# AIRBORNE LIDAR REPORT

# NRCS DICKINSON COUNTY, MICHIGAN LIDAR

**Task Order Number: G12PD00721**
**Woolpert Project Number: 72637**
**June 2013**

# AIRBORNE LIDAR TASK ORDER REPORT

## NRCS DICKINSON COUNTY, MICHIGAN LIDAR

## WOOLPERT PROJECT #72637

For:

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# SECTION 1: OVERVIEW

## PROJECT NAME: NRCS DICKINSON COUNTY, MICHIGAN LIDAR

## WOOLPERT PROJECT #72637

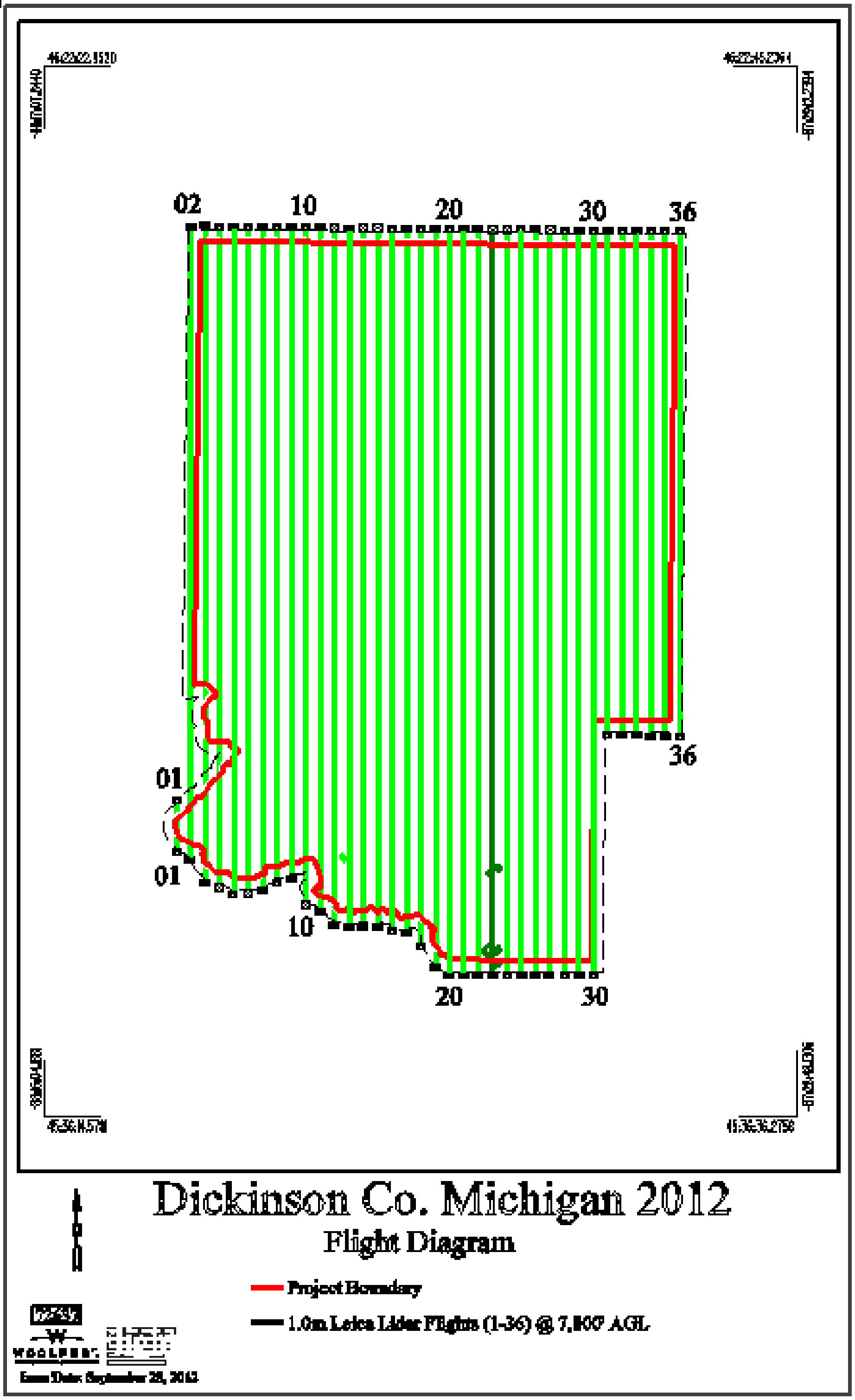
This report contains a comprehensive outline of the airborne LiDAR data acquisition consisting of a 776 square mile area for all of Dickinson County in Michigan for the United States Geological Survey (USGS). The LiDAR was collected and processed to meet a maximum Nominal Post Spacing (NPS) of 1 meter. 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 ALS70 500 kHz Multiple Pulses in Air (MPiA) LiDAR sensor system installed in a shock isolator sled mount. The sensors collect up to four returns (echoes) 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): | 3.28 ft / 1 m |
| AGL (Above Ground Level) average flying height: | 7,800 ft / 2,377 m |
| MSL (Mean Sea Level) average flying height: | 8,620 ft / 2,627 m |
| Average Ground Speed: | 150 knots / 173 mph |
| Field of View (full): | 40 degrees |
| Pulse Rate: | 230.0 kHz |
| Scan Rate: | 35.5 Hz |
| Side Lap (Minimum): | 25% |

LiDAR data was processed and projected in UTM, Zone 16, North American Datum of 1983 (NAD83) in units of meters. The vertical datum used for the task order was referenced to NAVD 1988, meters, GEOID12A

**Figure 1.1: Task Order and LiDAR Flight Layout - Dickinson County, MI**



# SECTION 2: ACQUISITION

The LiDAR data was acquired with a Leica ALS70 Multiple Pulses in Air (MPiA) LiDAR sensor system, on board a Cessna 404. This 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 system software is operated on an OC50 Operation Controller aboard the aircraft.

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

**Table 2.1: 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 NGS-PID-AA8108 for the airborne GPS support on both mission days. Coordinates: 45°48'12.78402' (N), 88°07'05.64416" (W), Elipsoid Height 310.552 meters.

The LiDAR data was collected in (2) 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. Data from delivery tile 16TDR170985 has a small void caused by smoke from a factory.

**Table 2.2: Airborne LiDAR Acquisition Flight Summary**

| Airborne LiDAR Acquisition Flight Summary | | | |
|---|---|---|---|
| Date of Mission/Sensor | Lines Flown | Mission Time (UTC)<br>Wheels Up/<br>Wheels Down | Mission Time (Local = EST)<br>Wheels Up/<br>Wheels Down |
| Nov 15, 2012 – S/N 7177 | 1-10, 31-36 | 20:35 – 00:22 | 02:35 PM – 06:22 PM |
| Nov 16, 2012 – S/N 7177 | 11-30 | 13:59 – 19:46 | 07:59 AM – 01:46 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. 13.003.

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. 13.003.
5. All water bodies greater than two acres and all rivers with a nominal 100 foot width or larger were hydro-flattened using stereo compilation methods.
   **Software:** LP360, proprietary tools, Microstation v8**,** TerraScan v.13.003.

## 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 Station for the airborne GPS support. The GNSS base station operated during the LiDAR acquisition missions is listed below:

**Table 3.1: GNSS Base Stations**

| Station | Latitude | Longitude | Ellipsoid Height (L1 Phase Center) |
|---|---|---|---|
| Name | (DMS) | (DMS) | (Meters) |
| NGS-PID-AA8108 | N 45° 48' 50.78" | W 88° 07' 05.64" | 310.552 |

## DATA PROCESSING

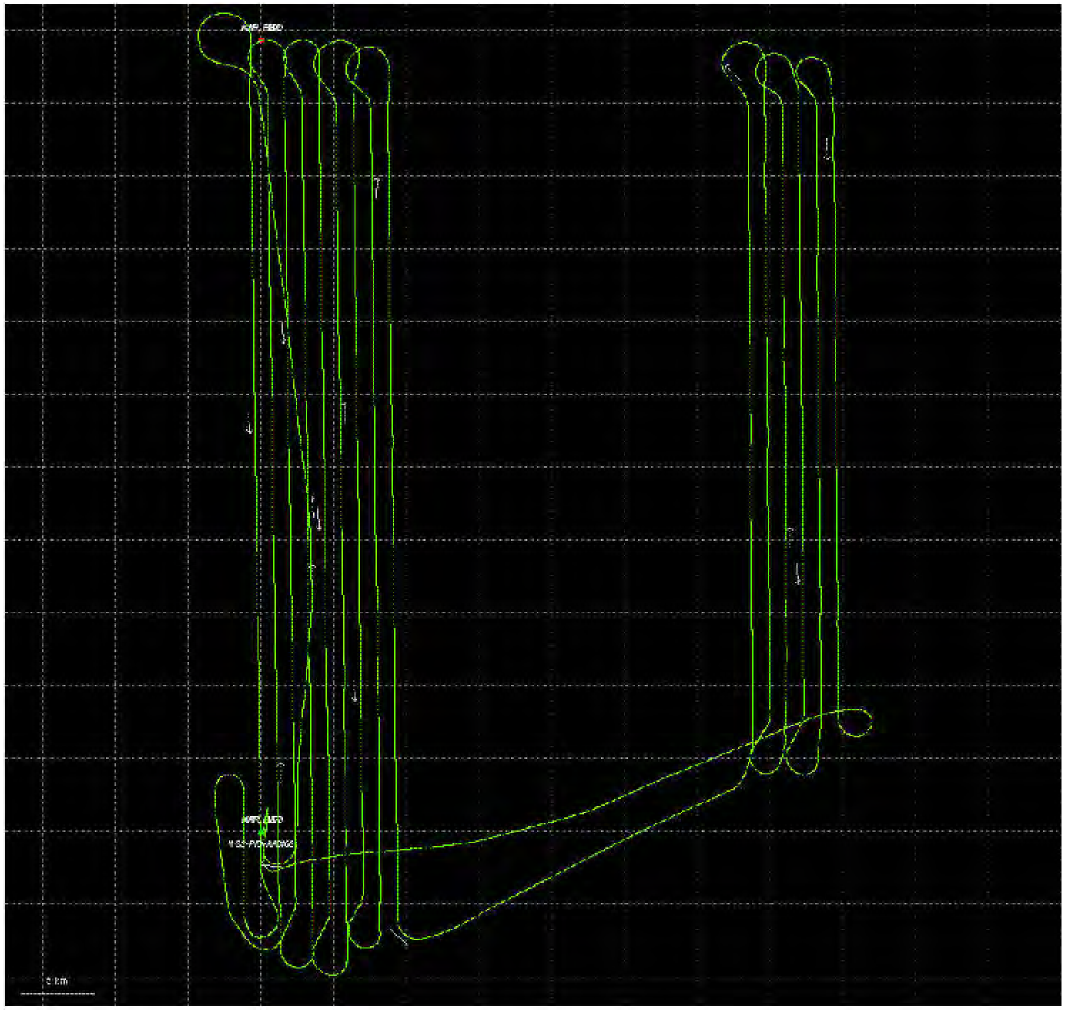
All airborne GNSS and IMU data was post-processed and quality controlled using Applanix 5.3 MMS software. GNSS data was processed at a 1 and 2 Hz data capture rate and the IMU data was processed at 200 Hz.

## 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 Day320: N475RC**



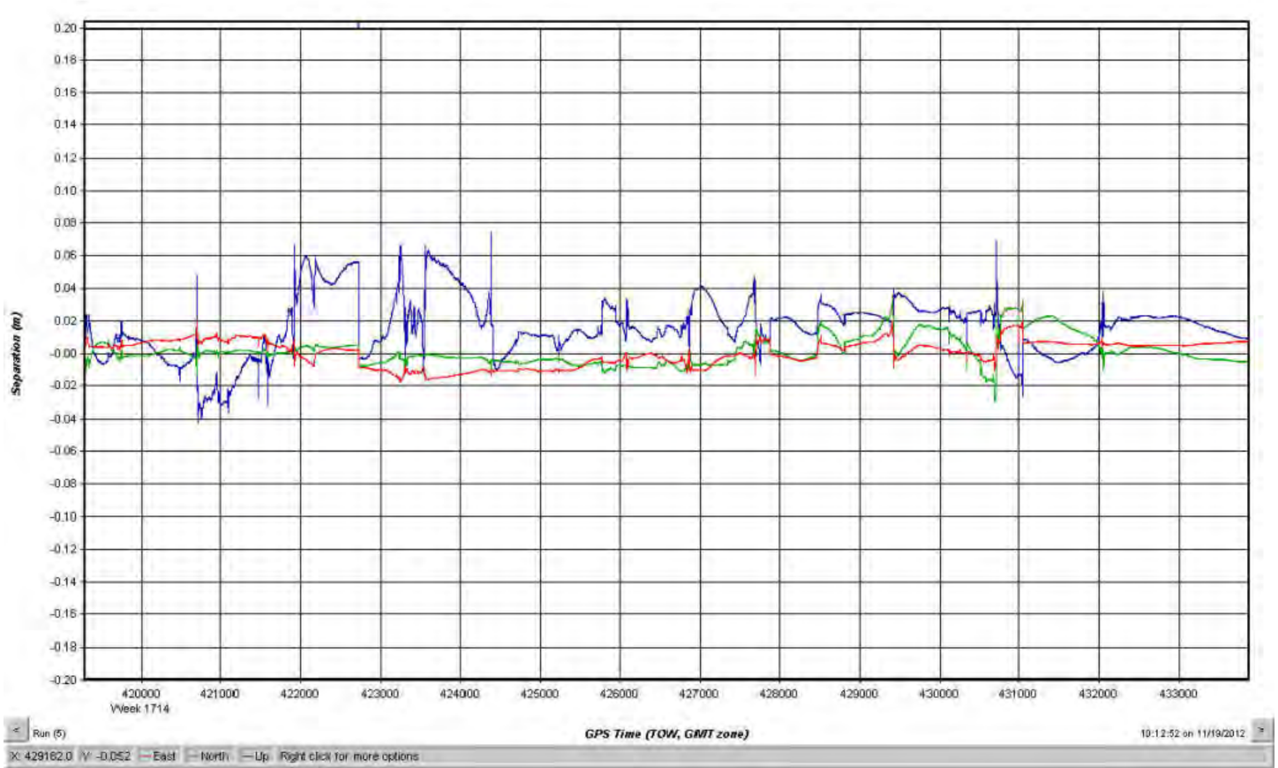
Within the trajectory processing, there are many factors that affect the overall quality, but the most indicative are the Combined Separation, the Estimated Positional Accuracy, and the Positional Dilution of Precision (PDOP).

## 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 Day320 of Combined Separation**

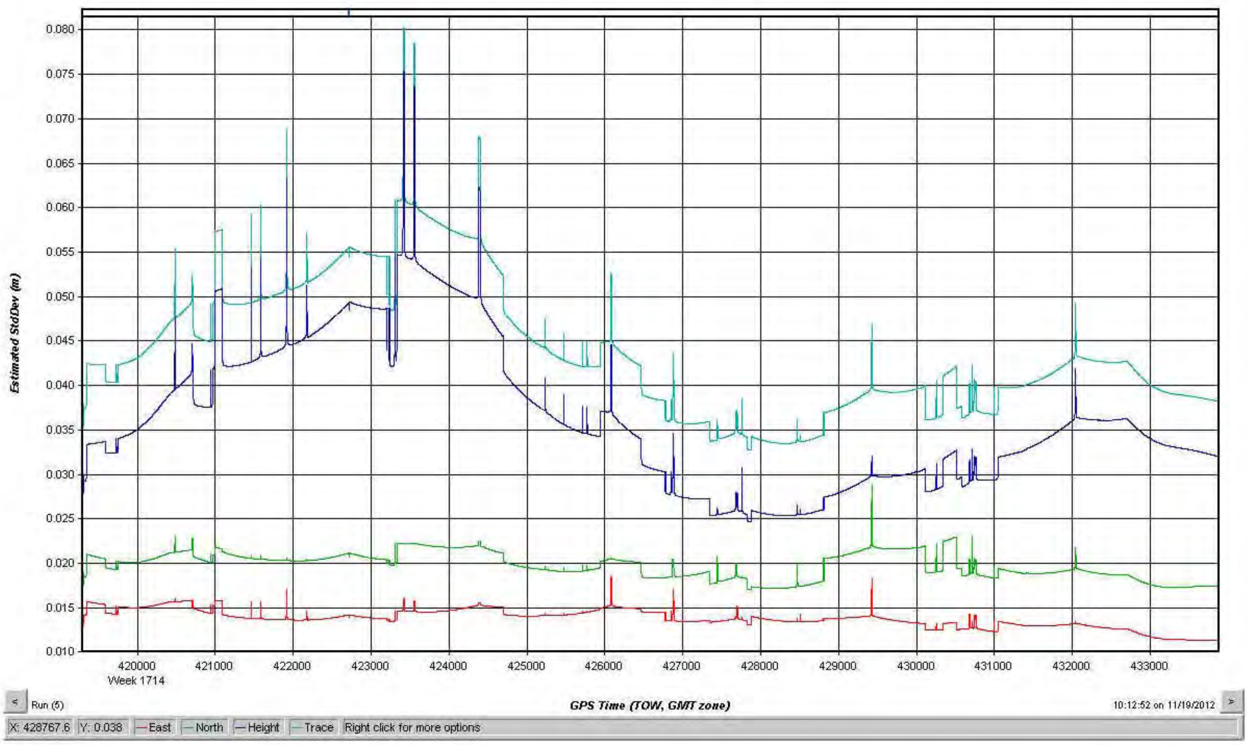


## Estimated Positional Accuracy

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.

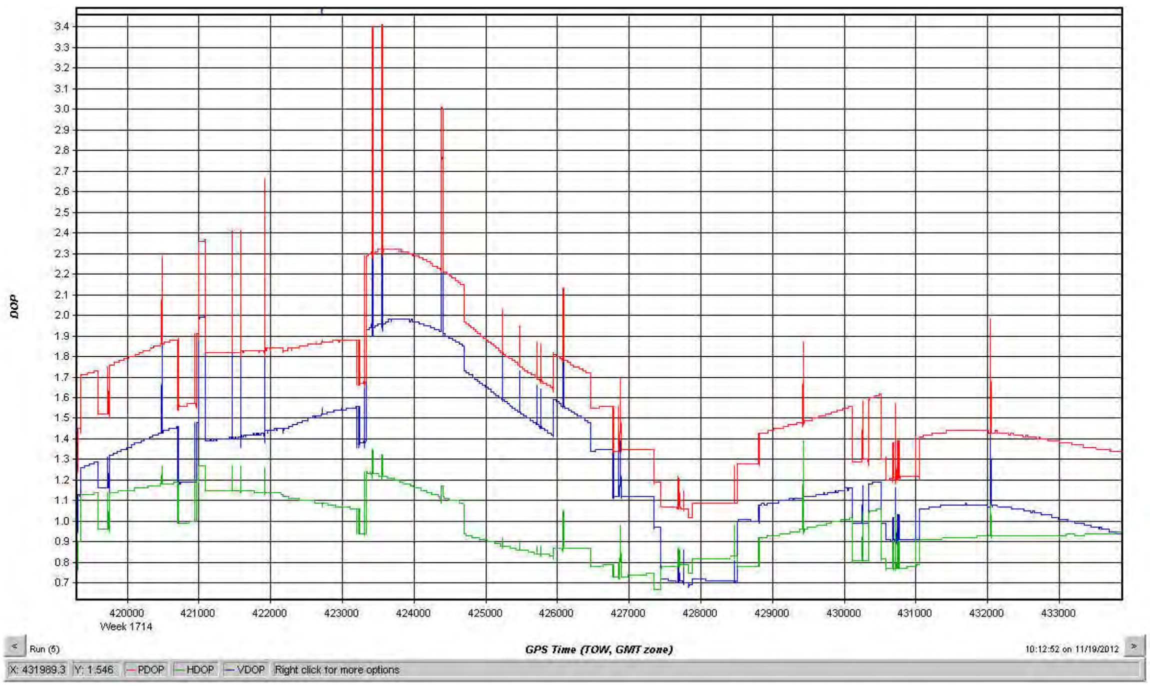
**Figure 3.3: Representative Graph from Day320 of Positional Accuracy**



## 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 Day 320 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 water body features that were greater than 2 acres and rivers and streams of 30.5 meters (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), Noise (Class 7), Model Key Point (Class 8), Water (Class 9) Ignored Ground (Class 10), Overlap Default (Class 17), and Overlap Ground (Class 18).

- 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 16N, North American Datum of 1983. Coordinate positions were specified in units meters for Dickinson County. The vertical datum used for the task order was referenced to NAVD 1988, meters, GEOID12A.

# 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

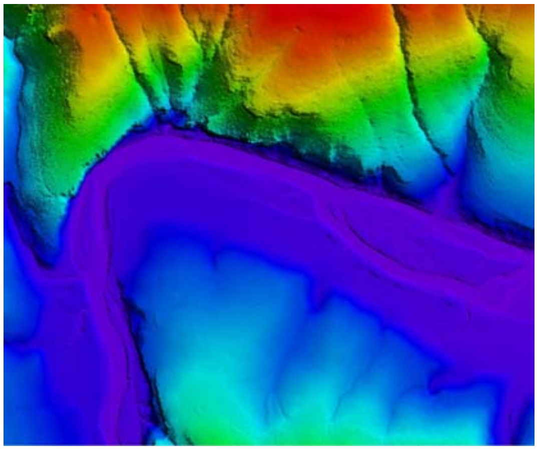
Woolpert utilized the following steps to hydrologically flatten the water bodies and for gradient hydrologic flattening of the double line streams within the existing LiDAR data.

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. Google Earth 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. During the collection of linework, the technical staff used a program that displayed the polygon measurement area as a reference to identify lakes larger than 2-acres. 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 feet) 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 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 v14, 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 IMG DEM, the area was cross referenced by tile number, corrected accordingly, a new IMG DEM 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, Dickinson County, MI | | |
|---|---|---|
| Average error | -0.016 | meters |
| Minimum error | -0.119 | meters |
| Maximum error | 0.076 | meters |
| Average magnitude | 0.041 | meters |
| Root mean square | 0.05 | meters |
| Standard deviation | 0.048 | meters |

**Table 5.2: QA/QC Analysis, UTM 16N, NAD83, Dickinson County, MI**

| Point ID | Easting (UTM meters) | Northing (UTM meters) | Elevation (meters) | Dz (meters) |
|---|---|---|---|---|
| 2000 | 415721.327 | 5110511.95 | 430.454 | -0.074 |
| 2001 | 415739.784 | 5110480.862 | 430.62 | -0.05 |
| 2002 | 415774.284 | 5110487.753 | 431.142 | -0.022 |
| 2003 | 415803.89 | 5110508.569 | 430.274 | 0.016 |
| 2004 | 415792.125 | 5110547.335 | 429.389 | -0.119 |
| 2005 | 426274.585 | 5087710.727 | 329.621 | 0.019 |
| 2006 | 426271.677 | 5087748.762 | 327.987 | -0.047 |
| 2007 | 425368.641 | 5087148.227 | 321.717 | 0.023 |
| 2008 | 425332.328 | 5087163.382 | 323.269 | -0.069 |
| 2009 | 425351.31 | 5087198.705 | 323.182 | -0.012 |
| 2010 | 425384.172 | 5087224.032 | 322.926 | -0.036 |
| 2011 | 425395.152 | 5087185.75 | 322.389 | -0.069 |
| 2015 | 419535.042 | 5093061.695 | 370.109 | -0.079 |
| 2016 | 423259.668 | 5100884.779 | 393.199 | -0.059 |
| 2017 | 416008.473 | 5104356.154 | 452.66 | -0.1 |
| 2018 | 418295.447 | 5115621.374 | 430.802 | 0.068 |

| Table 5.2: QA/QC Analysis, UTM 16N, NAD83, Dickinson County, MI | | | | |
|---|---|---|---|---|
| Point ID | Easting (UTM meters) | Northing (UTM meters) | Elevation (meters) | Dz (meters) |
| 2019 | 430480.447 | 5109193.352 | 363.804 | 0.076 |
| 2020 | 424538.409 | 5079631.655 | 313.793 | 0.037 |
| 2021 | 415190.634 | 5076891.448 | 343.159 | 0.011 |
| 2500 | 441724.435 | 5114129.874 | 371.794 | -0.034 |
| 2501 | 437999.173 | 5119583.938 | 406.603 | 0.047 |
| 2502 | 446833.208 | 5115268.815 | 353.169 | 0.031 |
| 2503 | 449488.347 | 5121253.125 | 361.508 | -0.088 |
| 2504 | 439949.125 | 5108877.511 | 374.71 | 0 |
| 2505 | 442014.056 | 5111785.378 | 354.599 | 0.011 |
| 2506 | 442381.439 | 5090571.347 | 313.915 | 0.035 |
| 2508 | 446578.552 | 5094387.82 | 324.583 | -0.033 |
| 2509 | 435636.068 | 5090606.661 | 359.734 | 0.026 |
| 2510 | 438269.014 | 5085415.492 | 298.206 | -0.036 |
| 2511 | 434063.178 | 5082373.599 | 321.652 | -0.072 |
| 2512 | 434225.086 | 5076460.449 | 316.537 | -0.047 |
| 2513 | 433289.473 | 5073517.169 | 300.425 | -0.025 |
| 2514 | 429259.155 | 5069071.348 | 297.41 | 0.04 |
| 2515 | 433035.684 | 5067130.931 | 255.692 | -0.012 |
| 2516 | 442066.389 | 5068272.285 | 283.437 | -0.027 |
| 2517 | 441245.729 | 5080885.677 | 294.72 | -0.03 |
| 2518 | 440169.723 | 5076161.979 | 298.08 | 0 |
| 2520 | 450517.367 | 5103506.883 | 338.94 | 0.03 |
| 2521 | 434511.923 | 5096451.97 | 351.592 | 0.038 |
| 4507 | 448822.458 | 5099589.501 | 364.603 | -0.003 |

## VERTICAL ACCURACY CONCLUSIONS

LAS Swath Fundamental Vertical Accuracy (FVA) Tested 0.098 meters fundamental vertical accuracy at a 95 percent confidence level, derived according to NSSDA, in open terrain using (RMSEz) x 1.96000 Tested against the TIN using independent check points.

Bare-Earth DEM Fundamental Vertical Accuracy (FVA) Tested 0.097 meters fundamental vertical accuracy at a 95 percent confidence level, derived according to NSSDA, in open terrain using (RMSEz) x 1.96000 Tested against the DEM using independent check points.

## SUPPLEMENTAL VERTICAL ACCURACY ASSESSMENTS

**Table 5.3: QA/QC Analysis, Bare Earth and Open Terrain, UTM 16N, NAD83, Dickinson County, MI**

| Point ID | Easting (UTM meters) | Northing (UTM meters) | Elevation (meters) | Absolute Dz (meters) |
|---|---|---|---|---|
| 2000 | 415721.327 | 5110511.95 | 430.454 | 0.064 |
| 2001 | 415739.784 | 5110480.862 | 430.62 | 0.04 |
| 2002 | 415774.284 | 5110487.753 | 431.142 | 0.032 |
| 2003 | 415803.89 | 5110508.569 | 430.274 | 0.006 |
| 2004 | 415792.125 | 5110547.335 | 429.389 | 0.129 |
| 2005 | 426274.585 | 5087710.727 | 329.621 | 0.019 |
| 2006 | 426271.677 | 5087748.762 | 327.987 | 0.047 |
| 2007 | 425368.641 | 5087148.227 | 321.717 | 0.023 |
| 2008 | 425332.328 | 5087163.382 | 323.269 | 0.069 |
| 2009 | 425351.31 | 5087198.705 | 323.182 | 0.002 |
| 2010 | 425384.172 | 5087224.032 | 322.926 | 0.036 |
| 2011 | 425395.152 | 5087185.75 | 322.389 | 0.079 |
| 2015 | 419535.042 | 5093061.695 | 370.109 | 0.069 |
| 2016 | 423259.668 | 5100884.779 | 393.199 | 0.039 |
| 2017 | 416008.473 | 5104356.154 | 452.66 | 0.1 |
| 2018 | 418295.447 | 5115621.374 | 430.802 | 0.068 |
| 2019 | 430480.447 | 5109193.352 | 363.804 | 0.076 |
| 2020 | 424538.409 | 5079631.655 | 313.793 | 0.037 |

| Table 5.3: QA/QC Analysis, Bare Earth and Open Terrain, UTM 16N, NAD83, Dickinson County, MI | | | | |
|---|---|---|---|---|
| Point ID | Easting (UTM meters) | Northing (UTM meters) | Elevation (meters) | Absolute Dz (meters) |
| 2021 | 415190.634 | 5076891.448 | 343.159 | 0.011 |
| 2500 | 441724.435 | 5114129.874 | 371.794 | 0.034 |
| 2501 | 437999.173 | 5119583.938 | 406.603 | 0.047 |
| 2502 | 446833.208 | 5115268.815 | 353.169 | 0.021 |
| 2503 | 449488.347 | 5121253.125 | 361.508 | 0.088 |
| 2504 | 439949.125 | 5108877.511 | 374.71 | 0.01 |
| 2505 | 442014.056 | 5111785.378 | 354.599 | 0.001 |
| 2506 | 442381.439 | 5090571.347 | 313.915 | 0.035 |
| 2508 | 446578.552 | 5094387.82 | 324.583 | 0.033 |
| 2509 | 435636.068 | 5090606.661 | 359.734 | 0.056 |
| 2510 | 438269.014 | 5085415.492 | 298.206 | 0.056 |
| 2511 | 434063.178 | 5082373.599 | 321.652 | 0.062 |
| 2512 | 434225.086 | 5076460.449 | 316.537 | 0.037 |
| 2513 | 433289.473 | 5073517.169 | 300.425 | 0.025 |
| 2514 | 429259.155 | 5069071.348 | 297.41 | 0.03 |
| 2515 | 433035.684 | 5067130.931 | 255.692 | 0.012 |
| 2516 | 442066.389 | 5068272.285 | 283.437 | 0.017 |
| 2517 | 441245.729 | 5080885.677 | 294.72 | 0.04 |
| 2518 | 440169.723 | 5076161.979 | 298.08 | 0.01 |
| 2520 | 450517.367 | 5103506.883 | 338.94 | 0.01 |
| 2521 | 434511.923 | 5096451.97 | 351.592 | 0.048 |
| 4507 | 448822.458 | 5099589.501 | 364.603 | 0.003 |

## ACCURACY CONCLUSIONS

Bare Earth/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 2004, Easting 415792.125, Northing 5110547.335, Z-Error 0.129 meters

**Table 5.4: QA/QC Analysis, Brush Lands and Trees, UTM 16N, NAD83, Dickinson County, MI**

| Point ID | Easting (UTM meters) | Northing (UTM meters) | Elevation (meters) | Absolute Dz (meters) |
|---|---|---|---|---|
| 5000 | 418374.761 | 5081401.753 | 358.803 | 0.047 |
| 5001 | 418394.787 | 5081395.403 | 358.379 | 0.051 |
| 5002 | 418366.774 | 5081368.194 | 358.255 | 0.095 |
| 5003 | 418343.655 | 5081353.583 | 358.264 | 0.056 |
| 5004 | 418380.288 | 5081458.423 | 358.602 | 0.018 |
| 5005 | 421863.927 | 5121066.555 | 437.991 | 0.109 |
| 5006 | 421896.693 | 5121050.096 | 437.93 | 0.06 |
| 5007 | 421932.494 | 5121046.426 | 437.429 | 0.131 |
| 5008 | 421958.786 | 5121023.672 | 435.95 | 0.02 |
| 5009 | 421939.495 | 5120986.274 | 435.381 | 0.089 |
| 5010 | 421897.177 | 5120983.957 | 435.506 | 0.024 |
| 5011 | 421855.855 | 5120980.156 | 435.473 | 0.037 |
| 5015 | 421185.939 | 5085426.44 | 372.979 | 0.179 |
| 5016 | 421194.076 | 5085414.6 | 373.269 | 0.111 |
| 5017 | 417615.852 | 5101088.429 | 412.725 | 0.135 |
| 5018 | 429399.455 | 5109158.058 | 368.119 | 0.021 |
| 5500 | 446831.909 | 5115241.009 | 353.572 | 0.058 |
| 5501 | 453146.009 | 5114503.945 | 354.639 | 0.029 |
| 5502 | 450104.866 | 5120690.269 | 358.041 | 0.119 |
| 5503 | 442275.196 | 5101888.084 | 382.075 | 0.065 |

| Table 5.4: QA/QC Analysis, Brush Lands and Trees, UTM 16N, NAD83, Dickinson County, MI | | | | |
|---|---|---|---|---|
| Point ID | Easting (UTM meters) | Northing (UTM meters) | Elevation (meters) | Absolute Dz (meters) |
| 5504 | 436467.696 | 5099134.417 | 348.037 | 0.023 |
| 5505 | 436493.2 | 5099149.404 | 347.947 | 0.083 |
| 5506 | 428984.689 | 5095139.643 | 361.965 | 0.065 |
| 5507 | 447586.574 | 5098064.011 | 359.429 | 0.041 |
| 5508 | 438317.864 | 5085329.893 | 297.916 | 0.174 |
| 5509 | 434261.324 | 5084873.814 | 322.006 | 0.044 |
| 5510 | 443751.561 | 5075692.261 | 293.302 | 0.022 |
| 5511 | 442344.892 | 5080055.179 | 306.961 | 0.039 |
| 5512 | 428248.128 | 5074760.309 | 332.492 | 0.028 |
| 5513 | 441917.477 | 5112063.114 | 357.5 | 0.15 |
| 5514 | 441147.603 | 5116232.211 | 368.002 | 0.008 |
| 5515 | 440456.42 | 5092448.398 | 331.252 | 0.038 |

## ACCURACY CONCLUSIONS

Brush Lands and Trees Land Cover Classification Supplemental Vertical Accuracy (SVA) Tested 0.176 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 5015, Easting 421185.939, Northing 5085426.44, Z-Error 0.179 meters

| Table 5.5: QA/QC Analysis, Forested and Fully Grown, UTM 16N, NAD83, Dickinson County, MI | | | | |
|---|---|---|---|---|
| Point ID | Easting (UTM meters) | Northing (UTM meters) | Elevation (meters) | Absolute Dz (meters) |
| 6000 | 437333.566 | 5101644.488 | 370.631 | 0.111 |
| 6001 | 437302.533 | 5101644.689 | 370.574 | 0.054 |
| 6002 | 437271.54 | 5101644.929 | 370.045 | 0.095 |
| 6003 | 437263.46 | 5101681.28 | 371.865 | 0.125 |

| Table 5.5: QA/QC Analysis, Forested and Fully Grown, UTM 16N, NAD83, Dickinson County, MI | | | | |
|---|---|---|---|---|
| Point ID | Easting (UTM meters) | Northing (UTM meters) | Elevation (meters) | Absolute Dz (meters) |
| 6004 | 437299.267 | 5101691.531 | 372.712 | 0.062 |
| 6005 | 437338.356 | 5101693.611 | 373.346 | 0.006 |
| 6006 | 425135.721 | 5114748.54 | 409.091 | 0.091 |
| 6007 | 425132.047 | 5114778.934 | 409.398 | 0.068 |
| 6008 | 425129.131 | 5114808.239 | 409.237 | 0.017 |
| 6009 | 425159.815 | 5114823.318 | 409.787 | 0.047 |
| 6010 | 425159.363 | 5114793.329 | 409.461 | 0.019 |
| 6011 | 425150.815 | 5114759.409 | 409.332 | 0.002 |
| 6012 | 425840.942 | 5077812.445 | 328.379 | 0.081 |
| 6013 | 425808.903 | 5077810.693 | 329.574 | 0.084 |
| 6014 | 425773.895 | 5077812.363 | 330.563 | 0.103 |
| 6015 | 425769.313 | 5077844.919 | 329.545 | 0.105 |
| 6016 | 425806.637 | 5077849.95 | 328.876 | 0.166 |
| 6017 | 425842.142 | 5077851.02 | 328.258 | 0.088 |
| 6018 | 443318.072 | 5079146.389 | 310.774 | 0.006 |
| 6019 | 443288.051 | 5079144.243 | 311.48 | 0.08 |
| 6020 | 443256.326 | 5079140.087 | 313.311 | 0.011 |
| 6021 | 443229.266 | 5079141.868 | 313.655 | 0.015 |
| 6022 | 443194.41 | 5079139.627 | 314.188 | 0.022 |
| 6023 | 443175.388 | 5079138.56 | 314.637 | 0.087 |
| 6025 | 416082.683 | 5093809.445 | 381.206 | 0.254 |
| 6500 | 441982.131 | 5113752.141 | 378.567 | 0.037 |

## ACCURACY CONCLUSIONS

Forested and Fully Grown Land Cover Classification Supplemental Vertical Accuracy (SVA) Tested 0.223 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 6025, Easting 416082.683, Northing 5093809.445 Z-Error 0.254 meters

**Table 5.6: QA/QC Analysis, Tall Weeks and Crops, UTM 16N, NAD83, Dickinson County, MI**

| Point ID | Easting (UTM meters) | Northing (UTM meters) | Elevation (meters) | Absolute Dz (meters) |
|---|---|---|---|---|
| 4000 | 420356.644 | 5082306.151 | 373.606 | 0.034 |
| 4001 | 420321.337 | 5082309.943 | 373.661 | 0.049 |
| 4002 | 420286.727 | 5082316.895 | 372.796 | 0.084 |
| 4003 | 418382.371 | 5081439.489 | 358.592 | 0.068 |
| 4004 | 418368.325 | 5081405.394 | 358.868 | 0.012 |
| 4005 | 425442.092 | 5108658.085 | 405.129 | 0.141 |
| 4006 | 425468.227 | 5108666.276 | 404.969 | 0.111 |
| 4007 | 425610.653 | 5108697.838 | 404.286 | 0.084 |
| 4008 | 425626.718 | 5108720.184 | 405.65 | 0.13 |
| 4009 | 425641.776 | 5108774.747 | 409.598 | 0.092 |
| 4010 | 425656.859 | 5108756.44 | 407.636 | 0.034 |
| 4011 | 417315.094 | 5073355.939 | 346.28 | 0 |
| 4015 | 422905.268 | 5085751.498 | 367.748 | 0.052 |
| 4016 | 417766.916 | 5095069.071 | 384.263 | 0.077 |
| 4017 | 422253.42 | 5120914.895 | 431.502 | 0.048 |
| 4500 | 443896.123 | 5104203.392 | 363.683 | 0.087 |
| 4501 | 436058.887 | 5106621.313 | 351.392 | 0.088 |
| 4502 | 436077.386 | 5106623.445 | 351.399 | 0.001 |
| 4503 | 434950.999 | 5106696.101 | 354.223 | 0.027 |
| 4504 | 434919.973 | 5106706.318 | 354.488 | 0.072 |

| Table 5.6: QA/QC Analysis, Tall Weeks and Crops, UTM 16N, NAD83, Dickinson County, MI | | | | |
|---|---|---|---|---|
| Point ID | Easting (UTM meters) | Northing (UTM meters) | Elevation (meters) | Absolute Dz (meters) |
| 4505 | 434981.279 | 5106698.317 | 354.116 | 0.074 |
| 4506 | 448734.343 | 5099392.865 | 368.3 | 0.03 |
| 4507 | 433312.152 | 5073525.673 | 300.633 | 0.107 |
| 4508 | 432824.069 | 5067169.49 | 256.194 | 0.076 |
| 4509 | 436809.32 | 5069306.935 | 280.336 | 0.164 |
| 4510 | 442035.21 | 5068255.955 | 283.441 | 0.129 |
| 4511 | 443860.332 | 5068283.933 | 313.564 | 0.136 |
| 4513 | 443564.178 | 5082116.406 | 311.7 | 0.09 |
| 4514 | 449966.686 | 5088189.23 | 326.26 | 0.07 |
| 4515 | 435918.421 | 5093879.932 | 352.954 | 0.216 |

## ACCURACY CONCLUSIONS

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 4515, Easting 435918.421, Northing 5093879.932, Z-Error 0.216 meters

| Table 5.7: QA/QC Analysis, Urban, UTM 16N, NAD83, Dickinson County, MI | | | | |
|---|---|---|---|---|
| Point ID | Easting (UTM meters) | Northing (UTM meters) | Elevation (meters) | Absolute Dz (meters) |
| 3000 | 416853.012 | 5104249.497 | 436.596 | 0.116 |
| 3001 | 416884.079 | 5104247.409 | 436.646 | 0.056 |
| 3002 | 416917.197 | 5104249.786 | 436.555 | 0.015 |
| 3003 | 416947.516 | 5104264.204 | 436.654 | 0.064 |
| 3004 | 416948.728 | 5104299.224 | 436.82 | 0.03 |
| 3005 | 417300.501 | 5073406.91 | 346.442 | 0.022 |
| 3006 | 417298.452 | 5073371.15 | 346.402 | 0.022 |
| 3007 | 417282.574 | 5073349.367 | 346.394 | 0.064 |

| Table 5.7: QA/QC Analysis, Urban, UTM 16N, NAD83, Dickinson County, MI | | | | |
|---|---|---|---|---|
| Point ID | Easting (UTM meters) | Northing (UTM meters) | Elevation (meters) | Absolute Dz (meters) |
| 3008 | 417281.22 | 5073320.357 | 346.392 | 0.032 |
| 3009 | 417280.821 | 5073285.437 | 346.042 | 0.018 |
| 3010 | 417280.369 | 5073257.611 | 345.861 | 0.001 |
| 3011 | 419466.226 | 5073561.745 | 349.969 | 0.021 |
| 3012 | 419485.05 | 5073536.121 | 349.375 | 0.025 |
| 3500 | 439468.134 | 5106463.139 | 347.066 | 0.004 |
| 3501 | 439403.708 | 5106430.876 | 347.094 | 0.016 |
| 3502 | 439391.017 | 5106148.539 | 347.504 | 0.006 |
| 3503 | 439368.733 | 5106025.345 | 347.643 | 0.047 |
| 3504 | 439390.205 | 5106005.337 | 348.196 | 0.004 |
| 3505 | 439383.384 | 5106231.93 | 347.262 | 0.038 |
| 3506 | 435757.73 | 5093980.206 | 356.818 | 0.072 |
| 3507 | 436061.05 | 5094011.147 | 362.079 | 0.061 |
| 3508 | 436151.586 | 5093985.102 | 364.078 | 0.008 |
| 3509 | 429065.048 | 5071048.096 | 284.812 | 0.002 |
| 3510 | 432185.809 | 5070150.608 | 287.76 | 0.03 |
| 3511 | 436600.845 | 5069761.375 | 272.128 | 0.002 |

## ACCURACY CONCLUSIONS

Urban Land Cover Classification Supplemental Vertical Accuracy (SVA) Tested 0.103 meters supplemental vertical accuracy at the 95th percentile in Urban. Tested against the DEM. Urban Errors larger than 95th percentile include:

- Point 3000, Easting 416853.012, Northing 5104249.497, Z-Error 0.116 meters

## CONSOLIDATED ACCURACY CONCLUSIONS

Consolidated Vertical Accuracy (CVA) Tested 0.144 meters consolidated vertical accuracy at the 95th percentile level, derived according to ASPRS Guidelines for Vertical Accuracy Reporting for LiDAR Data. The data set was tested against the DEM using independent test points, based on the 95th percentile error in all land cover categories combined.

- Point 5513, Easting 441917.477, Northing 5112063.114, Z-Error 0.150 meters
- Point 4509, Easting 436809.320, Northing 5069306.935, Z-Error 0.164 meters
- Point 6016, Easting 425806.637, Northing 5077849.950, Z-Error 0.166 meters
- Point 5508, Easting 438317.864, Northing 5085329.893, Z-Error 0.174 meters
- Point 5015, Easting 421185.939, Northing 5085426.440Z-Error 0.179 meters
- Point 4515, Easting 435918.421, Northing 5093879.932 Z-Error 0.216 meters
- Point 6025, Easting 416082.683, Northing 5093809.445 Z-Error 0.254 meters

| Approved By: | | | |
|---|---|---|---|
| Title | Name | Signature | Date |
| Associate<br>LiDAR Specialist<br>Certified Photogrammetrist #1281 | Qian Xiao | | June 1, 2013 |

# 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
- Tile Layout and data extent provided as ESRI shapefile
- Control points provided as ESRI shapefile
- FGDC compliant metadata per product in XML format
- LiDAR processing report in pdf format
- Survey report in pdf format

WOOLPERT

DESIGN | GEOSPATIAL | INFRASTRUCTURE