Dewberry Engineers Inc.
1000 North Ashley Drive, Suite 801
Tampa, FL 33602
813.225.1325
813.225.1385 fax
www.dewberry.com

Fish Springs Topobathymetric Lidar

Report Produced for U.S. Geological Survey

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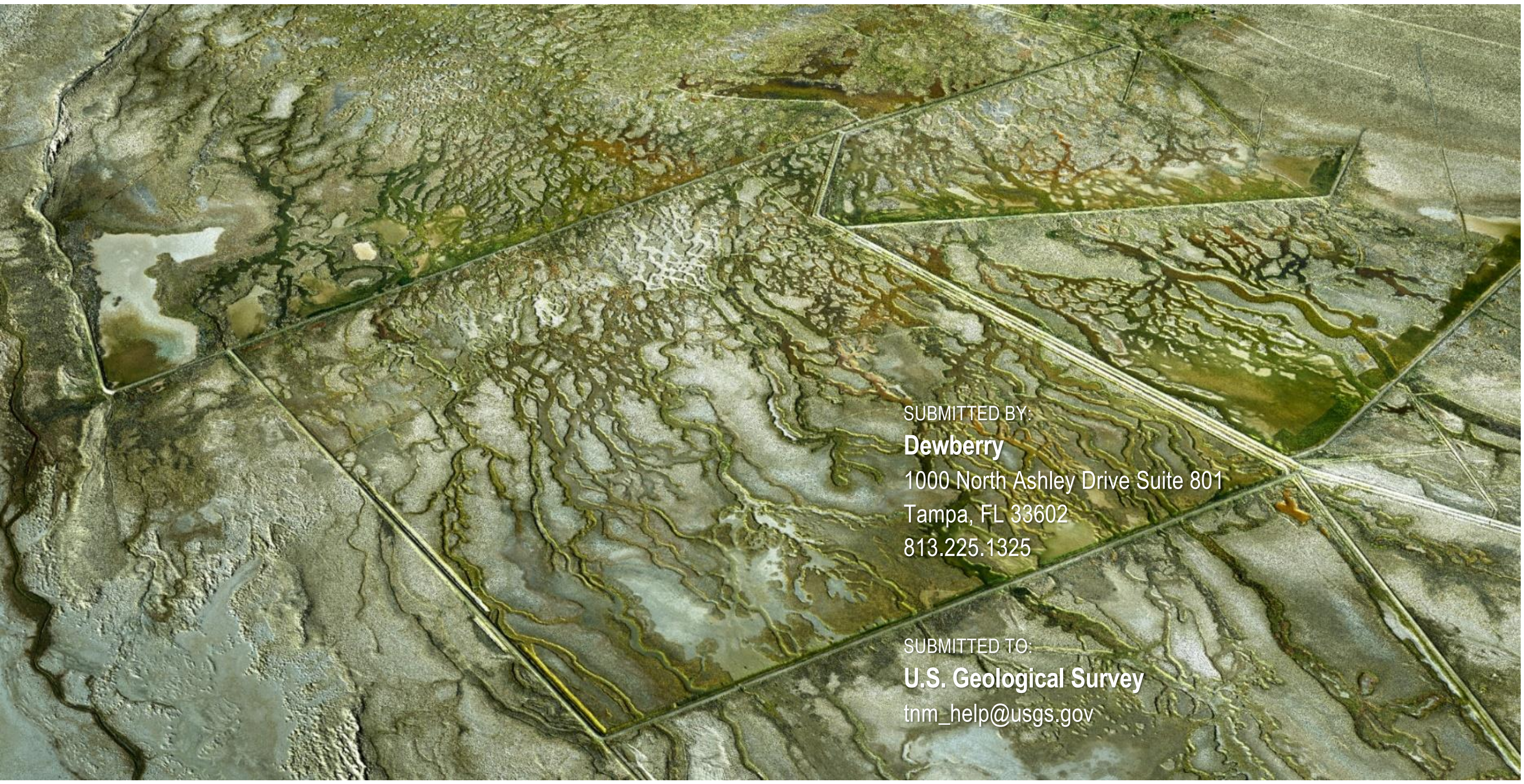

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1. EXECUTIVE SUMMARY

The primary purpose of this project was to develop a consistent and accurate surface elevation dataset derived from high-accuracy Light Detection and Ranging (lidar) technology for the Fish Springs Topobathymetric Lidar Project Area.

Lidar data and derivative products produced in compliance with this task order are based on the “National Geospatial Program Lidar Base Specification 2022, Revision A”. The Utah Fish Springs Topobathymetric Lidar project called for the planning, acquisition, processing and derivative products of lidar data to be collected at a nominal pulse spacing (NPS) of 0.35 meters (QL1) for topographic areas and 0.71 meter (QL2) for bathymetric areas. Detailed refraction extents and bare-earth Digital Elevation Models (DEMs) were produced for the project area. Data was formatted according to tiles with each tile covering an area of 1000m by 1000m. A total of 98 tiles were produced for the project encompassing an area of approximately 29.5 sq. miles.

Digital orthoimagery was acquired for the project area. Imagery was tiled according to a 1,000 m by 1,000 m tile grid. A total of 93 imagery tiles were produced.

1.1 The Project Team

Dewberry served as the prime contractor for the project. In addition to project management, Dewberry was responsible for LAS classification, all lidar products, breakline production, Digital Elevation Model (DEM) production, and quality assurance. Dewberry was also responsible for ortho-imagery production, including ortho-rectification and quality assurance of the ortho-mosaics.

Dewberry completed the ground survey for the project and delivered surveyed checkpoints. Ground control points and checkpoints were surveyed for the project. Ground control points were used in calibration activities and checkpoints were used in independent testing of the vertical accuracy of the lidar and the lidar-derived surface model. Dewberry completed lidar data acquisition and data calibration for the project area.

1.2 Survey Area

Fish Springs Topobathymetric Lidar project area covers approximately 29.5 square miles. The project tile grid contains 98 1,000 m by 1,000 m tiles. The project area boundary and overview are shown in Figure 1.

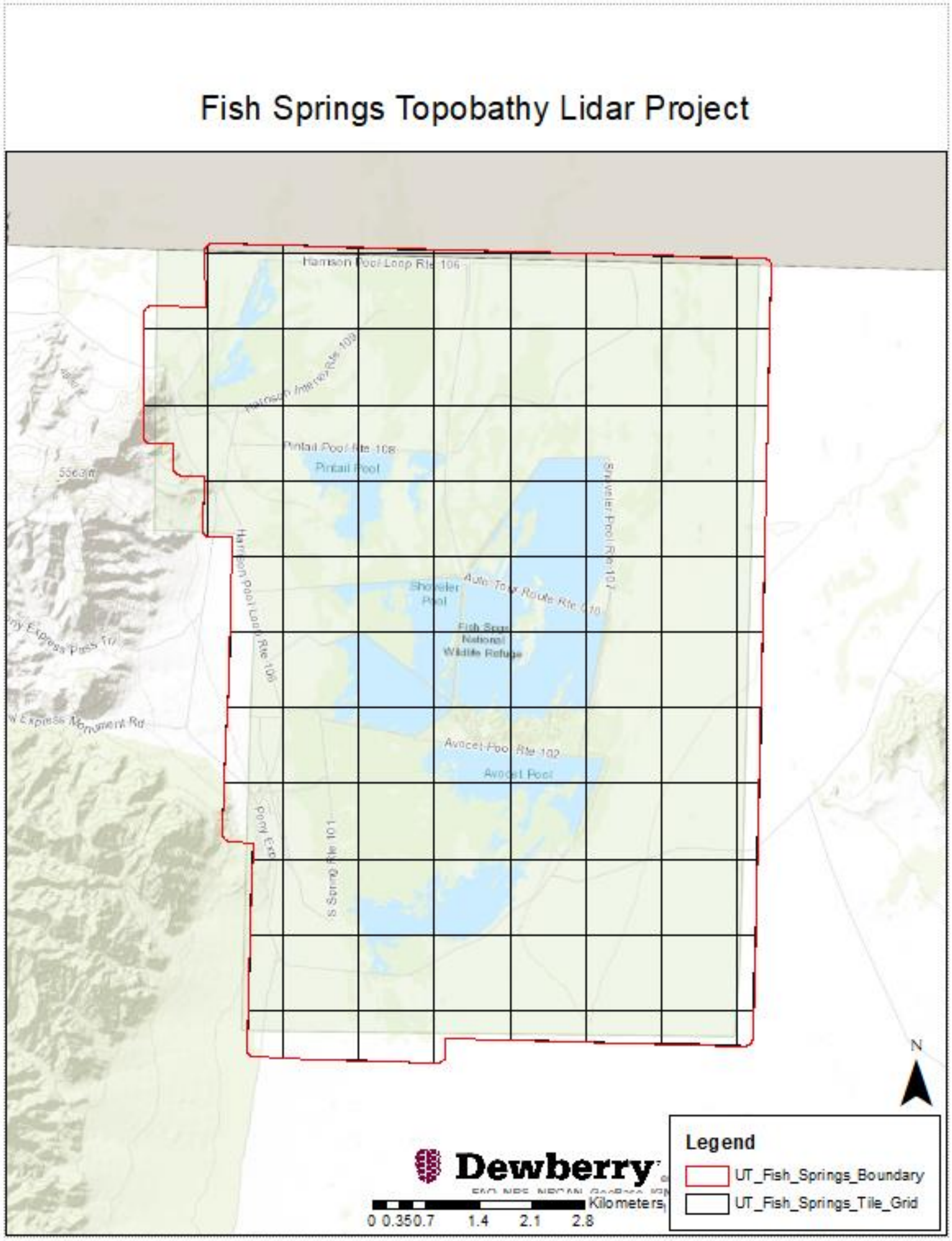

Figure 1. The image shows Fish Springs Topobathymetric Lidar collection area.

1.3 Date of Survey

The lidar aerial acquisition was conducted on September 24, 2022.

1.4 Coordinate Reference System

Data produced for the project were delivered in the following reference system:

Horizontal Datum: North American Datum of 1983 with the 2011 Adjustment (NAD 83 (2011))

Vertical Datum: North American Vertical Datum of 1988 (NAVD88)

Coordinate System: UTM zone 12 North

Units: Meters

Geoid Model: Geoid18

1.5 Lidar Vertical Accuracy

For the Fish Springs Topobathymetric Lidar Project, the tested $RMSE_z$ of the classified lidar data for checkpoints in non-vegetated terrain is **4.1 cm** and the non-vegetated vertical accuracy (NVA) of the classified lidar data computed using $RMSE_z$ x 1.9600 is **8.0 cm**.

For the Fish Springs Topobathymetric Lidar Project, the tested $RMSE_z$ of the classified lidar data for checkpoints in submerged topography is **17.5 cm** and the bathymetric vertical accuracy (BVA) of the classified lidar data computed using $RMSE_z$ x 1.9600 is **34.4 cm**.

For the Fish Springs Topobathymetric Lidar Project, the tested vegetated vertical accuracy (VVA) of the classified lidar data computed using the 95^{th} percentile is **10.3 cm**.

Additional accuracy information and statistics for the classified lidar data, raw swath data, and topobathymetric DEM data are found in sections 5 and 6 of this report.

1.6 Project Deliverables

The deliverables for the project are listed below.

1. Classified Point Cloud Data (Tiled)
2. Bare Earth Surface (GeoTiff format)
3. Intensity Images (GeoTIFF format)
4. Swath Separation Images (GeoTiff format)
5. Maximum Surface Height Raster (GeoTiff format)
6. Refraction Extent Data (SHP)
7. Flightline Extent (SHP)
8. Void Polygons (SHP)
9. Independent Survey Checkpoint Data (Report, Photos, Coordinates & Geopackage)
10. Calibration Control Points (Report, Photos, Coordinates & Geopackage)
11. Metadata
12. Project Report
13. Project Extents, including a shapefile derived from the lidar deliverable

2. LIDAR ACQUISITION CONTROL

Dewberry acquired and calibrated the lidar data for this project. Acquisition was completed on September 24, 2022.

2.1 Lidar Acquisition Details

Dewberry flew 25 lines to collect the project area, consisting of 24 production lines and 1 crossline for calibration. The flight plan was flown with procedural turns at the end of each line to prevent IMU drift associated with all IMU systems. To reduce any margin for error in the flight plan, Dewberry followed FEMA's Appendix A "guidelines" for flight planning and, at a minimum, includes the following criteria:

- A digital flight line layout using Topoflight 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 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.

Dewberry monitored weather and atmospheric conditions and conducted lidar missions only when no conditions existed below the sensor that would affect the collection of data. These conditions include no snow, rain, fog, smoke, mist, and low clouds. Dewberry accessed reliable weather sites and indicators (webcams) to establish the highest probability for successful collection to position our sensor to maximize successful data acquisition. Overflight access to Dugway Proving Grounds airspace was pre-coordinated to ensure no conflicts during aerial collection.

Within 72-hours prior to the planned day of acquisition, Dewberry closely monitored the weather, checking all sources for forecasts at least twice daily. In particular, Dewberry ensured no heavy rain events would take place in the days leading up to the collection since this would negatively impact water clarity in the Fish Springs pools. As soon as weather conditions were conducive to acquisition, our aircraft mobilized to the project site to begin data collection.

Prior to collection of the project, Dewberry calibrated the lidar sensor at a designated site located in Salt Lake City, UT that has established ground control.

2.2 Lidar System Parameters

Dewberry operated a Cessna T206 Turbo Stationair (Tail # N7269T) outfitted with a Riegl VQ-880GH Topobathy lidar system during the collection of the project area. Table 1 illustrates Dewberry's system parameters for lidar acquisition on this project.

Table 1: Dewberry's lidar system parameters

Item	Parameter
System	Riegl VQ-880GH
Altitude (AGL meters)	700
Approx. Flight Speed (knots)	140
Scanner Pulse Rate (kHz)	550 Green, 145 NIR
Scan Frequency (hz)	80 Green, 115 NIR

Pulse Duration of the Scanner (nanoseconds)	1.5 Green, 3 NIR
Pulse Width of the Scanner (m)	0.445 Green,0.899 NIR
Swath width (m)	510
Central Wavelength of the Sensor Laser (nanometers)	532 Green Channel, 1064 NIR Channel
Did the Sensor Operate with Multiple Pulses in The Air? (yes/no)	Yes
Beam Divergence (milliradians)	1.1 Green, 0.2 NIR
Nominal Swath Width on the Ground (m)	510
Swath Overlap (%)	30
Total Sensor Scan Angle (degree)	40
Computed Down Track spacing (m) per beam	.9 Green, .626 NIR
Computed Cross Track Spacing (m) per beam	.148 Green, 1.23 NIR
Nominal Pulse Spacing (single swath), (m)	0.258 Green, 0.887 NIR
Nominal Pulse Density (single swath) (ppsm), (m)	15 Green, 1.27 NIR
Aggregate NPS (m) (if ANPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.258 Green, 0.887 NIR
Aggregate NPD (m) (if ANPD was designed to be met through single coverage, ANPD and NPD will be equal)	15 Green, 1.27 NIR
Maximum Number of Returns per Pulse	10 Green, 10 NIR

2.3 Acquisition Status Report and Flightlines

Upon notification to proceed, the flight crew loaded the flight plans and validated the flight parameters. 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. Figure 2 shows the combined trajectory of the flightlines.

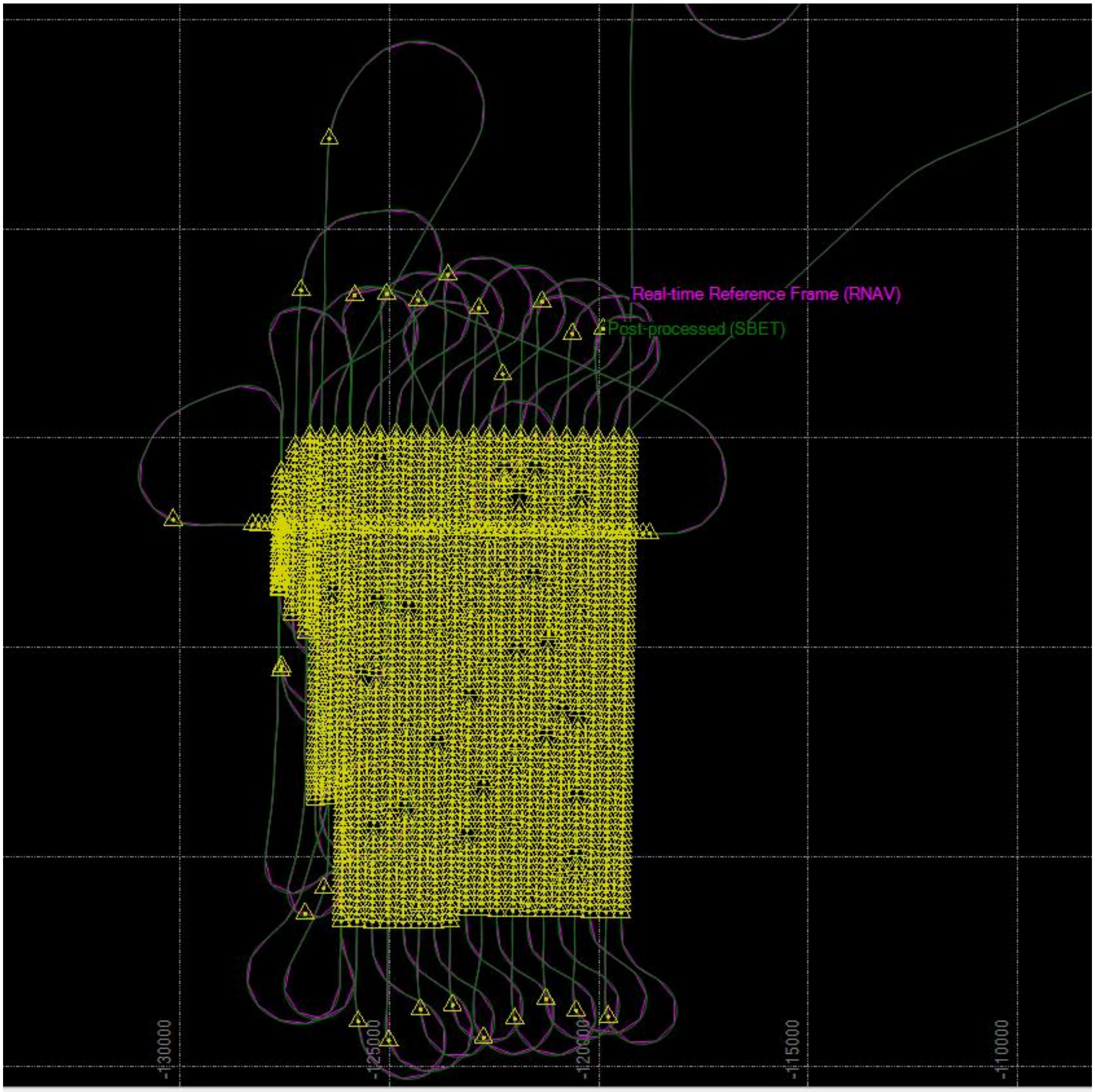

Figure 2: Collection Trajectory as flown by Dewberry

2.4 Airborne Kinematic Control

Airborne INS-GPS data was processed using the Applanix PosPac software suite. Flights were flown with a minimum of 18 satellites in view and with PDOP less than 1.5.

The Position Error RMS for the entire collection was under 2.5cm in the down direction, and less than 1.5cm in the North and East position.

2.5 Generation and Calibration of Raw Lidar Data

Availability and status of all required GPS and laser data were verified against field reports and any data inconsistencies were addressed.

The initial point generation for each mission calibration was verified within Microstation/TerraScan for calibration errors. If a calibration error greater than specification was observed, the appropriate roll, pitch and scanner scale corrections were calculated. The point data were then regenerated with the new calibration values and validated internally again to ensure that the errors were fully addressed.

Data collected by the lidar unit was reviewed for completeness, acceptable density, and to make sure all data were captured without errors or corrupted values. All GPS, aircraft trajectory, mission information, and ground control files were reviewed and logged. A supplementary coverage check was carried out (Figure 3) to ensure that there were no unreported gaps in data coverage.

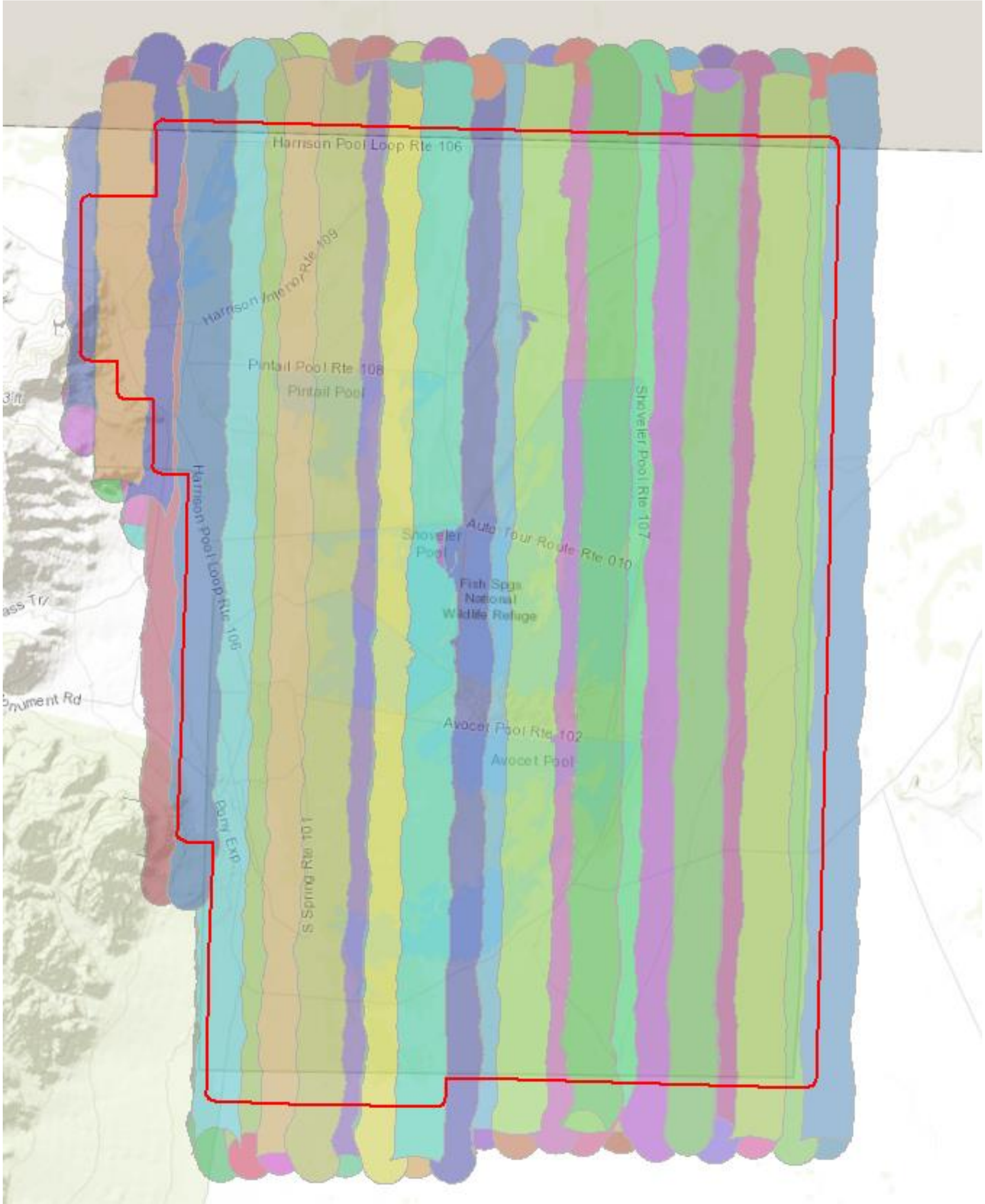

Figure 3. Lidar swath output showing complete coverage.

2.6 Boresight and Relative accuracy

The initial points for each mission calibration were 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 were optimized during the calibration process until relative accuracy requirements were met (Figure 4).

Relative accuracy and internal quality were checked using at least three regularly spaced QC blocks in which points from all lines were loaded and inspected. Vertical differences between ground surfaces of each line were displayed. Color scale was adjusted to flag errors that were not within project specifications. Cross sections were visually inspected across each block to validate point to point, flight line to flight line, and mission to mission agreement.

The following relative accuracy specifications were used for this project:

- ≤ 6 cm maximum difference within individual swaths (intra-swath); and
- ≤ 8 cm RMSDz between adjacent and overlapping swaths (inter-swath).

A different set of QC blocks were generated for final review after any necessary transformations were applied.

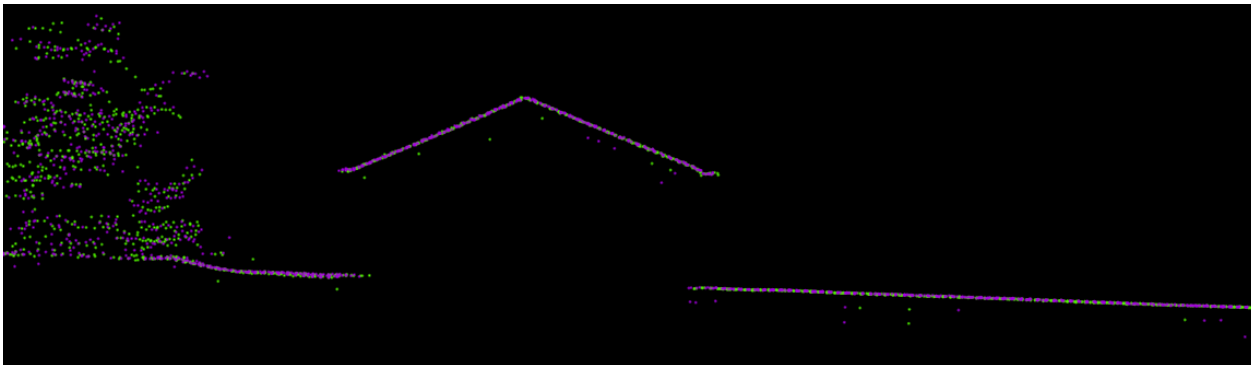

Figure 4. Profile view showing result of roll and pitch adjustments.

2.7 Refraction Correction

Bathymetric data must have a refraction correction applied. This process corrects the horizontal and vertical (depth) positions of each data point by accounting for the change in direction and speed of light as it enters and travels through water. The refraction correction for this dataset was performed by Dewberry using Dewberry's proprietary tool.

2.8 Preliminary Vertical Accuracy Assessment

Dewberry performed a preliminary $RMSE_z$ error check in the raw lidar dataset against GPS static and kinematic data and compared the results to project specifications. The lidar data was examined in non-vegetated, flat areas away from breaks. An automated grounding routine was used to classify an initial ground surface for this analysis.

The calibrated Fish Springs Topobathymetric Lidar dataset was tested to 0.073 m $RMSE_z$ and 0.143 m vertical accuracy at the 95% confidence level when compared to 10 control points (Table 2) surveyed by Dewberry.

The results of the preliminary vertical accuracy assessment conducted by Dewberry are summarized in Table 3.

The calibrated lidar data products collected by Dewberry met or exceeded the requirements set out in the Statement of Work. The quality control requirements of Dewberry's quality management program were adhered to throughout the data acquisition stage.

Table 2. Surveyed control points used for preliminary vertical accuracy assessment.

Number	NAD83(2011) UTM zone 12, m		NAVD88 Geoid 18, m		Delta z (m)
	Easting (x)	Northing (y)	Survey z	Lidar z	
GCP-1	299576.052	4419793.496	1307.547	1307.574	0.027
GCP-2	293748.435	4417863.911	1313.311	1313.363	0.052
GCP-3	297386.321	4415724.571	1311.322	1311.331	0.009
GCP-4	300326.325	4412126.709	1311.995	1311.932	-0.063
GCP-5	298412.931	4411579.498	1313.121	1313.151	0.030
GCP-6	294962.657	4410664.785	1324.494	1324.461	-0.033
GCP-7	295482.327	4413909.100	1313.336	1313.307	-0.029
BCP-1	299123.406	4419784.460	1305.226	1305.284	0.058
BCP-2	296261.516	4415616.847	1309.534	1309.474	-0.060
BCP-3	299202.564	4413259.974	1310.339	1310.529	0.190

Table 3. Summary of vertical accuracy assessment results.

Land Cover Type	# of Points	$RMSE_z$ (m)	NVA (m)	Mean (m)	Std Dev (m)	Min (m)	Max (m)
Project Specification	**-**	**0.100**	**0.196**	**-**	**-**	**-**	**-**
Non-Vegetated Terrain	10	0.073	0.143	0.018	0.075	-0.063	0.190

3. LIDAR PROCESSING & QUALITATIVE ASSESSMENT

3.1 Initial Processing

Dewberry performed vertical accuracy validation of the swath data, inter-swath relative accuracy validation, intra-swath relative accuracy validation, verification of horizontal alignment between swaths, validation of the refraction correction, and confirmation of point density and spatial distribution. This initial assessment allowed Dewberry to determine whether the data was suitable for full-scale production. Details are provided in the following sections.

3.1.1 Final Swath Vertical Accuracy Assessment

Dewberry tested the vertical accuracy of the non-vegetated terrain swath data prior to further processing. Swath vertical accuracy was tested using 21 non-vegetated (open terrain and urban) independent survey checkpoints. Checkpoints were compared to a triangulated irregular network (TIN) 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 to remove vegetation, buildings, and other artifacts from the ground surface.) Dewberry used LP360 software to test the swath lidar vertical accuracy.

This raw lidar swath dataset 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 $RMSE_z$ = 4.2 cm, equating to ± 8.3 cm at the 95% confidence level. Project specifications required a NVA of 19.6 cm based on the $RMSE_z$ (10 cm) x 1.96. The swath data for the Fish Springs Topobathymetric Lidar Project satisfied these criteria. Table 4 shows calculated statistics for the raw swath data.

Table 4. NVA at the 95% confidence level for raw swaths.

Land Cover Type	# of Points	$RMSE_z$ (m)	NVA (m)	Mean (m)	Median (m)	Skew	Std Dev (m)	Min (m)	Max (m)	Kurtosis
Project Specification	**-**	**0.100**	**0.196**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Non-Vegetated Terrain	21	0.042	0.083	0.015	0.019	-0.116	0.041	-0.060	0.093	-0.415

3.1.2 Interswath Relative Accuracy

According to the SOW, USGS Lidar Base Specifications, and *ASPRS Positional Accuracy Standards for Digital Geospatial Data*, data required to meet 10 cm accuracy class standards must have an interswath (between-swath) relative accuracy of 8 cm $RMSD_Z$ or less.

Prior to classification, Dewberry validated the relative accuracy of the lidar calibration by creating delta-Z (DZ) rasters to visualize interswath accuracy. These rasters were generated with 1 m cell resolution based on the maximum difference in elevation between undifferentiated only returns in non-vegetated areas of overlap between flight lines. Each pixel of the raster was colorized according to the resulting value. Cells where overlapping flight lines were within 8 cm of each other were colored green, cells where overlapping flight lines had elevation differences between 8 cm and 16 cm were colored yellow, and cells where overlapping flight lines had elevation differences greater than 16 cm were colored red. Pixels that did not contain points from overlapping flight lines were colored by intensity.

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 rasters. Bathymetric areas can also appear yellow or red due to factors like different tidal stages between missions. Large or continuous sections of yellow or red pixels following terrain features or land cover zones are typically reflective of variable or unfavorable (e.g., vegetated) conditions for DZ measurements, whereas large or continued sections of yellow or red pixels following flight line patterns can indicate acquisition or calibration issues. The interswath DZ rasters for Fish Springs Topobathymetric Lidar Project are shown in Figure 5. Based on visual inspection, no issues with swath-to-swath calibration were noted.

Figure 5. Single return interswath DZ rasters for the Fish Springs Topobathymetric Lidar Project.

Dewberry also delivers DZ orthoimagery created from the final classified data for validation of interswath relative accuracy. Additional details about this product are provided in Section 4.4 of this report.

3.1.3 Intraswath Relative Accuracy

According to the SOW, USGS Lidar Base Specifications, and *ASPRS Positional Accuracy Standards for Digital Geospatial Data*, data required to meet 10 cm accuracy class standards must have an intraswath (within-swath) relative accuracy of 6 cm maximum difference or less.

Dewberry validated the intraswath relative accuracy prior to classification by generating and reviewing intraswath rasters. These rasters were generated with 1 m cell resolution based on the maximum difference in elevation between undifferentiated only returns of single flight line coverage. Each pixel of the raster was colorized according to the max elevation difference between all points within a raster cell. Cells where the maximum elevation difference between points was within 6 cm were colored green, and cells where the maximum difference was greater than 6 cm were colored red.

Areas of vegetation and steep slopes (slopes with 6 cm or more of valid elevation change across 1 linear meter) are expected to appear red in the intraswath rasters, as are areas of bathymetric coverage since bathymetric returns are typically not only returns. Overlap areas can also appear red due to different acquisition conditions between missions. Large or continuous sections of red pixels following terrain features or land cover zones are typically reflective of variable or unfavorable (e.g., vegetated) conditions for within swath measurements, whereas large or continued sections of red pixels in flat, relatively featureless areas can indicate sensor issues. The intraswath rasters for Fish Springs Topobathymetric Lidar are shown in Figure 6. Based on visual inspection, no issues with hard surface repeatability were noted.

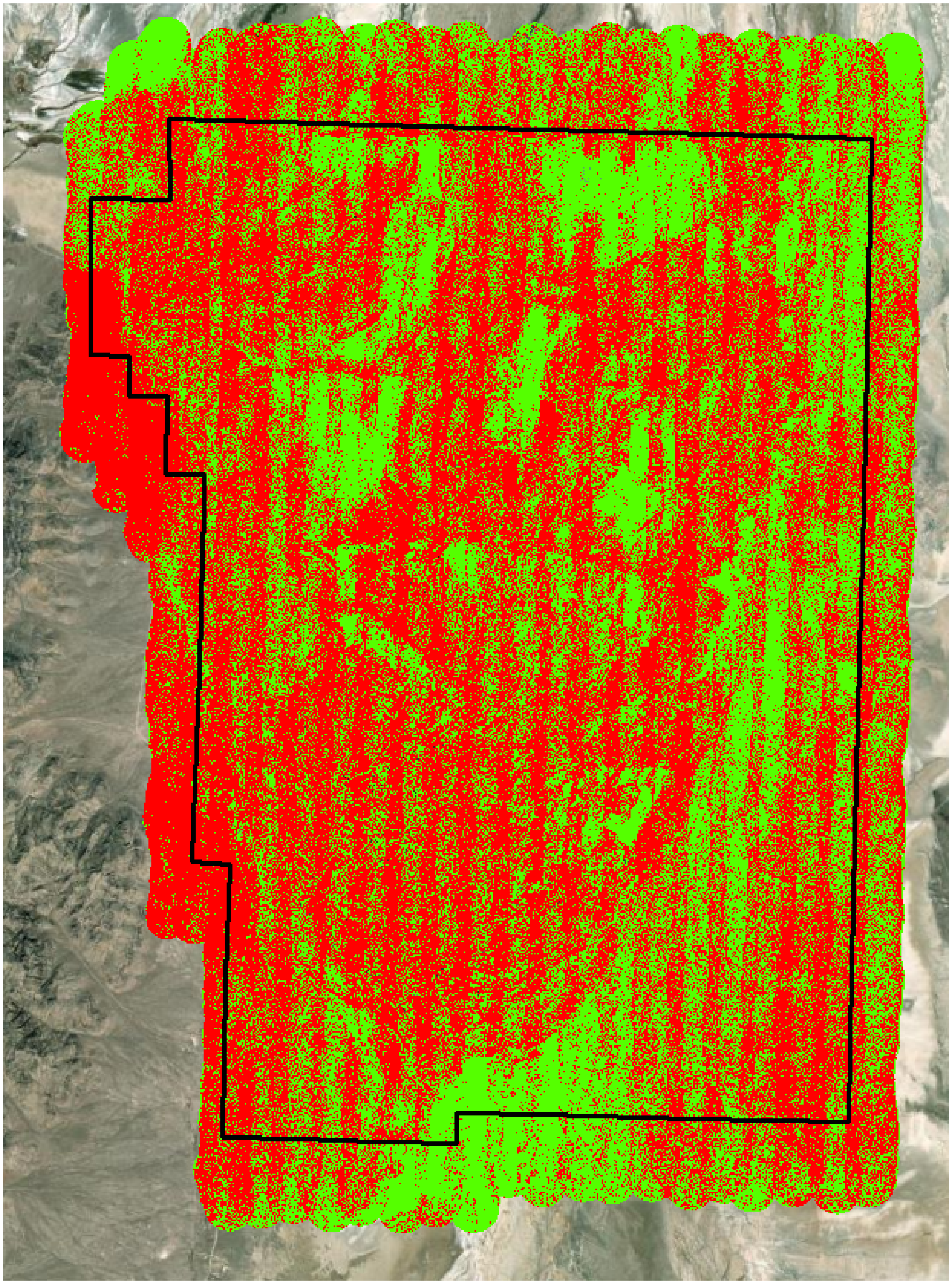

Figure 6. Intraswath rasters for the Fish Springs Topobathymetric Lidar Project.

3.1.4 Horizontal Alignment

To ensure horizontal alignment between adjacent or overlapping flight lines, Dewberry reviews point cloud profiles in areas of overlap to identify horizontal shifts or misalignments between swaths on roof tops and other elevated planar surfaces. Figure 7 shows an example of the horizontal alignment between swaths for Fish Springs Topobathymetric Lidar; no horizontal alignment issues were identified.

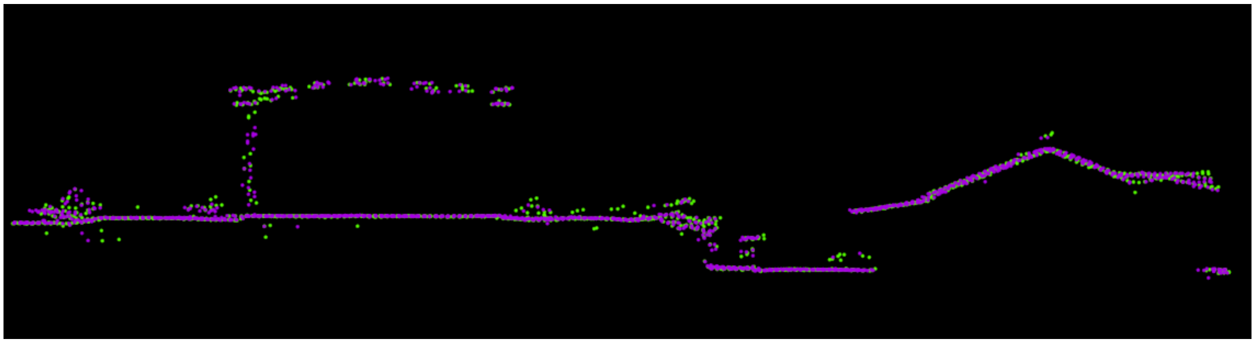

Figure 7. Two separate flight lines are differentiated by color (green/purple) to determine whether horizontal misalignments are present. This is a representative example; there is no visible offset between these flight lines.

3.1.5 Point Density

The required Aggregate Nominal Point Spacing (ANPS) for this project is no greater than 0.35 meters, which equates to an Aggregate Nominal Point Density (ANPD) of 8 points per square meter (ppsm) or greater for topo and an ANPD of no greater than 0.71 meters, which equates to and ANPD of 2 ppsm for bathy; however, it is understood that a required ANPD may not be met in the bathymetric domain due to environmental conditions. Density calculations were performed using only first return data located in the geometrically usable center portion (typically ~90%) of each swath.

Spatial distribution was reviewed to verify that there was no clustering of points or unacceptable void areas. This evaluation was based on the number of 1-meter cells in the dataset that contained at least one lidar point. No distribution anomalies were noted.

3.2 Data Classification and Editing

Once the calibration, absolute swath vertical accuracy, and relative accuracy of the data were validated, the lidar dataset was moved into processing and production. These steps included refraction extent creation to define the land/water interface and constrain void polygons, automated and manual editing of the lidar tiles, QA/QC, and final formatting of all products.

3.2.1 Point Cloud Processing

Dewberry utilized Riegl's RiProcess and TerraScan software for processing. The acquired raw point clouds were imported into RiProcess for conversion to LAS format and output with an initial classification schema based on stored sensor data. The LAS were tiled according to the project tile grid. Once tiled, the laser points were classified using a proprietary routine in TerraScan. This routine classified 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 were geometrically unusable were flagged as withheld and classified to a separate class so that they would be excluded from the initial ground algorithm. After points that could negatively affect the ground were removed from class 1, the ground layer was extracted from this remaining point cloud using an iterative surface model.

After the initial automated ground routine, each tile was imported into TerraScan and a surface model was created. Dewberry analysts visually reviewed the topo-bathymetric surface model and corrected errors in the ground classification such as vegetation, buildings, bridges, and grounded water column or surface that were in ground classes following the initial processing. Analysts also looked for features that were present in the point cloud but not reflected in the ground model, including obstacles to marine navigation.

The withheld bit was set for points deemed to be outliers, blunders, or geometrically unreliable outside the flight line overlap areas.

The final classification schema is detailed in Table 5.

Table 5. Final classification schema used in delivered lidar data.

Class	Definition
1	Unclassified, used for all other features that do not fit into the Classes 2, 7, 17, 18, 40, 41, or 45. Includes vegetation, buildings, etc.
2	Bare-Earth Ground
7	Low Noise
17	Bridge Deck
18	High Noise
40	Bathymetric Point, Submerged Topography
41	Water Surface
45	Water Column, Neither surface nor bottom

After manual classification, the LAS tiles were peer reviewed and then underwent a final independent QA/QC (detailed in Section 3.3). After the final QA/QC and corrections, all headers, appropriate point data records, and variable length records, including spatial reference information, were updated and verified using proprietary Dewberry tools.

3.3 Lidar Qualitative Assessment

Dewberry's qualitative assessment of lidar point cloud data utilized a combination of statistical analyses and visual interpretation. Methods and products used in the assessment included profile- and map view-based point cloud review, pseudo image products (e.g., intensity orthoimages), TINs, DEMs, DSMs and point density rasters. This assessment looked for incorrect classification and other errors sourced in the LAS data. Lidar data are peer reviewed, reviewed by task leads (senior level analysts), and verified by an independent QA/QC team at key points within the lidar workflow.

3.3.1 Qualitative Review

The following table describes Dewberry's standard editing and review guidelines for specific types of features, land covers, and lidar characteristics.

Table 6. Lidar editing and review guidelines.

Category	Editing Guideline	Additional Comments
No Data Voids	The SOW for the project defines unacceptable data voids as voids	No unacceptable voids were identified in this dataset

	greater than 4 x $ANPS^2$, or 1.96 m^2, that are not related to water bodies or other areas of low near-infrared reflectivity and are not appropriately filled by data from an adjacent swath. The LAS files were used to produce density grids based on Class 2 (ground) and class 40 (bathymetric bottom) points for review.	
Artifacts	Artifacts in the point cloud are typically caused by misclassification of points in vegetation or man-made structures as ground. Low-lying vegetation and buildings are difficult for automated grounding algorithms to differentiate and often must be manually removed from the ground class. Dewberry identified these features during lidar editing and reclassified them to Class 1 (unassigned). Artifacts up to 0.3 m above the true ground surface may have been left as Class 2 because they do not negatively impact the usability of the dataset.	None
Culverts and Bridges	It is Dewberry's standard operating procedure to leave culverts in the bare earth surface model and remove bridges from the model. In instances where it is difficult to determine whether the feature was a culvert or bridge, Dewberry errs on the side of culverts, especially if the feature is on a secondary or tertiary road.	None
In-Ground Structures	In-ground structures typically occur on military bases and at facilities designed for munitions testing and storage. When present, Dewberry identifies these structures in the project and includes them in the ground classification.	No in-ground structures present in this dataset
Dirt Mounds	Irregularities in the natural ground, including dirt piles and boulders, are common and may be misinterpreted as artifacts that should be removed. To verify their inclusion in the ground class, Dewberry checked the features	No dirt mounds or other irregularities in the natural ground were present in this dataset

	for any points above or below the surface that might indicate vegetation or lidar penetration and reviews ancillary layers in these locations as well. Whenever determined to be natural or ground features, Dewberry edits the features to class 2 (ground)	
Flight Line Ridges	Flight line ridges occur when there is a difference in elevation between adjacent flight lines or swaths. If ridges are visible in the final DEMs, Dewberry ensures that any ridges remaining after editing and QA/QC are within project relative accuracy specifications.	No flight line ridges are present in the data
Temporal Changes	If temporal differences are present in the dataset, the offsets are identified with a shapefile.	No temporal offsets are present in the data
Low NIR Reflectivity	Some materials, such as asphalt, tars, and other petroleum-based products, have low NIR reflectivity. Large-scale applications of these products, including roadways and roofing, may have diminished to absent lidar returns. USGS LBS allow for this characteristic of lidar but if low NIR reflectivity is causing voids in the final bare earth surface, these locations are identified with a shapefile.	No Low NIR Reflectivity is present in the data
Laser Shadowing	Shadows in the LAS can be caused when solid features like trees or buildings obstruct the lidar pulse, preventing data collection on one or more sides of these features. First return data is typically collected on the side of the feature facing toward the incident angle of transmission (toward the sensor), while the opposite side is not collected because the feature itself blocks the incoming laser pulses. Laser shadowing typically occurs in areas of single swath coverage because data is only collected from one direction. It can be more pronounced at the outer edges of the single coverage area where higher	No Laser Shadowing is present in the data

	scanning angles correspond to more area obstructed by features. Building shadow in particular can be more pronounced in urban areas where structures are taller. Data are edited to the fullest extent possible within the point cloud. As long as data meet other project requirements (density, spatial distribution, etc.), no additional action taken.	

3.3.2 Formatting

After the final QA/QC was performed and all corrections were applied to the dataset, all lidar files were updated to the final format requirements as defined in the SOW. These requirements are detailed in Table 7.

Table 7. Final formatting of the delivered data.

Parameter	Requirement
LAS Version	1.4
Point Data Record Format	6
Coordinate Reference System	NAD83 (2011) UTM zone 12, meters and NAVD88 (Geoid 18), meters in WKT Format
Global Encoder Bit	17 (for Adjusted GPS Time)
Time Stamp	Adjusted GPS Time (unique timestamps)
Intensity	16 bit, recorded for each pulse
Withheld Points	Withheld flags, properly set including for classes 7 and 18

4. DERIVATIVE LIDAR PRODUCTS

USGS required several derivative lidar products to be created. Each type of derived product is described below.

4.1 Void Polygons

Void polygons delineating areas of extremely sparse or no valid bathymetric returns have been created for this project area. The polygons reflect void areas greater than or equal to 9 square meters in area and were utilized to constrain interpolation in the bathymetry domain in the final merged topo-bathymetric DEM.

4.2 Refraction Extents

The refraction extents are auto-generated first to an expansive version of “potential” areas requiring refraction correction. This version is used to help us determine where water may be present. These refraction extents are then reviewed and revised, using a combination of DEMs, ortho imagery, intensity, Max Height Separation Raster (MHSR), difference rasters, and additional ancillary datasets, to reflect the actual extent of bathy bottom deep enough to require refraction correction. Priority is given to substantial areas that were clearly wet or could be perceived as wet. Some nominal areas of potentially wet ground were not collected when perceived dense vegetation was also present (Figure 8). These vegetated areas often appear as darker features in the intensity but do no correlate well to the ortho imagery and/or MHSR. In addition, Dewberry did not include areas that could be perceived as dry or mostly dry floodplains as they did not meet the depth criteria for refraction corrections, nor could they be clearly perceived as wet. Further refinement of the refraction extents was discussed with USGS and stakeholders to prioritize the use of the ortho-imagery collected, rather than prioritizing the lidar point cloud (Figure 9).

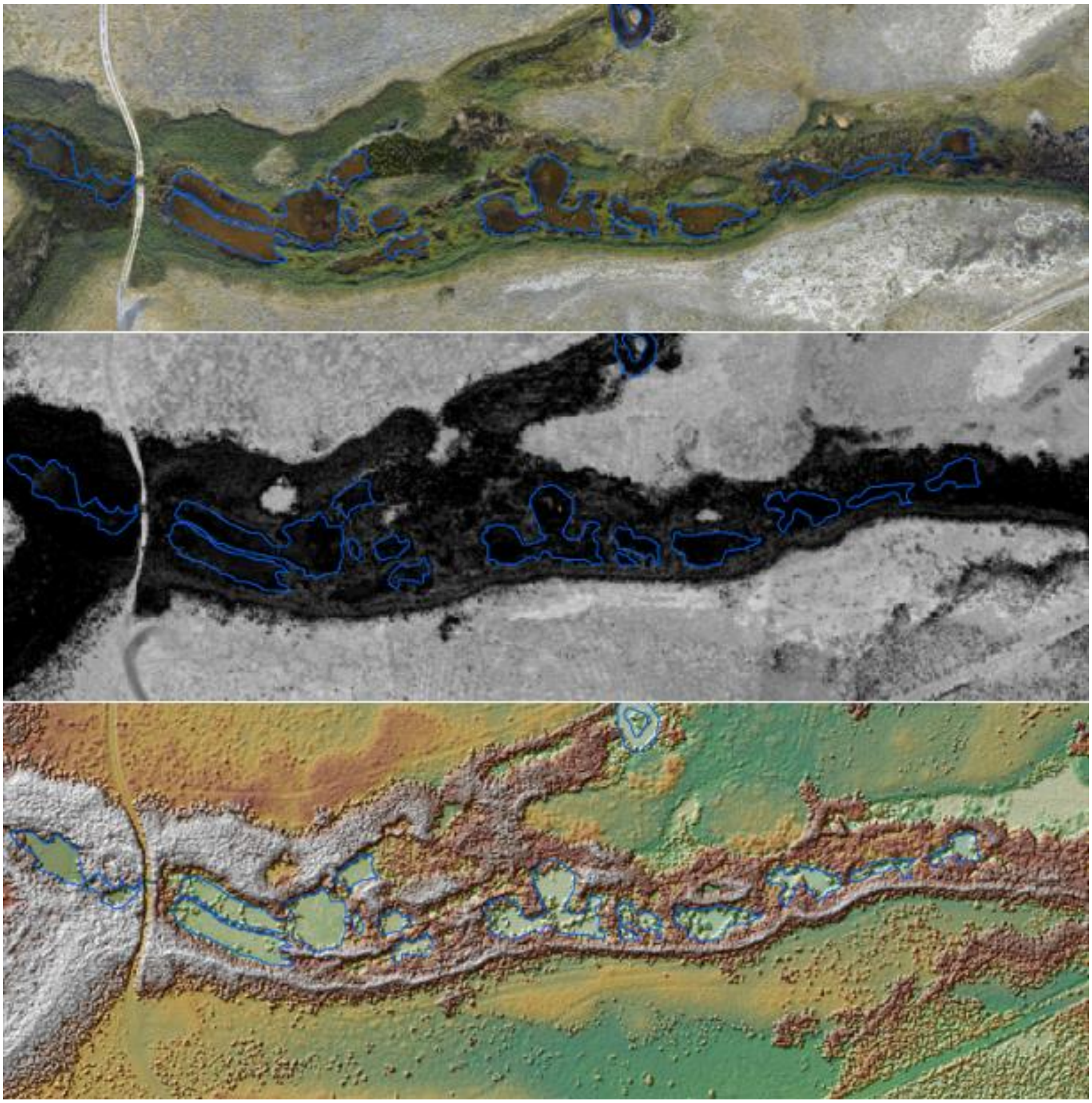

Figure 8. An example of a nominal area of potentially wet ground, as suggested by the intensity, that was not collected in the refraction extents (blue polygons) due to the perceived dense vegetation. Only the "pools" of open water containing bathy bottom and detected water surface points were refracted.

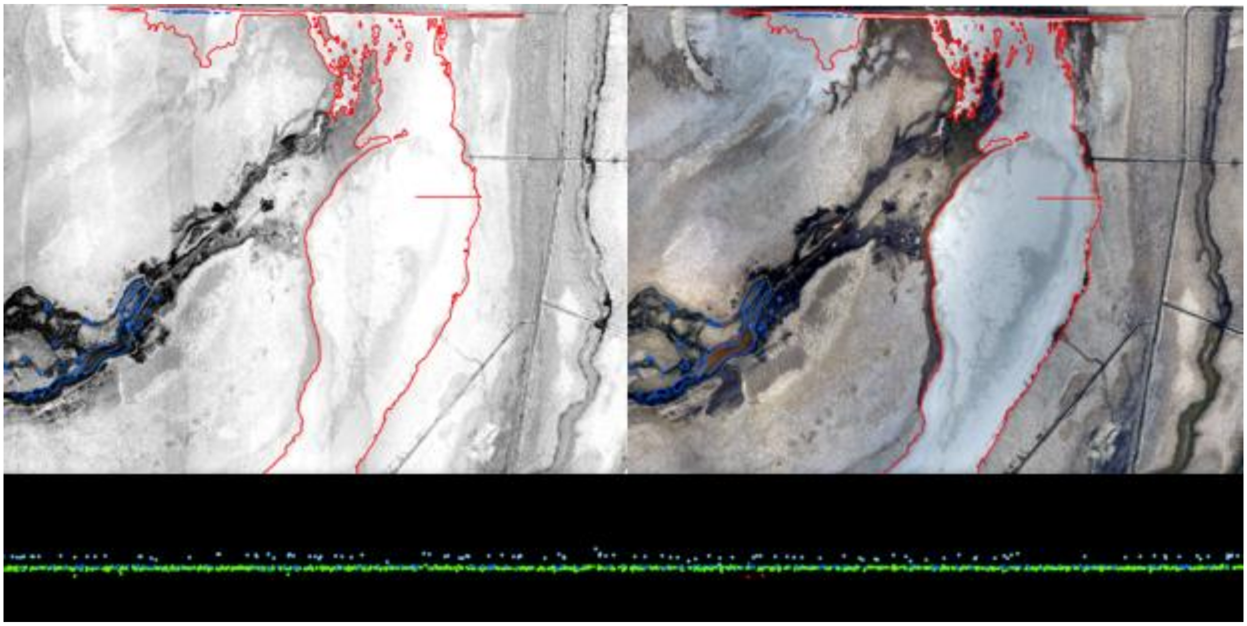

Figure 9. An example of an area (red polygon) that was initially collected as part of the refraction extents but later removed as part of the discussion with USGS and stakeholders. The profile (bottom image) show points that were initially interpreted as water surface in light blue but after discussions with the client priority was given to the orthoimagery (upper right image) and intensity (upper left image), which show the feature is currently dry at the time of collect. The lidar returns that were interpreted as water surface could be a function of the environment at the time of collection, including possible dust layer above the dry bed.

Dewberry applies ground (class 2) and bathy bottom (class 40) classifications based on the refraction extents so that all grounded points within the refraction extents are classed to class 40 and all grounded points outside of the refraction extents are classed to class 2.

4.3 Flightline Extents

Flightline extents are delivered as polygons in an Esri shapefile, delineating actual coverage of each swath used in the project deliverables. Dewberry delivered this shapefile using USGS's provided template so that each polygon contains the following attributes:

- Lift/Mission ID (unique per lift/mission)
- Point Source ID (unique per swath)
- Type of Swath (project, cross-tie, fill-in, calibration, or other)
- Start time in adjusted GPS seconds
- End time in adjusted GPS seconds

Prior to delivery, a final flightline shapefile is created from the final, tiled point cloud deliverables to ensure all correct swaths are represented in the flightline extents. The flightline shapefile is then reviewed for complete coverage and correct formatting.

4.4 Intensity Imagery

Intensity orthoimages representing normalized seabed reflectance have been created for the entire project area on a per-tile basis. Each 1-meter grid cell has an associated 16-bit intensity value, 256 color gray scale. The intensity layer extents are the same as the extents for the final classified topo-bathymetric LAS and DEMs.

4.5 Swath Separation Images (SSIs)

Dewberry verified inter-swath or between swath relative accuracy of the dataset by generating swath separation images in conjunction with interswath polygons. Color-coding is used to help visualize elevation differences between overlapping swaths. Pixels that do not contain points from overlapping flight lines are colored according to their intensity values.

The swath separation images are symbolized by the following ranges:

- 0-8 cm: **Green**
- 8-16 cm: **Yellow**
- >16 cm: **Red**

Areas of vegetation and steep slopes (slopes with 16 cm or more of valid elevation change across one raster pixel) are expected to appear yellow or red in the SSIs. Flat, open areas are expected to be green in the SSIs. Large or continuous sections of yellow or red pixels following flight line patterns and not the terrain or vegetation can indicate the data was not calibrated correctly or that there were issues during acquisition that could affect the usability of the data.

Dewberry generated swath separation images using LP360 software. These images were created from the last return of all points except points classified as noise and/or flagged as withheld. Point Insertion was used as the Surface Method and the cell size was set to a 1 meter cell size. The three interval bins used are bulleted above and the parameter to “Modulate source differences by Intensity” was set to 50%. The output GeoTIFF rasters are tiled to the project tile grid, clipped to the master DPA, and formatted (including defining the CRS which matches the project CRS) using GDAL software, version 2.4.0.

4.6 Maximum Surface Height Rasters

Maximum height separation rasters (MHSR) have been created for the entire project areas on a per-tile basis. The rasters provide a method for quickly assessing withheld-flagged points in the lidar. They are created using the highest non-withheld point. Properly flagged points will produce rasters with uniform appearance. The maximum surface height rasters are tiled according to the tile grid. GDAL version 2.4.0 used for MHSR formatting.

5. LIDAR POSITIONAL ACCURACY

5.1 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. For accuracy testing, Dewberry typically uses proprietary software, which utilizes both Esri and lastools software within its workflow, to test the swath lidar vertical accuracy and classified lidar vertical accuracy.

Horizontal accuracy testing requires survey checkpoints located such that the checkpoints are photo-identifiable in the intensity imagery. No photo-identifiable checkpoints were surveyed for this project, so the horizontal accuracy was not tested.

5.2 Survey Vertical Accuracy Checkpoints

Dewberry surveyed 49 checkpoints for the project. Survey checkpoints were located within bare earth/open terrain, grass/weeds/crops, brush/low trees, forested/fully grown, and submerged topography land cover categories. Checkpoints were evenly distributed throughout the project area to cover as many flight lines as possible. The locations of the QA/QC checkpoints used to test the positional accuracy of the dataset are shown in Figure 10.

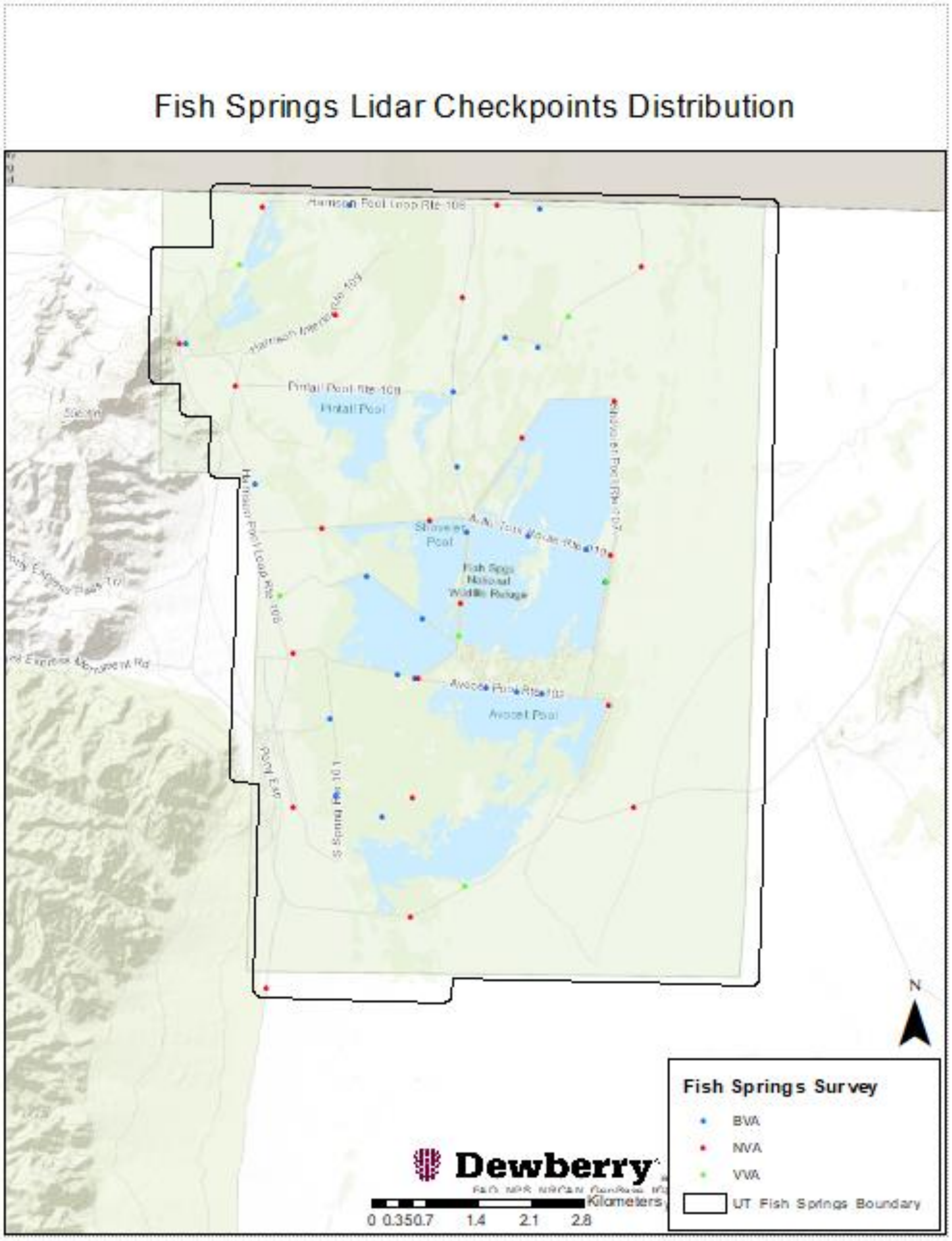

Figure 10. Location of all surveyed checkpoints

Six checkpoints were removed from the classified lidar vertical accuracy testing. Even without these checkpoints, there were enough total checkpoints and enough checkpoints per land cover category to satisfy project requirements. One checkpoint BVA_17 showed a 0.394-meter difference between the surveyed elevation and the lidar elevation, with no issues in the lidar data to support the discrepancy. Other survey points within the same flight line tested within specified thresholds. The checkpoint was therefore considered low confidence and removed from the final vertical accuracy testing.

Six checkpoints (BVA_02, BVA_08, BVA_10, BVA_11, BVA_13, and BVA_17) were removed from the classified lidar vertical accuracy testing due to the low confidence being surveyed over heavy aquatic vegetation. Per the task order, checkpoints should not be located within 5 meters of a significant change in slope. Breaks in the terrain may cause erroneous vertical accuracy results due to interpolation of the surface. Points on such terrain do not adequately test how well a sensor or a vegetation filtering technique performed. The coordinates of these checkpoints are provided in Table 8 and photos showing checkpoints located near breaks in the terrain are shown in Figure 11 and Figure 12.

Table 8. Checkpoints removed from vertical accuracy testing

Point ID	NAD83(2011) UTM zone 12, m		NAVD88 Geoid 18, m
	Easting (x)	Northing (y)	Elevation (z)
BVA-2	4416174.716	294569.065	1311.726
BVA-8	4412039.647	295625.960	1312.318
BVA-10	4413056.709	295561.330	1312.214
BVA-11	4413592.986	296681.839	1310.549
BVA-13	4413639.734	296441.535	1310.593
BVA-17	4419842.741	295814.159	1304.338

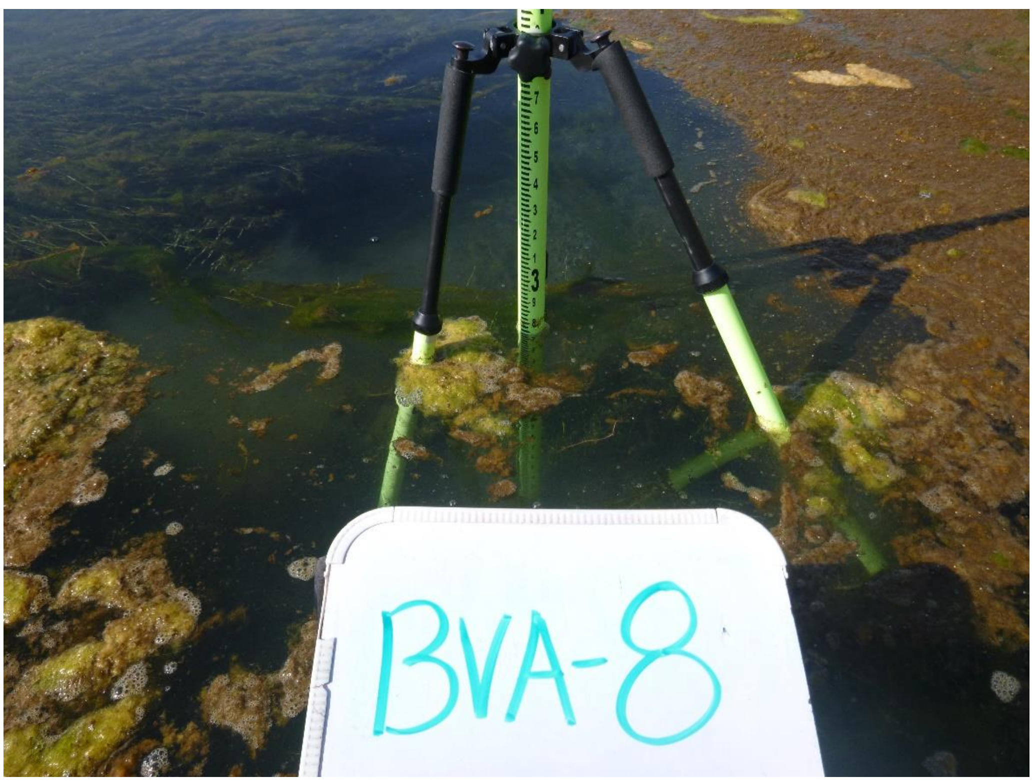

Figure 11. Checkpoint BVA_08 is located near heavy submerged vegetation and pond scum. This checkpoint was removed from final classified vertical accuracy testing due to its location.

Figure 12. Checkpoint BVA_13 is located over heavy submerged aquatic vegetation. This checkpoint was removed from final classified vertical accuracy testing.

5.3 Vertical Accuracy Test Procedures

NVA reflects the calibration and performance of the lidar sensor. NVA was determined with checkpoints located only in non-vegetated terrain, including open terrain (grass, dirt, sand, and/or rocks) and urban areas. In these locations it is likely that the lidar sensor detected the bare-earth ground surface and random errors are expected to follow a normal error distribution. Assuming a normal error distribution, the vertical accuracy at the 95% confidence level is computed as the vertical root mean square error ($RMSE_z$) of the checkpoints x 1.9600. For the Fish Springs Topobathymetric lidar project, the vertical accuracy specification is 19.6 cm or less based on an $RMSE_z$ of 10 cm x 1.9600.

BVA was determined with check points located only on submerged topography. With a normal error distribution, the vertical accuracy at the 95% confidence level is computed as the vertical root mean square error ($RMSE_z$) of the checkpoints x 1.9600. The $RMSE_z$ for the BVA is a depth-dependent value that takes into account increasing uncertainty with depth using two uncertainty coefficients. For the Fish Spring Topobathy lidar project, the $RMSE_z$ specification is 18.5 cm. For the Fish Springs Topobathymetric Lidar project, bathymetric vertical accuracy specification is 36.3 cm or less based on an $RMSE_z$ of 18.5 cm x 1.9600.

VVA was determined with all checkpoints in vegetated land cover categories, including tall grass, weeds, crops, brush and low trees, and fully forested areas. In these locations 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 95th percentile error for all checkpoints in all vegetated land cover categories combined. The Fish Springs Topobathymetric Lidar project VVA specification is 30.0 cm based on the 95th percentile. The VVA is accompanied by a listing of the 5% outliers that are larger than the 95th percentile used to compute the VVA. In addition to the combined VVA, separate assessments were conducted for tall grass/weeds/crops and fully forested land cover categories.

The relevant testing criteria are summarized in Table 9.

Table 9. Vertical accuracy acceptance criteria

Land Cover Type	Quantitative Criteria	Measure of Acceptability
NVA	Accuracy in open terrain and urban land cover categories using $RMSE_z$ *1.9600	19.6 cm
BVA	Accuracy in submerged topography using $RMSE_z$ *1.9600	36.3 cm
VVA	Accuracy in vegetated land cover categories combined at the 95th percentile	30.0 cm

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

1. Dewberry's team surveyed X, Y, and z coordinates for discrete checkpoints in accordance with project specifications.
2. Dewberry interpolated the bare-earth lidar DTM to determine a lidar surface z coordinate for every surveyed X and Y coordinate.
3. Dewberry computed difference between each surveyed z coordinate and lidar surface z coordinate.
4. The resulting differences were analyzed by Dewberry to assess the accuracy of the data. The overall descriptive statistics of each dataset were computed to assess any trends or anomalies. The results are provided in the following section.

5.4 Vertical Accuracy Results

Table 10 summarizes the tested vertical accuracy of the classified lidar LAS files.

Table 10. Classified lidar vertical accuracy results

Land Cover Type	# of Points	NVA (m)	BVA (m)	VVA (m)
Project Specification		**0.196**	**0.363**	**0.300**
NVA	21	0.080		
BVA	16		0.344	
VVA	6			0.103

The topographic portion of this LAS dataset 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 $RMSE_z$ = 4.1 cm, equating to ± 8.0 cm at 95% confidence level. Actual VVA accuracy was found to be ± 10.3 cm at the 95th percentile. The bathymetric portion of this DEM dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for an 18.5 cm $RMSE_z$ Vertical Accuracy

Class. Actual bathymetric vertical accuracy was found to be $RMSE_z$ = 17.5 cm, equating to ± 34.4 cm at 95% confidence level.

The VVA 5% outliers are listed in Table 11. Descriptive statistics for all categories are presented in Table 12.

Table 11. VVA 5% outliers

Point ID	UTM zone 12N\ NAD83(2011), m		NAVD88 Geoid 18, m		Delta z (m)
	Easting (x)	Northing (y)	Survey z	Lidar z	
VVA-6	297270.078	4414149.308	1311.101	1311.210	0.113

Table 12. Classified lidar vertical accuracy descriptive statistics

Land Cover Type	# of Points	$RMSE_z$ (m)	Mean (m)	Median (m)	Skew	Std Dev (m)	Min (m)	Max (m)	Kurtosis
NVA	21	0.041	0.010	0.019	-0.359	0.040	-0.078	0.067	-0.409
BVA	16	0.175	0.105	0.127	-0.955	0.145	-0.196	0.288	0.557
VVA	6	N/A	0.028	0.018	0.571	0.057	-0.026	0.113	-1.308

Based on the vertical accuracy testing conducted by Dewberry, the lidar dataset for the Fish Springs Topobathymetric Lidar project satisfies the project's pre-defined vertical accuracy criteria.

6. DEM PROCESSING & QUALITATIVE ASSESSMENT

6.1 DEM Production Methodology

Dewberry utilized a proprietary routine to generate DEM products. ArcGIS, LP360, LAStools, and proprietary tools were used for QA/QC.

The DEM bare earth surface was sourced from the final classified lidar points in bare earth classes—class 2 for bare-earth ground and class 40 for submerged topography (bathymetry). The final DEM was created with the LAStools "blast2dem" utility, which uses standard linear interpolation. Void polygons were enforced in the final raster to delineate areas larger than 9 square meters where no valid bathymetric returns were received. The DEM was reviewed for any issues requiring corrections, including lidar point misclassification and processing artifacts. After corrections were applied, the DEM was split into tiles per the project tiling scheme. The formatting of the DEM tiles was verified before a final qualitative review was conducted by an independent review department within Dewberry.

For the raised channel feature identified by the US Fish and Wildlife Service (USFWS) in tile 12STK980190 (Figure 13), it was discussed with USGS and the stakeholders to specifically remove this feature from the bathymetric bottom - class 40 classification and to interpolate across this particular feature whereas all other bathymetric bottom coverage gaps were voided (Figure 14). Dewberry investigated this channel and verified that this feature has always been raised/elevated in all versions of data; the higher elevations were not introduced from refraction correction, or any other processing performed by Dewberry. From imagery, it appears as though the channel could be vegetated, but the point cloud does not represent variations in lidar returns typically associated with vegetation, even low vegetation. There is a potential that algae or some other smooth aquatic vegetation was present in the channel at the time of collect.

FWS went out to perform field verification for the feature in question, however, wind and wave action coupled with turbid water made it difficult to get eyes on the exact location in question. It was determined that the bulk of the feature was vegetated, mostly with spiral ditchgrass which is present throughout the refuge (Figure 15).

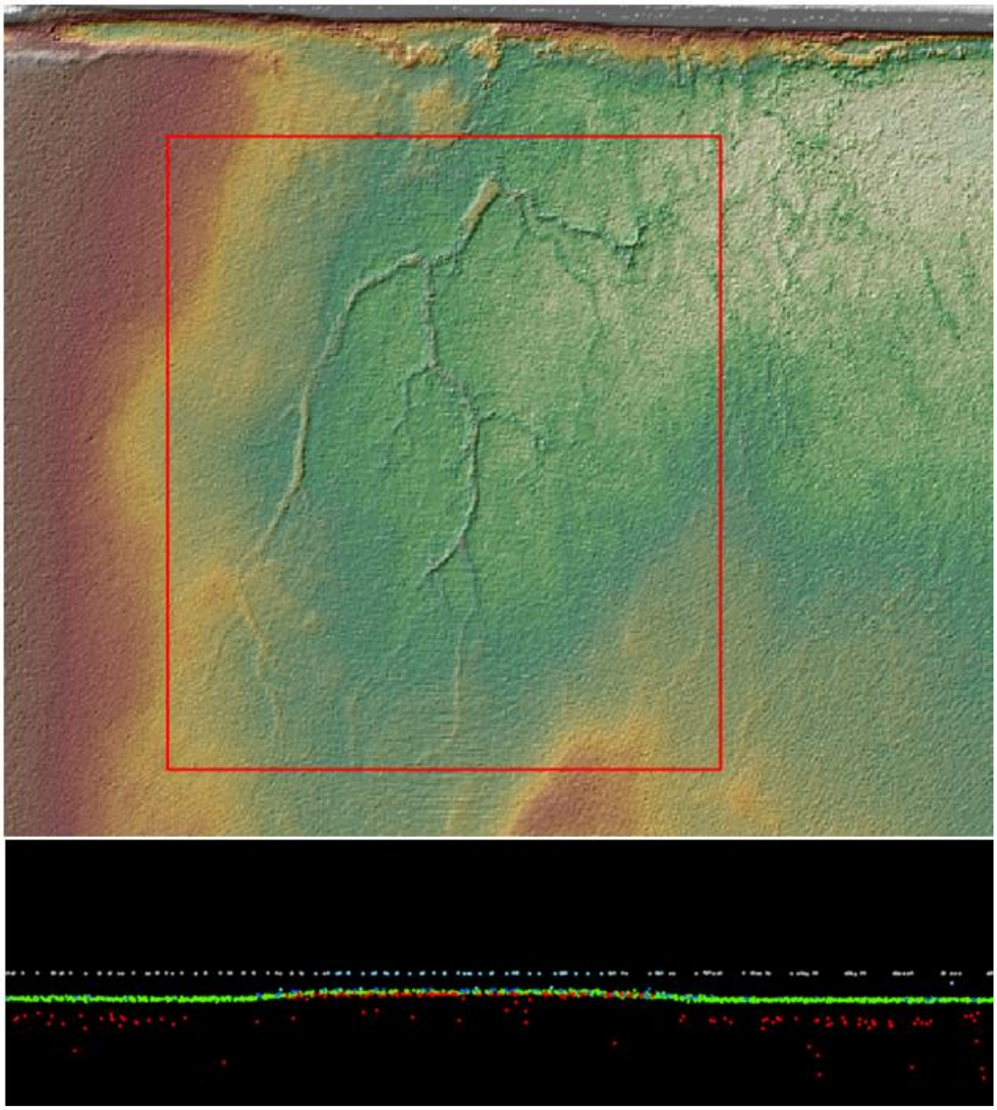

Figure 13. A lidar cross-section of the feature in question shows that the bathymetric ground surface is raised in the initial delivery. Profile shows a gradual and natural elevation gradient with no obvious indication of vegetation. Class 1 (unclassified) is shown in grey, class 7 (low noise) is shown in red, class 40 (bathymetric ground) is shown in green, class 41 (water surface) is show in light blue, and class 45 (water column) is shown in dark blue.

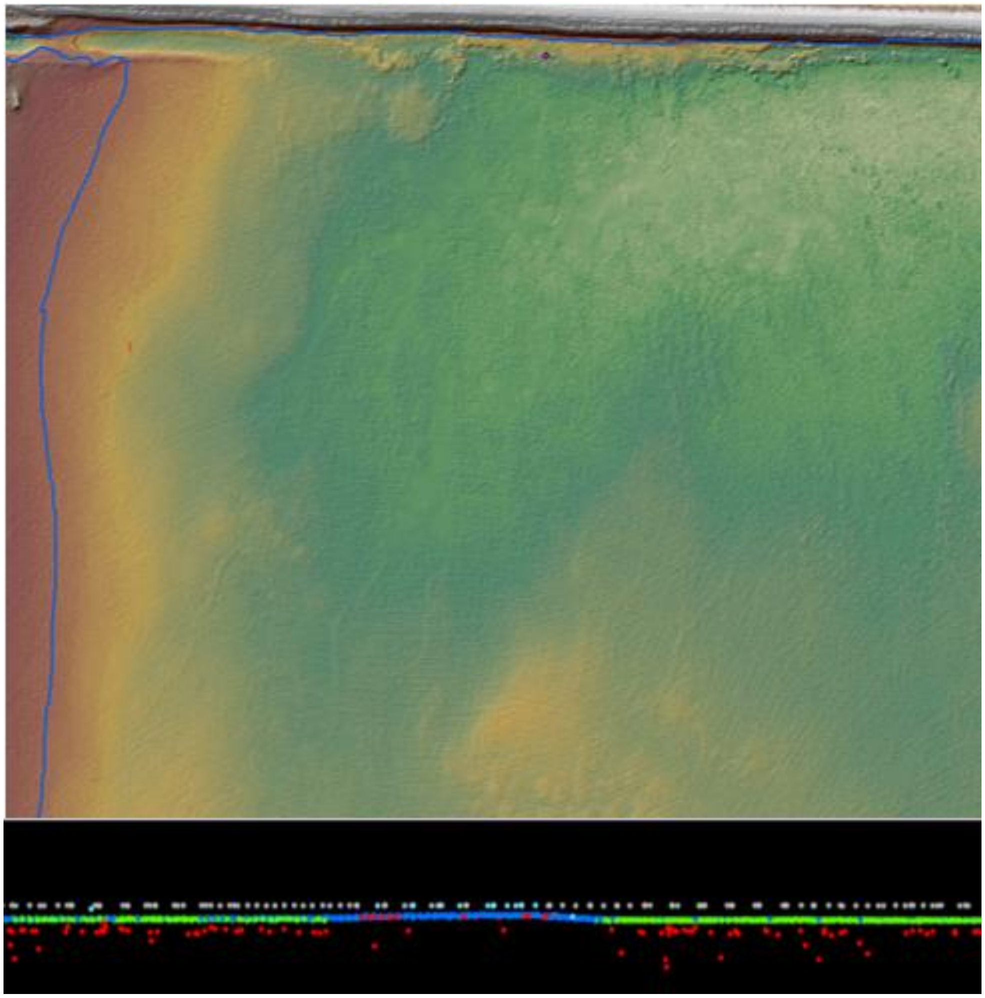

Figure 14. A lidar cross-section of the feature in question shows the results when bathymetric ground classification is adjusted to remove the slightly raised area. Additional voids are introduced in the DEM due to a lack of sufficient bathy bottom coverage, but per discussion with USGS and stakeholders the coverage gaps were interpolated across. This lack of coverage is based on the assumption that the raised area is part of some sort of algae or aquatic vegetation and there does not appear to be any surface beneath to indicate bathy bottom coverage was acquired for this particular area. Class 1 (unclassified) is shown in grey, class 7 (low noise) is shown in red, class 40 (bathymetric ground) is shown in green, class 41 (water surface) is show in light blue, and class 45 (water column) is shown in dark blue.

Figure 15. FWS image of spiral ditchgrass within the Gadwall drainage.

6.2 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. Dewberry conducted the review in ArcGIS using a hillshade model of the full dataset with a partially transparent colorized elevation model overlaid. The tiled DEMs were reviewed at a scale of 1:5,000 to verify all properties of the tiled DEMs including coordinate reference system information, cell size, cell extents, and that compression is not applied to the tiled DEMs. GDAL version 2.4.0 used for all DEM formatting and to verify correct enforcement of void areas.

6.3 DEM Vertical Accuracy Results

The same 43 checkpoints that were used to test the vertical accuracy of the lidar were used to validate the vertical accuracy of the final DEM products. DEMs were created by averaging the elevations of ground points within each pixel, which may result in slightly different elevation values at each survey checkpoint when compared to the linearly interpolated TIN created from the source LAS. The vertical accuracy of the DEM was tested by comparing the elevation of a given surveyed checkpoint with the elevation of the horizontally coincident pixel in the DEM. Dewberry used ArcGIS to test the DEM vertical accuracy.

The survey checkpoints used to test this topobathymetric dataset are listed in the previously delivered ground survey report previously delivered. Table 13 summarizes the tested vertical accuracy results from the final DEM dataset.

Table 13. DEM vertical accuracy results

Land Cover Type	# of Points	NVA (m)	BVA (m)	VVA (m)
Project Specification		**0.196**	**0.363**	**0.300**
NVA	21	0.078		
BVA	16		0.329	
VVA	6			0.084

The topographic portion of this DEM dataset 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 $RMSE_z$ = 4.0 cm, equating to ± 7.8 cm at 95% confidence level. Actual VVA accuracy was found to be ± 8.4 cm at the 95th percentile. The bathymetric portion of this DEM dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for an 18.5 cm $RMSE_z$ Vertical Accuracy Class. Actual bathymetric vertical accuracy was found to be $RMSE_z$ = 16.8 cm, equating to ± 32.9 cm at 95% confidence level.

The VVA 5% outliers are listed in Table 14. Descriptive statistics for all categories are presented in Table 15.

Table 14. VVA 5% outliers

Point ID	UTM zone 12N NAD83(2011), m		NAVD88 Geoid 18, m		Delta z (m)
	Easting (x)	Northing (y)	Survey z	Lidar z	
VVA-6	4414149.308	297270.078	1311.101	1311.188	0.087

Table 15. Classified lidar vertical accuracy descriptive statistics

Land Cover Type	# of Points	$RMSE_z$ (m)	Mean (m)	Median (m)	Skew	Std Dev (m)	Min (m)	Max (m)	Kurtosis
NVA	21	0.040	0.008	0.006	-0.267	0.040	-0.074	0.068	-0.627
BVA	16	0.168	0.102	0.116	-1.023	0.138	-0.205	0.286	0.817
VVA	6	N/A	0.026	0.020	0.267	0.048	-0.024	0.087	-2.274

Based on the vertical accuracy testing conducted by Dewberry, the DEM dataset for the Fish Springs Topobathymetric Lidar Project satisfies the project's pre-defined vertical accuracy criteria.

6.4 DEM Checklist

The following table represents a portion of the high-level steps in Dewberry's DEM Production and QA/QC checklist that were performed for this project.

Table 16. A subset of the high-level steps from Dewberry's bare earth DEM Production and QA/QC checklist performed for this project.

Pass/Fail	Validation Step
Pass	Final void polygons are created
Pass	DEM created from Triangulated Irregular Network (TIN) of ground classes in LAStools. DEMs are tiled without overlaps or gaps, show no edge artifact or mismatch, DEM deliverables are .tif format. DEMs are not compressed. Areas outside survey boundary are coded as NoData. Internal voids are coded as NoData (-999999)
Pass	Final void polygons used to clip areas of large interpolation (>9 sqm) in DEM
Pass	Manually review topobathymetric DEMs to check for issues
Pass	Special attention should be paid along the land/water interface
Pass	DEMs should be seamless across tile boundaries
Pass	Bridges should NOT be present in final topobathy DEMs.
Pass	All qualitative issues present in the DEMs as a result of lidar processing and editing issues must be marked for corrections in the lidar These DEMs will need to be recreated after the lidar has been corrected.
Pass	Calculate DEM Vertical Accuracy including NVA, VVA, BVA and other statistics
Pass	Split the DEMs into tiles according to the project tiling scheme
Pass	Verify all properties of the tiled DEMs, including coordinate reference system information, cell size, cell extents, and that compression has not been applied to the tiled DEMs. GDAL version 2.4.0 used for all DEM formatting.
Pass	Load all tiled DEMs into Global Mapper to verify complete coverage to the (buffered) project boundary and that no tiles are corrupt.

7. METADATA

Project level metadata files were delivered in XML format for all project deliverables including lidar, DEMs, imagery, refraction extents, bridge breakline, and void polygons. All metadata files are FGDC compliant and were verified to be error-free according to the USGS MetaParser utility.

8. ORTHOIMAGERY

Dewberry acquired three-band (Red, Green, and Blue, or RGB channels) digital imagery covering the project area. Imagery acquisition occurred concurrently with lidar acquisition. Dewberry performed the aerotriangulation and processing of image frames.

8.1 Orthoimagery Processing and Qualitative Assessment

Dewberry created photo-center shapefiles from the image frames and all images were loaded into SOCET GXP for stereo viewing.

Dewberry used SimActive's Correlator 3D software to aerotriangulate and ortho-rectify the imagery. The lidar dataset collected for this project was used to generate the orthorectification reference surface. Seamlines were auto-generated and then reviewed prior to creating the orthoimage tiles. Three-band (RGB), uncompressed orthoimage tiles (1000 m x 1000 m) in GeoTIFF format with 10 cm Ground Sample Distance (GSD) were created for the project area. All ortho-mosaics have the same coordinate reference system as the lidar data:

Horizontal Datum: North American Datum of 1983 with the 2011 Adjustment (NAD 83 (2011))

Coordinate System: UTM zone 12 North

Units: Meters

Once the orthoimagery mosaics were created, all formatting was verified for adherence to project parameters. Tiles were loaded into ArcGIS or Global Mapper software to verify completeness, continuity, and integrity. A manual review was performed to identify any usability and quality issues, such as voids, misalignments, warped features, and smears. A sliver gap of missing imagery approximately 900 m^2 in size was identified within tile Ortho_12STK990150 due to adjacent image frames not overlapping in this area Figure 16. Data void in orthoimagery shown in red.. As agreed with USGS, other available orthoimagery was used to fill in the void area. The imagery used to fill in the void area was publicly available USDA NAIP orthoimagery collected on June 20, 2021 at native 60cm resolution resampled to 10cm to match the resolution of the orthoimagery produced for this project.

Figure 16. Data void in orthoimagery shown in red.

USFWS stakeholders noted several areas on the delivered orthoimagery that contained smearing or other anomalies. The original orthos were created utilizing lidar that was not 100% finalized in order to meet the delivery deadline. Some of the above ground features that had not been completely classified out resulted in a surface that caused these anomalies. All orthos were reprocessed with the finalized lidar, which corrected the noted smears and anomalies (Figure 17).

Figure 17. An example of area that was impacted by the surface anomaly. Top image shows the warp caused by the powerlines and in the bottom image it is repaired.

There is one area of seamlines that did not color balance and blend as well in the reprocessing (Figure 18). Due to the nature of seamlines in such a vast open and flat area such as the desert or over open water there are often visible edges similar to this. Since all orthos were reprocessed it is also not possible to use the old tiles for this area as they would not match perfectly along the edges leading to visible pixel mismatch along the edges of the tiles.

Figure 18. Area affected by seamline visibility.