New York State
Airborne LiDAR Processing & Accuracy Report

For

Southwest 17, Spring 2017

Prepared For

New York State
Office of Information Technology Services
GIS Program Office
10B Airline Drive,
Albany, New York 12235

Axis Project Number 13367-1706
Lot 17, Area 1 (Spring 2017 Collection Area)

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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 parts of Chautauqua, Cattaraugus, Allegany, Wyoming and Genesee Counties, in western New York State. The project area covered approximately 3,878 square miles or 10,044 square kilometers.

As detailed in the acquisition report for this project, only a portion of the original project area was acquired in the Spring 2017. Collection covered all of Chautauqua County and the western half of Cattaraugus County. The following report describes the data processing and accuracy assessment for the reduced area (1,722 square miles). The remaining area will be processed and reported separately, with ties and checks to ensure consistency.

This project was completed to meet USGS 3D Elevation Program (3DEP) requirements including USGS publication "LiDAR Base Specification", ver. 1.2. 3DEP Quality Level 2 LiDAR data was processed and projected to UTM Zone 17 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 (DEM). 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; Southwest 17; Axis Project 13367-1706"*.

2) A thorough review of the survey techniques and parameters surrounding the field work and processing of the ground control points can be found in a report entitled: "*GNSS Survey Report: 2017 Southwest 17 LiDAR; Ground Control Survey Report*".

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 value of the project Non-Vegetated Vertical Accuracy (NVA) check points;
5) Comparison of the LiDAR DEM data with the surveyed elevation value 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 provided 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 surveyed ground control points. The third assessment compares the swath data with 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 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. 1.2, Page 8, Table 2 identifies that QL2 data will have a swath overlap difference of < 8 cm with a maximum swath difference of +/- 16 cm. For this dataset, the RMSz of the relative adjustment is 3.5 cm and the maximum difference between points observed is 30.2 cm.

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. Thirty-two (32) control points were utilized. For this dataset, the average difference of the LiDAR data with the ground control points is +0.4 cm, with a standard deviation of 4.5 cm and an RMSEz of 4.5 cm.

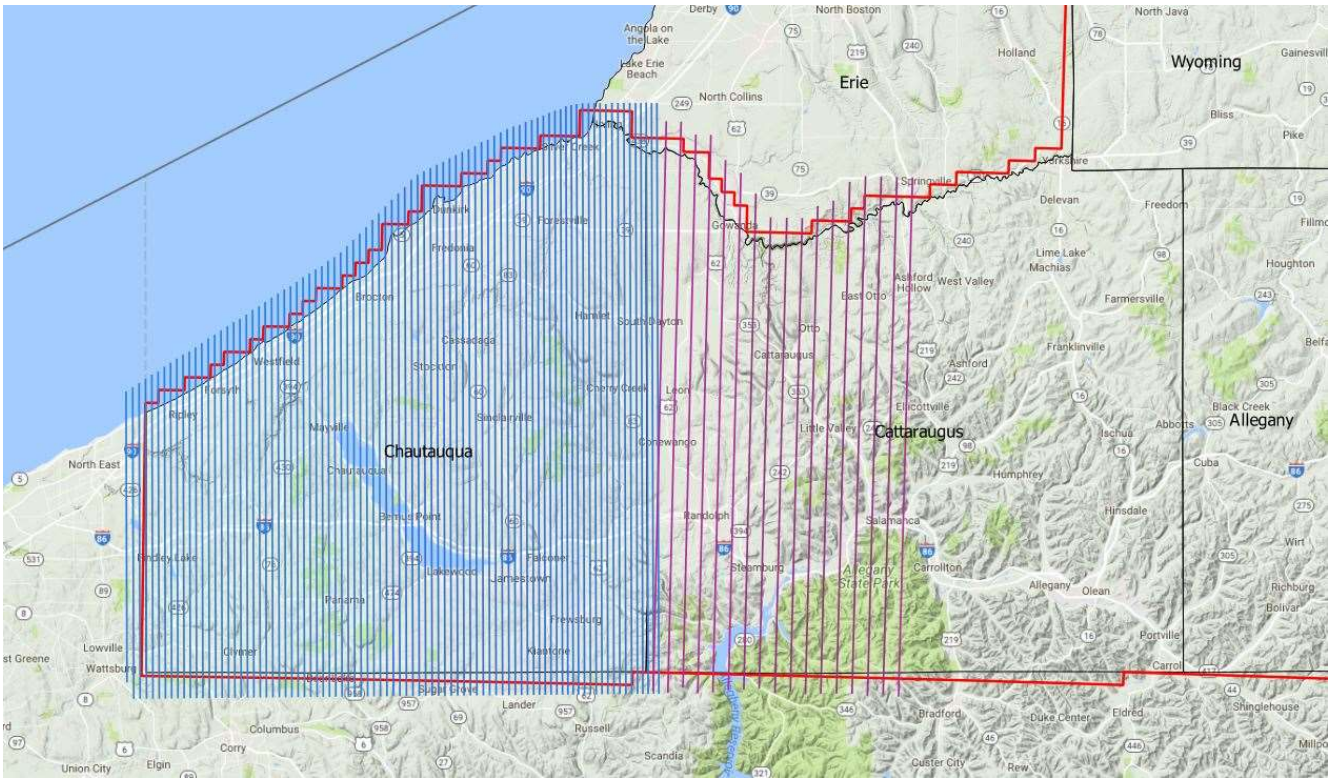
Non-Vegetated Vertical Accuracy (NVA) Check Points were also independently surveyed and compared to the swath data. For the NVA checkpoints, the overall RMSEz is 4.8 centimeters.

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 Southwest 17 Spring LiDAR Actual Flight Line Alignment is displayed below.



Southwest 17 Spring LiDAR Flight Lines

One-hundred, nineteen (119) flight lines including cross strips, were processed. The image above illustrates the lines except for the ten (10) cross strips.

The Aggregate Nominal Pulse Spacing for the Southwest 17 project is 0.51 m with an Aggregate Nominal Pulse Density of 3.7 pts/m^2.

Table 1: Point Cloud Statistics	
Total Points	39,360,928,973
Aggregate Nominal Pulse Spacing (m)	0.51
Aggregate Nominal Pulse Density (pts/m²)	3.7

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: TerraMatch Tie Lines; Average Magnitude per Line (m)							
Line	Z	Line	Z	Line	Z	Line	Z
1	0.010	17	0.009	33	0.009	49	0.011
2	0.010	18	0.010	34	0.009	50	0.010
3	0.009	19	0.014	35	0.013	51	0.010
4	0.010	20	0.012	36	0.014	52	0.010
5	0.011	21	0.009	37	0.010	53	0.011
6	0.010	22	0.009	38	0.010	54	0.011
7	0.010	23	0.011	39	0.010	55	0.011
8	0.010	24	0.011	40	0.009	56	0.009
9	0.010	25	0.010	41	0.010	57	0.009
10	0.010	26	0.011	42	0.011	58	0.010
11	0.009	27	0.010	43	0.011	59	0.010
12	0.009	28	0.010	44	0.011	60	0.009
13	0.009	29	0.009	45	0.010	61	0.010
14	0.010	30	0.010	46	0.010	62	0.011
15	0.009	31	0.010	47	0.009	63	0.011
16	0.009	32	0.010	48	0.010	64	0.013
Line	Z	Line	Z	Line	Z	Line	Z
65	0.013	81	0.011	97	0.027	5003	0.013
66	0.010	82	0.010	98	0.026	5004	0.012
67	0.010	83	0.013	99	0.027	5005	0.016
68	0.010	84	0.014	100	0.027	5006	0.013
69	0.009	85	0.016	101	0.027	5007	0.034
70	0.009	86	0.019	102	0.028	5008	0.033
71	0.009	87	0.020	103	0.027	5009	0.034
72	0.009	88	0.029	104	0.025		
73	0.010	89	0.031	1088	0.027		
74	0.011	90	0.033	1089	0.030		
75	0.010	91	0.032	1090	0.026		
76	0.010	92	0.030	1091	0.027		
77	0.011	93	0.029	1092	0.028		
78	0.010	94	0.024	5000	0.012		
79	0.010	95	0.024	5001	0.012		
80	0.010	96	0.025	5002	0.011		

Table 3: Overall Relative Accuracy (m)	
Category	Mismatch
Average 3D Mismatch	0.02102
Average Z Mismatch	0.02102

Table 4: Internal Observation Statistics (m)			
Category	X	Y	Z
Average Magnitude	0.000	0.000	0.021
RMS Values	0.000	0.000	0.035
Maximum Values	0.000	0.000	0.305
Observation Weight	-	-	0.04138

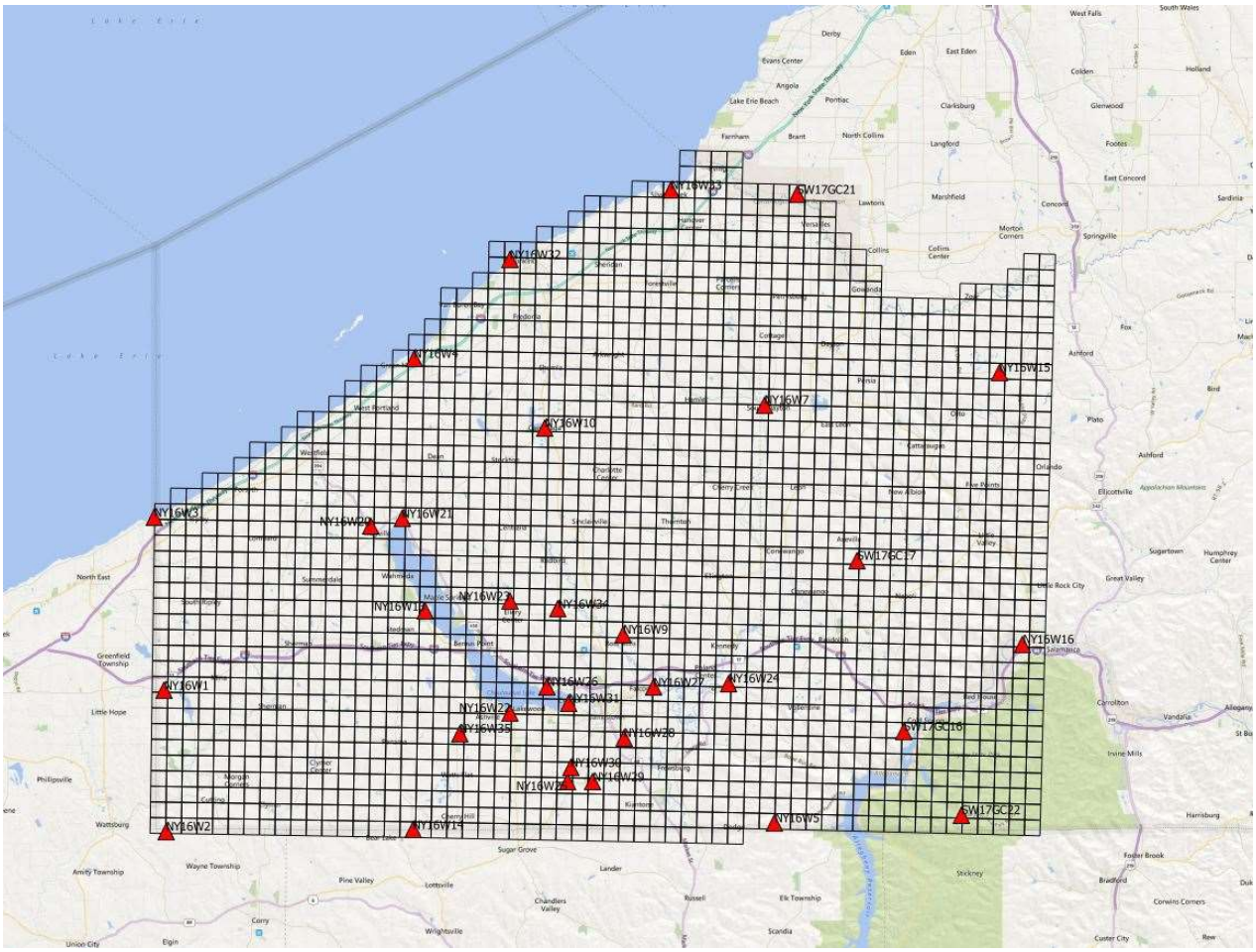
Table 5: TerraMatch Tie Lines	
Category	Observations
Section Lines	16,522,443

Absolute Adjustment Accuracy Results

Twenty-eight (28) of the thirty-two (32) ground control points utilized for Southwest 17 swath adjustments were surveyed for the 2016 New York State West Digital Orthophoto Project. The existing point coordinates were translated from NY State Plane West Zone, NAD83 (2011), NAVD88, Geoid 12B to UTM Zone 17 N, NAD83 (2011), NAVD88, Geoid 12B utilizing Leica Infinity (vers. 2.2) conversion software. A detailed description of the existing points utilized (denoted with the prefix NY16W) can be found in the report entitled *"GNSS Survey Report State Wide Digital Orthophoto Production Lot 16; 2016 West Area Digital Orthophoto Ground Control;"* dated 11-4-2016; delivered under a separate cover.

Axis determined that four (4) additional points were needed for the absolute adjustment. These points are identified with the prefix SW17. The report describing the survey for these points is cited earlier in this document.

A graphic displaying the locations and distribution of the thirty-two (32) ground control points is provided below.



A vertical accuracy assessment of the thirty-two (32) control points against the LiDAR swath surface can be found in the table below. The coordinates provided are in NAD83 (2011), UTM Zone 17N, NAVD88 (Geoid12B), Meters.

Table 6: Ground Control Point Assessment (Swath) (m)						
Point ID	**Easting**	**Northing**	**Known Z**	**Laser Z**	**Description**	**Delta Z**
NY16W1	603172.519	4663665.883	492.455	492.41	Mag hub in north cor of conc drive	-0.045
NY16W2	603533.673	4650196.374	517.409	517.34	Mag hub in NW cor of conc drive	-0.069
NY16W3	601947.766	4680157.147	185.048	185.06	Mag hub in SE cor of conc drive	0.012
NY16W4	626520.557	4695703.58	195.534	195.54	Mag hub in north cor of asphalt	0.006
NY16W5	662006.694	4652095.147	640.849	640.95	Mag hub in SW cor of conc pad	0.101
NY16W7	660088.94	4692007.065	397.461	397.53	Mag nail inside cor of SW	0.069
NY16W9	647067.677	4669806.154	393.745	393.74	Mag hub in SE cor of SW	-0.005
NY16W10	639157.882	4689342.364	405.885	405.92	Mag hub in west cor of conc walk	0.035
NY16W13	628052.193	4671648.609	400.966	400.95	Mag hub in SW cor of conc drive	-0.016
NY16W14	627221.026	4650724.748	461.616	461.59	Mag hub in SW cor of conc slab	-0.026
NY16W15	682435.778	4695629.859	417.577	417.57	Mag hub in SE cor of conc drive	-0.007
NY16W16	685385.913	4669771.685	417.63	417.62	Mag hub in SW inside cor of SW	-0.01
NY16W20	622700.874	4679648.062	451.836	451.8	Mag Hub in NE cor of conc walk	-0.036
NY16W21	625648.931	4680447.575	403.098	403.06	Mag hub in north cor of conc pad	-0.038
NY16W22	636398.791	4662096.726	399.722	399.76	Mag hub in SE cor of conc drive	0.038
NY16W23	636137.424	4672760.557	529.393	529.41	Mag hub in SW cor of conc drive	0.017
NY16W24	657235.769	4665348.028	390.373	390.48	Mag hub in SW cor of paver drive	0.107
NY16W25	641997.822	4655601.166	418.145	418.18	Mag hub in SE cor of asphalt drive	0.035
NY16W26	639846.515	4664667.147	405.209	405.21	Mag hub in SW cor of conc walk	0.001
NY16W27	650053.57	4664806.769	382.003	382.02	Mag Nail in NE cor of conc walk	0.017
NY16W28	647317.062	4659934.269	470.985	470.94	Mag hub in SE cor of conc walk	-0.045
NY16W29	644458.939	4655652.482	398.808	398.77	Mag hub in NE cor of asph drive	-0.038
NY16W30	642258.3	4656972.726	487.479	487.44	Mag hub in SW cor of conc drive	-0.039
NY16W31	641951.144	4663118.974	406.374	406.35	Mag nail in SW cor of conc walk	-0.024
NY16W32	635503.312	4705278.811	183.873	183.87	Mag hub in NW cor of drive	-0.003
NY16W33	650709.366	4712204.001	198.939	198.99	Mag hub in south inside cor of SW	0.051
NY16W34	640766.92	4672100.988	493.209	493.24	Mag hub in NE cor of conc walk	0.031
NY16W35	631557.441	4660047.44	421.932	421.98	Mag nail in SE cor of conc pad	0.048
SW17GC21	662761.225	4712051.037	193.221	193.16	Mag nail in asphalt	-0.061
SW17GC17	669316.172	4677368.716	511.155	511.09	Mag nail in asphalt	-0.065
SW17GC16	674176.947	4661170.689	421.155	421.21	Mag nail in asphalt	0.055
SW17GC22	679922.057	4653310.184	452.511	452.53	Mag nail in corner of sidewalk	0.019

An overall statistical assessment summary of the control points can be found in Table 7 below.

Table 7: Control Point Error Statistics (m)						
Category	**# of Points**	**Min (m)**	**Max (m)**	**Mean (m)**	**Std Dev (m)**	**$RMSE_Z$ (m)**
Control Points	32	-0.069	0.107	0.004	0.045	0.045

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) LASInfo 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 NVA check points against the swath surface can be found in Table 8 below. Of the 80 NVA points surveyed, five (5) were eliminated from the analysis due to questions about the survey accuracy. Overall, the results proved to be satisfactory. The overall $RMSE_z$ for the NVA checkpoints was 4.8 cm and compared favorably to the USGS specification of $\leq$ 10 cm, (USGS *"LiDAR Base Specification",* Page 10, Table 4;). The NVA at the 95% confidence level was 9.3 cm which is less than the USGS specification of $\leq$ 19.6 cm. (USGS *"LiDAR Base Specification",* Page 10, Table 4;).

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	75	-.0.037	0.117	0.032	0.035	0.048

For a complete listing of the NVA points, see Table 9. The coordinates provided are in NAD83 (2011), UTM Zone 17N, NAVD88 (Geoid12B), Meters.

Table 9: NVA Check Point Assessment (swath surface) (m)						
Point ID	**Easting**	**Northing**	**Known Z**	**DEM Z**	**Delta Z**	**Description**
NVA01	680450.270	4679461.750	501.268	501.310	0.042	Flat area in parking lot
NVA02	680523.600	4679380.110	492.294	492.380	0.086	Bare Earth dirt
NVA03	680448.080	4679508.210	501.514	501.580	0.066	Short grass
NVA04	679934.680	4653252.550	449.700	449.750	0.050	Flat area on road
NVA05	679909.170	4653243.100	449.254	449.280	0.026	Flat area in the parking lot
NVA06	679883.750	4653256.250	449.138	449.190	0.052	Short grass
NVA07	662799.550	4712039.720	193.413	193.440	0.027	Flat area in parking lot
NVA08	662756.100	4712058.290	193.225	193.270	0.045	Short grass
NVA09	662705.670	4712055.020	192.460	192.470	0.010	Flat area on the road
NVA10	635681.000	4704901.400	181.755	181.790	0.035	Flat area in parking lot
NVA11	635659.810	4704913.090	182.074	182.090	0.016	Short grass
NVA12	635660.040	4704880.320	181.719	181.720	0.001	Flat area on the road
NVA13	603418.150	4679895.830	201.455	201.520	0.065	Short grass
NVA14	603482.590	4679832.150	201.782	201.830	0.048	Flat area in the road
NVA15	603521.830	4679832.510	201.920	201.970	0.050	Unpaved parking lot
NVA16	603412.590	4652897.050	415.307	415.270	-0.037	Flat area in the road
NVA17	603328.350	4652853.670	417.879	removed	*	Flat area in the road
NVA18	603337.050	4652849.520	416.034	416.030	-0.004	Short grass
NVA19	642103.710	4655349.660	415.575	415.640	0.065	Flat area in parking lot
NVA20	642086.890	4655295.040	415.157	415.210	0.053	Flat dirt area
NVA21	642052.300	4655374.880	416.203	416.290	0.087	Short grass
NVA22	642921.740	4679645.890	405.043	405.100	0.057	Flat area in parking lot
NVA23	642828.580	4679685.250	405.811	405.870	0.059	Flat area in unpaved parking lot
NVA24	642975.470	4679666.230	405.487	405.560	0.073	In the playground.
NVA25	642836.700	4679663.890	405.860	405.920	0.060	Flat area in parking lot
NVA26	687225.520	4706494.810	322.965	323.060	0.095	Flat area in the road
NVA27	687151.740	4706464.250	323.129	removed	*	Short grass
NVA28	687211.400	4706490.000	323.062	323.140	0.078	Flat area in the road
NVA29	687305.390	4706504.270	323.607	323.690	0.083	Flat dirt area
NVA30	659962.420	4692093.730	398.248	398.260	0.012	Flat area in parking lot
NVA31	659949.310	4692063.410	398.205	398.230	0.025	Flat area in parking lot
NVA32	659975.860	4692093.760	398.689	398.690	0.001	Short grass
NVA33	660005.480	4692070.950	398.253	398.250	-0.003	Flat dirt area
NVA34	617815.460	4668887.900	482.283	482.310	0.027	Short grass
NVA35	617816.680	4668898.200	482.500	482.500	0.000	Flat area in parking lot
NVA36	617834.840	4668911.630	483.035	483.070	0.035	Flat area in parking lot
NVA37	617738.650	4668857.080	482.139	482.150	0.011	Flat area in parking lot
NVA38	673672.470	4663668.030	431.678	431.740	0.062	Flat area in parking lot
NVA39	673621.320	4663663.510	431.393	431.510	0.117	Short grass
NVA40	665988.970	4669410.180	408.200	408.220	0.020	Flat area in parking lot
NVA41	665922.250	4669399.110	408.716	408.700	-0.016	Flat area in parking lot
NVA42	666014.530	4669290.870	408.565	removed	*	Flat area in parking lot
NVA43	604897.710	4664262.620	443.801	443.870	0.069	Flat area in parking lot
NVA44	604905.390	4664179.480	444.302	removed	*	Flat area in parking lot
NVA45	604912.320	4664266.900	443.983	444.000	0.017	Short grass
NVA46	604822.450	4664205.540	436.979	437.020	0.041	Unpaved parking lot

Table 9: NVA Check Point Assessment (swath surface) (m)						
Point ID	**Easting**	**Northing**	**Known Z**	**DEM Z**	**Delta Z**	**Description**
NVA47	604876.470	4664272.670	442.807	442.840	0.033	Short grass
NVA48	621964.650	4689985.910	234.732	234.720	-0.012	Unpaved parking lot.
NVA49	621924.470	4689965.510	234.946	234.930	-0.016	Flat area in parking lot
NVA50	621934.950	4689970.310	234.730	234.730	0.000	Flat area in parking lot
NVA51	621919.340	4690018.290	233.390	233.380	-0.010	Short grass
NVA52	621851.020	4689934.580	233.123	233.100	-0.023	Flat area in the road
NVA53	638729.840	4688848.140	401.050	401.030	-0.020	Flat area in parking lot
NVA54	638668.830	4688873.020	402.045	402.020	-0.025	Short grass
NVA55	638781.910	4688754.590	400.581	400.560	-0.021	Flat area in parking lot
NVA56	638787.090	4688629.090	399.738	399.730	-0.008	Dirt of the baseball diamond.
NVA57	676310.010	4689155.220	405.187	405.240	0.053	Center of hard surface sidewalk.
NVA58	676237.270	4689177.500	405.275	405.340	0.065	Flat area in parking lot
NVA59	676288.870	4689198.080	404.627	404.630	0.003	Surface of basketball court
NVA60	676261.690	4689201.440	404.905	404.920	0.015	Short grass
NVA61	676049.130	4689197.650	408.361	408.340	-0.021	Unpaved parking lot
NVA62	639938.840	4664654.040	404.221	404.260	0.039	Flat area in parking lot
NVA63	673628.790	4663662.120	431.426	431.490	0.064	On the asphalt sidewalk
NVA64	639987.420	4664637.500	403.787	403.810	0.023	Unpaved parking lot
NVA65	639953.020	4664710.080	404.609	404.650	0.041	Short grass
NVA1000	659953.270	4692103.730	398.164	398.210	0.046	Nail set in grass
NVA1001	659945.400	4692039.220	397.435	397.470	0.035	Nail set in grass
NVA1100	642126.360	4655356.860	415.562	415.620	0.058	Nail set in grass
NVA1101	642018.050	4655378.080	416.365	slope	*	Mag nail set in asphalt
NVA1200	639969.650	4664619.640	403.980	404.030	0.050	Nail set in grass
NVA1201	639870.860	4664615.480	403.556	403.630	0.074	Nail set in grass
NVA1301	642919.650	4679636.820	404.996	405.050	0.054	Nail set in grass
NVA1800	673750.650	4663651.730	432.205	432.280	0.075	Nail set in grass
NVA1900	603310.050	4652852.570	416.512	416.480	-0.032	Mag nail set in asphalt
NVA1901	603429.530	4652904.630	414.984	414.970	-0.014	Mag nail set in asphalt
NVA600	676277.030	4689169.000	404.826	404.920	0.094	Mag nail set in asphalt
NVA800	665980.700	4669321.770	408.757	408.810	0.053	Mag nail set in asphalt
NVA801	665961.600	4669411.810	408.086	408.120	0.034	Mag nail set in asphalt
NVA900	679895.270	4653239.320	448.982	449.010	0.028	Mag nail set in asphalt
NVA901	679985.540	4653265.780	451.062	451.100	0.038	Mag nail set in asphalt

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 compared to the DEM data. For the NVA checkpoints, the overall $RMSE_z$ is 4.3 centimeters. This compares favorably to the USGS specification of $\leq$ 10 cm. (USGS *"LiDAR Base Specification",* Page 10, Table 5;). The NVA at the 95% confidence level is 8.5 centimeters which is within the USGS specification of < 19.6 cm. (USGS *"LiDAR Base Specification",* Page 10, Table 5;)

VVA Check Point RMSEz is 9.3 centimeters and the VVA at the 95th percentile is 15.3 centimeters. The USGS specification for VVA at the 95th percentile is < 29.4 cm. (USGS *"LiDAR Base Specification",* Page 10, Table 5;)

Section 7: Classification

Classification was conducted in accordance with USGS publication **"***LiDAR Base Specification*", Version 1.2 November 2014; Table 6. "*Minimum classified point cloud classification scheme";* Page 11.

Code	Description
1	Processed, but unclassified.
2	Bare earth.
7	Low noise.
9	Water
10	Ignored Ground
17	Bridge decks.
18	High noise.

The calibrated dataset, omitting any crosslines used in the calibration process, was used to create the classification point cloud dataset. Also omitted were lines 001 and 002 because they were outside the requested DEM extent. Additionally, line 104 was withheld for later use in the transition to planned additional collection on the eastern edge.

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 and for water bodies 2 acres or larger. 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:

1) Generates relative and absolute adjustment reports;
    a) 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

1) LASInfo 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) Validate project classifications;
   a) "lasinfo" creates text files that are reviewed to check that only project classifications are populated.
3) Using Las-to-Las in "LAS-Tools" data are converted to LAS version 1.4.
   a) "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".
4) 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) 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.
2) 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".
3) 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.
4) 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 NVA check points against the final DEM surface can be found in Table 10 below. Overall, the results proved to be satisfactory. The overall $RMSE_z$ for the NVA checkpoints was 4.3 cm and compared favorably to the USGS specification of < 10 cm, (USGS *"LiDAR Base Specification",* Page 10, Table 5;). The NVA at the 95% confidence level was 8.5 cm which is less than the USGS specification of < 19.6 cm. (USGS *"LiDAR Base Specification",* Page 10, Table 5;).

Table 10: NVA Check Point DEM Error Statistics (m)

Category	# of Points	Min (m)	Max (m)	Mean (m)	Std Dev (m)	$RMSE_z$ (m)
Check Points	75	-0.038	0.120	0.025	0.035	0.043

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. Overall, the results proved to be satisfactory. The overall $RMSE_z$ for the VVA checkpoints was 9.3 cm and the VVA at the 95th Percentile was 15.3 cm. The USGS specification for the VVA at the 95th Percentile is < 29.4 cm. (USGS *"LiDAR Base Specification",* Page 10, Table 5;).

Table 11: VVA Check Point DEM Error Statistics (m)						
Category	**# of Points**	**Min (m)**	**Max (m)**	**Mean (m)**	**Std Dev (m)**	**$RMSE_Z$ (m)**
Check Points	53	-0.056	0.291	0.071	0.059	0.093

For a complete listing of the NVA points, see Table 12. The coordinates provided are in NAD83 (2011), UTM Zone 17N, NAVD88 (Geoid12B), Meters.

For a complete listing of the VVA points, see Table 13. The coordinates provided are in NAD83 (2011), UTM Zone 17N, NAVD88 (Geoid12B), Meters.

Table 12: NVA Check Point Assessment (DEM) (m)						
Point ID	**Easting**	**Northing**	**Known Z**	**DEM Z**	**Delta Z**	**Description**
NVA01	680450.270	4679461.750	501.268	501.310	0.042	Flat area in parking lot
NVA02	680523.600	4679380.110	492.294	492.362	0.068	Bare Earth dirt
NVA03	680448.080	4679508.210	501.514	501.586	0.072	Short grass
NVA04	679934.680	4653252.550	449.700	449.702	0.002	Flat area on road
NVA05	679909.170	4653243.100	449.254	449.245	-0.009	Flat area in the parking lot
NVA06	679883.750	4653256.250	449.138	449.161	0.023	Short grass
NVA07	662799.550	4712039.720	193.413	193.419	0.006	Flat area in parking lot
NVA08	662756.100	4712058.290	193.225	193.241	0.016	Short grass
NVA09	662705.670	4712055.020	192.460	192.432	-0.028	Flat area on the road
NVA10	635681.000	4704901.400	181.755	181.769	0.014	Flat area in parking lot
NVA11	635659.810	4704913.090	182.074	182.085	0.011	Short grass
NVA12	635660.040	4704880.320	181.719	181.739	0.020	Flat area on the road
NVA13	603418.150	4679895.830	201.455	201.510	0.055	Short grass
NVA14	603482.590	4679832.150	201.782	201.827	0.045	Flat area in the road
NVA15	603521.830	4679832.510	201.920	201.961	0.041	Unpaved parking lot
NVA16	603412.590	4652897.050	415.307	415.269	-0.038	Flat area in the road
NVA18	603337.050	4652849.520	416.034	416.042	0.008	Short grass
NVA19	642103.710	4655349.660	415.575	415.639	0.064	Flat area in parking lot
NVA20	642086.890	4655295.040	415.157	415.203	0.046	Flat dirt area
NVA21	642052.300	4655374.880	416.203	416.287	0.084	Short grass
NVA22	642921.740	4679645.890	405.043	405.103	0.060	Flat area in parking lot
NVA23	642828.580	4679685.250	405.811	405.864	0.053	Flat area in unpaved parking lot
NVA24	642975.470	4679666.230	405.487	405.530	0.043	In the playground.
NVA25	642836.700	4679663.890	405.860	405.908	0.048	Flat area in parking lot
NVA26	687225.520	4706494.810	322.965	323.085	0.120	Flat area in the road
NVA28	687211.400	4706490.000	323.062	323.156	0.094	Flat area in the road
NVA29	687305.390	4706504.270	323.607	323.654	0.047	Flat dirt area
NVA30	659962.420	4692093.730	398.248	398.255	0.007	Flat area in parking lot
NVA31	659949.310	4692063.410	398.205	398.207	0.002	Flat area in parking lot
NVA32	659975.860	4692093.760	398.689	398.678	-0.011	Short grass
NVA33	660005.480	4692070.950	398.253	398.245	-0.008	Flat dirt area
NVA34	617815.460	4668887.900	482.283	482.314	0.031	Short grass
NVA35	617816.680	4668898.200	482.500	482.518	0.018	Flat area in parking lot
NVA36	617834.840	4668911.630	483.035	483.060	0.025	Flat area in parking lot
NVA37	617738.650	4668857.080	482.139	482.144	0.005	Flat area in parking lot
NVA38	673672.470	4663668.030	431.678	431.733	0.055	Flat area in parking lot
NVA39	673621.320	4663663.510	431.393	431.507	0.114	Short grass
NVA40	665988.970	4669410.180	408.200	408.220	0.020	Flat area in parking lot
NVA41	665922.250	4669399.110	408.716	408.691	-0.025	Flat area in parking lot
NVA43	604897.710	4664262.620	443.801	443.854	0.053	Flat area in parking lot
NVA45	604912.320	4664266.900	443.983	443.974	-0.009	Short grass
NVA46	604822.450	4664205.540	436.979	437.018	0.039	Unpaved parking lot
NVA47	604876.470	4664272.670	442.807	442.828	0.021	Short grass
NVA48	621964.650	4689985.910	234.732	234.723	-0.009	Unpaved parking lot.

Table 12: NVA Check Point Assessment (DEM) (m)						
Point ID	**Easting**	**Northing**	**Known Z**	**DEM Z**	**Delta Z**	**Description**
NVA49	621924.470	4689965.510	234.946	234.913	-0.033	Flat area in parking lot
NVA50	621934.950	4689970.310	234.730	234.710	-0.020	Flat area in parking lot
NVA51	621919.340	4690018.290	233.390	233.382	-0.008	Short grass
NVA52	621851.020	4689934.580	233.123	233.107	-0.016	Flat area in the road
NVA53	638729.840	4688848.140	401.050	401.019	-0.031	Flat area in parking lot
NVA54	638668.830	4688873.020	402.045	402.013	-0.032	Short grass
NVA55	638781.910	4688754.590	400.581	400.569	-0.012	Flat area in parking lot
NVA56	638787.090	4688629.090	399.738	399.724	-0.014	Dirt of the baseball diamond.
NVA57	676310.010	4689155.220	405.187	405.203	0.016	Center of hard surface sidewalk.
NVA58	676237.270	4689177.500	405.275	405.337	0.062	Flat area in parking lot
NVA59	676288.870	4689198.080	404.627	404.652	0.025	Surface of basketball court
NVA60	676261.690	4689201.440	404.905	404.926	0.021	Short grass
NVA61	676049.130	4689197.650	408.361	408.417	0.056	Unpaved parking lot
NVA62	639938.840	4664654.040	404.221	404.250	0.029	Flat area in parking lot
NVA63	673628.790	4663662.120	431.426	431.489	0.063	On the asphalt sidewalk
NVA64	639987.420	4664637.500	403.787	403.818	0.031	Unpaved parking lot
NVA65	639953.020	4664710.080	404.609	404.667	0.058	Short grass
NVA1000	659953.270	4692103.730	398.164	398.200	0.036	Nail set in grass
NVA1001	659945.400	4692039.220	397.435	397.464	0.029	Nail set in grass
NVA1100	642126.360	4655356.860	415.562	415.606	0.044	Nail set in grass
NVA1200	639969.650	4664619.640	403.980	403.607	0.051	Nail set in grass
NVA1201	639870.860	4664615.480	403.556	405.030	0.034	Nail set in grass
NVA1301	642919.650	4679636.820	404.996	432.294	0.089	Nail set in grass
NVA1800	673750.650	4663651.730	432.205	416.491	-0.021	Mag nail set in asphalt
NVA1900	603310.050	4652852.570	416.512	414.963	-0.021	Mag nail set in asphalt
NVA1901	603429.530	4652904.630	414.984	404.849	0.023	Mag nail set in asphalt
NVA600	676277.030	4689169.000	404.826	408.801	0.044	Mag nail set in asphalt
NVA800	665980.700	4669321.770	408.757	408.095	0.009	Mag nail set in asphalt
NVA801	665961.600	4669411.810	408.086	448.954	-0.028	Mag nail set in asphalt
NVA900	679895.270	4653239.320	448.982	451.088	0.026	Mag nail set in asphalt
NVA901	679985.540	4653265.780	451.062	398.200	0.036	Nail set in grass

Table 13: VVA Check Point Assessment (DEM) (m)						
Point ID	**Easting**	**Northing**	**Known Z**	**DEM Z**	**Delta Z**	**Description**
VVA01	680458.610	4679395.980	495.536	495.639	0.103	High grass
VVA02	680519.390	4679484.660	490.886	491.037	0.151	Heavy brush
VVA03	680509.580	4679515.580	494.887	494.986	0.099	Wooded area
VVA04	679982.490	4653230.360	450.319	450.350	0.031	High grass
VVA05	679891.220	4653227.780	448.852	448.858	0.006	High grass
VVA06	662753.160	4712106.690	193.466	193.575	0.109	Brush
VVA07	662692.020	4712092.370	191.961	192.087	0.126	Wooded area
VVA08	662730.040	4712138.640	193.111	193.152	0.041	Crop field
VVA09	635653.430	4704908.480	182.059	182.127	0.068	Brush
VVA10	635593.850	4704860.330	180.467	180.758	0.291	Heavy brush
VVA11	603368.450	4679936.800	201.495	201.604	0.109	Brush
VVA12	603546.670	4679918.740	200.542	200.639	0.097	High grass
VVA13	603404.410	4652912.620	414.036	414.048	0.012	Tall weeds
VVA14	603378.590	4652901.310	415.481	415.425	-0.056	High grass
VVA15	642164.210	4655319.580	414.080	414.182	0.102	Wooded area
VVA16	642242.830	4655344.680	412.320	412.397	0.077	High grass
VVA17	642745.850	4679703.750	405.665	405.693	0.028	Heavy brush
VVA18	642769.220	4679579.920	404.720	404.811	0.091	Heavy brush
VVA19	642901.500	4679556.950	403.783	403.865	0.082	Wooded area
VVA20	687230.810	4706500.390	322.566	322.723	0.157	High grass
VVA21	687199.610	4706494.980	321.775	321.877	0.102	High grass
VVA22	687209.620	4706469.570	322.454	322.561	0.107	Trees
VVA23	687189.800	4706446.700	320.660	320.789	0.129	High grass
VVA24	659965.790	4692017.600	396.215	396.256	0.041	Heavy brush
VVA25	659943.220	4692029.100	397.386	397.432	0.046	High grass
VVA26	617872.040	4668889.060	482.659	482.700	0.041	Wooded area
VVA27	617766.410	4668967.870	483.664	483.695	0.031	Crop field
VVA28	617833.240	4669018.670	484.893	484.913	0.020	High grass
VVA29	665899.070	4669395.750	409.254	409.317	0.063	High grass
VVA30	665903.060	4669350.920	409.638	409.704	0.066	Heavy brush
VVA31	665965.850	4669286.880	409.937	409.973	0.036	Wooded area
VVA32	673698.760	4663684.470	430.096	430.227	0.131	Wooded area
VVA33	604875.150	4664167.870	440.818	440.833	0.015	High grass
VVA34	604942.370	4664177.860	446.391	446.509	0.118	Wooded area
VVA35	604971.780	4664197.810	450.393	450.469	0.076	High grass
VVA36	604974.780	4664150.350	450.473	450.508	0.035	Wooded area
VVA37	621989.410	4689958.930	233.914	233.913	-0.001	Crop field
VVA38	621931.820	4690072.240	230.372	230.419	0.047	Wooded area
VVA39	621827.910	4690006.410	229.146	229.101	-0.045	High grass
VVA40	621853.410	4689929.830	233.170	233.167	-0.003	High grass
VVA41	638769.000	4688845.120	401.266	401.296	0.030	Crop field
VVA42	638702.310	4688718.440	400.351	400.333	-0.018	High grass
VVA43	638772.940	4688707.670	398.912	399.013	0.101	Wooded area
VVA44	638852.160	4688658.820	399.466	399.460	-0.006	High grass

Table 13: VVA Check Point Assessment (DEM) (m)						
Point ID	**Easting**	**Northing**	**Known Z**	**DEM Z**	**Delta Z**	**Description**
VVA45	676036.750	4689245.170	407.406	407.461	0.055	High grass
VVA46	675992.680	4689289.660	407.044	407.148	0.104	High grass
VVA47	676029.670	4689345.710	405.323	405.450	0.127	High Grass
VVA48	675982.740	4689267.730	409.259	409.434	0.175	Heavy brush
VVA49	675967.440	4689245.720	415.654	415.729	0.075	Wooded area
VVA50	639901.300	4664605.940	403.529	403.611	0.082	Weeds
VVA51	639862.780	4664589.650	403.495	403.612	0.117	High grass
VVA52	639831.980	4664599.310	403.875	403.922	0.047	Trees
VVA53	673673.030	4663652.990	430.585	430.694	0.109	Heavy brush