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CA SaltonSea EarthMRI 2021 D21- Final Accuracy Report

Report Produced for U.S. Geological Survey

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1. EXECUTIVE SUMMARY

The following report documents the comprehensive final project accuracy results for the CA SaltonSea EarthMRI 2021 D21 lidar project. Preliminary accuracy testing was verified for each WUID to ensure project-wide accuracy would meet specification.

The CA SaltonSea EarthMRI 2021 D21 lidar project survey report includes all information regarding the survey checkpoints, please refer to that report for details on the survey.

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, Esri software to test the horizontal lidar accuracy, and Esri software to test the DEM vertical accuracy. Below is a description of the types of checkpoints utilized and the acceptable criteria for the SaltonSea EarthMRI 2021 D21 lidar project accuracy requirements.

NVA (Non-vegetated Vertical Accuracy) 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.

VVA (Vegetated Vertical Accuracy) 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 95^{th} percentile error for all checkpoints in all vegetated land cover categories combined. The VVA is accompanied by a listing of the 5% outliers that are larger than the 95^{th} percentile used to compute the VVA.

The relevant testing criteria are summarized in the table below.

Table 1. Vertical accuracy acceptance criteria

Land Cover Type	Quantitative Criteria	Measure of Acceptability
NVA	Accuracy in open terrain and urban land cover categories using RMSEz *1.9600	19.6 cm ($RMSE_z$ 10 cm)
VVA	Accuracy in vegetated land cover categories combined at the 95^{th} percentile	30 cm

1.1 Project Area

The SaltonSea EarthMRI 2021 D21 lidar project encompasses approximately 5,818 square miles within the state of California, including full and partial counties of Imperial, Riverside, and San Diego. The figure below shows the CA SaltonSea EarthMRI 2021 D21 project and the checkpoints that were collected.

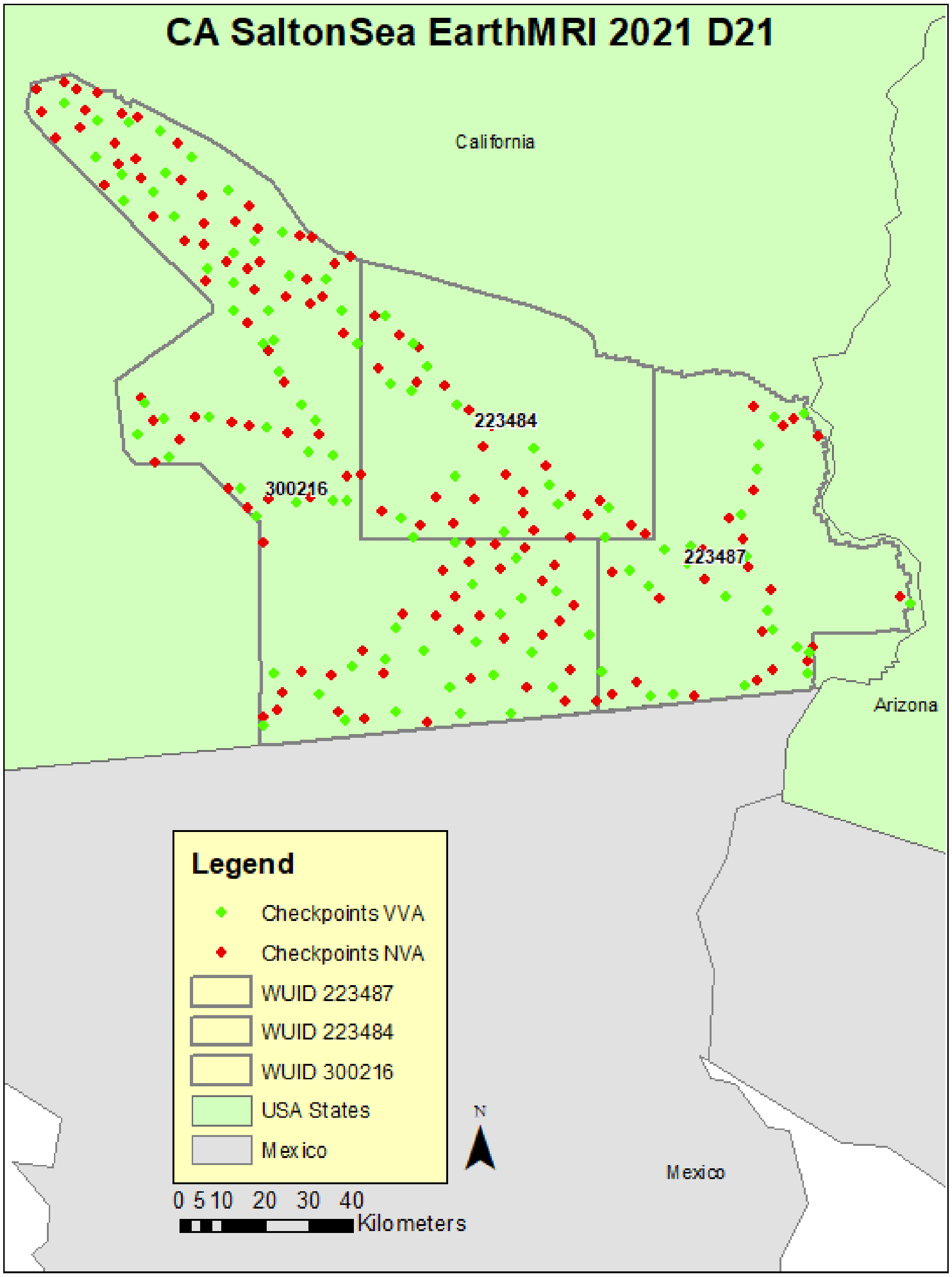

Figure 1. Project map with the three WUIDs outlined and checkpoints displayed.

1.2 Coordinate Reference System

Data produced for the project are delivered in the following spatial 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)
Geoid Model:	Geoid18
Coordinate System:	UTM Zone 11N
Horizontal Units:	Meter
Vertical Units:	Meter

2. LIDAR POSITIONAL ACCURACY

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

2.1 Final Swath Vertical Accuracy Assessment

Dewberry tested the vertical accuracy of the non-vegetated terrain swath data prior to additional processing. Dewberry tested the vertical accuracy of the swath data using the non-vegetated (open terrain and urban) independent survey checkpoints. The vertical accuracy is tested by comparing survey checkpoints in non-vegetated terrain to a triangulated irregular network (TIN) that is created from the raw swath points. Only checkpoints in non-vegetated terrain can be tested against raw swath data because the data has not undergone classification techniques to remove vegetation, buildings, and other artifacts from the ground surface. Checkpoints are always compared to interpolated surfaces from the lidar point cloud because it is unlikely that a survey checkpoint will be located at the location of a discrete lidar point. Dewberry typically uses LP360 software to test the swath lidar vertical accuracy. The table below summarizes the swath project accuracy specification, the amount of NVA points tested, and the final tested swath accuracy results.

Table 2. NVA at 95% Confidence Level for Raw Swaths

100% of Totals	Total Points	$RMSE_Z$ (m)	NVA (m)	Mean (m)	Median (m)	Skew	Std Dev (m)	Min (m)	Max (m)	Kurtosis
NVA	138	0.073	0.143	-0.010	0.005	-1.925	0.072	-0.365	0.144	6.201

2.2 Classified Lidar Vertical Accuracy Results

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

Table 3. Tested NVA and VVA for the classified lidar

Land Cover Type	# of Points	NVA (m)	VVA (m)
Project Specification	**239**	**0.196**	**0.3**
NVA	138	0.144	-
VVA	101	-	0.131

This lidar dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ =7 cm, equating to +/- 14 cm at 95% confidence level. Actual VVA accuracy was found to be +/- 13 cm at the 95th percentile.

Table 4 lists the 5% outliers that are larger than the VVA 95th percentile.

Table 4. VVA 5% Outliers

Point ID	UTM Zone 11N NAD83(2011), m		NAVD88 Geoid 18, m		Delta Z (m)
	Easting X (m)	Northing Y (m)	Survey Z (m)	Lidar Z (m)	
VVA-007	586767.900	3625749.567	241.973	241.740	-0.233
VVA-020	589037.345	3728156.007	388.928	388.440	-0.488
VVA-066	584499.196	3613652.145	885.904	885.600	-0.304
VVA-077	567833.294	3745418.868	334.705	334.460	-0.245
VVA-096	576243.967	3737714.592	100.318	100.110	-0.208

Table 5 provides overall descriptive statistics.

Table 5. Classified lidar vertical accuracy descriptive Statistics

100 % of Totals	# of Points	RMSEz (m) NVA	Mean (m)	Median (m)	Skew	Std Dev (m)	Kurtosis	Min (m)	Max (m)
NVA	138	0.073	-0.009	0.001	-2.030	0.073	6.770	-0.381	0.130
VVA	101	N/A	-0.011	0.001	-2.789	0.083	11.908	-0.484	0.104

2.3 Final Horizontal Accuracy Results

Dewberry tested the horizontal accuracy of lidar datasets when checkpoints were photo-identifiable in the intensity imagery. Photo-identifiable checkpoints included checkpoints located at the ends of paint stripes on concrete or asphalt surfaces or checkpoints located at 90 degree corners of different reflectivity, e.g. a sidewalk corner adjoining a grass surface. The XY coordinates of checkpoints as viewed in the intensity imagery were compared to surveyed XY coordinates for each photo-identifiable checkpoint. The horizontal differences were used to compute the tested horizontal accuracy of the lidar.

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.

Horizontal accuracy testing was not required for this project.

2.3.1 Horizontal Accuracy Test Procedures

Horizontal accuracy testing requires well-defined checkpoints that can be identified in the dataset. Elevation datasets, including lidar datasets, do not always contain well-defined checkpoints suitable for horizontal accuracy assessment. However, the ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) recommends at least half of the NVA vertical checkpoints should be located at the ends of paint stripes or other point features visible on the lidar intensity image, allowing them to double as horizontal checkpoints.

Dewberry reviews all NVA checkpoints to determine which, if any, of these checkpoints are located on photo-identifiable features in the intensity imagery. This subset of checkpoints are then used for horizontal accuracy testing.

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

1. Dewberry's team surveyed QA/QC vertical checkpoints in accordance with the project's specifications and tried to locate half of the NVA checkpoints on features photo-identifiable in the intensity imagery.
2. Next, Dewberry identified the well-defined features in the intensity imagery.
3. Dewberry then computed the associated xy-value differences between the coordinates of the well-defined feature in the lidar intensity imagery and the ground truth survey checkpoints.
4. The data were analyzed by Dewberry to assess the accuracy of the data. Horizontal accuracy was assessed using NSSDA methodology where horizontal accuracy is calculated at the 95% confidence level. This report provides the results of the horizontal accuracy testing.

2.3.2 Horizontal Accuracy Results

One checkpoint was determined to be photo-identifiable in the intensity imagery and were used to test the horizontal accuracy of the lidar dataset. As only one (1) checkpoint was photo-identifiable, the results are not statistically significant enough to report as a final tested value, but the results of the testing are still shown in the table below.

Using NSSDA methodology (endorsed by the ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014)), horizontal accuracy at the 95% confidence level (called ACCURACYr) is computed by the formula RMSEr * 1.7308 or RMSExy * 2.448.

No horizontal accuracy requirements or thresholds were provided for this project. However, this data set was produced to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 41 cm $RMSE_x/RMSE_y$ horizontal accuracy class which equates to a positional horizontal accuracy = ± 1 meter at the 95% confidence level. Using this small sample of 1 photo-identifiable checkpoints, positional accuracy of this dataset was found to be $RMSE_x$ = 2.5 cm and $RMSE_y$ = 3.4 cm, which equates to ± 7.30 cm at the 95% confidence level.

Table 6. Horizontal accuracy of the classified lidar data at the 95% confidence level

Land Cover Type	# of Points	$RMSE_x$ (m)	$RMSE_y$ (m)	$RMSE_r$ (m)	$Accuracy_r$ (m)
Project Target	**-**	**0.410**	**0.410**	**0.580**	**1.000**
Non-Vegetated Terrain	1	0.025	0.034	0.042	0.073

3. DEM POSITIONAL ACCURACY

The same 239 checkpoints that were used to test the vertical accuracy of the lidar were used to validate the vertical accuracy of the final DEM products. Accuracy results may vary between the source lidar and final DEM deliverable. DEMs are created by averaging several lidar points within each pixel, which may result in slightly different elevation values at each survey checkpoint when compared to the 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.

Table 7. DEM vertical accuracy results

Land Cover Category	# of Points	NVA (m)	VVA (m)
Project Specification	**239**	**0.196**	**0.3**
NVA	138	0.143	-
VVA	101	-	0.124

This DEM dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ =7 cm, equating to +/- 14 cm at 95% confidence level. Actual VVA accuracy was found to be +/- 12 cm at the 95th percentile.

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

Table 8. DEM VVA 5% outliers

Point ID	UTM Zone 11N NAD83(2011), m		NAVD88 Geoid 18, m		Delta Z,
	Easting (X)	Northing (Y)	Survey Z	Lidar Z	m
VVA-007	586767.900	3625749.567	241.973	241.736	-0.237
VVA-020	589037.345	3728156.007	388.928	388.444	-0.484
VVA-066	584499.196	3613652.145	885.904	885.603	-0.301
VVA-077	567833.294	3745418.868	334.705	334.468	-0.237
VVA-096	576243.967	3737714.592	100.318	100.111	-0.207

Table 9 provides overall descriptive statistics.

Table 9. Overall Descriptive Statistics

Land Cover Type	# of Points	$RMSE_z$ (m)	Mean (m)	Median (m)	Skew	Std Dev (m)	Min (m)	Max (m)	Kurtosis
NVA	138	0.073	-0.009	0.001	-2.030	0.073	-0.381	0.130	6.770
VVA	101	-	-0.011	0.001	-2.789	0.083	-0.484	0.104	11.908

4. FINAL ACCURACY SUMMARY

Based on the accuracy testing conducted by Dewberry, the lidar and DEM dataset for the CA SaltonSea EarthMRI 2021 D21 lidar project satisfies the project's pre-defined accuracy criteria as described throughout this report.