AIRBORNE LIDAR TASK ORDER REPORT TIER 3

INDIANA STATEWIDE IMAGERY AND LIDAR PROGRAM

INDIANA OFFICE OF INFORMATION TECHNOLOGY

WOOLPERT PROJECT NUMBER: 73112

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WOOLPERT

DESIGN | GEOSPATIAL | INFRASTRUCTURE

AIRBORNE LIDAR TASK ORDER REPORT

INDIANA STATEWIDE IMAGERY AND LIDAR PROGRAM

For:

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SECTION 1: OVERVIEW

TASK ORDER NAME: INDIANA STATEWIDE IMAGERY AND LIDAR PROGRAM

WOOLPERT PROJECT #73112

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.

Tier 3 data was collected using a Leica ALS70 and Optech Gemini LiDAR sensors. Both 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:

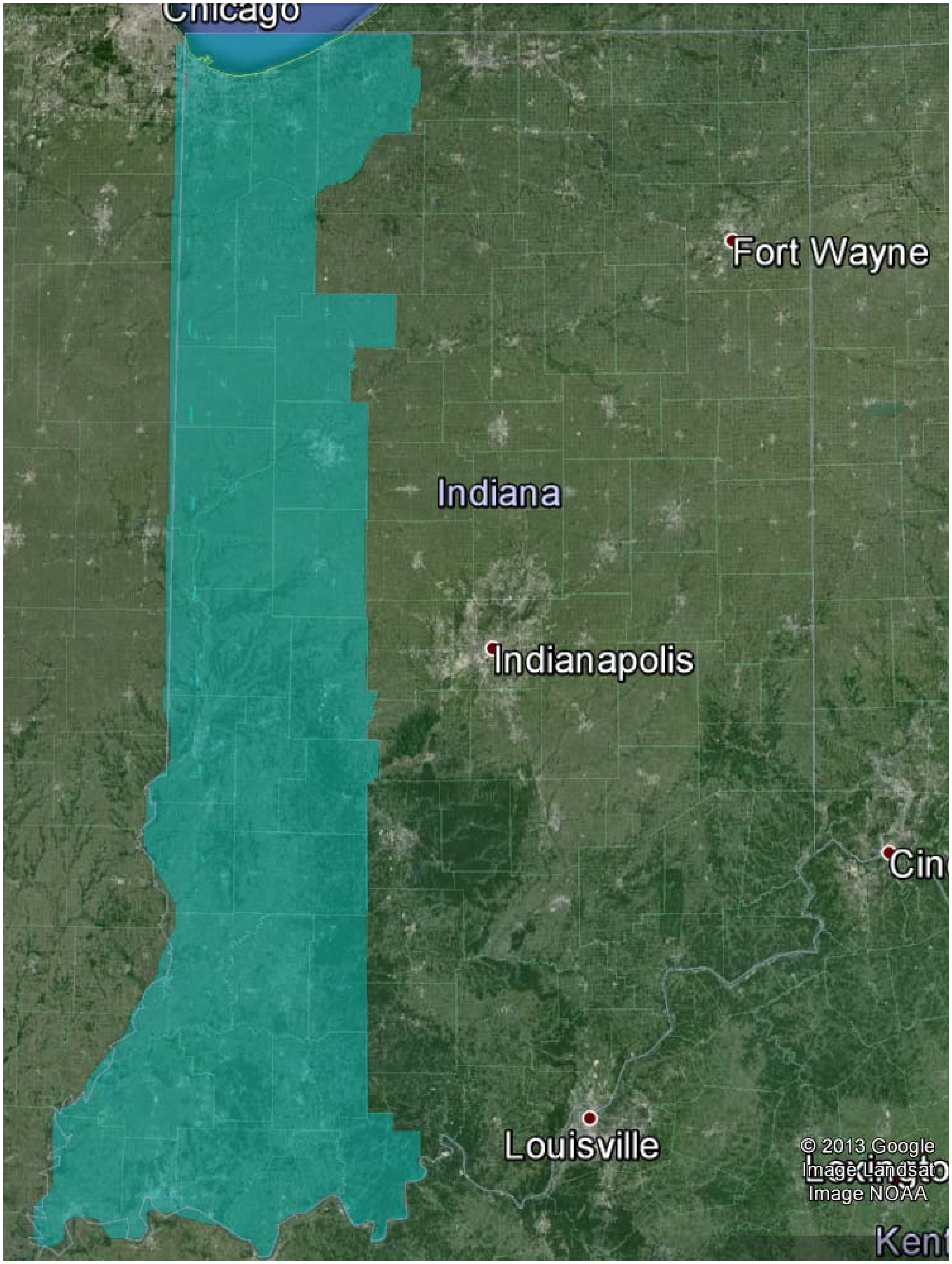
Post Spacing (Minimum):	4.92 ft / 1.5 m
AGL (Above Ground Level) average flying height:	7,800 ft / 2,377 m
MSL (Mean Sea Level) average flying height:	8,600 ft / 2,621 m
Average Ground Speed:	150 knots / 173 mph
Field of View (full):	40 degrees
Pulse Rate:	99.0 kHz
Scan Rate:	38.0 Hz
Side Lap (Minimum):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

The LiDAR was collected and processed to meet a Nominal Post Spacing (NPS) of 1.5 meters for all counties except the buy-up counties of Lake, LaPorte, Porter, Tippecanoe, and Newton which were collected and processed to meet a Nominal post Spacing of 1.0 meter. Purdue University and Tippecanoe County sites were collected and processed to meet a Nominal Post Spacing (NPS) of 0.4 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 West (1302), North American Datum of 1983 (NAD83) in units of survey 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 Indiana Statewide Area 3



SECTION 2: ACQUISITION

The LiDAR data was acquired with 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.

Table 2.1: 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 2.2 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 51 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 12 Acquisition

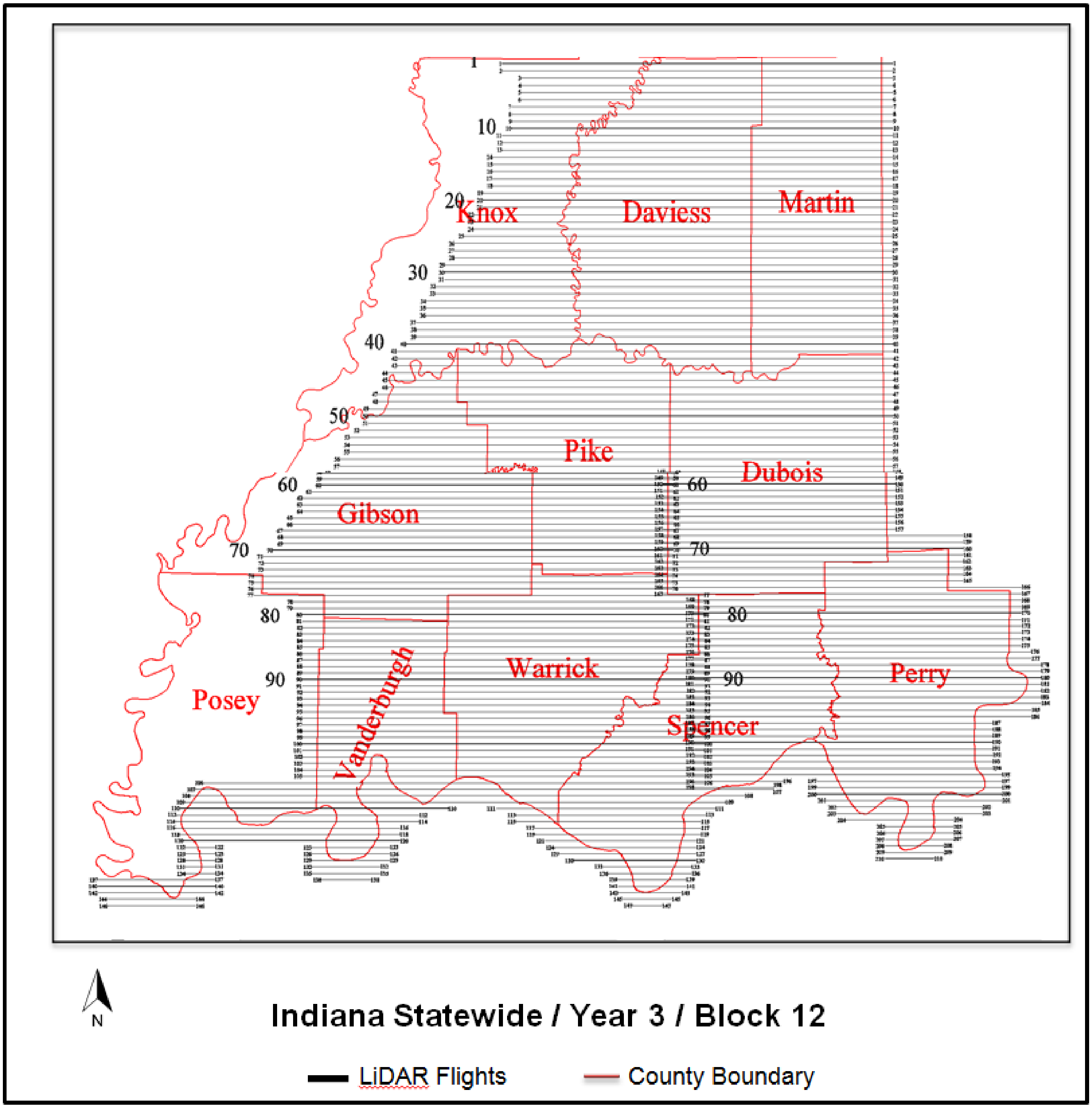


Figure 2.2 LiDAR Flight Layout, Block 11 Acquisition

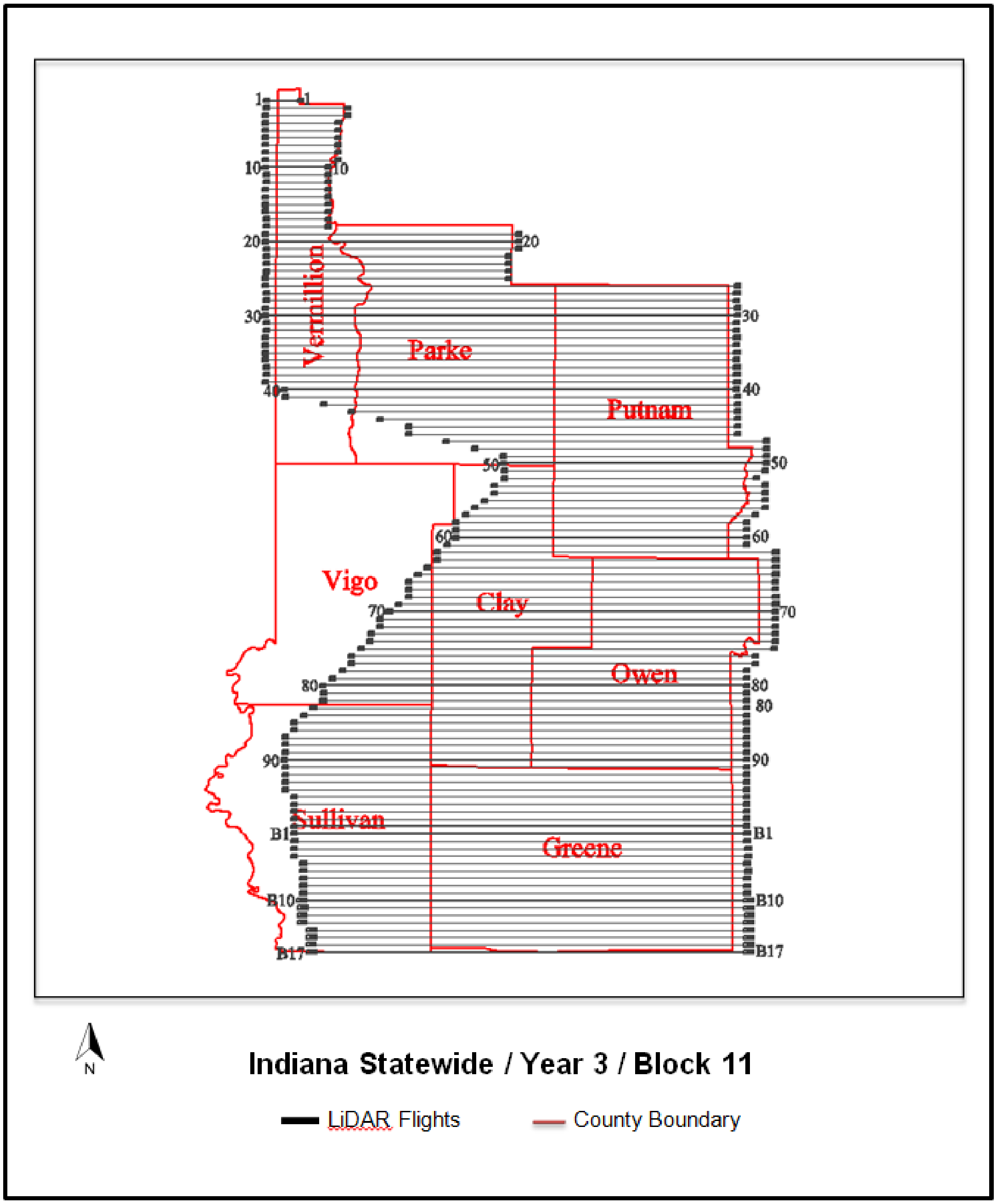


Figure 2.3 LiDAR Flight Layout, Block 10 Acquisition

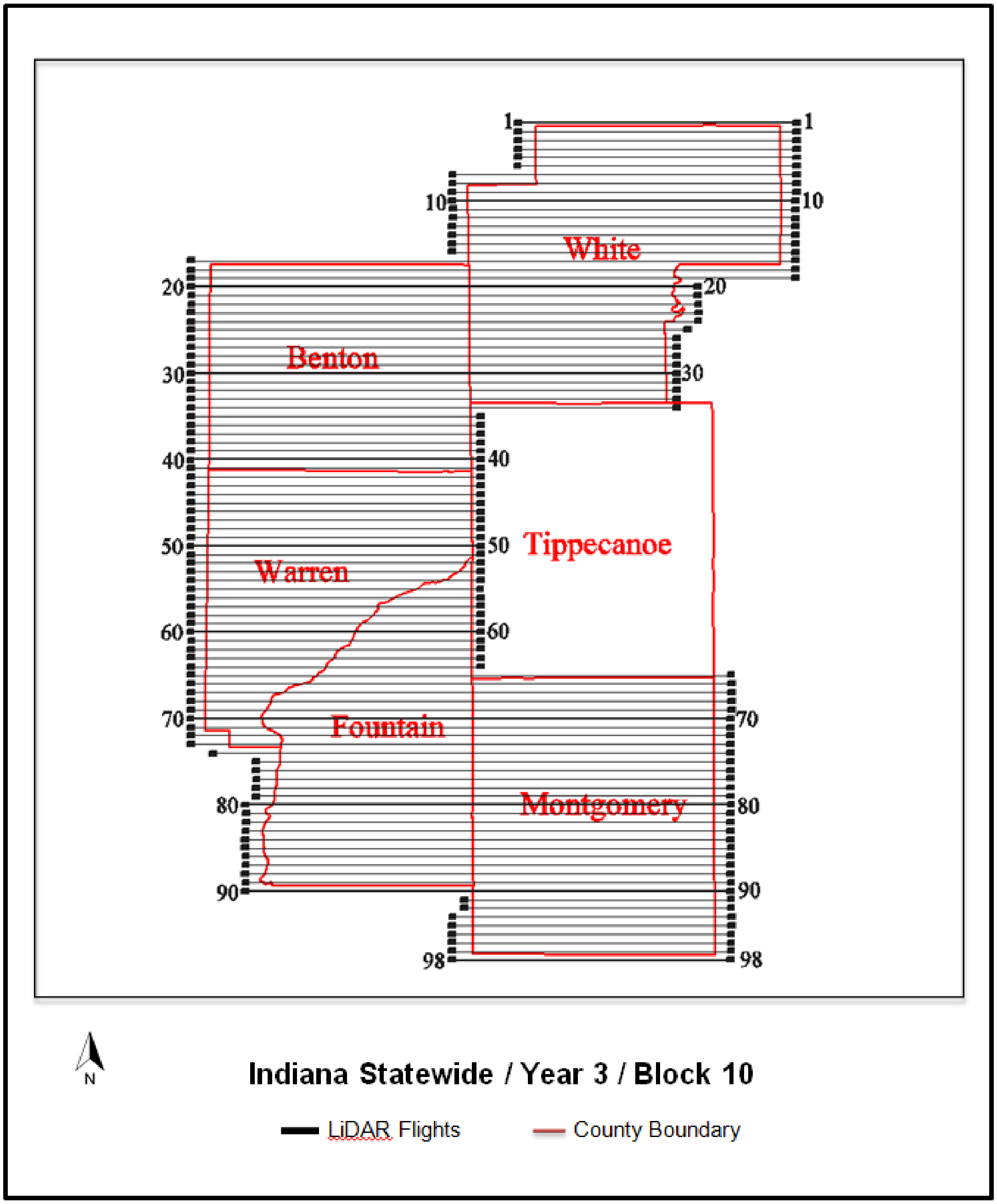


Figure 2.4 LiDAR Flight Layout, Block 9 Acquisition

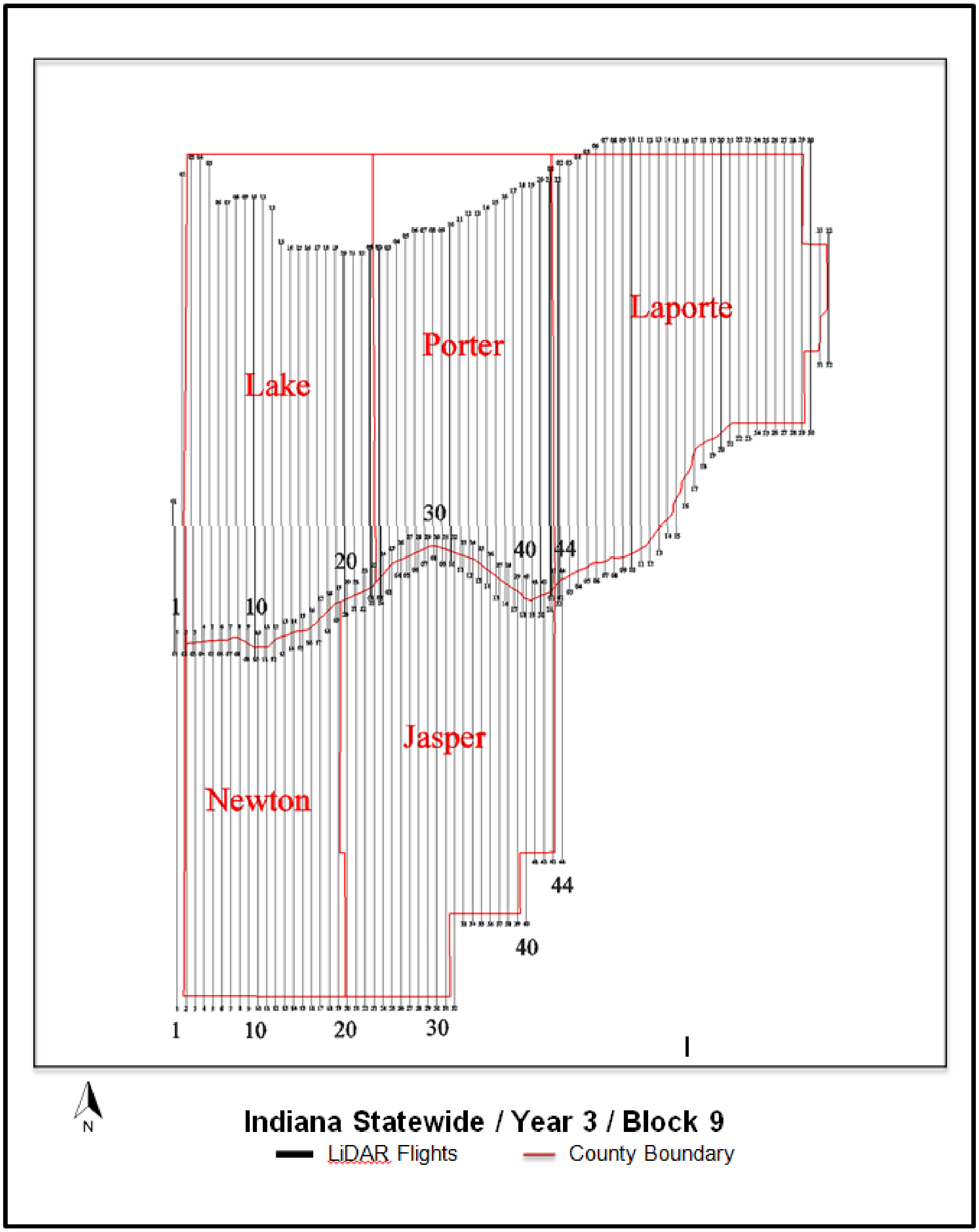


Table 2.3 Area 3 Airborne LiDAR Acquisition Flight Summary

Area 3 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
February 14, 2013	12	122, 125, 128, 131, 134, 137, 140, 142, 144, 146	22:30 - 00:05	05:30 PM - 07:50 PM
February 16, 2013 A	12	109-112, 114, 116, 118, 120, 123, 126, 129, 132, 138	23:30 - 03:22	06:30 PM - 10:22 PM
February 16, 2013 B	12	106-109, 113, 115, 117, 119, 121, 124, 127, 130, 133, 136, 139, 141, 143, 145, 147	00:57 - 04:15	7:57 PM - 11:15 PM
February 17, 2013 A	12	92-105	15:13 - 02:29	09:13 AM - 02:29 PM
February 17, 2013 B	12	84-91	22:30 - 00:50	05:30 PM - 07:50 PM
February 18, 2013	12	72-83	15:04 - 20:14	09:04 AM - 02:14 PM
February 19, 2013	12	60-71	23:50 - 04:35	06:50 PM - 11:35 PM
February 20, 2013	12	58-59, 148-153	22:05 - 01:31	05:05 PM - 07:31 PM
February 23, 2013	12	154-171	18:00 - 23:30	01:00 PM - 06:30 PM
February 23, 2013	12	172-185	14:00 - 18:43	09:00 AM - 01:43 PM
February 24, 2013	12	186-198	22:05 - 00:50	05:05 PM - 07:50 PM
February 25, 2013 A	12	54-57, 200-210	14:30 - 18:55	09:30 AM - 01:55 PM
February 25, 2013 B	12	46-53	22:30 - 00:25	05:30 PM - 07:25 PM
March 3, 2013 A	12	62, 81, 88, 90, 107, 109, 111, 115	13:50 - 17:10	08:50 AM - 12:10 PM
March 3, 2013 B	12	36-45, 151	20:05 - 01:10	03:05 PM - 08:10 PM
March 4, 2013	12	30-35	18:50 - 21:50	01:50 PM - 04:50 PM
March 9, 2013 A	12	19-30	13:50 -18:45	08:50 AM - 01:45 PM
March 9, 2013 B	12	9-18	20:02 - 00:25	03:02 PM - 07:25 PM
March 10, 2013	12	35-42	13:50 - 15:50	08:50 AM - 10:50 PM
March 14, 2013 A	12	81-83	14:10 - 15:40	09:10 AM - 10:40 AM
March 14, 2013 B	11	61-70	11:30 - 15:14	06:30 AM - 10:14 AM
March 15, 2013	11	52-61	16:16 - 19:50	11:16 AM - 02:50 PM
March 19, 2013 A	12/11	1-8, 133-135	12:50 - 19:50	07:50 AM - 02:50 PM
March 19, 2013 B	11	83-92	18:35 - 19:00	01:35 PM - 02:00 PM
March 19, 2013 C	Tipp/Purdue ,10	1-17, 96-98	21:14 - 23:55	04:14 PM - 06:55 PM
March 19, 2013 D	11	39-62	23:34 - 05:08	06:34 PM - 12:08 AM
March 21, 2013 A	11	1-25	13:15 - 17:45	08:15 AM - 12:45 PM
March 21, 2013 B	11/12	5-8, 26-30, 87-88	13:15 - 17:30	08:15 AM - 12:30 PM
March 21, 2013 C	Newton/ Jasper	34-44	12:15 - 20:00	07:15 AM - 03:00 PM
March 21, 2013 D	Tippecanoe	1-14	12:15 - 16:10	07:15 AM - 11:10 AM
March 22, 2013 A	11	31-40	18:10 - 22:35	01:10 PM - 05:35 PM

Area 3 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 22, 2013 B	10	81-95	13:04 - 18:13	08:04 AM - 01:13 PM
March 22, 2013 C	10	69-80	19:32 - 00:05	02:32 PM - 07:05 PM
March 22, 2013 D	Tippecanoe Newton/ Jasper	Tippecanoe 14-30 Newton/Jasper 26-33	13:40 - 20:00	08:40 AM - 03:00 PM
March 23, 2013 A	11	41-45	15:30 - 16:15	10:30 AM - 11:30 AM
March 23, 2013 B	10	62-68	16:56 - 19:50	11:56 AM - 02:50 PM
March 29, 2013	LaPorte	16-32	19:05 - 23:03	02:05 PM - 06:03 PM
March 30, 2013	LaPorte	1-15	13:35 - 18:05	08:35 AM - 01:05 PM
April 2, 2013 A	10	1-2	12:25 - 17:19	07:25 AM - 12:19 PM
April 2, 2013 B	Tippecanoe Newton/ Jasper	Tippecanoe 15,18,19 Newton/Jasper 37,38,41	17:15 - 19:00	12:15 PM - 02:15 PM
April 3, 2013	Newton/ Jasper	18-25	12:45 - 15:35	07:45 AM - 10:35 AM
April 4, 2013	Porter	1-22	17:30 - 23:29	12:30 PM - 06:29 PM
April 5, 2013 A	11	B05 - B15	20:32 - 01:03	03:32 PM - 08:03 PM
April 5, 2013 B	Lake	1-24	13:45 - 21:25	08:45 AM - 04:25 PM
April 6, 2013 A	11	83-99	13:35 - 20:15	08:35 AM - 03:15 PM
April 6, 2013 B	10/11	2-9, B1-B4	18:20 - 23:46	01:20 PM - 06:46 PM
April 7, 2013	10	10-23	20:50 - 01:50	03:50 PM - 08:50 PM
April 14, 2013 A	10, Newton/ Jasper	10 24-27 Newton/Jasper 1-17	16:00 - 23:10	11:00 AM - 06:10 PM
April 14, 2013 B	10	28-30	00:30 - 03:30	07:30 PM - 10:30 PM
April 14, 2013 C	10/11	47-61, 92	15:50 - 21:13	10:50 AM - 04:13 PM
April 14, 2013 D	10/11	31-46	23:00 - 02:40	06:00 PM - 09:40 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.1.35.

2. Calculated laser point position by associating the SBET position to each laser point return time, scan angle, intensity, etc. Created raw laser point cloud data for the entire survey in .LAS format. Automated line-to-line calibrations were then performed for system attitude parameters (pitch, roll, heading), mirror flex (scale) and GPS/IMU drift.
   Software: ALS Post Processing Software v.2.70, Proprietary Software, TerraMatch v. 13.01.

3. Imported processed .LAS point cloud data into the task order tiles. Resulting data were classified as ground and non-ground points with additional filters created to meet 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.13.015

4. The .LAS files were evaluated through a series of manual QA/QC steps to eliminate remaining artifacts and small undulations from the ground class.
   Software: TerraScan v.13.015

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.13.015, 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)
KEVV	38° 02' 09.93937"	-87° 32'12.69305"	85.330
KHNB	38° 14' 52.81424"	-86° 57' 24.68354"	123.535
INJS	38° 24' 30.04843"	-86° 56' 19.27121"	155.744
KHUF	39° 27' 30.47235"	-86° 18' 19.55017"	141.601
INLN	39° 01' 46.98735"	-87° 09' 12.11432"	129.495
KLAF	40° 24' 51.79476"	-86° 56' 09.46650"	148.925
INNP	39° 52' 09.11492"	-87° 24' 38.90940"	169.358
INCR	40° 04' 55.78297"	-86° 54' 17.47985"	206.941
INMO	40° 43' 33.35270"	-86° 45' 09.94410"	167.294
INAS	39° 23' 22.22916"	-87° 06' 39.62930"	154.516
INWL	40° 27' 28.46823"	-86° 55' 34.30802"	188.150
INRN	40° 56' 46.97712"	-87° 08' 22.51310"	177.581
KVPZ	41° 27' 03.16644"	-87° 00' 42.59413"	197.420
INLP	41° 35' 06.73325"	-86° 41' 33.07244"	217.431

Table 3.2 GNSS Base Station Days Utilized

Station Name	Day(s) Utilized
KEVV	04513, 04613, 04713, 04813, 04913, 05013
KHNB	05113, 05413, 05513
INJS	05613
KHUF	07313, 07413, 07813, 08013, 08113, 08213
INLN	07813, 09513, 09613
KLAF	07813, 08013, 08113, 08103, 07813
INNP	08113
INCR	08113, 08213
INMO	09213, 09713, 09713, 10413
INAS	09613
INWL	10413, 09213
INRN	09213, 10413
KVPZ	09313, 09513, 08913, 09413, 09513
INLP	08813

DATA PROCESSING

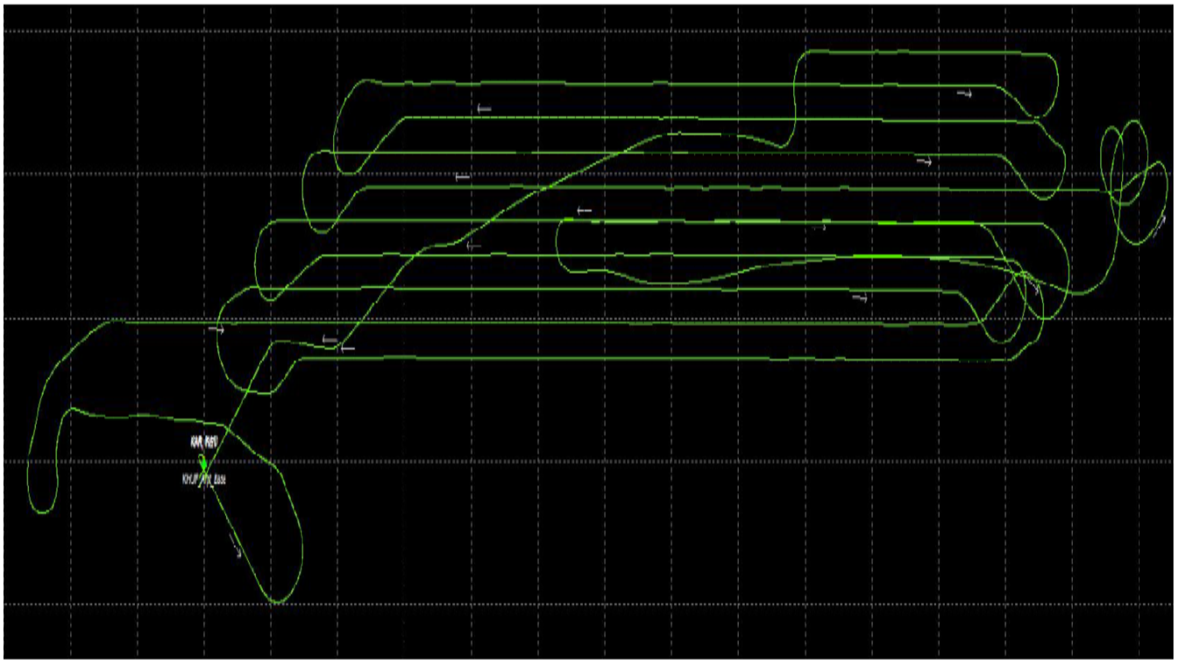
All airborne GNSS and IMU data was post-processed and quality controlled using Applanix 5.3 MMS software. GNSS data was processed at a 1 and 2 Hz data capture rate and the IMU data was processed at 200 Hz.

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 Day07413 of flight trajectory



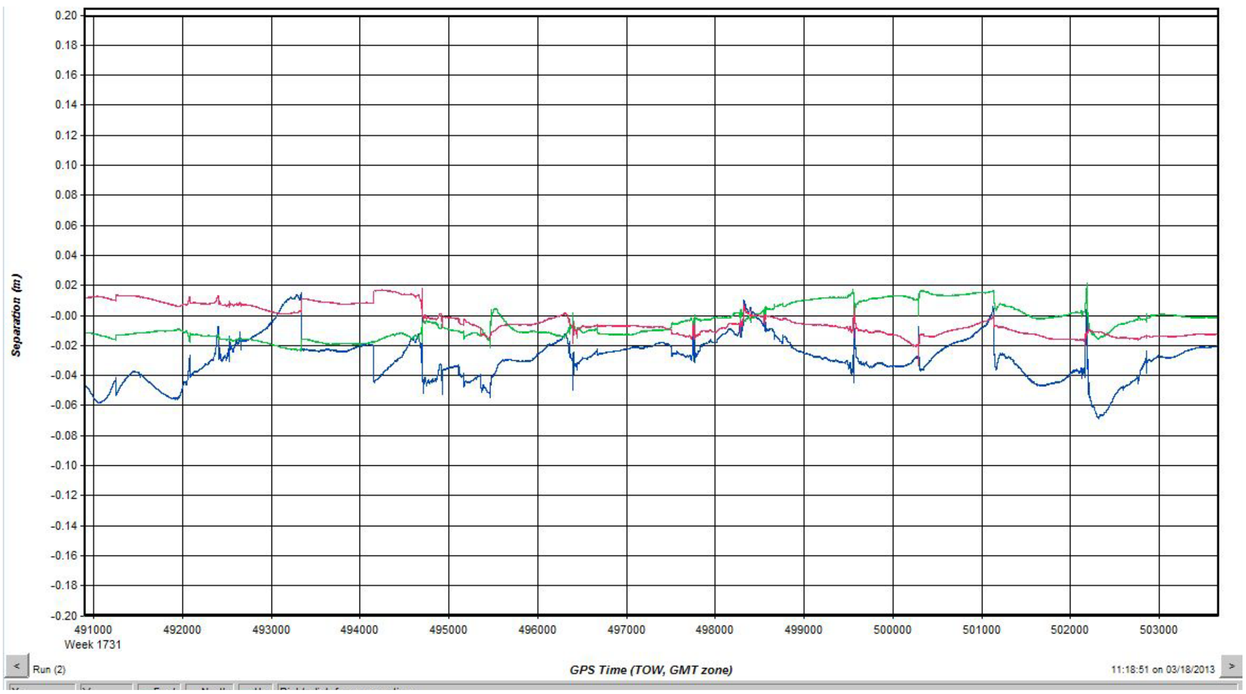
Within the trajectory processing, there are many factors that affect the overall quality, but the most indicative are the Combined Separation, the Estimated Positional Accuracy, and the Positional Dilution of Precision (PDOP).

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 Day07413 of Combined Separation

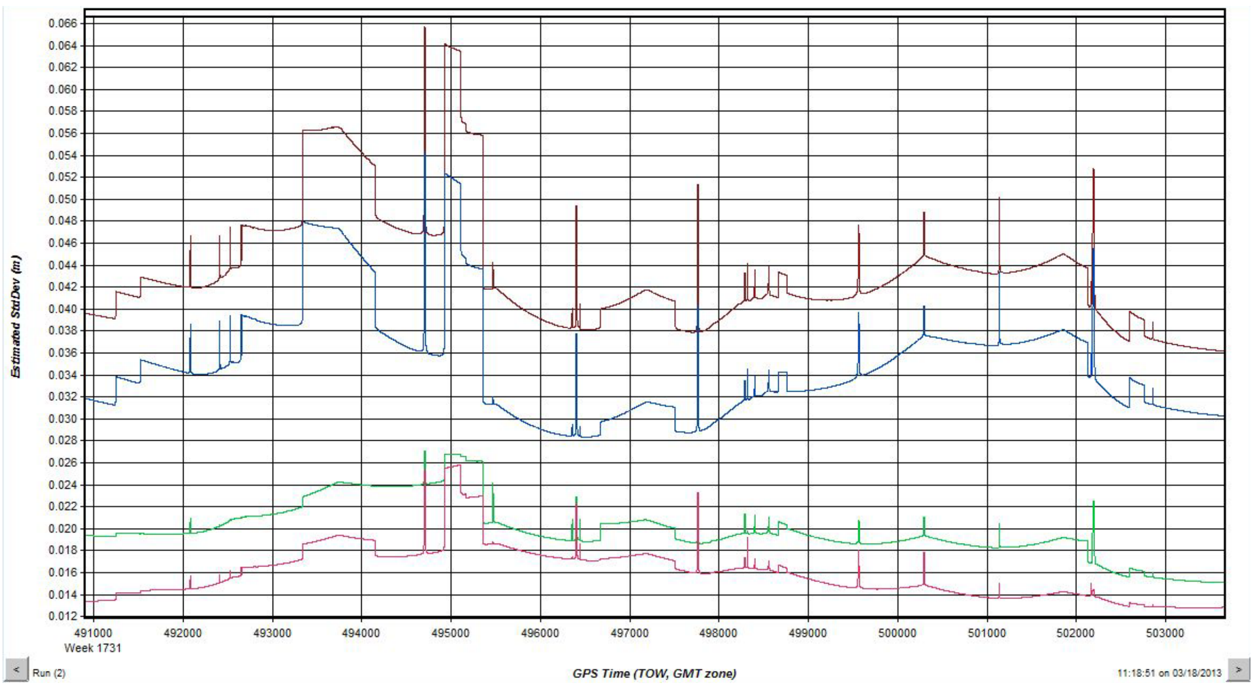


Estimated Positional Accuracy

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.

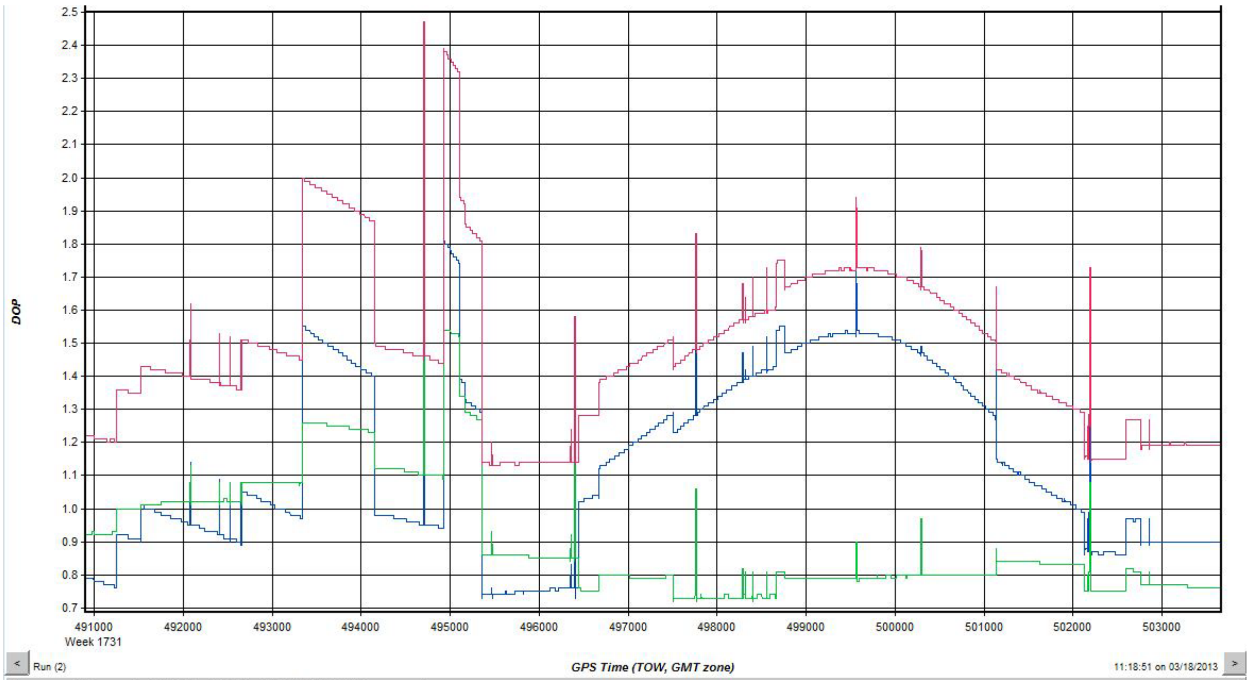
Figure 3.3 Graph from Day07413 of Positional Accuracy



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 Day07413 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 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

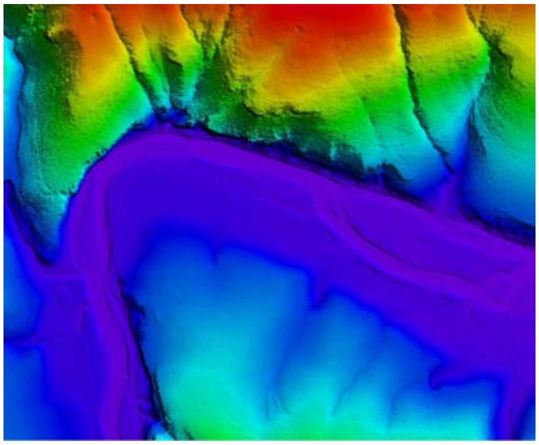
Woolpert utilized the following steps to hydrologically flatten the water bodies and for gradient hydrologic flattening of the double line streams within the existing LiDAR data.

1. Woolpert used existing (legacy) data along with newly acquired (2013) 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

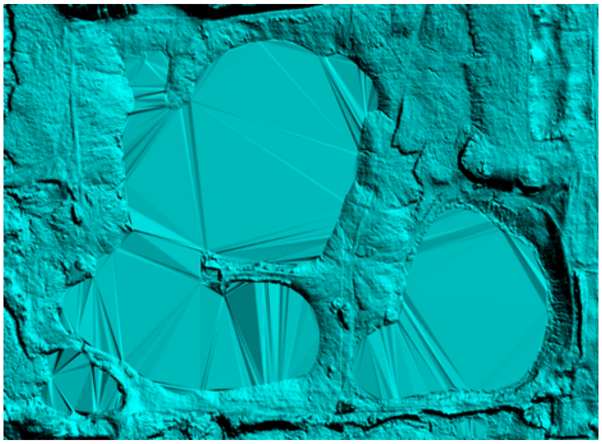


Figure 4.3

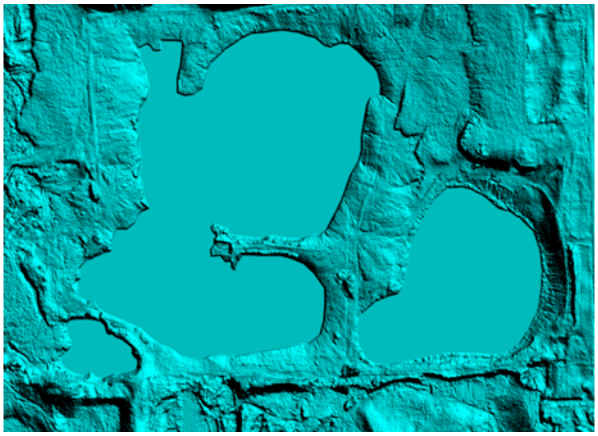


Figure 4.2 reflects a DEM generated from original LiDAR bare earth point data prior to the hydrologic flattening process. Note the "tinning" across the lake surface.

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 West, 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 “in2013_” 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 v14, by reviewing the grids and hydrologic breakline features.

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

SECTION 5: FINAL ACCURACY ASSESSMENT

FINAL VERTICAL ACCURACY ASSESSMENT

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

Table 5.1: Overall Vertical Accuracy Statistics for Indiana Tier 3

Average error	0.033	feet
Minimum error	-0.425	feet
Maximum error	+0.448	feet
Average magnitude	0.157	feet
Root mean square	0.193	feet
Standard deviation	0.189	feet

Table 5.2 QA/QC Analysis, Tier 3 Indiana Statewide, Indiana State Plane West, NAD 83 NAVD 88 GEOID 09

Tier 3 Indiana Statewide					
Point ID	Easting (US feet)	Northing (US feet)	Elevation (feet)	Laser Elevation (feet)	DZ (feet)
QC_220_LIDAR	2851907.550	2146302	647.853	647.650	-0.203
QC_201_LIDAR	3081342.010	2341671	811.573	811.700	0.127
QC_202_LIDAR	3074132.000	2292781	745.721	745.860	0.139
QC_203_LIDAR	3036215.680	2245551	714.082	714.160	0.078
QC_204_LIDAR	3026290.180	2318708	854.203	854.230	0.027
QC_205_LIDAR	2975932.660	2312838	704.876	704.820	-0.056
QC_206_LIDAR	2967860.460	2222081	696.656	696.490	-0.166
QC_207_LIDAR	2940265.850	2224154	715.446	715.610	0.164
QC_208_LIDAR	2936851.210	2289731	664.942	664.670	-0.272
QC_213_LIDAR	2971385.580	2153669	698.442	698.270	-0.172
QC_214_LIDAR	2962048.360	2105043	682.881	682.880	-0.001
QC_215	2930635.320	2073025	661.645	661.760	0.115
QC_209_LIDAR	2894683.820	2281000	626.189	625.870	-0.319
QC_210_LIDAR	2888995.300	2202456	692.183	692.310	0.127
QC_211_LIDAR	2857215.760	2204668	713.677	713.850	0.173
QC_212_LIDAR	2856184.610	2290893	617.208	616.920	-0.288
QC_216_LIDAR	2924122.180	2152078	712.141	712.290	0.149
QC_217_LIDAR	2889283.040	2146172	687.440	687.240	-0.200
QC_218_LIDAR	2884930.610	2045894	647.156	647.160	0.004
QC_219_LIDAR	2853607.700	2015060	668.982	668.910	-0.072

Tier 3 Indiana Statewide					
Point ID	Easting (US feet)	Northing (US feet)	Elevation (feet)	Laser Elevation (feet)	DZ (feet)
QC_225_LIDAR	2917366.130	1972775	746.472	746.920	0.448
QC-237_LIDAR	2955428.570	1792031	776.205	776.620	0.415
QC-238_LIDAR	3040099.640	1770129	786.335	786.720	0.385
QC-282	2996809.540	1883512	613.182	613.470	0.288
QC-233_LIDAR	2829998.780	1802512	721.464	721.680	0.216
QC-228_LIDAR	3047353.400	1923916	634.700	634.890	0.190
QC_226_LIDAR	2868183.860	1919979	752.221	752.390	0.169
QC-230_LIDAR	3040192.190	1834402	774.508	774.670	0.162
QC-235_LIDAR	2870056.060	1782978	628.203	628.340	0.137
QC-221_LIDAR	3046150.770	2052274	667.462	667.540	0.078
QC-223	3037722.820	1949133	645.927	646.000	0.073
QC-240_LIDAR	2985433.740	1716713	779.945	779.980	0.035
QC_231_LIDAR	2906488.470	1894991	693.127	693.140	0.013
QC-239	3033104.490	1700015	824.346	824.330	-0.016
QC_232_LIDAR	2844002.200	1881932	719.813	719.710	-0.103
QC-236_LIDAR	2934634.390	1771383	719.185	719.080	-0.105
QC-222	3007876.930	2043689	670.378	670.250	-0.128
QC-227_LIDAR	2925584.090	1918144	694.473	694.340	-0.133
QC-281_LIDAR	2989153.040	1890644	670.802	670.650	-0.152
QC-234_LIDAR	2934807.980	1805035	707.174	706.990	-0.184
QC-229_LIDAR	2968452.210	1877546	578.239	578.010	-0.229
QC-224	2968628.020	1951717	728.586	728.230	-0.356
QC241LIDAR	2854428.960	1749789	541.505	541.340	-0.165
QC242LIDAR	2861251.630	1611400	503.767	503.550	-0.217
QC243	2919206.580	1689157	581.814	581.530	-0.284
QC244	2955034.190	1640412	723.854	723.940	0.086
QC245	2878530.010	1561861	496.504	496.620	0.116
QC246	2841231.000	1500955	477.944	477.940	-0.004
QC247	2948204.660	1559324	686.038	685.990	-0.048
QC248LIDAR	2945090.960	1467597	604.008	603.900	-0.108
QC249LIDAR	2980329.120	1678893	823.349	823.390	0.0410
QC250LIDAR	3059590.890	1575098	797.236	797.020	-0.216
QC251LIDAR	3015905.540	1598869	868.762	869.000	0.238
QC252LIDAR	3028795.270	1523991	718.076	718.070	-0.006
QC253LIDAR	3044381.090	1469462	548.749	548.750	0.001
QC254LIDAR	2827765.160	1423832	472.541	472.760	0.219
QC255LIDAR	2861963.570	1353089	521.374	521.490	0.116
QC256LIDAR	2899989.050	1393706	571.243	571.250	0.007

Tier 3 Indiana Statewide					
Point ID	Easting (US feet)	Northing (US feet)	Elevation (feet)	Laser Elevation (feet)	DZ (feet)
QC257LIDAR	2923593.760	1379173	530.533	530.660	0.127
QC258LIDAR	2971217.690	1338578	560.720	561.010	0.290
QC259LIDAR	2983321.650	1409820	524.122	524.090	-0.032
QC260LIDAR	3050953.990	1377711	819.468	819.670	0.202
QC265LIDAR	3004536.100	1328474	599.707	599.830	0.123
QC253_LIDAR	3044381.090	1469462	548.749	548.750	0.001
QC258_LIDAR	2971217.690	1338578	560.720	561.010	0.290
QC260_LIDAR	3050953.990	1377711	819.468	819.670	0.202
QC_254_LIDAR	2827765.160	1423832	472.541	472.760	0.219
QC_255_LIDAR	2861963.570	1353089	521.374	521.490	0.116
QC_264_LIDAR	2957702.400	1242067	534.659	534.650	-0.009
QC_269_LIDAR	2888879.970	1154518	477.361	477.800	0.439
QC_271_LIDAR	2988478.000	1161069	475.346	475.590	0.244
QC_272_LIDAR	3026495.510	1117227	564.210	564.130	-0.080
QC_273_LIDAR	2743533.360	981755	378.494	378.490	-0.004
QC_274_LIDAR	2790820.830	1029402	517.465	517.540	0.075
QC_275_LIDAR	2870603.670	1008368	454.470	454.490	0.020
QC_276_LIDAR	2945883.270	1077351	507.908	508.060	0.152
QC_279_LIDAR	3057194.280	1053451	413.275	412.850	-0.425
QC_279_LIDAR	3025098.720	1064767	567.569	567.500	-0.069
QC_280_LIDAR	3049842.740	984043	525.507	525.690	0.183
QC_284_LIDAR	2986931.440	1116964	474.252	474.200	-0.052
QC_285_LIDAR	2993092.250	1104105	515.011	514.920	-0.091
QC257_LIDAR	2923593.760	1379173	530.533	530.660	0.127
QC259_LIDAR	2983321.650	1409820	524.122	524.090	-0.032
QC265_LIDAR	3004536.100	1328474	599.707	599.830	0.123
QC_261	2834196.990	1254887	430.886	431.130	0.244
QC_262	2888449.390	1285123	541.262	541.460	0.198
QC_263	2932886.150	1296151	467.243	467.520	0.277
QC_266	3040061.850	1245849	499.149	499.220	0.071
QC_267	2764597.550	1103697	468.218	468.590	0.372
QC_268	2849026.020	1123526	464.471	464.730	0.259
QC_270	2936004.630	1099643	622.533	622.110	-0.423
QC_277	2928347.660	985110	389.485	389.640	0.155
QC_278	3025134.100	1064776	567.946	567.840	-0.106
QC_283	2824887.050	1238287	423.097	423.300	0.203

VERTICAL ACCURACY CONCLUSIONS

Bare-Earth DEM Fundamental Vertical Accuracy (FVA): Tested 0.378 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		November 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.