Airborne Lidar Report

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WI Dodge County Lidar 2017 B17

Contract Number: G16PC00022
Task Number: G17PD00370

Contractor: Woolpert, Inc.
Woolpert Project # 77511

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Section 1: Overview

TASK ORDER NAME: WI Dodge County Lidar 2017 B17

Project: # 77511

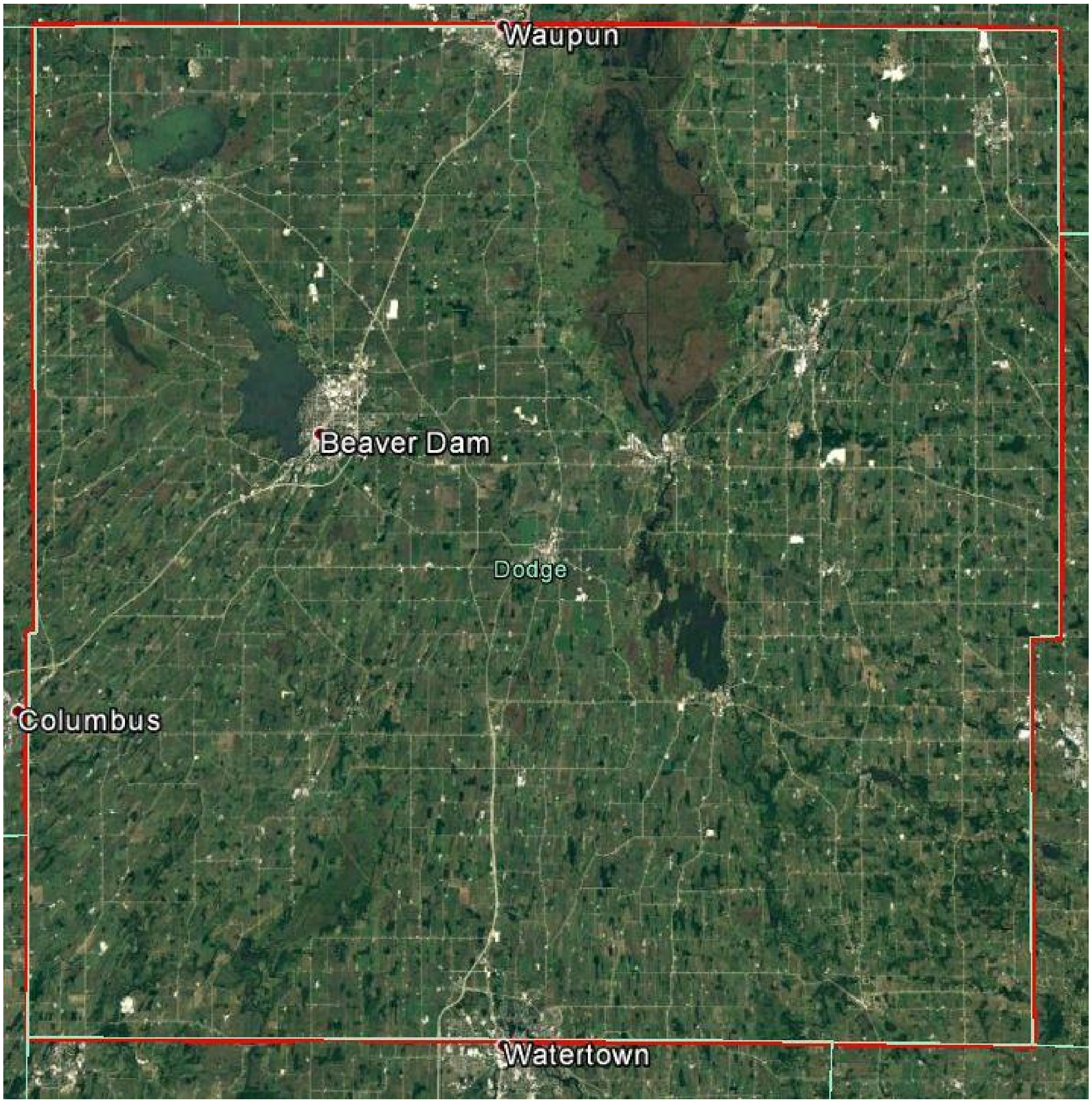
This report contains a comprehensive outline of the WI Dodge County Lidar 2017 B17 task order. Processing task order for the United States Geological Survey (USGS). This task is issued under USGS Contract No. G16PC00022, Task Order No. G17PD00370 This task order requires lidar data to be acquired covering approximately ±907 square miles of Dodge County along with a 100-meter buffer zone. The lidar data was acquired and processed in compliance with U.S. Geological Survey National Geospatial Program Lidar Base Specification version 1.2 at a nominal pulse spacing (NPS) of 0.7 meters. The NPS assessment is made against single swath, first return data located within the geometrically usable center portion (typically ~90%) of each swath.

The data was collected using Leica ALS70 500 kHz Multiple Pulses in Air (MPiA) lidar sensor. The ALS70 sensor collects up to four returns per pulse, as well as intensity data, for the first three returns. If a fourth return was captured, the system does not record an associated intensity value. The aerial lidar was collected at the following sensor specifications:

Table 1.1: ALS70 Specifications	
Post Spacing	0.70 m
AGL (Above Ground Level) average flying height	1,500 m
Average Ground Speed:	150 knots
Field of View (full)	50 degrees
Pulse Rate	177.4 kHz
Scan Rate	25.8 Hz
Side Lap	33.36%

The horizontal datum used for the task order was referenced to NAD 1983 2011 WISCRS Dodge and Jefferson US Feet. The vertical datum used for the task order was referenced to NAVD 1988, US Feet, GEOID12B.

Figure 1.1: WI Dodge County Lidar 2017 B17 Task Order AOI



Section 2: Acquisition

The lidar data was acquired with Leica ALS70 500 kHz Multiple Pulses in Air (MPiA) lidar sensors system. The ALS70 lidar system, developed by Leica Geosystems of Heerbrugg, Switzerland, includes the simultaneous first, intermediate and last pulse data capture module, the extended altitude range module, and the target signal intensity capture module.

The ALS70 500 kHz Multiple Pulses in Air (MPiA) Lidar System has the following specifications:

Table 2.2: ALS 70 Lidar System Specifications	
Operating Altitude	200 – 3,500 meters
Scan Angle	0 to 75° (variable)
Swath Width	0 to 1.5 X altitude (variable)
Scan Frequency	0 – 200 Hz (variable based on scan angle)
Maximum Pulse Rate	500 kHz (Effective)
Range Resolution	Better than 1 cm
Elevation Accuracy	7 - 16 cm single shot (one standard deviation)
Horizontal Accuracy	5 – 38 cm (one standard deviation)
Number of Returns per Pulse	7 (infinite)
Number of Intensities	3 (first, second, third)
Intensity Digitization	8 bit intensity + 8 bit AGC (Automatic Gain Control) level
MPiA (Multiple Pulses in Air)	8 bits @ 1nsec interval @ 50kHz
Laser Beam Divergence	0.22 mrad @ $1/e^2$ (~0.15 mrad @ 1/e)
Laser Classification	Class IV laser product (FDA CFR 21)
Eye Safe Range	400m single shot depending on laser repetition rate
Roll Stabilization	Automatic adaptive, range = 75 degrees minus current FOV
Power Requirements	28 VDC @ 25A
Operating Temperature	0-40°C
Humidity	0-95% non-condensing
Supported GNSS Receivers	Ashtech Z12, Trimble 7400, Novatel Millenium

Prior to mobilizing to the project site, flight crews coordinated with the necessary Air Traffic Control personnel to ensure airspace access.

Crews were onsite, operating a Global Navigation Satellite System (GNSS) Base Station for the airborne GPS support.

The Lidar data was collected in Six (6) missions, flown as close together as the weather permitted, to ensure consistent ground conditions across the project area. An initial quality control process was performed immediately on the Lidar data to review the data coverage, airborne GPS data, and trajectory solution. Collection of lidar data took place from April 12 through April 23 of 2017.

Figure 2.1: Lidar Flight Layout, WI Dodge County Lidar 2017 B17

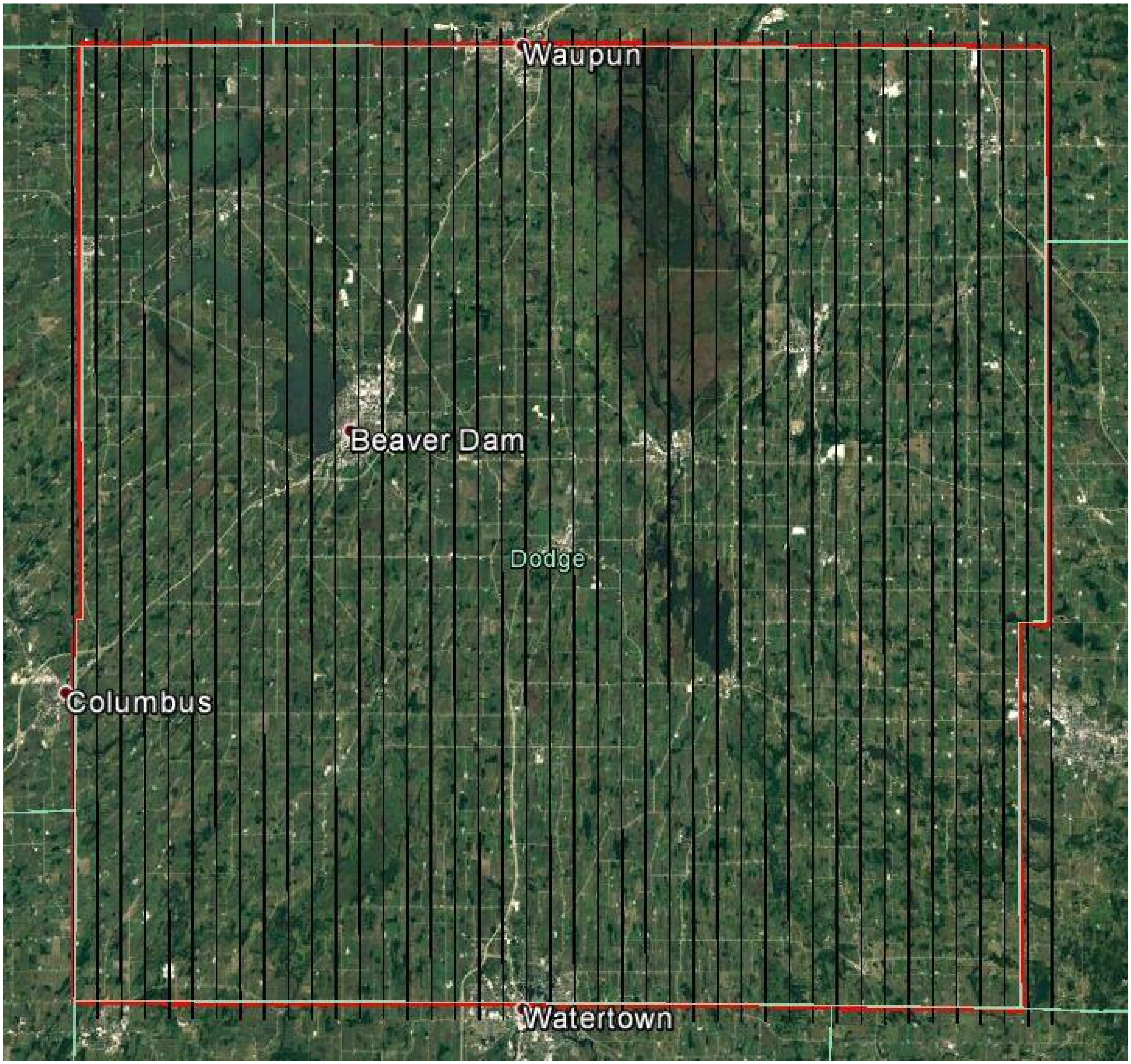


Table 2.3: Airborne Lidar Acquisition Flight Summary

Date of Mission	Lines Flown	Mission Time (UTC)
April 12, 2017_A	**00001-00016**	**15:42 – 19:58**
April 12, 2017_B	**00017-00025**	**21:26 – 23:52**
April 14, 2017	**00026 - 00042**	**20:41 – 1:20**
April 15, 2017	**00048-00057, 01042**	**13:39 – 16:54**
April 17, 2017	**00043-00047, 01002, 01003**	**14:41 – 17:29**
April 23, 2017	**01025, 01052, 01054**	**16:46 – 17:17**

Section 3: LiDAR Data Processing

Applications and Work Flow Overview

1. Resolved kinematic corrections for three subsystems: inertial measurement unit (IMU), sensor orientation information and airborne GPS data. Developed a blending post-processed aircraft position with attitude data using Kalman filtering technology or the smoothed best estimate trajectory (SBET).
Software: POSPac Software v. 5.3, IPAS Pro v.1.35., Novatel Inertial Explorer v8.60.6129
2. Calculated laser point position by associating the SBET position to each laser point return time, scan angle, intensity, etc. Created raw laser point cloud data for the entire survey in LAS format. Automated line-to-line calibrations were then performed for system attitude parameters (pitch, roll, heading), mirror flex (scale) and GPS/IMU drift.
Software: ALS Post Processing Software v.2.75 build #25, Proprietary Software, TerraMatch v. 17., Add Leica Cloud Pro v1.2.3
3. Imported processed LAS point cloud data into the task order tiles. Resulting data were classified as ground and non-ground points with additional filters created to meet the task order classification specifications. Statistical absolute accuracy was assessed via direct comparisons of ground classified points to ground RTK survey data. Based on the statistical analysis, the lidar data was then adjusted to reduce the vertical bias when compared to the survey ground control.
Software: TerraScan v.17.
4. The LAS files were evaluated through a series of manual QA/QC steps to eliminate remaining artifacts from the ground class.
Software: TerraScan v.17.

Global Navigation Satellite System (GNSS)–Inertial Measurement Unit (IMU) Trajectory Processing

Equipment

The pilots are skilled at maintaining their planned trajectory, while holding the aircraft steady and level. If atmospheric conditions are such that the trajectory, ground speed, roll, pitch and/or heading cannot be properly maintained, the mission is aborted until suitable conditions occur.

Base stations were set by acquisition staff and were used to support the Lidar data acquisition. The GNSS base station operated during the Lidar acquisition missions is listed below:

Table 3.1: GNSS Base Station

Station (Name)	Latitude (DMS)	Longitude (DMS)	Ellipsoid Height (L1 Phase center) (Meters)
NGS PID AH5313	43°25'49.84179"	88°41'44.20202"	249.723

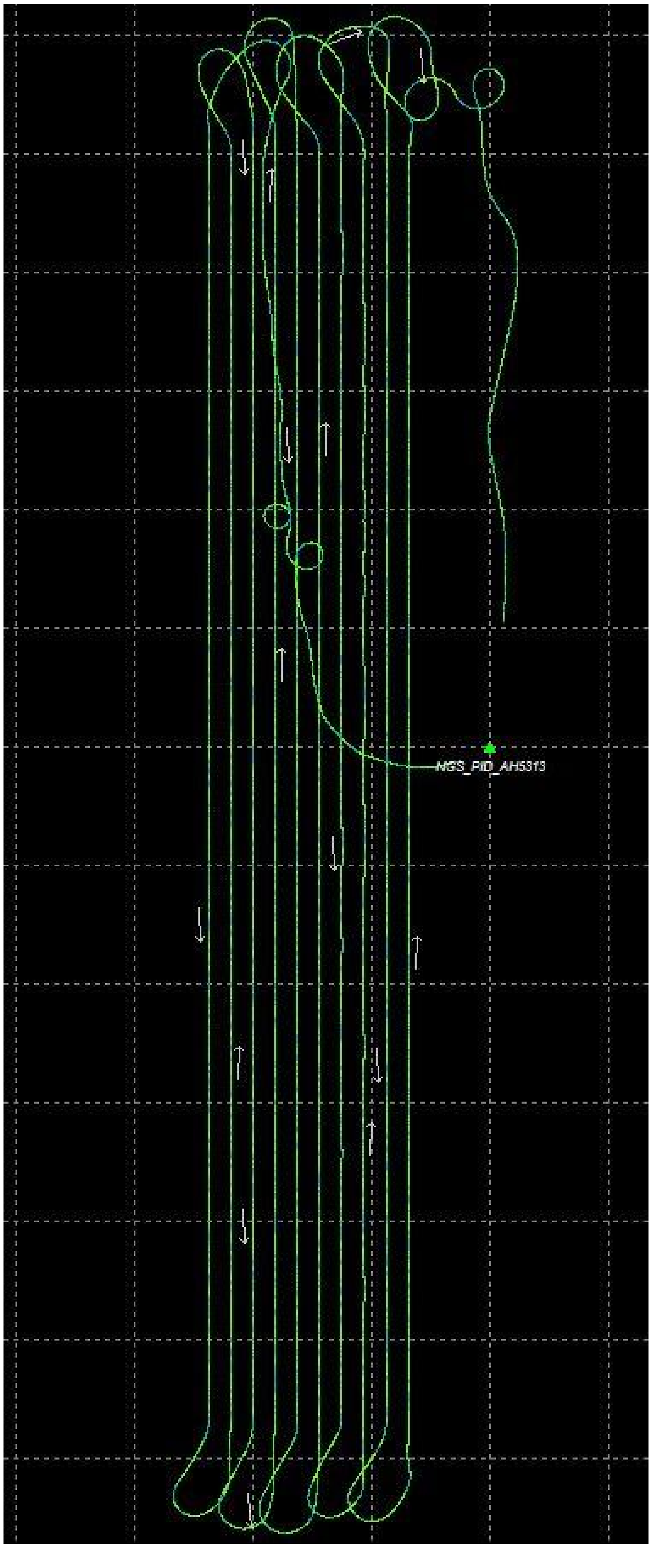
Data Processing

All airborne GNSS and IMU data was post-processed and quality controlled using Applanix MMS software. GNSS data was processed at a 1 and 2 Hz data capture rate and the IMU data was processed at 200 Hz.

Trajectory Quality

The GNSS Trajectory, along with high quality IMU data are key factors in determining the overall positional accuracy of the final sensor data. Within the trajectory processing, there are many factors that affect the overall quality, but the most indicative are the combined separation, the estimated positional accuracy, and the Positional Dilution of Precision (PDOP).

Figure 3.1: Trajectory, Day10217

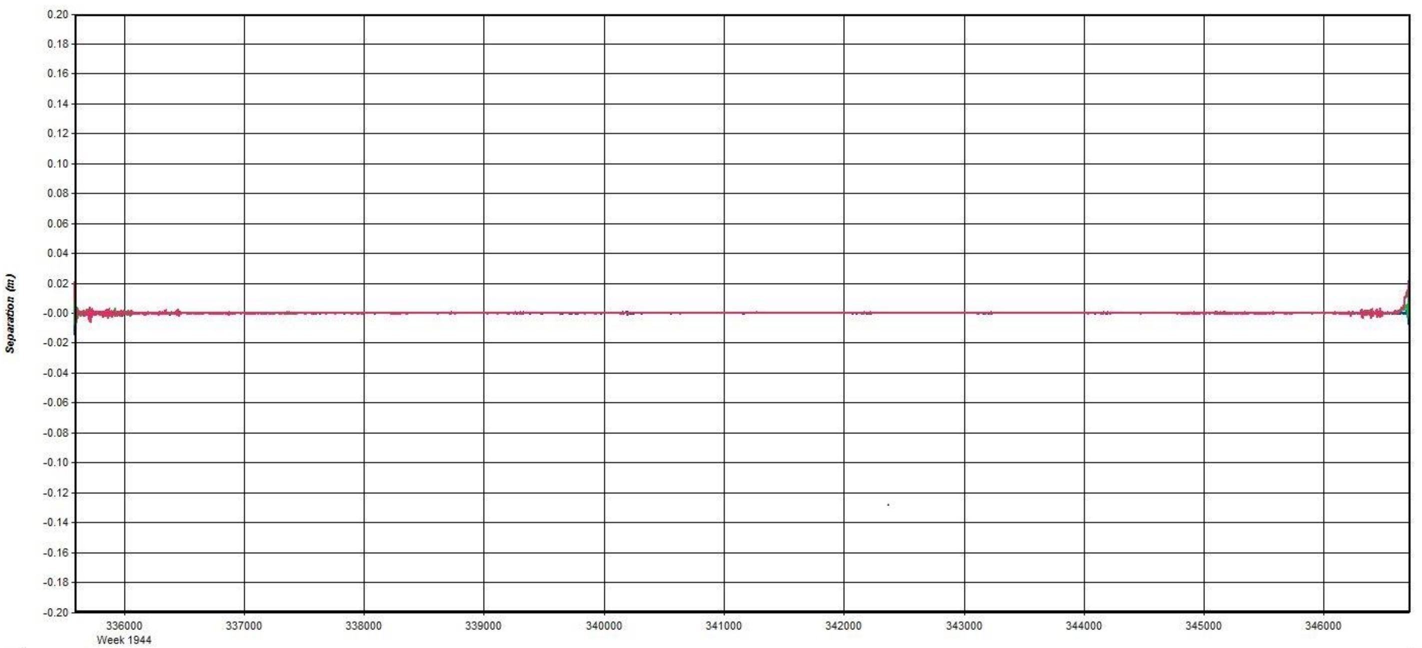


Combination Separation

The Combined Separation is a measure of the difference between the forward run and the backward run solution of the trajectory. The Kalman filter is processed in both directions to remove the combined directional anomalies. In general, when these two solutions match closely, an optimally accurate reliable solution is achieved.

Woolpert's goal is to maintain a Combined Separation Difference of less than ten (10) centimeters. In most cases we achieve results below this threshold.

Figure 3.2: Combined Separation, Day10217

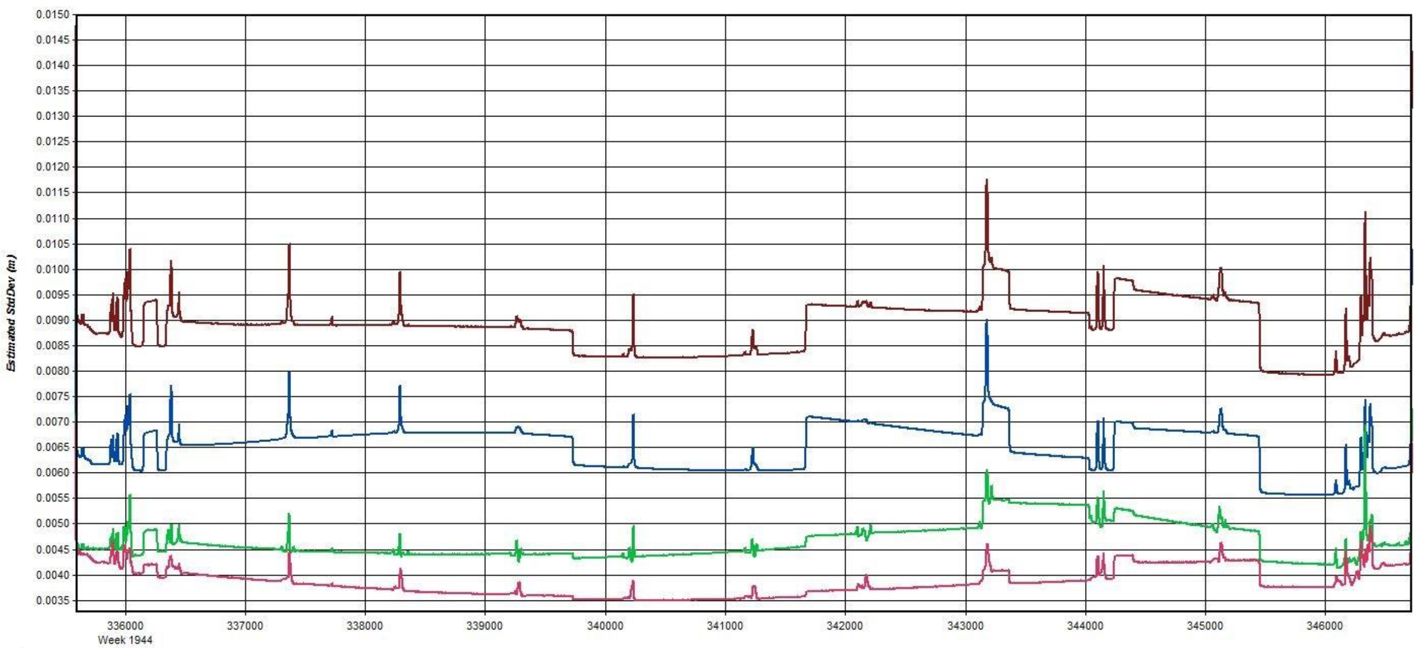


Estimated Positional Accuracy

The Estimated Positional Accuracy plots the standard deviations of the east, north, and vertical directions along a time scale of the trajectory. It illustrates loss of satellite lock issues, as well as issues arising from long baselines, noise, and/or other atmospheric interference.

Woolpert's goal is to maintain an Estimated Positional Accuracy of less than ten (10) centimeters, often achieving results well below this threshold.

Figure 3.3: Estimated Positional Accuracy, Day10217

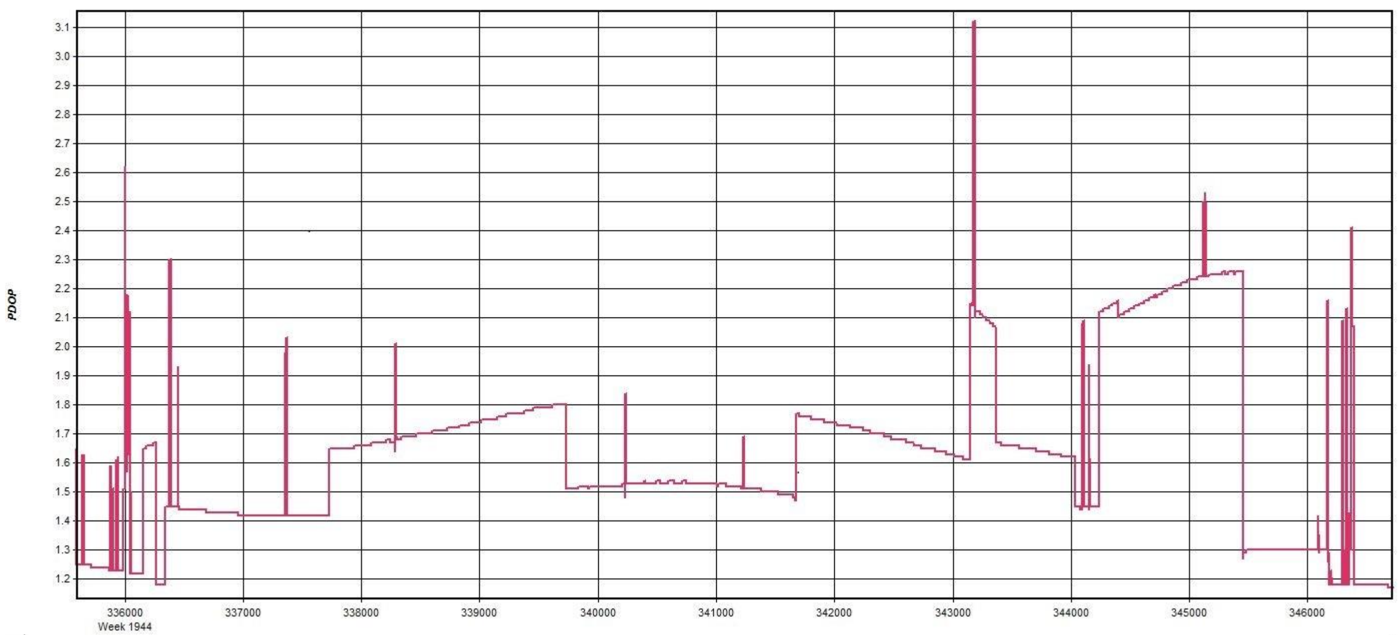


PDOP

The PDOP measures the precision of the GPS solution in regards to the geometry of the satellites acquired and used for the solution.

Woolpert's goal is to maintain an average PDOP value below 3.0. Brief periods of PDOP over 3.0 are acceptable due to the calibration and control process if other metrics are within specification.

Figure 3.4: PDOP, Day10217



LiDAR Data Processing

When the sensor calibration, data acquisition, and GPS processing phases were complete, the formal data reduction processes by Woolpert lidar specialists included:

- Processed individual flight lines to derive a raw “Point Cloud” LAS file. Matched overlapping flight lines, generated statistics for evaluation comparisons, and made the necessary adjustments to remove any residual systematic error.
- Calibrated LAS files were imported into the task order tiles and initially filtered to create a ground and non-ground class. Then additional classes were filtered as necessary to meet client specified classes.
- Once all project data was imported and classified, survey ground control data was imported and calculated for an accuracy assessment. As a QC measure, Woolpert has developed a routine to generate accuracy statistical reports by comparisons against the TIN and the DEM using surveyed ground control of higher accuracy. The lidar is adjusted accordingly to meet or exceed the vertical accuracy requirements.
- The lidar tiles were reviewed using a series of proprietary QA/QC procedures to ensure it fulfills the task order requirements. A portion of this requires a manual step to ensure anomalies have been removed from the ground class.
- The lidar LAS files are classified into the Processed, but unclassified (Class 1), Bare earth (Class 2), Low Noise (Class 7), Water (Class 9), Ignored Ground (Class10), Bridge Decks (Class 17), High Noise (Class 18) classifications.
- FGDC Compliant metadata was developed for the task order in .xml format per product.
- The horizontal datum used for the task order was referenced to NAD 1983 2011 WISCRS Dodge and Jefferson US Feet. The vertical datum used for the task order was referenced to NAVD 1988, Meters, GEOID12B

Section 4: Hydrologic Flattening

HYDROLOGIC FLATTENING OF LIDAR DEM DATA

WI Dodge County Lidar 2017 B17 processing task order required the compilation of breaklines defining water bodies and rivers. The breaklines were used to perform the hydrologic flattening of water bodies, and gradient hydrologic flattening of double line streams and rivers. Lakes, reservoirs and ponds, at a minimum size of 2-acre or greater, were compiled as closed polygons. The closed water bodies were collected at a constant elevation. Rivers and streams, at a nominal minimum width of 30 meters (100 feet), were compiled in the direction of flow with both sides of the stream maintaining an equal gradient elevation.

LIDAR DATA REVIEW AND PROCESSING

Woolpert utilized the following steps to hydrologically flatten the water bodies and for gradient hydrologic flattening of the double line streams within the existing lidar data.

1. Woolpert used the newly acquired lidar data to manually draw the hydrologic features in a 2D environment using the lidar intensity and bare earth surface. Open Source imagery was used as reference when necessary.
2. Woolpert utilizes an integrated software approach to combine the lidar data and 2D breaklines. This process “drapes” the 2D breaklines onto the 3D lidar surface model to assign an elevation. A monotonic process is performed to ensure the streams are consistently flowing in a gradient manner. A secondary step within the program verifies an equally matching elevation of both stream edges. The breaklines that characterize the closed water bodies are draped onto the 3D lidar surface and assigned a constant elevation at or just below ground elevation.
3. The lakes, reservoirs and ponds, at a minimum size of 2-acre or greater and streams at a minimum size of 30 meters (100 feet) nominal width, were compiled to meet task order requirements. **Figure 4.1** illustrates an example of 30 meters (100 feet) nominal streams identified and defined with hydrologic breaklines. The breaklines defining rivers and streams, at a nominal minimum width of 30 meters (100 feet), were draped with both sides of the stream maintaining an equal gradient elevation.
4. All ground points were reclassified from inside the hydrologic feature polygons to water, class nine (9).
5. All ground points were reclassified from within a buffer along the hydrologic feature breaklines to buffered ground, class ten (10).
6. The lidar ground points and hydrologic feature breaklines were used to generate a new digital elevation model (DEM).

Figure 4.1: Example Hydrologic Breaklines

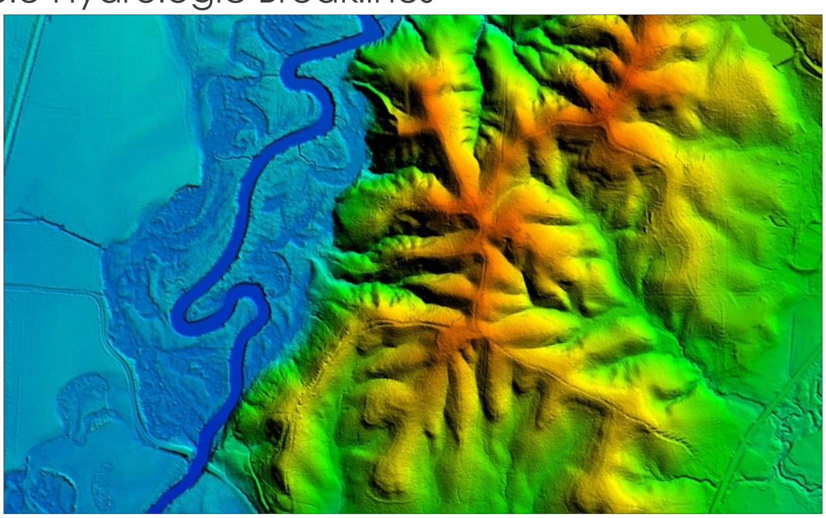


Figure 4.2 reflects a DEM generated from original lidar bare earth point data prior to the hydrologic flattening process. Note the "tinning" across the lake surface.

Figure 4.3 reflects a DEM generated from lidar with breaklines compiled to define the hydrologic features. This figure illustrates the results of adding the breaklines to hydrologically flatten the DEM data. Note the smooth appearance of the lake surface in the DEM.

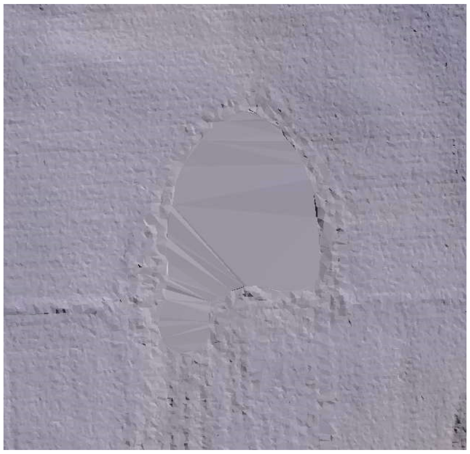


Figure 4.2

Figure 4.3

Terrascan was used to add the hydrologic breakline vertices and export the lattice models. The hydrologically flattened DEM data was provided to USGS in ERDAS .IMG format.

The hydrologic breaklines compiled as part of the flattening process were provided to the USGS in ESRI shapefile format. The breaklines defining the water bodies greater than 2-acre and for the gradient flattening of all rivers and streams at a nominal minimum width of 30 meters (100 feet) were provided in geodatabase as a Polygon-Z and Polyline-Z shape file, respectively.

DATA QA/QC

Initial QA/QC for this task order was performed in Global Mapper v17, by reviewing the grids and hydrologic breakline features. Additionally, ESRI software and proprietary methods were used to review the overall connectivity of the hydrologic breaklines.

Edits and corrections were addressed individually by tile. If a water body breakline needed to be adjusted to improve the flattening of the DEM data, the area was cross referenced by tile number, corrected accordingly, a new DEM file was regenerated and reviewed.

Section 5: ACCURACY ASSESSMENT

Accuracy Assessment

The vertical accuracy statistics were calculated by comparison of all lidar points to the ground surveyed QC points.

Table 5.1: Overall Vertical Accuracy Statistics		
Average error	0.05	US Feet
Minimum error	-0.255	US Feet
Maximum error	0.414	US Feet
Average magnitude	0.113	US Feet
Root mean square	0.142	US Feet
Standard deviation	0.134	US Feet

Table 5.2: RAW Swath Quality Check Point Analysis NVA

Point ID	Easting (US Feet)	Northing (US Feet)	Elevation (US Feet)	TIN Elevation (US Feet)	Dz (US Feet)
2001	802995.346	787603.436	1020.205	1020.300	0.095
2002	840681.396	787624.119	942.153	941.977	-0.176
2003	879218.451	787503.520	887.391	887.440	0.049
2004	925725.810	787258.234	1126.125	1126.109	-0.016
2005	963012.488	787061.862	1030.715	1030.733	0.018
2006	963335.437	753843.381	971.933	972.080	0.147
2007	963363.372	723504.092	1034.629	1034.853	0.224
2008	963284.735	692112.675	1082.768	1082.876	0.108
2009	958762.398	665072.996	978.538	978.598	0.060
2010	959185.188	627955.148	961.726	961.806	0.080
2011	924415.365	628419.971	846.438	846.473	0.035
2012	877143.611	628820.708	813.807	813.775	-0.032
2013	840789.792	628883.235	794.362	794.316	-0.046
2014	801582.162	628938.516	847.467	847.881	0.414
2015	801642.030	663440.185	867.916	867.929	0.013
2016	802433.806	691676.337	840.197	840.504	0.307
2017	802664.876	721366.934	943.873	943.968	0.095
2018	802703.346	755718.856	961.763	961.758	-0.005
2019	836961.178	755791.697	930.980	930.982	0.002
2020	878874.340	755758.044	902.720	902.628	-0.092
2021	929020.975	750000.657	1038.208	1038.333	0.125
2022	839674.579	709384.097	878.682	878.618	-0.064

2023	882422.903	706367.332	912.803	912.663	-0.140
2024	924351.920	710422.678	912.238	912.368	0.130
2025	844825.033	666602.603	822.331	822.360	0.029
2026	878033.072	668588.457	914.181	914.261	0.080
2027	928339.902	667963.167	889.127	889.385	0.258
2028	819345.371	764470.098	897.348	897.459	0.111
2029	856539.476	740360.341	970.266	970.483	0.217
2030	911442.236	709103.098	891.576	891.321	-0.255
2031	902906.734	650785.073	930.171	930.202	0.031
2032	947906.466	745909.407	964.621	964.614	-0.007
2033	942374.478	709133.134	1115.316	1115.517	0.201
2034	818735.941	742097.675	900.495	900.745	0.250
2035	818951.102	710915.378	882.211	882.259	0.048
2036	818417.254	677635.622	820.371	820.272	-0.099
2037	823126.816	655063.236	809.793	809.821	0.028
2038	862446.455	768887.270	966.372	966.622	0.250
2039	861645.200	709979.206	891.502	891.534	0.032
2040	861848.482	681874.488	799.867	799.917	0.050
2041	864844.528	652696.902	862.651	862.833	0.182
2042	904780.720	771657.975	911.737	911.863	0.126
2043	913277.999	747676.252	868.673	868.558	-0.115
2044	899532.525	682303.289	898.649	898.524	-0.125
2045	949769.293	772393.330	1020.366	1020.300	-0.066
2046	940242.621	680957.544	1068.214	1068.266	0.052
2047	940350.572	649210.950	927.384	927.270	-0.114
2048	885466.009	737399.967	878.208	878.034	-0.174
2049	851181.258	697562.595	828.564	828.751	0.187
2050	836394.737	735274.060	874.489	874.505	0.016
2051	937072.095	731385.659	939.596	939.421	-0.175
2052	868677.107	718698.909	899.254	899.394	0.140
2053	881949.780	655023.899	888.264	888.393	0.129
2054	903601.422	723602.485	869.655	869.862	0.207
2055	828291.966	782710.537	953.964	954.101	0.137
2056	902099.897	633848.624	935.315	935.201	-0.114
2057	926184.599	692074.155	893.995	894.020	0.025
2058	925912.793	771113.676	1027.934	1027.970	0.036

VERTICAL ACCURACY CONCLUSIONS

Raw Swath Non-Vegetated Vertical Accuracy (NVA) Tested 0.084 Meters Non vegetated vertical accuracy at a 95 percent confidence level, derived according to NSSDA, in open terrain using (RMSEz) 0.043 x 1.96000 as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation Program (NDEP)/ASPRS Guidelines and tested against the TIN using all lidar points against 58 NVA points.

LAS Swath Non-Vegetated Vertical Accuracy (NVA) Tested 0.080 Meters Non vegetated vertical accuracy at a 95 percent confidence level, derived according to NSSDA, in open terrain using (RMSEz) 0.041 x 1.96000 as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation Program (NDEP)/ASPRS Guidelines and tested against the TIN using lidar ground points against 58 NVA points.

Table 5.3: NVA Check Point Analysis DEM

Point ID	Easting (US Feet)	Northing (US Feet)	Elevation (US Feet)	DEM Elevation (US Feet)	Dz (US Feet)
2001	802995.346	787603.436	1020.205	1020.107	-0.098
2002	840681.396	787624.119	942.153	941.836	-0.317
2003	879218.451	787503.520	887.391	887.266	-0.125
2004	925725.810	787258.234	1126.125	1126.032	-0.093
2005	963012.488	787061.862	1030.715	1030.616	-0.099
2006	963335.437	753843.381	971.933	971.980	0.047
2007	963363.372	723504.092	1034.629	1034.497	-0.132
2008	963284.735	692112.675	1082.768	1082.681	-0.087
2009	958762.398	665072.996	978.538	978.556	0.018
2010	959185.188	627955.148	961.726	961.627	-0.099
2011	924415.365	628419.971	846.438	846.718	0.280
2012	877143.611	628820.708	813.807	813.707	-0.100
2013	840789.792	628883.235	794.362	794.343	-0.019
2014	801582.162	628938.516	847.467	847.694	0.227
2015	801642.030	663440.185	867.916	867.952	0.036
2016	802433.806	691676.337	840.197	840.272	0.075
2017	802664.876	721366.934	943.873	943.877	0.004
2018	802703.346	755718.856	961.763	961.815	0.052
2019	836961.178	755791.697	930.980	930.919	-0.061
2020	878874.340	755758.044	902.720	902.548	-0.172
2021	929020.975	750000.657	1038.208	1038.216	0.008
2022	839674.579	709384.097	878.682	878.535	-0.147
2023	882422.903	706367.332	912.803	912.683	-0.120
2024	924351.920	710422.678	912.238	912.293	0.055
2025	844825.033	666602.603	822.331	822.227	-0.104

2026	878033.072	668588.457	914.181	914.166	-0.015
2027	928339.902	667963.167	889.127	889.338	0.211
2028	819345.371	764470.098	897.348	897.603	0.255
2029	856539.476	740360.341	970.266	970.295	0.029
2030	911442.236	709103.098	891.576	891.271	-0.305
2031	902906.734	650785.073	930.171	930.179	0.008
2032	947906.466	745909.407	964.621	964.818	0.197
2033	942374.478	709133.134	1115.316	1115.531	0.215
2034	818735.941	742097.675	900.495	900.484	-0.011
2035	818951.102	710915.378	882.211	882.418	0.207
2036	818417.254	677635.622	820.371	820.267	-0.104
2037	823126.816	655063.236	809.793	809.859	0.066
2038	862446.455	768887.270	966.372	966.564	0.192
2039	861645.200	709979.206	891.502	891.469	-0.033
2040	861848.482	681874.488	799.867	799.877	0.010
2041	864844.528	652696.902	862.651	862.611	-0.040
2042	904780.720	771657.975	911.737	911.778	0.041
2043	913277.999	747676.252	868.673	868.391	-0.282
2044	899532.525	682303.289	898.649	898.540	-0.109
2045	949769.293	772393.330	1020.366	1020.321	-0.045
2046	940242.621	680957.544	1068.214	1068.066	-0.148
2047	940350.572	649210.950	927.384	927.092	-0.292
2048	885466.009	737399.967	878.208	877.936	-0.272
2049	851181.258	697562.595	828.564	828.691	0.127
2050	836394.737	735274.060	874.489	874.405	-0.084
2051	937072.095	731385.659	939.596	939.301	-0.295
2052	868677.107	718698.906	899.254	899.413	0.159
2053	881949.780	655023.899	888.264	888.371	0.107
2054	903601.422	723602.485	869.655	869.798	0.143
2055	828291.966	782710.537	953.964	954.023	0.059
2056	902099.897	633848.624	935.315	935.342	0.027
2057	926184.599	692074.155	893.995	894.072	0.077
2058	925912.793	771113.676	1027.934	1027.992	0.058

VERTICAL ACCURACY CONCLUSIONS

Bare-Earth DEM Non-Vegetated Vertical Accuracy (NVA) Tested 0.088 Meters Non-Vegetated vertical accuracy at a 95 percent confidence level, derived according to NSSDA, in open terrain using (RMSEz) 0.045 x 1.96000 as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation Program (NDEP)/ASPRS Guidelines and tested against the DEM against 58 NVA points.

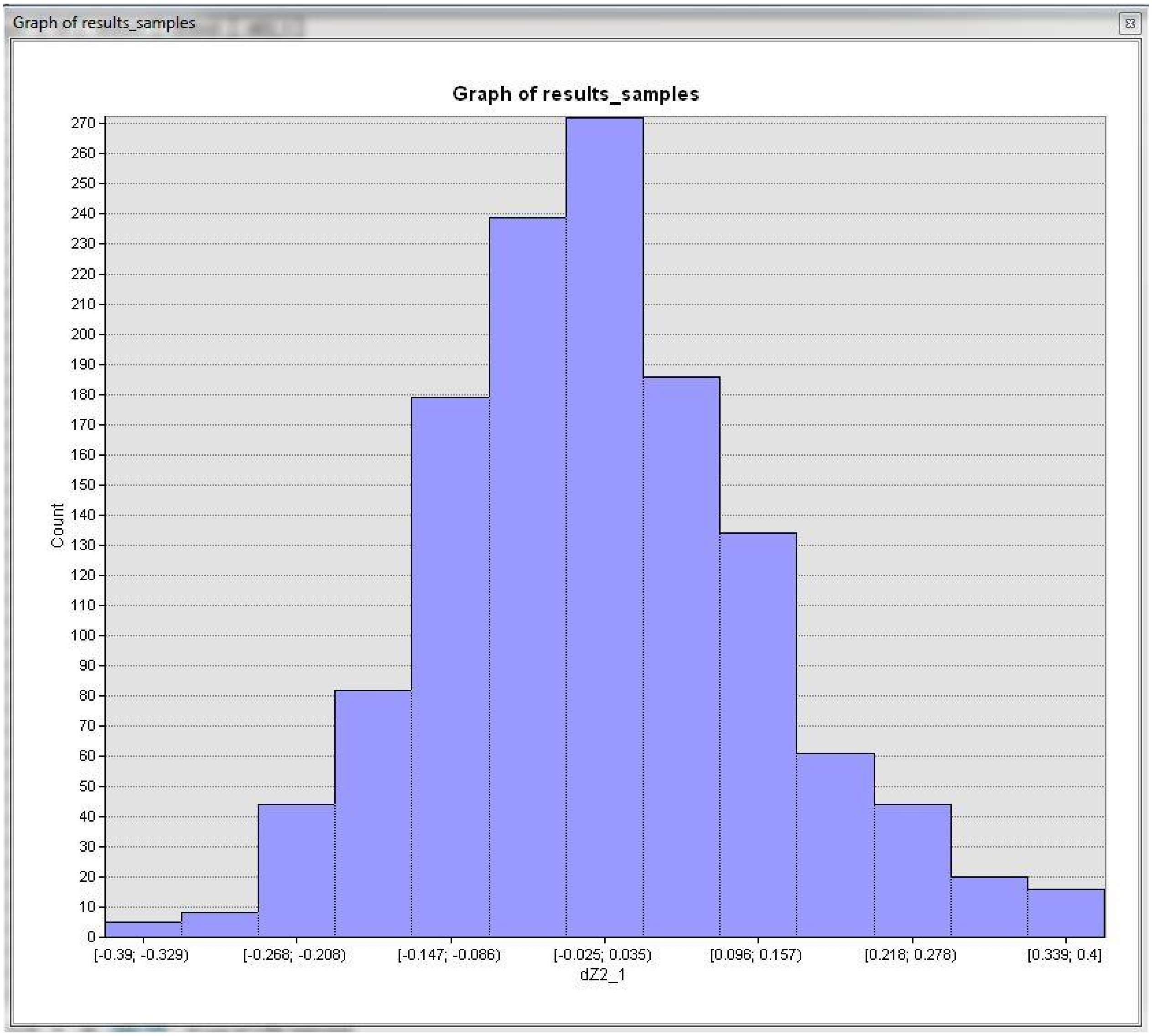
Table 5.4: VVA Quality Check Point Analysis DEM					
Point ID	**Easting (US Feet)**	**Northing (US Feet)**	**Elevation (US Feet)**	**DEM Elevation (US Feet)**	**Dz (US Feet)**
3001	802884.557	787535.996	1017.055	1017.456	0.401
3002	928295.795	667931.867	888.220	888.408	0.188
3003	925701.793	714337.614	978.508	978.911	0.403
3004	925031.983	771142.328	1029.049	1029.899	0.850
3005	843450.001	664892.205	854.940	855.032	0.092
3006	801727.305	628903.427	852.512	852.857	0.345
3007	957361.078	627979.572	983.290	983.391	0.101
3008	837334.568	755840.311	942.481	942.956	0.475
3009	879627.318	786964.109	889.169	889.422	0.253
3010	804097.167	755823.177	950.333	950.443	0.110
3011	861803.505	720541.059	851.425	851.609	0.184
3012	902022.493	633794.647	935.111	935.516	0.405
3013	840167.218	628938.955	793.464	793.554	0.090
3014	963377.887	755064.179	971.346	971.614	0.268
3015	818997.795	710534.483	925.226	925.699	0.473
3016	879947.450	755714.575	899.109	899.123	0.014
3017	957745.890	786977.424	1026.781	1026.908	0.127
3018	817830.779	675354.796	840.473	840.757	0.284
3019	899623.694	684239.257	892.390	892.157	-0.233
3020	906905.050	723718.098	878.327	878.401	0.074
3021	878510.376	667975.622	891.107	891.260	0.153
3022	852670.686	697516.421	806.292	807.018	0.726
3023	930394.671	749872.796	990.642	990.971	0.329
3024	802985.274	691253.146	836.495	837.059	0.564
3025	963236.829	693741.548	1052.604	1052.620	0.016
3026	884910.635	708952.799	921.348	921.661	0.313
3027	841324.209	787555.290	929.032	928.975	-0.057
3028	874619.156	630309.132	834.145	834.177	0.032
3029	963218.720	723459.511	1030.109	1030.170	0.061
3030	907225.349	771573.650	870.464	870.559	0.095
3031	861746.528	681819.691	796.905	797.002	0.097
3032	862482.006	768877.587	965.373	965.998	0.625
3033	836055.005	740015.439	878.561	878.849	0.288
3034	939498.623	649329.148	902.978	903.135	0.157
3035	885426.833	737431.842	876.592	876.749	0.157
3036	823439.054	654081.184	801.801	802.144	0.343
3037	941534.799	707850.651	1111.015	1111.574	0.559

3038	856042.065	740047.990	960.088	960.843	0.755
3039	802626.660	721514.147	939.986	940.204	0.218
3040	865384.430	652649.094	856.161	856.517	0.356
3041	925430.150	692058.417	870.928	871.733	0.805
3042	840818.038	709813.182	881.825	881.675	-0.150
3043	925708.434	787197.220	1125.700	1125.627	-0.073
3044	958716.785	665079.419	974.826	974.945	0.119
3045	814632.840	743891.364	873.707	874.526	0.819
3046	898163.113	666425.623	923.621	923.666	0.045
3047	898769.409	750533.422	856.840	857.483	0.643
3048	835807.372	693666.439	825.092	825.526	0.434

VERTICAL ACCURACY CONCLUSIONS

Vegetated Vertical Accuracy (VVA) Tested 0.248 Meters at the 95th percentile reported using National Digital Elevation Program (NDEP)/ASPRS Guidelines and tested against the DEM against 48 VVA points. VVA Errors larger than 95th percentile include:
Point 3004, Easting 925031.983, Northing 771142.328, Z-Error 0.259 Meters

Figure 5.1: Lidar Relative Accuracy Histogram



RELATIVE ACCURACY ASSESSMENT AND CONCLUSION

Relative accuracy also known as "between swath" accuracy was tested through a series of well distributed flight line overlap locations. The relative accuracy for the WI Dodge County Lidar 2017 B17 measured at 0.127 US Feet RMSDz.

Approved by:	Name	Signature	Date
Associate Member, Lidar Specialist Certified Photogrammetrist #1381	Qian Xiao		December 2017

Section 6: Flight Logs

Flight logs for the project are shown on the following pages:

Woolpert

Leica LIDAR	MM/DD/YEAR	Day of Year	Project #	Phase #	Project Name
	4/12/2017			1	Woolpert Dodge County

Operator	Aircraft	HOBBS Start	Local Start Time	ZULU Start Time	Base
Other					
Pilot	**Sensor Type**	**HOBBS END**	**Local End Time**	**Zulu End Time**	**PID**
Other	OTHER				

Wind Dir/Speed	Visibility	Ceiling	Cloud Cover %	Temp	Dew Point	Pressure	Haze/Fire/Cloud		
220@15	10	clr				30.35	none	Departing	
								Arriving	

Scan Angle (FOV)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power %	Fixed Gain		Mode		Threshold Values	
50	47	343	100	Gain - Course/Up		Single		A	
				Gain - Fine/Down		Multi		B	

Air Speed		AGL		MSL		Waveform Used				Waveform Mode	Pre-Trigger Dist.
150	Kts	5000	Ft		Ft	Yes		No	X	@ NS	Ft

Line #	Dir.	Line Start Time	Line End Time	Time On Line	SV's	HDOP	PDOP	Line Notes/Comments
Test	n/a			n/a	n/a	n/a	n/a	GPS Began Logging At:
		↕ Times entered are Zulu / GMT ↕						Verify S-Turns Before Mission Yes X No
1	s	10:42:30	10:55:30		16	0.8	1.4	
2	n	10:58:00	11:11:11		18	0.6	1.1	rain northern section
3	s	11:16:00	11:28:30		18	0.6	1.1	rain northern section
4	n	11:31:00	11:44:30		17	0.7	1.3	Gap 5 miles from the South
5	s	11:47:30	12:01:00		18	0.6	1.2	
6	n	12:04:00	12:17:00		20	0.6	1.1	
7	s	12:20:00	12:33:30		20	0.6	1	
8	n	12:36:00	12:49:00		17	0.7	1.2	
9	s	12:52:00	1:05:00		17	0.6	1.2	
10	n	1:07:30	1:21:00		17	0.7	1.3	
11	s	1:24:00	2:38:00		16	0.7	1.5	
12	n	1:41:00	1:53:30		16	0.7	1.4	
13	s	1:56:30	2:10:00		16	0.7	1.3	
14	n	2:13:00	2:25:00		16	0.7	1.3	
15	s	2:28:00	2:42:00		18	0.6	1.2	
16	n	2:44:30	2:57:00		19	0.6	1.2	
17	s	4:21:30	4:41:00		18	0.6	1.1	
18	n	4:44:00	4:57:00		15	0.8	1.3	
19	s	5:00:00	5:13:00		16	0.7	1.1	
20	n	5:16:00	5:28:30		18	0.7	1.3	
21	s	5:32:00	5:45:30		16	0.8	1.3	
22	n	5:48:30	6:01:00		16	0.7	1.3	
23	s	6:04:00	6:18:00		17	0.7	1.1	
24	n	6:20:00	6:34:00		18	0.7	1.1	
25	s	6:37:00	6:51:00		17	0.7	1.1	
26	n	6:53:00	7:07:00		20	0.6	1	rain
↑ Times entered are Zulu / GMT ↑				Page		1		Verify S-Turns After Mission Yes X No

Additional Comments: | Drive #

Woolpert

Leica LIDAR	MM/DD/YEAR	Day of Year	Project #	Phase #	Project Name
	4/12/2017			1	Woolpert Dodge County

Operator	Aircraft	HOBBS Start	Local Start Time	ZULU Start Time	Base
Other					
Pilot	**Sensor Type**	**HOBBS END**	**Local End Time**	**Zulu End Time**	**PID**
Other	OTHER				

Wind Dir/Speed	Visibility	Ceiling	Cloud Cover %	Temp	Dew Point	Pressure	Haze/Fire/Cloud	Departing	
220@15	10	clr				30.35	none	Arriving	

Scan Angle (FOV)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power %	Fixed Gain		Mode		Threshold Values	
50	47	343	100	Gain - Course/Up		Single		A	
				Gain - Fine/Down		Multi		B	

Air Speed		AGL		MSL		Waveform Used				Waveform Mode	Pre-Trigger Dist.
150	Kts	5000	Ft		Ft	Yes		No	X	@ NS	Ft

Line #	Dir.	Line Start Time	Line End Time	Time On Line	SV's	HDOP	PDOP	Line Notes/Comments
Test	n/a			n/a	n/a	n/a	n/a	GPS Began Logging At:
		↕ Times entered are Zulu / GMT ↕						Verify S-Turns Before Mission Yes X No
1	s	10:42:30	10:55:30		16	0.8	1.4	
2	n	10:58:00	11:11:11		18	0.6	1.1	rain northern section
3	s	11:16:00	11:28:30		18	0.6	1.1	rain northern section
4	n	11:31:00	11:44:30		17	0.7	1.3	Gap 5 miles from the South
5	s	11:47:30	12:01:00		18	0.6	1.2	
6	n	12:04:00	12:17:00		20	0.6	1.1	
7	s	12:20:00	12:33:30		20	0.6	1	
8	n	12:36:00	12:49:00		17	0.7	1.2	
9	s	12:52:00	1:05:00		17	0.6	1.2	
10	n	1:07:30	1:21:00		17	0.7	1.3	
11	s	1:24:00	2:38:00		16	0.7	1.5	
12	n	1:41:00	1:53:30		16	0.7	1.4	
13	s	1:56:30	2:10:00		16	0.7	1.3	
14	n	2:13:00	2:25:00		16	0.7	1.3	
15	s	2:28:00	2:42:00		18	0.6	1.2	
16	n	2:44:30	2:57:00		19	0.6	1.2	
17	s	4:21:30	4:41:00		18	0.6	1.1	
18	n	4:44:00	4:57:00		15	0.8	1.3	
19	s	5:00:00	5:13:00		16	0.7	1.1	
20	n	5:16:00	5:28:30		18	0.7	1.3	
21	s	5:32:00	5:45:30		16	0.8	1.3	
22	n	5:48:30	6:01:00		16	0.7	1.3	
23	s	6:04:00	6:18:00		17	0.7	1.1	
24	n	6:20:00	6:34:00		18	0.7	1.1	
25	s	6:37:00	6:51:00		17	0.7	1.1	
26	n	6:53:00	7:07:00		20	0.6	1	rain
↑ Times entered are Zulu / GMT ↑				Page	1			Verify S-Turns After Mission Yes X No

Additional Comments:

Drive #

Woolpert

Leica LIDAR	MM/DD/YEAR	Day of Year	Project #	Phase #	Project Name
	4/14/2017			1	Dodge County

Operator	Aircraft	HOBBS Start	Local Start Time	ZULU Start Time	Base
Other					
Pilot	**Sensor Type**	**HOBBS END**	**Local End Time**	**Zulu End Time**	**PID**
Other	OTHER				

Wind Dir/Speed	Visibility	Ceiling	Cloud Cover %	Temp	Dew Point	Pressure	Haze/Fire/Cloud	Departing / Arriving
180 @ 15	10	6000	100			30.21	none	

Scan Angle (FOV)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power %	Fixed Gain		Mode		Threshold Values	
50	47	343	100	Gain - Course/Up		Single		A	
				Gain - Fine/Down		Multi		B	

Air Speed	AGL	MSL	Waveform Used	Waveform Mode	Pre-Trigger Dist.
150 Kts	5000 Ft	Ft	Yes / No X	@ NS	Ft

Line #	Dir.	Line Start Time	Line End Time	Time On Line	SV's	HDOP	PDOP	Line Notes/Comments
Test	n/a			n/a	n/a	n/a	n/a	GPS Began Logging At:
↕ Times entered are Zulu / GMT ↕								Verify S-Turns Before Mission Yes X No
26	s	3:42:30	3:58:00		18	0.7	1.1	Reflight
27	n	4:01:00	4:12:30		18	0.7	1.1	
28	s	4:15:00	4:31:00		18	0.6	1	
29	n	4:33:15	4:44:30		18	0.6	1	
30	s	4:47:30	5:03:30		15	0.7	1.2	
31	n	5:06:00	5:17:30		16	0.8	1.3	
32	s	5:20:00	5:36:00		16	0.8	1.3	
33	n	5:39:00	5:50:00		16	0.7	1.3	
34	s	5:53:00	6:09:00		17	0.7	1.1	
35	n	6:12:15	6:23:30		18	0.6	1	
36	s	6:27:00	6:43:00		17	0.7	1.2	
37	n	6:45:30	6:56:30		18	0.7	1.1	
38	s	7:00:00	7:15:30		17	0.6	1.1	
39	n	7:18:00	7:29:15		18	0.6	1.2	
40	s	7:32:15	7:48:00		18	0.6	1.1	
41	n	7:51:00	8:02:00		19	0.6	1.1	
42	s	8:05:30	8:20:00		19	0.6	1.1	rain last few miles/ southern port
↑ Times entered are Zulu / GMT ↑				Page		1		Verify S-Turns After Mission Yes X No

Additional Comments:

Drive #

Woolpert

Leica LIDAR	MM/DD/YEAR	Day of Year	Project #	Phase #	Project Name
	4/15/2017	80	17-6602-04-102	1	Dodge County

Operator	Aircraft	HOBBS Start	Local Start Time	ZULU Start Time	Base
Other					
Pilot	**Sensor Type**	**HOBBS END**	**Local End Time**	**Zulu End Time**	**PID**
Other	OTHER				

Wind Dir/Speed	Visibility	Ceiling	Cloud Cover %	Temp	Dew Point	Pressure	Haze/Fire/Cloud	Departing / Arriving
270@15	10	clr				30.21	none	

Scan Angle (FOV)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power %	Fixed Gain		Mode		Threshold Values	
50	47	355	100	Gain - Course/Up		Single		A	
				Gain - Fine/Down		Multi		B	

Air Speed	AGL	MSL	Waveform Used	Waveform Mode	Pre-Trigger Dist.
150 Kts	5000 Ft	Ft	Yes No X	@ NS	Ft

Line #	Dir.	Line Start Time	Line End Time	Time On Line	SV's	HDOP	PDOP	Line Notes/Comments
Test	n/a			n/a	n/a	n/a	n/a	GPS Began Logging At:
		↕ Times entered are Zulu / GMT ↕						Verify S-Turns Before Mission Yes X No
4	n	8:16:15	8:26:00		19	0.8	1.2	reflight for a gap
59	s	8:27:00	8:39:00		20	0.7	1.1	
57	n	8:44:00	8:52:00		19	0.7	1.1	
56	s	8:54:00	9:11:00		19	0.7	1.1	
55	n	9:13:45	9:26:00		15	0.8	1.5	
54	s	9:29:00	9:45:00		17	0.7	1.3	
53	n	9:48:00	10:00:00		16	0.7	1.4	
52	s	10:03:00	10:20:00		17	0.7	1.2	
51	n	15:22:30	10:34:00		16	0.8	1.5	
50	s	10:37:30	10:54:00		17	0.8	1.4	
49	n	10:56:30	11:08:15		18	0.8	1.3	
48	s	11:11:00	11:28:00		18	0.7	1.1	
47	n	11:30:00	11:36:00		18	0.6	1.1	cloud- line aborted
42	n	11:48:00	11:51:00		20	0.6	1.1	reflight for rain

↑ Times entered are Zulu / GMT ↑ | Page 1 | Verify S-Turns After Mission Yes X No

Additional Comments:

Drive #

Woolpert

Leica LIDAR	MM/DD/YEAR	Day of Year	Project #	Phase #	Project Name
	4/17/2017	80	17-6602-04-102	1	Dodge County, WI

Operator	Aircraft	HOBBS Start	Local Start Time	ZULU Start Time	Base
Other					
Pilot	**Sensor Type**	**HOBBS END**	**Local End Time**	**Zulu End Time**	**PID**
Other	OTHER				

Wind Dir/Speed	Visibility	Ceiling	Cloud Cover %	Temp	Dew Point	Pressure	Haze/Fire/Cloud	Departing	
290 @ 10	10	clr				30.21	none	Arriving	

Scan Angle (FOV)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power %	Fixed Gain		Mode		Threshold Values	
50	47	343	100	Gain - Course/Up		Single		A	
				Gain - Fine/Down		Multi		B	

Air Speed		AGL		MSL		Waveform Used				Waveform Mode	Pre-Trigger Dist.
150	Kts	5000	Ft		Ft	Yes		No	X	@ NS	Ft

Line #	Dir.	Line Start Time	Line End Time	Time On Line	SV's	HDOP	PDOP	Line Notes/Comments
Test	n/a			n/a	n/a	n/a	n/a	GPS Began Logging At:
		↕ Times entered are Zulu / GMT ↕						Verify S-Turns Before Mission Yes X No
43	s	9:42:30	9:56:00		16	0.7	1.2	
44	n	9:59:00	10:12:00		17	0.6	1.1	
45	s	10:15:00	10:28:30		17	0.7	1.3	noise first 3 miles
46	n	10:31:30	10:45:00		17	0.8	1.3	rain
58	w	10:52:00	11:09:00		16	0.8	1.4	
2	s	11:11:10	11:17:00		17	0.7	1.3	patch work
3	s	11:24:15	11:28:00		18	0.6	1.2	patch work
4	s	11:34:30	11:37:00		18	0.7	1.2	patch work
58	e	11:42:00	11:53:30		20	0.6	1	reflight for rain
47	s	11:58:30	12:12:30		19	0.6	1.1	
46	n	12:15:00	12:27:30		19	0.6	1.1	reflight for rain
45	s	12:30:00	12:32:00		17	0.6	1.2	reflight for rain

↑ Times entered are Zulu / GMT ↑		Page	1	Verify S-Turns After Mission Yes X No
Additional Comments:				Drive #

Woolpert

Leica LIDAR	MM/DD/YEAR	Day of Year	Project #	Phase #	Project Name
	4/23/2017	80	17-6602-04-102	1	Dodge County, WI

Operator	Aircraft	HOBBS Start	Local Start Time	ZULU Start Time	Base
Other					
Pilot	**Sensor Type**	**HOBBS END**	**Local End Time**	**Zulu End Time**	**PID**
Other	OTHER				

Wind Dir/Speed	Visibility	Ceiling	Cloud Cover %	Temp	Dew Point	Pressure	Haze/Fire/Cloud		
190 @ 10	10	clr				30.21	none	Departing	
								Arriving	

Scan Angle (FOV)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power %	Fixed Gain		Mode		Threshold Values	
50	47	343	100	Gain - Course/Up		Single		A	
				Gain - Fine/Down		Multi		B	

Air Speed		AGL		MSL		Waveform Used				Waveform Mode	Pre-Trigger Dist.
150	Kts	5000	Ft		Ft	Yes		No	X	@ NS	Ft

Line #	Dir.	Line Start Time	Line End Time	Time On Line	SV's	HDOP	PDOP	Line Notes/Comments
Test	n/a			n/a	n/a	n/a	n/a	GPS Began Logging At:
		↕ Times entered are Zulu / GMT ↕						Verify S-Turns Before Mission Yes X No
54R	N	11:32:00	11:33:00		19	0.7	1.1	
54R	S	11:35:00	11:36:00		17	0.7	1.2	
52R	S	11:40:00	11:41:00		18	0.8	1.2	
52R	N	11:43:00	11:44:00		18	0.7	1.2	
25R	S	11:54:30	11:57:00		18	0.6	1.1	
25R	N	11:59:30	12:03:15		17	0.7	1.1	

↑ Times entered are Zulu / GMT ↑		Page	1	Verify S-Turns After Mission	Yes	X	No
Additional Comments:							Drive #

Section 7: Final Deliverables

The final lidar deliverables are listed below.

- LAS v1.4 classified point cloud
- Hydro Breaklines as ESRI GDB
- Bridge Breaklines as ESRI GDB
- Digital Elevation Model in ERDAS .IMG format
- Digital Elevation Model in ESRI ArcGrid format
- County Wide Mosaic Bare Earth Surface (Raster DEM) in ERDAS .IMG format
- County Wide Mosaic Bare Earth Surface (Raster DEM) in ESRI ArcGrid format
- 8-bit gray scale intensity images in .TIF format
- Tile layout provided as ESRI shapefile
- Control Points provided as ESRI shapefile
- Flight Lines provided as ESRI shapefile
- FGDC compliant metadata per product in XML format
- Lidar processing report in pdf format
- Survey report in pdf format