FUGRO EARTHDATA, INC.

Project Report – USGS Lidar

Upper Delta Plain, LA Lidar

Prepared for:

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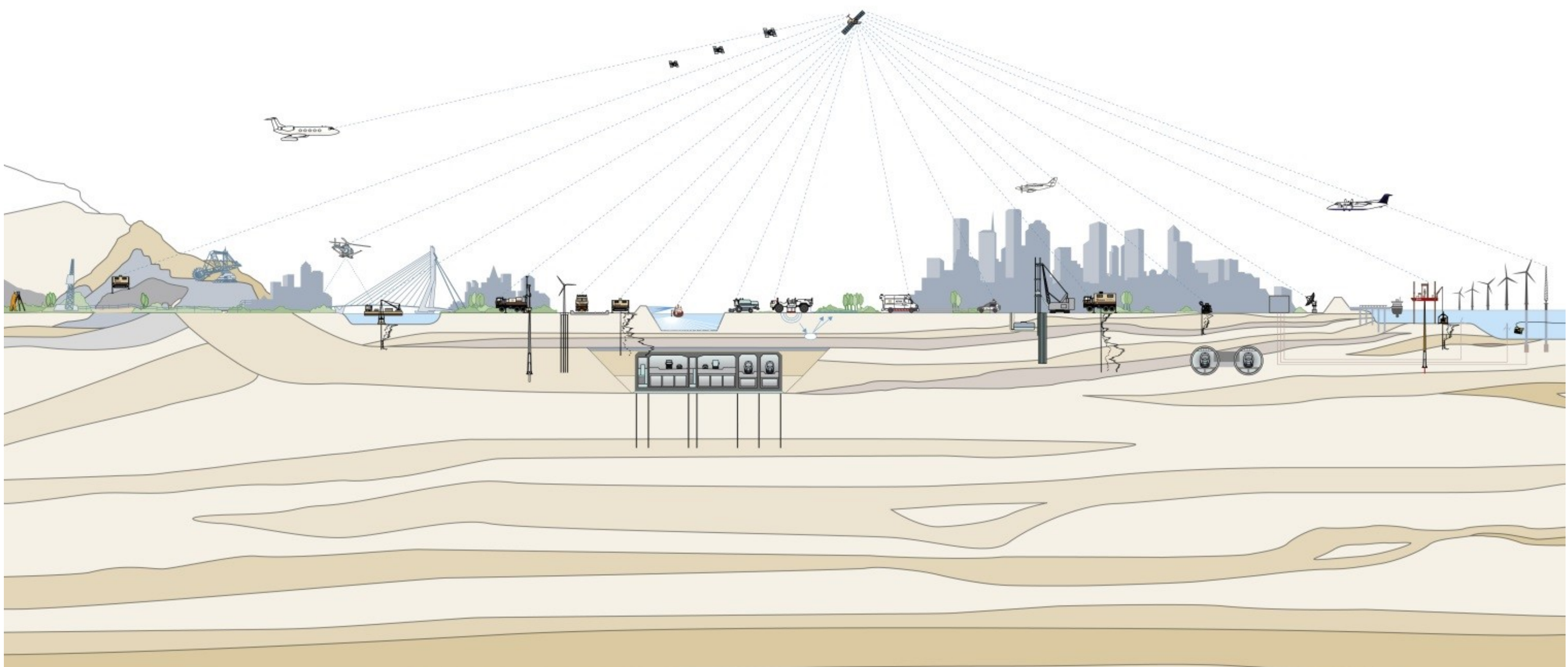

1. PROJECT OVERVIEW

Fugro EarthData, Inc. (Fugro) was tasked with planning, acquiring, processing, and producing derivative products of lidar data collected at an aggregate nominal pulse spacing (ANPS) of 0.7 meters (2ppsm), including overlap, for an Area of Interest (AOI) defined as the Upper Delta Plain in the south eastern portion of Louisiana.

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 1.2”.

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. The initial kick-off meeting was held in November 2015 for an acquisition window of December 15, 2015 through March 15, 2016; however, due to flooding the acquisition window did not open and the project was postponed a year. The second kick-off meeting occurred in November 2016 and acquisition occurred between January 23 and March 20, 2017; with a re-flight occurring on April 24, 2017. The AOI covers approximately 3,805 square miles. A 100-meter buffer was added to the AOI covering approximately 3,843 square miles; all products were generated to the limit of this buffered boundary except for the hydro breaklines which extend slightly beyond the boundary in some locations.

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 at the operational airports 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 ID/IQ subcontractor Terrasurv, Inc. A total of 63 ground control points to support the lidar collection; along with 101 non-vegetated vertical accuracy (NVA) and 78 vegetated vertical accuracy (VVA) checkpoints were collected. The National Spatial Reference System (NSRS) was used to provide control for the network. A Virtual Reference System (VRS) was used to survey each of the lidar control points. GULFNet is a network of Continuously Operating Reference Stations (CORS) network operated by the Louisiana Spatial Reference Center which is tightly aligned with the CORS of the National Spatial Reference System (NSRS). Using this methodology and VRS network was crucial to being able to obtain accurate heights due to known subsidence issues with the passive (i.e. ground monumented stations) NSRS marks in the area. Many of the GULFNet stations are also part of the National CORS Network. The horizontal datum was the North American Datum of 1983 – NAD83 (2011), epoch 2010.0. The vertical datum was the North American Vertical Datum of 1988 (NAVD88), realized with GEOID12B.

The National Geodetic Survey has the following statement on their GEOID12B page (https://www.ngs.noaa.gov/GEOID/GEOID12B/):

Differences between GEOID12A and GEOID12B

When using the geoid models, please be advised that GEOID12B should supersede previous models GEOID12 and GEOID12A. GEOID12B is identical to GEOID12A everywhere, except in Puerto Rico and Virgin island region. For more detail, please read Technical details.

A new hybrid geoid model has been computed for the Puerto Rico/U.S. Virgin Islands region based on a corrected set of heights. Although the only change to GEOID12A occur in the Puerto Rico/U.S. Virgin Islands region, NGS released an entirely new set of hybrid geoid model grids under the name "GEOID12B." In all areas other than the Puerto Rico/U.S. Virgin Islands region, GEOID12B is identical to GEOID12A.

No new data from Puerto Rico/Virgin Islands were included in the computation of GEOID12B. Observations are currently being collected on approximately 10 new bench marks by our remote sensing team which will be included in the next hybrid geoid model.

The locations are shown within Figure 1 below along with the planned flight lines. Please refer to the Survey Report for further details.

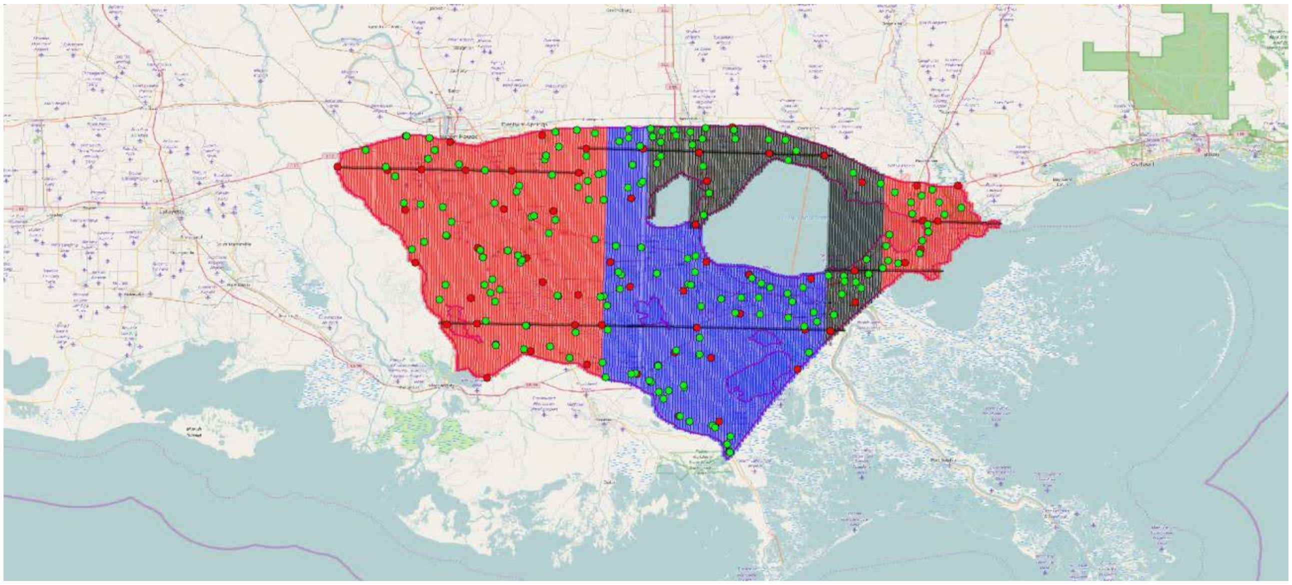

Figure 1: Ground Control Points (red circles) and Checkpoints (green circles)

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 the Task Order Detail. A 100-meter buffer was added to the USGS defined collection area; all products were generated to the limit of this buffered boundary (except for the hydro breaklines which extend slightly beyond the boundary in some locations). The graphic below is a visual of the planned flight lines based on the buffered boundary.

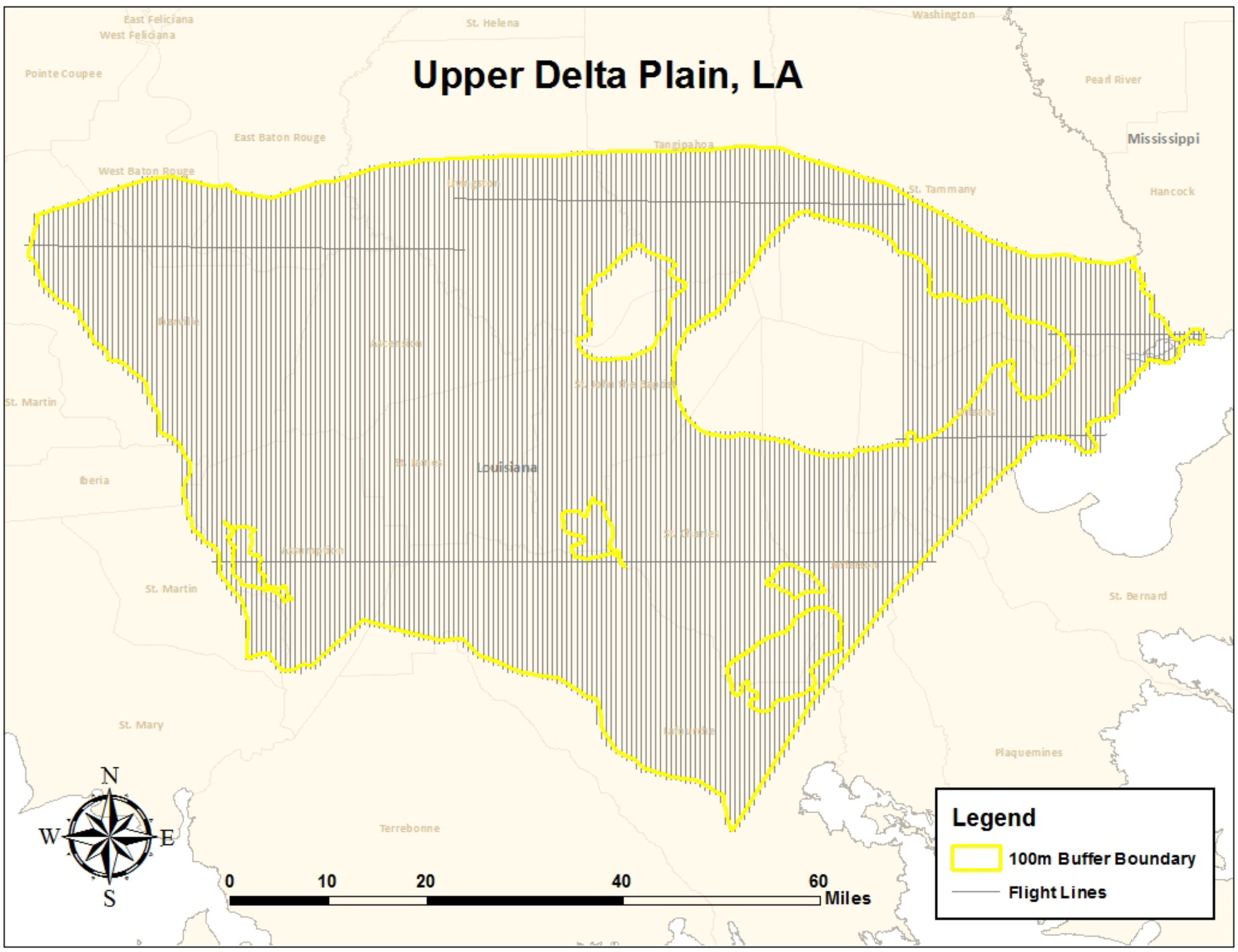

Figure 2: Flight Plan

4.2 Lidar Data Acquisition Considerations

Fugro collected Riegl-derived lidar over the Upper Delta Plain, Louisiana AOI with 0.7 meters ANPS. Data was collected when environmental conditions meet the criteria specified. To be specific, the following conditions existed prior to launch of the aircraft:

- Water levels for either Grand Isle, LA or Shell Beach, LA were below -0.10 meters (mean sea level), for flight lines that were considered tidal
- Passage of a moderate to strong high-pressure system generating northerly winds in excess of 5 knots
- 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 utilized the Riegl LMS-Q680i and Riegl LMS-Q780 airborne laser scanners. The Riegl LMS-Q680i and LMS-Q780 collects high density lidar with their 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.

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 sensors can adequately produce the required 0.7 meters NPS.

4.4 Project Design

The following is detail on the lidar acquisition covering the Upper Delta Plain, LA lidar buffered boundary:

Collections:	32
Collection Dates:	January 23rd – March 20th, 2017; April 24th, 2017
Field of View (FOV):	60 degrees
Average Point Density (planned):	2 ppsm
Flight Level(s) AMT:	3281 ft, 4400 ft
Sensor Type(s):	Riegl LMS-Q680i, Riegl LMS-Q780
Sensor Serial Number(s):	165, 961, 216

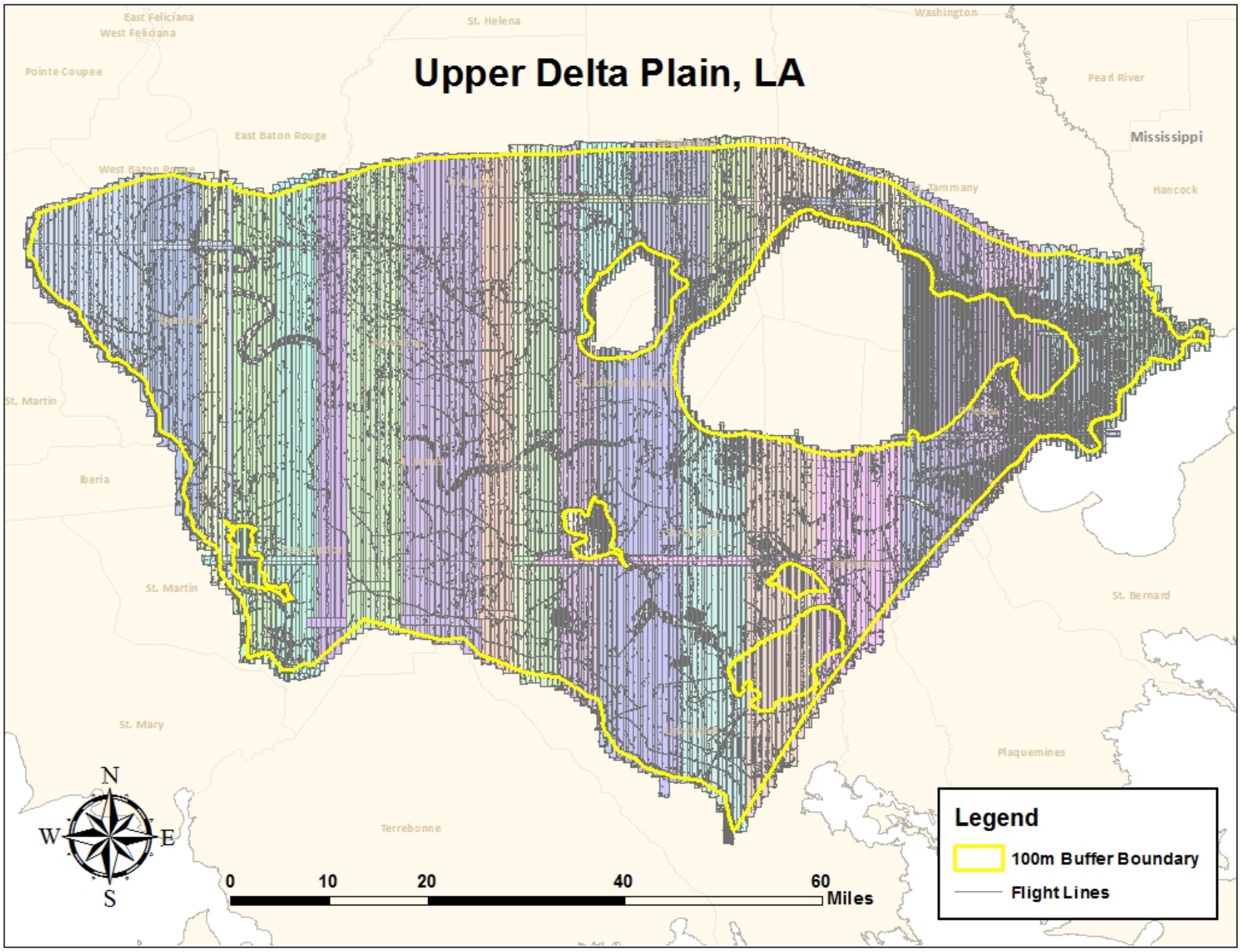

Figure 3: Executed Flight Trajectories

Please refer to the Collection Report (*UpperDeltaPlainLA_Lidar_Collection_Report.pdf*) 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.

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 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 0.7 m aggregate nominal post spacing (ANPS). 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 0.7 m ANPS 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 within 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 as well as between flight line overlaps.
- 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 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 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 ≤ 6 cm within individual swaths (smooth surface repeatability) and ≤ 8 cm RMSD within swath overlap (between adjacent swaths) with a maximum difference of ± 16 cm.

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 $RMSE_Z$ (non-vegetated) ≤ 10 cm, NVA ≤ 19.6 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 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 low noise points, high 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. Bridge deck points were classified as well during the interactive editing 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).

5.2.4 Product Development

After the lidar went through all initial processing and was checked for quality, we began the process of derivative product development to the project requirements and specifications.

5.2.4.1 Raw Point Cloud Data

All collected flight lines were included in generating this product, after boresight was completed and the adjustment was made to match the data to the ground control. The flight lines went through the following processes: 1) Assign flight line ID to each point and file source ID to each flight line based upon the flight line trajectory; 2) Re-project flight lines files to deliverable projection/datum and unit; 3) Package final LAS 1.4 format deliverable and QC.

The raw point cloud data was delivered in fully compliant LAS v1.4, Point Record Format 6 with Adjusted Standard GPS Time. The flight lines include all collected points and were fully calibrated, georeferenced, and adjusted to ground. Correct and properly formatted georeference information as Open Geospatial Consortium (OGC) well known text (WKT) was assigned in all LAS file headers. Intensity values are included for each point, normalized to 16-bit. This deliverable was organized and delivered in their original swath, one file per swath, one swath per file.

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 v1.4. It was also re-projected to UTM Zone 15 north; NAD83 (2011), meters; NAVD88

(GEOID12B), meters. 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. Water points were classified to Class 9 and Ignored ground points were classified to Class 10 using the collected hydro breaklines.

This product was delivered in fully compliant LAS v1.4, Point Record Format 6 with Adjusted Standard GPS Time at a precision sufficient to allow unique timestamps for each pulse. Correct and properly formatted georeference information as Open Geospatial Consortium (OGC) well known text (WKT) was assigned in all LAS file headers. Each tile has unique File Source ID assigned. The Point Source ID matches to the flight line ID in the flight trajectory files. Intensity values are included for each point, normalized to 16-bit.

The following classifications are included:

(01) Class 1 – Processed, but unclassified
(02) Class 2 – Bare earth ground
(03) Class 3 – Low Vegetation (3 meters or less)
(04) Class 7 – Low Noise
(05) Class 9 – Water
(06) Class 10 – Ignored Ground
(07) Class 17 – Bridge Decks
(08) Class 18 – High Noise

The classified point cloud data was delivered in tiles without overlap using the project tiling scheme.

5.2.4.3 Bare Earth Surface (Raster DEM)

The bare earth DEM was generated using the lidar bare earth points and 3D hydro breaklines to a resolution of 1.0 meter. Where needed, supplemental breaklines were collected and used in DEM generation under the bridges to ensure a logical terrain surface below a bridge. This was delivered as a separate shapefile.

The bare earth points that fell within 1*NPS along the hydro breaklines (points in class 10) 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 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 1.0 meter GSD. Water bodies (inland ponds and lakes), inland streams and rivers, and island holes 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 industry-standard, GIS-compatible, 32-bit floating point raster format (LZW compressed 32-bit GeoTIFFs). 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.

5.2.4.4 Digital Surface Model

The Digital Surface Model (DSM) was generated using the lidar First Return points to a resolution of 1.0 meter after the high and low noise points were filtered out.

The technicians used Fugro proprietary software for the production of the DSM in initial grid format at 1.0 m GSD. The technicians checked the tiles to ensure that the grid spacing meets specifications and complete project coverage. The tiles were then converted to industry-standard, GIS-compatible, 32-bit floating point raster format (LZW compressed 32-bit GeoTIFFs). Georeference information is included in the raster files. Void areas (i.e., areas outside the project boundary but within the tiling scheme) will be coded using a unique "NODATA" value.

5.2.4.5 Intensity Images

Upon the completion of lidar point cloud product creation, First Return points were used for intensity image generation automatically. The software considers points from neighboring tiles while creating the images for seamless edge matching. The initial intensity images were generated at 1.0 meter resolution in 16bit TIFF format. They were then converted to 8bit format. Georeferencing information was assigned to all images. The technician QC'ed the final intensity images before delivery. The intensity images were delivered in GeoTIFF with TFW format.

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 (Lakes)

- Approximately 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, were treated as rivers.

Inland Streams and Rivers (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.
- The bare earth surface below a bridge is a continuous logical interpolation of the apparent terrain lateral to the bridge deck. Where abutments are clearly visible, the bare earth interpolation begins at the junction of the bridge deck and approach structure. Where this junction is not clear, Fugro utilized their professional judgment to delineate the separation of below-bridge terrain from elevated bridge surface.
- No geometric changes were made to the originally computed lidar points. Bare earth lidar points that are near breaklines were classified as Ignored Ground and excluded from the DEM generation process.
- Streams, rivers, and water bodies meeting the criteria for hydro flattening are monotonically continuous where bridge decks have been removed.
- All breaklines used to enforce a logical terrain surface below a bridge were delivered as a separate shapefile and delivered with the hydro product.

2D Topological QC: After initial collection, features were then 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, Supplemental Breaklines etc.).
- 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.
- Double stream bankline vertices were re-assigned based on the vertices of the closest adjusted double stream connector line.
- Proprietary profile tool was used to QC bank-to-bank flatness, monotonicity, and lake flatness.

The hydro breaklines were delivered as polygons in Esri ArcGIS version 10.3 geodatabase format.

5.3 Pilot Area Processing

The pilot consisted of four areas defined as Pearl River, Labranche, Lake Boeuf, and Attakapas Landing. The Pearl River and Labranche pilot datasets were delivered in May 2017 and the Lake Boeuf and Attakapas Landing pilot datasets were delivered in June 2017. Technical calls were held in July and August 2017 to address pilot review concerns. The feedback obtained from the pilot reviews/technical exchanges was incorporated into the final delivery.

The pilot datasets included the following deliverables:

- **Pearl River:** raw point cloud data in LAS v1.4, Point Record Format 6 for Fugro's internal production block 1; 11 classified point cloud tiles in LAS v1.4, Point Record Format 6; hydro-flattened breaklines in ArcGIS version 10.3 geodatabase format; 11 hydro-flattened bare earth surface (raster DEM) tiles in LZW compressed 32-bit GeoTIFF format; 11 DSM tiles in LZW compressed 32-bit GeoTIFF format; 11 intensity image tiles in GeoTIFF format; tile layout in shapefile format; acquisition status reports in shapefile format (previously submitted) for the entire project; accuracy reports for the Pearl River pilot AOI and Fugro's internal production block 1 which the Pearl River pilot AOI falls within; collection report in PDF format and trajectories in ArcGIS version 10.3 geodatabase format for the entire project; survey report in PDF, Excel, and shapefile formats for the entire project; and project level metadata in XML format.
- **Labranche:** 12 classified point cloud tiles in LAS v1.4, Point Record Format 6; hydro-flattened breaklines in ArcGIS version 10.3 geodatabase format; 12 hydro-flattened bare earth surface (raster DEM) tiles in LZW compressed 32-bit GeoTIFF format; 12 DSM tiles in LZW compressed 32-bit GeoTIFF format; 12 intensity image tiles in GeoTIFF format; and tile layout in shapefile format.
- **Lake Boeuf:** 9 classified point cloud tiles in LAS v1.4, Point Record Format 6; hydro-flattened breaklines in ArcGIS version 10.3 geodatabase format; 9 hydro-flattened bare earth surface (raster DEM) tiles in LZW compressed 32-bit GeoTIFF format; 9 DSM tiles in LZW compressed 32-bit GeoTIFF format; 9 intensity image tiles in GeoTIFF format; and tile layout in shapefile format.
- **Attakapas Landing:** 14 hydro-flattened bare earth surface (raster DEM) tiles in LZW compressed 32-bit GeoTIFF format; 14 DSM tiles in LZW compressed 32-bit GeoTIFF format; and tile layout in shapefile 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

Before classification and development of derivative products from the point cloud, the absolute and relative vertical accuracies of the point cloud were verified.

The absolute accuracy is reported in the attachment, *UpperDeltaPlainLA_QC_Master_Control_NVA_Checkpoints_Raw_FlightLines.pdf*.

6.2 Absolute Vertical Accuracy

Unclassified Lidar Point Cloud Data: The Non-Vegetated Vertical Accuracy (NVA) 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: 19.6 cm at a 95% confidence level, derived according to NSSDA, i.e., based on $RMSE_Z$ of 10 cm in the "open terrain" and/or "Urban" land cover categories. This is a required accuracy. Please refer to the table below for the achieved accuracies. The raw swath point cloud data met the required accuracy levels before point cloud classification and derivative product generation.

Table 1: Accuracy of the Lidar Point Cloud Data

Raw Flight Lines	$RMSE_Z$ (non-vegetated)	NVA at 95-percent confidence level
Specification (cm)	≤ 10	≤ 19.6
Calculated Values (cm)	4.9	9.7
Specification (m)	*≤ 0.100*	*≤ 0.196*
Calculated Values (m)	*0.049*	*0.097*
Number of points	101	101

Bare Earth Surface: The accuracy (ACC_Z) of the derived DEM was calculated and is being reported in three (3) ways:

1. **$RMSE_Z$ (Non-Vegetated):** The required $RMSE_Z$ is ≤ 10 cm.
2. **Non-Vegetated Vertical Accuracy (NVA):** The required NVA is: ≤ 19.6 cm at a 95% confidence level, derived according to NSSDA, i.e., based on $RMSE_Z$ of 10 cm in the "open terrain" and/or "Urban" land cover categories. This is a required accuracy.
3. **Vegetated Vertical Accuracy (VVA):** The required VVA is: ≤ 29.4 cm at a 95^{th} percentile level, derived according to ASPRS Guidelines, Vertical Accuracy for Reporting LiDAR Data, i.e. based on the 95^{th} percentile error in Vegetated land cover categories combined (Tall Grass, Brush, Forested Areas). This is a required accuracy.

Please refer to the table below for the achieved accuracies.

Table 2: Accuracy of the Derived DEM

DEM	$RMSE_Z$ (non-vegetated)	NVA at 95-percent confidence level	VVA at 95th percentiles
Specification (cm)	≤ 10	≤ 19.6	≤ 29.4
Calculated Values (cm)	5.5	10.8	19.5
Specification (m)	*≤ 0.100*	*≤ 0.196*	*≤ 0.294*
Calculated Values (m)	*0.055*	*0.108*	*0.195*
Number of points	101	101	78

6.3 Relative Accuracy

Smooth Surface Repeatability: In ideal theoretical conditions, smooth surface repeatability is a measure of variations documented on a surface that would be expected to be flat and without variation. Users of lidar technology commonly refer to these variations as "noise." Single-swath data was assessed using only single returns in non-vegetated areas. Repeatability was evaluated by measuring departures from planarity of single returns from hard planar surfaces, normalizing for actual variation in the surface elevation. Repeatability of only single returns was then assessed at multiple locations within hard surfaced areas (for example, parking lots or large rooftops).

Each sample area was evaluated using a signed difference raster (maximum elevation − minimum elevation) at a cell size equal to twice the ANPS, rounded up to the next integer. Sample areas were approximately 50 square meters (m^2). The maximum acceptable variations within sample areas for this project is 6 cm. Isolated noise is expected within the sample areas and was disregarded.

The evaluation was done on 21 flat open sample areas over the project area. The results are shown in the table below, please also refer to
UpperDeltaPlainLA_Lidar_Relative_Accuracy_Smooth_Surface_Repeatability.shp.

Table 3: Relative Accuracy, Smooth Surface Repeatability

Max_DZ (m)	Area (sq m)
0.05	658
0.05	116
0.02	276
0.05	75
0.04	227
0.04	117
0.03	134
0.03	224
0.05	53
0.03	55
0.03	27
0.01	95
0.03	117
0.04	88
0.04	134

0.04	117
0.04	131
0.04	86
0.03	64
0.05	74
0.04	84

Overlap Consistency: Overlap consistency is a measure of geometric alignment of two overlapping swaths; the principles used with swaths can be applied to overlapping lifts and projects as well. Overlap consistency is the fundamental measure of the quality of the calibration or boresight adjustment of the data from each lift, and is of particular importance as the match between the swaths of a single lift is a strong indicator of the overall geometric quality of the data, establishing the quality and accuracy limits of all downstream data and products.

Overlap consistency was assessed at multiple locations within overlap in non-vegetated areas of only single returns.

Each overlap area was evaluated using a signed difference raster with a cell size equal to twice the ANPS, rounded up to the next integer. The difference rasters are visually examined using a bicolor ramp from the negative acceptable limit to the positive acceptable limit. Although isolated excursions beyond the limits are expected and accepted, differences in the overlaps shall not exceed the following limits:

1. Swath overlap difference, RMSDz ≤ 8 cm
2. Swath overlap difference, maximum ± 16 cm

The difference rasters are also statistically summarized to verify that root mean square difference in z (RMSDz) values do not exceed the. Consideration will be given for the effect of the expected isolated excursions over limits.

The result of the evaluation over 27 samples throughout the project area is shown in the table below, please also refer to *UpperDeltaPlainLA_Lidar_Relative_Accuracy_Flightline_Overlap.shp*.

Table 4: Relative Accuracy, Overlap Consistency

RMS_DZ (m)	Max_DZ (m)	Min_DZ (m)	Area (sq m)
0.0255	0.0487	-0.0066	613
0.0444	-0.0132	-0.0688	689
0.0300	0.0144	-0.0689	612
0.0157	0.0606	-0.0537	454
0.0576	0.1400	-0.0259	767
0.0268	0.0350	-0.1445	720
0.0350	0.0342	-0.1049	815
0.0233	0.0812	-0.0653	130
0.0185	0.0717	-0.1300	123
0.0230	0.1078	-0.0889	123

0.0336	0.1356	-0.0478	296
0.0167	0.0593	-0.0572	304
0.0247	0.1183	-0.0298	209
0.0148	0.0328	-0.0458	883
0.0256	0.0841	-0.0443	197
0.0249	0.0468	-0.0759	205
0.0271	0.0844	-0.1363	536
0.0310	0.0779	-0.0447	171
0.0240	0.0548	-0.0223	266
0.0204	0.0967	-0.0778	117
0.0188	0.1022	-0.0570	188
0.0184	0.0951	-0.0654	260
0.0162	0.0515	-0.0503	176
0.0192	0.0747	-0.0594	158
0.0104	0.0342	-0.0221	397
0.0293	0.0842	-0.0971	146
0.0163	0.0599	-0.0416	208

7. REFERENCES

7.1 Survey Report

Which includes the following deliverables:

UpperDeltaPlainLA_Lidar_Survey_Report.pdf
UpperDeltaPlainLA_Lidar_Checkpoint_Coordinates.shp
UpperDeltaPlainLA_Lidar_Checkpoint_Coordinates.xlsx
UpperDeltaPlainLA_Lidar_GCP_Coordinates.shp
UpperDeltaPlainLA_Lidar_GCP_Coordinates.xlsx

7.2 Collection Report

UpperDeltaPlainLA_Lidar_Collection_Report.pdf

7.3 Attachment A: Positional Accuracy Report

UpperDeltaPlainLA_QC_Master_Control_NVA_Checkpoints_Raw_FlightLines.pdf

7.4 Attachment B: Relative Accuracy, Smooth Surface Repeatability Report

UpperDeltaPlainLA_Lidar_Relative_Accuracy_Smooth_Surface_Repeatability.shp

7.5 Attachment C: Relative Accuracy, Overlap Consistency Report

UpperDeltaPlainLA_Lidar_Relative_Accuracy_Flightline_Overlap.pdf