New York State
Airborne LiDAR Processing & Accuracy Final Report

For

Southwest 17-B, Fall 2017

Prepared For

New York State
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GIS Program Office
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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 3,906 square miles or 10,116 square kilometers.

As detailed in the acquisition report for this project, this completes the acquisition for the original Southwest 17 project area. The initial acquisition occurred in the Spring of 2017 and covered all of Chautauqua and the western half of Cattaraugus County. The second acquisition occurred in the Fall of 2017 and covered the eastern half of Cattaraugus County, the portion of the project in Allegany County, Wyoming County and the portion of the project in southern Genesee County. The Fall 2017 acquisition effort consisted of acquiring airborne LiDAR for an area of approximately 2,185 square miles.

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 (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; Southwest 17-B (Fall)"; Axis Project 13367-1710.*

2) Information related to the airborne LiDAR reacquisition which occurred in April, 2018, may be found in the report entitled: *"New York State Airborne LiDAR Acquisition Report Addendum; Southwest 17-B (Fall)"; Axis Project 13367-1710 and dated July, 2018.*

3) 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 17; 2017 Southwest 17B (Fall) LiDAR Ground Control and Check Point Survey Report*". Dated 02-29-2018.

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. 1.2, 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 2.3 cm and the maximum difference between points observed is 16.9 cm. (one point from 2.8 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. Seventeen (17) control points were utilized. For this dataset, the average difference of the LiDAR data with the ground control points is -0.8 cm, with a standard deviation of 3.4 cm and an RMSEz of 3.5 cm.

Non-Vegetated Vertical Accuracy (NVA) Check Points were also independently surveyed and compared to the swath data. For the NVA checkpoints, the overall $RMSE_z$ is 3.4 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 3.2 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 6.3 centimeters which is within the USGS specification of < 19.6 cm. (USGS *"LiDAR Base Specification",* Page 10, Table 5;)

Vegetated Vertical Accuracy (VVA) Check Point RMSEz is 8.4 centimeters and the VVA at the 95th percentile is 16.5 centimeters. The USGS specification for VVA at the 95th percentile is < 29.4 cm. (USGS *"LiDAR Base Specification",* Page 10, Table 5;)

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-B Fall LiDAR Actual Flight Line Alignment is displayed below (Figure 1). The re-flight lines are displayed in the second image below (Figure 2). Seventy-two (72) flight lines were acquired for completing the Southwest 17-B project area. Nine (9) re-flight lines were acquired.

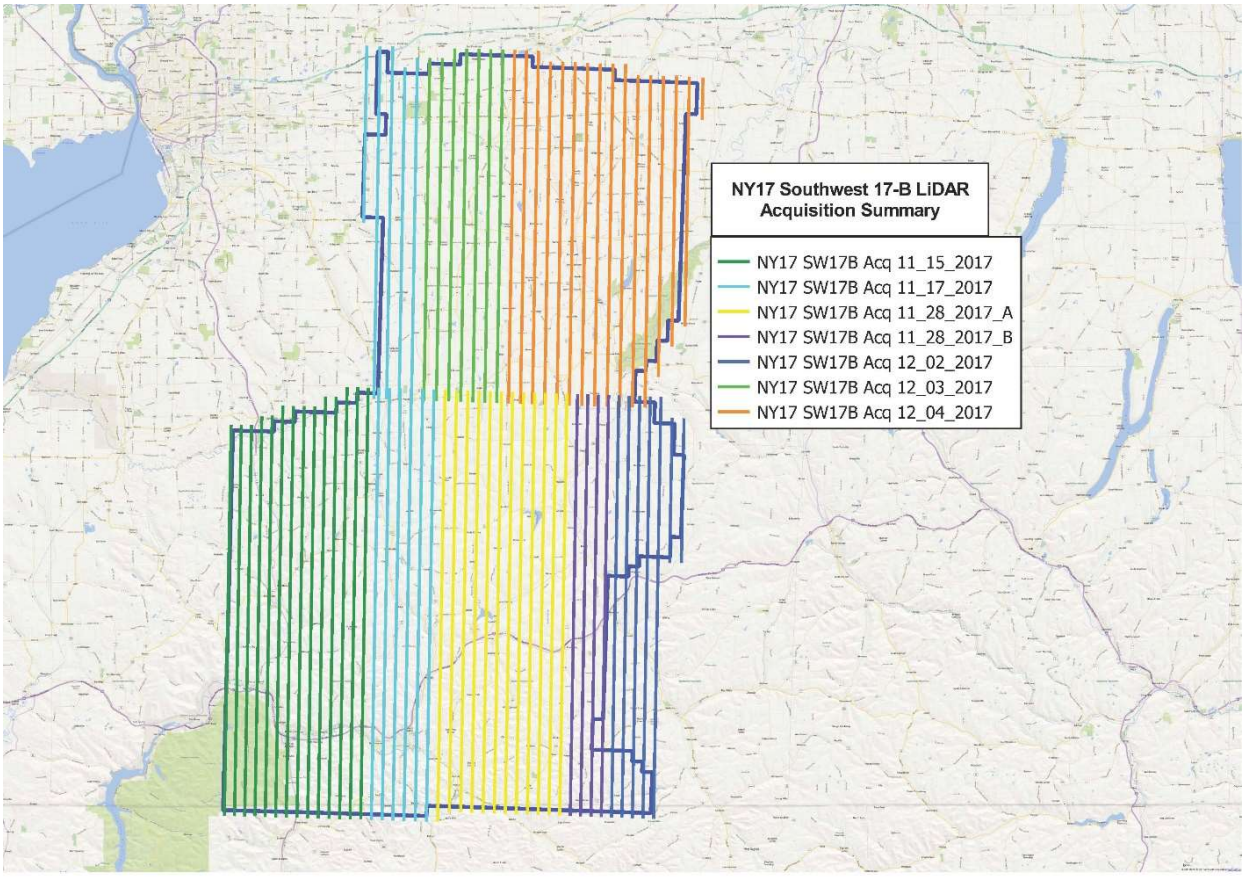

Figure 1: Southwest 17-B Actual Flight Lines Acquired (Fall 2017Acquisition)

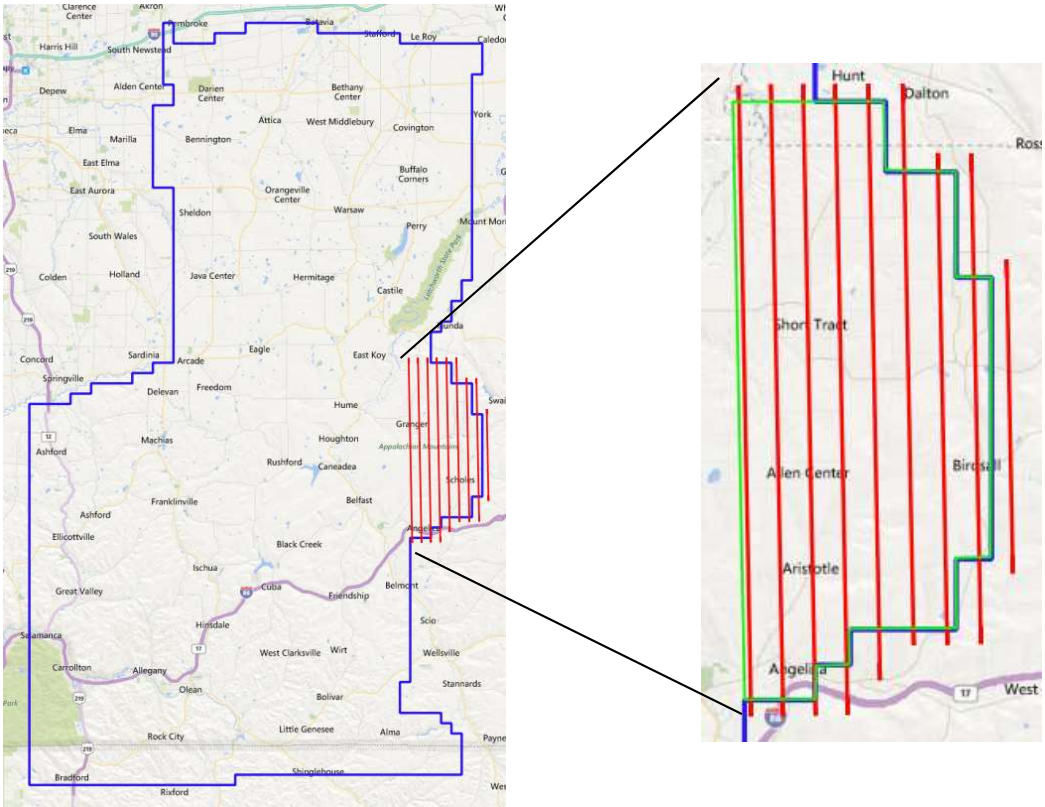

Figure 2: Southwest 17-B Actual Re-Flight Lines Acquired (Spring 2018 Acquisition)

The Aggregate Nominal Pulse Spacing for the Southwest 17-B project is 0.39 m with an Aggregate Nominal Pulse Density of 6.3 pts/m^2.

Table 1: Point Cloud Statistics	
Total Points	38,446,021,203
Aggregate Nominal Pulse Spacing (m)	.3969
Aggregate Nominal Pulse Density (pts/m^2)	6.3984

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	0.016	9	0.017	17	0.016	25	0.035
2	0.017	10	0.017	18	0.016	26	0.037
3	0.017	11	0.017	19	0.016	27	0.038
4	0.016	12	0.017	20	0.017	28	0.038
5	0.017	13	0.017	21	0.026	29	0.037
6	0.017	14	0.017	22	0.031	30	0.034
7	0.017	15	0.017	23	0.031	31	0.034
8	0.017	16	0.017	24	0.031	32	0.033

Table 2: TerraMatch Tie Lines; Average Magnitude per Line (m)							
Line	Z	Line	Z	Line	Z	Re-Flights	
33	0.037	46	0.015	59	0.021	Line	Z
34	0.034	47	0.015	60	0.021	1036	0.018
35	0.035	48	0.015	61	0.023	1037	0.018
36	0.033	49	0.022	62	0.020	1038	0.016
37	0.032	50	0.020	63	0.019	1039	0.014
38	0.035	51	0.020	64	0.020	1040	0.013
39	0.032	52	0.022	65	0.021	1041	0.013
40	0.032	53	0.025	66	0.020	1042	0.012
41	0.026	54	0.025	67	0.019	1043	0.014
42	0.021	55	0.023	68	0.019	1044	0.013
43	0.019	56	0.020	69	0.018		
44	0.013	57	0.021	70	0.016		
45	0.014	58	0.020	71	01015		

Table 3: Overall Relative Accuracy (m)	
Category	Mismatch
Average 3D Mismatch	0.01631
Average Z Mismatch	0.01631

Table 4: Internal Observation Statistics (m)			
Category	X	Y	Z
Average Magnitude	0.0	0.0	0.016
RMS Values	0.0	0.0	0.024
Maximum Values	0.0	0.0	0.169
Observation Weight			8227793

Table 5: TerraMatch Tie Lines	
Category	Observations
Surface Lines	360167

Absolute Adjustment Accuracy Results

A graphic (Figure 3) displaying the locations and distribution of the seventeen (17) ground control points is provided below.

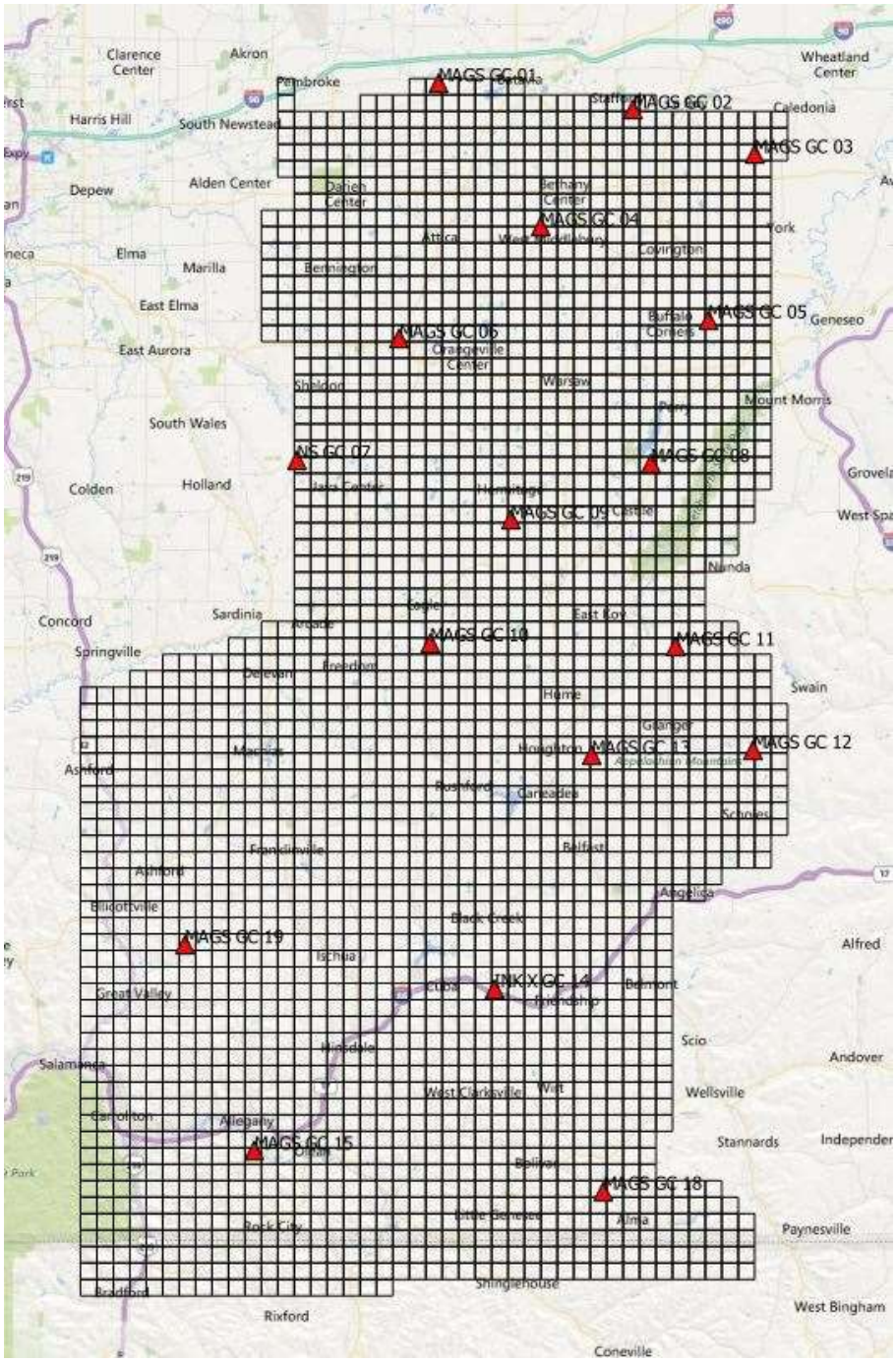

Figure 3: Seventeen (17) Ground Control Locations

A vertical accuracy assessment of the seventeen (17) 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**
MAGS GC_01	720146.094	4762101.487	271.982	271.990	Mag nail set in asphalt	0.008
MAGS GC_02	737937.588	4759630.454	282.041	282.070	Mag nail set in asphalt	0.029
MAGS GC_03	748967.967	4755589.299	280.668	280.680	Mag nail set in corner of stop bar	0.012
MAGS GC_04	729472.539	4748944.521	466.507	466.540	Mag nail set end of paint line	0.033
MAGS GC_05	744748.685	4740529.623	426.865	426.870	Mag nail set end of paint line	0.005
MAGS GC_06	716595.319	4738738.906	504.009	503.980	Mag nail set in asphalt	-0.029
NS GC_7	707216.602	4727728.019	420.368	420.330	Nail set in gravel parking lot	-0.038
MAGS GC_08	739532.119	4727420.866	430.830	430.800	Mag nail set end of paint line	-0.030
MAGS GC_09	726732.050	4722253.921	584.322	584.330	Mag nail set in asphalt	0.008
MAGS GC_10	719377.622	4711067.514	608.174	608.180	Mag nail set in asphalt	0.006
MAGS GC_11	741853.139	4710692.537	352.311	352.260	Mag nail set in asphalt	-0.051
MAGS GC_12	748856.533	4701294.097	508.649	508.710	Mag nail set in asphalt	0.061
MAGS GC_13	734127.360	4700797.448	365.637	365.570	Mag nail set end of paint line	-0.067
INK X GC_14	725232.522	4679520.892	454.620	454.630	Ink X at corner of paint lines	0.010
MAGS GC_15	703374.711	4664724.020	429.179	429.150	Mag nail set end of paint line	-0.029
MAGS GC_18	735186.829	4661068.101	501.093	501.040	Mag nail set corner of blue paint	-0.053
MAGS GC_19	697012.268	4683543.665	502.948	502.930	Mag nail set in asphalt	-0.018

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 17N, 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	17	-0.067	0.061	-0.008	0.034	0.035

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 17N, NAVD88 (Geoid12B), Meters. Overall, the results proved to be satisfactory. The overall $RMSE_z$ for the NVA checkpoints was 3.4 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 6.7 cm which is less than the USGS specification of $\leq$ 19.6 cm. (USGS *"LiDAR Base Specification",* Page 10, Table 4;).

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

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	77	-0.074	0.019	-0.020	0.028	0.034

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

Point ID	Easting	Northing	Known Z	DEM Z	Delta Z	Description
NVA_01	720153.980	4762119.070	271.899	271.910	0.011	Paved parking lot
NVA_02	720153.120	4762109.950	271.870	271.880	0.010	Paved parking lot
NVA_03	720101.340	4762093.960	271.815	271.810	-0.005	Unpaved parking lot
NVA_04	737940.750	4759616.050	282.384	282.390	0.006	Paved road
NVA_05	737932.660	4759597.790	282.534	282.550	0.016	Unpaved shoulder
NVA_06	737930.300	4759624.690	282.174	282.180	0.006	Flat area in road pavement
NVA_08	748941.480	4755583.470	280.795	280.800	0.005	Paved shoulder
NVA_10	729475.460	4748945.110	466.426	466.410	-0.016	Paved shoulder
NVA_11	729462.440	4748955.430	466.656	466.670	0.014	Paved road
NVA_12	729473.540	4748981.390	465.366	465.370	0.004	Flat dirt area beside the road shoulder
NVA_13	744691.190	4740519.480	425.681	425.700	0.019	Unpaved shoulder
NVA_14	744745.470	4740522.780	426.593	426.600	0.007	Paved road
NVA_15	744762.830	4740542.730	426.739	426.740	0.001	Unpaved driveway
NVA_16	716620.860	4738835.750	504.664	504.590	-0.074	Broken pavement area
NVA_17	716604.820	4738739.040	504.368	504.310	-0.058	Paved road
NVA_18	716606.960	4738835.550	504.320	504.260	-0.060	Broken pavement area
NVA_19	707213.650	4727530.590	423.444	423.400	-0.044	Unpaved parking lot
NVA_20	707244.310	4727530.910	422.201	422.170	-0.031	Short grass
NVA_21	707262.180	4727507.760	422.095	422.040	-0.055	Unpaved driveway
NVA_22	739528.030	4727447.000	430.989	430.950	-0.039	Paved parking lot
NVA_23	739533.110	4727456.170	430.912	430.930	0.018	Short grass
NVA_24	739527.510	4727405.980	430.885	430.840	-0.045	Paved parking lot
NVA_25	726209.810	4722058.640	593.418	593.420	0.002	Unpaved road
NVA_26	726231.240	4722247.920	590.113	590.110	-0.003	Paved road
NVA_27	726238.520	4722211.810	590.682	590.680	-0.002	Unpaved road
NVA_28	719377.680	4711081.780	607.892	607.910	0.018	Short grass
NVA_29	719370.970	4711061.060	608.272	608.280	0.008	Paved road
NVA_30	719337.680	4711074.800	608.094	608.080	-0.014	Paved road

Table 9: NVA Check Point Assessment (swath surface) (m)						
Point ID	**Easting**	**Northing**	**Known Z**	**DEM Z**	**Delta Z**	**Description**
NVA 31	741853.730	4710666.710	351.327	351.290	-0.037	Short grass
NVA 32	741856.130	4710682.820	352.121	352.080	-0.041	Paved road
NVA 33	741841.300	4710671.660	351.807	351.740	-0.067	Paved road
NVA 34	748829.260	4701289.910	509.198	509.180	-0.018	Paved parking lot
NVA 35	748825.680	4701284.080	508.605	508.620	0.015	Short grass
NVA 36	748898.650	4701293.440	508.018	507.990	-0.028	Short grass/dirt
NVA 37	734138.800	4700779.810	365.517	365.470	-0.047	Paved parking lot
NVA 38	734211.090	4700790.040	365.044	365.030	-0.014	Short grass
NVA 39	734194.000	4700834.840	365.332	365.290	-0.042	Paved parking lot
NVA 40	734219.860	4700886.710	365.722	365.670	-0.052	Unpaved road
NVA 41	725172.360	4679527.450	454.631	454.620	-0.011	Paved parking lot
NVA 42	725232.230	4679523.560	454.563	454.580	0.017	Paved parking lot
NVA 43	725239.130	4679541.900	454.477	454.490	0.013	Paved parking lot
NVA 44	703358.640	4664723.310	429.146	429.110	-0.036	Paved parking lot
NVA 45	703323.260	4664686.980	429.225	429.160	-0.065	Paved parking lot
NVA 46	703312.330	4664701.520	428.956	428.950	-0.006	Short grass
NVA 53	734908.200	4660944.860	495.165	495.100	-0.065	Paved sidewalk
NVA 54	734873.460	4660933.010	493.967	493.900	-0.067	Short grass
NVA 55	734885.510	4660926.280	494.174	494.120	-0.054	Paved road
NVA 56	697019.790	4683543.980	503.103	503.070	-0.033	Paved road
NVA 57	697043.470	4683600.140	503.202	503.180	-0.022	Unpaved driveway
NVA 58	696982.700	4683535.950	501.324	501.330	0.006	Short grass
NVA 74	697318.680	4652079.470	439.020	439.020	0.000	Paved parking lot
NVA 75	697249.310	4652089.750	432.905	432.900	-0.005	Unpaved parking lot
NVA 76	697301.640	4652094.600	438.277	438.280	0.003	Short grass
NVA 81	689615.420	4706212.620	397.688	397.690	0.002	Paved parking lot
NVA 82	689601.770	4706214.390	397.652	397.660	0.008	Short grass
NVA 83	689615.710	4706128.530	397.709	397.720	0.011	Paved parking lot
NVA 84	689558.930	4706408.540	398.902	398.880	-0.022	Unpaved parking lot
NVA 85	706168.920	4758865.400	260.123	260.090	-0.033	Paved road
NVA 86	734934.800	4660971.770	498.097	498.030	-0.067	Paved Sidewalk
NVA 87	706286.110	4758872.230	260.065	260.040	-0.025	Unpaved shoulder
NVA 88	734926.420	4660953.070	496.942	496.890	-0.052	Playground surface
NVA 89	706241.440	4758879.570	259.289	259.260	-0.029	Paved road
NVA 98	706399.140	4698804.100	509.336	509.330	-0.006	Paved parking lot
NVA 99	706415.930	4698826.920	509.522	509.470	-0.052	Unpaved parking lot
NVA 100	706361.300	4698812.650	509.058	509.010	-0.048	Paved parking lot
NVA 101	706349.160	4698811.280	509.042	509.050	0.008	Short grass
NVA 102	720166.230	4762081.910	272.227	272.240	0.013	Paved road
NVA 103	744772.780	4740509.750	426.195	426.170	-0.025	Paved road
NVA 104	719384.920	4711070.640	608.064	608.060	-0.004	Unpaved shoulder
NVA 105	739119.140	4678663.690	453.138	453.080	-0.058	Paved road
NVA 106	739182.370	4678714.780	450.204	450.170	-0.034	Short grass
NVA 107	739278.620	4678668.460	448.905	448.880	-0.025	Paved parking lot
NVA_A1	703376.830	4664704.590	429.473	429.410	-0.063	Paved parking lot
NVA_A2	734941.470	4660947.980	496.942	496.880	-0.062	Paved parking lot

Table 9: NVA Check Point Assessment (swath surface) (m)						
Point ID	**Easting**	**Northing**	**Known Z**	**DEM Z**	**Delta Z**	**Description**
NVA_A3	719374.080	4711039.620	608.334	608.320	-0.014	Paved road
NVA_A4	720054.440	4762058.820	272.030	272.040	0.010	Paved shoulder
NVA_A5	748970.010	4755552.520	280.669	280.680	0.011	Paved road

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 3.2 centimeters. This compares favorably to the USGS specification of < 10 cm. (USGS "LiDAR Base Specification", Page 10, Table 5;). The NVA at the 95% confidence level is 6.3 centimeters which is within the USGS specification of < 19.6 cm. (USGS "LiDAR Base Specification", Page 10, Table 5;)

Vegetated Vertical Accuracy (VVA) Check Point RMSEz is 8.4 centimeters and the VVA at the 95th percentile is 16.5 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. 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 17N, NAVD88 (Geoid12B), Meters. Overall, the results proved to be satisfactory. The overall $RMSE_z$ for the NVA checkpoints was 3.2 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 6.3 cm which is less than the USGS specification of < 19.6 cm. (USGS *"LiDAR Base Specification",* Page 10, Table 5;).

For a complete listing of the NVA points, see Table 7.

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	77	-0.073	0.017	-0.019	0.026	0.032

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 6, below. The coordinates provided are in NAD83 (2011), UTM Zone 17N, NAVD88 (Geoid12B), Meters. Overall, the results proved to be satisfactory. The overall $RMSE_z$ for the VVA checkpoints was 8.4 cm and the VVA at the 95th Percentile was 16.5 cm. The USGS specification for the VVA at the 95th Percentile is < 29.4 cm. (USGS *"LiDAR Base Specification",* Page 10, Table 5;).

For a complete listing of the VVA points, see Table 8.

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	62	-0.045	0.294	0.049	0.069	0.084

Table 12: NVA Check Point Assessment (DEM) (m)						
Point ID	**Easting**	**Northing**	**Known Z**	**DEM Z**	**Delta Z**	**Description**
NVA_01	720153.980	4762119.070	271.899	271.906	0.007	Paved parking lot
NVA_02	720153.120	4762109.950	271.870	271.874	0.004	Paved parking lot
NVA_03	720101.340	4762093.960	271.815	271.806	-0.009	Unpaved parking lot
NVA_04	737940.750	4759616.050	282.384	282.388	0.004	Paved road
NVA_05	737932.660	4759597.790	282.534	282.545	0.011	Unpaved shoulder
NVA_06	737930.300	4759624.690	282.174	282.178	0.004	Flat area in road pavement
NVA_08	748941.480	4755583.470	280.795	280.798	0.003	Paved shoulder
NVA_10	729475.460	4748945.110	466.426	466.418	-0.008	Paved shoulder
NVA_11	729462.440	4748955.430	466.656	466.670	0.014	Paved road
NVA_12	729473.540	4748981.390	465.366	465.374	0.008	Flat dirt area beside the road shoulder
NVA_13	744691.190	4740519.480	425.681	425.684	0.003	Unpaved shoulder
NVA_14	744745.470	4740522.780	426.593	426.598	0.005	Paved road
NVA_15	744762.830	4740542.730	426.739	426.726	-0.013	Unpaved driveway
NVA_16	716620.860	4738835.750	504.664	504.600	-0.064	Broken pavement area
NVA_17	716604.820	4738739.040	504.368	504.305	-0.063	Paved road
NVA_18	716606.960	4738835.550	504.320	504.265	-0.055	Broken pavement area
NVA_19	707213.650	4727530.590	423.444	423.408	-0.036	Unpaved parking lot
NVA_20	707244.310	4727530.910	422.201	422.171	-0.030	Short grass
NVA_21	707262.180	4727507.760	422.095	422.080	-0.015	Unpaved driveway
NVA_22	739528.030	4727447.000	430.989	430.930	-0.059	Paved parking lot
NVA_23	739533.110	4727456.170	430.912	430.914	0.002	Short grass
NVA_24	739527.510	4727405.980	430.885	430.839	-0.046	Paved parking lot
NVA_25	726209.810	4722058.640	593.418	593.427	0.009	Unpaved road
NVA_26	726231.240	4722247.920	590.113	590.107	-0.006	Paved road
NVA_27	726238.520	4722211.810	590.682	590.679	-0.003	Unpaved road
NVA_28	719377.680	4711081.780	607.892	607.893	0.001	Short grass
NVA_29	719370.970	4711061.060	608.272	608.274	0.002	Paved road
NVA_30	719337.680	4711074.800	608.094	608.064	-0.030	Paved road
NVA_31	741853.730	4710666.710	351.327	351.295	-0.032	Short grass
NVA_32	741856.130	4710682.820	352.121	352.079	-0.042	Paved road
NVA_33	741841.300	4710671.660	351.807	351.743	-0.064	Paved road
NVA_34	748829.260	4701289.910	509.198	509.192	-0.006	Paved parking lot
NVA_35	748825.680	4701284.080	508.605	508.595	-0.010	Short grass
NVA_36	748898.650	4701293.440	508.018	507.982	-0.036	Short grass/dirt
NVA_37	734138.800	4700779.810	365.517	365.483	-0.034	Paved parking lot
NVA_38	734211.090	4700790.040	365.044	365.024	-0.020	Short grass
NVA_39	734194.000	4700834.840	365.332	365.286	-0.046	Paved parking lot
NVA_40	734219.860	4700886.710	365.722	365.671	-0.051	Unpaved road
NVA_41	725172.360	4679527.450	454.631	454.648	0.017	Paved parking lot
NVA_42	725232.230	4679523.560	454.563	454.566	0.003	Paved parking lot
NVA_43	725239.130	4679541.900	454.477	454.479	0.002	Paved parking lot
NVA_44	703358.640	4664723.310	429.146	429.103	-0.043	Paved parking lot
NVA_45	703323.260	4664686.980	429.225	429.165	-0.060	Paved parking lot
NVA_46	703312.330	4664701.520	428.956	428.954	-0.002	Short grass

Table 12: NVA Check Point Assessment (DEM) (m)						
Point ID	**Easting**	**Northing**	**Known Z**	**DEM Z**	**Delta Z**	**Description**
NVA_53	734908.200	4660944.860	495.165	495.092	-0.073	Paved sidewalk
NVA_54	734873.460	4660933.010	493.967	493.903	-0.064	Short grass
NVA_55	734885.510	4660926.280	494.174	494.114	-0.060	Paved road
NVA_56	697019.790	4683543.980	503.103	503.076	-0.027	Paved road
NVA_57	697043.470	4683600.140	503.202	503.185	-0.017	Unpaved driveway
NVA_58	696982.700	4683535.950	501.324	501.341	0.017	Short grass
NVA_74	697318.680	4652079.470	439.020	439.028	0.008	Paved parking lot
NVA_75	697249.310	4652089.750	432.905	432.905	0.000	Unpaved parking lot
NVA_76	697301.640	4652094.600	438.277	438.284	0.007	Short grass
NVA_81	689615.420	4706212.620	397.688	397.689	0.001	Paved parking lot
NVA_82	689601.770	4706214.390	397.652	397.665	0.013	Short grass
NVA_83	689615.710	4706128.530	397.709	397.720	0.011	Paved parking lot
NVA_84	689558.930	4706408.540	398.902	398.894	-0.008	Unpaved parking lot
NVA_85	706168.920	4758865.400	260.123	260.082	-0.041	Paved road
NVA_86	734934.800	4660971.770	498.097	498.035	-0.062	Paved Sidewalk
NVA_87	706286.110	4758872.230	260.065	260.047	-0.018	Unpaved shoulder
NVA_88	734926.420	4660953.070	496.942	496.881	-0.061	Playground surface
NVA_89	706241.440	4758879.570	259.289	259.256	-0.033	Paved road
NVA_98	706399.140	4698804.100	509.336	509.326	-0.010	Paved parking lot
NVA_99	706415.930	4698826.920	509.522	509.490	-0.032	Unpaved parking lot
NVA_100	706361.300	4698812.650	509.058	509.015	-0.043	Paved parking lot
NVA_101	706349.160	4698811.280	509.042	509.054	0.012	Short grass
NVA_102	720166.230	4762081.910	272.227	272.225	-0.002	Paved road
NVA_103	744772.780	4740509.750	426.195	426.189	-0.006	Paved road
NVA_104	719384.920	4711070.640	608.064	608.060	-0.004	Unpaved shoulder
NVA_105	739119.140	4678663.690	453.138	453.102	-0.036	Paved road
NVA_106	739182.370	4678714.780	450.204	450.175	-0.029	Short grass
NVA_107	739278.620	4678668.460	448.905	448.883	-0.022	Paved parking lot
NVA_A1	703376.830	4664704.590	429.473	429.418	-0.055	Paved parking lot
NVA_A2	734941.470	4660947.980	496.942	496.887	-0.055	Paved parking lot
NVA_A3	719374.080	4711039.620	608.334	608.321	-0.013	Paved road
NVA_A4	720054.440	4762058.820	272.030	272.039	0.009	Paved shoulder
NVA_A5	748970.010	4755552.520	280.669	280.685	0.016	Paved road

Table 13: VVA Check Point Assessment (DEM) (m)						
Point ID	**Easting**	**Northing**	**Known Z**	**DEM Z**	**Delta Z**	**Description**
VVA_1	720134.790	4762147.400	272.234	272.26	0.026	Woods
VVA_2	720159.130	4762079.580	272.466	272.49	0.024	Tall grass
VVA_3	737922.180	4759608.920	281.895	281.879	-0.016	Tall grass
VVA_4	737797.640	4759594.850	280.558	280.679	0.121	Tall weeds
VVA_5	748936.220	4755601.410	280.306	280.369	0.063	Tall weeds
VVA_6	748986.040	4755609.380	279.840	280.064	0.224	Tall weeds
VVA_7	748995.730	4755561.910	279.810	279.845	0.035	Woods
VVA_8	729461.080	4748921.960	465.809	465.944	0.135	Weeds
VVA_9	729450.430	4748959.420	466.334	466.321	-0.013	Crop field
VVA_10	729465.230	4748992.920	465.846	465.881	0.035	Brush
VVA_11	744688.470	4740529.660	424.958	424.982	0.024	Crop field
VVA_12	744688.120	4740508.720	425.375	425.42	0.045	Tall grass
VVA_13	716615.720	4738798.440	504.209	504.164	-0.045	Woods
VVA_14	716585.780	4738787.680	502.643	502.614	-0.029	Crop field
VVA_15	716584.000	4738745.600	503.162	503.173	0.011	Brush
VVA_16	707229.220	4727525.000	422.451	422.617	0.166	Tall weeds
VVA_17	707294.230	4727505.200	419.864	419.933	0.069	Tall weeds
VVA_18	739565.300	4727399.180	430.488	430.472	-0.016	Tall grass
VVA_19	739452.370	4727481.120	431.114	431.112	-0.002	Woods
VVA_20	726236.870	4722098.990	592.841	592.967	0.126	Tall weeds
VVA_21	726257.560	4722114.010	593.026	593.038	0.012	Tall weeds
VVA_22	719370.510	4711092.470	607.570	607.634	0.064	Tall grass
VVA_23	719364.760	4711042.690	607.691	607.756	0.065	Brush
VVA_24	741882.960	4710686.610	348.757	348.777	0.020	Woods
VVA_25	741828.790	4710684.350	352.112	352.131	0.019	Tall grass
VVA_26	741854.530	4710644.560	349.422	349.409	-0.013	Tall weeds
VVA_27	748833.190	4701320.020	512.016	512.012	-0.004	Tall weeds
VVA_28	748887.880	4701288.180	507.933	507.951	0.018	Brush
VVA_29	734134.350	4700755.620	365.104	365.174	0.070	Tall weeds
VVA_30	734251.530	4700866.610	366.063	366.034	-0.029	Brush
VVA_31	734196.690	4700776.770	365.073	365.072	-0.001	Tall grass
VVA_32	725057.920	4679451.310	454.948	454.976	0.028	Tall weeds
VVA_33	725058.280	4679416.010	454.569	454.709	0.140	Woods
VVA_34	703355.190	4664756.750	428.859	429.083	0.224	Tall grass
VVA_35	703384.500	4664762.400	428.860	429.154	0.294	Tall weeds
VVA_41	734960.070	4660879.730	501.522	501.488	-0.034	Woods
VVA_42	734939.780	4660893.330	493.496	493.508	0.012	Woods
VVA_43	697031.690	4683545.690	502.922	502.992	0.070	Tall grass
VVA_44	697026.530	4683525.590	502.504	502.506	0.002	Crop field
VVA_45	696995.330	4683558.500	501.789	501.85	0.061	Tall grass
VVA_57	697250.270	4652020.340	432.206	432.253	0.047	Woods
VVA_58	697220.350	4652033.750	431.278	431.335	0.057	Tall weeds
VVA_62	689561.200	4706331.580	398.335	398.436	0.101	Tall grass
VVA_63	689553.100	4706384.720	398.395	398.483	0.088	Tall grass

Table 13: VVA Check Point Assessment (DEM) (m)						
Point ID	**Easting**	**Northing**	**Known Z**	**DEM Z**	**Delta Z**	**Description**
VVA_64	689603.010	4706056.170	398.347	398.345	-0.002	Woods
VVA_65	689596.130	4706360.430	397.548	397.683	0.135	Tall weeds
VVA_66	706154.710	4758845.380	259.460	259.43	-0.030	Woods
VVA_67	706193.770	4758878.230	259.911	259.92	0.009	Woods
VVA_68	706192.990	4758857.300	259.898	259.854	-0.044	Tall grass
VVA_74	706426.540	4698803.920	509.430	509.414	-0.016	Tall grass
VVA_75	706511.550	4698812.180	509.471	509.456	-0.015	Woods
VVA_100	720026.230	4762083.400	272.011	272.078	0.067	Woods
VVA_101	744790.460	4740498.720	425.230	425.256	0.026	Tall grass
VVA_102	719287.250	4711086.310	607.416	607.469	0.053	Tall weeds
VVA_103	739130.710	4678627.950	450.066	450.095	0.029	Woods
VVA_104	739104.140	4678648.940	451.276	451.376	0.100	Tall weeds
VVA_105	739308.630	4678640.070	447.281	447.339	0.058	Tall grass
VVA_A1	720159.280	4762040.100	272.624	272.698	0.074	Tall weeds
VVA_A2	737807.320	4759570.490	280.700	280.853	0.153	Tall weeds
VVA_A3	726259.030	4722075.340	594.515	594.524	0.009	Woods
VVA_A4	697266.130	4652041.050	432.351	432.469	0.118	Tall weeds
VVA_A5	739261.050	4678588.850	446.738	446.735	-0.003	Tall weeds