AIRBORNE LIDAR TASK ORDER REPORT TIER 2

INDIANA STATEWIDE IMAGERY AND LIDAR PROGRAM

INDIANA OFFICE OF INFORMATION TECHNOLOGY

WOOLPERT PROJECT NUMBER: 72134

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WOOLPERT

DESIGN | GEOSPATIAL | INFRASTRUCTURE

AIRBORNE LIDAR TASK ORDER REPORT

INDIANA STATEWIDE IMAGERY AND LIDAR PROGRAM

For:

Indiana Office of Information Technology
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SECTION 1: OVERVIEW

TASK ORDER NAME: INDIANA STATEWIDE IMAGERY AND LIDAR PROGRAM

WOOLPERT PROJECT #72134

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.

Area 2 data was collected using a Leica ALS50-II, Leica ALS60, Leica ALS70 and Optech Gemini LiDAR sensors. All four 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 Lidar was collected for all four blocks, at the following sensor specifications for 1.5 NPS:

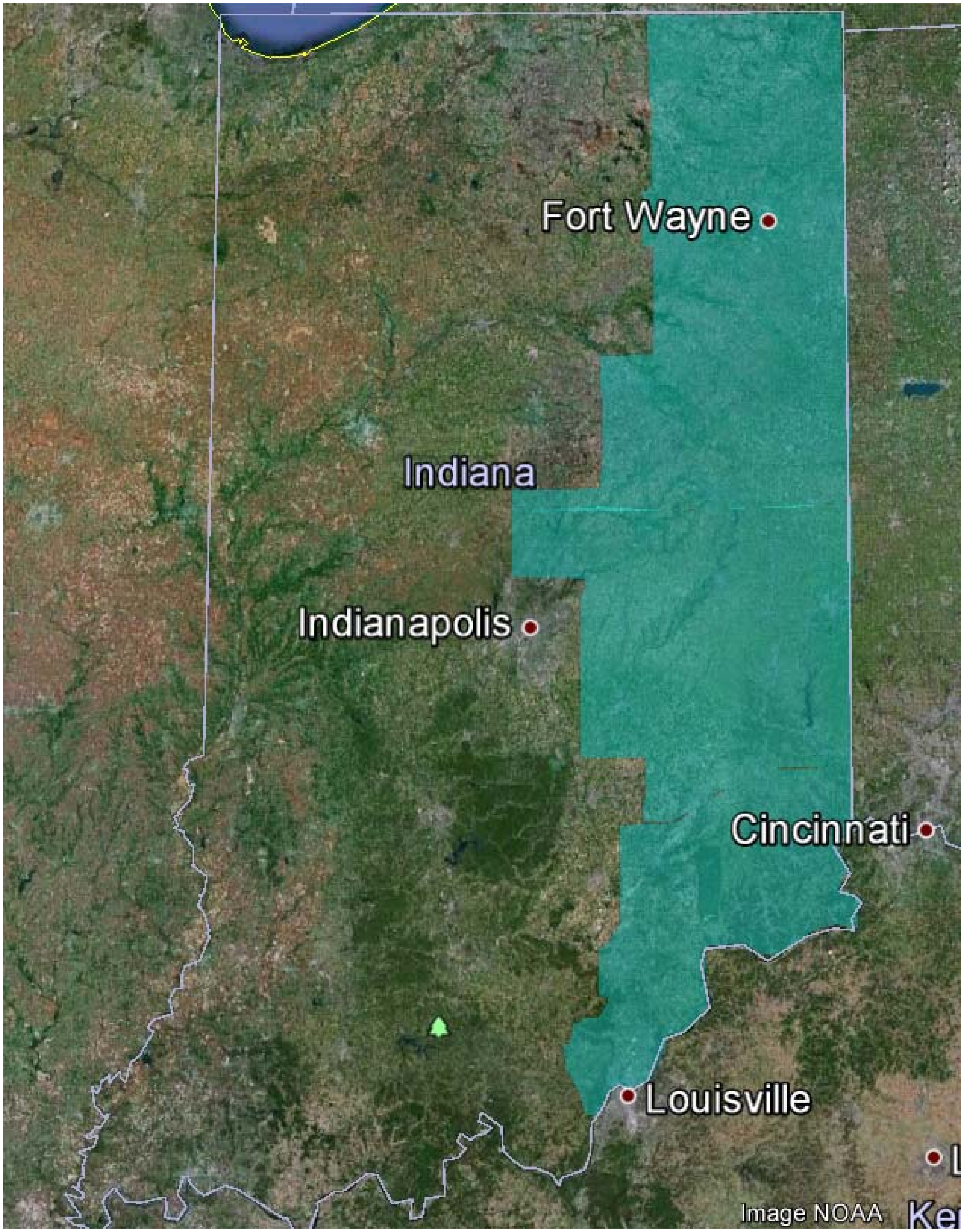
Post Spacing (Minimum):	4.92 ft / 1.5 m
AGL (Above Ground Level) average flying height:	7,800 ft / 2,377 m
MSL (Mean Sea Level) average flying height:	8,600 ft / 2,621 m
Average Ground Speed:	150 knots / 173 mph
Field of View (full):	40 degrees
Pulse Rate:	99.0 kHz
Scan Rate:	38.0 Hz
Side Lap (Minimum):	27.7%

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

LiDAR data was processed and projected in Indiana State Plane East (1301), North American Datum of 1983 (NAD83) in units of feet. The vertical datum used for the project was referenced to NAVD 1988, feet, GEOID09.

In addition, breaklines defining water bodies 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 2



SECTION 2: ACQUISITION

The LiDAR data was acquired with a Leica ALS50-II 150 kHz Multiple Pulses in Air (MPiA) LiDAR sensor, a Leica ALS60 200 kHz MPiA LiDAR sensor, a Leica ALS70 500 kHz MPiA LiDAR sensor, and an Optech Gemini 167 kHz MPiA LiDAR sensor on board a Cessna 404. A Dell Precision laptop computer serves as the operator interface using ALTM-NAV™ Flight Management Software.

The ALS LiDAR systems, developed by Leica Geosystems of Heerbrugg, Switzerland, include the simultaneous first, intermediate and last pulse data capture module, the extended altitude range module, and the target signal intensity capture module. The system software is operated on an OC50 Operation Controller 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: ALS70 LiDAR System Specifications

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

Table 2.4 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 personnel were onsite, operating Global Navigation Satellite System (GNSS) Base Stations for the airborne GPS support (see Table 3.1).

The LiDAR data was collected in 30 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, 4 Counties Acquisition

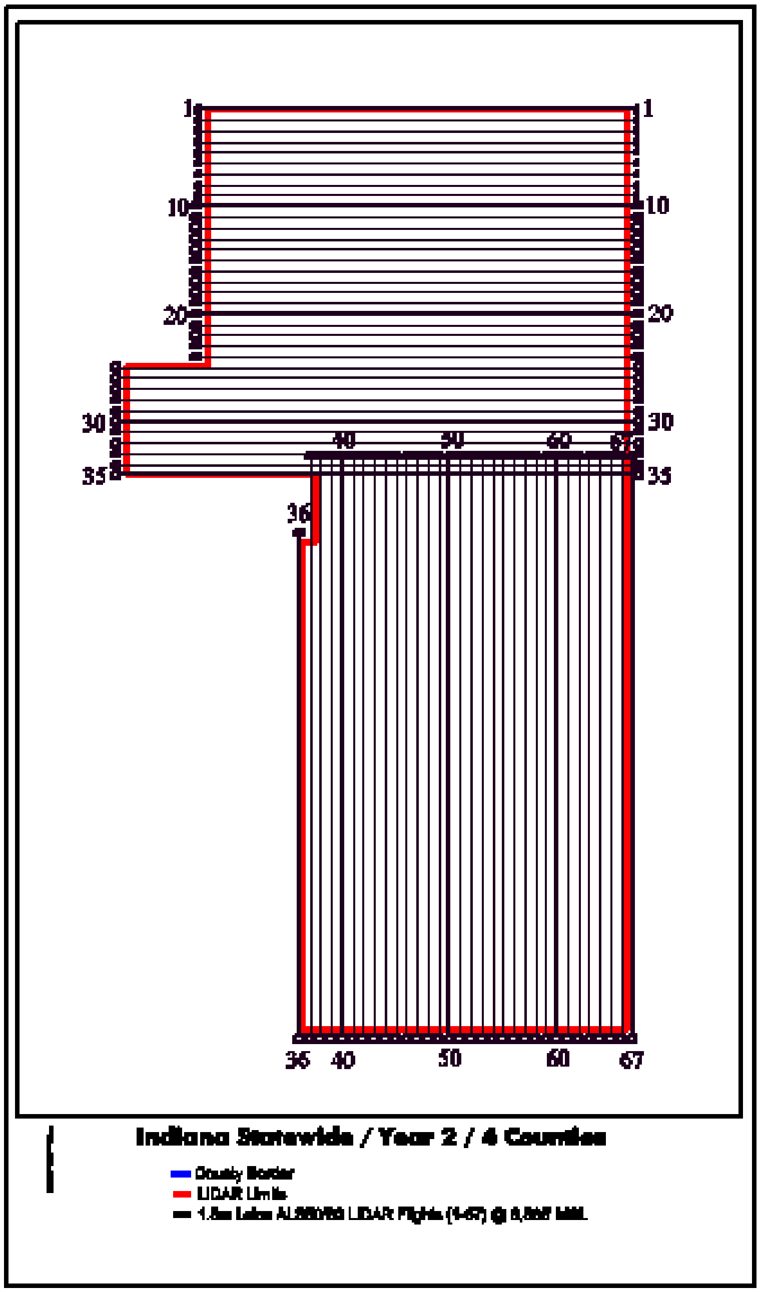


Figure 2.2 LiDAR Flight Layout, Block 5 Acquisition

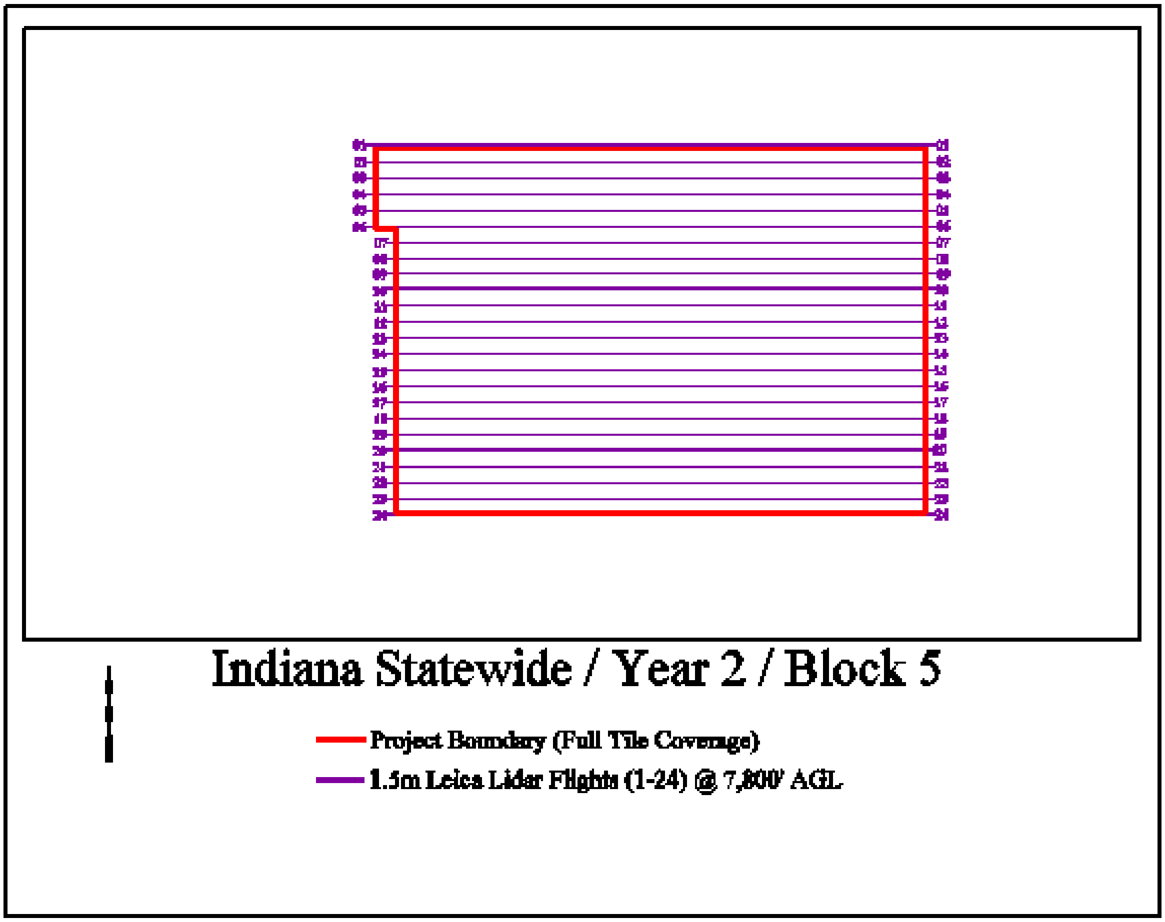


Figure 2.3 LiDAR Flight Layout, Block 6 Acquisition

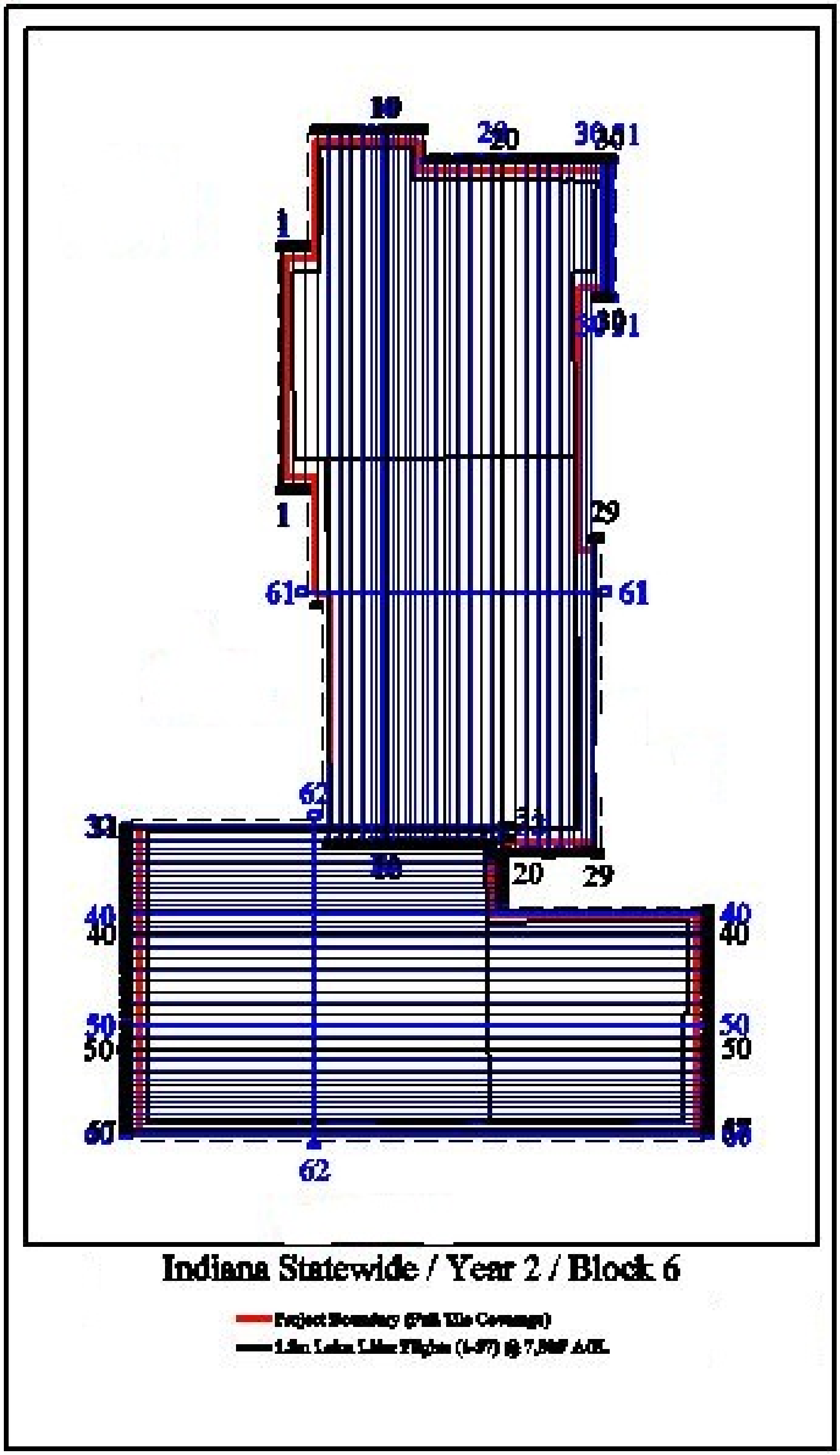


Figure 2.4 LiDAR Flight Layout, Block 7 Acquisition

*Note: Due to extenuating circumstances, for certain flight lines, an Optech Gemini sensor was used.

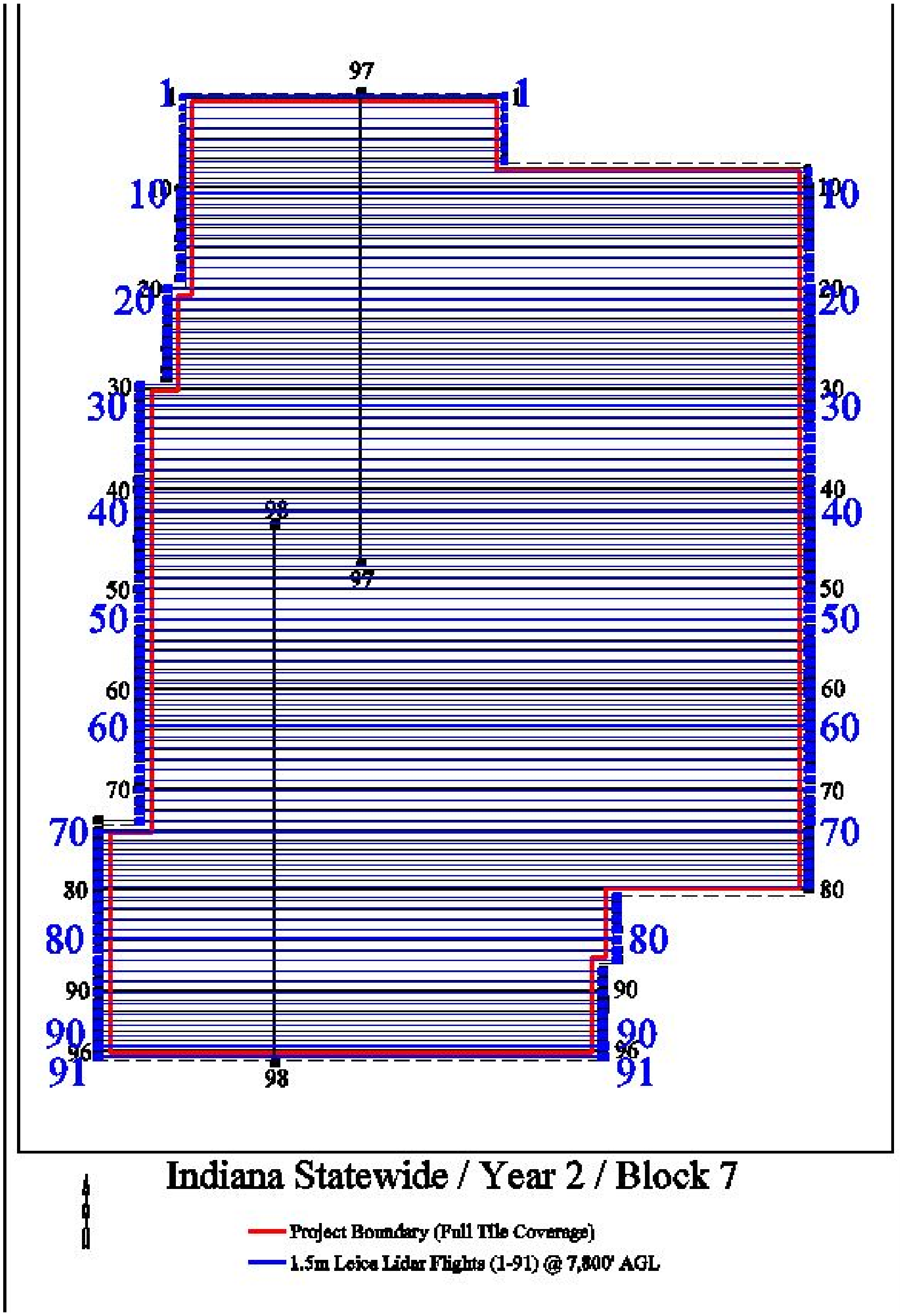


Figure 2.5 LiDAR Flight Layout, Block 8 Acquisition

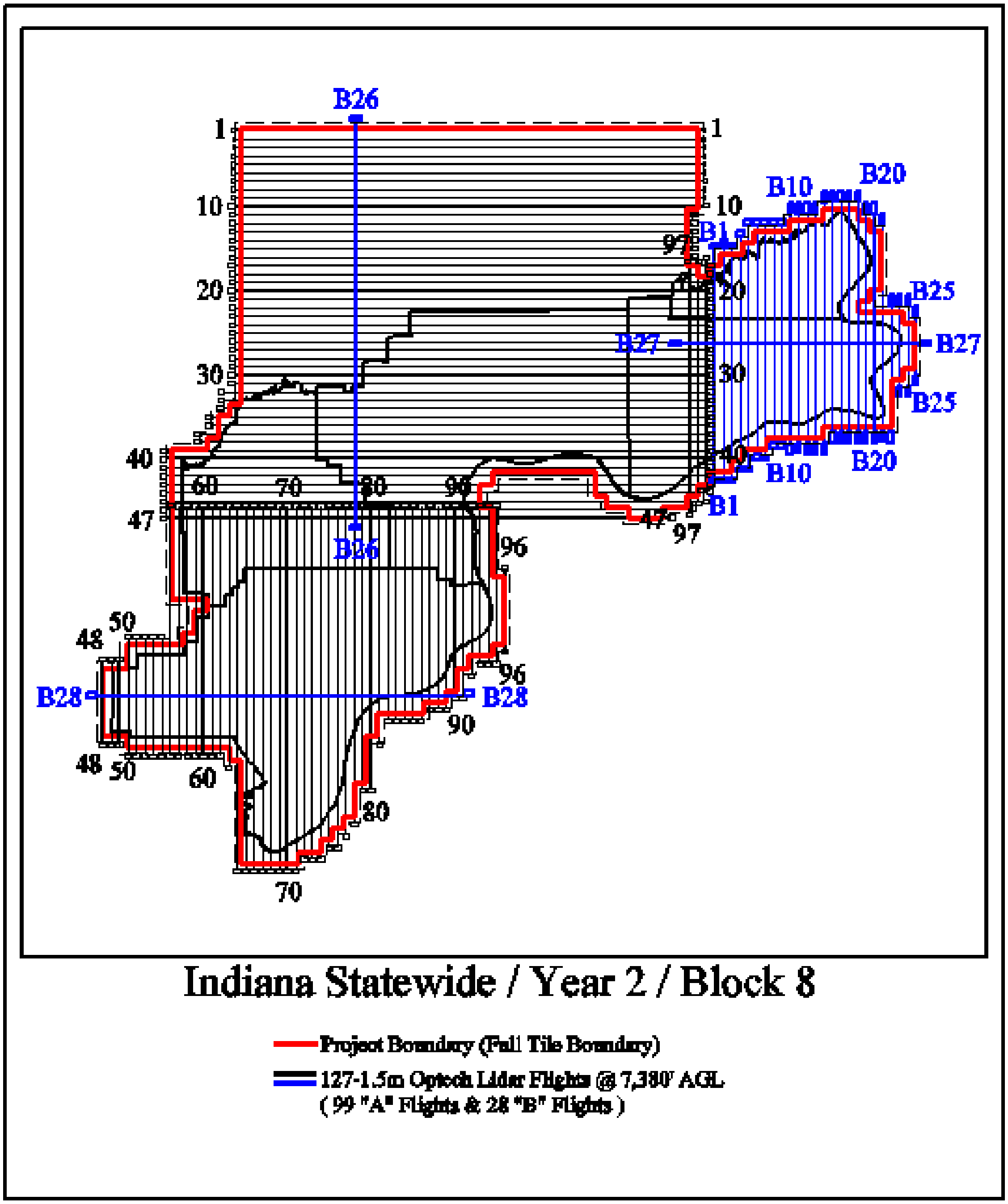


Table 2.5 Area 2 Airborne LiDAR Acquisition Flight Summary

Area 2 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
December 5, 2012 A	7	69-78	14:27 - 18:19	09:27 AM - 01:19 PM
December 5, 2012 B	7	53-57, 66-68	14:26 - 18:02	09:26 AM - 01:02 PM
December 12, 2012	7	30, 56, 57, 66-68	14:46 - -17:07	09:46 AM - 12:07 PM
February 22, 2012 A	8	62-63	19:27 - 19:52	02:27 PM - 02:52 PM
February 22, 2012 B	8	48-61	14:30 - 17:32	09:30 AM - 12:42 PM
February 27, 2012 A	8	70-79	20:29 - 23:50	03:29 PM - 06:50 PM
February 27, 2012 B	8	48, 52, 64-69	16:22 - 19:21	11:22 AM - 02:21 PM
February 28, 2012 A	8	44-47	20:27 - 22:45	03:27 PM - 05:45 PM
February 28, 2012 B	8	80-96	14:24 - 18:23	09:24 AM - 01:23 PM
March 1, 2012 A	8	30-37	21:17 - 00:57	04:17 PM- 07:57 PM
March 1, 2012 B	8	38-43, 63	16:43 - 20:05	11:43 AM - 03:05 PM
March 3, 2012	7	20-21	14:00 - 16:00	10:00 AM - 12:00 PM
March 6, 2012	8	B7 - B25	17:23 - 21:27	12:23 PM - 04:27 PM
March 7, 2012 A	7	36-39, 40, 50	15:47 - 18:13	10:47 AM - 01:13 PM
March 7, 2012 B	8	1-4, 48, 64, B28	13:40 - 17:34	08:40 AM - 12:34 PM
March 9, 2012 A	8	18-29	16:36 - 21:13	11:36 AM - 04:13 PM
March 9, 2012 B	7	94-96	13:10 - 15:09	08:10 AM - 10:09 AM
March 10, 2012 A	7	82-93	19:45 - 23:36	03:45 PM - 07:36 PM
March 10, 2012 B	8	9 - 17	13:42 - 17:20	08:42 AM - 12:20 PM
March 11, 2012 A	8	5-10, B7, B25, B26	21:30 - 03:10	05:30 PM - 10:10 PM
March 11, 2012 B	5	1-24	13:45 - 20:06	08:45 AM - 03:27 PM
March 13, 2012 A	6	31-49	14:36 - 21:17	10:36 AM - 05:15 PM
March 13, 2012 B	7	1-8, 50	23:30 - 04:07	07:30 PM - 11:07 PM
March 20 , 2012 A	6	27-30, 40, 50-57, 62	13:45 - 18:23	09:45 AM - 02:23 PM
March 20, 2012 B	6	27-30, 40, 50-57, 62	13:45 - 18:23	09:45 AM - 02:23 PM
March 26, 2012 A	6	1-14	13:41 - 20:31	09:41AM - 04:31 PM
March 26, 2012 B	6	1-14	13:41 - 20:31	09:41 AM - 04:31 PM
March 28, 2012 A	6	15-27	14:18 - 20:02	10:18 AM - 04:07 PM
March 29, 2012	7	40-50	13:44 - 15:59	09:44 AM - 11:59 AM
April 2, 2012	7	24-31, 58-65	13:47 - 20:45	09:47 AM - 04:45 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. 5.4, 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 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 to reduce the vertical bias when compared to the survey ground control.
   Software: TerraScan v.12.010

4. The .LAS files were evaluated through a series of manual QA/QC steps to eliminate remaining artifacts and small undulations from the ground class.
   Software: TerraScan v.12.010.

5. All water bodies greater than two acres and all rivers with a nominal 100 foot width or larger were hydro-flattened using a combination of COTS software and Woolpert's proprietary software.
   Software: TerraScan v.12.010, TerraModeler v.11.004, ESRI ArcMap 10.0, LP360 2011.1.54.1

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 Woolpert personnel. 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)
INBF	40° 44' 29.24192"	-85° 16' 34.17057"	228.062
INAB	40° 17' 53.68811"	-85° 12' 41.20243"	267.107
INGG	39° 21' 35.41569"	-85° 30' 53.73813"	254.683
INFC	38° 20' 48.31613"	-85° 44' 58.83104"	110.648
KYBO	39° 02' 18.03347"	-84° 43' 25.11820"	235.038
INVR	39° 02' 52.70139"	-85° 15' 41.77708"	268.567
INSB	39° 52' 01.86077"	-84° 56' 27.05100"	292.028
INPD	39° 58' 23.49429"	-85° 46' 10.77357"	235.453
INLB	39° 37' 54.25310"	-85° 00' 44.60554"	272.448
INAG	41° 37' 58.87400"	-85° 01' 40.06297"	306.578
INMD	38° 50' 03.07959"	-85° 25' 16.18894"	232.539

Table 3.2 GNSS Base Station Days Utilized

Station	Day(s) Utilized
Name	
INBF	05112, 07312, 08012, 08812
INAB	06012, 06712, 06912
INGG	06912
INFC	05312, 05812, 05912, 06112, 06712
KYBO	06612
INVR	07012, 07112
INSB	07312, 07412, 34012, 34712
INPD	07412
INLB	08912, 09012, 09312
INAG	07112
INMD	06112

DATA PROCESSING

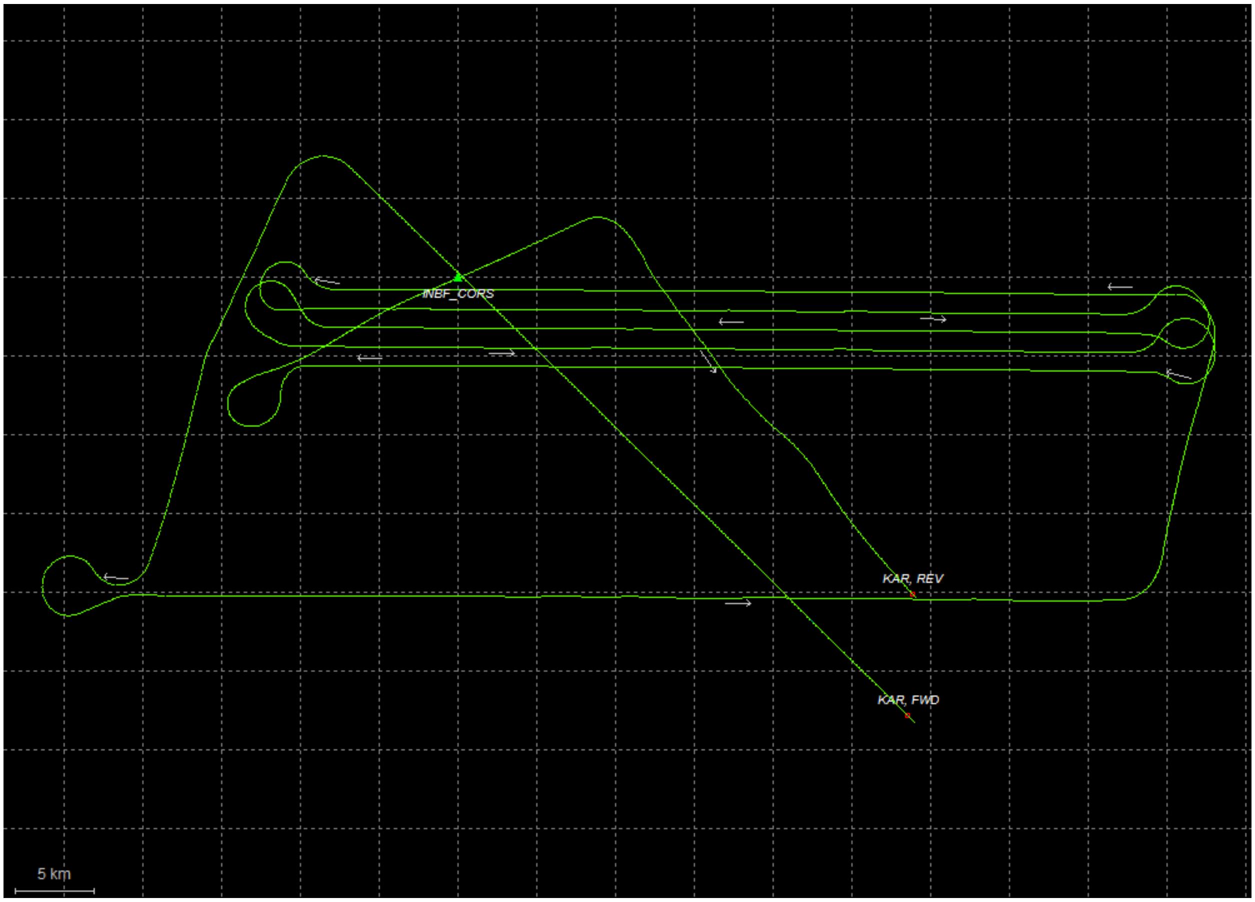
All airborne GNSS and IMU data was post-processed and quality controlled using Applanix 5.3 MMS software. GNSS data was processed at a 1 and 2 Hz data capture rate and the IMU data was processed at 200 Hz.

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 Day03612



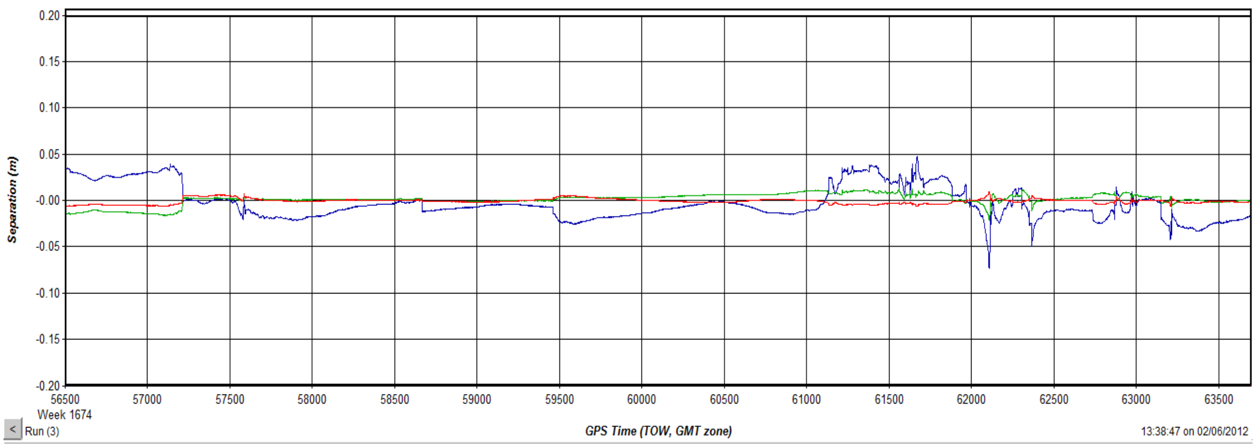
Within the trajectory processing, there are many factors that affect the overall quality, but the most indicative are the Combined Separation, the Estimated Positional Accuracy, and the Positional Dilution of Precision (PDOP).

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 Day03612 of Combined Separation

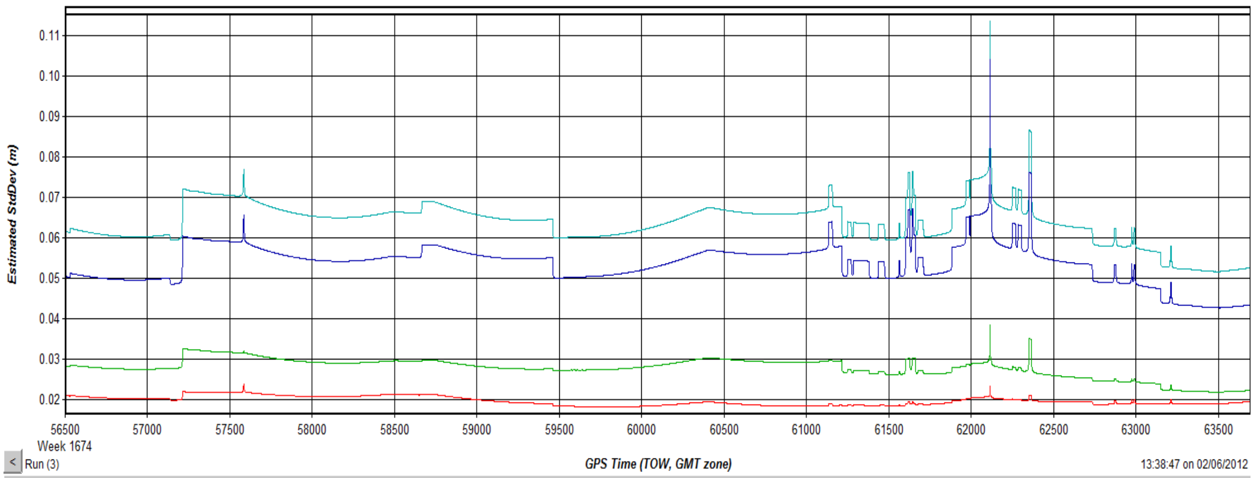


Estimated Positional Accuracy

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.

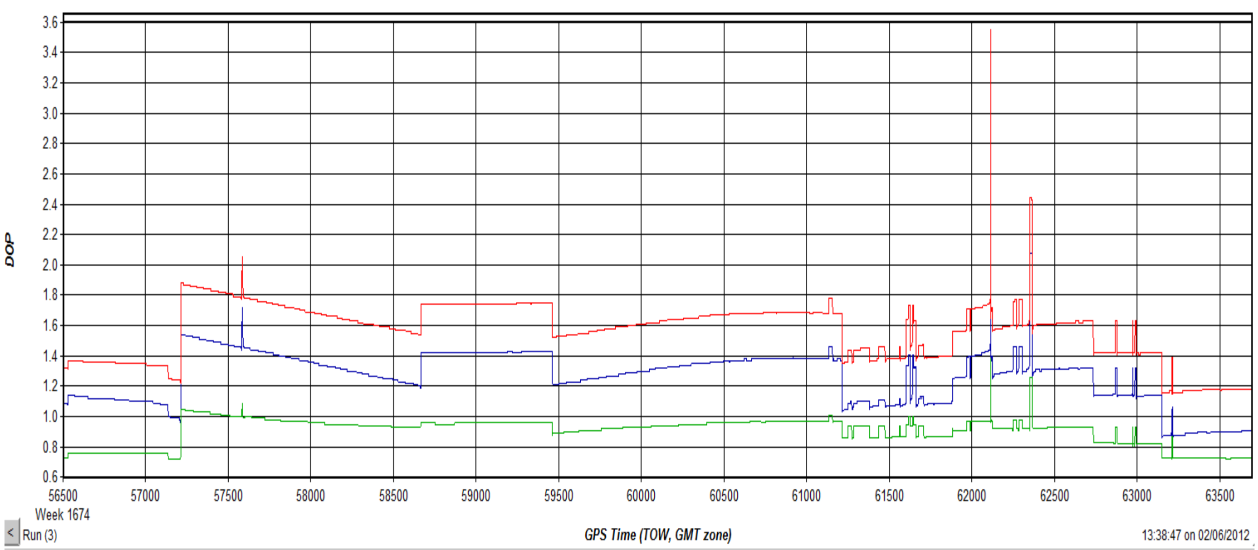
Figure 3.3 Graph from Day03612 of Positional Accuracy



PDOP

Position Dilution of precision (DOP) is a measure of the quality of the GPS data being received from the satellites.

Figure 3.4 Representative Graph from Day03612 PDOP



LIDAR DATA PROCESSING

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

- Processed individual flight lines to derive a raw "Point Cloud" LAS file. Matched overlapping flight lines, generated statistics for evaluation comparisons, and made the necessary adjustments to remove any residual systematic error.
- Calibrated LAS files were imported into the task order tiles and initially filtered to create a ground and non-ground class. Then additional classes were filtered as necessary to meet client specified classes.
- Once all of the task order data was imported and classified, cross flights and survey ground control data was imported and calculated for an accuracy assessment. As a QA/QC measure, Woolpert has developed a routine to generate accuracy statistical reports by comparison among LiDAR points, ground control, and TINs. The LiDAR is adjusted accordingly to reduce any vertical bias to meet or exceed the vertical accuracy requirements.
- The LiDAR tiles were reviewed using a series of proprietary QA/QC procedures to ensure it fulfills the task order requirements. A portion of this requires a manual step to ensure anomalies have been removed from the ground class.
- The bare earth DEM surface was hydrologically flattened for waterbody features that were greater than 2 acres and rivers and streams of 100 feet and greater nominal width.
- The LiDAR LAS files for this task order have been classified into the Default (Class 1), Ground (Class 2), 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, 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

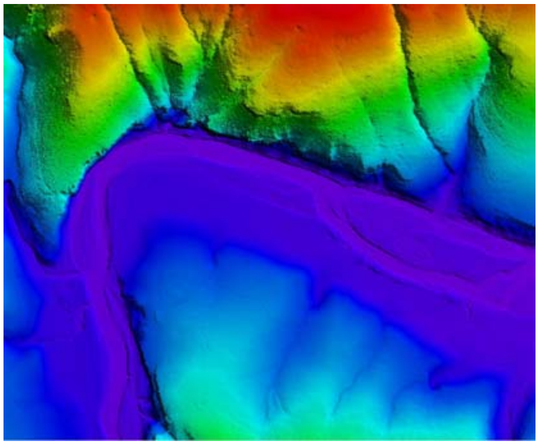
Woolpert utilized the following steps to hydrologically flatten the water bodies and for gradient hydrologic flattening of the double line streams within the existing LiDAR data.

1. Woolpert used existing (legacy) data along with newly acquired (2012) LiDAR data to manually draw the hydrologic features in a 2D environment using the LiDAR intensity data and point cloud data. Google Earth and Bing Maps 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. **Figures 4.1 through 4.3** illustrate good examples 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 while 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

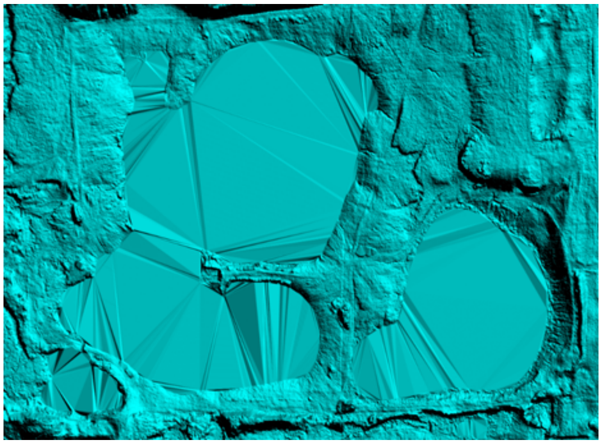


Figure 4.3

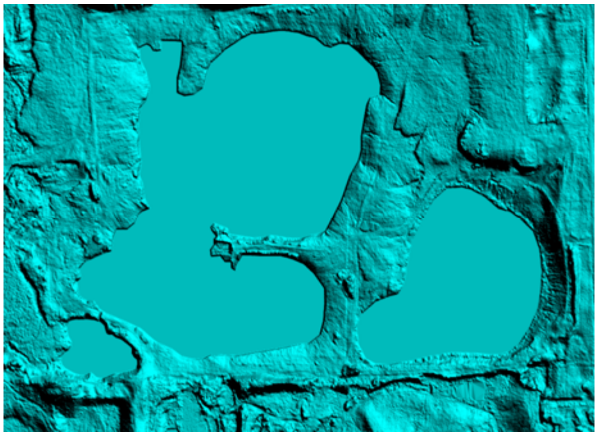


Figure 4.2 reflects a DEM generated from original LiDAR bare earth point data prior to the hydrologic flattening process. Note the "tinning" across the lake surface.

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 Indiana State plane East, survey feet projection tiling format, based on a modular layout. The tiles were clipped to eliminate overlap between adjacent tiles. The 5,000 foot x 5,000 foot tile file name was derived from the southwest corner of each tile. A prefix of "in2012_" 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: Overall Vertical Accuracy Statistics for Indiana Tier 2

Average error	0.009	feet
Minimum error	-0.494	feet
Maximum error	+0.558	feet
Average magnitude	0.157	feet
Root mean square	0.199	feet
Standard deviation	0.200	feet

Table 5.2 QA/QC Analysis, Tier 2 Indiana Statewide, Indiana State Plane East, NAD 83 NAVD 88 GEOID 09

Tier 2 Indiana Statewide					
Point ID	Easting (US feet)	Northing (US feet)	Elevation (feet)	Laser Elevation (feet)	DZ (feet)
QC_146_LIDAR	448438.3	1801870	1021.517	1021.82	0.303
QC_147_LIDAR	478927.9	1802324	1036.826	1036.85	0.024
QC_149_LIDAR	472724.2	1912497	882.11	881.75	-0.36
QC_150_LIDAR_A	552123.2	1870582	958.13	958.36	0.23
QC_150_LIDAR_B	552185.2	1870593	959.705	959.57	-0.135
QC_157_LIDAR	417803.5	1948070	851.236	851.42	0.184
QC_164	425468.7	2357894	945.71	945.64	-0.07
QC_165	351808.9	2346499	893.59	893.78	0.19
QC_166	395683.4	2305184	919.952	919.8	-0.152
QC_180	340513	2362139	846.576	846.67	0.094
QC_181	339898.1	2330536	899.714	899.78	0.066
QC_182	336487.3	2295941	906.855	906.87	0.015
QC_183	362581.5	2359962	842.485	842.46	-0.025
QC_184	362896.9	2333648	919.299	919.16	-0.139
QC_185	362875.6	2301618	918.455	918.8	0.345
QC_186	394120.4	2360414	880.671	880.59	-0.081
QC_187	394043.2	2325515	969.794	969.59	-0.204
QC_188	408224.5	2297533	930.148	930.28	0.132
QC_189	424311.5	2323820	967.909	967.92	0.011
QC_190	421807.3	2301456	970.649	970.82	0.171

Tier 2 Indiana Statewide					
Point ID	Easting (US feet)	Northing (US feet)	Elevation (feet)	Laser Elevation (feet)	DZ (feet)
QC_191	432408	2292333	993.851	994.18	0.329
QC_192	444392.1	2368872	933.936	933.93	-0.006
QC_193	448860	2349050	957.26	957.25	-0.01
QC_194	445399.9	2323861	942.041	942.02	-0.021
QC_195	444403.9	2303889	980.961	981	0.039
QC_196	400340.4	2342184	889.564	889.42	-0.144
QC_143_LIDAR	278717.4	1863330	871.374	871.32	-0.054
QC_145_LIDAR	395357.9	1867237	924.646	924.71	0.064
QC_151_LIDAR	354274.7	2057276	809.793	809.63	-0.163
QC_152_LIDAR	300754.7	1939331	845.604	845.6	-0.004
QC_158	392487.8	2060704	795.985	795.87	-0.115
QC_143	278701.2	1863330	871.699	871.42	-0.279
QC_145	395358.9	1867265	924.613	924.69	0.077
QC_151	354263.3	2057248	809.214	809.09	-0.124
QC_152	300738	1939345	845.448	845.35	-0.098
QC_153	346342.5	1911106	852.416	852.32	-0.096
QC_159	393427.6	1984160	837.665	837.71	0.045
QC_159	393427.6	1984160	837.75	837.72	-0.03
QC_160	409827.4	1897030	919.104	919.56	0.456
QC_127	390687.3	1733077	1049.78	1049.81	0.03
QC_128	441727.2	1680085	1097.19	1097.47	0.28
QC_129_LIDAR	471097.7	1698635	983.55	983.6	0.05
QC_130	527539.9	1664247	1066.64	1066.59	-0.05
QC_131	356689.9	1635651	899.48	899.37	-0.11
QC_133	446613	1638065	1053	1052.94	-0.06
QC_134	489766.6	1572100	1073.64	1073.97	0.33
QC_135	554790.2	1616281	1104.52	1104.42	-0.1
QC_137_LIDAR	527909.7	1531602	994.51	994.58	0.07
QC_132	414727.6	1564442	1033.903	1034.04	0.137
QC_101_LIDAR	318912.5	1388479	697.44	697.32	-0.12
QC_102_LIDAR	358661.8	1353068	772.853	772.89	0.037
QC_103	408494.4	1393829	908.963	908.82	-0.143
QC_109_LIDAR	550834.9	1316676	869.562	869.66	0.098
QC_110	497523.5	1292940	794.521	794.52	-0.001
QC_104	459277.1	1346729	953.705	953.54	-0.165
QC_108	530369.3	1352332	885.242	884.84	-0.402
QC_111	432901.1	1317992	952.752	952.64	-0.112
QC_112	386402.8	1263341	783.334	783.66	0.326

Tier 2 Indiana Statewide					
Point ID	Easting (US feet)	Northing (US feet)	Elevation (feet)	Laser Elevation (feet)	DZ (feet)
QC_113_LIDAR	294092.3	1279401	573.306	573	-0.306
QC_114	339696.3	1239951	634.266	634.21	-0.056
QC_115	363973.4	1207135	719.897	719.57	-0.327
QC_116	323088.7	1151944	524.863	525.08	0.217
QC_117_LIDAR	289627.5	1188378	537.134	537.2	0.066
QC_118_LIDAR	235550	1138896	825.85	826.3	0.45
QC38A	286460.3	1415008	636.102	636.66	0.558
QC_141_LIDAR	183000	1783911	939.27	939.44	0.17
QC_198	204577.1	1802923	892.044	891.66	-0.384
QC_199	241398.1	1803035	849.355	849.6	0.245
QC_200	262659.7	1803449	844.298	844.03	-0.268
QC_201	200169.5	1781440	906.97	906.85	-0.12
QC_202	234737.8	1784470	841.146	841.31	0.164
QC_203_LIDAR	266015.4	1784860	830.215	830.09	-0.125
QC_204	177844.9	1757800	939.516	939.6	0.084
QC_205	201523.4	1757346	894.268	894.25	-0.018
QC_206	237305.7	1757020	775.982	776.15	0.168
QC_207	267508.7	1758022	835.785	835.41	-0.375
QC_208	172925.8	1733326	901.113	901.28	0.167
QC_209	212437	1733448	825.257	824.91	-0.347
QC_210	268508.2	1734078	853.914	853.75	-0.164
QC_211	178259.8	1712123	875.524	875.79	0.266
QC_212	206841.1	1712564	768.568	768.77	0.202
QC_213	237623.4	1711448	787.761	787.68	-0.081
QC_214_LIDAR	264742.5	1712990	796.1	796.2	0.1
QC_105_LIDAR	546982.6	1452274	912.825	912.98	0.155
QC_106_LIDAR	507924.1	1451263	998.596	998.72	0.124
QC_107	508074.3	1388299	856.071	855.89	-0.181
QC_108	530369.3	1352332	885.242	885.25	0.008
QC-118	235420.2	1138933	828.287	828.21	-0.077
QC-119	250129	1097034	923.81	923.94	0.13
QC_146	448453.7	1801893	1021.878	1021.99	0.112
QC_147	478938.9	1802362	1037.198	1037.46	0.262
QC_148	529906.1	1751019	1173.916	1173.82	-0.096
QC_149	472757.4	1912501	882.144	881.65	-0.494
QC_150	552175	1870577	959.383	959.5	0.117
QC_154	540109.8	2037517	799.207	799.36	0.153
QC_155	520435.2	1969122	876.418	876.24	-0.178

Tier 2 Indiana Statewide					
Point ID	Easting (US feet)	Northing (US feet)	Elevation (feet)	Laser Elevation (feet)	DZ (feet)
QC_157	417792.8	1948064	851.172	851.16	-0.012

VERTICAL ACCURACY CONCLUSIONS

Bare-Earth DEM Fundamental Vertical Accuracy (FVA): Tested 0.390 feet fundamental vertical accuracy at a 95 percent confidence level, derived according to NSSDA, in open terrain using RMSE(z) x 1.96000.

Approved By:			
Title	Name	Signature	Date
Associate Member LiDAR Specialist Certified Photogrammetrist #1281	Qian Xiao		January 8, 2013

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 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.