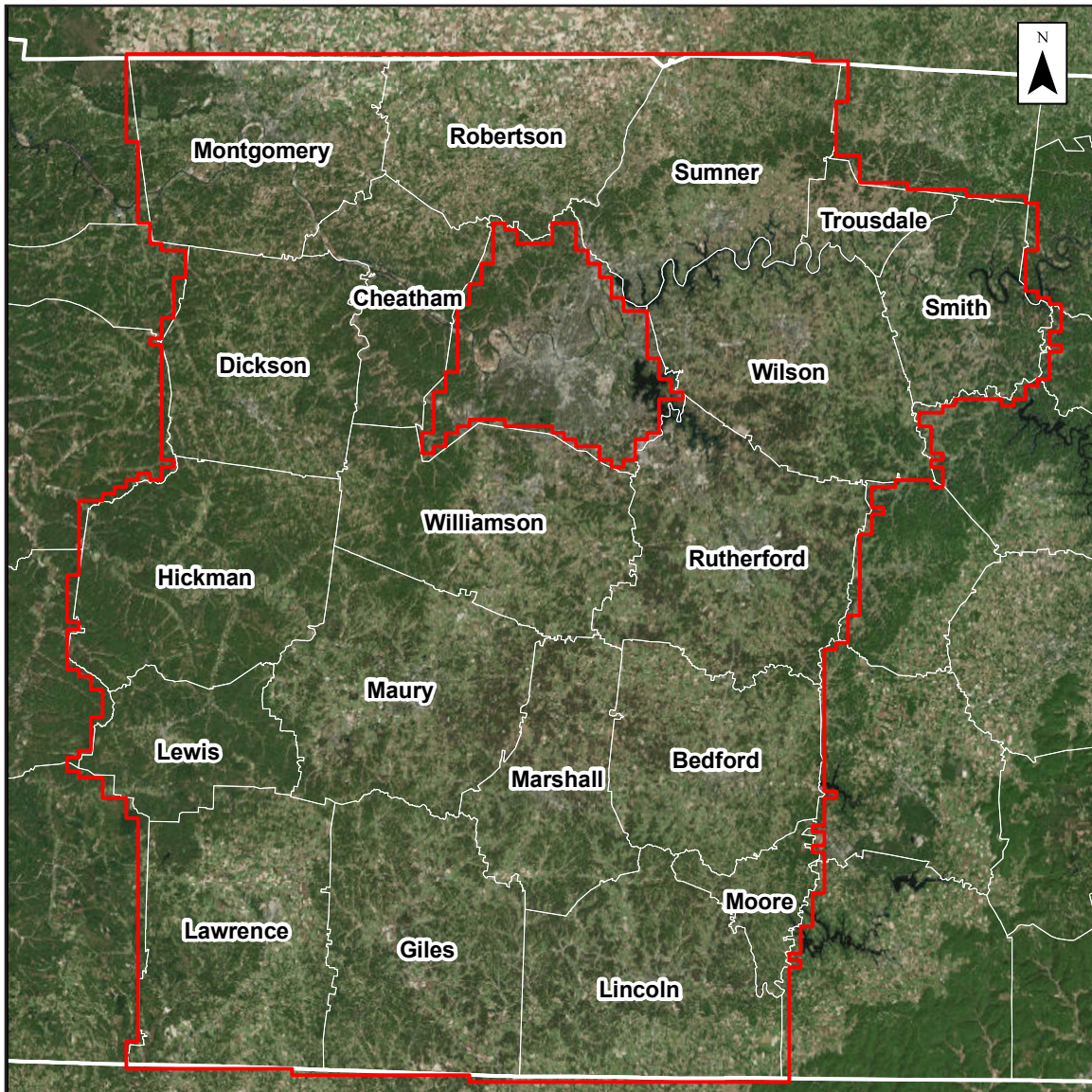


TN Middle TN 2018 B18

Airborne Lidar Report

June 2019



Contract # G16PC00022
Task Order # 140G0218F0142



Contractor Woolpert
Project # 78363

Table of Contents

1. Overview	1
About.....	1
Purpose.....	1
Specifications	1
Spatial Reference	2
Deliverables	3
2. Acquisition	5
Flight Planning	5
Lidar Sensor Information	6
GNSS and IMU Equipment.....	8
Timeline.....	8
Acquisition Quality Assurance	9
3. Processing	11
Processing Summary	11
GNSS-IMU Trajectory Processing	11
Geometric Calibration	12
Lidar Data Classification.....	12
Hydrologic Flattening	13
Digital Elevation Model	14
Intensity Imagery	14
Building Footprints	14
Metadata.....	14
4. Accuracy Assessment	15
Results Summary	15
Raw Lidar Swath Testing	15
Digital Elevation Model Testing.....	15
Inter-Swath Testing	17

Table of Contents

List of Figures

Figure 1-1. Project Area 4
 Figure 2-1: Flown Flight Lines 10
 Figure 4-1: Inter-Swath Histogram..... 17

List of Tables

Table 1-1. Spatial Reference System 2
 Table 1-2. Deliverables 3
 Table 2-1. Acquisition Requirements..... 5
 Table 2-2. Leica ALS80 Sensor Info 6
 Table 2-3. Riegl LMS Q1560 Sensor Info..... 7
 Table 2-4. GNSS Base Stations..... 8
 Table 2-5. Acquisition Specifications..... 9
 Table 4-1. Vertical Accuracy Summary..... 15
 Table 4-2. VVA Errors 16

Appendix Documents

- Appendix 1: Flight Logs
- Appendix 2: Raw Swath NVA Checkpoint Results
- Appendix 3: DEM NVA Checkpoint Results
- Appendix 4: DEM VVA Checkpoint Results

1. Overview

About

This project contains a comprehensive outline of the 140G0218F0142 TN Middle TN 2018 B18 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 one area of interest covering approximately 9,244 square miles in central Tennessee.

Data fully covers the following counties:

- Bedford, Cheatham, Dickson, Giles, Hickman, Lawrence, Lewis, Lincoln, Marshall, Maury, Montgomery, Moore, Robertson, Rutherford, Smith, Sumner, Trousdale, Williamson, and Wilson

Purpose

Data was collected 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, and water resource management.

Specifications

Data for this task order was acquired and produced to meet USGS Lidar Base Specification v1.2 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	6576
	Datum	NAD83 (2011)
	Projection	State Plane Tennessee Zone 5301 (FIPS Zone 4100)
	Units	US survey feet
Vertical	Datum	NAVD88
	Geoid	GEOID12B
	Units	US survey feet
	Height Type	Orthometric

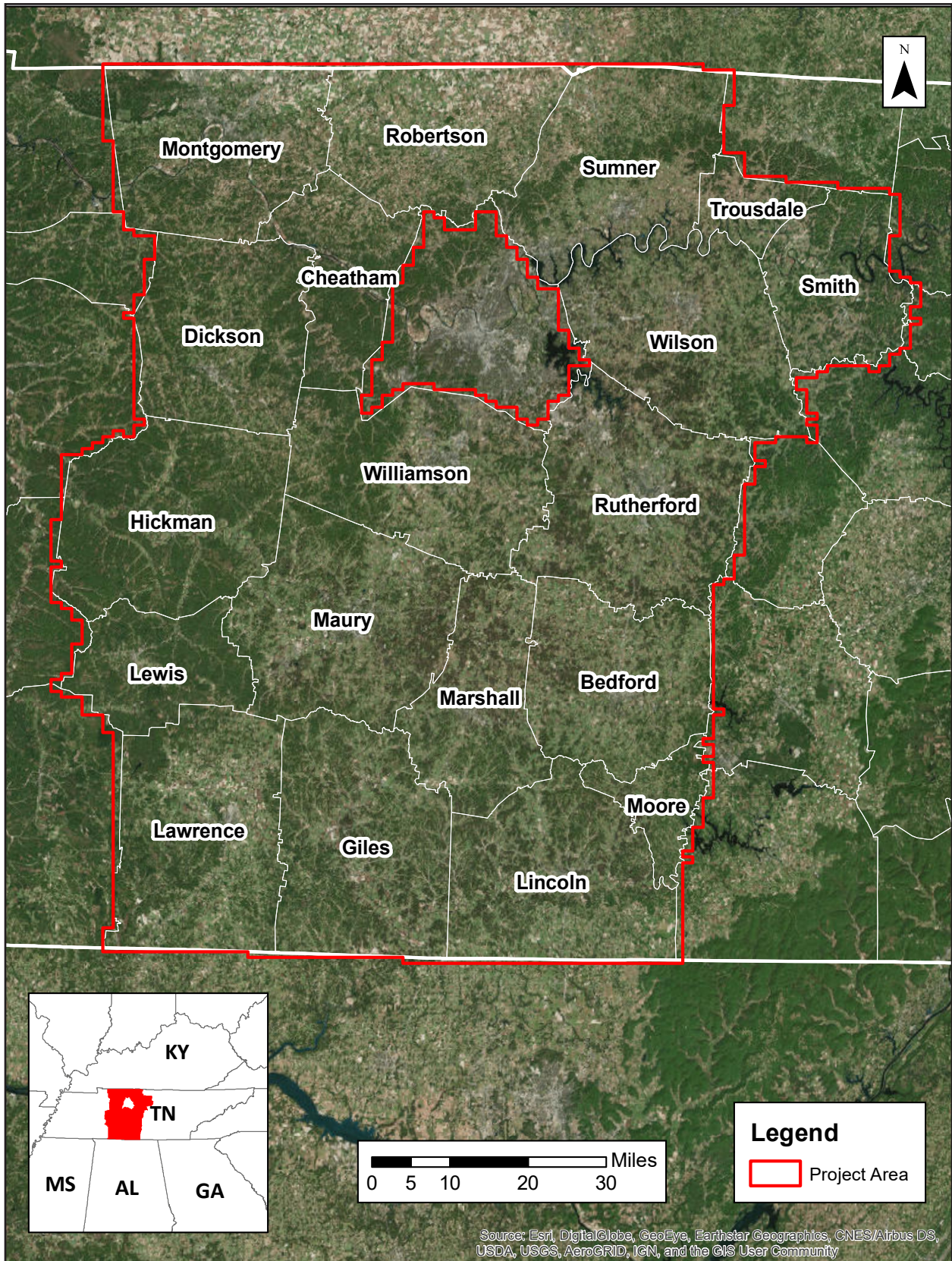
Deliverables

All data products produced as part of this task order are listed below. All tiled deliverables had a tile size of 7,000-feet x 4,000-feet

Table 1-2. Deliverables

Lidar Data	
Classified lidar point cloud data	Tiles in .las v1.4 format Classes <ul style="list-style-type: none"> • 1 – Processed, not Classified • 2 – Ground • 6 – Buildings • 7 – Low Noise • 9 – Water • 10 – Ignored Ground • 17 – Bridge Decks • 18 – High Noise
Breaklines used for hydro-flattening	<ul style="list-style-type: none"> • Lake and River features as feature classes in an Esri file geodatabase <ul style="list-style-type: none"> • 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)	2.5-foot pixel size, 32-bit floating-point; no bridges or overpass structures ERDAS .img format
Intensity Imagery	2.5-foot pixel size, 8-bit gray-scale (linear rescaling from 16-bit intensity) GeoTIFF format
Flight Line Index	Polygon feature class 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	Project-, deliverable-, and lift-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	<ul style="list-style-type: none"> • 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	A period of annual minimal water level in the spring 2018 leaf off window
Acquisition Conditions	<ul style="list-style-type: none"> • 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 <ul style="list-style-type: none"> • 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 ALS80 and Riegl LMS Q1560 lidar sensor systems. A total of 328 flight lines were collected.

Table 2-2. Leica ALS80 Sensor Info

Leica ALS80	
Operating Altitude	100 – 3,500 m AGL nominal, 10% reflective target
Scan Angle	0 to 72° (variable)
Swath Width	0 to 1.5 X altitude (variable)
Scan Frequency	0 – 200 Hz (variable based on scan angle)
Maximum Pulse Rate	1000 kHz (Effective)
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)
Number of Returns per Pulse	Unlimited
Number of Intensities	3 (first, second, third)
Intensity Digitization	8-bit measurement range
MPIA (Multiple Pulses in Air)	2-6 pulses in air
Laser Beam Divergence	Dual Divergence: .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
Roll Compensation	±5° at full FOV
Power Requirements	28 VDC @ 25A
Operating Temperature	0-40°C
Humidity	0-95% non-condensing
Supported GNSS Receivers	Ashtech Z12, Trimble 7400, Novatel Millennium

Table 2-3. Riegl LMS Q1560 Sensor Info

Riegl LMS Q1560	
Manufacturer	Riegl
Model	LMS Q1560
Platform	Fixed-wing
Scan Angle °	58
Field of view (°)	0 - 58
Maximum Pulse rate (kHz)	800
Maximum Flying height (m AGL)	3300
Pulse Rate (ns)	3
Pulse Wavelength (nm)	1064
Beam Divergence (mrad)	0.25
Number of returns	12
Number of intensity measurements	12
Roll stabilization (automatic adaptive, °)	58 - active FOV
Number of intensity measurements	12
Roll stabilization (automatic adaptive, °)	58 - active FOV
Storage media	removable 800 GB SSD
Storage capacity (hours @ max pulse rate)	5
Weight (kg)	62
Operating Temperature	0 - 40 °C
Flight Management	Ri-Acquire
Power Consumption	18.0v – 32.0v DC

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 2-4. GNSS Base Stations

Station Name	Latitude (DMS)	Longitude (DMS)	Ellipsoid Height L1 Phase Center (Meters)
KJWN Airport	36° 10' 42.70750"	86° 52' 58.89097"	113.948
TN31 CORS	36° 10' 13.05619"	86° 52' 14.38401"	113.2
KJWN Airport -2	36° 10' 47.45554"	86° 53' 02.90339"	112.14
Rebar-KM33	36°22'44.50339"	86°24'35.30376"	142.66100
Rebar-KMRC	35° 33' 20.53472"	87° 10' 50.16475"	172.923
Rebar-KSYI	35° 33' 36.97934"	86° 26' 40.72844"	211.917
Rebar-M33	36° 22' 44.50339"	86° 24' 35.30376"	142.661
TN38 CORS	35° 53' 45.97549"	86° 26' 37.28682"	141.419

Timeline

Lidar data was collected from January 30, 2018 through April 5, 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	Riegl LMS Q1560
Max. Number of Returns	Infinite	12
Nominal Point Spacing	0.7 m	1.01 m
Nominal Point Density	2 ppsm	2.76 ppsm
Flying Height Above Ground Level	2,377 m	1,950 m
Flight Speed	150 knots	150 knots
Scan Angle	40°	58°
Scan Rate Used	35.5 Hz	50 Hz
Pulse Rate Used	346 kHz	700 kHz
Multi-Pulse in Air	Enabled	Enabled
Swath Width	1,731 m	2,163 m
Swath Overlap	25%	30%

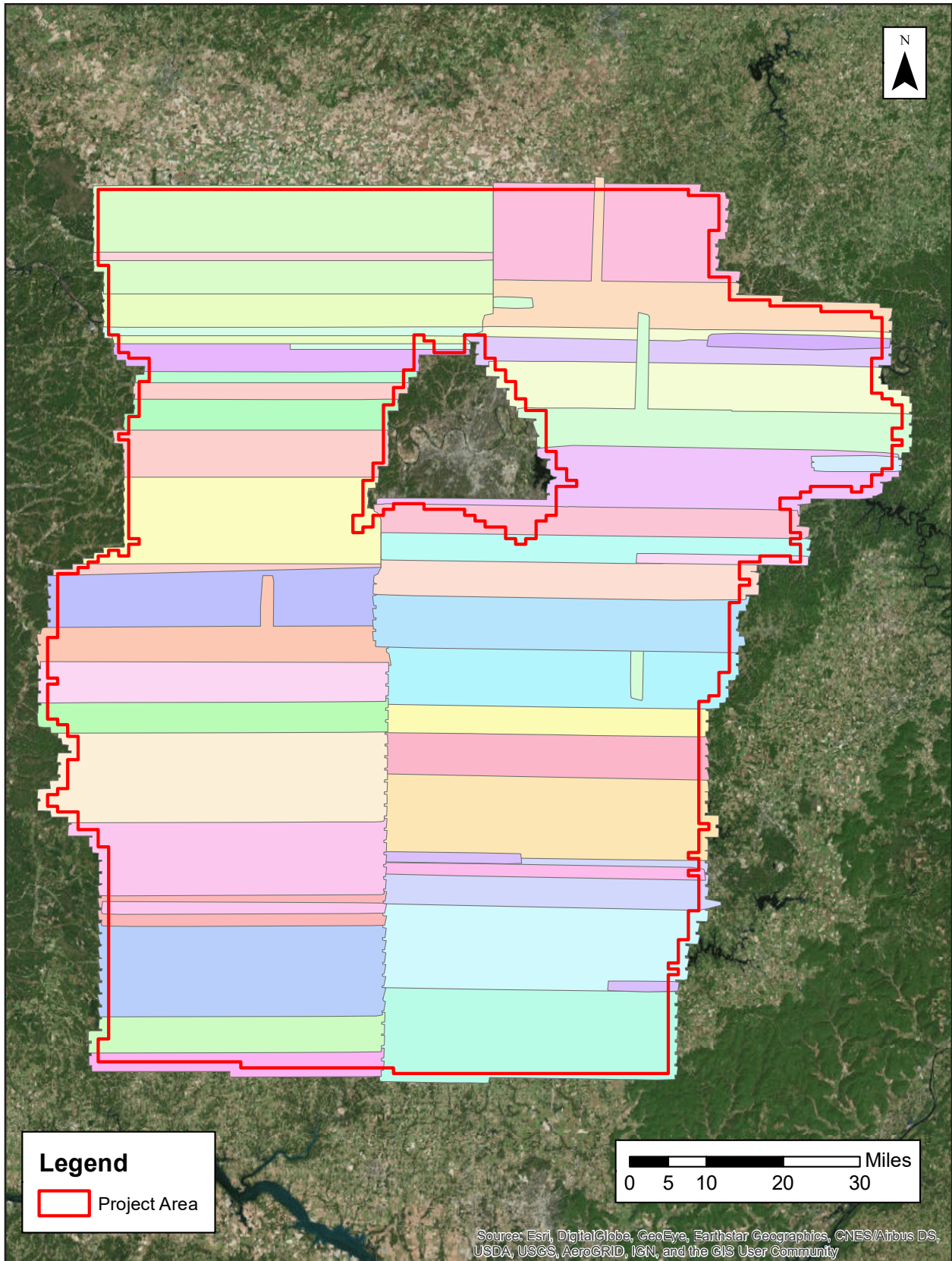
For more information, see the Flight Logs in Appendix 1.

Acquisition Quality Assurance

Woolpert developed a quality assurance and validation plan to ensure the acquired lidar data meets the USGS Base Specification Version 1.2. 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 $(4 \times \text{ANPS})^2$ 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 6 – Buildings
- Class 7 – Low Noise
- Class 9 – Water
- Class 10 – Ignored Ground
- Class 17 – Bridge Decks
- Class 18 – High Noise

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 ten (10). 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.

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 bridge removal 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 as well bridge breaklines were used to create a 2.5-foot hydro-flattened bare-earth raster DEM. Using automated scripting routines within ArcMap, a 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 a 2.5-foot pixel, 8-bit, 256 gray scale GeoTIFF format intensity images clipped to match the task order tiling scheme.

Software: TerraScan v18

Building Footprints

Automated feature extraction was performed using proprietary Woolpert software. The raw lidar and bare earth model datasets were processed to extract and attribute building and vegetation features. Automated extraction was followed by detailed Q/C to verify completeness and accuracy of extraction. Final Q/C'ed features were attributed with geometrically derived attributes based on feature extents, reflective surface DEM and bare earth DEM. Extracted and attributed features were reviewed for completeness and consistency. Projection information and metadata were added to final vector data files.

Software: Proprietary Software, Esri ArcMap v10.4

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, delivery diagram, and a georeferenced, polygonal representation of the detailed extents of each acquired lidar swath.

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	0.060 m	184	199
DEM NVA RMSEz at 95% Confidence Level	0.196 m	0.064 m	184	199
DEM VVA RMSEz at 95th Percentile	0.294 m	0.162 m	131	139

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 184 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 199 checkpoints. These checkpoints were surveyed using GPS techniques. See the survey report for acquisition methodologies. This dataset was tested to be 0.060 meters using an RMSEz of 0.031 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 29.4 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 184 independent checkpoints falling on bare earth and urban (non-vegetated) classes. VVA had a minimum of checkpoints requirement of 131 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 0.064 meters using an RMSEz of 0.033 meters x 1.9600 using 199 checkpoints. VVA tested 0.162 meters at the 95th percentile using 139 checkpoints.

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

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

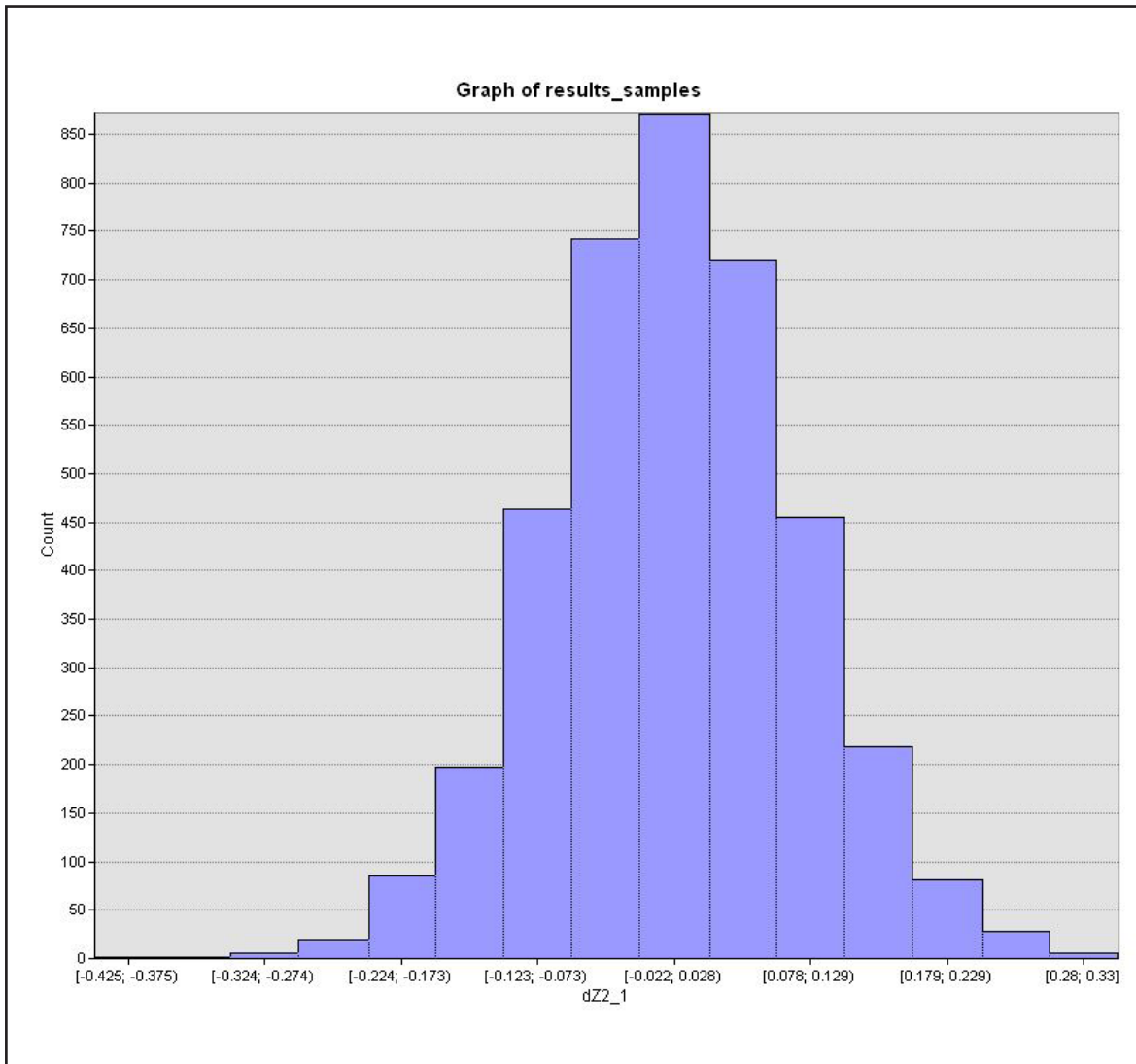
Table 4-2. VVA Errors

PID	Easting (ft)	Northing (ft)	Z-Error (m)
3009	828664.760	1678471.080	0.232
3036	736057.220	1847576.980	0.183
3043	351495.500	1827987.540	0.311
3056	301261.550	1777844.200	0.766
3097	376364.710	1504614.470	0.833
3137	711687.740	1971419.970	0.196

Inter-Swath Testing

Inter-swath accuracy was tested against well-distributed flight line overlap locations. The relative accuracy for the lidar measured at 0.0277 meters RMSEz.

Figure 4-1: Inter-Swath Histogram



Values are in survey feet.

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

Appendix 1: Flight Logs

Appendix 2: Raw Swath NVA Checkpoint Results

Coordinate values are in NAD83 (2011) State Plane Tennessee Zone 5301 (FIPZ Zone 4100), US Survey Feet; NAVD88 (GEOID12B) US Survey Feet

Summary	
Point Count	199
Average dZ	+0.039
Minimum dZ	-0.250
Maximum dZ	+0.310
Average Magnitude	0.082
Root Mean Square	0.104
Standard Deviation	0.097

Point ID	Easting	Northing	Known Z	Laser Z	dZ
2001	1682438.340	811040.350	621.640	621.690	0.050
2002	1919623.190	752457.540	480.820	480.950	0.130
2003	1916118.280	669958.860	637.690	637.600	-0.090
2004	1645994.160	472995.220	609.580	609.540	-0.040
2005	1609397.980	749862.020	591.240	591.230	-0.010
2006	1511039.070	741424.210	618.160	618.340	0.180
2007	1772872.010	745489.160	693.920	693.950	0.030
2009	1734659.770	494065.910	776.120	776.290	0.170
2010	1615721.030	586589.580	727.760	727.760	0.000
2011	1772921.750	793686.720	800.200	800.230	0.030
2012	1847078.670	824930.450	868.930	868.910	-0.020
2013	1766171.890	358055.330	760.150	760.260	0.110
2014	1847136.930	626135.440	565.190	565.280	0.090
2015	1743489.590	476828.230	686.260	686.370	0.110
2016	1981846.140	643064.740	677.670	677.650	-0.020
2017	1686291.510	720572.180	764.210	764.220	0.010
2018	1506855.420	644444.110	783.170	783.250	0.080
2019	1698341.920	443999.460	671.280	671.250	-0.030
2020	1581539.330	599612.980	879.940	879.960	0.020
2021	1715157.420	802904.250	667.350	667.430	0.080

Point ID	Easting	Northing	Known Z	Laser Z	dZ
2022	1771139.370	593146.820	626.440	626.410	-0.030
2023	1776296.190	536942.280	784.120	784.160	0.040
2024	1563445.430	250739.030	765.030	765.020	-0.010
2025	1758097.260	739190.920	518.180	518.360	0.180
2026	1618319.800	368837.830	1031.810	1032.040	0.230
2027	1785141.610	812056.310	730.650	730.440	-0.210
2028	1747017.460	514014.110	866.770	866.910	0.140
2029	1858429.100	424267.230	840.480	840.510	0.030
2030	1516523.090	578933.610	801.550	801.670	0.120
2031	1873256.330	432776.800	832.350	832.440	0.090
2032	1672585.280	646076.150	879.620	879.700	0.080
2033	1750356.400	570666.260	729.410	slope	*
2034	1524862.880	403319.030	925.460	925.210	-0.250
2035	1797412.540	552452.610	706.600	706.740	0.140
2036	1953795.030	668171.400	787.070	787.150	0.080
2037	1736312.860	534586.180	889.320	889.490	0.170
2038	1528684.020	455902.870	839.130	839.200	0.070
2039	1722301.880	789130.400	696.350	696.300	-0.050
2040	1482525.050	425638.670	799.700	799.720	0.020
2041	1548552.770	610010.240	692.650	692.690	0.040
2042	1781849.660	756293.080	569.280	569.290	0.010
2043	1858786.050	816717.510	832.960	833.030	0.070
2044	1897204.120	747658.550	584.380	584.430	0.050
2045	1630009.630	380680.160	767.670	767.690	0.020
2046	1866851.960	631220.530	593.460	593.390	-0.070
2047	1841890.750	346468.360	805.600	805.770	0.170
2048	1507550.980	326793.020	876.830	877.020	0.190
2049	1742133.080	833899.390	665.040	665.240	0.200
2050	1737681.270	809223.710	740.170	740.360	0.190
2051	1686668.630	272531.740	624.870	624.850	-0.020
2052	1880855.050	322363.520	1023.740	1023.820	0.080
2053	1856467.150	263552.910	934.950	935.160	0.210
2054	1846866.780	322314.460	773.250	773.340	0.090
2055	1779367.920	728769.680	616.990	617.160	0.170

Point ID	Easting	Northing	Known Z	Laser Z	dZ
2056	1564987.050	335732.000	870.860	870.890	0.030
2057	1662443.060	622128.480	546.930	547.000	0.070
2058	1624120.280	520680.020	894.870	894.870	0.000
2059	1633172.200	803821.320	557.140	557.130	-0.010
2060	1897984.950	510224.220	883.140	883.210	0.070
2061	1901635.350	808627.270	876.490	876.500	0.010
2062	1473014.360	545412.770	617.080	617.060	-0.020
2063	1783463.730	274944.810	957.270	957.330	0.060
2064	1556685.600	486594.200	871.800	871.880	0.080
2065	1656934.830	425141.590	836.360	836.440	0.080
2066	1550910.230	436615.570	982.150	982.180	0.030
2067	1552524.970	584445.010	815.350	815.390	0.040
2068	2009341.910	691525.920	656.110	656.210	0.100
2069	1662506.490	472089.550	623.530	623.500	-0.030
2070	1650139.800	694995.780	656.360	656.590	0.230
2071	1889574.760	796644.350	603.340	603.120	-0.220
2072	1982158.040	689182.530	513.460	513.450	-0.010
2073	1687754.140	340377.600	1018.500	1018.410	-0.090
2074	1496188.890	807521.240	653.580	653.570	-0.010
2075	1542104.120	354160.410	945.540	945.440	-0.100
2076	1849684.000	534268.540	606.820	606.760	-0.060
2077	1756928.690	598804.310	651.930	652.040	0.110
2078	1594150.790	420551.180	792.200	792.190	-0.010
2079	1886031.110	485309.940	770.000	769.940	-0.060
2080	1749635.820	253905.120	899.200	899.190	-0.010
2081	1777912.450	301229.070	647.800	647.710	-0.090
2082	1662194.710	494443.300	685.180	685.260	0.080
2083	1580992.330	247502.670	852.550	852.570	0.020
2084	1892102.410	501965.970	788.660	788.720	0.060
2085	1997777.910	691793.470	526.110	526.230	0.120
2086	1650597.520	592897.910	607.970	607.960	-0.010
2087	1537601.330	479103.660	589.250	589.200	-0.050
2088	1869968.970	586028.760	587.630	587.520	-0.110
2089	1637162.820	705474.570	676.060	676.070	0.010

Point ID	Easting	Northing	Known Z	Laser Z	dZ
2090	1511988.080	805353.390	621.280	621.200	-0.080
2091	1520629.320	287749.840	828.020	828.200	0.180
2092	1813669.460	243914.220	775.150	775.310	0.160
2093	1727857.720	331983.510	779.940	779.930	-0.010
2094	1487892.920	474878.790	587.080	587.190	0.110
2095	1567631.200	390583.900	837.080	837.190	0.110
2096	1600490.070	325015.460	987.740	987.720	-0.020
2097	1805988.410	302407.390	686.730	686.730	0.000
2098	1599796.540	245487.970	815.080	815.060	-0.020
2099	1571842.480	254484.870	839.890	839.850	-0.040
2100	1813194.540	726373.420	527.780	527.940	0.160
2101	1510314.350	730120.050	454.740	454.800	0.060
2102	1735901.010	740729.530	900.680	900.590	-0.090
2103	1660128.160	379780.530	731.130	731.140	0.010
2104	1837772.750	445423.400	788.140	788.150	0.010
2105	1700302.160	818454.310	712.810	713.120	0.310
2106	1668217.820	587115.980	701.080	701.080	0.000
2107	1843137.220	646904.210	587.670	587.680	0.010
2108	1634984.760	291480.900	931.600	931.590	-0.010
2109	1638035.590	778481.710	592.220	592.160	-0.060
2110	1987271.360	651224.010	560.710	560.820	0.110
2111	1768203.920	551399.580	759.670	759.890	0.220
2112	1600791.510	838867.290	562.160	562.170	0.010
2113	1580262.420	581205.990	881.910	881.900	-0.010
2114	1845944.860	736699.690	559.490	559.560	0.070
2115	1750601.910	594586.890	683.110	682.980	-0.130
2116	1489694.040	436391.870	868.670	868.730	0.060
2117	1504614.260	751831.540	602.780	602.950	0.170
2118	1580962.220	280339.870	776.050	775.940	-0.110
2119	1845562.170	330221.050	754.910	755.000	0.090
2120	1558349.410	339136.050	893.990	894.050	0.060
2121	1835678.460	242416.400	913.130	913.300	0.170
2122	1618014.340	624082.480	744.210	744.320	0.110
2123	1708290.470	452333.760	641.970	642.030	0.060

Point ID	Easting	Northing	Known Z	Laser Z	dZ
2124	1704820.120	617008.180	671.550	671.580	0.030
2125	1504337.500	376317.440	1018.950	1019.010	0.060
2126	1462102.220	565011.360	431.910	431.950	0.040
2127	1874242.240	468734.670	908.490	908.570	0.080
2128	1702851.390	804950.800	720.140	720.180	0.040
2129	1507767.580	360989.800	1011.180	1011.150	-0.030
2130	1648761.810	746043.930	669.130	669.040	-0.090
2131	1903079.450	688973.350	610.830	610.770	-0.060
2132	1676813.430	828305.030	561.870	562.100	0.230
2133	1827982.660	351470.040	793.550	slope	*
2134	1864234.300	283211.260	967.130	967.320	0.190
2135	1799354.860	296325.350	671.970	671.900	-0.070
2136	1579496.810	783694.820	505.970	505.880	-0.090
2137	1563630.670	473222.110	637.730	slope	*
2138	1959317.950	690152.550	614.220	614.350	0.130
2139	1614135.670	754789.130	622.700	622.900	0.200
2140	1599390.290	393281.880	1004.170	1004.100	-0.070
2141	1971295.300	709465.290	543.500	543.630	0.130
2142	1562570.270	616248.700	810.260	810.390	0.130
2143	1872756.570	720061.570	499.380	499.340	-0.040
2144	1777121.540	806644.750	716.730	716.780	0.050
2145	1667925.780	315779.720	703.830	703.870	0.040
2146	1899088.030	561226.840	591.450	591.560	0.110
2147	1883335.950	469645.280	938.290	938.250	-0.040
2148	1878688.290	372701.090	1085.300	1085.540	0.240
2149	1668908.150	781964.920	646.700	646.900	0.200
2150	1537493.060	328855.960	873.630	873.670	0.040
2151	1548949.980	833602.060	503.220	503.220	0.000
2152	1585716.570	746223.490	576.470	576.430	-0.040
2153	1524970.550	486370.510	673.170	673.360	0.190
2154	1830965.260	451205.110	796.720	796.620	-0.100
2155	1902955.230	589455.170	673.080	673.080	0.000
2156	1576692.650	535567.210	614.260	614.300	0.040
2157	1767098.480	727411.060	504.390	504.520	0.130

Point ID	Easting	Northing	Known Z	Laser Z	dZ
2158	1825019.340	816577.430	832.130	832.100	-0.030
2159	1546775.940	366818.710	992.530	992.550	0.020
2160	1678354.780	673315.180	505.170	505.200	0.030
2161	1850002.010	788614.060	652.420	652.490	0.070
2162	1512223.640	513979.630	562.310	562.410	0.100
2163	1674792.220	426515.720	739.630	739.590	-0.040
2164	1556740.020	637658.570	790.330	790.350	0.020
2165	1829073.930	432886.450	762.090	762.100	0.010
2166	1621676.360	742289.170	631.800	631.610	-0.190
2167	1902700.950	513778.060	839.960	840.160	0.200
2168	1881380.370	355302.140	1095.210	1095.320	0.110
2169	1466190.190	559257.730	575.400	575.480	0.080
2170	1879244.340	795544.910	617.490	617.470	-0.020
2171	1583597.010	333827.370	926.340	926.400	0.060
2172	1627318.550	467674.850	696.560	696.510	-0.050
2173	1541187.750	487331.330	550.880	551.050	0.170
2174	1740252.370	782463.860	704.270	704.200	-0.070
2175	1525978.590	520742.940	578.690	578.790	0.100
2176	1596937.380	359779.920	932.530	932.600	0.070
2177	1616746.000	724044.110	388.660	388.670	0.010
2178	1785628.740	454263.210	675.450	675.560	0.110
2179	1500793.670	395660.580	979.540	979.440	-0.100
2180	1512101.200	760532.510	369.980	369.980	0.000
2181	1800857.500	246609.270	899.860	899.980	0.120
2182	1709651.090	301632.560	774.620	774.760	0.140
2183	1741590.220	252666.490	908.860	908.710	-0.150
2184	1630474.600	616297.070	769.630	769.570	-0.060
2185	1811122.630	791675.460	788.000	787.810	-0.190
2186	1619964.570	647085.800	799.650	799.650	0.000
2187	1612327.320	529554.310	871.390	871.500	0.110
2188	1984078.190	747364.470	559.980	559.960	-0.020
2189	1929008.170	642225.590	658.780	658.750	-0.030
2190	1809740.480	701755.890	570.320	570.370	0.050
2191	1741211.380	435852.370	673.370	673.380	0.010

Point ID	Easting	Northing	Known Z	Laser Z	dZ
2192	1701787.260	543350.420	777.760	777.740	-0.020
2193	1550126.810	704649.960	666.790	666.650	-0.140
2194	1946772.720	739394.510	502.870	502.940	0.070
2195	1736695.900	409385.810	714.880	715.000	0.120
2196	1643458.970	349972.240	770.660	770.730	0.070
2197	1724387.260	386044.610	805.170	805.090	-0.080
2198	1781190.770	695740.720	465.760	465.960	0.200
2199	1863112.730	769949.130	560.980	560.940	-0.040
2528	1747178.500	512824.050	965.380	965.410	0.030

Appendix 3: DEM NVA Checkpoint Results

Coordinate values are listed in the following spatial reference system:

Horizontal: NAD83 (2011) State Plane Tennessee Zone 5301 (FIPZ Zone 4100), US Survey Feet

Vertical: NAVD88 (GEOID12B) US Survey Feet

Summary	
Point Count	199
Root Mean Square Error	0.110 ft (0.033 m)
95% Confidence Level	0.216 ft (0.064 m)
Mean of Residuals	0.086 ft
Standard Deviation	0.068 ft

Point ID	Easting	Northing	Known Z	DEM Z	dZ
2001	811040.35	1682438.34	621.64	621.642	0.002
2002	752457.540	1919623.190	480.820	480.922	0.102
2003	669958.860	1916118.280	637.690	637.573	-0.117
2004	472995.220	1645994.160	609.580	609.682	0.102
2005	749862.020	1609397.980	591.240	591.232	-0.008
2006	741424.210	1511039.070	618.160	618.352	0.192
2007	745489.160	1772872.010	693.920	693.933	0.013
2009	494065.910	1734659.770	776.120	776.303	0.183
2010	586589.580	1615721.030	727.760	727.813	0.053
2011	793686.720	1772921.750	800.200	800.323	0.123
2012	824930.450	1847078.670	868.930	868.873	-0.057
2013	358055.330	1766171.890	760.150	760.283	0.133
2014	626135.440	1847136.930	565.190	565.142	-0.048
2015	476828.230	1743489.590	686.260	686.273	0.013
2016	643064.740	1981846.140	677.670	677.583	-0.087
2017	720572.180	1686291.510	764.210	764.213	0.003
2018	644444.110	1506855.420	783.170	783.243	0.073
2019	443999.460	1698341.920	671.280	671.173	-0.107
2020	599612.980	1581539.330	879.940	879.934	-0.006
2021	802904.250	1715157.420	667.350	667.413	0.063

Point ID	Easting	Northing	Known Z	DEM Z	dZ
2022	593146.820	1771139.370	626.440	626.413	-0.027
2023	536942.280	1776296.190	784.120	784.163	0.043
2024	250739.030	1563445.430	765.030	764.963	-0.067
2025	739190.920	1758097.260	518.180	518.382	0.202
2026	368837.830	1618319.800	1031.810	1031.974	0.164
2027	812056.310	1785141.610	730.650	730.433	-0.217
2028	514014.110	1747017.460	866.770	866.863	0.093
2029	424267.230	1858429.100	840.480	840.513	0.033
2030	578933.610	1516523.090	801.550	801.583	0.033
2031	432776.800	1873256.330	832.350	832.453	0.103
2032	646076.150	1672585.280	879.620	879.694	0.074
2033	570666.260	1750356.400	729.410	729.583	0.173
2034	403319.030	1524862.880	925.460	925.154	-0.306
2035	552452.610	1797412.540	706.600	706.783	0.183
2036	668171.400	1953795.030	787.070	787.143	0.073
2037	534586.180	1736312.860	889.320	889.444	0.124
2038	455902.870	1528684.020	839.130	839.183	0.053
2039	789130.400	1722301.880	696.350	696.403	0.053
2040	425638.670	1482525.050	799.700	799.733	0.033
2041	610010.240	1548552.770	692.650	692.573	-0.077
2042	756293.080	1781849.660	569.280	569.272	-0.008
2043	816717.510	1858786.050	832.960	832.923	-0.037
2044	747658.550	1897204.120	584.380	584.402	0.022
2045	380680.160	1630009.630	767.670	767.643	-0.027
2046	631220.530	1866851.960	593.460	593.312	-0.148
2047	346468.360	1841890.750	805.600	805.803	0.203
2048	326793.020	1507550.980	876.830	876.954	0.124
2049	833899.390	1742133.080	665.040	665.213	0.173
2050	809223.710	1737681.270	740.170	740.283	0.113
2051	272531.740	1686668.630	624.870	624.853	-0.017
2052	322363.520	1880855.050	1023.740	1023.864	0.124
2053	263552.910	1856467.150	934.950	935.174	0.224
2054	322314.460	1846866.780	773.250	773.343	0.093
2055	728769.680	1779367.920	616.990	617.152	0.162

Point ID	Easting	Northing	Known Z	DEM Z	dZ
2056	335732.000	1564987.050	870.860	870.923	0.063
2057	622128.480	1662443.060	546.930	546.992	0.062
2058	520680.020	1624120.280	894.870	894.844	-0.026
2059	803821.320	1633172.200	557.140	557.142	0.002
2060	510224.220	1897984.950	883.140	883.194	0.054
2061	808627.270	1901635.350	876.490	876.564	0.074
2062	545412.770	1473014.360	617.080	617.082	0.002
2063	274944.810	1783463.730	957.270	957.284	0.014
2064	486594.200	1556685.600	871.800	871.853	0.053
2065	425141.590	1656934.830	836.360	836.433	0.073
2066	436615.570	1550910.230	982.150	982.254	0.104
2067	584445.010	1552524.970	815.350	815.393	0.043
2068	691525.920	2009341.910	656.110	656.163	0.053
2069	472089.550	1662506.490	623.530	623.502	-0.028
2070	694995.780	1650139.800	656.360	656.453	0.093
2071	796644.350	1889574.760	603.340	603.182	-0.158
2072	689182.530	1982158.040	513.460	513.382	-0.078
2073	340377.600	1687754.140	1018.500	1018.414	-0.086
2074	807521.240	1496188.890	653.580	653.573	-0.007
2075	354160.410	1542104.120	945.540	945.374	-0.166
2076	534268.540	1849684.000	606.820	606.742	-0.078
2077	598804.310	1756928.690	651.930	651.963	0.033
2078	420551.180	1594150.790	792.200	792.163	-0.037
2079	485309.940	1886031.110	770.000	769.973	-0.027
2080	253905.120	1749635.820	899.200	899.124	-0.076
2081	301229.070	1777912.450	647.800	647.653	-0.147
2082	494443.300	1662194.710	685.180	685.293	0.113
2083	247502.670	1580992.330	852.550	852.513	-0.037
2084	501965.970	1892102.410	788.660	788.673	0.013
2085	691793.470	1997777.910	526.110	526.212	0.102
2086	592897.910	1650597.520	607.970	607.962	-0.008
2087	479103.660	1537601.330	589.250	589.202	-0.048
2088	586028.760	1869968.970	587.630	587.532	-0.098
2089	705474.570	1637162.820	676.060	676.093	0.033

Point ID	Easting	Northing	Known Z	DEM Z	dZ
2090	805353.390	1511988.080	621.280	621.222	-0.058
2091	287749.840	1520629.320	828.020	828.193	0.173
2092	243914.220	1813669.460	775.150	775.283	0.133
2093	331983.510	1727857.720	779.940	779.933	-0.007
2094	474878.790	1487892.920	587.080	587.182	0.102
2095	390583.900	1567631.200	837.080	837.053	-0.027
2096	325015.460	1600490.070	987.740	987.704	-0.036
2097	302407.390	1805988.410	686.730	686.753	0.023
2098	245487.970	1599796.540	815.080	815.063	-0.017
2099	254484.870	1571842.480	839.890	839.733	-0.157
2100	726373.420	1813194.540	527.780	527.932	0.152
2101	730120.050	1510314.350	454.740	454.882	0.142
2102	740729.530	1735901.010	900.680	900.414	-0.266
2103	379780.530	1660128.160	731.130	731.123	-0.007
2104	445423.400	1837772.750	788.140	788.153	0.013
2105	818454.310	1700302.160	712.810	713.033	0.223
2106	587115.980	1668217.820	701.080	701.113	0.033
2107	646904.210	1843137.220	587.670	587.682	0.012
2108	291480.900	1634984.760	931.600	931.574	-0.026
2109	778481.710	1638035.590	592.220	592.172	-0.048
2110	651224.010	1987271.360	560.710	560.842	0.132
2111	551399.580	1768203.920	759.670	759.863	0.193
2112	838867.290	1600791.510	562.160	562.182	0.022
2113	581205.990	1580262.420	881.910	881.944	0.034
2114	736699.690	1845944.860	559.490	559.562	0.072
2115	594586.890	1750601.910	683.110	682.973	-0.137
2116	436391.870	1489694.040	868.670	868.613	-0.057
2117	751831.540	1504614.260	602.780	603.002	0.222
2118	280339.870	1580962.220	776.050	775.923	-0.127
2119	330221.050	1845562.170	754.910	755.003	0.093
2120	339136.050	1558349.410	893.990	894.064	0.074
2121	242416.400	1835678.460	913.130	913.254	0.124
2122	624082.480	1618014.340	744.210	744.313	0.103
2123	452333.760	1708290.470	641.970	642.123	0.153

Point ID	Easting	Northing	Known Z	DEM Z	dZ
2124	617008.180	1704820.120	671.550	671.593	0.043
2125	376317.440	1504337.500	1018.950	1019.024	0.074
2126	565011.360	1462102.220	431.910	431.972	0.062
2127	468734.670	1874242.240	908.490	908.624	0.134
2128	804950.800	1702851.390	720.140	720.263	0.123
2129	360989.800	1507767.580	1011.180	1011.054	-0.126
2130	746043.930	1648761.810	669.130	669.033	-0.097
2131	688973.350	1903079.450	610.830	610.752	-0.078
2132	828305.030	1676813.430	561.870	562.042	0.172
2133	351470.040	1827982.660	793.550	793.763	0.213
2134	283211.260	1864234.300	967.130	967.264	0.134
2135	296325.350	1799354.860	671.970	671.943	-0.027
2136	783694.820	1579496.810	505.970	505.872	-0.098
2137	473222.110	1563630.670	637.730	637.653	-0.077
2138	690152.550	1959317.950	614.220	614.292	0.072
2139	754789.130	1614135.670	622.700	622.872	0.172
2140	393281.880	1599390.290	1004.170	1004.024	-0.146
2141	709465.290	1971295.300	543.500	543.652	0.152
2142	616248.700	1562570.270	810.260	810.373	0.113
2143	720061.570	1872756.570	499.380	499.392	0.012
2144	806644.750	1777121.540	716.730	716.783	0.053
2145	315779.720	1667925.780	703.830	703.873	0.043
2146	561226.840	1899088.030	591.450	591.552	0.102
2147	469645.280	1883335.950	938.290	938.264	-0.026
2148	372701.090	1878688.290	1085.300	1085.504	0.204
2149	781964.920	1668908.150	646.700	646.913	0.213
2150	328855.960	1537493.060	873.630	873.634	0.004
2151	833602.060	1548949.980	503.220	503.172	-0.048
2152	746223.490	1585716.570	576.470	576.412	-0.058
2153	486370.510	1524970.550	673.170	673.413	0.243
2154	451205.110	1830965.260	796.720	796.623	-0.097
2155	589455.170	1902955.230	673.080	673.103	0.023
2156	535567.210	1576692.650	614.260	614.242	-0.018
2157	727411.060	1767098.480	504.390	504.512	0.122

Point ID	Easting	Northing	Known Z	DEM Z	dZ
2158	816577.430	1825019.340	832.130	832.113	-0.017
2159	366818.710	1546775.940	992.530	992.504	-0.026
2160	673315.180	1678354.780	505.170	505.262	0.092
2161	788614.060	1850002.010	652.420	652.503	0.083
2162	513979.630	1512223.640	562.310	562.342	0.032
2163	426515.720	1674792.220	739.630	739.643	0.013
2164	637658.570	1556740.020	790.330	790.303	-0.027
2165	432886.450	1829073.930	762.090	762.103	0.013
2166	742289.170	1621676.360	631.800	631.453	-0.347
2167	513778.060	1902700.950	839.960	840.003	0.043
2168	355302.140	1881380.370	1095.210	1095.414	0.204
2169	559257.730	1466190.190	575.400	575.532	0.132
2170	795544.910	1879244.340	617.490	617.462	-0.028
2171	333827.370	1583597.010	926.340	926.364	0.024
2172	467674.850	1627318.550	696.560	696.533	-0.027
2173	487331.330	1541187.750	550.880	551.012	0.132
2174	782463.860	1740252.370	704.270	704.223	-0.047
2175	520742.940	1525978.590	578.690	578.982	0.292
2176	359779.920	1596937.380	932.530	932.674	0.144
2177	724044.110	1616746.000	388.660	388.652	-0.008
2178	454263.210	1785628.740	675.450	675.503	0.053
2179	395660.580	1500793.670	979.540	979.464	-0.076
2180	760532.510	1512101.200	369.980	369.961	-0.019
2181	246609.270	1800857.500	899.860	899.914	0.054
2182	301632.560	1709651.090	774.620	774.793	0.173
2183	252666.490	1741590.220	908.860	908.664	-0.196
2184	616297.070	1630474.600	769.630	769.593	-0.037
2185	791675.460	1811122.630	788.000	787.763	-0.237
2186	647085.800	1619964.570	799.650	799.573	-0.077
2187	529554.310	1612327.320	871.390	871.523	0.133
2188	747364.470	1984078.190	559.980	559.942	-0.038
2189	642225.590	1929008.170	658.780	658.803	0.023
2190	701755.890	1809740.480	570.320	570.352	0.032
2191	435852.370	1741211.380	673.370	673.333	-0.037

Point ID	Easting	Northing	Known Z	DEM Z	dZ
2192	543350.420	1701787.260	777.760	777.703	-0.057
2193	704649.960	1550126.810	666.790	666.723	-0.067
2194	739394.510	1946772.720	502.870	502.902	0.032
2195	409385.810	1736695.900	714.880	714.913	0.033
2196	349972.240	1643458.970	770.660	770.693	0.033
2197	386044.610	1724387.260	805.170	805.103	-0.067
2198	695740.720	1781190.770	465.760	465.802	0.042
2199	769949.130	1863112.730	560.980	560.912	-0.068
2528	512824.050	1747178.500	965.380	965.464	0.084

Appendix 4: DEM VVA Checkpoint Results

Coordinate values are listed in the following spatial reference system:

Horizontal: NAD83 (2011) State Plane Tennessee Zone 5301 (FIPZ Zone 4100), US Survey Feet

Vertical: NAVD88 (GEOID12B) US Survey Feet

Summary	
Point Count	139
Root Mean Square Error	0.433 ft (0.132 m)
95th Percentile	0.532 ft (0.162 m)
Mean of Residuals	0.286 ft
Standard Deviation	0.326 ft

Point ID	Easting	Northing	Known Z	DEM Z	dZ
3001	1511903.110	805428.640	617.480	617.632	0.1525
3002	1512073.060	760603.360	371.590	371.791	0.2015
3003	1637289.410	705219.610	667.400	667.843	0.4427
3004	1772710.440	745571.920	704.060	704.273	0.2128
3005	1889278.770	797118.830	603.410	603.572	0.1624
3007	2009144.550	691577.300	650.800	651.083	0.2826
3008	1825424.980	817463.880	823.080	823.173	0.0933
3009	1678471.080	828664.760	538.890	539.652	0.7622
3010	1626953.100	467997.240	692.380	692.753	0.3728
3011	1545964.380	366953.180	990.310	990.554	0.244
3012	1802787.490	246118.650	894.310	894.524	0.2136
3013	1874748.620	432131.500	796.360	796.643	0.2832
3014	1640027.700	778657.640	639.300	639.183	0.1174
3015	1849624.630	534244.660	605.930	605.942	0.0124
3016	1929568.610	642446.000	652.270	652.593	0.3226
3017	1577040.690	536080.610	627.650	627.673	0.0225
3018	1562311.840	249378.630	761.260	761.293	0.033
3019	1830765.530	450977.170	787.230	787.183	0.0469
3020	1899039.450	561212.660	588.390	588.612	0.2224
3021	1897160.100	747685.660	580.200	580.382	0.1823

Point ID	Easting	Northing	Known Z	DEM Z	dZ
3022	1863473.860	770200.390	566.430	566.732	0.3023
3023	1555466.470	636893.580	746.030	746.313	0.283
3024	1701775.180	543322.140	775.480	775.763	0.2831
3025	1741504.870	435642.520	684.750	684.833	0.0827
3026	1843944.360	647342.000	592.460	592.542	0.0824
3027	1715180.410	802955.580	666.530	666.783	0.2527
3028	1785241.190	812131.660	724.130	723.943	0.1871
3029	1579486.490	783572.940	508.880	508.802	0.078
3030	1552917.780	584382.170	818.670	818.853	0.1833
3031	1508954.990	511862.760	595.210	595.322	0.1124
3032	1658205.980	424749.660	833.320	833.653	0.3333
3033	1766851.930	357986.140	769.940	770.143	0.2031
3034	1880909.640	322305.570	1027.310	1027.804	0.4941
3035	1768200.060	551339.520	750.880	751.303	0.423
3036	1847576.980	736057.220	536.720	537.322	0.6021
3037	1772870.620	793693.090	796.020	796.213	0.1932
3038	1585690.690	746250.170	574.440	574.602	0.1623
3039	1550436.330	704862.540	682.670	682.713	0.0427
3040	1619980.160	646617.510	775.500	776.013	0.5131
3041	1650523.170	592824.070	605.280	605.662	0.3824
3042	1747251.620	512779.140	977.650	977.784	0.1339
3043	1827987.540	351495.500	790.910	791.933	1.0232
3044	1630065.420	382082.940	768.680	769.113	0.4331
3045	1710445.640	302741.520	796.980	797.463	0.4832
3046	1539094.080	485738.180	544.420	544.722	0.3022
3047	1734762.390	494007.750	766.760	766.893	0.1331
3048	1869974.600	584902.500	570.410	570.912	0.5023
3049	1903112.560	688990.190	608.770	608.582	0.1876
3050	1946946.540	739137.030	493.850	493.982	0.132
3051	1648741.650	745928.860	667.430	667.493	0.0627
3052	1510255.820	730208.110	436.550	436.522	0.0283
3053	1617960.490	624240.120	743.910	743.973	0.063
3054	1809242.020	702734.160	555.980	556.122	0.1422
3055	1785686.980	454288.520	674.260	674.603	0.3427

Point ID	Easting	Northing	Known Z	DEM Z	dZ
3056	1777844.200	301261.550	648.150	650.663	2.5126
3057	1749622.440	253938.530	899.890	900.014	0.1236
3058	1847975.330	321759.760	775.860	776.283	0.4231
3059	1551038.510	436581.530	980.380	980.494	0.1139
3060	1508761.710	644173.510	713.360	713.553	0.1929
3061	1581351.910	599627.060	874.870	875.024	0.1535
3062	1678227.290	673282.880	508.020	508.262	0.242
3063	1621715.610	742340.960	635.370	635.543	0.1725
3064	1682336.040	810645.740	635.850	635.923	0.0725
3065	1600783.380	838930.390	561.510	561.512	0.0022
3066	1612300.760	529598.400	874.040	874.184	0.1435
3067	1886166.980	485105.300	757.140	757.163	0.023
3068	1959853.820	688939.970	667.980	668.243	0.2627
3069	1999819.600	691834.050	498.970	499.502	0.532
3070	1866779.610	631184.940	590.900	590.992	0.0924
3071	1769909.180	593597.620	609.300	609.822	0.5224
3072	1704588.970	615495.530	671.100	671.303	0.2027
3073	1735023.780	740855.110	889.880	890.124	0.2436
3074	1850129.400	788766.130	667.440	667.883	0.4427
3075	1859691.080	817677.020	775.070	775.253	0.1831
3076	1742063.100	833930.580	665.370	665.533	0.1627
3077	1616196.590	724494.990	391.520	391.752	0.2316
3078	1650188.520	694925.760	661.770	662.163	0.3926
3079	1615862.100	586303.820	751.150	751.403	0.253
3080	1668252.890	586941.140	694.370	694.523	0.1528
3081	1749467.970	571333.440	730.310	730.593	0.2829
3082	1902178.480	589255.820	645.170	645.403	0.2326
3083	1981716.090	643181.270	681.900	682.393	0.4927
3084	1638719.660	294726.250	950.650	950.734	0.0838
3085	1669345.220	315844.600	722.150	722.663	0.5129
3086	1688675.160	340854.940	1068.330	1068.404	0.0743
3087	1723985.890	385730.000	807.110	807.253	0.1432
3088	1739110.610	407916.350	756.430	756.723	0.293
3089	1727838.120	332039.330	778.030	778.163	0.1331

Point ID	Easting	Northing	Known Z	DEM Z	dZ
3090	1644318.280	349112.210	731.510	731.703	0.1929
3091	1599374.590	324674.150	969.530	969.904	0.3739
3092	1564631.070	335942.170	899.940	900.064	0.1236
3093	1538536.790	328628.710	821.570	821.533	0.0367
3094	1519939.350	287632.720	794.890	795.073	0.1832
3095	1507609.650	327105.820	878.310	878.604	0.2935
3096	1506555.460	362658.460	990.210	990.654	0.444
3097	1504614.470	376364.710	1020.130	1022.864	2.7341
3098	1524855.450	403241.670	928.240	928.364	0.1237
3099	1482711.410	425765.820	785.610	785.813	0.2031
3100	1489793.910	436267.630	852.190	852.373	0.1834
3101	1526015.850	455307.400	929.810	930.284	0.4737
3102	1488181.460	474596.960	588.360	588.672	0.3124
3103	1525227.870	486200.710	673.320	673.543	0.2227
3104	1561088.820	469000.770	655.540	655.953	0.4126
3105	1556639.600	486534.020	870.270	870.693	0.4235
3106	1472980.590	545639.390	611.100	611.202	0.1024
3107	1466187.780	559169.190	571.310	571.482	0.1723
3108	1462082.020	564869.170	422.860	422.962	0.1017
3109	1516814.890	579172.720	793.300	793.543	0.2432
3110	1548801.140	610056.450	704.370	704.673	0.3028
3111	1561491.720	614497.970	812.750	813.153	0.4033
3112	1554466.020	621846.250	644.650	645.063	0.4126
3113	1630518.870	616409.470	770.660	771.073	0.4131
3114	1686218.390	720560.700	761.720	761.873	0.153
3115	1722332.270	789059.120	696.840	697.143	0.3028
3116	1738089.040	809110.920	728.700	728.933	0.2329
3117	1808530.410	789003.490	895.860	896.234	0.3736
3118	1847440.840	824945.170	863.730	863.913	0.1835
3119	1739769.850	782495.190	710.970	711.123	0.1528
3120	1655630.590	493945.000	779.490	780.003	0.5131
3121	1624090.800	520652.670	890.100	890.444	0.3436
3122	1662287.270	622288.540	568.670	569.132	0.4623
3123	1672541.410	645999.140	877.520	877.824	0.3035

Point ID	Easting	Northing	Known Z	DEM Z	dZ
3124	1669649.780	781232.570	649.150	649.543	0.3926
3125	1633179.360	803564.410	559.770	559.792	0.0222
3126	1704021.300	803374.570	716.640	716.813	0.1729
3127	1700426.410	817719.510	685.700	685.993	0.2927
3128	1742980.290	477962.780	698.490	698.713	0.2228
3129	1776354.390	536868.620	779.370	779.623	0.2531
3130	1797471.450	552541.670	703.880	704.153	0.2728
3131	1897928.440	510279.870	882.010	882.154	0.1435
3132	1903273.330	514521.850	837.300	837.533	0.2334
3133	1882549.990	470219.140	963.520	963.674	0.1539
3134	1847048.160	626242.730	564.400	564.592	0.1923
3135	1750505.390	594533.820	685.840	686.023	0.1827
3136	1872232.700	719989.890	489.960	490.262	0.302
3137	1971419.970	711687.740	498.540	499.182	0.642
3138	1548532.370	833500.410	495.350	495.622	0.272
3139	1504768.780	751727.300	606.500	606.762	0.2624
3140	1706819.300	454544.720	649.410	649.573	0.1626