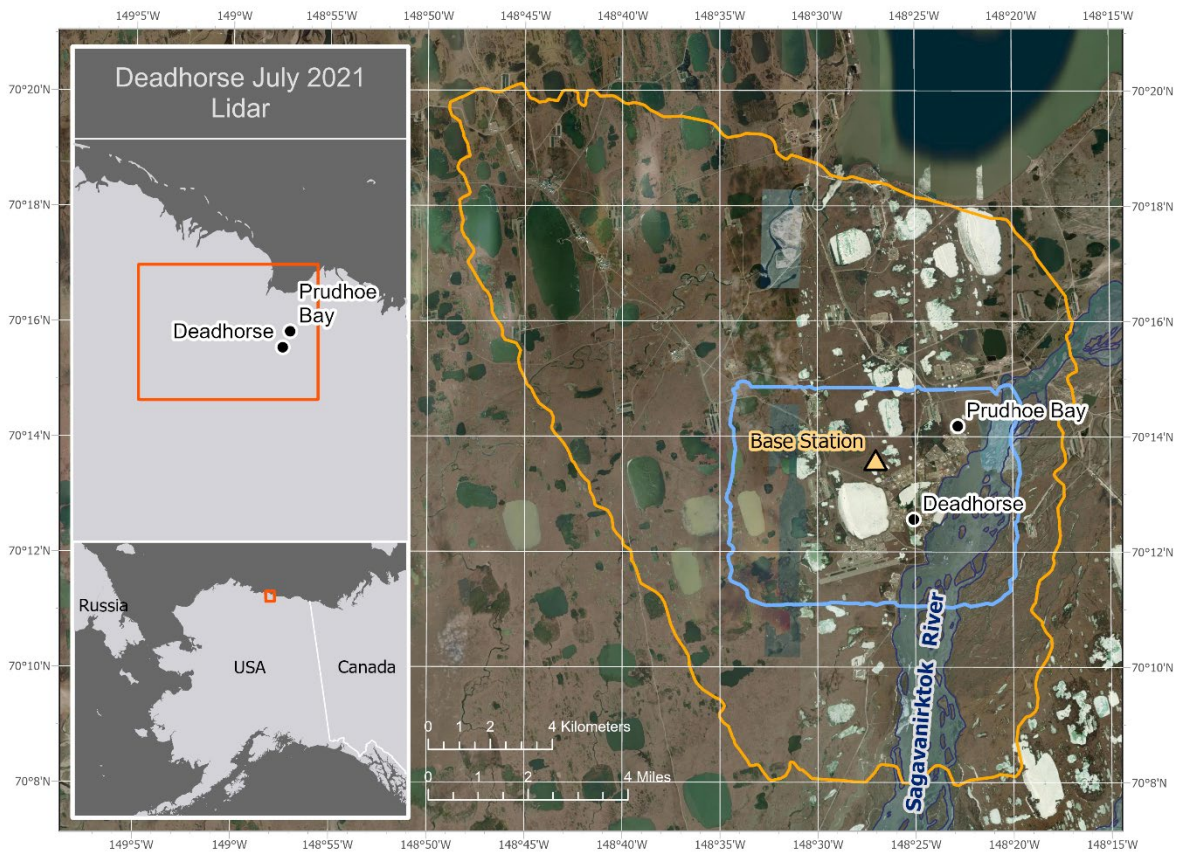


# LIDAR-DERIVED ELEVATION DATA FOR DEADHORSE, NORTHERN ALASKA, COLLECTED JULY 16–18, 2021

Jenna M. Zechmann, Ronald P. Daanen, and J. Barrett Salisbury

Raw Data File 2024-15



Location map of survey area.

This report has not been reviewed for technical content or for conformity to the editorial standards of DGGS.

2024  
STATE OF ALASKA  
DEPARTMENT OF NATURAL RESOURCES  
DIVISION OF GEOLOGICAL & GEOPHYSICAL SURVEYS



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## In Memorial



*Ronnie Daanen, along with colleagues Justin Germann and Tori Moore and pilot Tony Higdon, passed away in July 2023 in a helicopter crash while conducting fieldwork supporting DGGs's mission on the North Slope. This publication is released in their memory.*

# **LIDAR-DERIVED ELEVATION DATA FOR DEADHORSE, NORTHERN ALASKA, COLLECTED JULY 16-18, 2021**

Jenna M. Zechmann<sup>1</sup>, Ronald P. Daanen<sup>1</sup>, and J. Barrett Salisbury<sup>1</sup>

## **INTRODUCTION**

The Alaska Division of Geological & Geophysical Surveys (DGGS) used aerial lidar to produce a classified point cloud, digital surface model (DSM), digital terrain model (DTM), and an intensity model of Deadhorse, Northern Alaska, during leaf-on conditions (cover figure). The survey provides snow-free surface elevations for use in snowpack assessment. Aerial lidar data were collected July 16-18, 2021, and ground control data were collected July 17 and 19, 2021, and subsequently merged and processed using a suite of geospatial processing software. This data collection is released as a Raw Data File with an open end-user license. All files are available to download on the DGGS website at <https://doi.org/10.14509/31273>.

## **LIST OF DELIVERABLES**

- Classified Points
- DSMs and DTMs
- Intensity Image
- Metadata

## **MISSION PLAN**

### **Aerial Lidar Survey Details**

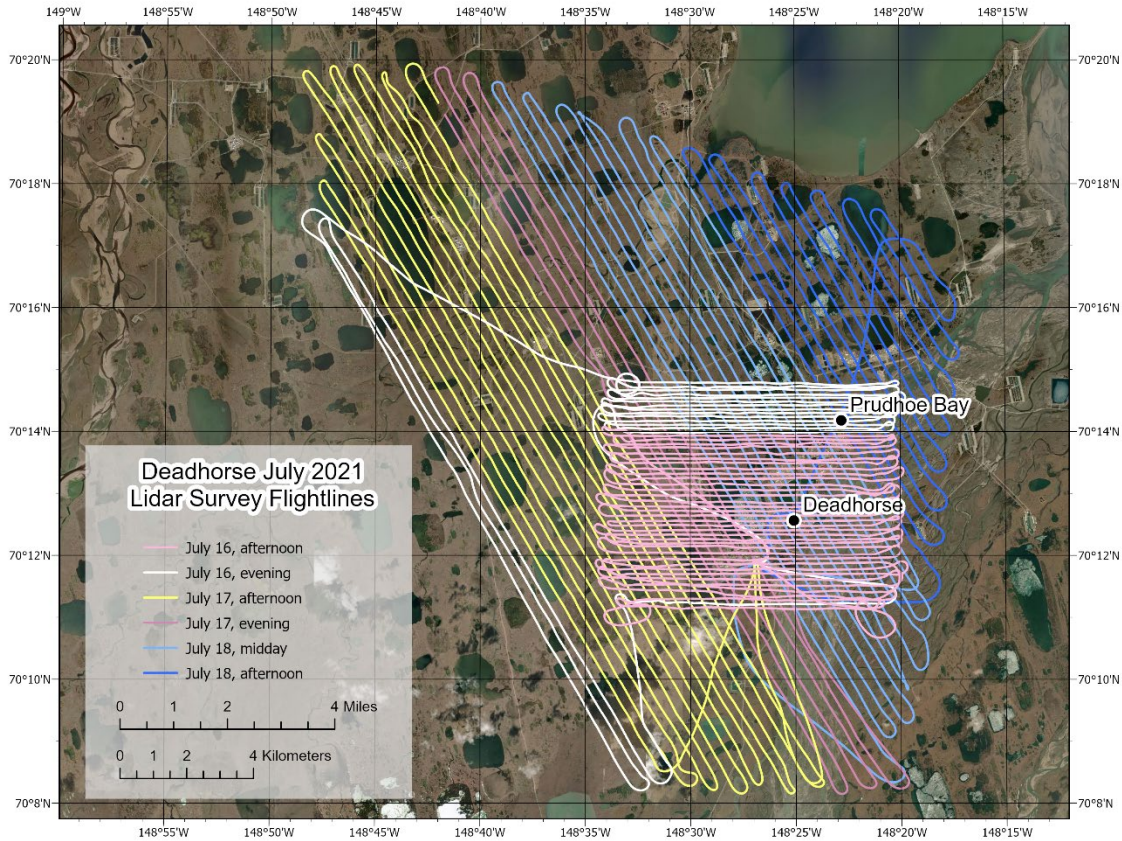
DGGS used a Riegl VUX1-LR laser scanner with a global navigation satellite system (GNSS) and Northrop Grumman LN-200C inertial measurement unit (IMU) integrated by Phoenix LiDAR Systems. The sensor can collect a maximum of 820,000 points per second at a range of 215 m, or a minimum of 50,000 points per second at 820 m (ranges assume  $\geq 20$  percent natural reflectance). The scanner operated with a pulse refresh rate of 400,000-820,000 pulses per second at a scan rate of 100-200 revolutions per second. We used an R-44 helicopter to survey from an elevation of approximately 80–200 m above ground level, at a ground speed of approximately 30 m/s, and with a scan angle set from 80 to 280 degrees. The total survey area covers approximately 304.8 km<sup>2</sup> (outlined in yellow in the cover figure), with a 63.5 km<sup>2</sup> block of that area containing a higher density of flightlines (outlined in blue in the cover figure).

### **Weather Conditions and Flight Times**

The survey area was accessed by air from Deadhorse Airport (fig. 1). Table 1 shows the start and end times of data collection and weather conditions.

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<sup>1</sup> Alaska Division of Geological & Geophysical Surveys, 3354 College Road, Fairbanks, AK 99709



**Figure 1.** Lidar data collection flightlines.

**Table 1.** Data collection start and end times and weather conditions for the lidar collection survey.

Date	Start time (AKST)	End time (AKST)	Weather conditions
16 July 2021	12:45 pm	3:50 pm	Partly cloudy
16 July 2021	4:30 pm	6:35 pm	Partly cloudy with wind
17 July 2021	12:15 pm	3:05 pm	Overcast with light wind
17 July 2021	3:40 pm	5:10 pm	Overcast with wind
18 July 2021	11:30 am	1:55 pm	Partly cloudy with wind
18 July 2021	2:30 pm	4:00 pm	Partly cloudy with wind

**PROCESSING REPORT**

**Lidar Dataset Processing**

We processed point data in Spatial Explorer for initial filtering and multiple-time-around (MTA) disambiguation. MTA errors, corrected in this process, result from ambiguous interpretations of received pulse time intervals and occur more frequently with higher pulse refresh rates. IMU and GNSS data were processed in Inertial Explorer, and flightline information was integrated

with the point cloud in Spatial Explorer. We calibrated the point data at an incrementally precise scale of sensor movement and behavior, incorporating sensor velocity, roll, pitch, and yaw fluctuations throughout the survey. For the entire lidar data collection, the average pulse density is 28.2 pulses/m<sup>2</sup>, and the average pulse spacing is 18.8 cm. Within the higher-density region, the average pulse density is 80.2 pulses/m<sup>2</sup>, and the average pulse spacing is 11.2 cm.

We created a macro (an ordered list of point classification commands tailored to this dataset) in Terrasolid software and classified points in accordance with the American Society for Photogrammetry & Remote Sensing (ASPRS) 2019 guidelines (ASPRS, 2019). Once classified, we applied a geometric transformation and converted the points from ellipsoidal heights to GEOID12B (Alaska) orthometric heights.

Raster products were derived from the point cloud in ArcGIS Pro. A 50-cm DSM was interpolated from maximum ground, vegetation, bridge deck, overhead structure, and building classes using a binning method. A 50-cm DTM was interpolated from all ground-class returns using a binning method and minimum values. We also produced a 50-cm intensity image for the entire area using average binning in ArcGIS Pro, with no normalization or corrections applied.

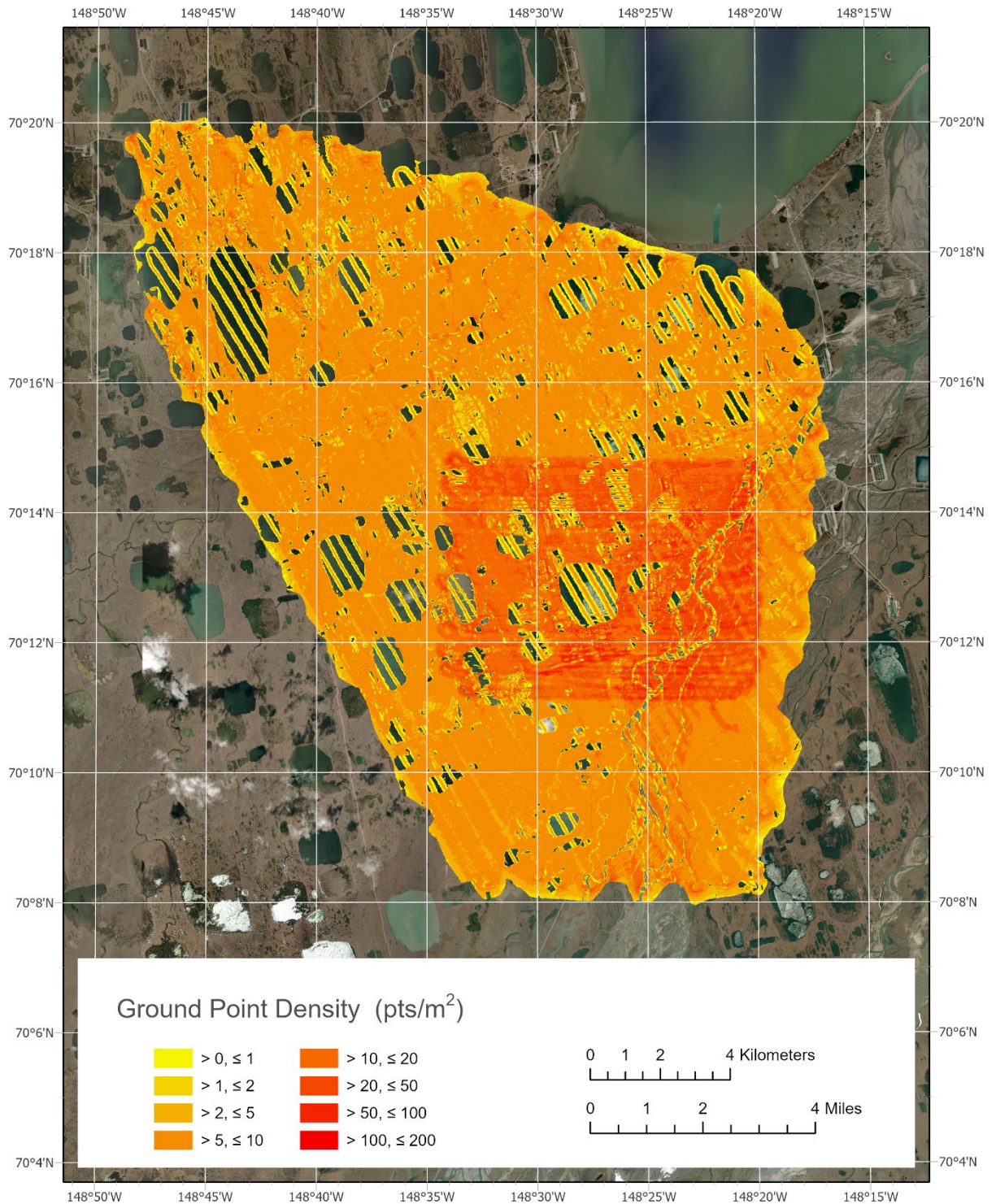
Higher-resolution elevation products were also produced from the higher-density region. A 20-cm DSM was interpolated from ground, vegetation, bridge deck, overhead structure, and building classes using a triangulation method. A 20-cm DTM was made using a triangulation interpolation from all ground-class returns.

### Classified Point Cloud

Classified point cloud data are provided in LAZ format. Data are classified following ASPRS 2019 guidelines (table 2) and contain return and intensity information. For classified ground points, the average point density (fig. 2) is 8.8 pts/m<sup>2</sup>, and the average spacing is 33.6 cm; within the higher-density region, the average ground point density is 18.6 pts/m<sup>2</sup>, and the average spacing is 23.2 cm.

**Table 2.** Point cloud class code definitions.

Class Code	Description
1	Unclassified
2	Ground
3	Low Vegetation, $\geq 0.0\text{m}$ , $< 0.2\text{m}$
4	Medium Vegetation, $\geq 0.2\text{m}$ , $< 1\text{m}$
6	Building
7	Low Noise
14	Wire
17	Bridge Deck
18	High Noise
19	Overhead structure (pipes, vehicles)
30	Noise (manually classified)



**Figure 2.** Ground point density for the survey displayed as a raster.

### **Digital Surface Model**

The DSMs represent surface elevations, including heights of vegetation, buildings, powerlines, pipes, bridge decks, etc. The overall DSM is a single-band, 32-bit GeoTIFF file of 50-cm resolution. No Data value is set to  $-3.40282306074e+38$  (32-bit, floating-point minimum). The DSM from the higher pulse density area is a single-band, 32-bit GeoTIFF file of 20-cm resolution, with a No Data value of  $-3.40282306074e+38$ .

### **Digital Terrain Model**

The DTMs represent bare earth elevations, excluding vegetation, bridge decks, buildings, etc. The overall DTM is a single-band, 32-bit GeoTIFF file of 50-cm resolution. No Data value is set to  $-3.40282306074e+38$ . The DTM from the higher pulse density area is a single-band, 32-bit GeoTIFF file of 20-cm resolution, with a No Data value of  $-3.40282306074e+38$ .

### **Lidar Intensity Image**

The lidar intensity image describes the relative amplitude of reflected signals contributing to the point cloud. Lidar intensity is (1) primarily a function of scanned object reflectance in relation to the signal frequency, (2) dependent on ambient conditions, and (3) not necessarily consistent between separate scans. The intensity image is a single-band, 32-bit GeoTIFF file of 50-cm resolution. No Data value is set to  $-3.40282306074e+38$ .

## **SURVEY REPORT**

### **Ground Survey Details**

Ground control points were collected July 17 and 19, 2021. We deployed a Trimble R12i GNSS base receiver to provide a base station occupation and real-time kinematic (RTK) corrections to points we surveyed with a rover Trimble R8-4 GNSS receiver. A pingo north of Deadhorse Airport served as the base station location (cover figure). We collected 405 ground control points and checkpoints to use for calibration and to assess the vertical accuracy of the point cloud. Checkpoints were collected on bare earth or in tundra vegetation.

### **Coordinate System and Datum**

We processed and delivered all data in NAD83 (2011) UTM6N and vertical datum NAVD88 GEOID12B.

### **Horizontal Accuracy**

Horizontal accuracy was not measured for this collection.

### **Vertical Accuracy**

We measured a mean elevation offset of +271.3 cm between 90 control points and the point cloud (app. 1). This offset was reduced to +0.2 cm in non-vegetated areas (app. 2) and +9.1 cm in vegetated areas (app. 3) by applying a constant vertical correction to the lidar point data. We used 91 non-vegetated and 224 vegetated checkpoints to determine the vertical accuracy of the point cloud ground class using a Triangulated Irregular Network (TIN) approach. The project vertical accuracy has a root mean square error (RMSE) of 9.3 cm in non-vegetated areas (app. 2) and 12.6



cm in vegetated areas (app. 3). We evaluated the relative accuracy for this dataset as the interswath overlap consistency and measured it at 4.8 cm RMSE.

### **Data Consistency and Completeness**

This is a full-release dataset. There was no over-collect. Data quality is consistent throughout the survey, save for gaps over bodies of water.

### **ACKNOWLEDGMENTS**

This survey area is on the traditional homelands of the Iñupiat peoples. This work was funded by a National Science Foundation grant, federal award No. ICER-1928237 made to the University of Alaska, with State of Alaska as a sub-recipient under subaward number UA 21-0135. We thank Pollux Aviation for their expertise and contribution to these data products. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the State of Alaska.

### **REFERENCES**

The American Society for Photogrammetry & Remote Sensing (ASPRS), 2019, LAS Specification 1.4 - R15. [https://www.asprs.org/wp-content/uploads/2019/07/LAS\\_1\\_4\\_r15.pdf](https://www.asprs.org/wp-content/uploads/2019/07/LAS_1_4_r15.pdf)

**APPENDIX 1: GROUND CONTROL POINTS**

<b>GCP</b>	<b>Easting (m)</b>	<b>Northing (m)</b>	<b>GCP Z (m)</b>	<b>Pointcloud Z (m)</b>	<b>Elevation Difference (Pointcloud Z - GCP Z) (m)</b>
<b>GCP1002</b>	443667.759	7791697.827	13.868	16.612	2.744
<b>GCP1004</b>	443677.557	7791741.463	13.618	16.358	2.740
<b>GCP1006</b>	443656.013	7791777.669	13.464	16.234	2.770
<b>GCP1008</b>	443657.304	7791737.726	13.795	16.594	2.799
<b>GCP1010</b>	443641.622	7791644.536	13.470	16.245	2.775
<b>GCP1012</b>	443634.059	7791596.361	13.730	16.475	2.745
<b>GCP1014</b>	443656.895	7791670.361	13.578	16.246	2.668
<b>GCP1016</b>	445090.612	7791088.271	13.656	16.330	2.674
<b>GCP1018</b>	445127.913	7791075.099	13.734	16.466	2.732
<b>GCP1020</b>	445142.763	7791101.822	13.894	16.632	2.738
<b>GCP1022</b>	445861.517	7790119.442	12.728	15.441	2.713
<b>GCP1024</b>	445917.815	7790114.213	12.657	15.371	2.714
<b>GCP1026</b>	445970.304	7790104.391	12.754	15.433	2.679
<b>GCP1028</b>	445881.320	7790132.814	12.692	15.375	2.683
<b>GCP1030</b>	446983.496	7790260.348	12.283	15.025	2.742
<b>GCP1032</b>	447050.788	7790266.071	12.507	15.263	2.756
<b>GCP1034</b>	447126.324	7790272.087	12.301	15.034	2.733
<b>GCP1036</b>	447196.460	7790259.987	9.177	11.896	2.719
<b>GCP1038</b>	447173.492	7790183.326	9.009	11.743	2.734
<b>GCP1040</b>	447271.304	7790271.613	9.101	11.835	2.734
<b>GCP1042</b>	447395.232	7790273.934	9.152	11.896	2.744
<b>GCP1044</b>	447513.200	7790179.543	9.831	12.537	2.706
<b>GCP1046</b>	447464.500	7790083.785	10.018	12.764	2.746
<b>GCP1048</b>	447870.719	7792670.233	11.864	14.560	2.696
<b>GCP1050</b>	447909.565	7792673.790	11.869	14.557	2.688
<b>GCP1052</b>	447907.120	7792630.660	11.833	14.533	2.700
<b>GCP1054</b>	447877.570	7792649.775	11.886	14.613	2.727
<b>GCP1056</b>	447644.391	7792145.782	11.079	13.895	2.816
<b>GCP1058</b>	447688.457	7792184.543	11.135	13.941	2.806
<b>GCP1060</b>	443862.096	7790845.381	14.270	17.069	2.799
<b>GCP1062</b>	443906.146	7790788.815	14.512	17.285	2.773
<b>GCP1064</b>	443931.260	7790719.885	14.341	17.089	2.748
<b>GCP1066</b>	443916.456	7790774.697	14.496	17.274	2.778
<b>GCP1068</b>	443865.267	7790860.614	14.215	16.985	2.770
<b>GCP1070</b>	444292.579	7789446.809	14.468	17.134	2.666
<b>GCP1072</b>	444322.252	7789396.331	13.897	16.565	2.668
<b>GCP1074</b>	444347.999	7789357.096	14.253	16.926	2.673
<b>GCP1076</b>	444282.305	7788717.587	16.739	19.446	2.707
<b>GCP1078</b>	444189.843	7788695.288	16.781	19.480	2.699
<b>GCP1080</b>	444100.279	7788649.255	17.041	19.735	2.694

<b>GCP</b>	<b>Easting (m)</b>	<b>Northing (m)</b>	<b>GCP Z (m)</b>	<b>Pointcloud Z (m)</b>	<b>Elevation Difference (Pointcloud Z - GCP Z) (m)</b>
<b>GCP1082</b>	444017.151	7788604.724	17.049	19.712	2.663
<b>GCP1084</b>	443980.898	7788543.917	16.830	19.541	2.711
<b>GCP1086</b>	444095.609	7788572.057	17.492	20.167	2.675
<b>GCP1088</b>	446059.518	7788191.907	13.287	15.957	2.670
<b>GCP1090</b>	446027.810	7788139.362	13.465	16.137	2.672
<b>GCP1092</b>	446000.103	7788077.535	13.467	16.108	2.641
<b>GCP1094</b>	445969.898	7787951.318	13.241	15.953	2.712
<b>GCP1096</b>	445964.487	7787823.509	13.500	16.195	2.695
<b>GCP1098</b>	445928.886	7787711.626	13.372	16.072	2.700
<b>GCP1100</b>	445896.498	7787818.134	13.496	16.194	2.698
<b>GCP1102</b>	444771.894	7785033.479	17.015	19.567	2.552
<b>GCP1104</b>	444759.051	7785015.648	19.187	21.883	2.696
<b>GCP1106</b>	444754.096	7784967.439	19.783	22.383	2.600
<b>GCP1108</b>	444746.672	7784924.985	20.200	22.656	2.456
<b>GCP1110</b>	444737.080	7784839.591	20.369	22.957	2.588
<b>GCP1112</b>	444706.475	7784770.631	19.572	22.059	2.487
<b>GCP1114</b>	444633.914	7784779.246	20.409	23.100	2.691
<b>GCP1116</b>	444542.576	7784786.998	19.073	21.609	2.536
<b>GCP1118</b>	444487.541	7784793.783	20.119	22.520	2.401
<b>GCP1120</b>	444373.857	7784798.388	19.901	22.407	2.506
<b>GCP001</b>	445248.422	7791878.920	15.068	17.601	2.533
<b>GCP002</b>	445258.855	7791937.752	11.700	14.413	2.713
<b>GCP003</b>	445258.747	7791986.512	11.757	14.529	2.772
<b>GCP004</b>	445258.156	7792030.990	11.532	14.265	2.733
<b>GCP005</b>	445244.908	7792108.412	11.350	14.109	2.759
<b>GCP006</b>	445242.620	7792189.709	11.425	14.218	2.793
<b>GCP008</b>	445233.401	7792330.271	11.841	14.657	2.816
<b>GCP010</b>	445258.784	7792393.607	11.877	14.646	2.769
<b>GCP012</b>	445314.701	7792454.026	11.372	14.096	2.724
<b>GCP014</b>	445418.376	7792485.936	11.073	13.827	2.754
<b>GCP016</b>	445550.125	7792507.670	11.096	13.881	2.785
<b>GCP018</b>	445260.134	7788841.946	16.839	19.564	2.725
<b>GCP020</b>	445243.035	7788914.925	16.763	19.474	2.711
<b>GCP022</b>	445296.310	7788962.447	17.051	19.799	2.748
<b>GCP024</b>	445312.267	7789037.433	16.378	19.063	2.685
<b>GCP026</b>	446884.605	7789790.571	12.471	15.158	2.687
<b>GCP028</b>	446952.852	7789818.310	12.443	15.181	2.738
<b>GCP030</b>	446924.921	7789820.447	12.468	15.212	2.744
<b>GCP032</b>	447242.856	7791636.097	12.585	15.365	2.780
<b>GCP034</b>	447271.919	7791608.266	12.359	15.137	2.778
<b>GCP036</b>	447329.353	7791636.803	12.056	14.837	2.781

<b>GCP</b>	<b>Easting (m)</b>	<b>Northing (m)</b>	<b>GCP Z (m)</b>	<b>Pointcloud Z (m)</b>	<b>Elevation Difference (Pointcloud Z - GCP Z) (m)</b>
<b>GCP038</b>	446511.279	7791644.767	12.977	15.794	2.817
<b>GCP040</b>	446526.081	7791837.471	12.575	15.396	2.821
<b>GCP042</b>	446549.217	7792112.436	10.691	13.549	2.858
<b>GCP044</b>	446565.683	7792293.422	10.378	13.172	2.794
<b>GCP046</b>	446578.098	7792437.836	10.463	13.228	2.765
<b>GCP048</b>	446592.107	7792603.034	10.459	13.225	2.766
<b>GCP050</b>	446647.108	7792813.578	10.687	13.423	2.736
<b>GCP052</b>	446727.831	7793117.186	10.649	13.385	2.736
<b>GCP054</b>	446855.068	7793594.733	11.100	13.910	2.810
<b>Average elevation difference (dZ) (m)</b>	2.713				
<b>Minimum dZ (m)</b>	2.401				
<b>Maximum dZ (m)</b>	2.858				
<b>Average magnitude error (m)</b>	2.713				
<b>Root mean square error (m)</b>	2.714				
<b>Standard deviation (m)</b>	0.081				

**APPENDIX 2: NON-VEGETATED CHECK POINTS**

<b>Check Point</b>	<b>Easting (m)</b>	<b>Northing (m)</b>	<b>Checkpoint Z (m)</b>	<b>Corrected Pointcloud Z (m)</b>	<b>Elevation Difference (Corrected Pointcloud Z - Checkpoint Z) (m)</b>
<b>GCP1001</b>	443658.711	7791711.441	13.820	13.920	0.100
<b>GCP1003</b>	443692.935	7791701.298	13.998	14.045	0.047
<b>GCP1005</b>	443668.973	7791776.645	13.399	13.426	0.027
<b>GCP1007</b>	443647.609	7791769.149	13.422	13.550	0.128
<b>GCP1009</b>	443653.086	7791689.085	13.589	13.686	0.097
<b>GCP1011</b>	443627.736	7791598.198	13.688	13.746	0.058
<b>GCP1013</b>	443644.377	7791627.908	13.489	13.401	-0.088
<b>GCP1015</b>	445098.404	7791099.900	13.687	13.714	0.027
<b>GCP1017</b>	445104.798	7791081.278	13.723	13.747	0.024
<b>GCP1019</b>	445136.141	7791086.266	13.689	13.718	0.029
<b>GCP1021</b>	445862.328	7790134.567	12.940	12.948	0.008
<b>GCP1023</b>	445885.844	7790125.601	12.662	12.648	-0.014
<b>GCP1025</b>	445949.792	7790104.557	12.794	12.783	-0.011
<b>GCP1027</b>	445922.291	7790118.395	12.680	12.687	0.007
<b>GCP1029</b>	446963.901	7790257.011	12.125	12.158	0.033
<b>GCP1031</b>	447020.839	7790267.928	12.311	12.331	0.020
<b>GCP1033</b>	447084.997	7790276.848	12.713	12.780	0.067
<b>GCP1035</b>	447154.131	7790270.366	11.226	11.154	-0.072
<b>GCP1037</b>	447189.377	7790221.706	8.967	8.980	0.013
<b>GCP1039</b>	447216.947	7790263.283	9.189	9.221	0.032
<b>GCP1041</b>	447320.951	7790272.291	9.188	9.252	0.064
<b>GCP1043</b>	447530.178	7790249.404	9.679	9.719	0.040
<b>GCP1045</b>	447484.417	7790125.832	9.935	9.905	-0.030
<b>GCP1047</b>	447407.026	7789971.245	10.076	10.125	0.049
<b>GCP1049</b>	447890.189	7792689.295	11.729	11.727	-0.002
<b>GCP1051</b>	447918.696	7792647.079	11.988	11.998	0.010
<b>GCP1053</b>	447884.573	7792619.100	11.741	11.721	-0.020
<b>GCP1055</b>	447633.549	7792135.872	11.032	11.126	0.094
<b>GCP1057</b>	447663.742	7792163.393	11.163	11.240	0.077
<b>GCP1059</b>	447709.454	7792210.955	10.976	11.046	0.070
<b>GCP1061</b>	443891.573	7790812.178	14.388	14.475	0.087
<b>GCP1063</b>	443920.359	7790745.825	14.310	14.434	0.124
<b>GCP1065</b>	443931.928	7790742.428	14.339	14.341	0.002
<b>GCP1067</b>	443898.761	7790807.524	14.411	14.481	0.070
<b>GCP1069</b>	444284.907	7789461.108	14.623	14.576	-0.047
<b>GCP1071</b>	444304.580	7789426.329	14.081	14.034	-0.047
<b>GCP1073</b>	444334.945	7789376.096	14.013	13.986	-0.027
<b>GCP1075</b>	444370.466	7789331.058	14.606	14.577	-0.029

<b>Check Point</b>	<b>Easting (m)</b>	<b>Northing (m)</b>	<b>Checkpoint Z (m)</b>	<b>Corrected Pointcloud Z (m)</b>	<b>Elevation Difference (Corrected Pointcloud Z - Checkpoint Z) (m)</b>
<b>GCP1077</b>	444245.623	7788713.016	16.793	16.786	-0.007
<b>GCP1079</b>	444135.350	7788674.354	16.920	16.902	-0.018
<b>GCP1081</b>	444063.132	7788626.477	17.072	17.040	-0.032
<b>GCP1083</b>	443965.567	7788582.556	16.583	16.565	-0.018
<b>GCP1085</b>	444037.752	7788555.910	17.579	17.556	-0.023
<b>GCP1087</b>	446068.448	7788202.305	13.123	13.084	-0.039
<b>GCP1089</b>	446038.831	7788160.269	13.425	13.382	-0.043
<b>GCP1091</b>	446016.094	7788121.204	13.445	13.395	-0.050
<b>GCP1093</b>	445980.896	7788004.152	13.536	13.528	-0.008
<b>GCP1095</b>	445966.860	7787897.962	13.323	13.317	-0.006
<b>GCP1097</b>	445956.832	7787764.498	13.566	13.561	-0.005
<b>GCP1099</b>	445908.741	7787757.323	13.351	13.327	-0.024
<b>GCP1101</b>	444797.767	7785031.265	17.101	16.966	-0.135
<b>GCP1103</b>	444738.015	7785035.886	15.353	15.196	-0.157
<b>GCP1105</b>	444756.328	7784989.101	19.584	19.248	-0.336
<b>GCP1107</b>	444753.613	7784956.716	19.878	19.730	-0.148
<b>GCP1109</b>	444738.574	7784885.184	20.030	19.705	-0.325
<b>GCP1111</b>	444729.513	7784810.049	20.693	20.520	-0.173
<b>GCP1113</b>	444678.567	7784775.634	20.766	20.613	-0.153
<b>GCP1115</b>	444622.854	7784780.887	20.126	19.939	-0.187
<b>GCP1117</b>	444521.464	7784788.030	19.506	19.280	-0.226
<b>GCP1119</b>	444398.806	7784790.993	19.354	19.169	-0.185
<b>GCP1121</b>	444367.968	7784815.481	20.266	20.045	-0.221
<b>GCP0001</b>	445552.122	7792262.310	11.385	11.403	0.018
<b>GCP0002</b>	445486.501	7792301.845	11.129	11.209	0.080
<b>GCP0003</b>	445473.762	7792310.105	11.206	11.297	0.091
<b>GCP0004</b>	445463.238	7792317.140	11.339	11.400	0.061
<b>GCP0005</b>	445422.325	7792328.042	11.519	11.581	0.062
<b>GCP007</b>	445224.062	7792269.983	11.501	11.595	0.094
<b>GCP009</b>	445257.859	7792366.588	11.928	11.980	0.052
<b>GCP011</b>	445274.683	7792428.928	11.697	11.829	0.132
<b>GCP013</b>	445363.525	7792464.250	11.089	11.161	0.072
<b>GCP015</b>	445498.404	7792504.947	10.877	10.937	0.060
<b>GCP017</b>	445263.876	7788825.596	16.851	16.869	0.018
<b>GCP019</b>	445253.122	7788871.820	16.840	16.834	-0.006
<b>GCP021</b>	445234.517	7788945.742	16.718	16.700	-0.018
<b>GCP023</b>	445293.082	7789006.941	16.688	16.707	0.019
<b>GCP025</b>	445345.398	7789078.335	16.403	16.420	0.017
<b>GCP027</b>	446926.965	7789788.664	12.465	12.483	0.018
<b>GCP029</b>	446982.535	7789831.252	11.655	11.684	0.029

Check Point	Easting (m)	Northing (m)	Checkpoint Z (m)	Corrected Pointcloud Z (m)	Elevation Difference (Corrected Pointcloud Z - Checkpoint Z) (m)
<b>GCP031</b>	446893.491	7789819.992	12.445	12.450	0.005
<b>GCP033</b>	447246.768	7791606.208	12.467	12.523	0.056
<b>GCP035</b>	447292.579	7791616.840	12.296	12.372	0.076
<b>GCP037</b>	447363.461	7791642.738	12.032	12.100	0.068
<b>GCP039</b>	446520.037	7791759.814	12.689	12.777	0.088
<b>GCP041</b>	446540.840	7792003.048	11.643	11.777	0.134
<b>GCP043</b>	446559.654	7792213.410	10.606	10.683	0.077
<b>GCP045</b>	446571.569	7792369.817	10.480	10.579	0.099
<b>GCP047</b>	446584.583	7792520.613	10.413	10.462	0.049
<b>GCP049</b>	446621.091	7792716.701	10.449	10.515	0.066
<b>GCP051</b>	446691.334	7792981.615	11.431	11.490	0.059
<b>GCP053</b>	446788.866	7793346.274	10.817	10.860	0.043
<b>GCP055</b>	446949.347	7793741.113	11.827	11.911	0.084
<b>Average elevation difference (dZ) (m)</b>	0.002				
<b>Minimum dZ (m)</b>	-0.336				
<b>Maximum dZ (m)</b>	0.134				
<b>Average magnitude error (m)</b>	0.067				
<b>Root mean square error (m)</b>	0.093				
<b>Standard deviation (m)</b>	0.093				

### APPENDIX 3: VEGETATED CHECK POINTS

Check Point	Easting (m)	Northing (m)	Checkpoint Z (m)	Corrected Pointcloud Z (m)	Elevation Difference (Corrected Pointcloud Z - Checkpoint Z) (m)
<b>GCPT6001</b>	445142.439	7792363.857	11.246	11.793	0.547
<b>GCPT6002</b>	445147.269	7792364.739	11.773	11.800	0.027

Check Point	Easting (m)	Northing (m)	Checkpoint Z (m)	Corrected Pointcloud Z (m)	Elevation Difference (Corrected Pointcloud Z - Checkpoint Z) (m)
GCPT6003	445152.216	7792365.578	11.728	11.830	0.102
GCPT6004	445157.126	7792366.369	11.663	11.889	0.226
GCPT6005	445162.081	7792367.138	11.943	11.909	-0.034
GCPT6006	445167.015	7792367.914	11.967	12.026	0.059
GCPT6007	445171.936	7792368.754	11.937	12.043	0.106
GCPT6009	445181.752	7792370.435	11.991	12.081	0.090
GCPT6010	445186.701	7792371.200	11.940	12.013	0.073
GCPT6011	445191.612	7792371.965	12.009	12.054	0.045
GCPT6012	445196.562	7792372.834	12.051	12.058	0.007
GCPT6013	445201.497	7792373.684	11.978	12.025	0.047
GCPT6014	445206.413	7792374.519	12.015	12.081	0.066
GCPT6015	445211.318	7792375.324	11.978	12.094	0.116
GCPT6016	445216.267	7792376.122	12.066	12.099	0.033
GCPT6017	445221.160	7792376.948	11.901	12.202	0.301
GCPT6018	445226.141	7792377.769	12.083	11.981	-0.102
GCPT6019	445231.069	7792378.448	11.465	12.047	0.582
GCPT6020	445235.982	7792379.297	11.896	12.007	0.111
GCPT6021	445240.908	7792380.096	11.942	12.085	0.143
GCPT6022	445245.874	7792380.952	11.961	11.866	-0.095
GCPT6023	445250.796	7792381.754	11.803	11.899	0.096
GCPT6024	445255.733	7792382.574	11.792	11.905	0.113
GCPT6025	445260.677	7792383.357	11.748	11.840	0.092
GCPT6026	445265.620	7792384.159	11.501	11.881	0.380
GCPT6027	445270.518	7792384.976	11.812	11.782	-0.030
GCPT6028	445275.432	7792385.787	11.159	11.458	0.299
GCPT6031	445290.315	7792388.111	11.894	11.870	-0.024
GCPT6032	445295.185	7792388.976	11.781	11.827	0.046
GCPT6033	445300.121	7792389.803	11.662	11.522	-0.140
GCPT6034	445305.082	7792390.601	11.164	11.712	0.548
GCPT6035	445309.995	7792391.384	11.661	11.732	0.071
GCPT6036	445314.937	7792392.189	11.612	11.721	0.109
GCPT6037	445319.896	7792393.033	11.107	11.537	0.430
GCPT6038	445324.812	7792393.792	11.606	11.713	0.107
GCPT6039	445329.710	7792394.603	11.597	11.692	0.095
GCPT6040	445334.663	7792395.410	11.600	11.662	0.062
GCPT6041	445339.539	7792396.082	11.400	11.515	0.115
GCPT6042	445366.804	7792188.746	11.497	11.548	0.051
GCPT7001	445366.811	7792188.752	11.503	11.549	0.046
GCPT7002	445371.537	7792190.548	11.359	11.653	0.294
GCPT7003	445376.243	7792192.233	11.352	11.434	0.082



Check Point	Easting (m)	Northing (m)	Checkpoint Z (m)	Corrected Pointcloud Z (m)	Elevation Difference (Corrected Pointcloud Z - Checkpoint Z) (m)
GCPT7004	445380.930	7792193.979	11.255	11.329	0.074
GCPT7005	445385.598	7792195.628	11.232	11.312	0.080
GCPT7006	445390.322	7792197.405	11.232	11.308	0.076
GCPT7007	445395.042	7792199.078	11.214	11.292	0.078
GCPT7008	445399.711	7792200.827	11.197	11.270	0.073
GCPT7009	445404.402	7792202.523	11.183	11.280	0.097
GCPT7010	445409.070	7792204.288	11.201	11.302	0.101
GCPT7011	445413.796	7792206.018	11.256	11.284	0.028
GCPT7012	445420.273	7792208.519	11.235	11.456	0.221
GCPT7013	445423.116	7792209.557	11.390	11.457	0.067
GCPT7014	445427.774	7792211.310	11.309	11.405	0.096
GCPT7015	445432.483	7792213.045	11.351	11.476	0.125
GCPT7016	445437.151	7792214.828	11.450	11.467	0.017
GCPT7017	445441.870	7792216.493	11.371	11.399	0.028
GCPT7018	445446.526	7792218.242	11.277	11.385	0.108
GCPT7019	445451.257	7792220.018	11.300	11.398	0.098
GCPT7020	445455.906	7792221.714	11.443	11.428	-0.015
GCPT7021	445460.647	7792223.292	11.374	11.413	0.039
GCPT7022	445465.356	7792225.038	11.326	11.400	0.074
GCPT7023	445470.035	7792226.761	11.299	11.370	0.071
GCPT7024	445474.731	7792228.506	11.253	11.338	0.085
GCPT7025	445479.426	7792230.246	11.263	11.347	0.084
GCPT7026	445484.133	7792231.956	11.196	11.333	0.137
GCPT7027	445488.817	7792233.670	11.227	11.354	0.127
GCPT7028	445493.508	7792235.407	11.339	11.326	-0.013
GCPT7029	445498.213	7792237.121	11.210	11.318	0.108
GCPT7030	445502.896	7792238.839	11.230	11.321	0.091
GCPT7031	445507.577	7792240.552	11.232	11.329	0.097
GCPT7032	445512.262	7792242.303	11.331	11.360	0.029
GCPT7033	445516.958	7792244.034	11.172	11.355	0.183
GCPT7034	445521.631	7792245.752	11.287	11.398	0.111
GCPT7035	445526.354	7792247.449	11.214	11.372	0.158
GCPT7036	445531.066	7792249.163	11.345	11.470	0.125
GCPT7037	445535.751	7792250.864	11.318	11.397	0.079
GCPT7038	445540.437	7792252.566	11.412	11.378	-0.034
GCPT7039	445545.138	7792254.268	11.246	11.347	0.101
GCPT7040	445549.862	7792255.960	11.362	11.415	0.053
GCPT7041	445554.447	7792257.773	11.248	11.272	0.024
GCPT8001	444838.449	7792275.489	11.141	11.255	0.114
GCPT8002	444842.962	7792277.785	11.159	11.269	0.110

Check Point	Easting (m)	Northing (m)	Checkpoint Z (m)	Corrected Pointcloud Z (m)	Elevation Difference (Corrected Pointcloud Z - Checkpoint Z) (m)
GCPT8003	444847.400	7792279.996	11.187	11.293	0.106
GCPT8004	444851.856	7792282.255	11.150	11.270	0.120
GCPT8005	444856.343	7792284.492	11.175	11.296	0.121
GCPT8006	444860.796	7792286.715	11.188	11.268	0.080
GCPT8007	444865.229	7792288.987	11.169	11.285	0.116
GCPT8008	444869.731	7792291.258	11.176	11.284	0.108
GCPT8009	444874.203	7792293.472	11.160	11.278	0.118
GCPT8010	444878.662	7792295.706	11.146	11.292	0.146
GCPT8011	444883.146	7792297.853	11.174	11.254	0.080
GCPT8012	444887.595	7792300.223	11.171	11.281	0.110
GCPT8013	444892.058	7792302.491	11.181	11.298	0.117
GCPT8014	444896.536	7792304.746	11.332	11.303	-0.029
GCPT8015	444900.986	7792306.986	11.194	11.308	0.114
GCPT8016	444905.430	7792309.225	11.200	11.305	0.105
GCPT8017	444909.904	7792311.473	11.207	11.305	0.098
GCPT8018	444914.403	7792313.682	11.205	11.353	0.148
GCPT8019	444918.884	7792315.911	11.250	11.328	0.078
GCPT8020	444923.371	7792318.113	11.261	11.335	0.074
GCPT8021	444927.836	7792320.290	11.367	11.473	0.106
GCPT8023	444936.708	7792324.992	11.364	11.434	0.070
GCPT8024	444941.149	7792327.274	11.329	11.434	0.105
GCPT8025	444945.652	7792329.515	11.321	11.421	0.100
GCPT8026	444950.126	7792331.737	11.379	11.411	0.032
GCPT8027	444954.595	7792333.973	11.269	11.412	0.143
GCPT8028	444959.109	7792336.224	11.307	11.431	0.124
GCPT8029	444963.604	7792338.408	11.309	11.414	0.105
GCPT8030	444968.077	7792340.607	11.281	11.410	0.129
GCPT8031	444972.500	7792342.810	11.332	11.387	0.055
GCPT8032	444976.982	7792345.145	11.288	11.412	0.124
GCPT8033	444981.397	7792347.456	11.294	11.410	0.116
GCPT8034	444985.891	7792349.706	11.314	11.413	0.099
GCPT8035	444990.332	7792351.943	11.357	11.452	0.095
GCPT8036	444994.803	7792354.231	11.338	11.427	0.089
GCPT8037	444999.261	7792356.496	11.326	11.427	0.101
GCPT8038	445003.721	7792358.741	11.401	11.460	0.059
GCPT8039	445008.159	7792360.997	11.430	11.478	0.048
GCPT8040	445012.640	7792363.221	11.493	11.540	0.047
GCPT8041	445017.167	7792365.386	11.536	11.579	0.043
GCPT9001	444998.845	7792396.576	11.368	11.481	0.113
GCPT9002	445003.759	7792397.966	11.434	11.473	0.039

Check Point	Easting (m)	Northing (m)	Checkpoint Z (m)	Corrected Pointcloud Z (m)	Elevation Difference (Corrected Pointcloud Z - Checkpoint Z) (m)
GCPT9003	445008.583	7792399.274	11.403	11.525	0.122
GCPT9004	445013.411	7792400.546	11.434	11.531	0.097
GCPT9005	445018.235	7792401.860	11.484	11.647	0.163
GCPT9006	445023.056	7792403.181	11.499	11.551	0.052
GCPT9007	445027.881	7792404.457	11.547	11.523	-0.024
GCPT9008	445032.723	7792405.737	11.565	11.654	0.089
GCPT9009	445037.552	7792406.995	11.580	11.658	0.078
GCPT9010	445042.344	7792408.284	11.637	11.785	0.148
GCPT9011	445047.154	7792409.534	11.732	11.751	0.019
GCPT9012	445052.023	7792410.883	11.692	11.810	0.118
GCPT9013	445056.846	7792412.167	11.695	11.885	0.190
GCPT9014	445061.664	7792413.465	11.803	11.762	-0.041
GCPT9015	445066.517	7792414.761	11.838	11.912	0.074
GCPT9016	445071.333	7792416.078	11.803	11.973	0.170
GCPT9017	445076.139	7792417.344	11.898	11.984	0.086
GCPT9018	445081.011	7792418.597	11.919	11.989	0.070
GCPT9019	445085.849	7792419.922	11.765	11.995	0.230
GCPT9020	445090.654	7792421.245	11.926	12.112	0.186
GCPT9021	445095.406	7792422.523	11.654	11.907	0.253
GCPVEG0006	445381.321	7792304.207	11.461	11.575	0.114
GCPVEG0007	445363.554	7792302.743	11.571	11.615	0.044
GCPVEG0008	445334.446	7792287.919	11.425	11.508	0.083
GCPVEG0009	445290.440	7792287.628	11.635	11.698	0.063
GCPVEG0010	445259.836	7792295.029	11.630	11.657	0.027
GCPVEG0011	445227.211	7792304.278	11.863	11.951	0.088
GCPVEG0012	445194.212	7792313.782	11.902	11.975	0.073
GCPVEG0013	445172.171	7792312.185	11.768	11.846	0.078
GCPVEG0014	445129.070	7792298.353	11.753	11.811	0.058
GCPVEG0015	445091.943	7792293.618	11.768	11.821	0.053
GCPVEG0016	445049.909	7792286.282	11.656	11.714	0.058
GCPVEG0017	444999.506	7792266.330	11.393	11.503	0.110
GCPVEG0018	444928.630	7792240.412	11.205	11.302	0.097
GCPVEG0019	444886.380	7792224.027	11.230	11.317	0.087
GCPVEG0020	444819.862	7792204.035	11.254	11.327	0.073
GCPVEG0021	444758.412	7792138.432	11.264	11.271	0.007
GCPVEG0022	444744.983	7792087.457	11.192	11.257	0.065
GCPVEG0023	444745.942	7792069.609	11.198	11.361	0.163
GCPVEG0024	444732.365	7792036.064	11.173	11.277	0.104
GCPVEG0025	444706.761	7792018.627	11.161	11.291	0.130
GCPVEG0026	444696.774	7791985.550	11.145	11.307	0.162

Check Point	Easting (m)	Northing (m)	Checkpoint Z (m)	Corrected Pointcloud Z (m)	Elevation Difference (Corrected Pointcloud Z - Checkpoint Z) (m)
GCPVEG0027	444731.175	7791952.753	11.265	11.395	0.130
GCPVEG0028	444777.232	7791910.151	12.152	12.256	0.104
GCPVEG0029	444798.998	7791874.513	12.657	12.692	0.035
GCPVEG0030	444902.369	7791815.024	12.494	12.556	0.062
GCPVEG0031	444974.501	7791839.459	12.111	12.161	0.050
GCPVEG0032	445035.789	7791882.784	11.859	11.936	0.077
GCPVEG0033	445121.882	7791900.996	11.653	11.765	0.112
GCPVEG0034	445173.431	7791878.432	11.899	11.982	0.083
GCPVEG0035	445197.377	7791853.213	11.883	11.922	0.039
GCPVEG0036	445237.873	7791869.368	14.055	14.056	0.001
GCPVEG0037	445238.959	7791877.333	14.934	14.958	0.024
GCPVEG0038	445259.979	7791855.808	12.173	12.125	-0.048
GCPVEG0039	445295.342	7791832.924	11.708	11.729	0.021
GCPVEG0040	445341.756	7791810.079	11.627	11.633	0.006
GCPVEG0041	445390.648	7791788.998	11.560	11.574	0.014
GCPVEG0042	445474.743	7791753.512	11.811	11.756	-0.055
GCPVEG0043	445557.941	7791714.138	11.725	11.720	-0.005
GCPVEG0044	445637.680	7791679.530	11.698	11.690	-0.008
GCPVEG0045	445679.378	7791640.592	11.724	11.750	0.026
GCPVEG0046	445698.533	7791617.430	11.737	11.713	-0.024
GCPVEG0047	445776.096	7791498.355	11.841	11.854	0.013
GCPVEG0048	445821.905	7791436.162	12.110	12.122	0.012
GCPVEG067	446506.477	7793197.977	9.934	9.934	0.000
GCPVEG068	446467.642	7793120.192	9.900	9.997	0.097
GCPVEG069	446439.249	7793061.398	9.787	9.874	0.087
GCPVEG070	446440.234	7793002.028	9.872	9.982	0.110
GCPVEG071	446378.313	7792945.621	9.979	10.064	0.085
GCPVEG072	446321.055	7792932.719	10.033	10.054	0.021
GCPVEG073	446257.585	7792887.555	9.985	10.080	0.095
GCPVEG074	446273.834	7792828.191	9.965	10.055	0.090
GCPVEG075	446253.465	7792764.585	10.014	10.079	0.065
GCPVEG076	446218.591	7792728.684	9.994	10.133	0.139
GCPVEG077	446166.549	7792696.018	10.784	10.875	0.091
GCPVEG078	446116.763	7792626.967	11.242	11.311	0.069
GCPVEG079	446069.113	7792609.274	11.088	11.197	0.109
GCPVEG080	446007.446	7792583.465	11.007	11.191	0.184
GCPVEG081	445986.677	7792571.341	11.077	11.160	0.083
GCPVEG082	445230.482	7792361.611	12.059	12.180	0.121
GCPVEG083	445219.128	7792394.020	12.016	12.094	0.078
GCPVEG084	445190.094	7792403.556	11.761	11.878	0.117

Check Point	Easting (m)	Northing (m)	Checkpoint Z (m)	Corrected Pointcloud Z (m)	Elevation Difference (Corrected Pointcloud Z - Checkpoint Z) (m)
<b>GCPVEG085</b>	445153.790	7792413.453	11.882	11.945	0.063
<b>GCPVEG086</b>	445095.836	7792438.605	12.006	12.084	0.078
<b>GCPVEG087</b>	445064.833	7792438.261	11.875	11.945	0.070
<b>GCPVEG088</b>	445003.747	7792440.726	11.385	11.463	0.078
<b>GCPVEG089</b>	444946.320	7792418.100	11.314	11.421	0.107
<b>GCPVEG090</b>	444892.226	7792388.507	11.298	11.393	0.095
<b>GCPVEG091</b>	444846.540	7792354.531	11.218	11.323	0.105
<b>GCPVEG092</b>	444821.627	7792315.320	11.157	11.273	0.116
<b>GCPVEG093</b>	444819.040	7792282.658	11.143	11.274	0.131
<b>GCPVEG094</b>	444829.280	7792258.462	11.267	11.333	0.066
<b>GCPVEG095</b>	444845.112	7792256.701	11.181	11.310	0.129
<b>Average elevation difference (dZ) (m)</b>	0.091				
<b>Minimum dZ (m)</b>	-0.140				
<b>Maximum dZ (m)</b>	0.582				
<b>Average magnitude error (m)</b>	0.098				
<b>Root mean square error (m)</b>	0.126				
<b>Standard deviation (m)</b>	0.087				