LiDAR Acquisition and Processing Report: Goshen County, WY

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APPROVALS

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01 Goshen County, WY LiDAR Collection Overview

Compass has provided FEMA with planning, acquisition, processing, and derivative product generation from LiDAR data over the area of interest (AOI) defined as Goshen County, WY. The collection design required LiDAR be acquired to an aggregate nominal pulse spacing (ANPS) of 0.7 meters (2ppsm), including overlap, and processed according to the United States Geological Survey (USGS) National Geospatial Program (NGP) LiDAR Base Specification v1.2, to which FEMA Standards for Flood Risk Analysis and Mapping defer. The total area of the AOI is approximately 2,244 square miles. LiDAR were collected to the extent of the buffered project area (with a 100-meter buffer of the AOI) and derivative products produced in compliance with this task order and the USGS NGP specifications.

The purpose of the Goshen County LiDAR collection is to support various risk analyses including hydrologic analysis, hydraulic analysis, and non-regulatory product development (e.g. depth grids and risk probability grids).

LiDAR data were processed immediately after acquisition to ensure coverage, density, relative accuracy and nonvegetated vertical accuracy (NVA) met project specifications. LiDAR data were then classified using TerraScan processing and modeling software into ground and non-ground points. Classifications include 1) Processed, but unclassified; 2) Bare earth; 7) Low Noise; 9) Water; 10) Ignored ground (near a breakline); 17) Bridge decks; 18) High noise. Independent QA/QC was performed on all data acquisition, processing, and final deliverables. The LiDAR point cloud and derivative DEMs are assured to meet FEMA and USGS vertical accuracy requirements.

02 LiDAR Acquisition

2.1 Collection Area

Goshen County, Wyoming's footprint represents the project area. The buffered project area (100 meter buffer) represents the buffered project area to which all collection and deliverable products extent.

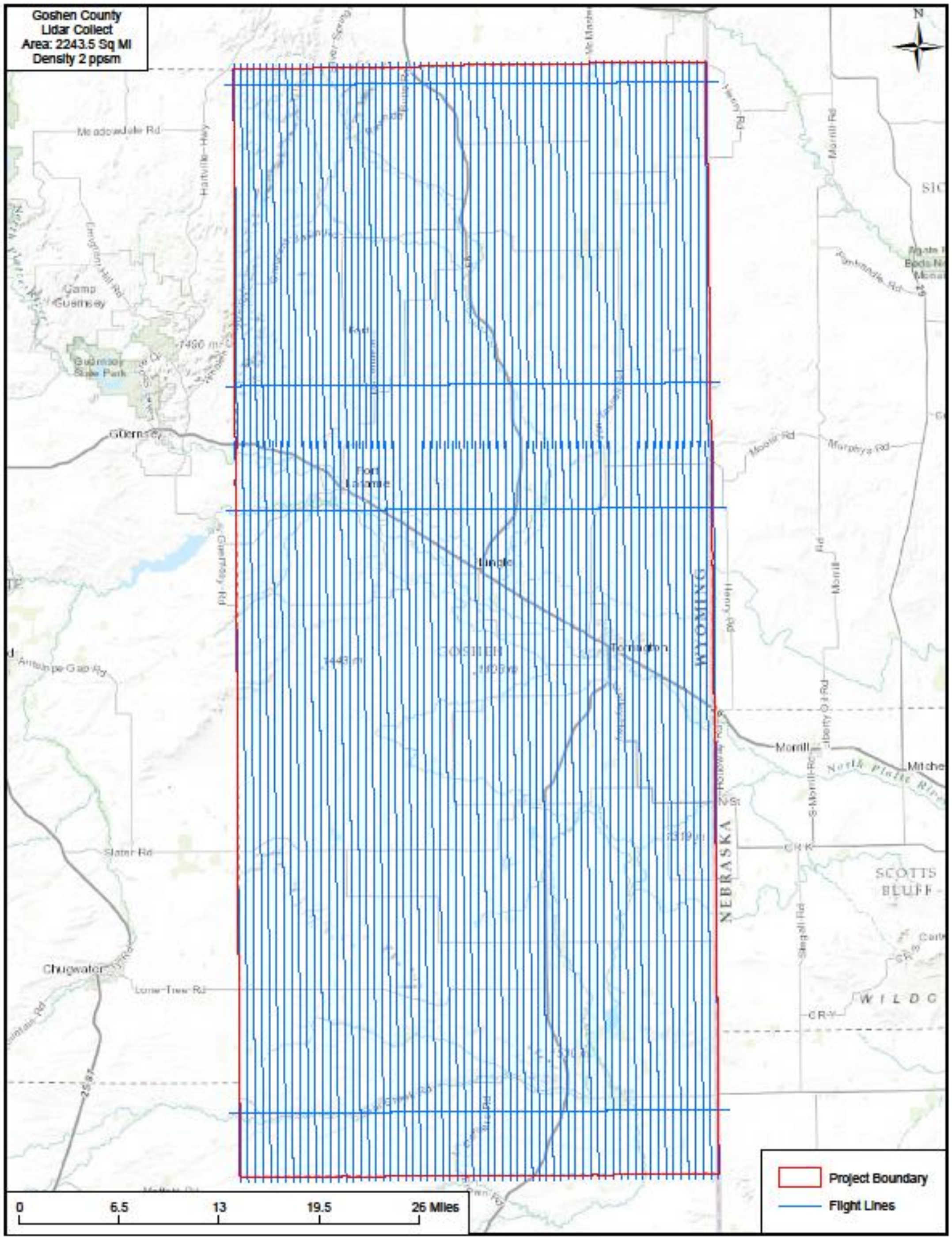

Figure 1: Buffered Project Area with Planned Flight Lines

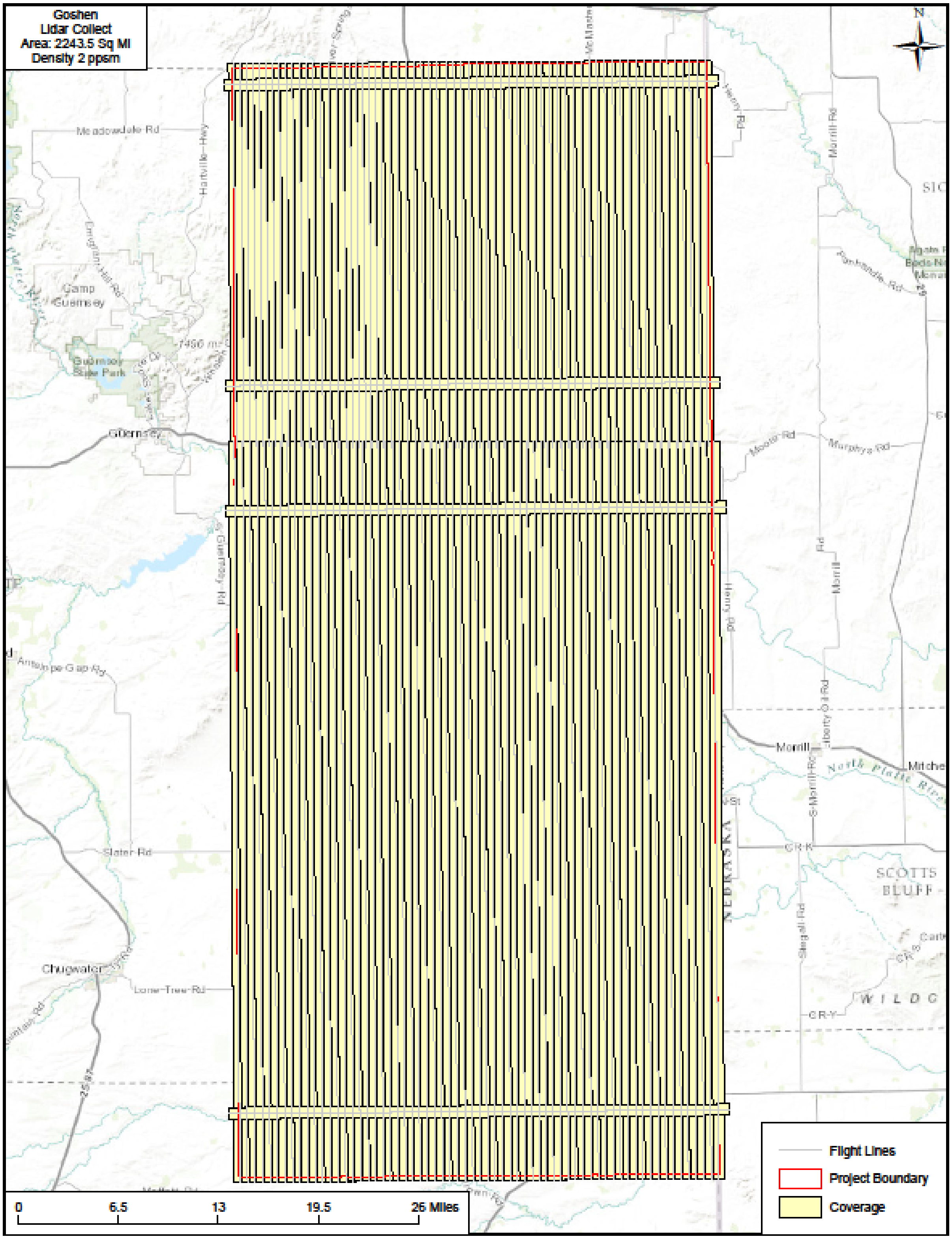

Figure 2: Flight Line Footprints

2.2 LiDAR Data Acquisition Considerations

LiDAR data were acquired using a twin engine aircraft equipped with an antenna and receiver for airborne GPS collection. Flight status was communicated during data collection.

Data were collected when the following environmental conditions allowed:

- Cloud and fog-free between the aircraft and ground
- Leaf off
- Snow free

2.3 Project Design

The following detail specifics regarding the sensor parameters at the time of collection:

Collections (Lifts):	14
Collection Dates:	Oct. 15, 2016 – Nov. 1, 2016
Field of View (FOV):	60 degrees
Average Point Density (planned):	2 pts/m^2
Flight Level(s) AMT:	3,400 feet
Sensor Type:	RIEGL LMS-Q680i
Sensor Serial Number(s):	9999165

Detailed flight logs have been provided as part of the deliverable data package.

03 LiDAR Processing

3.1 Verification of Data Usability

All acquired LiDAR data went through an initial 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 were run through a complete iteration of processing to ensure that it was complete, uncorrupted, and that the entire project area has been covered without gaps between flight lines.

3.1.1 GPS/IMU Processing

Airborne GPS and IMU data were 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.

3.1.2 Raw LiDAR Data Processing

Technicians processed the raw data to LAS format flight lines with full resolution output before performing internal QC. A starting configuration file was 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.

The following internal quality control checks were 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.
- Thorough review of the data were 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.

3.1.3 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 were incorporated throughout each step and are described in the following sections.

3.1.3.1 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 were 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 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. 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.

3.1.3.2 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.

3.1.3.3 Post-processing

The automated classification routines were applied to the tiled data first. The flight line Overlap points, low noise points, high noise points and ground points were classified automatically in this process. We utilized commercial software, as well as proprietary, in-house developed software for automatic filtering. The parameters used in the process are customized for each terrain type per project to obtain optimum results. The algorithm has the ability to process large amounts of elevation point data in batch mode. Conceptually, the goal of automated processing is to classify the points to their proper classification as accurate as possible automatically, thereby reducing the amount of manual editing that is required.

Once the automated filtering had been 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 have been filtered out, the data were either run through a different filter within the local area or is corrected during the manual filtering process. Bridge deck points were classified as well during the interactive editing process. The interactive editing was completed in visualization software that provides manual and automatic point classification tools. All manually inspected tiles then 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.

04 LiDAR Product Development

4.1 Raw Point Cloud Data

All collected flight lines that meet project acquisition criteria were included in generating this product after the boresight is completed and the adjustment was made to match data to the ground control. The flight lines went through the following processes:

- Assign flight line ID to each point and file source ID to each flight line based upon the flight line trajectory.
- Flag flight line Overlap points
- Re-project flight lines files to deliverable projection/datum and unit.
- Normalize intensity values to 16bit.
- Package final LAS 1.4 format deliverable and QC.

The raw point cloud data are delivered in fully compliant LAS v1.4 format, Point Record Format 6 with Adjusted Standard GPS Time. The flight lines included all collected and accepted 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 were included for each point, normalized to 16-bit. This deliverable are organized and delivered in their original swath, one file per swath, one swath per file.

4.2 Classified Point Cloud Data

Once manual inspection, QC and final autofilter is complete for the LiDAR tiles, the LAS data were 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 NAD 83 Wyoming State Plane East (4901), feet and the vertical datum is the NAVD88 (Geoid 12B), 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 is delivered in fully compliant LAS v1.4 format, 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 flight trajectory files. Intensity values are included for each point, normalized to 16-bit. The following classification scheme were included:

Class 1	Processed, but Unclassified
Class 2	Bare Earth Ground
Class 7	Low Noise (low, manually identified, if necessary)
Class 9	Water
Class 10	Ignored Ground (Breakline Proximity)
Class 17	Bridge Decks
Class 18	High Noise

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

4.3 LiDAR Hydro Breakline Collection

LiDAR Hydro Breaklines were collected and produced based on USGS LiDAR Base Specification version 1.2. The following hydro features are included:

- Inland Ponds and Lakes
- Inland Streams and Rivers
- Non-tidal Boundary Water
- Tidal Water

4.4 Hydro Flattened DEM

The Hydro Flattened DEM was generated using the LiDAR bare earth points and 3D hydro flattening polygons to a resolution of 1.0 meter.

The bare earth points that fall within 1*ANPS 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 a batch process, using proprietary software.

The technicians used proprietary software for the production of LiDAR-derived hydro-flattened bare earth DEM surface using TIN model in initial grid format at 1m GSD. Water bodies (inland ponds and lakes), inland streams and rivers, and other non-tidal water bodies were hydro-flattened within the DEM. Hydro-flattening was applied to all water impoundments, natural or man-made, that are larger than ~2 acres in area, to all streams that are nominally wider than 100’, and to all non-tidal boundary waters bordering the project area, regardless of size. This process was done in batch.

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

05 Conclusions

The Goshen County, Wyoming LiDAR collection, acquired to complete LiDAR coverage for FEMA's flood study project area, includes the following deliverable products that were collected and controlled to FEMA and USGS-NGP (QL2) standards and specifications:

- Raw LiDAR Point Cloud
- Classified LiDAR Point Cloud
- Hydro Breaklines
- Hydro-Flattened DEM (3-foot)
- USGS Metadata
- LiDAR Acquisition and Processing Report
- Independent QA/QC Report
- Survey Report
- FEMA Data Capture Technical Reference files

All products were independently assessed and assured to meet FEMA and USGS standards and specifications.