South Dakota QL2+ Topographic Lidar Project

Project Report

March 29, 2018

Prepared for:

United States Geological Survey,
National Geospatial Technical Operations Center

Prepared by:

Precision Aerial Reconnaissance, LLC

In partnership with:

CONTRACT: G17PC00007

TASK ORDER: G17PD00536

Contents

Introduction

Precision Aerial Reconnaissance was tasked by the United States Geological Survey to acquire and process QL2+ topographic lidar data for 4,073 square miles in South Dakota, including Butte, Harding, Perkins, and Meade Counties. These lidar data will be used to produce a high resolution bare earth Digital Elevation Model of the entire project area. This report describes the data acquisition, ground survey, data processing, quality control, and data validation activities related to producing the final deliverables for this project.

The lidar data were processed in accordance with this task order's Statement of Work, as well as the USGS' NGP Lidar Base Specification version 1.2 (November 2014).

Project Team

Precision Aerial Reconnaissance, LLC (PAR), served as the prime contractor of this task order, was responsible for managing all project related activities. PAR was directly responsible for topographic lidar acquisition and calibration, manual editing of twenty-five percent (25%) of the lidar data, and performing QA/QC on all final deliverables. All ground survey activities required to collect ground control and accuracy checkpoints were performed by Gustin, Cothern & Tucker, Inc. and validated by Bohannon Huston, Inc., the Professional Land Surveyor in Responsible Charge of the final survey. PAR subcontracted the data processing activities to Dewberry who were responsible for manual editing of seventy-five (75%) of the lidar data, compiling all hydrographic breaklines, and generating the final DEMs for the entire project area. Dewberry also performed all data validation and accuracy tests to ensure the lidar data met the requirements listed in this task order.

Coordinate Reference System

The lidar data and derived products were delivered in the following reference system.

Horizontal Datum: North American Datum 1983, 2011 adjustment (NAD83 (2011))
Vertical Datum: North American Vertical Datum of 1988, (NAVD88)
Coordinate System: Universal Transverse Mercator (UTM) Zone 13 North
Units: Horizontal units are in meters to 2 decimal places, Vertical units are in meters to 2 decimal places.
Geoid Model: Geoid12B (used to convert ellipsoid heights to orthometric heights)

Lidar Vertical Accuracy

The tested RMSEz of the classified lidar data for checkpoints in non-vegetated terrain is 5.4 cm, compared to the 10 cm specification. The NVA of the classified lidar data computed using RMSEz x 1.96 is 10.5 cm, compared to the 19.6 cm specification.

The tested VVA of the classified lidar data computed using the 95^{th} percentile is equal to 10.1 cm, compared to the 29.4 cm specification.

Project Deliverables

The deliverable for the project are as follows:

1. Classified Point Cloud Data (Tiled)
2. Bare Earth Surface (Raster DEM – IMG Format)
3. Intensity Images (8-bit gray scale, tiled, GeoTIFF format)
4. Breakline Data (File GDB)
5. Independent Survey Checkpoint Data (Report, Photos, & Points)
6. Calibration Points
7. Metadata
8. Project Report (Acquisition, Processing, QC)

10. Project Extents, Including a shapefile derived from the lidar deliverable.

Lidar Acquisition

PAR planned 235 passes for the South Dakota project area and a parallel flight line for the purposes of quality control. In order to reduce any margin for error in the flight plan, PAR followed FEMA's Appendix A "guidelines" for flight planning and, at a minimum, includes the following criteria:

- A digital flight line layout using LEICA MISSION PRO flight design software for direct integration into the aircraft flight navigation system.
- Planned flight lines; flight line numbers; and coverage area.
- Lidar coverage extended by a predetermined margin (300m) beyond all project borders to ensure necessary over-edge coverage appropriate for specific task order deliverables.
- Local restrictions related to air space and any controlled areas have been investigated so that required permissions can be obtained in a timely manner with respect to schedule. Additionally, PAR filed our flight plans as required by local Air Traffic Control (ATC) prior to each mission.

PAR monitored weather and atmospheric conditions and conducted lidar missions only when no conditions exist below the sensor that will affect the collection of data. These conditions include leaf-off for hardwoods, no snow, rain, fog, smoke, mist and low clouds. lidar systems are active sensors, not requiring light, thus missions may be conducted during night hours when weather restrictions do not prevent collection. PAR accesses reliable weather sites and indicators (webcams) to establish the highest probability for successful collection in order to position our sensor to maximize successful data acquisition.

Within 72-hours prior to the planned day(s) of acquisition, PAR closely monitored the weather, checking all sources for forecasts at least twice daily. As soon as weather conditions were conducive to acquisition, our aircraft mobilized to the project site to begin data collection. Once on site, the acquisition team took responsibility for weather analysis.

PAR's lidar sensors are calibrated at a designated site located at the Shreveport downtown Airport in Shreveport LA and are periodically checked and adjusted to minimize corrections at project sites.

The lidar survey was conducted between May 11, 2017 and June 9, 2017.

Lidar System Parameters

PAR operated a Cessna 206\G (Tail # N799AC) outfitted with a LEICA ALS70cm LiDAR system (S/N 7169) during the collection of the study area.

Table 1 lists PAR's system parameters for lidar acquisition on this project.

Item	Parameter
System	Leica ALS-70 HP
Altitude (AGL meters)	1525
Approx. Flight Speed (knots)	115
Scanner Pulse Rate (kHz)	356.6
Scan Frequency	48.4
Pulse Duration of the Scanner (nanoseconds)	10
Pulse Width of the Scanner (m)	3
Swath width (m)	1110.11

Central Wavelength of the Sensor Laser (nanometers)	1064
Did the Sensor Operate with Multiple Pulses in The Air? (yes/no)	Yes
Beam Divergence (milliradians)	0.22
Nominal Swath Width on the Ground (m)	1110.11
Swath Overlap (%)	30
Total Sensor Scan Angle (degree)	40
Computed Down Track spacing (m) per beam	1.22
Computed Cross Track Spacing (m) per beam	0.76
Nominal Pulse Spacing (single swath), (m)	0.44
Nominal Pulse Density (single swath) (ppsm), (m)	5.2
Aggregate NPS (m) (if ANPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.44
Aggregate NPD (m) (if ANPD was designed to be met through single coverage, ANPD and NPD will be equal)	5.2
Maximum Number of Returns per Pulse	7

Table 1. Precision Aerial Reconnaissance's lidar system parameters.

Acquisition Status Report and Flight Lines

Upon notification to proceed, the flight crew loaded the flight plans and validated the flight parameters. The Acquisition Manager contacted air traffic control and coordinated flight pattern requirements. Lidar acquisition began immediately upon notification that control base stations were in place. During flight operations, the flight crew monitored weather and atmospheric conditions. Lidar missions were flown only when no condition existed below the sensor that would affect the collection of data. The pilot constantly monitored the aircraft course, position, pitch, roll, and yaw of the aircraft. The sensor operator monitored the sensor, the status of PDOPs, and performed the first Q/C review during acquisition. The flight crew constantly reviewed weather and cloud locations. Any flight lines impacted by unfavorable conditions were marked as invalid and re-flown immediately or at an optimal time.

Figure 1 shows the combined trajectory of the flight lines.

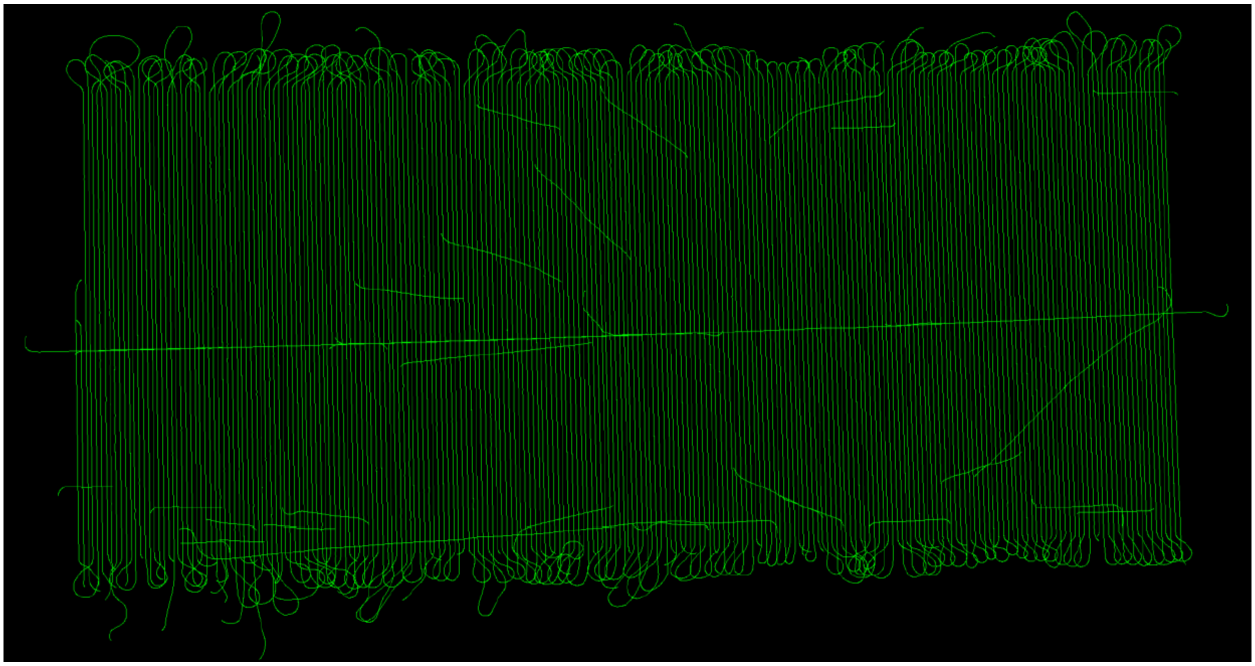


Figure 1. Trajectories as flown by PAR.

Lidar Ground Control

Three existing NGS monuments base stations listed in Table 2 were used to control the lidar acquisition for the South Dakota Lidar project area. A Trimble R10 GNSS receiver logging at 2 Hertz affixed to a 2-meter range pole was used that the base stations during acquisition. The coordinates of all used base stations are provided in Table 2.

Name	NAD83 (2011) UTM 13		Ellipsoid Ht (m)	Orthometric Ht (NAVD88 Geoid12B, m)
	Easting X (m)	Northing Y (m)		
D07-2	734958.672	4990735.272	765.363	785.626
QT0500	654237.305	4988786.984	870.503	888.468
PU2653	589874.865	4954601.724	951.306	966.754

Table 2. Listing of NGS monuments used for ground control of the lidar data.

Airborne GPS Kinematic

GPS and IMU processing reports are included in the Acquisition report: Appendix A.

Generation and Calibration of Laser Points

The initial step of calibration is to verify availability and status of all needed GPS and Laser data against field notes and compile any data if not complete.

Subsequently the mission points are output using Leica's Cloud Pro, initially with default values from Leica or the last mission calibrated for the system. The initial point generation for each mission calibration is verified within Microstation/Terrascan for calibration errors. If a calibration error greater than specification is observed within the mission, the roll, pitch and scanner scale corrections that need to be applied are calculated. The missions with the new calibration values are regenerated and validated internally once again to ensure quality.

Data collected by the lidar unit is reviewed for completeness as illustrated in Figure 2, acceptable density and to make sure all data is captured without errors or corrupted values. In addition, all GPS, aircraft trajectory, mission information, and ground control files are reviewed and logged into a database.

On a project level, a supplementary coverage check is carried out to ensure no data voids unreported by Field Operations are present.

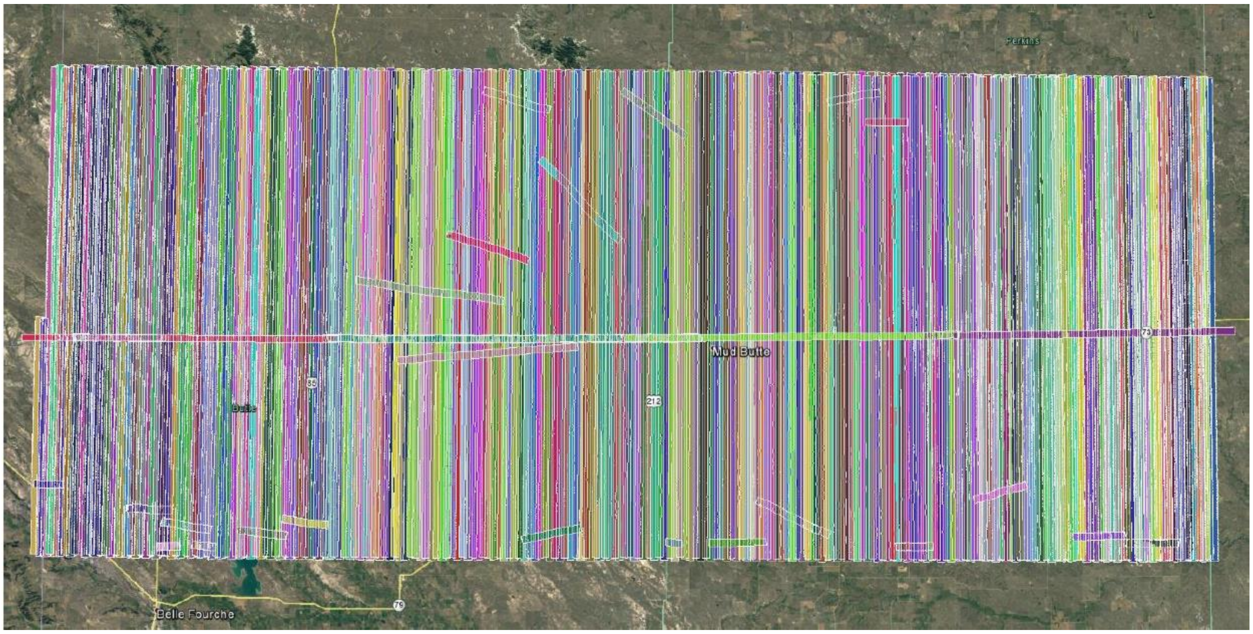


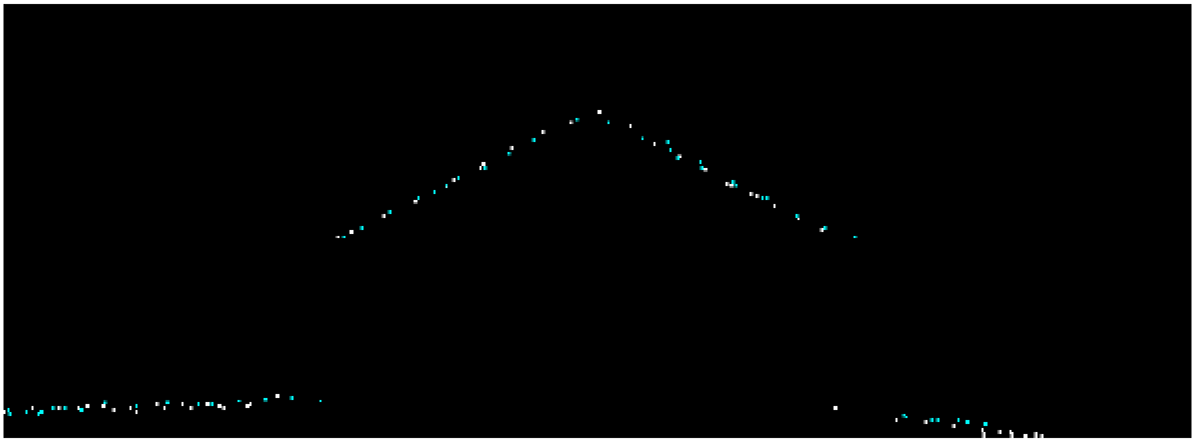
Figure 2. Lidar Swath output showing complete coverage.

Boresight and Relative Accuracy

The initial points for each mission calibration are inspected for flight line errors, flight line overlap, slivers or gaps in the data, point data minimums, or issues with the lidar unit or GPS. Roll, pitch and scanner scale are optimized during the calibration process until the relative accuracy is met.

Relative accuracy and internal quality are checked using at least 3 regularly spaced QC blocks in which points from all lines are loaded and inspected. Vertical differences between ground surfaces of each line are displayed. Color scale is adjusted so that errors greater than the specifications are flagged. Cross sections are visually inspected across each block to validate point to point, flight line to flight line and mission to mission agreement. An example of this review is illustrated in Figure 3.

For this project the specifications used are as follows:
Relative accuracy <= 8 cm maximum differences within individual swaths and <=16 cm RMSDz between adjacent and overlapping swaths.



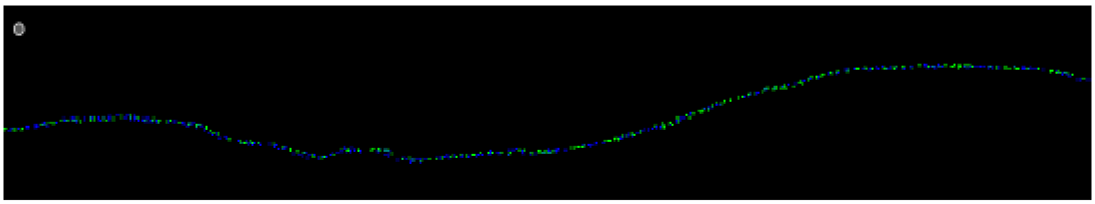


Figure 3. Profile views showing correct roll and pitch adjustments.

A different set of QC blocks are generated for final review after all transformations have been applied.

Lidar Processing & Quantitative Assessment

Initial Processing

PAR delivered the calibrated lidar swath data to Dewberry for processing. Dewberry performed several validations on the dataset prior to starting full-scale production on the project. These validations include vertical accuracy of the swath data, inter-swath (between swath) relative accuracy validation, intra-swath (within a single swath) relative accuracy validation, verification of horizontal alignment between swaths, and confirmation of point density and spatial distribution. This initial assessment allows Dewberry to determine if the data are suitable for full-scale production. Addressing issues at this stage allows the data to be corrected while imposing the least disruption possible on the overall production workflow and overall schedule.

Final Swath Vertical Accuracy Assessment

Once Dewberry received the calibrated swath data from PAR, Dewberry tested the vertical accuracy of the non-vegetated terrain swath data prior to additional processing. Dewberry tested the vertical accuracy of the swath data using one hundred and one (101) non-vegetated (open terrain and urban) independent survey check points. The vertical accuracy is tested by comparing survey checkpoints in non-vegetated terrain to a triangulated irregular network (TIN) that is created from the raw swath points. Only checkpoints in non-vegetated terrain can be tested against raw swath data because the data has not undergone classification techniques to remove vegetation, buildings, and other artifacts from the ground surface. Checkpoints are always compared to interpolated surfaces from the lidar point cloud because it is unlikely that a survey checkpoint will be located at the location of a discrete lidar point. Dewberry typically uses LP360 software to test the swath lidar vertical accuracy, Terrascan software to test the classified lidar vertical accuracy, and Esri ArcMap to test the DEM vertical accuracy so that three different software programs are used to validate the vertical accuracy for each project. Project specifications require a NVA of 19.6 cm based on the $RMSE_z$ (10 cm) x 1.96. The dataset for the South Dakota QL2+

Lidar Project satisfies this criteria. This raw lidar swath data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm $RMSE_z$ Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ = 5.4 cm, equating to +/- 10.5 cm at 95% confidence level. Table 3 shows all calculated statistics for the raw swath data.

100 % of Totals	# of Points	$RMSE_z$ NVA Spec=0.10 m	NVA –Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=0.196 m	Mean (m)	Median (m)	Skew	Std Dev (m)	Min (m)	Max (m)	Kurtosis
Non-Vegetated Terrain	101	0.054	0.105	-0.003	-0.004	-0.316	0.053	-0.190	0.126	0.584

Table 3: NVA at 95% Confidence Level for Raw Swaths

Inter-Swath Relative Accuracy

Dewberry verified inter-swath or between swath relative accuracy of the dataset by creating Delta-Z (DZ) orthos. According to the SOW, USGS Lidar Base Specifications v1.2, and ASPRS Positional Accuracy Standards for Digital Geospatial Data, 10 cm Vertical Accuracy Class or QL2 data must meet inter-swath relative accuracy of 8 cm RMSDz or less with maximum differences less than 16 cm. These measurements are to be taken in non-vegetated and flat open terrain using single or only returns from all classes. Measurements are calculated in the DZ orthos on 1-meter pixels or cell sizes. Areas in the dataset where overlapping flight lines are within 8 cm of each other within each pixel are colored green, areas in the dataset where overlapping flight lines have elevation differences in each pixel between 8 cm to 16 cm are colored yellow, and areas in the dataset where overlapping flight lines have elevation differences in each pixel greater than 16 cm are colored red. Pixels that do not contain points from overlapping flight lines are colored according to their intensity values. Areas of vegetation and steep slopes (slopes with 16 cm or more of valid elevation change across 1 linear meter) are expected to appear yellow or red in the DZ orthos. If the project area is heavily vegetated, Dewberry may also create DZ Orthos from the initial ground classification only, while keeping all other parameters consistent. This allows Dewberry to review the ground classification relative accuracy beneath vegetation and to ensure flight line ridges or other issues do not exist in the final classified data.

Flat, open areas are expected to be green in the DZ orthos. Large or continuous sections of yellow or red pixels can indicate the data was not calibrated correctly or that there were issues during acquisition that could affect the usability of the data, especially when these yellow/red sections follow the flight lines and not the terrain or areas of vegetation. The DZ orthos for the South Dakota QL2+ Lidar Project are shown in Figure 4; this project meets inter-swath relative accuracy specifications.

Figure 4. Delta-Z orthoimage raster generated to test inter-swath relative accuracy. Areas in the dataset where overlapping flight lines are within 8 cm of each other within each pixel are colored green, areas in the dataset where overlapping flight lines have elevation differences in each pixel between 8 cm to 16 cm are colored yellow, and areas in the dataset where overlapping flight lines have elevation differences in each pixel greater than 16 cm are colored red.

Intra-Swath Relative Accuracy

Dewberry verifies the intra-swath or within swath relative accuracy by using Quick Terrain Modeler (QTM) scripting and visual reviews. QTM scripting is used to calculate the maximum difference of all points within each 1-meter pixel/cell size of each swath. Dewberry analysts then identify planar surfaces acceptable for repeatability testing and analysts review the QTM results in those areas. According to the SOW, USGS Lidar Base Specifications v1.2, and ASPRS Positional Accuracy Standards for Digital Geospatial Data, 10 cm Vertical Accuracy Class or QL2 data must meet intra-swath relative accuracy of 6 cm maximum difference or less. Figure 5 shows two examples of the intra-swath relative accuracy of the South Dakota QL2+ lidar data; this project meets intra-swath relative accuracy specifications.

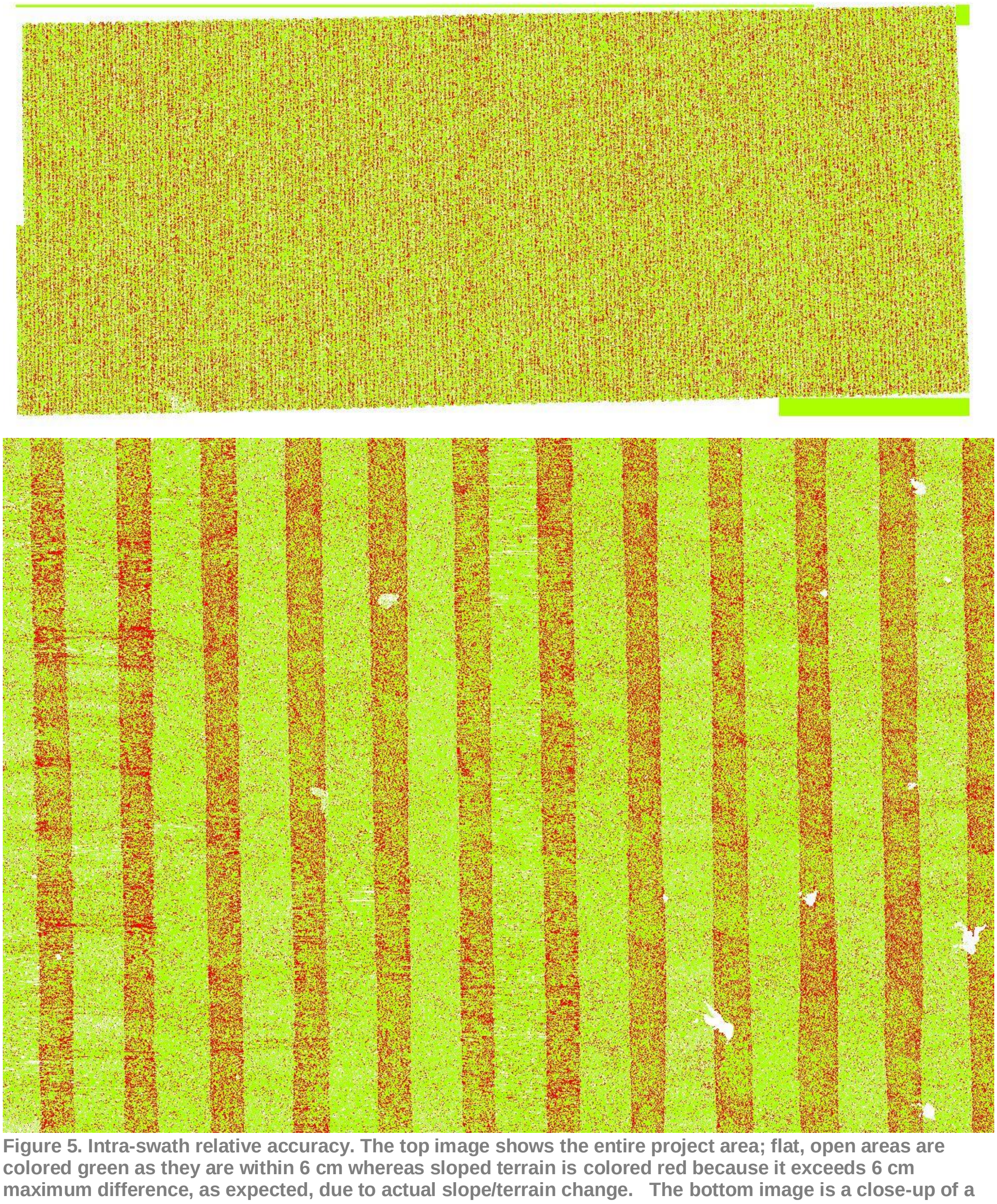


Figure 5. Intra-swath relative accuracy. The top image shows the entire project area; flat, open areas are colored green as they are within 6 cm whereas sloped terrain is colored red because it exceeds 6 cm maximum difference, as expected, due to actual slope/terrain change. The bottom image is a close-up of a flat area. With the exception of vegetated areas (shown as red speckling/mottling as the elevation/height difference in vegetated areas will exceed 6 cm) and swath sidelap/overlap (red striping), this open flat area is acceptable for repeatability testing. Intra-swath relative accuracy passes specifications.

Horizontal Alignment

To ensure horizontal alignment between adjacent or overlapping flight lines, Dewberry uses QTM scripting and visual reviews. QTM scripting is used to create files similar to DZ orthos for each swath but this process highlights planar surfaces, such as roof tops. In particular, horizontal shifts or misalignments between swaths on roof tops and other elevated planar surfaces are highlighted. Visual reviews of these features, including additional profile verifications, are used to confirm the results of this process. Figure 6 shows an example of the horizontal alignment between swaths for the South Dakota QL2+ lidar data.

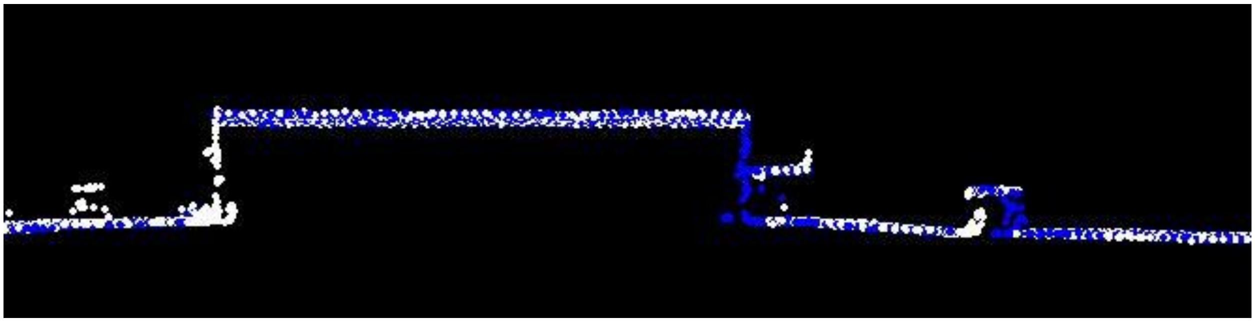


Figure 6. Profile of a lidar point cloud cross section of a buildings. Points are colorized by flight line number.

Point Density and Spatial Distribution

The required Aggregate Nominal Point Spacing (ANPS) for this project is no greater than 0.5 meters, which equates to an Aggregate Nominal Point Density (ANPD) of 4 points per square meter or greater. Density calculations were performed using first return data only located in the geometrically usable center portion (typically ~90%) of each swath. By utilizing statistics, the project area was determined to have an ANPS of 0.35 meters or an ANPD of 8 points per square meter which satisfies the project requirements.

The spatial distribution of points must be uniform and free of clustering. This specification is tested by creating a grid with cell sizes equal to the design NPS*2. QTM scripting is then used to calculate the number of first return points of each swath within each grid cell. At least 90% of the cells must contain 1 lidar point, excluding acceptable void areas such as water or low NIR reflectivity features, i.e. some asphalt and roof composition materials.

To perform this test, Dewberry generated a Spatial Distribution raster grid from first-return lidar points illustrated in Figure 7. This grid was generated for all tiles that intersect the project area. Tiles populated with lidar data but are outside of the project area were omitted from this test. Dewberry calculated the number of raster cells in the Spatial Distribution raster that contain at least one lidar point. Based on this calculation, 99.8% of cells contain at least one lidar point for all tiles intersecting the project area.

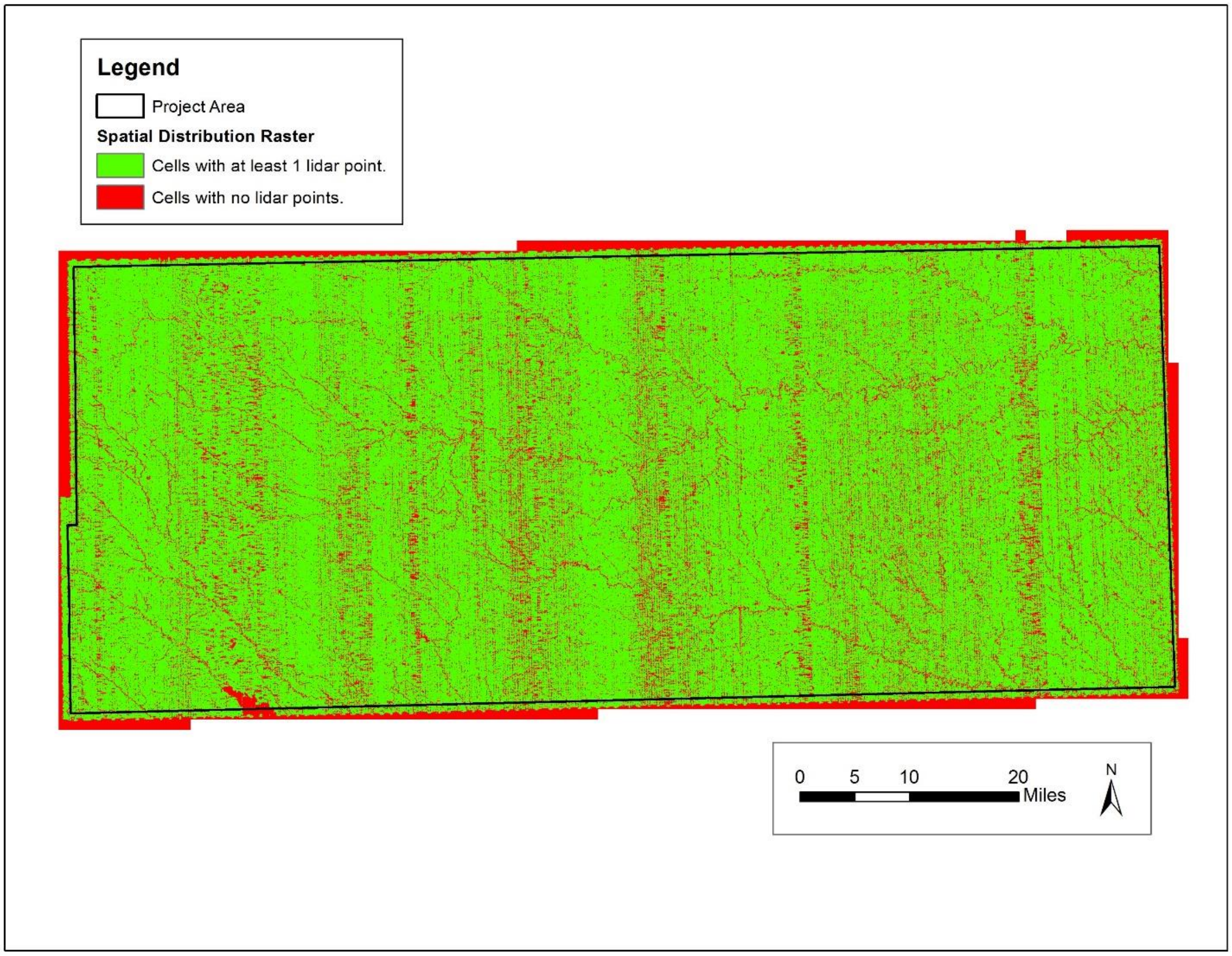


Figure 7. Raster generated from first-return lidar pulses to test spatial distribution of the lidar data.

Data Classification and Editing

Once the calibration, absolute swath vertical accuracy, and relative accuracy of the data was confirmed, Dewberry utilized a variety of software suites for data processing. The data was processed using GeoCue and TerraScan software. The initial step is the setup of the GeoCue project, which is done by importing a project defined tile boundary index encompassing the entire project area. The acquired 3D laser point clouds, in LAS binary format, were imported into the GeoCue project and tiled according to the project tile grid. Once tiled, the laser points were classified using a proprietary routine in TerraScan. This routine classifies any obvious low outliers in the dataset to class 7 and high outliers in the dataset to class 18. Points along flight line edges that are geometrically unusable are identified as withheld and classified to a separate class so that they will not be used in the initial ground algorithm. After points that could negatively affect the ground are removed from class 1, the ground layer is extracted from this remaining point cloud. The ground extraction process encompassed in this routine takes place by building an iterative surface model.

This surface model is generated using three main parameters: building size, iteration angle and iteration distance. The initial model is based on low points being selected by a "roaming window" with the assumption that these are the ground points. The size of this roaming window is determined by the building size parameter. The low points are triangulated and the remaining points are evaluated and subsequently added to the model if they meet the iteration angle and distance constraints. This process is repeated until no additional points are added within iterations. A second critical parameter is the maximum terrain angle constraint, which determines the maximum terrain angle allowed within the classification model.

Each tile was then imported into Terrascan and a surface model was created to examine the ground classification. Dewberry analysts visually reviewed the ground surface model and corrected errors in the ground classification such as vegetation, buildings, and bridges that were present following the initial processing conducted by Dewberry. Dewberry analysts employ 3D visualization techniques to view the point cloud at multiple angles and in profile to ensure that non-ground points are removed from the ground classification. Bridge decks are classified to class 17 using bridge breaklines compiled by Dewberry. After the ground classification corrections were completed, the dataset was processed through a water classification routine that utilizes breaklines compiled by Dewberry to automatically classify hydro features. The water classification routine selects ground points within the breakline polygons and automatically classifies them as class 9, water. During this water classification routine, points that are within 1x NPS or less of the hydrographic features are moved to class 10, an ignored ground due to breakline proximity. Overage points are then identified in Terrascan and GeoCue is used to set the overlap bit for the overage points and the withheld bit is set on the withheld points previously identified in Terrascan before the ground classification routine was performed.

The lidar tiles were classified to the following classification schema:

- Class 1 = Unclassified, used for all other features that do not fit into the Classes 2, 7, 9, 10, 17, or 18, including vegetation, buildings, etc.
- Class 2 = Bare-Earth Ground
- Class 7 = Low Noise
- Class 9 = Water, points located within collected breaklines
- Class 10 = Ignored Ground due to breakline proximity
- Class 17 = Bridge Decks
- Class 18 = High Noise

After manual classification, the LAS tiles were peer reviewed and then underwent a final QA/QC. After the final QA/QC and corrections, all headers, appropriate point data records, and variable length records, including spatial reference information, are updated in GeoCue software and then verified using proprietary Dewberry tools.

Lidar Qualitative Assessment

Dewberry's qualitative assessment utilizes a combination of statistical analysis and interpretative methodology or visualization to assess the quality of the data for a bare-earth digital terrain model (DTM). This includes creating pseudo image products such as lidar orthos produced from the intensity returns, Triangular Irregular Network (TIN)'s, Digital Elevation Models (DEM) and 3-dimensional models as well as reviewing the actual point cloud data. This process looks for anomalies in the data, areas where man-made structures or vegetation points may not have been classified properly to produce a bare-earth model, and other classification errors. This report will present representative examples where the lidar and post processing had issues as well as examples of where the lidar performed well.

Visual Review

The following sections describe common types of issues identified in lidar data and the results of the visual review for the South Dakota QL2+ lidar data.

Data Voids

Dewberry identified several voids in the lidar data that were larger than USGS' tolerance for acceptable data voids as defined in the task order. According to the USGS Lidar Base Specification, data voids are gaps in point cloud coverage greater or equal to $(4*ANPS)^2$ measured using only first returns within a single swath.

Therefore any data voids larger than 4 square meters are not acceptable unless they are caused by water bodies, low near infra-red (NIR) reflectivity such as asphalt or composition roofing, or where appropriately filled-in by another swath.

Dewberry tested the entire project area for data voids using USGS' parameters. This test is based on a 1 meter raster generated using first return lidar pulses where cells are classified based on the number of discrete returns. Using this raster, cells not containing any lidar pulses were converted to polygons and stored in an Esri geodatabase. The total area of each polygon is calculated, and those greater or equal to 4 square meters are saved as the test result. Dewberry also removed all voids that were caused by water bodies and would not be cause for rejection. An overview map of these void polygons is provided in Figure 8. These voids are more prevalent in specific swaths, however they were detected throughout the project area.

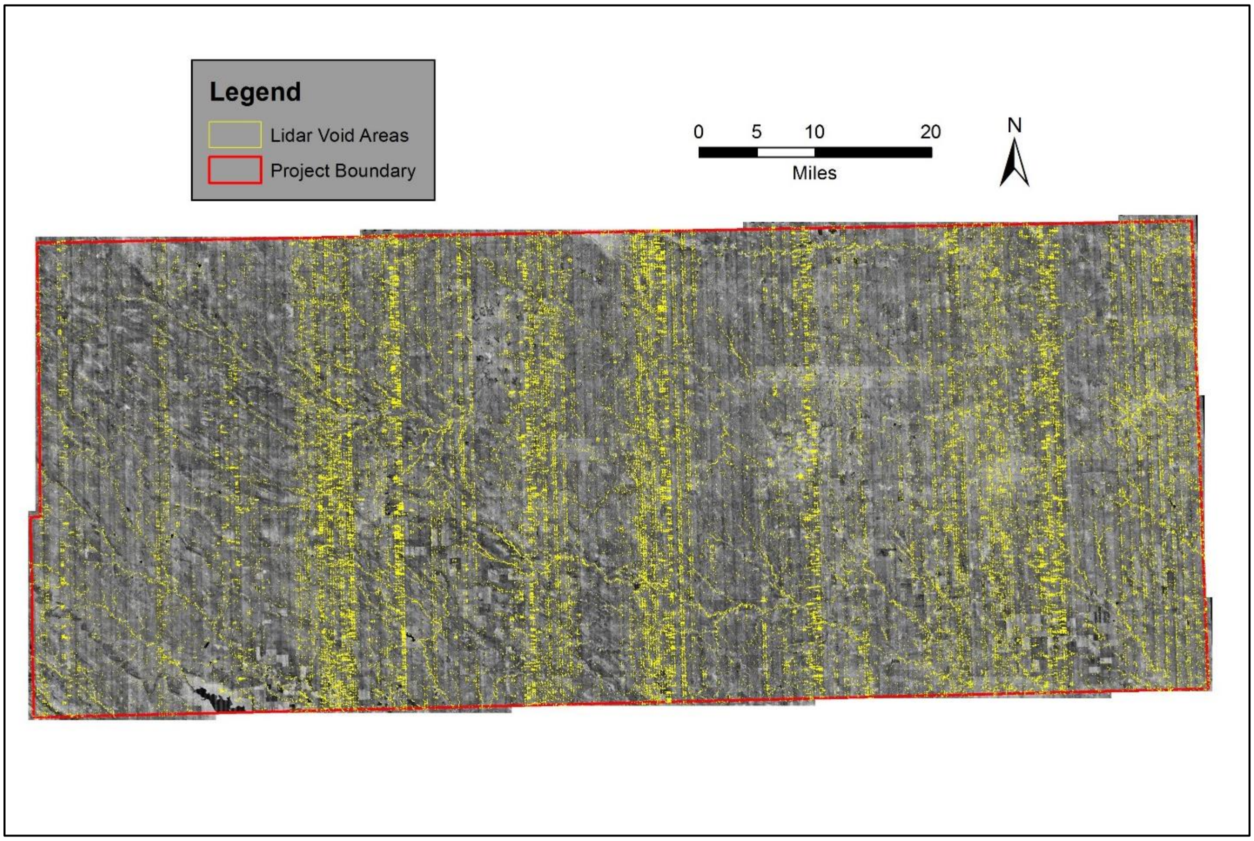


Figure 8. Project overview of lidar data void polygons greater than 4 square meters.

Dewberry further examined these voids to determine their impact on the bare earth DEM. Figure 9 shows the bare earth DEM overlaid with the void polygons at 1:1,200 scale. The profile drawn along the road surface in Figure 9 descends approximately 40 cm across the transect. This profile does not present any divots greater than 6 cm that are the result of the voids. Also, the bare earth DEM does not present any artifacts in the void areas. While some cornrowing is present and visible in the DEMs, the cornrowing does not exceed 6 cm.

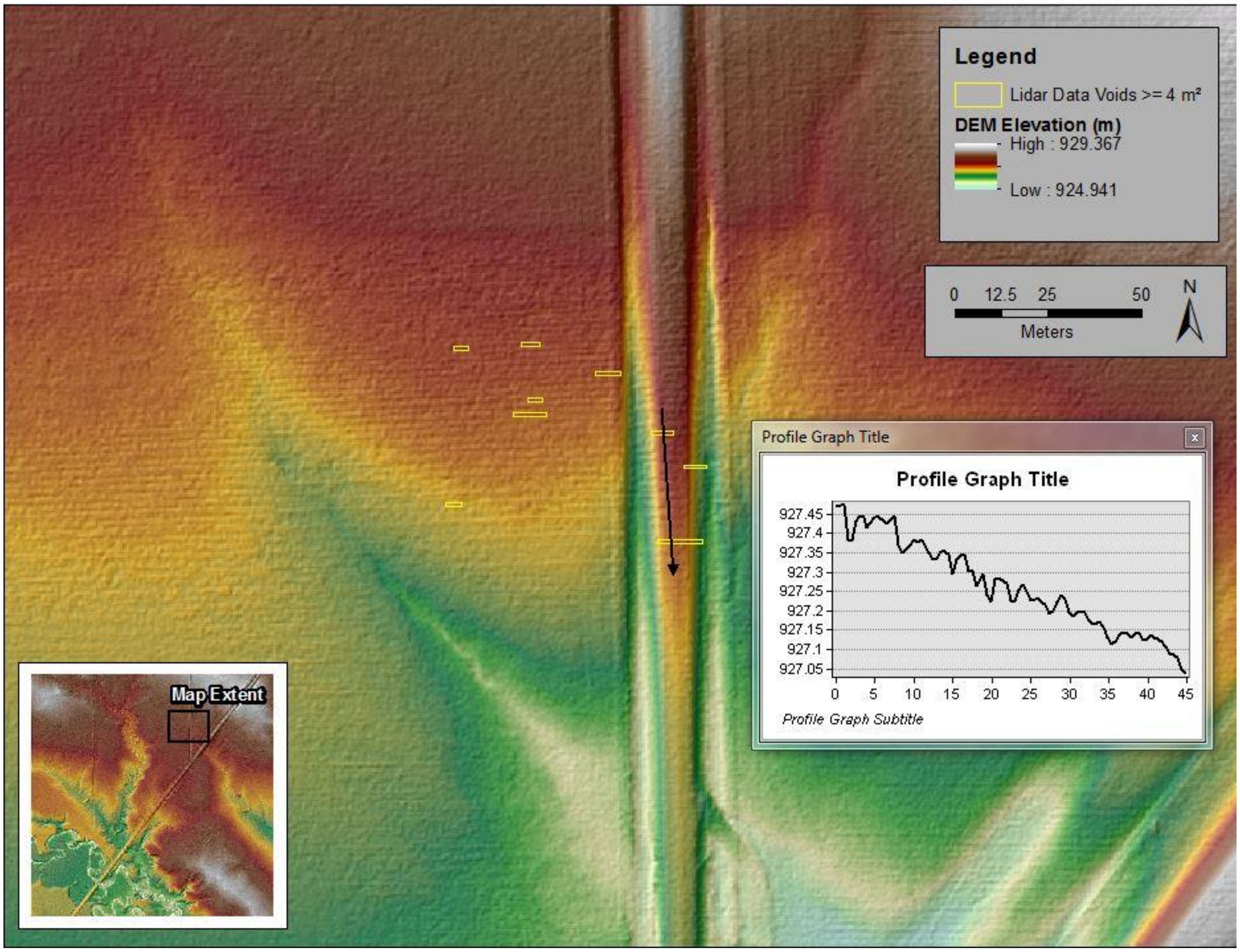
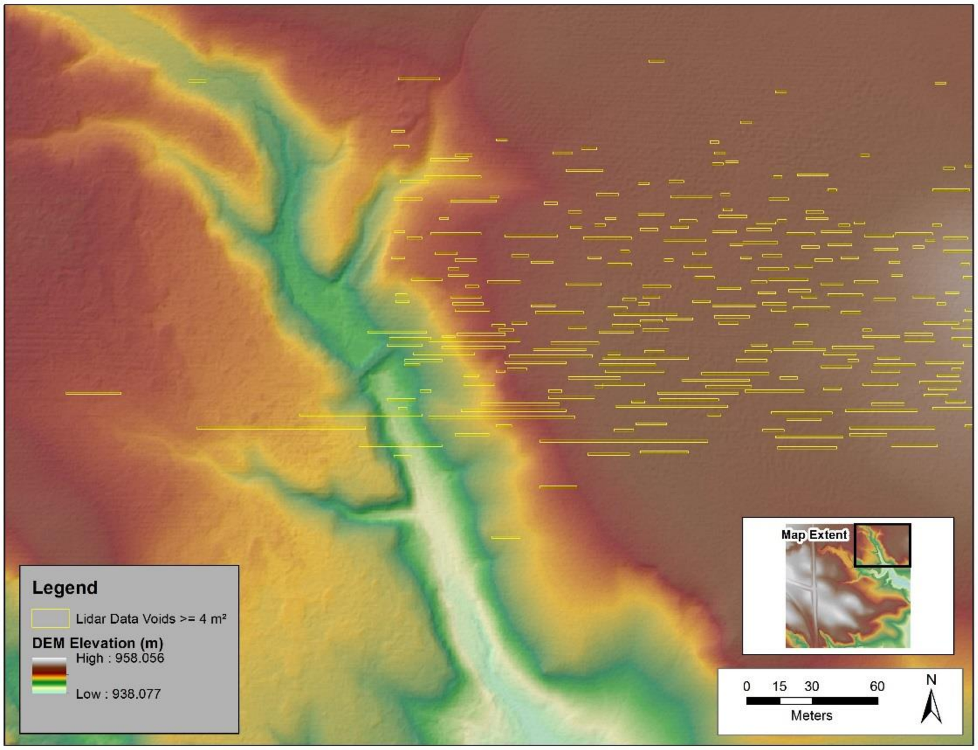


Figure 9. Example of bare earth DEM overlaid with lidar data void polygons viewed at 1:1,200 scale. The profile of the road surface does not present any divots or cornrowing greater than 6 cm caused by voids in the lidar point cloud data.

Dewberry examined the bare earth DEM in the northeast corner of the tile where the voids are more pronounced. Dewberry's review of the DEM shown in Figure 10 did not identify any interpolation errors, divots, or artifacts that would affect the usability of the DEM for surface modeling.



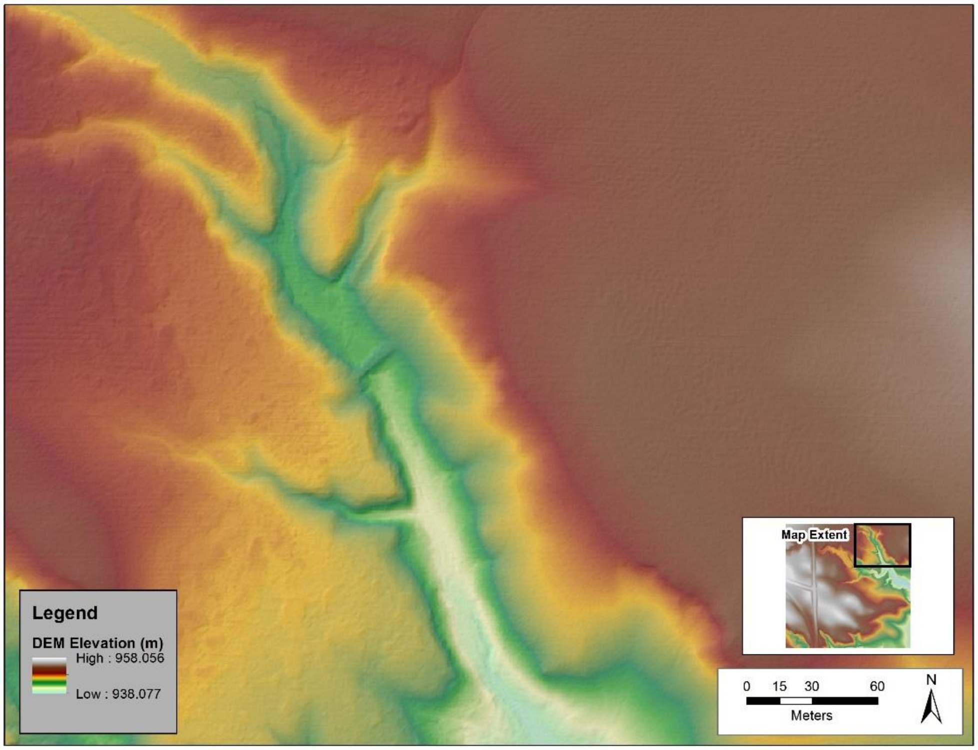


Figure 10. Top view: Example of bare earth DEM overlaid with lidar data void polygons viewed at 1:1,600 scale. Bottom view: The bare earth DEM does not portray any artifacts that would affect the usability of the DEM for surface modeling.

Dewberry also generated elevation profiles across the void areas in the DEM to determine if any divots or artifacts were present. Figure 11 shows an example of a profile drawn across a slope in the DEM where the elevation decreases 2 meters. The elevation profile does not show any noticeable divots or artifacts that would affect surface modeling based from this DEM.

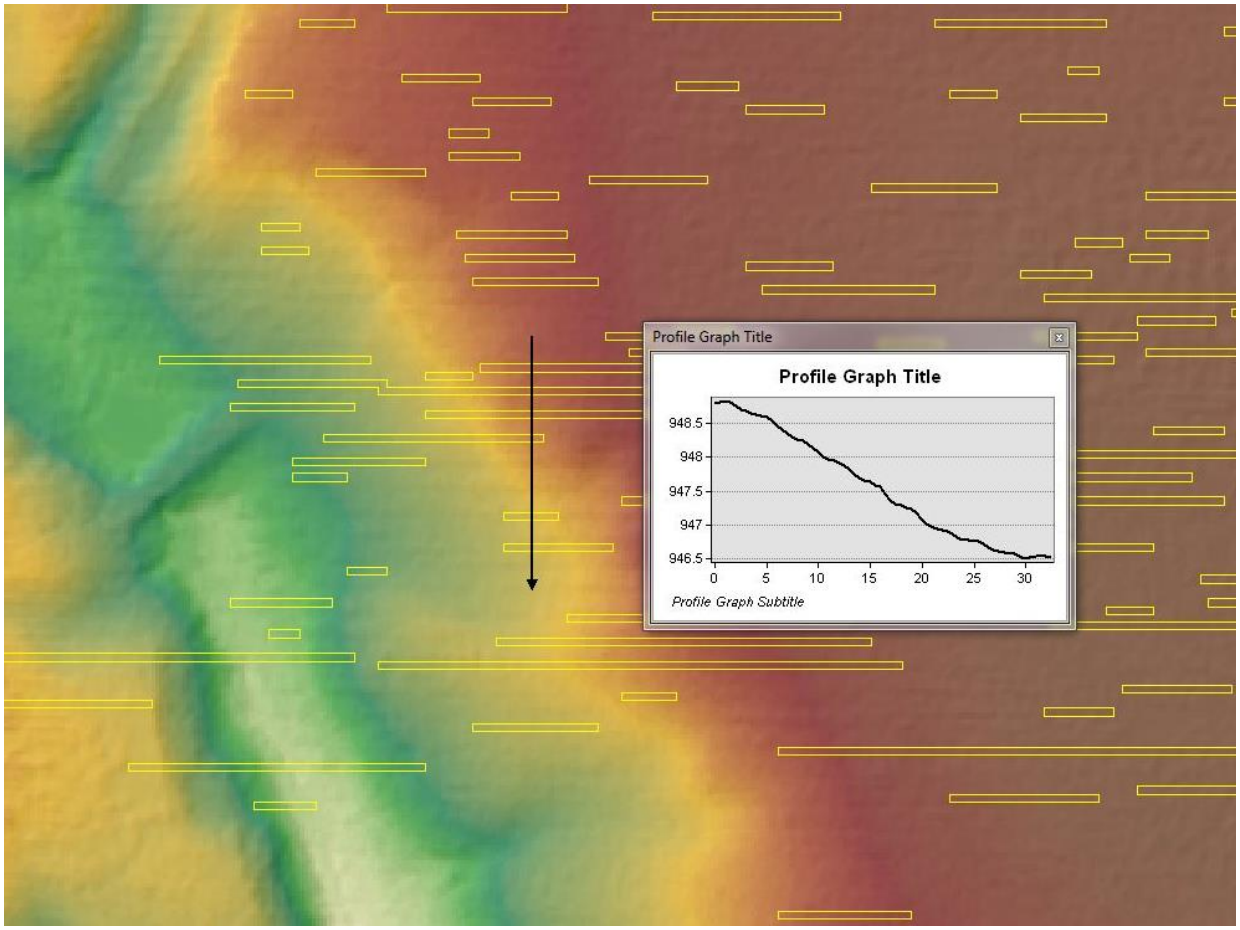


Figure 11. Elevation profile drawn over a 2-meter slope in the DEM. This example does not portray any divots or artifacts that would affect surface modeling and is representative of other areas tested in the DEM.

The voids in the lidar point cloud data account for less than one half of one percent (0.05%) of the overall project area. Furthermore, based on Dewberry's examination of the data, these voids do not appear to affect the usability of the bare earth DEM product. After discussing this issue with USGS, Dewberry received guidance to proceed with data production on the entire project.

Boulders

During the visual review of the lidar data, the PAR team identified numerous boulders throughout the project area as illustrated in Figure 12. PAR contacted USGS for guidance on how boulders should be classified. In an email from USGS' Amanda Lowe dated December 19, 2017, we were advised, "Boulders are Bare earth. Do not remove." Hence, boulders were included in Class 2 (Bare Ground).

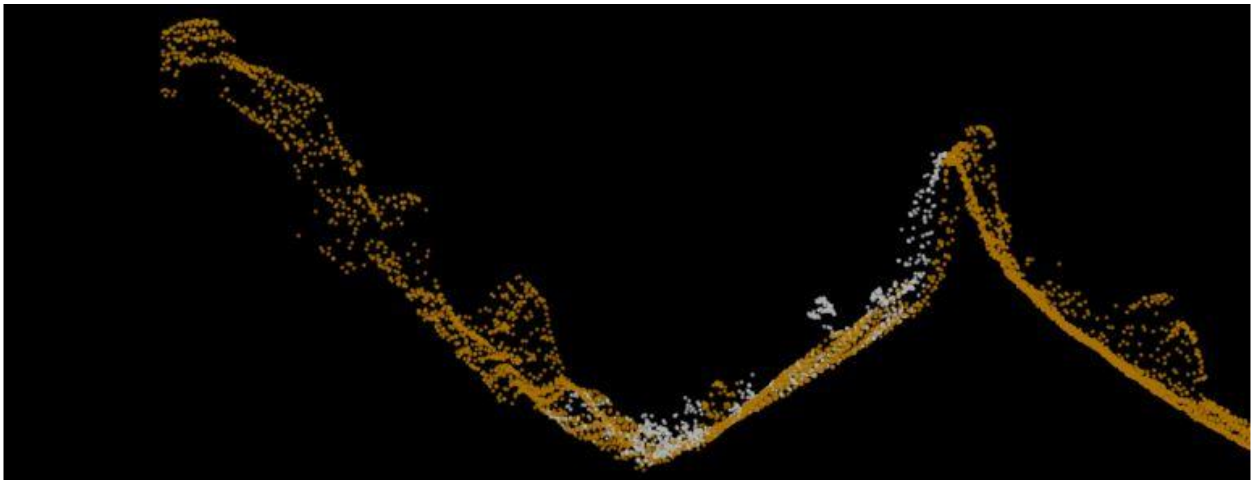


Figure 12. Example of boulders that were identified throughout the project area. Boulders are classified as Class 2 (Bare Ground) in the point cloud data.

Formatting

After the final QA/QC is performed and all corrections have been applied to the dataset, all lidar files are updated to the final format requirements and the final formatting, header information, point data records, and variable length records are verified using Dewberry proprietary tools. Table 4 lists some of the main lidar header fields that are updated and verified.

Classified Lidar Formatting		
Parameter	**Requirement**	**Pass/Fail**
LAS Version	1.4	Pass
Point Data Format	Format 6	Pass
Coordinate Reference System	NAD83 (2011) Universal Transverse Mercator (UTM) Zone 13 North, meters and NAVD88 (Geoid 12B), meters in WKT Format	Pass
Global Encoder Bit	Should be set to 17 for Adjusted GPS Time	Pass
Time Stamp	Adjusted GPS Time (unique timestamps)	Pass
System ID	Should be set to the processing system/software and is set to NIIRS10 for GeoCue software	Pass
Multiple Returns	The sensor shall be able to collect multiple returns per pulse and the return numbers are recorded	Pass
Intensity	16 bit intensity values are recorded for each pulse	Pass
Classification	Required Classes include: Class 1: Unclassified Class 2: Ground Class 7: Low Noise Class 9: Water Class 10: Ignored Ground Class 17: Bridge Decks Class 18: High Noise	Pass

Overlap and Withheld Points	Overlap (Overage) and Withheld points are set to the Overlap and Withheld bits	Pass
Scan Angle	Recorded for each pulse	Pass
XYZ Coordinates	Unique Easting, Northing, and Elevation coordinates are recorded for each pulse	Pass

Table 4. Classified Lidar Formatting.

Lidar Positional Accuracy

Background

Dewberry quantitatively tested the dataset by testing the vertical accuracy of the lidar. The vertical accuracy is tested by comparing the discreet measurement of the survey checkpoints to that of the interpolated value within the three closest lidar points that constitute the vertices of a three-dimensional triangular face of the TIN. Therefore, the end result is that only a small sample of the lidar data is actually tested. However there is an increased level of confidence with lidar data due to the relative accuracy. This relative accuracy in turn is based on how well one lidar point "fits" in comparison to the next contiguous lidar measurement, and is verified as part of the initial processing. If the relative accuracy of a dataset is within specifications and the dataset passes vertical accuracy requirements at the location of survey checkpoints, the vertical accuracy results can be applied to the whole dataset with high confidence due to the passing relative accuracy. Dewberry typically uses LP360 software to test the swath lidar vertical accuracy, Terrascan software to test the classified lidar vertical accuracy, and Esri ArcMap to test the DEM vertical accuracy so that three different software programs are used to validate the vertical accuracy for each project.

Survey Vertical Accuracy Checkpoints

For the final vertical accuracy assessment, one hundred eighty-nine (189) check points were surveyed for the project and are located within bare earth/open terrain, grass/weeds/crops, and forested/fully grown land cover categories. Please see the included survey report found in the survey folder of the deliverables structure which details and validates how the survey was completed for this project.

Checkpoints were evenly distributed throughout the project area so as to cover as many flight lines as possible using the “dispersed method” of placement.

Table 5 lists the location of the QA/QC checkpoints used to test the positional accuracy of the dataset.

Point ID	NAD83(2011)/UTM Zone 13N		NAVD88 (Geoid 12B)
	Easting X (m)	Northing Y (m)	Elevation (m)
9	636603.292	4960676.634	882.478
32	645651.293	4968211.769	900.451
38	691665.636	4972322.156	804.048
56	658864.955	4977850.666	845.803
97	635504.861	4994715.809	867.168

101	665959.379	4994314.357	814.883
117	619074.542	5000606.599	893.004
120	642717.565	5002114.265	922.747
121	649364.547	5000296.538	880.219
122	659935.080	5001302.883	844.903
123	665478.974	5002312.009	814.344
124	671952.840	5007332.133	804.627
161	620875.679	5020560.967	932.594
2004	600728.340	4959007.429	928.237
2016	684746.837	4962488.107	856.540
2020	719247.653	4963488.315	757.079
2024	585722.690	4965787.557	944.370
2026	600268.930	4967870.427	895.938
2029	624412.707	4968174.605	914.816
2031	635400.130	4969295.715	949.633
2040	704824.953	4970709.093	784.728
2042	718586.894	4969918.639	752.964
2044	733422.999	4972057.869	718.065
2045	577526.630	4977333.832	982.597
2046	583725.328	4974710.819	997.565
2047	590364.316	4976835.568	961.009
2048	596854.418	4976747.220	969.907
2054	643688.818	4976994.743	860.846
2060	691476.496	4978722.222	844.301
2064	717089.603	4979504.374	755.581
2068	584221.283	4983747.551	991.131
2070	596715.670	4985426.341	1021.375
2072	616104.382	4985472.812	964.856
2073	624109.680	4986215.484	951.611
2075	639227.720	4986661.494	912.299
2083	695983.603	4988487.759	867.469
2084	702376.612	4987540.288	865.265
2090	586676.369	4991842.199	1006.157
2094	614245.827	4993481.906	892.609
2098	646076.115	4992909.406	826.226
2102	673180.766	4994518.904	823.347
2106	704095.925	4995156.020	796.297
2110	733117.301	4996329.672	770.463
2112	585367.903	5001458.181	1006.213
2114	599303.207	5002500.876	963.136
2116	614101.316	5001325.932	892.056
2126	687545.068	5004542.333	788.878
2132	732849.618	5004633.801	739.194
2134	585387.014	5009748.521	1017.284
2136	598747.756	5007951.125	933.094
2138	613878.472	5009721.210	963.488
2140	628846.706	5014310.494	943.968
2142	643025.552	5012989.358	870.989

2146	673116.603	5010957.656	850.438
2148	686044.709	5012138.684	831.630
2150	702213.993	5013724.873	779.188
2158	599415.585	5017088.962	981.337
2159	607056.788	5017172.319	964.118
2160	613791.140	5018261.915	951.453
2164	644077.119	5019336.649	887.351
2172	701744.675	5019473.515	765.634
2174	716746.041	5023216.994	815.240
2176	732229.683	5021307.453	728.333
2200	590692.400	4956581.837	1010.063
2201	590995.616	4964497.758	919.804
2202	596698.695	4969754.146	905.019
2203	603455.834	4973947.460	942.272
2204	610516.367	4978300.677	978.910
2205	581636.747	5013807.756	1049.156
2207	596570.217	4993598.461	978.773
2210	606380.041	5004085.505	916.235
2211	611338.718	5005992.948	920.591
2212	620271.966	5014206.679	936.038
2215	614853.080	4956497.978	865.695
2216	624588.329	4957856.341	875.035
2217	632868.868	4958155.122	876.139
2218	649336.818	4971113.070	877.120
2220	661523.342	5016706.080	928.301
2222	716088.561	5011878.804	735.113
2223	724032.908	5007314.843	710.092
2225	701630.169	4962131.069	762.483
3079	667306.608	4985710.210	876.810
3080	678939.608	4987951.707	922.451
3081	684996.610	4988281.607	923.229
3082	689573.663	4988295.731	875.471
3083	695629.815	4988485.876	868.756
3087	732787.170	4990044.586	793.762
3088	732834.577	4989213.867	777.085
3109	733486.740	4989830.468	790.493
3110	733459.904	4989236.870	781.797
3132	734863.974	4990821.231	785.719
4058	675271.404	4977036.429	814.446
4062	705914.668	4978589.412	809.795
4092	597024.111	4992614.871	973.687
125	679752.716	5003503.944	782.811
2080	676183.019	4984741.130	847.820
156A	582191.796	5023219.456	1023.463
D 410	695355.258	4956908.805	820.499
F 410	695333.500	4962069.203	799.489
GCT-SD02	574729.803	4957128.577	977.074
GCT-SD04	647425.263	5023757.389	1068.446

GCT-SD05	693601.068	5022383.629	788.115
GCT-SD06	732238.952	5021319.088	728.569
M 395 Reset	733096.272	4960115.193	691.954
10	646009.624	4957710.543	897.053
162	627596.908	5019160.716	909.575
163	638717.225	5019492.705	905.458
4001	577908.506	4959766.678	974.879
4005	606938.875	4959942.466	878.036
4006	614914.918	4959794.652	893.240
4007	622973.452	4958825.060	878.622
4008	629405.559	4960181.692	880.059
4011	650623.359	4958489.244	903.364
4012	659880.061	4960225.882	866.852
4014	674409.671	4961183.439	900.030
4016	684745.640	4962341.995	857.224
4018	704245.844	4960788.213	736.724
4020	719386.305	4963006.588	763.594
4022	732968.513	4963525.927	723.156
4027	606666.106	4968907.958	932.188
4030	627471.821	4966282.218	885.837
4032	645067.651	4967792.102	913.243
4036	673497.689	4971796.523	796.532
4038	691676.093	4972330.509	803.554
4039	694978.139	4970091.191	806.945
4042	718597.755	4969909.089	752.280
4044	733420.370	4972070.306	718.310
4050	614749.724	4976192.070	956.954
4051	624291.323	4976495.027	926.811
4052	630713.886	4979091.535	932.935
4053	637025.659	4975945.032	912.968
4054	644121.233	4976891.271	859.197
4056	659175.145	4977991.312	839.489
4060	691488.210	4978508.976	840.685
4064	717133.999	4979519.544	752.777
4067	575897.822	4982689.814	1035.027
4073	624107.692	4986201.637	950.843
4076	645251.634	4985233.387	943.038
4079	667215.763	4987761.636	867.555
4080	675411.814	4984715.149	844.162
4082	688450.604	4988271.011	871.430
4083	695243.308	4986893.016	922.451
4083A	695959.668	4988486.826	866.635
4086	718412.103	4988431.642	806.580
4088	732840.957	4988155.581	762.945
4090	586613.419	4992264.753	1006.759
4094	614245.972	4993451.127	892.918
4096	629630.572	4991867.174	890.369
4097	635559.068	4994827.280	864.475

4098	646063.386	4992872.125	825.018
4104	689652.128	4994637.550	830.422
4108	717956.015	4994480.028	790.794
4110	733140.135	4996311.275	770.909
4114	599683.754	5002566.822	970.550
4116	614046.577	5001718.860	893.830
4117	619089.245	5000622.518	893.677
4118	625268.586	5001531.075	897.557
4120	642709.125	5002084.770	922.493
4122	660198.230	5000572.340	843.910
4124	671902.920	5007378.817	803.531
4126	688116.066	5004574.698	780.459
4128	702812.505	5003369.720	734.253
4129	712136.227	4998094.520	751.821
4131	725730.121	5004205.816	732.349
4134	585529.779	5009362.092	1027.367
4138	613906.184	5009745.016	961.472
4139	623478.940	5009925.370	924.286
4140	628858.831	5014303.821	943.525
4144	658919.684	5011332.855	842.161
4146	673123.914	5011003.084	851.499
4148	686089.027	5012136.445	829.871
4152	717362.219	5012355.664	705.426
4157	593041.303	5017159.276	974.958
4160	613797.255	5018291.600	949.296
4164	644082.531	5019365.810	886.631
4167	664848.893	5018880.822	864.891
4168	673044.097	5019425.848	830.906
4172	701698.809	5019497.699	765.525
4174	716760.110	5023184.620	814.225
4176	732319.668	5021267.354	726.661
4200	590687.275	4956571.683	1010.168
4202	596715.826	4969762.624	903.432
4206	580221.484	5020372.110	1046.725
4226	654348.995	4988741.648	883.895
4227	639490.302	5010956.261	922.894
4228	685868.225	5022191.859	803.127
5149	695195.825	5010983.901	794.795
D07-1	734757.951	4990946.407	785.687
D07-2	734958.672	4990735.272	785.626
DRY	590455.161	4956625.818	1016.868
GCT-SD01	614866.578	4956451.772	864.630
GCT-SD03	580180.377	5021245.332	1043.260

Table 5. Ground Surveyed Vertical Accuracy Check Points.

Vertical Accuracy Test Procedures

Non-vegetated Vertical Accuracy

NVA (Non-vegetated Vertical Accuracy) is determined with check points located only in non-vegetated terrain, including open terrain (grass, dirt, sand, and/or rocks) and urban areas, where there is a very high probability that the lidar sensor will have detected the bare-earth ground surface and where random errors are expected to follow a normal error distribution. The NVA determines how well the calibrated lidar sensor performed. With a normal error distribution, the vertical accuracy at the 95% confidence level is computed as the vertical root mean square error (RMSEz) of the checkpoints x 1.9600. For the South Dakota QL2+ Lidar Project, vertical accuracy must be 19.6 cm or less based on an RMSEz of 10 cm x 1.9600.

Vegetated Vertical Accuracy

VVA (Vegetated Vertical Accuracy) is determined with all checkpoints in vegetated land cover categories, including tall grass, weeds, crops, brush and low trees, and fully forested areas, where there is a possibility that the lidar sensor and post-processing may yield elevation errors that do not follow a normal error distribution. VVA at the 95% confidence level equals the 95^{th} percentile error for all checkpoints in all vegetated land cover categories combined. The South Dakota QL2+ lidar project VVA standard is 29.4 cm based on the 95^{th} percentile. The VVA is accompanied by a listing of the 5% outliers that are larger than the 95^{th} percentile used to compute the VVA; these are always the largest outliers that may depart from a normal error distribution. Here, $Accuracy_z$ differs from VVA because $Accuracy_z$ assumes elevation errors follow a normal error distribution where RMSE procedures are valid, whereas VVA assumes lidar errors may not follow a normal error distribution in vegetated categories, making the RMSE process invalid.

The relevant testing criteria are summarized in Table 6.

Quantitative Criteria	Measure of Acceptability
Non-Vegetated Vertical Accuracy (NVA) in open terrain and urban land cover categories using $RMSE_z$ *1.9600	19.6 cm (based on $RMSE_z$ (10 cm) * 1.9600)
Vegetated Vertical Accuracy (VVA) in all vegetated land cover categories combined at the 95% confidence level	29.4 cm (based on 95^{th} percentile)

Table 6. Acceptance Criteria

The primary QA/QC vertical accuracy testing steps used by Dewberry are summarized as follows:

1. The ground team surveyed QA/QC vertical checkpoints in accordance with the project's specifications.
2. Next, Dewberry interpolated the bare-earth lidar DTM to provide the z-value for every checkpoint.
3. Dewberry then computed the associated z-value differences between the interpolated z-value from the lidar data and the ground truth survey checkpoints and computed NVA, VVA, and other statistics.
4. The data were analyzed by Dewberry to assess the accuracy of the data. The review process examined the various accuracy parameters as defined by the scope of work. The overall descriptive statistics of each dataset were computed to assess any trends or anomalies. This report provides tables, graphs and figures to summarize and illustrate data quality.

Vertical Accuracy Results

Table 7 summarizes the tested vertical accuracy resulting from a comparison of the surveyed checkpoints to the elevation values present within the fully classified lidar LAS files.

Land Cover Category	# of Points	NVA — Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=19.6 cm	VVA — Vegetated Vertical Accuracy (95th Percentile) Spec=29.4 cm
NVA	101	10.5 cm	
VVA	88		10.1 cm

Table 7. Tested NVA and VVA

This lidar dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ =5.4 cm, equating to +/- 10.5 cm at 95% confidence level. Actual VVA accuracy was found to be +/- 10.1 cm at the 95th percentile.

Figure 13 illustrates the magnitude of the differences between the QA/QC checkpoints and lidar data. This shows that the majority of lidar elevations were within +/- 8 cm of the checkpoints elevations, but there were some outliers where lidar and checkpoint elevations differed by 19 cm.

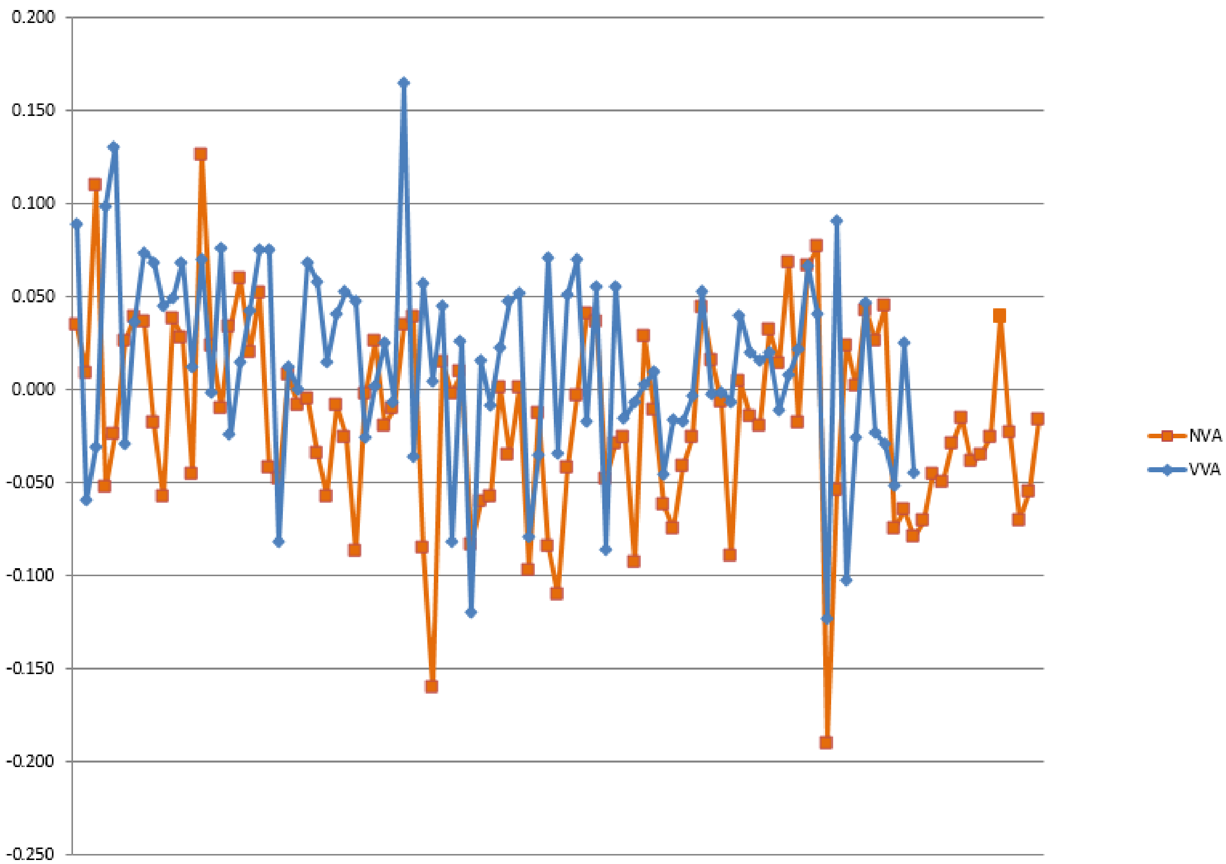


Figure 13. Magnitude of elevation discrepancies (in meters) per land cover category. Units are in meters.

Table 8 lists the 5% outliers that are larger than the VVA 95th percentile.

Point ID	NAD83 (2011) UTM Zone 13 North		NAVD88 (Geoid 12B)	Lidar Z (m)	Delta Z	AbsDeltaZ
	Easting X (m)	Northing Y (m)	Survey Z (m)			
4227	639490.302	5010956.261	922.894	922.792	-0.102	0.102

4090	586613.419	4992264.753	1006.759	1006.640	-0.119	0.119
4206	580221.484	5020372.110	1046.725	1046.602	-0.123	0.123
4005	606938.875	4959942.466	878.036	878.167	0.131	0.131
4079	667215.763	4987761.636	867.555	867.720	0.165	0.165

Table 8. 5% Outliers

Table 9 provides overall descriptive statistics.

100 % of Totals	# of Points	RMSEz (m) NVA Spec=0.1 m	Mean (m)	Median (m)	Skew	Std Dev (m)	Kurtosis	Min (m)	Max (m)
NVA	101	0.054	-0.015	-0.014	-0.290	0.052	0.947	-0.190	0.126
VVA	88	N/A	0.015	0.015	-0.241	0.053	0.443	-0.123	0.165

Table 9. Overall Descriptive Statistics

Figure 14 illustrates a histogram of the associated elevation discrepancies between the QA/QC checkpoints and elevations interpolated from the lidar triangulated irregular network (TIN). The frequency shows the number of discrepancies within each band of elevation differences. Although the discrepancies vary between a low of -0.19 meters and a high of +0.17 meters. The vast majority of points are within the ranges of +/-0.075 meters.

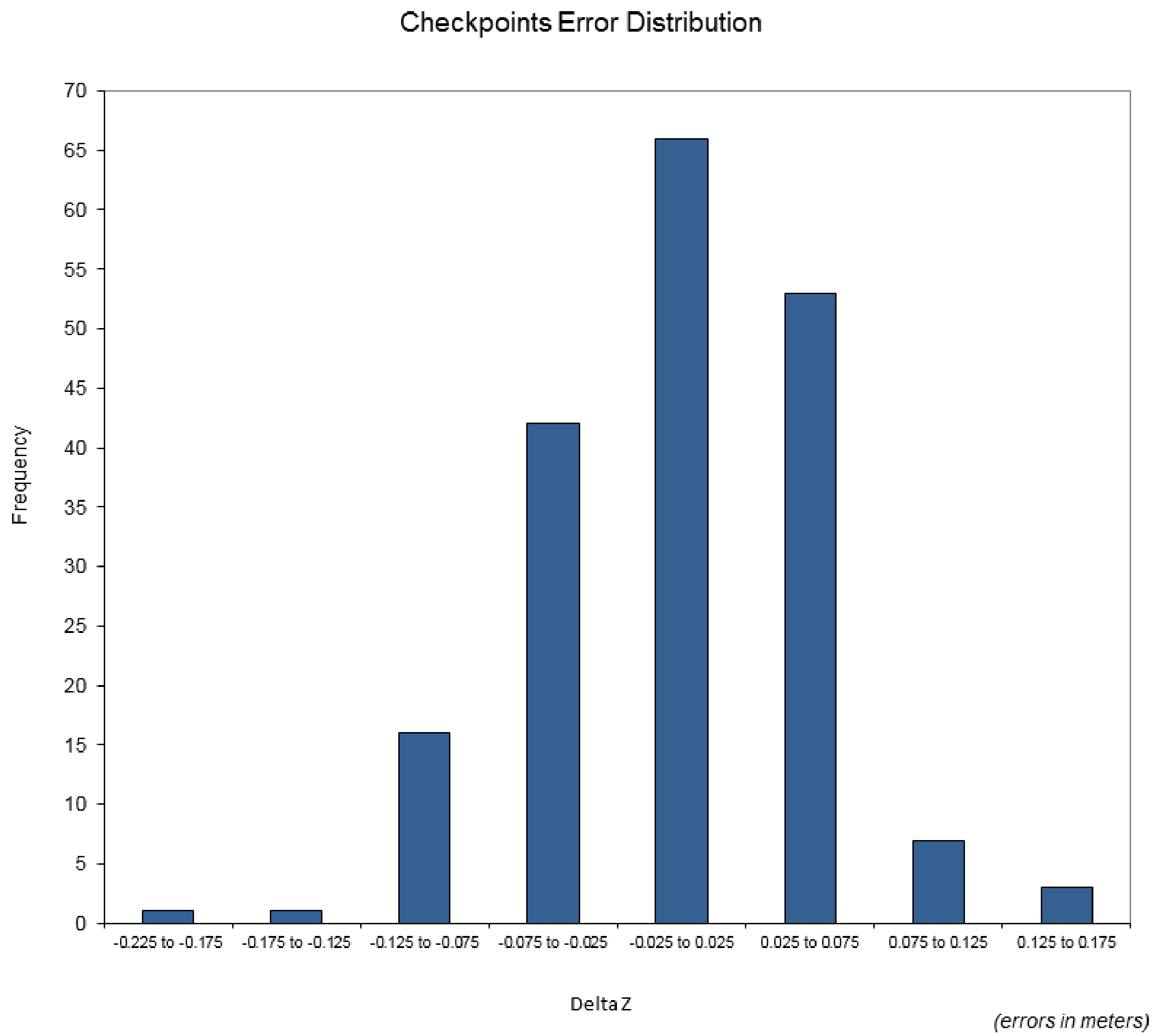


Figure 14. Histogram of Elevation Discrepancies with errors in meters

Based on the vertical accuracy testing conducted by Dewberry, the lidar dataset for the South Dakota QL2+ Lidar Project satisfies the project's pre-defined vertical accuracy criteria.

Breakline Production & Qualitative Assessment Report

Breakline Production Methodology

Dewberry compiled the project's hydrographic breaklines stereographically from lidar intensity imagery. This technique, known as lidargrammetry, enables Dewberry to produce accurate 3D hydrographic breaklines for features that are consistent with the lidar data at the time of airborne survey. All drainage breaklines are monotonically enforced to show downhill flow. Water bodies are at a constant elevation where the water body has been captured at the lowest elevation. Bridge deck breaklines are compiled directly from the project's DEMs. Bridge Breaklines are used where necessary to enforce the terrain beneath bridge decks and to prevent bridge saddles in the bare earth DEMs. All features were compiled in accordance with the project's Data Dictionary.

Breakline Qualitative Assessment

Completeness and horizontal placement is verified through visual reviews against lidar intensity imagery. Automated checks are applied on all breakline features to validate topology, including the 3D connectivity of features, enforced monotonicity on linear hydrographic breaklines, and flatness on water bodies. After all corrections and edits to the breakline features, the breaklines are imported into the final GDB and verified for correct formatting.

Breakline Data Dictionary

The following data dictionary was used for this project.

Horizontal and Vertical Datum

The horizontal datum shall be North American Datum of 1983, 2011 adjustment (NAD83 2011), Units in Meters. The vertical datum shall be referenced to the North American Vertical Datum of 1988, Units in Meters. Geoid12B shall be used to convert ellipsoidal heights to orthometric heights.

Coordinate System and Projection

All data shall be projected to Universal Transverse Mercator (UTM) Zone 13 North, Horizontal Units in Meters and Vertical Units in Meters.

Inland Streams and Rivers

Feature Dataset: BREAKLINES
Feature Type: Polygon
Contains Z Values: Yes
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: STREAMS_AND_RIVERS
Contains M Values: No
Annotation Subclass: None
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Description

This polygon feature class will depict linear hydrographic features with a width greater than 100 feet.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Software
SHAPE_AREA	Double	Yes			0	0		Calculated by Software

Feature Definition

Description	Definition	Capture Rules
Streams and Rivers	Linear hydrographic features such as streams, rivers, canals, etc. with an average width greater than 100 feet. In the case of embankments, if the feature forms a natural dual line channel, then capture it consistent with the capture rules. Other natural or manmade embankments will not qualify for this project.	Capture features showing dual line (one on each side of the feature). Average width shall be greater than 100 feet to show as a double line. Each vertex placed should maintain vertical integrity. Generally both banks shall be collected to show consistent downhill flow. There are exceptions to this rule where a small branch or offshoot of the stream or river is present. The banks of the stream must be captured at the same elevation to ensure flatness of the water feature. If the

		elevation of the banks appears to be different see the task manager or PM for further guidance. Breaklines must be captured at or just below the elevations of the immediately surrounding terrain. Under no circumstances should a feature be elevated above the surrounding lidar points. Acceptable variance in the negative direction will be defined for each project individually. These instructions are only for docks or piers that follow the coastline or water's edge, not for docks or piers that extend perpendicular from the land into the water. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water. Every effort should be made to avoid breaking a stream or river into segments. Dual line features shall break at road crossings (culverts). In areas where a bridge is present the dual line feature shall continue through the bridge. Islands: The double line stream shall be captured around an island if the island is greater than 1 acre. In this case a segmented polygon shall be used around the island in order to allow for the island feature to remain as a "hole" in the feature.

Inland Ponds and Lakes

Feature Dataset: BREAKLINES
Feature Type: Polygon
Contains Z Values: Yes
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: PONDS_AND_LAKES
Contains M Values: No
Annotation Subclass: None
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Description

This polygon feature class will depict closed water body features that are at a constant elevation.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Software
SHAPE_AREA	Double	Yes			0	0		Calculated by Software

Feature Definition

Description	Definition	Capture Rules
Ponds and Lakes	Land/Water boundaries of constant elevation water bodies such as lakes, reservoirs, ponds, etc. Features shall be defined as closed polygons and contain an elevation value that reflects the best estimate of the water elevation at the time of data capture. Water body features will be captured for features 2 acres in size or greater. "Donuts" will exist where there are islands within a closed water body feature.	Water bodies shall be captured as closed polygons with the water feature to the right. The compiler shall take care to ensure that the z-value remains consistent for all vertices placed on the water body. Breaklines must be captured at or just below the elevations of the immediately surrounding terrain. Under no circumstances should a feature be elevated above the surrounding lidar points. Acceptable variance in the negative direction will be defined for each project individually. An Island within a Closed Water Body Feature that is 1 acre in size or greater will also have a "donut polygon" compiled. These instructions are only for docks or piers that follow the coastline or water's edge, not for docks or piers that extend perpendicular from the land into the water. If it can be reasonably determined where the edge of water most probably falls, beneath the dock or pier, then the edge of water will be collected at the elevation of the water where it can be directly measured. If there is a clearly-indicated headwall or bulkhead adjacent to the dock or pier and it is evident that the waterline is most probably adjacent to the headwall or bulkhead, then the water line will follow the headwall or bulkhead at the elevation of the water where it can be directly measured. If there is no clear indication of the location of the water's edge beneath the dock or pier, then the edge of water will follow the outer edge of the dock or pier as it is adjacent to the water, at the measured elevation of the water.

Beneath Bridge Breaklines

Feature Dataset: BREAKLINES
Feature Type: Polyline
Contains Z Values: Yes
XY Resolution: Accept Default Setting
XY Tolerance: 0.003

Feature Class: Bridge_Breaklines
Contains M Values: No
Annotation Subclass: None
Z Resolution: Accept Default Setting
Z Tolerance: 0.001

Description

This polyline feature class is used to enforce terrain beneath bridge decks where ground data may not have been acquired. Enforcing the terrain beneath bridge decks prevents bridge saddles.

Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software

SHAPE	Geometry							Assigned by Software
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Software

Feature Definition

Description	Definition	Capture Rules
Bridge Breaklines	Bridge Breaklines should be used where necessary to enforce terrain beneath bridge decks and to prevent bridge saddles in the bare earth DEMs.	Bridge breaklines should be collected beneath bridges where bridge saddles exist or are likely to exist in the bare earth DEMs. Bridge breaklines should be collected perpendicular to the bridge deck so that the endpoints are on either side of the bridge deck. Typically two bridge breaklines are collected per bridge deck, one at either end of the bridge deck to enforce the terrain under the full bridge deck. The endpoints of the bridge breaklines will match the elevation of the ground at their xy position to enforce the ground/bare earth elevations beneath the bridge deck and prevent bridge saddles from forming.

DEM Production & Qualitative Assessment

DEM Production Methodology

Dewberry generates a project wide DEM using Esri ArcGIS software. Once the DEM is created, it is reviewed in ArcGIS for any issues requiring corrections, including remaining lidar mis-classifications, erroneous breakline elevations, poor hydro-flattening or hydro-enforcement, and processing artifacts. After corrections are applied, the DEM is then split into individual tiles in accordance with the project tiling scheme. The tiles are verified for final formatting and then loaded into Global Mapper to ensure no missing or corrupt tiles and to ensure seamlessness across tile boundaries.

DEM Qualitative Assessment

Dewberry performed a comprehensive qualitative assessment of the bare earth DEM deliverables to ensure that all tiled DEM products were delivered with the proper extents, were free of processing artifacts, and contained the proper referencing information. This process was performed in ArcGIS software with the use of a tool set Dewberry has developed to verify that the raster extents match those of the tile grid and contain the correct projection information. The DEM data was reviewed at a scale of 1:5000 to review for artifacts caused by the DEM generation process and to review the hydro-flattened features. To perform this review Dewberry creates hillshade models and overlays a partially transparent colorized elevation model to review for these issues. All corrections are completed using Dewberry's proprietary correction workflow. Upon completion of the corrections, the DEM data is loaded into Global Mapper for its second review and to verify corrections. Once the DEMs are tiled out, the final tiles are again loaded into Global Mapper to ensure coverage, extents, and that the final tiles are seamless.

DEM Vertical Accuracy Results

Only one hundred eighty-eight(188) checkpoints of the 189 that were used to test the vertical accuracy of the lidar were used to validate the vertical accuracy of the final DEM products. One point was removed because it fell outside of the boundary to which the DEMs were clipped. Accuracy results may vary between the source lidar and final DEM deliverable. DEMs are created by averaging several lidar points within each pixel which may result in slightly different elevation values at each survey checkpoint when compared to the source LAS, which does not average several lidar points together but may interpolate (linearly) between two or three points to derive an elevation value. The vertical accuracy of the DEM is tested by extracting the elevation of the pixel that contains the x/y coordinates of the checkpoint and comparing these DEM elevations to the surveyed elevations. Dewberry typically uses LP360 software to test the swath lidar vertical accuracy, Terrascan software to test the classified lidar vertical accuracy, and Esri ArcMap to test the DEM vertical accuracy so that three different software programs are used to validate the vertical accuracy for each project.

Table 10 summarizes the tested vertical accuracy results from a comparison of the surveyed checkpoints to the elevation values present within the final DEM dataset.

Land Cover Category	# of Points	NVA — Non-vegetated Vertical Accuracy (RMSE$_z$ x 1.9600) Spec=19.6 cm	VVA — Vegetated Vertical Accuracy (95th Percentile) Spec=29.4 cm
NVA	101	10 cm	
VVA	87		10.8 cm

Table 10. DEM tested NVA and VVA

This DEM dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be RMSE$_z$ =5.1 cm, equating to +/- 10 cm at 95% confidence level. Actual VVA accuracy was found to be +/- 10.8 cm at the 95th percentile. Table 11 lists the 5% outliers that are larger than the VVA 95th percentile.

Point ID	NAD83 (2011) UTM Zone 13 N		NAVD88 (Geoid 12B)	DEM Z (m)	Delta Z	AbsDelta Z
	Easting X (m)	Northing Y (m)	Survey Z (m)			
4001	577908.506	4959766.678	974.879	974.989	0.110	0.110
4090	606938.875	4959942.466	1006.759	1006.645	-0.114	0.114
4038	691676.093	4972330.509	803.554	803.675	0.121	0.121
4005	667215.763	4987761.636	878.036	878.179	0.143	0.143
4079	586613.419	4992264.753	867.555	867.716	0.161	0.161

Table 11. 5% Outliers

Table 12 provides overall descriptive statistics.

100 % of Totals	# of Points	RMSEz (m) NVA Spec=0.1 m	Mean (m)	Median (m)	Skew	Std Dev (m)	Kurtosis	Min (m)	Max (m)
NVA	101	0.051	-0.013	-0.015	-0.206	0.050	0.606	-0.160	0.118
VVA	87	N/A	0.018	0.018	-0.047	0.052	0.305	-0.114	0.161

Table 12. Overall Descriptive Statistics

Based on the vertical accuracy testing conducted by Dewberry, the DEM dataset for the South Dakota QL2+ Lidar Project satisfies the project's pre-defined vertical accuracy criteria.

Appendix A: IMU and GPS Processing Reports