

**New York State
Airborne LiDAR Processing & Accuracy Report**

For

Cayuga-Oswego Counties

Prepared For



**New York State
Office of Information Technology Services
GIS Program Office
10B Airline Drive,
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Section 2: Introduction

The New York State Office of Information Technology Services, GIS Program Office requested delivery of three-dimensional classified point cloud and terrain data derived from LiDAR (Light Detection and Ranging) technology for the New York LiDAR project area covering Cayuga County and parts of Oswego County, in Central New York State. The project area covered approximately 1,720 square miles or 4,455 square kilometers.

This project was completed to meet USGS 3D Elevation Program (3DEP) requirements including USGS publication “LiDAR Base Specification”, ver. 1.3. 3DEP Quality Level 2 LiDAR data was processed and projected to UTM Zone 18 North, referenced to the North American Datum 1983 (NAD83) (2011), in units of meters. The vertical datum used for the project was the North American Vertical Datum 1988 (NAVD88) with units expressed in meters. Orthometric heights were referenced to Geoid 12B.

This document explains the process and procedures used to create and verify the accuracy of georeferenced swath data, classified point cloud and hydroflattened bare-earth digital elevation models (DEMs). This is the third report in a series of reports examining project data at various stages of production. The two previous reports were delivered under separate cover and are listed below for reference:

- 1) For a more detailed report on the LiDAR acquisition, see the report entitled: “*New York State Airborne LiDAR Acquisition Report; Cayuga-Oswego Counties; Axis Project 13367-1811*”. Dated Oct. 2018
- 2) A thorough review of the survey techniques and parameters surrounding the field work and processing of the ground control and check points can be found in a report entitled: “*GNSS Survey Report: New York Statewide LiDAR Acquisition Lot 18; 2018 Lot 18 LiDAR Ground Control and Check Point Survey Report*”. Dated 11-16-2018.

The data tested in this report include:

- 1) The Relative Accuracy assessment of the LiDAR swaths;
- 2) A comparison of the adjusted LiDAR swath data with the surveyed coordinates of the project Ground Control Points;
- 3) A comparison of the adjusted LiDAR swath data with the surveyed coordinates of the project Non-Vegetated Accuracy (NVA) check points;
- 4) Comparison of the LiDAR DEM data with the surveyed elevation values of the project Non-Vegetated Vertical Accuracy (NVA) check points;
- 5) Comparison of the LiDAR DEM data with the surveyed elevation values of the project Vegetated Vertical Accuracy (VVA) check points;

Section 3: Summary of Swath Data Results

A brief summary of the accuracy assessments performed with the swath data is discussed below.

The first assessment measures the relative match of the LiDAR points in the overlap areas of the acquisition swaths. The second assessment provides an analysis of the adjusted LiDAR points with the surveyed ground control points. The third assessment compares the swath data with the independent surveyed check points located in non-vegetated areas.

An initial analysis of the swath data involves comparing the elevation values of points from one swath to the points from a neighboring swath. Points within the overlapping swath areas are observed and compared. Swaths are adjusted with the intent of reducing the elevation differences between points within the overlapping swaths.

USGS publication “LiDAR Base Specification”, ver. 1.3, Page 23, Table 2 identifies that QL2 data will have a swath overlap difference of ≤ 8 cm. For this dataset, the RMSz of the relative adjustment is 1.9 cm and the maximum difference between points observed is 16.9 cm. (one point from 11.75 million section lines)

A second analysis provides a statistical measure of how well the adjusted swath point cloud data have been merged together and adjusted to ground control points whose coordinates have been surveyed. Forty-Eight (48) control points were utilized.

Ground control coordinates from previous New York State LiDAR projects were used in addition to the Cayuga-Oswego ground control points. Ground control coordinates from the 2015 NY State project and ground control from the Great Gully were used. For additional information for the 2015 points, see the GNSS survey reports from 2015 and Great Gully delivered under a separate letter. For the Cayuga-Oswego dataset, the average difference of the LiDAR data with the ground control points is +0.2 cm, with a standard deviation of 3.2 cm and an RMSE_z of 3.9 cm.

Non-Vegetated Vertical Accuracy (NVA) Check Points were also independently surveyed and compared to the swath data. For the NVA checkpoints, the overall RMSE_z is 3.2 centimeters

Non-Vegetated Vertical Accuracy (NVA) Check Points and Vegetated Vertical Accuracy (VVA) Check Points were also independently surveyed and compared to the DEM data. For the NVA checkpoints, the overall RMSE_z is 3.1 centimeters. This compares favorably to the USGS specification of ≤ 10 cm. (USGS "LiDAR Base Specification", ver. 1.3, Page 24, Table 4;). The NVA at the 95% confidence level is 6.1 centimeters which is within the USGS specification of < 19.6 cm. (USGS "LiDAR Base Specification", ver. 1.3, Page 24, Table 4;).

Vegetated Vertical Accuracy (VVA) Check Point RMSE_z is 6.6 centimeters and the VVA at the 95th percentile is 11.9 centimeters. The USGS specification for VVA at the 95th percentile is < 30 cm. (USGS "LiDAR Base Specification", ver. 1.3, Page 24, Table 4;)

Section 4: Merging Swaths

Generation and Calibration of Laser Points

The initial step of calibration is to verify availability and status of all needed 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. The initial point generation for each mission calibration is completed within TerraSolid using TerraMatch. Using LASTools, a Z-difference intensity ortho is created to verify relative swath to swath adjustments. If a calibration error greater than specification is observed within the mission, the roll, pitch and scanner scale corrections that need to be applied are re-calculated.

The NY18 Cayuga-Oswego LiDAR Actual Flight Line Alignment is displayed below (Figure 1). Eighty-three (83) flight lines were acquired for completing the NY18 Cayuga-Oswego LiDAR project area. No re-flight lines were acquired. Eight (8) lines were collected for calibration purposes and removed before production.

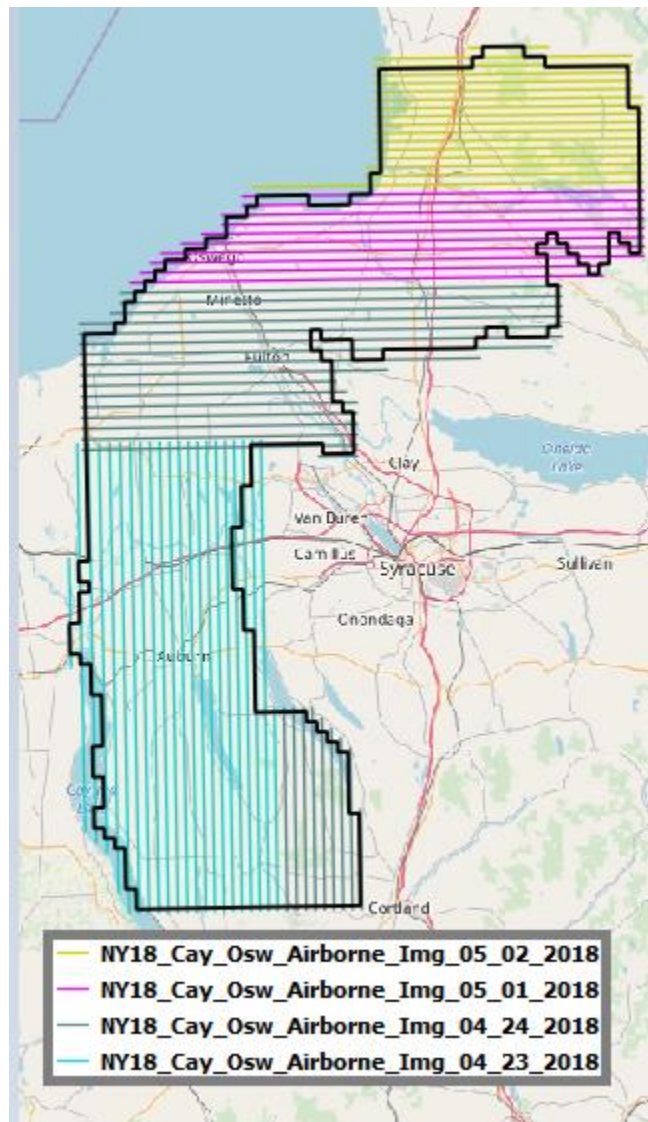


Figure 1: Cayuga Oswego Actual Flight Lines Acquired (Spring 2018 Acquisition)

The Aggregate Nominal Pulse Spacing for the NY18 Cayuga-Oswego LiDAR project is 0.40 m with an Aggregate Nominal Pulse Density of 3.17 pts/m².

Table 1: Point Cloud Statistics	
Total Points	34,121,724,458
Aggregate Nominal Pulse Spacing (m)	.40m
Aggregate Nominal Pulse Density (pts/m ²)	3.17ppsm

Relative Accuracy Assessment

For effective data management, each imported mission is tiled out in TerraScan to a project specific tile scheme or index. Relative accuracy and internal quality are then checked using a number of carefully selected tiles in which points from all lines are loaded and inspected. Vertical differences between ground surfaces of each line are displayed by the generation of Z-Difference colored intensity orthos in TerraScan. The color scale of these orthos are 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 alignment. When available, surveyed control points are used to supplement and verify the calibration of the data.

The Relative and Absolute Adjustment Workflows are summarized below:

- a. Search for Tie Lines for Relative Adjustments –To find the difference between flightlines, Axis utilizes a function in TerraMatch called Search Tie Line. The automatic tie line search provides a statistical report of the average mismatch between flightlines.
- b. Find Tie Line Match & Generate Correction Values - Find Tie Line Match tool analyzes the mismatch in the tie lines and provides correction values.
- c. Apply Correction Values to the LiDAR – Utilizing the correction values that were calculated, a macro applies the corrections.
- d. Analyze and Fit Data to Control for Absolute Adjustment –For the absolute adjustments, the LiDAR data is adjusted to known control points. LiDAR is adjusted using average Dz mismatches to the control.
- e. Gather Intensity Images of Horizontal Alignment of Control – Axis generates intensity imagery to check the horizontal accuracy of the LiDAR.
- f. Create a Report of Relative and Absolute Adjustments – Terrascan provides:
 - i. Tie-line Output Report – Average Z mismatch between each strip.
 - ii. Output Control Report – Match between the control and the LiDAR.

Relative Adjustment Accuracy Results

An overall statistical assessment of the relative accuracy, using TerraMatch Tie Line Report between LiDAR swaths, can be found in Table 2 below. The values provided are in Meters.

Table 2: Average Magnitude per line (m)					
Line	Z	Line	Z	Line	Z
1	0.012	26	0.016	51	0.015
2	0.013	27	0.016	52	0.012
3	0.013	28	0.013	53	0.012
4	0.014	29	0.013	54	0.013
5	0.012	30	0.013	55	0.013
6	0.013	31	0.013	56	0.013
7	0.013	32	0.012	57	0.012
8	0.013	33	0.013	58	0.011
9	0.014	34	0.012	59	0.011
10	0.014	35	0.011	60	0.011
11	0.013	36	0.011	61	0.011
12	0.012	37	0.012	62	0.011
13	0.012	38	0.012	63	0.011
14	0.012	39	0.012	64	0.013
15	0.013	40	0.012	65	0.015
16	0.012	41	0.012	66	0.013
17	0.013	42	0.012	67	0.012
18	0.014	43	0.022	68	0.012
19	0.014	44	0.010	69	0.012
20	0.012	45	0.014	70	0.012
21	0.013	46	0.013	71	0.012
22	0.012	47	0.015	72	0.012
23	0.014	48	0.014	73	0.012
24	0.015	49	0.013	74	0.013
25	0.016	50	0.018	75	0.012

Table 3: Overall Relative Accuracy (m)	
Category	Mismatch
Average 3D Mismatch	.01318
Average Z Mismatch	.01318

Table 4: Internal Observation Statistics (m)			
Category	X	Y	Z
Average Magnitude	0.0	0.0	.013
RMS Values	0.0	0.0	.019
Maximum Values	0.0	0.0	.200
Observation Weight	0.0	0.0	24646116.0

Table 5: TerraMatch Tie Lines	
Category	Observations
Surface Lines	11755891

Absolute Adjustment Accuracy Results

A graphic is provided below (Figure 2) displaying the locations and distribution of the forty-eight (48) ground control points.

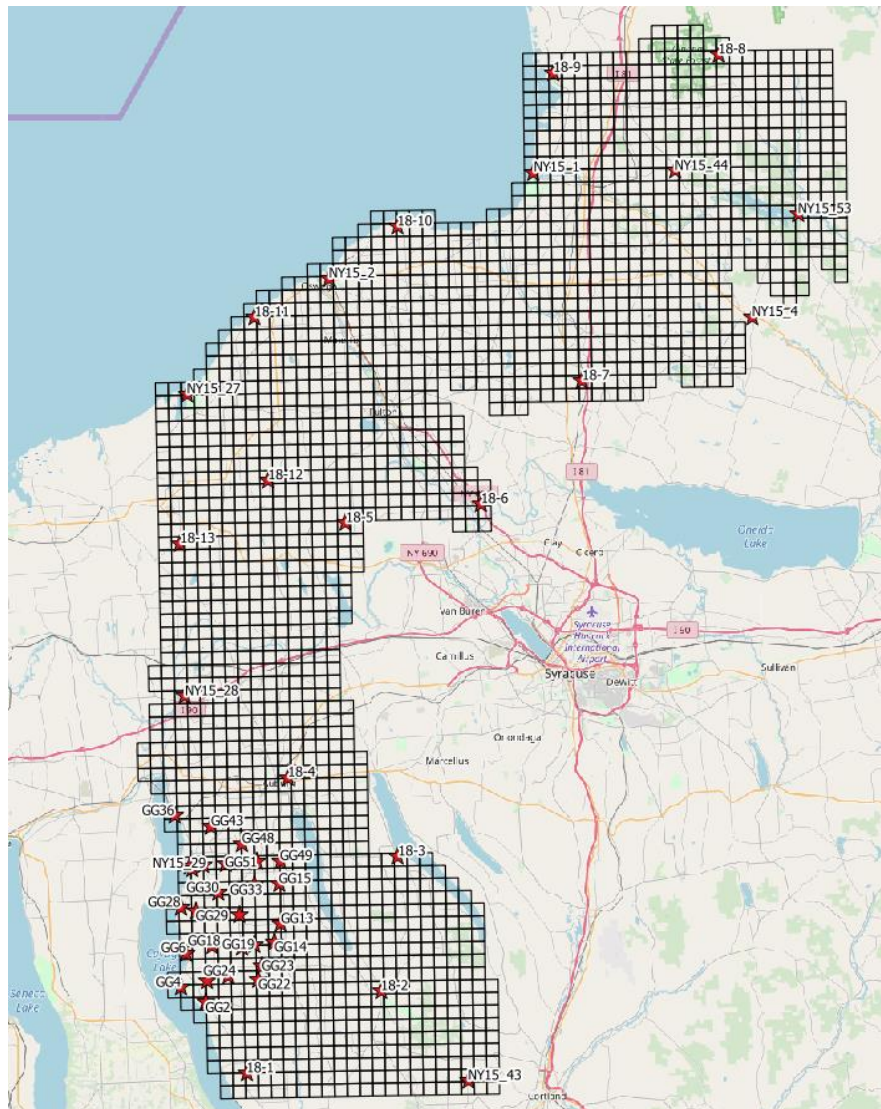


Figure 2: Forty-Eight (48) Ground Control Locations

A vertical accuracy assessment of the forty-eight (48) control points against the LiDAR swath surface can be found in the table below. The coordinates provided are in NAD83 (2011), UTM Zone 18N, NAVD88 (Geoid12B), Meters.

Table 6: Ground Control Point Assessment (Swath) (m)						
Point ID	Easting	Northing	Known Z	Laser Z	Description	Delta Z
18-1	367603.570	4720456.369	271.759	271.78	Mag nail set in asphalt paint line	0.021
18-10	387086.771	4819163.449	83.835	83.84	Mag nail set in asphalt paint line	0.005
18-11	370245.727	4808906.141	108.208	108.23	Mag nail set in asphalt	0.022
18-12	371468.860	4789903.056	136.885	136.89	Mag nail set in asphalt	0.005
18-13	361005.942	4782708.486	135.63	135.64	Mag nail set in asphalt paint line	0.01
18-2	383644.027	4729840.231	225.598	225.62	Mag nail set in asphalt paint line	0.022
18-3	385954.310	4745625.461	299.932	299.88	Mag nail set in asphalt paint line	-0.052
18-4	373134.394	4755116.867	234.053	234.09	Mag nail set in asphalt paint line	0.037
18-5	380473.903	4784749.338	131.993	132.01	Mag nail set in asphalt	0.017
18-6	396324.620	4786707.158	121.124	121.13	Mag nail set in asphalt	0.006
18-7	408357.572	4800891.554	145.932	145.94	Mag nail set in gravel	0.008
18-8	424712.491	4838574.663	390.785	390.84	Mag nail set in asphalt paint line	0.055
18-9	405514.596	4836705.177	77.669	77.65	Mag nail set in asphalt paint line	-0.019
GG2	367194.498	4739139.058	205.485	205.52	Mag nail set in asphalt paint line	0.035
GG4	372008.546	4737947.653	117.503	117.5	point in open grass field	-0.003
GG6	371178.274	4735815.516	124.82	124.81	Mag nail corner of concrete	-0.01
GG10	371823.070	4742642.122	291.46	291.46	Mag nail set in asphalt paint line	0
GG13	363848.767	4735471.660	354.268	354.28	Mag nail set in asphalt paint line	0.012
GG14	368840.691	4735608.512	306.151	306.2	Mag nail set in asphalt paint line	0.049
GG15	362901.473	4728850.406	318.672	318.7	Mag nail set in asphalt paint line	0.028
GG18	367401.662	4735278.431	247.72	247.81	Mag nail set in asphalt paint line	0.09
GG19	369197.969	4731449.860	331.171	331.24	Mag nail set in asphalt paint line	0.069
GG20	369639.483	4733071.641	320.128	320.17	Mag nail set in asphalt paint line	0.042
GG22	365595.302	4731893.330	321.692	321.72	Mag nail set in asphalt	0.028
GG23	363110.528	4731467.818	344.695	344.73	Mag nail set in asphalt	0.035
GG24	360177.788	4740093.859	280.524	280.5	Mag nail set in asphalt	-0.024
GG26	361983.691	4739651.827	202.687	202.71	Mag nail set in asphalt	0.023
GG28	364738.570	4741721.072	133.03	133.04	Mag nail set in gravel	0.01
GG29	368929.310	4742562.891	178.522	178.54	Mag nail set in asphalt paint line	0.018
GG30	359675.415	4750861.821	243.282	243.27	Mag nail set in asphalt	-0.012
GG33	360034.374	4730682.197	283.788	283.81	Mag nail set in gravel	0.022
GG36	361414.378	4744940.185	119.974	120	Mag nail set in gravel	0.026
GG41	363976.984	4749555.836	118.605	118.65	Mag nail set in asphalt	0.045
GG43	362991.534	4745054.853	170.842	170.89	Mag nail set in asphalt	0.048
GG44	365632.029	4745147.721	168.867	168.97	Mag nail set in gravel	0.103
GG46	367573.766	4747435.704	210.928	210.89	Mag nail set in gravel	-0.038
GG48	372029.549	4745343.582	223.492	223.55	Mag nail set in asphalt	0.058
GG49	369347.548	4745264.964	272.922	272.96	Mag nail set in gravel	0.038
GG51	360715.440	4734724.383	263.061	263.1	Mag nail set in asphalt	0.039
NY15_1	403071.162	4825194.710	77.444	77.51	Capped spike corner of driveway	0.066
NY15_2	378987.540	4813259.609	85.591	85.57	Mag Nail corner of sidewalk	-0.021
NY15_4	362147.333	4800128.260	183.444	183.5	Capped spike corner of sidewalk	0.056
NY15_27	361214.122	4764862.376	85.207	85.23	Mag Nail corner of concrete	0.023
NY15_28	361712.168	4744635.781	125.98	125.99	Mag Nail corner of concrete	0.01

NY15_29	428302.612	4808080.775	128.522	128.54	Dock Spike corner of sidewalk	0.018
NY15_43	393783.435	4719132.501	415.276	415.33	Mag Nail corner of stop bar	0.054
NY15_44	419475.168	4825146.336	245.307	245.37	Capped spike corner of concrete	0.063
NY15_53	433783.014	4819980.322	288.415	288.39	Capped spike corner of sidewalk	-0.025

An overall statistical assessment summary of the control points can be found in Table 7 below. The coordinates provided are in NAD83(2011), UTM Zone 18N, NAVD88 (Geoid12B), Meters.

Table 7: Control Point Error Statistics (m)						
Category	# of Points	Min (m)	Max (m)	Mean (m)	Std Dev (m)	RMSE _z (m)
Control Points	48	-0.052	+0.103	+0.023	.032	.039

Section 5: Swath NVA QA/QC

Using TerraScan, Non-Vegetated Vertical Accuracy (NVA) Check Points were compared to the swath data and checked for consistency and compliance with project specifications.

TerraScan:

- 1) Generates relative and absolute adjustment reports;
 - a) The Check Points are loaded into Terrascan using a function called "Output Control Report". Using the ground class, a control report is generated and examined to determine whether the Dz is within tolerance of the specifications.
- 2) Calculating the NVA Report

The NVA points and the swath data are loaded into TerraScan to run a statistical report of the elevation differences between features. The elevation difference between the QA points and the swath data is calculated and embedded, via attribute, to the NVA file.

LASTools

- 1) LAS Info used to check completeness of data;
 - a) LASinfo provides additional details in the header to validate project parameters. If an error is discovered, then changes can be made
- 2) Using Las-to-Las in "LAS-Tools" data are converted to LAS version 1.4.
 - a) lastolas is used to convert the LAS v1.2 files to LAS v1.4. The data is exported with the Point Data Record Format (PDRF) changed for each file from 1 to 6 in order for the file to be converted correctly. Changing the PDRF to 6 is necessary because it supports added elements such as "Overlap" bit flags, Coordinate Reference Systems (CRS) and Well Known Text (WKT). The new version number is also specified in the line of code in order to export tiles whose headers read "1.4".
- 3) Overlap Points flagged to adhere to specifications.
 - a) "lasoverage" is used to create "Overlap" bit flags along the edges of crossing flightlines.

Global Mapper

- 1) Overlap points checked for correct classification flag
 - a. Swath data is loaded into Global Mapper and points are tag/selected in overlap regions in order to see in the attribute table that the Overlap bit read "Y" for "Yes".

A summary of the vertical accuracy assessment of the Non-Vegetated Vertical Accuracy (NVA) check points against the swath surface can be found in Table 8 below. The coordinates provided are in NAD83 (2011), UTM Zone 18N, NAVD88 (Geoid12B), Meters. The overall RMSE_z for the NVA checkpoints was 3.4 cm.

Table 8: NVA Check Point Error Statistics (m)

Category	# of Points	Min (m)	Max (m)	Mean (m)	Std Dev (m)	RMSE _Z (m)
Check Points	69	-0.068	+0.102	+0.010	0.031	0.032

For a complete listing of the NVA points, see Table 9.

Table 9: NVA Check Point Assessment (swath surface) (m)

Point ID	Easting	Northing	Known Z	Laser Z	Delta Z	Description
NVA_01	367583.6399	4720462.2314	272.183	272.2	0.017	Paved Road
NVA_02	367588.0461	4720475.8898	271.887	271.91	0.023	Short Grass
NVA_03	367611.2721	4720462.7768	271.570	271.6	0.03	Paved Shoulder
NVA_04	383606.9292	4729832.9729	225.987	225.99	0.003	Short Grass
NVA_05	383524.9697	4729889.4801	225.308	225.3	-0.007	Paved Parking Lot
NVA_06	383698.5425	4729852.6280	225.941	225.93	-0.011	Loose Gravel
NVA_07	385956.6594	4745629.4407	299.637	299.63	-0.007	Paved Parking Lot
NVA_08	385927.1003	4745640.7434	299.667	299.64	-0.027	Paved Sidewalk
NVA_09	385891.4026	4745631.3483	301.835	301.82	-0.015	Short Grass
NVA_10	396364.4994	4717823.0919	433.668	433.66	-0.008	Paved Road
NVA_11	396377.6958	4717822.5505	433.707	433.72	0.013	Short Grass
NVA_12	396452.5100	4717813.8178	433.865	433.86	-0.005	Unpaved Shoulder
NVA_13	364817.7210	4736902.4720	266.117	266.12	0.003	Paved Road
NVA_14	364811.7721	4736818.3793	266.019	266.02	0.001	Short Grass
NVA_15	364808.3748	4736779.9993	265.659	265.66	0.001	Paved Parking Lot
NVA_16	373156.5973	4755081.4040	234.478	234.49	0.012	Paved Parking Lot
NVA_17	373124.3907	4755074.1383	233.406	233.38	-0.026	Paved Sidewalk
NVA_18	373128.6219	4755112.7574	233.995	233.99	-0.005	Short Grass
NVA_19	355819.4257	4756744.6563	137.935	137.99	0.055	Paved Parking Lot
NVA_20	355861.6932	4756675.7588	138.898	138.96	0.062	Unpaved Parking Lot
NVA_21	355795.9040	4756734.8545	137.161	137.21	0.049	Short Grass
NVA_22	367806.5381	4767977.2498	120.425	120.43	0.005	Paved Road
NVA_23	367785.4638	4767933.7493	122.978	123.01	0.032	Unpaved Road
NVA_24	367710.6204	4767922.3013	122.916	122.9	-0.016	Unpaved Shoulder
NVA_25	361048.2111	4782219.1996	133.991	134.08	0.089	Paved Road
NVA_26	361052.7658	4782238.2598	134.808	134.91	0.102	Flat Dirt Area Beside Road
NVA_27	361021.3280	4782579.3961	137.049	137.08	0.031	Unpaved Driveway
NVA_28	380461.8647	4784744.9638	131.788	131.8	0.013	Paved Road

Table 9: NVA Check Point Assessment (swath surface) (m)

Point ID	Easting	Northing	Known Z	Point Z	Delta Z	Description
NVA_29	380618.5378	4784748.4295	131.196	131.2	0.004	Unpaved Driveway
NVA_30	380464.6224	4784759.1953	131.728	131.76	0.032	Short Grass
NVA_31	396309.5567	4786678.8125	120.887	120.89	0.003	Paved Parking Lot
NVA_32	396310.8408	4786619.2117	122.183	122.2	0.017	Short Grass
NVA_33	396518.3395	4786533.5284	119.162	119.19	0.028	Unpaved Driveway
NVA_34	371475.8578	4789908.8704	136.867	136.91	0.043	Paved Parking Lot
NVA_35	371481.4678	4789888.1775	136.523	136.54	0.017	Short Grass
NVA_36	371499.3531	4789878.2463	135.577	135.6	0.023	Unpaved Driveway
NVA_37	370284.1797	4808900.4029	109.198	109.21	0.012	Unpaved Driveway
NVA_38	370151.2912	4808895.8009	105.030	105.04	0.01	Paved Road
NVA_39	370244.5922	4808907.1154	108.165	108.2	0.035	Short Grass
NVA_40	408355.7814	4800909.0334	146.756	146.73	-0.026	Short Grass
NVA_41	408338.8798	4800891.2668	146.351	146.34	-0.011	Paved Road
NVA_42	408300.9155	4800878.9753	145.563	145.54	-0.023	Unpaved Driveway
NVA_43	390583.1877	4808648.9409	136.446	136.42	-0.026	Paved Road
NVA_44	390562.1863	4808651.5314	135.327	135.32	-0.007	Unpaved Driveway
NVA_45	390616.1007	4808709.3427	137.268	137.2	-0.068	Unpaved Shoulder
NVA_46	387077.2547	4819164.6767	83.754	83.74	-0.014	Paved Parking Lot
NVA_47	387093.5864	4819187.6741	82.966	82.96	-0.006	Short Grass
NVA_48	387024.9549	4819164.0580	82.603	82.59	-0.013	Unpaved Shoulder
NVA_49	414556.1192	4816425.0469	178.339	178.37	0.031	Unpaved Shoulder
NVA_50	414579.3916	4816415.5129	177.748	177.77	0.022	Paved Road
NVA_51	414491.9113	4816448.6759	179.451	179.47	0.019	Short Grass
NVA_52	435243.6099	4816173.8743	296.316	296.38	0.064	Paved Road
NVA_53	435224.8043	4816175.9705	295.895	295.95	0.055	Unpaved Driveway
NVA_54	435223.7040	4816190.7793	295.859	295.88	0.021	Unpaved Driveway
NVA_55	424663.532	4838689.999	388.321	388.31	-0.011	Unpaved Driveway
NVA_56	424661.9899	4838696.4316	388.341	388.37	0.029	Unpaved Driveway
NVA_57	424701.7778	4838575.4389	390.033	390.04	0.007	Unpaved Shoulder
NVA_58	405533.3707	4836693.8481	77.008	76.98	-0.027	Paved Road
NVA_59	405552.6565	4836662.8700	77.105	77.08	-0.025	Unpaved Parking Lot
NVA_60	405535.2565	4836675.5045	77.424	77.4	-0.024	Short Grass
NVA_61	405555.3097	4836615.1607	77.706	77.67	-0.036	Paved Shoulder
NVA_62	367615.5977	4720452.7775	271.854	271.88	0.026	Unpaved Driveway
NVA_63	367787.2282	4767897.2027	122.482	122.49	0.008	Paved Road
NVA_64	390553.4967	4808671.7763	135.386	135.36	-0.026	Paved Shoulder
NVA_65	370184.4659	4808893.2627	105.859	105.87	0.011	Unpaved Driveway
NVA_66	380552.9232	4784745.4976	131.322	131.33	0.008	Short Grass
NVA_67	383622.7838	4729815.5709	225.784	225.78	-0.004	Paved Parking Lot
NVA_68	361012.0584	4782562.3438	137.283	137.37	0.087	Short Grass
NVA_69	396380.2931	4786621.1517	121.033	121.03	-0.003	Paved Parking Lot

Section 6: Summary of Classified LAS and DEM Results

A brief summary of accuracy assessments performed with the classified LiDAR data and hydroflattened DEM is provided below.

Non-Vegetated Vertical Accuracy (NVA) Check Points and Vegetated Vertical Accuracy (VVA) Check Points were also independently surveyed and compared to the DEM data. For the NVA checkpoints, the overall RMSEz is 3.1 centimeters. This compares favorably to the USGS specification of < 10 cm. (USGS “LiDAR Base Specification vers. 1.3”, Page 24, Table 4;). The NVA at the 95% confidence level is 6.1 centimeters which is within the USGS specification of < 19.6 cm. (USGS “LiDAR Base Specification vers. 1.3”, Page 24, Table 4;)

Vegetated Vertical Accuracy (VVA) Check Point RMSEz is 6.6 centimeters and the VVA at the 95th percentile is 11.9 centimeters. The USGS specification for VVA at the 95th percentile is < 29.4 cm. (USGS “LiDAR Base Specification vers. 1.3”, Page 24, Table 4;)

Section 7: Classification

Classification was conducted in accordance with USGS publication “LiDAR Base Specification, Version 1.3” February 2018; Table 5. “Minimum light detection and ranging data classification scheme”; Page 24

Code	Description
1	Processed, but unclassified.
2	Bare earth.
7	Low noise.
9	Water.
17	Bridge decks.
18	High noise.
20	Ignored ground
21	Snow
22	Temporal exclusion

The calibrated dataset, omitting any crosslines used in the calibration process, was used to create the classification point cloud dataset. The classification point cloud was produced with TerraScan in LAS file format with attributes for each return including but not limited to time, easting, northing, elevation, intensity, return number, and return classification. Utilizing both automated and manual methods, the point cloud was filtered to identify bare-earth surface points removing above ground features and erroneous noise.

The TerraSolid suite of software packages were used for the automated method of macro based bare-earth filtering. Multiple iterations of automated filtering were utilized to address the ever changing terrain while retaining a homogenous surface. After automated filtering, manual editing was completed using TerraScan and TerraModeler in MicroStation. Editing was performed to ensure that 100% of the identified bare-earth surface was visually inspected for errors, completeness, and accuracy. In addition, hydro features were classified but not verified against vector features. Bridge decks were also classified. Points floating above or positioned below the bare earth surface were designated as low noise and high noise.

Breaklines were compiled for this project. The 3D lines were compiled for rivers and streams over 30 m wide. The breaklines were utilized to generate hydro-flattened water features. The breaklines were incorporated within the Digital Elevation Model (DEMS) to create hydro-flattened DEMS. Breaklines were delivered in ESRI shapefile format.

Section 8: Final Classified LAS and DEM QA/QC

Both automated and manual procedures were utilized to check the final products prior to delivery. Using TerraScan and LP360, the completeness, classification, headers, and attributes were checked for consistency and compliance with project specifications. GeoCue and Global Mapper were used for a final bare earth surface review.

TerraScan:

- 3) Generates relative and absolute adjustment reports;
 - b) The Ground Control and/or Check Points are loaded into Terrascan using a function called “Output Control Report”. Using the ground class, a control report is generated and examined to determine whether the Dz is within tolerance of the specifications.

LP 360

- 1) Check header format;
 - a) Files are loaded into LP360 and the header information displayed. The data is checked to validate correctness and consistency.
- 2) Check version numbers;
- 3) Review the project parameters in the header;

LASTools

- 4) LAS Info used to check completeness of data;
 - b) LASinfo provides additional details in the header to validate project parameters. If an error is discovered, then changes can be made
- 5) Validate project classifications;
 - a) “lasinfo” creates text files that are reviewed to check that only project classifications are populated.
- 6) Using Las-to-Las in “LAS-Tools” data are converted to LAS version 1.4.
 - b) “Las-to-Las” is used to convert the LAS v1.2 files to LAS v1.4. The data is exported with the Point Data Record Format (PDRF) changed for each file from 1 to 6 in order for the file to be converted correctly. Changing the PDRF to 6 is necessary because it supports added elements such as “Overlap” bit flags, Coordinate Reference Systems (CRS) and Well Known Text (WKT). The new version number is also specified in the line of code in order to export tiles whose headers read “1.4”.
- 7) Overlap Points flagged to adhere to specifications.
 - b) “lasoverage” is used to create “Overlap” bit flags along the edges of crossing flightlines.

Global Mapper

- 2) Final DEMs checked for edge-matching, geo-referencing and data voids
 - a. Map catalog is created to load all the data at one time and then is examined using traditional QC/QA methods to validate correctness.
- 3) Overlap points checked for correct classification flag
 - a. LiDAR tiles are loaded into global mapper and points are tag/selected in overlap regions in order to see in the attribute table that the Overlap bit read “Y” for “Yes”.
- 4) Tile names checked to coincide with tile index.
 - a. A tile grid is loaded with labels of the “Photohead” turned on and the corresponding tile is then loaded. If the lidar tile appears in the correct tile, then the tile is named in accordance with the tile grid.
- 5) Calculating NVA and VVA Reports
 - a. The NVA, VVA and Final DEMs of the LiDAR are loaded into Global Mapper to run a statistical report of the elevation differences between features. The elevation difference between the QA points and the DEMs is calculated and embedded, via attribute, to both the NVA and VVA files. These files are then exported from Global Mapper and statistics are calculated.

A summary of the vertical accuracy assessment of the Non-Vegetated Vertical Accuracy (NVA) check points against the final DEM surface can be found in Table 5 below. The coordinates provided are in NAD83 (2011), UTM Zone 18N, NAVD88 (Geoid12B), Meters. Overall, the results proved to be satisfactory. The overall RMSE_z for the NVA checkpoints was 3.1 cm

and compared favorably to the USGS specification of < 10 cm, (USGS “LiDAR Base Specification, vers. 1.3”, Page 24, Table 4). The NVA at the 95% confidence level was 6.1 cm which is less than the USGS specification of < 19.6 cm. (USGS “LiDAR Base Specification, vers. 1.3”, Page 24, Table 4).

For a complete listing of the NVA points, see Table 12

Table 10: NVA Check Point Error Statistics (m)						
Category	# of Points	Min (m)	Max (m)	Mean (m)	Std Dev (m)	RMSE _z (m)
Check Points	69	-0.05	0.092	0.010	0.029	0.031

A summary of the vertical accuracy assessment of the Vegetated Vertical Accuracy (VVA) check points against the final DEM surface can be found in Table 11, below. The coordinates provided are in NAD83 (2011), UTM Zone 18N, NAVD88 (Geoid12B), Meters. Overall, the results proved to be satisfactory. The overall RMSE_z for the VVA checkpoints was 6.6 cm and the VVA at the 95th Percentile was 11.9 cm. The USGS specification for the VVA at the 95th Percentile is < 29.4 cm. (USGS “LiDAR Base Specification, vers. 1.3”, Page 24, Table 4).

For a complete listing of the VVA points, see Table 13.

Table 11: VVA Check Point Error Statistics (m)						
Category	# of Points	Min (m)	Max (m)	Mean (m)	Std Dev (m)	RMSE _z (m)
Check Points	56	-0.118	0.145	0.033	0.057	0.066

Table 12: NVA Check Point Assessment (DEM) (m)

Point ID	Easting	Northing	Known Z	DEM Z	Delta Z	Description
NVA19	355819.4257	4756744.6563	137.9350	137.9910	0.0560	Paved Parking Lot
NVA21	355795.9040	4756734.8545	137.1610	137.2160	0.0550	Short Grass
NVA20	355861.6932	4756675.7588	138.8980	138.9530	0.0550	Unpaved Parking Lot
NVA51	414491.9113	4816448.6759	179.4510	179.4570	0.0060	Short Grass
NVA49	414556.1192	4816425.0469	178.3390	178.3820	0.0430	Unpaved Shoulder
NVA50	414579.3916	4816415.5129	177.7480	177.7600	0.0120	Paved Road
NVA24	367710.6204	4767922.3013	122.9160	122.9040	-0.0120	Unpaved Shoulder
NVA63	367787.2282	4767897.2027	122.4820	122.4940	0.0120	Paved Road
NVA22	367806.5381	4767977.2498	120.4250	120.4390	0.0140	Paved Road
NVA23	367785.4638	4767933.7493	122.9780	123.0130	0.0350	Unpaved Road
NVA54	435223.7040	4816190.7793	295.8590	295.8910	0.0320	Unpaved Driveway
NVA53	435224.8043	4816175.9705	295.8950	295.9280	0.0330	Unpaved Driveway
NVA52	435243.6099	4816173.8743	296.3160	296.3630	0.0470	Paved Road
NVA68	361012.0584	4782562.3438	137.2830	137.3540	0.0710	Short Grass
NVA27	361021.3280	4782579.3961	137.0490	137.0820	0.0330	Unpaved Driveway
NVA26	361052.7658	4782238.2598	134.8080	134.9000	0.0920	Flat Dirt Area Beside Road
NVA25	361048.2111	4782219.1996	133.9910	134.0670	0.0760	Paved Road
NVA56	424661.9899	4838696.4316	388.3410	388.3960	0.0550	Unpaved Driveway
NVA57	424701.7778	4838575.4389	390.0330	390.0550	0.0220	Unpaved Shoulder
NVA55	424663.5320	4838689.9990	388.3210	388.3040	-0.0170	Unpaved Driveway
NVA10	396364.4994	4717823.0919	433.6680	433.6610	-0.0070	Paved Road
NVA11	396377.6958	4717822.5505	433.7070	433.7210	0.0140	Short Grass
NVA12	396452.5100	4717813.8178	433.8650	433.8710	0.0060	Unpaved Shoulder
NVA61	405555.3097	4836615.1607	77.7060	77.6790	-0.0270	Paved Shoulder
NVA59	405552.6565	4836662.8700	77.1050	77.0820	-0.0230	Unpaved Parking Lot
NVA60	405535.2565	4836675.5045	77.4240	77.3990	-0.0250	Short Grass
NVA58	405533.3707	4836693.8481	77.0080	76.9800	-0.0280	Paved Road
NVA01	367583.6399	4720462.2314	272.1830	272.2030	0.0200	Paved Road
NVA03	367611.2721	4720462.7768	271.5700	271.5910	0.0210	Paved Shoulder
NVA62	367615.5977	4720452.7775	271.8540	271.8740	0.0200	Unpaved Driveway
NVA02	367588.0461	4720475.8898	271.8870	271.9120	0.0250	Short Grass
NVA47	387093.5864	4819187.6741	82.9660	82.9450	-0.0210	Short Grass
NVA46	387077.2547	4819164.6767	83.7540	83.7210	-0.0330	Paved Parking Lot
NVA48	387024.9549	4819164.0580	82.6030	82.5910	-0.0120	Unpaved Shoulder
NVA34	371475.8578	4789908.8704	136.8670	136.9000	0.0330	Paved Parking Lot
NVA36	371499.3531	4789878.2463	135.5770	135.6060	0.0290	Unpaved Driveway
NVA35	371481.4678	4789888.1775	136.5230	136.5410	0.0180	Short Grass
NVA37	370284.1797	4808900.4029	109.1980	109.2420	0.0440	Unpaved Driveway
NVA39	370244.5922	4808907.1154	108.1650	108.1980	0.0330	Short Grass
NVA65	370184.4659	4808893.2627	105.8590	105.8680	0.0090	Unpaved Driveway
NVA38	370151.2912	4808895.8009	105.0300	105.0440	0.0140	Paved Road
NVA29	380618.5378	4784748.4295	131.1960	131.1970	0.0010	Unpaved Driveway

Table 12: NVA Check Point Assessment (DEM) (m)

Point ID	Easting	Northing	Known Z	DEM Z	Delta Z	Description
NVA66	380552.9232	4784745.4976	131.3220	131.3390	0.0170	Short Grass
NVA30	380464.6224	4784759.1953	131.7280	131.7700	0.0420	Short Grass
NVA28	380461.8647	4784744.9638	131.7880	131.7930	0.0050	Paved Road
NVA45	390616.1007	4808709.3427	137.2680	137.2180	-0.0500	Unpaved Shoulder
NVA43	390583.1877	4808648.9409	136.4460	136.4120	-0.0340	Paved Road
NVA44	390562.1863	4808651.5314	135.3270	135.3270	0.0000	Unpaved Driveway
NVA64	390553.4967	4808671.7763	135.3860	135.3580	-0.0280	Paved Shoulder
NVA15	364808.3748	4736779.9993	265.6590	265.6650	0.0060	Paved Parking Lot
NVA14	364811.7721	4736818.3793	266.0190	266.0190	0.0000	Short Grass
NVA13	364817.7210	4736902.4720	266.1170	266.1180	0.0010	Paved Road
NVA42	408300.9155	4800878.9753	145.5630	145.5510	-0.0120	Unpaved Driveway
NVA41	408338.8798	4800891.2668	146.3510	146.3330	-0.0180	Paved Road
NVA40	408355.7814	4800909.0334	146.7560	146.7280	-0.0280	Short Grass
NVA04	383606.9292	4729832.9729	225.9870	226.0170	0.0300	Short Grass
NVA67	383622.7838	4729815.5709	225.7840	225.7900	0.0060	Paved Parking Lot
NVA06	383698.5425	4729852.6280	225.9410	225.9330	-0.0080	Loose Gravel
NVA05	383524.9697	4729889.4801	225.3080	225.3120	0.0040	Paved Parking Lot
NVA31	396309.5567	4786678.8125	120.8870	120.8890	0.0020	Paved Parking Lot
NVA32	396310.8408	4786619.2117	122.1830	122.2000	0.0170	Short Grass
NVA69	396380.2931	4786621.1517	121.0330	121.0400	0.0070	Paved Parking Lot
NVA33	396518.3395	4786533.5284	119.1620	119.1840	0.0220	Unpaved Driveway
NVA17	373124.3907	4755074.1383	233.4060	233.3830	-0.0230	Paved Sidewalk
NVA16	373156.5973	4755081.4040	234.4780	234.4840	0.0060	Paved Parking Lot
NVA18	373128.6219	4755112.7574	233.9950	233.9660	-0.0290	Short Grass
NVA8	385927.1003	4745640.7434	299.6670	299.6350	-0.0320	Unpaved Road
NVA7	385956.6594	4745629.4407	299.6370	299.6400	0.0030	Paved Road
NVA9	385891.4026	4745631.3483	301.8350	301.8190	-0.0160	Paved Road

Table 13: VVA Check Point Assessment (DEM) (m)						
Point ID	Easting	Northing	Known Z	DEM Z	Delta Z	Description
VVA01	367508.0940	4720470.7920	270.8480	270.9450	0.0970	Tall Grass
VVA16	355838.8720	4756645.4470	139.5590	139.6250	0.0660	High Grass
VVA17	355833.7940	4756650.3600	139.2550	139.3330	0.0780	Trees
VVA18	355901.8020	4756636.2390	141.3370	141.4180	0.0810	High Weeds
VVA38	414610.8020	4816414.0220	175.7180	175.7920	0.0740	Tall Grass
VVA39	414628.5310	4816418.8920	174.4420	174.5230	0.0810	Trees
VVA20	367782.3770	4767946.7260	122.7000	122.8220	0.1220	Trees
VVA19	367823.7820	4767925.5340	122.8130	122.8540	0.0410	Tall Weeds/Brush
VVA51	367845.0050	4767915.3960	122.6820	122.7090	0.0270	Tall Grass/Brush
VVA42	435220.9440	4816269.4560	294.4520	294.4760	0.0240	Trees
VVA41	435240.8630	4816235.8870	292.0460	292.0800	0.0340	Tall Brush
VVA40	435256.8670	4816222.1750	292.3240	292.3870	0.0630	Tall Brush
VVA21	361046.6710	4782331.5440	135.2440	135.3890	0.1450	Tall Grass
VVA55	361015.3320	4782538.5450	137.0460	137.1510	0.1050	Tall Grass
VVA22	361093.1470	4782303.4660	131.2720	131.3900	0.1180	Trees
VVA46	424684.0770	4838662.1780	386.6210	386.7340	0.1130	Brush
VVA44	424660.6130	4838592.6720	389.2620	389.1440	-0.1180	Trees
VVA43	424683.0894	4838575.7459	389.7670	389.8940	0.1270	Tall Brush
VVA45	424708.8480	4838555.6430	390.6030	390.5690	-0.0340	Tall Brush
VVA8	396354.3650	4717804.3160	434.1080	434.0960	-0.0120	Crop Field
VVA9	396351.7290	4717839.2820	431.5130	431.5770	0.0640	Tall Weeds/Brush
VVA10	396479.9100	4717807.9680	435.2950	435.2820	-0.0130	Trees
VVA49	405571.2280	4836609.4590	77.1310	77.1360	0.0050	Tall Brush
VVA48	405564.1240	4836673.7550	76.4640	76.4450	-0.0190	Weeds/Tall Grass
VVA47	405528.7380	4836711.7580	75.3850	75.4010	0.0160	Trees
VVA50	367622.0000	4720396.7210	272.0830	272.1330	0.0500	Crop Field
VVA02	367571.4160	4720469.5690	271.8660	271.9180	0.0520	Trees
VVA37	387112.8900	4819181.1460	82.9670	82.9800	0.0130	High Brush
VVA36	386997.8780	4819127.7980	83.1010	83.0010	-0.1000	Trees
VVA28	371459.1350	4789923.0330	137.8520	137.9170	0.0650	Tall Weeds/Grass
VVA29	371443.4250	4789930.6200	138.9480	139.0190	0.0710	Trees
VVA30	370275.8300	4808855.6540	107.4220	107.4740	0.0520	Tall Grass/Weeds
VVA53	370084.6210	4808896.2630	102.7630	102.7960	0.0330	Tall Brush/Weeds
VVA31	370144.4350	4808851.7500	101.9340	101.9400	0.0060	Trees
VVA54	380508.4290	4784760.2750	132.2010	132.1570	-0.0440	Tall Grass/Weeds
VVA24	380443.9390	4784736.7250	130.5240	130.5470	0.0230	Tall Grass/Weeds
VVA23	380421.1140	4784741.0530	129.7710	129.8300	0.0590	Trees
VVA34	390609.2230	4808661.1730	136.5820	136.5870	0.0050	Trees
VVA35	390605.6730	4808632.5160	136.3840	136.3480	-0.0360	Tall Grass/Weeds
VVA52	390617.1860	4808618.6340	136.2350	136.2060	-0.0290	Tall Grass/Weeds
VVA11	364807.7580	4736850.9630	265.5060	265.5330	0.0270	Crop Field
VVA12	364808.0250	4736901.9650	265.3680	265.3130	-0.0550	Trees
VVA13	364859.2770	4736922.3500	267.2170	267.1390	-0.0780	Heavy Grass/Weeds
VVA33	408358.5980	4800925.7670	147.4160	147.4480	0.0320	High Grass

Table 13: VVA Check Point Assessment (DEM) (m)						
Point ID	Easting	Northing	Known Z	DEM Z	Delta Z	Description
VVA32	408375.5970	4800901.7920	146.5610	146.6080	0.0470	Trees
VVA03	383681.4810	4729886.1440	225.9760	226.0460	0.0700	Trees
VVA04	383463.0250	4729877.5980	224.6580	224.7300	0.0720	High Brush
VVA56	396252.3580	4786678.6430	122.0370	122.1130	0.0760	Tall Brush
VVA25	396423.3720	4786606.6550	119.1350	119.1860	0.0510	High Brush
VVA26	396466.1250	4786542.4480	118.5000	118.5870	0.0870	High Grass/Weeds
VVA27	396534.2390	4786531.4550	119.7880	119.8730	0.0850	Trees
VVA15	373131.8550	4755145.6550	233.8680	233.8670	-0.0010	Tall Grass
VVA14	373122.3670	4755147.3040	233.6180	233.6220	0.0040	Trees
VVA6	385933.1760	4745549.9450	302.8860	302.8580	-0.0280	Crop Field
VVA5	385922.6390	4745592.8920	300.8720	300.8280	-0.0440	Trees
VVA7	385927.5210	4745650.6830	299.9230	299.9220	-0.0010	High/Tall Brush