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PROJECT REPORT

For the

USGS Salton Sea LiDAR Project

USGS Contract:

G10PC00013

Task Order Number:

G10PD02249

Prepared for:

USGS

Prepared by:

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1 Executive Summary

The goal of the Salton Sea LiDAR Task Order is to develop a dataset for pre-construction planning and for locating geologic features such as faults. The project encompasses Salton Sea with a 5 kilometer buffer around it. The deliverables as required in the task order are raw point cloud data (swath data), classified point cloud data (LAS), bare earth surface models (raster DEM), supplemental metadata, and reports. This report documents the development of the deliverable products including the planning, acquisition, and processing of the LiDAR data as well as the derivation of LiDAR products.

Dewberry served as the primary contractor for the project. In addition to project management, Dewberry was responsible for LiDAR classification, breakline production, DEM development and quality assurance. Dewberry's staff performed the final post-processing of the LAS files for the project, produced the breaklines used to enhance the LiDAR-derived surface, generated the 1 meter DEMs, and performed quality assurance inspections on all subcontractor generated data and reports. Towill Incorporated performed the LiDAR data acquisition including data calibration. McGee Surveying Consulting performed an independent control survey. Their reports can be found in the Appendices.

Dewberry received the final survey data in both ellipsoidal heights and orthometric heights so that a check could be done without the effects of a Geoid model. The unclassified LiDAR was delivered in ellipsoid heights. After the classification was complete the Geoid model was applied and the data were reprojected to orthometric heights. As per the contract, the data are delivered in NAD1983 UTM Zone 11N, NAVD88 Geoid 09 meters, and NAD1983 UTM Zone 11N, Ellipsoid meters. Lastly, the low lying farmland mixed with rugged mountains added complexity to the classification; the use of proprietary, area-based classification macros allowed for a smooth transition between terrain types.

The outcome of the Salton Sea project is a highly accurate LiDAR dataset. The LiDAR points were collected with a nominal point spacing of 0.5 meter or better and achieved an RMSE of 3.5cm. The Fundamental Vertical Accuracy (RMSEz x 1.9600) was 6.8cm. The task order required a vertical accuracy of 9.25cm.

2 Project Tiling Footprint

The LiDAR delivery consists of six hundred and twenty three (623) tiles (Figure 1). Each tile's extent is 1500 meters by 1500 meters. The tiles which intersect the project boundary have been clipped.

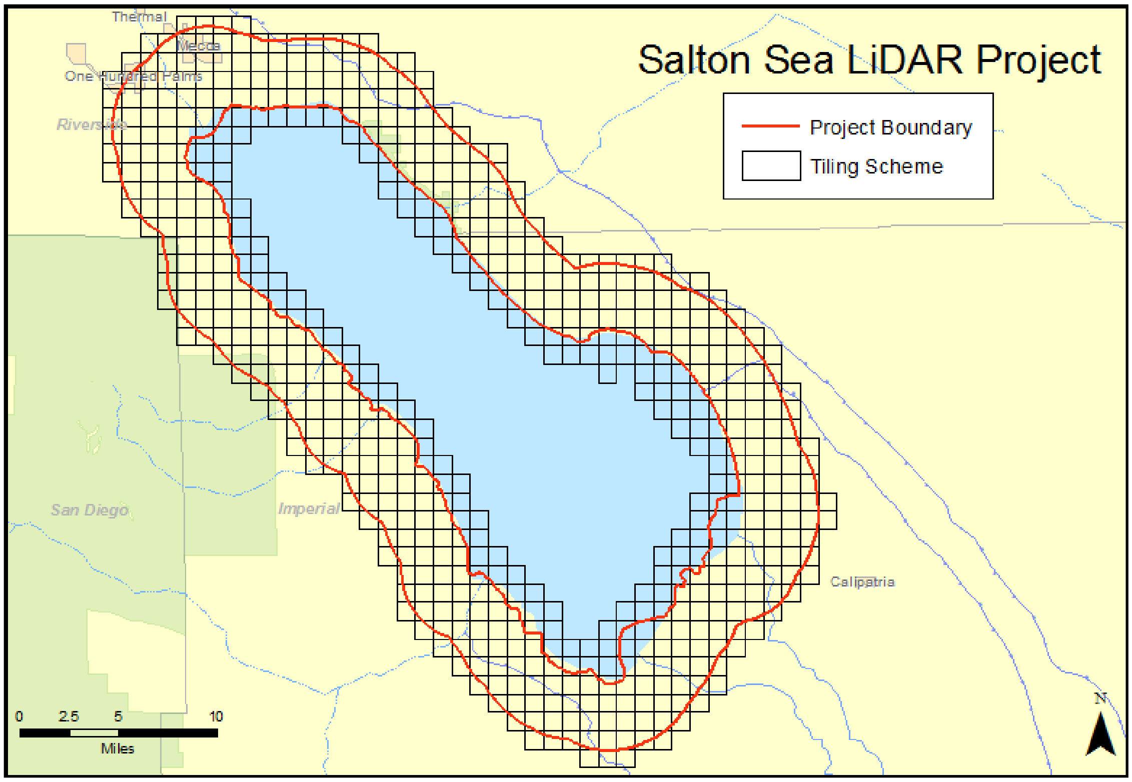

Figure 1 - Project maps showing extent of project boundary and the delivered tiling scheme

3 LiDAR Acquisition, Calibration and Control Survey Report

The LiDAR acquisition was completed in nine separate flight missions between November 9th and November 13th. Towill completed a separate report documenting all of the steps in their acquisition process. That document can be found in Appendix A. Their report includes the LiDAR collection parameters, planned flight path maps, flight line trajectories, forward/reverse or combined separation plots, flight logs, and GPS base log sheets. A control survey report is included in Appendix A and contains the details on the fully constrained control network and control station descriptions used by Towill.

4 Independent Survey Report

Dewberry contracted McGee Surveying Consulting to perform an independent survey of the Salton Sea area. The purpose of McGee's survey is to establish ground truthing points for validation of LiDAR measurements and to establish a survey reference framework for which future LiDAR surveys can be based. This survey established 21 QA/QC test points around the perimeter of the Salton Sea. The Salton Sea is straddled by earthquake faults and subject to subsidence. The recent April 4, 2010 earthquake caused a 1-4 centimeter horizontal shift around the Salton Sea shore. Subsidence in the agricultural areas at the southerly portion of the Sea is estimated to be 1-2 centimeters per year.

Fundamental QA/QC Test Points were established every four to five miles along public roads within 5 kilometers of the shoreline. The points were set in bare earth or short grasses and located on nearly level smooth surfaces away from terrain breaks. A permanent 8" or 10" bridge spike and shiner was set for all points in bare earth. The points were surveyed to a relative vertical accuracy of 5 centimeters or better which was achieved as reported in Appendix B. Sufficient redundant independent measurements were made to assure the quality of the survey results. The full Survey Report which can be found in Appendix B covers datum's, reference control, networks, adjustments, analysis, data collection, equipment and accuracy.

CGPS (continuously operated GPS reference stations) exists throughout the region and were used to reference this survey. National Geodetic Survey (NGS) Benchmarks were used to recover the North American Vertical Datum of 1988 (NAVD88). The three dimensional GPS positions are provided in NAD83, 2010.73 Epoch and grid coordinates are Universal Transverse Mercator grid system (UTM) in meters. Elevations relative to the NAVD88 benchmarks were establish by applying the Geoid 09 Model to measured ellipsoid height differences constrained to a published NAVD88 height addressed in Appendix B.

LiDAR Vertical Accuracy Statistics & Analysis

The survey points collected by McGee were tested by Dewberry against the LiDAR and the LiDAR data are within project specification. The RMSE for the Salton project measured using Orthometric Heights is 0.035 m. The task order required the LiDAR to be collected at a vertical accuracy NSSDA RMSEz = 0.0925 m. Figure 2 shows the distribution of check points throughout the dataset.

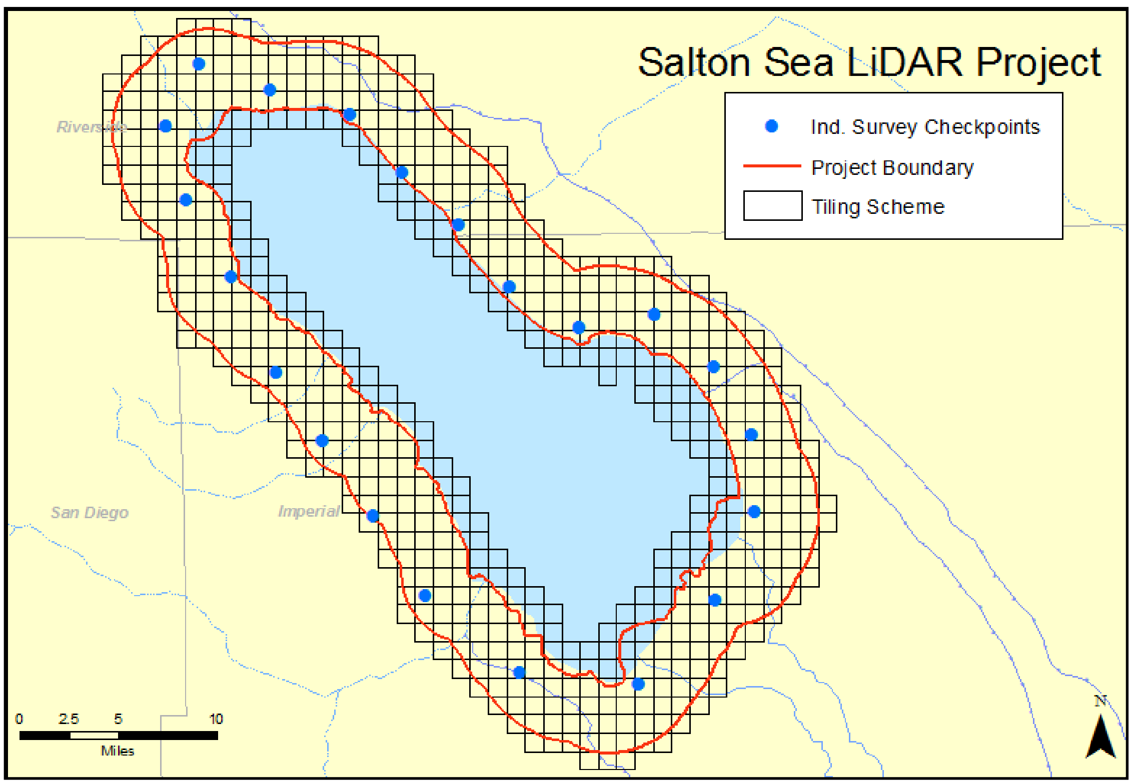

Figure 2 – Checkpoint Map shows that checkpoints are well distributed throughout project area.

The tables below show the vertical accuracy statistics and results based on calculations using the NAVD88 Geoid09 survey checkpoints. FVA (Fundamental Vertical Accuracy) is determined with check points located only in land cover category (1), open terrain (grass, dirt, sand, and/or rocks), 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 FVA 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 Salton Sea Project, the scope of work required the FVA to be 0.18 m at the 95% confidence level (based on an RMSEz of 0.0925 m.)

CVA (Consolidated Vertical Accuracy) is determined with all checkpoints in all land cover categories combined where there is a possibility that the LiDAR sensor and post-processing may yield elevation errors that do not follow a normal error distribution. CVA at the 95% confidence level equals the 95th percentile error for all checkpoints in all land cover categories combined. The project CVA standard is 0.181m at the 95% confidence level. The CVA is accompanied by a listing of the 5% outliers that are larger than the 95th percentile used to compute the CVA; these are always the largest outliers that may depart from a normal error distribution. Here, Accuracyz differs from CVA because Accuracyz assumes elevation errors follow a normal error distribution where RMSE procedures are valid, whereas CVA assumes LiDAR errors may not follow a normal error distribution in vegetated categories, making the RMSE process invalid.

Table 1 – Overall Descriptive Statistics for Checkpoints

RMSE (m) Spec=0.0925m	Mean (m)	Median (m)	Skew	Std Dev (m)	# of Points	Min (m)	Max (m)
0.035	-0.024	-0.026	0.690	0.025	21	-0.060	0.033

Table 2 – FVA and CVA Vertical Accuracy at the 95% confidence level

# of Points	FVA — Fundamental Vertical Accuracy (RMSEz x 1.9600) Spec=0.181 m	CVA — Consolidated Vertical Accuracy (95th Percentile) Spec=0.181 m
21	0.068	0.058

Based on the vertical accuracy testing conducted by Dewberry, the LiDAR dataset for the USGS Salton Sea project satisfies the project's pre-defined vertical accuracy criteria.

5 *LiDAR Processing & Qualitative Assessment*

The LiDAR is tiled into the 1500m x 1500m tiles named using the US National Grid nomenclature. The data were processed using GeoCue and TerraScan software. The initial step is the setup of the GeoCue project, which is done by importing the project defined tile boundary index. The acquired 3D laser point clouds, in LAS binary format, were imported into the GeoCue project and divided into tiles. Once tiled, the laser points were tested to ensure accuracy from flightline to flightline. This is check is done by creating a set of deltaZ ortho images. This process measures the relative accuracy between flight lines (how well one flight line fits an overlapping flight line vertically).

Dewberry identified one area that contained a discrepancy between two adjacent flights. These flight lines were sent back to Towill to be reprocessed. Once adjustments were made, Dewberry checked the deltaZ ortho images again and no issues were identified. The image below (Figure 3) shows "before and after" deltaZ ortho images of the flight line discrepancy. The red and yellow colors in the image represent elevation differences above the 10 cm project specification from swath to swath. The image on the left shows the flight line prior to correction and the image on the right shows the same flight line after it was corrected.

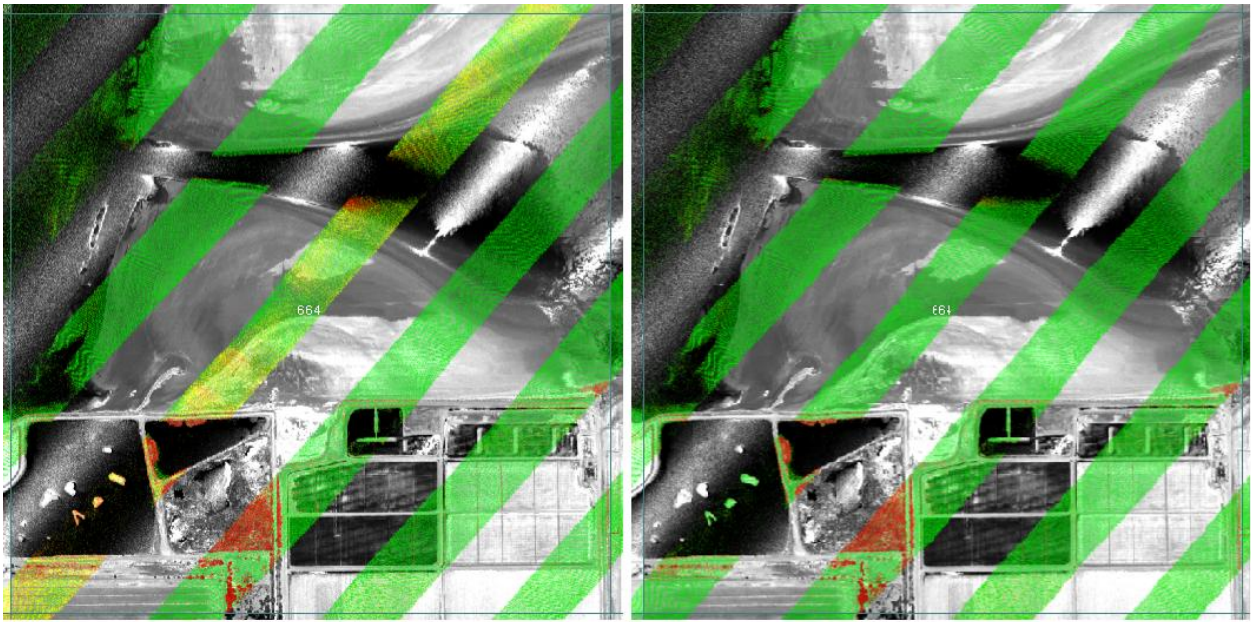

Figure 3 - DeltaZ Ortho Images of the same area showing the affect the cororection that Towill applied had on the flight line discrepancy.

After these checks, the data is classified using a proprietary routine in TerraScan. This routine classifies out any obvious outliers from the dataset following which the ground layer is extracted from the 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 is 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.

Once the automated classification has finished each tile is imported into Terrascan and a surface model is created to examine the ground classification. Often times, low lying buildings, porches, bridges, and small vegetation artifacts which are not caught during the automated classification are edited during this step. Dewberry analysts visually review the ground surface model and corrected errors in the ground classification such as vegetation and buildings that are present following the initial processing. 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. Due to the complex and varying terrain within the Salton Sea area, Dewberry analysts were required to more thoroughly review the terrain manually to ensure an accurate representation of the ground. Three examples are provided below that represent three of the major terrain types prevalent in the Salton Sea project area (Figure 4 to Figure 6). Each image shows a colored DEM with a hillshade. Both products are derived from the classified LiDAR.

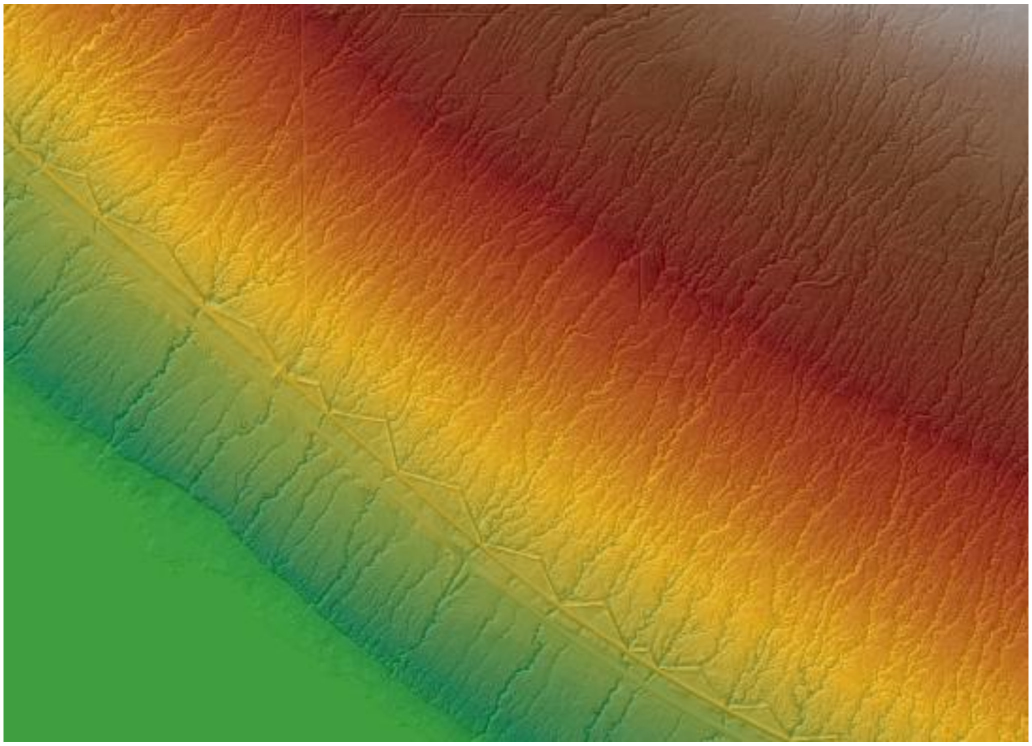

Figure 4 - Colored digital elevation model with a hillshade behind for illumination. The complex hydrology in the area required additional manual classification to ensure an accurate ground model. Elevation difference within picture is 30 meters.

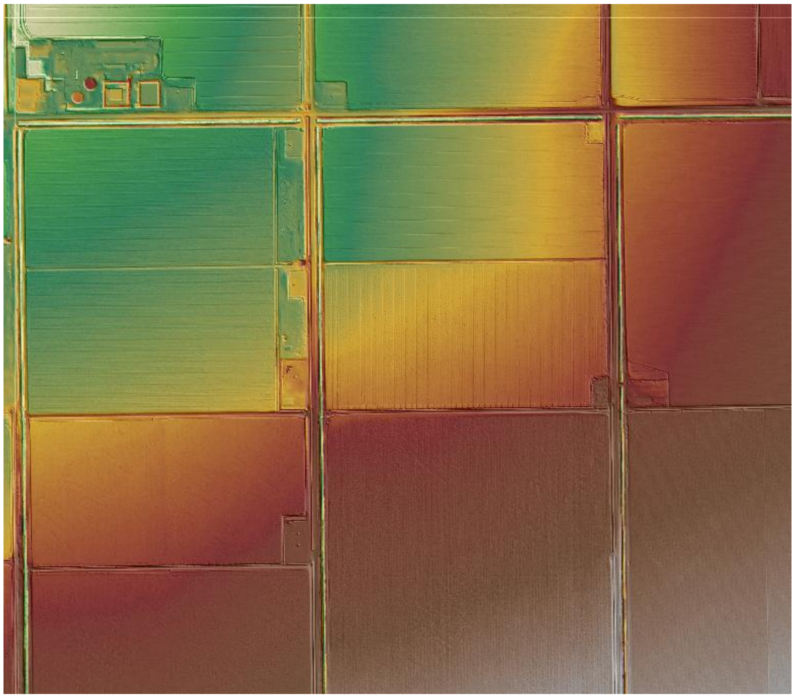

Figure 5 - Colored digital elevation model with a hillshade behind for illumination. Additional time was required to ensure all man-made berms and irrigation canals were accurately classified. Elevation difference in picture is 6 meters.

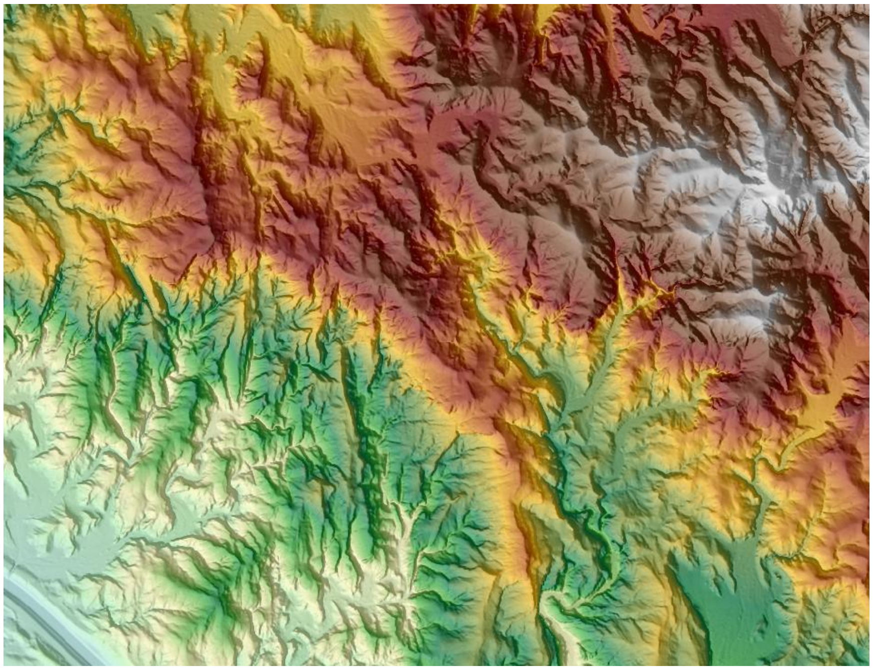

Figure 6 - Colored digital elevation model with a hillshade behind for illumination. Again, additional time was needed during the manual classification stage to ensure areas of steep slope found within the mountainous regions were accurately classified as ground. Elevation difference in picture is 140 meters.

After the ground classification corrections are complete, the dataset is processed through a water classification routine that utilizes breaklines compiled by Dewberry to automatically classify hydro features. The water classification routine selects points within the breakline polygon and automatically classifies them as class 9, water. The water classification routine also buffers the breakline polygon by 0.5m and classifies points with that buffered polygon to class 10, ignored ground for DEM production. Once the data classification is finalized, the LAS format 1.0 format points are converted to LAS 1.2 Point Data Record Format 1 and converted to the required ASPRS classification scheme.

- Class 1 = Unclassified, and used for all other features that do not fit into the Classes 2, 7, 9, or 10, including vegetation, buildings, etc.
- Class 2 = Ground
- Class 7 = Noise
- Class 9 = Water
- Class 10 = Ignored Ground due to breakline proximity.

The following fields within the LAS files are populated to the following precision: GPS Time (0.000001 second precision), Easting (0.01 foot precision), Northing (0.01 foot precision), Elevation (0.01 foot precision), Intensity (integer value - 12 bit dynamic range), Number of Returns (integer - range of 1-4), Return number (integer range of 1-4), Scan Direction Flag (integer - range 0-1), Classification (integer), Scan Angle Rank (integer), Edge of flight line (integer, range 0-1), User bit field (integer - flight line information encoded). The LAS file also contains a Variable length record in the file header.

Following the completion of LiDAR point classification, the Dewberry qualitative assessment process flow for the USGS Salton Sea project incorporated the following reviews:

1. Format: Using Terrascan, Dewberry verified that all points were classified into valid classes according to project specifications.
    a. LAS format 1.2, point data record format 1
    b. All points contain populated intensity values.
    c. All LAS files contain Variable Length Records with georeferencing information.
    d. All LiDAR points in the LAS files are classified in accordance with project specifications.

2. Spatial Reference Checks: The LAS files were imported into the GeoCue processing environment. As part of the Dewberry process workflow, the GeoCue import produced a minimum bounding polygon for each data file. This minimum bounding polygon was one of the tools used in conjunction with the statistical analysis to verify spatial reference integrity.
    a. No issues were identified with the spatial referencing of this dataset.

3. Data density, data voids: The LAS files are used to produce Digital Elevation Models using the commercial software package "QT Modeler" which creates a 3-dimensional data model derived from Class 2 (ground points) in the LAS files. Grid spacing is based on the project density deliverable requirement for un-obscured areas. For the USGS Salton Sea project it is stipulated that the minimum post spacing in un-obscured areas should be 1 point per 1 square meters.
    a. Acceptable voids (areas with no LiDAR returns in the LAS files) that are present in the majority of LiDAR projects include voids caused by bodies of water and large buildings found along the coast. These are considered to be acceptable voids.
    b. No other issues were discovered.

4. Bare earth quality: Dewberry assured the cleanliness of the bare earth during classification by removing all artifacts, including vegetation, buildings, bridges, and other features not valid for inclusion in the ground surface model.

LiDAR Processing Conclusion

Based on the procedures and quality assurance checks, the classification conforms to project specifications set by the scope of work. All issues found during the qualitative QC were fixed. The dataset conforms to project specifications for format and header values. The quality control steps taken by Dewberry to assure the classified LAS meet project specifications are detailed below.

Classified LiDAR QA\QC Checklist

Project Number/Description: Salton Sea

Overview

☒ Correct number of files delivered and all files adhere to project format specifications

☒ LAS statistics are run to check for inconsistencies

☒ Dewberry quantitative review process is completed

☒ Dewberry qualitative review process is completed

☒ Create LAS extent geometry

Data Inventory and Coverage

☒ All tiles present and labeled according to the project tile grid

Dewberry Quantitative Review Process

☒ LAS statistics review:

- ☒ LAS format 1.2
- ☒ Point data record format 1
- ☒ Georeference information is populated and accurate
  - NAD83 UTM 11N, Meters
  - NAVD88, Meters (Ellipsoid, Meters in alternate deliverable)
- ☒ GPS time recorded as Adjusted GPS Time, with 0.01 precision
- ☒ Points have intensity values
- ☒ Files contain multiple returns (minimum First, Last, and one Intermediate)

- ☒ Scan angle < 40°

☒ Data meets Nominal Pulse Spacing requirement: <=1 meters

- ☒ Tested on single swath, first return data only;
- ☒ Tested on geometrically usable portion (90%) of swath

☒ Data passes Geometric Grid Data Density Test

- ☒ Tested on 1 meter grid
- ☒ Tested on first return data only
- ☒ At least 90% of grid cells contain at least 1 point

☒ Data tested for vertical accuracy – Using NGS control points

- ☒ Checkpoint inventory
- ☒ Vertical accuracy assessment. LiDAR compiled to meet the following requirements:
  - ☒ NSSDA RMSEz = 9.5cm or better,
  - ☒ NSSDA Accuracyz @ 95% = 18.5cm or better

Completion Comments: Complete – Approved

6 Breakline Production

In order to hydro-flatten the Salton Sea, one breakline was created along to edge of the sea. The breakline was created using a combination of LiDAR-derived models. Intensity and hillshade images provided the basis for determining the land-water interface. Digital elevation models (DEMs) were created and colored by elevation such that elevations above and below sea level were easily distinguishable. These classified DEMs were overlaid on top of the intensity and hillshade images to help guide breakline digitization in hard to determine areas. The DEMs also assured that the breakline remained within a discrete elevation range, thus reducing the “stair-stepping” effect that often accompanies hydro-flattening. Once the breakline was compiled, Dewberry analyzed the elevations and assigned one elevation to all the breakline vertices.

Many of the checks used to test the accuracy of breaklines are not applicable to the Salton Sea project because only one breakline was collected for the sea. The only applicable check was to compare the elevation of the breakline vertices against the elevation extracted from an ESRI Terrain built from the LiDAR ground points. A discrepancy is expected because of the hydro-enforcement applied to the breakline vertices and because interpolated imagery is used to acquire the breaklines.

There are over one million vertices on the waterbody breakline. Each vertex was tested against a terrain built from ground and water points. None of the vertices on the breakline are floating above the sea’s surface and less than 0.05% are digging into the terrain more than two feet. The majority (80%) of the vertices are between 0 and 0.3 meters of the LiDAR surface. A graph showing the full results is shown below (Figure 7).

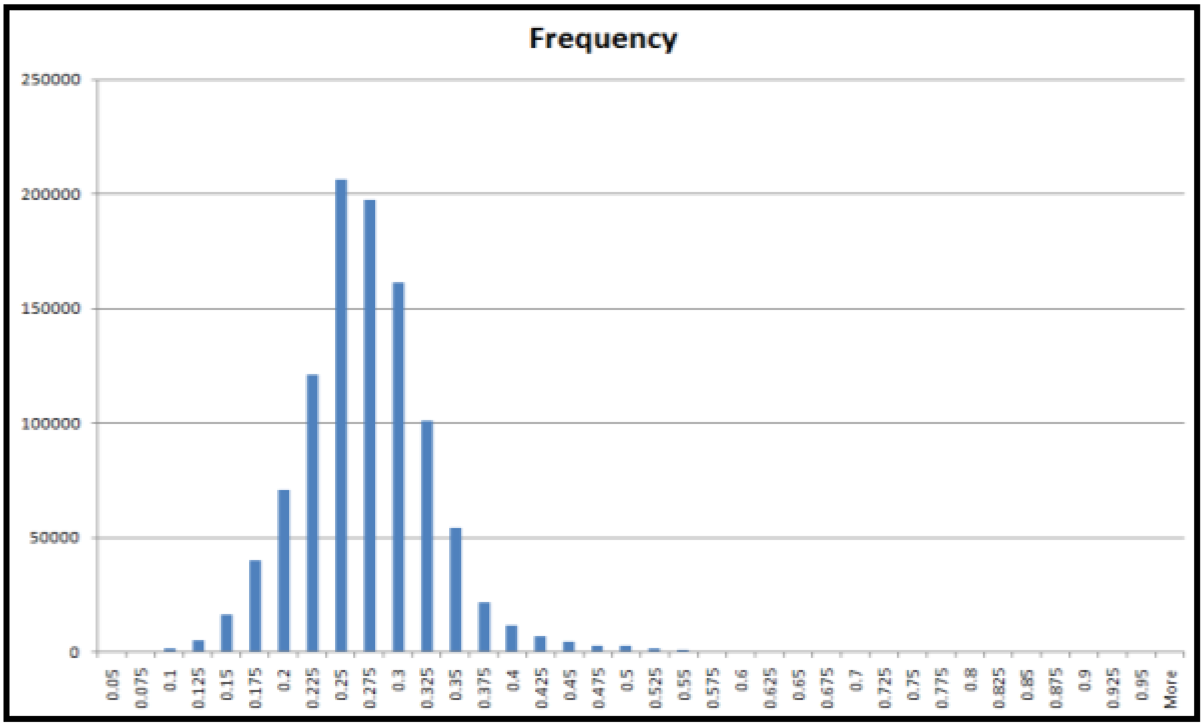

Figure 7 – Histogram of Waterbody Vertices. The x-axis is elevation difference in meters and the y-axis is a count of vertices.

7 DEM Production & Qualitative Assessment

DEM Production Methodology

Dewberry's utilizes ESRI software and Global Mapper for the DEM production and QC process. ArcGIS software is used to generate the products and the QC is performed in both ArcGIS and Global Mapper. The DEM workflow is described in Figure 8.

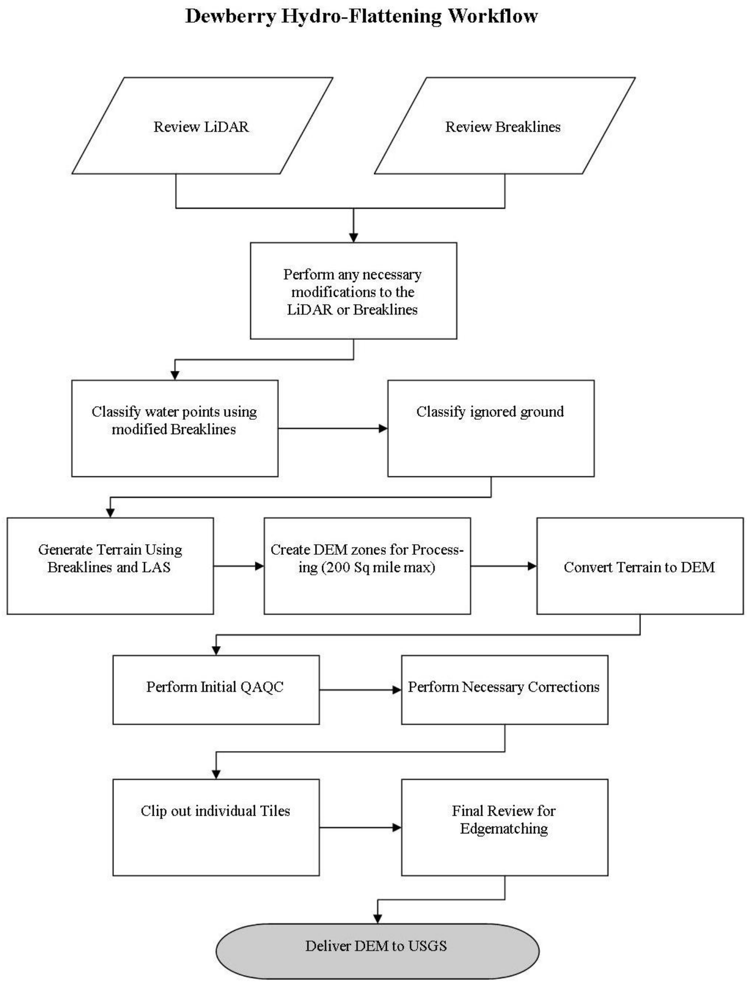

Figure 8 – Dewberry's DEM workflow

1. Classify Water Points: LAS point falling within hydrographic breaklines shall be classified to ASPRS class 9 using TerraScan. Breaklines must be prepared correctly prior to performing this task.
2. Classify Ignored Ground Points: Classify points in close proximity to the breaklines from Ground to class 10 (Ignored Ground). Close proximity will be defined as equal to the nominal point spacing on either side of the breakline (0.5 meters for the USGS Salton Sea project). Breaklines will be buffered using this specification and the subsequent file will need to be prepared in the same manner as the water breaklines for classification. This process will be performed after the water points have been classified and only run on remaining ground points.
3. Terrain Processing: A Terrain will be generated using the Breaklines and LAS data that has been imported into ArcGIS as a Multipoint File. If the final DEMs are to be clipped to a project boundary that boundary will be used during the generation of the Terrain.
4. Create DEM Zones for Processing: Create DEM Zones that are buffered by 14m around the edges. Zones should be created in a logical manner to minimize the number of zones without creating zones to large for processing. Dewberry will make zones no larger than 200 square miles (taking into account that a DEM will fill in the entire extent not just where LiDAR is present). Once the first zone is created it must be verified against the tile grid to ensure that the cells line up perfectly with the tile grid edge.

5. Convert Terrain to Raster: Convert Terrain to raster using the DEM Zones created in step 4. Utilizing the natural neighbors interpolation method. In the environmental properties set the extents of the raster to the buffered Zone. For each subsequent zone, the first DEM will be utilized as the snap raster to ensure that zones consistently snap to one another.
6. Perform Initial QAQC on Zones: During the initial QA process anomalies will be identified and corrective polygons will be created.
7. Correct Issues on Zones: Corrections on zones will be performed following Dewberry's in-house correction process.
8. Extract Individual Tiles: Individual Tiles will be extracted from the zones utilizing the Dewberry created tool.
9. Final QA: Final QA will be performed on the dataset to ensure that tile boundaries are seamless.

DEM Qualitative Assessment

Dewberry performed a comprehensive qualitative assessment of the 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. Upon completion of this review the DEM data is loaded into Global Mapper to ensure that all files are readable and that no artifacts exist between tiles.

The quality control steps taken by Dewberry are outlined in the QA Checklist below.

DEM QA/QC Checklist

Project Number/Description: Salton Sea

Overview

☒ Correct number of files is delivered and all files are in ERDAS IMG format

☒ All files are visually inspected to be free of artifacts and processing anomalies.

☒ DEM extent geometry shapefile is created

Review

☒ All files are tiled with a 1 meter cell size

☒ All files are 32 bit, floating point

☒ Georeference information is present and correct:

- NAD83 UTM 11N, Meters
- NAVD88, Meters

☒ Vertical accuracy is verified by comparing the LAS to the DEM.

☒ Water Bodies, wide streams and rivers and other non-tidal water bodies as defined in Section III are NOT to be hydro-flattened within the DEM.

☒ Manually review bare-earth DEMs with a hillshade to check for processing issues or any general anomalies enforcement process or any general anomalies that may be present.

☒ DEM extent geometry in ESRI shapefile format, with correct projection:

- NAD83 UTM 11N, Meters

Completion Comments: Complete – Approved

8 Conclusion

Dewberry was tasked by the USGS to collect LiDAR data and create derived LiDAR products around the Salton Sea, California. In summary, Towill Inc. was subcontracted to perform the LiDAR acquisition and calibration. Once Dewberry received the LiDAR data, initial QA/QC checks on the raw LAS swaths were performed. The LiDAR data were compiled to meet a vertical accuracy of 9.25 cm and based on independently survey checkpoints (collected by McGee Surveying Consulting) the RMSEz is 3.5 cm. Dewberry then classified the data according to project specifications and the classification was checked to ensure its accuracy. Due to the complexity of the terrain in the Salton Sea area, Dewberry required extra time to ensure the ground was classified accurately and thoroughly. In addition, 3D breaklines were collected for the sea. These breaklines and the LiDAR ground points were used to generate a DEM with a hydro-flattened sea. Finally metadata were created for all tiled deliverables, the lift data, and the project. Based on the scope of work, all delivered products for the Salton Sea project conform to project specifications.