Elevation Data QA/QC Report
San Diego County, California
September 30, 2016

STARR II Strategic Alliance for Risk Reduction

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FEMA

RiskMAP
Increasing Resilience Together

1. INTRODUCTION

The purpose of this project is to provide FEMA high quality elevation datasets derived from Light Detection and Ranging (LiDAR) point clouds. STARR II is responsible for the collection, post processing, and independent quality control of all datasets and derived products. The overall goal of these tasks is to assure all LiDAR related data are of sufficient quality to meet the USGS 3DEP Quality Level 2 (QL2) requirements and thus eligible to be included in the 3DEP national database. The derived datasets are to be used for future FEMA Risk MAP projects.

This report summarizes all quality assurance testing completed on the LiDAR datasets based on the following specifications:

- USGS Lidar Base Specification Version 1.2, November 2014
- ASPRS LAS Specification Version 1.4 – R13 July 15, 2013
- ASPRS Positional Accuracy Standards for Digital Geospatial Data (Edition 1, Version 1.0. – November, 2014)

The FEMA Data Capture Standards format for terrain deliverables is the basis for this submission. For the sake of brevity, all test documents are available in the supplemental directory within the quality assurance supporting documentation folder. This report shall include checklists, review based conclusions and test results where applicable.

2. PROJECT AREA DESCRIPTION AND REQUIREMENTS

The San Diego County project spans across the central portion of the county. Figure 1 provides a map of the area of interest. Data was collected from October 30 through November 23 in 2015 in 23 lifts. For specific information pertaining to mission planning and flight details, please refer to the flight collection report and flight logs included with this submission.

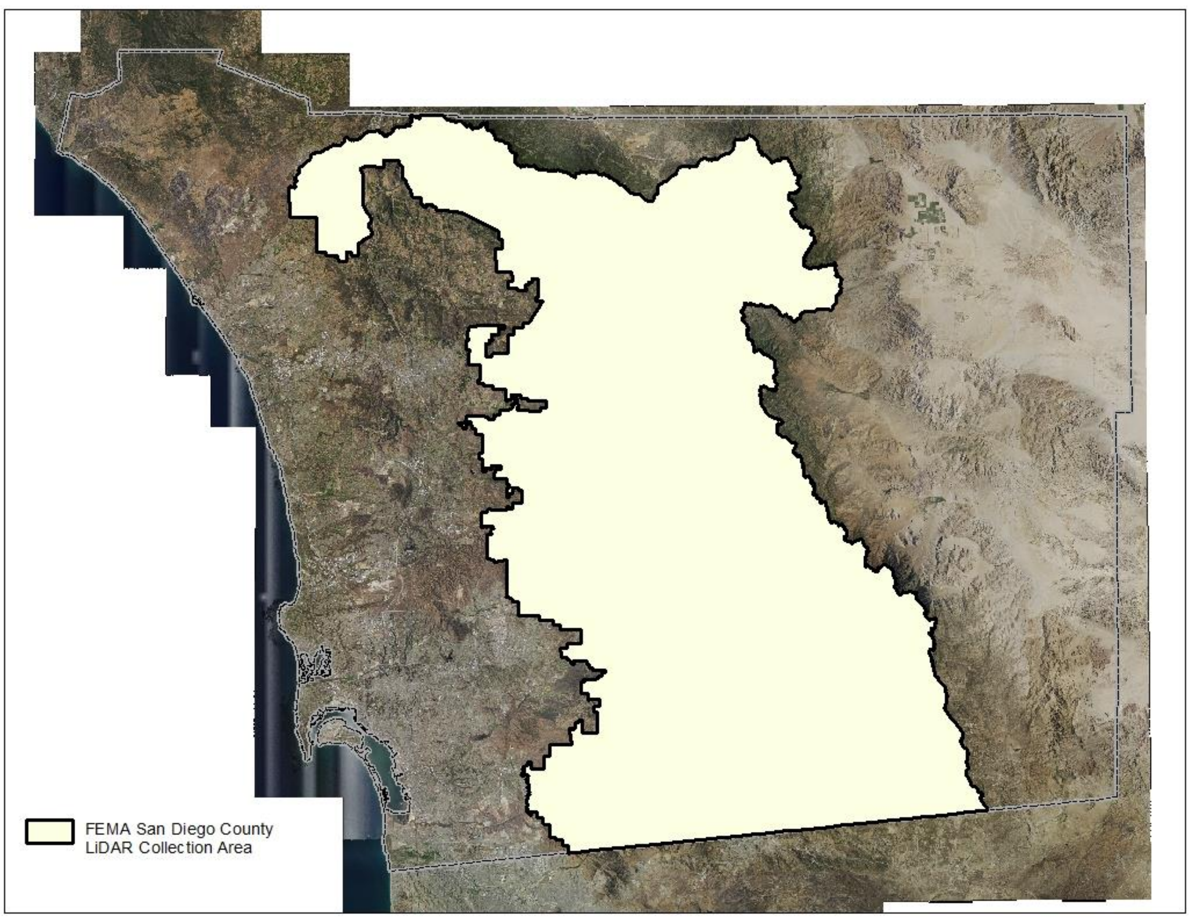
The scope of work for San Diego County specifies the following prerequisites:

- A collection area of 1617 square miles
- LAS version 1.4 in point record 6 format
- LiDAR pulse density of > 2 pulses per square meter
- LiDAR point spacing of <= 0.71 meters
- Raw point cloud LiDAR and DEM absolute vertical accuracy in Non Vegetated Areas
    - <= 10 cm RMSEz
    - <= 19.6 cm at the 95% confidence interval
- DEM absolute vertical accuracy in Vegetated Areas
    - <= 29.4 cm at 95th percentile

- Visual Review
  - 5% of raw LiDAR swaths
  - 20% of classified LiDAR tiles and Hydro-flattened DEMs
- Spatial Reference
  - Coordinate Reference System: State Plane California VI FIPS 0406
  - Horizontal Datum: NAD83 2011
  - Horizontal Units: US Survey Feet
  - Vertical Datum: NAVD88
  - Vertical Units: US Survey Feet
  - Geoid Model: Geoid 12B

- For additional information regarding the scope of work and deliverables, please refer to the TSDN project narrative included with this submission.

Figure 1: Map of Project Area



3. REVIEW OF PROJECT DOCUMENTATION

Descriptive reports and metadata files delivered with the LiDAR data required by the USGS specification 1.2 must provide adequate project details. Text reports should be easy to read and include tables, charts, maps, graphics, etc. to assist the reader in understanding the intention of each document. Metadata is required to comply with the Federal Geographic Data Committee (FGDC) standards and must be in XML format. In addition, all metadata submitted for a project must include a block of LiDAR related tags and pass the USGS parser.

To confirm the project documentation meets the specification standards, reports and metadata undergo an editorial review. Reports are reviewed to ensure they are complete and comprehendible. Metadata are reviewed to ensure correct format and that they provide the necessary project details. Any comments and responses are included with the quality assurance supporting documentation.

Table 1: LiDAR Report Quality Control Checklist

Reports	
☒	Preflight collection report detailing mission planning
☒	Post flight collection report
☒	Flight logs
☒	Survey report detailing the collection of all ground control
☒	Includes map of control points used to calibrate and process LiDAR
☒	Includes map of checkpoints used to validate LiDAR
☒	Processing report
☒	Includes LiDAR Calibration Details
☒	Includes LiDAR Classification Details
☒	Breakline collection procedures
☒	Hydro-flattening procedures
☒	QA/QC report, detailing procedures for analysis, accuracy assessment and validation
☒	Point data (absolute vertical accuracy [NVA], relative vertical accuracy)
☒	Bare-earth surface (absolute vertical accuracy [NVA and VVA])

Conclusion:

All required reports are included. Reports provided for this project are complete and include necessary details for each specific task. For simplicity the preflight, post flight, processing report, and flight logs have been combined into a single report pdf and included under the general directory with this submission.

Table 2: LiDAR Metadata Quality Control Checklist

Metadata	
☒	Overall Project (boundary, intent, types of data, deliverables, other) in XML format
☒	Each Lift (extents, swaths included, GPS base stations, calibration, adjustment, other) in XML format
☒	Raw point cloud in XML format
☒	Classified Point Cloud in XML format
☒	Breaklines in XML format
☒	Bare Earth DEMs in XML format
☒	Metadata files include USGS specified tags and passes the USGS Metadata Parser

Conclusion:

All required metadata are included. Metadata files provided for this project are in the correct format, follow the USGS LiDAR metadata template and contain all of the required information for the intended task or dataset.

4. RAW POINT CLOUD DATA

Raw point cloud data collected during a lift has to meet several conditions prior to point classification and other post processing tasks. These datasets commonly referred to as swaths, have specific requirements detailed in the collection, data processing and handling, and deliverable sections within the USGS LiDAR Base Specification 1.2.

Quality control procedures for swath data evaluate the LiDAR system performance. This provides vital information in determining if the proper quality assurance procedures were used during the acquisition. Several checks are performed on the raw point cloud to confirm the data meet planned LiDAR collection expectations. Using a combination of visual examination (5% of swaths) and the Merrick Advanced Remote Sensing (MARS) quality control modules make available necessary information to determine data quality and specification compliance.

To assess the absolute vertical accuracy of the raw point cloud, a collection of discreet surveyed checkpoints is dispersed throughout the project area in non-vegetated open spaces. A TIN created from the irregularly spaced LiDAR points is compared with the survey elevation measurements at each checkpoint coordinate location. The differences between the interpolated surface and checkpoint elevations are used to statistically determine the vertical error. The results of this test must meet the specified requirements for absolute accuracy before any LiDAR post processing can begin.

Outputs from testing results, checkpoint locations, and comment responses are included with the survey report and quality assurance supporting documentation.

Table 3: LiDAR Swath Quality Assurance Checklist

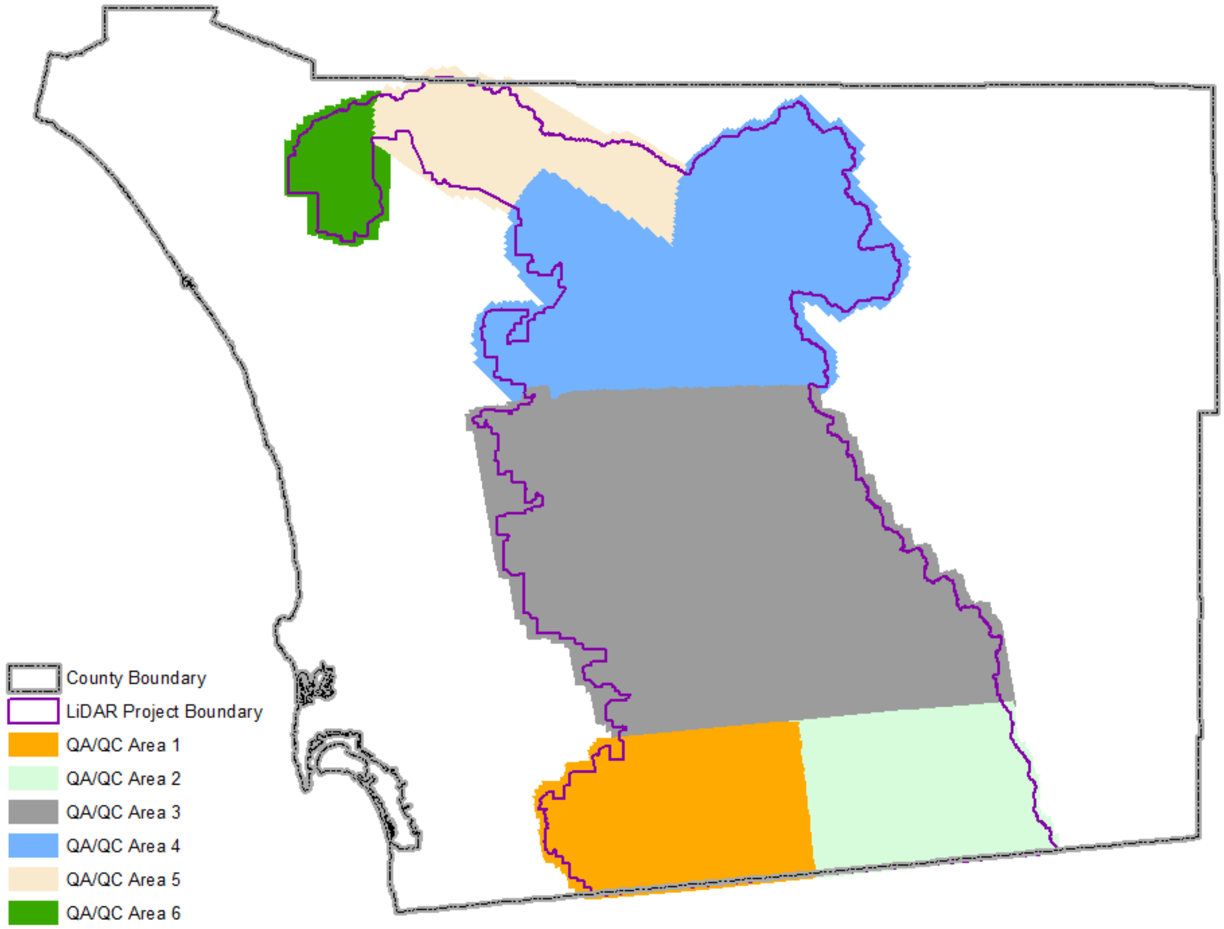
Raw Swath Point Cloud Testing	
☒	All collected points delivered as swaths, complete coverage and functional
☒	Correct Georeferencing
☒	Swath visual review (blunders, anomalies, and edge matching)
☒	Swath segmentation (if applicable)
☒	Collection Conditions (included in flight report)
☒	LAS File Format
☒	Pulse spacing and density
☒	Overlap and Sidelap
☒	Data voids
☒	Spatial distribution regularity
☒	Relative accuracy
☒	Checkpoints
☒	Absolute vertical accuracy for LiDAR swaths
Swath LAS File Testing	
☒	Version 1.4
☒	Point record format 6-10
☒	Swath ID matches point ID
☒	Multiple returns (Minimum of three)
☒	Point families (Multiple returns from a single pulse)
☒	Intensity
☒	WKT georeferencing
☒	Adjusted GPS time
☒	Withheld flags
☒	Overlap flags
☒	Waveform (if applicable)
☒	Header consistency

Conclusion:

The swath point cloud data review was organized into 6 separate areas, this was due to the size of the project and to match the acquisition collection extents. Figure 2 depicts the 6 areas used to review the raw point cloud swath data. Test results for each area are evaluated independently with results aggregated for the project area to confirm USGS specification compliance.

Original swath LAS files submitted for review had incorrect OGC WKT formatting and were missing withheld and overlap classification flags. This was brought to the attention of the LiDAR data producer. Swath files were resubmitted and those issues have been properly resolved.

Figure 2: Raw Point Cloud QA/QC Areas



Raw point cloud data meet the necessary requirements. Swath files are in LAS format, not segmented, functional and cover the project area with expected georeferencing. Visually reviewed swaths do not have any issues and edge match as expected. Collection conditions are compliant for data acquisition. LiDAR pulse density and spacing meet specifications; swaths have sufficient overlap and do not have gaps between flight lines, data voids meet the USGS exception criteria, and spatial distribution is well within expectations.

Table 4: Pulse Density and Spacing Results

Aggregate Pulse Density and Point Spacing Testing	
Requirements	Independent Aggregate Test Results
>= 2 pulses per m^2	6 pulses per m^2
<= 0.71 m point spacing	0.4 m point spacing

Table 5: Raw Point Cloud Spatial Distribution

Spatial Distribution Test Results Swath Dataset			
Requirement	Cells with No Data	Cells with Point	Percentage
90% Density Grid Cells with 1 Point	6,507,309	899,925,106	99.21

Relative accuracy was tested by using Delta Z jpeg2000 rasters to depict flight line separation. These rasters depict the magnitude of the vertical separation. The rasters are modulated by intensity to show land cover features so returns occurring in open areas can be distinguished from vegetated returns. The relative accuracy was found to be compliant with QL 2 requirements. Please see flight collection report included with this report for more information.

Non-vegetated vertical accuracy checkpoints meet the ASPRS and USGS specifications for number of points, point distribution, and point location (open areas). The absolute vertical accuracy test using the non-classified swath data meet all requirements for QL2. For detailed information regarding the field survey, please refer to the survey report included with this submission.

Table 6: Raw Point Cloud NVA Absolute Accuracy

Swath Non-Vegetated Absolute Accuracy Results	
Requirements	Independent Test Results
RMSEz <= 10 (cm)	RMSEz = 4.6 cm
NVA at 95% Confidence Interval <= 19.6 (cm)	NVA at 95% Confidence Interval = 9 cm

All submitted LAS files meet specification requirements. File headers are consistent and the OGC WKT georeferencing information is correct.

Figure 3: OGC COORDINATE SYSTEM WKT

```
COMPD_CS["NAD83(2011) / California zone 6 (ftUS) + NAVD88 height(ftUS)",
 PROJCS["NAD83(2011) / California zone 6 (ftUS)",
  GEOGCS["NAD83(2011)",
   DATUM ["NAD83 (National Spatial Reference System 2011)",
    SPHEROID ["GRS 1980",6378137,298.257222101,
     AUTHORITY["EPSG","7019"]],
    AUTHORITY["EPSG","1116"]],
   PRIMEM ["Greenwich",0,
    AUTHORITY["EPSG","8901"]],
   UNIT ["degree",0.0174532925199433,
    AUTHORITY["EPSG","9122"]],
   AUTHORITY["EPSG","6318"]],
  PROJECTION["Lambert_Conformal_Conic_2SP"],
  PARAMETER["standard_parallel_1",33.88333333333333],
  PARAMETER["standard_parallel_2",32.78333333333333],
  PARAMETER["latitude_of_origin",32.16666666666666],
  PARAMETER ["central_meridian”, -116.25],
  PARAMETER["false_easting",6561666.667],
  PARAMETER["false_northing",1640416.667],
  UNIT ["US survey foot",0.3048006096012192,
   AUTHORITY["EPSG","9003"]],
  AXIS ["X”, EAST],
  AXIS ["Y”, NORTH],
  AUTHORITY["EPSG","6426"]],
 VERT_CS ["NAVD88 height (ftUS)",
  VERT_DATUM ["North American Vertical Datum 1988",2005,
   AUTHORITY["EPSG","5103"]],
  UNIT ["US survey foot",0.3048006096012192,
   AUTHORITY["EPSG","9003"]],
   AXIS ["Up”, UP],
   AUTHORITY["EPSG","6360"]]]
```

Table 7: Swath LAS File Information Summary

Swath LAS File Content Check Results	
Requirements	Independent Test Results
LAS Format 1.4	Pass
Point Record Format 6-10	Pass Format 6
Swath ID matches Point ID	Pass
Multiple returns (Minimum of 3)	Pass
Point Families Present	Pass
Intensity Normalized 16 bit	Pass within proper range 0-65535
WKT georeferencing	Pass
Adjusted GPS Time	Pass
Withheld and Overlap Flags Set	Pass
Horizontal Datum	NAD83(2011)
Horizontal Units	US Survey Foot
Vertical Datum	NAVD88 – Geoid 12b
Vertical Units	US Survey Foot
Coordinate Reference System	State Plane California VI FIPS 0406
Waveform Data Present	No

5. CLASSIFIED POINT CLOUD DATA

Classified LiDAR data is of particular importance for a FEMA Risk MAP project. All final derived elevation datasets depend upon correct LIDAR processing. ASPRS and USGS specification details provide a framework for the confirmation of data reliability. Classification of all LiDAR swath points not identified as withheld must meet the ASPRS LAS 1.4 standards.

- No points assigned to class zero
- All overage points must be identified using the overlap flag
- Classifications must follow the minimum classification scheme

Table 8: ASPRS 1.4 Minimum Classification Scheme

Code	Description
1	Processed but not classified
2	Bare Earth
7	Low Noise
9	Water
10	Ignored Ground (near a breakline)
17	Bridge Decks
18	High Noise

Point classifications must be accurate and consistent across the entire project. Within a 1-square kilometer area, no more than 1% of non-withheld will have classification errors. There cannot be any noticeable variations in the character, texture or quality between swaths or tiles.

Several checks performed on the classified point cloud confirm the data meet applicable standards. Using a combination of visual examination (20% of tiles) and MARS quality control modules make available necessary information to determine data compliance. Outputs from testing results, geospatial files, and comment responses are included with the quality assurance supporting documentation.

Table 9: Classified LiDAR Data Quality Assurance Checklist

Classified Point Cloud Testing	
☒	All collected points delivered as tiles, complete coverage and functional
☒	Geospatial Tile index
☒	LAS Files
☒	LAS point cloud classifications (minimum schema)
☒	Classification accuracy and consistency visual review
Tiled LAS File Testing	
☒	Version 1.4
☒	Point record format 6-10
☒	Swath ID matches point ID
☒	Multiple returns (Minimum of three)
☒	Point families (Multiple returns from a single pulse)
☒	Intensity
☒	WKT georeferencing
☒	Adjusted GPS time
☒	Withheld flags
☒	Overlap flags
☒	Waveform (if applicable)
☒	Header consistency

Using a LiDAR viewer, to turn on and off classifications, analysts are able to evaluate point classification assignments. For example, class 17 (bridges) is the only class visible and should only be located over roads that span over water or other roads. Class nine (water) should only be located within water bodies and so on. Profiling bare earth (class 2) verifies error free surfaces. Edge matching adjacent LAS tiles ensure that classifications are consistent from tile to tile.

Conclusion:

Classified point cloud data meet requirements. The data is in LAS format, are functional, tiled, and cover the project area. LAS files are correct with expected classifications. All data reviewed for classification accuracy and consistency are compliant with specification requirements.

Table 10: Classification Schema Test Results

Tiled LAS Classification Test Results	
Class(es) Expected: 1,2,7,9,10,17,18	Class(es) Present: 1,2,7,9,10,17,18
Use of LAS Withheld Flag	TRUE
Use of LAS Overlap Flag	TRUE
Use of LAS Class 0	FALSE
Class 1- Processed but not classified	14,430,064,761
Class 2 - Ground	15,829,530,516
Class 7 – Low Noise	5,882,611
Class 9 - Water	38,633,472
Class 10 – Ignored Ground	201,808
Class 17 – Bridge Decks	296,243
Class 18 – High Noise	149, 840

Table 11: Classified LAS File Summary

Classified LAS File Content Check Results	
Requirements	Independent Test Results
LAS Format 1.4	Pass
Point Record Format 6-10	Pass Format 6
Swath ID matches Point ID	Pass
Multiple returns (Minimum of 3)	Pass
Point Families Present	Pass
Intensity Normalized 16 bit	Pass within proper range 0-65535
WKT georeferencing	Pass
Adjusted GPS Time	Pass
Withheld and Overlap Flags Set	Pass
Horizontal Datum	NAD83(2011)
Horizontal Units	US Survey Foot
Vertical Datum	NAVD88 – Geoid 12b
Vertical Units	US Survey Foot
Coordinate Reference System	State Plane California VI FIPS 0406
Waveform Data Present	No

6. HYDRO FLATTENED DEMS

The creation of LiDAR derived bare earth DEMs requires hydro flattening. Waterbodies such as ponds, lakes, inland streams and tidal areas are expected have uniform elevations and appear flat on the final DEM. The goal is to create topographic DEMs that contain water surfaces free of unnatural triangulation effects and other elevation inconsistencies. DEMs produced in this manner allow for greater accuracy in hydrologic and hydraulic modeling, resulting in high quality floodplain and floodway delineations.

USGS requirements for hydro flattening provide detailed guidance for the creation of DEMs and breaklines. By enforcing these requirements, bare earth DEMs are seamless from project to project. This ensures that DEMs integrated into the National Elevation Dataset (NED) possess uniform characteristics. Quality assurance of this data is critical to support the USGS 3DEP program and the NED since this data is available free to the public supporting a myriad of applications.

As mentioned above, LiDAR derived hydro flattened DEMs integrated into the NED must meet specific requirements. USGS organizes these requirements into five distinct water body categories: Inland ponds and lakes, inland streams and rivers, non-tidal boundary waters, tidal waters, and islands. For San Diego County, CA inland ponds, lakes, streams, rivers, and islands are applicable.

The quality assurance for DEMs consists of three categorical areas:

1. Breaklines
2. DEM bare earth surface and hydro flattening
3. NVA and VVA absolute vertical accuracy using the final bare earth surface

A combination of visual inspection and automated data testing performed for each category confirm products comply with specifications.

Breakline checks for elevation monotonicity and connectivity include topology, visual inspection, and vertex testing. Breakline topology tests for connectivity, intersections, and overlaps. A visual inspection of breaklines confirms proper placement based upon hydro flattening requirements using either intensity or ortho imagery. Finally, breakline vertices compared against adjacent elevations provide confirmation of static water surface for ponds and lakes and stream or river bank-to-bank elevation gradients.

Bare earth surface evaluation in combination with the breakline placement visual inspection provides a comprehensive evaluation of hydro flattened surface. The DEM surface is hillshaded and visually compared with a hillshade derived from a first return Digital Surface Model (DSM). This comparison confirms the proper removal of artifacts such as vegetation, buildings and bridges. Each breakline reviewed using the bare earth hillshade reveals any triangulation or unusual elevation changes. Cross section and centerline profiles created in hydro flattened areas within the DEM confirm proper elevation values and they are at or below the surrounding terrain.

To finalize the LiDAR data submission an absolute vertical accuracy test for both non-vegetated and vegetated areas is required. NVA checkpoints tested against the DEM use the same QL2 requirements for validating the unclassified LiDAR vertical accuracy. This confirms no significant changes to surface elevations occurred during post processing. The vegetated checkpoints are collected in tall grass, brush, and forested land cover. This is due to the presence of multiple LiDAR returns. Testing vegetated locations against the bare earth surface also validate the post processing. Meeting the quality level two requirements for both assessments validate the surface consistency and reliability of elevation values. This is of particular importance when determining base flood elevations for FEMA Risk MAP regulatory products.

Table 12: Breakline Quality Control Checklist

Breaklines	
☒	Delivered as polylineZ or polygonZ shapefile or file geodatabase and functional
☒	Correct georeferencing
☒	Topologically correct
☒	Complete coverage with no missing hydrographic features
☒	Elevations are consistent, flattened, and are at or below surrounding terrain

Table 13: Hydro Flattened DEM Quality Assurance Checklist

Bare Earth Surface	
☒	All rasters delivered, tiled, complete coverage and functional
☒	DEM as 32-bit floating point ERDAS .img with 1-meter resolution
☒	Correct georeferencing
☒	No overlaps or quilted appearance
☒	All rasters delivered, tiled, complete coverage and functional
☒	Artifacts have been properly removed from the bare earth surface and edge match correctly
Inland Ponds, Lakes, Streams, and Rivers	
☒	Ponds and lakes have a minimum surface area of 2 acres
☒	Inland streams and rivers have a nominal width of 100 feet
☒	Long impoundments tested as inland streams and rivers
☒	Flattened ponds and lakes has a flat and level water surface along its edge
☒	Flattened streams and rivers has a flat and level water surface bank to bank
☒	Flattened streams and rivers has a gradient downhill water surface following surrounding terrain
☒	Flattened streams and rivers have breaks at culverts
☒	All bridges are removed from DEM
☒	Flattened streams and rivers are continuous at bridge locations
☒	Structures which cannot be definitively determined to be a bridge are culverts
Islands	
☒	Permanent islands greater than or equal to 1 acre are delineated within waterbodies
Absolute Vertical Accuracy (NVA and VVA)	
☒	QA/QC analysis materials for the absolute vertical assessment included
☒	Absolute NVA and VVA vertical accuracy reports for bare-earth
☒	Absolute DEM VVA vertical accuracy testing results meet QL2 specifications
☒	Absolute DEM NVA vertical accuracy testing results meet QL2 specifications

Conclusion:

Breaklines have the correct format (polylineZ shapefile) function as expected, and include a.prj file with correct coordinate reference system. Topology is valid with correct feature geometry. Hydrologic features that meet specification requirements have correct coverage within the project area. Breakline elevation monotonicity is correct and consistent and at or below the surrounding terrain. There are no floating hydro flattened hydrological features.

DEMs have the correct format (32-bit ERDAS imagine) with a 2.5-foot resolution. DEMs are functional, have correct statistics, and display properly without overlaps or a quilted appearance. They cover the project area seamlessly and match the tile index.

The manual hillshade DEM review revealed no processing issues, artifacts and proper breakline placement. Ponds and lakes elevations are uniform and flattened properly. Streams and rivers have water surface elevations with a continuous downhill flow from bank to bank. Bridges and culverts are correct and streams and rivers flow as expected. DEMs have been correctly hydro flattened and meet USGS specifications.

Absolute vertical accuracy of the bare earth surface for checkpoint documentation is complete and includes calculations. Vertical accuracy testing meets the quality level two specifications for the DEM. For detailed information regarding the field survey please refer to the survey report included with this submission.

Table 14: Bare Earth Surface Absolute Accuracy

Bare Earth Surface Absolute Accuracy Results	
Requirements	Independent Test Results
NVA RMSEz <= 10 (cm)	NVA RMSEz = 4.6 cm
NVA at 95% Confidence Interval <= 19.6 (cm)	NVA at 95% Confidence Interval = 9 cm
VVA at 95th Percentile <= 29.4 (cm)	VVA at 95th Percentile = 18.4 cm

7. ADDITIONAL LIDAR DERIVED PRODUCTS

Additional products produced for the project include:

- ESRI Terrain Dataset
- Contours

Converting and filtering class 2 points from the classified LAS files into a multipoint feature class, adding hard and soft breaklines, and using the buffered project area as a soft clip, compiled the ESRI terrain dataset. This data is stored within a file geodatabase. The Terrain dataset was tested for functionality, correct georeferencing, project coverage, and proper display using ESRI software.

Contours were created using the hydro-flattened DEMs at a 5-foot interval. Geoprocessing scripts were used to reduce as much contour noise as possible. In order to reduce the number of files the contours are indexed using a 10,000 square foot tiling scheme. Individual contour files were output into shapefile format. Contours were reviewed for functionality, correct georeferencing, project coverage, proper display, and correct elevation interval attributes.

Table 15: LiDAR Derived Products Quality Control Checklist

ESRI Terrain Quality Control	
☒	ESRI Terrain Dataset is functional and has correct georeferencing
☒	ESRI Terrain Dataset covers project area and displays properly
Contour Quality Control	
☒	Contour files are functional and have correct georeferencing
☒	Contour files cover project area and display properly
☒	Contour intervals are correct

Conclusion:

ESRI Terrain is functional and not corrupted with the correct georeferencing. The dataset displays correctly using ArcGIS ArcMAP software and covers the project area. Contour files are functional with correct georeferencing, cover the project area and display correctly. Elevation attributes are correct with the expected 5-foot intervals.

8. FINAL CONCLUSION

Under task order HSFE09-15-J-0001, STARR II completed an independent quality assurance review for the San Diego County, CA LiDAR data acquisition, post processing, and derived datasets. Based upon the vertical accuracy test results, project documentation, unclassified swaths, classified tiles, breaklines, hydro flattened DEMs, and additional LiDAR derived dataset reviews all data meets the requirements for use in flood risk analysis. In addition, this data conforms to the USGS Quality Level 2 specifications for integration with the National Elevation Dataset for public use.

Deliverables follow the FEMA Data Capture Standards for Terrain format and includes all ancillary information.

Approvals

QA Team Lead: **James L. Huffines** **Date:** **09/30/2016**