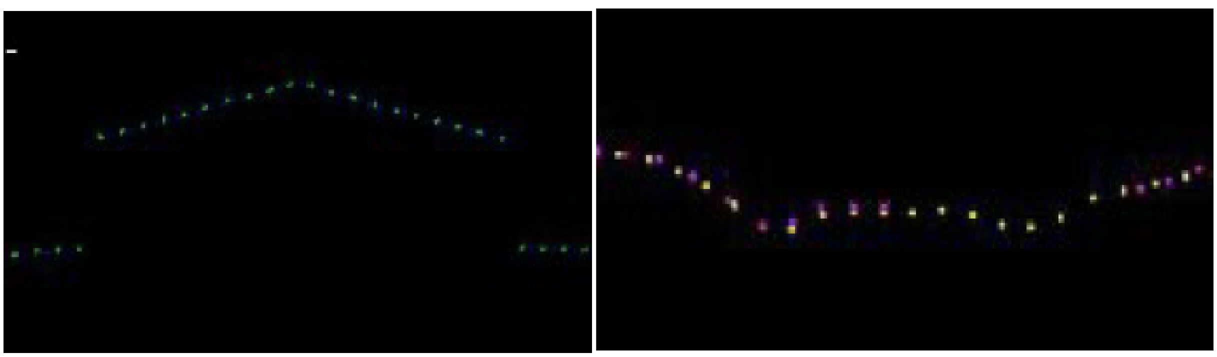

Figure 4 – Profile views showing correct roll and pitch adjustments.

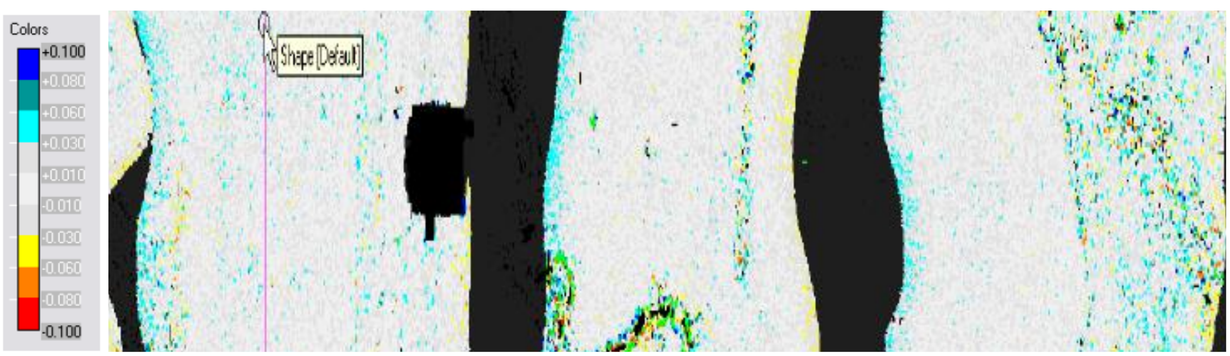

Figure 5 – QC block colored by distance to ensure accuracy at swath edges.

A different set of QC blocks are generated for final review after all transformations have been applied.

Final Calibration Verification

Dewberry conducted the survey for ground control points (GCPs) which were used to test the accuracy of the calibrated swath data. These GCPs were available to use as control in case the swath data exhibited any biases which would need to be adjusted or removed. The coordinates of all GCPs, accuracy results from testing the calibrated swath data against the GCPs, and vertical bias adjustments per project area are provided in table below;

WV SOUTH CENTRAL CONTROL REPORT

Point Name	CA SPCS NAD83(2011) Epoch 2010.00		NAVD88 (GEOID 12B)		
	Easting X (m)	Northing Y (m)	Known Z (m)	Laser Z (m)	Dz (m)
GCP-43	1259998.078	1712097.899	391.691	391.70	0.009
GCP-44	1248438.228	1722789.783	378.814	378.80	-0.014
GCP-46	1226912.430	1762758.651	209.853	209.80	-0.053
GCP-47	1242616.581	1745850.651	291.480	291.47	-0.010
GCP-48	1268474.150	1733697.526	604.054	604.06	0.006
GCP-49	1278799.479	1717416.415	495.792	495.80	0.008
GCP-51	1284109.640	1737347.709	771.657	770.34	**-1.317***
GCP-52	1269841.813	1753006.843	416.876	416.81	-0.066
GCP-53	1249077.806	1764038.579	225.900	225.84	-0.060
GCP-54	1241173.220	1772239.557	214.069	214.00	-0.069
GCP-55	1223531.528	1779583.185	227.379	227.34	-0.039
GCP-56	1220603.710	1792314.529	184.530	184.53	0.000
GCP-58	1251765.800	1781734.029	187.899	187.89	-0.009
GCP-59	1264595.135	1771567.052	232.810	232.77	-0.040
GCP-60	1286268.022	1760740.812	597.104	597.12	0.016
GCP-61	1304930.043	1767013.917	701.413	701.44	0.027
GCP-62	1288419.887	1779099.433	407.879	407.92	0.041
GCP-63	1269728.816	1781530.196	194.691	194.73	0.039
GCP-64	1263955.814	1789997.816	259.052	259.08	0.028
GCP-65	1251102.445	1804028.277	232.651	232.67	0.019
GCP-66	1262969.673	1808333.418	308.109	308.10	-0.009
GCP-67	1271961.580	1804594.171	368.267	368.32	0.053
GCP-68	1274796.133	1788719.342	451.979	452.00	0.021
GCP-69	1262185.195	1801703.530	294.546	294.49	-0.056
GCP-70	1284072.029	1789848.023	214.634	214.65	0.016
GCP-71	1304694.794	1784311.414	611.826	611.87	0.044
GCP-73	1278485.202	1800233.807	299.461	299.48	0.019
GCP-74	1269188.244	1816670.669	196.550	196.56	0.010
GCP-75	1284133.195	1815294.215	215.115	215.16	0.045
GCP-76	1278236.558	1824851.362	241.338	241.31	-0.028

GCP-77	1301122.415	1800280.010	465.653	465.65	-0.003
GCP-78	1312512.548	1797677.447	657.863	657.91	0.047
GCP-80	1342404.589	1813220.632	695.187	695.05	**-0.137***
GCP-81	1323301.432	1817318.346	755.186	755.25	0.064
GCP-82	1302511.438	1818592.055	342.886	342.92	0.034
GCP-84	1285208.846	1832848.007	291.891	291.86	-0.031
GCP-85	1268717.260	1850176.645	233.635	233.61	-0.025
GCP-86	1296917.057	1843017.238	283.421	283.41	-0.011
GCP-87	1313495.217	1842882.646	255.977	255.96	-0.017
GCP-88	1335558.814	1836564.814	377.286	377.32	0.034
GCP-89	1338504.155	1854812.314	390.851	390.93	0.079
GCP-90	1351535.351	1863039.668	565.134	565.14	0.006
GCP-92	1306193.459	1867951.880	230.420	230.32	-0.100
GCP-93	1287151.934	1860292.506	220.476	220.46	-0.016
GCP-94	1275527.987	1866169.476	211.209	211.20	-0.009
GCP-95	1262545.779	1866713.054	309.855	309.87	0.015

*GCP-51 & GCP-81 omitted from reporting as >3-sigma outliers

100 % of Totals	# of Points	RMSEz NVA Spec=0.100 (m)	NVA at 95% Spec=0.196 (m)	Mean (m)	Std Dev (m)	Min (m)	Max (m)
Non-Vegetated Terrain	46	0.038	0.074	0.00	0.039	-0.100	+0.079