
# Project Report

TASK ORDER NAME: 2018 Kansas QL2 LiDAR
CONTRACT ID: 00000000000000000000039891
EVENT ID: EVT0003259
ATLANTIC PROJECT NUMBER: 18006
PROJECT BLOCK NUMBER: Block 4B

# *TABLE OF CONTENTS*

# SECTION I: PROJECT OVERVIEW & PURPOSE

## 1. Aerial LiDAR Project

### a. Project Overview

The State of Kansas Contract 00000000000000000000039891 required Leaf-off 2018 QL 2 LiDAR surveys to be collected over 54,663 square miles covering part or all of 86 counties in Kansas in support of the Kansas Department of Agriculture and Kansas Data Access and Support Center. Aerial LiDAR data for this task order was planned, acquired, processed and produced at an aggregate nominal pulse spacing (ANPS) of 0.71 meters and in compliance with USGS National Geospatial Program LiDAR Base Specification version 1.2. Project Block 4B encompasses part or all of 6 counties in Kansas and covers approximately 2624 square miles.

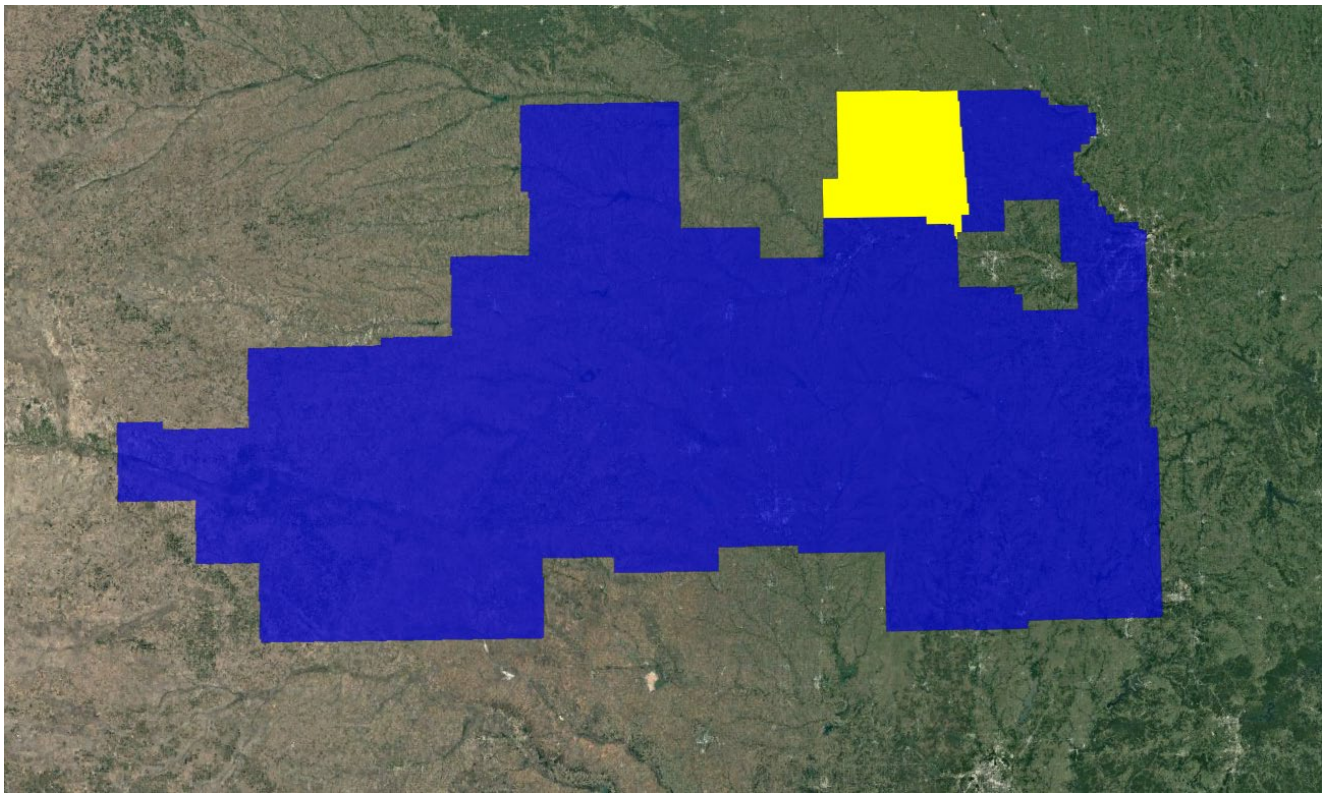


*Figure 1: Aerial LiDAR Project Overview – Defined Project Area (DPA) and Associated Areas of Interest (AOIs)*

The State of Kansas, on behalf of the Kansas Department of Agriculture and Kansas Data Access and Support Center, has contracted with Atlantic for professional services related to the development of Light Detection and Ranging (LiDAR). Additional partners include the USDA Natural Resource Conservation Service, the U.S. Geological Survey, the Kansas GIS Policy Board, the Kansas Department of Transportation, and the Kansas Water Office. These LiDAR elevation data will be used for conservation planning, design, research, floodplain mapping, wetlands identification, dam safety assessments, hydrologic modeling, and subsidence monitoring.

## c. Client Contact Information

| Client Contact Information | |
|---|---|
| **Name of Contact** | Tara Lanzrath, CFM |
| **Organization** | Kansas Department of Agriculture |
| **Position** | Floodplain Mapping Coordinator |
| **Telephone** | 785-296-2513 |
| **E-Mail Address** | Tara.Lanzrath@ks.gov |
| **Mailing Address** | 6531 SE Forbes Ave., Suite B |
| **City** | Topeka |
| **State or Province** | Kansas |
| **Postal Code** | 66619 |

*Table 1: Aerial LiDAR Client Contact Information*

## d. Contract Deliverables

| Item | Specification/Format |
|---|---|
| **Metadata** | FGDC compliant, xml format |
| **Project Report** | .pdf format |
| **Raw Point Cloud** | Swaths, LAS 1.4 |
| **Classified Point Cloud** | LAS 1.4 |
| **Bare Earth DEM** | ERDAS .IMG format, Hydroflattened |
| **First Return DSM** | ERDAS .IMG format |
| **Hydro Polygon Breaklines** | .gdb format |
| **Intensity Imagery** | ERDAS .IMG format |

*Table 2: Aerial LiDAR Contract Deliverables*

# SECTION II: FIELD OPERATIONS

## 1. Aerial LiDAR Project – Aerial Acquisition

### a. Aircraft & Sensor Information

Atlantic operated a Cessna (N732JE) outfitted with a Leica ALS70-HP LiDAR system during the collection of the project area. The specifications of this system are presented in the following table:

| Parameter | Specification |
|---|---|
| **Model** | ALS70-HP |
| **Manufacturer** | Leica |
| **Platform** | Fixed-Wing |
| **Scan Pattern** | Sine, Triangle, Raster |
| **Maximum Scan Rate (Hz)** | Sine: 200<br>Triangle: 158<br>Raster: 120 |
| **Field of View (°)** | 0 – 75 (Full Angle, User Adjustable) |
| **Maximum Pulse Rate (kHz)** | 500 |
| **Maximum Flying Height (m AGL)** | 3500 |
| **Number of Returns** | Unlimited |
| **Number of Intensity Measurements** | 3 (First, Second, Third) |
| **Roll Stabilization (Automatic Adaptive, °)** | 75 - Active FOV |
| **Storage Media** | Removable 500 GB SSD |
| **Storage Capacity (Hours @ Max Pulse Rate)** | 6 |
| **Size (cm)** | Scanner: 37 W x 68 L x 26 H<br>Control Electronics: 45 W x 47 D x 36 H |
| **Weight (kg)** | Scanner: 43<br>Control Electronics: 45 |
| **Operation Temperature (°C)** | 0 – 40 |
| **Flight Management** | FCMS |
| **Power Consumption** | 927 @ 22.0 – 30.3 VDC |

*Table3: System Specifications – ALS70-HP*

### b. Sensor Acquisition Information

The following table illustrates project specific system parameters for LiDAR acquisition on this project:

| Parameter | Specification |
|---|---|
| **System** | Leica ALS70-HP |
| **Nominal Pulse Spacing (m)** | 0.71 |
| **Nominal Pulse Density (pls/m²)** | 2.2 |
| **Nominal Flight Height (AGL meters)** | 2000 |
| **Nominal Flight Speed (kts)** | 130 |
| **Pass Heading (°)** | 0 |
| **Sensor Scan Angle (°)** | 45 |
| **Scan Frequency (Hz)** | 33.9 |
| **Pulse Rate of Scanner (kHz)** | 256,400 |
| **Line Spacing (m)** | 1,171 |

| Parameter | Specification |
|---|---|
| Pulse Duration of Scanner (ns) | 4 |
| Pulse Width of Scanner (m) | .35 |
| Central Wavelength of Sensor Laser (nm) | 1064 |
| Sensor Operated with Multiple Pulses | 2 |
| Beam Divergence (mrad) | .15 |
| Nominal Swath Width (m) | 1,740 |
| Nominal Swath Overlap (%) | 20 |
| Scan Pattern | TRIANGLE |

*Table 4: Aerial LiDAR Sensor Acquisition Parameters*

## c. Flight Plan Execution

Atlantic acquired 130 passes of the AOI as a series of perpendicular and/or adjacent flight-lines executed in 19 flight missions conducted between March 1, 2018 and April 26, 2018. Onboard differential Global Navigation Satellite System (GNSS) unit(s) recorded sample aircraft positions at 2 hertz (Hz) or more frequency. LiDAR data was only acquired when a minimum of six (6) satellites were in view.

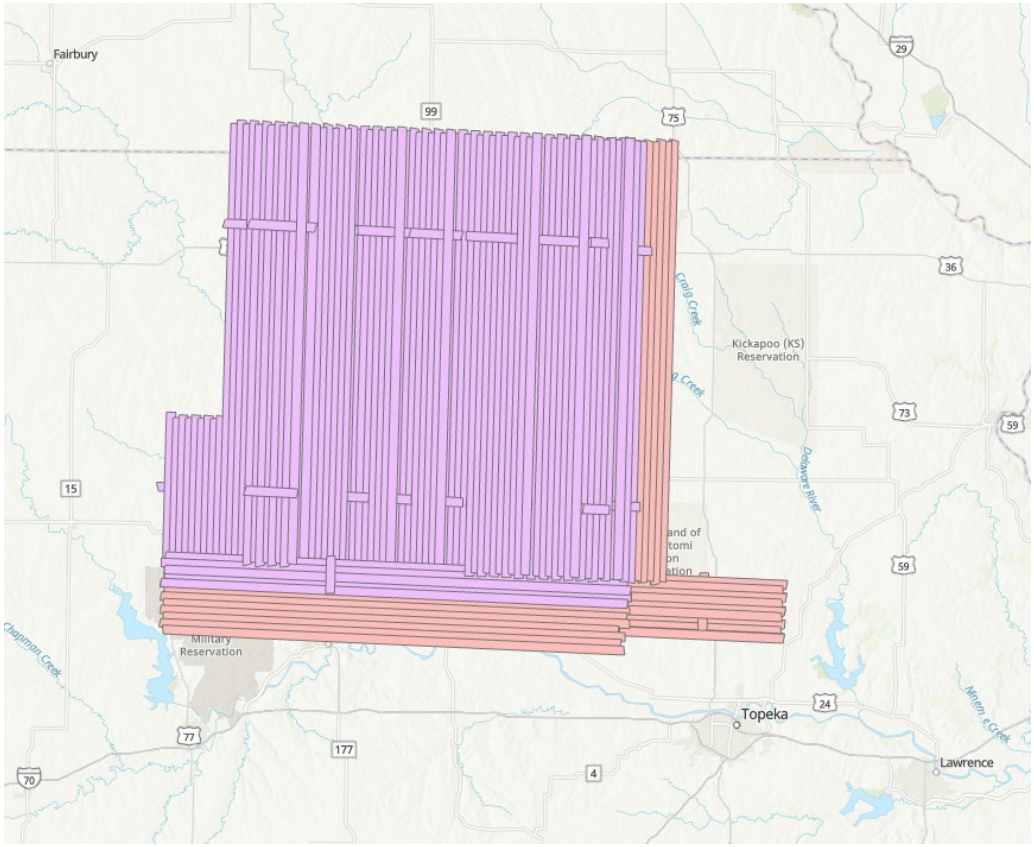



*Figure 2: Orientation of Executed Flight-lines and LiDAR DPA*

## d. GNSS Reference Stations

Twenty-five (25) Continuously Operating Reference Stations (CORS) were used to control the LiDAR acquisition for the defined project area. The coordinates provided in below are in NAD83 (2011), Geographic Coordinate System, Ellipsoid, Meters.

| Designation | Type | PID | Latitude (N) | Longitude (W) | Elevation |
|---|---|---|---|---|---|
| **ICT3** | CORS | ICT3 | N37°45'09.33290" | W97°12'58.42243" | 401.242 |
| **KSAY** | CORS | KSAY | N37°08'40.33068" | W98°01'49.57453" | 383.653 |
| **KSBU** | CORS | KSBU | N38°11'44.89654" | W95°44'17.09576" | 289.926 |
| **KSBK** | CORS | KSBK | N37°33'03.90852" | W99°38'06.26885" | 717.084 |
| **KSBR** | CORS | KSBR | N39°06'56.69775" | W94°55'43.07246" | 251.885 |
| **KSCC** | CORS | KSCC | N39°22'55.99556" | W97°10'10.61980" | 349.885 |
| **KSCO** | CORS | KSCO | N39°36'37.76224" | W97°39'44.33598" | 400.376 |
| **KSCP** | CORS | KSCP | N38°58'16.54525" | W97°01'11.91593" | 320.533 |
| **KSCW** | CORS | KSCW | N37°16'24.87324" | W99°19'39.34067" | 624.848 |
| **KSEM** | CORS | KSEM | N38°24'14.61668" | W96°10'42.33264" | 341.335 |
| **KSHW** | CORS | KSHW | N39°51'04.21656" | W95°33'34.79184" | 324.675 |
| **KSKG** | CORS | KSKG | N37°39'01.96639" | W98°05'39.96395" | 450.922 |
| **KSLW** | CORS | KSLW | N38°57'44.05427" | W95°14'33.27350" | 306.695 |
| **KSMH** | CORS | KSMH | N39°10'44.46539" | W96°34'25.38239" | 290.838 |
| **KSOG** | CORS | KSOG | N38°38'14.33272" | W95°49'49.98264" | 307.468 |
| **KSPR** | CORS | KSPR | N37°41'26.44138" | W98°44'27.53387 | 573.45 |
| **KSSN** | CORS | KSSN | N39°50'30.90620" | W96°03'19.35788" | 314.962 |
| **KSTK** | CORS | KSTK | N39°05'22.98823" | W95°42'09.76216" | 248.525 |
| **KSU1** | CORS | KSU1 | N39°06'02.70007" | W96°36'34.13585" | 325.564 |
| **MOPL** | CORS | MOPL | N39°23'04.09584" | W94°47'00.08368" | 211.99 |
| **MOSB** | CORS | MOSB | N38°49'48.71034" | W94°32'04.48758" | 301.135 |
| **MOWE** | CORS | MOWE | N39°25'19.76974" | W94°53'44.61076" | 242.722 |
| **NEBE** | CORS | NEBE | N40°15'58.00997" | W96°44'41.62308" | 365.679 |
| **NEHU** | CORS | NEHU | N40°10'07.61592" | W95°56'48.84828" | 302.862 |
| **ZKC1** | CORS | ZKC1 | N38°52'48.57351" | W94°47'27.00464" | 305.466 |

*Table 5: GNSS Reference Stations*

# 2. Aerial LiDAR Project – Ground Acquisition

## a. Ground Control Survey

A total of 104 ground survey points were collected in support of this project, including 28 LiDAR Control Points (LCP), 45 Non-vegetated Vertical Accuracy (NVA) and 31 Vegetated Vertical Accuracy (VVA).

Point cloud data accuracy was tested against a Triangulated Irregular Network (TIN) constructed from LiDAR points in clear and open areas. A clear and open area can be characterized with respect to topographic and ground cover variation such that a minimum of five (5) times the Nominal Pulse Spacing (NPS) exists with less than 1/3 of the RMSEZ deviation from a low-slope plane. Slopes that exceed ten (10) percent were avoided.

Each land cover type representing ten (10) percent or more of the total project area were tested and reported with a VVA. In land cover categories other than dense urban areas, the tested points did not have obstructions forty-five (45) degrees above the horizon to ensure a satisfactory TIN surface. The VVA value is provided as a target. It is understood that in areas of dense vegetation, swamps, or extremely difficult terrain, this value may be exceeded.

The NVA value is a requirement that must be met, regardless of any allowed "busts" in the VVA(s) for individual land cover types within the project. Checkpoints for each assessment (NVA & VVA) are required to be well-distributed throughout the land cover type, for the entire project area.

The following tables and figures outline the coordinate values and distribution of LCP, NVA and VVA points collected in support of this project:

| ID | Easting | Northing | Elevation |
|---|---|---|---|
| **LCP601** | 756504.97 | 4376762.508 | 404.896 |
| **LCP602** | 756634.403 | 4361970.386 | 364.437 |
| **LCP603** | 754769.852 | 4404727.461 | 360.149 |
| **LCP604** | 746478.92 | 4428622.079 | 362.138 |
| **LCP605** | 739075.719 | 4425400.25 | 377.784 |
| **LCP606** | 735098.963 | 4421876.59 | 412.554 |
| **LCP608** | 751234.83 | 4352925.552 | 364.859 |
| **LCP615** | 738326.38 | 4359014.528 | 314.486 |
| **LCP616** | 740178.814 | 4362298.311 | 318.626 |
| **LCP617** | 732799.68 | 4368555.294 | 397.985 |
| **LCP618** | 734437.59 | 4392039.564 | 400.557 |
| **LCP619** | 738542.61 | 4397769.782 | 394.897 |
| **LCP620** | 734675.443 | 4410591.047 | 395.933 |
| **LCP621** | 715572.626 | 4426087.624 | 423.843 |
| **LCP622** | 716499.931 | 4431760.809 | 407.604 |
| **LCP623** | 716438.703 | 4398735.869 | 378.507 |
| **LCP624** | 710301.465 | 4405019.152 | 392.452 |
| **LCP625** | 692115.283 | 4428737.298 | 404.865 |

| ID | Easting | Northing | Elevation |
|---|---|---|---|
| **LCP626** | 708009.9 | 4384174.061 | 357.15 |
| **LCP627** | 721842.349 | 4384383.266 | 386.126 |
| **LCP628** | 704362.578 | 4356188.007 | 333.052 |
| **LCP629** | 694829.79 | 4383941.701 | 416.341 |
| **LCP631** | 691543.935 | 4361136.443 | 412.688 |
| **LCP658** | 753966.146 | 4398284.577 | 405.845 |
| **LCP661** | 730582.42 | 4387486.482 | 391.059 |
| **LCP662** | 694253.435 | 4404719.675 | 405.984 |
| **LCP663** | 708004.838 | 4375161.66 | 430.6 |
| **LCP105** | 247031.473 | 4344901.254 | 298.338 |

*Table 6: LiDAR Control Point Coordinates*

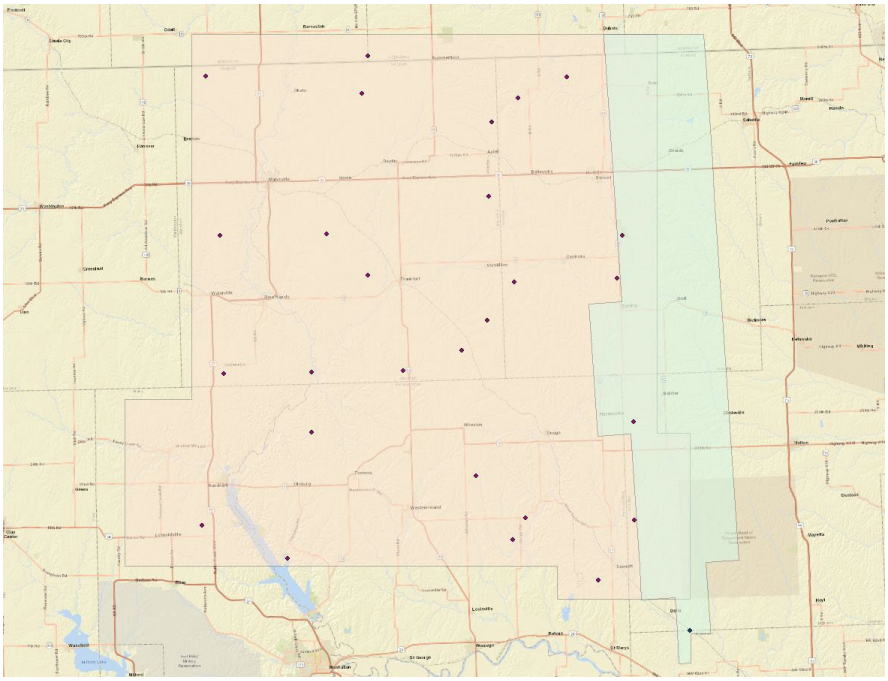


*Figure 3: LiDAR Control Point Distribution*

| ID | Easting | Northing | Elevation |
|---|---|---|---|
| **NVA1000** | 745974.881 | 4401240.567 | 397.077 |
| **NVA1001** | 743373.371 | 4374950.674 | 342.645 |
| **NVA1002** | 730583.354 | 4375984.386 | 459.8 |
| **NVA1003** | 722840.199 | 4363603.543 | 363.989 |
| **NVA1004** | 692748.661 | 4366963.398 | 375.396 |
| **NVA1024** | 750224.126 | 4425707.571 | 319.138 |
| **NVA1026** | 725025.753 | 4371643.653 | 424.436 |

| ID | Easting | Northing | Elevation |
|---|---|---|---|
| **NVA1027** | 726990.095 | 4405511.682 | 376.255 |
| **NVA1028** | 697151.866 | 4420240.594 | 357.709 |
| **NVA1029** | 707014.467 | 4363836.399 | 381.281 |
| **NVA937** | 692118.399 | 4428772.814 | 404.614 |
| **NVA938** | 704390.45 | 4356193.988 | 333.059 |
| **NVA939** | 740198.333 | 4362253.393 | 317.11 |
| **NVA940** | 756657.174 | 4361955.618 | 364.67 |
| **NVA941** | 721875.725 | 4384377.811 | 385.886 |
| **NVA942** | 734463.039 | 4392017.278 | 400.967 |
| **NVA943** | 754791.321 | 4404753.494 | 358.553 |
| **NVA944** | 746455.045 | 4428632.907 | 361.668 |
| **NVA945** | 694811.024 | 4383915.559 | 417.048 |
| **NVA947** | 716507.22 | 4431783.632 | 406.947 |
| **NVA948** | 734717.376 | 4410599.594 | 397.774 |
| **NVA949** | 735116.011 | 4421844.576 | 414.442 |
| **NVA953** | 751267.819 | 4352933.453 | 364.478 |
| **NVA968** | 711912.059 | 4421200.744 | 421.952 |
| **NVA969** | 694273.544 | 4404702.116 | 405.564 |
| **NVA970** | 687863.596 | 4373177.721 | 379.976 |
| **NVA971** | 740890.975 | 4383330.387 | 384.813 |
| **NVA972** | 708057.79 | 4375185.942 | 427.834 |
| **NVA973** | 715054.01 | 4367338.227 | 429.999 |
| **NVA974** | 734380.949 | 4366113.342 | 396.109 |
| **NVA975** | 749724.828 | 4392652.35 | 394.334 |
| **NVA976** | 704327.236 | 4389481.337 | 359.871 |
| **NVA978** | 750403.357 | 4422012.697 | 352.304 |
| **NVA992** | 748826.837 | 4366267.611 | 402.479 |
| **NVA993** | 701127.462 | 4412825.201 | 352.415 |
| **NVA994** | 705015.305 | 4426478.014 | 385.871 |
| **NVA995** | 720942.147 | 4415455.22 | 399.03 |
| **NVA996** | 740804.007 | 4414255.566 | 399.346 |
| **NVA997** | 750979.566 | 4414230.517 | 348.312 |
| **NVA998** | 700840.058 | 4395053.917 | 350.646 |
| **NVA999** | 721443.396 | 4398148.466 | 351.644 |
| **NVA175** | 251003.176 | 4393091.138 | 358.874 |
| **NVA259** | 251699.8 | 4373823.608 | 379.077 |
| **NVA37** | 247019.151 | 4344916.045 | 298.157 |
| **NVA977** | 242388.225 | 4382888.112 | 405.445 |

*Table 7: Non-Vegetated Vertical Accuracy (NVA) Point Coordinates*

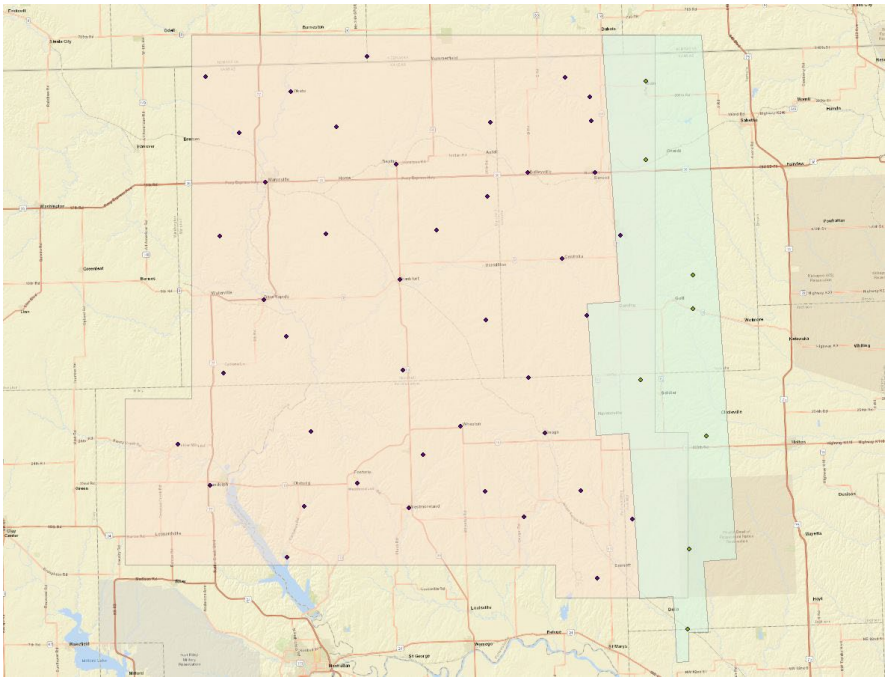


*Figure 4: Non-Vegetated Vertical Accuracy (NVA) Point Distribution*

| ID | Easting | Northing | Elevation |
|---|---|---|---|
| **VVA671** | 708021.13 | 4384153.084 | 356.108 |
| **VVA672** | 732763.978 | 4368632.468 | 398.016 |
| **VVA673** | 756489.063 | 4376718.592 | 407.458 |
| **VVA674** | 715561.766 | 4426065.083 | 422.835 |
| **VVA675** | 739093.228 | 4425368.7 | 375.103 |
| **VVA676** | 716406.12 | 4398722.381 | 378.923 |
| **VVA677** | 738537.829 | 4397777.762 | 394.87 |
| **VVA678** | 691520.514 | 4361149.164 | 413.21 |
| **VVA687** | 694836.719 | 4375635.996 | 393.262 |
| **VVA688** | 745805.694 | 4410948.726 | 383.651 |
| **VVA689** | 697181.24 | 4420289.5 | 357.222 |
| **VVA690** | 712230.077 | 4410626.707 | 399.648 |
| **VVA691** | 726968.101 | 4405564.925 | 376.529 |
| **VVA692** | 725071.205 | 4371650.358 | 422.378 |
| **VVA693** | 751990.364 | 4366845.949 | 398.815 |
| **VVA694** | 743957.445 | 4391500.983 | 412.313 |
| **VVA699** | 694418.984 | 4398213.78 | 402.242 |
| **VVA700** | 750204.518 | 4425735.324 | 319.236 |
| **VVA701** | 703154.926 | 4429016.797 | 391.446 |

| ID | Easting | Northing | Elevation |
|---|---|---|---|
| **VVA703** | 730591.769 | 4387459.297 | 391.303 |
| **VVA704** | 738155.635 | 4359016.018 | 315.567 |
| **VVA705** | 753990.071 | 4398342.172 | 408.626 |
| **VVA706** | 725705.919 | 4411927.955 | 420.872 |
| **VVA708** | 754465.828 | 4354707.57 | 309.739 |
| **VVA724** | 720965.887 | 4415437.113 | 397.184 |
| **VVA725** | 701123.821 | 4412819.862 | 352.45 |
| **VVA726** | 715049.924 | 4367286.309 | 430.45 |
| **VVA115** | 252972.769 | 4430248.34 | 403.033 |
| **VVA181** | 245344.087 | 4416100.265 | 361.167 |
| **VVA59** | 251684.372 | 4373769.455 | 381.56 |
| **VVA62** | 251266.846 | 4398112.297 | 369.201 |

*Table 8: Vegetated Vertical Accuracy (VVA) Point Coordinates*

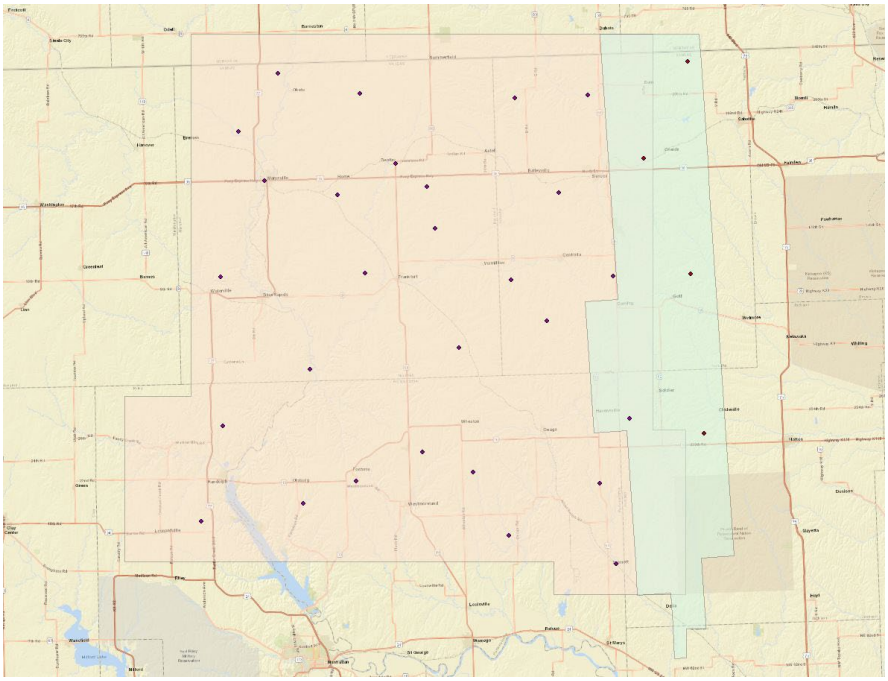


*Figure 5: Vegetated Vertical Accuracy (VVA) Point Distribution*

# SECTION III: DATA PRODUCTION

## 3. Aerial LiDAR Project – Calibration/Classification

### a. LiDAR Point Cloud Generation

Atlantic used Leica software products to download the IPAS ABGNSS/IMU data and raw laser scan files from the airborne system. Waypoint Inertial Explorer is used to extract the raw IPAS ABGNSS/IMU data, which is further processed in combination with controlled base stations to provide the final Smoothed Best Estimate Trajectory (SBET) for each mission. The SBETs are combined with the raw laser scan files to export the LiDAR ASCII Standard (*.las) formatted swath point clouds.

### b. Coordinate Reference System

**Horizontal Datum:** NAD83(HARN)
**Coordinate System:** UTM, 14N
**Vertical Datum:** NAVD88
**Geoid Model:** 12B
**Units of Reference:** Meter

### c. LiDAR Point Cloud Statistics

| Category | Value |
|---|---|
| **Total Points (Nominal)** | 20,840,342,661 |
| **Nominal Pulse Spacing (M)** | 0.6607 |
| **Nominal Pulse Density (PLS/M^2)** | 2.2911 |
| **Total Points (Aggregate)** | 20,406,200,876 |
| **Aggregate Pulse Spacing (M)** | 0.6625 |
| **Aggregate Pulse Density (PLS/M^2)** | 2.1601 |

*Table 9: LiDAR Point Cloud Statistics*

### d. Smooth Surface Repeatability (Interswath)

Departures from planarity of first returns within single swaths in non-vegetated areas were assessed at multiple locations with hard surface areas (parking lots or large rooftops) inside the project area. Each area was evaluated using signed difference rasters (maximum elevation – minimum elevation) at a cell size equal to 2 x ANPS, rounded to the next integer.

### e. LiDAR Calibration

Using a combination of GeoCue, TerraScan and TerraMatch; overlapping swath point clouds are corrected for any orientation or linear deviations to obtain the best fit swath-to-swath calibration. Relative calibration was evaluated using advanced plane-matching analysis and parameter corrections derived. This process was repeated interactively until residual errors between overlapping swaths, across all project missions, was reduced to ≤2cm. A final analysis of the calibrated lidar is preformed using a TerraMatch tie line report for an overall statistical model of the project area. Individual control point assessments for this project can be found in Section VI of this report.

Upon completion of the data calibration, a complete set of elevation difference intensity rasters (dZ Orthos) are produced. A user-defined color ramp is applied depicting the offsets between overlapping swaths based

on project specifications. The dZ orthos provide an opportunity to review the data calibration in a qualitative manner. Atlantic assigns green to all offset values that fall below the required RMSDz requirement of the project. A yellow color is assigned for offsets that fall between the RMSDz value and 1.5x of that value. Finally, red values are assigned to all values that fall beyond 1.5x of the RMSDz requirements of the project.

## f. LiDAR Classification

Multiple automated filtering routines are applied to the calibrated LiDAR point cloud identifying and extracting bare-earth and above ground features. GeoCue, TerraScan, and TerraModeler software was used for the initial batch processing, visual inspection and any manual editing of the LiDAR point clouds. Atlantic utilized collected breakline data to preform classification for classes 9 (Water) and 10 (Ignored Ground).

| Code | Description |
|---|---|
| **1** | Unclassified |
| **2** | Ground |
| **7** | Low point (noise) |
| **9** | Water |
| **10** | Ignored ground (breakline proximity) |
| **17** | Bridge |
| **18** | High point (noise) |

*Table 10: LiDAR Point Classification Codes and Descriptions*

## g. LiDAR Intensity Imagery

LiDAR intensity imagery was created from the final calibrated and classified lidar point cloud. Intensity images were produced from all classified points and posted to a 1.0-meter cell size. Intensity images were cut to match the tile index and its corresponding tile names and delivered in .img format.

## h. Hydro-line Collection/Conflation

Hydro breaklines were compiled using LiDAR intensity data and surface terrain models of the entire project area. After the collection, all delineated hydro features were validated for monotonicity and vertical variance. This procedure ensures that no points were floating above ground. Hydro-lines were then encoded into the LiDAR surface and used to hydro-enforce/flatten all significant water bodies. These final hydro-lines were then used in the production of bare Earth digital models to hydro flatten significant water bodies. This product was delivered as an ESRI geodatabase for the entire project area.

## i. Bare-Earth Surface – Digital Elevation Model (DEM)

Bare earth Digital Elevation Models (DEMs) were derived using the hydro-lines and bare earth (ground) LiDAR points. All DEMs were created with a grid spacing of 1 meter. DEMs for this project were cut to match the tile index and its corresponding tile names and delivered in 32-bit floating point .img format.

## j. Surface-Digital Elevation Model (DSM)

Surface digital elevation models (DSMs) were derived using all first return LiDAR points, excluding LiDAR points classified as high or low noise. All DSMs were created with a grid spacing of 1 meter. DSMs for this project were cut to match the tile index and its corresponding tile names and delivered in 32-bit floating point .img format.

# SECTION IV: ACCURACY ASSESSMENT

## 1. Aerial LiDAR Project – Vertical Accuracy Assessment

### a. Requirements

Per the table below, the Vertical Accuracy Assessment utilized the required parameters for Vertical Data Accuracy Class IV.

| Vertical Data Accuracy Class | RMSEz in Non-Vegetated Terrain (cm) | Non-Vegetated Vertical Accuracy (NVA) at 95% Confidence Level (cm) | Vegetated Vertical Accuracy (VVA) at 95$^{th}$ Percentile (cm) |
|---|---|---|---|
| **I** | 1.0 | 2.0 | 2.9 |
| **II** | 2.5 | 4.9 | 7.4 |
| **III** | 5.0 | 9.8 | 14.7 |
| **IV** | 10.0 | 19.6 | 29.4 |
| **V** | 12.5 | 24.5 | 36.8 |
| **VI** | 20.0 | 39.2 | 58.8 |
| **VII** | 33.3 | 65.3 | 98.0 |
| **VIII** | 66.7 | 130.7 | 196.0 |
| **IX** | 100.0 | 196.0 | 294.0 |
| **X** | 333.3 | 653.3 | 980.0 |

*Table 11: Vertical Accuracy Standards, Source: ASPRS Positional Accuracy Standards for Digital Geospatial Data v1.0 (2014)*

*The terms NVA and VVA are from the American Society for Photogrammetry and Remote Sensing (ASPRS) Positional Accuracy Standards for Digital Geospatial Data v1.0 (2014). The term NVA refers to assessments in clear, open areas (which typically produce only single LiDAR returns); the term VVA refers to assessments in vegetated areas (typically characterized by multiple return LiDAR).

### b. Results

An overall statistical assessment of the check points can be found in the following two tables (values provided in meters):

| Broad Land Cover Type | Points (#) | RMSEz | Confidence Level (95%) | Percentile (95th) |
|---|---|---|---|---|
| **NVA (Point Cloud)** | 45 | 0.0773 | 0.1514 | 0.1238 |
| **NVA (DEM)** | 45 | 0.0910 | 0.1783 | 0.1614 |
| **VVA (Point Cloud)** | 31 | 0.1592 | 0.3120 | 0.2705 |
| **VVA (DEM)** | 31 | 0.1966 | 0.3853 | 0.1976 |

*Table 12: NVA/VVA Accuracies*

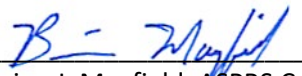
# SECTION V: CERTIFICATION STATEMENTS

## *1. Aerial LiDAR Project*

This accuracy assessment confirms that the data may be used for the intended applications stated in Section I of this document. This dataset may also be used as a topographic input for other applications, but the user should be aware that this LiDAR dataset was designed with a specific purpose and was not intended to meet specifications and/or requirements of users outside of the United States Geological Survey.

It should also be noted that LiDAR points do not represent a continuous surface model. LiDAR points are discrete measurements of the surface and any values derived within a triangle of three LiDAR points are interpolated. As such, the user should not use the resultant LiDAR dataset for vertical placement of a planimetric feature such as a headwall, building footprint or any other planimetric feature unless there is an associated LiDAR point that can be reasonably located on this structure.

Consideration should be given by the end user of this dataset to the fact that this LiDAR dataset was developed differently and separately than previous LiDAR datasets that may be available for this geographic location. It is likely that the data in this project was created using different geodetic control, a different Geoid, newer LiDAR technology and more up-to-date processing techniques. As such, any direct comparative analysis performed between this dataset and previous datasets could result in misleading or inaccurate results. Users are encouraged to proceed with caution while performing this type of comparative analysis and to completely understand the variables that make each of these datasets unique and not corollary.
It is encouraged that the user refers to the full FGDC Metadata and project reports for a complete understanding on the content of this dataset.
I, hereby, certify to the extent of my knowledge that the statements and statistics represented in this document are true and factual.



Brian J. Mayfield, ASPRS Certified Photogrammetrist #R1276

# SECTION VI: CONTROL POINT ASSESSMENTS

## 1. Aerial LiDAR Project

### a. Point Cloud Check Point Assessment

| Point ID | Given (X) | Given (Y) | Given (Z) | Laser (Z) | Delta (Z) | Report Point Type |
|---|---|---|---|---|---|---|
| NVA1000 | 745974.8810 | 4401240.5670 | 397.0770 | 397.1000 | 0.0230 | NVA |
| NVA1001 | 743373.3710 | 4374950.6740 | 342.6450 | 342.7600 | 0.1150 | NVA |
| NVA1002 | 730583.3540 | 4375984.3860 | 459.8000 | 459.7700 | -0.0300 | NVA |
| NVA1003 | 722840.1990 | 4363603.5430 | 363.9890 | 363.9800 | -0.0090 | NVA |
| NVA1004 | 692748.6610 | 4366963.3980 | 375.3960 | 375.3100 | -0.0860 | NVA |
| NVA1024 | 750224.1260 | 4425707.5710 | 319.1380 | 319.0900 | -0.0480 | NVA |
| NVA1026 | 725025.7530 | 4371643.6530 | 424.4360 | 424.4900 | 0.0540 | NVA |
| NVA1027 | 726990.0950 | 4405511.6820 | 376.2550 | 376.2700 | 0.0150 | NVA |
| NVA1028 | 697151.8660 | 4420240.5940 | 357.7090 | 357.6800 | -0.0290 | NVA |
| NVA1029 | 707014.4670 | 4363836.3990 | 381.2810 | 381.3700 | 0.0890 | NVA |
| NVA175 | 251003.1759 | 4393091.1380 | 358.8740 | 359.1000 | 0.2260 | NVA |
| NVA259 | 251699.8002 | 4373823.6080 | 379.0770 | 378.9400 | -0.1370 | NVA |
| NVA37 | 247019.1513 | 4344916.0450 | 298.1570 | 298.1100 | -0.0470 | NVA |
| NVA937 | 692118.3990 | 4428772.8140 | 404.6140 | 404.5000 | -0.1140 | NVA |
| NVA938 | 704390.4500 | 4356193.9880 | 333.0590 | 333.1100 | 0.0510 | NVA |
| NVA939 | 740198.3330 | 4362253.3930 | 317.1100 | 317.1200 | 0.0100 | NVA |
| NVA940 | 756657.1740 | 4361955.6180 | 364.6700 | 364.6000 | -0.0700 | NVA |
| NVA941 | 721875.7250 | 4384377.8110 | 385.8860 | 385.8900 | 0.0040 | NVA |
| NVA942 | 734463.0390 | 4392017.2780 | 400.9670 | 400.9000 | -0.0670 | NVA |
| NVA943 | 754791.3210 | 4404753.4940 | 358.5530 | 358.5400 | -0.0130 | NVA |
| NVA944 | 746455.0450 | 4428632.9070 | 361.6680 | 361.6700 | 0.0020 | NVA |
| NVA945 | 694811.0240 | 4383915.5590 | 417.0480 | 416.9800 | -0.0680 | NVA |
| NVA947 | 716507.2200 | 4431783.6320 | 406.9470 | 407.0300 | 0.0830 | NVA |
| NVA948 | 734717.3760 | 4410599.5940 | 397.7740 | 397.7100 | -0.0640 | NVA |
| NVA949 | 735116.0110 | 4421844.5760 | 414.4420 | 414.4200 | -0.0220 | NVA |
| NVA953 | 751267.8190 | 4352933.4530 | 364.4780 | 364.4200 | -0.0580 | NVA |
| NVA968 | 711912.0590 | 4421200.7440 | 421.9520 | 422.0600 | 0.1080 | NVA |
| NVA969 | 694273.5440 | 4404702.1160 | 405.5640 | 405.5100 | -0.0540 | NVA |
| NVA970 | 687863.5960 | 4373177.7210 | 379.9760 | 379.8100 | -0.1660 | NVA |
| NVA971 | 740890.9750 | 4383330.3870 | 384.8130 | 384.8500 | 0.0370 | NVA |
| NVA972 | 708057.7900 | 4375185.9420 | 427.8340 | 427.9600 | 0.1260 | NVA |
| NVA973 | 715054.0100 | 4367338.2270 | 429.9990 | 430.0000 | 0.0010 | NVA |
| NVA974 | 734380.9490 | 4366113.3420 | 396.1090 | 396.1900 | 0.0810 | NVA |
| NVA975 | 749724.8280 | 4392652.3500 | 394.3340 | 394.3800 | 0.0460 | NVA |
| NVA976 | 704327.2360 | 4389481.3370 | 359.8710 | 360.0200 | 0.1490 | NVA |

| Point ID | Given (X) | Given (Y) | Given (Z) | Laser (Z) | Delta (Z) | Report Point Type |
|---|---|---|---|---|---|---|
| NVA977 | 242388.2249 | 4382888.1120 | 405.4450 | 405.3400 | -0.1050 | NVA |
| NVA978 | 750403.3570 | 4422012.6970 | 352.3040 | 352.3600 | 0.0560 | NVA |
| NVA992 | 748826.8370 | 4366267.6110 | 402.4790 | 402.4100 | -0.0690 | NVA |
| NVA993 | 701127.4620 | 4412825.2010 | 352.4150 | 352.4100 | -0.0050 | NVA |
| NVA994 | 705015.3050 | 4426478.0140 | 385.8710 | 385.9200 | 0.0490 | NVA |
| NVA995 | 720942.1470 | 4415455.2200 | 399.0300 | 399.0600 | 0.0300 | NVA |
| NVA996 | 740804.0070 | 4414255.5660 | 399.3460 | 399.3300 | -0.0160 | NVA |
| NVA997 | 750979.5660 | 4414230.5170 | 348.3120 | 348.2600 | -0.0520 | NVA |
| NVA998 | 700840.0580 | 4395053.9170 | 350.6460 | 350.6400 | -0.0060 | NVA |
| NVA999 | 721443.3960 | 4398148.4660 | 351.6440 | 351.6400 | -0.0040 | NVA |
| VVA115 | 252972.7688 | 4430248.3400 | 403.0330 | 403.1300 | 0.0970 | VVA |
| VVA181 | 245344.0874 | 4416100.2650 | 361.1670 | 360.8900 | -0.2770 | VVA |
| VVA59 | 251684.3717 | 4373769.4550 | 381.5600 | 381.5100 | -0.0500 | VVA |
| VVA62 | 251266.8464 | 4398112.2970 | 369.2010 | 369.5200 | 0.3190 | VVA |
| VVA671 | 708021.1300 | 4384153.0840 | 356.1080 | 356.6200 | 0.5120 | VVA |
| VVA672 | 732763.9780 | 4368632.4680 | 398.0160 | 398.2100 | 0.1940 | VVA |
| VVA673 | 756489.0630 | 4376718.5920 | 407.4580 | 407.4400 | -0.0180 | VVA |
| VVA674 | 715561.7660 | 4426065.0830 | 422.8350 | 422.9000 | 0.0650 | VVA |
| VVA675 | 739093.2280 | 4425368.7000 | 375.1030 | 375.1600 | 0.0570 | VVA |
| VVA676 | 716406.1200 | 4398722.3810 | 378.9230 | 378.9200 | -0.0030 | VVA |
| VVA677 | 738537.8290 | 4397777.7620 | 394.8700 | 395.0400 | 0.1700 | VVA |
| VVA678 | 691520.5140 | 4361149.1640 | 413.2100 | 413.1300 | -0.0800 | VVA |
| VVA687 | 694836.7190 | 4375635.9960 | 393.2620 | 393.3200 | 0.0580 | VVA |
| VVA688 | 745805.6940 | 4410948.7260 | 383.6510 | 383.6800 | 0.0290 | VVA |
| VVA689 | 697181.2400 | 4420289.5000 | 357.2220 | 357.4200 | 0.1980 | VVA |
| VVA690 | 712230.0770 | 4410626.7070 | 399.6480 | 399.7800 | 0.1320 | VVA |
| VVA691 | 726968.1010 | 4405564.9250 | 376.5290 | 376.5400 | 0.0110 | VVA |
| VVA692 | 725071.2050 | 4371650.3580 | 422.3780 | 422.6000 | 0.2220 | VVA |
| VVA693 | 751990.3640 | 4366845.9490 | 398.8150 | 398.8500 | 0.0350 | VVA |
| VVA694 | 743957.4450 | 4391500.9830 | 412.3130 | 412.3400 | 0.0270 | VVA |
| VVA699 | 694418.9840 | 4398213.7800 | 402.2420 | 402.1100 | -0.1320 | VVA |
| VVA700 | 750204.5180 | 4425735.3240 | 319.2360 | 319.3800 | 0.1440 | VVA |
| VVA701 | 703154.9260 | 4429016.7970 | 391.4460 | 391.6400 | 0.1940 | VVA |
| VVA703 | 730591.7690 | 4387459.2970 | 391.3030 | 391.4400 | 0.1370 | VVA |
| VVA704 | 738155.6350 | 4359016.0180 | 315.5670 | 315.7400 | 0.1730 | VVA |
| VVA705 | 753990.0710 | 4398342.1720 | 408.6260 | 408.5400 | -0.0860 | VVA |
| VVA706 | 725705.9190 | 4411927.9550 | 420.8720 | 420.9200 | 0.0480 | VVA |
| VVA708 | 754465.8280 | 4354707.5700 | 309.7390 | 309.7200 | -0.0190 | VVA |
| VVA724 | 720965.8870 | 4415437.1130 | 397.1840 | 397.2500 | 0.0660 | VVA |

| Point ID | Given (X) | Given (Y) | Given (Z) | Laser (Z) | Delta (Z) | Report Point Type |
|---|---|---|---|---|---|---|
| VVA725 | 701123.8210 | 4412819.8620 | 352.4500 | 352.4200 | -0.0300 | VVA |
| VVA726 | 715049.9240 | 4367286.3090 | 430.4500 | 430.4400 | -0.0100 | VVA |

*Table 13: Point Cloud Check Point Assessment*

## b. Digital Elevation Model (DEM) Check Point Assessment

| Point ID | Given (X) | Given (Y) | Given (Z) | DEM (Z) | DEM (DZ) | Report Point Type |
|---|---|---|---|---|---|---|
| NVA1000 | 745974.8810 | 4401240.5670 | 397.0770 | 397.0624 | 0.0146 | NVA |
| NVA1001 | 743373.3710 | 4374950.6740 | 342.6450 | 342.7500 | -0.1050 | NVA |
| NVA1002 | 730583.3540 | 4375984.3860 | 459.8000 | 459.7640 | 0.0360 | NVA |
| NVA1003 | 722840.1990 | 4363603.5430 | 363.9890 | 364.0342 | -0.0452 | NVA |
| NVA1004 | 692748.6610 | 4366963.3980 | 375.3960 | 375.2167 | 0.1793 | NVA |
| NVA1024 | 750224.1260 | 4425707.5710 | 319.1380 | 319.1396 | -0.0016 | NVA |
| NVA1026 | 725025.7530 | 4371643.6530 | 424.4360 | 424.4761 | -0.0401 | NVA |
| NVA1027 | 726990.0950 | 4405511.6820 | 376.2550 | 376.2469 | 0.0081 | NVA |
| NVA1028 | 697151.8660 | 4420240.5940 | 357.7090 | 357.7246 | -0.0156 | NVA |
| NVA1029 | 707014.4670 | 4363836.3990 | 381.2810 | 381.2618 | 0.0192 | NVA |
| NVA175 | 251003.1759 | 4393091.1380 | 358.8740 | 359.0733 | -0.1993 | NVA |
| NVA259 | 251699.8002 | 4373823.6080 | 379.0770 | 378.8585 | 0.2185 | NVA |
| NVA37 | 247019.1513 | 4344916.0450 | 298.1570 | 298.1078 | 0.0492 | NVA |
| NVA937 | 692118.3990 | 4428772.8140 | 404.6140 | 404.4349 | 0.1791 | NVA |
| NVA938 | 704390.4500 | 4356193.9880 | 333.0590 | 333.1327 | -0.0737 | NVA |
| NVA939 | 740198.3330 | 4362253.3930 | 317.1100 | 317.1368 | -0.0268 | NVA |
| NVA940 | 756657.1740 | 4361955.6180 | 364.6700 | 364.6551 | 0.0149 | NVA |
| NVA941 | 721875.7250 | 4384377.8110 | 385.8860 | 385.9030 | -0.0170 | NVA |
| NVA942 | 734463.0390 | 4392017.2780 | 400.9670 | 400.9269 | 0.0401 | NVA |
| NVA943 | 754791.3210 | 4404753.4940 | 358.5530 | 358.4960 | 0.0570 | NVA |
| NVA944 | 746455.0450 | 4428632.9070 | 361.6680 | 361.5775 | 0.0905 | NVA |
| NVA945 | 694811.0240 | 4383915.5590 | 417.0480 | 416.9810 | 0.0670 | NVA |
| NVA947 | 716507.2200 | 4431783.6320 | 406.9470 | 407.0269 | -0.0799 | NVA |
| NVA948 | 734717.3760 | 4410599.5940 | 397.7740 | 397.6857 | 0.0883 | NVA |
| NVA949 | 735116.0110 | 4421844.5760 | 414.4420 | 414.3844 | 0.0576 | NVA |
| NVA953 | 751267.8190 | 4352933.4530 | 364.4780 | 364.4201 | 0.0579 | NVA |
| NVA968 | 711912.0590 | 4421200.7440 | 421.9520 | 421.9980 | -0.0460 | NVA |
| NVA969 | 694273.5440 | 4404702.1160 | 405.5640 | 405.5093 | 0.0547 | NVA |
| NVA970 | 687863.5960 | 4373177.7210 | 379.9760 | 379.8954 | 0.0806 | NVA |
| NVA971 | 740890.9750 | 4383330.3870 | 384.8130 | 384.8228 | -0.0098 | NVA |
| NVA972 | 708057.7900 | 4375185.9420 | 427.8340 | 427.9800 | -0.1460 | NVA |
| NVA973 | 715054.0100 | 4367338.2270 | 429.9990 | 429.9667 | 0.0323 | NVA |
| NVA974 | 734380.9490 | 4366113.3420 | 396.1090 | 396.2897 | -0.1807 | NVA |

| Point ID | Given (X) | Given (Y) | Given (Z) | DEM (Z) | DEM (DZ) | Report Point Type |
|---|---|---|---|---|---|---|
| NVA975 | 749724.8280 | 4392652.3500 | 394.3340 | 394.3957 | -0.0617 | NVA |
| NVA976 | 704327.2360 | 4389481.3370 | 359.8710 | 360.0752 | -0.2042 | NVA |
| NVA977 | 242388.2249 | 4382888.1120 | 405.4450 | 405.4014 | 0.0436 | NVA |
| NVA978 | 750403.3570 | 4422012.6970 | 352.3040 | 352.4314 | -0.1274 | NVA |
| NVA992 | 748826.8370 | 4366267.6110 | 402.4790 | 402.4457 | 0.0333 | NVA |
| NVA993 | 701127.4620 | 4412825.2010 | 352.4150 | 352.3854 | 0.0296 | NVA |
| NVA994 | 705015.3050 | 4426478.0140 | 385.8710 | 385.9088 | -0.0378 | NVA |
| NVA995 | 720942.1470 | 4415455.2200 | 399.0300 | 399.1444 | -0.1144 | NVA |
| NVA996 | 740804.0070 | 4414255.5660 | 399.3460 | 399.2728 | 0.0732 | NVA |
| NVA997 | 750979.5660 | 4414230.5170 | 348.3120 | 348.2709 | 0.0411 | NVA |
| NVA998 | 700840.0580 | 4395053.9170 | 350.6460 | 350.6815 | -0.0355 | NVA |
| NVA999 | 721443.3960 | 4398148.4660 | 351.6440 | 351.6767 | -0.0327 | NVA |

| Point ID | Given (X) | Given (Y) | Given (Z) | DEM (Z) | DEM (DZ) | Report Point Type |
|---|---|---|---|---|---|---|
| VVA115 | 252972.7688 | 4430248.3400 | 403.0330 | 403.1644 | -0.1314 | VVA |
| VVA181 | 245344.0874 | 4416100.2650 | 361.1670 | 360.7424 | 0.4246 | VVA |
| VVA59 | 251684.3717 | 4373769.4550 | 381.5600 | 381.4356 | 0.1244 | VVA |
| VVA62 | 251266.8464 | 4398112.2970 | 369.2010 | 369.5682 | -0.3672 | VVA |
| VVA671 | 708021.1300 | 4384153.0840 | 356.1080 | 356.6416 | -0.5336 | VVA |
| VVA672 | 732763.9780 | 4368632.4680 | 398.0160 | 398.1209 | -0.1049 | VVA |
| VVA673 | 756489.0630 | 4376718.5920 | 407.4580 | 407.1872 | 0.2708 | VVA |
| VVA674 | 715561.7660 | 4426065.0830 | 422.8350 | 422.8835 | -0.0485 | VVA |
| VVA675 | 739093.2280 | 4425368.7000 | 375.1030 | 375.2695 | -0.1665 | VVA |
| VVA676 | 716406.1200 | 4398722.3810 | 378.9230 | 378.8207 | 0.1023 | VVA |
| VVA677 | 738537.8290 | 4397777.7620 | 394.8700 | 394.9742 | -0.1042 | VVA |
| VVA678 | 691520.5140 | 4361149.1640 | 413.2100 | 413.1052 | 0.1048 | VVA |
| VVA687 | 694836.7190 | 4375635.9960 | 393.2620 | 393.3627 | -0.1007 | VVA |
| VVA688 | 745805.6940 | 4410948.7260 | 383.6510 | 383.6798 | -0.0288 | VVA |
| VVA689 | 697181.2400 | 4420289.5000 | 357.2220 | 357.3436 | -0.1216 | VVA |
| VVA690 | 712230.0770 | 4410626.7070 | 399.6480 | 399.7790 | -0.1310 | VVA |
| VVA691 | 726968.1010 | 4405564.9250 | 376.5290 | 376.5661 | -0.0371 | VVA |
| VVA692 | 725071.2050 | 4371650.3580 | 422.3780 | 422.6031 | -0.2251 | VVA |
| VVA693 | 751990.3640 | 4366845.9490 | 398.8150 | 398.8555 | -0.0405 | VVA |
| VVA694 | 743957.4450 | 4391500.9830 | 412.3130 | 412.3036 | 0.0094 | VVA |
| VVA699 | 694418.9840 | 4398213.7800 | 402.2420 | 402.1181 | 0.1239 | VVA |
| VVA700 | 750204.5180 | 4425735.3240 | 319.2360 | 319.5231 | -0.2871 | VVA |
| VVA701 | 703154.9260 | 4429016.7970 | 391.4460 | 391.6442 | -0.1982 | VVA |
| VVA703 | 730591.7690 | 4387459.2970 | 391.3030 | 391.4412 | -0.1382 | VVA |

| Point ID | Given (X) | Given (Y) | Given (Z) | DEM (Z) | DEM (DZ) | Report Point Type |
|---|---|---|---|---|---|---|
| VVA704 | 738155.6350 | 4359016.0180 | 315.5670 | 315.9197 | -0.3527 | VVA |
| VVA705 | 753990.0710 | 4398342.1720 | 408.6260 | 408.5356 | 0.0904 | VVA |
| VVA706 | 725705.9190 | 4411927.9550 | 420.8720 | 420.7621 | 0.1099 | VVA |
| VVA708 | 754465.8280 | 4354707.5700 | 309.7390 | 309.7368 | 0.0022 | VVA |
| VVA724 | 720965.8870 | 4415437.1130 | 397.1840 | 397.3086 | -0.1246 | VVA |
| VVA725 | 701123.8210 | 4412819.8620 | 352.4500 | 352.3771 | 0.0729 | VVA |
| VVA726 | 715049.9240 | 4367286.3090 | 430.4500 | 430.4312 | 0.0188 | VVA |

*Table 14: DEM Check Point Assessment*

# SECTION VII: ADDENDUM

## 7.1 Low Confidence Polygons

Low confidence polygons have been delivered with this dataset. These polygons represent areas where heavy vegetation or inundated areas greatly diminish penetration of the lidar pulse, resulting in a bare earth surface that is potentially less accurate due to the lack of lidar returns from the ground beneath the vegetation or surface water. Low confidence polygons delineate areas where conformance to VVA standards may not be met. The low confidence polygons created for this dataset were delineated according to the criteria and assumptions outlined in the ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014). Low confidence areas are identified using a ground density raster. All areas with a Nominal Ground Point Density less than the threshold of 0.5 pts/$m^2$ are identified as low confidence cells in the ground density raster. The low confidence cells are exported to polygons and aggregated into larger shapes. Areas of expected low density in the ground, such as water or where buildings/structures have been removed, are deleted from the aggregated low confidence polygons. The size of all polygons is then calculated and polygons below the minimum size threshold of 5 acres are removed from the final low confidence polygon dataset.