Parallel Canyon – Cherry Creek, AZ
NAIP Point Cloud DEM Evaluation

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Prepared by:
Quantum Spatial, Inc.
523 Wellington Way, Suite 375
Lexington, KY 40503
859-277-8700
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For:
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1.1 Overview

The principal goal of this project was to determine if a topographic elevation model finer than 5 meters (m) resolution could be supported by a photogrammetric point cloud derived from USDA National Agriculture Imagery Program (NAIP) photography. Using a test site within the Tonto National Forest in central Arizona, QSI evaluated the point density patterns, accuracy, and associated supported DEM resolution using client-provided photogrammetric point cloud data from 60-cm NAIP stereo aerial photography collected in 2017. We were able to produce a reliable 1-m and 2.5-m DEM, exceeding the 5-m threshold requested by the USFS.

1.2 Coverage

The project boundary covers 21.6 square miles and encompasses the 13,848-acre Parallel Creek-Cherry Creek Watershed of Tonto National Forest in Central Arizona (Figure 1).

Figure 1. Project Boundary.
1.3 Scope

For the 2017 NAIP in Arizona, Surdex Corporation collected aerial photography with an ADS100 Digital Mapping Camera and post-processed the imagery into a photogrammetric point cloud with Leica Geosystems XPro software and a semi-global matching (SGM) algorithm. The US Bureau of Land Management (BLM) purchased the resulting “SGM-derived” point cloud, which was furnished to Quantum Spatial for this project. The BLM did not purchase nor make available the source stereo imagery. The specifications of the source imagery and photogrammetric point cloud datasets are summarized in Table 1.

Table 1. Specifications of Client-Provided Data

<table>
<thead>
<tr>
<th></th>
<th>Resolution</th>
<th>Quality</th>
<th>Bands</th>
<th>Tiles</th>
<th>Shapefiles</th>
<th>Other</th>
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</thead>
<tbody>
<tr>
<td>Orthoimagery</td>
<td>60 cm resolution</td>
<td>NAIP standards</td>
<td>4-band (RGBN) 8-bit</td>
<td>DOQQ in GeoTIFF</td>
<td>Seamline shapefiles</td>
<td>FGDC-compliant metadata</td>
</tr>
<tr>
<td>Photogrammetric DSM</td>
<td>160 cm ground</td>
<td>Unedited</td>
<td>LAZ in RGB and CIR/NRG</td>
<td>Agreed upon</td>
<td>Extent and tile shapefiles</td>
<td></td>
</tr>
<tr>
<td></td>
<td>spacing</td>
<td></td>
<td></td>
<td>tile layout</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1.4 Deliverables

The following products were produced and delivered:

- Classified Point Cloud, LAS v1.4, tiled
- 1-m Bare Earth DEM derived from photogrammetric point cloud data
- 2.5-m Bare Earth DEMs derived from photogrammetric point cloud data with supplemental NED:
  - 10-m feathering
  - 50-m feathering
  - 100-m feathering
- Void polygons, ESRI Shapefile (> 900m²)
- 1-m Bare Earth DEM Difference Rasters
  - SGM with no feathering compared to LiDAR
  - SGM with NED supplemental compared to LiDAR
  - LiDAR compared to NED
  - SGM compared to NED
- FOCUS on Accuracy Reports for SGM, LiDAR, and NED datasets
- FGDC-compliant metadata
- DEM evaluation report explaining methodology, DEM accuracy, evaluation and recommendations in PDF format

All geospatial deliverables were produced with a horizontal datum/projection of NAD83 (2011) UTM Zone 12N, meters and a vertical datum/projection of NAVD88 GEOID12.
2.1 Workflow Overview

The following is a summary of the QSI workflow, from the photogrammetric point cloud source data, to DEM generation, to the quality control check and product finalization:

**Initiation and Point Processing**
- Initiate project and ingest data into GeoCue
- Run automated grounding macro on the point cloud using distributive processing
- Perform manual cleanup to remove any erroneously (non-ground) ground classified features

**DEM Production**
- Generate a draft TIN/DEM
- Merge the cleaned point cloud with the secondary NED data source for voids

**QC Check and Finalization**
- Check the full DEM for any remaining voids or misclassifications
- Produce final DEMs
- Run QC checks and diagnostics

2.2 Point Cloud Processing

QSI Analysts classified the point cloud into ground and default values using both automated and manual editing techniques. Upon receipt of all source data furnished by the government, QSI ingested the LAS v1.4-point record format 8 (includes RGBNIR) file into GeoCue. GeoCue aids in managing and taking full advantage of distributed processing when running subsequent steps on the dataset. The principal difference between an SGM-derived point cloud and a LiDAR point cloud is the degree to which the dataset includes accurate ground points (i.e., effectively penetrated vegetation). This presents unique challenges with respect to handling the data and producing a surface that is both accurate and aesthetically pleasing. QSI has developed custom ground macros to maximize the information inherent in SGM-derived point clouds. Our point cloud filtering methodology is also customized to relate to project-specific terrain, density of vegetation, and presence and prominence of urban development (urban, suburban, and rural). A filtering methodology (automated and manual) was used to process the digital surface model (DSM) dataset to bare earth conditions. TerraScan and TerraModeler software, coupled with proprietary QSI filtering routines, were used for these operations.

Typically, about 75-80% of the automatically classified points are correctly classified to the ground class by QSI’s automated terrain filtering methodology. LiDAR Analysts further filtered the remaining ground points and performed interactive processing on 100% of the data to achieve a defensible ground point dataset for DEM production.

2.3 DEM Production

DEM production steps included creating a triangulated surface (TIN) between ground-classified points and exporting TINs as raster grids at the specified pixel resolution (5-m or better). We used proprietary tools to ensure there were no tile-edge artifacts, and that consistent model output criteria were met. We also took care to ensure pixels were snapped between raster models. QSI conducted a QC review of the DEM throughout the workflow to ensure that all blunders/misclassifications were corrected, and that the DEM was the best model of the ground surface that could be achieved and supported given the limitations of the dataset.

*Parallel Canyon-Cherry Creek Watershed, NAIP Point Cloud DEM Evaluation*
2.4 Raster Feathering

SGM-derived point clouds inherently have void areas (areas of no data) due to dense vegetation canopy, shadowing, or high-relief displacement. To create a working DEM with no voids, QSI used a proprietary feathering tool to supplement the dataset in these areas with existing USGS National Elevation Dataset (NED) data. To define what constituted a void, we first evaluated the distribution size of atypically large TIN triangles as well as their size range (min, max) across the AOI. Using this determined void size, we then identified all voids meeting this threshold criteria to generate a void polygon layer across the AOI and applied the data feathering procedure to these polygons.

The feathering process involves blending the NED data with the existing SGM data within a specified distance of the void polygon boundary. For example, for a distance of 100 m, feathering would be applied for the void polygon itself to within a 100 m buffer around the outside of the polygon. The greatest difference in elevation measurements among datasets will occur at the void polygon boundary and dissipate to zero radiating away from the boundary. QSI evaluated the impact of three void polygon buffering distances – 10-m, 50-m, 100-m – on the feathering results for the Parallel Creek-Cherry Creek Watershed AOI.

2.5 Accuracy Testing

QSI evaluated the SGM-derived point cloud and DEM accuracy in two ways: 1) through standard NVA assessment (using ground checkpoint data), and 2) qualitative and geospatial visualization via raster differing comparisons.

2.5.1 NVA Assessment

To evaluate the accuracy of the SGM-derived DEM, we utilized the existing LiDAR data and quality control checkpoints collected within the Four Forest Restoration Initiative (4FRI) project area (within which the Parallel Creek-Cherry Creek Watershed AOI lies). These data were collected in early fall 2013, at 8 pulses/m², by QSI. GPS surveying methods, including static and RTK observations, were used to establish the 3D position of all ground checkpoints.

Using QSI’s Final Observed and Calculated User Statistics (‘FOCUS’) tool, 25 QA points collected within the study area (Figure 2) were utilized to assess the Non-Vegetated Vertical Accuracy (NVA) of the SGM-derived surface model, as well as of the LiDAR and NED datasets to provide context. At each checkpoint location, modeled elevations from each dataset (LiDAR, SGM, and NED) were compared to the elevation values of the survey check points. We evaluated whether all surface models met the industry requirement and standard for Non-Vegetated Vertical Accuracy (NVA) of 19.6 cm (1.96*RMSE; USGS LBS v1.3 and ASPRS Positional Accuracy Standards for Geospatial Data 2014).
2.5.2 DEM comparisons

As a qualitative evaluation of accuracy, QSI also compared all combinations of DEMs through difference raster calculations (1:1 grid cell subtraction). Distribution of grid differences were examined across the study area to investigate effect of landscape on results.
3.1 Point Density, Raster Resolution & Smoothness

Across the study area, we observed variable ground point densities due to factors such as vegetation and terrain relief. Not surprisingly, in many of the areas with little to no vegetation, we observed ground point densities of 0.2 to 0.3 points/m², whereas areas with denser vegetation or variable terrain yielded ground point densities of only 0-0.1 points/m². For comparison, the 4FRI LiDAR project (collected at 8 pulses/m²) resulted in average ground point densities of 3-4 points/m².

Our next challenge was to determine a logical raster grid cell size for the entire project area that was both supported by the data but also conducive to working with the surrogate data used to fill the gaps. On average, the SGM-derived point density was 0.27 points/m², supporting a raster resolution of 2.75 m. However, given the 10-m raster size of the NED data, a 2.5-m resolution for the SGM-derived data would be more feasible for the feathering step. In addition, given 2.75-m is closer to 1-m (LiDAR) than to 10-m (NED), we also created an SGM-derived raster at 1-m resolution.

When compared to a photogrammetric surface model, the LiDAR DEM is always going to appear less noisy and smoother (Figures 3-4). Roughness is more prominent in vegetated areas. A smooth, less noisy surface could be derived by omitting points, but the SGM surface model would be less defined and less accurate. QSI decided to sacrifice smoothness for a more defensible ground model.

![Figure 3. Comparison of SGM-surface roughness (left) and LiDAR surface roughness (right) in same area of the Parallel Creek-Cherry Creek Watershed.](image-url)
3.2 Void Size & Feathering

Examination of TIN results revealed conspicuous gaps in the SGM-derived dataset in areas where vegetation cover was relatively dense or steep terrain prevented photogrammetric ground modeling. These areas of low ground model confidence were on the order of 900 sq. meters (1/4 acre) or larger (Figure 5). With this void size threshold, we then generated a void polygon layer against which to apply the feathering exercise at variable distances of 10 m, 50 m, and 100 m, to determine the best resolution for DEM supplementation.

Figure 4. LiDAR-SGM difference raster for same area illustrated in Figure 3, demonstrating geospatial regions where variations in dataset handling of noise is most evident.

Figure 5. Illustration of low confidence polygons (left) with voids ≥ 900 sq meters identified in inset area (right).
As a first attempt to supplement the ground model via the NED feathering methodology, we used a 10-m distance from polygon boundaries. This conservative short distance yielded stark “floating” and “digging” surface anomalies with abrupt gradients (Figure 6). Using a 50-m distance, the transition from the NED to SGM-derived data is still noticeable though not as dramatic as that with the 10-m buffer. The 100-m distance resulted in the most homogenous surface estimation among the three distances. Note that accuracy of the dataset at void sites is lower than other areas where data does exist, regardless of which feathering resolution was used. Void areas filled by the 10-m NED are provided to the USFS (shapefile feature class polygons). The deliverable package also includes the original SGM-derived DEM without any void supplementation. The metadata summarizes the methodology and source data used to fill all data voids.

Figure 6. Comparison of feathering distance results for 10-m (top), 50-m (left), and 100 m (right).
A difference raster between LiDAR and the 100-m feathered SGM surface illustrates that supplementing voids with NED data results in a less accurate surface model for void areas (Figure 7), questioning the validity of using the NED at all. For future endeavors, void identification could be refined to include parameters such as slope to identify the most egregious void candidates for NED data supplementation. We would recommend that voids that are in flat terrain should remain unfilled, keeping greater fidelity to the source SGM-derived data for TIN generation.

![Values in Meters](image)

**Figure 7. Difference raster between LiDAR surface and SGM-derived DEM with 100-m NED void feathering**

### 3.3 Accuracy

#### 3.3.1 NVA Assessment

The accuracy of the SGM-derived DEM is presented in Table 2, as compared to that achieved by the LiDAR and the NED data (Tables 3-4). The delivered FOCUS on Accuracy Report provides comprehensive details on all accuracy testing. Not surprisingly, the LiDAR dataset is most accurate (4.34 cm RMSE), the SGM-derived RMSE value (9.61 cm) is also within specification as per USGS LBS v1.3 (required < 10 cm RMSE).
The high RMSE value for the NED data illustrates its very coarse nature, low accuracy and unreliability as a supplemental dataset for augmenting the gaps in the SGM-derived DEM.

Table 2. SGM-derived Accuracy

<table>
<thead>
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<tr>
<td>RMSE</td>
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<td>95% Confidence Level</td>
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Table 3. LiDAR Accuracy

<table>
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<tbody>
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<td>95% Confidence Level</td>
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Table 4. NED Accuracy

<table>
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<th>Nonvegetated Vertical Accuracy (DEM)</th>
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<tr>
<td>95% Confidence Level</td>
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<tr>
<td>Mean</td>
</tr>
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<td>Count</td>
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3.3.2 DEM Comparisons

SGM to LiDAR Comparisons

The DEM comparison illustrated high congruence between the SGM-derived and LiDAR DEMs. While SGM to LiDAR differences ranged from a maximum of 21.2 m to a minimum of -34.6 m, differences were only 0.25 m or less for the majority of the AOI (Figure 8). Areas of greatest disparity consistently occurred where steep valley walls or vegetation are prevalent.

![Figure 8. LiDAR/SGM difference raster for AOI (left) and close-up view of the high difference areas (also void areas of low confidence) in Parallel Canyon (right).](image)

We also observed a systematic difference that was not related to landscape features along a north-south swath on the east side of the study area (Figure 9). We determined this was due to unadjusted flight line offsets. Points from these flight lines were not omitted from our analysis so as not to lower sample size, however their inclusion invariably impacts overall accuracy of the SGM-derived DEM. QSI recommends flightline matching and relative accuracy testing for future NAIP photogrammetric point cloud analysis.

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NED to LiDAR & SGM Comparisons

As expected, the LiDAR and NED (9.1 m) datasets differed substantially from each other with difference values ranging from a maximum of 40.3 m to a minimum of -33.2 m. The overall pattern between the differences correlated significantly with slope aspect.
The NED to SGM surface comparison yielded comparable results to the NED to LiDAR comparison (Figure 11), with large discrepancies in elevation values among surfaces.

Figure 11. SGM – NED Difference Raster
The SGN-derived point density and supported raster resolution was highly variable across the Parallel Canyon-Cherry Creek Watershed. This was due to variability in the amount of vegetation penetration and terrain relief across the study area. However, the average point density across the study area supported a resolution of ~2.5m; accuracy results as determined for non-vegetated surfaces (NVA) were within specification for topographic modeling and comparable to LiDAR for most of the study area; and the SGM and LiDAR datasets coincided closely in some portions of the study area. Within different landscapes where vegetation is of greater density, and terrain is more variable for a larger proportion of the study area, a 2.5 m DEM or finer resolutions may not be supported. For any project area, we recommend greater scrutiny of flight lines for alignment before the ground point classification to reduce noise in overlap areas while also ensuring greater ground point densities for elevation modeling.

Though the void feathering process using NED data resulted in more esthetic results in the ground model smoothness, surface elevation accuracy was degraded due to the coarseness of the NED data. We would recommend foregoing feathering and retaining the SGM surface triangulation across larger voids. Nevertheless, for AOIs in the American Southwest, a void polygon representing approximately 900 sq. meters or larger should be generated to alert users of low confidence areas within the dataset.

In summary, the photogrammetric point cloud derived from NAIP photography was able to support a 2.5 to 3-m DEM, which is of finer resolution than the targeted 5-m resolution for this project. Although less accurate than LiDAR, the SGM-derived DEM appears to be a viable option for topographic modeling at 5 m resolution or better within the American Southwest.