Final Report

For project:

St Lawrence Hazard Mapping LiDAR

Prepared for:

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Introduction

The South Nation River Conservation Authority contracted Airborne Imaging, A Clean Harbors Company, in the fall of 2018 to acquire and deliver digital elevation data derived from airborne LiDAR (Light Detection and Ranging) to cover an area in Ontario: South Nation.

The collection of Lidar data started in the fall of 2018, but an early snow fall prevented further data collection. In the spring of 2019, the remaining of the project was collected.

This report covers both the 2018 and 2019 acquisition seasons to collect data over the St Lawrence Hazard Mapping project area between Cornwall and Brockville, Ontario. It focuses on LiDAR acquisition details, such as flight parameters, project control, ground truthing results, data processing techniques and deliverables.

The original contracted area for South Nation is 798.07 km^2.

Project Schedule & Personnel

During the periods Airborne Imaging was collecting Lidar data, one Lidar Operator / Surveyor was tasked with collecting ground truth points on days when the weather didn't allow Lidar data collection.

A typical Lidar acquisition crew consisted of one Project Manager, one Lidar Operator and one Pilot. Due to crew rotation, various individuals were assigned to this project. Below is a list of personnel:

Project Manager	**Lidar Operator**	**Pilot**
Allyson Fox	Ryan Gemmel	Fahad Hashmi
Tim Willms	Andrew Blair	Alex Lavaliere
Gerry Bouma		
Bruce Whiteley		

For the acquisition period in the fall of 2018, one aircraft was dedicated to data acquisition. Two missions were acquired on November 11 and 14, 2018. It was mutually agreed between Airborne Imaging and South Nation as to when the leaf-off and snow-off start and end date would be. Weather was unfortunately less than optimal in the fall period.

For the spring of 2019, two more missions were acquired on April 17 and 22, 2019. During the spring of 2019, an additional surveyor (Donald Tarr) was sent to the site to collect additional ground truth points.

LiDAR System & Flight Parameters

One aircraft provider provided the Piper Navajo aircraft for this project. KASI Aviation, from Montreal had aircraft C-GKSX assigned for this project for both the fall and spring acquisitions.

A Riegl LMS Q-1560 (serial number 54) LiDAR system was used for the fall missions and a Riegl LMS Q-1560 (serial number 64) for the spring missions.

See Appendix A for a table of the lifts with their flight parameters.

See Appendix B for a table of the Daily Lidar Field Acquisition Report.

Project Control

Datum

The control network and therefore all subsequent Lidar data are based on the Nad83 CSRS (epoch 2010.0) horizontal datum and the CGVD2013 vertical datum (CGG2013 undulation model).

Base Stations

In order to acquire the LiDAR data three NRCan compliant CAN-Net stations, COR3, MORS, and BROC were used as primary base stations. Baseline distances from each CAN-Net station to the aircraft did not exceed 30 km at any time during LiDAR acquisition. Also, two alternate CAN-Net stations, KEMP and EMBN, were monitored but were not used for the LiDAR or ground surveys. Raw GNSS static data for each CAN-Net station are continuously logged at 1 Hz sample rate and were downloaded in RINEX file format for each hour logged. NRCan continuously monitors the CAN-Net stations to ensure coordinate compliance is maintained.

Equipment

Airborne Imaging utilized two Trimble R8 GNSS RTK receivers as RTK rovers, and Can-Net continuously operating reference stations as base stations for the RTK survey and for static observations. The CAN-Net stations are comprised of Trimble NetR9 infrastructure receivers with Zephyr antennas. More information on the CAN-Net network and the NRCan published coordinates can be viewed at the following links.
http://gpsweb.can-net.ca/Map/SensorMap.aspx
https://webapp.geod.nrcan.gc.ca/geod/data-donnees/rtk.php?locale=en

For the full control survey report with coordinate listings, station reports and monument photos, please refer to document “SouthNation_Control_Report.pdf” under the following folder:

FINAL_REPORT\ControlReport

Check Points

Control check points were surveyed from different methods to use as vertical check and accuracy assessment. The kinematic method was used for calibration purposes. The RTK method was used for Non-Vegetated Vertical Accuracy Assessment (NVA). For the Vegetated Vertical Accuracy Assessment (VVA), the RTK method was used in open areas and conventional surveying in areas where the trees obstructed the sky.

The CAN-Net stations were also used as base stations for the Real Time Kinematic (RTK) check point survey.
During the RTK check point survey 13 COSINE station monuments and 3 NRCan high precision 3D stations were observed as ties points and to verify each day’s survey.
During the fall of 2018, only low brush vegetated points were surveyed. In the spring of 2019, extra vegetated points have been surveyed in other vegetation types such as low grass, tall grass, corn field, coniferous and deciduous trees.

Listings of the different check points will be discussed in the accuracy section of this document.

<u>Kinematic GPS</u>

The first method called kinematic are profiles surveyed on open roads from a truck-mounted GPS receiver while driving. The post-processed kinematic coordinates, collected at an interval of one second are derived from a base station that is part of our geodetic network.

Whenever possible, we try to select roads that are perpendicular to the flight line azimuth, so the control points intersect as many Lidar strips as possible.

The output coordinates are analyzed and filtered to ensure only very reliable positions are kept. All points collected while moving slower than 2 meters per second are rejected. This removes all points when the truck was stationary that could skew the statistics.
The following points are also rejected:

- Points with a Quality Level worse than 1.
- Points with a forward/reverse vertical separation worse than 3 cm.
- Points with less than two solutions (forward & reverse).
- Points with a standard deviation worse than 2sigma.

Many sections of roads were surveyed throughout the project giving us more than 2558 surveyed points. We estimate that the vertical accuracy of these points is better than 5 cm.

During the calibration of the Lidar strips, the Lidar strips are matched vertically to these reliable kinematic points. These points are not used for the vertical accuracy assessment of the Lidar point cloud, but rather just for calibration monitoring and shifting.

Real-time Kinematic GPS (RTK)

The Second method called Real-Time Kinematic are individual points surveyed on open surfaces from a pole-mounted GPS receiver. A nearby base station broadcasted via radio modem the differential corrections to the roving GPS receiver. The surveyor held the pole and antenna in a fixed position for a period necessary for the differential corrections from the base station to indicate that a fixed solution was acquired. The static period usually last about six epochs (6 seconds).

70 points were surveyed in open areas distributed throughout the project. These points are used to assess the Non-Vegetated vertical Accuracy (NVA).

The same RTK method was used to survey points in low vegetation areas like grass, crops and brush.

Conventional Survey

A conventional survey on the South Nation project was done in the spring of 2019 to collect ground points under the tree canopy that was not reliably obtainable using the RTK GPS method. Airborne established a network of RTK points controlled by the local Can-Net stations. These subsequent points were then used in the conventional survey. The field surveyor would occupy one of the known points with a Real Time Total Station, observe a second known point to establish an orientation then with the onboard collection start the survey for the vegetated under canopy points.

Field Calibration of Lidar Strips

Generation and Calibration of Laser Points (raw data)

The initial step of calibration is to verify availability and status of all needed GNSS and Laser data against field notes and compile any data if not complete. Subsequently the mission points are output using Riegl's RiProcess, initially with default values calibration for the system. The initial point generation for each mission calibration is verified within Microstation/Terrascan for calibration errors. If a calibration error greater than specification is observed within the mission, the roll, pitch, and yaw corrections that need to be applied are calculated using Riegl's Scan Data Adjustment within RiProcess. The Scan Data Adjustment utility uses plane matching to determine roll, pitch, and yaw corrections for each swath. The missions with the new calibration values are regenerated and validated internally once again to ensure quality.

Data collected by the LiDAR unit is reviewed for completeness, acceptable density and to make sure all data is captured without errors or corrupted values. In addition, all

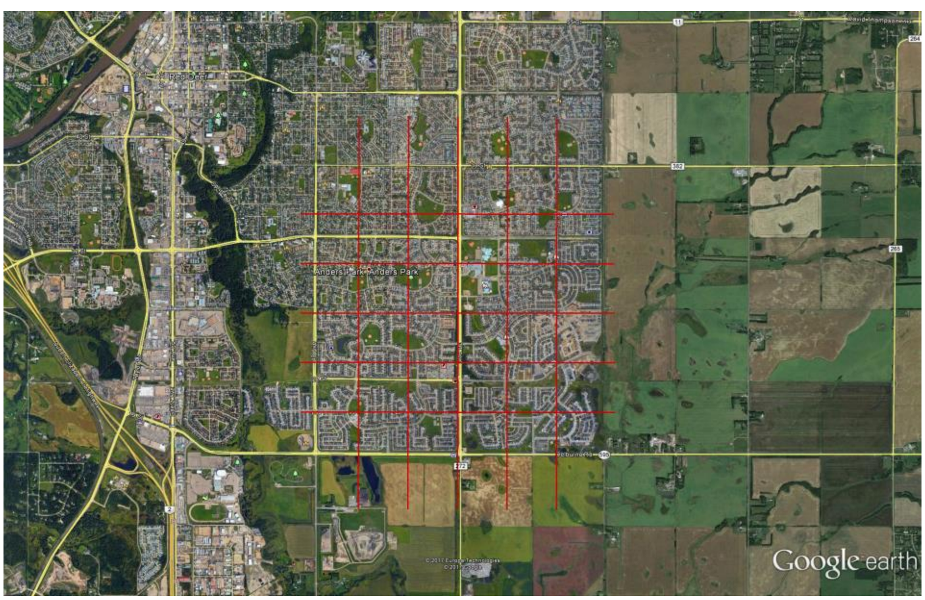
GNSS, aircraft trajectory, mission information, and ground control files are reviewed and archived. On a project level, a supplementary coverage check is carried out to ensure no data voids unreported by field operations are present.

<u>Boresight Site Selection</u>

The boresight is chosen based on the features it presents. As the bundled adjustment uses tie-planes, urban environments are preferred since the sloped rooflines face multiple directions giving a dense set of tie planes with multiple slopes and aspects. This represent the best scenario for tie plane based block adjustments. In addition to this, sites with minimal tree cover are preferred since trees offer obscure rooflines (planes).
Airborne routinely uses pre-selected sites that have the best conditions to perform boresight adjustments. In western Canada, Airborne Imaging preferentially uses the City of Red Deer Alberta for these flights. It's close to home base, has relatively light tree cover, low air traffic, has continuously operating reference stations (CORS), has a publicly available weather station for correcting atmospheric effects and is sufficiently populated with residential housing to present numerous tie planes. As an additional benefit of reusing this site, we have established a healthy volume of ground truth data, and continuously revisiting the same sights allows us to detect sensor anomalies (such as intensity dependent range drift).

<u>Flight Design</u>

The boresight flight plan consists of 10 short flight lines. 5 parallel lines are orientated E/W and 5 additional flight lines are orientated N/S and directly overlap the E/W lines. Spacing is designed for 60% side lap to maximize the overlap between adjacent lines and length is kept short to minimize IMU drift. Altitude is kept moderate (900m AGL) so that there are a sufficient number of points from each pass to adequately define the tie planes. The image below illustrates the Red Deer calibration site with its associated flight lines overlaid.



Data Evaluation

Once collected, the data for the Riegl Q1560 sensor is processed within Riegl's RiProcess suite. The two channels are allowed to float independently of each other and individual flight line adjustments are disabled.
The software is set to automatically extract tie planes from overlapping flight lines. Tie plane filtering is enabled to reduce the number of tie planes (speeds calculations and evens out the distribution of tie planes across the site). The adjustment is run, and the results are evaluated. Generally, very little deviation is seen over time and multiple boresight adjustments.

A final, more in depth calibration takes also place later when the field produced point cloud arrives in the office in Calgary.

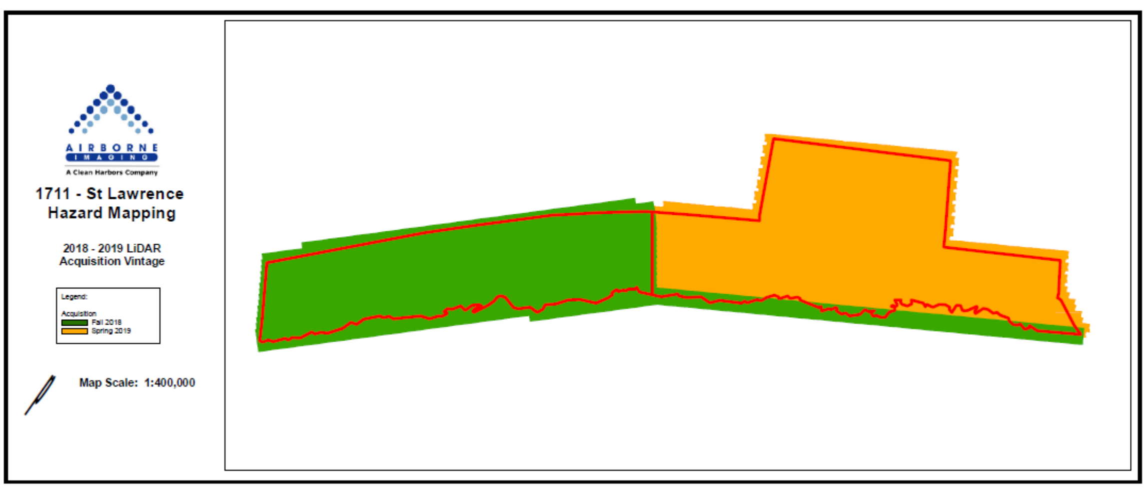
Lidar Acquisition

As mentioned in the Project Schedule and Personnel section above, the Lidar acquisition was done in one leaf-off/snow-off season of fall 2018 and spring 2019.

See table below for a summary of acquisition dates.

Season	Acquisition Start	Acquisition End	# of missions flown
Fall 2018	November 11, 2018	November 14, 2018	2
Spring 2019	April 17, 2019	April 22, 2019	2

See map below for the areas covered during the acquisition season (2018 in green and 2019 in orange).



For the flight logs of the 4 missions, see .pdf files in the "Flightlogs" folder on the final report deliverables hard drive.

LiDAR Data Processing

Tiling

The South Nation project falls entirely within UTM zone 18. The point cloud is therefore tiled into 1000m X 1000m tiles based on the UTM18 projection. The extents fall on the even integer and the tiles named according to the lower left Easting and Northing (truncated). The software used for point cloud manipulation is TerraSolid's TerraScan/TerraModeler applications. At this stage, the files are stored in .las version 1.2.

Calibration

Once the field calibration values are obtained, the mission point cloud data is then generated in the field as preliminary calibrated. The point cloud and supporting files are copied to external hard drives and shipped to the processing center in Calgary.

Once the data has arrived in the office, an experienced calibration specialist reviews the field calibration. The strips are imported into tiles and the TerraMatch software is used to assess and improve any flight line separation between passes. Typically, the adjustments are made on the entire mission for roll and pitch. Occasionally, further corrections are required by individual flight lines for roll, pitch and DZ.

Once the flight lines fit well relatively to one another, the unclassified point cloud is compared to the kinematic profiles surveyed on roads. If any vertical biases are observed, an elevation correction (DZ) is applied to the mission. Below is a table of calibration tracking and any shifting to kinematic ground truthing that was performed.

South Nation / Kinematic results					
			Statistics after Bayes Match and after Dz shift (kinematic)		
Mission	**Bayes Match**	**Dz Applied**	**Dz**	**Std Dev**	**RMS**
5418315a	**Yes**	**-0.13**	**0.01**	**0.02**	**0.029**
5418318a	**Yes**	**0.07**	**0.01**	**0.035**	**0.035**
6419107a	**Yes**	**-0.02**	**0.00**	**0.02**	**0.025**
6419112b	**Yes**	**-0.02**	**0.006**	**0.03**	**0.027**

Intensity normalization

The native intensity values collected generally range between approximately 15000 and 55000 for the Riegl sensors. The native intensity values were then normalized to 16bit. For the Riegl, their values first had 16000 subtracted, then multiplied by 1.5. The resulting intensities range between 0 and 65535.

Point Cloud Classification

Point classification is done with the TerraScan software, using macros that are set-up to measure the angles and distances between points to determine what classification a point should be: ground, non-ground, ... The angle and distance values in the macros can be varied to be more or less aggressive with the classification of points from the unclassified class to ground by varying the incidence angles and estimated distances among neighboring points.

Following the USGS minimum classification scheme, the points are classified in the following classes:

Code	Description
1	Processed, but unclassified
2	Bare earth
7	Low noise
9	Water
17	Bridge decks
18	High noise
20	Ignored ground (near a breakline)

To better understand areas where the classification (mathematical models) did not represent the ground accurately, the points that are classified as bare earth are extracted and turned into viewable TIN and grid surfaces. These surfaces are viewed in conjunction with the point cloud for inspection of areas that appear rough, artificially flattened or cut, no data areas, or have other viewable anomalies. In cleaning up ground points, an effort is concentrated in areas where few ground points have been left in the bare earth model and the ground appears rough or lower and flatter than it may be in reality. The scarcity of ground points may be a result from no penetration through a dense vegetation layer, or too aggressive values with the macro. A manual inspection of these areas plays a major role in resolving any issues or irregularities with the bare earth model. A manual effort is also made to make sure that bridge decks have been classified to class 17. Both Bare Earth and Full Feature grids are created to visually inspect the data. The Bare Earth grids are produced by using the ground classified points, where the grid is created from the TIN. The Full Feature grids are produced by using all non-noise points and creating a grid surface of the highest elevations within the cell size.

Water Classification & Hydro-Flattening

Once the ground class has reached the final level of classification accuracy, the water delineation process is initiated. The rivers and water bodies are digitized as break lines according to USGS specifications of a minimum of 8000 m² for water bodies and 30 m nominal width for streams and rivers. Ponds and lakes have their elevations set constant to just below ground. Stream and river hydro lines are collected using the downstream method. Once all hydro lines have been collected for an area, the ground points inside the hydro lines are classified to class 9 – Water. The ground points outside of the hydro lines but within 35 cm are classified to class 20 – Ignored ground (near breaklines). Using the TIN of class 2 – Bare earth, the hydro lines are used as constraints to generate the final 50 cm hydro-flattened DEMs in XYZ format, then converted to ERDAS .img format with the Global Mapper software.

Deliverables

See below for a table of the folder structure and description of deliverables.

Folder	Sub-Folder (s)	Content and Description	File Names
15076_SouthNation_Final	DTM	Hydro-flattened 50cm Bare Earth DEMs, 1km X 1km (ERDAS Imagine .img format)	e.g. 123_4567.img
	FINAL_REPORT	Final report in .doc & pdf formats	South_Nation_Lidar_Final_Report_June_2019.doc
	AccuracyReporting	Spreadsheets and photos of NVA and VVA check points	NVA & VVA accuracy comparisons (.xlsx)
	ControlReport	Control Survey report	SouthNation_Control_Report.pdf
	FlightLogs	Flight logs of Lidar data acquisition	FltLog_........ .pdf
	Metadata	FGDC compliant (.xml format) for each of the following 4 deliverables:	
		Breaklines, DEM, LAS & Project	(.xml) & Lidar Summary page (.pdf)
	Project_Shapefiles	Shape files of: hydro breaklines, lift_metadata, project boundary, tile index, vintage	(.shp)
	POINTCLOUD	Classified Point Cloud, 1km X 1km (zipped .laz v1.4 format)	e.g. 123_4567.laz
	RAWPOINTCLOUD	Calibrated unclassified 1km X 1km (zipped .laz v1.4 format)	e.g. 123_4567_v14_raw.laz

Horizontal Accuracy Assessment

Calculated Horizontal Accuracy (CHA)

The calculated horizontal accuracy was determined from the parameters of the LiDAR system used in acquisition and the altitude the project was flown at. The calculated horizontal accuracy at 95% or 2 sigmas was determined to be 22.5 cm or better.

Absolute Horizontal Accuracy

Horizontal accuracy was also determined through an examination directly from the LiDAR point cloud and using the horizontal check points that were collected for this project. Due to the resolution capabilities of the LiDAR point cloud only a subset of the surveyed check points could be used for this accuracy check. A listing of the check points used and the differences between surveyed/observations is provided in Appendix C. The actual graphical measurements are also provided in Appendix C.

Vertical Accuracy Assessment

Kinematic

Below is a summary of the statistics between the point cloud TIN from the ground class and the kinematic points surveyed on the road:

Number of points:	1005	
Average dz:	0.01	m
Minimum dz:	-0.109	m
Maximum dz:	0.072	m
Average magnitude:	0.023	m
Root mean square:	0.029	m
Std deviation:	0.027	m

Kinematic Non-Vegetated Vertical Accuracy (95%):	5.7	cm

For a complete listing of the kinematic points and their differences, please refer to the spreadsheet named “South_Nation_NVA_Kinematic_comparison_Final.xlsx” provided with the deliverables.

This Kinematic vertical accuracy assessment is provided only as a reference. It is biased because during calibration, the point cloud was vertically shifted to these points. It should not be used as an independent check for accuracy assessments.

Non-Vegetated Vertical Accuracy (NVA)

All RTK points surveyed on the road as well as the horizontal points have been combined to assess the vertical accuracy on flat hard surfaces.

Below is a summary of the statistics between the point cloud TIN from the ground class and the hard surface points:

Number of points:	70	
Average dz:	0.007	m
Minimum dz:	-0.042	m
Maximum dz:	0.070	m
Average magnitude:	0.018	m
Root mean square:	0.023	m
Std deviation:	0.022	m

Non-Vegetated Vertical Accuracy (95%):	4.5 cm

For a complete listing of the check points and their differences, please refer to the spreadsheet named " SouthNation_NVA_Comparisons_Final.xlsx " provided with the deliverables under the following folder:
15076_SouthNation_Final\FINAL_REPORT\AccuracyReporting
The photos of each check point are also provided under the following folder:
"FINAL_REPORT\AccuracyReporting\Check_point_photos\NVA".

Note that of the 78 originally surveyed points, only 70 fell within the deliverable boundary. The following eight points have not been included in the accuracy calculations: 2002, 2004, 2005, 2007, 2008, 2023, 4025 & 4033.

Vegetated Vertical Accuracy (VVA)

In the fall of 2018, the check points collected in vegetated areas were all in the "low brush" category. In the spring of 2019, extra vegetated points have been surveyed in other classes. The final number of points surveyed in different classes are:

Vegetation type	Number of points surveyed
Low Brush	31
Low Grass	27
Tall Grass	3
Corn crop	1
Coniferous	37
Deciduous	34
Mixed (Coniferous & Deciduous)	6
Total:	**139**

For each of the vegetation types above, vertical differences between the Lidar ground surface and each vegetation type have been computed. All the spreadsheets have been delivered with this report under the following folder:
"FINAL_REPORT\AccuracyReporting\Separated_vegetation_classes".

The elevations of all the points surveyed in various vegetated land cover types have been merged and compared to the Lidar ground surface to compute the Vegetated Vertical Accuracy for the project. Since the elevation differences for this type of accuracy do not follow a normal distribution, the 95th percentile method is used and not the 95% confidence level. For the 139 VVA points, sorting the absolute differences from the smallest to the largest gives the accuracy at the 95th percentile. For this sample, the 95th percentile was calculated by multiplying 139 times 95. The resultant of 132.02 was rounded to the nearest whole number. The 132rd difference gives the accuracy at the 95th percentile, which is 14.8 cm.

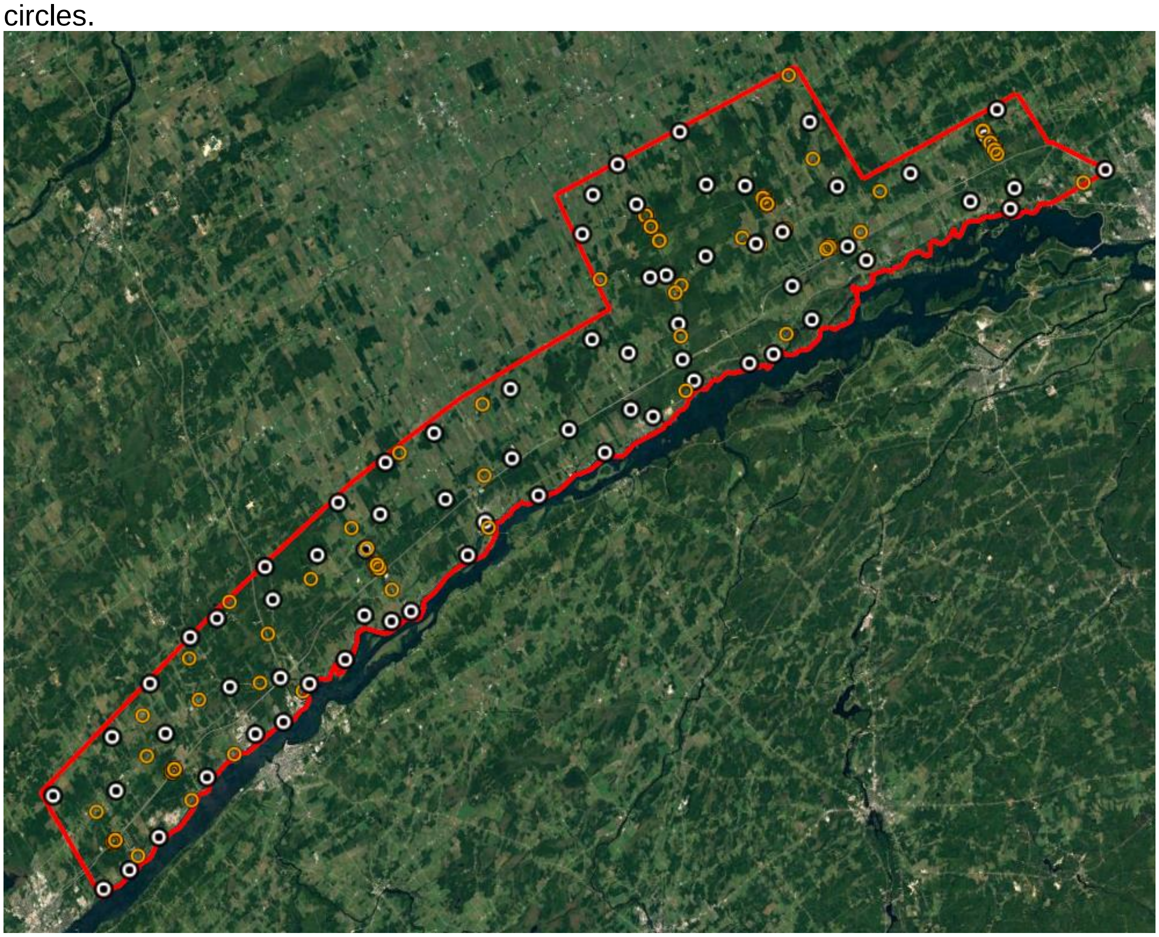
Vegetated Vertical Accuracy (95th percentile):	14.8 cm

This is slightly below the required specifications of 15.0 cm (the QL0 VVA specification).

For a complete listing of the VVA points and their differences, please refer to the spreadsheet named "SouthNation_VVA_Comparisons_Final.xlsx" provided with the deliverables under the following folder:
15076_SouthNation_Final\FINAL_REPORT\AccuracyReporting

The photos of each check point are also provided, separated by vegetation type under the following folder:
“FINAL_REPORT\AccuracyReporting\Check_point_photos\VVA” folder.

Below is a map of the location of NVA points as white circles and VVA points as orange circles.



Conclusion

This project could unfortunately not be all completed in the fall of 2018 as originally planned, because of an early snow fall. Preliminary products were delivered for what was flown and delivered in January 2019. The full deliverables are now being delivered in June 2019.

A large number of check points were collected to support vertical accuracy reporting. Accuracies for the non-vegetated areas are excellent at 4.5 cm (95%) while the requirements are 9.8 cm. For the vegetated areas, the 14.8 cm accuracy reported at the 95th percentile ended up being within the USGS QL0 requirement of 15.0 cm and because of this provides a great data set for flood hazard mapping.

Appendix A

Table of Lifts and Flight Parameters

FlightDate	JulianDay	Lift	FlightHours	System	AGL_m	Speed_kts	PulseRate_kHz	ScanRate_Hz	FOV_deg	ProjectManager	Operator	Aircraft_Co	Aircraft
11/11/2018	315a	5418315a	4.4	Q1560 (54)	700	150	800	313	60	B. Whiteley	R. Gemmel	KALUS	C-GKSX
14/11/2018	318a	5418318a	6.0	Q1560 (54)	700	150	800	313	60	A. Fox	R. Gemmel	KALUS	C-GKSX
17/04/2019	107a	6419107a	5.6	Q1560 (64)	700	150	800	313	60	A. Fox	A. Blair	KALUS	C-GKSX
22/04/2019	112a	6419112a	5.4	Q1560 (64)	700	150	800	313	60	A. Fox	A. Blair	KALUS	C-GKSX

Appendix B

Daily Lidar Field Acquisition Report

Daily Lidar Field Acquisition Report

Project: 1711 SouthNation

	Aircraft	C-GKSX	
	System	Riegl Q1560 (54)	
Date	Acquisition	Mission number	Comments / Weather
November 11,2018	Yes	5418315a	Collected lines 1001 - 1008. Abort mission early due to low clouds and severe turbulence.
November 12,2018	No		Light snow/rain, low clouds.
November 13,2018	No		Light snow/rain, low clouds.
November 14,2018	Yes	5418318a	Full mission.
November 15,2018	No		Aircraft unavailable - completed another project.
November 16,2018	No		Maintenance - Snow/rain.
November 17,2018	No		Snow
November 18,2018	No		Snow
November 19,2018	No		Snow
November 20,2018	No		Snow
November 21,2018	No		Over 10cm snow on the ground in the project area.
November 22,2018	No		Over 10cm snow on the ground in the project area.
November 23,2018	No		Over 10cm snow on the ground in the project area.
November 24,2018	No		Over 10cm snow on the ground in the project area.
November 25,2018	No		Over 10cm snow on the ground in the project area.
November 26,2018	No		Over 10cm snow on the ground in the project area.
November 27,2018	No		Over 10cm snow on the ground in the project area.
		Riegl Q1560 (64)	
April 17, 2019	Yes	6419107a	Collected lines 2021 - 2027 on EastAOI. Crew flew in from lower NY - sensor issues... unable to complete block.
April 18, 2019	No		Low clouds
April 19, 2019	No		Low clouds and rain
April 20, 2019	No		Low clouds and rain
April 21, 2019	No		Low clouds
April 22, 2019	Yes	6419112a	Collected lines 2001 - 2020. Project is now complete.

Appendix C

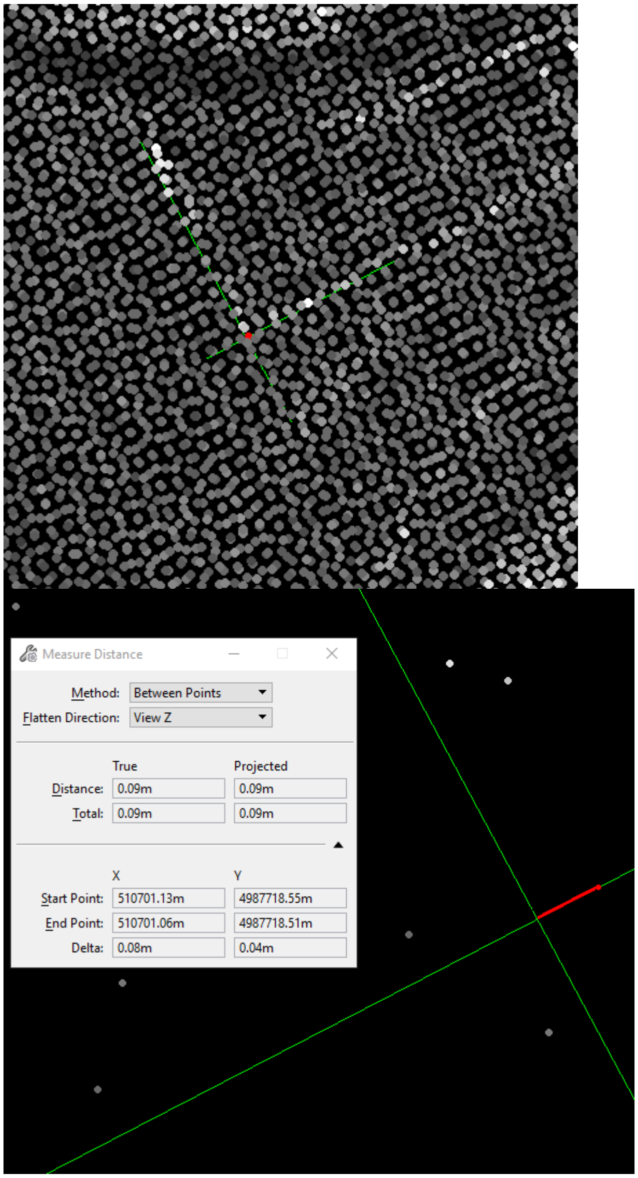
Measured Horizontal Accuracy Report

	Measured Values [meters]		Survey Checkpoint Values [meters]		Residues (errors) [meters]		Comments
Point ID	Easting (x)	Northing (y)	Easting (x)	Northing (y)	x Easting	y Northing	
4001	N/A	N/A	500696.953	4982911.577	N/A	N/A	Resolution not suitable
4002	N/A	N/A	503694.396	4988726.187	N/A	N/A	Resolution not suitable
4003	N/A	N/A	508756.498	4991216.952	N/A	N/A	Resolution not suitable
4004	510701.050	4987718.500	510701.131	4987718.547	-0.081	-0.047	
4005	N/A	N/A	496919.881	4992196.772	N/A	N/A	Resolution not suitable
4006	N/A	N/A	488182.271	4991558.442	N/A	N/A	Resolution not suitable
4007	N/A	N/A	489943.615	4988016.057	N/A	N/A	Resolution not suitable
4008	495056.850	4984829.920	495056.832	4984829.930	0.018	-0.010	
4009	N/A	N/A	489893.037	4983217.562	N/A	N/A	Resolution not suitable
4010	487229.700	4981965.060	487229.747	4981965.061	-0.047	-0.001	
4011	N/A	N/A	483998.677	4989385.951	N/A	N/A	Resolution not suitable
4012	N/A	N/A	481593.176	4984733.209	N/A	N/A	Resolution not suitable
4013	N/A	N/A	488034.294	4978688.239	N/A	N/A	Resolution not suitable
4014	N/A	N/A	489075.039	4974880.488	N/A	N/A	Resolution not suitable
4015	N/A	N/A	495710.441	4981208.275	N/A	N/A	Resolution not suitable
4016	N/A	N/A	492798.415	4976037.696	N/A	N/A	Resolution not suitable
4017	N/A	N/A	486314.854	4972489.840	N/A	N/A	Resolution not suitable
4018	N/A	N/A	483063.177	4970092.512	N/A	N/A	Resolution not suitable
4019	475005.890	4965465.720	475005.786	4965465.739	0.104	-0.019	
4020	N/A	N/A	469998.012	4959499.882	N/A	N/A	Resolution not suitable
4021	N/A	N/A	466945.519	4963639.659	N/A	N/A	Resolution not suitable
4022	N/A	N/A	516836.091	4988940.960	N/A	N/A	Resolution not suitable
4023	N/A	N/A	507720.384	4986836.075	N/A	N/A	Resolution not suitable
4024	482227.190	4977665.840	482227.155	4977665.803	0.035	0.037	
4025	N/A	N/A	472956.756	4973924.401	N/A	N/A	Resolution not suitable
4026	N/A	N/A	467950.265	4966015.947	N/A	N/A	Resolution not suitable
4027	460706.320	4960321.680	460706.344	4960321.779	-0.024	-0.099	
4028	N/A	N/A	465564.405	4956294.729	N/A	N/A	Resolution not suitable
4029	N/A	N/A	476818.774	4969723.487	N/A	N/A	Resolution not suitable
4030	N/A	N/A	456943.797	4959077.010	N/A	N/A	Resolution not suitable
4031	N/A	N/A	452422.528	4954725.786	N/A	N/A	Resolution not suitable
4032	N/A	N/A	445863.398	4947222.954	N/A	N/A	Resolution not suitable
4033	N/A	N/A	446533.686	4943829.899	N/A	N/A	Resolution not suitable
4034	453446.470	4951372.910	453446.531	4951372.855	-0.061	0.055	
4035	N/A	N/A	457808.273	4954482.043	N/A	N/A	Resolution not suitable
4036	N/A	N/A	459504.019	4951326.770	N/A	N/A	Resolution not suitable
4037	452974.620	4944431.050	452974.606	4944430.978	0.014	0.072	
4038	N/A	N/A	449238.530	4940948.651	N/A	N/A	Resolution not suitable
Number of Checkpoints					8	8	
Mean Error					-0.005	-0.002	
Standard Deviation					0.060	0.056	
Root Mean Square Error RMSE, 1dRMSE at 68% Confidence Level					0.057	0.052	
Radial Horizontal Accuracy RMESEr, 1dRMESEr at 63% Confidence Level					0.077		

4004

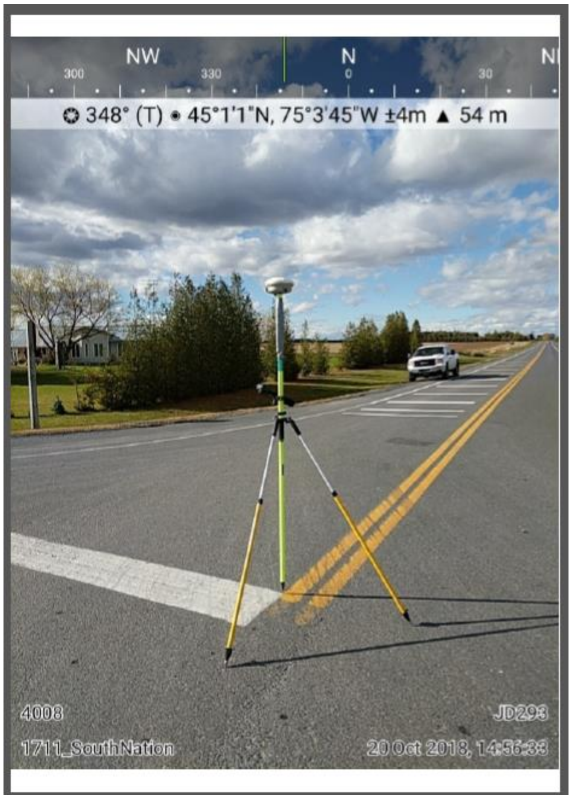

E
90
120
SE
150
S
180
148°SE (T) 45°2'34"N, 74°51'50"W ±9m ▲ 45 m
4004
JD292
1711_SouthNation
19 Oct 2018, 17:12:39

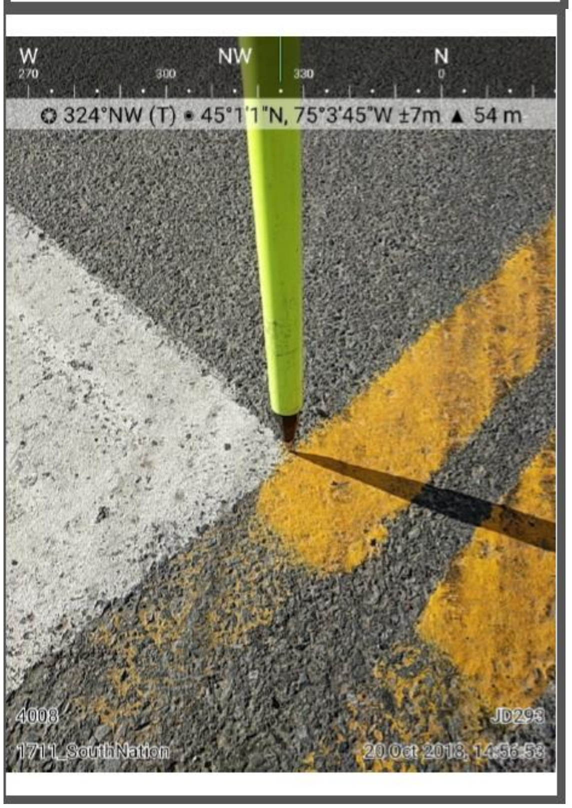

NE
60
E
90
120
SE
150
101°E (T) 45°2'34"N, 74°51'50"W ±8m ▲ 40 m
4004
JD292
1711_SouthNation
19 Oct 2018, 17:12:54

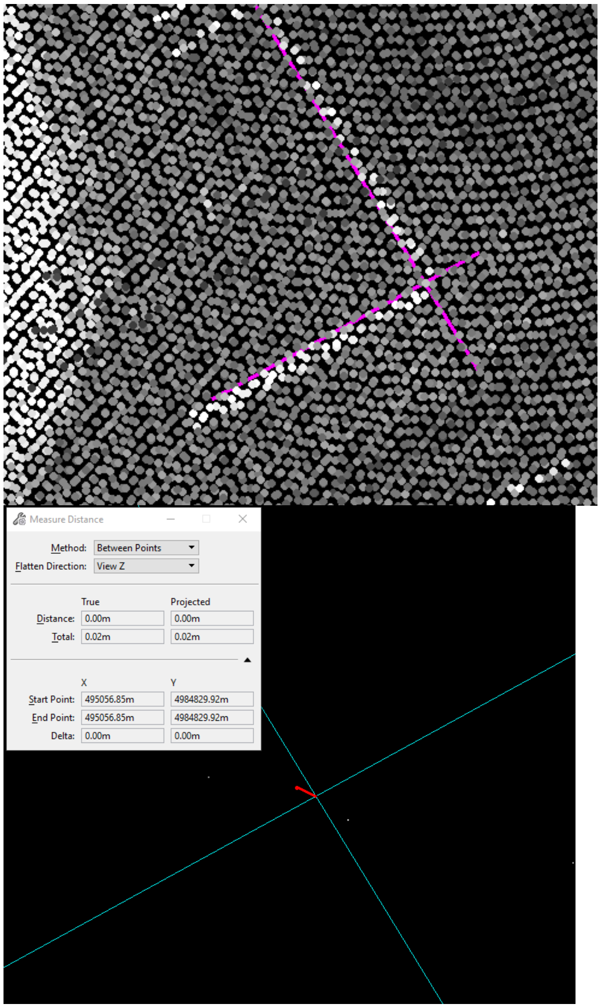


9cm horizontal displacement

4008

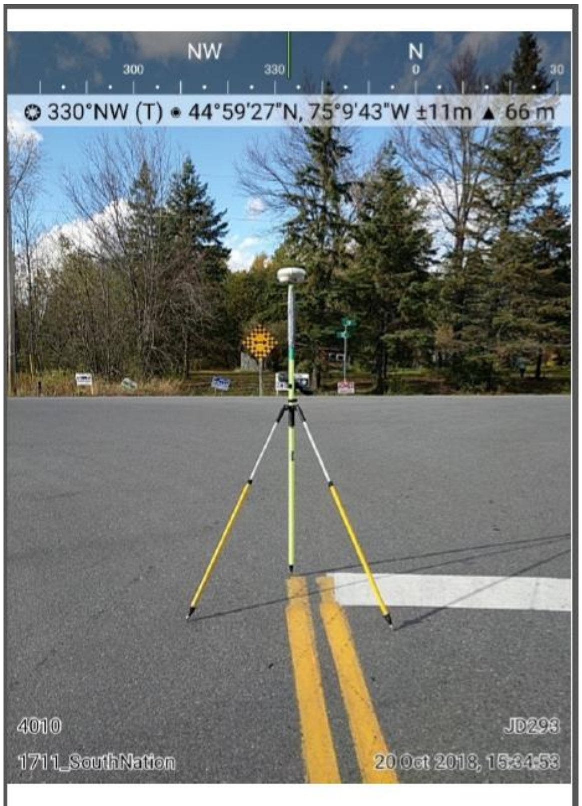

NW
N
300
330
0
30
348° (T) 45°1'1"N, 75°3'45"W ±4m ▲ 54 m
4008
JD293
1711_SouthNation
20 Oct 2018, 14:56:33


W
NW
N
270
300
330
0
324°NW (T) 45°1'1"N, 75°3'45"W ±7m ▲ 54 m
4008
JD293
1711_SouthNation
20 Oct 2018, 14:56:53

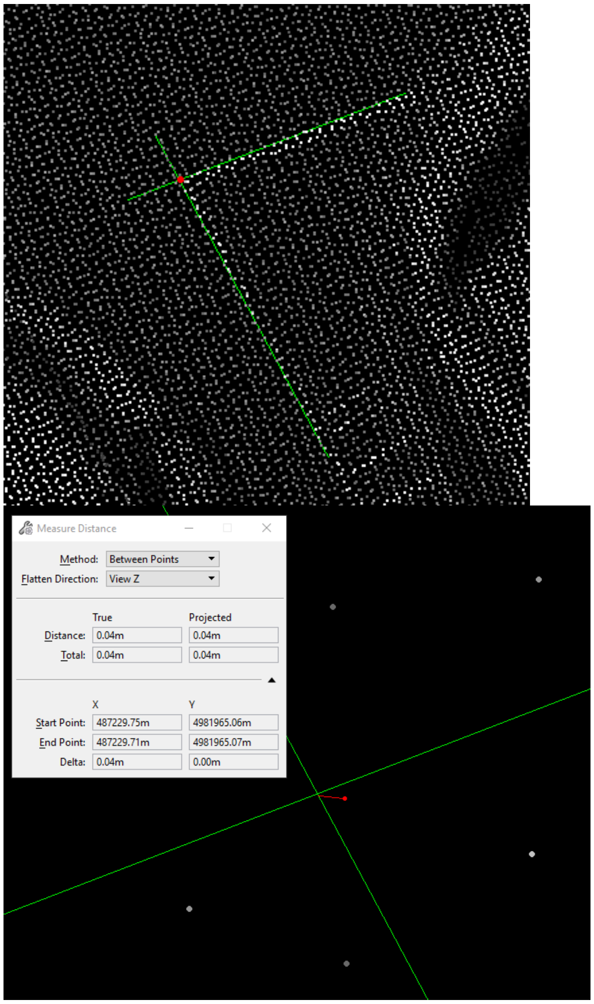


2cm horizontal displacement

4010


NW
N
300
330
0
30
330°NW (T) 44°59'27"N, 75°9'43"W ±11m ▲ 66 m
4010
JD293
1711_SouthNation
20 Oct 2018, 15:34:53


E
SE
S
90
120
150
180
131°SE (T) 44°59'27"N, 75°9'43"W ±8m ▲ 53 m
4010
JD293
1711_SouthNation
20 Oct 2018, 15:35:48

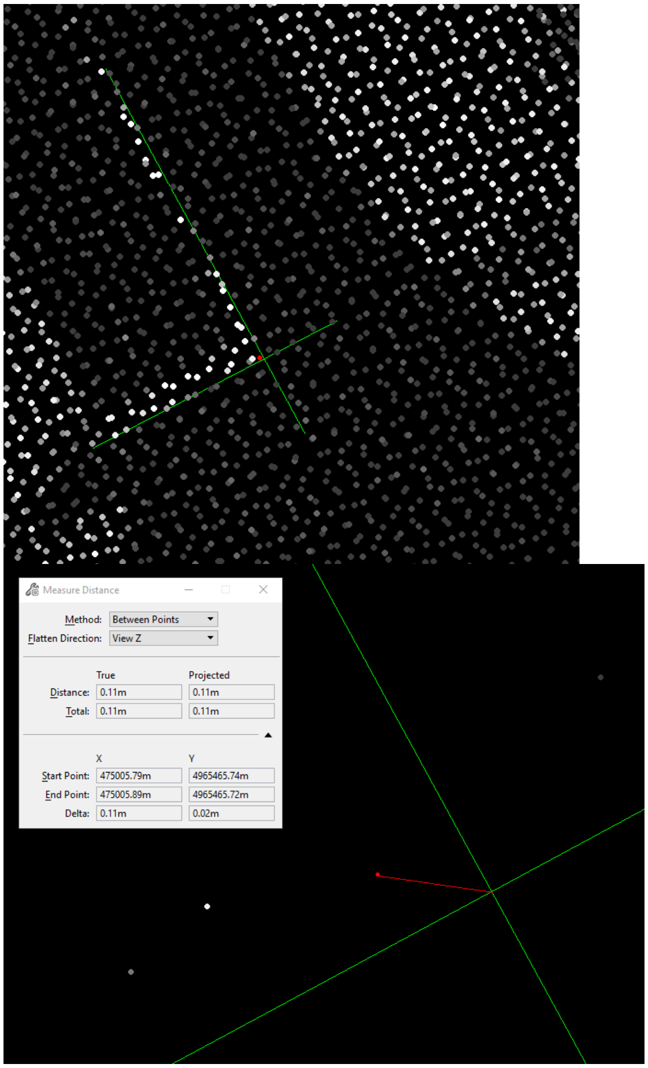


4cm horizontal displacement

4019

S
SW
W
226°SW (T) • 44°50'32"N, 75°18'58"W ±3m ▲ 57 m

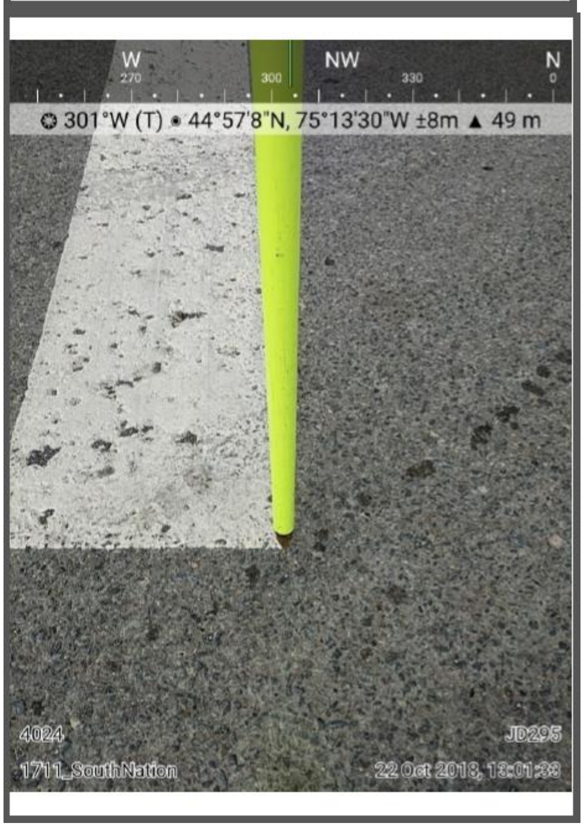
W
270
300
NW
330
N
0
326°NW (T) • 44°50'31"N, 75°18'58"W ±6m ▲ 51 m
4019
JD294
1711_SouthNation
21 Oct 2018, 15:33:53

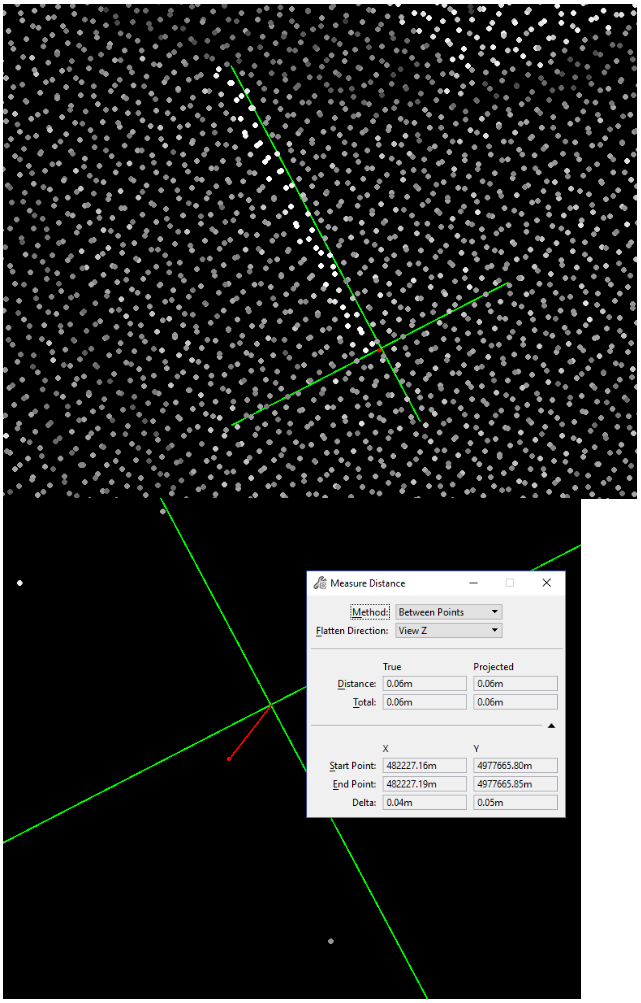


11cm horizontal displacement

4024


S
SW
208°S (T) 44°57'8"N, 75°13'30"W ±17m ▲ 49 m
4024
JD295
1711_SouthNation
22 Oct 2018, 13:01:20


W
NW
N
301°W (T) 44°57'8"N, 75°13'30"W ±8m ▲ 49 m
4024
JD295
1711_SouthNation
22 Oct 2018, 13:01:33

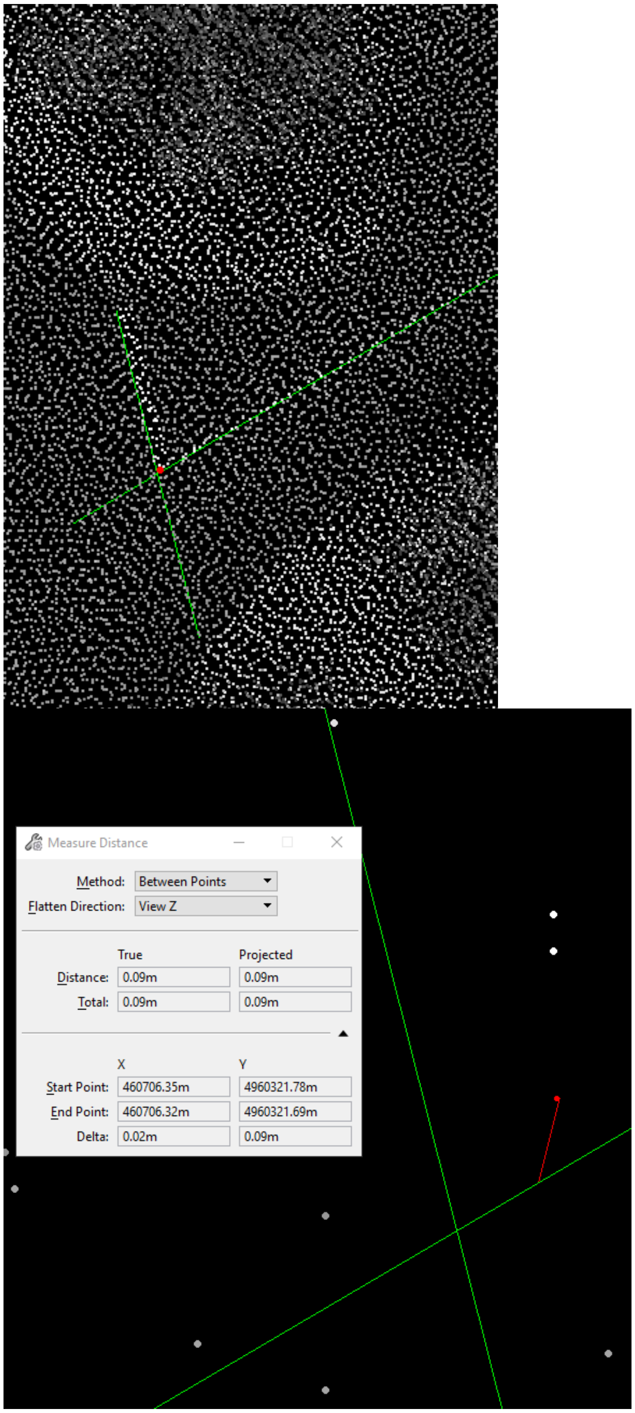


6cm horizontal displacement

4027


SE
S
SW
150
180
210
240
197°S (T) 44°47'43"N, 75°29'49"W ±14m ▲ 58 m
4027
JD295
1711_SouthNation
22 Oct 2018, 15:34:51


N
NE
E
0
30
60
90
51°NE (T) 44°47'43"N, 75°29'48"W ±13m ▲ 59 m
4027
JD295
1711_SouthNation
22 Oct 2018, 15:35:09

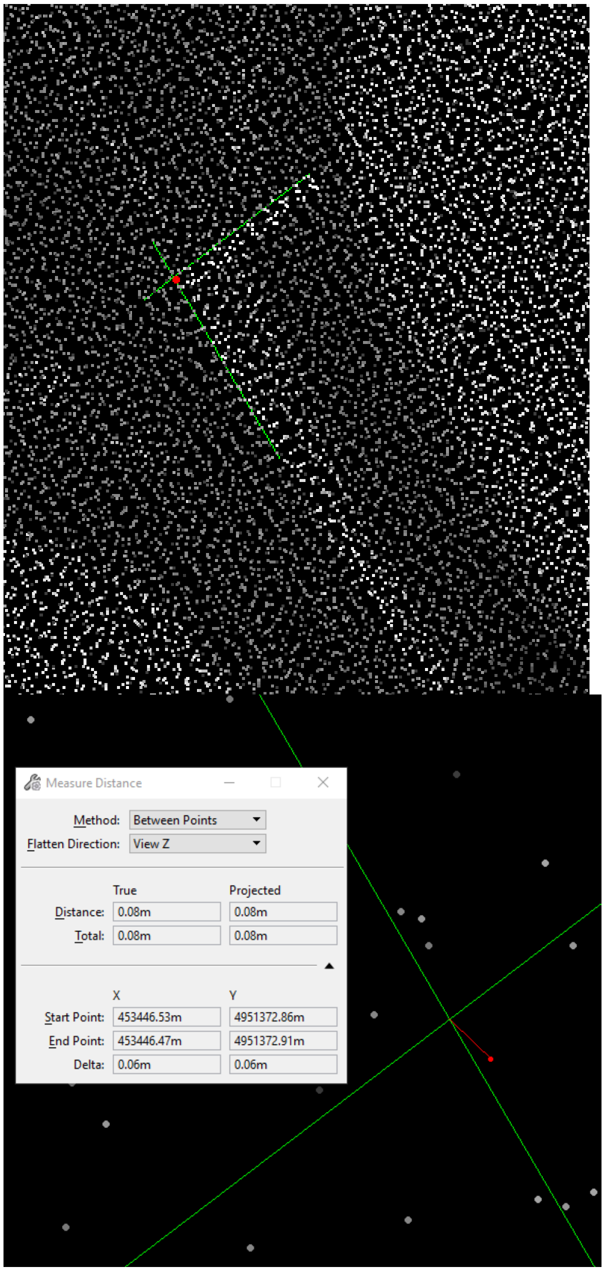


9cm horizontal displacement

4034


S
SW
150
180
210
240
198°S (T) 44°42'51"N, 75°35'16"W ±8m ▲ 56 m
4034
JD296
1711_SouthNation
23 Oct 2018, 14:12:50

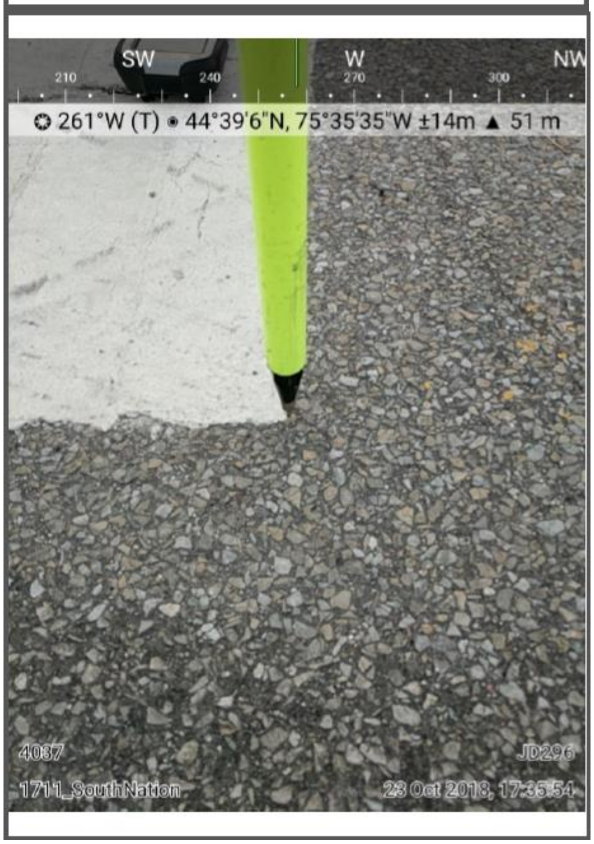

SE
S
SW
150
180
210
240
188°S (T) 44°42'51"N, 75°35'15"W ±10m ▲ 64 m
4034
JD296
1711_SouthNation
23 Oct 2018, 14:13:01

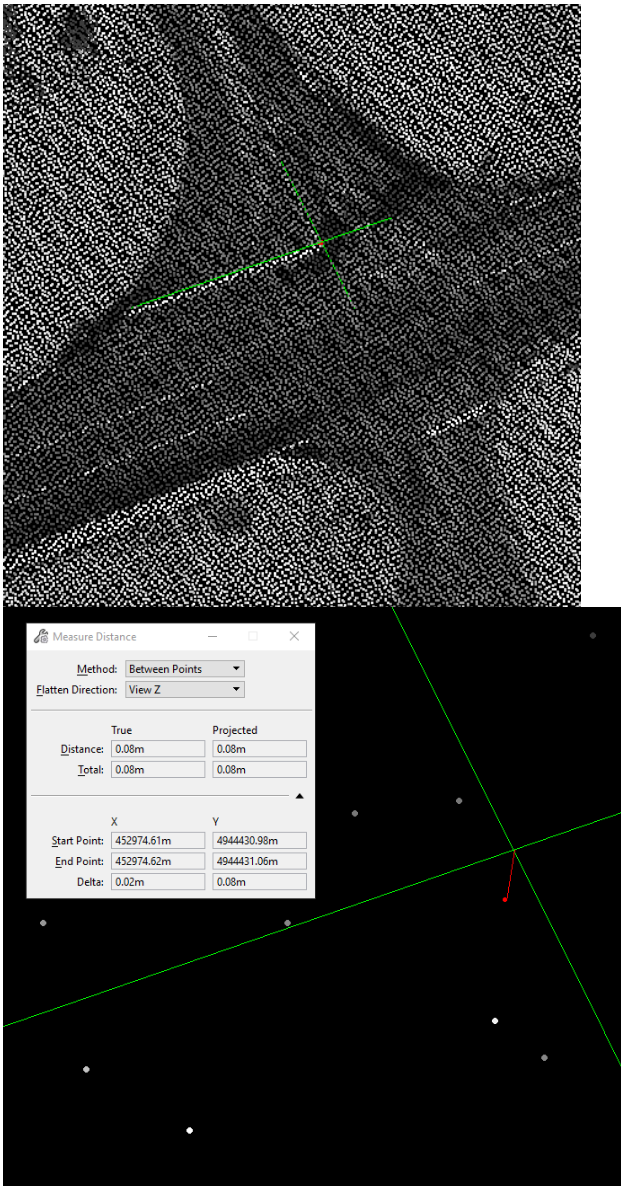


8cm horizontal displacement

4037


SE
S
SW
120
150
180
210
175°S (T) 44°39'6"N, 75°35'34"W ±7m ▲ 55 m
4037
JD296
1711_SouthNation
23 Oct 2018, 17:35:38


SW
W
NW
210
240
270
300
261°W (T) 44°39'6"N, 75°35'35"W ±14m ▲ 51 m
4037
JD296
1711_SouthNation
23 Oct 2018, 17:35:54



8cm horizontal displacement

Summary

Horizontal Point	Horizontal Displacement	
4004	9	cm
4008	2	cm
4010	4	cm
4019	11	cm
4024	6	cm
4027	9	cm
4034	8	cm
4037	8	cm

Average	7.1	cm
RMS	7.64	cm