AIRBORNE LiDAR ACQUISITION REPORT

2012 STATE OF MINNESOTA LIDAR PROJECT: WORK ORDER #5 CENTRAL LAKES REGION

MINNESOTA DEPARTMENT OF NATURAL RESOURCES

WOOLPERT PROJECT NUMBER: 72304

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WOOLPERT
DESIGN | GEOSPATIAL | INFRASTRUCTURE

AIRBORNE LIDAR ACQUISITION REPORT

2012 STATE OF MINNESOTA LIDAR PROJECT

WORK ORDER #5

MINNESOTA CENTRAL LAKES REGION LIDAR

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Summary of Contents

List of Figures

List of Tables

SECTION 1: OVERVIEW

2012 STATE OF MINNESOTA LIDAR PROJECT: WORK ORDER #5 CENTRAL LAKES REGION

WOOLPERT PROJECT #72304

This report contains a comprehensive outline of the airborne LiDAR data acquisition of Work Order #5 Minnesota Central Lakes Region. The Minnesota Elevation mapping project was developed by the Minnesota Digital Elevation Mapping Committee and executed by Minnesota State agencies with the assistance of the federal government and county governments to acquire a highly accurate land surface elevation dataset for the State of Minnesota. High accuracy elevation data are essential to improving water quality, improving disaster preparedness, protecting existing infrastructure, planning flood and drought damage mitigation reports, enhancing natural resource protection, and strengthening decision-making capacity at all levels of government. The geographic area of this work order includes the Minnesota counties of Aitkin, Cass, Hubbard, Itasca, Todd, Wadena and a portion of Koochiching. There are a total of 3,663 - 1/16 USGS 1:24,000 scale quadrangle tiles covering a land area of approximately 11,690 sq. miles, along with a 100-meter buffer beyond the project tile boundary.

The data was collected using a Leica ALS60 LiDAR sensor, Leica ALS70 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 LiDAR was collected at the following sensor specifications for 1.5 NPS:

ALS60 Specifications

Post Spacing (Minimum):	4.92 ft / 1.5 m
AGL (Above Ground Level) average flying height:	7,800 ft / 2,377.4 m
MSL (Mean Sea Level) average flying height:	9,000 ft / 2712.7 m
Average Ground Speed:	150 knots / 172.6 mph
Field of View (full):	40 degrees
Pulse Rate:	99 kHz
Scan Rate:	38 Hz
Side Lap (Minimum):	25%

ALS70 Specifications

Post Spacing (Minimum):	4.92 ft / 1.5 m
AGL (Above Ground Level) average flying height:	7,800 ft / 2,377.4 m
MSL (Mean Sea Level) average flying height:	9,075 ft / 2766 m
Average Ground Speed:	150 knots / 172.6 mph
Field of View (full):	40 degrees
Pulse Rate:	115.3 kHz
Scan Rate:	25.1 Hz
Side Lap (Minimum):	25%

Optech ALTM Gemini Specifications

Post Spacing (Minimum):	4.92 ft / 1.5 m
AGL (Above Ground Level) average flying height:	6,800 ft / 2,072.6 m
MSL (Mean Sea Level) average flying height:	9,000 ft / 2712.7 m
Average Ground Speed:	150 knots / 172.6 mph
Field of View (full):	40 degrees
Pulse Rate:	99.1 kHz
Scan Rate:	38 Hz
Side Lap (Minimum):	25%

The LiDAR was collected and processed to meet a Nominal Post Spacing (NPS) of 1.5 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 UTM 15, North American Datum of 1983 (NAD83) in units of meters. The vertical datum used for the project was referenced to NAVD 1988, meters, 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 LiDAR Flight Layout

SECTION 2: ACQUISITION

The LiDAR data was acquired with a Leica ALS60 200 kHz Multiple Pulses in Air (MPiA) LiDAR sensor system and a Leica ALS70 500 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 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 ALS60 200 kHz Multiple Pulses in Air (MPiA) LiDAR System has the following specifications:

Table 2.1 ALS60 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 – 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

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

Table 2.2 ALS70 LiDAR System Specifications

Specification	
Operating Altitude	200 – 3,500 meters
Scan Angle	0 to 75° (variable)
Swath Width	0 to 1.5 X altitude (variable)
Scan Frequency	0 – 200 Hz (variable based on scan angle)
Maximum Pulse Rate	500 kHz (Effective)
Range Resolution	Better than 1 cm
Elevation Accuracy	7 - 16 cm single shot (one standard deviation)
Horizontal Accuracy	5 – 38 cm (one standard deviation)
Number of Returns per Pulse	7 (infinite)
Number of Intensities	3 (first, second, third)
Intensity Digitization	8 bit intensity + 8 bit AGC (Automatic Gain Control) level
MPiA (Multiple Pulses in Air)	8 bits @ 1nsec interval @ 50kHz
Laser Beam Divergence	0.22 mrad @ $1/e^2$ (~0.15 mrad @ 1/e)
Laser Classification	Class IV laser product (FDA CFR 21)
Eye Safe Range	400m single shot depending on laser repetition rate
Roll Stabilization	Automatic adaptive, range = 75 degrees minus current FOV
Power Requirements	28 VDC @ 25A
Operating Temperature	0-40°C
Humidity	0-95% non-condensing
Supported GNSS Receivers	Ashtech Z12, Trimble 7400, Novatel Millenium

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

Table 2.3 ALTM Gemini LiDAR System 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 31 separate missions, flown as close together as the weather permitted, to ensure consistent ground conditions across the project area.

An initial quality control process was performed immediately on the LiDAR data to review the data coverage, airborne GPS data, and trajectory solution. Any gaps found in the LiDAR data were relayed to the flight crew, and the area was re-flown.

Figure 2.1 LiDAR Flight Layout

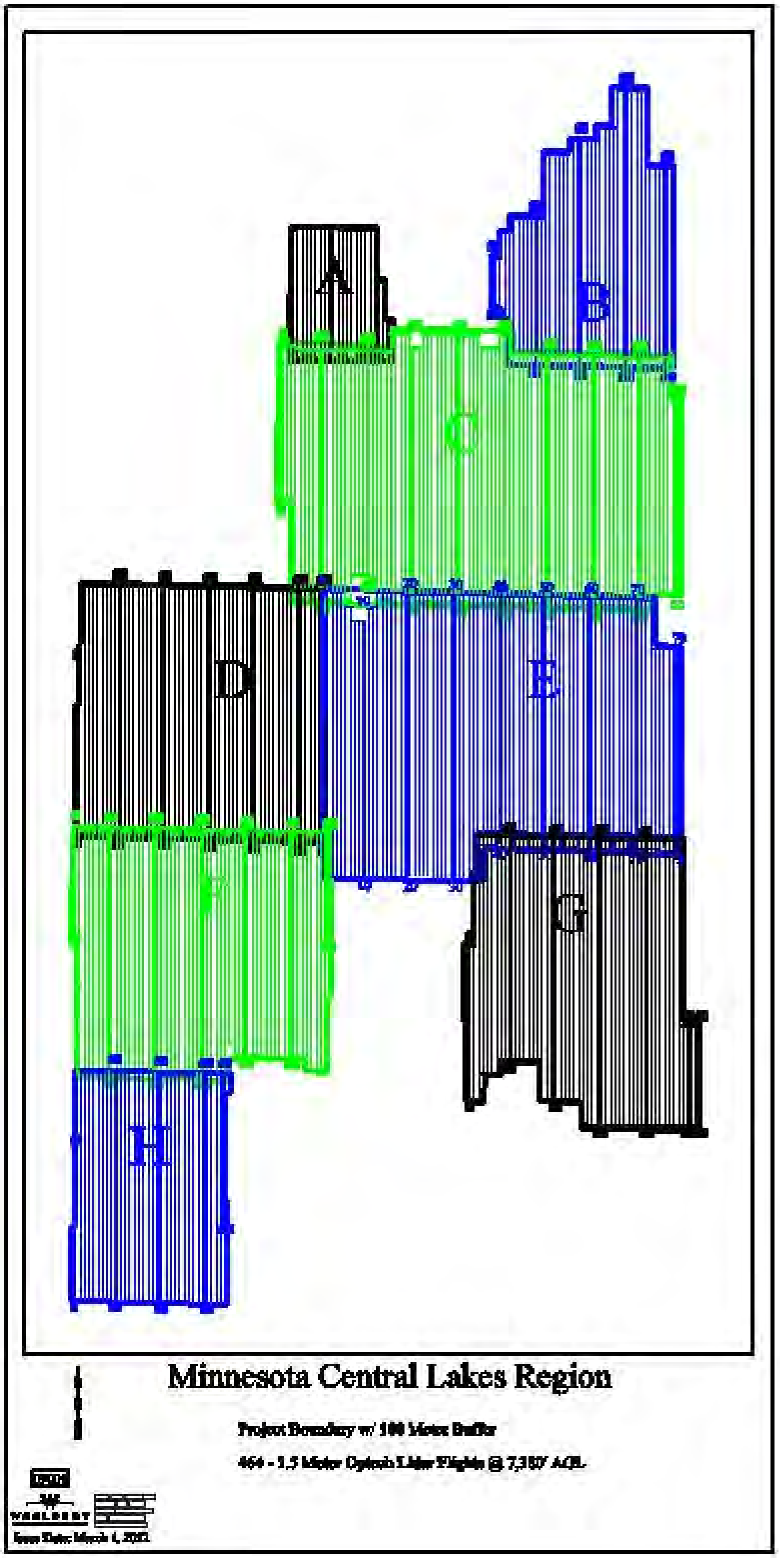


Table 2.4 Airborne LiDAR Acquisition Flight Summary

	Airborne LiDAR Acquisition Flight Summary		
Date of Mission – Sensor Number	Lines Flown	Mission Time (UTC) Wheels Up/ Wheels Down	Mission Time (Local = CDT) Wheels Up/ Wheels Down
April 5, 2012 ALS60_SN6157_N475RC	1-8 Block E	19:46 – 22:59	2:46PM -5:59PM
April 6, 2012 ALTM_SN56108_N1107Q	1-13, 47 Block B	20:24 – 23:15	3:24PM – 6:15PM
April 6, 2012 – "A" Flight ALS60_SN6157_N475RC	9-21, 23 Block E	13:19 - 18:40	8:19AM - 1:40PM
April 6, 2012 – "B" Flight ALS60_SN6157_N475RC	22, 24-30 Block E	19:56 – 23:08	2:56PM – 6:08 PM
April 10, 2012 ALTM_SN56108_N1107Q	14-23 Block B	23:31 – 03:21	06:31PM – 11:21PM
April 11, 2012 – "A" Flight ALS60_SN064_N27NW	18-34 Block H	13:26 – 18:39	08:26AM – 01:39PM
April 11, 2012 – "B" Flight ALS60_SN064_N27NW	1-17 Block E	13:26 – 18:39	08:26AM – 01:39PM
April 11, 2012 ALTM_SN56108_N1107Q	24-35 Block B	19:27 – 24:00	02:27PM – 07:00PM
April 11, 2012 – "A" Flight ALS60_SN064_N27NW	31-46 Block H	12:55 – 18:24	7:55PM – 01:24AM
April 11, 2012 – "B" Flight ALS60_SN6157_N475RC	47-60 Block B	19:25 – 00:06	2:25PM - 07:00PM
April 11, 2012 – 7177 ALS70_SN7177_N7079F	32 – 55 Block D	14:30 – 21:30	9:30AM – 4:30PM
April 12, 2012 ALS60_SN064_N27NW	30-51 Block H	13:53 – 21:10	08:53AM – 03:10PM
April 12, 2012 ALTM_SN56108_N1107Q	36-46 Block B	14:27 – 18:39	09:27AM – 01:39PM
April 12, 2012 ALS60_SN6157_N475RC	61-79 Block E	13:00 – 19:10	08:00AM – 02:10PM
April 12, 2012 – "A" Flight ALS70_SN7177_N7079F	20-31 Block D	14:18 – 17:45	9:18AM -12:45PM
April 12, 2012 – "B" Flight ALS70_SN7177_N7079F	8-19 Block D	20:07 – 23:20	03:07PM – 06:20PM
April 14, 2012 ALS60_SN064_N27NW	19-30 Block F	13:23 – 17:37	8:23AM – 12:37PM
April 19, 2012 ALS60_SN064_N27NW	31-58 Block F	13:33 – 20:38	8:33AM – 3:38PM
April 19, 2012 ALS60_SN6157_N475RC	44 Block E	17:52 – 17:58	12:52PM – 12:58PM
April 20, 2012 ALS60_SN064_N27NW	17-29 Block G	13:45 - 18:24	8:45AM – 1:24PM

Airborne LiDAR Acquisition Flight Summary			
Date of Mission – Sensor Number	Lines Flown	Mission Time (UTC) Wheels Up/ Wheels Down	Mission Time (Local = CDT) Wheels Up/ Wheels Down
April 23, 2012 ALS60_SN064_N27NW	1-14 Block F	13:26 - 17:48	8:26AM – 12:48PM
April 24, 2012 – "A" Flight ALS60_SN064_N27NW	15-19, 31, 44-47 Block F 7-16 Block G	13:40 – 20:13	8:40AM – 3:13PM
April 24, 2012 – "B" Flight ALS60_SN064_N27NW	1-6 Block G 34, 36 Block F	20:52 – 23:25	3:52PM - 6:25PM
April 26, 2012 ALS70_SN7177_N7079F	1-22 Block A 1-7 Block D	16:13 – 23:02	11:13AM – 6:02PM
April 26, 2012 ALS60_SN6157_N475RC	73-88 Block C	13:59 - 21:06	8:59AM - 4:06PM
April 26, 2012 ALS60_SN064_N27NW	14 Block F 17-23 Block G	15:08 – 18:18	10:08AM – 1:18PM
April 27, 2012 – "A" Flight ALS60_SN6157_N475RC	59-72 Block C	13:31 – 18:54	8:31AM – 1:54PM
April 27, 2012 – "B" Flight ALS60_SN6157_N475RC	49-58 Block C	20:06 – 00:21	3:06PM – 7:21PM
April 27, 2012 ALS70_SN7177_N7079F	1-20 Block C	15:08 – 21:18	10:08AM – 4:18PM
April 28, 2012 ALS60_SN6157_N475RC	34-48 Block C	13:47 – 20:20	8:47AM – 3:20PM
April 28, 2012 ALS70_SN7177_N7079F	21-33 Block C	13:56 – 19:03	8:56AM – 2:03PM

SECTION 3: LIDAR DATA PROCESSING

APPLICATIONS AND WORK FLOW OVERVIEW

1. Resolved kinematic corrections for three subsystems: inertial measurement unit (IMU), sensor orientation information and airborne GPS data. Developed a blending post-processed aircraft position with attitude data using Kalman filtering technology or the smoothed best estimate trajectory (SBET).
   Software: POSPac Software v. 5.3, IPAS Pro v.1.3.

2. Calculated laser point position by associating the SBET position to each laser point return time, scan angle, intensity, etc. Created raw laser point cloud data for the entire survey in .LAS format. Automated line-to-line calibrations were then performed for system attitude parameters (pitch, roll, heading), mirror flex (scale) and GPS/IMU drift.
   Software: ALS Post Processing Software v.2.75, Dashmap v5.1061 Proprietary Software, TerraMatch v. 12.05.

3. Imported processed .LAS point cloud data into project tiles. Resulting data were classified as ground and non-ground points with additional filters created to meet the project classification specifications. Statistical absolute accuracy was assessed via direct comparisons of ground classified points to ground RTK survey data. Based on the statistical analysis, the LiDAR data was then adjusted to reduce the vertical bias when compared to the survey ground control.
   Software: TerraScan v.12.05

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.12.05

5. All water bodies greater than two acres and all rivers with a nominal 100 foot width or larger were hydro-flattened using proprietary software.
   Software: TerraScan v.12.05, TerraModeler v.12.05, ArcMAP 10.1, LP360, Proprietary Software

GLOBAL NAVIGATION SATELLITE SYSTEM (GNSS)-INERTIAL MEASUREMENT UNIT (IMU) TRAJECTORY PROCESSING

EQUIPMENT

Flight navigation during the LiDAR data acquisition mission is performed using IGI CCNS (Computer Controlled Navigation System). The pilots are 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 crew 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

Mission (Julian Day - Sensor)	Station	Latitude	Longitude	Ellipsoid Height (L1 Phase Center)
DDDYY_Sensor	Name	(DMS)	(DMS)	(Meters)
Day09612_SH6157	KGPZ Airport Base	47°12'52.01820"	93°30'55.10799"	366.480
Day09712_OP108	NGS PID TB0641	48°34'04.82222"	93°23'53.74087"	328.631
Day09712_SH6157_A	KGPZ Airport Base	47°12'52.01820"	93°30'55.10799"	366.480
Day09712_SH6157_B	KGPZ Airport Base	47°12'52.01820"	93°30'55.10799"	366.480
Day10112_OP108	NGS PID TB0641	48°34'04.82222"	93°23'53.74087"	328.631
Day10212_NWG064_A	KBRD Airport Base	46°23'38.59723"	94°08'20.63021"	344.931
Day10212_NWG064_B	KBRD Airport Base	46°23'38.59723"	94°08'20.63021"	344.931
Day10212_OP108	NGS PID TB0641	48°34'04.82222"	93°23'53.74087"	328.631
Day10212_SH6157_A	KGPZ Airport Base	47°12'52.01820"	93°30'55.10799"	366.480
Day10212_SH6157_B	KGPZ Airport Base	47°12'52.01820"	93°30'55.10799"	366.480
Day10212_SH7177	KBJI Airport Base	47°30'27.09621"	94°56'07.17758"	393.880
Day10312_NWG064	PLNY CORS	46°20'22.33803"	93°15'43.48541"	355.082
Day10312_OP108	NGS PID TB0641	48°34'04.82222"	93°23'53.74087"	328.631
Day10312_SH6157	KGPZ Airport Base	47°12'52.01820"	93°30'55.10799"	366.480
Day10312_SH7177_A	KBJI Airport Base	47°30'27.09621"	94°56'07.17758"	393.880
Day10312_SH7177_B	KBJI Airport Base	47°30'27.09621"	94°56'07.17758"	393.880
Day10512_NWG064	KBRD Airport Base	46°23'38.59723"	94°08'20.63021"	344.931
Day11012_NWG064	KBRD Airport Base	46°23'38.59723"	94°08'20.63021"	344.931
Day11012_SH6157	GRPD CORS	47°13'24.95798"	93°29'02.62251"	370.104
Day11112_NWG064	KBRD Airport Base	46°23'38.59723"	94°08'20.63021"	344.931
Day11412_NWG064	KBRD Airport Base	46°23'38.59723"	94°08'20.63021"	344.931
Day11512_NWG064_A	KBRD Airport Base	46°23'38.59723"	94°08'20.63021"	344.931
Day11512_NWG064_B	KBRD Airport Base	46°23'38.59723"	94°08'20.63021"	344.931
Day11712_SH7177	KBJI Airport Base	47°30'27.09621"	94°56'07.17758"	393.880
Day11712_SH6157	GRPD CORS	47°13'24.95798"	93°29'02.62251"	370.104
Day11712_NWG064	KBRD Airport Base	46°23'38.59723"	94°08'20.63021"	344.931
Day11812_SH6157_A	GRPD CORS	47°13'24.95798"	93°29'02.62251"	370.104
Day11812_SH6157_B	GRPD CORS	47°13'24.95798"	93°29'02.62251"	370.104
Day11812_SH7177	KBJI Airport Base	47°30'27.09621"	94°56'07.17758"	393.880
Day11912_SH6157	KBJI Airport Base	47°30'27.09621"	94°56'07.17758"	393.880

Mission (Julian Day – Sensor)	Station	Latitude	Longitude	Ellipsoid Height (L1 Phase Center)
DDDYY_Sensor	Name	(DMS)	(DMS)	(Meters)
Day11912_SH7177	KBJI Airport Base	47°30’27.09621”	94°56’07.17758”	393.880

DATA PROCESSING

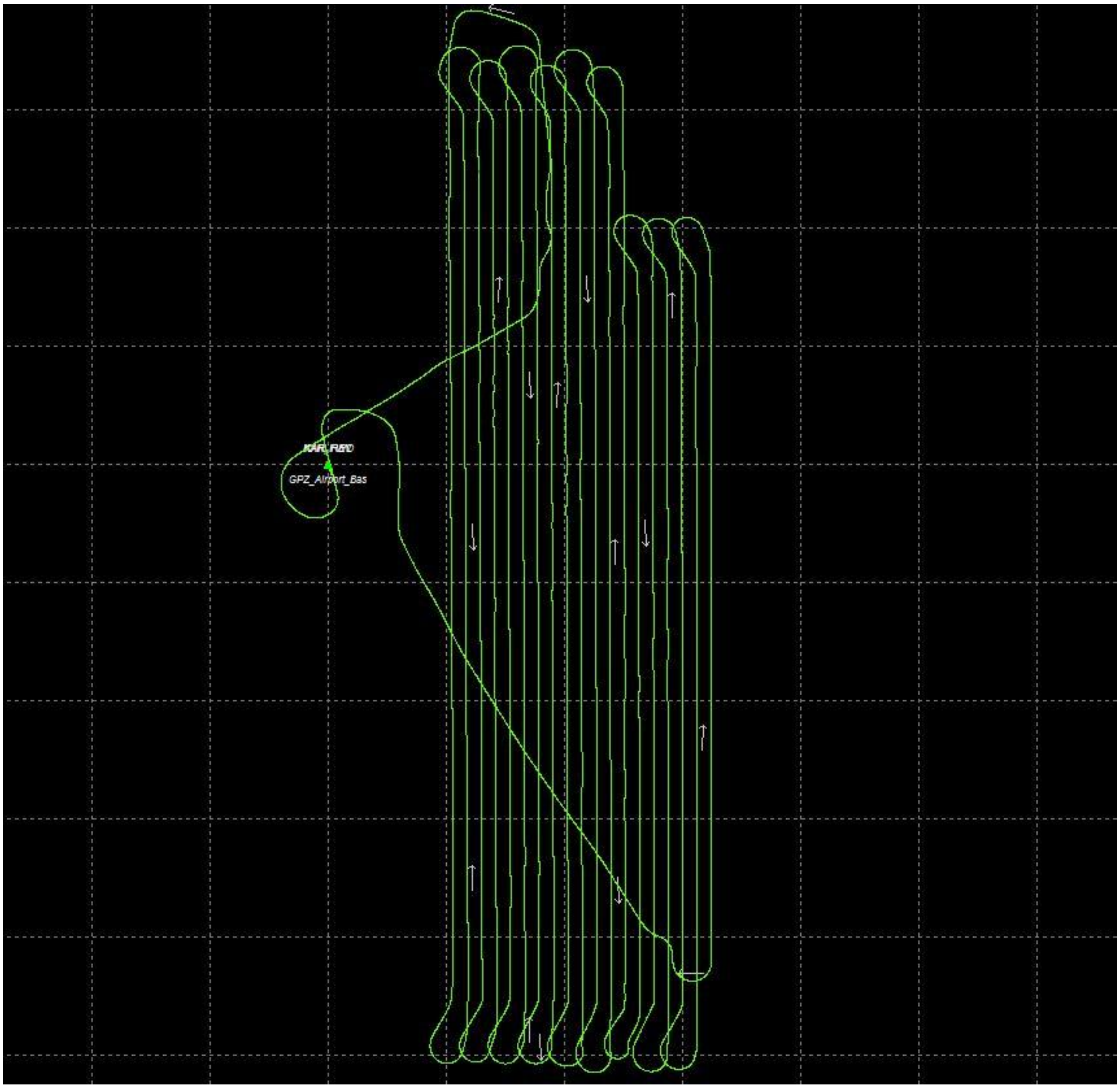
All airborne GNSS and IMU data was post-processed and quality controlled using Applanix 5.3 MMS software. GNSS data was processed at a 1 and 2 Hz data capture rate and the IMU data was processed at 200 Hz.

TRAJECTORY QUALITY

The GNSS Trajectory, along with high quality IMU data are key factors in determining the overall positional accuracy of the final sensor data. See **Figure 3.1** for the flight trajectory.

Flight Trajectory

Figure 3.1: Representative Graph from Day10312: N475RC



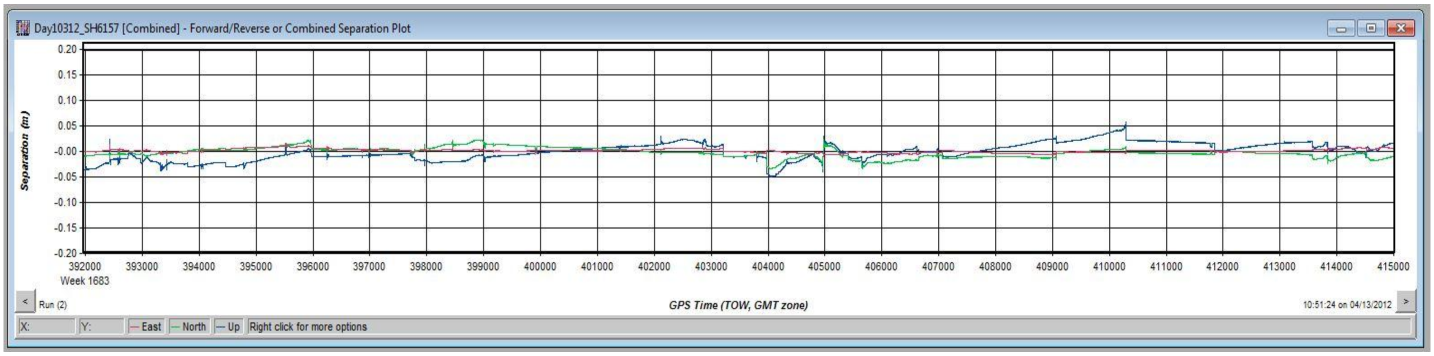
Within the trajectory processing, there are many factors that affect the overall quality, but the most indicative are the Combined Separation, the Estimated Positional Accuracy, and the Positional Dilution of Precision (PDOP).

Combined Separation

The Combined Separation is a measure of the difference between the forward run and the backward run solution of the trajectory. The Kalman filter is processed in both directions to remove the combined directional anomalies. In general, when these two solutions match closely, an optimally accurate reliable solution is achieved.

Woolpert's goal is to maintain a Combined Separation Difference of less than ten (10) centimeters. In most cases we achieve results below this threshold. See **Figure 3.2** for the combined separation graph.

Figure 3.2: Representative Graph from Day10312: N475RC of Combined Separation

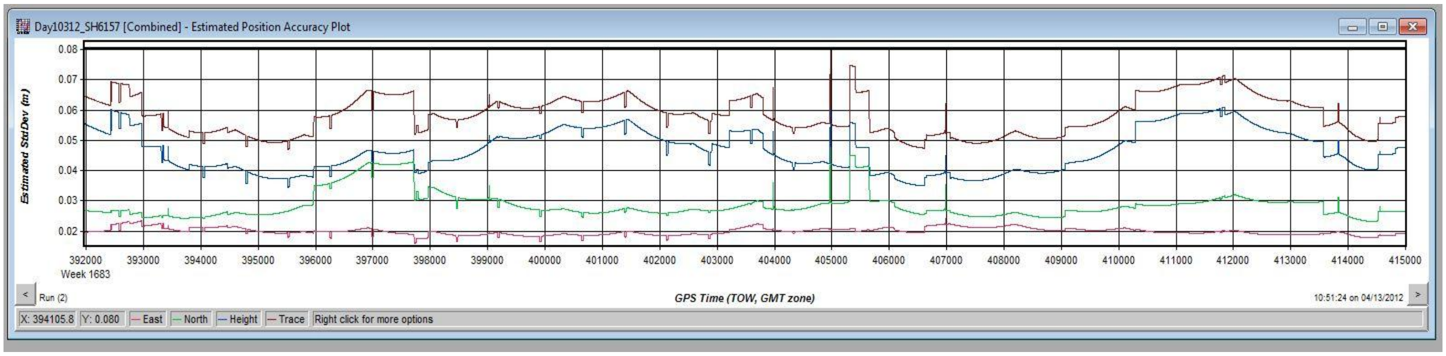


Estimated Positional Accuracy

The Estimated Positional Accuracy plots the standard deviations of the east, north, and vertical directions along a time scale of the trajectory. It illustrates loss of satellite lock issues, as well as issues arising from long baselines, noise, and/or other atmospheric interference.

Woolpert's goal is to maintain an Estimated Positional Accuracy of less than ten (10) centimeters, often achieving results well below this threshold.

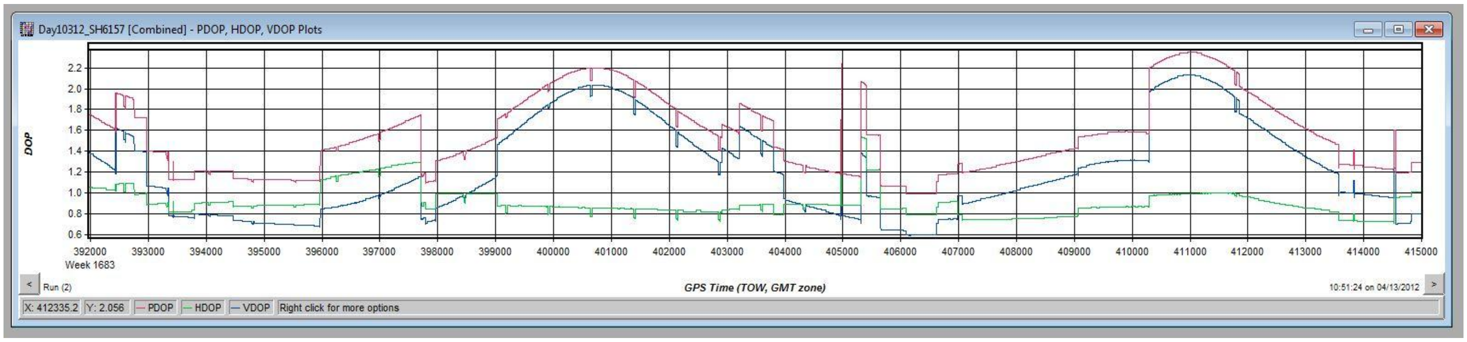
Figure 3.3: Representative Graph from Day10312: N475RC of Positional Accuracy



Positional DILUTION OF PRECISION (PDOP)

The PDOP measures the precision of the GPS solution in regards to the geometry of the satellites acquired and used for the solution. Woolpert's goal is to maintain an average PDOP value below 3.0. Brief periods of PDOP over 3.0 are acceptable due to the calibration and control process if other metrics are within specification. See **Figure 3.4** for plots of PDOP of each mission and sensor.

Figure 3.4: Representative Graph from Day10312: N475RC of PDOP



LIDAR DATA PROCESSING

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

- Processed individual flight lines to derive a raw "Point Cloud" LAS file. Matched overlapping flight lines, generated statistics for evaluation comparisons, and made the necessary adjustments to remove any residual systematic error.

- Calibrated LAS files were imported into the task order tiles and initially filtered to create a ground and non-ground class. Then additional classes were filtered as necessary to meet client specified classes.

- Once all of the task order data was imported and classified, cross flights and survey ground control data was imported and calculated for an accuracy assessment. As a QA/QC measure, Woolpert has developed a routine to generate accuracy statistical reports by comparison among LiDAR points, ground control, and TINs. The LiDAR is adjusted accordingly to reduce any vertical bias to meet or exceed the vertical accuracy requirements.

- The LiDAR tiles were reviewed using a series of proprietary QA/QC procedures to ensure it fulfills the task order requirements. A portion of this requires a manual step to ensure anomalies have been removed from the ground class.

- The bare earth DEM surface was hydrologically flattened for waterbody features that were greater than 2 acres and rivers and streams of 30.5 meters (100 feet) and greater nominal width.

- The LiDAR LAS files for this task order have been classified into the Default (Class 1), Ground (Class 2), Low Vegetation (Class 3), Medium Vegetation (Class 4), High Vegetation (Class 5) Buildings (Class 6), Noise (Class 7), Model Keypoints (Class 8), Water (Class 9), Ignored Ground (Class 10), bridges (Class 14), and Overlap (Class 17) 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 UTM 15N and North American Datum of 1983. Coordinate positions were specified in units of meters. The vertical datum used for the task order was referenced to NAVD 1988, meters, 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 30.5 meters (100 feet), were compiled in the direction of flow with both sides of the stream maintaining an equal gradient elevation.

LIDAR DATA REVIEW AND PROCESSING

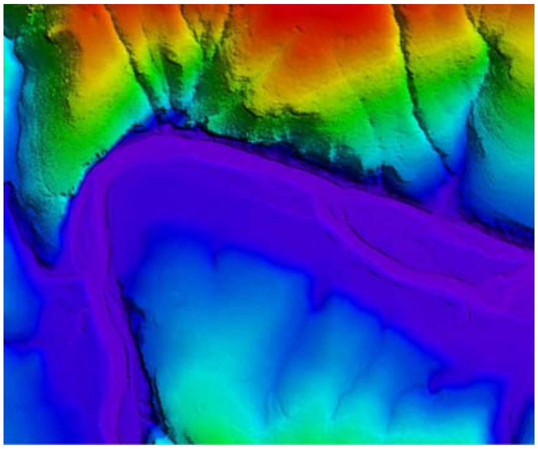
Woolpert utilized the following steps to hydrologically flatten the water bodies and for gradient hydrologic flattening of the double line streams within the existing LiDAR data.

1. Woolpert used a combination of Intensity data and digital elevation models from the 2012 lidar collection as well imagery from open source imagery to manually draw the hydrologic features in a 2D environment

2. Woolpert utilizes an integrated software approach to combine the LiDAR data and 2D breaklines. This process “drapes” the 2D breaklines onto the 3D LiDAR surface model to assign an elevation. A monotonic process is performed to ensure the streams are consistently flowing in a gradient manner. A secondary step within the program verifies an equally matching elevation of both stream edges. The breaklines that characterize the closed water bodies are draped onto the 3D LiDAR surface and assigned a constant elevation at or just below ground elevation.

3. The lakes, reservoirs and ponds, at a minimum size of 2-acres or greater, were compiled as closed polygons. **Figure 4.1** illustrates a good example of 2-acre lakes and 30.5 meters (100-feet) nominal streams identified and defined with hydrologic breaklines. The breaklines defining rivers and streams, at a nominal minimum width of 30.5 meters (100-feet), were draped with both sides of the stream maintaining an equal gradient elevation.

Figure 4.1



4. All ground points were reclassified from inside the hydrologic feature polygons to water, class nine (9).

5. All ground points were reclassified from within a 1.5 meter (5-foot) buffer along the hydrologic feature breaklines to buffered ground, class ten (10).

6. The LiDAR ground points and hydrologic feature breaklines were used to generate a new digital elevation model (DEM).

Figure 4.2

Figure 4.3

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

Figure 4.3 reflects a DEM generated from LiDAR with breaklines compiled to define the hydrologic features. This figure illustrates the results of adding the breaklines to hydrologically flatten the DEM data. Note the smooth appearance of the lake surface in the DEM.

Terrascan was used to add the hydrologic breakline vertices and export the lattice models. The hydrologically flattened DEM data was provided to MNDNR in ArcGRID 32-bit FLOAT format at a 1-meter cell size. The final LiDAR data was delivered in a client provided projection tiling format, based on 1:24,000 scale quadrangle tiles.

The hydrologic breaklines compiled as part of the flattening process were provided to the MNDNR as an ESRI Polygon Z shapefile in file geodatabase format.

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 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

Average error	0.004	meters
Minimum error	-0.102	meters
Maximum error	0.097	meters
Average magnitude	0.038	meters
Root mean square	0.05	meters
Standard deviation	0.051	meters

Table 5.2: QA/QC Analysis UTM 15N, NAD83

Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Laser Elevation (meters)	Dz (meters)
2000	478887.8	5120680	380.93	380.93	0
2001	473888.7	5135987	392.265	392.31	0.045
2002	469254.2	5153780	387.021	387.05	0.029
2003	471148.7	5206692	385.646	385.64	-0.006
2004	415387.4	5243290	400.794	400.74	-0.054
2005	430178.9	5211876	408.632	408.53	-0.102
2006	485336	5280758	445.424	445.43	0.006
2007	479672.2	5328187	400.721	400.7	-0.021
2008	339501.7	5177714	429.025	428.93	-0.095
2009	371010.4	5105779	375.15	375.14	-0.01
2011	428029	5286806	406.262	406.29	0.028
2012	391604.4	5154494	404.661	404.62	-0.041
2013	341561	5098319	420.952	421.04	0.088
2101	475657.1	5370591	341.153	341.18	0.027
2102	384631.8	5190746	406.683	406.72	0.037
2103	365768.5	5083274	376.168	376.19	0.022
2201	397301.5	5340328	364.413	364.42	0.007
2202	342948.9	5246622	435.803	435.9	0.097

Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Laser Elevation (meters)	Dz (meters)
2203	350241.6	5230298	431.463	431.52	0.057
2204	339941.6	5166814	423.646	423.61	-0.036
2205	340176	5079094	404.76	404.76	0

VERTICAL ACCURACY CONCLUSIONS

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

Approved By:			
Title	Name	Signature	Date
Associate Member LiDAR Specialist Certified Photogrammetrist #1281	Qian Xiao		June 5, 2013

SECTION 6: FINAL DELIVERABLES

FINAL DELIVERABLES

The final deliverables are listed below. The final LiDAR data was delivered in a UTM/Meter projection tiling format, based on 1:24,000 scale quadrangle tiles. The tiles were provided with 50 meters of overlap between adjacent tiles and along the project border. LAS v1.2 classified point cloud.

- 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. These were delivered as part of a file geodatabase.
- ESRI multipoint feature class representing bare earth. These were delivered as part of a file geodatabase.
- 1 meter ArcGrid DEM. These were delivered as part of a file geodatabase.
- FGDC compliant metadata by file in XML format.

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