AIRBORNE LIDAR REPORT

NRCS SAGINAW BAY, MI LIDAR TASK ORDER

Woolpert Project Number: 071804
November 2012

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NRCS SAGINAW BAY, MI LIDAR

WOOLPERT PROJECT #071804

For:

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SECTION 1: OVERVIEW

PROJECT NAME: NRCS SAGINAW BAY, MI LIDAR

WOOLPERT PROJECT #071804

This report contains a comprehensive outline of the airborne LiDAR data acquisition consisting of a 1,632 square mile area near Saginaw Bay, Michigan for the United States Geological Survey (USGS). The LiDAR was collected and processed to meet a maximum 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 a Leica ALS50-II 150 kHz, Leica ALS60 200 kHz and a Leica ALS70 500 kHz Multiple Pulses in Air (MPiA) LiDAR sensor. The sensors collect up to four returns (echos) per pulse, recording attributes such as time stamp and 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:

Post Spacing (Minimum):	2.30 ft / 0.7 m
AGL (Above Ground Level) average flying height:	6,500 ft / 1,981 m
MSL (Mean Sea Level) average flying height:	7,075 ft / 2,156 m
Average Ground Speed:	130 knots / 150 mph
Field of View (full):	36 degrees (ALS 50/60) / 40 degrees (ALS 70)
Pulse Rate:	121.2 kHz (ALS 50/60) / 276.1 kHz (ALS 70)
Scan Rate:	63.9 Hz (ALS 50/60) / 39.7 Hz (ALS 70)
Side Lap (Minimum):	25.5%

LiDAR data was processed and projected in UTM, Zone 17N, North American Datum of 1983 (NAD83) in units of meters. The vertical datum used for the task order was referenced to NAVD 1988, meters, Geoid 09

Figure 1.1: Task Order and LiDAR Flight Layout – Saginaw Bay, Michigan

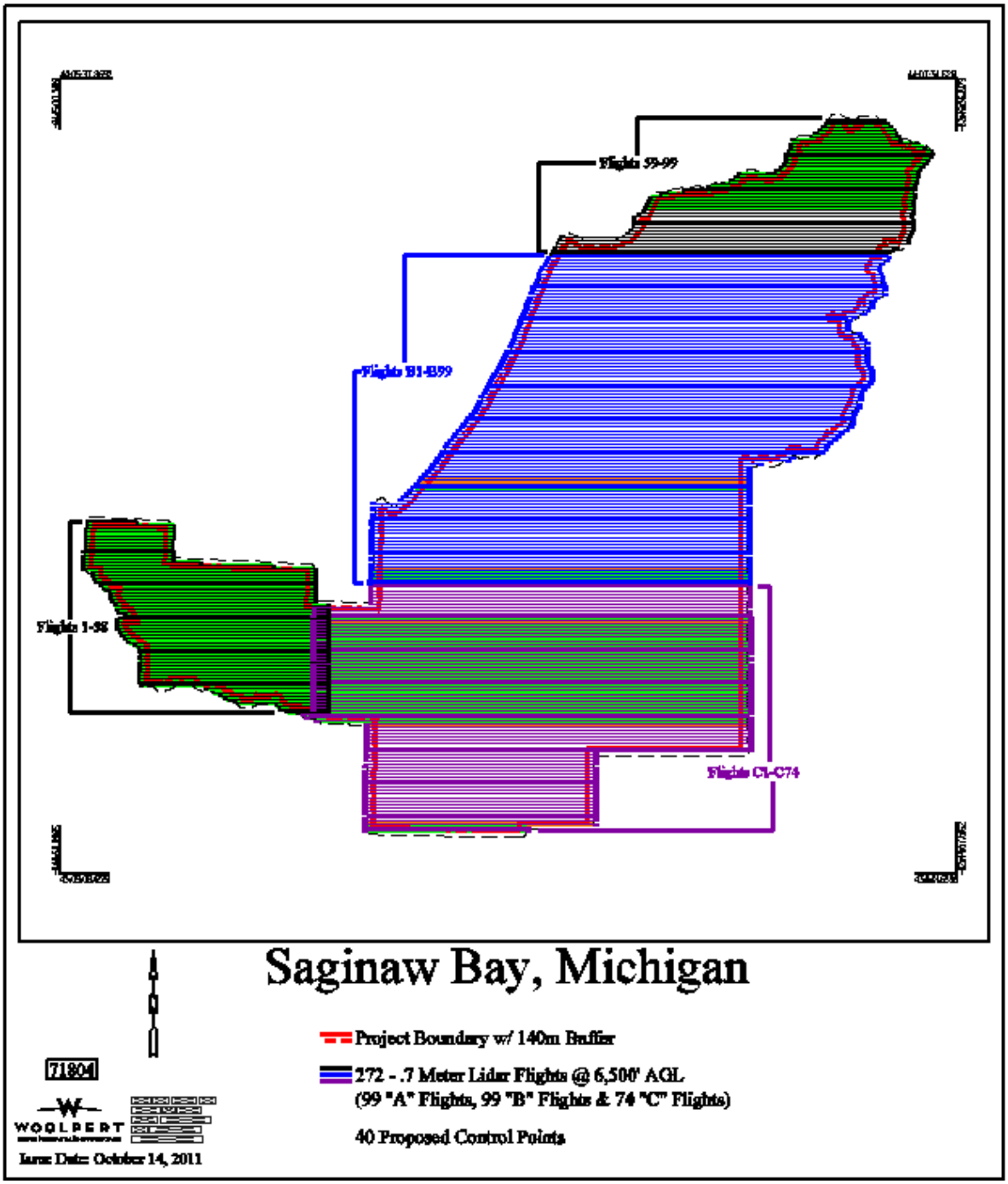
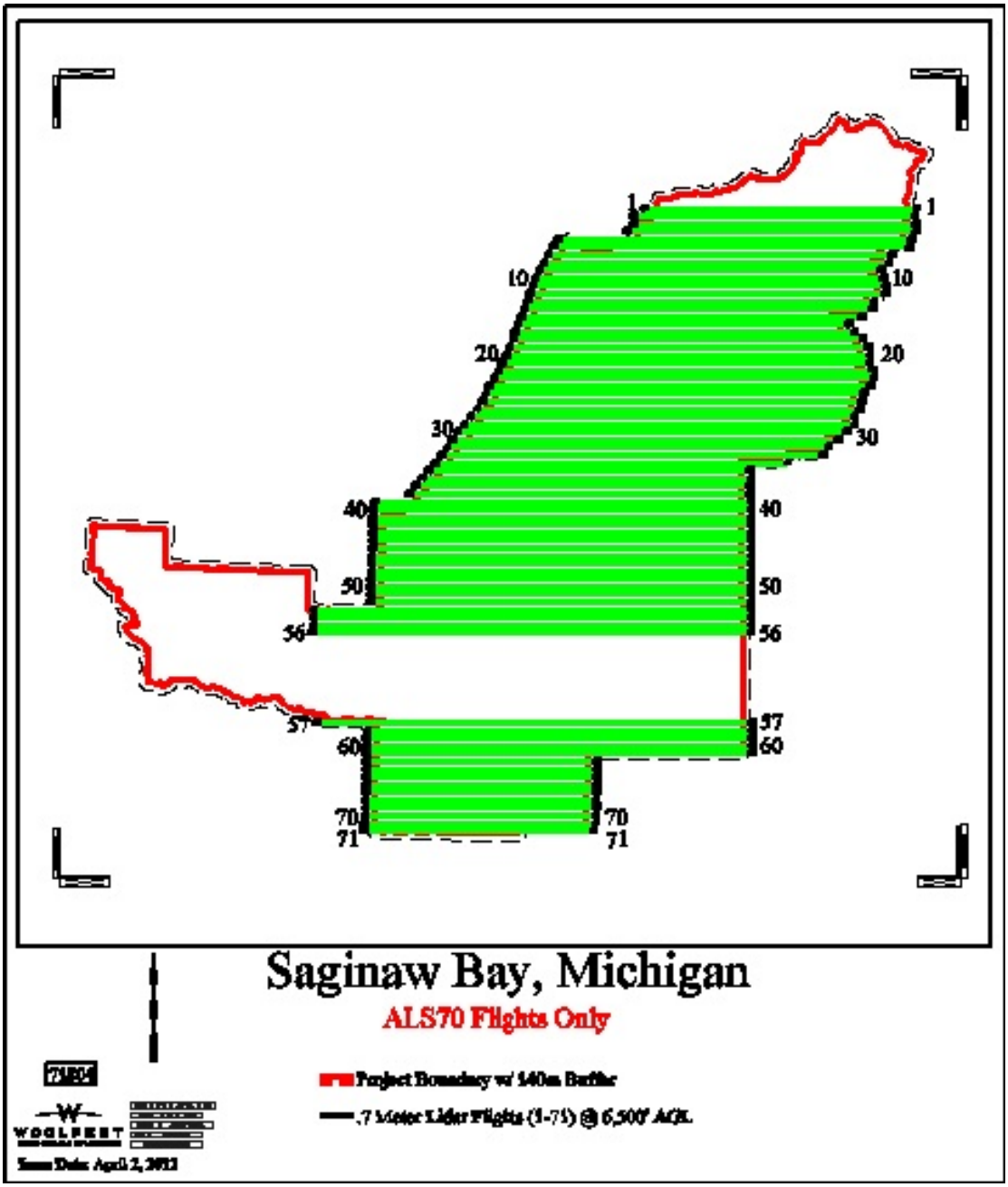


Figure 1.2: Task Order and LiDAR Flight Layout – Saginaw Bay ALS70 Flights Only



SECTION 2: ACQUISITION

The LiDAR data was acquired with a Leica ALS50-II 150 kHz, Leica ALS60 200 kHz, and a Leica ALS70 Multiple Pulses in Air (MPiA) LiDAR sensor system, on board a Cessna 404. These LiDAR systems, developed by Leica Geosystems of Heerbrugg, Switzerland, include the simultaneous first, intermediate and last pulse data capture module, the extended altitude range module, and the target signal intensity capture module. The system software is operated on an OC50 Operation Controller aboard the aircraft.

The ALS50-II 150 kHz Multiple Pulses in Air (MPiA) LiDAR System has the following specifications:

Table 2.1: ALS50-II LiDAR System Specifications

Specification	
Operating Altitude	200 - 6,000 meters
Scan Angle	0 to 75° (variable)
Swath Width	0 to 1.5 X altitude (variable)
Scan Frequency	0 – 90 Hz (variable based on scan angle)
Maximum Pulse Rate	150 kHz
Range Resolution	Better than 1 cm
Elevation Accuracy	8 – 24 cm single shot (one standard deviation)
Horizontal Accuracy	7 – 64 cm (one standard deviation)
Number of Returns per Pulse	4 (first, second, third, last)
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

The ALS60 200 kHz Multiple Pulses in Air (MPiA) LiDAR System has the following specifications:

Table 2.2: ALS60 LiDAR System Specifications	
Specification	
Operating Altitude	200 - 6,000 meters
Scan Angle	0 to 75° (variable)
Swath Width	0 to 1.5 X altitude (variable)
Scan Frequency	0 – 100 Hz (variable based on scan angle)
Maximum Pulse Rate	200 kHz
Range Resolution	Better than 1 cm
Elevation Accuracy	8 – 24 cm single shot (one standard deviation)
Horizontal Accuracy	7 – 64 cm (one standard deviation)
Number of Returns per Pulse	4 (first, second, third, last)
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

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

Table 2.3: ALS70 LiDAR System Specifications	
Specification	
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 task order site, Woolpert flight crews coordinated with the necessary Air Traffic Control personnel to ensure airspace access.

Woolpert survey crews were onsite, operating a Global Navigation Satellite System (GNSS) Base Station at the MBS International Airport (MBS) for the airborne GPS support on days 32211, 32511, 32611, and 32711. Coordinates 43°31'52.84983"(N), 84°05'19.76102"(W), Ellipsoid Height 168.142 meters.

Woolpert survey crews were onsite, operating a Global Navigation Satellite System (GNSS) Base Station at the MBS International Airport 2 (MBS) for the airborne GPS support on days 09512, 09612, and 09712. Coordinates 43°31'51.66227"(N), 84°05'19.79310"(W), Ellipsoid Height 169.993 meters.

Woolpert survey crews were onsite, operating a Global Navigation Satellite System (GNSS) Base Station at MIVA CORS for the airborne GPS support on days 36011 and 09512. Coordinates 43°22'42.97497"N, 83°35'07.25051"W, Ellipsoid Height 180.159 meters.

The LiDAR data was collected in (12) missions.

An initial quality control process was performed immediately on the LiDAR data to review the data coverage, airborne GPS data, and trajectory solution. Any gaps found in the LiDAR data were relayed to the flight crew, and the area was re-flown.

Table 2.4: Airborne LiDAR Acquisition Flight Summary

Airborne LiDAR Acquisition Flight Summary			
Date of Mission/Sensor	Lines Flown	Mission Time (UTC) Wheels Up/ Wheels Down	Mission Time (Local = EST) Wheels Up/ Wheels Down
Nov 18, 2011 – S/N 77 A	43-58	15:06 – 21:31	10:06 AM – 16:31 PM
Nov 18, 2011 – S/N 6157 B	1-28	15:25 – 21:12	10:25 AM -16:12 PM
Nov 21, 2011 – S/N 77 A	29-42, 72-74	22:18 – 02:01	17:18 PM -21:01 PM
Nov 21, 2011 – S/N 6157 B	23-41	22:00 – 05:00	17:00 PM – 00:00 AM
Nov 22, 2011 – S/N 77 A	80-99	16:18 – 22:25	11:18 AM – 17:25 PM
Nov 22, 2011 – S/N 6157 B	20-22, 60,70	15:30 – 18:20	10:30 AM – 13:20 PM
Nov 23, 2011 – S/N 6157	19,21,23,36,68	13:00 – 15:14	08:00 AM – 10:14 AM
Nov 26, 2011 – S/N 77	10-18,20,49	16:36 – 18:48	11:36 AM – 13:48 PM
Apr 4, 2012 – S/N 7177 A	50-71	14:48 – 20:32	09:48 AM – 16:32 PM
Apr 4, 2012 – S/N 7177 B	36-49	21:50 – 01:58	17:50 PM – 21:58 PM
Apr 5, 2012 – S/N 7177	20-35	23:50 – 04:22	18:50 PM – 23:22 PM
Apr 6, 2012 – S/N 7177	1-10	14:29 – 19:27	09:29 AM – 15:27 PM

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.

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.2.70, Proprietary Software, TerraMatch v. 12.01.

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.12.005.

4. The .LAS files were evaluated through a series of manual QA/QC steps to eliminate remaining artifacts and small undulations from the ground class.
   Software: TerraScan v.12.005.

5. All water bodies greater than two acres and all rivers with a nominal 30.5 meters (100 foot) width or larger were hydrologically flattened using proprietary methods.
   Software: ESRI 10.0, Microstation v8**,** TerraScan v.12.005, LP360, Woolpert Proprietary Tools.

GLOBAL NAVIGATION SATELLITE SYSTEM (GNSS)-INERTIAL MEASUREMENT UNIT (IMU) TRAJECTORY PROCESSING

EQUIPMENT

Flight navigation during the LiDAR data acquisition mission is performed using IGI CCNS (Computer Controlled Navigation System). 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.

The aircraft are all configured with a NovAtel Millennium 12-channel, L1/L2 dual frequency Global Navigation Satellite System (GNSS) receivers collecting at 2 Hz.

All Woolpert aerial sensors are equipped with a Litton LN200 series Inertial Measurement Unit (IMU) operating at 200 Hz.

A base-station unit was mobilized for each acquisition mission, and was operated by a member of the Woolpert survey crew. Each base-station setup consisted of one Trimble 4000 – 5000 series dual-

frequency receiver, one Trimble Compact L1/L2 dual frequency antenna, one 2-meter fixed-height tripod, and essential battery power and cabling. Ground planes were used on the base-station antennas. Data was collected at 1 or 2 Hz.

Woolpert survey crews were onsite, operating a Global Navigation Satellite System (GNSS) Base Stations at the Sidney-Richland Municipal Airport (SDY) and DH9106 for the airborne GPS support. The GNSS base stations operated during the LiDAR acquisition missions is listed below:

Table 3.1: GNSS Base Stations

Station Name	Latitude (DMS)	Longitude (DMS)	Ellipsoid Height (L1 Phase Center) (Meters)
MBS	N 43° 31' 52.85"	W 84° 05' 19.76"	168.142
MBS 2	N 43° 31' 51.66"	W 84° 05' 19.79"	169.993
MIVA	N 43° 22' 42.97"	W 83° 35' 07.25"	180.159

DATA PROCESSING

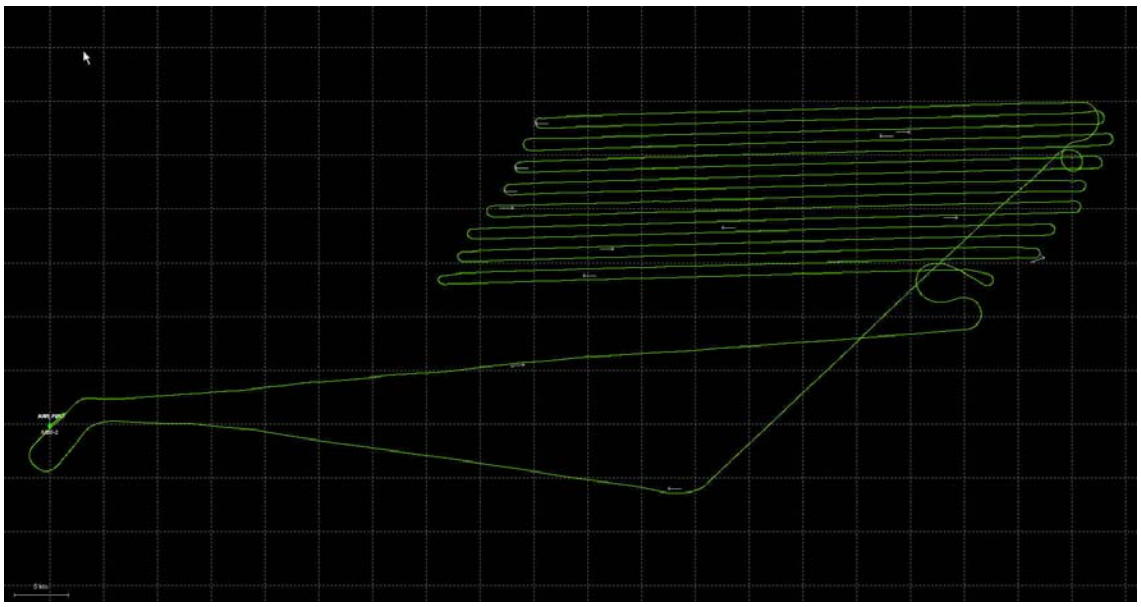
All airborne GNSS and IMU data was post-processed and quality controlled using Applanix 5.3 MMS software. GNSS data was processed at a 1 and 2 Hz data capture rate and the IMU data was processed at 200 Hz.

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. See **Figure 3.1** for the flight trajectory.

Flight Trajectory

Figure 3.1: Representative Graph from Day09612



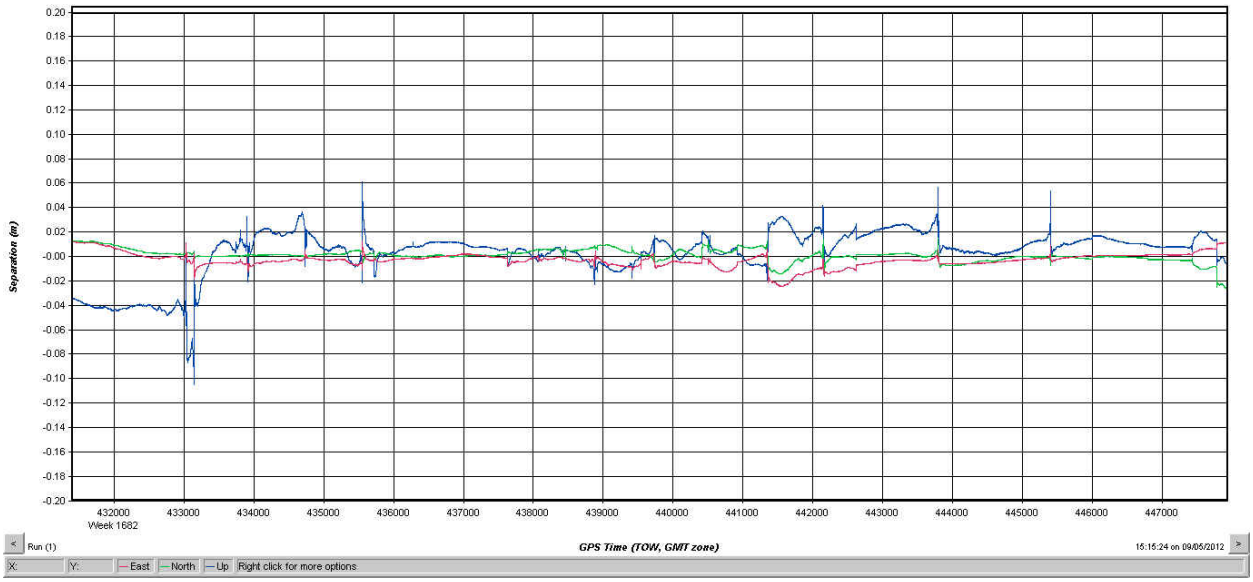
Within the trajectory processing, there are many factors that affect the overall quality, but the most indicative are the Combined Separation, the Estimated Positional Accuracy, and the Positional Dilution of Precision (PDOP).

Combined 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. See **Figure 3.2** for the combined separation graph.

Figure 3.2: Representative Graph from Day09612 of Combined Separation

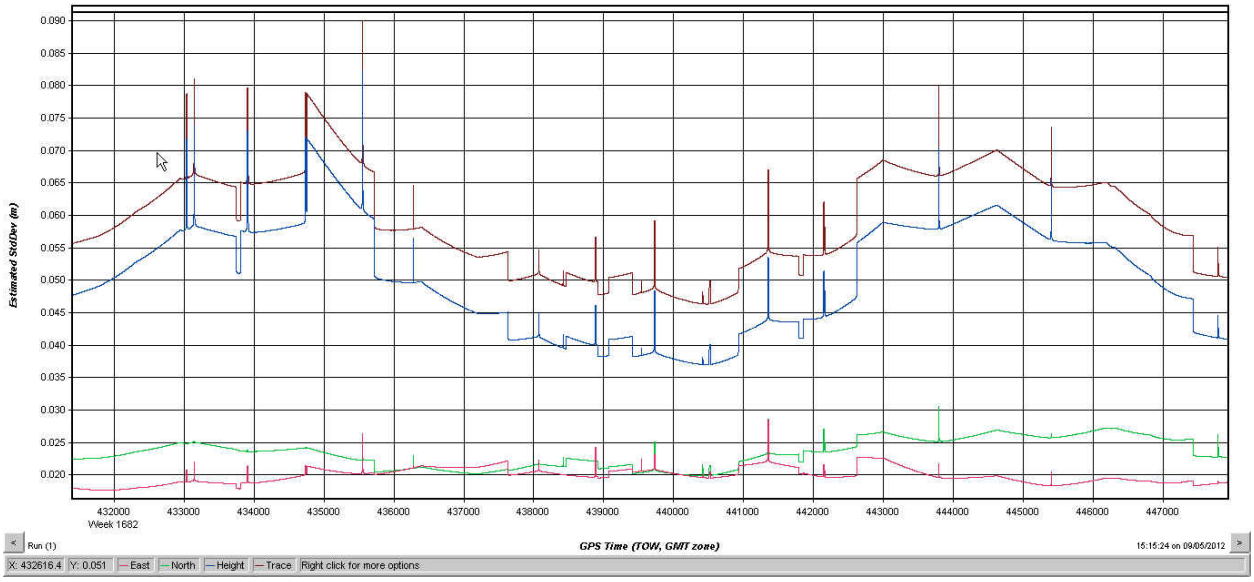


Estimated Positional Accuracy

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.

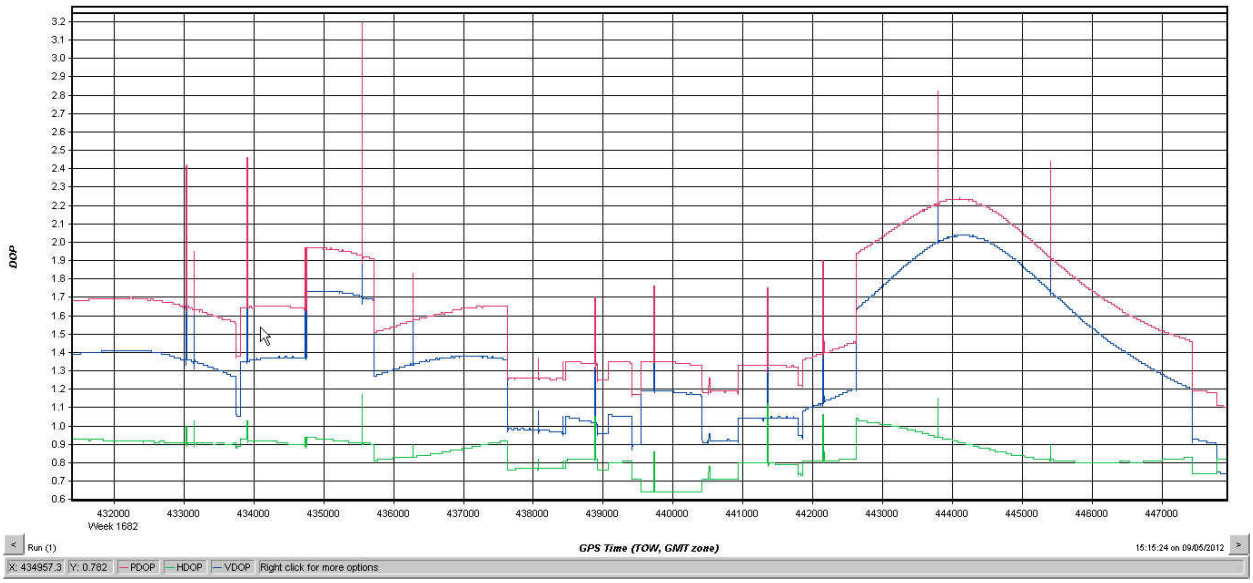
Figure 3.3: Representative Graph from Day09612 of Positional Accuracy



PDOP

Position Dilution of precision (DOP) is a measure of the quality of the GPS data being received from the satellites. Woolpert's goal is to maintain an average PDOP of 3 or less.

Figure 3.4: Representative Graph from Day09612 of PDOP



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 of the task order data was imported and classified, cross flights and survey ground control data was imported and calculated for an accuracy assessment. As a QA/QC measure, Woolpert has developed a routine to generate accuracy statistical reports by comparison among LiDAR points, ground control, and TINs. The LiDAR is adjusted accordingly to reduce any vertical bias 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 bare earth DEM surface was hydrologically flattened for waterbody features that were greater than 2 acres and rivers and streams of 100 feet and greater nominal width.

- The LiDAR LAS files for this task order have been classified into the Default (Class 1), Ground (Class 2), High Vegetation (Class 5), Building (Class 6), Noise (Class 7), Water (Class 9), Ignored Ground (Class 10), Overlap Default (Class 17), and Overlap Ground (Class 18) classifications.

- FGDC Compliant metadata was developed for the task order in .xml format for the final data products.

- The horizontal datum used for the task order was referenced to UTM, 17N, North American Datum of 1983. Coordinate positions were specified in units of meters for Saginaw Bay. The vertical datum used for the task order was referenced to NAVD 1988, meters, Geoid09.

- Smoke from a factory blocked LiDAR penetration on portions of tiles 17TKJ294801 and 17TKJ304815. See figure 3.5 and 3.6 for examples of these voids.

Figure 3.5: Factory Smoke Void 17TKJ294801

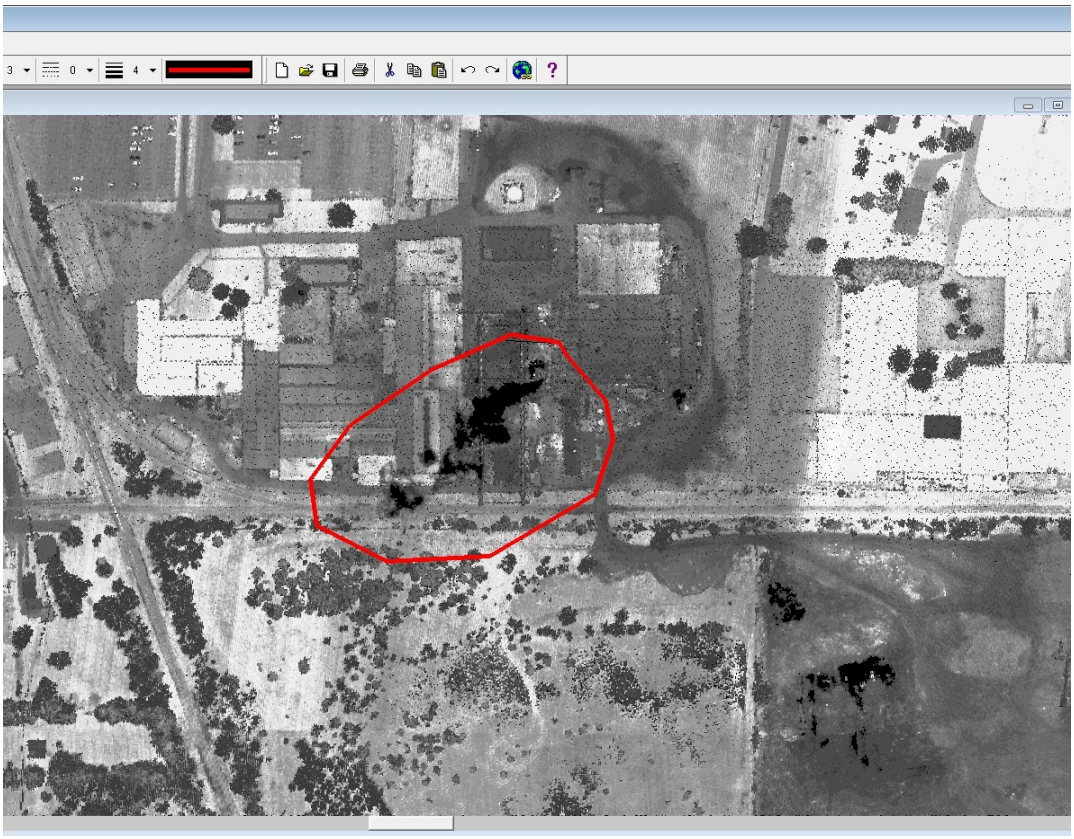
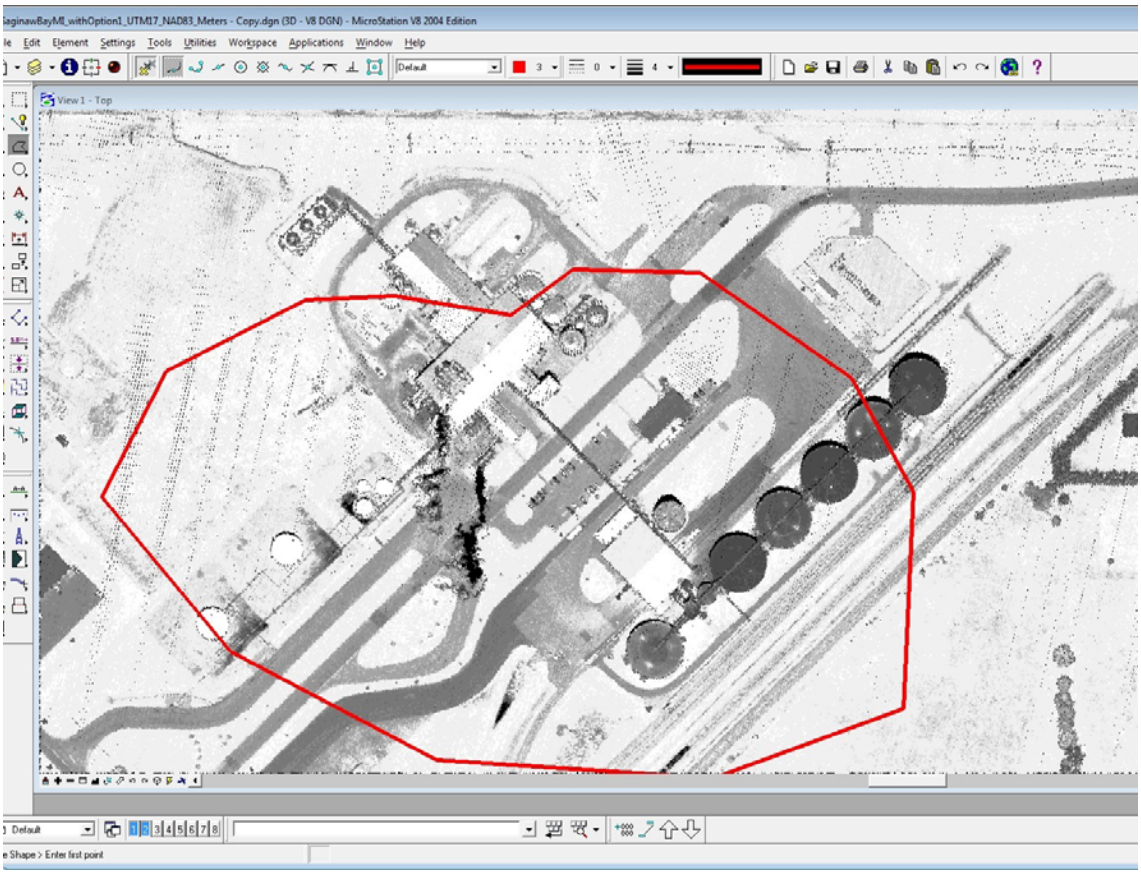


Figure 3.6: Factory Smoke Void 17TKJ304815



SECTION 4: HYDROLOGIC FLATTENING AND FINAL QUALITY CONTROL

HYDROLOGIC FLATTENING OF LIDAR DEM DATA

This task 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-acres 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 30.5 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

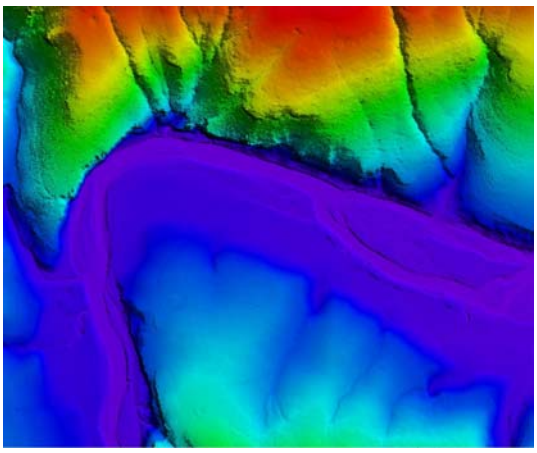
Woolpert utilized the following steps to hydrologically flatten the water bodies and for gradient hydrologic flattening of the double line streams within the existing LiDAR data.

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-acres or greater, were compiled as closed polygons. **Figure 4.1** illustrates a good example of 2-acre lakes and 30.5 meters (100 feet) nominal streams identified and defined with hydrologic breaklines. The breaklines defining rivers and streams, at a nominal minimum width of 30.5 meters (100 feet), were draped with both sides of the stream maintaining an equal gradient elevation.

Figure 4.1



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 1.5 meter (5 foot) 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 4.2 **Figure 4.3**

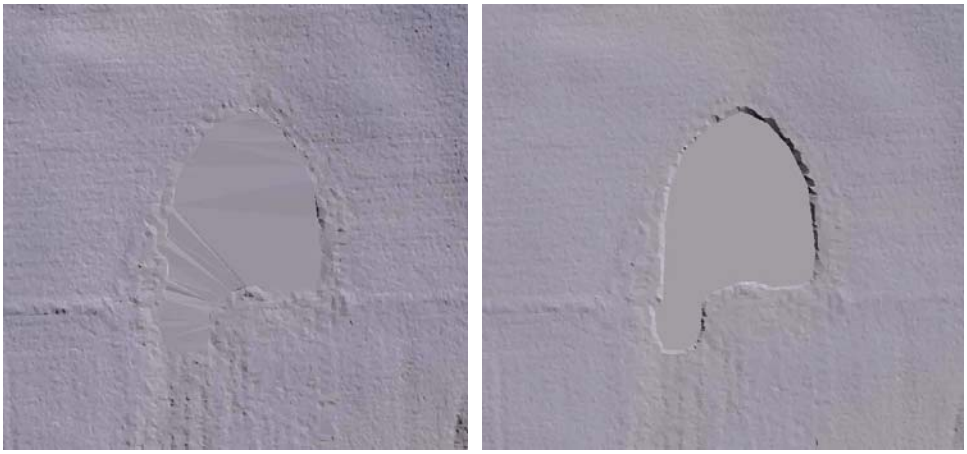


Figure 4.2 reflects a DEM generated from original LiDAR bare earth point data prior to the hydrologic flattening process. Note the "tinning" across the lake surface.

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.

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 at a 1-meter cell size. The hydrologic breaklines compiled as part of the flattening process were provided to the USGS as an ESRI shapefile. The breaklines defining the water bodies greater than 2-acres were provided as a PolygonZ file. The breaklines compiled for the gradient flattening of all rivers and streams at a nominal minimum width of 30.5 meters (100 feet) were provided as a PolylineZ file.

DATA QA/QC

Initial QA/QC for this task order was performed in Global Mapper v11, by reviewing the grids and hydrologic breakline features.

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

SECTION 5: FINAL ACCURACY ASSESSMENT

FINAL VERTICAL ACCURACY ASSESSMENT

The vertical accuracy statistics were calculated by comparison of the LiDAR bare earth points to the ground surveyed QA/QC points.

Table 5.1: Overall Vertical Accuracy Statistics, Saginaw Bay, Michigan		
Average error	+0.002	meters
Minimum error	-0.166	meters
Maximum error	+0.136	meters
Average magnitude	0.053	meters
Root mean square	0.069	meters
Standard deviation	0.070	meters

Table 5.2: QA/QC Analysis, UTM17N, NAD83, Saginaw Bay, Michigan

Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Laser Elevation (meters)	Dz (meters)
1	244160.594	4828921.434	190.196	190.03	-0.166
2	253676.028	4828319.657	190.512	190.37	-0.142
3	253412.589	4823385.577	194.11	193.96	-0.15
4	272307.566	4822670.594	180.462	180.4	-0.062
5	273697.475	4817832.446	180.041	179.99	-0.051
6	281817.015	4817529.915	184.544	184.52	-0.024
7	283502.086	4829157.434	177.945	177.96	0.015
8	293883.884	4839601.248	177.908	177.95	0.042
9	307329.636	4853934.685	178.459	178.44	-0.019
10	307040.335	4864955.117	178.814	178.95	0.136
11	322721.118	4872184.636	182.378	182.43	0.052
12	343346.946	4879924.985	188.274	188.33	0.056
13	351553.215	4877780.087	180.102	180.14	0.038
14	350259.241	4867272.124	213.715	213.76	0.045

Table 5.2: QA/QC Analysis, UTM17N, NAD83, Saginaw Bay, Michigan					
Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Laser Elevation (meters)	Dz (meters)
15	345477.2	4858219.21	227.542	227.6	0.058
16	344499.043	4850324.74	234.311	234.24	-0.071
17	338710.82	4841401.521	243.86	243.91	0.05
18	328496.19	4829706.192	225.904	226.02	0.116
19	329519.622	4813775.178	238.023	238.03	0.007
20	327816.692	4799849.893	257.325	257.36	0.035
21	308899.897	4789618.156	249.033	249.07	0.037
22	281234.571	4788930.419	224.39	224.43	0.04
23	281324.279	4803334.414	203.177	203.19	0.013
24	274840.142	4805123.453	195.321	195.41	0.089
25	273847.244	4809573.313	186.948	186.99	0.042
26	260327.546	4808144.505	178.371	178.39	0.019
27	251297.555	4808332.668	180.885	180.89	0.005
28	248634.642	4818515.11	188.099	188.06	-0.039
29	244341.423	4823190.067	189.4	189.26	-0.14
30	294596.232	4799423.861	213.471	213.43	-0.041
31	316575.699	4807702.269	261.237	261.29	0.053
32	294276.537	4813321.067	237.371	237.46	0.089
33	294569.601	4827623.234	186.483	186.46	-0.023
34	314927.133	4827387.621	236.994	236.99	-0.004
35	330851.732	4841265.73	226.941	226.95	0.009
37	337452.968	4856185.252	223.256	223.24	-0.016
38	318328.875	4859739.969	186.901	186.85	-0.051
39	339204.979	4867165.857	211.945	211.97	0.025
40	259196.751	4816853.874	186.406	186.41	0.004

VERTICAL ACCURACY CONCLUSIONS

Bare-Earth DEM Fundamental Vertical Accuracy (FVA): Tested 0.135 meters fundamental vertical accuracy at a 95 percent confidence level, derived according to NSSDA, in open terrain using RMSE(z) x 1.96000. Tested against the DEM.

Based on the analysis of the LiDAR data, the accuracy of the data meets the task order requirements.

SUPPLEMENTAL VERTICAL ACCURACY ASSESSMENT (SVA)

Table 5.3: Bare Earth and Open Terrain QA/QC Analysis, UTM17N, NAD83, Saginaw Bay, Michigan

Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Laser Elevation (meters)	Dz (meters)
1044	310227.071	4825015.013	232.765	232.71	-0.055
1058	324543.717	4835476.229	233.153	233.19	0.037
1047	316593.694	4804123.522	252.602	252.66	0.058
1059	326415.951	4842774.125	222.736	222.73	-0.006
1063	308633.67	4842759.316	191.893	191.98	0.087
1074	317060.653	4853877.5	191.112	191.18	0.068
1078	307106.245	4852321.934	180.149	180.14	-0.009
1083	342228.204	4846330.138	233.991	234.04	0.049
1087	345417.477	4868777.397	216.761	216.74	-0.021
1006	256786.577	4813747.914	189.559	189.55	-0.009
1090	326313.152	4863656.656	190.14	190.11	-0.03
1098	339827.82	4871863.542	199.802	199.84	0.038
1011	281492.768	4808644.466	194.835	194.84	0.005
1012	268189.128	4810838.722	184.998	185.03	0.032
1022	291038.067	4808891.304	216.944	216.98	0.036
1027	295026.951	4788790.163	249.758	249.84	0.082
1030	302498.371	4821067.666	211.02	210.96	-0.06
1034	322934.719	4813820.983	235.707	235.8	0.093

Table 5.3: Bare Earth and Open Terrain QA/QC Analysis, UTM17N, NAD83, Saginaw Bay, Michigan					
Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Laser Elevation (meters)	Dz (meters)
1036	288014.26	4818359.667	193.195	193.13	-0.065
1094	332635.139	4871736.078	180.009	180.11	0.101
1039	293078.362	4836468.613	179.316	179.39	0.074
1003	253133.611	4820334.149	193.925	193.78	-0.145

Bare Earth and Open Terrain Land Cover Classification Supplemental Vertical Accuracy (SVA): Tested 0.099 meters supplemental vertical accuracy at the 95th percentile in Bare Earth/Open Terrain. Tested against the DEM. Errors larger than 95th percentile include:

- Point 1003, Easting 253133.611, Northing 4820334.149, Z-Error -0.145
- Point 1094, Easting 332635.139, Northing 4871736.078, Z-Error 0.101

Table 5.4: Brush Lands and Trees QA/QC Analysis, UTM17N, NAD83, Saginaw Bay, Michigan					
Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Laser Elevation (meters)	Dz (meters)
1002	246563	4827901	196.908	196.83	-0.078
1045	321381.7	4807342	246.757	246.8	0.043
1057	324113.3	4826620	219.065	219.2	0.135
1061	318414.1	4836133	215.661	215.67	0.009
1064	301227.1	4842391	179.87	180.02	0.15
1067	326153	4848488	209.503	209.55	0.047
1075	314927.4	4858659	183.137	183.26	0.123
1080	327192.8	4858855	191.032	191.04	0.008
1084	339442	4860640	221.278	221.34	0.062
1089	332692.2	4862560	202.242	202.25	0.008
1092	325004.8	4868441	182.982	182.99	0.008
1004	259596.1	4819768	183.277	183.18	-0.097

Table 5.4: Brush Lands and Trees QA/QC Analysis, UTM17N, NAD83, Saginaw Bay, Michigan					
Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Laser Elevation (meters)	Dz (meters)
1099	336451.9	4874876	185.804	185.79	-0.014
1106	340206	4876629	189.485	189.68	0.195
1010	284598.3	4799966	192.42	192.48	0.06
1021	293243.5	4803027	205.921	206.04	0.119
1024	302582.6	4796084	281.336	281.41	0.074
1031	299114.3	4818370	212.24	212.23	-0.01
1033	314648.3	4810577	230.607	230.72	0.113
1042	298611.6	4828185	193.655	193.73	0.075
1043	310221.2	4828422	212.024	212.02	-0.004

Brush Lands and Trees Land Cover Classification Supplemental Vertical Accuracy (SVA): Tested 0.190 meters supplemental vertical accuracy at the 95th percentile in Brush Lands and Trees. Tested against the DEM. Brush Lands and Trees Errors larger than 95th percentile include:

- Point 1106, Easting 340205.979, Northing 4876629.209, Z-Error 0.195

Table 5.5: Urban QA/QC Analysis, UTM17N, NAD83, Saginaw Bay, Michigan					
Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Laser Elevation (meters)	Dz (meters)
1000	249818.246	4823886.202	204.458	204.3	-0.158
1048	309288.94	4800949.297	277.92	277.9	-0.02
1056	324503.759	4829801.889	226.476	226.55	0.074
1060	317380.689	4844256.208	195.91	195.92	0.01
1065	302549.593	4845008.425	179.436	179.45	0.014
1066	324872.417	4853935.547	195.424	195.43	0.006
1076	309075.418	4857803.221	180.911	180.95	0.039
1082	339047.993	4851844.831	230.642	230.66	0.018

Table 5.5: Urban QA/QC Analysis, UTM17N, NAD83, Saginaw Bay, Michigan					
Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Laser Elevation (meters)	Dz (meters)
1085	339713.852	4867089.363	213.827	213.8	-0.027
1093	317670.731	4867746.129	182.704	182.69	-0.014
1095	340339.956	4878770.806	181.274	181.28	0.006
1005	262040.38	4812886.839	181.077	181.1	0.023
1096	348082.817	4879853.196	179.474	179.57	0.096
1009	282300.094	4814381.721	190.476	190.54	0.064
1020	290774.799	4805320.68	191.487	191.54	0.053
1025	294747.734	4795241.013	229.236	229.22	-0.016
1029	306209.679	4818037.262	219.777	219.82	0.043
1035	322693.323	4820181.342	226.057	226.04	-0.017
1038	296873.22	4826834.292	195.307	195.32	0.013
1041	303919.588	4832309.902	196.501	196.45	-0.051

Urban Land Cover Classification Supplemental Vertical Accuracy (SVA): Tested 0.094 meters supplemental vertical accuracy at the 95th percentile in Urban. Urban Errors larger than 95th percentile include:

- Point 1000, Easting 249818.246, Northing 4823886.202, Z-Error -0.158
- Point 1096, Easting 348082.817, Northing 4879853.196, Z-Error 0.096

Table 5.6: Tall Weeds and Crops QA/QC Analysis, UTM17N, NAD83, Saginaw Bay, Michigan					
Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Laser Elevation (meters)	Dz (meters)
1001	247257.061	4824664.841	189.372	189.28	-0.092
1046	321369.837	4801048.741	261.966	262.06	0.094
1055	316767.662	4829811.79	235.742	235.74	-0.002

Table 5.6: Tall Weeds and Crops QA/QC Analysis, UTM17N, NAD83, Saginaw Bay, Michigan					
Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Laser Elevation (meters)	Dz (meters)
1062	313348.039	4836233.567	198.681	198.78	0.099
1073	319882.012	4849916.727	194.982	194.96	-0.022
1077	311849.419	4851585.611	189.479	189.58	0.101
1079	305503.48	4849061.618	182.039	182.07	0.031
1081	332656.017	4854168.805	218.347	218.39	0.043
1086	345472.575	4863953.953	218.589	218.59	0.001
1088	334302.249	4866393.331	199.529	199.63	0.101
1091	321518.366	4863558.865	187.372	187.42	0.048
1007	256066.054	4812000.483	187.498	187.57	0.072
1097	347039.895	4874313.189	203.81	204	0.19
1008	274893.689	4814689.248	182.603	182.68	0.077
1023	295683.262	4806981.758	194.631	194.73	0.099
1026	287191.416	4794630.864	207.897	207.93	0.033
1028	302260.039	4814380.286	207.496	207.6	0.104
1032	302148.551	4808990.026	210.341	210.45	0.109
1037	288141.174	4824242.864	181.958	182.1	0.142
1040	301020.052	4836354.341	188.562	188.62	0.058

Tall Weeds/Crops Land Cover Classification Supplemental Vertical Accuracy (SVA): Tested 0.187 meters supplemental vertical accuracy at the 95th percentile in Tall Weeds/Crops. Tested against the DEM. Tall Weeds/Crops Errors larger than 95th percentile include:

- Point 1097, Easting 347039.895, Northing 4874313.189, Z-Error 0.190

Table 5.7: Forested and Fully Grown QA/QC Analysis, UTM17N, NAD83, Saginaw Bay, Michigan					
Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Laser Elevation (meters)	Dz (meters)
1014	266143.419	4811687.121	183.858	183.89	0.032
1015	266165.937	4811655.094	183.739	183.77	0.031
1016	266138.576	4811652.274	183.426	183.52	0.094
1017	266106.393	4811658.194	183.575	183.62	0.045
1018	266094.777	4811630.886	183.572	183.54	-0.032
1019	266125.472	4811614.792	183.548	183.6	0.052
1049	308502.161	4811758.536	225.35	225.47	0.12
1050	308554.281	4811774.671	225.088	225.23	0.142
1051	308604.52	4811720.133	224.599	224.78	0.181
1052	308616.851	4811777.541	225.576	225.72	0.144
1053	308654.86	4811815.512	225.294	225.48	0.186
1054	308566.364	4811853.02	224.616	224.71	0.094
1068	334526.643	4842936.29	233.717	233.79	0.073
1069	334580.125	4842934.893	234.322	234.32	-0.002
1070	334639.971	4842932.591	234.429	234.47	0.041
1071	334700.086	4842932.525	235.315	235.37	0.055
1072	334768.718	4842941.028	234.999	235.02	0.021
1100	336847.641	4877058.753	181.474	181.55	0.076
1101	336876.721	4877113.706	181.594	181.67	0.076
1102	336905.105	4877051.389	181.531	181.55	0.019
1103	336880.473	4876993.666	181.544	181.55	0.006
1104	336828.405	4876989.643	182.217	182.29	0.073
1105	336785.263	4876931.503	181.063	181.06	-0.003

Forested and Fully Grown Land Cover Classification Supplemental Vertical Accuracy (SVA): Tested 0.185 meters supplemental vertical accuracy at the 95th percentile in Forested and Fully Grown. Tested against the DEM. Forested and Fully Grown Errors larger than 95th percentile include:

- Point 1053, Easting 308654.86, Northing 4811815.512, Z-Error 0.186

CONSOLIDATED VERTICAL ACCURACY ASSESMENT (CVA)

Table 5.8: QA/QC Analysis, UTM17N, NAD83, Saginaw Bay, Michigan

Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Laser Elevation (meters)	Dz (meters)
1000	249818.246	4823886.202	204.458	204.3	-0.158
1001	247257.061	4824664.841	189.372	189.28	-0.092
1002	246562.952	4827900.717	196.908	196.83	-0.078
1003	253133.611	4820334.149	193.925	193.78	-0.145
1004	259596.079	4819768.031	183.277	183.18	-0.097
1005	262040.38	4812886.839	181.077	181.1	0.023
1006	256786.577	4813747.914	189.559	189.55	-0.009
1007	256066.054	4812000.483	187.498	187.57	0.072
1008	274893.689	4814689.248	182.603	182.68	0.077
1009	282300.094	4814381.721	190.476	190.5	0.024
1010	284598.34	4799966.018	192.42	192.48	0.06
1011	281492.768	4808644.466	194.835	194.84	0.005
1012	268189.128	4810838.722	184.998	185.03	0.032
1014	266143.419	4811687.121	183.858	183.89	0.032
1015	266165.937	4811655.094	183.739	183.77	0.031
1016	266138.576	4811652.274	183.426	183.52	0.094
1017	266106.393	4811658.194	183.575	183.62	0.045
1018	266094.777	4811630.886	183.572	183.54	-0.032
1019	266125.472	4811614.792	183.548	183.6	0.052

Table 5.8: QA/QC Analysis, UTM17N, NAD83, Saginaw Bay, Michigan					
Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Laser Elevation (meters)	Dz (meters)
1020	290774.799	4805320.68	191.487	191.54	0.053
1021	293243.524	4803027.388	205.921	206.04	0.119
1022	291038.067	4808891.304	216.944	216.98	0.036
1023	295683.262	4806981.758	194.631	194.73	0.099
1024	302582.645	4796083.814	281.336	281.41	0.074
1025	294747.734	4795241.013	229.236	229.22	-0.016
1026	287191.416	4794630.864	207.897	207.93	0.033
1027	295026.951	4788790.163	249.758	249.84	0.082
1028	302260.039	4814380.286	207.496	207.6	0.104
1029	306209.679	4818037.262	219.777	219.82	0.043
1030	302498.371	4821067.666	211.02	210.96	-0.06
1031	299114.287	4818370.456	212.24	212.23	-0.01
1032	302148.551	4808990.026	210.341	210.45	0.109
1033	314648.264	4810576.767	230.607	230.72	0.113
1034	322934.719	4813820.983	235.707	235.8	0.093
1035	322693.323	4820181.342	226.057	226.04	-0.017
1036	288014.26	4818359.667	193.195	193.13	-0.065
1037	288141.174	4824242.864	181.958	182.1	0.142
1038	296873.22	4826834.292	195.307	195.32	0.013
1039	293078.362	4836468.613	179.316	179.39	0.074
1040	301020.052	4836354.341	188.562	188.62	0.058
1041	303919.588	4832309.902	196.501	196.45	-0.051
1042	298611.642	4828184.919	193.655	193.73	0.075
1043	310221.158	4828421.675	212.024	212.02	-0.004

Table 5.8: QA/QC Analysis, UTM17N, NAD83, Saginaw Bay, Michigan					
Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Laser Elevation (meters)	Dz (meters)
1044	310227.071	4825015.013	232.765	232.71	-0.055
1045	321381.689	4807342.308	246.757	246.8	0.043
1046	321369.837	4801048.741	261.966	262.06	0.094
1047	316593.694	4804123.522	252.602	252.66	0.058
1048	309288.94	4800949.297	277.92	277.9	-0.02
1049	308502.161	4811758.536	225.35	225.47	0.12
1050	308554.281	4811774.671	225.088	225.23	0.142
1051	308604.52	4811720.133	224.599	224.78	0.181
1052	308616.851	4811777.541	225.576	225.72	0.144
1053	308654.86	4811815.512	225.294	225.48	0.186
1054	308566.364	4811853.02	224.616	224.71	0.094
1055	316767.662	4829811.79	235.742	235.74	-0.002
1056	324503.759	4829801.889	226.476	226.55	0.074
1057	324113.291	4826620.343	219.065	219.2	0.135
1058	324543.717	4835476.229	233.153	233.19	0.037
1059	326415.951	4842774.125	222.736	222.73	-0.006
1060	317380.689	4844256.208	195.91	195.92	0.01
1061	318414.115	4836133.345	215.661	215.67	0.009
1062	313348.039	4836233.567	198.681	198.78	0.099
1063	308633.67	4842759.316	191.893	191.98	0.087
1064	301227.146	4842391.352	179.87	180.02	0.15
1065	302549.593	4845008.425	179.436	179.45	0.014
1066	324872.417	4853935.547	195.424	195.43	0.006
1067	326152.992	4848487.883	209.503	209.55	0.047

Table 5.8: QA/QC Analysis, UTM17N, NAD83, Saginaw Bay, Michigan					
Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Laser Elevation (meters)	Dz (meters)
1068	334526.643	4842936.29	233.717	233.79	0.073
1069	334580.125	4842934.893	234.322	234.32	-0.002
1070	334639.971	4842932.591	234.429	234.47	0.041
1071	334700.086	4842932.525	235.315	235.37	0.055
1072	334768.718	4842941.028	234.999	235.02	0.021
1073	319882.012	4849916.727	194.982	194.96	-0.022
1074	317060.653	4853877.5	191.112	191.18	0.068
1075	314927.393	4858658.551	183.137	183.26	0.123
1076	309075.418	4857803.221	180.911	180.95	0.039
1077	311849.419	4851585.611	189.479	189.58	0.101
1078	307106.245	4852321.934	180.149	180.14	-0.009
1079	305503.48	4849061.618	182.039	182.07	0.031
1080	327192.849	4858855.165	191.032	191.04	0.008
1081	332656.017	4854168.805	218.347	218.39	0.043
1082	339047.993	4851844.831	230.642	230.65	0.008
1083	342228.204	4846330.138	233.991	234.04	0.049
1084	339441.978	4860640.404	221.278	221.34	0.062
1085	339713.852	4867089.363	213.827	213.8	-0.027
1086	345472.575	4863953.953	218.589	218.59	0.001
1087	345417.477	4868777.397	216.761	216.74	-0.021
1088	334302.249	4866393.331	199.529	199.63	0.101
1089	332692.236	4862560.062	202.242	202.25	0.008
1090	326313.152	4863656.656	190.14	190.11	-0.03
1091	321518.366	4863558.865	187.372	187.42	0.048

Table 5.8: QA/QC Analysis, UTM17N, NAD83, Saginaw Bay, Michigan					
Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Laser Elevation (meters)	Dz (meters)
1092	325004.834	4868441.138	182.982	182.99	0.008
1093	317670.731	4867746.129	182.704	182.69	-0.014
1094	332635.139	4871736.078	180.009	180.11	0.101
1095	340339.956	4878770.806	181.274	181.28	0.006
1096	348082.817	4879853.196	179.474	179.57	0.096
1097	347039.895	4874313.189	203.81	204	0.19
1098	339827.82	4871863.542	199.802	199.84	0.038
1099	336451.943	4874876.309	185.804	185.79	-0.014
1100	336847.641	4877058.753	181.474	181.55	0.076
1101	336876.721	4877113.706	181.594	181.67	0.076
1102	336905.105	4877051.389	181.531	181.55	0.019
1103	336880.473	4876993.666	181.544	181.55	0.006
1104	336828.405	4876989.643	182.217	182.29	0.073
1105	336785.263	4876931.503	181.063	181.06	-0.003
1106	340205.979	4876629.209	189.485	189.68	0.195

Consolidated Vertical Accuracy (CVA): Tested 0.147 meters consolidated vertical accuracy at the 95th percentile level, derived according to ASPRS Guidelines for Vertical Accuracy Reporting for LiDAR Data. Tested against the DEM. Based on the 95th percentile error in all land cover categories combined. Consolidated Vertical Accuracy Errors larger than the 95th percentile include:

- Point 1000, Easting 249818.246, Northing 4823886.202, Z-Error -0.158
- Point 1064, Easting 301227.146, Northing 4842391.352, Z-Error 0.150
- Point 1051, Easting 308604.52, Northing 4811720.133, Z-Error 0.181
- Point 1053, Easting 308654.86, Northing 4811815.512, Z-Error 0.186
- Point 1097, Easting 347039.895, Northing 4874313.189, Z-Error 0.190
- Point 1106, Easting 340205.979, Northing 4876629.209, Z-Error 0.195

Approved By:			
Title	Name	Signature	Date
Associate LiDAR Specialist Certified Photogrammetrist #1281	Qian Xiao		November 2012

SECTION 6: FINAL DELIVERABLES

FINAL DELIVERABLES

The final LiDAR deliverables are listed below:

- LAS v1.2 classified point cloud.
- LAS v1.2 raw unclassified point cloud flight line strips no greater than 2GB. Long swaths greater than 2GB will be split into segments.
- Hydrologically flattened Polygon z and Polyline z shapefiles.
- Hydrologically flattened bare earth 1-meter DEM in ERDAS .IMG format.
- Hydrologically flattened bare earth in ESRI Terrain Object File Geodatabase.
- First Return Only in 1-meter DEM in .IMG format.
- First Return Only in ESRI Terrain Object File Geodatabase.
- 1-meter pixel 8-bit lidar intensity imagery in GeoTIFF format.
- Tile Layout and data extent provided as an ESRI shapefile.
- Control points provided as an ESRI shapefile.
- FGDC compliant metadata by product in XML format.
- Ground control report in .PDF format.
- LiDAR processing report in pdf format.

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