Processing Report *Final*

Santa Fe County 2014 Regional LiDAR Project

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G14AC00125

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PO 145402, CO #1, PO 152019, CO #1

Contents

List of Figures

List of Tables

1. Project Overview

Santa Fe County (County) and Bohannan Huston, Inc. (BHI) (Contractor) are pleased to submit this technical report to accompany project LiDAR deliverable data. The report is produced under USGS Base LiDAR specification version 1.2 (November 2014).[1] The defined project area (DPA)[2] covers more than 3,000 square miles of north central New Mexico with light detection and ranging (LiDAR) data and derivative products. Centered on the City of Santa Fe, this area is focused on the greater Santa Fe County region and portions of key contributing watershed areas. From east to west, the project provides geographic data coverage between the Sangre de Cristo Mountain range and Rio Grande River. From north to south, the project covers areas starting to the north of the confluence of the Rio Grande and Chama Rivers around the Black Mesa plateau near Dixon, NM and NM Highway 68 and it extends southward for approximately 85 miles into the Estancia basin near Interstate 40 and Clines Corners, NM. The area is characterized by diverse geography incorporating urbanized areas, surface irrigated riparian areas, badlands, high desert plains and mountainous landscapes.

The data collection and developed products have been designed to support United States Geological Survey (USGS) Quality Level (QL) 2 LiDAR elevation data products. Quality Level 2 elevation data is the minimum standard for the USGS 3D Elevation Program (3DEP).[3] Data meeting the QL2 standard can be used to support numerous purposes including urban, community and regional planning, project infrastructure planning and reporting, floodplain mapping, storm water management, vegetation analysis, change detection and many others.[4]

A. Summary and Background Information

This technical processing report is developed in response to production requirements outlined in the project specifications as well as elements contained in the project Scope of Work (SOW) and subsequent project development activities implemented in close coordination with the County. The focus of this report is squarely on aspects of the LiDAR tasks including calibration, classification, and product generation procedures including hydro-flattening methodolgy. In addition to the LiDAR collection and processing tasks, however, the project also included a number of additional data collection and processing components, some of which are unique to County-specific deliverables. Principal among these additional project tasks were items such as orthophotography and hydrographic flow line data production services. Additional project tasks may be referenced and highlighted in the report especially in regard to their relationship to the LiDAR data.

The project was executed under a regime of weekly progress reporting. Continuous weekly progress reporting was one of the project's significant achievements. It not only contributed to informed decision making and control throughout the life of the multi-phased project. It also provided for detailed documentation of project activities over a long-term multi-year time frame with comprehensive issue resolution

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[1] http://pubs.usgs.gov/tm/11b4/pdf/tm11-B4.pdf USGS Base LiDAR specification version 1.2 (November 2014)

[2] http://bl.ocks.org/anonymous/raw/e462defe36be1ee4049d/ Santa Fe County Defined Project Area (DPA)

[3] http://nationalmap.gov/3DEP/ USGS 3D Elevation Program

[4] Project Scope of Work (SOW) Purpose Section

documentation. Details contained in those series of reports have been selected in summary form for inclusion into this processing report.

1. Startup – USGS Cooperative Agreement

The project commenced in February 2014 as a multi phased mapping initiative of Santa Fe County. Project schedule, boundary and task execution elements were defined according to a staged funding protocol which divided the project into two primary phases. Phase one (I) of the project included data acquisition and phase two (II) provided for data processing. Initial funding was focused on key aspects of data acquisition including LiDAR, aerial photography and ground control surveying for both of these data collection activities. Paneling of existing Santa Fe County photo control monumentation started in earnest upon release of contract purchase order in February 2014. With control survey panels positioned, flight operations for both LiDAR and aerial photography began in March 2014 in order to capture data predominantly during leaf-off conditions. The boundaries of the project were initially defined to encompass approximately 2,500 square miles of LiDAR data collection. Coverage areas were delineated and organized around portions of the USGS 7.5' Quadrangle map series. As outlined initially, the project comprised more than 45 quadrangles. At the end of April 2014, the USGS joined the project by providing additional project funding through a cooperative agreement. The additional funding allowed for expansion of the ongoing data acquisition. In May 2014, the project was thus officially extended to the north with a designated "add-on" area, which completed the project's DPA and provided for full coverage of 50 USGS 7.5' Quadrangles (Figure 1).

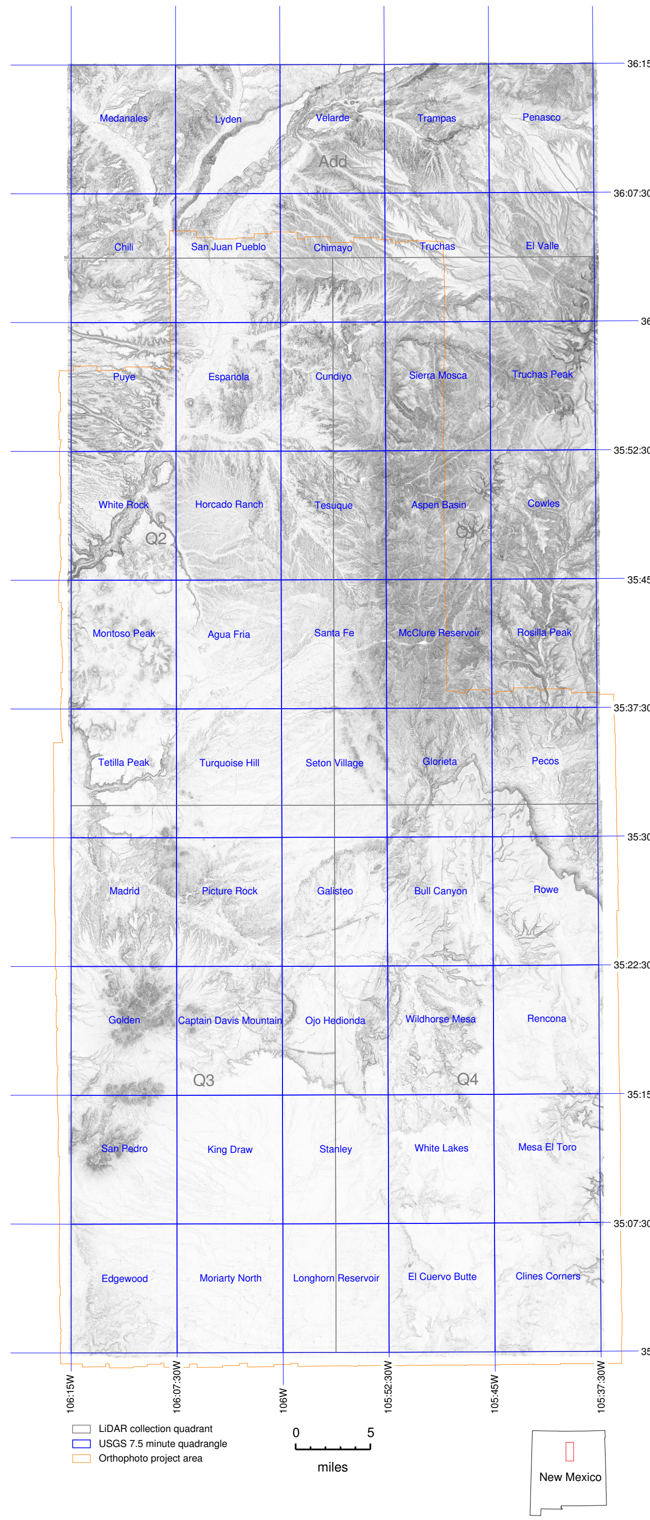


Figure 1. Overview map with LiDAR acquisition quadrants and orthophotography Area of Interest (AOI) / Defined Project Area (DPA).

2. Phase IA Source Data Acquisition

Phase I activities proceeded with ground control survey ahead of airborne (LiDAR and 4-band digital imagery for the production of 0.5 foot pixel resolution orthophotography) collection work. The boundaries of the project's digital photography capture area covered approximately 75% of the overall LiDAR DPA. A secondary GPS ground control survey campaign was organized in May and June to collect additional ground survey control supporting control primarily for LiDAR control and in particular to collect control over the northern add-on collection quadrant. A significant work delay in aerial data acquisition occurred during the month of July 2014 as a result of a NOTAM issued for essentially the entire State of New Mexico. This interruption corresponded to GPS jamming experiments emanating from White Sands Missile Range (WSMR). The project opted to wait for the conclusion of the WSMR NOTAM before resuming final flight operations again in August. Flight data control processing activities concluded in September. Raw airborne and survey control data review and packaging activities were carried out through October 2014 culminating in delivery to the County of all Phase I datasets in at the beginning of November 2014.

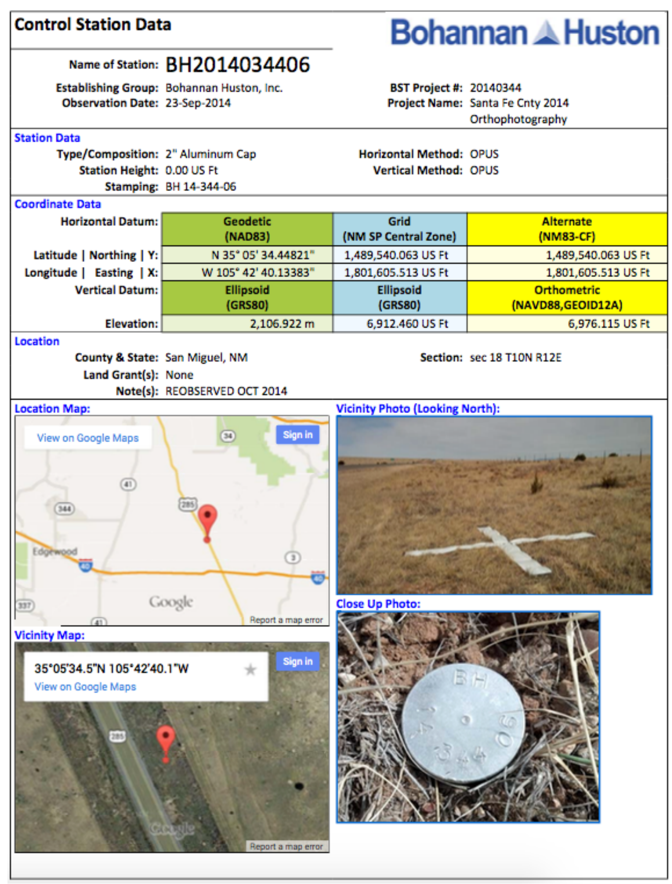
Table 1. Summary of LiDAR acquisition.

Quadrant	Dates of 2014 Collection	Flight Lines
Quadrant 1	5/4, 5/29, 5/30, 5/31, 8/5. 8/6, 8/7, 8/8. 8/9, 8/10, 8/11	119
Quadrant 2	4/18, 4/19, 5/2, 5/3	74
Quadrant 3	3/16, 3/17, 3/24, 3/25, 4/15, 4/18	72
Quadrant 4	3/12, 3/13, 3/17, 3/18, 4/15, 4/16, 4/17	69
Add on	5/31, 6/1, 6/2, 6/3, 6/5, 6/6	75

A. Field Survey Control Campaigns

1. Project Photo Control

BHI mobilized ground survey crews to the project AOI initially to establish ground control for aerial photography. Survey control targets were repaneled at control locations of previous Santa Fe County orthophotography projects. New photo control was also established to complete the control network based on the configuration of the 2014 orthophotography boundary. Standard photo control monumentation was set with 5/8" x 18" rebar with 2" aluminum cap. For photo control most points were re-paneled with plastic material for identification in photography (Figure 2). Observed control was processed according to NGS Online Positioning User Service (OPUS) procedures with solution reports included in the


Control Station Data

Bohannan Huston

Name of Station: BH2014034406

Establishing Group: Bohannan Huston, Inc.
Observation Date: 23-Sep-2014

BST Project #: 20140344
Project Name: Santa Fe Cnty 2014 Orthophotography

Station Data

Type/Composition: 2" Aluminum Cap
Station Height: 0.00 US Ft
Stamping: BH 14-344-06

Horizontal Method: OPUS
Vertical Method: OPUS

Coordinate Data

Horizontal Datum:	Geodetic (NAD83)	Grid (NM SP Central Zone)	Alternate (NM83-CF)
Latitude | Northing | Y:	N 35° 05' 34.44821"	1,489,540.063 US Ft	1,489,540.063 US Ft
Longitude | Easting | X:	W 105° 42' 40.13383"	1,801,605.513 US Ft	1,801,605.513 US Ft
Vertical Datum:	Ellipsoid (GRS80)	Ellipsoid (GRS80)	Orthometric (NAVD88,GEOID12A)
Elevation:	2,106.922 m	6,912.460 US Ft	6,976.115 US Ft

Location

County & State: San Miguel, NM
Land Grant(s): None
Note(s): REOBSERVED OCT 2014

Section: sec 18 T10N R12E

Location Map:

Vicinity Photo (Looking North):

Vicinity Map:

Close Up Photo:

Figure 2. Sample photo control point data sheet.

project control report. The survey control report[5] provides control data sheets for all photo control used on the project including a compilation of previously published control data sheets. Photo control coordinate values (northing, easting and orthometric height) were incorporated into the analytical aerotriangulation solution during the project's production phase. Photo control values were also utilized in calibration and control of LiDAR flight line strip/swath data.

2. LiDAR Supplemental Control

To supplement LiDAR control and calibration, an additional field control campaign was initiated to capture additional control coordinate values. A number of these LiDAR ID points were surveyed on hard, level surfaces often at the ends of paint stripes to provide for visibility in LiDAR intensity. Supplemental control used for LiDAR acquisition were primarily collected using GPS GPS real-time kinematic (RTK) survey. RTK surveying was performed with Trimble R8 receivers, Trimble Tablet Rugged PC, and Trimble TRIMMARK™ 3 radio modem broadcasting.

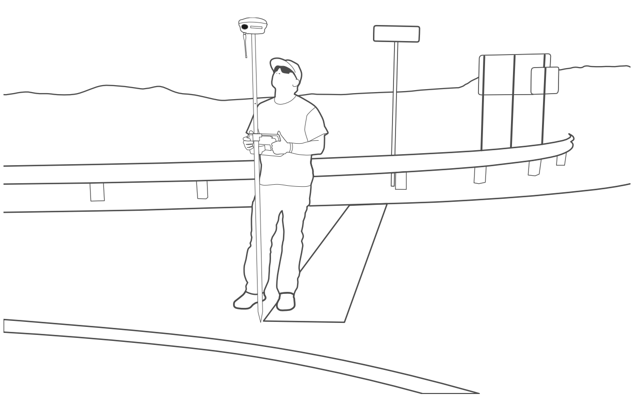


Figure 3. Example LiDAR ID point collection at stop bar corner for LiDAR mission ground control calibration.

Table 2. Summary survey control point collection.

Survey Campaign	Number of Points
Photo Control	68
LiDAR ID Control	316
Independent checkpoint	41

3. Independent Checkpoints

In the fall of 2016, a final field survey control campaign was mounted to collect a set of independent checkpoints for the purpose of testing the vertical positional accuracy of the QL2 LiDAR Digital Elevation Model (DEM). To achieve checkpoint vertical accuracy requirements of 3.3 cm (i.e., at least three times more accurate than the absolute vertical accuracy requirement of QL DEM data), all checkpoints were observed using static GPS surveying methods recommended by National Geodetic Survey (NGS) Guidelines for Establishing GPS-Derived Orthometric Heights.[6] Checkpoints were observed for a minimum of two independent two-hour sessions to facilitate OPUS-Projects[7] processing and full network triangulation to achieve final adjusted coordinate values. The long observation times and complicated logistics for checkpoints collection across the AOI implicated high costs for achieving this level of high accuracy. As a result, the project budgeted collection of 38 checkpoints, substantially less than the ASPRS recommended number (155) based on project size (3,000 square miles).[8] Nonetheless, this number (38) and distribution of checkpoints was determined by mutual agreement among the project participants. Additional criteria such as landcover, slope and accessibility were

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[5] Survey Control Report for Santa Fe County, Alan R. Benham, Revised 10-27-2014, Signed.

[6] http://www.ngs.noaa.gov/PUBS_LIB/NGS592008069FINAL2.pdf NOAA Technical Memorandum Nos Ngs 59

[7] http://www.ngs.noaa.gov/OPUS/about.jsp#about NGS OPUS: Online Positioning User Service

[8] http://www.asprs.org/a/society/committees/standards/ASPRS_Positional_Accuracy_Standards_Edition1_Version100_November2014.pdf Asprs Positional Accuracy Standards For Digital Geospatial Data (Edition 1, Version 1.0. - November, 2014); Page A19.

considered in the planning of checkpoint locations. Analysis of the National Land Cover Database (NLCD)[9] indicate that the predominant (> 90%) landcover classes across the project extents are Evergreen Forest, Shrub/Scrub, Grassland/Herbaceous.

B. Aerial Photography

Upon completion of the ground photo control field work, a Piper Malibu aircraft operated by project acquisition partner, Aero-Graphics, Inc. (AGI), with Microsoft/Vexcel UltraCam Eagle (UCE) sensor on board was mobilized to Santa Fe County for four-band digital imagery acquisition. The UCE sensor was integrated with a SOMAG Gyro Stabilization Mount (GSM) (GSM-3000) to provide for dynamic airborne sensor stabilization.

Figure 4. Aerial photo acquisition performed from Piper Malibu aircraft.

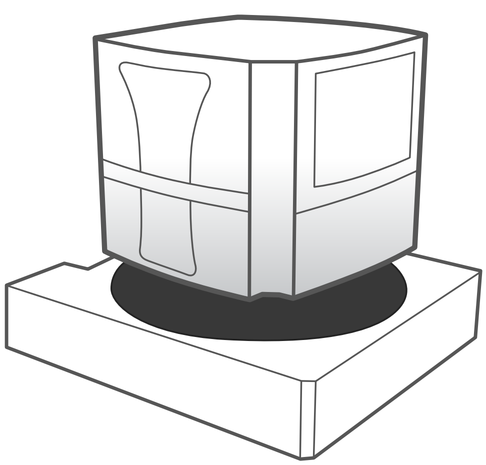

Figure 5. Illustration of UCE digital camera installed in GSM-3000.

This digital sensor (Serial Number UC-Eagle-1-70012378-f100) has undergone geometric and radiometric sensor calibration.

UltraCamEagle, Serial Number UC-Eagle-1-70012378-f100

VEXCEL IMAGING a Microsoft company

Calibration Report

Summary

ULTRACAM EAGLE

Camera:	**UltraCam Eagle, S/N UC-Eagle-1-70012378-f100**
Manufacturer:	**Vexcel Imaging GmbH, A-8010 Graz, Austria**
Date of Calibration:	**Sep-03-2013**
Date of Report:	**Oct-02-2013**
Revision of Camera:	**Rev01**
Version of Report:	**V01**

The following calibrations have been performed for the above mentioned digital aerial mapping camera:

- Geometric Calibration
- Verification of Lens Quality and Sensor Adjustment
- Radiometric Calibration
- Calibration of Defective Pixel Elements
- Shutter Calibration
- Sensor and Electronics Calibration

This equipment is operating fully within specification as defined by Vexcel Imaging GmbH.

Dr. Michael Gruber
Chief Scientist, Photogrammetry
Vexcel Imaging GmbH

Ing. Peter Prassl
Senior Calibration Engineer
Vexcel Imaging GmbH

Vexcel Imaging GmbH • Anzengrubergasse 8/4 • A-8010 Graz, Austria
Phone: +43-316-849-0660 • Fax: +43-316-849-0669 • www.microsoft.com/ultracam

Page 53 of 53

Figure 6. Signature page for UC-Eagle-1-70012378-f100 sensor.

Table 3. Digital imagery flight plan summary.

Flight Parameters	Number of Points
Camera/Sensor:	Microsoft/Vexcel UltraCam Eagle (UCE)
Altitude (ft, AGL)	9,466 ft AGL
GSD/Resolution (in)	6 inch
Flight lines	36
Overlap/Sidelap (%)	60/30
Images	5,833 (including re-flight)
Dates (2014)	3/10, 3/11, 3/12, 3/13, 3/15, 3/18,3/21, 6/4, 6/20

The UCE leaf off imagery collection was undertaken primarily during mid March 2014. Image acquisition times were programmed to

[9] http://pubs.usgs.gov/fs/2012/3020/fs2012-3020.pdf ThE National Land Cover Database (Nlcd) Fact Sheet, Colin Homer And Joyce Fry.

consider all flight conditions for meeting ASPRS image quality requirements related to snow, shadow, smoke, fog, and optimal sun elevation. In fact, additional imagery collection was also performed during the month of June 2014 to acquire snow free images in areas of high elevation.

Data from continuously operating reference stations (CORS), along with precise ephemeris data was used to provide a post-processed navigation trajectory and positional refinement of photo exposure station exterior observations. Additional aerial acquisition details for both imagery and LiDAR are discussed in the airborne data collection report.[10]

[10] Santa Fe County Lidar & Imagery Acquisition Santa Fe County, New Mexico, March-August, 2014.

3. Phase IB - LIDAR Data Acquisition

LiDAR survey data acquisition proceeded simultaneous to photo acquisition. The LiDAR acquisition period started on March 12, 2014 and finished on August 11, 2014. LiDAR collection was performed with AGI's turbocharged Cessna 206 operating an Optech Airborne Laser Terrain Mapping (ALTM) Orion H300 LiDAR sensor, installed in a GSM 3000 mount. The mount allowed for dynamic sensor stabilization and compensation for in-flight aircraft movement. Operating flight parameters were designed to capture LiDAR data with a nominal pulse spacing (NPS) of 0.7 meters. Given the elevation ranges across the project, nominal LiDAR flight design parameters were tailored specifically to the general terrain relief characteristics (i.e. mountain vs. plain) of the quadrants.

Figure 7. Cessna 206 LiDAR airborne collection platform.

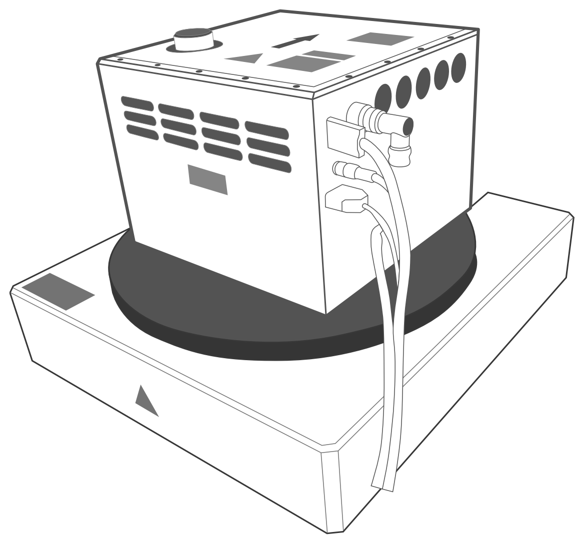

Figure 8. Schematic diagram of Optech ALTM Orion H300 LiDAR sensor installed in GSM-3000 gyro stabilization mount.

Table 4. LiDAR survey flight parameter summary.

Parameter	Q1 & Add on	Q2, Q3, Q4
Altitude (ft AGL)	4,039	3,250
Overlap (%)	30	30
Speed (kts)	105	120
PRF (kHz)	75	100
Scan Freq (Hz)	42.3	44
Scan Angle ° (full)	24	38
PPM2 (mean)	2.42	2.37
Post spacing Down Track (m)	0.6993	0.7015
Post spacing Down Track (m)	0.7002	0.7016
Swath Width (m)	523.36	682.18

LiDAR flight missions adhered to acquisition conditions similar to those followed under imagery collection providing for ideal atmospheric and ground conditions. Project data collection was nominally interrupted during the month of July 2014 due to an FAA published advisory notice issued to notify pilots that White Sands Missile Range (WSMR) would be conducting GPS interference for 385 nautical miles (NM) at 10,000 ft above ground level (AGL).[11] After the FAA advisory expired, project LiDAR data acquisition continued primarily within Quadrant 1 and concluded in August 2014.

Typical logistics for a collection day started with flight crew preparations at the airport (file flight plans/upload flight data/conduct weather analysis/airspace issues). This was followed by pre-take off systems initialization checks. Once airborne an airborne systems calibration was performed by way of a local flight maneuver to initialize systems and prepare for on-line flight

[11] https://www.faasafety.gov/files/notices/2014/Jun/WSMR_14-07_GPS_Flight_Advisory.pdf FAA Flight Advisory GPS Interference Testing.

acquisition. All planned flight line capture operations were guided with Optech FMS Planner Flight Management System Software. LiDAR sensor operations were monitored using real-time data recorded and viewed in the FMS system by the LiDAR sensor operator. This system provided for constant visual feedback to verify in-air LiDAR swath data collection parameters. After mission collection and data acquisition, the air crew performed quick analysis of real time swath data with later preprocessing of trajectories performed by the sensor operator for mission quality control (QC) assessment. More details regarding LiDAR acquisition are provided in the aerial collection report.

LiDAR coverage over the DPA was accomplished with no voids or gaps in coverage other than for permissible non-reflective surfaces such as open water over the Rio Grande system and isolated bodies of water.

4. Phase II - Data Production

A. Background Narrative

This section summarizes processing methodologies and product generation procedures for task data produced under the Santa Fe County 2014 Regional LiDAR project. Deliverable datasets were developed to meet federal specifications and professional standards. These standards and specifications are primarily the LiDAR Base Specification Version 1.2, November 2014[12], ASPRS Positional Accuracy Standards for Digital Geospatial Data[13], and ASPRS LAS Specification Version 1.4.[14]

All Phase I project aerial LiDAR and photography acquisition deliverables were competed and delivered in September and October 2014 prior to the publication of base specification. LiDAR data production was also underway at that time. With the November 2014 release of the new standards, these were reviewed for changes and potential opportunities to improve upon project data.

One noteworthy change from the initial 1.0 base LiDAR specification was modification to the minimum point cloud classification scheme. Key among the modifications was inclusion of bridge decks (class 17) into the new minimum scheme. In coordination with the County, National Bridge Inventory (NBI)[15] data were used in conjunction with County road data to help guide the targeted classification of bridge decks. After initial deliveries of both pilot product data to USGS in January 2015 and a full draft delivery of product data in May 2015, project participants engaged in further coordination efforts to determine a plan for the upgrade of project deliverables to the current QL2 base LiDAR specification. After a series of teleconferences, a "way forward plan" was developed in July 2015 to outline potential steps for updating to version 1.2 specifications.

Through the remainder of 2015, coordination continued on key pending processing items. A joint November 12, 2015 telephone conference clarified these items and paved the way for the conclusion of the project's remaining processing tasks as well as the associated extension of the project cooperative agreement with the USGS.

Table 5. Summary of base specification technical changes.

Clarifications for LiDAR Base Specification v1.2 data update
Delivery of both raw and classified point clouds in LAS file format 1.4 with point data record format 6.
Removal of and deletion of the UTM projection delivery option.
Ignored Ground points shall be coded as Class 10 as per Table 6 of the Lidar Base Specification, Version 1.2; and such coding will be specifically defined and documented in the project metadata files.
Independent checkpoints shall be located only within areas of less than 10 degrees slope.
Vertical accuracy shall be assessed for Non- Vegetated Vertical Accuracy (NVA) and Vegetated Vertical Accuracy (VVA)
New survey of independent checkpoints shall be limited to a minimum of thirty eight (38) well distributed locations.

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12 Heidemann, Hans Karl, 2014, LiDAR base specification (ver. 1.2, November 2014): U.S. Geological Survey Techniques and Methods, book 11, chap. B4, 67 p. with appendices, http://dx.doi.org/10.3133/tm11B4 or http://pubs.usgs.gov/tm/11b4/pdf/tm11-B4.pdf

13 ASPRS Positional Accuracy Standards for Digital Geospatial Data (Edition 1, Version 1.0. - November, 2014) http://www.asprs.org/a/society/committees/standards/ASPRS_Positional_Accuracy_Standards_Edition1_Version100_November2014.pdf

14 ASPRS LAS Specification Version 1.4 – R13 15 July 2013; http://www.asprs.org/a/society/committees/standards/LAS_1_4_r13.pdf

15 https://www.fhwa.dot.gov/bridge/nbi/ascii.cfm Federal Highway Administration - Download NBI ASCII files

B. Analytical Aero Triangulation

Standard photogrammetric practices were employed to derive an aero triangulation (AT) solution using available source data inputs. Source digital aerial imagery (5,433 photos) were loaded into Hexagon's ImageStation Automatic Triangulation (ISAT) software (v2014) along with airborne GPS, IMU data, survey control in concert with fundamental camera sensor parameters collected from the UCE camera calibration report.

Procedures for aerial triangulation included block creation and measurement of control within the photo block. Control import was verified against control data sheets to verify consistency in reported control values. Subsequently, automatic tie point processing was performed to develop matched tie points among conjugate image pairs within the photogrammetric project.

Before computing a final bundle adjustment, tie point measurements were analyzed for number of rays (number of images matched). Working in a GIS feature database environment enabled analytical review of the AT project for strength of solution and other characteristics such as GPS correction. A key step in this analysis is to remove 2-ray points in areas of triple photo coverage or greater prior to incorporation of these measurements into the project. After weak areas of the photo block were supplemented with additional tie points, the AT bundle adjustment was calculated with results analyzed for statistical performance toward meeting a 95% confidence level in horizontal positional accuracy of +/- 2 feet or better at a map scale of 1 inch 100 feet for orthophotography. A final AT report was issued for procedural, coordinate system, as well as triangulation statistics documentation. This AT solution would serve as source material to support additional data collection production pertaining to features integrated into other project (i.e. LiDAR) tasks utilizing project digital orthophotography (DOI).

C. Classified Point Cloud

This section describes procedures employed to obtain classified point cloud deliverables—post data acquisition. While LiDAR data processing control and calibration procedures are documented in the project Collection Report, the calibration procedures are summarized here again along with more processing details provided in relation to LiDAR classification and product generation.

1. Calibration

After acquisition, LiDAR data were initially processed at AGI offices in Salt Lake City, UT. AGI employed a series of LiDAR processing workflow and calibration tasks which take the collected data from raw point cloud to adjusted and controlled point clouds for subsequent classification work.

Table 6. LiDAR Calibration Workflow.

Calibration Step	Software
Absolute Sensor Calibration	Optech LiDAR Mapping Suite
Kinematic Air Point Processing	Applanix POSPac
Raw LiDAR Point Processing	Optech LiDAR Mapping Suite
Relative Calibration	Optech LiDAR Mapping Suite
Absolute Accuracy Assessment	TerraScan

The sensor-acquired positional data were first calibrated to correct for heading and aircraft orientation error relative to surveyed ground control. Next, airborne kinematic GPS positions were processed to develop a differentially corrected GPS solution for aircraft position and trajectory (i.e. a smoothed best estimate of trajectory (SBET)) using precise GPS ephemeris data from ground stations. By flight strip, these data were further calibrated in Optech's LiDAR Mapping Suite (LMS) to calculate a position for each laser point through the association of SBET data with raw LiDAR range data. LMS software was further used for relative calibration to adjust adjacent LiDAR strips to meet the relative accuracy specification of the QL2 LiDAR survey. Finally, absolute accuracy assessment of laser points to ground control points was made through comparison of laser elevation (Z) values to control elevation values. Full reporting of both relative and absolute accuracy is documented in the project's airborne acquisition technical collection report.

2. Classification

Automated Classification

After initial LiDAR data calibration post processing, the controlled point cloud data were cut into quadrant based production tiles and subjected to an initial automated ground classification using TerraScan® commercial software. Initial point cloud classification discriminated data as either ground (class 2) or non-ground points (class 1).

High noise points in the dataset were primarily related to points captured near the altitude of the aircraft during data acquisition. These points were classified as high noise using a statistically expected minimum-maximum range of elevation values for non-noise points within a flight strip. Points falling high above this range threshold were automatically reclassified as noise. Noise points held outside of production processing and later were merged into final classified point clouds after all other classification work.

Production Staging

In areas of overlap between airborne collection quadrants, production tiles were organized to create a comprehensive set of full non-overlapping production tiles. The objective of this data organization and production staging effort is to ensure full classification of all LiDAR data sources without duplication. After production staging by production tiling, a comprehensive project wide set of quality control (QC) shaded relief image products were generated using the initial ground classification for review and reclassification work. Throughout the execution of the project, Geospatial Data Abstraction Library (GDAL) Utilities were used to iteratively create shaded relief datasets as point cloud classification edits were made. Data processing priorities were also established with higher priority given to production tiles over areas of project orthophotography coverage.

Point classification call development

Assignments for review of shaded relief QC images were made across all production tiles. As analysts reviewed data tiles, they made GIS feature based error "calls" for inspection and/or point cloud reclassification. Simultaneous to analyst review an automated outlier detection methodology was deployed project-wide to statistically detect small surface pits. As these outliers were detected they were also added to the database of potential error calls. Error calls were categorized with type attribution to guide subsequent processing and reclassification.

Table 7. Frequency count of LiDAR error calls by type.

Call Type	Count
Bridge	598
Building	1168
Pit/Spike	77269
Drainage	3662
Mine	1914
Ridge	12784
Other	369

Refined Classification

Relying on the GIS feature calls made to identify issues in initial automated classification, project geospatial analysts evaluated each and, at these locations, classified point cloud data according to the minimum LiDAR classified point cloud classification scheme.

Table 8. Minimum LiDAR classified point cloud classification.

Code	Description
1	Processed, but unclassified
2	Bare earth
7	Low noise
9	Water
10	Ignored ground (near a breakline)
17	Bridge decks
18	High noise

Building

Manual reclassification of points was primarily performed in ERDAS Imagine software. Typical reclassification operations, for example, at building call locations necessitated changing point classification from ground or bare earth (2) to unclassified (1). Analysts utilized supporting reference data including building footprints, for example, over the City of Santa Fe to guide reclassification.

Bridge

Bridge feature calls drove 3D stereo collection of breakline features. Project imagery and National Agricultural Inventory Program (NAIP) imagery primarily supported horizontal placement of breakline feature with the interpretive value of optical imagery resources. Due to vertical differences in photo source scale as compared to LiDAR vertical precision, subsequent manual review of breakline data was performed to ensure correct classification of all ground points around breaklines and bridge decks. Vertical conditioning of individual breaklines was performed to adjust these data with a vertical offset attributional value for appropriate fit to LiDAR vertical elements. Final 3D vertical values for breakline geometry record the LiDAR conditioned values.

Pit/Spike

Pit/Spike calls were addressed through automatically reclassification by statistical means. Automated procedures were developed in Safe Software Feature Manipulation Engine (FME®) to explore for data outliers falling outside of three (3) standard deviations from the mean surface surrounding the pit/spike call feature. In these cases, data outside of the pit/spike threshold data were reclassified appropriately.

Drainage

The drainage feature call type was used primarily as a subset of pit calls where some additional analysis was performed with regard to proximity to road bed features. Many of these calls correspond to built infrastructure features, for example, where LiDAR point(s) may in fact penetrate grates covering drainage structures with drop-down entrance (e.g. catch basins, curb opening inlet, drop inlet, etc.). Although these calls were identified separately, this was only done for call tracking purposes and did not implicate any substantial processing difference relative to other pit calls.

Mine

Mine type feature calls were another secondary class of calls similar to pit/spike feature calls. As with the drainage (pit) call features, the mine feature calls were made primarily over specific geographic areas related to apparent mining-influenced pit features. Many of these calls, for example were encountered over the Ortiz Mountains related to early gold mining and other mining activities in the region.[16] Mine calls were primarily interpreted over project or other source imagery where old boards or timbers appeared to cover open shafts or similar openings of apparent abandon mines. Again as with drainage and

[16] New Mexico Energy, Minerals and Natural Resources Department, Real de Dolores Mine Safeguard Project; description of historical mining activities in the Ortiz Mountains. http://www.emnrd.state.nm.us/MMD/AML/RealdeDolores.html

other pit calls, these mine calls did not involve any special case of processing apart from other pit processing.

Ridge

Difficult classification situations can present themselves in areas of steep terrain where overly aggressive carving away of the ridge may result as a common artifact in automated classification. These artifacts often lead to unsightly DEM output due to unnatural triangulation effects from missing ground data in the surface model. To remedy these types of artifacts and restore appropriate ground/bare earth points to the surface model, polygon ridge calls were used as a data clipper to extract relevant sections of the point cloud for reclassification of these sections using ERDAS Imagine automated reclassification methods. After the ridge segment was reclassified in ERDAS, it was merged back into the original production tile classified point cloud with FME®. For each tile, updated shaded relief imagery was generated at the end of the review and classification process for classification feedback and assessment of manual and/or automated reclassification results. After call features were addressed and signed off on, a second geospatial analyst would conduct a peer review of shaded relief imagery resulting from point cloud classification edit processing.

Other

The "other" attribute for LiDAR review feature calls was reserved for identification of special issues not captured by the previously mentioned domain options for call type attribution. Many of these calls related to areas identified for re-classification due to edge effects at project outer edge boundaries. The "other" type was also employed to handle spike artifacts at flight line strip ends.

Breakline Classification

Breakline features were integrated for use in classification of point cloud data. Breaklines were used as reference in particular to classify water (9), Ignored ground (near a breakline) (10) and bridge decks (17). The order of operations for breakline classification included priority treatment of bridges, then water, breakline, wall, and culvert spans. River waterbody point classification took precedence over breakline classification.

Water

For waterbodies, extracted breaklines were conditioned to the LiDAR elevation using a review of (1 ft contour interval) contours and shaded relief imagery. LiDAR DEM data were also utilized to extract a geomorphic definition of the Rio Grande and Rio Chama channel system. This polygon was verified over 2014 imagery and used to classify water points using area overlay analysis and subsequently in DEM hydro-flattening procedures on USGS data tiles. Waterbody breakline polygons were also extracted automatically using the spectral definitions of water in orthophotography. This technique was also employed over areas without project photography where NAIP imagery was utilized to derive area waterbody breadline features.

Ignored Breakline

Bridges, breakline and wall (special breakline) features were buffered 2 ft on either side to classify about 1 point on each side of the breakline as class ten (10).

Bridge Decks

The objective of bridge deck point classification was to obtain a 3D classification of bridge decks portraying these features as a plane with appropriate classification (17). Depending on the design of the bridge, these often possess additional vertical superstructure design elements both above and below the bridge (guard rails, piers, etc.). Classification of these elements attempted to separate and classify the bridge deck (17) as a plane with remaining vertical superstructure classified as

(1). In some cases, classification of bridge desks may be further complicated by overhanging vegetation which also was classified as (1) in order to preserve the deck as a classified plane of points.

D. Bare-Earth DEM

1. Product Generation

Product generation processing of bare-earth digital elevation models (DEM) was accomplished using FME® software to triangulate the classified point cloud.

Triangulation

Using classified point cloud source data as an input, classes 2 (ground) and 9 (water), where applicable, were triangulated with a tolerance setting of 0.0 (i.e. no surface filtering or approximation). Class 10 points (Ignored ground (near a breakline)) were excluded from triangulation which results in creating a buffer between the LiDAR and the breakline for a smooth transition in the resulting DEM modeling at breakline locations.

Breakline Integration

Breakline features were analyzed and tracked according to whether or not they support or were integrated into DEM surface modeling. Breakline features contributing to elevation modeling and DEM product generation were marked with a "usage" attribute indicating weather or not the feature should be incorporated into the surface model. Elevation model processing filtered breakline data where usage was equal to "yes." For bridge features, these breaklines were clipped by a bridge deck polygon feature and therefore, the breakline data at bridge locations supplemented surface modeling primarily under the deck where no LiDAR points were present. Breaklines were also combined into the surface modeling process at wall locations and culvert spans. End line segments where bridge decks touch the road were also processed into breakline features through feature manipulation of the bridge deck polygon. Here, the bridge deck polygon is chopped by two vertices segments through spatial analysis to automatically extract the bridge abutment at the road elevation as a breakline.

Product Tiling

Triangulation processing was performed to generate two (2) sets of DEM output deliverable data tiles.

Santa Fe County (SFCO) Tiling

One project tiling scheme, designated "SFCO," is organized according to the Public Land Survey System (PLSS) section-based overlapping tiles. These tiles are approximately 1 mile x 1 mile centered on PLSS sections. The file naming convention of this tiling scheme follows the County norm using a six digit numbering scheme that describes the Township number, Range number, and Section number in sequence. Given the PLSS basis for the SFCO tiling scheme, product data tiles do not have a uniform file size. Nonetheless, overlapping features were edge-matched across tile boundaries. To facilitate comprehensive horizontal and vertical data edge matching both sets of tiling schemes utilized a 999-foot buffer distance for surface interpolation and processing of DEM data at the tile level. A large buffer distance helped ensure edge match consistency in particular where triangulation across large features such as buildings may be required to ensure reliable elevation data production. There are 3,256 SFCO tiles.

US Geological Survey (USGS) Tiling

The other tiling scheme, designated "USGS," is composed of non-overlapping, edge-matched 5000'x5000' gridded tiles. Both tiling schemes adhere to the same horizontal and vertical coordinate system, pixel resolution and source data inputs. In addition, both the SFCO and USGS tiling schemes are rounded to nearest ten (10) coordinate value units (U.S. Survey Feet) and both fall on even foot coordinates. Each tile is also divisible by two—the resolution of the DEM raster grid output. After triangulation with the 999 ft buffer, each tile was clipped back to its corresponding tile definition upon output. Again, this processing methodology ensures uniformly consistent and coincident data when modeling point cloud inputs to 2 ft grid pixels at tile edges where clipping occurs. The naming convention for the USGS tiling scheme uses a concatenation of the first four digits of the lower left coordinate (easting + northing) pair of each tile. There are 3,627 USGS tiles.

Edge Analysis

For partial data tiles (i.e. those tiles at the outer edge of the project boundary extents), special edge data handling procedures were implemented to meet two objectives. Steps were applied to ensure that data tiles conformed to the appropriate tile dimensions and that spurious data values were removed near data voids occurring near the edge.

Tile Dimension Uniformity

To completely fill a partial data tile with “nodata", an artificial nodata raster (with a fill value of -32767) and a zero (0) elevation las point cloud were generated to fill the nodata portions of the tile. To produce a full raster data tile, the zero (0) values were replaced with nodata values (-32767) by way of a clipper which defined the interface between data and nodata.

Data Void Removal

For edge data clipping, the strip geometry spatial metadata defining the spatial extents of the LiDAR coverage was used as a clipper to clip the zero elevation data which was inserted into the triangulation. In some areas, due to the spatial resolution of the metadata clipper, clipper boundaries were refined iteratively to further eliminate additional falsely triangulated DEM values. Generation and assessment of 1-foot contours were used to ensure that the clipper extents conformed to actual lidar source or true derived elevation product data. Contouring across void areas would generate high density contour features over voids, the locations of which were used to refine the extents and thus exclude these voids from data production.

DEM Quality Control

A full project mosaic for each DEM product tiling scheme was produced. Since these two independent tiling schemes were designed to produce identical data, the product mosaics were subtracted from one another to produce a vertical difference map to detect and identify any areas which could be systematically incomplete or contain inconsistent data among the tiling schemes.

2. Hydro-Flattening Methodology

Non-river Waterbody Hydro-Flattening

Ponds and lakes greater than two (2) acres in size were processed during the DEM processing workflow through the use of breakline (polygons) data defining the extent of these water body features at the water/land interface. National Hydrography Dataset (NHD) polygons were initially used to target the possible locations of these waterbodies. Additional manual identification and extraction of waterbodies not in NHD supplemented the waterbodies dataset for hydro-flattening. Breakline data at these locations were acquired from photogrammetric sources (project orthophotography and NAIP orthophotography[17]) collected over the project in 2014. After polygon delineation, the breaklines were fit to the appropriate LiDAR elevation at or below the water surface using 1-foot contours to assess and determine the

[17] http://gis.apfo.usda.gov/arcgis/rest/services/NAIP New_Mexico_2014_1m utilized for waterbody delineation outside project orthophoto coverage areas.

appropriate waterbody elevation. A point cloud at this defined elevation was inserted into the DEM triangulation (surface modeling) process using the polygon features for flattening of the water body at the appropriate level. Non-river waterbodies meeting two (2) acre size criteria were hydro-flattened in both project tiling schemes.

River Waterbody Hydro-Flattening

US Geological Survey (USGS) Tiles

The river hydro-flattening methodology employed the use of the project's 3D river area polygon breakline feature dataset. A monotonic surface model was generated through the use of contour modeling along the linear extent of the Rio Grande / Rio Chama system. Monotonically flat elevation planes were constructed at 1-foot intervals throughout the river reach channel. Spatial guidelines or cross section cutlines for these planes were automatically constructed through the spatial intersection of 1-foot contours and the river polygon feature. For river area hydro-flattening, the general definition of cutlines is similar to cutlines developed in support of hydraulic modeling.[18] In this case, cutline orientation was typically perpendicular to the direction of water flow across the channel from bank to bank. All automatically derived cutlines were reviewed with manual adjustments performed as needed to ensure logical cutline placement. Using these planes a hydro-flattened DEM was interpolated as a bank-to-bank DEM without islands. Hydro-flattened elevation values then replaced the initial triangulated ground surface model values within the extents of the river polygon. Islands within the river channel were retained and restored to the DEM after the application of hydro-flattening. A set of 1-foot contour data derived from the final hydro-flattened DEM was utilized to assess hydro-flatting results and review that the contours approximated "cartographic" contours in that they cross the river with nearly right angle configuration.[19] River hydro-flattening was only

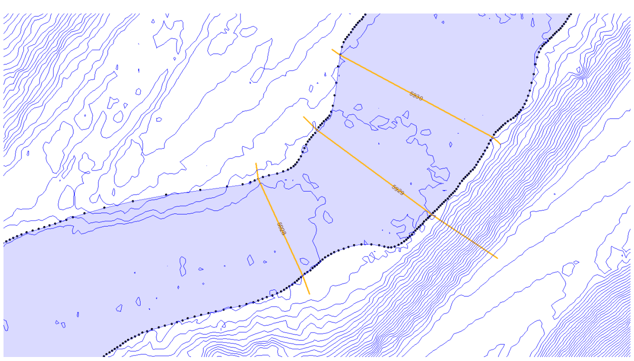

Figure 9. Bank-to-bank cutline orientation with 1 ft. contours.

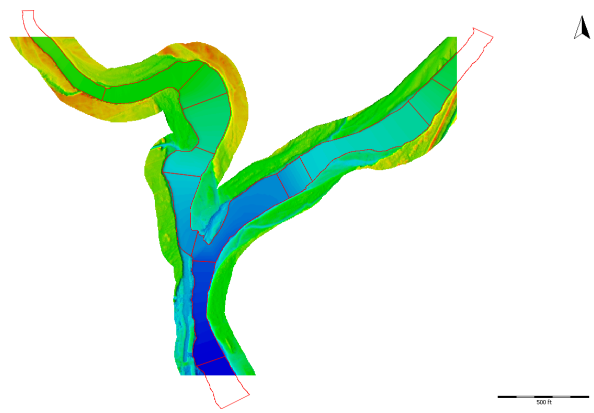

Figure 10. Hydro-flattening cutlines without holes (islands).

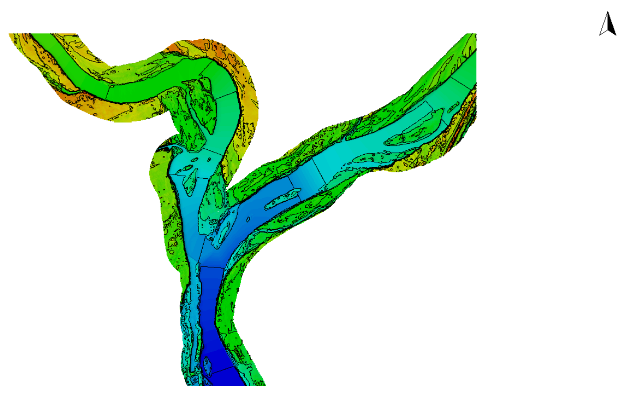

Figure 11. River hydro-flattening with contours and islands.

[18] USACE HEC-GeoRAS User's Manual version 1.0, March 1999. http://www.hec.usace.army.mil/software/hec-georas/downloads/archive/HEC-GeoRAS_1.0_UsersManual.pdf See cut line definition; page 3-9.

[19] Tyler, D.J., and Greenlee, S.K., 2012, Creation of digital contours that approach the characteristics of cartographic contours: U.S. Geological Survey Scientific Investigations Report 2012–5167, 31 p. with appendixes. http://pubs.usgs.gov/sir/2012/5167/sir2012-5167.pdf

performed on USGS tiling scheme deliverable DEM data.

Santa Fe County (SFCO) Tiles

For the SFCO deliverable tiles, river hydro-flattening was not applied. Instead, SFCO tiles preserve the initial ground classification at water level. Without hydro-flattening, the SFCO DEM dataset preserves, to the extent possible with LiDAR, within channel detail encountered at water-surface level. Such details, for example, might include long-time in-channel human alterations for acequias and other related irrigation diversion infrastructure throughout the Rio Chama and Rio Grande.[20] Also represented in the SFCO tile, river surface data are natural and permanent features within the channel including rapids and pool-and-riffle features typical of the Rio Grande.[21]

E. Breakline Collection

Over areas of 2014 6-inch project orthophotography coverage, 3D breaklines were derived through stereo interpretation of water body areas, walls, bridges and breaklines. Bridges located outside of project orthophoto coverage were collected using NAIP imagery. Similarly waterbodies located outside of project orthophoto coverage were extracted from NAIP orthophotography. Depending upon source material, the line work was captured as either three or two dimensional lines with associated x,y,z coordinates.

All collected breaklines were reviewed and assessed for their contributing value to the improvement of the bare-earth digital elevation model (DEM) production. A binary attribute was added to provide a determination of whether or not the breakline feature should be integrated into the DEM model. Only breaklines contributing to the bare-earth suface model are included in this dataset. Based on 3D analysis and review of shaded relief imagery, every breakline was assigned an individualized offset attribute value in order to optimize the 3D breaklines fit to underlying LiDAR surface data. Water body breaklines were also assessed in conjunction with 1 ft contour interval data.

A 3D monotonic river breakline dataset was constructed for hydro flattening purposes over the entire contiguous double line drainage river complex course within the project (i.e. both the Rio Chama and Rio Grande). Starting with a geomorphologically defined 2D polygon, initial raster-based polygon was generalized with line smoothing algorithms and vertices were subsequently densified by 1 ft in order to construct the 3D breakline data. To visualize the relationship between river water level and the defined polygon, a preliminary orthophoto mosaic was generated from project photography and used to inspect for visually acceptable bank and island geometry of the primarily geomorphologic polygon. Methodologies were developed to automatically develop (from 1 ft contours) river crossing transect guidelines at locations where 1 ft contours entered the river bank feature. The river breakline data were used to create a flat river surface model which was integrated into hydro flattened DEM data with incorporation of non-water islands into the final DEM processing.

F. Orthoproduction

Orthorectification was performed with the input of the AT solution. Using final AT exterior orientations (EO), UCE Images were rectified to correct for camera tilt, lens distortion and relief/

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[20] Ackerly, Neal W. *A Review of the Historic Significance of and Management Recommendations for Preserving New Mexico's Acequia Systems.* Santa Fe: New Mexico Historic Preservation Division, 1996. http://www.nmacequiacommission.state.nm.us/Publications/nackerly_aceq_rpt96.pdf

[21] Nordin, Carl F., Jr. and Joseph P. Beverage. Sediment transport in the Rio Grande, New Mexico. Geological Survey Professional Paper 462-F. Washington: US GPO. 1965. 40pp. http://pubs.usgs.gov/pp/0462f/report.pdf

terrain displacement. Each image in the project was differentially rectified to the newly generated LiDAR ground surface model. Cubic convolution interpolation methods for digital orthorectification were employed using Intergraph (Hexagon) ImageStation OrthoPro software. Orthorecification was automated and optimized through batch processing scripts with established and tested parameters. Orthorectification scripts were processed on high-end servers with at least 64 GB of RAM to ensure rapid throughput of 0.5 foot ground sample distance (GSD) orthorectified imagery.

Using Trimble OrthoVista® software, images were color balanced and color corrected individually to ensure color consistency between flight lines, time(s) of day, and date(s) of capture. Images were mosaicked into large aggregate tiles and automatic seamlines were used to combine the most nadir components of individual images. Orthomosaicking with feature detection and seamline generation were performed as a north, central and south block. Aggregate tiles were again tonally balanced and color corrected with the entire project in view. A second global color adjustment was performed to minimize color changes across blocks. Project deliverable SFCO tiles were cut from the mosaic and formatted for delivery.

Draft deliverable orthomosaic tiles were inspected by geospatial analysts using GIS feature based error tracking for review and correction of orthophoto issues. Inspection included review for typical issues related to seam line, bridge warping and overall tile review for general appearance of radiometry and tonal qualities or any potential imagery artifacts. Adobe Photoshop® was used to remedy issues identified by call features with a final verification performed by an independent analyst prior to deliverable formatting—GeoTIFF and ECW.

G. Single-line Hydro Stream Features

1. Hydro-enforcement

To develop and improve the spatial accuracy of Santa Fe County's surface stream vector network data layer, hydro-enforcement processing was performed on project DEM data. This work primarily consisted of conditioning of the initial LiDAR DEM through the construction of single-line hydro feature breakline to allow for the simulation of natural surface water flow modeling primarily across road/rail bed (fill) features where flow is directed through culverts.[22]

Preliminary Flow Models

A preliminary flow line stream dataset was produced over the project area; using a preliminary LiDAR DEM without all bridges removed nor with culverts enforced. This data supported both prototype stream development as well as targeted semi-automated culvert cutline placement during hydro-enforcement processing. Flow modeling of both preliminary and final hydro-enforced streams were performed with raster based GRASS software scripting routines.[23]

Culvert Detection

Santa Fe County provided culvert locations to support data driven analysis for hydro enforcement of DEMs at these sites. This dataset consisted of primarily point features placed within the roadbed between the approximate inlet and outlet points of the corresponding culvert. Additional culverts supplemented this dataset through the use of culverts identified during the LiDAR bridge deck

[22] Poppenga, S.K., Worstell, B.B., Danielson, J.J., Brock, J.C., Evans, G.A., and Heidemann, H.K., 2014, Hydrologic enforcement of lidar DEMs: U.S. Geological Survey Fact Sheet 2014–3051, 4 p., http://dx.doi.org/10.3133/ fs20143051. ISSN 2327-6932 (online) http://pubs.usgs.gov/fs/2014/3051/pdf/fs2014-3051.pdf

[23] GRASS Development Team, 2015. Geographic Resources Analysis Support System (GRASS) Software, Version 7.0. Open Source Geospatial Foundation. http://grass.osgeo.org

classification effort. Still further supplemental culvert identification was also performed using GIS proximity analysis of existing NHD flow lines in relation to transportation (road/rail) networks. In other words, this additional search process anticipated that a culvert should typically be nearby NHD and/or road network features.

Automatic Culverts Cutlines

Additional derivative data including geomorphology were developed at small sites (400 x 400 feet) nominally centered on seed culvert locations. Automatically defined candidate cutline features were developed through the use of the preliminary stream in proximity to the seed culvert point. A start point for the cutline was extracted at the point of inflection where the 3D stream data began increasing in elevation values. Analysis was then conducted from the start point by generating a search fan of lines to the next lowest proximate elevation point. The shortest cutline feature was identified as the most likely cutline. Further analysis of start and endpoints falling within valley or depression geomorphological features improved the likelihood of automatic definition of an acceptable cutline for hydro-enforcement. All (2,000+) cutlines were inspected and adjusted manually if necessary.

Hydro-Enforced DEMs

To prevent multiple culverts in close proximity to one another from overlapping and potentially interfering with hydro-enforcement, narrow cutline based DEM data were constructed using bounding box analysis. The 3D definition of the cutline supported hydro-enforcement of the DEM by cutting a v-shaped channel at the spatial location of the determined line. These small hydro-enforced DEM data were integrated into a full project-wide hydro-enforced DEM for flow modeling.

Flow Modeling

Due to the computational complexity of network flow modeling for a project of this size, flow path models were calculated by splitting the hydro-enforced DEM by 7.5' USGS Quadrangle. Each of the project's 50 quadrangles were buffered by 5,000 feet to facilitate edge matching of vectors as well as attributional network analysis of Strahler stream ordering across the overall project. Strahler stream ordering was considered a fundamental network attribute for both watershed analysis potential as well as data management and organization. Key flow modeling processing steps included flow accumulation and direction modeling, stream network extraction, vectorization, and generalization

Stream Network Data Assembly/Validation

Quadrangle-based stream datasets were clipped and processed for edge matching at quadrangle boundaries with vector snapping and line joining by like stream order attribution. After geometric data connectivity analysis, line snapping at edge boundaries was verified to conduct network calculations and delineation of cohesive watershed units of analysis on a project-wide scale. The entire assembled project database maintains approximately 25 million vector data segments. To run the full network has required specialized computing resources since network calculations need to incorporate the entire network of stream data to fully encompass the watersheds within the project. Network topology calculations with FME® software were performed on stream flow path geometry to calculate and validate network connectivity, quality and integrity of complete drainage basins.

H. TIN / DTM

Processing procedures for generating TIN/DTM data relied on automated batch processing using Arc Python scripting environments with python calls to process DEM and breakline features to TIN datasets. ESRI® software commands (RASTERTIN3D and EDITTIN3D) were employed to facilitate automated TIN data processing production.

I. 1-foot Contours

Two sets of contour datasets (SFCO and USGS tiling scheme product) were cut from project-wide DEM datasets. Contours were generated for all project areas at a 1-foot contour interval (“ci”) with GDAL utilities. Contours were further filtered with a four (4) square foot minimum closed contour size criteria. Analysis of closed contours in FME® helps to reduce spurious contour data amounting to high spatial frequency noise on the order of a single pixel not representative of discernible terrain features at the QL2 product resolution or scale. Contours were loaded into a project-wide spatial database to provide for quality control and assessment of start and end points among data tiles to ensure that no crossing contour lines were present in the dataset. Within the database environment project contours were comprehensively checked for 1) completeness, 2) tile edge matching connectivity, 3) start/end point logical consistency and 4) attributional discrepancies (depression/elevation). Residing in a spatial database also facilitated contour reprocessing and data tile update. Analysis of depressions in FME® similarly utilized concentric contour/closed polygon analysis with a size criteria of a quarter square mile (0.25) in area to identify and appropriately attribute depression contours. In addition, every fifth contour line (5 foot isolines) was attributed as an index contour. Elevation values were further attributed as numeric values assigned to product contour lines.

5. Delivery

A. Data Processing and Handling

All deliverable data products were processed and delivered in a single local State Plane Coordinate System (SPCS) in conformance with base LiDAR specification recommendations. These data adhered to the following project coordinate reference system (CRS) projection:

- NAD83 HARN State Plane New Mexico Central (3002), US Survey Feet
- North American Vertical of Datum of 1988 (NAVD88), US Survey Feet

Project CRS georeferencing for LiDAR point data deliverables was stored in LAS v1.4 formatted files with the CRS recorded in Open Geospatial Consortium (OGC) well known text (WKT) format. As noted earlier, additional processing was performed on both raw and classified point clouds to format LAS files according to ASPRS LAS version 1.4.[24]

1. ASPRS LAS version 1.4 Processing

Data formatting for LAS version 1.4 deliverables involved two key processing steps. First "tenderloin" / overage geometry was developed and second LAS files were processed according to LAS version 1.4 specifications. To identify overage points in both raw and classified point cloud deliveries analysis was performed to construct "tenderloin" / overage geometry from LiDAR flight line swath data using FME®. Interior tenderloin area geometry was generated for each of the project collection quadrants. This process analyzed start and end point swath data where tenderloin geometry joins with adjacent flight line geometry. Analysis of these juncture locations was also performed to determine segmentation divisions where these tenderloins join spatially. These geometry then drove the assignment of overage flag point categorization within LAS point clouds. A multi-step software workflow was employed to correctly implement LAS version 1.4 point cloud formatting. The point cloud translation and version update approach relies on the following steps.

Table 9. ASPRS LAS version 1.4 point cloud update.

LAS version 1.4 Translation Steps	Software
Update input LAS file with PDRF equal to "6" and set WKT CRS information.	PDAL
Add "Overlap" classification bit fields through point cloud splitting based upon developed "overage/tenderloin" geometries.	FME®
Ensure WKT definition with appropriate vertical CRS definition.	PDAL
Verify LAS header information.	LASINFO

Two project tiling schemes were developed for deliverable data formatting to accommodate both base LiDAR specifications and local Santa Fe County data production requirements. Data provided to the USGS included those datasets developed specifically in the non-overlapping USGS tiling scheme corresponding to the primary LiDAR-related product groups. Project-level metadata files were created in XML format for deliverable product groups according to the FGDC Content Standard for Digital Geospatial Metadata (1998) and validated with USGS Metadata Parser (USGS, P. Schweitzer).[25]

Additional data products developed primarily in the overlapping SFCO tiling scheme were not provided to USGS. Prior to delivery, final data products were tested in Santa Fe County production software environment (ArcGIS™) and packaged for delivery on external USB portable hard drives. ⊠

[24] ASPRS LAS Specification Version 1.4 – R13 15 July 2013; http://www.asprs.org/a/society/committees/standards/LAS_1_4_r13.pdf

[25] Peter N. Schweitzer. mp: A compiler for formal metadata, USGS http://geology.usgs.gov/tools/metadata/tools/doc/mp.html