PROJECT REPORT – USGS LIDAR

Lower NC Pottawatomie - OK

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Prepared for

United States Geological Survey
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Table of Contents

1 PROJECT OVERVIEW

The resulting maps from Task Order number G12PD00042 – FEMA VI – Lower NC Pottawatomie are intended for use as high resolution dataset of LiDAR covering 735 square miles, to assist in floodplain mapping of portions the Lower North Canadian region in Pottawatomie County and surrounding areas, in Central Oklahoma.

2 PROJECT PLAN

Fugro EarthData acquired all aerial LiDAR data using the Leica ALS60 MPiA (Multiple Pulse in the Air) laser scanning measurement system, combined with airborne GPS and inertial measurement (IMU) data. This project was acquired to achieve a nominal post spacing (NPS) of 2 meters covering 735 square miles of the Lower North Canadian region in Pottawatomie County, OK, as defined by the USGS in Attachment A and B of the Task Order Detail.

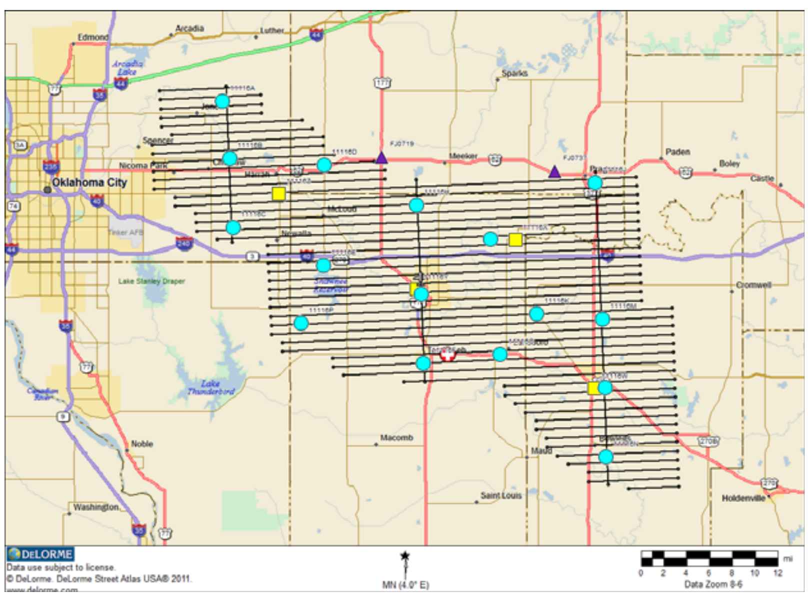
A kick-off meeting was held to outline communication procedures that were followed for data acquisition with respect to verification of local ground conditions and vegetation requirements. This meeting was used as a forum to clarify and resolve collection condition issues. Local contact(s) were established to provide ground condition updates. The kick-off meeting was held within two (2) weeks after contract award and prior to data acquisition.

3 GROUND CONTROL AND BASE STATION LOCATIONS

Flight crew and GPS survey crews were in communication to ensure that GPS base stations were operating during airborne acquisition and that the GPS constellation had an adequate number of satellites above the horizon to ensure sufficient Position Dilution of Precision (PDOP).

Under Fugro EarthData's direction, all surveying activities were performed by our approved ID/IQ subcontractor TerraSurv. TerraSurv collected ground control to support the LiDAR collection and included check points uniformly dispersed in the most commonly occurring (>10% coverage) land cover categories.

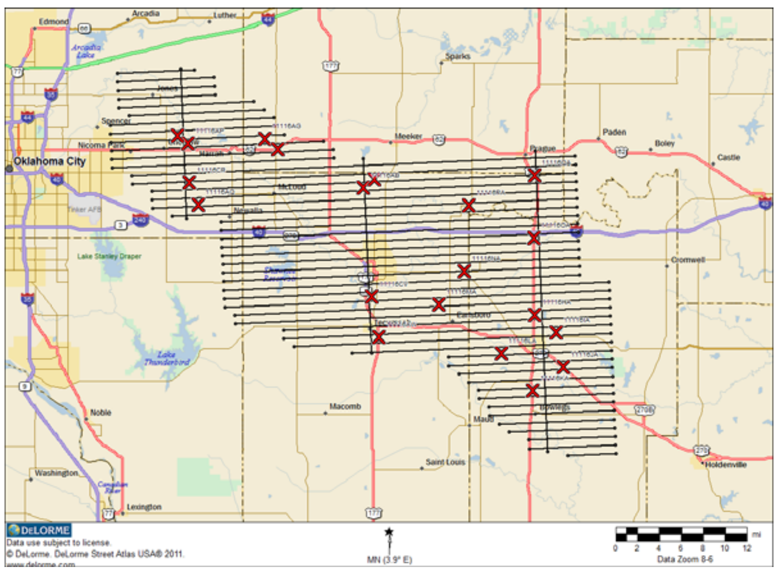
Ground control locations:



The map legend is summarized below:

Symbol	Description	Quantity
Blue Circle	LiDAR Control Points	16
Yellow Square	Temporary base stations	4
Red circle/white cross	CORS	1
Airplane	ABGPS base stations	1
Purple triangle	NSRS benchmark	2

In addition, 60 Quality Control (QC) points were established, with 20 in each of three land cover categories (bare earth/open terrain, tall weeds/crops, and forested and fully grown). These were set at 20 discrete locations, with three points, one in each of the three categories, included at the 20 locations. The locations are shown in the figure below:



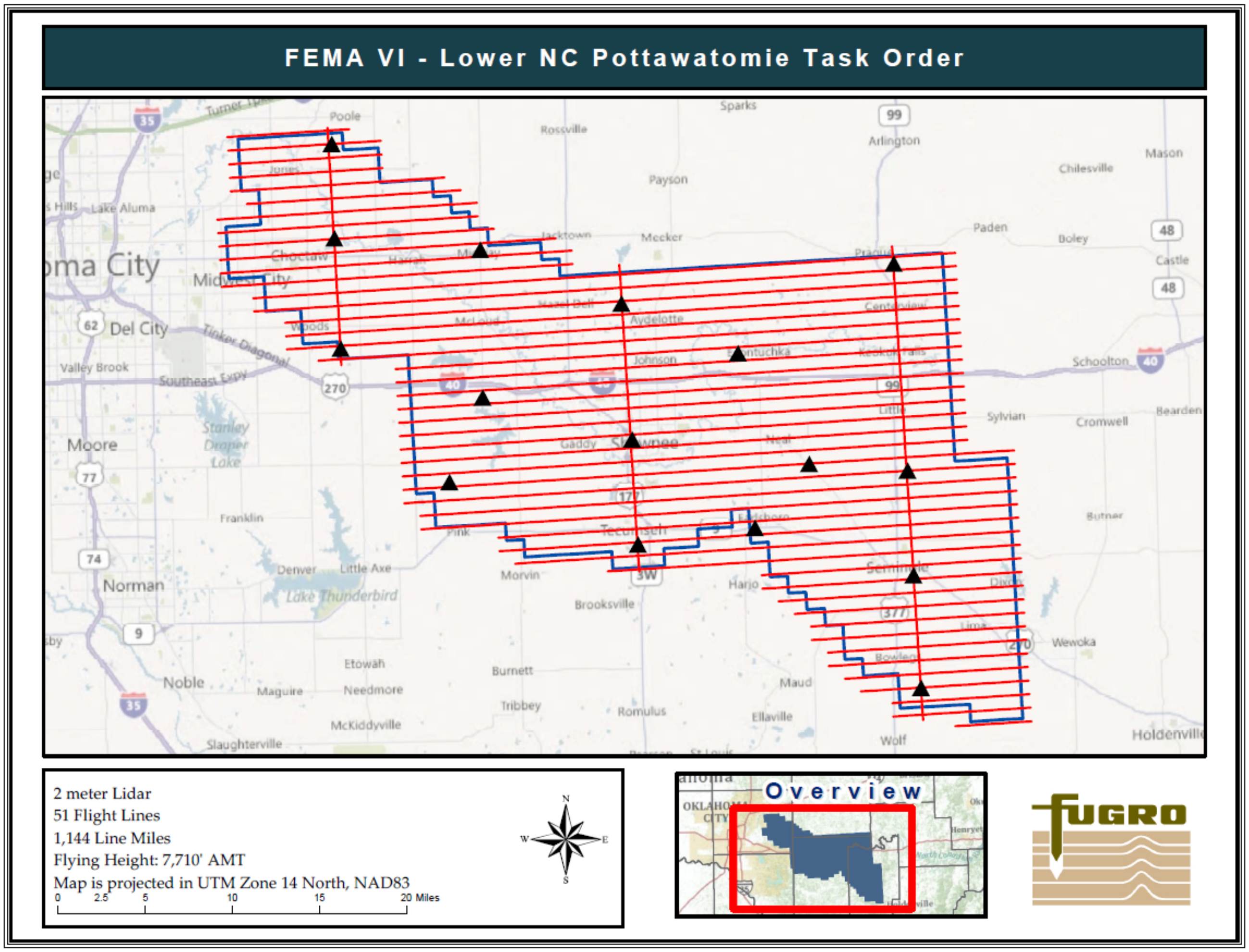
The ground survey is documented in the project metadata, as well as in the final survey report. Please refer to Attachment A: Survey Report for further details.

4 DATA ACQUISITION / COLLECTION

4.1 Collection Area

The collection area was defined by the Attachment A of the Task Order Detail and further delineated by the ESRI shape file provided as “Attachment B – Shape Files”, also included with Task Order Detail.

The below graphic is a visual of the planned flight lines based on the AOI as provided.



4.2 LiDAR Data Acquisition Considerations

Fugro EarthData planned all aircraft operations to be undertaken from the closest airport to the project area. LiDAR data was acquired using a twin engine aircraft equipped with an antenna and receiver for airborne GPS collection. Flight status was communicated during data collection.

Data was collected when environmental conditions meet the criteria specified. To be specific, the following conditions existed prior to launch of the aircraft:

- Streams and rivers were within their normal banks
- Snow free
- Cloud free and fog-free
- Air traffic restrictions were accounted for (flight crews coordinated with air traffic controllers and the military facility prior to data collection)
- Leaf off

4.3 Description of the Laser Scanning System

For this project, Fugro EarthData utilized the Leica ALS60 MPiA (Multiple Pulse in the Air) laser scanning measurement system. The ALS60 MPiA System is capable of recording four range points, and three intensity values for each emitted laser pulse. The ALS60 MPiA is a state-of-the-art LiDAR sensor with the following operational specifications:

- Variable field of view from 5° to 75° (Field of view and altitude combination allow variable swath widths).
- Up-to 200 kHz laser pulse rate (200,000 pulses per second).
- Altitude capability of 200 meters to 5000 meters AMT.

The LiDAR system has a wide operational window and can be operated at night, to facilitate data acquisition in high traffic areas where daytime flight restrictions may be imposed.

The sensor can adequately produce the required 2 meter NPS.

4.4 Project Design

To achieve a project scope with a NPS of 2 meters, Fugro EarthData planned to fly 48 east/west flight lines to cover the 735 square mile AOI with 3 north/south cross tie flight lines perpendicular to the main flight lines.

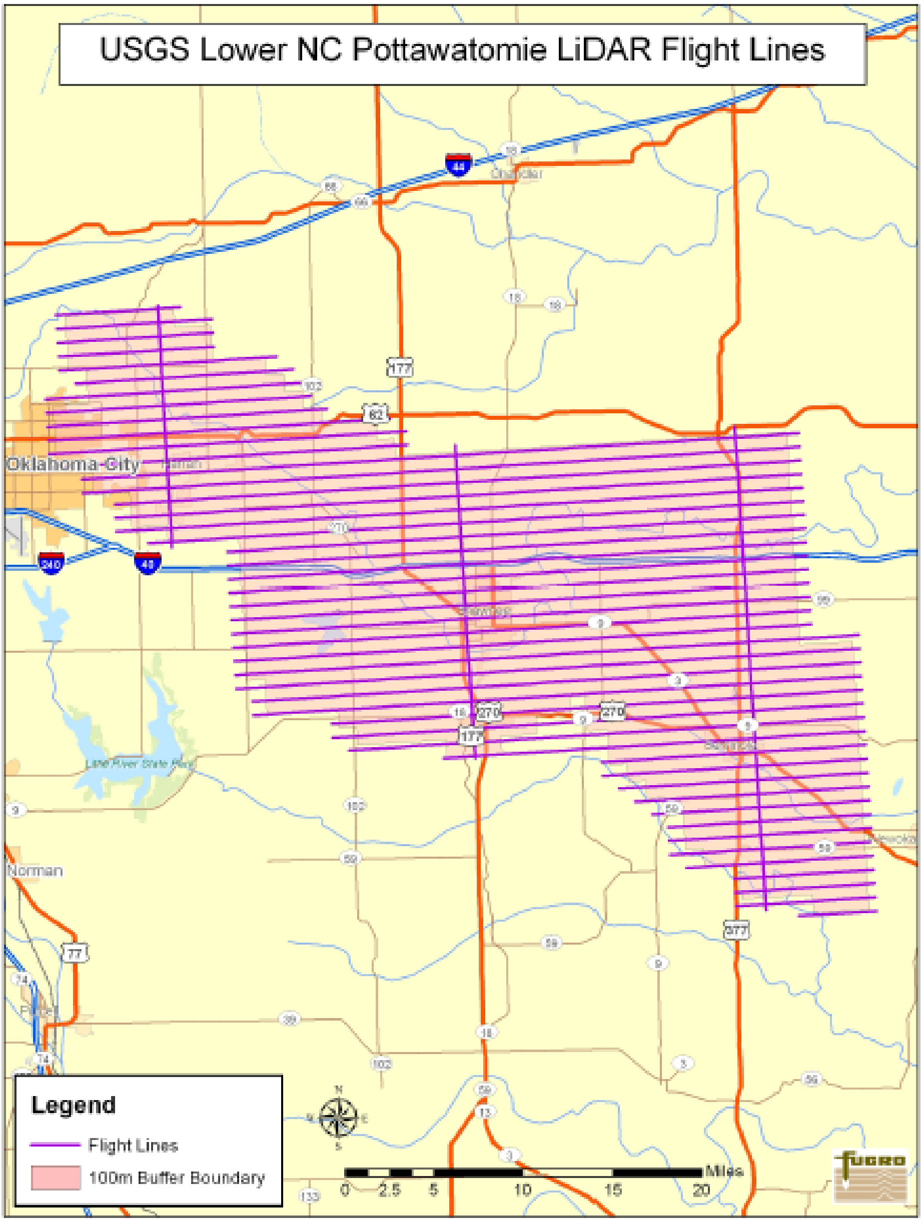
The below information lists the LiDAR collection parameters as taken from the ALS60 acquisition/Flight Plan.

Area	Flying Height (feet AMT)	Scan FOV	Pulse Rate	Scan Rate	Side-lap (planned)	Average point-spacing (meter)
735 sq miles	7710	38	99000	34.5 Hz	20 %	2

The following is detail on the LiDAR acquisition covering the Lower NC Pottawatomie OK AOI:

Collections: 03
Collection Date: December 08th and 10th, 2011
Number of Lines: 48 east/west, 3 north/south cross tie flight lines
Field of View (FOV): 38 degrees
Average Point Density (planned): 2 pts/m^2
Flight Level(s): 2350 / 7710 m/ft
Sensor Type: Leica ALS60
Sensor Serial Number: 113

Please refer to Attachment B: Acquisition Report for further details.



5 DESCRIPTION OF LIDAR PRODUCTION PROCESSES

5.1 Verification of Data Usability

All acquired LiDAR data went through a preliminary review to assure that complete coverage had been obtained and that there were no gaps between flight lines before the flight crew left the project site. Once back in the office, the data was run through a complete iteration of processing to ensure that it is complete, uncorrupted, and that the entire project area has been covered without gaps between flight lines. There are essentially three steps to this processing.

5.1.1 GPS/IMU Processing

Airborne GPS and IMU data was immediately processed using the airport GPS base station data, which was available to the flight crew upon landing the plane. This ensures the integrity of all the mission data. These results were also used to perform the initial LiDAR system calibration test.

5.1.2 Raw LiDAR Data Processing

Technicians processed the raw data to LAS format flight lines with full resolution output before performing QC. A starting configuration file is used in this process, which contains the latest calibration parameters for the sensor. The technicians also generated flight line trajectories for each of the flight lines during this process.

5.1.3 Verification of Coverage and Data Quality

The following steps and quality control measures verify complete coverage and ensure data quality:

- Technicians checked flight line trajectory files to ensure completeness of acquisition for project flight lines, calibration lines, and cross flight lines.
- The intensity images were generated for the entire lift at the required 2 meter NPS for the project.
- The technician visually checked the intensity images against the acquisition boundary to ensure full coverage to the 100 meter buffer beyond the project boundary.
- The intensity histogram was analyzed to ensure the quality of the intensity values.
- The technician also thoroughly reviewed the data for any gaps in project area.
- The technician generated a sample TIN surface to ensure no anomalies were present in the data.
- Turbulence was inspected for and if it affected the quality of the data, the flight line was rejected and reflown.
- The technician also evaluated the achieved post spacing against project specified 2 meter NPS as well as making sure no clustering in point distribution.

5.2 LiDAR Data Processing

Data processing includes the following three production steps for generating the final deliverables:

- Raw data processing and boresight
- Pre-processing
- Post-processing

Quality control steps are incorporated throughout each step and are described in the following sections.

5.2.1 Raw Data Processing and Boresight

The boresight for each lift was done individually as the solution may change slightly from lift to lift. The following steps describe the Raw Data Processing and Boresight process:

- Technician processed the raw data to LAS format flight lines using the final GPS/IMU solution. This LAS data set was used as source data for boresight.
- Technician first used commercial software to calculate initial boresight adjustment angles based on sample areas selected in the lift- mini project. These areas cover calibration flight lines collected in the lift, cross tie and production flight lines. These areas are well distributed in the lift coverage and cover multiple terrain types that are necessary for boresight angle calculation. The technician then analyzed the result and made any necessary additional adjustment until it is acceptable for the mini project.
- Once the boresight angle calculation was done for the mini project, the adjusted settings were applied to all of the flight lines of the lift and checked for consistency. The technician utilized commercial and

proprietary software packages to analyze the matching between flight line overlaps for the entire lift and adjusted as necessary until the results met the project specifications.

- Once all lifts were completed with boresight adjustment individually, the technician checked and corrected the vertical misalignment of all flight lines and also the matching between data and ground truth. The Relative accuracy was <= 7cm RMSEZ within individual swaths and <=10 cm RMSEZ or within swath overlap (between adjacent swaths).
- The technician ran a final vertical accuracy check of the boresighted flight lines against the surveyed check points after the z correction to ensure meeting the requirement of FVA = 24.5 cm 95% Confidence Level (Required Accuracy).

5.2.2 Pre-processing

Once boresighting is complete for the project, the project was set up for automatic classification first. The LiDAR data was cut to production tiles. The flight line overlap points, Noise points and Ground points were classified automatically in this process.

5.2.3 Post-processing

Fugro EarthData has developed a unique method for processing LiDAR data to identify and re-classify elevation points falling on vegetation, building, and other above ground structures into separate data layers. The steps are as follows:

- Fugro EarthData utilized commercial software as well as proprietary software for automatic filtering. The parameters used in the process were customized for each terrain type to obtain optimum results.
- The Automated Process typically re-classifies 90-98% of points falling on vegetation depending on terrain type. Once the automated filtering was completed, the files were run through a visual inspection to ensure that the filtering was not too aggressive or not aggressive enough. In cases where the filtering was too aggressive and important terrain features were filtered out, the data was either run through a different filter within local area or was corrected during the manual filtering process.
- Interactive editing was completed in visualization software that provides manual and automatic point classification tools. Fugro EarthData, Inc. utilized commercial and proprietary software for this process. Vegetation and artifacts remaining after automatic data post-processing were reclassified manually through interactive editing. The hard edges of ground features that were automatically filtered out during the automatic filtering process were brought back into ground class during manual editing. The technician reviewed the LiDAR points with color shaded TINs for anomalies in ground class during interactive filtering.
- All LAS tiles went through peer review after the first round of interactive editing was finished. This helps to catch misclassification that may have been missed by the interactive editing.
- Upon the completion of peer review and finalization of bare earth filtering, all tiles went through another final automated classification routine. This process ensures only the required classifications are used in the final product (all points classified into any temporary classes during manual editing were re-classified into the USGS specified classifications). The classified LiDAR point cloud work tiles went through a water classification routine based on the collected water polygons. Also, during this process, the points originally classified as flight line overlap went through an automated classification to filter ground points and low points inside overlap areas. The points in these areas were classified to 16+Standard Class Value.

5.3 Product Development

5.3.1 Raw Point Cloud Data

All collected flight lines were included in generating this product. The flight lines went through the following processes: 1) assign flight line ID to each point based on flight line trajectory; 2) cut long flight lines to under 2GB file size; 3) re-project flight lines files to deliverable projection/datum and unit; 4) assign file source ID; and 5) final QC of data format and coverage.

The data was delivered in fully compliant LAS v1.2, Point Record Format 1 with Adjusted Standard GPS Time. Georeference information is included in all LAS file headers. Intensity values are included for each point. The long swaths were cut to a file size that does not exceed 2GB, 1 file per swath, 1 swath per file. Each swath was assigned a unique File Source ID. The Point Source ID matches to the flight line ID in flight trajectory files and is the same that is used in classified point cloud data.

5.3.2 Classified Point Cloud Data

Once manual inspection, QC and final autofilter is done for the LiDAR tiles, the LAS data was packaged to the project specified tiling scheme, clipped to project boundary and LAS delivery format. It was also re-projected to UTM Zone 14 north; NAD83(NSRS2007), meters; NAVD88(GEOID09), meters. The file header was formatted to meet project specification with File Source ID assigned. This Classified Point Cloud product was used for the generation of derived products.

This product was delivered in fully compliant LAS v1.2, Point Record Format 1 with Adjusted Standard GPS Time. Georeference information is included in all LAS file headers. Intensity values are included for each point. Each tile has unique File Source ID assigned. The Point Source ID matches to the flight line ID in flight trajectory files.

The following classifications are included:

(01) Code 1 – Processed, but unclassified
(02) Code 2 – Bare-earth ground
(03) Code 7 – Noise (low or high, manually identified, if needed)
(04) Code 9 – Water
(05) Code 10 – Ignored Ground (Breakline Proximity)
(06) Code 17 – Unclassified in flight line overlap areas
(07) Code 18 – Auto-filtered Bare-Earth ground points in flight line overlap areas
(08) Code 23 – Auto-filtered Noise (low or high, manually identified, if needed) in flight line overlap areas
(09) Code 25 – Water in flight line overlap areas

5.3.3 LiDAR Hydro Breakline Collection

Hydro linework is produced by heads-up digitizing using classified LiDAR datasets. Additionally, products created from LiDAR including intensity images, shaded-relief TIN surfaces, and contours are used.

Hydrographic features were collected as separate feature types:

Inland Ponds and Lakes

- ~2-acre or greater surface area (~350' diameter for a round pond).
- Flat and level water bodies (single elevation for every bank vertex defining a given water body).
- The entire water surface edge must be at or just below the immediately surrounding terrain.
- Long impoundments such as reservoirs, inlets, and fjords, whose water surface elevations drop when moving downstream, will be treated as rivers.

Inland Streams and Rivers

- 100' nominal width: Short segments below the 100' threshold were captured to avoid unnecessary segmentation.
- Flat and level bank-to-bank (perpendicular to the apparent flow centerline); gradient to follow the immediately surrounding terrain.
- The entire water surface edge is at or just below the immediately surrounding terrain.
- Streams break at road crossings (culvert locations). These road fills were not removed from the DEM. Streams and rivers do not break at bridges. Bridges were removed from the DEM. When the

identification of a feature as a bridge or culvert could not be made reliably, the feature was regarded as a culvert.

5.3.3.1 2D Topological QC

After initial collection, linework was then checked for the following topological and attribution rules:

- Lines must be attributed with the correct feature code (stream, stream bankline, etc.).
- Lakes, ponds, and shore/bay must form closed polygons.

5.3.3.2 3D Attribution

Hydro features were collected as vector linework using LiDAR and its derived products listed above. This linework is initially 2D, meaning that it does not have elevation values assigned to individual line vertices. Vertex elevation values were assigned IDW (Inverse Distance Weighted) Interpolation.

After the initial vertex elevation was assigned, the linework elevation values were further adjusted based on the following rules:

- Lake feature vertices were re-assigned (flattened) to lowest vertex elevation value.
- Stream connector line vertices were adjusted so that subsequent vertices are lower than previous ones based on line direction
- Double stream bankline vertices were re-assigned based on the vertices of the closest adjusted double stream connector line.

5.3.3.3 3D Topological QC

After assignment of 3D values, the stream network is checked to ensure the following does not exist:

- Large differences between initial assigned elevation and adjusted elevation values.
- Elevation differences between nodes.
- Elevation values flowing in an uphill direction.

The hydro breaklines were delivered in ESRI shapefile format.

5.3.4 Bare Earth Surface (Raster DEM)

The hydro-flattened bare earth DEM was generated using the bare earth points, as well as the 3D hydro breaklines. Once the deliverable LAS files were generated for the entire project area and were QC'ed, and 3D breaklines were collected and QC'ed, they were used to produce the hydro-flattened bare earth DEM. First the bare earth points that fell within 1*NPS along the hydro breaklines were classified as class 10 so that these points were excluded from the DEM generation process. This is analogous to the removal of mass points for the same reason in a traditional photogrammetrically compiled DTM. This process was done in batch mode using Fugro EarthData proprietary software.

The technician then used Fugro EarthData proprietary software for the production of LiDAR-derived hydro-flattened bare earth DEM surface in initial grid format at 2 meter GSD. Inland ponds and lakes and inland streams and rivers were hydro-flattened within the DEM. Hydro-flattening was applied to water impoundments, natural or man-made, that are larger than ~2 acres in area and to streams that are nominally wider than 100'. This process was done in batch mode.

The hydro-flattened bare earth DEM generated in initial grid format was then clipped to the approved DEM product boundary. Once the initial, hydro-flattened bare earth DEM was generated, the technician checked the tiles to ensure that the grid spacing met specifications and checked the surface to ensure proper hydro-flattening. The data was cut to the approved tile layout; the DEM tiles followed the USGS approved tiling scheme without overlap. The transition of the surface from tile to tile is seamless. The entire data set was checked for completed project coverage and to ensure it was free of anomalies. Once the data was checked, the tiles were then converted to ERDAS Imagine format. Georeference information is included in raster files.

Void areas (i.e. areas outside the project boundary but within the tiling scheme) are coded using "NODATA" value -9999.

5.4 Pilot Area Processing

A pilot area comprising a minimum of five square miles of classified LAS data in each of the primary land cover categories (SVA categories) was provided. Also included were the corresponding Hydro-flattened bare earth DEM tiles, as well as, an FVA report based on the unclassified point cloud data.

The feedback obtained from the pilot review indicated that the pilot dataset was acceptable; the specific feedback that was included as part of the report was incorporated into the final submittal dataset.

6 ACCURACY REPORTING

Data collected under this Task Order meets the National Standard for Spatial Database Accuracy (NSSDA) accuracy standards. The NSSDA standards specify that vertical accuracy be reported at the 95 percent confidence level for data tested by an independent source of higher accuracy.

6.1 Positional Accuracy

The absolute and relative accuracy of the data, both horizontal and vertical, relative to known control, were verified prior to classification and subsequent product development.

6.2 Relative Accuracy

Relative accuracy is <= 7cm RMSEZ within individual swaths and <=10 cm RMSEZ or within swath overlap (between adjacent swaths).

6.3 Accuracy of the LiDAR Point Cloud Data

The Fundamental Vertical Accuracy (FVA) of the LiDAR Point Cloud data was calculated against TINs derived from the final calibrated and controlled swath data. The required accuracy (ACC_Z) is: 24.5 cm at a 95% confidence level, derived according to NSSDA, i.e., based on RMSE of 12.5 cm in the "open terrain" land cover category. This is a required accuracy.

The achieved accuracy is 7.3 cm. Please refer to Attachment C: Raw Point Cloud FVA Report for further details.

6.4 Accuracy of the Derived DEM

The accuracy (ACC_Z) of the derived DEM was calculated and reported in three (3) ways:

1. **Fundamental Vertical Accuracy (FVA):** The required FVA is: 24.5 cm at a 95% confidence level, derived according to NSSDA, i.e., based on RMSE of 12.5 cm in the "open terrain" land cover category. This is a required accuracy.

2. **Supplemental Vertical Accuracy (SVA):** SVAs shall be reported for each of the land cover classes. The target SVA is: 36.3 cm at a 95th percentile level, derived according to ASPRS Guidelines, Vertical Accuracy Reporting for LiDAR Data, i.e., based on the 95th percentile error for each required land cover class. These are target accuracies.

3. **Consolidated Vertical Accuracy (CVA):** The required CVA is: 36.3 cm at a 95th percentile level, derived according to ASPRS Guidelines, Vertical Accuracy Reporting for LiDAR Data, i.e., based on the 95th percentile error in all land cover categories combined. This is a required accuracy.

Please refer to the table below for the achieved accuracies; the table shows the FVA calculated at 95% confidence level from the DEM; and CVA and SVA calculated as 95 percentile error from the DEM.

Land Cover Category	**# of Points**	**FVA** Fundamental Vertical Accuracy ($RMSE_Z$ * 1.960) Spec=24.5 cm *From DEM*	**CVA** Consolidated Vertical Accuracy (95 Percentile) Spec=36.3 cm *From DEM*	**SVA** Supplemental Vertical Accuracy (95 Percentile) Spec=36.3 cm *From DEM*
Consolidated	60		20.1 cm	
Bare Earth / Open Terrain	20	7.5 cm		6.2 cm
Tall Weeds / Crops	20			21.8 cm
Forested and Fully Grown	20			17.0 cm

7 ATTACHMENTS

7.1 Attachment A: Survey Report

Which includes the previously submitted deliverables:

USGS_Lower_NC_Pottawatomie_Survey_Report.pdf

OK Lidar production survey coords.xlsx

Pottawatomie QC coords.xlsx

7.2 Attachment B: Acquisition Report

USGS_Lower_NC_Pottawatomie_Acquisition_Report.pdf; which was previously submitted

7.3 Attachment C: Raw Point Cloud FVA Report

QC_MASTER_POTTAWATTOMIE.pdf; which was previously submitted