AIRBORNE LIDAR TASK ORDER REPORT

INDIANA STATEWIDE IMAGERY AND LIDAR PROGRAM

INDIANA OFFICE OF INFORMATION TECHNOLOGY

WOOLPERT PROJECT NUMBER: 71177

PREPARED BY: WOOLPERT

4454 Idea Center Boulevard
Dayton, OH 45430.1500

November 2011

WOOLPERT

DESIGN | GEOSPATIAL | INFRASTRUCTURE

AIRBORNE LIDAR TASK ORDER REPORT

INDIANA STATEWIDE IMAGERY AND LIDAR PROGRAM

For:

Indiana Office of Information Technology
Supporting Agencies: Federal: USGS, State: IGIC, Local: IMAGIS
100 North Senate Ave., Room N551
Indianapolis, IN 46204

By:

Woolpert
4454 Idea Center Boulevard
Dayton, OH 45430-1500
Tel 937.461.5660

Summary of Contents

List of Figures

List of Tables

SECTION 1: OVERVIEW

TASK ORDER NAME: INDIANA STATEWIDE IMAGERY AND LIDAR PROGRAM

WOOLPERT PROJECT #71177

This report contains a comprehensive outline of the statewide airborne LiDAR data acquisition of Indiana for the Indiana Office of Information Technology. The project has been divided into three project areas. Area 1 will be the center tier and performed in 2011. Area 2 will be the eastern tier and performed in 2012. Area 3 will be the western tier and performed in 2013. The project area will contain both existing LiDAR data and new LiDAR data to be collected by Woolpert beginning in 2011. The boundary limits for the new LiDAR data will be the same as the orthoimagery and cover ±29,218 square miles. However, unlike the orthoimagery, full tiles will not be delivered. The new LiDAR data will only be delivered to the 1,000-foot buffer or to the opposite river bank whichever is greater.

The existing LiDAR is ±7,200 sq. miles and consists of complete and partial counties: Complete Counties - Porter, Steuben, Noble, De Kalb, Allen, Madison, Delaware, Hendricks, Marion, Hancock, Morgan, Johnson, Shelby, and Monroe; Partial Counties – Vermillion, Parke, Vigo, Clay, Sullivan, Knox, Gibson, and Posey.

The Area 1 data was collected using a Leica ALS50-II, Leica ALS60 LiDAR sensor and an Optech ALTM Gemini LiDAR sensor. All three sensors collects up to four returns (echo) 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 for Area 1 was broken down into four individual blocks and consisted of 390 flight lines (see Figure 1.1).

The Lidar was collected for all four blocks, at the following sensor specifications for 1.5 NPS:

Post Spacing (Minimum):	4.92 ft / 1.5 m
AGL (Above Ground Level) average flying height:	6,500 ft / 1,981.2 m
MSL (Mean Sea Level) average flying height:	7,270 ft / 2,215 m
Average Ground Speed:	130 knots / 149 mph
Field of View (full):	40 degrees
Pulse Rate:	115.6 kHz
Scan Rate:	41.8 Hz
Side Lap (Minimum):	25%

The Lidar was collected at the following sensor specifications for 1.0 NPS:

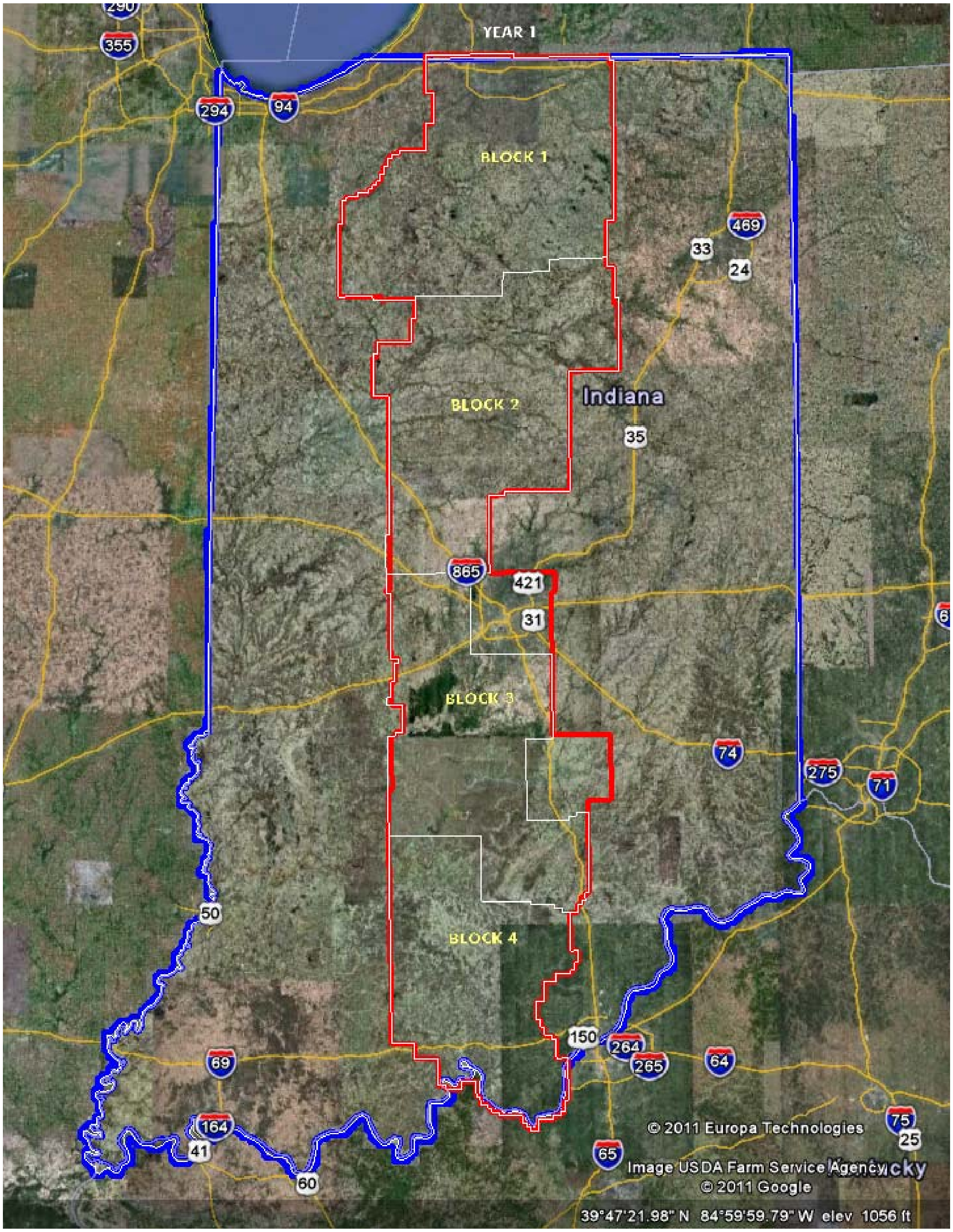
Post Spacing (Minimum):	3.28 ft / 1.0 m
AGL (Above Ground Level) average flying height:	6,500 ft / 1,981.2 m
MSL (Mean Sea Level) average flying height:	7,270 ft / 2,215 m
Average Ground Speed:	130 knots / 149 mph
Field of View (full):	40 degrees
Pulse Rate:	115.6 kHz
Scan Rate:	41.8 Hz
Side Lap (Minimum):	25%

The LiDAR was collected and processed to meet a Nominal Post Spacing (NPS) of 1.0 meter for Boone County while the remaining counties were collected and processed to meet a Nominal Post Spacing (NPS) of 1.5 meter. The NPS assessment is made against single swath, first return data located within the geometrically usable center portion (typically ~90%) of each swath.

LiDAR data was processed and projected in Indiana State Plane East (1301) and Indiana State Plane West (1302), North American Datum of 1983 (NAD83) (NSRS2007) in units of feet. The vertical datum used for the project was referenced to NAVD 1988, feet, Geoid09.

In addition, breaklines defining waterbodies and streams were used to hydrologically flatten the DEM surface. This surface will be inserted into the 1/9 arc-second (3-meter) National Elevation Database.

Figure 1.1 Project Overview Area 1 (Outlined in Red)



SECTION 2: ACQUISITION

The LiDAR data was acquired with a Leica ALS50-II 150 kHz Multiple Pulses in Air (MPiA) LiDAR sensor system and a Leica ALS60 200 kHz MPiA LiDAR sensor, on board a Cessna 404. In addition, data was acquired with an ALTM Gemini, developed by Optech Incorporated of Ontario, Canada. A Dell Precision laptop computer serves as the operator interface using ALTM-NAV™ Flight Management Software.

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 and an OC60 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

Table 2.2 ALS60 LiDAR System Specifications

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

Table 2.3 ALTM Gemini LiDAR System Specifications

The Optech Gemini 167 kHz Multiple Pulses in Air (MPiA) LiDAR System has the following specifications:

Specification	
Operating Altitude	150 - 4, 000 m AGL nominal, 10% reflective target
Scan Angle	0 to 50° (variable)
Swath Width	0 to 1.5 X altitude (variable)
Scan Frequency	0 – 70 Hz (variable based on scan angle)
Maximum Pulse Rate	167 kHz
Range Resolution	Better than 1 cm
Elevation Accuracy	5 -35 cm single shot 1 σ (one standard deviation)
Horizontal Accuracy	1/5, 5000 x altitude (m AGL)
Number of Returns per Pulse	4 (first, second, third, last)
Number of Intensities	3 (first, second, third)
Intensity Digitization	12 bit dynamic measurement range
Laser Beam Divergence	Dual divergence: 0.25 mrad (1/e) and 0.8 mrad (1/e), nominal
Laser Classification	Class IV laser product (FDA CFR 21)
Eye Safe Range	400m single shot depending on laser repetition rate
Roll compensation	±5° at full FOV
Power Requirements	28 VDC @ 35A
Data storage	Ruggedized removable SCSI hard disk

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 for the airborne GPS support.

The LiDAR data was collected in 48 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, Block 1

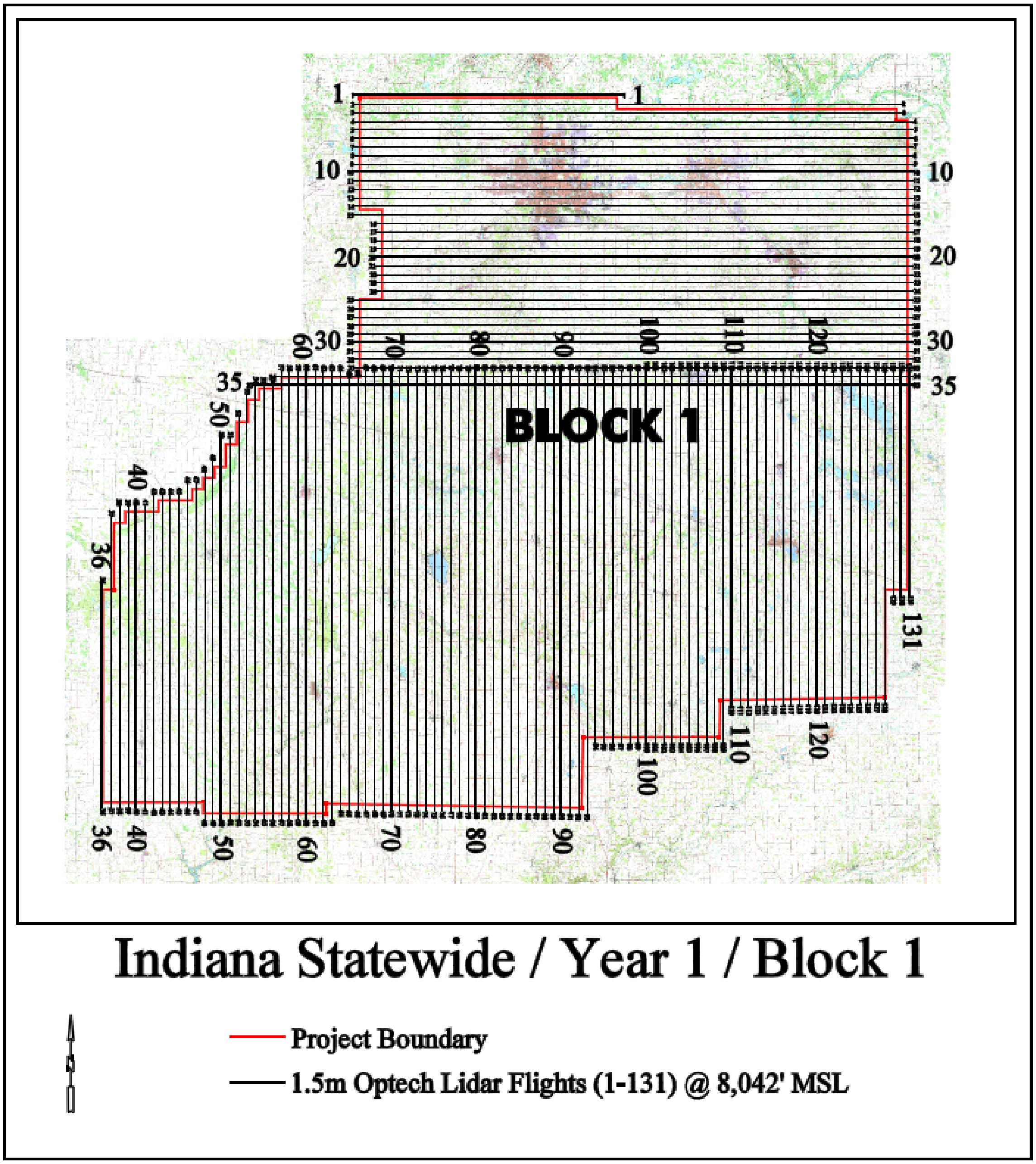


Figure 2.2 LiDAR Flight Layout, Block 2

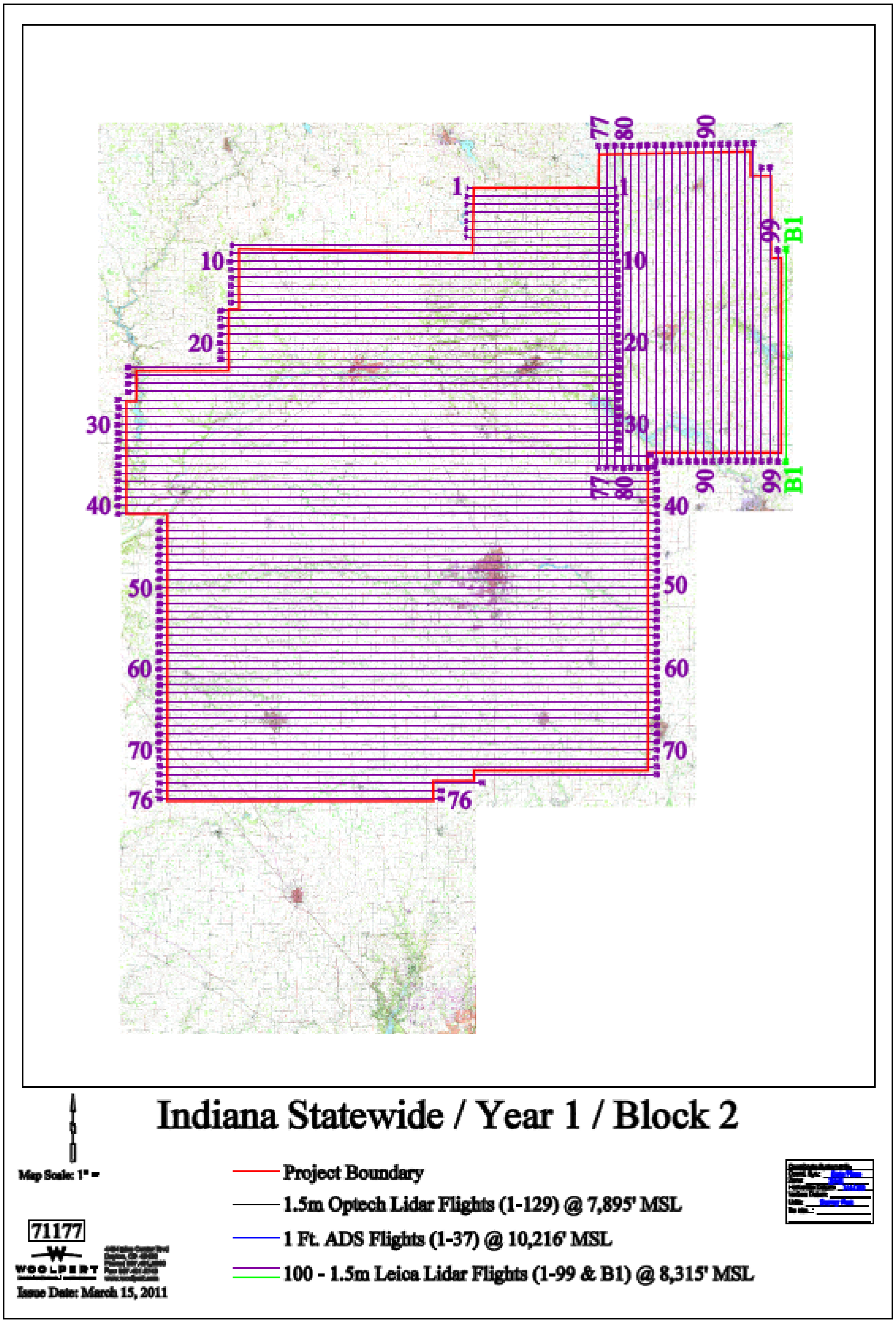


Figure 2.3 LiDAR Flight Layout, Block 3

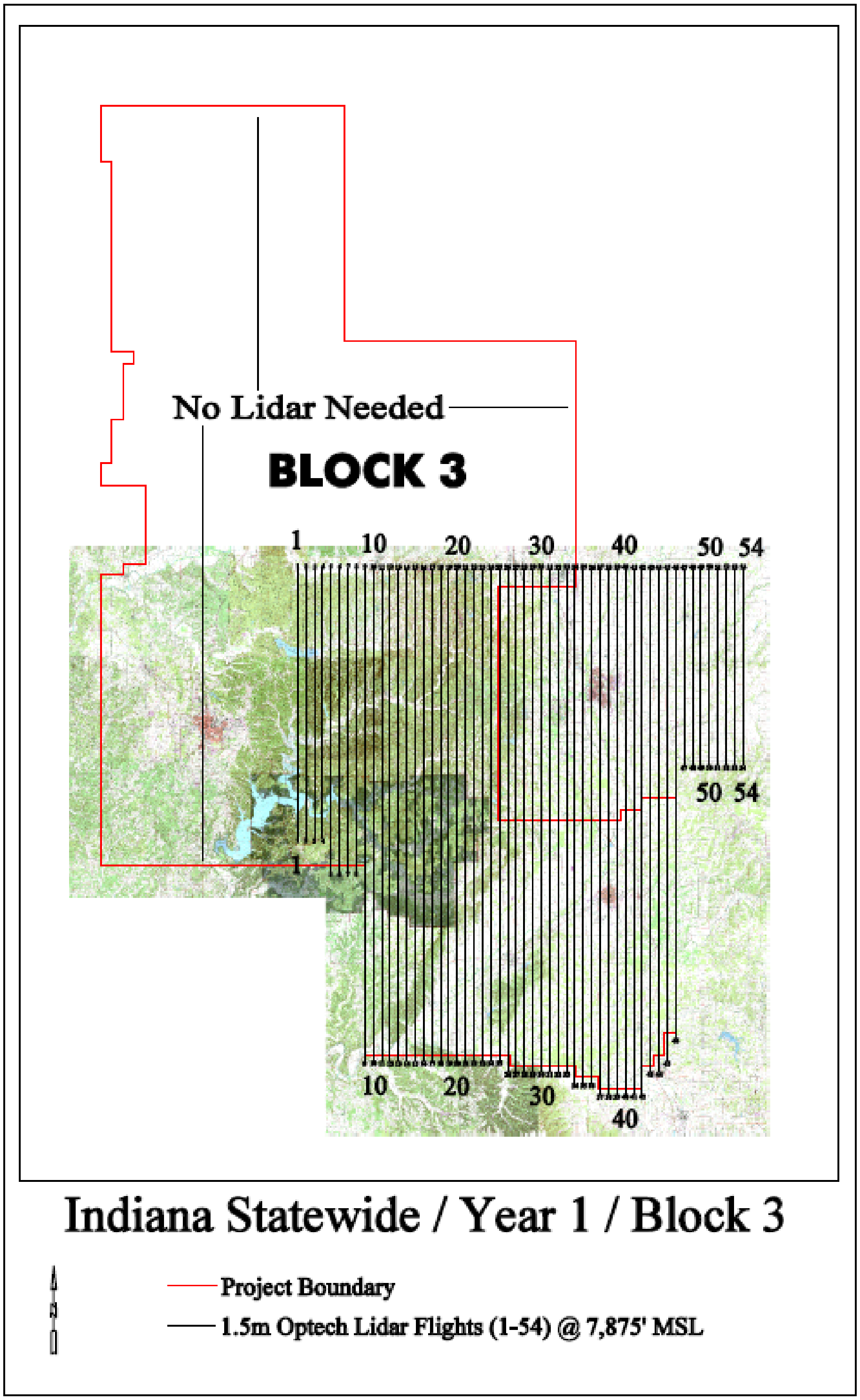


Figure 2.4 LiDAR Flight Layout, Block 4

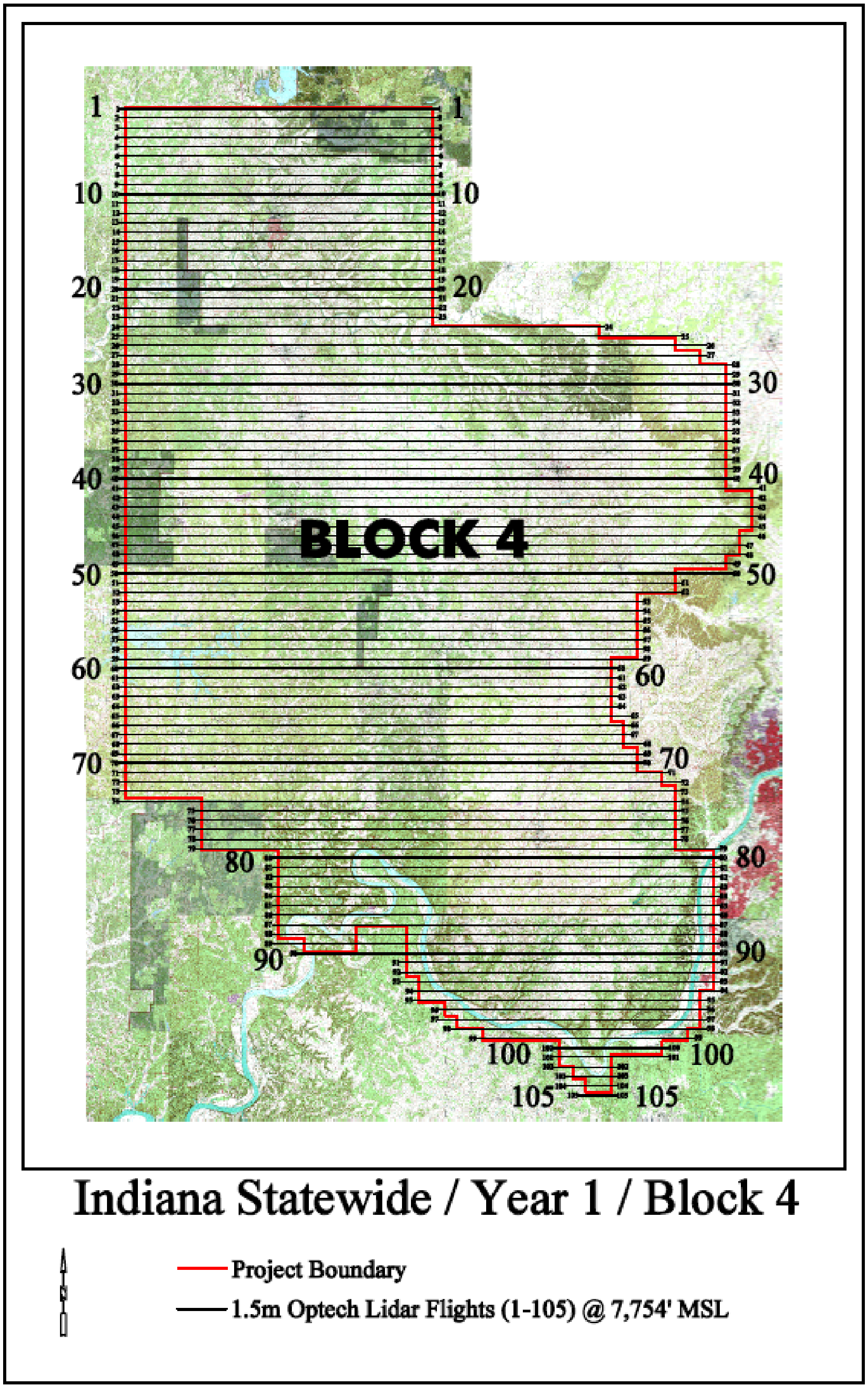


Table 2.4 Area 1 Airborne LiDAR Acquisition Flight Summary

Area 1 Airborne LiDAR Acquisition Flight Summary				
Date of Mission - Sensor Number	Block	Lines Flown	Mission Time (UTC) Wheels Up/ Wheels Down	Mission Time (Local = EDT) Wheels Up/ Wheels Down
March 13, 2011A - 108	4	15-17, 22, 35, 50-55	19:29 - 16:35	08:29 AM - 12:35 PM
March 13, 2011B - 108	4	44-49, 56-60	17:55 - 22:20	13:55 PM - 18:20 PM
March 16, 2011A - 108	4	1-4	16:48 - 18:09	12:48 PM - 14:09 PM
March 16, 2011B - 108	4	5-14, 16-25	21:59 - 02:33	17:59 PM - 22:33 PM
March 16, 2011 - 6157	2	1-31, 1010-1011, 1031	15:41 - 23:38	11:41 AM - 07:38 PM
March 17, 2011A - 108	4	27-34, 36, 1025	12:27 - 17:00	08:27 AM - 13:00 PM
March 17, 2011B - 108	4	37-43, 61-62, 64, 1035	20:25 - 00:55	16:25 PM - 18:55 PM
March 17, 2011C - 108	4	65-68	03:05 - 05:26	21:05 PM - 01:25 AM
March 18, 2011 - 108	1	1-10	21:20 - 01:49	17:20 PM - 21:49 PM
March 18, 2011 - 6157	2	1-7, 79-100	15:45 - 22:20	11:44 AM - 18:20 PM
March 19, 2011A - 108	1	11-16	02:55 - 05:55	22:55 PM - 01:55 AM
March 19, 2011B - 108	1	63, 69-79, 1068	15:13 - 19:57	11:13 PM - 15:57 PM
March 19, 2011C - 108	3	1-8	22:06 - 00:18	18:06 PM - 20:18 PM
March 19, 2011 - 46	2	62-76	15:25 - 20:55	11:25 AM - 16:55 PM
March 20, 2011A - 108	3	9-19	02:09 - 06:50	22:09 PM - 02:50 AM
March 20, 2011B - 108	3	20	03:30 - 03:30	03:30 AM - 03:30 AM
March 20, 2011C - 108	3	20-27	22:14 - 01:18	18:14 PM - 21:18 PM
March 21, 2011A - 108	3	27-30, 53	03:30 - 06:44	23:30 PM - 02:44 AM
March 21, 2011B - 108	3	30	14:15 - 15:30	10:15 AM - 11:30 AM
March 22, 2011A - 108	3	30, 51-54	15:00 - 17:50	11:00 AM - 13:50 PM
March 23, 2011A - 108	3	30-40	00:35 - 05:10	20:35 PM - 01:10 AM
March 23, 2011B - 108	3	41-42	23:40 - 00:00	19:40 PM - 01:00 AM
March 26, 2011A - 6157	2	6, 32, 2009	12:39 - 22:01	08:39 AM - 06:01 PM
March 26, 2011B - 6157	2	1082, 1089	12:39 - 22:01	08:39 AM - 06:01 PM
March 26, 2011 - 77	2	36	12:40 - 13:40	08:40 AM - 09:40 AM
March 27, 2011A - 46	2	48-61	16:42 - 22:04	12:42 PM - 18:04 PM
March 27, 2011B - 46	2	36-47	23:06 - 03:44	19:06 PM - 23:49 PM
March 28, 2011A - 108	3	43-50, 55, 1042, 1052	00:30 - 04:07	20:30 PM - 00:07 AM
March 28, 2011B - 108	4	86-105	18:18 - 23:00	14:18 PM - 19:00 PM
March 29, 2011A - 108	4	23, 25, 80-85, 106, 1036, 1066	01:15 - 04:55	21:15 PM - 00:55 AM

Area 1 Airborne LiDAR Acquisition Flight Summary				
Date of Mission – Sensor Number	Block	Lines Flown	Mission Time (UTC) Wheels Up/ Wheels Down	Mission Time (Local = EDT) Wheels Up/ Wheels Down
March 29, 2011B - 108	1	17-28	19:15 - 00:10	15:10 PM - 20:10 PM
March 30, 2011A - 108	1	29-35	00:36 - 04:07	20:36 PM - 00:07 AM
March 30, 2011B - 108	1	36-50	14:55 - 19:20	10:55 PM - 15:20 PM
March 30, 2011C - 108	1	51-62	21:18 - 01:15	17:18 PM - 00:15 AM
March 31, 2011 - 46	2	28-35, 58, 77, 90, 1090, 2090, 1093	17:13 - 22:26	13:13 PM - 18:26 PM
March 31, 2011A - 108	1	81-89	23:16 - 03:00	19:16 PM - 23:00 PM
March 31, 2011 - 77	2	8-22	17:33 - 22:29	01:33 PM - 06:29 PM
March 31, 2011 - 108	1	90-102	03:28 - 07:13	23:28 PM - 03:13 AM
April 01, 2011 - 108	1	63-74	23:55 - 04:55	19:55 PM - 00:40 AM
April 03, 2011B - 108	1	75-80, 103-108	05:19- 09:45	01:19 AM - 05:45 AM
April 05, 2011 - 108	1	110-112, 127-131	11:48- 13:47	07:48 AM - 09:47 AM
April 06, 2011 - 108	1	64, 109, 113-122, 1109, 1112	18:43- 23:55	14:43 PM - 19:55 PM
April 06, 2011 - 108	1	123-133, 2042 (Block3)	00:30- 05:20	20:30 PM - 01:20 AM
April 10, 2011A - 108	1	67-74	11:33- 14:43	07:33 AM - 10:43 AM
April 10, 2011B - 108	1	63, 65-67	15:14- 17:30	11:14 AM - 13:30 PM
April 10, 2011 - 6157	1	1005 (Boone), 23-27, 1015, 1017-1018, 1021, 1058	14:47- 18:01	10:47 AM - 14:01 PM
April 13, 2011 - 46	1	26	13:13- 15:49	09:13 AM - 10:49 AM
April 20, 2011 - 46	1	1028	02:16- 03:20	22:16 PM - 23:20 PM

Special Note: All planned lines are listed in the “Lines Flown” column. Any reflight is listed as line number plus 1000 (i.e. a reflight of line 2 would be listed as 1002)

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. 5.4, 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. 11.05.

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.11.006.

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.11.006.

5. All water bodies greater than two acres and all rivers with a nominal 100 foot width or larger were hydro-flattened using Woolpert's proprietary software.
   Software: TerraScan v.11.006, TerraModeler v.11.004, ESRI ArcMap 9.3.1.

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 the imagery acquisition mission, and was operated by a member of the Woolpert survey and/or flight crew. Each base-station setup consisted of one (1) Trimble 5000 series dual frequency receiver, one (1) Trimble Zephyr Geodetic L1/L2 dual frequency antenna, one (1) 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 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)
INBD	38° 51' 47.10456"	86° 31' 20.30561"	162.404
INBR	41° 27' 28.72642"	86° 11' 33.44301"	225.211
INFR	40° 16' 42.15457"	86° 31' 57.71300"	237.023
INPA	38° 33' 57.70664"	86° 29' 30.63539"	201.431
INSY	38° 57' 36.28053"	85° 51' 42.43309"	158.732
INTP	40° 16' 49.30737"	86° 03' 19.84657"	236.809
INTU	38° 03' 36.15295"	86° 37' 32.84300"	213.534
INUB	39° 11' 50.49564"	85° 57' 42.93269"	164.969
INWB	40° 49' 29.02368"	85° 48' 11.62274"	218.56
INWN	41° 04' 45.83567"	86° 36' 15.44568"	189.257
IUUO	39° 10' 26.60566"	86° 30' 23.18316"	230.758
KOKOMO BASE	40° 32' 00.16758"	86° 03' 28.73979	216.263
MINI	41° 48' 33.75211"	86° 13' 25.54665"	202.015
PID DI3637	41° 31' 26.27363"	85° 47' 35.13483"	216.585
PID IB2708	40° 02' 22.76758"	86° 15' 06.33656"	246.943

DATA PROCESSING

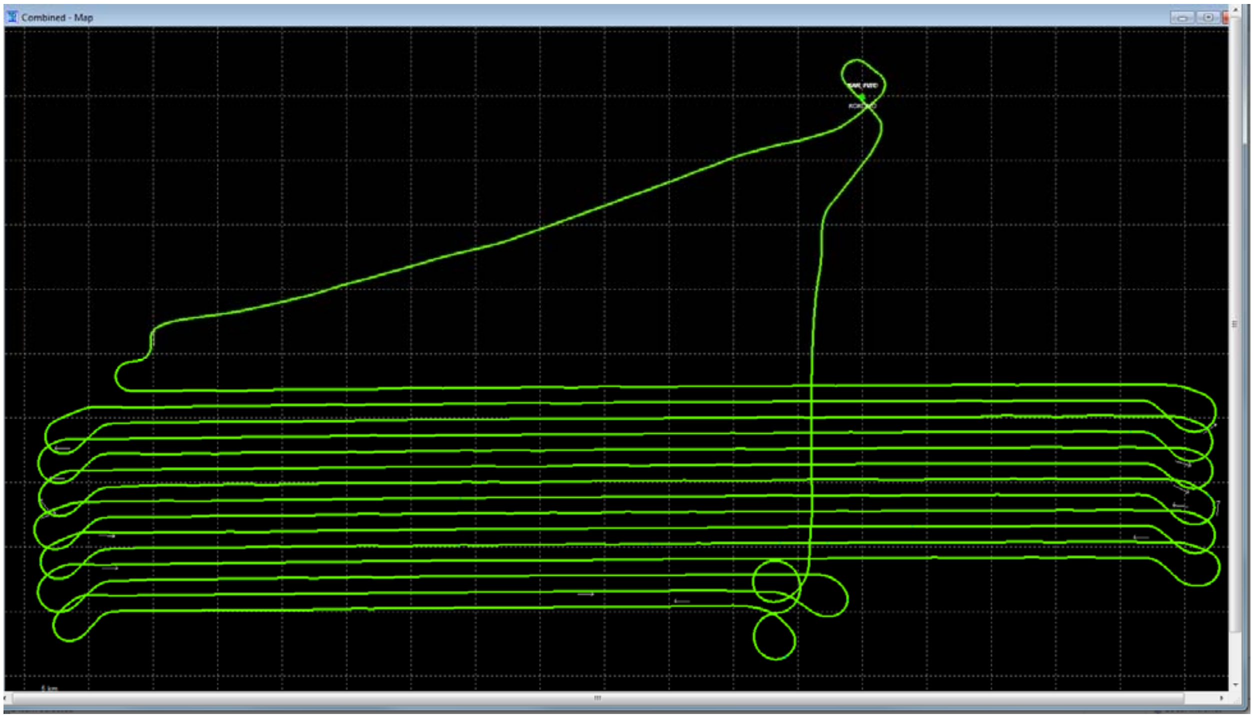
All airborne GNSS and IMU data was post-processed and quality controlled using Applanix 5.3 MMS software. GNSS data was processed at a 1 and 2 Hz data capture rate and the IMU data was processed at 200 Hz.

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 Graph from Day07811



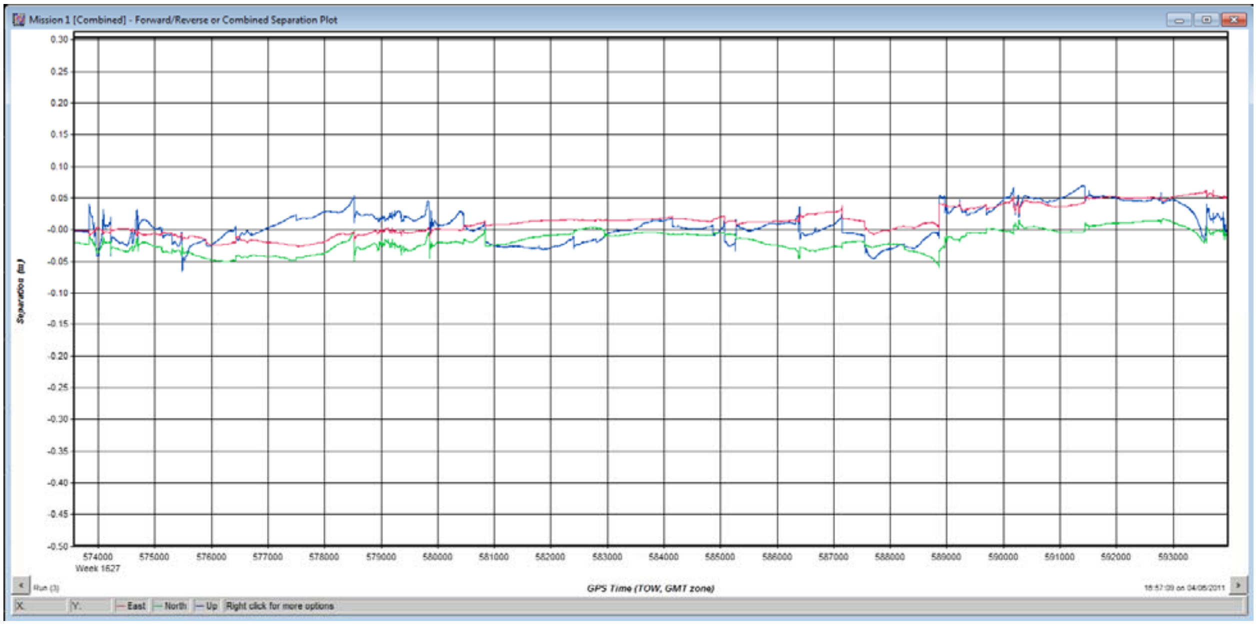
Within the trajectory processing, there are many factors that affect the overall quality, but the most indicative are the Combined Separation, the Estimated Positional Accuracy, and the Positional Dilution of Precision (PDOP).

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 Graph from Day07811 of Combined Separation

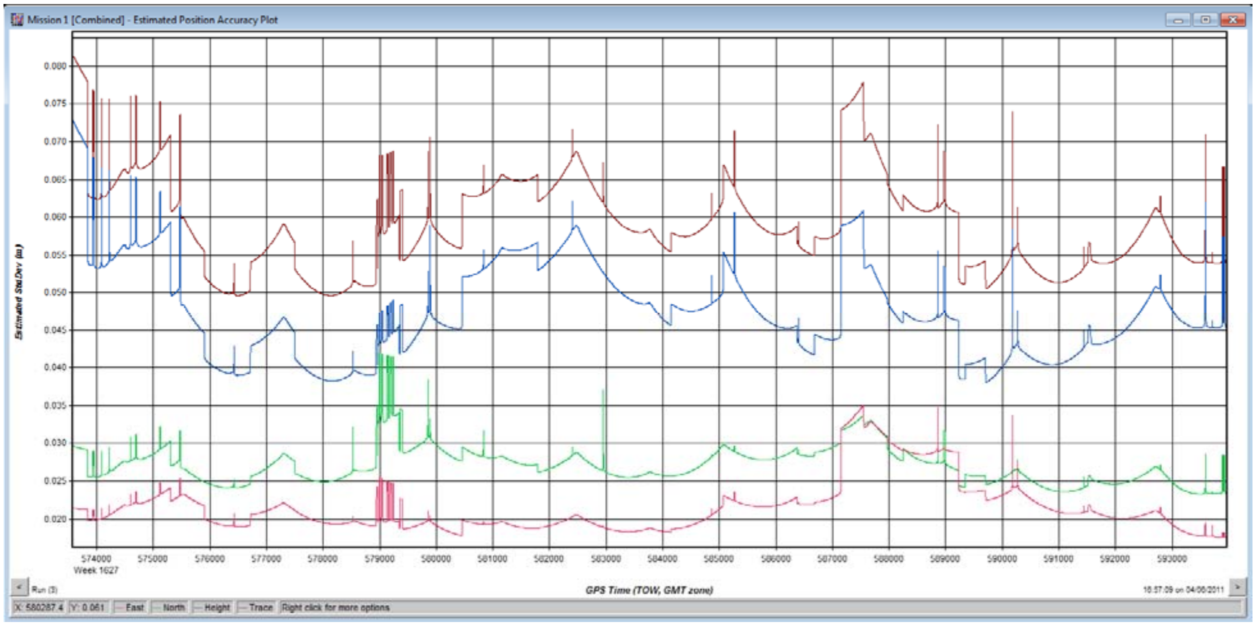


Estimated Positional Accuracy

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 Graph from Day07811 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 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), Noise (Class 7), Water (Class 9), Ignored Ground (Class 10), Overlap (Class 12) and Bridge (Class 13) 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 Indiana State Plane East and West, North American Datum of 1983 (NSRS 2007). Coordinate positions were specified in units of feet. The vertical datum used for the task order was referenced to NAVD 1988, feet, Geoid09.

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 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 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 DEM data was performed for inclusion in the National Elevation Dataset (NED).

LIDAR DATA REVIEW AND PROCESSING

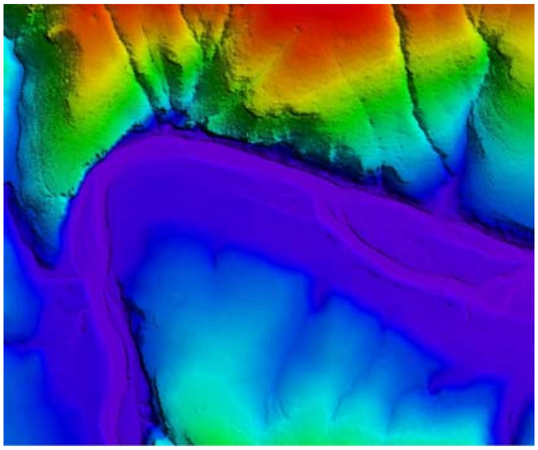
Woolpert utilized the following steps to hydrologically flatten the water bodies and for gradient hydrologic flattening of the double line streams within the existing LiDAR data.

1. Woolpert used five (5) counties of pre-existing LiDAR data; Monroe, Morgan, Hendricks, Johnson, and Marion along with newly acquired (2011) LiDAR data to manually draw the hydrologic features in a 2D environment using the LiDAR bare earth surface and LiDAR intensity data. Google Earth 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 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 (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

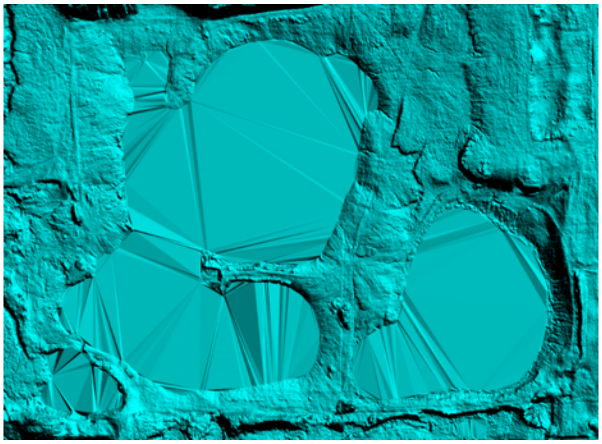


Figure 4.3

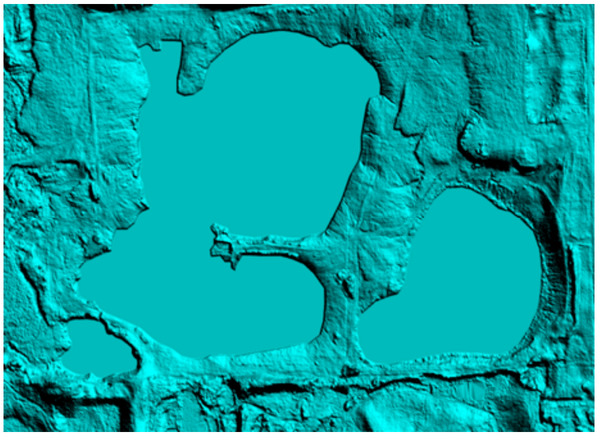


Figure 4.2 reflects a DEM generated from original LiDAR bare earth point data prior to the hydrologic flattening process. Note the "tinning" across the lake surface.

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 in 32-bit FLOAT IMG format at a 5-foot cell size. The final LiDAR data was delivered in a State plane East and West, survey feet projection tiling format, based on a modular layout. The tiles were clipped to eliminate overlap between adjacent tiles. The 5,000 meter x 5,000 meter tile file name was derived from the southwest corner of each tile and was based on the U.S. National Grid. The file names include the Grid Zone Designation (GZD), 100,000 meter block designator and the X and Y grid coordinates truncated to 100 meters. A prefix of "in2011_" was added to represent the year of collection. In addition, a suffix of "_12" was added.

The hydrologic breaklines compiled as part of the flattening process were provided 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 100-feet were provided as a PolylineZ file. The shape files were provided per county as a deliverable.

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 ArcGRID DEM, the area was cross referenced by tile number, corrected accordingly, a new ArcGRID 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 QA/QC Analysis, Block 1 Indiana East Projection

Block 1 Indiana East Projection					
Point ID	Easting (US feet)	Northing (US feet)	Elevation (feet)	Laser Elevation (feet)	DZ (feet)
65A	194878.583	2096597.493	832.186	832.19	0.004
76	94583.861	2371100.563	781.167	781.26	0.093
77A	154203.413	2372374.729	797.526	797.33	-0.196
78A	220011.552	2369524.179	793.945	794.12	0.175
79A	273321.943	2369598.069	780.886	780.89	0.004
80	329196.131	2371727.064	813.527	813.75	0.223
81A	100650.277	2316196.121	705.159	705.31	0.151
82A	158073.983	2317758.126	814.176	814.03	-0.146
83	220435.601	2317455.425	811.004	811.07	0.066
84	267602.677	2316465.511	784.088	784.46	0.372
85A	331569.392	2306833.69	916.562	916.49	-0.072
86	100981.189	2253795.467	715.623	715.31	-0.313
87	153265.803	2269613.576	884.07	884.16	0.09
88	220538.72	2251139.02	842.027	842.24	0.213
89	273849.575	2252698.461	826.364	826.53	0.166
90A	330518.71	2251881.273	871.96	872.05	0.09
93A	164257.594	2211684.819	835.361	835.37	0.009
94	223542.498	2197908.502	815.183	814.94	-0.243
95	277320.027	2195127.7	836.633	836.88	0.247
96	334503.852	2198474.318	904.128	903.88	-0.248
100A	107233.717	2158198.425	730.495	730.26	-0.235
101	169640.096	2158305.404	894.664	894.65	-0.014
102	220754.037	2158372.467	811.267	811.34	0.073
103A	286758.55	2147209.733	877.588	877.63	0.042
104	334018.133	2162478.731	955.772	955.65	-0.122
107A	108055.796	2121324.757	741.316	741.17	-0.146
108A	171021.559	2117859.168	776.132	776.11	-0.022
109A	228930.761	2111074.171	852.342	852.48	0.138
112	215117.352	2272465.509	833.746	833.49	-0.256
QC61A	131442.288	2347306.138	729.215	728.95	-0.265

Block 1 Indiana East Projection					
Point ID	Easting (US feet)	Northing (US feet)	Elevation (feet)	Laser Elevation (feet)	DZ (feet)
QC62	181065.268	2353620.639	740.515	740.14	-0.375
QC63	226723.509	2348663.396	757.907	757.66	-0.247
QC64	287054.904	2358801.129	753.296	753.35	0.054
QC65	162007.643	2289609.755	855.072	855.28	0.208
QC66	294485.941	2285610.086	822.992	823.01	0.018
QC69A	208497.52	2179259.22	783.649	783.82	0.171
QC70A	150248.669	2243761.409	822.343	822.51	0.167
QC71A	254326.399	2226895.826	832.025	831.82	-0.205
QC72A	294998.254	2229057.832	889.28	889.28	0
QC73	265903.174	2123230.601	905.528	905.5	-0.028
QC77	127332.821	2178189.703	742.59	742.56	-0.03
QC78	122701.311	2102604.129	780.363	780.8	0.437
QC79	180922.667	2118154.284	780.27	780.37	0.1
QC80	317026.171	2167921.497	918.485	918.27	-0.215
QC80	317026.171	2167921.497	918.485	918.27	-0.215

Table 5.2 QA/QC Analysis, Block 1 Indiana West Projection

Block 1 Indiana West Projection					
Point ID	Easting (US feet)	Northing (US feet)	Elevation (feet)	Laser Elevation (feet)	DZ (feet)
QC75	3008739.07	2089223.587	682.409	682.61	0.201
106	3083580.178	2115466.905	710.449	710.59	0.141
QC74	3004975.315	2124449.547	687.317	687.41	0.093
107A	3123347.431	2120923.265	741.316	741.39	0.074
98	2991907.962	2144676.678	694.36	694.41	0.05
92A	3118097.226	2200280.572	737.439	737.46	0.021
QC76A	3092819.436	2102594.208	709.422	709.43	0.008
100A	3121925.918	2157777.859	730.495	730.47	-0.025
110A	2997051.622	2063159.24	676.291	676.26	-0.031
QC67	3037236.873	2174776.648	699.971	699.92	-0.051
64	3091819.182	2062959.995	708.512	708.45	-0.062
QC68	3098372.455	2237267.434	707.312	707.24	-0.072
99	3063748.029	2158155.842	710.241	710.14	-0.101
86	3114114.358	2253257.642	715.623	715.5	-0.123
105A	3002841.82	2089281.476	689.63	689.5	-0.13

Table 5.3 QA/QC Analysis, Block 2 Indiana East Projection

Block 2 Indiana East Projection					
Point ID	Easting (US feet)	Northing (US feet)	Elevation (feet)	Laser Elevation (feet)	DZ (feet)
75A	334907.617	2041737.1	731.361	731.78	0.419
QC45	166878.889	1973019.13	764.557	764.92	0.363
60A	270526.057	1957885.811	817.308	817.67	0.362
71	202338.559	1912566.907	819.009	819.35	0.341
56A	149203.105	1890593.468	840.206	840.53	0.324
QC44	281428.125	2087051.567	759.152	759.46	0.308
QC54	247485.222	1863389.204	864.696	865	0.304
QC42	173648.005	2046760.188	793.308	793.6	0.292
QC41	97464.311	2047012.64	733.573	733.84	0.267
57A	273643.454	1884239.503	856.277	856.54	0.263
QC46	228994.691	1970603.489	809.016	809.25	0.234
QC47	296591.901	2000758.927	798.205	798.42	0.215
61A	330538.161	1970876.815	881.084	881.27	0.186
QC50	219780.669	1889043.577	851.483	851.66	0.177
70A	218212.092	1848153.056	879.581	879.69	0.109
QC43	214496.92	2046471.454	708.413	708.51	0.097
74	257241.314	2017284.957	658.09	658.14	0.05
QC60A	236928.833	1926587.87	848.139	848.11	-0.029
73	132168.17	2009523.488	610.448	610.37	-0.078
QC53A	183680.282	1830818.125	922.323	922.24	-0.083
64	75590.463	2063878.345	708.512	708.4	-0.112
111A	194270.315	2059069.612	827.952	827.83	-0.122
63	188637.291	2009872.843	683.097	682.95	-0.147
54A	273535.182	1810509.439	831.193	831	-0.193
59	138719.32	1938532.456	763.08	762.78	-0.3

Table 5.4 QA/QC Analysis, Block 2 Indiana West Projection

Block 2 Indiana West Projection					
Point ID	Easting (US feet)	Northing (US feet)	Elevation (feet)	Laser Elevation (feet)	DZ (feet)
QC52	3114073.632	1814442.646	880.908	880.43	-0.478
QC51	3074258.36	1872670.37	732.345	732.81	0.465
QC59	3162536.899	1867206.797	882.447	882.87	0.423
52	3063547.224	1801159.25	834.25	833.99	-0.26
69	3118400.386	1836561.818	850.464	850.85	0.386
58A	3044056.815	1936270.226	634.658	634.49	-0.168
QC48A	3071557.419	1969213.83	675.279	675.49	0.211
QC49	3108242.952	1904078.655	741.075	741.04	-0.035
72	3103844.769	1953277.396	675.656	675.67	0.014
55	3061048.167	1889594.695	681.283	681.36	0.077

Table 5.5 QA/QC Analysis, Blocks 3 & 4 Indiana East Projection

Blocks 3 & 4 Indiana East Projection					
Point ID	Easting (US feet)	Northing (US feet)	Elevation (feet)	Laser Elevation (feet)	DZ (feet)
48A	281331.171	1291411.063	562.425	562.88	0.455
6a	224960.096	1153188.02	839.108	839.5	0.392
19	206966.844	1223454.947	777.991	778.3	0.309
10a	218456.559	989012.532	441.915	442.19	0.275
QC33	187651.901	1416498.138	599.068	599.31	0.242
QC17	170072.274	1124576.74	651.443	651.66	0.217
QC34	184962.91	1303575.918	526.194	526.4	0.206
21	195270.978	1118439.984	727.65	727.84	0.19
QC15a	170901.433	1187104.313	756.567	756.73	0.163
QC14a	228714.637	1238289.487	884.429	884.58	0.151
47A	290497.968	1397484.93	646.903	647.03	0.127
51	220851.631	1324563.797	649.087	649.21	0.123
QC19	196983.164	1079287.813	544.616	544.72	0.104
QC16a	221143.625	1192805.997	872.934	873	0.066
QC35	255615.644	1347038.238	567.143	567.2	0.057
44	264911.537	1443067.168	635.405	635.45	0.045
22a	181662.511	1049959.712	677.654	677.69	0.036
3a	154485.48	1277463.042	682.58	682.61	0.03
42A	323032.896	1493949.911	815.58	815.59	0.01
QC13	164604.747	1260973.288	766.047	766.05	0.003

Blocks 3 & 4 Indiana East Projection					
Point ID	Easting (US feet)	Northing (US feet)	Elevation (feet)	Laser Elevation (feet)	DZ (feet)
QC37	299207.454	1470423.635	716.273	716.27	-0.003
5a	262796.454	1188325.586	788.606	788.6	-0.006
QC38A	286460.26	1415007.779	636.102	636.09	-0.012
13a	157477.704	1157769.572	774.977	774.94	-0.037
45	324734.341	1414926.792	734.243	734.2	-0.043
50	166087.593	1440909.977	660.241	660.17	-0.071
QC39	243592.307	1412709.647	628.632	628.56	-0.072
46	214504.287	1381181.723	634.194	634.09	-0.104
8a	260733.853	1068015.065	431.12	430.99	-0.13
9	252816.865	1014163.496	430.24	430.09	-0.15
11	173994.994	1011760.927	427.391	427.23	-0.161
QC32	162996.082	1465064.651	755.874	755.7	-0.174
QC36	245746.823	1472325.02	654.259	654.08	-0.179
QC18a	221419.479	1110052.062	831.727	831.47	-0.257
4	260537.055	1257925.366	567.199	566.93	-0.269
43A	209209.462	1446475.222	947.901	947.6	-0.301
23	230662.947	1045310.77	740.448	740.05	-0.398
2	155253.907	1349870.679	871.508	871.05	-0.458
QC20	210067.746	1034935.477	699.289	698.81	-0.479

Table 5.6 QA/QC Analysis, Blocks 3 & 4 Indiana West Projection

Blocks 3 & 4 Indiana West Projection					
Point ID	Easting (US feet)	Northing (US feet)	Elevation (feet)	Laser Elevation (feet)	DZ (feet)
24	3119527.53	1310166.607	678.378	678.72	0.342
12	3179571.689	1086491.729	630.255	630.39	0.135
QC4	3077173.005	1294287.048	500.477	500.6	0.123
QC1a	3105832.603	1336559.721	671.262	671.38	0.118
QC9	3096955.483	1123613.256	766.019	766.11	0.091
QC5	3087374.599	1209249.126	524.677	524.73	0.053
QC2a	3140272.257	1321518.358	633.974	634.01	0.036
3a	3183157.423	1277902.705	682.58	682.61	0.03
QC10	3128667.067	1086075.196	697.713	697.74	0.027
15a	3070817.887	1103633.767	747.596	747.6	0.004
QC7a	3088776.238	1173354.953	678.505	678.49	-0.015
QC3	3122792.684	1269254.25	713.179	713.15	-0.029
13a	3187995.361	1158266.251	774.977	774.94	-0.037

Blocks 3 & 4 Indiana West Projection					
Point ID	Easting (US feet)	Northing (US feet)	Elevation (feet)	Laser Elevation (feet)	DZ (feet)
2	3182802.636	1350315.454	871.508	871.47	-0.038
16	3067395.869	1149850.936	607.722	607.66	-0.062
18	3129686.372	1204972.185	606.842	606.76	-0.082
14a	3143791.478	1048054.225	428.384	428.24	-0.144
QC12	3161127.977	1092722.986	732.339	732.19	-0.149
QC8	3149438.368	1161216.847	606.198	606.02	-0.178
QC11	3162216.23	1125513.797	875.382	875.2	-0.182
17	3070731.715	1265615.798	552.365	552.06	-0.305

VERTICAL ACCURACY CONCLUSIONS

- **Data Accuracy** was tested per Block designation of Year One as RMSE vertical accuracy at 95% percent confidence level.
- **Block 1 East:** Tested 0.366 foot vertical accuracy at 95-percent confidence level
- **Block 1 West:** Tested 0.184 foot vertical accuracy at 95-percent confidence level
- **Block 2 East:** Tested 0.241 foot vertical accuracy at 95-percent confidence level
- **Block 2 West:** Tested 0.593 foot vertical accuracy at 95-percent confidence level
- **Block 3 & 4 East:** Tested 0.421 foot vertical accuracy at 95-percent confidence level
- **Block 3 & 4 West:** Tested 0.268 foot vertical accuracy at 95-percent confidence level
- **Program Year 1 LiDAR:** Tested 0.393 foot vertical accuracy at 95-percent confidence level

Table 5.7 Vertical Accuracy Summary

	RMSE	Fundamental Vertical Accuracy	Number of Control Points
Block 1 East	0.187'	0.366'	44
Block 1 West	0.094'	0.184'	15
Block 2 East	0.241	0.241'	25
Block 2 West	0.303'	0.593'	10
Blocks 3 & 4 East	0.215'	0.421'	39
Blocks 3 & 4 West	0.137'	0.268'	21
Overall	0.201	0.393'	154

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

POINT DENSITY CONCLUSIONS

- The final measured point density was 1.35 points per sq. meter for the 1.5 NPS areas and 0.9 points per sq. meter for Boone County. The NPS assessment is made against single swath, first return data located within the geometrically usable center portion (typically ~90%) of each swath.

Approved By:			
Title	Name	Signature	Date
Associate Member LiDAR Specialist Certified Photogrammetrist #1281	Qian Xiao		Nov 7, 2011

SECTION 6: FINAL DELIVERABLES

FINAL DELIVERABLES

The final deliverables are listed below.

- Hydrologically flattened bare earth 5-foot DEM in IMG format, per county.
- LAS v1.2 classified point cloud, per county.
- LAS v1.2 raw unclassified point cloud flight line strips no greater than 2GB, per area. Long swaths greater than 2GB will be split into segments).
- Breaklines compiled as part of the hydrologic flattening process were provided as ESRI PolygonZ and PolylineZ shapefiles, per county.
- Tile Layout provided as ESRI shapefile.
- Control points provided as ESRI shapefile.
- 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 hydrologically flattened bare earth data was delivered in IMG 32-bit FLOAT format at a 5-foot posting.