AIRBORNE LIDAR TASK ORDER REPORT

BENTON LAKE NWR 0.7M NPS LIDAR
UNITED STATES GEOLOGICAL SURVEY (USGS)

CONTRACT NUMBER: G10PC00057

TASK ORDER NUMBER: G14PD00481

Woolpert Project Number: 74472
November 2014

WOOLPERT
DESIGN | GEOSPATIAL | INFRASTRUCTURE

PROJECT REPORT

BENTON LAKE NWR 0.7NPS LIDAR

WOOLPERT PROJECT #74472

For:

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SECTION 1: OVERVIEW

PROJECT NAME: BENTON LAKE NWR 0.7NPS LIDAR

WOOLPERT PROJECT #74472

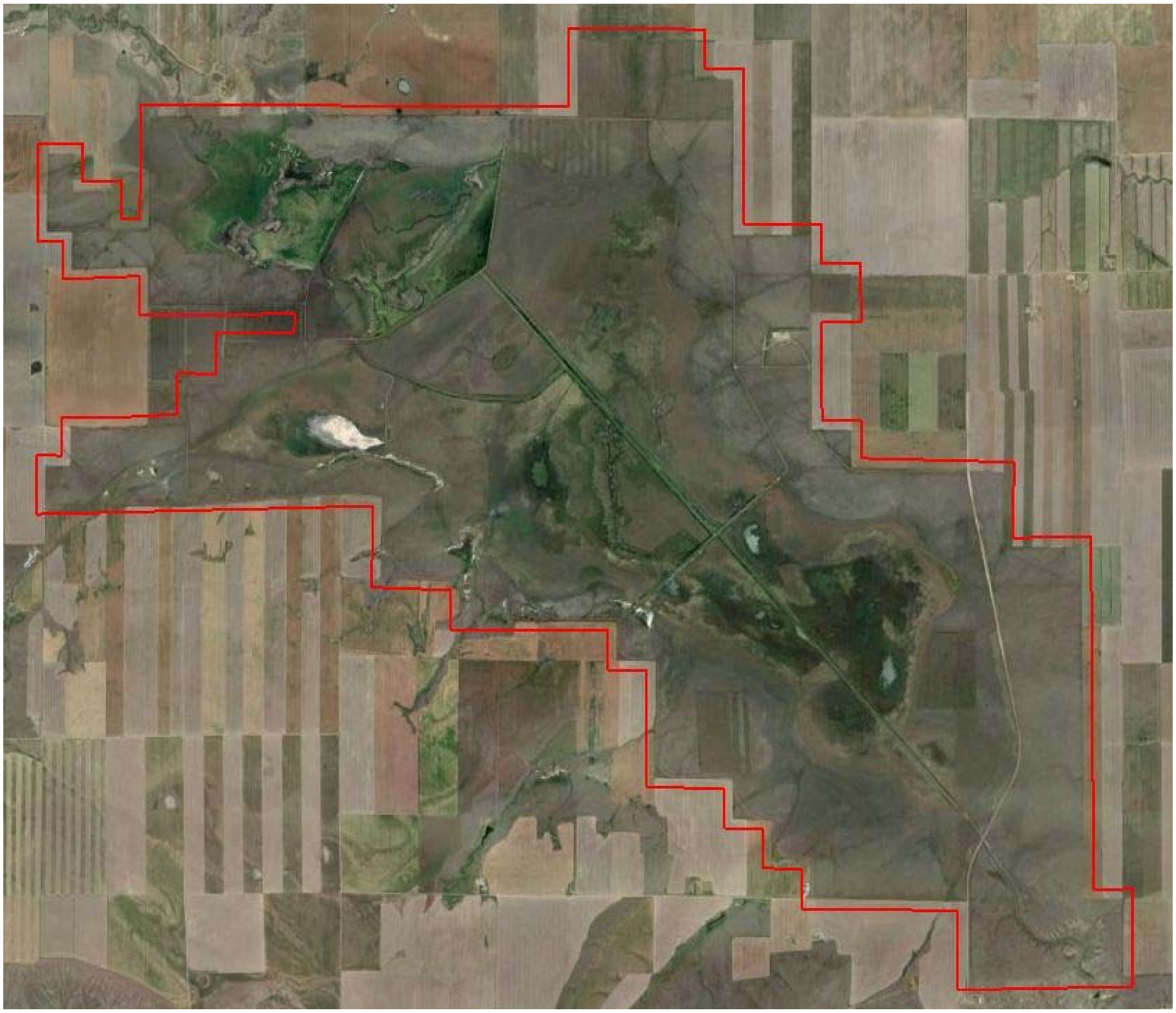
This report contains a comprehensive outline of the Benton Lake NWR 0.7M NPS Lidar Processing task order for the United States Geological Survey (USGS). This task is issued under Contract Number G10PC00057, as task order number G14PD00481. The project area covers approximately 5 square miles over the Benton Lake National Wildlife Refuge in Montana. The lidar was collected and processed to meet a maximum Nominal Post Spacing (NPS) of 0.7 meters. The NPS assessment is made against single swath, first return data located within the geometrically usable center portion (typically ~90%) of each swath.

The data was collected using a Leica ALS70 500 kHz Multiple Pulses in Air (MPiA) lidar sensor installed in a Leica gyro-stabilized PAV30 mount. The ALS70 sensor collects up to four returns per pulse, as well as intensity data, for the first three returns. If a fourth return was captured, the system does not record an associated intensity value. The aerial lidar was collected at the following sensor specifications:

Post Spacing (Minimum):	2.1 ft / 0.35m
AGL (Above Ground Level) average flying height:	4,500 ft / 1,372 m
Average Ground Speed:	135 knots / 155mph
Field of View (full):	24 degrees
Pulse Rate:	372 kHz
Scan Rate:	63.6 Hz
Side Lap (Average):	25%

The lidar data was processed and projected in UTM, Zone 12N, North American Datum of 1983 (2011) in units of meters. The vertical datum used for the task order was referenced to NAVD 1988, GEOID12A, in units of meters.

Figure 1.1 Lidar Task Order AOI



SECTION 2: ACQUISITION

The existing lidar data was acquired with a Leica ALS70 500 kHz Multiple Pulses in Air (MPiA) lidar sensor system, on board a Cessna Titan 404. The ALS70 lidar system, developed by Leica Geosystems of Heerbrugg, Switzerland, includes the simultaneous first, intermediate and last pulse data capture module, the extended altitude range module, and the target signal intensity capture module. The system software is operated on an OC50 Operation Controller aboard the aircraft.

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

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 one (1) mission.

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

Figure 2.1: Lidar Flight Layout

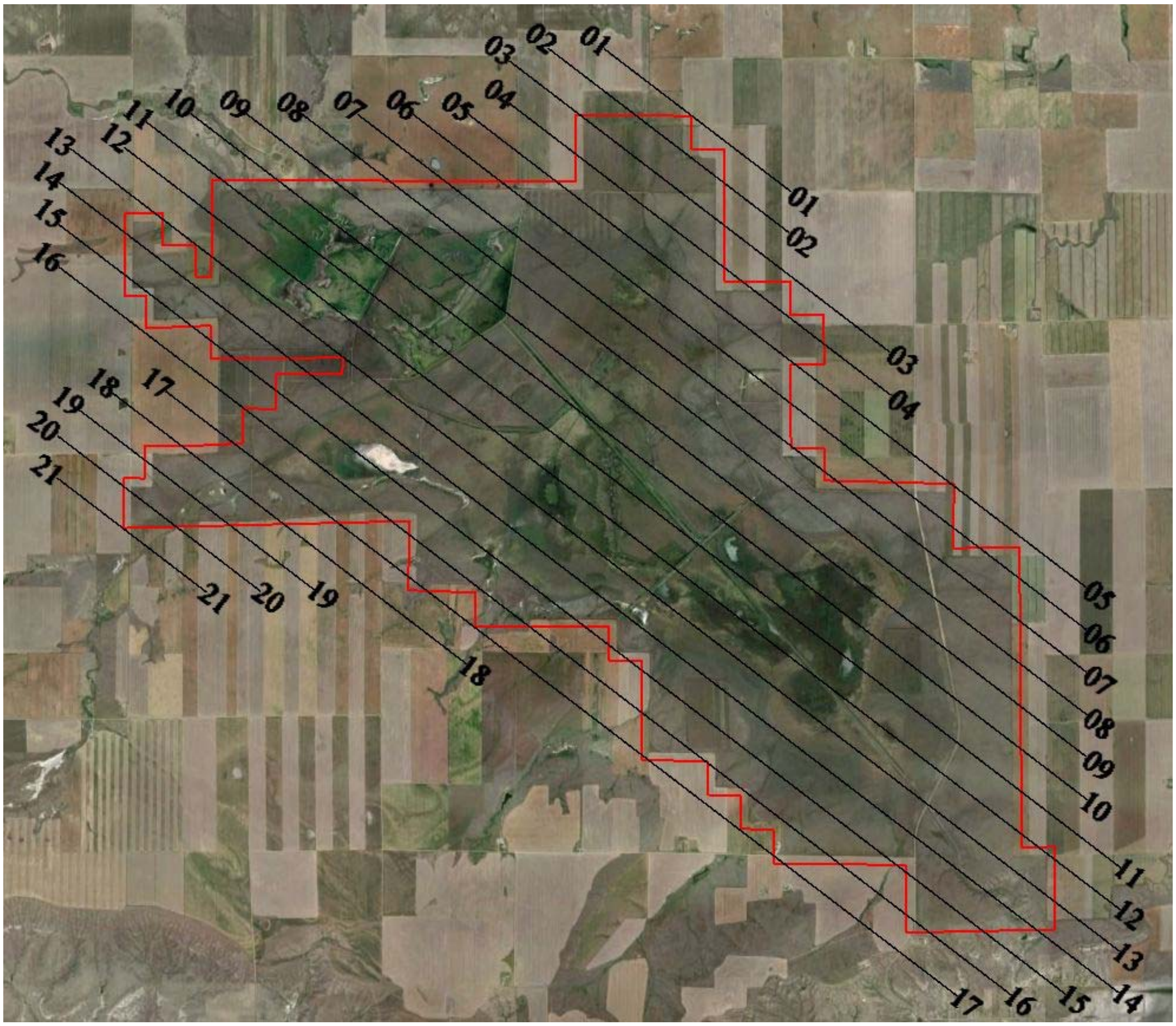


Table 2.2: Airborne Lidar Acquisition Flight Summary

Airborne LiDAR Acquisition Flight Summary			
Date of Mission	Lines Flown	Mission Time (UTC) Wheels Up/ Wheels Down	Mission Time (Local) Wheels Up/ Wheels Down
August 28, 2014 – Sensor 7177	1-21	17:00 – 19:45	11:00AM – 13:45pm

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.1.35.

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.2.75 build #25, Proprietary Software, TerraMatch v. 14.01.

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 the task order classification specifications. Statistical absolute accuracy was assessed via direct comparisons of ground classified points to ground RTK survey data. Based on the statistical analysis, the lidar data was then adjusted to reduce the vertical bias when compared to the survey ground control.
   Software: TerraScan v.14.011.

4. The LAS files were evaluated through a series of manual QA/QC steps to eliminate remaining artifacts from the ground class.
   Software: TerraScan v.14.011.

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 acquisition mission, and was operated by a member of the Woolpert acquisition team. Each base-station setup consisted of one Trimble 4000 – 5000 series dual frequency receiver, one Trimble Compact L1/L2 dual frequency antenna, one 2-meter fixed-height tripod, and essential battery power and cabling. Ground planes were used on the base-station antennas. Data was collected at 1 or 2 Hz.

Woolpert's acquisition team was on site, operating a GNSS base station at Great Falls International Airport.

The GNSS base station operated during the lidar acquisition missions is listed below:

Table 3.1: GNSS Base Station

Station	Latitude	Longitude	Ellipsoid Height (L1 Phase center)
Name	(DMS)	(DMS)	(Meters)
KGTP Airport Base	47°28' 12.09987"	-111°22' 40.80453"	1106.039

DATA PROCESSING

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

TRAJECTORY QUALITY

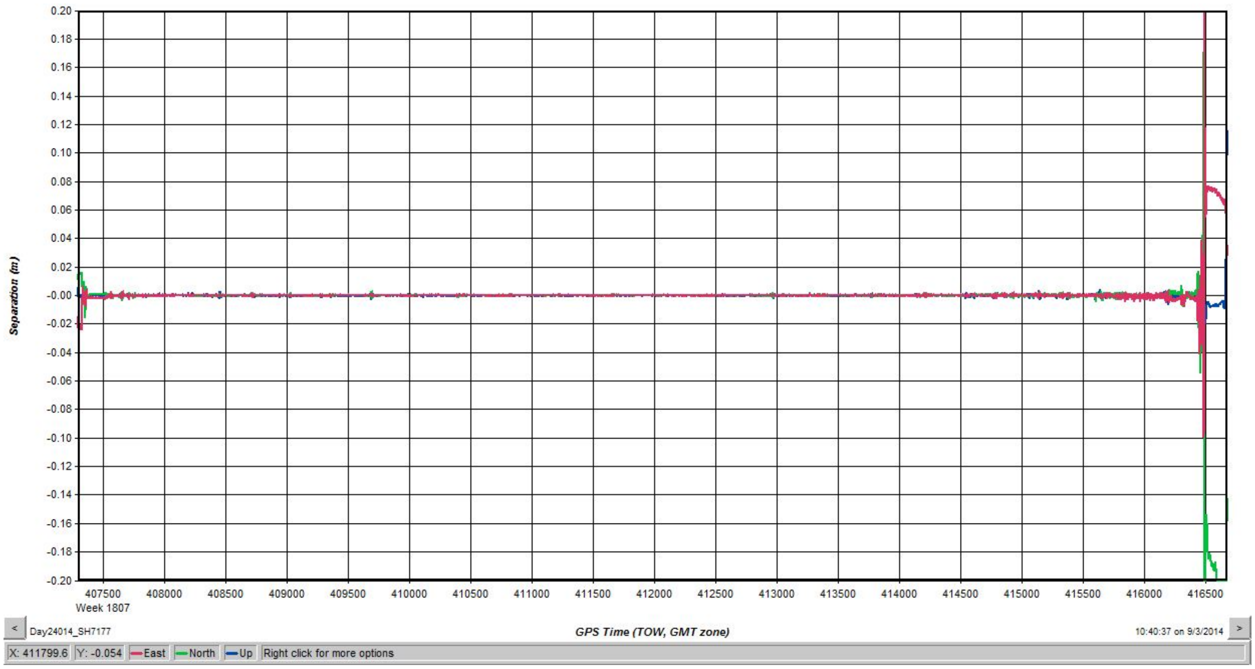
The GNSS Trajectory, along with high quality IMU data are key factors in determining the overall positional accuracy of the final sensor data. Within the trajectory processing, there are many factors that affect the overall quality, but the most indicative are the Combined Separation, the Estimated Positional 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.

Figure 3.1: Combined Separation, Day24014 SH7177

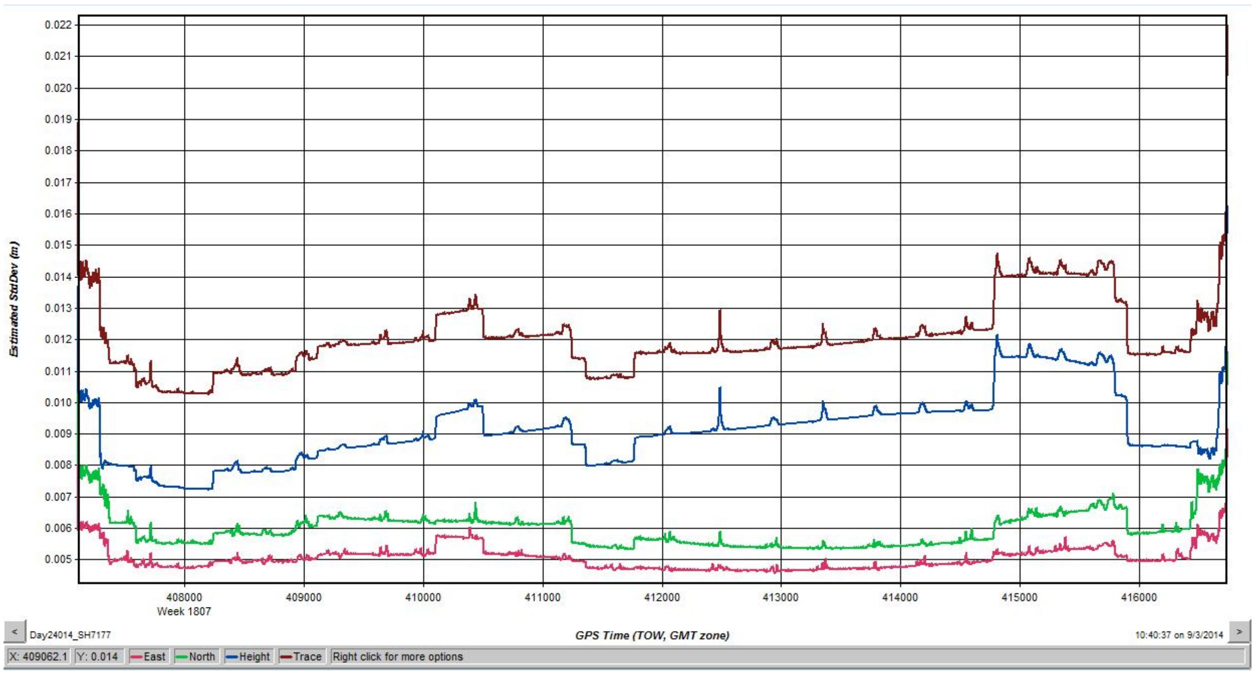


Estimated Positional Accuracy

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 3.2: Estimated Positional Accuracy, Day24014 SH7177

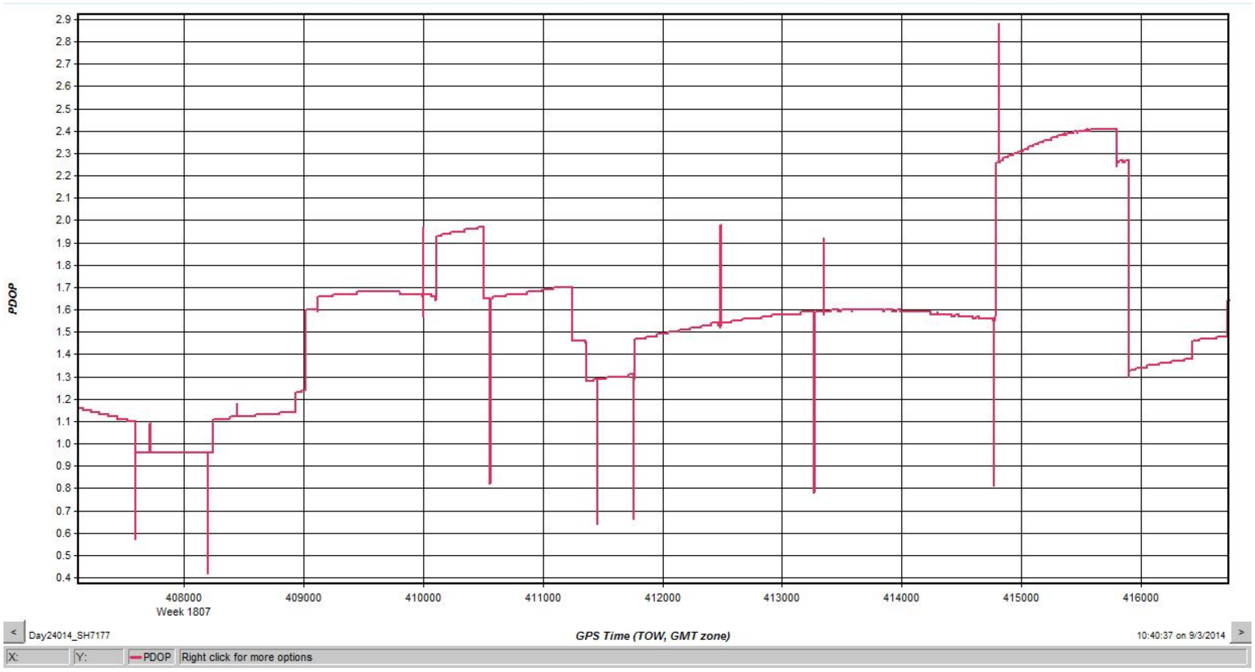


PDOP

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.

Figure 3.3: PDOP, Day24014 SH7177



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 project data was imported and classified, survey ground control data was imported and calculated for an accuracy assessment. As a QC measure, Woolpert has developed a routine to generate accuracy statistical reports by comparisons against the TIN and the DEM using surveyed ground control of higher accuracy. The lidar is adjusted accordingly 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 lidar LAS files are classified into the Default (Class 1), Ground (Class 2), Noise (Class 7), Water (Class 9), Ignored Ground (Class 10), Overlap default (Class 17), and Overlap Ground (Class 18) 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 UTM12N American Datum of 1983 (2011). The vertical datum used for the task order was referenced to NAVD 1988, meters, GEOID12A. Coordinate positions were specified in units of meters.

SECTION 4: HYDROLOGIC FLATTENING

HYDROLOGIC FLATTENING OF LIDAR DEM DATA

Benton lake NWR 0.7m NPS Lidar Processing task order required the compilation of breaklines defining water bodies. 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. The water was at lower than normal levels due to dry season data acquisition which affected the hydrologic breakline collection. Woolpert used professional practice in determining any open water meeting the task order size requirement remaining during the dry season.

LIDAR DATA REVIEW AND PROCESSING

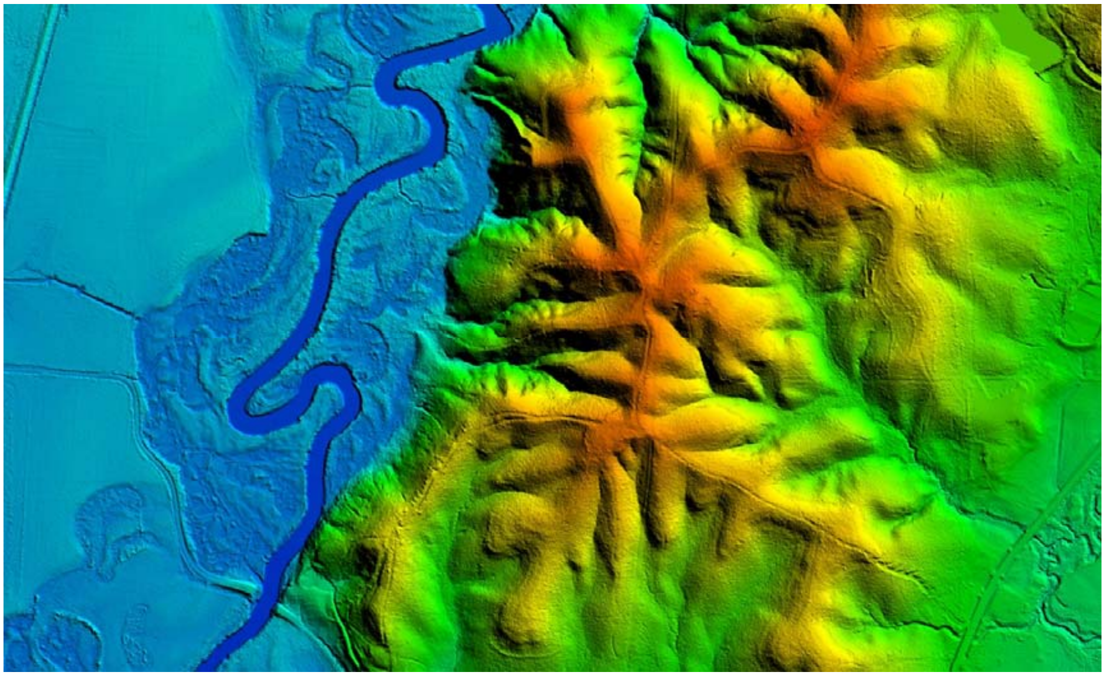
Woolpert utilized the following steps to hydrologically flatten the water bodies and for gradient hydrologic flattening of the double line streams within the existing lidar data.

1. Woolpert used the newly acquired lidar data to manually draw the hydrologic features in a 2D environment using the lidar intensity and bare earth surface. Open Source imagery was used as reference when necessary.

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

3. The lakes, reservoirs and ponds, at a minimum size of 2-acres or greater, were compiled as closed polygons. **Figure 4.1** illustrates an example of 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 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**

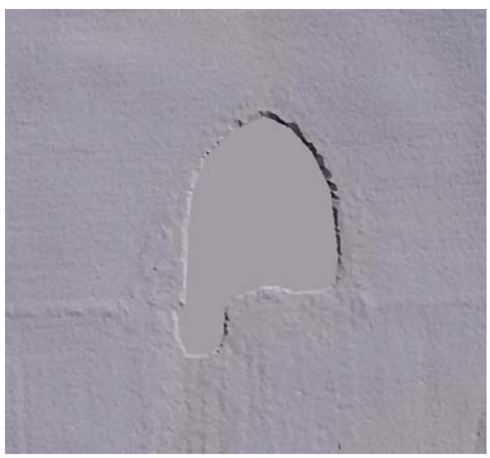


Figure 4.2 reflects a DEM generated from original lidar bare earth point data prior to the hydrologic flattening process. Note the "tinning" across the lake surface.

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 USGS in ERDAS .IMG format at a 1-meter cell size.

The hydrologic breaklines compiled as part of the flattening process were provided to the USGS 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 30.5 meters (100 feet) were provided as a PolylineZ file.

DATA QA/QC

Initial QA/QC for this task order was performed in Global Mapper v15, by reviewing the grids and hydrologic breakline features. Additionally, ESRI software and proprietary methods were used to review the overall connectivity of the hydrologic breaklines.

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

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 quality check points.

Table 5.1: Overall Vertical Accuracy Statistics

Average error	-0.023	meters
Minimum error	-0.335	meters
Maximum error	0.053	meters
Root mean square	0.079	meters
Standard deviation	0.078	meters

Table 5.2: Swath Quality Check Point Analysis, FVA, UTM 12N (2011), NAD83, NAVD88 GEOID12A

Point ID	Easting (UTM meters)	Northing (UTM meters)	TIN Elevation (meters)	Dz (meters)
2001	469272.7	5278823	1114.63	0.029
2002	469295.6	5281675	1113.52	0.027
2003	474078.7	5282798	1111.05	0.063
2004	473798.3	5281225	1105.63	0.026
2005	476719.8	5280416	1113.73	0.038
2006	473161.2	5278019	1120.18	-0.015
2007	478800.5	5273900	1132.74	-0.01
2008	476179.4	5278502	1104.53	0.009
2010	475990.3	5283597	1113.58	0.044
2011	469303.5	5282430	1115.91	0.018
2012	471975	5280884	1120.46	-0.022
2013	472612	5282351	1108.86	0.025
2014	472767.7	5278929	1119.42	0.004
2015	475199.7	5277611	1113.76	0.01
2016	475651.3	5276057	1113.4	-0.017

Point ID	Easting (UTM meters)	Northing (UTM meters)	TIN Elevation (meters)	Dz (meters)
2017	477780.8	5274723	1124.21	-0.061
2018	478922.5	5275390	1107.72	0.021
2019	478810.6	5279133	1121.79	-0.335
2020	477027.3	5280470	1116.56	-0.028
2021	476855.2	5279058	1104.76	0.037
2022	476072.2	5281837	1109.97	-0.003

VERTICAL ACCURACY CONCLUSIONS

LAS Swath Fundamental Vertical Accuracy (FVA) Tested 0.155 meters fundamental vertical accuracy at 95 percent confidence level, derived according to NSSDA, in open terrain in open using (RMSEz) x 1.9600, tested against the TIN.

Bare-Earth DEM Fundamental Vertical Accuracy (FVA) Tested 0.155 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 DEM.

SUPPLEMENTAL VERTICAL ACCURACY ASSESSMENT

Table 5.3: Quality Check Point Analysis, Tall Weeds and Crops, UTM 12N (2011), NAD83, NAVD88 GEOID12A

Point ID	Easting (UTM meters)	Northing (UTM meters)	DEM Elevation (meters)	Absolute Dz (meters)
4001	469291.996	5278833.954	1113.687	0.023
4002	469319.394	5281671.435	1112.625	0.045
4003	474105.053	5282768.442	1110.185	0.055
4004	473789.815	5281187.062	1103.507	0.093
4005	476713.143	5280451.729	1113.813	0.037
4006	473157.534	5278073.861	1120.503	0.007
4007	478817.291	5273900.974	1131.254	0.016
4008	476210.286	5278526.31	1102.865	0.125
4009	478985.726	5278021.133	1106.012	0.058

Point ID	Easting (UTM meters)	Northing (UTM meters)	DEM Elevation (meters)	Absolute Dz (meters)
4010	475985.539	5283573.127	1113.262	0.048
4011	469322.255	5282427.635	1115.49	0.01
4012	471997.913	5280882.414	1119.704	0.056
4013	472653.659	5282328.589	1108.609	0.011
4014	472791.471	5278920.6	1119.232	0.008
4015	475218.316	5277590.874	1114.478	0.032
4016	475665.326	5276068.822	1113.054	0.026
4017	477783.964	5274736.468	1123.257	0.053
4018	478913.186	5275419.562	1105.939	0.061
4019	478837.803	5279132.879	1120.797	0.013
4020	477038.593	5280480.571	1116.034	0.004
4021	476873.909	5279038.704	1103.646	0.064
4022	476090.971	5281847.973	1109.871	0.001

ACCURACY CONCLUSIONS

Tall Weeds and Crops Land Cover Classification Supplemental Vertical Accuracy (SVA) Tested 0.120 meters supplemental vertical accuracy at the 95th percentile, tested against the DEM. Tall Weeds and Crops Errors larger than 95th percentile include:

- Point 4008, Easting 476210.286, Northing 5278526.31, Z-Error 0.125 meters

CONSOLIDATED VERTICAL ACCURACY ASSESSMENT

ACCURACY CONCLUSIONS

Consolidated Vertical Accuracy (CVA) Tested 0.119 meters consolidated vertical accuracy at the 95th percentile level, tested against the DEM. Consolidated errors larger than 95th percentile include:

- Point 4008, Easting 476210.286, Northing 5278526.31, Z-Error 0.125 meters
- Point 2019, Easting 478810.574, Northing 5279132.521, Z-Error 0.335 meters

Approved By:			
Title	Name	Signature	Date
Associate Lidar Specialist Certified Photogrammetrist #1281	Qian Xiao		November 2014

SECTION 6: FLIGHT LOG

FLIGHT LOG

Flight log for the project is shown on the following page.

Woolpert

Leica LIDAR

MM/DD/YEAR	Day of Year	Project #	Phase #	Project Name
8/28/2014	240	74472	2	Benton Lake NWR, MT

Operator	Aircraft	Hobbs Start	Local Start Time	Zulu Start Time	Base
SIMMONS	N475RC	5129.7	11:00:00	17:00:00	WOOLPERT PIN
Pilot	**Sensor Type**	**Hobbs END**	**Local End Time**	**Zulu End Time**	**PID**
SWAIN	ALS-7177	5135.2	13:45:00	19:45:00	

Wind Dir/Speed	Visibility	Ceiling	Cloud Cover %	Temp	Dew Point	Pressure	Haze/Fire/Cloud		
266 @25	10	CLR						Departing	KJAC
								Arriving	KJAC

Scan Angle (FOV)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power %	Fixed Gain	X	Mode		Threshold Values	
24	63.6	372	100	Gain - Course/Up		Single		A	170
				Gain - Fine/Down		Multi	X	B	150

Air Speed		AGL		MSL		Waveform Used				Waveform Mode	Pre-Trigger Dist.
135	Kts	4500	Ft		Ft	Yes		No	X	@ NS	Ft

Line #	Dir.	Line Start Time	Line End Time	Time On Line	SV's	HDOP	PDOP	Line Notes/Comments
Test	n/a			n/a	n/a	n/a	n/a	GPS Began Logging At:
⇩ Times entered are Zulu / GMT ⇩								Verify S-Turns Before Mission Yes X No
1	NW	17:24:00	17:25:00	10:56:00				*SEE NOTES BELOW
2	SE	17:27:00	17:29:00	0:00:00				
3	NW	17:32:00	17:34:00	0:00:00				
4	SE	17:37:00	17:39:00	0:00:00				
5	NW	17:43:00	17:45:00	0:00:00				
6	SE	17:48:00	17:51:00	0:00:00				
7	NW	17:55:00	17:58:00	0:00:00				
8	SE	18:01:00	18:04:00	0:00:00				
9	NW	18:07:00	18:11:00	0:00:00				
10	SE	18:14:00	18:18:00	0:00:00				
11	NW	18:21:00	18:25:00	0:00:00				
12	SE	18:28:00	18:33:00	0:00:00				
13	NW	18:36:00	18:40:00	0:00:00				
14	SE	18:43:00	18:47:00	0:00:00				
15	NW	18:50:00	18:55:00	0:00:00				
16	SE	18:57:00	19:01:00	0:00:00				
17	NW	19:04:00	19:07:00	0:00:00				
18	SE	19:10:00	19:12:00	0:00:00				
19	NW	19:15:00	19:16:00	0:00:00				
20	SE	19:19:00	19:20:00	0:00:00				
21	NW	19:24:00	19:25:00	0:00:00				
				0:00:00				
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↑ Times entered are Zulu / GMT ↑				Page		1		Verify S-Turns After Mission Yes X No

Additional Comments:	Drive #
*WINDS WERE GUSTING AND SHIFTING THE ENTIRE FLIGHT. HARD TO KEEP A CONSTANT SPEED AND HARD ALTITUDE. I NEVER GET AIR SICK BUT TODAY I WAS NAUSEOUS.....THAT'S INDICATIVE OF HOW THE WINDS WERE TODAY.	

SECTION 7: FINAL DELIVERABLES

FINAL DELIVERABLES

The final LiDAR deliverables are listed below.

- LAS v1.2 classified point cloud
- LAS v1.2 raw unclassified point cloud flight line strips no greater than 2GB. Long swaths greater than 2GB will be split into segments)
- Hydrologically flattened Polygon z shapefiles
- Hydrologically flattened bare earth 1-meter DEM in ERDAS .IMG format
- 8-bit gray scale intensity images
- Collected flight lines provided as ESRI shapefile
- Tile Index and data extent provided as ESRI shapefile
- Control points provided as ESRI shapefile
- FGDC compliant metadata per product in XML format
- Lidar processing report in pdf format
- Survey report in pdf format

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