AIRBORNE LIDAR TASK ORDER REPORT

LAKE ERIE LIDAR
UNITED STATES GEOLOGICAL SURVEY (USGS)

CONTRACT NUMBER: G10PC00057

TASK ORDER NUMBER: G10PD02054

Woolpert Project Number: 70840
April 2011

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LAKE ERIE LIDAR

USGS CONTRACT: G10PC0057

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For:

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(USGS)
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SECTION 1: OVERVIEW

TASK ORDER NAME: LAKE ERIE LIDAR

WOOLPERT PROJECT #70840

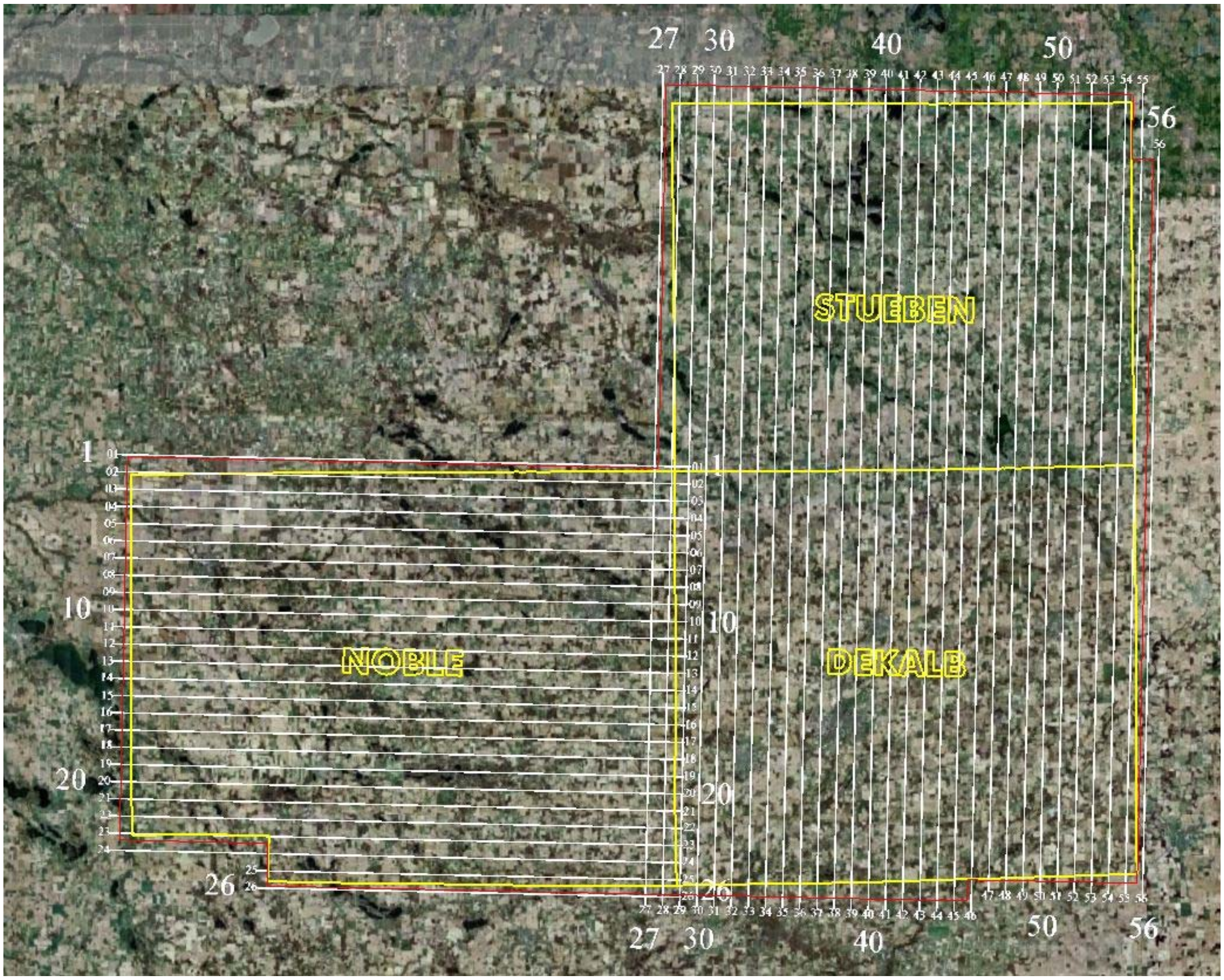
This report contains a comprehensive outline of the airborne LiDAR data acquisition for three contiguous counties in Indiana; DeKalb, Noble and Steuben; Contract Number G10PC00057; Task Order Number G10PD02054, for the United States Geological Survey (USGS). The project area was approximately 1,104 square miles, which includes a 400 meter buffer. The LiDAR was collected and processed to meet the Nominal Pulse Spacing (NPS) requirement of 2.0 meters. The NPS assessment is made against single swath, first return data located within the geometrically usable center portion (typically ~90%) of each swath. In addition, the LiDAR was hydrologically flattened.

The data was collected using a Leica ALS50-II 150 kHz Multiple Pulses in Air (MPiA) LiDAR sensor installed in a Leica gyro-stabilized PAV30 mount. The ALS50-II 150 kHz 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:

Post Spacing (Minimum):	4.9 ft / 1.5 m
AGL (Above Ground Level) average flying height:	7,800 ft / 2,377 m
MSL (Mean Sea Level) average flying height:	8,560 ft / 2,609 m
Average Ground Speed:	130 knots / 149 mph
Field of View (full):	40 degrees
Pulse Rate:	99 kHz
Scan Rate:	35.3 Hz
Side Lap (Minimum):	25%

LiDAR data was produced in Universal Transverse Mercator (UTM) Zone 16N, North American Datum of 1983 (NAD83) for DeKalb, Noble, and Steuben counties. Coordinate positions were specified in units of meters. The vertical datum used for the project was referenced to NAVD 1988, meters, Geoid09.

Figure 1.1 Task Order and LiDAR Flight Layout



SECTION 2: ACQUISITION

The LiDAR data was acquired with a Leica ALS50-II 150 kHz Multiple Pulses in Air (MPiA) LiDAR sensor system, on board a Cessna 404. The ALS50-II 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 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

Prior to mobilizing to the project 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 Kendallville FBO (C62) for the airborne GPS support.

The LiDAR data was collected in four (4) separate 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. Any gaps found in the LiDAR data were relayed to the flight crew, and the area was re-flown.

Figure 2.1 LiDAR Flight Layout

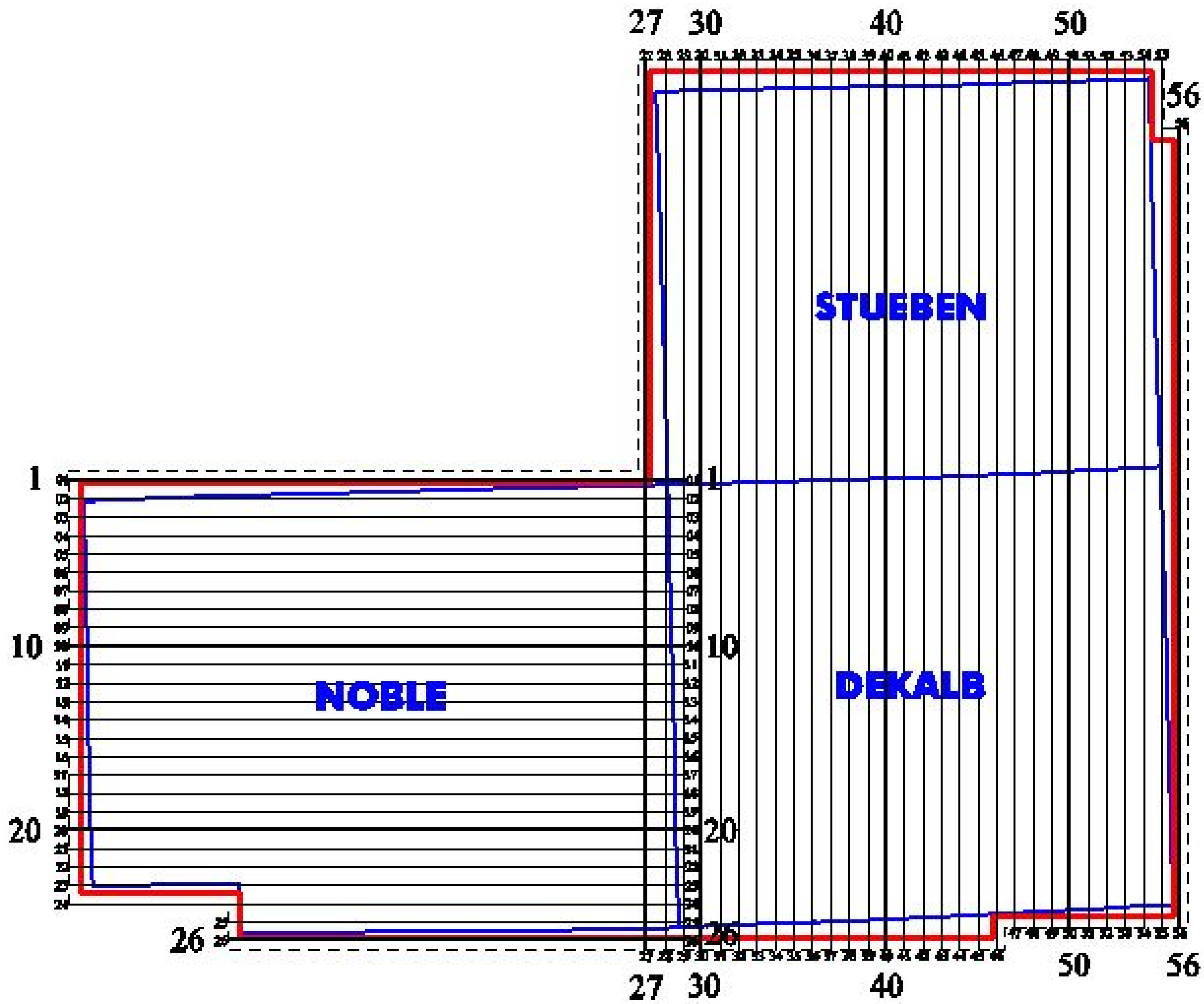


Table 2.2 Airborne LiDAR Acquisition Flight Summary

Airborne LiDAR Acquisition Flight Summary			
Date of Mission	Lines Flown	Mission Time (UTC) Wheels Up/ Wheels Down	Mission Time (Local = EDT) Wheels Up/ Wheels Down
November 23, 2010 – Sensor 46	15-32	23:41 - 05:17	06:41PM - 12:17AM
November 23, 2010 – Sensor 77	1-14, 49-56	23:00 - 05:23	06:00PM - 12:23AM
November 28, 2010 – Sensor 46	33-40	13:38 - 17:36	08:38AM - 12:36PM
November 28, 2010 – Sensor 77	41-48, 49RF	13:44 - 16:51	08:44AM - 11:51AM

SPECIAL CIRCUMSTANCES

During the flight acquisition over DeKalb County, smoke was being emitted in the atmosphere from the Steel Dynamics, Inc. plant and preventing LiDAR returns from the ground surface. The affected area was in flight lines 47 and 48. Woolpert flight crews made multiple attempts to acquire smoke free data none of which produced non occluded data.

The plant is located near the intersection of County Road 59 and County Road 44.
UTM16N Coordinates: East=673982.837 North=4582013.783
Geographic Coordinates: 41° 22’ 15.0412” N, 84° 55’ 10.6700” W

The occluded data is located within delivery tiles 673581 and 673582.

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.1.3.

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. 10.04.

3. Imported processed .LAS point cloud data into project tiles. Resulting data were classified as ground and non-ground points with additional filters created to meet the project 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 in relation to the survey ground control.
   Software: TerraScan v.10.018.

4. The .LAS files were evaluated through a series of QA/QC steps to eliminate remaining artifacts and small undulations from the ground class.
   Software: TerraScan v.10.018.

5. All water bodies greater than two acres and all rivers with a nominal 100 foot width or larger were hydro-flattened using proprietary software.
   Software: TerraScan v.10.018, TerraModeler v.10.006, ArcMap 9.3.1, Proprietary Software.

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 highly 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 at the Kendallville FBO (C62) for the airborne GPS support. The GNSS base station operated during the LiDAR acquisition missions is listed below:

Table 3.1: GNSS Base Station

Station	Latitude	Longitude	Ellipsoid Height (L1 Phase Center)
Name	(DMS)	(DMS)	(Meters)
Kendallville Base	N 41° 28' 17.44407"	W 85° 15' 50.90209"	269.807

DATA PROCESSING

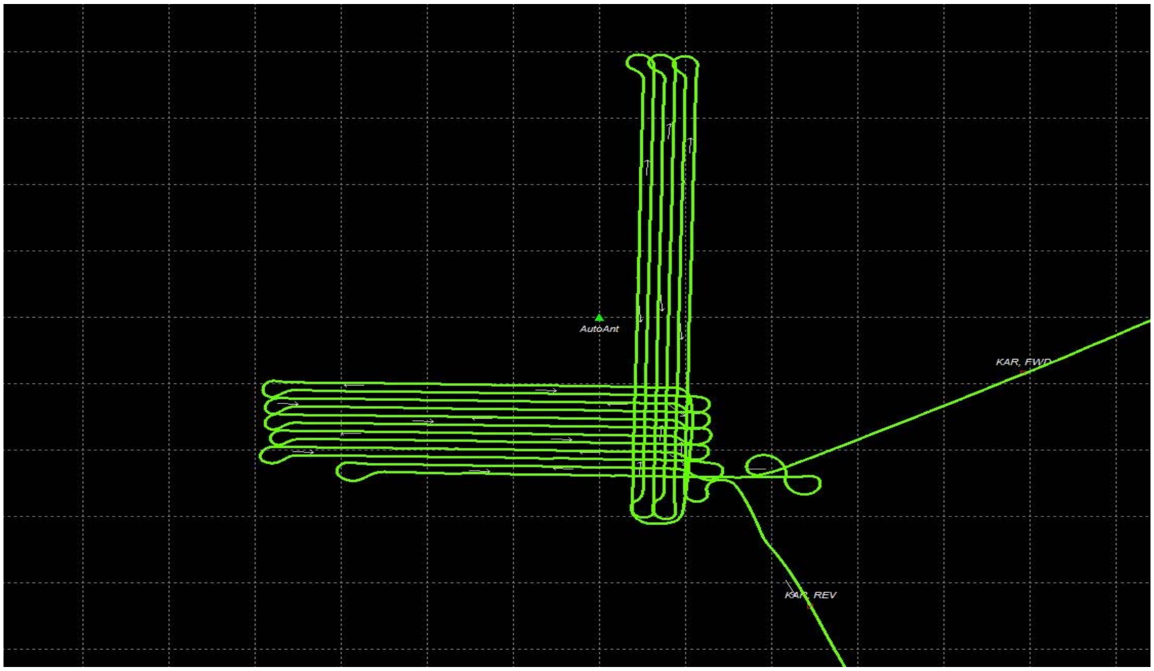
All airborne GNSS and IMU data was post-processed and quality controlled using Applanix MMS software. GNSS data was processed at a 1 and 2 Hz data capture rate and the IMU data was processed at 200 Hz.

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

Flight Trajectory

Figure 3.1: Representative Graph from Day32710: N7079F and ALS LiDAR S/N46



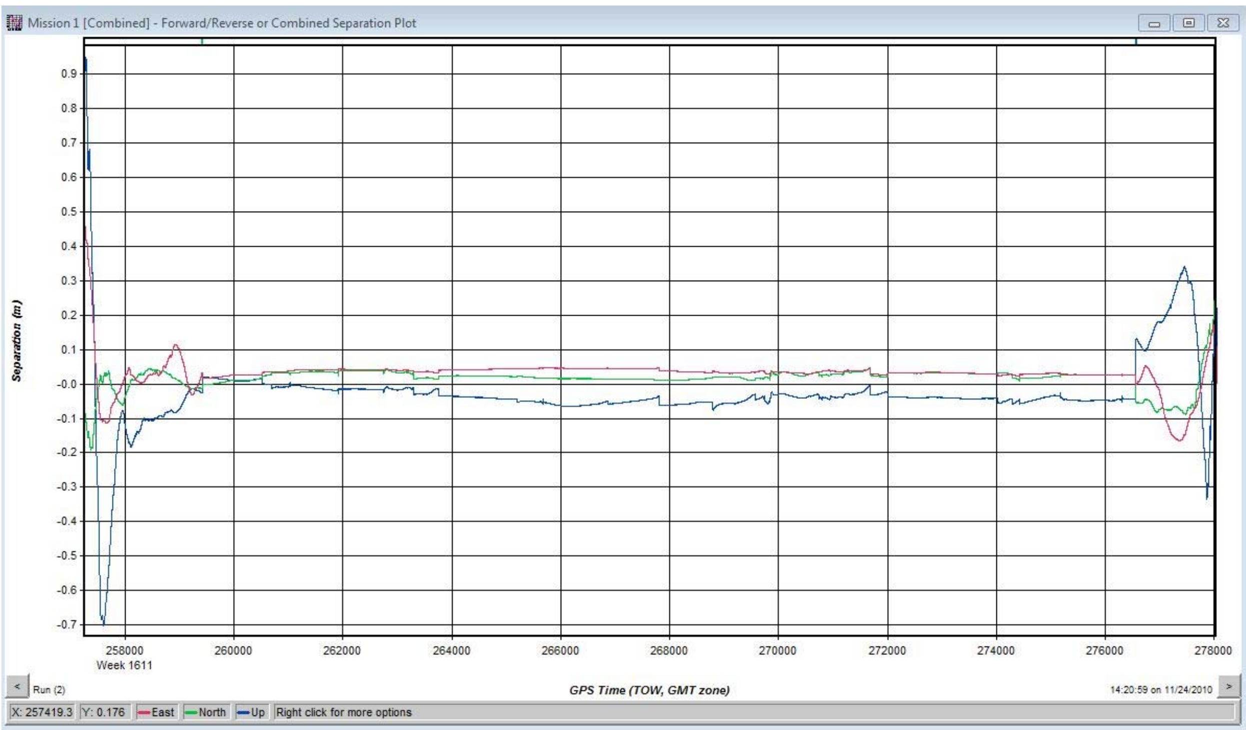
Within the trajectory processing, there are many factors that affect the overall quality, but the most indicative are the Combined Separation, the Estimated Positional Accuracy, and the Positional Dilution of Precision (PDOP).

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 Day32710 of Combined Separation

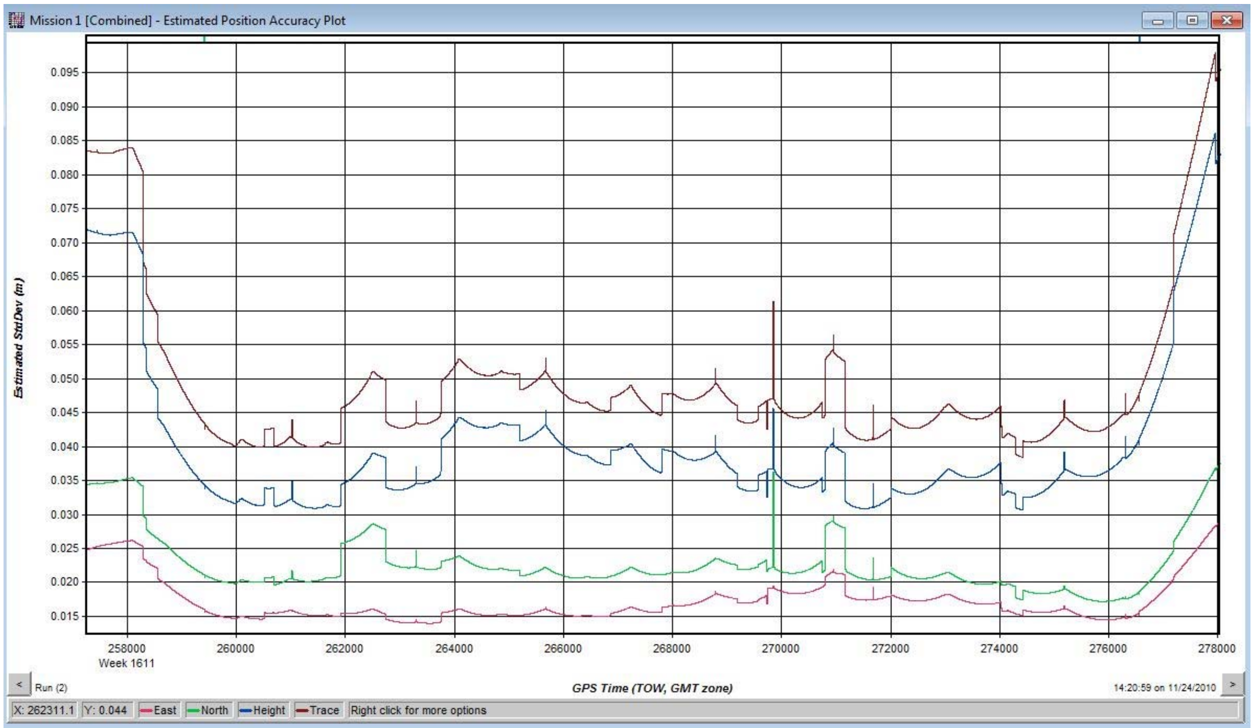


Estimated Positional Accuracy

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 Day32710 of Positional Accuracy



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 “Point Cloud”. 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 project tiles and initially filtered to create a ground and non-ground class. Then additional classes are filtered as necessary to meet client specified classes.

- Once all project 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 meet or exceed the vertical accuracy requirements.

- The LiDAR data in LAS format was reviewed using a series of proprietary QA/QC procedures to ensure it fulfills the project requirements.

- Hydrologically flattening procedures are performed on water bodies greater than 2 acres and rivers and streams of 30.5 meters (100 feet) and greater nominal width.

- The LiDAR LAS files for this project have been classified into the Default (Class 1), Ground (Class 2), Noise (Class 7), Water (Class 9) and Ignored Ground (Class 10) classifications.

- Project metadata was developed in .xml format for the deliverable products.

- Final deliverable data was derived from the adjusted classified LiDAR data.

- For DeKalb, Noble, and Steuben Counties the horizontal datum used for the project was referenced to UTM 16N and North American Datum of 1983. Coordinate positions were specified in units of meters. The vertical datum used for the project was referenced to NAVD 1988, meters, Geoid09.

SECTION 4: HYDROLOGIC FLATTENING AND FINAL QUALITY CONTROL

HYDROLOGIC FLATTENING OF LIDAR 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 rivers. Lakes, reservoirs and ponds, at a nominal 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. The hydrologic flattening of the LiDAR data was performed for inclusion in the National Elevation Dataset (NED). The project area encompassed approximately 1,104 square miles comprised of three (3) contiguous counties of DeKalb, Noble, and Steuben in northeastern Indiana.

LIDAR DATA REVIEW AND PROCESSING

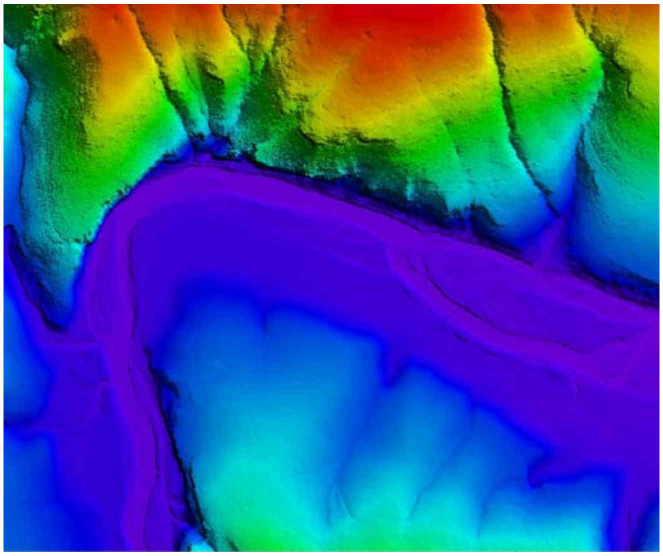
Woolpert utilized the following steps to hydrologically flatten the water bodies and for gradient hydrologic flattening of the double line streams within the existing LiDAR data.

1. Woolpert used the newly acquired (2010) LiDAR bare-earth data and the existing 2009 NAIP color (RGB) imagery. The hydrologic features were manually drawn in a 2D environment using the LiDAR bare earth surface along with the NAIP imagery as a reference.

2. Woolpert utilized an integrated software approach to combine the LiDAR data and 2D breaklines. This process "drapes" the 2D breaklines onto the 3D LiDAR surface model. A monotonicity process is performed on the data to ensure the streams are consistently flowing in a gradient manner. A procedure within the processing validates the elevation of the stream edges. The breaklines that characterize the closed water bodies are draped onto the 3D LiDAR surface and assigned a constant elevation.

3. The lakes, reservoirs and ponds, at a nominal minimum size of 2-acres or greater, were compiled as closed polygons. **Figure 4.1** illustrates a good example of approximate 2-acre lakes and 30.5 meters (100-feet) nominal streams identified and defined with hydrologic breaklines in a dataset. 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-foot) buffer along the hydrologic feature breaklines to buffered ground, class ten (10).

6. The LiDAR mass points and hydrologic feature breaklines were used to generate a new digital elevation model.

Figure 4.2

Figure 4.3

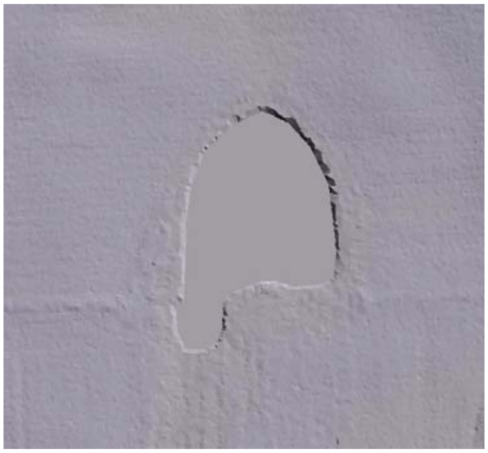


Figure 4.2 reflects a DEM generated from original LiDAR bare earth point data prior to the hydrologic flattening process. Note the "tinning" across the lake surface.

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.

The hydrologically flattened DEM data was provided to USGS in ArcGRID 32-bit FLOAT format at a 3-meter cell size, in 1,500 meter x 1,500 meter tiles. Terrascan was used to add the hydrologic breakline vertices and export the lattice models.

The hydrologic breaklines compiled as part of the flattening process were provided to the USGS as a shapefile. The breaklines defining the water bodies greater than 2-acres were provided as a Polygon Z 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 Polyline Z file.

DATA QA/QC

Initial QA/QC for this task order was performed in Global Mapper, 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 ArcGRID DEM, the area was cross referenced by tile number, edited, a new ArcGRID DEM was regenerated by individual tile and 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

Average error	0.001	meters
Minimum error	-0.088	meters
Maximum error	0.134	meters
Average magnitude	0.057	meters
Root mean square	0.065	meters
Standard deviation	0.067	meters

Table 5.2: QA/QC Analysis UTM 16N, NAD83

Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Laser Elevation (meters)	Dz (meters)
1	651094.587	4624684.410	286.770	286.720	-0.050
6	652434.008	4611810.920	285.627	285.700	+0.073
7	660717.698	4611222.139	299.711	299.810	+0.099
9	679043.871	4610928.260	303.658	303.590	-0.068
12	668072.797	4595303.768	294.789	294.750	-0.039
13	675765.501	4594948.129	288.536	288.450	-0.086
14	683325.516	4594358.634	263.297	263.310	+0.013
16	662480.348	4582623.756	265.809	265.840	+0.031
20	657247.025	4571396.901	260.329	260.390	+0.061
21	665737.739	4571535.831	259.756	259.760	+0.004
26	614028.465	4586405.349	268.800	268.720	-0.080
27	630737.412	4584137.240	280.463	280.530	+0.067
28	614411.536	4572420.533	280.695	280.720	+0.025
33	655704.712	4603768.948	302.014	302.010	-0.004
34	666751.458	4604115.635	301.781	301.720	-0.061
35	681589.798	4603111.700	278.800	278.850	+0.050
36	654739.313	4591722.870	304.164	304.210	+0.046
42	619953.181	4593186.402	293.882	293.800	-0.082
43	621268.809	4583652.862	278.588	278.500	-0.088
44	616729.108	4577831.337	268.149	268.120	-0.029
48	646220.424	4582038.064	307.496	307.630	+0.134

VERTICAL ACCURACY CONCLUSIONS

- **Data Accuracy** tested 0.065 meters RMSE vertical accuracy at 95% percent confidence level.

- **Fundamental Vertical Accuracy (FVA)** tested 0.1274 meters vertical accuracy at 95% percent confidence level.

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

Approved By:			
Title	Name	Signature	Date
Associate Member LiDAR Specialist Certified Photogrammetrist #1281	Qian Xiao		April 28, 2011

SECTION 6: FINAL DELIVERABLES

FINAL DELIVERABLES

The final deliverables are listed below:

- One set of hydrologically flattened LiDAR data bare earth tiles in ArcGRID format in 1,500 meter x 1,500 meter tiles.
- LAS v1.2 classified point cloud and bare earth point files in tile format.
- LAS v1.2 raw unclassified flight line strips no greater than 2GB.
- Breaklines compiled as part of the hydrologic flattening process were provided as ESRI PolygonZ and PolylineZ shape files.
- Tile Layout provided as ESRI shape file.
- QA/QC control points as ESRI shape file.
- FGDC compliant metadata by file in XML format.
- The project data was delivered on external USB 2.0 hard drives.

The DEMs produced under this task order met the following specifications:

- The water body hydrologic flattening was completed using the methodology described in this report and Woolpert's original proposal in response to the task order.
- The DEMs were edge joined.
- The hydrologically flattened bare earth data was delivered in ArcGRID FLOAT format at a three meter posting.