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SECTION 1: OVERVIEW

The LiDAR portion of the Anderson County Project calls for the following:

- ✓ LiDAR data was collected to support digital terrain modeling according to the FEMA Map Modernization guidelines.

This report contains a review of the project requirements and detailed information for LiDAR data acquisition and quality control (QC) including:

- ✓ Documentation specifying altitude, airspeed, scan angle, scan rate, LiDAR pulse rates, and other flight and equipment information deemed appropriate
- ✓ A LiDAR Data Acquisition report
- ✓ A LiDAR Data Processing report

Project Requirements

General standards for the LiDAR mission include:

- ✓ High density LiDAR data acquisition within the project limits (see Appendix A: Project Boundary/LiDAR Coverage) at a sufficient altitude and density to support digital terrain model (DTM) with a Vertical Accuracy of 2.4 feet RMSE at a 90% confidence level & a Horizontal Accuracy of 11 feet RMSE at a 90% confidence level.
- ✓ Avoid inclement weather for flight missions.
- ✓ Choose a flight path that provides satisfactory coverage of the study area, including both parallel and enough cross flight lines to allow for proper quality control.
- ✓ Document flight mission date, time, flight altitude, airspeed, scan angle, scan rate, laser pulse rates and other information deemed pertinent.

SECTION 2: LIDAR DATA ACQUISITION

This section provides an overview of the LiDAR acquisition methodology employed by Woolpert, Inc. on the LiDAR portion of Anderson County. Typical LiDAR system parameters include:

- ✓ Altitude
- ✓ Airspeed
- ✓ Scan angle
- ✓ Scan rate
- ✓ Laser pulse repetition rate

Flight and equipment information is also included.

LiDAR Overview

- Obtain new LiDAR data of the entire project area (± 780 sq . miles) consisting of point number, X coordinate, Y coordinate, Z coordinate, along with an intensity value.

- Post process the entire project area consisting of the following:
  - Average post spacing of 1.5 meters
  - Provide ground and non ground data

- Removal of artifacts to create a bare earth terrain surface. Woolpert will use the corrected Aiken County data set as the guideline for the artifact removal for Anderson County. Woolpert will take special care in processing and QC/QA of artifacts around bridges, culverts, and vegetation.
- Removal of flight line seams
- Vertical Accuracy- 2.4 feet RMSE 90% confidence level
- Horizontal Accuracy -11 feet RMSE 90% confidence level

- Produce 3-D breaklines for up to 360 sq. miles of stream corridors
- Remove LiDAR from large streams within the 360 sq. mi1es

- (see Appendix A: Project Boundary/LiDAR Coverage)

LiDAR Mission

The LiDAR data acquisition was executed in 5 sessions, from March 7 to March 9, 2007.

The airborne GPS (ABGPS) base stations supporting the LiDAR acquisition consisted of the bases set up by the flight crews at the Anderson Airport (KAND). Dual Frequency data was logged continuously for the duration of each LiDAR flight mission at a one-second sampling rate or better.

The flight plan for LiDAR consisted of parallel flights in a north-south extent across the site (see Appendix A: Project Boundary/LiDAR Coverage). Fifty-four (54) flight lines of LiDAR data were acquired.

No problems were encountered during the LiDAR data acquisition phase of the project which would adversely affect the final accuracy, nor schedule of the final deliverables.

Documentation of the specific LiDAR Acquisition missions can be found in Appendix B: LiDAR Flight Data

LiDAR Statistical Data

The LiDAR parameters are as follows:

Aircraft Speed .... 125 knots indicated air speed
Flying Height .... 7,500 feet above ground level
Scanner Field of View ....30 degrees
Scan Frequency... 28.5 Hertz
Pulse Repetition Rate.. 48,000 Hertz

SECTION 3: DATA PROCESSING AND QUALITY CONTROL

LiDAR Data Processing

In this process, Woolpert employed GPS differential processing and Kalman filtering techniques to derive an aircraft trajectory solution at 1-second intervals for each base station within the project limits. Statistics for each solution (base station) were generated and studied for quality. The goal for each solution is to have:

- maintained satellite lock throughout the session
- position standard deviation of less than 5 centimeters
- low ionospheric noise
- few or no cycle slips
- a fixed integer ambiguity solution throughout the trajectory
- a maximum number of satellites for a given constellation
- a low (3.0 or less) Position Dilution of Precision (PDOP)

Often times a solution for a given base station will meet all of the above parameters in certain portions of the trajectory while the other base station might meet the above conditions in different portions of the trajectory solution. In this case, further processing was done to form different combinations of base station solutions and/or satellites to arrive at the optimal trajectory.

When the calibration, data acquisition, and GPS processing phases were complete, the formal data reduction process began. Woolpert LiDAR specialists:

- ✓ Studied individual flight lines and how these lines match adjacent flight lines to ensure the accuracy meets expectations.

- ✓ Identified and removed systematic error locally (by flight) which is not possible if the lines are combined into a block. This is sometimes the case when a satellite loss of lock occurs during a flight and the GPS solution fixes on the wrong integer ambiguity.

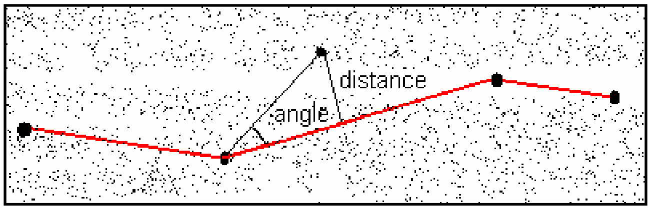
- ✓ Adjusted any small residual error (due to system noise) between flight lines and across all flight lines to survey ground control (or existing mapping if available).

- ✓ Clipped the overlap region of each flight line to obtain a single homogenous coverage across the project area. This eliminated redundant, overlapping point data that could overwhelm terrain modeling software packages.

- ✓ Processed individual flight lines to derive "Point Cloud."

  Given the airborne GPS aircraft trajectory and the raw LiDAR data subdivided by flight lines, we used manufacturer software to reduce raw information to a LiDAR point cloud on the ground. Woolpert has developed proprietary software to generate parameter files, allowing the manufacturer's software to process a block; this allows us to batch process any number of flight lines. As part of this process, outliers in the data are removed. Typical outlying data points are a result of returns from clouds.

✓ Classified the point cloud data into ground and non-ground points
The classification algorithm classifies ground points by iteratively building a triangulated surface model. The routine starts by selecting some local low points as sure hits on the ground then builds an initial Triangulated Irregular Network (TIN) from selected low points. The routine then starts developing the ground model upward by iteratively adding new laser points to it. Each added point makes the model follow the ground surface more closely. Two iteration parameters, iteration angle and iteration distance, determine how close a point must be to a triangle plane so that the point can be accepted to the ground model. **Iteration angle** is the maximum angle between points, its projection on triangle plane and closest triangle vertex. **Iteration distance** parameter makes sure that the iteration does not make big jumps upwards when triangles are large. This helps to keep low buildings out of the ground model.



The vegetation and buildings are removed to obtain bare-earth. Even in areas covered by dense vegetation, ground points are correctly classified.

✓ Filtered the bare-earth data to remove small undulations.

Small random errors exist in the data due to electronic noise within the system. These errors manifest themselves as small undulations in the data. Woolpert developed a software application based on a Gaussian operator modified to fit LiDAR data and remove small undulations. The filter controls accuracy by an elevation tolerance setting to meet a given accuracy threshold. The tolerance determines the maximum allowable elevation change of laser points. We developed a data structure suitable for LiDAR so that the searching routine is very fast [O(1)] computational complexity] making this algorithm quite efficient.

✓ Edge matched individual flight lines, generated statistics on the fit, and clipped the flight lines to butt match each other.

The next step in our process is to clip individual flight lines such that adjacent flight lines butt match and a homogenous LiDAR coverage is provided across the entire mapping limit, without overlap. A software routine was developed to follow the overlap region between two adjacent flight lines and place a "cut line" in the middle of the overlap region. The software will also generate statistics along each seamline as to how well each flight matches with its neighbor in flight.

If all flights are consistent within the mapping specifications, ground control data is imported and studied for fit. As a QC measure, Woolpert has developed software to generate accuracy statistical reports by comparison among LiDAR points, ground control, and TINs generated by LiDAR points. The absolute accuracy is determined by comparison with ground control. Statistical analysis is then performed on the fit between the LiDAR data and the ground control. Based on the statistical analysis, the LiDAR data is then adjusted in relation to the ground control.

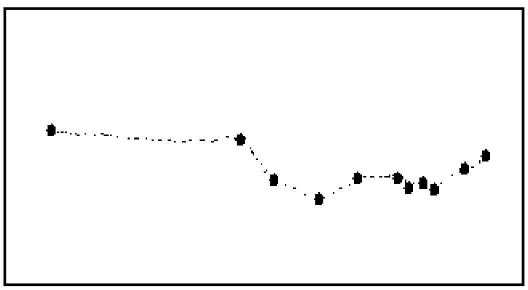
✓ Smoothed edges along flight lines if necessary.

Note, this is rarely required but in some instances the portions of opposing flight lines will not edge match exactly due to terrain features. For example, on the side of a very steep hill the opposing flight lines will have a slightly different elevation when ranged from an uphill direction as opposed to a downhill direction. The accuracy is controlled by an elevation tolerance setting.

✓ Determined key points for the DTM. Used the key points to reduce the overall number of points within the DTM.

Because LiDAR produces extremely dense data that requires a tremendous amount of storage and processing power, Woolpert has developed software to reduce the amount of data while preserving the integrity and accuracy of the terrain model.

The algorithm selects key points from points classified as ground by iteratively building a triangulated surface model. The accuracy is controlled by an elevation tolerance setting. This determines the maximum allowable elevation difference from a ground laser point to a triangulated model. The application will try to find a relatively small set of points (=keypoints) which would create a triangulated model of given accuracy. The point density is also ensured by a grid size setting.



✓ Translated the Bare-Earth Data Into the Appropriate Map Projection

Once all of the data has been reduced and quality controlled, the bare-earth data is translated into the final map projection. Note that the airborne GPS aircraft trajectory is processed in the target datums in relation to the orthometric height. Woolpert used National Geodetic Survey’s GEOID99 software to derive the orthometric height.

As a quality control step, the orthometric heights are compared against ground survey results. In our experience, GEOID’s are sometimes inaccurate in certain areas of the country. If a problem is detected, we will have to acquire additional ground control that will allow us to calculate our own transformation by determining the rotation matrix.

3D Compilation Breaklines using LiDAR Intensity images & supplementing with Orthophotography Images:

Woolpert produced intensity stereo images covering just the 360 sq. miles of detailed study area. SCDNR provided a boundary map of the detailed study area.

The compilation team stereoscopically compiled break lines in the detailed study area and remove LiDAR data from the large streams.

Other Lidar Data Requirements

- **Obscured Areas:** Heavily vegetated areas such as dense forested areas, mangroves, palmetto scrub, where the Lidar bare earth point spacing is too sparse to accurately model the terrain surface, shall be delineated by “obscured area” polygons.

- **Data Cleanliness:** To facilitate the hydraulic modeling of riverine study areas, it is important to remove points on bridges and large box culverts (culverts 24’ in width and greater) from the bare earth data set. Bridge and culvert points should be given a unique classification in the .LAS file. Woolpert will take special care in processing and QC/QA of artifacts around bridges, culverts, using the corrected Aiken County data set as a guide.

- **Water Points:** 3D Polygons should be captured for all closed water body greater that ¼ acre in size as described above, **ALL** water points should be reclassified as water in the all-points Lidar deliverable; they should be removed from the bare earth point file.

Data Format

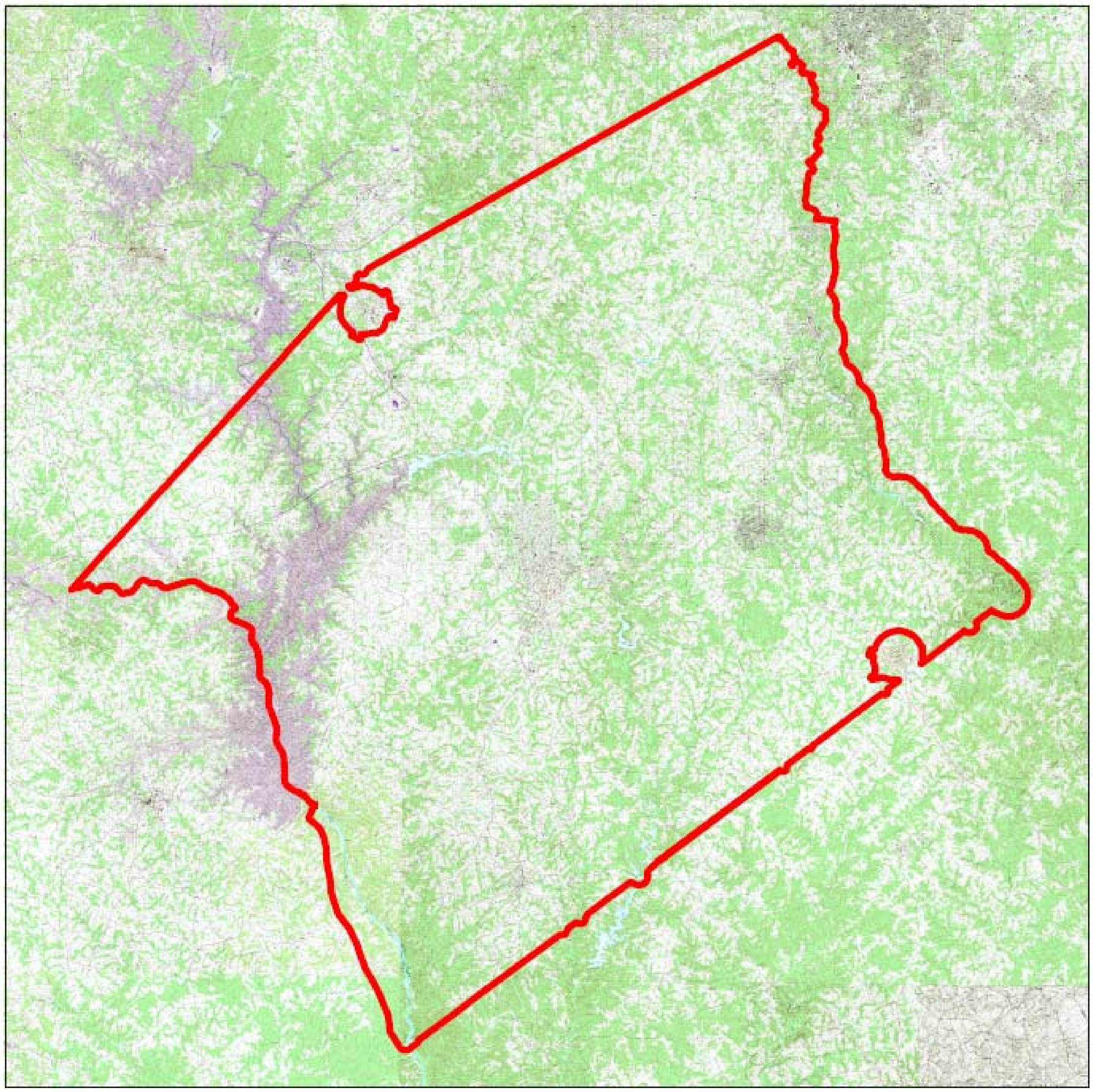
- Breaklines -.SHP
- DEM -.LAS (compatible with *LAS Specification LAS 1.1*)
- DEM – ESRI grid raster format at a 2.5-foot post spacing
- Tile size -10,000 ft by 10,000 ft

LiDAR QA/QC Verification

LiDAR QA/QC verification will be provided by SCDNR through their contractor URS Corporation.

The complete LiDAR data set for the entire project area was delivered to URS on August 15, 2007. URS conducted a data assessment. URS provided the review comments on October 10, 2007. URS indicated the LiDAR data met the vertical and horizontal accuracy requirements for the project and would not require any additional work.

APPENDIX A: PROJECT BOUNDARY/LIDAR COVERAGE



APPENDIX B: LIDAR FLIGHT DATA

Project: Anderson County, SC

The LiDAR parameters are as follows:

Aircraft Speed:	125 knots indicated air speed
Flying Height:	7,500 feet above ground level
Scanner Field of View:	30 degrees
Scan Frequency:	28.5 Hertz
Pulse Repetition Rate:	48,000 Hertz
Number of Flights:	54

Date: March 7, 2007 – Flights 1,2,3,4,5,6,7
Takeoff Time: 10:35
Landing Time: 21:31
Laser Time On: 19:34
Laser Time Off: 21:25

Date: March 8, 2007 – Flights 8,9,10,11,12,13,14,15,16,17,18,19,20,21,22
Takeoff Time: 7:21
Landing Time: 12:00
Laser Time On: 7:29
Laser Time Off: 11:45

Date: March 8, 2007 – Flights 23,24,25,26,27,28,29,30,31,32,33,34
Takeoff Time: 14:09
Landing Time: 17:49
Laser Time On: 14:15
Laser Time Off: 17:38

Date: March 8, 2007 – Flights 35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54
Takeoff Time: 18:33
Landing Time: 23:19
Laser Time On: 18:42
Laser Time Off: 23:06

Date: March 9, 2007 – Re-Do Flights 1,2,3,4,5,6,7,8,9,10
Takeoff Time: 13:43
Landing Time: 14:56
Laser Time On: 13:47
Laser Time Off: 14:09