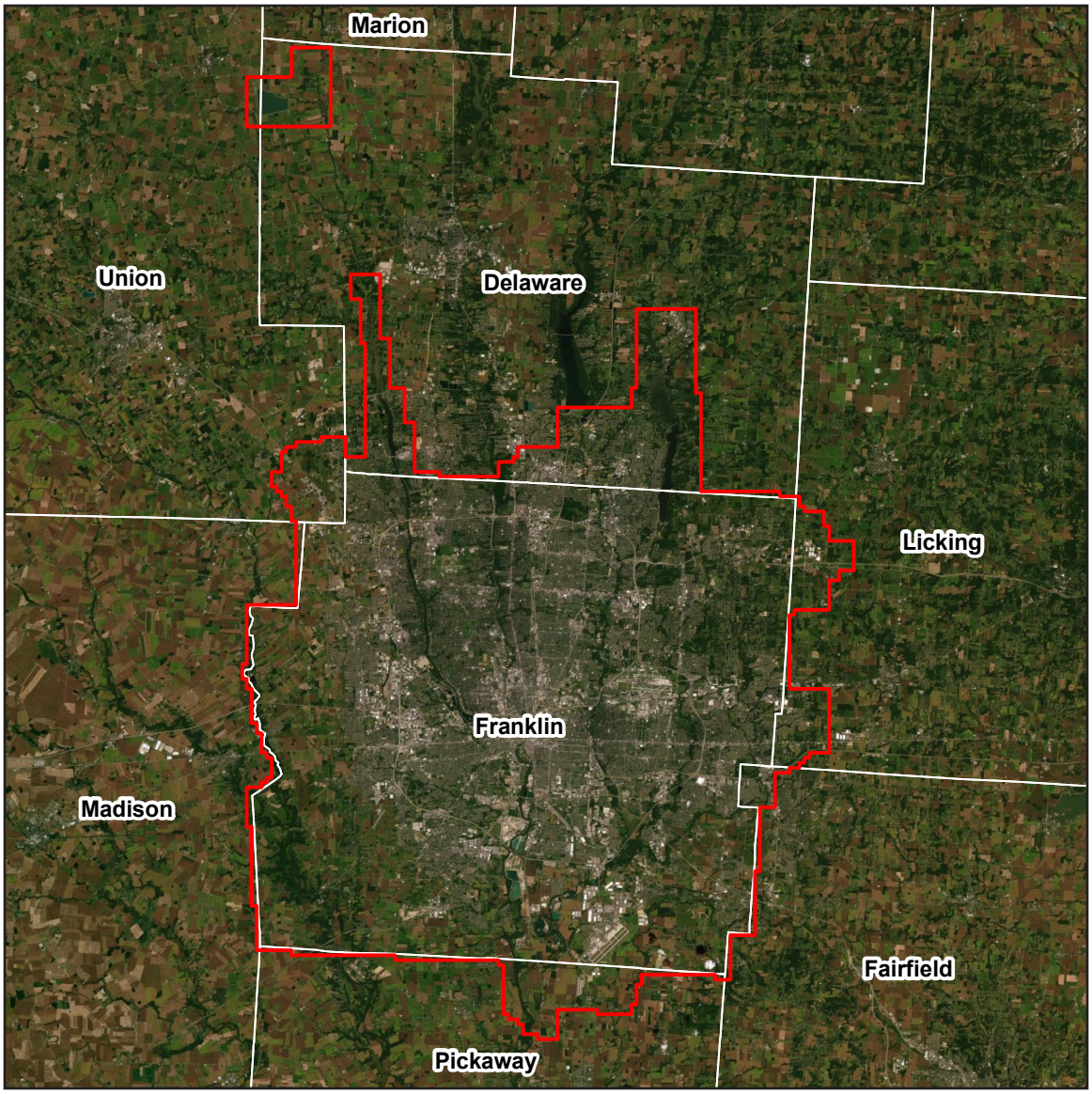
OH Columbus 2019 B19

Airborne Lidar Report

November 2019



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Contract # G16PC00022
Task Order # 140G0219F0111

WOOLPERT

Contractor Woolpert
Project # 79674

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1. Overview

About

This project contains a comprehensive outline of the 140G0219F0111 OH Columbus 2019 B19 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 QL0 data over one area of interest covering approximately 755 square miles across the City of Columbus area surrounding counties.

Data fully covers the following counties:

- Franklin

Data partially covers the following counties:

- Delaware, Fairfield, Licking, Madison, Marion, Pickaway, and Union

Purpose

The purpose of this project was to support the 3DEP mission, the Natural Resources Conservation Service (NRCS) high resolution elevation enterprise program and the Federal Emergency Management Agency (FEMA) Risk Mapping, Assessment and Planning (MAP) program.

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 - State Plane

Area of Interest		
Horizontal	**EPSG Code**	3754
	Datum	NAD83 (HARN)
	Projection	State Plane Ohio South Zone
	Units	U.S. survey feet
Vertical	**Datum**	NAVD88
	Geoid	GEOID12B
	Units	U.S. survey feet
	Height Type	Orthometric Heights

After acceptance by NCTOC, a secondary dataset was produced in the following system.

Table 1-2. Spatial Reference System - Albers

Area of Interest		
Horizontal	**EPSG Code**	6350
	Datum	NAD83 (2011)
	Projection	Albers Equal Area
	Units	meters
Vertical	**Datum**	NAVD88
	Geoid	GEOID12B
	Units	meters
	Height Type	Orthometric Heights

Deliverables

All data products produced as part of this task order are listed below. All tiled deliverables had a tile size of 1,250-feet x 1,250-feet. Tile names are derived from the OGRIP tile index.

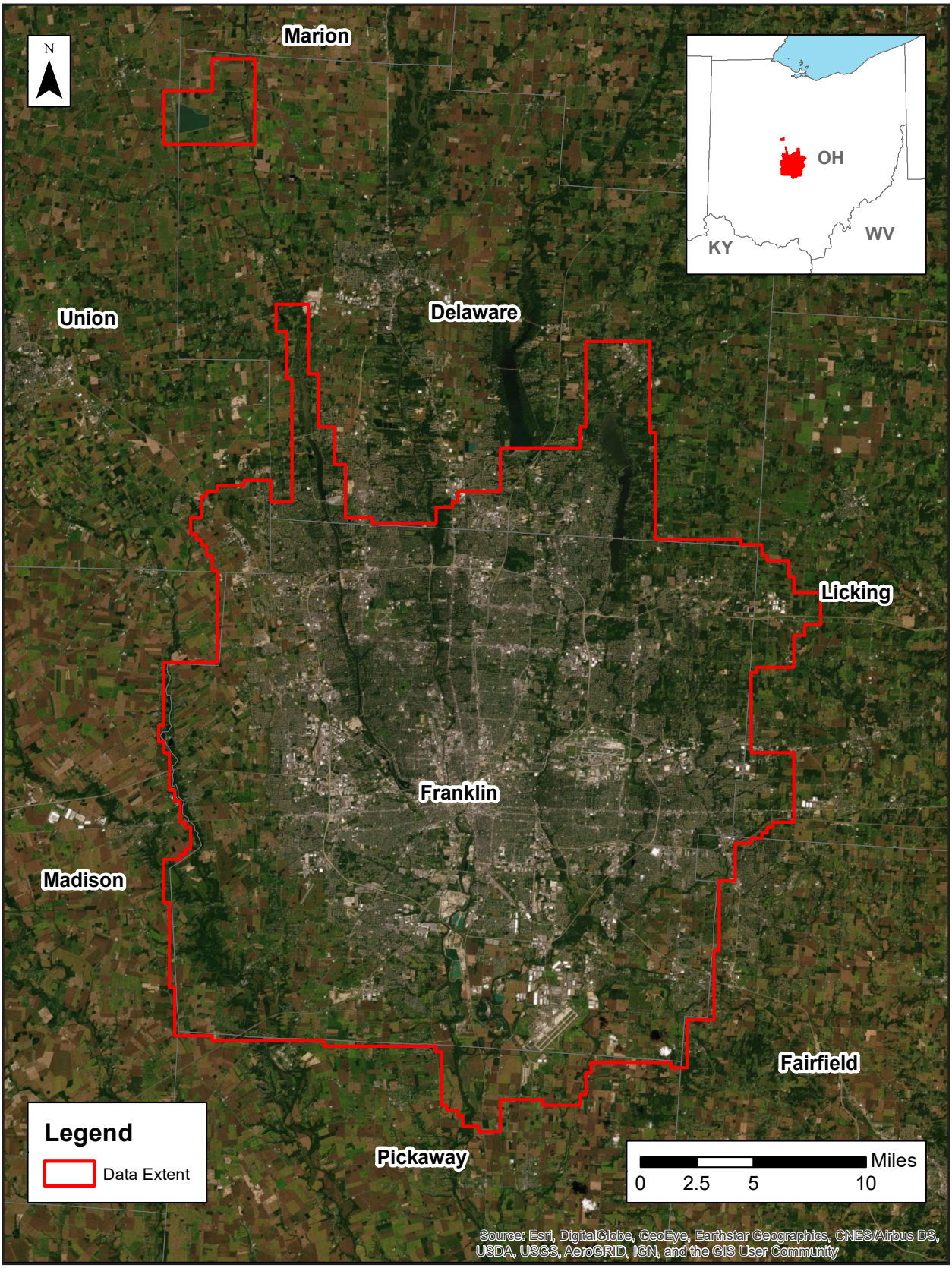
Table 1-2. Deliverables

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
	• Bridges used in DEM generation as point features in Esri shapefile format

Hydro-flattened bare earth digital elevation model (DEM)	1-foot pixel size, 32-bit floating-point; no bridges or overpass structures GeoTIFF format
Intensity Imagery	1-foot 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
Tile Index	Esri shapefile format
Metadata and Reports	
Metadata	Product-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	• 12 points per square meter • 0.29 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	At a period of annual minimal water level in the spring 2019 leaf-off window running through April 30, 2019
Acquisition Conditions	• Cloud and fog-free between the aircraft and ground • Ground is snow free; very light undrafted snow may be acceptable in special cases, with prior approval • 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 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 Terrain Mapper lidar sensor system. A total of 99 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

Source: Leica TerrainMapper Data Sheet
https://leica-geosystems.com/en-US/products/airborne-systems/topographic-lidar-sensors/leica-terrainmapper

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)
COLB_CORS	39° 57 '35.11256"	83° 02' 44.74693"	186.508
OHUN_CORS	40° 13' 58.84901"	83° 21' 39.07467"	279.679

Timeline

Lidar data was collected from March 24, 2019 through April 7, 2019. 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 2-4. Acquisition Specifications

Settings	#SENSOR#
Max. Number of Returns	15
Nominal Point Spacing	0.29 m
Nominal Point Density	12.58 ppsm
Flying Height Above Ground Level	1,372 m
Flight Speed	130 knots
Scan Angle	40°
Scan Rate Used	150 Hz
Pulse Rate Used	1,320 kHz
Multi-Pulse in Air	Enabled
Swath Width	999 m
Swath Overlap	25%

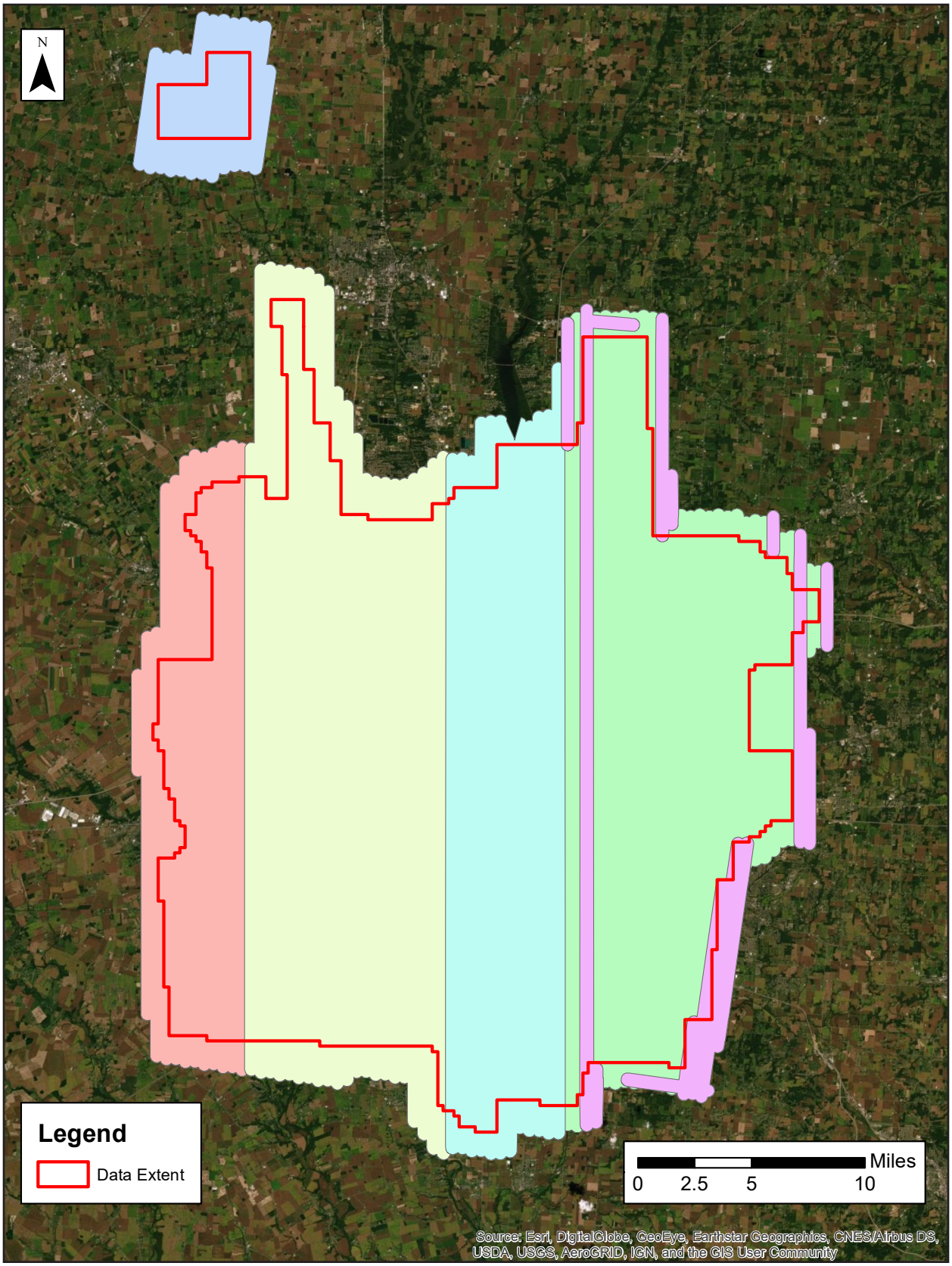
For more information, see the #Flight Logs in Appendix 1.

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-foot hydro-flattened bare-earth raster DEM files. Using automated scripting routines within ArcMap, an 32-bit floating point raster GeoTIFF 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-foot 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 data 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

Horizontal Accuracy

This data set was produced to meet ASPRS "Positional Accuracy Standards for Digital Geospatial Data" (2014) for a 10.1 cm RMSEx / RMSEy Horizontal Accuracy Class which equates to Positional Horizontal Accuracy = +/- 24.9 cm at a 95% confidence level.

Table 4-1. Vertical Accuracy Summary

Testing Categories	Target	Measured	Minimum Points	Points Used
Raw Swath NVA RMSEz 95% at Confidence Level	0.098 m	0.050 m	45	55
DEM NVA RMSEz at 95% Confidence Level	0.098 m	0.052 m	45	55
DEM VVA RMSEz at 95th Percentile	0.15 m	0.122 m	35	37

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 9.8 cm at a 95% confidence level using an RMSEz target value of 5 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 45 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 55 checkpoints. These checkpoints were surveyed using GPS techniques. See the survey report for acquisition methodologies. This dataset was tested to be 0.050 meters using an RMSEz of 0.026 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 9.8 cm at a 95% confidence level using an RMSEz target value of 5 cm x 1.9600. VVA was required to meet 0.15 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 45 independent checkpoints falling on bare earth and urban (non-vegetated) classes. VVA had a minimum requirement of 35 independent checkpoints 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 0.052 meters using an RMSEz of 0.027 meters x 1.9600 using 55 checkpoints. VVA tested 0.122 meters at the 95th percentile using 37 checkpoints.

VVA errors larger than the 95th percentile are listed below.

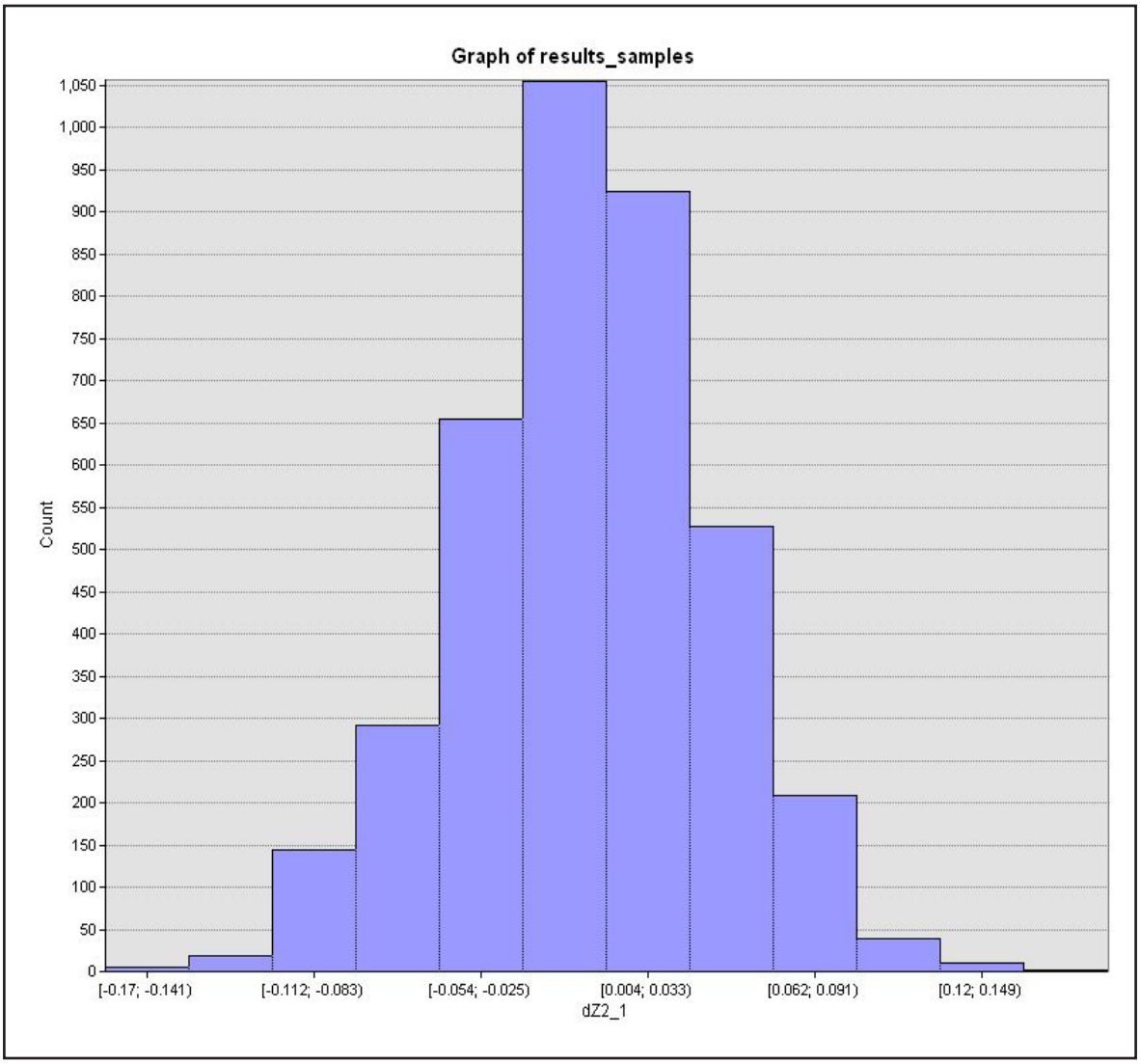
For full checkpoint results, see the tables in Appendix 3 and 4.

Table 4-2. VVA Errors

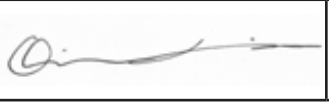
Point ID	Easting (ft)	Northing (ft)	Z-Error (m)
3009_2019_OH	1860523.945	767878.439	0.139

Inter-Swath Testing

Inter-swath accuracy was tested against well-distributed flight line overlap locations. The relative accuracy for the lidar measured at 0.013 meters RMSE.



Values are in meters.

Approved By	Name	Signature	Date
Associate Member, Lidar Specialist Certified Photogrammetrist #1381	Qian Xiao		August 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 0.010 meters RMSDz.

Appendix 1: Flight Logs

Woolpert Lidar Acquisition Log

Project Info			Date		
Project #	**Project Name**	**Unique ID**	**Flight Date (UTC)**	**Day of Year**	**Flight #**
79674	OH Columbus 2019 B19	Day083_90515	03/24/2019	083	

Crew	Equipment	Time			Airports
Pilot	**Aircraft Make / Model / Tail #**	**Hobbs Start**	**Local Start**	**UTC Start**	**Departing**
Oleary	Reims 406 - N406SD	175.1	08:14:00	12:14:00	DAY
Operator	**Sensor Make / Model / Serial #**	**Hobbs End**	**Local End**	**UTC End**	**Arriving**
Nardone	Leica Terrain Mapper - 90515	186.6	02:59:00	18:59:00	DAY

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
180	5	6	25,000	Broken	3		30.27

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
130	4,500	5,200	700

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
0.3	12	40	150	1320	100

Verify S-Turns Before Mission

Line #	Direction	Start Time (UTC)	End Time (UTC)	Time On-Line	Satellite	PDOP	Line Notes/Comments
80	N	12:50:00	12:51:00	00:01:00	19	1.2	We flew lines at (5,300 - 5,500) Altitude
79	S	12:55:00	12:56:00	00:01:00	19	1.2	" "
78	N	13:00:00	13:01:00	00:01:00	22	1.1	" "
77	S	13:05:00	13:10:00	00:05:00	21	1	" "
76	N	13:13:00	13:19:00	00:06:00	20	1.1	" "
75	S	13:22:00	13:27:00	00:05:00	18	1.1	" "
74	N	13:30:00	13:36:00	00:06:00	17	1.2	" "
73	S	13:39:00	13:45:00	00:06:00	17	1.1	" "
72	N	13:48:00	13:54:00	00:06:00	18	1.1	" "
71	S	14:01:00	14:08:00	00:07:00	16	1.5	" "
70	N	14:11:00	14:18:00	00:07:00	19	1	" "
69	S	14:21:00	14:29:00	00:08:00	17	1.1	" "
68	N	14:32:00	14:41:00	00:09:00	17	1.2	" "
67	S	14:44:00	14:54:00	00:10:00	16	1.3	" "
66	N	14:57:00	15:07:00	00:10:00	16	1.4	" "
65	S	15:10:00	15:20:00	00:10:00	16	1.4	" "
64	N	15:23:00	15:33:00	00:10:00	16	1.5	" "
63	S	15:36:00	15:47:00	00:11:00	18	1.3	" "
62	N	15:50:00	16:03:00	00:13:00	18	1.2	" "
61	S	16:06:00	16:20:00	00:14:00	21	1	" "
60	N	16:22:00	16:36:00	00:14:00	20	1.1	" "
59	S	16:39:00	16:52:00	00:13:00	19	1.2	Flew lines at (5,150 - 5,250)
58	N	16:55:00	17:08:00	00:13:00	21	1.2	" "
57	S	17:11:00	17:24:00	00:13:00	19	1.3	" "
56	N	17:28:00	17:41:00	00:13:00	19	1.3	" "

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 #
79674	OH Columbus 2019 B19	Day083_90515	03/24/2019	83	

Crew	Equipment	Time			Airports
Pilot	Aircraft Make / Model / Tail #	Hobbs Start	Local Start	UTC Start	Departing
Oleary	Reims 406 - N406SD	175.1	08:14:00	12:14:00	DAY
Operator	Sensor Make / Model / Serial #	Hobbs End	Local End	UTC End	Arriving
Nardone	Leica Terrain Mapper - 90515	186.6	02:59:00	18:59:00	DAY

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
180	5	6	25,000	Broken	3		30.27

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
130	4,500	5,200	700

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
0.3	12	40	150	1320	100

Verify S-Turns Before Mission

Line #	Direction	Start Time (UTC)	End Time (UTC)	Time On-Line	Satellite	PDOP	Line Notes/Comments
55	S	17:44:00	17:58:00	00:14:00	18	1.2	" "
54	N	18:01:00	18:15:00	00:14:00	17	1.5	" "
53	S	18:18:00	18:31:00	00:13:00	19	1.5	" "

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 #**
79674	OH Columbus 2019 B19 - North & South Block	Day085_90515	03/26/2019	085	

Crew	Equipment	Time			Airports
Pilot	**Aircraft Make / Model / Tail #**	**Hobbs Start**	**Local Start**	**UTC Start**	**Departing**
Oleary	Reims 406 - N406SD	183.7	10:05:00	14:05:00	DAY
Operator	**Sensor Make / Model / Serial #**	**Hobbs End**	**Local End**	**UTC End**	**Arriving**
Nardone	Leica Terrain Mapper - 90515	188.6	04:17:00	20:17:00	DAY

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
30	17	10		Clear	1	-16	30.39

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
130	4,500	5,200	700

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
0.3	12	40	150	1320	100

Verify S-Turns Before Mission

Line #	Direction	Start Time (UTC)	End Time (UTC)	Time On-Line	Satellite	PDOP	Line Notes/Comments
1	S	16:05:00	16:07:00	00:02:00	22	1.1	Maint Hobbs: 5190.9
2	N	16:10:00	16:13:00	00:03:00	21	1.1	
3	S	16:15:00	16:17:00	00:02:00	21	1.1	
4	N	16:20:00	16:22:00	00:02:00	22	1.1	
5	S	16:25:00	16:28:00	00:03:00	21	1.2	
6	N	16:31:00	16:34:00	00:03:00	21	1.2	
7	S	16:37:00	16:39:00	00:02:00	23	1	
8	N	16:42:00	16:45:00	00:03:00	23	1.1	
9	S	16:48:00	16:51:00	00:03:00	23	1.1	
10	N	16:54:00	16:57:00	00:03:00	22	1.1	
11	S	16:59:00	17:02:00	00:03:00	22	1.1	
12	N	17:05:00	17:07:00	00:02:00	21	1.2	
North Block							
1	S	17:19:00	17:21:00	00:02:00	21	1.3	
2	N	17:27:00	17:34:00	00:07:00	21	1.1	
3	S	17:37:00	17:44:00	00:07:00	21	1.1	
4	N	17:47:00	17:58:00	00:11:00	17	1.5	
5	S	18:01:00	18:11:00	00:10:00	17	1.6	
6	N	18:14:00	18:25:00	00:11:00	18	1.3	
7	S	18:28:00	18:38:00	00:10:00	21	1.1	
8	N	18:42:00	18:53:00	00:11:00	19	1.2	
9	S	18:55:00	19:06:00	00:11:00	20	1.2	
10	N	19:09:00	19:21:00	00:12:00	21	1.2	
11	S	19:23:00	19:34:00	00:11:00	21	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 #**
79674	OH Columbus 2019 B19 - North & South Block	Day085_90515	03/26/2019	85	

Crew	Equipment	Time			Airports
Pilot	**Aircraft Make / Model / Tail #**	**Hobbs Start**	**Local Start**	**UTC Start**	**Departing**
Oleary	Reims 406 - N406SD	183.7	10:05:00	14:05:00	DAY
Operator	**Sensor Make / Model / Serial #**	**Hobbs End**	**Local End**	**UTC End**	**Arriving**
Nardone	Leica Terrain Mapper - 90515	188.6	04:17:00	20:17:00	DAY

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
30	17	10		Clear	1	-16	30.39

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
130	4,500	5,200	700

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
0.3	12	40	150	1320	100

Verify S-Turns Before Mission

Line #	Direction	Start Time (UTC)	End Time (UTC)	Time On-Line	Satellite	PDOP	Line Notes/Comments
12	N	19:37:00	19:48:00	00:11:00	22	1.1	
South Block							

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 #**
79674	OH Columbus 2019 B19	Day086_90515	03/27/2019	086	

Crew	Equipment	Time			Airports
Pilot	**Aircraft Make / Model / Tail #**	**Hobbs Start**	**Local Start**	**UTC Start**	**Departing**
Oleary	Reims 406 - N406SD	188.9	09:12:00	13:12:00	DAY
Operator	**Sensor Make / Model / Serial #**	**Hobbs End**	**Local End**	**UTC End**	**Arriving**
Nardone	Leica Terrain Mapper - 90515	195.6	03:37:00	19:37:00	DAY

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
330	0	10		Clear	1	20	30.45

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
130	4,500	5,200	700

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
0.3	12	40	150	1320	100

		Verify S-Turns Before Mission	Yes

Line #	Direction	Start Time (UTC)	End Time (UTC)	Time On-Line	Satellite	PDOP	Line Notes/Comments
13	S	13:38:00	13:49:00	00:11:00	18	1	Main Hobbs: 5197.3
14	N	13:52:00	14:07:00	00:15:00	17	1.4	
15	S	14:09:00	14:24:00	00:15:00	18	1.2	
16	N	14:27:00	14:42:00	00:15:00	18	1.2	
17	S	14:46:00	15:01:00	00:15:00	16	1.4	Missed PAV, Reflew line. Not interns fault
18	N	15:04:00	15:19:00	00:15:00	15	1.5	
19	S	15:22:00	15:36:00	00:14:00	16	1.4	
20	N	15:39:00	15:53:00	00:14:00	19	1.2	
21	S	15:56:00	16:11:00	00:15:00	20	1	
22	N	16:13:00	16:26:00	00:13:00	20	1.1	
23	S	16:29:00	16:41:00	00:12:00	21	1.2	
24	N	16:44:00	16:55:00	00:11:00	21	1.2	
25	S	16:58:00	17:09:00	00:11:00	20	1.3	
26	N	17:12:00	17:22:00	00:10:00	22	1.3	
27	S	17:25:00	17:36:00	00:11:00	21	1.2	
28	N	17:38:00	17:49:00	00:11:00	21	1.2	
29	S	17:52:00	18:03:00	00:11:00	18	1.6	
30	N	18:10:00	18:22:00	00:12:00	19	1.5	
31	S	18:25:00	18:37:00	00:12:00	20	1.2	
32	N	18:40:00	18:52:00	00:12:00	19	1.2	
33	S	18:55:00	19:07:00	00:12:00	23	1	

	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 #**
79674	OH Columbus 2019 B19	Day087_90515	03/28/2019	087	

Crew	Equipment	Time			Airports
Pilot	**Aircraft Make / Model / Tail #**	**Hobbs Start**	**Local Start**	**UTC Start**	**Departing**
Oleary	Reims 406 - N406SD	195.6	08:47:00	12:48:00	DAY
Operator	**Sensor Make / Model / Serial #**	**Hobbs End**	**Local End**	**UTC End**	**Arriving**
Nardone	Leica Terrain Mapper - 90515	198.1	11:01:00	15:01:00	DAY

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
180	6	10	6,000	Overcast	4	-2	30.25

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
130	4,500	5,023	700

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
0.3	12	40	150	1320	100

Verify S-Turns Before Mission

Line #	Direction	Start Time (UTC)	End Time (UTC)	Time On-Line	Satellite	PDOP	Line Notes/Comments
34	N	13:14:00	13:26:00	00:12:00	19	1.2	
35	S	13:29:00	13:42:00	00:13:00	19	1.1	
36	N	13:48:00	14:00:00	00:12:00	19	1.4	Rain drops 20-30 Km in
37	S	14:11:00	14:25:00	00:14:00	19	1.1	
38	N						Aborted line before starting. Ceiling fell
							Maint Hobbs: 5199.5

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 #
79674	OH Columbus 2019 B19	Day091_90513	04/01/2019	091	

Crew	Equipment	Time			Airports
Pilot	Aircraft Make / Model / Tail #	Hobbs Start	Local Start	UTC Start	Departing
Oleary	Cessna 404 Titan - N7079F	2070.2	12:29:00	16:29:00	DAY
Operator	Sensor Make / Model / Serial #	Hobbs End	Local End	UTC End	Arriving
Nardone	Leica Terrain Mapper - 90513	2074.2	04:30:00	20:30:00	DAY

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
135	6	10		Clear	0	-5	30.43

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
130	4,300	5,000	700

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
0.3	12	40	150	1320	100

Verify S-Turns Before Mission

Line #	Direction	Start Time (UTC)	End Time (UTC)	Time On-Line	Satellite	PDOP	Line Notes/Comments
34	N	17:00:00	17:12:00	00:12:00	22	1.2	
35	S	17:15:00	17:27:00	00:12:00	19	1.3	
36	N	17:30:00	17:42:00	00:12:00	19	1.5	
37	S	17:46:00	17:59:00	00:13:00	21	1.3	
38	N	18:01:00	18:15:00	00:14:00	25	1	
39	S	18:17:00	18:31:00	00:14:00	22	1.5	
40	N	18:33:00	18:47:00	00:14:00	24	1.1	
41	S	18:49:00	19:02:00	00:13:00	23	1.3	44KM in yellow error "Overexposer"
42	N	19:06:00	19:18:00	00:12:00	24	1.2	6KM in yellow error "Overexposer"
43	S	19:21:00	19:34:00	00:13:00	23	1.2	
44	N	19:37:00	19:50:00	00:13:00	25	1	
45	S	19:52:00	20:06:00	00:14:00	24	1	

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 #**
79674	OH Columbus 2019 B19	Day097_90513	04/07/2019	097	

Crew	Equipment	Time			Airports
Pilot	**Aircraft Make / Model / Tail #**	**Hobbs Start**	**Local Start**	**UTC Start**	**Departing**
Oleary	Cessna 404 Titan - N7079F	2077.6	08:58:00	12:58:00	DAY
Operator	**Sensor Make / Model / Serial #**	**Hobbs End**	**Local End**	**UTC End**	**Arriving**
Nardone	Leica Terrain Mapper - 90513	2080.3	11:34:00	15:34:00	DAY

Conditions

Wind Dir (°)	Wind Speed (kts)	Visibility (mi)	Ceiling (ft)	Cloud Cover	Temp. (°C)	Dew Point (°C)	Pressure ("Hg)
0	3	10	10,000	Broken	27	13	30.09

Air Speed (kts)	Altitude AGL (ft)	Altitude MSL (ft)	Airfield Elevation (ft)
130	4,200	5,033	700

Settings

Point Spacing (m)	Point Density (ppsm)	Scan Angle/FOV (°)	Scan Frequency (Hz)	Pulse Rate (kHz)	Laser Power (%)
0.3	12	40	150	1320	100

Verify S-Turns Before Mission

Line #	Direction	Start Time (UTC)	End Time (UTC)	Time On-Line	Satellite	PDOP	Line Notes/Comments
55	N	13:27:00	13:42:00	00:15:00	22	1.1	
81	S	13:46:00	13:48:00	00:02:00	20	1.2	
82	E	13:52:00	13:53:00	00:01:00	19	1.3	
83	S	13:57:00	14:01:00	00:04:00	19	1.3	
84	N	14:04:00	14:05:00	00:01:00	19	1.4	
85	S	14:08:00	14:09:00	00:01:00	19	1.4	
86	S	14:13:00	14:19:00	00:06:00	19	1.4	
88	N	14:21:00	14:23:00	00:02:00	17	1.5	
87	N	14:25:00	14:26:00	00:01:00	19	1.5	
89	S	14:33:00	14:37:00	00:04:00	20	1.5	
90	N	14:42:00	14:46:00	00:04:00	22	1.4	
91	S	14:50:00	14:54:00	00:04:00	23	1.3	
92	N	14:56:00	14:58:00	00:02:00	26	1.2	
93	W	15:01:00	15:03:00	00:02:00	27	1	
94	S	15:06:00	15:07:00	00:01:00	25	1.1	

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 (HARN) State Plane Ohio South Zone, U.S. survey feet

Vertical: NAVD88 (GEOID12B) U.S. survey feet

Summary	
Point Count	55
Average dZ	0.001 ft
Minimum dZ	-0.184 ft
Maximum dZ	0.242 ft
Average Magnitude	0.067 ft
Root Mean Square	0.088 ft (0.26 m)
Standard Deviation	0.089 ft

Point ID	Easting	Northing	Known Z	Laser Z	dZ
2001_2019_OH	1774986.497	887445.132	918.200	918.170	-0.030
2002_2019_OH	1758750.123	870881.949	928.233	928.160	-0.073
2003_2019_OH	1768180.340	870188.972	918.417	918.450	0.033
2004A_2019_OH	1775199.943	871662.429	908.772	908.880	0.108
2004B_2019_OH	1775236.884	871671.731	908.706	908.790	0.084
2005_2019_OH	1783496.420	829306.523	916.565	916.750	0.185
2006_2019_OH	1787440.890	803368.161	918.430	918.560	0.130
2007_2019_OH	1788244.654	818559.610	879.235	879.270	0.035
2008_2019_OH	1787084.475	809901.778	920.495	920.510	0.015
2009_2019_OH	1790458.162	790357.828	884.762	884.690	-0.072
2010_2019_OH	1765953.978	785200.144	1019.890	1019.850	-0.040
2011_2019_OH	1781342.378	783633.407	991.347	991.380	0.033
2012_2019_OH	1775854.536	774332.372	935.773	935.710	-0.063
2013A_2019_OH	1774482.286	763777.048	942.414	942.420	0.006
2013B_2019_OH	1774512.174	763780.093	942.360	942.370	0.010
2014_2019_OH	1794943.024	764238.354	855.103	854.990	-0.113
2015_2019_OH	1814192.981	761759.030	840.967	841.030	0.063
2016_2019_OH	1835520.472	760871.603	905.548	905.500	-0.048
2017_2019_OH	1826780.980	774639.669	915.906	915.880	-0.026

Point ID	Easting	Northing	Known Z	Laser Z	dZ
2018_2019_OH	1839607.031	784081.087	873.294	873.260	-0.034
2019_2019_OH	1861484.831	780349.088	905.313	905.500	0.187
2020_2019_OH	1861754.481	814078.192	938.858	939.000	0.142
2021_2019_OH	1861732.888	791082.523	904.848	905.090	0.242
2022_2019_OH	1860337.895	768229.737	911.065	911.230	0.165
2023_2019_OH	1780086.805	748343.205	937.314	937.250	-0.064
2024A_2019_OH	1758615.833	732697.927	904.325	904.270	-0.055
2024B_2019_OH	1758599.365	732657.102	904.342	904.240	-0.102
2025_2019_OH	1886854.976	769317.656	1075.734	1075.750	0.016
2026_2019_OH	1886968.648	739071.422	1023.181	1023.090	-0.091
2027_2019_OH	1846879.424	733608.762	766.305	766.300	-0.005
2028_2019_OH	1810242.052	725515.319	769.422	769.280	-0.142
2029_2019_OH	1782862.823	712727.424	922.664	922.720	0.056
2030_2019_OH	1784241.262	687990.389	888.530	888.570	0.040
2031_2019_OH	1782460.337	668600.234	798.205	798.350	0.145
2032_2019_OH	1831008.673	646241.229	702.901	702.890	-0.011
2033_2019_OH	1811305.198	668272.108	783.533	783.510	-0.023
2033_HOR_2019_O	1811379.881	668150.460	779.337	779.290	-0.047
2034_2019_OH	1849839.365	666946.516	737.199	737.180	-0.019
2035A_2019_OH	1851832.377	679621.088	744.714	744.670	-0.044
2035B_2019_OH	1851874.283	679618.251	744.944	744.910	-0.034
2036_2019_OH	1861421.627	696467.378	737.577	737.580	0.003
2037_2019_OH	1872712.947	668098.602	752.830	752.800	-0.030
2038_2019_OH	1883490.306	708994.123	849.206	849.240	0.034
2039_2019_OH	1866401.401	720743.197	779.209	779.220	0.011
2040_2019_OH	1856749.790	711295.047	775.541	775.470	-0.071
2041_2019_OH	1841383.850	720729.149	774.814	774.730	-0.084
2042_2019_OH	1803596.243	712325.811	827.417	827.340	-0.077
2043_2019_OH	1801330.169	697297.377	843.604	843.600	-0.004
2044_2019_OH	1819969.925	687123.272	721.349	721.360	0.011
2045_2019_OH	1829359.198	701242.152	747.783	747.790	0.007
2046_2019_OH	1829485.453	659515.405	690.368	690.490	0.122
2047_2019_OH	1831991.371	684522.731	737.106	736.940	-0.166
2047_HOR_2019_O	1832045.046	684558.956	735.969	735.960	-0.009

Point ID	Easting	Northing	Known Z	Laser Z	dZ
2048_2019_OH	1828965.388	732223.546	839.114	838.930	-0.184
2049_2019_OH	1851089.673	653144.583	727.362	727.320	-0.042

Appendix 3: DEM NVA Checkpoint Results

Coordinate values are listed in the following spatial reference system:

Horizontal: NAD83 (HARN) State Plane Ohio South Zone, U.S. survey feet

Vertical: NAVD88 (GEOID12B) U.S. survey feet

Summary	
Point Count	55
Root Mean Square Error	0.089 ft (0.027 m)
95% Confidence Level	0.174 (0.052 m)
Mean of Residuals	0.07 ft
Standard Deviation	0.056 ft

Point ID	Easting	Northing	Known Z	DEM Z	dZ
2001_2019_OH	1774986.497	887445.132	918.200	918.174	0.0263
2002_2019_OH	1758750.123	870881.949	928.233	928.194	0.0393
2003_2019_OH	1768180.340	870188.972	918.417	918.464	0.0467
2004A_2019_OH	1775199.943	871662.429	908.772	908.884	0.1116
2004B_2019_OH	1775236.884	871671.731	908.706	908.784	0.0776
2005_2019_OH	1783496.420	829306.523	916.565	916.754	0.1887
2006_2019_OH	1787440.890	803368.161	918.430	918.554	0.1237
2007_2019_OH	1788244.654	818559.610	879.235	879.244	0.0085
2008_2019_OH	1787084.475	809901.778	920.495	920.514	0.0187
2009_2019_OH	1790458.162	790357.828	884.762	884.684	0.0785
2010_2019_OH	1765953.978	785200.144	1019.890	1019.874	0.0159
2011_2019_OH	1781342.378	783633.407	991.347	991.384	0.037
2012_2019_OH	1775854.536	774332.372	935.773	935.704	0.0693
2013A_2019_OH	1774482.286	763777.048	942.414	942.444	0.0298
2013B_2019_OH	1774512.174	763780.093	942.360	942.404	0.0438
2014_2019_OH	1794943.024	764238.354	855.103	854.993	0.1096
2015_2019_OH	1814192.981	761759.030	840.967	841.023	0.0564
2016_2019_OH	1835520.472	760871.603	905.548	905.504	0.0444
2017_2019_OH	1826780.980	774639.669	915.906	915.884	0.0223
2018_2019_OH	1839607.031	784081.087	873.294	873.263	0.0305

Point ID	Easting	Northing	Known Z	DEM Z	dZ
2019_2019_OH	1861484.831	780349.088	905.313	905.464	0.1506
2020_2019_OH	1861754.481	814078.192	938.858	938.994	0.1358
2021_2019_OH	1861732.888	791082.523	904.848	905.094	0.2456
2022_2019_OH	1860337.895	768229.737	911.065	911.234	0.1686
2023_2019_OH	1780086.805	748343.205	937.314	937.204	0.1103
2024A_2019_OH	1758615.833	732697.927	904.325	904.254	0.0714
2024B_2019_OH	1758599.365	732657.102	904.342	904.254	0.0884
2025_2019_OH	1886854.976	769317.656	1075.734	1075.754	0.0203
2026_2019_OH	1886968.648	739071.422	1023.181	1023.094	0.0869
2027_2019_OH	1846879.424	733608.762	766.305	766.293	0.0119
2028_2019_OH	1810242.052	725515.319	769.422	769.283	0.1389
2029_2019_OH	1782862.823	712727.424	922.664	922.734	0.0697
2030_2019_OH	1784241.262	687990.389	888.530	888.584	0.0536
2031_2019_OH	1782460.337	668600.234	798.205	798.313	0.1082
2032_2019_OH	1831008.673	646241.229	702.901	702.893	0.0082
2033_2019_OH	1811305.198	668272.108	783.533	783.503	0.0299
2033_HOR_2019_O	1811379.881	668150.460	779.337	779.273	0.0639
2034_2019_OH	1849839.365	666946.516	737.199	737.083	0.1161
2035A_2019_OH	1851832.377	679621.088	744.714	744.623	0.091
2035B_2019_OH	1851874.283	679618.251	744.944	744.903	0.041
2036_2019_OH	1861421.627	696467.378	737.577	737.573	0.004
2037_2019_OH	1872712.947	668098.602	752.830	752.803	0.027
2038_2019_OH	1883490.306	708994.123	849.206	849.273	0.0674
2039_2019_OH	1866401.401	720743.197	779.209	779.223	0.0141
2040_2019_OH	1856749.790	711295.047	775.541	775.533	0.0079
2041_2019_OH	1841383.850	720729.149	774.814	774.713	0.1009
2042_2019_OH	1803596.243	712325.811	827.417	827.353	0.0637
2043_2019_OH	1801330.169	697297.377	843.604	843.593	0.0106
2044_2019_OH	1819969.925	687123.272	721.349	721.363	0.0139
2045_2019_OH	1829359.198	701242.152	747.783	747.793	0.01
2046_2019_OH	1829485.453	659515.405	690.368	690.493	0.1248
2047_2019_OH	1831991.371	684522.731	737.106	736.943	0.1631
2047_HOR_2019_O	1832045.046	684558.956	735.969	735.953	0.0161
2048_2019_OH	1828965.388	732223.546	839.114	838.933	0.1806

Point ID	Easting	Northing	Known Z	DEM Z	dZ
2049_2019_OH	1851089.673	653144.583	727.362	727.293	0.0691

Appendix 4: DEM VVA Checkpoint Results

Coordinate values are listed in the following spatial reference system:

Horizontal: NAD83 (HARN) State Plane Ohio South Zone, U.S. survey feet

Vertical: NAVD88 (GEOID12B) U.S. survey feet

Summary	
Point Count	37
Root Mean Square Error	0.248 ft (0.076m)
95th Percentile	0.400 ft (0.122 m)
Mean of Residuals	0.224 ft
Standard Deviation	0.108 ft

Point ID	Easting	Northing	Known Z	DEM Z	dZ
3001_2019_OH	1774953.311	887458.482	919.048	919.244	0.1957
3002_2019_OH	1758786.260	870885.298	927.533	927.554	0.0207
3003_2019_OH	1782803.945	712743.626	922.690	923.084	0.3937
3004_2019_OH	1768155.025	870195.886	917.065	917.254	0.1887
3005_2019_OH	1775006.597	871656.528	908.305	908.444	0.1386
3006_2019_OH	1829393.052	659479.808	685.434	685.713	0.2787
3007_2019_OH	1787029.627	809897.436	920.839	920.984	0.1447
3008_2019_OH	1861586.178	780434.788	901.328	901.594	0.2656
3009_2019_OH	1860523.945	767878.439	885.937	886.394	0.4565
3010_2019_OH	1831061.611	646131.819	699.356	699.673	0.3168
3011_2019_OH	1851631.283	668729.045	734.364	734.693	0.3289
3012_2019_OH	1872817.568	668127.029	752.690	752.903	0.213
3013_2019_OH	1851070.791	653184.129	726.318	726.343	0.0249
3014_2019_OH	1860916.982	814510.121	928.510	928.884	0.3737
3015_2019_OH	1852552.902	679825.661	745.973	746.033	0.06
3016_2019_OH	1780077.113	748318.367	936.975	936.874	0.1013
3017_2019_OH	1886817.373	769404.247	1077.148	1077.224	0.0763
3018_2019_OH	1784250.335	687964.231	890.659	890.944	0.2846
3019_2019_OH	1782493.111	668610.792	795.536	795.703	0.1672
3020_2019_OH	1801257.727	697219.572	844.512	844.803	0.2914

Point ID	Easting	Northing	Known Z	DEM Z	dZ
3021_2019_OH	1811345.883	668308.642	783.764	783.943	0.1791
3022_2019_OH	1833530.787	683926.196	741.488	741.773	0.285
3023_2019_OH	1775215.828	764757.880	940.639	940.884	0.2448
3024_2019_OH	1780967.385	783614.668	996.940	996.994	0.054
3025_2019_OH	1841363.281	720739.340	776.839	777.073	0.2341
3026_2019_OH	1829306.900	701335.860	749.808	750.023	0.215
3027_2019_OH	1783446.174	829371.391	917.894	918.254	0.3597
3028_2019_OH	1788347.338	818422.300	878.163	878.264	0.1005
3029_2019_OH	1861702.891	791036.818	903.077	903.254	0.1766
3030_2019_OH	1838713.846	784622.041	898.732	898.884	0.1516
3031_2019_OH	1856676.244	711251.921	771.000	771.323	0.3231
3032_2019_OH	1883582.125	709495.178	845.888	846.083	0.1954
3033_2019_OH	1866353.697	720803.199	767.171	767.363	0.1921
3034_2019_OH	1814690.096	762702.045	813.817	814.093	0.2763
3035_2019_OH	1887041.249	739103.338	1023.986	1024.324	0.3381
3036_2019_OH	1846928.713	733482.137	761.703	762.013	0.31
3037_2019_OH	1787957.301	803170.777	904.415	904.734	0.3186