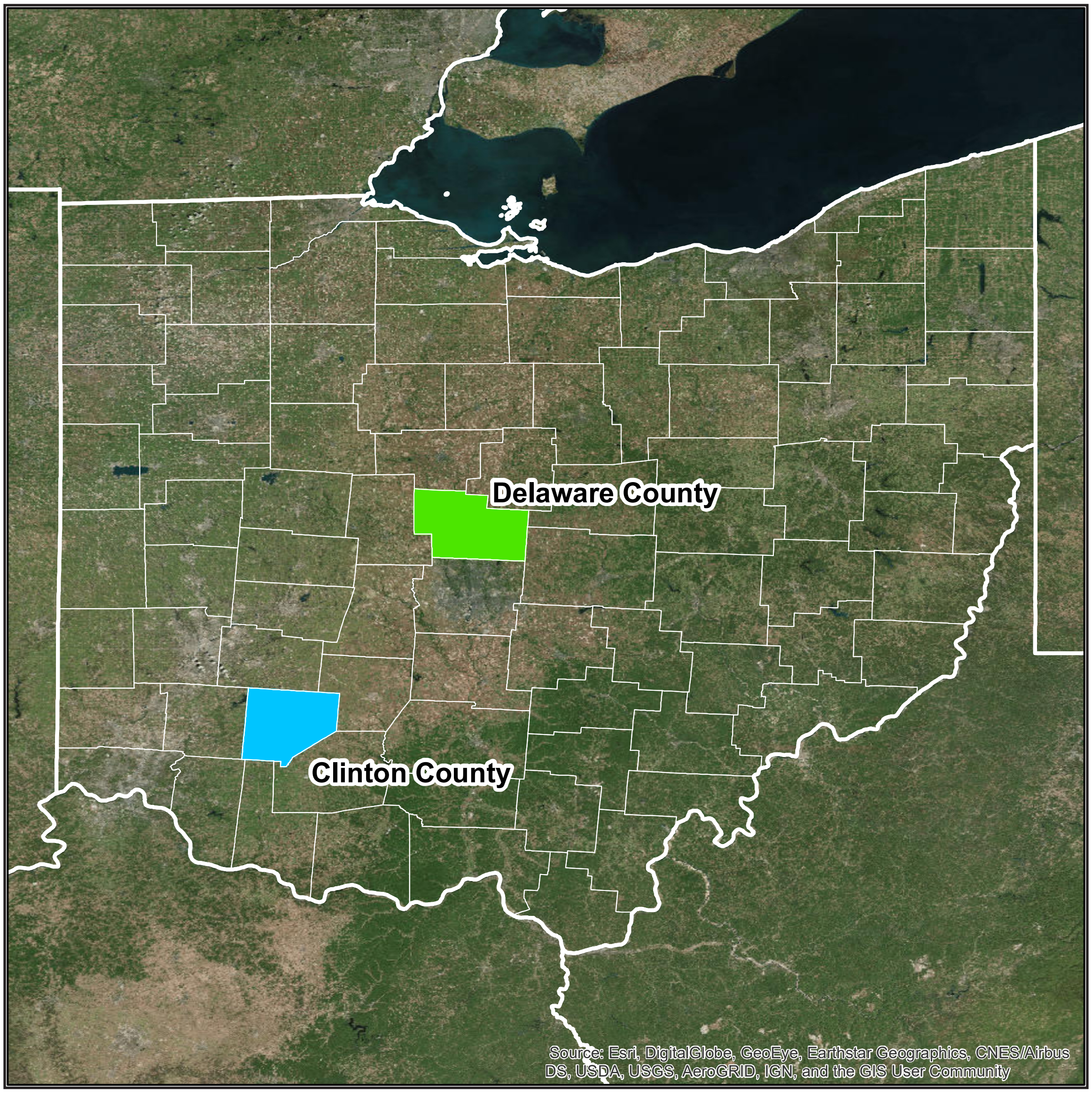
OH Clinton-Delaware 2018 B18

Airborne Lidar Report

March 2019



USGS science for a changing world

Contract # G16PC00022
Task Order # 140G0218F0168

WOOLPERT

Contractor Woolpert
Project # 78462

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1. Overview

About

This project contains a comprehensive outline of the 140G0218F0168 OH Clinton-Delaware 2018 D18 task order issued by the United States Geological Survey's National Geospatial Technical Operations Center (USGS-NGTOC). This task order called for the acquisition and processing of QL2 data over two areas of interest covering approximately 926 square miles across Clinton and Delaware Counties, OH; approximately 439 square miles over the Delaware County AOI.

Purpose

Data was collected as part of this task order to be used for the following: terrain mapping, conservation planning and design, support of easement/land stewardship programs, support of special emphasis programs, support of soil projects, fill gaps in existing lidar, water resource management.

Specifications

Data for this task order was acquired and produced to meet USGS Lidar Base Specification v1.3 standards and the American Society of Photogrammetry and Remote Sensing (ASPRS) Positional Accuracy Standards for Digital Geospatial Data (Edition 1, Version 1.0).

Spatial Reference

Geospatial data products were produced using the following horizontal and vertical spatial data reference system.

Table 1-1. Spatial Reference System

Area of Interest		
Horizontal	**EPSG Code**	6350
	Datum	NAD83 (2011)
	Projection	Contiguous USA Albers
	Units	Meters
Vertical	**Datum**	NAVD88
	Geoid	GEOID12B
	Units	Meters
	Height Type	Orthometric

Deliverables

All data products produced as part of this task order are listed below. All tiled deliverables had a tile size of 1,000-meters x 1,000-meters. Tiles are named using the values of the easting and northing locations of the lower left corner for each tile (ex.: w0002n0612).

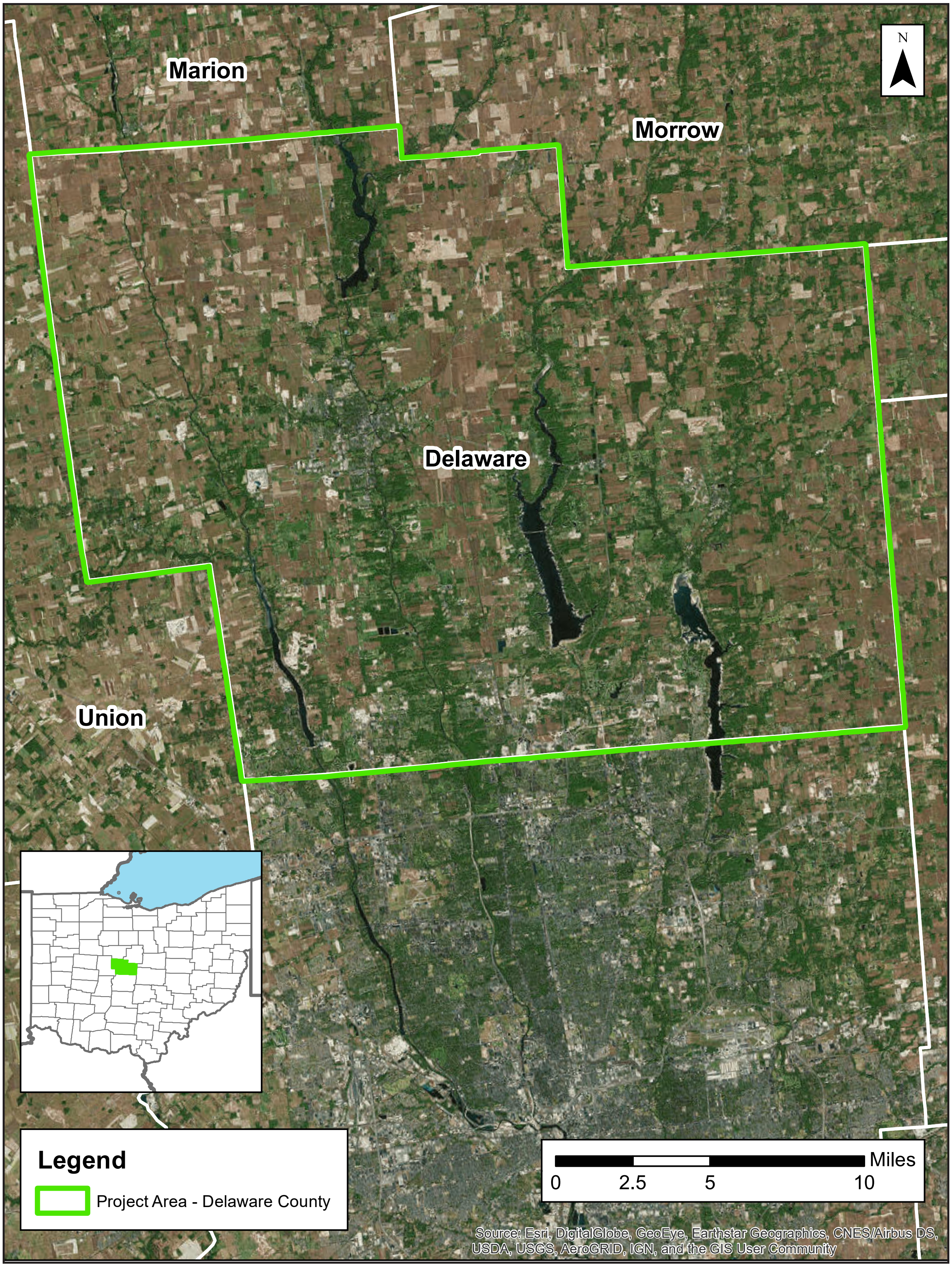
Table 1-2. Deliverables

Lidar Data	
Classified lidar point cloud data	Tiles in .las v1.4 format Classes • 1 – Processed, not Classified • 2 – Ground • 7 – Noise • 9 – Water • 17 – Bridge Decks • 18 – High Noise • 20 – Ignored Ground

Breaklines used for hydro-flattening	• Lake and River features as feature classes in an Esri file geodatabase
	  • Water bodies greater than 2 acres as polygon features
	  • Rivers 30.5 meters / 100 feet and greater in width as polyline features
	• Breaklines used in DEM generation as point features in Esri shapefile format

Hydro-flattened bare earth digital elevation model (DEM)	1-meter pixel size, 32-bit floating-point; no bridges or overpass structures ERDAS IMG format
Intensity Imagery	1-meter pixel size, 8-bit gray-scale (linear rescaling from 16-bit intensity) GeoTIFF format
Flight Line Index	Polygon features in an Esri file geodatabase
Control Data	
Lidar calibration points	Esri shapefile format
Lidar NVA checkpoints	Esri shapefile format
Lidar VVA checkpoints	Esri shapefile format
Other Data	
Data Extent	Esri shapefile format
Delivery Diagram	Esri shapefile format
Tile Index	Esri shapefile format
Metadata and Reports	
Metadata	Deliverable-level FGDC CSDGM/USGS MetaParser-compliant metadata in .xml format
Lidar Project Report	Project report with flight logs in .pdf format
Survey Report	Survey report in .pdf format

Figure 1-1. Project Area



2. Acquisition

Flight Planning

Aerial lidar data was collected using the specifications listed below.

Table 2-1. Acquisition Requirements

Specification	Target
Resolution	• 2 points per square meter • 0.7-meter nominal point spacing
Overlap	At contractor's discretion, but enough to ensure there are no data gaps between usable portions of the swath and nominal point density is achieved
Acquisition Window	During annual minimum water level in the Spring 2018 leaff-off window running March 1 0 April 30, 2018
Acquisition Conditions	• Cloud and fog-free between the aircraft and ground • Ground is snow free • Ground has no unusual flooding or inundation, except in cases where the goal of the collection is to map the inundation • Preference of vegetation is leaf-off
Data Voids	Not allowed except • Where caused by water bodies • Where caused by areas of low near infra-red (NIR) reflectivity (i.e. asphalt or composition roofing) • Where caused by lidar shadowing from buildings or other features • Where appropriately filled-in by another swath
Control	Airborne Global Positioning System (ABGPS) and Inertial Measurement Unit (IMU) data to be used along with differentially-corrected GPS ground control points

Lidar Sensor Information

Aerial lidar data was acquired using the Leica ALS80 and Leica Terrain Mapper lidar sensor systems. A total of 36 flight lines were collected.

Table 2-2. Leica Terrain Mapper Sensor Info

Sensor Specifications	
Operating Altitude (m AGL)	300 - 5,500 at 10% reflective target
Maximum Measurement Rate (kHz)	2,000
Scan Angle	20 - 40
Scan Width	Up to 70% of flight altitude
Scan Frequency	Programmable up to 125 Hz (7,500 RPM), 250 scan lines per second
Number of Returns	15
Number of intensity measurements	15
Pulse Mode(s)	Up to 35 pulses in air
Laser Specifications	
Laser Beam Divergence	0.25 mrad (1/e)
Laser Classification	Class 4 laser product
Accuracy	
Range Resolution	< 1 cm RMS
Elevation Accuracy	< 5 cm 1 σ
Horizontal Accuracy	< 13 cm 1 σ
Physical Specifications	
Size (cm), Weight (kg) • Scanner • Control Electronics	 • 37 W x 68 L x 26 H cm, 47 kg • 45 W x 47 D x 25 H cm, 33 kg
Operating Temperature • Scanner • Control Electronics	 • 0 - 40°C cabin-side temperature • 0 - 40°C
Flight Management	Leica FlightPro
Power Consumption	922 W @ 22.0 – 30.3 VDC

Table 2-3. Leica ALS80 Sensor Info

Sensor Specifications	
Operating Altitude (m AGL)	100 - 3,500 at 10% reflective target
Maximum Measurement Rate (kHz)	1,000
Field of view (degrees, full angle, user adjustable)	0 - 72
Roll stabilization (automatic adaptive, degrees)	72 - active FOV
Scan patterns (user selectable)	sine, triangle raster
Maximum Scan Rate (Hz) • Scan • Triangle • Raster	 • 200 • 158 • 120
Number of Returns	unlimited
Number of intensity measurements	3 (first, second, third)
Pulse Mode(s)	2 - 6 pulses in air
Laser Specifications	
Laser Beam Divergence	Dual Divergence: 0.20-0.26 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
Accuracy	
Range Resolution	Better than 1 cm
Elevation Accuracy	6 - 19 cm single shot (one standard deviation)
Horizontal Accuracy	1/5,500 x altitude (m AGL)
Physical Specifications	
Size (cm), Weight (kg) • Scanner • Control Electronics	 • 37 W x 68 L x 26 H cm, 47 kg • 45 W x 47 D x 25 H cm, 33 kg
Operating Temperature • Scanner • Control Electronics	 • 0 - 40°C cabin-side temperature • 0 - 40°C
Flight Management	Leica FlightPro
Power Consumption	922 W @ 22.0 – 30.3 VDC

GNSS and IMU Equipment

Prior to mobilizing to the project site, flight crews coordinated with the necessary air traffic control personnel to ensure airspace access. Crews were on-site, operating a Global Navigation Satellite System (GNSS) Base Station for the airborne GPS support.

Flight navigation during acquisition was 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.

Base stations were set by acquisition staff and was used to support the aerial data acquisition. See the table below for stations operated during acquisition.

Table 2-3. GNSS Base Stations

Station Name	Latitude (DMS)	Longitude (DMS)	Ellipsoid Height L1 Phase Center (Meters)
OHUN_CORS	40° 13’ 58.84901"	-83° 21’ 39.07467"	279.679

Timeline

Lidar data was collected from March 6, 2018 through December 11, 2018. Acquisition specifications are listed in the table below. An initial quality control process was immediately performed on to review the data coverage, airborne GPS data, and trajectory solution.

Table 2-5. Acquisition Specifications

Settings	Leica ALS80	Leica TM
Max. Number of Returns	Unlimited	15
Nominal Point Spacing	0.7 m	0.86 m
Nominal Point Density	2 ppsm	2.72 ppsm
Flying Height Above Ground Level	2,377 m	2,748 m
Flight Speed	150 knots	150 knots
Scan Angle	40°	40°
Scan Rate Used	35.5 Hz	89.5 Hz
Pulse Rate Used	346 kHz	600 kHz
Multi-Pulse in Air	Enabled	Enabled
Swath Width	1,731 m	1,8192 m
Swath Overlap	25.5%	28.5%

For more information, see the Flight Logs in Appendix 1.

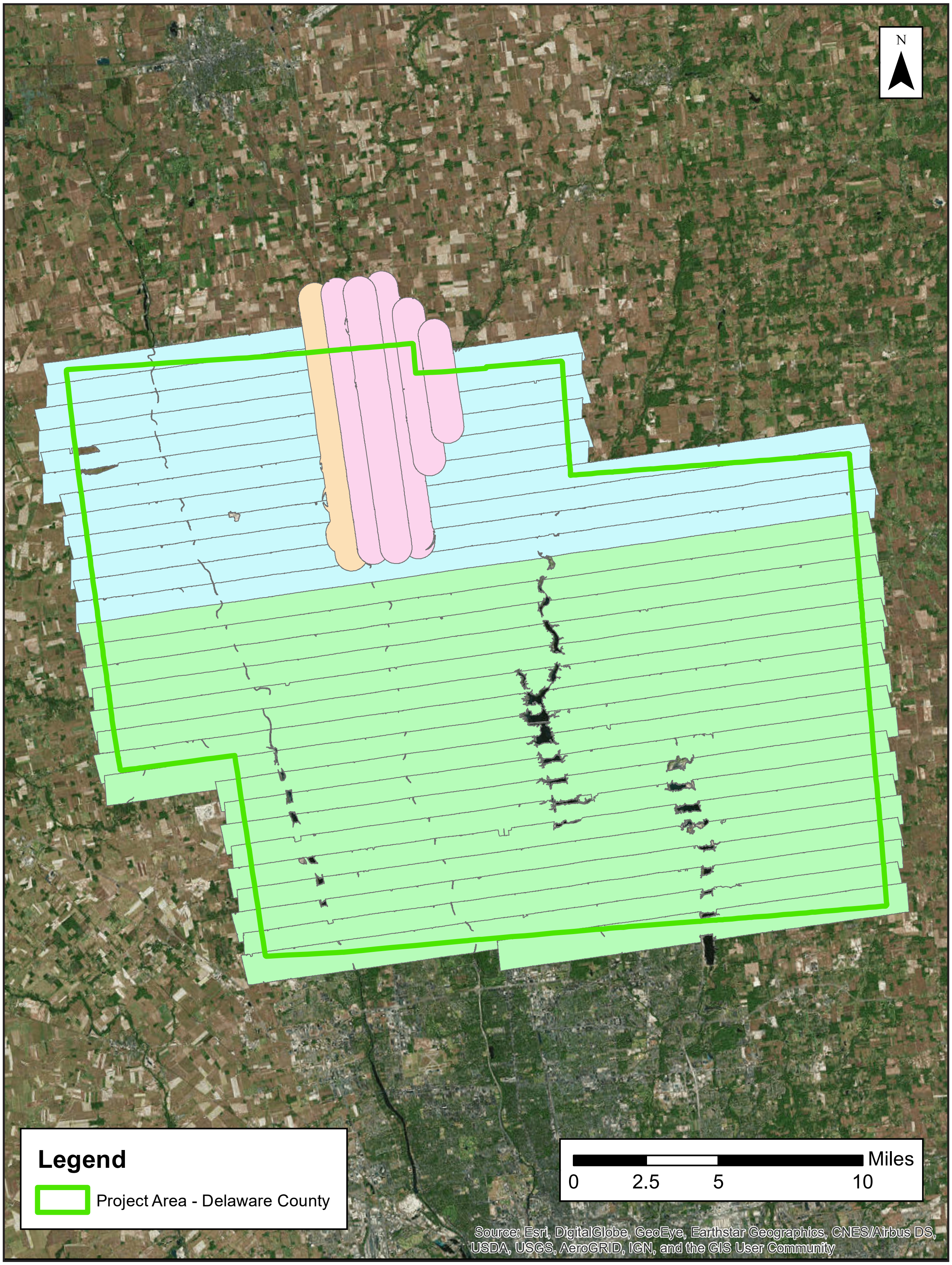
Note: There was flooding present in an area around Delaware Lake. This area was re-flown in Fall 2018, when leaf-off conditions were present.

Acquisition Quality Assurance

Woolpert developed a quality assurance and validation plan to ensure the acquired lidar data meets the USGS Base Specification Version 1.3. For quality assurance purposes, the lidar data was processed immediately following acquisition to verify the coverage has appropriate density, distribution, and no unacceptable data voids. Accompanying GPS data was post processed using differential and Kalman filter algorithms to derive a best estimate of trajectory. The quality of the solution was verified to be consistent with the accuracy requirements of the task order. Any required re-flights were scheduled at the earliest opportunity.

The spatial distribution of the geometrically usable first return lidar points was reviewed for density requirements as well as regular and uniform point distribution - verifying the lidar data is spaced so that 90% of the cells in a 2*NPS grid placed over the data contain at least one lidar point. The NPS assessment is made against single swath, first return data located within the geometrically usable center portion (typically ~90%) of each swath. Additionally, the data was reviewed for unacceptable data voids – verifying no area greater than or equal to $(4 \times ANPS)^2$ exhibited data coverage gaps.

Figure 2-1: Flown Flight Lines



3. Processing

Processing Summary

Once the lidar data passed initial QC, the dataset was corrected for aircraft orientation and movement. This process used airborne inertial, orientation, and GPS data collected during acquisition along with ground-based GPS data. The data went through a geometric calibration that further corrected each laser point. This calibrated data set was used to create the LAS point cloud. The LAS point data was initially classified into “ground” and “non-ground”, then further refined using the classes specified in this task order. Breaklines were drawn to denote hydrological features. After the hydro-flattening process, the final deliverables products were created.

GNSS-IMU Trajectory Processing

Kinematic corrections for the aircraft position were resolved using aircraft GPS and static ground GPS (1-Hz) for each geodetic control (base station) for three subsystems: inertial measurement unit (IMU), sensor orientation information, and airborne GPS data.

Post-processing of the IMU system data and aircraft position with attitude data was completed to compute an optimally accurate, blended navigation solution based on Kalman filtering technology, or the smoothed best estimate of trajectory (SBET).

Software: POSPac Software v. 5.3, IPAS Pro v.1.35., Novatel Inertial Explorer v8.60.6129

Trajectory Quality

The GNSS trajectory and 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).

Combination Separation

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

The data for this task order was processed with a goal to maintain a combined separation difference of less than ten (10) centimeters.

Estimated Positional Accuracy

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.

PDOP

The PDOP measures the precision of the GPS solution in regard to the geometry of the satellites acquired and used for the solution.

The data for this task order was processed with a goal 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.

Geometric Calibration

After the initial phase was complete, a formal reduction process was performed on the data. Laser point position was calculated by associating the SBET position to each laser point return time, scan angle, intensity, etc. Raw laser point cloud data was created for the whole project area 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. Statistical reports were generated for comparison and used to make the necessary adjustments to remove any residual systematic error.

Software: Proprietary Software, TerraMatch v18, Leica CloudPro 1.2.4

Lidar Data Classification

LAS data was 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 of higher accuracy.

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 the following client-specified classes:

- Class 1 – Default / Processed, but not Classified
- Class 2 – Bare Earth Ground
- Class 7 – Low Noise
- Class 9 – Water
- Class 17 – Bridge Decks
- Class 18 – High Noise
- Class 20 – Ignored Ground

Classified LAS files were evaluated through a series of manual QA/QC steps as well as a peer-based review to eliminate remaining artifacts from the ground class. This included a review of the DEM surface to remove artifacts and ensure topographic quality.

Software: Proprietary Software, TerraScan v18

Hydrologic Flattening

The lidar task order required compilation of breaklines defining the following types of water body features:

Lakes, reservoirs, ponds	Minimum of 2-acres or greater Compiled as closed polygons, collected at a constant elevation
Rivers, streams	Nominal width of 30.5 meters / 100 feet Compiled in direction of flow, with both sides maintaining an equal elevation gradient
Bridge breaklines	Breaklines used to enforce a logical terrain surface below a bridge

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. The newly acquired lidar data was utilized to manually compile 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. An integrated software approach was applied 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. All classified ground points from inside the hydrologic feature polygons were reclassified to water, class nine (9).
4. All classified ground points were reclassified from within a buffer along the hydrologic feature breaklines to buffered ground, class twenty (20). The buffer distance was approximately the task order designed nominal pulse spacing distance.
5. Breaklines used for bridge removal during the hydrologic flattening were included with the hydrologic breakline geodatabase deliverable. The purpose of these breaklines is for a more aesthetically pleasing DEM appearance.
6. The lidar ground points and breaklines were used to generate a digital elevation model (DEM).
7. QA/QC for this task was performed by reviewing the hydrologically flattened DEM and hydrologic breakline features. Additionally, a combined approach utilizing commercial off the shelf software and proprietary methods were used to review the overall connectivity of the hydrologic breaklines.

TerraScan was used to add the hydrologic breakline vertices and export the lattice models.

Breaklines defining the water bodies greater than 2-acres were provided as polygon features. Rivers and streams with a nominal minimum width of 30.5 meters (100 feet) were provided as polyline features. All lake and river breaklines compiled as part of the flattening process were provided in an Esri file geodatabase.

Breaklines used for DEM generation were provided as point features in Esri shapefile format.

Software: TerraScan v18, TerraModeler v18, Esri ArcMap v10.4, LP360 v2018.1.57.4

Digital Elevation Model

TerraScan was used to add the hydrologic breakline vertices and export the lattice models. Class 2 (ground) lidar points in conjunction with the hydro breaklines and bridge breaklines were used to create 1-meter hydro-flattened bare-earth raster DEM files. Using automated scripting routines within ArcMap, an 32-bit floating point raster ERDAS IMG file was created for each tile. Files were produced to the full extents of the tile boundaries. Each surface is reviewed using Global Mapper to check for any surface anomalies or incorrect elevations found within the surface.

Intensity Imagery

Lidar intensity data derived from the acquired lidar data was linearly rescaled from 16-bit intensity and provided as 1-meter pixel, 8-bit, 256 gray scale GeoTIFF format intensity imagery files. Files were produced to the full extents of the tile boundaries.

Software: TerraScan v18

Metadata

FGDC CSDGM/USGS MetaParser-compliant metadata was produced in XML format. The metadata includes a complete description of the task order client information, contractor information, project purpose, lidar acquisition and ground survey collection parameters, lidar acquisition and ground survey collection dates, spatial reference system information, data processing including acquisition quality assurance procedures, GPS and base station processing, geometric calibration, lidar classification, hydrologic flattening, intensity imagery development, and final product development.

Other metadata deliverables included Esri shapefiles of the ground control and QA/QC points, delivery tile index, and delivery extent. A georeferenced, polygonal representation of the detailed extents of each acquired lidar swath was produced as a polygon feature class in an Esri file geodatabase.

4. Accuracy Assessment

Results Summary

The tables below show a summary of all test results. The following sections describe the testing methods used.

Software: TerraScan v18, Esri ArcMap v10.4

Table 4-1. Vertical Accuracy Summary

Testing Categories	Target	Measured	Minimum Points	Points Used
Raw Swath NVA RMSEz 95% at Confidence Level	0.196 m	0.068 m	30	35
DEM NVA RMSEz at 95% Confidence Level	0.196 m	0.054 m	30	35
DEM VVA RMSEz at 95th Percentile	0.30 m	0.201 m	20	25

Raw Lidar Swath Testing

This project required Non-Vegetated Vertical Accuracy (NVA) to be tested on the raw lidar point cloud swath data. The dataset was required to meet a target value of 19.6 cm at a 95% confidence level using an RMSEz target value of 10 cm x 1.9600. Testing was assessed and reported using guidelines developed by the National Digital Elevation Program (NDEP) and the American Society for Photogrammetry and Remote Sensing (ASPRS).

The raw NVA was to be calculated with a minimum of 30 independent checkpoints that were not used in the calibration or post processing of the lidar point cloud data. Checkpoints were to be distributed throughout the project area and located in bare earth and urban (non-vegetated) land cover classes.

Testing was performed using TINs created from the final calibrated and controlled swath data. For each NVA checkpoint, an elevation value was derived from the TIN at the point's x,y location. This value was compared to the checkpoint's surveyed elevation value.

The raw NVA was tested using 35 checkpoints. These checkpoints were surveyed using GPS techniques. See the survey report for acquisition methodologies. This dataset was tested to be 0.068 meters using an RMSEz of 0.035 meters x 1.9600.

For full checkpoint results, see the tables in Appendix 2.

Digital Elevation Model Testing

This project required Non-Vegetated Accuracy (NVA) and Vegetated Vertical Accuracy (VVA) testing of the digital elevation model (DEM) dataset. The calculated NVA value was required to meet 19.6 cm at a 95% confidence level using an RMSEz target value of 10 cm x 1.9600. VVA was required to meet 0.30 cm at the 95th percentile error. Testing was assessed and reported using guidelines developed by the National Digital Elevation Program (NDEP) and the American Society for Photogrammetry and Remote Sensing

(ASPRS).

Testing was performed using the bare earth DEM created as part of this task order. For each checkpoint, an elevation value was derived from the DEM at the point's x,y location. This value was compared to the checkpoint's surveyed elevation value.

The NVA was to be calculated with a minimum of 30 independent checkpoints falling on bare earth and urban (non-vegetated) classes. VVA had a minimum of checkpoints requirement of 20 for the falling in brush/tall grass/weeds (vegetated) land cover classes. These points were not used in the calibration or post processing of the lidar point cloud data and distributed throughout the project area. Checkpoints were surveyed using GPS techniques. See the survey report for acquisition methodologies.

The DEM NVA measured 0.054 meters using an RMSEz of 0.028 meters x 1.9600 using 35 checkpoints. VVA tested 0.201 meters at the 95th percentile using 25 checkpoints.

VVA errors larger than the 95th percentile are listed below. All values are in meters.

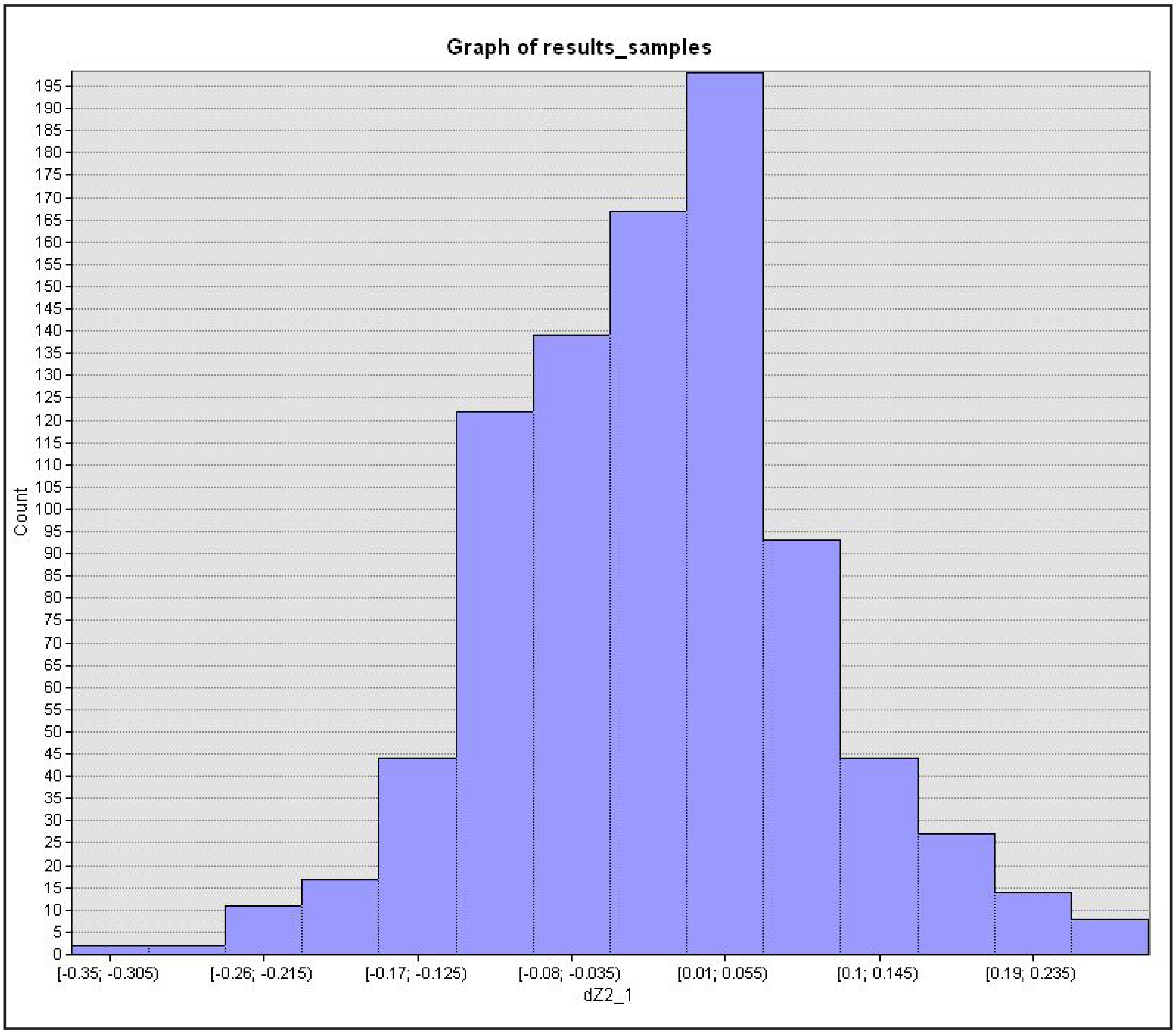
For full checkpoint results, see the tables in Appendix 3 and 4.

Table 4-2. VVA Errors

Point ID	Easting	Northing	Z-Error
3004	1095281.875	1995606.127	0.256
3016	1112147.216	1995286.821	0.210

Inter-Swath Testing

Inter-swath accuracy was tested against well-distributed flight line overlap locations. The relative accuracy for the lidar measured at 0.028 meters RMSE.



Values are in meters.

Approved By	Name	Signature	Date
Associate Member, Lidar Specialist Certified Photogrammetrist #1381	Qian Xiao		March 2019

Intra-Swath Testing

Intra-swath accuracy, also known as "within swath" accuracy, was tested against single swath first return data located in flat open areas. The intra-swath accuracy for the lidar measured at 0.006 meters RMSDz.

Appendix 1: Flight Logs

Woolpert

Leica LIDAR	MM/DD/YEAR	Day of Year	Project #	Phase #	Project Name
	3/6/2018	65	78459		Delaware

Operator	Aircraft	HOBBS Start	Local Start Time	ZULU Start Time	Base
Kat	475RC	1223.9	11:15:00	16:15:00	
Pilot	**Sensor Type/Number**	**HOBBS END**	**Local End Time**	**Zulu End Time**	**PID**
Russ	ALS 8130	1227.2	14:46	19:46	

Wind Dir/Speed	Visibility	Ceiling	Cloud Cover %	Temp	Dew Point	Pressure	Haze/Fire/Cloud	Departing	KDAY
200/08	10	150	FEW			2974		Arriving	KDAY

Scan Angle (FOV)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power %	Fixed Gain		Mode		Threshold Values	
40	35.5	346	100	Gain - Course/Up		Single		A	
				Gain - Fine/Down		Multi		B	

Air Speed		AGL		MSL		Waveform Used				Waveform Mode		Pre-Trigger Dist.	
150	Kts	7800	Ft	8570	Ft	Yes		No		@	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	277	16:47:00	16:51:00	0:04:00	18		1.2					
2	097	16:55:00	16:59:00	0:04:00	18		1.2					
3	277	17:03:00	17:10:00	0:07:00	16		1.4					
4	097	17:14:00	17:21:00	0:07:00	16		1.4					
5	277	17:24:00	17:31:00	0:07:00	17		1.4	Big Lake				
6	097	17:34:00	17:41:00	0:07:00	16		1.4	Big Lake				
7	277	17:45:00	17:52:00	0:07:00	17		1.2					
8	097	17:55:00	18:01:00	0:06:00	17		1.2					
9	277	18:07:00	18:18:00	0:11:00	20		1					
10	097	18:21:00	18:31:00	0:10:00	19		1.1					
11	277	18:35:00	18:45:00	0:10:00	21		1.1					
12	097	18:49:00	18:58:00	0:09:00	21		1.1					
30	277	19:05:00	19:11:00	0:06:00	20		1.4	Cloud on west end				
				0:00:00								
				0:00:00								
				0:00:00								
				0:00:00								
				0:00:00								
				0:00:00								
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				0:00:00								
		↑ Times entered are Zulu / GMT ↑		Page		1		Verify S-Turns After Mission	Yes	x	No	

Additional Comments:	Drive #
Flight 1/13-flown/17 remaining	

Woolpert

Leica LIDAR	MM/DD/YEAR	Day of Year	Project #	Phase #	Project Name
	3/10/2018	69	78459		Delaware County

Operator	Aircraft	HOBBS Start	Local Start Time	ZULU Start Time	Base
Kat	475RC	1227.2	9:05:00	14:05:00	
Pilot	**Sensor Type/Number**	**HOBBS END**	**Local End Time**	**Zulu End Time**	**PID**
Russ	ALS 8130	1232.2	14:05	19:05	

Wind Dir/Speed	Visibility	Ceiling	Cloud Cover %	Temp	Dew Point	Pressure	Haze/Fire/Cloud	Departing	KDAY
030/04	10	SKC	0	M01	M06	3004		Arriving	KDAY

Scan Angle (FOV)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power %	Fixed Gain		Mode		Threshold Values	
40	35.5		100	Gain - Course/Up		Single		A	
				Gain - Fine/Down		Multi		B	

Air Speed		AGL		MSL		Waveform Used		Waveform Mode		Pre-Trigger Dist.
150	Kts	7800	Ft	8570	Ft	Yes	No	@	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
13	E	14:33:00	14:42:00	0:09:00	17		1.4	
14	W	14:46:00	14:55:00	0:09:00	17		1.3	
15	E	14:59:00	15:08:00	0:09:00	19		1.1	
16	W	15:11:00	15:21:00	0:10:00	17		1.2	
17	E	15:24:00	15:33:00	0:09:00	17		1.2	
18	W	15:37:00	15:46:00	0:09:00	18		1.1	small cloud frame 9
19	E	15:49:00	15:59:00	0:10:00	19		1.1	
20	W	16:02:00	16:12:00	0:10:00	18		1.1	
21	E	16:15:00	16:23:00	0:08:00	19		1	
22	W	16:26:00	16:34:00	0:08:00	18		1.1	
23	E	16:37:00	16:45:00	0:08:00	18		1.1	
24	W	16:48:00	16:57:00	0:09:00	17		1.3	
25	E	17:00:00	17:08:00	0:08:00	17		1.3	
26	W	17:11:00	17:19:00	0:08:00	17		1.3	
27	E	17:22:00	17:30:00	0:08:00	17		1.2	IMU warning error at end of finished line
28	W	17:39:00	17:47:00	0:08:00	18		1.2	new static turns done before start of line
29	E	17:50:00	17:58:00	0:08:00	20		1	
30	W	18:01:00	18:06:00	0:05:00	18		1.1	
27	E	18:12:00	18:20:00	0:08:00	20		1.1	small cloud frame 14
				0:00:00				
				0:00:00				
				0:00:00				
				0:00:00				
				0:00:00				
				0:00:00				
				0:00:00				
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				0:00:00				
				0:00:00				
				0:00:00				
		↑ Times entered are Zulu / GMT ↑		Page		1		Verify S-Turns After Mission Yes No

Additional Comments:

Line 27 reflown because of IMU warning

Drive #

Woolpert

Leica LIDAR	MM/DD/YEAR	Day of Year	Project #	Phase #	Project Name
	4/27/2018	117	78462	91	Delaware county gaps

Operator	Aircraft	HOBBS Start	Local Start Time	ZULU Start Time	Base
Kat	7079F	1162.6	8:37:00	12:37:00	
Pilot	**Sensor Type/Number**	**HOBBS END**	**Local End Time**	**Zulu End Time**	**PID**
Ray	ALS 8194				

Wind Dir/Speed	Visibility	Ceiling	Cloud Cover %	Temp	Dew Point	Pressure	Haze/Fire/Cloud	Departing	KDAY
240/03	10	220	BKN	9	7	2979		Arriving	KDAY

Scan Angle (FOV)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power %	Fixed Gain		Mode		Threshold Values	
40	35.5	346	100	Gain - Course/Up		Single		A	
				Gain - Fine/Down		Multi		B	

Air Speed		AGL		MSL		Waveform Used		Waveform Mode		Pre-Trigger Dist.	
150	Kts	7800	Ft	8481	Ft	Yes	No	@	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 / No
33	E	13:15:00	13:16:00	0:01:00	16		1.3		
34	E	13:20:00	13:21:00	0:01:00	16		1.3		
32	W	13:28:00	13:29:00	0:01:00	15		1.5		
31	W	13:32:00	13:33:00	0:01:00	15		1.5		
				0:00:00				no s turns went to Clinton	
				0:00:00					
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		↑ Times entered are Zulu / GMT ↑		Page		1		Verify S-Turns After Mission	Yes / No

Additional Comments:	Drive #

Woolpert Lidar Acquisition Log

Project Info			Date		
Project #	Project Name	Unique ID	Flight Date (UTC)	Day of Year	Flight #
	TM TEST / DWTN TEST	---	12/11/18	345	1

Crew	Equipment	Time			Airports
Pilot	Aircraft Make / Model / Tail #	Hobbs Start	Local Start	UTC Start	Departing
GEBHART	404CP	6889.0	11:07	16:07	DAY
Operator	Sensor Make / Model / Serial #	Hobbs End	Local End	UTC End	Arriving
SMITH	TM 511	6892.1	2:12	19:12	DAY

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
220	13	6		CLR	-1	-6	3015

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)

Verify S-Turns Before Mission

Line #	Direction	Start Time (UTC)	End Time (UTC)	Time On-Line	Satellite	PDOP	Line Notes/Comments
2	N	16:21	16:24		19	1.1	CALIBRATION
1	S	16:27	16:30		21	1.0	
3	E	16:36	16:39		21	1.0	
4	W	16:42	16:46		20	1.1	
6	N	16:49	16:51		21	1.1	
5	S	16:54	16:56		21	1.1	
1	N	17:03	17:04		20	1.2	DWTN 10PPm TEST
2	S	17:07	17:09		20	1.2	
3	N	17:12	17:13		20	1.2	

Verify S-Turns After Mission

Additional Comments

Woolpert Lidar Acquisition Log

Project Info			Date		
Project #	Project Name	Unique ID	Flight Date (UTC)	Day of Year	Flight #
78462	CLINTON/DELAWARE	---	12/11/18	345	1

Crew	Equipment	Time			Airports
Pilot	Aircraft Make / Model / Tail #	Hobbs Start	Local Start	UTC Start	Departing
GEBHART	404 CP	6889.0	11:07	16:07	DAY
Operator	Sensor Make / Model / Serial #	Hobbs End	Local End	UTC End	Arriving
SMITH	TM 511	6892.1	2:12	19:12	DAY

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
220	13	6		CLR	-1	-6	3015

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
150	8202	9016	

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
		40	89	600	100

Verify S-Turns Before Mission: ✓

Line #	Direction	Start Time (UTC)	End Time (UTC)	Time On-Line	Satellite	PDOP	Line Notes/Comments
35	S	17:25	17:27		20	1.2	CLINTON
36	N	17:29	17:32		22	1.1	
37	S	17:37	17:39		23	1.0	
38	N	17:44	17:46		22	1.1	
35	N	18:07	18:11		22	1.1	DELAWARE
36	S	18:17	18:21		22	1.1	
37	N	18:23	18:28		21	1.1	
38	S	18:30	18:33		21	1.1	
39	N	18:36	18:38		22	1.0	
40	S	18:41	18:43		22	1.0	

Page 1 | Verify S-Turns After Mission:

Additional Comments

Appendix 2: Raw Swath NVA Checkpoint Results

Coordinate values are listed in the following spatial reference system:

Horizontal: NAD83 (2011) Contiguous USA Albers, Meters

Vertical: NAVD88 (GEOID12B), Meters

Summary	
Point Count	35
Average dZ	+0.007
Minimum dZ	-0.082
Maximum dZ	+0.112
Average Magnitude	0.026
Root Mean Square	0.035
Standard Deviation	0.035

Point ID	Easting	Northing	Known Z	Laser Z	dZ
2001	1112489.452	1984328.379	331.662	331.580	-0.082
2002	1085257.040	2001024.515	284.528	284.540	0.012
2003	1102247.133	1996239.254	286.900	286.890	-0.010
2004	1082352.269	1995855.513	293.061	293.070	0.009
2005	1098835.646	2000217.291	294.250	294.240	-0.010
2006	1077863.035	1998526.022	275.031	275.060	0.029
2007	1078478.687	2002357.806	283.509	283.550	0.041
2008	1108638.219	1978781.303	305.067	305.090	0.023
2009	1104694.052	1984080.429	279.454	279.460	0.006
2010	1089521.948	2005157.220	293.331	293.350	0.019
2011	1073430.065	1998356.672	281.465	281.500	0.035
2012	1095259.889	1995635.847	277.165	277.150	-0.015
2013	1086147.311	1988343.183	281.637	281.610	-0.027
2014	1091493.772	1982831.252	280.029	280.030	0.001
2015	1086498.085	1995803.679	265.797	265.790	-0.007
2016	1104847.378	1999440.051	315.118	315.230	0.112
2017	1093537.319	2006215.944	296.791	296.830	0.039
2018	1112132.662	1995278.464	342.588	342.580	-0.008
2019	1109761.202	1988575.880	321.836	321.820	-0.016

Point ID	Easting	Northing	Known Z	Laser Z	dZ
2020	1095779.048	1992727.356	284.262	284.230	-0.032
2021	1084797.651	1981598.866	286.050	286.050	0.000
2022	1079863.195	1991441.012	275.616	275.650	0.034
2023	1076133.262	1994357.554	283.555	283.510	-0.045
2024	1072784.963	1990175.263	292.282	292.290	0.008
2025	1101347.566	1981403.595	287.240	287.210	-0.030
2026	1090264.284	2007920.018	290.792	290.830	0.038
2027	1108851.278	2001937.782	350.153	350.150	-0.003
2028	1090128.026	1986979.410	287.248	287.260	0.012
2029	1081211.374	1986412.780	271.712	271.740	0.028
2030	1108281.427	1997486.655	329.646	329.670	0.024
2031	1076672.377	2007586.320	281.349	281.290	-0.059
2032	1104580.874	1991189.492	295.680	295.700	0.020
2033	1071774.922	2006028.725	280.456	280.490	0.034
2034	1082771.425	1983984.322	281.052	281.090	0.038
2035	1087335.915	1992292.633	269.636	269.650	0.014

Appendix 3: DEM NVA Checkpoint Results

Coordinate values are listed in the following spatial reference system:

Horizontal: NAD83 (2011) Contiguous USA Albers, Meters

Vertical: NAVD88 (GEOID12B), Meters

Summary	
Point Count	35
Root Mean Square Error	0.028 m
95% Confidence Level	0.054 m
Mean of Residuals	0.021 m
Standard Deviation	0.019 m

Point ID	Easting	Northing	Known Z	DEM Z	dZ
2001	1112489.452	1984328.379	331.662	331.600	-0.062
2002	1085257.04	2001024.515	284.528	284.550	0.022
2003	1102247.133	1996239.254	286.900	286.900	0.000
2004	1082352.269	1995855.513	293.061	293.070	0.009
2005	1098835.646	2000217.291	294.250	294.230	-0.020
2006	1077863.035	1998526.022	275.031	275.020	-0.011
2007	1078478.687	2002357.806	283.509	283.530	0.021
2008	1108638.219	1978781.303	305.067	305.080	0.013
2009	1104694.052	1984080.429	279.454	279.470	0.016
2010	1089521.948	2005157.22	293.331	293.330	-0.001
2011	1073430.065	1998356.672	281.465	281.480	0.015
2012	1095259.889	1995635.847	277.165	277.170	0.005
2013	1086147.311	1988343.183	281.637	281.640	0.003
2014	1091493.772	1982831.252	280.029	280.020	-0.009
2015	1086498.085	1995803.679	265.797	265.800	0.003
2016	1104847.378	1999440.051	315.118	315.180	0.062
2017	1093537.319	2006215.944	296.791	296.840	0.049
2018	1112132.662	1995278.464	342.588	342.600	0.012
2019	1109761.202	1988575.88	321.836	321.820	-0.016
2020	1095779.048	1992727.356	284.262	284.260	-0.002

Point ID	Easting	Northing	Known Z	DEM Z	dZ
2021	1084797.651	1981598.866	286.050	286.040	-0.010
2022	1079863.195	1991441.012	275.616	275.670	0.054
2023	1076133.262	1994357.554	283.555	283.510	-0.045
2024	1072784.963	1990175.263	292.282	292.280	-0.002
2025	1101347.566	1981403.595	287.240	287.220	-0.020
2026	1090264.284	2007920.018	290.792	290.830	0.038
2027	1108851.278	2001937.782	350.153	350.150	-0.003
2028	1090128.026	1986979.41	287.248	287.250	0.002
2029	1081211.374	1986412.78	271.712	271.750	0.038
2030	1108281.427	1997486.655	329.646	329.680	0.034
2031	1076672.377	2007586.32	281.349	281.320	-0.029
2032	1104580.874	1991189.492	295.680	295.690	0.010
2033	1071774.922	2006028.725	280.456	280.490	0.034
2034	1082771.425	1983984.322	281.052	281.100	0.048
2035	1087335.915	1992292.633	269.636	269.670	0.034

Appendix 4: DEM VVA Checkpoint Results

Coordinate values are listed in the following spatial reference system:

Horizontal: NAD83 (2011) Contiguous USA Albers, Meters

Vertical: NAVD88 (GEOID12B), Meters

Summary	
Point Count	25
Root Mean Square Error	0.093 m
95th Percentile	0.201 m
Mean of Residuals	0.068 m
Standard Deviation	0.064 m

Point ID	Easting	Northing	Known Z	DEM Z	dZ
3001	1085252.997	2000997.858	281.979	282.030	0.051
3002	1102239.036	1996221.709	284.736	284.750	0.014
3003	1105485.175	1983386.131	277.635	277.760	0.125
3004	1095281.875	1995606.127	275.954	276.210	0.256
3005	1080041.075	1991367.726	278.019	278.040	0.021
3006	1112487.175	1984343.188	331.516	331.480	-0.036
3007	1099267.442	2000337.214	297.307	297.290	-0.017
3008	1077744.954	1998525.659	276.089	276.160	0.071
3009	1099046.887	1986128.049	282.924	283.090	0.166
3010	1089555.300	2004705.825	293.083	293.080	-0.003
3011	1073106.512	1998355.485	281.468	281.510	0.042
3012	1086008.050	1988598.026	282.136	282.180	0.044
3013	1091873.668	1982332.317	283.758	283.800	0.042
3014	1082221.395	2005993.360	292.296	292.320	0.024
3015	1104843.615	1999425.082	315.200	315.260	0.060
3016	1112147.216	1995286.821	342.240	342.450	0.210
3017	1109766.142	1988460.075	322.051	322.070	0.019
3018	1095514.054	1993166.096	285.083	285.210	0.127
3019	1084571.306	1981527.100	282.402	282.490	0.088
3020	1076680.369	2007576.382	281.149	281.170	0.021

Point ID	Easting	Northing	Known Z	DEM Z	dZ
3021	1082487.594	1995446.369	285.186	285.180	-0.006
3022	1075256.180	2001152.904	271.020	271.050	0.030
3023	1093907.717	2007344.674	297.554	297.630	0.076
3024	1090381.030	1986300.937	284.356	284.420	0.064
3025	1108204.738	1997717.519	329.316	329.400	0.084