Fort Peck to Yellowstone LiDAR mapping

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1. Project Description

The purpose of this study is to acquire high resolution LiDAR data over the flooded areas of the North Platte River in eastern Montana to the North Dakota border. This data is to be used to visually denote and quantify inundation damage areas from no damage areas, as well as to visually denote and quantify degree of damage as heavy, moderate, or light, and for future H&H analysis.

1.1. Project Area

The project encompasses the area in the provided shapefile. Total project area in square miles is approximately 485 square miles. The graphic below, *Figure 1*, depicts the project boundary.

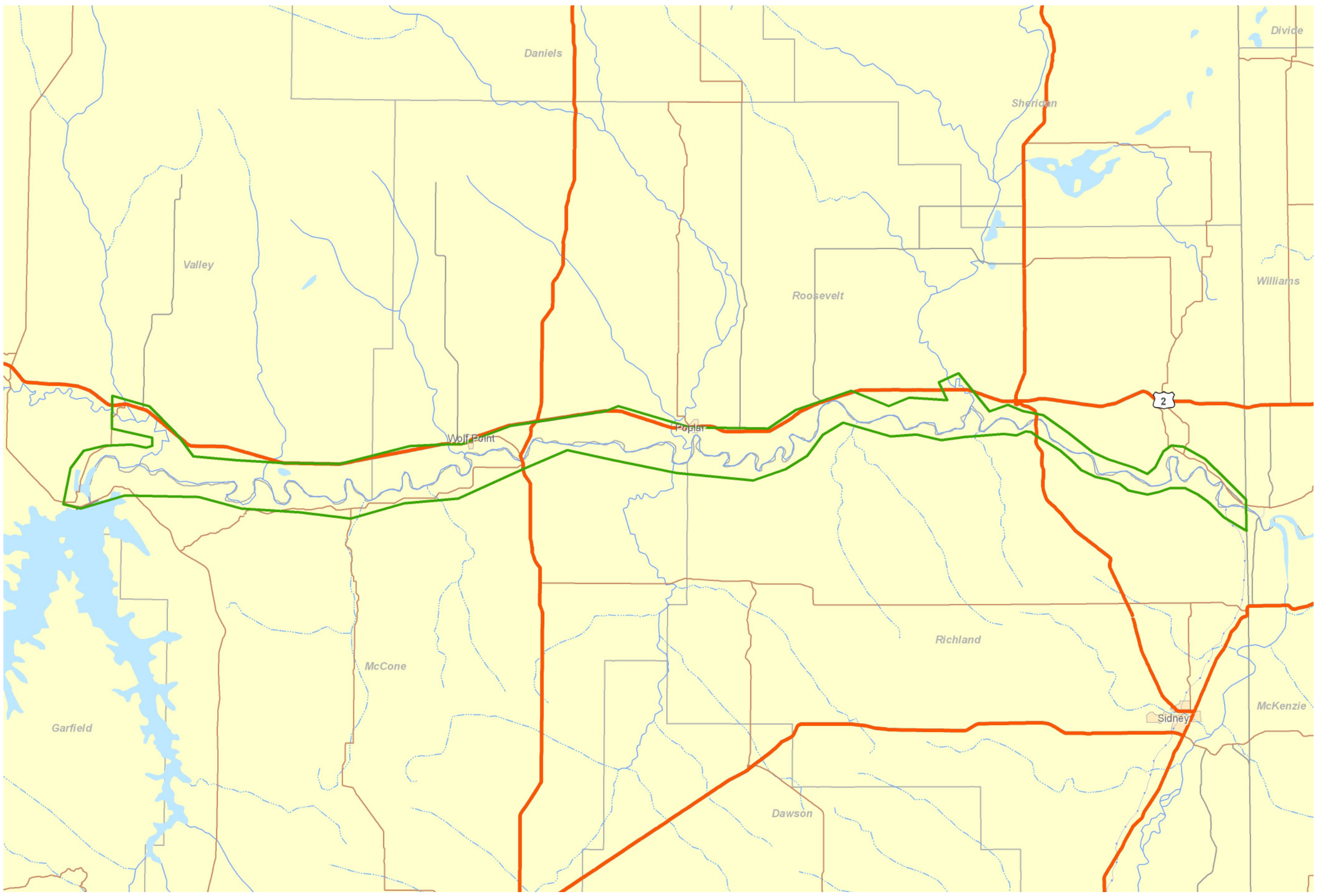

Figure 1 - Project Boundary

1.2. Project Team

Fugro Horizons was selected by the Saint Louis District Corps of Engineers to provide the data mentioned in the primary objective above. Fugro Horizons employed subcontractor DOWL HKM to survey the project ground control and QC checkpoints.

1.3. Project Methodology

1.3.1. LiDAR Acquisition

Fugro Horizons flight planning and data collection methodology entailed the following steps:

- Sensor – Sensor installation and configuration including survey of offsets from sensor head to GPS antenna.
- Flight planning – Using proprietary software to obtain required point density and related accuracy requirements.
- Ground survey – A minimum of two Continuously Operating References Stations (CORS) stations and one base station to collect data at 1Hz on surveyed points.
- Sensor calibration – Calibration flights are flown regularly to check for any roll, pitch, and scale errors of the sensor. Each survey flight is also tested using TerraSolid's TerraMatch to determine if any calibration errors are apparent and correct if necessary.
- Airborne data collection – The project was flown and data collected by Fugro Horizons operators.

1.3.2. Ground Control

DOWL HKM surveyors control report is provided "Platte_River_Report.pdf":

- Ground Control Site – Each site shall be reasonably flat with no buildings or structures within a radius of approximately 25'-30', with an open, unobstructed view of the sky.
- Ground – Ground surface shall be bare dirt, gravel, or short grassy areas.
- Contrast – Areas that are very light or dark, such as bright concrete or dark paved areas are to be avoided.

The data was processed in Trimble Business Center Ver. 2.60, project name "Final Fort Peck CNTL". Coordinates are derived from OPUS solutions based on the following acceptance criteria: at least 90% observations used, at least 50% of ambiguities fixed, and overall RMS less than 0.030 m. Fixed weighting for control coordinates was derived from OPUS peak to peak errors and was applied to latitude, longitude, and ellipsoid height for adjustment.

Following the adjustment, I compared network adjusted values to OPUS positions. The mean difference between OPUS positions and adjusted network values was 0.05' horizontal and 0.04' vertical, with the greatest horizontal outlier being 0.09' and the greatest vertical outlier being 0.15' (317). Comparisons of network adjusted values to HARN stations M 542 and M 548 2007 values were 0.12' or less horizontal and 0.02' or less vertical. Comparisons of network adjusted values to published NGS vertical benchmarks B 542, M 354, and G 544 were were 0.09' or less.

All units were for this job are survey feet, per client request. Elevations computed using GEOID09. Horizontal coordinates MTSPC NAD83(2007).

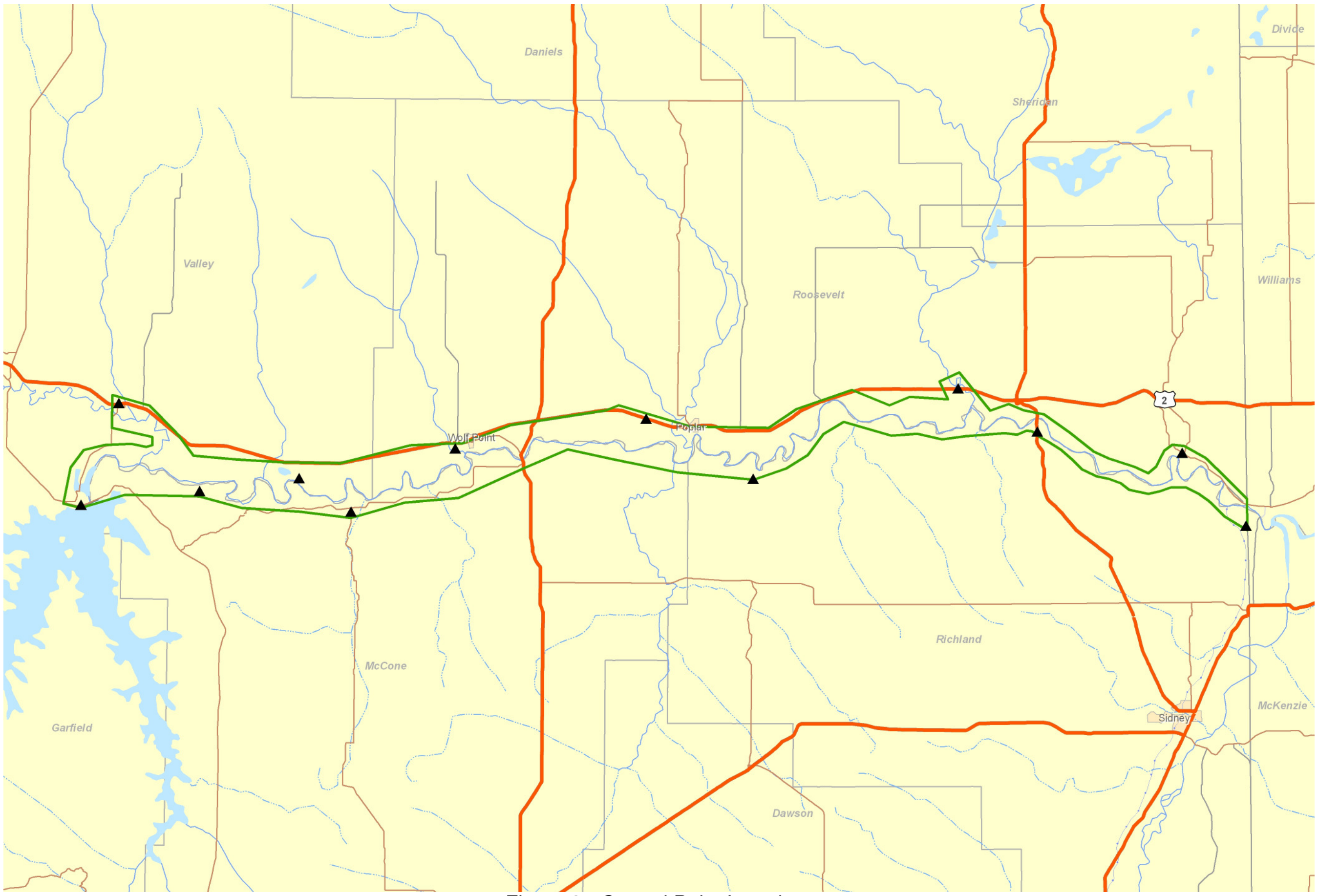

Figure 2 - Control Point Locations.

The following Datums were used for this project:

- Horizontal Datum: *North American Datum of 1983 (NAD83)*
- Vertical Datum: *North American Vertical Datum of 1988 (NAVD88)*
- Geoid Model: *Geoid09*
- Ellipsoid: *GRS80*
- Coordinate System: *NAD83(NSRS2007) Montana State Plane*
- Units: *US Survey Feet*

1.3.3. Pre-Processing of LiDAR

Fugro Horizons was responsible for the LiDAR data pre-processing, which consisted of the following methodology:

- GPS data processing and optimization – The aircraft trajectory was computed to tie in the air and ground GPS and ensuring solutions computed from the different ground stations compare. Inertial Measurement Unit (IMU) data is processed to refine the trajectory with the aircraft's attitude information.
- Raw data processing – Laser points are computed and output using Fugro Proprietary software.

- QA/QC – The laser points are compared to the QA/QC points collected on the ground and statistics generated of the standard deviation, mean, and RMSE.

1.3.4. LiDAR Data Processing

Fugro Horizons used the following methodology for the LiDAR data processing:

- Classification of first and last pulse – The first return, or "reflective surface," dataset consists of only the first returns of the LiDAR data collection, minus noise points.
- Canopy Data – The canopy dataset is created from the points classified as "above ground," points not part of the bare-earth.
- Automated filtering – The goal of automated processing is to identify and reclassify non-bare earth elevation points falling on vegetation, buildings, and other above-ground structures.
- Manual filtering – Vegetation and noise points remaining after automatic data post-processing are removed manually through interactive editing.

1.3.5. Deliverables

Fugro Horizons delivered the following products for the Fort Peck to Yellowstone LiDAR mapping project:

- 2' contour data in Microstation and ESRI Geodatabase formats
- 1m Bare Earth DEM is ESRI Grid format
- 1m Hillshade Images in color and grayscale
- Hydro Breaklines in ESRI Geodatabase format
- LAS data as Fully Classified as well as only Model Keypoint data

2. Flight Line Maps and Coverage Area

Fugro Horizons collected the LiDAR data in November 2011. *Figure 3* depicts the LiDAR data flight maps.

2.1. LiDAR Flight Map

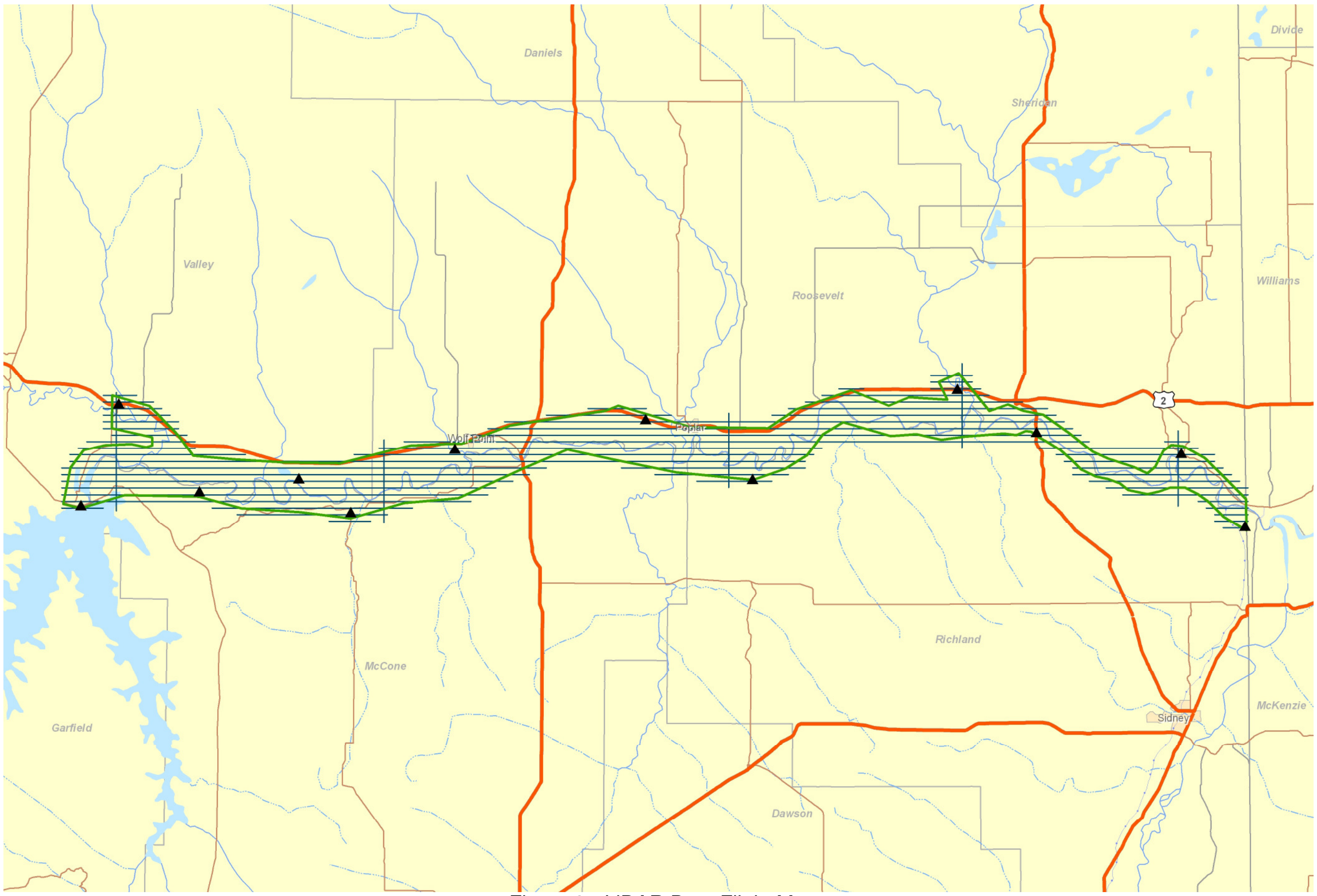

Figure 3 - LiDAR Data Flight Map

2.1.1. Sensor Specifications

The LiDAR data was captured with a Leica Geosystems ALS60. The flight was planned with a 7,000' AMT (above mean terrain) flight height with a field of view of 34 degrees. The pulse rate was set at the maximum 109,600 Hz for the flight height. The scan rate was set at 31.5 Hz to better distribute the points. The sensor settings used predicted a point spacing of better than 1.4m point spacing.

2.1.2. Point Spacing

It is the policy of Fugro Horizons to use only the first return of each pulse to measure point spacing. There is no guaranteed way of knowing before the flight how many pulses will result from multiple returns; and it is expected that some returns will not reach the ground in heavily vegetated areas. The sensor settings used predicted a point spacing of better than 1.4m point spacing.

3. Acquisition Conditions

3.1. LiDAR Acquisition Dates

The LiDAR was acquired November 10, 2011 through November 12, 2011. The flight logs are deliverd with the metadata. Please refer to the logs with any questions about dates and times of acquisition.

3.1.1. LiDAR Acquisition Plan

Horizons set-up base stations in order to ensure the aircraft was no more than 35 mile from a base station during the aerial acquisition. The aircraft was based out of Wolf Point, MT for the duration of the acquisition window. The sensor operator did a quality check of the LiDAR data after every mission to ensure coverage of the project area is complete.

GPS Collection Parameters

- Maximum PDOP – 3.0
- Minimum Number of Satellites – 6
- Ground Collection Rate – 1 Hz

4. Data Quality

4.1. LiDAR

4.1.1. Coverage

The sensor operator did a QC of the LiDAR data after each mission ensuring complete coverage of the project area. The sensor operator used a real-time ABGPS/IMU solution to process every 10th LiDAR point, and compared the flight lines to each other to ensure complete coverage with no data gaps.

4.1.2. Processing Steps

More extensive QC of the LiDAR data was conducted at the office to ensure the area was not only covered, but the data is usable and accurate. The QC showed the data to be accurate and usable, and no re-flights were called for accuracy, Airborne GPS/IMU issues, or weather related incidents.

The LiDAR processing started with the ABGPS and IMU processing. After receipt of the ground control from our surveyor, Professional mapping and Surveying, the coordinates surveyed for the base station locations were used in the post-processing of the ABGPS/IMU data. The ABGPS/IMU data was processed through a forward and reverse solution, and checked against each other to ensure the data met accuracy guidelines. The ABGPS/IMU data was used in addition to the raw scan files from the LiDAR sensor to start the processing of the LiDAR data itself.

The LiDAR technicians used proprietary software to calibrate the data, and find the mis-alignment angles to input back into the software to output the final calibrated LAS files. Overlapping LiDAR data was used to find the mis-alignment angles. The ground control points were withheld from the calibration step until the calibration looked successful. The proprietary software was also used to check the control data, as well as to adjust (z-bias) the LiDAR data to the ground control provided by Professional Mapping and Surveying.

Microstation V8 and TerraScan version 10 were used to combine and tile the LAS files. TerraScan was also used to run the first automated classification routine on the LiDAR point data. The automated routine looks at points in relation to the surrounding points, and classifies the points as ground and non-ground. The automated routine normally does an 85-90% solution on the ground classification, but in areas with high relief and dense vegetation seen in this project, the macro typically does an approximate 75-80% solution.

Proprietary software was used in the manual point classification phase. Technicians used 2D surface rendering in addition to cross-sections in classifying the remainder of the LiDAR points. The classified LiDAR data was quality checked by another technician before the data was moved to the next stage in deliverable development. The water classification was completed by manual collection of polygons surrounding water, which were subsequently given z-vales and serve as hydro breaklines, which are delivered under this contract.

The LiDAR was run through proprietary software to classify Keypoint LiDAR points. The Keypoint LiDAR data is a filtered point set that classifies the LiDAR points that are required to accurately model the surface with the fewest number of points. These points are re-classified in the LAS files to a unique point class, ASPRS class 8. The accuracy of the keypoint data set is comparable to the full bare earth data set, with tiles that are much easier to manage due to a significant reduction in file size.

4.1.3. Resulting Accuracy

The vertical accuracy of the LiDAR data was computed using proprietary software that compares the ground control coordinate with the surface the LiDAR data generates, and finds the residuals of the ground control points and calculates the RMS of the control. The RMS of the control compared to the LiDAR surface was calculated to be 10.0 cm in open areas, well within the contract requirement and Fugro guarantee of 18.5 cm RMSE.

The checkpoint QC data was calculated for each cover type and is reported below:

Survey Ground Control – 10.02cm RMSE

Survey Checkpoints – 10.79cm RMSE