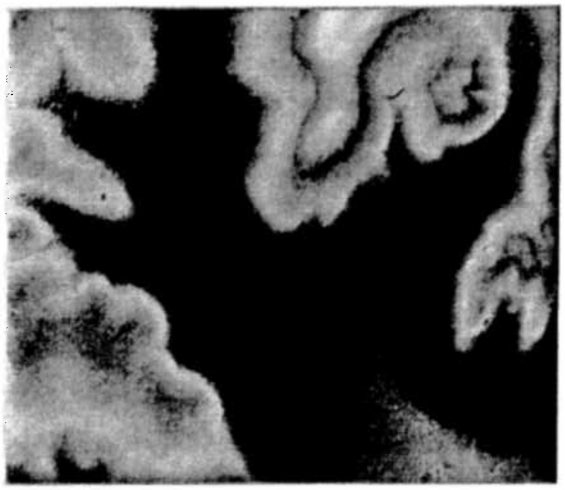
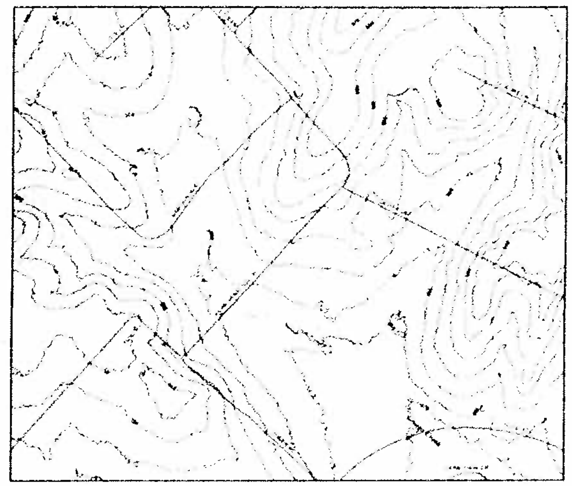
LIDAR Acquisition, QA/QC and Contour Mapping





Bastrop County, Texas

Prepared for

Bastrop County

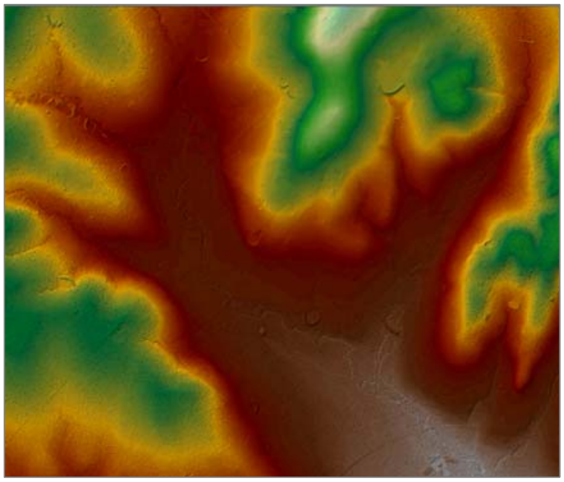
March 31, 2010

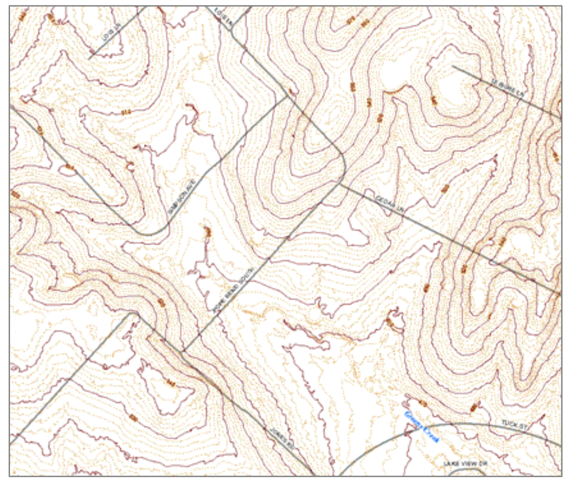
AVO 24646

HALFF

4030 West Braker Lane, Suite 450
Austin, TX 78759

LIDAR Acquisition, QA/QC and Contour Mapping





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Executive Summary

Bastrop County, in partnership with the Texas Water Development Board (TWDB) and the U.S. Army Corp of Engineers, is developing a Flood Protection Planning Study of Bastrop County, Texas. The first phase of the Flood Protection Planning Study includes the acquisition and quality control and assurance of Light Detection and Ranging (LiDAR) data for Bastrop County as well as developing a county wide 2 foot contour dataset.

In 2007, the Capital Area Council of Governments (CAPCOG) obtained detailed 1.4 meter LIDAR data for approximately 95 square miles of Bastrop County. The City of Austin participated in the cost sharing for this dataset. The coverage of these data was limited to the western portion of the county were it borders Travis County. In 2008, Bastrop County participated with CAPCOG in the cost sharing for the acquisition of high resolution 1.4 meter topographic data on the remaining 800 square miles. The airborne survey using LIDAR methods was performed, per the contract with CAPCOG, by the Sanborn Map Company, Inc. The LiDAR product, checked against GPS checkpoints, has a vertical root mean square error (RMSE) of 0.13 feet in bare areas and 0.31 feet in short grass areas and 0.23 feet in long grass areas. This is well within the CAPCOG specification of vertical accuracy for this project of 18.5 cm (0.6 feet) RMSE for bare earth and 37.0 cm (1.2 feet) RMSE for vegetated areas.

An independent review of the Sanborn LiDAR data to check and identify problems errors and issues with the delivered data was completed. Halff Associates subcontracted this work to 3cGeo (Third Coast Geospatial Technologies), an Austin firm that specializes quality control and validation of spatial information. 3cGeo performed a 100% comprehensive review of all 800 square miles of the LiDAR tiles. 3cGeo reports that the quality of the Sanborn Bastrop LiDAR project is exceptional. The review indicates a vertical RMSE of 0.467 feet when compared to the Level 1 National Geodetic Survey Control Points (NGS). 3cGeo verified the NGS points used by Sanborn as well as included an additional 60 points to validate the accuracy. The result shows that the data is within the CAPCOG standard of 18.5 cm (0.6 feet) RMSE for bare earth.

Halff Associates was contracted to develop a 2 foot contour dataset for Bastrop County using the 1.4 meter LiDAR data acquired from Sanborn. The contours provide a topographic data set that is much more manageable and useable for Bastrop County than the raw LiDAR data. The accuracy of the contour data was checked by comparing points along the contour lines to the LIDAR data. The results of this comparison indicate that the contouring method produced an additional vertical root mean square error of 0.41 feet. Smoothing was performed on the contour lines to remove the sharp angles inherent with contours produced from LIDAR data. These contours should be used for general visualization purposes only, actual elevations should be obtained from the LIDAR surface.

The 2 foot contour data set covers all of Bastrop County and is available in GIS shapefiles, PDF, and printed map books.

Introduction

Bastrop County, in partnership with the Texas Water Development Board (TWDB) and the U.S. Army Corp of Engineers, is developing a Flood Protection Planning Study of Bastrop County, Texas. The first phase of the Flood Protection Planning Study includes the acquisition and quality control and assurance of Light Detection and Ranging (LiDAR) data for Bastrop County as well as developing a county wide 2 foot contour dataset.

The scope of this project is divided into two tasks.

1) The first task is the acquisition and 100% quality control / quality assurance (QA/QC) review of Sanborn's 2008 LiDAR data for the Bastrop County area.

2) The second task is to generate 2 foot contour data from the FEMA grade LiDAR data. The generation of contours, would provide a topographic data set that would be much more manageable and useable for Bastrop County than the raw LiDAR data.

These two proposed tasks, to be paid entirely by Bastrop County, are intended to qualify as "in-kind" services for the "Comprehensive Flood Protection Planning Study of Selected Watersheds in Bastrop County". By authorizing these two tasks, as "in-kind" work the County will be receive a dollar per dollar match for the comprehensive flood study through the Texas Water Development Board Flood Protection Planning Grants (Phases 1 and 1B), already awarded to Bastrop County. Additionally, the U.S. Army Corp of Engineer's will also match this project's funding at two-to-one for the comprehensive flood study.

TASK 1: LiDAR ACQUISITION AND QAQC

LIDAR Acquisition:

In 2007, the Capital Area Council of Governments (CAPCOG) obtained detailed LiDAR data for approximately 95 square miles of Bastrop County. The City of Austin participated in the cost sharing for this dataset. The coverage of these data was limited to the western portion of the county were it borders Travis County. In 2008, Bastrop County participated with CAPCOG in the cost sharing for the acquisition of high resolution topographic data on the remaining 800 square miles. An airborne survey using LiDAR methods was performed, per the contract with CAPCOG, by the Sanborn Map Company, Inc. (Figure 1).

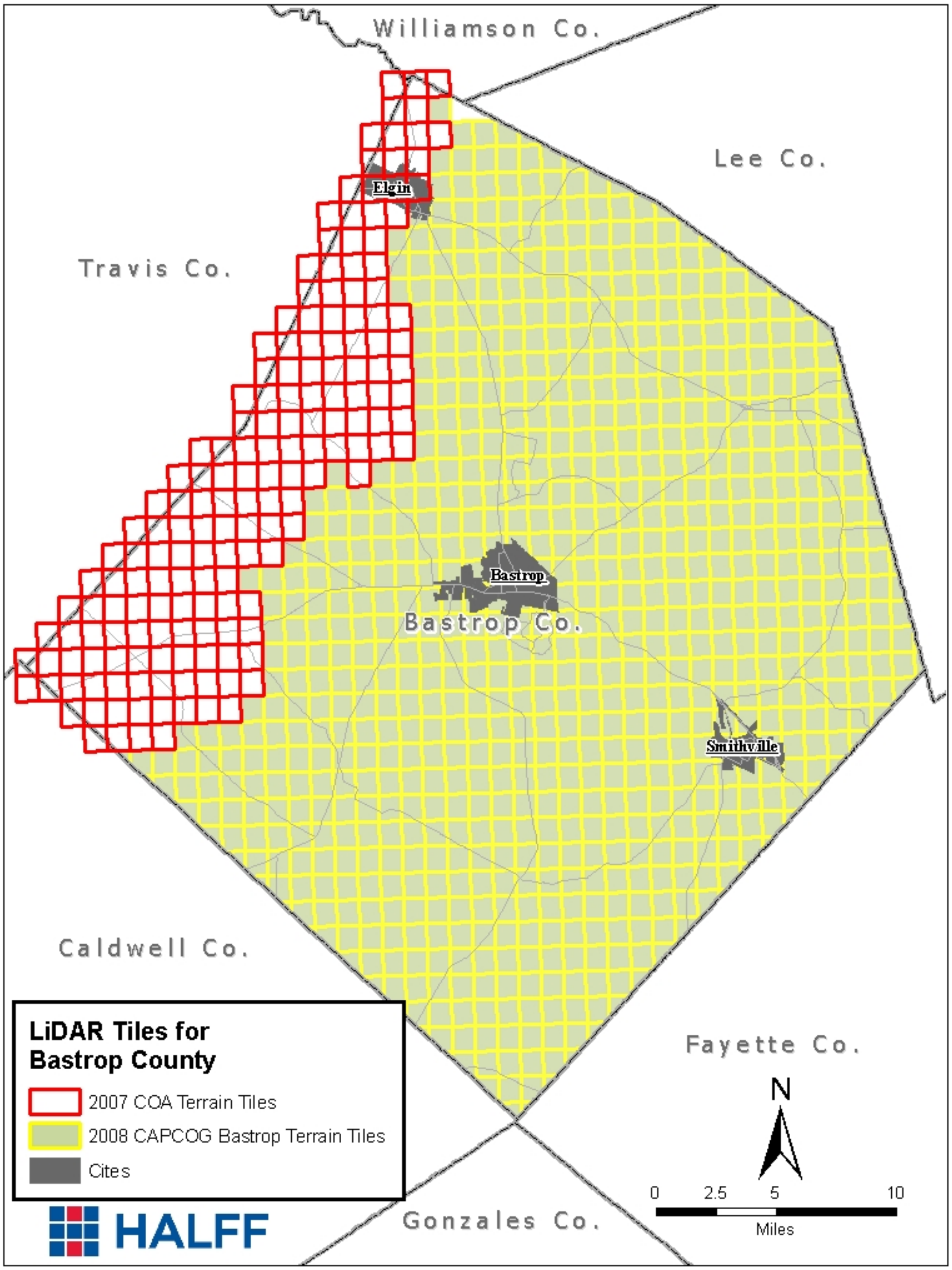

Figure 1. LiDAR Tile sources for Bastrop County

As delivered per the 2008 Sanborn contract, the LiDAR topographic data is a group of irregularly spaced points. The density of these points is primarily a function of flight path, elevation of the aircraft, air speed and scanning angle. The "first return" data generated by the LiDAR survey is also known as the reflective surface. These returns are the top of trees, building and grass fields. "Last return" data is representative of the lowest elevation that the airborne laser hit at each point.

To properly obtain a bare-earth surface model, as required for FEMA hydraulic models, LiDAR data must be processed by manual and/or automated post processing techniques to remove buildings, vegetation and any other area for which an inadequate last return was reported. The post-processing algorithms used to produce a bare-earth surface vary between different LiDAR vendors.

For the 800 square mile coverage area, Sanborn has provided the raw acquired terrain data, including the "first" and "last" return, in a Log ASCII Standard (LAS) format. Additionally, Sanborn has provided post-processed bare earth data in a comma delimited ASCII format. The LiDAR Final Report for CAPCOG 2008 prepared by Sanborn is shown in Appendix A, complete with a summary of Sanborn's methods, calibration and computed accuracy of their data.

The data accuracy is indicated in terms of root mean square error (RMSE) for this report. The RMSE, also known as the root mean square of the deviations (RMS or RMSD), is a measure of precision. It is a measure of the differences between known and estimated values. The reported standard deviation is also a measure of the variability of a dataset; however the standard deviation is an unbiased estimator while the RMSE includes biases. The National Standard for Spatial Data Accuracy (NSSDA) relates vertical accuracy at 95-percent confidence levels in terms of root mean square error such that

$$\text{Accuracy}_z = 1.96 \text{ X } \text{RMSE}_z$$

This Accuracy_z value is defined as "the linear uncertainty value, such that the true or theoretical location of the point falls within +/- of that linear uncertainty value 95-percent of the time" (NSSDA, 1998). FEMA specifies that LiDAR should have a vertical accuracy equal or smaller than 1.2 feet (37 centimeters) at the 95-percent confidence level which is equivalent to a maximum RMSE of 0.6 feet (18.5 centimeters) for flat terrain and a vertical accuracy equal or smaller than 2.4 feet (73 centimeters) at the 95-percent confidence level which is equivalent to a maximum RMSE of 1.2 feet (37 centimeters) for rolling to hilly terrain. The accuracy specifications in terms along with the corresponding RMSE values are shown in the following table.

Table 1. Vertical Accuracy Specifications

FEMA Specification	CAPCOG Specification	Accuracy_z at 95% confidence	RMSE_z
flat terrain	bare earth	1.2 feet (37 cm)	0.6 feet (18.5 cm)
Rolling to hilly terrain	vegetated	2.4 feet (73 cm)	1.2 feet (37 cm)

As reported in Appendix A, Sanborn's LiDAR product, checked against GPS checkpoints, has a vertical RMSE of 0.13 feet in bare areas and 0.31 feet in short grass areas and 0.23 feet in long grass areas. The CAPCOG specification of vertical accuracy for this project is 18.5 cm (0.6 feet) RMSE for bare earth and 37.0 cm (1.2 feet) RMSE for vegetated. The

CAPCOG specification is consistent with the Federal Emergency Management (FEMA) Guidelines and Specifications for Flood Hazard Mapping (FEMA 2003).

LIDAR QA/QC

This task includes the independent review of the Sanborn LiDAR data to check and identify problems errors and issues with the delivered data. Experience has shown that an independent review of the LiDAR data finds errors and issues that were missed in production and produces a better topographic product. Halff Associates subcontracted this work to 3cGeo (Third Coast Geospatial Technologies), an Austin firm that specializes in quality control and validation of spatial information. 3cGeo performed a 100% comprehensive review of all 800 square miles of the LiDAR tiles. 3cGeo reports that the quality of the Sanborn Bastrop LiDAR project is exceptional. The review by 3cGeo shown in Appendix B, indicates a vertical RMSE of 0.467 feet when compared to the Level 1 National Geodetic Survey Control Points. 3cGeo verified the NGS points used by Sanborn as well as included an additional 60 points to validate the accuracy. The result shows that the data is within the CAPCOG standard of 18 cm (0.61 feet) RMSE for bare earth.

TASK 2: CONTOUR GENERATION AND MAPPING

This task includes the generation of 2 foot interval contour data for the entire Bastrop County limits. Under Task 1, a digital FEMA compliant bare earth terrain model has been completed for the 800 square mile 2008 coverage area. These surface data combined with the bare earth data from the 95 square miles obtained in the CAPCOG 2007 survey provides complete coverage of Bastrop County.

Halff Associates Inc. created 2 foot interval contour data from the County wide bare-earth terrain. The contours produced did not include the addition of 3D breaklines. The contours reflect the contractually acceptable levels of outliers, vegetation, buildings and artifacts allowed in Sanborn's acquisition specifications.

The contours were created in ESRI GIS ArcInfo version 9.2 using the 3D Analyst and Spatial analyst extensions. A 5 foot digital elevation model (DEM) was created from the bare-earth LiDAR terrain data. Contours were smoothed using the following parameters:

- Resolution = 0 (All available terrain data was used)
- Cellsize = 5 feet (5 foot DEM)
- Contour Interval = 2 feet
- Smoothing Tolerance = 25 feet *
- Minimum Arc length = 500 feet (Contour lines were segmented at 500 feet or less)
- Maximum Arc length = 0 feet

* Smoothing is a type of generalization operation (ESRI, 1996) that smoothes a line to improve its aesthetic quality. A line is smoothed by utilizing an algorithm that calculates smoothed lines using a parametric continuous averaging technique. The smoothing tolerance specifies the length of a "moving" path along an input line used to calculate the

smoothed coordinates by the algorithm. Each new location is calculated using the information within the specified length of the path that is centered at the location.

Using Sanborn's data, Halff's method of contour generation will introduce vertical and horizontal error in relative to Sanborn's error. The contouring method may produce additional error that makes the contour data non-compliant with National Standard for Spatial Accuracy standards (NSSDA).

Specifications for the Contour Data:

Area	Bastrop County
Contour Mapping Area (sq. mi)	895
Projection	Texas State Plane
Zone	South Central (4203)
Horizontal Datum	NAD83
Vertical Datum	NAVD88
Units	US Foot
Contour Interval (ft)	2
Breakline Source	No breaklines will be provided
Tile Size	CAPCOG USGS Q4
Metadata	FGDC (xml)

Halff Associates Inc. performed a test on the Bastrop County contour data by comparing 100,000 taken along the contour lines in random locations within the county. The elevations of these points were compared to the elevation of a terrain dataset created from the LiDAR data. A Root Mean Square Error (RMSE) calculation of the new contours (relative to the unprocessed bare earth) was computed to quantify additional error that was introduced with the contour processing. This test showed that the contouring method produced a vertical root mean square error of 0.41 feet.

For the generated contours, Halff Associates Inc. ensured that (a) all contour features edge match adjacent tiles, (b) no contours shall cross or intersect and (c) all contours have appropriately assigned elevations.

All hard copy contour maps and metadata contain the following disclaimer:

"Contours were generated from LiDAR mass points having a vertical accuracy equivalent to NMAS 2 foot contour specification. Smoothing was performed on the contour lines to remove sharp angles inherent with contours produced from LiDAR data. These contours should be used for general visualization purposes only. Actual elevations should be obtained from the LiDAR surface."

Halff Associates produced a draft 24"X36" map book for Bastrop County at 1:12,000 scale A reduced scale version on 11"x17" was delivered to the TWDB. Also available are electronic versions of the map books as PDFs as well as Shapefiles of the contour datasets.

Appendix A:
CAPCOG 2008 Bastrop Final Report

LiDAR
Final Report
For
CAPCOG 2008
Bastrop County, Texas
July 2008

Prepared by:
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Colorado Springs, CO, 80920
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EXECUTIVE SUMMARY

In the spring of 2008, Sanborn was contracted by CAPCOG to execute a LiDAR (Light Detection and Ranging) survey campaign in the state of Texas. LiDAR data in the form of 3-dimensional positions of a dense set of mass points was collected for 800 square miles within Bastrop County. This data was used in the development of the bare-earth-classified elevation point data sets.

The Optech ALTM 2050 LiDAR system was used to collect the data for the Bastrop County survey campaign. The LiDAR system is calibrated by conducting flight passes over a known ground surface before and after each LiDAR mission. During final data processing, the calibration parameters are inserted into post-processing software.

Ten airborne GPS (Global Positioning System) base stations were used in this project. The base stations were set up at National Geodetic Survey (NGS) markers. NGS Monument PID: BM0920 located southwest of Austin, PID: BM0528 located west of Bastrop and PID: BM1077 located north of Winchester. The other existing NGS monuments used in the network are points PID: AX2420 located west of Fayetteville, PID: AX1088 located on the Schulenburg High School grounds and PID: AB3200 located at the Fayette Regional Air Center. Four new points were brought in numbered: 501, 502, 503 and 504 were tied to the other six NGS points to create a GPS survey network. The coordinates of these stations were checked against each other with the three dimensional GPS baseline created at the airborne support set up and determined to be within project specifications.

The acquired LiDAR data was processed to obtain first and last return point data. The last return data was further filtered to yield a LiDAR surface representing the bare earth.

The contents of this report summarize the methods used to establish the base station coordinate check, perform the LiDAR data collection and post-processing as well as the results of these methods.

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1 INTRODUCTION

This report contains the technical write-up of the CAPCOG LiDAR campaign, including system calibration techniques, the establishment of base stations by a differential GPS network survey, and the collection and post-processing of the LiDAR data.

1.1 Contact Information

Questions regarding the technical aspects of this report should be addressed to:

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Colorado Springs, CO 80920

Attention: --------- Andy Lucero (Project Manager)
------- James Young (LiDAR General Manager)
Telephone: ------ 1–719-264-5602
FAX: --------------- 1–719-264-5637
email: -------------- alucero@sanborn.com

1.2 Purpose of the LiDAR Acquisition

This LiDAR operation was designed to provide a highly detailed ground surface dataset to be used for the development of topographic, contour mapping and hydraulic modeling

1.3 Project Location

Bastrop County, Texas

1.4 Project Scope, Specifications and Time Line

The spring of 2007 LiDAR Flight Acquisition required the collection of 800 square miles of Bastrop County collected at a nominal point spacing of 1.4 meters and based on the Sanborn FEMA compliant LiDAR product specification.

Table 1: Project Specifications and Deliverable Coordinate and Datum Systems

Area (sq. mi)	800	**Product type**	1.4m avg posting Fema Compliant	**Projection**	Texas State Plane Central
Vertical RMSE (CM)	Bare Earth 18.5cm	**Check Points required**	Yes	**Horizontal Datum Vertical Datum**	NAD83/ NAVD88
Horizontal RMSE (CM)	100 cm	**Number Collected**	60	**Units**	US Survey Ft

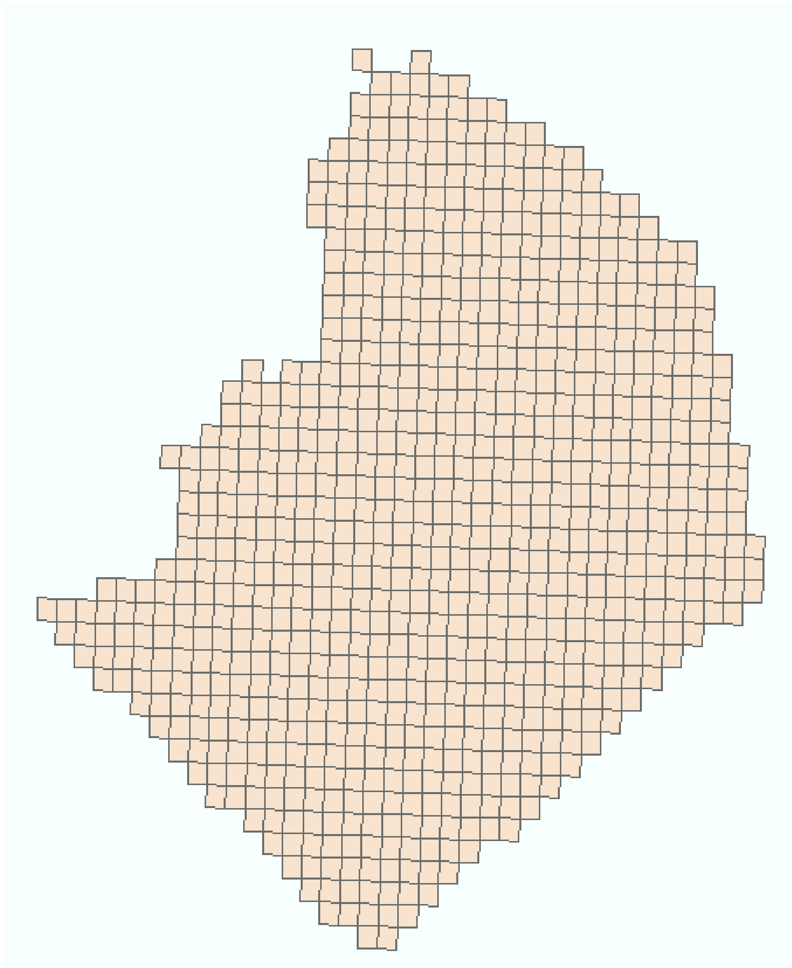

Figure 1: Area of Bastrop County LiDAR Collection

2 LiDAR CALIBRATION

2.1 Introduction

LiDAR calibrations are performed to determine and therefore eliminate systematic biases that occur within the hardware of the Optech ALTM 2050 system. Once the biases are determined they can be modeled out. The systematic biases are corrected for include scale, roll, and pitch.

The following procedures are intended to prevent operational errors in the field and office work, and are designed to detect inconsistencies. The emphasis is not only on the quality control (QC) aspects, but also on the documentation, i.e., on the quality assurance (QA).

2.2 Calibration Procedures

Sanborn performs two types of calibrations on its LiDAR system. The first is a building calibration, and it is done any time the LiDAR system has been moved from one plane to another. New calibration parameters are computed and compared with previous calibration runs. If there is any change, the new values are updated internally or during the LiDAR post-processing. These values are applied to all data collected with the plane/ALTM 2050 system configurations.

Once final processing calibration parameters are established from the building data, a precisely-surveyed surface is observed with the LiDAR system to check for stability in the system. This is done several times during each mission. An average of the systematic biases are applied on a per mission basis.

2.3 Building Calibration

Whenever the ALTM 2050 is moved to a new aircraft, a building calibration is performed. The rooftop of a large, flat, rectangular building is surveyed on the ground using conventional survey methods, and used as the LiDAR calibration target. The aircraft flies several specified passes over the building with the ALTM 2050 system set first in scan mode, then in profile mode, and finally in both scan and profile modes with the scan angle set to zero degrees.

Figure 2 shows a pass over the center of the building. The purpose of this pass is to identify a systematic bias in the scale of the system.

Figure 3 demonstrates a pass along a distinct edge of the building to verify the roll compensation performed by the Inertial Navigation System, INS.

Additionally, a pass is made in profile mode across the middle of the building to compensate for any bias in pitch.

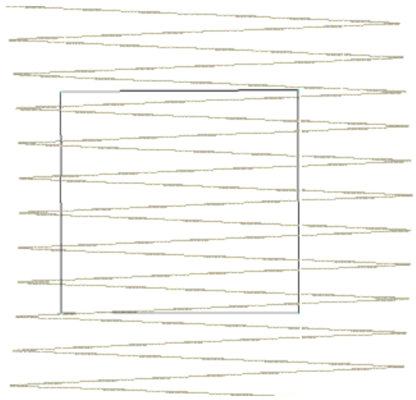

Figure 2: Calibration Pass 1

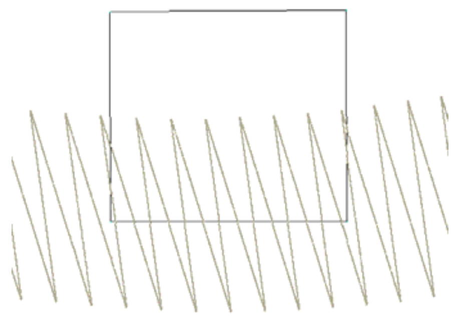

Figure 3: Calibration Pass 2

2.4 Runway Calibration, System Performance Validation

An active asphalt runway was precisely-surveyed at the Giddings-Lee County Airport for Bastrop County using kinematic GPS survey techniques (accuracy: $\pm$3cm at 1σ, along each coordinate axis) to establish an accurate digital terrain model of the runway surface. The LiDAR system is flown at right angles over the runway several times and residuals are generated from the processed data. Figure 4 shows a typical pass over the runway surface.

Approximately 25,000 LiDAR points are observed with each pass. A Triangulated Irregular Network (TIN) surface is created from these passes. The ground control x,y,z points are then compared with the z of the LiDAR surface to compute vertical residuals of the LiDAR data. After careful analysis of noise associated with non-runway returns, any system bias is documented and removed from the process.

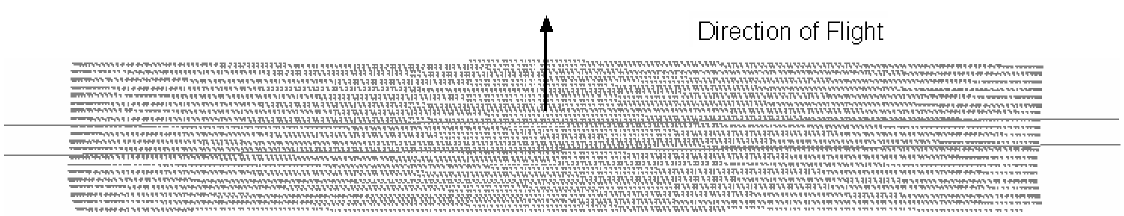

Figure 4: Runway Calibration

3 RUNWAY CALIBRATION, SYSTEM PERFORMANCE VALIDATION

3.1 Calibration Results

The LiDAR data captured over the building is used to determine whether there have been any changes to the alignment of the Inertial Measurement Unit, IMU, with respect to the laser system. The parameters are designed to eliminate systematic biases within certain system parameters.

The runway over-flights are intended to be a quality check on the calibration and to identify any system irregularities and the overall noise. IMU misalignments and internal system calibration parameters are verified by comparing the collected LiDAR points with the runway surface.

Figure 5 shows the typical results of a runway over-flight analysis. The X-axis represents the position along the runway. The overall statistics from this analysis provides evidence of the overall random noise in the data (typically, 7 cm standard deviation – an unbiased estimator, and 8 cm RMS which includes any biases) and indicates that the system is performing within specifications. As described in later sections of this report, this analysis will identify any peculiarities within the data along with mirror-angle scale errors (identified as a “smile” or “frown” in the data band) or roll biases.

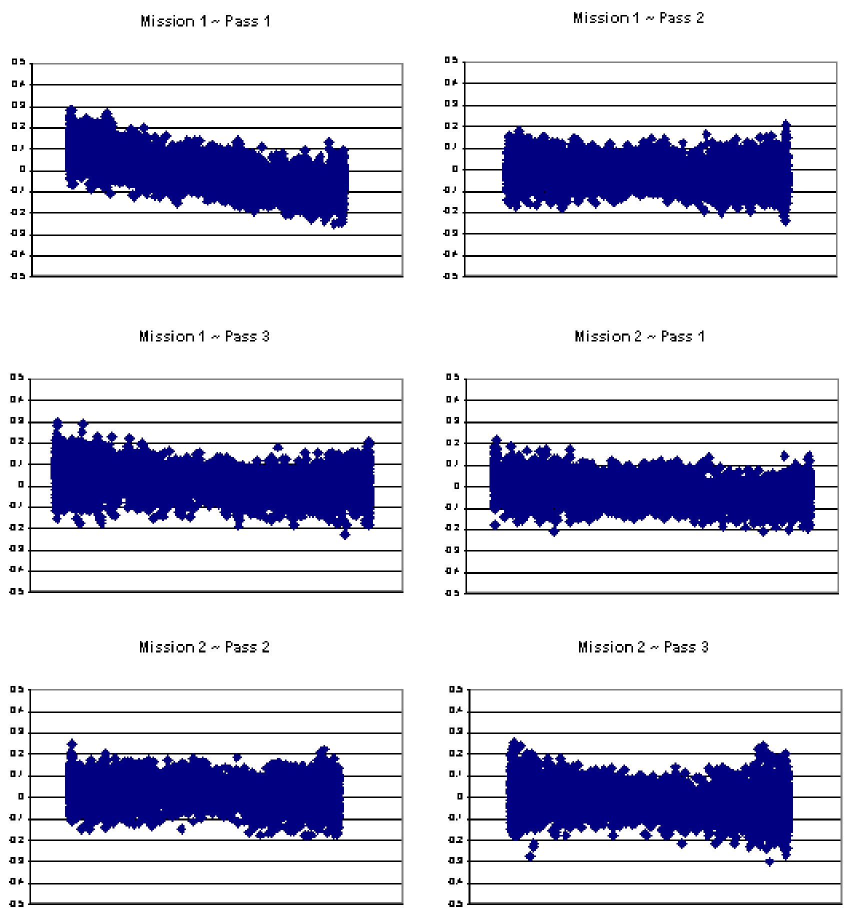

Figure 5: Runway Calibration Results

3.2 Daily Runway Performance/Data Validation Tests

Performance flights over the runway test field were performed before and after each mission. Table 2 shows the standard deviation and RMS values of the residuals between the test flights and the known surface of the test ranges for each pass. The maximum RMS value is 0.214 meters and the maximum standard deviation is 0.087 meters. The average RMS among all test flights is 0.0857 meters.

Table 2: Runway Validation Results for Bastrop County (Meters)

Mission	Passes	Standard Deviation	RMS
044a_Optech	4	0.034	0.035
044b_Optech	4	0.044	0.045
050a_Optech	4	0.052	0.052
050b_Optech	4	0.048	0.154
053a_Optech	4	0.047	0.047
054a_Optech	4	0.051	0.052
055a_Optech	4	0.077	0.084
056a_Optech	4	0.055	0.214
058a_Optech	4	0.087	0.087
058b_Optech	4	0.079	0.087

4 LiDAR FLIGHT AND SYSTEM REPORT

4.1 Introduction

This section addresses LiDAR system, flight reporting and data acquisition methodology used during the collection of Bastrop County for the CAPCOG campaign. Although Sanborn conducts all LiDAR with the same rigorous and strict procedures and processes, all LiDAR collections are unique.

4.2 Field Work Procedures

A minimum of two GPS base stations were set up, with one receiver located at the airport, and the secondary GPS receiver placed at a survey control point within the project area or within the required baseline specifications of the project.

Pre-flight checks such as cleaning the sensor head glass are performed. A four minute INS initialization is conducted on the ground, with the engines running, prior to flight, to establish fine-alignment of the INS. GPS ambiguities are resolved by flying within ten kilometers of the base stations.

The flight missions were typically four or five hours in duration including runway calibration flights flown at the beginning and the end of each mission. During the data collection, the operator recorded information on log sheets which includes weather conditions, LiDAR operation parameters, and flight line statistics. Near the end of the mission GPS ambiguities are again resolved by flying within ten kilometers of the base stations, to aid in post-processing.

Table 3 shows the planned LiDAR acquisition parameters with a flying height of 1400 meters above ground level (AGL) for the Optech system on a mission to mission basis.

Table 3: LiDAR Optech Acquisition Parameters

Average Altitude	1400 Meters AGL
Airspeed	120 Knots
Scan Frequency	40 Hertz
Scan Width Half Angle	16 Degrees
Pulse Rate	50,000 Hertz

Preliminary data processing was performed in the field immediately following the missions for quality control of GPS data and to ensure sufficient overlap between flight lines. Any problematic data could then be re-flown immediately as required. Final data processing was completed in the Colorado Springs office.

Table 4: Collection Dates, Times, Average Per Flight Collection Parameters and PDOP

Mission	Date	Sensor	Start Time	End Time	Altitude (m)	Airspeed (Knots)	Scan Angle	Scan Rate	Pulse Rate	PDOP
044a	Feb 13	Optech	15:05	18:08	1400	120	32°	40	50000	1.9
044b	Feb 13	Optech	20:22	23:17	1400	120	32°	40	50000	1.7
050a	Feb 19	Optech	16:44	20:19	1400	120	32°	40	50000	2.4
050b	Feb 19	Optech	21:35	23:11	1400	120	32°	40	50000	1.6
053a	Feb 22	Optech	18:36	21:32	1400	120	32°	40	50000	2.0
054a	Feb 23	Optech	19:11	22:53	1400	120	32°	40	50000	1.8
055a	Feb 24	Optech	18:58	23:51	1400	120	32°	40	50000	2.1
056a	Feb 25	Optech	19:09	21:25	1400	120	32°	40	50000	1.8
058a	Feb 27	Optech	16:32	19:49	1400	120	32°	40	50000	2.0
058b	Feb 27	Optech	22:04	23:24	1400	120	32°	40	50000	1.7

4.3 Final LiDAR Processing

Final post-processing of LiDAR data involves several steps. The airborne GPS data was post-processed using Waypoint's GravNAV™ software (version 7.5). A fixed-bias carrier phase solution was computed in both the forward and reverse chronological directions. The data was processed for both base stations and combined. In the event that the solution worsened as a result of the combination of both solutions the best of both solutions was used to yield more accurate data. LiDAR acquisition was limited to periods when the PDOP was less than 3.2.

The GPS trajectory was combined with the raw IMU data and post-processed using Applanix Inc.'s POSPROC (version 4.3) Kalman Filtering software. This results in a two-fold improvement in the attitude accuracies over the real-time INS data. The best estimated trajectory (BET) and refined attitude data are then re-introduced into the REALM Survey Suite OPTECH for the Optech system to compute the laser point-positions. The trajectory is then combined with the attitude data and laser range measurements to produce the 3-dimensional coordinates of the mass points.

All return values are produced within REALM Survey Suite OPTECH software for the Optech system. The multi-return information is processed to obtain the "Bare Earth Dataset" as a deliverable. All LiDAR data is processed using the binary LAS format 1.1 file format.

LiDAR filtering was accomplished using TerraSolid, TerraScan LiDAR processing and modeling software. The filtering process reclassifies all the data into classes with in the LAS formatted file based scheme set using the LAS format 1.1 specifications or by the client. Once the data is classified, the entire data set is reviewed and manually edited for anomalies that are outside the required guidelines of the product specification or contract guidelines, whichever apply. Table 5 indicates the required product specifications.

The coordinate and datum transformations are then applied to the data set to reflect the required deliverable projection, coordinate and datum systems as provided in the contract.

The client required deliverables are then generated. At this time, a final QC process is undertaken to validate all deliverables for the project. Prior to release of data for delivery, Sanborn's Quality control/ quality assurance department reviews the data and then releases it for delivery.

Table 5: Processing Accuracies and Requirements

Accuracy of LiDAR Data (Horizontal)	100 cm RMSE
Accuracy of LiDAR data in bare areas (vertical)	18.5 cm RMSE
Accuracy of LiDAR data in vegetated areas (vertical)	37.0 cm RMSE
Percent of artifacts removed (terrain and vegetation dependent)	90%
Percent of all outliers removed	95%
Percent of all vegetation removed	95%
Percent of all buildings removed	98%

5 GEODETIC BASE NETWORK

5.1 Network Scope

These four points were tied into the fully constrained network at was provided. During the LiDAR campaign, the Sanborn field crew conducted a GPS field survey to establish final coordinates of the ground base stations for final processing of the base-remote GPS solutions. NGS points BM0920, BM0528, BM1077, AX2420, AX1088, AB3200 and new points set on 501, 502, 503 and 504 were used for the LiDAR missions. See Table 6 for station names, orders and constraints.

5.2 Data Processing and Network Adjustment

The static baselines created between points BM0920, BM0528, BM1077, AX2420, AX1088, AB3200, 501, 502, 503, and 504 were processed using Trimble Geomatics Office™ (Ver. 1.62) software. Fixed bias solution was obtained for the baselines. The broadcast ephemeris was used, since the accuracy and extent of the network does not warrant the use of the precise ephemeris. The results were satisfactory; therefore, fulfilling project specifications for first order control network. See Table 7 for loop closure summary.

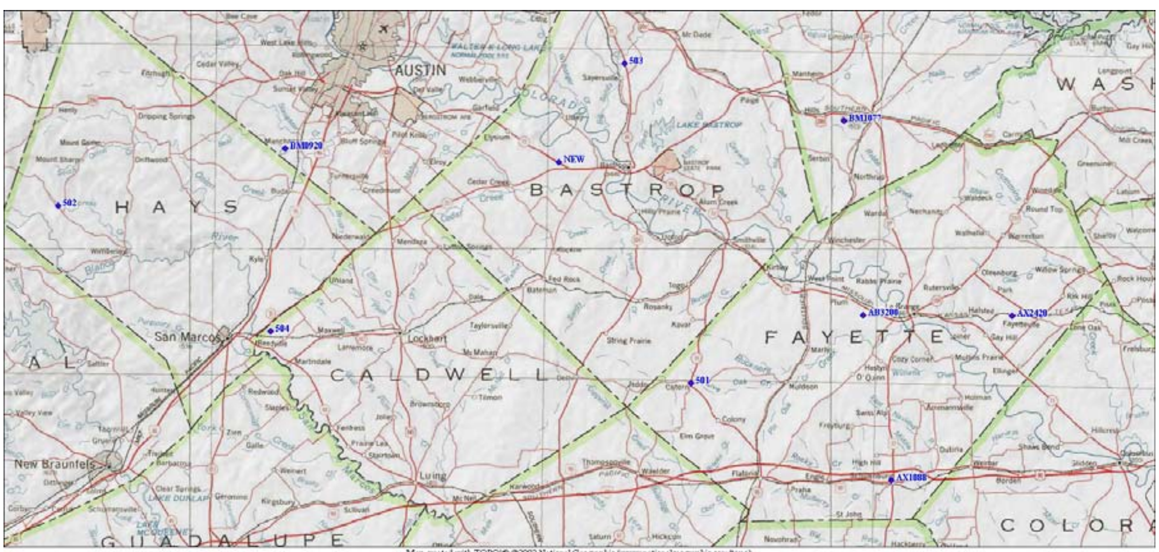

Figure 6: Survey Network Diagram

Table 6: NGS Control Constraints

Horizontal

Code	NGS Station Name	PID	Constrain
BM0920	MARBRIDGE	BM0920	Constrained
BM0528	M 1225	BM0528	Checkpoint
BM1077	GIDDPORT AZ MK	BM1077	Constrained
AX1088	SCHULENBURG	AX1088	Checkpoint
AX2420	B 1226	AX2420	Checkpoint
AB3200	3T5 A	AB3200	Constrained

Vertical

Code	NGS Station Name	PID	Constrain
BM0920	MARBRIDGE	BM0920	Constrained
BM0528	M 1225	BM0528	Checkpoint
BM1077	GIDDPORT AZ MK	BM1077	Checkpoint
AX1088	SCHULENBURG	AX1088	Checkpoint
AX2420	B 1226	AX2420	Checkpoint
AB3200	3T5 A	AB3200	Constrained

Table 7: Survey Loop Closure Summary

Loop	Δ Horiz (cm)	Δ Vert (cm)	Dist. (m)	ppm
AB3200: AX1088: AX2420: BM1077: 503: new: BM0920: 502: 504: 501: AB3200	1.8	4.4	352564	0.134

5.3 Final LiDAR Verification

The LiDAR data was evaluated using a collection of 60 GPS surveyed checkpoints. 20 points were collected in each bare earth, low grass, and urban vegetation classes. For CAPCOG the average standard deviation is 0.070 meters and the average root mean squared is 0.069 meters. The LiDAR data was compared to each of these classes yielding much better result than was required for the project. Tables 8, 9, and 10 indicate the results for the CAPCOG 2008 separated out by bare earth, short grass and tall grass.

Table 8: CAPCOG 2008 Bare Earth Checkpoint Results (Meters)

Number	Easting	Northing	Known Z	Laser Z	Dz
5	658827.498	3327228.037	100.520	100.560	+0.040
4	663205.872	3312483.409	116.423	116.460	+0.037
6	669078.625	3350984.347	131.097	131.130	+0.033
3	662358.911	3334218.387	98.551	98.540	-0.011
2	684848.515	3333028.222	108.931	108.880	-0.051
1	686143.425	3341938.477	135.413	135.360	-0.053

Average dz -0.001
Minimum dz -0.053
Maximum dz +0.040
Average magnitude 0.037
Root means square 0.040
Std deviation 0.044

Table 9: CAPCOG 2008 Short Grass Checkpoint Results (Meters)

Number	Easting	Northing	Known Z	Laser Z	Dz
4	671281.696	3314145.372	117.094	117.320	+0.226
7	657419.583	3356051.865	127.330	127.400	+0.070
8	654138.046	3338082.759	91.190	91.240	+0.050
3	676750.489	3319921.230	71.477	71.520	+0.043
6	666472.188	3360043.661	135.400	135.430	+0.030
1	683170.480	3340811.398	133.352	133.360	+0.008
5	660553.748	3331567.378	83.851	83.820	-0.031
2	666723.456	3330800.092	108.807	108.700	-0.107

Average dz +0.036
Minimum dz -0.107
Maximum dz +0.226
Average magnitude 0.071
Root means square 0.096
Std deviation 0.095

Table 10: CAPCOG 2008 Tall Grass Checkpoint Results (Meters)

Number	Easting	Northing	Known Z	Laser Z	Dz
1	684118.124	3329628.650	83.092	83.130	+0.038
2	678716.246	3324536.508	70.341	70.330	-0.011
3	673233.382	3326570.406	99.160	99.130	-0.030
4	663567.301	3323361.465	83.004	82.870	-0.134

Average dz	-0.034
Minimum dz	-0.134
Maximum dz	+0.038
Average magnitude	0.053
Root means square	0.071
Std deviation	0.072

6 GROUND CONTROL REPORT

6.1 Introduction

This section addresses Ground Control reporting in the Ellipsoid model used as part of the collection and the Geoid model used to compute orthometric heights.

6.2 Horizontal Datum

The horizontal datum associated with the LiDAR data is NAD83 (1993), as realized by the physical NGS control monuments used to constrain the survey control network.

6.3 Vertical Datum

The vertical datum associated with the LiDAR data is the NAVD88, as realized by the physical NGS benchmarks used to constrain the survey control network.

Appendix B:
3cGeo Bastrop LiDAR QA – Final Report

October 7th, 2008

Mr. Mike Moya, P.E., CFM
Halff Associates, Inc.
4030 West Braker Lane, Suite 450
Austin, TX 78759

Re: Quality Assurance Report of Bastrop LiDAR Data

Dear Mr. Moya:

3cGeo has provided a 100% quality control/assurance review of the Bastrop County 2007-2008 LiDAR. A separate invoice for 75% of the contract value will follow shortly. Sanborn has received a copy of the edit calls and numerous discussions have occurred to streamline the correction of all edit calls. Overall the quality of the data was exceptional and the small amount of edit calls and detailed analysis by 3cGeo will provide a corrected dataset for Halff and Associates and Bastrop Co. Following is our report.

LIDAR Independent QA/QC Processes

The following items were checked during the QA/QC procedures:

- **Data Organization:**
  - All tiles were delivered in a complete format with associated
    - metadata.,
    - flightlines
- **Data Format, Tiling Scheme:**
  - Tiling scheme of DOQQQ (1 CAPCOG 1-Square Mile) tile format was followed.
- **Point Spacing:**
  - Verified on every tile and meets or exceeds the contract specifications.
- **Datum, Projections, Coordinate System:**
  - State Plane Central NAD 83
- **Data Completeness (*Discontinuity, Artifacts, Visual Anomalies*)**
  - Data Coverage
  - Check remained artifacts,
  - Check data discontinuities,
  - Check data voids
  - Spot any visual anomaly
- **Horizontal Accuracy**
  - See Appendix A Vertical and Horizontal

- A check of the data under the SILC format where the RGB values of the CAPCOG 2006 orthophotos were used. These reflected that the LiDAR matched within contract specifications the horizontal accuracy.

- Also visually inspected the hill-shaded grid using the CAPCOG orthoimagery and vector highway data for errors and verify the contractor's horizontal RMSE

- **Vertical Accuracy**
  - Verify the area that constitutes the seam between the 2006 and 2008 collection for any vertical discrepancies.
  - Perform Accuracy Assessment with the following checkpoints:
    - Level 1 National Geodetic Survey (NGS) Control Points
    - TxDOT County Road Inventory GPS data (road intersections)
    - TxDOT Ground Control Points (for 1995-1996 DOQs)
    - Control Points from other available sources (LCRA, HALFF)
    - Most points are in open areas only
  - Verify contractor's vertical RMSE. The Accuracy assessment will result in a control report for the points classified as "ground" or "model keypoints" based on the following standards:
    1. National Standard for Spatial Data Accuracy (NSSDA)
    2. National Map Accuracy Standards (NMAS)
    3. American Society of Photogrammetry and Remote Sensing (ASPRS) Class I, II, III

2. Verify flight overlap areas – based on structures that are covered by at least two flight lines, create profiles and contours in buffer zones around the flight lines to determine the accuracy of flight lines in relation to each other (ie if the contours from different flight lines are in close proximity with each other, the data accuracy is consistent and the sensor calibration appropriate)

   An attempt will be made to provide at least one control point analysis (for both vertical and horizontal accuracy) for each of these land use classes: developed, open Space/Bare/Grasslands, Agriculture, Forest, Forest/Wetland, Scrub/Shrub and Water/Shore.

- Control Points in Report: The total number of control points in the project.

Acceptance Criteria

Sanborn Product: LiDAR Data

The statistics below reflect the acceptable percentages of above ground feature removal and outlier points within the entire dataset delivered. The remaining balance is within product acceptance tolerances and meet the requirements of this Work Order. There will be no (invalid) data voids due to system or lack of overlap. Dense vegetation valid data voids will be minimized by automatic removal process.

Outliers..95%

Artifacts 90%

Vegetation...95%

Buildings...98%

3cGeo also uses FEMA guidelines for additional criteria were appropriate such as removal of bridges.

TERMS and DELIVERABLES

1) The Bastrop QA will be a 100% comprehensive review of all tiles. The tiles are based on CAPCOG's USGS quarter-quarter-quarter quad map series of approximately 1 square mile per tile. **(Complete – Appendix C)**

2) 3cGeo will provide the following deliverables to Halff and these may be shared with Bastrop County, USACE, TWDB and Sanborn:
   a. Shapefile detailing the location and type of error found in the reviewed data and recommended methods of revision. **(Complete - Appendix B)**
   b. Written report detailing the results of the QA/QC process upon completion of review including:
      i. methods employed in the QC process **(Complete - below)**
      ii. results of horizontal and vertical RMSE checks
      iii. Calculations showing the percent of ground feature removal of outliers, artifacts, vegetation and buildings **(Complete -- This document)**
   c. Once the requested revisions have been completed by Sanborn, a report confirming that the requested revisions were made to 3cGeo's satisfaction and within the project specifications will be provided. **(The amounts of actual edit calls for a project this size were minor and forwarded to Sanborn. We have kept in constant contact with Sanborn and they have the staff ready to make these changes so that Halff and Associates may have the data within a short timeframe.)**

3) 3cGeo will coordinate directly with Sanborn to identify issues and provide verification of corrected data. All associated documents will be made available to 3cGeo prior to completion of the 30 day review window including:
   a. LiDAR final report which will include a vertical accuracy assessment
   b. Shapefile of the flight line for the entire county **(See Sanborn Correspondences)**

4) Client will not be providing any horizontal or vertical control points, so it is understood that 3cGeo survey control will be limited to the best publicly available NGS vertical control in Bastrop County with a vertical order of “2 or better” and a stability of “C or Better. **(Complete - Appendix A)**

Payment: 75% upon submission of 1st 100% review and remainder upon the final acceptance of the completed QA/QC project.

3cGeo
QA-QC Report

METHODOLGY

Checks involve a look at multiple tiles together, a check of the point's contours, and TIN Files

Tins: are used extensively for any spikes, or irregularities. The key to review of the tins's is to cover enough of an area so that the TIN is not overly exaggerated. There are areas where the TIN's seem to be "a bit spikey". It is almost universally due to the fact that the LAS points are in a forested area and thus the small changes in elevation combined with a lower (but within spec point density – creates the TIN – Spike effect). When large TIN spikes are encountered they are flagged unless they can be verified.

Orthophotos: 3cGeo utilized the CAPCOG 2006 orthophotos as a horizontal (through a SILC process where ortho values are burned onto an LAS file) and separately for validation of on the ground items. The orthos assisted in determining if any "data spikes" had a valid on the ground cause. In many cases the orthophotos confirmed the data seen on the LAS image.

Contours – Another Check that is utilized extensively is to invoke the contour function of the software in order to spot overall trends.

This is a report of QA-QC methodology, checks of ground feature removal of outliers, artifacts, vegetation and buildings, flightlines and tile consistency,

Items to note:

One of the best methods for verifying any possible irregularities within the Bastrop LAS files is found through a comparison with the 2006 CAPCOG-Bastrop Orthophotos. While this is an excellent method of checking the LiDAR data, and you will note many QC calls were actually verified by cross- checking to the orthophotos. These are good references for various types of irregularities that actually exist on the ground. There are two areas where the orthos must be related to the current environment.

Item 1: Bastrop has large areas of trees and this is obvious throughout the project. There are areas of dense trees where the point density averages approximately a number of meters between points, but these are rare and within specifications of LiDAR contract. In fact the ground penetration in some of Bastrop's forested areas is quite good.

Item 2: The 2006 orthophotos were completed in one of the wettest years of record. The LiDAR was flown a year later well into one of the worst droughts in history. This has created a wide difference in water bodies for the QA-QC process. Where the orthos show full ponds, lakes and streams, the LiDAR reflect lower, even dry ponds and rarely water in the streams. (See Water Bodies – in the text below)

Tile Boundary Check: Staff examined the LAS files for tile lines and rarely could identify any tile boundary lines or apparent splits. Each and every tile was examined with at least 2 other tiles for such lines.

Flight Lines Check: Flight lines are much more obvious and the flight line shape file inserted into the review to insure that flight lines are reviewed. With that said, there are three primary issues associated with flight lines:

1: Elevation Changes: These elevation mismatches may occur right at the seam of flight lines. When zoomed in close enough the raw bare-earth point file illustrates the seam of the flight line. These were randomly checked throughout – mostly through the use of TIN to illustrate a line similar to a fence line. These are a primary review criteria and when they are identified the flight line is checked. All checks of possible mismatched flightlines were checked. When spotted these were measured through a profile of the points on both sides to see if any elevation variation was found between flight lines. All variances that were checked were within the stated tolerances of the contract usually 0.2 of a foot, some specific areas up to 0.7 but no area was identified that exceeded these standards.

2: Corn rowing, which are minor "corn rows" created by the areas of overlap where two separate flightlines worth of data are in the same bare – earth file. This had been a problem in previous LiDAR deliveries throughout the industry, but appears to have been rectified in more recent LiDAR programs.

3: Lack of data points. These proved not to be an issue, although numerous areas were tagged on the first QC pass of multiple tiles. The point density far exceeded the contract parameters.

4: 3cGeo has found no tile gaps along a tile boundary that caused edit calls, although these are few and far between and mostly located in the Bastrop area.

Sanborn Coordination: As required under the terms of the contract, 3cGeo staff contacted Sanborn to identify errors, clarify processes and results and to discuss issues with any items identified. There were only three major issues that involved Sanborn on the QC for Bastrop County. They are as follows:

Control Points: Sanborn provided a quality control network of points. These were tied into certain NGS points and also from their on the ground survey's taken during the actual flight. 3cGeo verified these points and provided an additional 60 points to validate the accuracy of the points. Not all points were used as some had values significantly off of known elevations in the area. 3cGeo then finally identified control points that had a high level of confidence and confirmed the accuracy of the LiDAR data. See Appendix A – below.

Water Bodies: The issues of water bodies were one of extensive research and discussions as the LAS files did not reflect the orthophotos. 3cGeo was inspecting water bodies to insure that all points were removed. The issue throughout is that there were returns in certain bodies of water. Meaning that returns were indicated where the orthos showed water. After additional analysis it was determined that the "z" values were lower than the surrounding land returns. What was confusing is that the LiDAR returns mostly seem to reflect actual exposed land within certain ponds. There are many "stock ponds" that are in fact 100% dry or partially dry and these will have to be dealt with on a case by case basis. These can be removed manually to create a standard water layer or elevation but, with the exception of a few edit calls the data is within the scope of work.

Culverts: The issues of culverts were also a time consuming discussion as the contract and FEMA guidelines are less than specific. Basically, in discussions with Halff and Associates and Sanborn, it was decided to not to remove the roads from above culverts as was accomplished throughout most of the LAS files. In certain instances, there were culverts exposed and these edit calls were made.

ACCURACY STATEMENT

Point Density: This was also verified on each tile and overall.

One of the methods for rapid and comprehensive look at each tile was to look at 4 tiles at a time under a process where the tiles were merged and then thinned. These rapid reviews created areas where a note was made to verify the point density to insure there are no large data voids as edit calls. Often data voids were found in areas of trees or water areas and buildings. These areas were rechecked on the original files and the orthophotos to insure the appropriate density.

When each tile was called up a visual recordation of the number of points per tile was inspected. The calculation that follows is a conservative average across all tiles. Each 1 square mile tile was found to have approximately 5,000,000 LAS points resulting in an overall total in excess of 5,000,000,000 points. The point density was found to be well within the contract point specifications. Overall, the project has an average of 1.93 points per square meter.

Vegetation: 95% removed

Vegetation is handled through the overall review of the data by the TIN process and corresponding orthophotos. Bastrop is an area with significant vegetation and the removal of vegetation is well above the contract specifications. This is determined solely through the tile by tile review of the bare-earth data and lack of edit calls for vegetation.

Buildings:

<u>Buildings</u>: A detailed and comprehensive check of the tiles has revealed that the buildings and bridges are removed at the 99% or above level. No edit calls for bridges that remained in the bare-earth layer.

Outliers (90%) and Artifacts (95%):

Both of these contract specifications have been met. There were very few instances of either throughout the bare-earth dataset.

<u>Bridges and Culverts</u>: A few anomalies were detected where partial bridges were identified, but these were identified as railroad crossings. While not totally removed, these had bare earth below. The reason is found when it is realized that some railroad bridges are "open" in that they have railroad ties for the crossing

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and not a solid base. Thus the LiDAR return was accurate in reflecting the bridge and the ground.

Some bridges have been identified on edit calls where they were not totally removed. The bridges should be cut back to the embankment but sometimes were not cut back far enough. On a few other locations – specifically in downtown Bastrop area along Highway 71, raised embankments were eliminated when they should not have been. These have been identified through edit calls.

Culverts: This proved to be a major rework and analysis by 3cGeo. Throughout the dataset there are road culverts that have:

a) not been removed;
b) culverts where the road has been minimally cut out similar to a box culvert (small rectangle) allowing for hydro enforcement;
c) culverts where the road has been removed the length of the stream bottom.

The appropriate edit call is somewhat undefined by FEMA. 3cGeo, after discussions with Halff and Associates has determined that the road should not be removed above culverts. These have been identified in edit calls and will be corrected.

There are some edit calls, where it was the operator's decision, whether a road – stream crossing was a culvert or a small bridge crossing. These are judgment calls based on observations from the 2006 orthophotos.

Horizontal Check:

The main verification on horizontal accuracy follows in Appendix A. This statistical sampling was done for a sampling of tiles as available. 3cGeo utilized the CAPCOG 2006 orthophotos as a horizontal (through a SILC process where ortho values are burned onto an LAS file). The process of SILC'ing the orthophotos on a random basis provided further visual clues.

Vertical Check:

The main verification on vertical accuracy follows in Appendix A. This statistical sampling was done for a sampling of tiles as available.

Datum, Projections, Coordinate System:

- Complete - See Appendix C

2006 vs 2008

A random sampling of the 2006 LiDAR data acquired by the City of Austin and Lower Colorado River Authority was done along the western edge of Bastrop Co. This inspection found that both projects were within contract specifications and may need area by area modifications based on very detailed projects. For detailed analysis within a small area modifications may need to be done on a case by case basis to allow for the detailed anlaysis. Overall the two LiDAR datasets should prove accurate for basin digital elevation modeling and larger scale project.

SUMMARY – The quality of the Sanborn Bastrop LiDAR project is exceptional. It meets the following specs throughout the entire project and overall within each of the tiles, with the noted edit calls that have been forwarded to Sanborn Map Co. In discussions with Sanborn the edit calls were forwarded to Sanborn and a verbal commitment to complete the corrections in an immediate fashion was agreed upon.

Appendix A: Survey Check and Verification Report

--------- Report Disclaimer ---------

The report only reflects one statistical representation of the control points, LIDAR data and surface used.

--------- Report Summary ---------

Error Mean:	0.066	
Error Range:	[-0.811,1.913]	
Skew*:	0.856	
RMSE(z):	0.467	
NMAS/VMAS Accuracy(z)	(90% CI):	±0.768
ASPRS/NSSDA Accuracy(z)	(95% CI):	±0.915

* The skew exceeds ±0.5. Further investigation of the error values are recommended to determine if vertical errors follow a normal error distribution.

* 74 control points included in summary out of 1017
  - 9 control points turned off
  - 934 control points returned no-data

--------- End Report Summary ---------

--------- Surface Definition ---------

Surface Method: Triangulation (TIN)

Classification Filter Used:
- 0-Created, never classified (Turned Off)
- 1-Unclassified (Turned Off)
- 2-Ground
- 3-Low Vegetation (Turned Off)
- 4-Medium Vegetation (Turned Off)
- 5-High Vegetation (Turned Off)
- 6-Building (Turned Off)
- 7-Low Point (noise) (Turned Off)
- 8-Model Keypoint (mass point) (Turned Off)
- 9-Water (Turned Off)
- 10-Reserved (Turned Off)
- 11-Reserved (Turned Off)
- 12-Overlap Points (Turned Off)
- 13-Reserved (Turned Off)
- 14-Reserved (Turned Off)

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15-Reserved (Turned Off)
16-Reserved (Turned Off)
17-Reserved (Turned Off)
18-Reserved (Turned Off)
19-Reserved (Turned Off)
20-Reserved (Turned Off)
21-Reserved (Turned Off)
22-Reserved (Turned Off)
23-Reserved (Turned Off)
24-Reserved (Turned Off)
25-Reserved (Turned Off)
26-Reserved (Turned Off)
27-Reserved (Turned Off)
28-Reserved (Turned Off)
29-Reserved (Turned Off)
30-Reserved (Turned Off)
31-Reserved (Turned Off)

Return Combination Filter Used: -ALL return combinations used in filter

--------- End Surface Definition ---------

--------- Control Points ---------

	Name	Control X	Control Y	Control Z	Surface	Z Error
Turned Off	LAKE BASTROP	3264408.583	10032123.780	501.874	508.997	-7.123
Turned Off	BASTROP SW	3227162.756	10005960.590	363.665	368.634	-4.969
Turned Off	ELGIN EAST	3245221.950	10073201.590	410.645	413.915	-3.270
Turned Off	SMITHVILLE	3300079.423	9982370.029	322.002	323.680	-1.678
	MCDADE	3275732.497	10075676.580	559.521	560.332	-0.811
	LAKE BASTROP	3249813.146	10034239.980	483.688	484.439	-0.751
	SMITHVILLE	3301483.985	9979453.830	324.050	324.745	-0.695
	SMITHVILLE	3305502.573	9983550.278	320.324	321.012	-0.688
	WINCHESTER	3321435.105	10003874.010	376.764	377.389	-0.625
	ROSANKY	3257800.841	9961089.045	457.447	458.068	-0.621
	ELGIN EAST	3238125.722	10082976.780	554.283	554.859	-0.576
	ELGIN EAST	3245222.938	10073376.880	413.381	413.865	-0.484
	ELGIN EAST	3242437.836	10087947.590	572.966	573.426	-0.460
	WINCHESTER	3339714.146	10014794.640	462.377	462.819	-0.442
	JEDDO	3267523.624	9926848.796	436.128	436.542	-0.414
	SMITHVILLE	3301424.875	9985396.179	317.525	317.934	-0.409
	SMITHVILLE NW	3290755.629	10048254.350	490.662	491.059	-0.397
	SMITHVILLE	3293807.459	10019539.480	534.970	535.366	-0.396
	LAKE BASTROP	3264451.043	10031256.550	499.667	500.051	-0.384
	ELGIN WEST	3228240.999	10090125.340	509.156	509.460	-0.304
	ELGIN EAST	3237718.792	10088276.040	611.024	611.319	-0.295
	ELGIN EAST	3240525.815	10098142.430	535.427	535.708	-0.281
	BASTROP SW	3222779.229	9978663.687	477.427	477.703	-0.276
	BASTROP	3256916.768	10014979.300	511.027	511.281	-0.254

WINCHESTER	3318763.969	9984554.240	312.735	312.975	-0.240
UTLEY	3204619.238	10025833.540	576.847	577.074	-0.227
SMITHVILLE	3300701.176	9979876.891	325.758	325.860	-0.102
UTLEY	3207702.833	10023750.510	538.573	538.658	-0.085
LAKE BASTROP	3241280.950	10031760.130	403.664	403.743	-0.079
BASTROP SW	3223633.059	9978234.177	477.015	477.065	-0.050
LAKE BASTROP	3248059.366	10048599.140	471.463	471.494	-0.031
UTLEY	3211742.268	10021166.080	505.354	505.377	-0.023
UTLEY	3223735.202	10035746.610	385.508	385.529	-0.021
SMITHVILLE	3288183.096	9991882.951	328.303	328.324	-0.021
BASTROP	3253412.121	10013561.640	430.626	430.632	-0.006
LAKE BASTROP	3234447.571	10047071.490	451.313	451.311	0.002
SMITHVILLE	3274078.102	9980734.751	378.744	378.740	0.004
BASTROP	3239234.942	10013453.770	364.423	364.407	0.016
SMITHVILLE	3293008.743	10005704.420	454.398	454.346	0.052
UTLEY	3210838.753	10021974.960	509.563	509.498	0.065
LAKE BASTROP	3257450.165	10032887.340	391.705	391.631	0.074
BASTROP	3232013.803	10016416.100	456.719	456.642	0.077
UTLEY	3205073.389	10026255.660	554.362	554.284	0.078
LAKE BASTROP	3264215.759	10031080.290	492.640	492.546	0.094
LAKE BASTROP	3248883.972	10024191.720	359.768	359.664	0.104
BASTROP	3251559.070	10017696.270	368.450	368.342	0.108
PAIGE	3325013.375	10028934.420	434.974	434.834	0.140
BASTROP	3247757.432	10017895.530	337.170	337.003	0.167
LAKE BASTROP	3251049.533	10023706.790	423.027	422.810	0.217
SMITHVILLE NW	3306909.154	10025263.060	506.699	506.463	0.236
LAKE BASTROP	3257554.086	10034907.830	457.885	457.645	0.240
ROSANKY	3255997.194	9971689.480	450.360	450.116	0.244
LAKE BASTROP	3264529.613	10029296.610	476.738	476.490	0.248
SMITHVILLE	3278260.708	10006628.440	412.275	412.016	0.259
TOGO	3291276.397	9938634.107	404.474	404.215	0.259
RED ROCK	3208999.590	9961483.227	504.106	503.831	0.275
SMITHVILLE	3285924.417	10015764.490	392.735	392.448	0.287
LAKE BASTROP	3242989.009	10023458.100	392.157	391.861	0.296
ROSANKY	3256908.358	9966355.081	496.477	496.180	0.297
BASTROP	3247501.471	10020512.220	374.177	373.872	0.305
BASTROP	3246626.041	10015460.510	362.445	362.138	0.307
BASTROP	3252162.924	10020749.940	386.474	386.133	0.341
BASTROP SW	3213521.909	10020039.830	477.896	477.537	0.359
BASTROP	3254479.112	9996772.840	362.273	361.909	0.364
UTLEY	3212866.051	10025228.270	474.656	474.281	0.375
BASTROP	3239449.576	10014712.660	365.399	364.995	0.404
SMITHVILLE	3277414.772	10001232.280	397.837	397.394	0.443
PAIGE	3328834.066	10053901.050	520.250	519.794	0.456
MCDADE	3272114.955	10079099.540	520.489	520.014	0.475
BASTROP	3259837.935	10001500.570	332.661	332.181	0.480

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	LAKE BASTROP	3257961.132	10032148.980	458.905	458.417	0.488
	LAKE BASTROP	3251161.970	10023150.900	414.520	414.028	0.492
	PAIGE	3310086.179	10065768.960	586.401	585.809	0.592
	BASTROP	3267664.253	10009683.790	500.574	499.863	0.711
	BASTROP	3260490.303	10002199.690	329.639	328.870	0.769
	BASTROP	3252029.200	9989896.547	339.713	338.850	0.863
	BASTROP	3251093.989	10001150.050	353.037	351.646	1.391
	ELGIN EAST	3246389.062	10070872.970	449.230	447.317	1.913
Turned Off	SMITHVILLE	3311848.234	9981451.142	329.459	311.460	17.999
Turned Off	LAKE BASTROP	3264411.304	10031023.090	495.235	474.560	20.675
Turned Off	BASTROP	3258565.353	10017936.010	549.659	526.365	23.294
Turned Off	ELGIN EAST	3262962.356	10103123.650	566.055	489.506	76.549
Turned Off	ELGIN EAST	3262362.077	10102095.310	560.851	424.744	136.107

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Appendix B: Shapefile Edit Calls of QA-QC

Attached Shapefile

- Includes edit calls
- Includes notes for specific follow up checks. This sometimes is meant to identify and bring to the attention of a more experienced LiDAR expert.
- Includes unique features identified in the bare-earth LAS files.

Appendix C: Tile Report of QA-QC

Attached.

Appendix C:
Digital Data CD

- Contour Map PDF files
  - BASTROP_Contour_Mapbook.zip
- Contour Map Tile Metadata
  - BASTROP_Metadata_Contours/
- Contour Map - Data Dictionary Metadata
  - BASTROP_Metadata_DataDictionary/
- LIDAR Tile Index for Bastrop County
  - LiDAR Tiles for Bastrop County.xls
- Contour Shapefiles
  - CONTOUR_SHAPEFILES.zip
- Report PDF
  - LIDAR QAQC and Contour Mapping Report.pdf