PROJECT AND COLLECTION REPORT – MCKENZIE LIDAR

McKenzie County, North Dakota LiDAR

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Prepared for

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1 PROJECT OVERVIEW

Fugro Geospatial, Inc. (Fugro) was tasked with planning, acquiring, processing, and producing derivative products of LiDAR data collected at a nominal pulse spacing (NPS) of 0.7 meters, including overlap, for an Area of Interest (AOI) that covers McKenzie County, North Dakota.

LiDAR data, and derivative products produced in compliance with this task order were based on the "U.S. Geological Survey National Geospatial Program LiDAR Base Specification Version 1.0".

2 PROJECT PLAN

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 prior to data acquisition.

All acquisition occurred during leaf off conditions between October 1 and 31, 2014 by Fugro's owned and operated aircraft and sensor as well as back-up aircraft and sensor from approved subcontractor, Richard Crouse & Associates, Inc. (RC&A). This project was acquired to achieve a nominal post spacing (NPS) of 0.7 meters. The AOI covers approximately 3013 square miles; all products were generated to the limit of this buffered boundary.

3 BASE STATION AND GROUND CONTROL LOCATIONS

During LiDAR data collection the airborne GPS receiver was collecting data at 2 Hz frequency and the Dilution of Precision (PDOP) was monitored. Multiple GPS base stations were also running in the project area and were recording data at 1 Hz. The airborne GPS data was post-processed in DGPS mode together with base station data to provide high accuracy aircraft positions. The GPS trajectory then was combined with the IMU data using loosely coupled approach to yield high accuracy aircraft positions and attitude angles. Then the LiDAR data was processed using the aircraft trajectory and raw LiDAR data.

Under Fugro's direction, all surveying activities were performed by Fugro's approved subcontractor Professional Mapping and Surveying collected 28 ground control points to support the LiDAR collection. KLJ collected check points uniformly dispersed in the most commonly occurring (>10% coverage) land cover categories; a total of 241 check points were established.

4 DATA ACQUISITION / COLLECTION

4.1 Collection Area

The collection area was defined by the USGS as Attachment A – Project Description and Diagram of the Task Order Detail and further delineated by Attachment B –Shape File(s), also included with Task Order Detail.

4.2 LiDAR Data Acquisition Considerations

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:

- Cloud and fog-free between the aircraft and ground
- Snow free
- No unusual flooding or inundation
- Leaf off

4.3 Description of the Laser Scanning System

For this project, Fugro and subcontractor, Richard Crouse and Associates, Inc. (RC&A) utilized the Riegl LMS-Q680i airborne laser scanner. The Riegl LMS-Q680i collects high density LiDAR with its powerful laser source, multiple time around (MTA) processing technology and full waveform digitization. With a variable scan rate of 10 to 200 scan lines per second and variable pulse rate from 80,000 to 400,000 ranges per second, the system incorporates a rotating polygon mirror with fixed 60 degree field of view, thus eliminating the torsion errors inherent with oscillating mirror LiDAR Systems. The rotating mirror technology results in improved positional accuracy to the edge of the field of view and greater coverage while achieving overall vertical accuracies of 9-15 cm RMSE with up to 15 discrete returns per LiDAR pulse (offering more foliage detail - exceeding project specifications).

The rotating mirror, variable scan rate and variable laser pulse rate results in a highly uniform point density and distribution in both the laser sensor cross track and along track. This allows for the use of the entire collection swath thus resulting in greater collection efficiency. The rotating mirror provides a continuous view at nadir creating a smooth evenly distributed LiDAR point cloud with reduced point to point variability and thus greater accuracy.

The sensor can adequately produce the required 0.7 meters NPS.

4.4 Project Design

The following is detail on the LiDAR acquisition covering the Kidder County, North Dakota LiDAR buffered boundary:

Collections:	19
Collection Dates:	October 18 – October 31, 2014
Field of View (FOV):	60 degrees
Average Point Density (planned):	2 pts/m^2
Flight Level(s) AMT:	4000 ft,
Sensor Type:	Riegl Q-680i
Sensor Serial Number(s):	884/165

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 quality control checks are performed to verify complete coverage and ensure data quality:

- Trajectory files were checked to ensure completeness of acquisition for the flight lines, calibration lines, and cross flight lines.
- Intensity images were generated for the entire lift at the required 0.7m nominal post spacing. Visual checks of the intensity images against the project boundary were performed 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.
- Thorough review of the data was performed to identify any data gaps in project area.
- A sample TIN surface was generated to ensure no anomalies are present in the data.
- Turbulence was inspected for each flight line. If any adverse quality issues were discovered, the flight line was rejected and re-flown.
- The achieved post spacing was evaluated against the project specified 0.7m NPS and also checked to make sure there is no clustering in point distribution.

5.2 LiDAR Data Processing

Data processing includes the following four (4) production steps for generating the final deliverables:

1. Raw data processing and boresight
2. Pre-processing
3. Post-processing
4. Product development

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

5.2.1 Raw Data Processing and Boresight

Raw data processing is the reduction of raw LiDAR, IMU, and GPS data into XYZ points. This is a hardware-specific, vendor-proprietary process. The raw LiDAR data processing algorithms use the sensor's complex set of electronic timing signals to compute ranges or distances to a reflective surface. The ranges must be combined with positional information from the GPS/IMU system to orient those ranges in 3D space and to produce XYZ points.

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:

- Technicians 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.
- Technicians first used Fugro proprietary and commercial software to calculate initial boresight adjustment angles based on sample areas selected in the lift. 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 results and made any necessary additional adjustment until it is acceptable for the selected areas. The boresight angle adjustment process ensures proper alignment between different look angles and between flight line overlap.
- Once the boresight angle calculation was completed for the selected areas, the adjusted settings were applied to all of the flight lines of the lift and checked for consistency. The technicians utilized commercial and proprietary software packages to analyze how well flight line overlaps match for the entire lift and adjusted as necessary until the results met the project specifications.

Once all lifts were completed with individual boresight adjustment, the technicians checked and corrected the vertical misalignment of all flight lines and also the matching between data and ground truth. The relative accuracy was <= 7 cm $RMSE_Z$ within individual swaths and <= 10 cm $RMSE_Z$ or within swath overlap (between adjacent swaths).

The technicians ran a final vertical accuracy check of the boresighted flight lines against the surveyed check points after the z correction to ensure the requirement of FVA = 17.64 cm 95% Confidence Level (Required Accuracy) was met.

5.2.2 Pre-processing

Once boresighting was complete for the project and all lifts were tied to the ground control, the project was set up for filtering. The LiDAR data was cut to production tiles and flight line overlap points were reclassified temporarily for editing purposes.

5.2.3 Post-processing

Fugro has developed a unique method for processing LiDAR data.

Once boresighting was complete for the project, the project was first set up for automatic classification. The LiDAR data was cut to production tiles. The flight line Overlap points, Noise points and Ground points were classified automatically in this process. Fugro utilized commercial software, as well as proprietary, in-house developed software for automatic filtering. The parameters used in the process were customized for each terrain type to obtain optimum results.

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 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 utilized commercial and proprietary software for this process. All manually inspected tiles went through a peer review to ensure proper editing and consistency.

After the manual editing and peer review, 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 will be re-classified into the project specified classifications). During this process, the points originally classified as flight line overlap were tagged as withheld points.

5.2.4 Product Development

5.2.4.1 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 upon flight line trajectory; 2) Re-project flight lines files to deliverable projection/datum and unit; 3) assign file source ID; 4) final QC of data format and coverage.

The raw, unclassifed 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. Each swath was assigned a unique File Source ID. The Point Source ID matches the Point Source ID in the classified point cloud data.

5.2.4.2 Classified Point Cloud Data

Once manual inspection, QC and final autofilter is complete for the LiDAR tiles, the LAS data was packaged to the project specified tiling scheme, clipped to project boundary including the 100 meter buffer and formatted to LAS v1.2. It was also re-projected to State Plane Coordinate System North Dakota North; NAD83(NSRS2007), International Feet; NAVD88(GEOID03), feet. The file header was formatted to meet the 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 at a precision sufficient to allow unique timestamps for each return. 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:

Class 1 – Processed, but unclassified
Class 2 – Bare-earth ground
Class 3 – Low Vegetation
Class 4 – Medium vegetation
Class 5 – High Vegetation
Class 6 - Building
Class 7 – Noise (low or high, manually identified, if needed)
Class 9 – Water
Class 10 – Ignored Ground (Breakline Proximity)

5.2.4.3 Bare Earth Surface (Raster DEM)

The bare earth DEM and the 3D hydro breaklines were generated to the project limits and include the buffer area. Once the deliverable LAS files were generated for the entire project area and QC'ed, and the 3D breaklines were collected and QC'ed, they were used to produce the bare earth DEM to the specified cell size of 2.0 feet.

First the bare earth points that fall within 1*NPS along the hydro breaklines were classified as class 10 to be 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 using proprietary software.

The technicians then used Fugro proprietary software for the production of the LiDAR-derived hydro flattened bare earth DEM surface in initial grid format at 2 foot GSD. Water bodies (inland ponds and lakes) and inland streams and rivers were hydro flattened within the DEM. Hydro flattening was applied to all water impoundments, natural or man-made, that are larger than approximately 2 acres in area and to all streams that are nominally wider than 100 feet. This process was done in batch.

Once the initial, hydro flattened bare earth DEM was generated, the technicians checked the tiles to ensure that the grid spacing met specifications. The technicians also checked the surface to ensure proper hydro flattening. The entire data set was checked for complete project coverage. Once the data was checked, the tiles were then converted to ERDAS Imagine format. Georeference information is included in the raster files. Void areas (i.e., areas outside the project boundary but within the tiling scheme) are coded using a unique "NODATA" value.

5.2.5 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 classes:

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 that narrowed to 65' and back to100' for a ½ mile stretch 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.

2D Topological QC: After initial collection, features were combined into working regions based on watershed sub-basins. Linework was then checked for the following topological and attribution rules:

- Lines must be attributed with the correct feature code (River, Lake).
- Lake and stream banklines (River) must form closed polygons.

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 using a distance weighted distribution of LiDAR points closest to each vertex. This is similar to draping the 2D linework to a surface modeled from the LiDAR points. After the initial 'drape', the linework elevation values were further adjusted based on the following rules:

- Lake feature vertices were re-assigned (flattened) to lowest draped vertex value, excluding any noise points.
- Proprietary profile tool was used to QC bank to bank flatness.
- Stream centerline 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.

The hydro flattened breaklines were delivered in Geodatabase format.

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, relative to known control, were verified prior to classification and subsequent product development.

The achieved accuracy of the Raw LiDAR Point Cloud in the "open terrain" land cover category of the ground control and check points is 8.23 cm tested at 95% confidence level. Please refer to McKenzie_LiDAR_Accuracy_Report.docx for further details.

6.2 Relative Accuracy

Relative accuracy is <= 7 cm $RMSE_Z$ within individual swaths and <=10 cm $RMSE_Z$ 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: 17.64 cm at a 95% confidence level, derived according to NSSDA, i.e., based on RMSE of 9 cm in the "open terrain" land cover category. This is a required accuracy.

The achieved accuracy of the Raw LiDAR Point Cloud in the "open terrain" land cover category of the check points is 8.23 cm tested at 95% confidence level. Please refer to McKenzie_LiDAR_Accuracy_Report.docx 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: 17.64 cm at a 95% confidence level, derived according to NSSDA, i.e., based on RMSE of 9 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: 26.2 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: 26.2 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 95th percentile error from the DEM.

Land Cover Category	**# of Points**	**FVA** Fundamental Vertical Accuracy ($RMSE_Z$ * 1.960) Spec=17.64 cm *DEM Accuracy*	**CVA** Consolidated Vertical Accuracy (95th Percentile) Spec=26.2 cm *DEM Accuracy*	**SVA** Supplemental Vertical Accuracy (95th Percentile) Spec=26.2 cm *DEM Accuracy*
Consolidated	241		17.07 cm	
Bare Earth / Open Terrain(SPOTBARE)	63	8.23 cm		7.92 cm
Grass(SPOTLOW)	66			17.68 cm
Shrubs(SPOTMED)	62			24.69 cm
Trees(SPOTHIGH)	50			15.54 cm

Table 1: Accuracy of the Derived DEM

7 REFERENCES

7.1 Survey Report

Which includes the following deliverables:

McKenzieCoND_LiDAR_Survey_Report.pdf

McKenzie_County_nad832007_ndsp_north_navd88_geoid03_ift.txt

McKenzie_County_nad832011_utm13_grs80_meters.txt

McKenzie_County_nad832007_ndsp_north_navd88_geoid03_ift.shp

McKenzie_County_nad832007_ndsp_north_navd88_geoid03_ift_checkpoints.shp