Puerto Rico Advisory Data and Products

Post-Hurricanes Irma and Maria

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STARR II Strategic Alliance for Risk Reduction

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1.0 Project Summary

Hurricane Irma passed to the north of Puerto Rico on September 6, 2017, as a Category 5 hurricane, with winds of up to Category 3 levels (Presidential Disaster Declaration FEMA-4336-DR). Hurricane Maria made landfall on the Southeastern side of Puerto Rico as a Category 4 hurricane on September 20, 2017 (Presidential Disaster Declaration FEMA-4339-DR). Both hurricanes caused extensive damage across the Commonwealth, including the Islands of Culebra and Vieques. Hurricane Irma caused minor flooding; however wind damages were significant in Puerto Rico. Hurricane Maria caused extensive coastal storm surge, erosion, and stream flooding in many areas of Puerto Rico, including the Islands of Vieques and Culebra. In addition, there were areas within the current effective 1-percent and 0.2-percent annual chance floodplains that did not receive significant storm surge, but experienced wind damages. In the aftermath of these disasters, updated risk information is vital in order to inform rebuilding efforts across Puerto Rico.

This project provides advisory data and product development for Puerto Rico in an effort to increase resilience and reduce vulnerabilities within Puerto Rico. Data and products include:

1. Riverine Advisory Data
    - Hydrologic analyses
    - Hydraulic analyses
    - 1-percent and 0.2-percent annual chance floodplain mapping and water surface elevation grids
2. Coastal Advisory Data
    - 1-percent annual chance floodplain boundary
    - Limit of Moderate Wave Action ("LiMWA") mapping
    - 0.2 percent coastal modeling and mapping
    - Long-term shoreline change
    - Storm induced coastal erosion
3. Supporting Advisory Products
    - Map change products
    - Critical facility flood risk summaries

All of the products in this project were developed using the STARR II Quality Management Plan. Quality review checklists were developed and used to ensure complete and consistent product reviews. In addition, quality review checklists were utilized in detailed peer reviews, independent technical reviews for each project task, and milestones to technically verify data inputs, analysis assumptions, and outputs.

This report documents the methodologies, assumptions, and data sources used to develop the advisory flood hazard data and associated products.

2.0 Data Acquisition

Table 2-1 summarizes the data collected for development of the advisory flood information products and their origins.

Table 2-1: Data Sources and Notes

Data	Source/Notes
Topography Data	• USGS 2017 Light Detection and Ranging ("LiDAR") provided the base topographic data source for the project. This dataset was utilized for coastal modeling, riverine modeling, and erosion assessments. • 30 meter Digital Elevation Models ("DEM") from USGS National Elevation Dataset ("NED") were used only for hydrologic analyses. • 2000 USGS/NASA ATM LiDAR DEM was utilized for long-term shoreline change analyses.
Bathymetry Data	Seamless Topographic/Bathymetric DEMs developed for the 2009 effective Flood Insurance Rate Map ("FIRM") study for Puerto Rico and Municipalities. Only the bathymetric portion of the data was utilized as topographic data was provided by USGS 2017 LiDAR.
Streamlines	USGS National Hydrographic Dataset ("NHD") streamlines were utilized for developing hydrologic model stream network. The dataset also included Hydrologic Unit Code – 10 ("HUC-10") boundaries, used for data management and work distribution.
Effective FIRM Data	Effective data for the study area was obtained from published FIRM databases and the National Flood Hazard Layer.
Coordinated Needs Management Data ("CNMS")	FEMA's Coordinated Needs Management Data ("CNMS") was utilized to identify and validate the scope for riverine advisory data development.
Stillwater Elevations	Stillwater elevations developed as part of the effective coastal FEMA Flood Insurance Study ("FIS") update for Puerto Rico and Municipalities, 2009.
Pre-storm Imagery	Storm erosion analyses utilized aerial imagery from NOAA and Google Earth.
Post-storm Imagery	Storm erosion analyses utilized post-storm aerial imagery from Vexcel and NOAA.
Coastal Modeling Transects	Overland wave modeling data and transects developed as part of the effective coastal FEMA FIS update for Puerto Rico and Municipalities, 2009.

3.0 Advisory Data

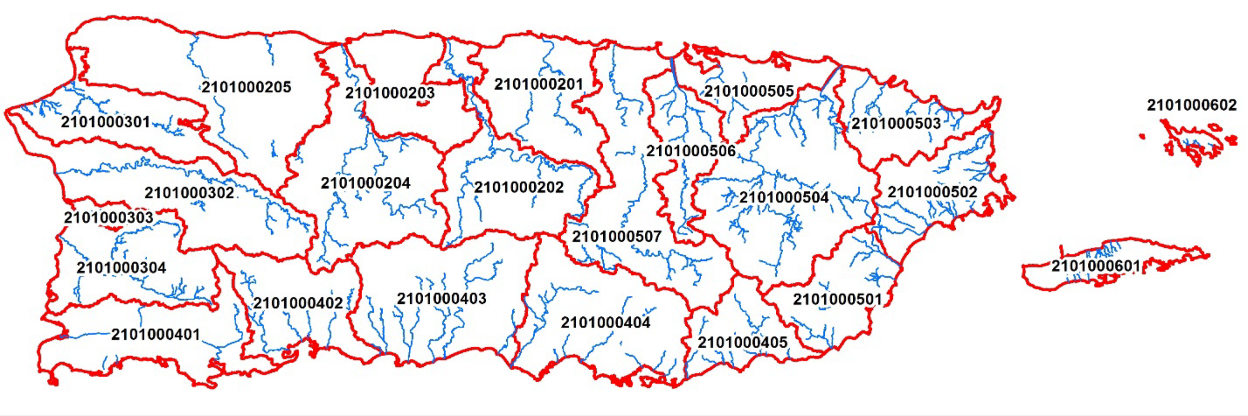
3.1 Riverine Advisory Data Development

Final riverine advisory data development deliverables include:

1. A geographic information system (“GIS”) line shapefile representing the 1-percent and 0.2-percent annual chance riverine boundaries delineated with the new U.S. Geological Survey (“USGS") 2017 LiDAR, as well as GIS polygons coving the 1-percent and 0.2-percent annual chance floodplain.
2. 1- and 0.2-percent annual chance water surface elevation grids.
3. A GIS line-shapefile of Base Level Engineer (“BLE”) analysis cross sections and stream centerlines and cross sections; these include water surface elevations for all recurrence intervals analyzed.
4. All network hydrologic and hydraulic models, including the BLE inputs and outputs.

Figure 3-1 shows the HUC-10 watersheds and stream reaches (1,400 miles) where advisory data was developed.

Figure 3-1: HUC-10 Watersheds and Stream Reaches



These products are intended for digital delivery and dissemination for desktop GIS and/or Web-GIS platforms. The following sections provide information on data sources and limitations, production procedures, and guidance on usability for each of the riverine advisory data deliverables.

3.1.1 Terrain Processing

STARR II developed a custom tool to mosaic the USGS 2017 LiDAR and NED DEMs, as needed, to fill any gaps that may occur in the processing of the terrain mosaic. The tool used bilinear resampling to determine cell value and used the mosaic process to make sure that all gaps were properly addressed. For well registered data tiles (i.e., same cell size, as well as same x and y registration of cell corners), the application mosaicked the dataset first with neighboring tiles before resampling. The data developed by this custom tool was utilized in the riverine analyses only.

3.1.2 Hydrologic Analyses

Gridded hydrology was developed for the main island of Puerto Rico, as well as the island-municipalities of Culebra and Vieques. Peak flows for the 10-percent, 4-percent, 2-percent, 1-percent, 1-percent plus, and 0.2-percent events were computed utilizing regression equations. The USGS report, “Estimation of Magnitude and Frequency of Floods for Streams in Puerto Rico: New Empirical Models”, (Ramos-Ginés, 1999) requires bedrock depth data. Since this data was not available, the two-parameter regression equations published by USGS (Lopez, et al, 1979) and reported in the current report (Ramos-Ginés, 1999) were used to compute all peak flows except for the 0.2-percent event. For each island, a grid was generated for each of the regression parameters and each of the flow events. Each grid cell had a value for the drainage area and other regression parameters associated with the basin draining to that cell.

The primary steps for the development of hydrologic data included:

1. Prepared stream network, hydrologic network, and delineated watersheds;
2. Developed gridded input parameters and peak flows from the rural regression equations;
3. Adjusted regression flows with gage data and flows from the FEMA FIS for Puerto Rico and Municipalities where appropriate.

The details for each of these steps are discussed in the following sections.

3.1.2.1 Stream Network Preparation and Watershed Delineation

The stream network was derived from the NHD high-definition flow lines for the watershed, and used as a basis for stream centerlines and for developing hydrologic flow paths and drainage basins.

The NHD lines are available at:

ftp://nhdftp.usgs.gov/DataSets/Staged/SubRegions/FileGDB/HighResolution/.

These features are frequently updated, and the versions used for this project were dated May to August 2016.

The steps used to develop the stream network, delineate watersheds, and compute drainage areas are outlined below:

1. A 30-meter DEM topography set was created. These DEMs were extracted from NED 1/3 arcsecond (about 10 meter) rasters, and were downloaded from ftp://rockyftp.cr.usgs.gov/vdelivery/Datasets/Staged/Elevation/13/GridFloat.
2. The NED 1/3 arcsecond data, as it existed from mid-2016, was utilized. These were mosaicked as needed and re-projected in 30 meter grids. The sampling method utilized

during re-projection was bilinear resampling. Note that this DEM was **<u>only used to develop hydrologic parameters</u>** and was not used for hydraulic modeling.

3. All NHD high-definition lines that intersected the contributing basins were extracted and the lines classified as coastlines were deleted.

4. The NHD lines were joined to create the stream network, and the stream network was reviewed and modified as follows:

   - Split flow locations were reviewed and the primary flow path identified. The alternate flow paths were deleted from the network.
   - NHD lines classified as canals, underground conduits, and pipelines were removed from the network if they did not correspond to "natural" flow paths or scoped streams.
   - Streamlines were added where there was no NHD flowline associated with a CNMS line.

5. All streamlines within 50 meters of CNMS lines were reviewed. At locations where the two alignments were noticeably different, the aerial photography and topography were reviewed to determine the correct alignment, and the NHD flowline was modified if appropriate.

6. The NHD stream network was then used as the basis for development of an adjusted DEM – the "burn" layer. In the burn process, DEM cells that crossed burn lines were modified to have lower elevations. The 'burn' layer was necessary to accurately locate the flooding sources.

7. Sinks were inserted into the DEM at locations of physical depressions and at stream outlines into the ocean. Initial sink locations were identified using the San Juan Ultra Data Catalog http://sanjuanultra.org/wp-content/shares/sjultra/catalogo.html. Additional sinks were inserted, where appropriate, based upon review of the topographic and hydrologic flow paths. A sink was added by converting a DEM cell to a "null" value. When sinks were inserted, the flowlines would terminate at the sink, therefore sinks were only inserted when it was believed with a high degree of confidence that the 1-percent annual chance event would not have sufficient volume to overflow the depression.

8. A flow direction grid was created from the filled DEM, where each cell pointed to the next downstream cell.

9. Watershed delineation was performed (i.e., flowlines and basins are created from the flow direction grids). Basins were delineated up to a threshold of 0.1 square miles, and hydrologic flowlines were also created up the 0.1 square miles of drainage area, which is the threshold recommended for hydrologic computations.

The following reviews were performed:

1. Delineated watersheds and flowlines were examined for consistency with the expected flow paths for the basin. The flow directions and alignments between the NHD stream

network and the hydrologic network were reviewed and differences were highlighted with automated tools. Generally, differences occurred when two burn lines were too close together and the flow direction grid was incorrect. At these locations, only the larger stream line was burned into the DEM to correct the direction.

2. A drainage area grid was computed along the flow paths and checked against stream gage drainage areas and spot locations in the NHD Plus Version 2 data (http://www.horizon-systems.com/NHDPlus/NHDPlusV2_home.php). If the flowlines or basins appeared to be in error, then the NHD stream network was modified. For larger drainage areas, differences within 15-percent were considered acceptable. Where the differences between the computed and USGS gage drainage areas were between 10-percent and 15-percent, the computed values were compared with the NHD Version 2 data. If there was agreement, no modifications were made. Please note that StreamStats does not currently include Puerto Rico and could not be used for spot checks.

3. The flowlines were checked at the HUC-10 boundaries to make sure there were no cross-basin flows. Sinks were added where appropriate to eliminate drainage into adjacent HUC-10 watersheds.

4. If modifications were made, the fill, flow direction, and watershed delineation steps were repeated and drainage areas recalculated. The flagged locations were then checked again.

During the review process, the following differences in drainage areas between this study and published data were noted:

1. Rio Grande De Anasco (50144000): The drainage basin matched with the USGS data. However, the USGS subtracted 36 square miles from the total drainage area to account for diversions. This study used the total drainage area and natural flow paths to be conservative in computing flood flows for the Advisory Base Flood Elevations (ABFEs).

2. Rio Tanama at Charco Hondo (50028400): The USGS drainage area was computed using the area of the larger drainage basin. However, there were two upstream locations which lacked sufficient volume to overflow the depression during a 1-percent annual chance flood event, due to a 100+ foot increase in topography. Because of this, sinks were modeled at these locations to reduce the computed contributing drainage area. Please note that this was not a modeled stream.

The spatial files developed are described in the table below.

Table 3-1: Stream Network Preparation and Watershed Delineation Spatial Files

File Name	Type	Description
***.nhd_prj.shp**	polyline	NHD high-definition flowlines in the contributing drainage area

File Name	Type	Description
***_topo.bil**	grid	Mosaicked 30-meter USGS DEM covering the contributing drainage area
***_burn_reaches.shp**	polyline	Connected stream network derived from modified NHD flowlines.
_sinks_V2.shp	point	Sinks inserted into the DEM
***_topo_burn.bil**	grid	30-meter topography with stream network (i.e., burn reaches) burned in and sinks inserted
***_fd.bil**	grid	Flow direction grid
***_fa.bil**	grid	Flow accumulation grid
***_sqmi.tif**	grid	Contributing drainage area (in square miles) for all drainage areas of 0.1 square miles or greater
***_basinpolys_0.1.shp**	polygon	Basins delineated up to a threshold of 0.1 square miles of drainage area
***_basinpaths_0.1_join.shp**	polyline	Hydrologic flow paths up to 0.1 square miles of drainage area
***_basinpolys_1.shp**	polygon	Basins delineated up to a threshold of 1 square mile of drainage area
***_basinpaths_1_join.shp**	polyline	Hydrologic flow paths up to 1 square mile of drainage area
***_basinpolys_5.shp**	polygon	Basins delineated up to a threshold of 5 square miles of drainage area
***_basinpaths_5_join.shp**	polyline	Hydrologic flow paths up to 5 square miles of drainage area
***_basinpolys_10.shp**	polygon	Basins delineated up to a threshold of 10 square miles of drainage area
***_basinpaths_10_join.shp**	polyline	Hydrologic flow paths up to 10 square miles of drainage area
***_basinpolys_100.shp**	polygon	Basins delineated up to a threshold of 100 square miles of drainage area
***_basinpaths_100_join.shp**	polyline	Hydrologic flow paths up to 100 square miles of drainage area

Please note that there were no adjustments to the regression flows for Culebra and Vieques, these were the final flows used in the modeling.

3.1.2.2 Peak Flows Computed from Regression Equations Only

Peak flows for the 10-percent, 4-percent, 2-percent, 1-percent, and 0.2-percent frequency events were computed utilizing the published USGS regression equations (Lopez, 1979 and Ramos-Ginés, 1999). 1-percent plus discharges were computed by adding one standard error. The most recent regression equations included a depth to bedrock parameter. The Soil Survey Geographic

Database (“SSURGO”) data was incomplete for the study area. Dr. Orlando Ramos-Ginés was contacted, and he stated that the GIS data used in his study was not available. As such, the 1979 equations developed by Lopez and others in Table 5 in the regression report were used to compute the regression flows through the 1-percent event. The 0.2-percent annual chance flows were computed using the equation in Table 6 of the regression report. The contributing drainage area (“CDA”) and area-weighted mean annual rainfall (“MAR”) were the basin characteristics used to estimate the flows. Flow grids were developed for each frequency event and the input parameters described above were developed for drainage areas of 0.1 square mile or greater.

The mean annual rainfall (1963-1995) gridded spatial data was obtained from the Caribbean Landscape Conservation Cooperative. More recent data was not readily available. The precipitation values were converted to inches and clipped to the study area. A grid of the area-weighted basin average precipitation was created for all of the drainage areas of 0.1 square mile or greater. The lower and upper values for precipitation were 46.61 and 200 inches, respectively. All basin averaged precipitation values were within this range for the study area.

The average standard error of prediction for a 1-percent chance exceedance was 44.5-percent. The 1-percent plus flows were computed by multiplying the 1-percent flows by 1.445.

The spatial files developed are described in the table below.

Table 3-2: Spatial Files for Computation of Peak Flows from Regression Equations Only

File Name	Type	Description
***_sqmi.tif**	grid	Contributing drainage area in square miles (CDA) for all drainage areas of 0.1 square miles or greater
***_precip_inches.bil**	grid	PRISM precipitation grid clipped to the contributing drainage area, re-projected to USGS Albers NAD83, adjusted to 30-meter grid cells, and converted to inches
***_basinavgprecip.tif**	grid	Area-weighted basin average precipitation (MAR) for all drainage areas of 0.1 square miles or greater
***_Q10_eqs_only.tif**	grid	Regression equation peak streamflows with 10-percent chance exceedance for all drainage areas of 0.1 square miles or greater
***_Q25_eqs_only.tif**	grid	Regression equation streamflows with 4-percent chance exceedance for all drainage areas of 0.1 square miles or greater
***_Q50_eqs_only.tif**	grid	Regression equation streamflows with 2-percent chance exceedance for all drainage areas of 0.1 square miles or greater
***_Q100_eqs_only.tif**	grid	Regression equation streamflows with 1-percent chance exceedance for all drainage areas of 0.1 square miles or greater
***_Q100_plus1_eqs_only.tif**	polyline	Regression equation 1-percent plus peak stream flows

File Name	Type	Description
***_Q500_eqs_only.tif**	grid	Regression equation peak streamflows with 0.2-percent chance exceedance for all drainage areas of 0.1 square miles or greater

3.1.2.3 Gage Analyses

The data for all surviving USGS gages following the recent hurricanes was downloaded and analyzed as part of the Puerto Rico Post Irma / Maria Watershed Prioritization Report (October 5, 2017). As part of that effort, PeakFQ Bulletin 17B return period analyses were completed for peak flows through 2016. The peak flows from the recent events were compared to the computed return periods at each gage. The return period for the peak September 2017 flows was estimated from those results (see Table 2 of the above referenced report.)

As part of this study, the September 2017 peak flows were added to the historic data and the return periods recomputed with PeakFQ wherever they were greater than the 10-year event. The PeakFQ files are included with the electronic data.

Table 3-3 shows a comparison of the 1-percent and 0.2-percent annual chance flows before and after the 2017 flows were incorporated into the PeakFQ analysis.

The published USGS flow rates for Hurricane Maria were not available. The flow estimates from the daily data on the USGS website were used in this analysis. Since many of the stream gages stopped functioning during the event, the peak flows used in this study are likely to be lower than what will be published by the USGS.

Table 3-3: Flows Before and After Incorporating September 2017 Flows into the PeakFQ Analysis

Gage	Description	Gage Record Length (years)	Flows for Return Period Through 2016 (cfs)		Flows for Return Period Including 2017 (cfs)		Sept 2017 Peak Flow (cfs)
			1-Perc	0.2-Perc	1-Perc	0.2-Perc	
50014800	RIO CAMUY NR BAYANEY, PR	33	11,340	13,160	13,460	19,170	12,000
50025155	RIO SALIENTE AT COABEY NR JAYUYA, PR	27	18,470	29,030	35,580	70,920	42,100
50026025	RIO CAONILLAS AT PASO PALMA, PR	21	46,910	75,800	59,030	99,170	35,900
50028000	RIO TANAMA NR UTUADO, PR	58	16,160	18,310	17,250	23,040	14,200
50031200	RIO GRANDE DE MANATI NR MOROVIS, PR	51	71,180	118,800	77,290	130,700	45,100

Gage	Description	Gage Record Length (years)	Flows for Return Period Through 2016 (cfs)		Flows for Return Period Including 2017 (cfs)		Sept 2017 Peak Flow (cfs)
50035000	RIO GRANDE DE MANATI AT CIALES, PR	65	151,000	192,100	168,200	295,700	124,000
50038100	RIO GRANDE DE MANATI AT HWY 2 NR MANATI, PR	56	212,200	314,600	227,800	345,200	135,000
50039500	RIO CIBUCO AT VEGA BAJA, PR	59	58,670	110,500	67,920	132,900	50,000
50044810	RIO GUADIANA NR GUADIANA, NARANJITO PR	17	13,160	17,930	16,890	23,220	11,600
50051800	RIO GRANDE DE LOIZA AT HWY 183 SAN LORENZO, PR	28	10,060	12,120	67,620	110,200	17,500
50055750	RIO GURABO BLW EL MANGO, PR	27	21,660	40,540	30,300	49,190	18,000
50064200	RIO GRANDE NR EL VERDE, PR	42	27,960	33,410	30,390	46,070	19,200
50106100	RIO COAMO AT HWY 14 AT COAMO, PR	31	82,650	127,900	91,740	243,900	27,700
50112500	RIO INABON AT REAL ABAJO, PR	54	11,400	22,010	11,990	23,260	5,870
50124200	RIO GUAYANILLA NEAR GUAYANILLA, PR	36	31,810	62,020	34,910	69,080	17,000
50126150	RIO YAUCO ABV DIVERSION MONSERRATE NR YAUCO, PR	23	20,900	29,900	41,640	71,930	24,300
50136400	RIO ROSARIO NR HORMIGUEROS, PR	32	16,420	26,000	18,440	29,760	12,200
50138000	RIO GUANAJIBO NR HORMIGUEROS, PR	42	114,000	31,400	138,800	380,400	64,600
50144000	RIO GRANDE DE ANASCO NR SAN SEBASTIAN, PR	54	137,300	265,600	161,300	324,800	132,000
50148890	RIO CULEBRINAS AT MARGARITA DAMSITE NR AGUADA, PR	19	5,583	6,147	5,963	6,659	5,580

3.1.2.4 Adjustments with Gage and FIS Flows

The computed regression flows were compared with the Bulletin 17B gage flows, as well as the FIS flows on major streams. For gaged streams where the differences were significant and the years of record were long, the regression flows were adjusted to more closely match the gage flows. In addition, the regression-based flows were adjusted where there were noticeable differences between the FIS flows on major streams. To be conservative for ABFE development, there was greater emphasis on adjusting the regression flow where the FIS flows were higher.

The method for adjusting the regression flow on gaged streams, presented in the regression report (Ramos-Ginés, 1999), was not applied because it would have caused the flows to decrease in the downstream direction. Because the USGS weighting procedure appeared to give unrealistic results, the discharges estimated at the stream gage were transferred to other locations of the stream using the drainage area at the location of interest.

A weighted least-squares regression was performed, where the explanatory variable was the log of the drainage area, and the dependent variable was the log of the discharge of the gage and/or FIS flow. The weight of each gage for the weighted least-squares regression was the number of valid years in the peak flow record. The FIS flows had a weight of one. The reasonableness of the final flows were assessed and some adjustments to the weighted regression estimates were made.

The September 2017 hurricane peak flows were lower than the final 100-year peak flow except at the Gage 50026025, Rio Caonillas at Paso Palma. For this gage, the hurricane flow was between the computed 1-percent and 0.2-percent annual chance flows, and therefore reflected in the floodplain mapping and computed water surface elevations.

Table 3-4 lists the streams where the flows were adjusted and identifies where gage and FIS flows were used. The streamid represents the identity of the hydrology flow path(s) the stream follows in the *_basinpaths_0.1_join.shp. The streamid of a reach corresponds to the name of the HEC-RAS model. **Table 3-4** also provides the streamids of the HEC-RAS models and their corresponding stream names.

Table 3-4: List of Streams and Method of Flow Adjustments

HEC-RAS Model Streamid	Flooding Source Name	Method of Flow Adjustment
17263	Quebrada Blanca at El Jagual	Gage data
16050, 16054	Quebrada Margerita	FIS flows
17283	Quebrada Salvatierra Nr San Lorenzo	Gage data
17725	Rio Bairoa	FIS flows
2027	Rio Bucana d/s of reservoir	Gage data
17646	Rio Caguitas	Gage data and FIS flows
9956	Rio Camuy	Gage data
10355	Rio Caonillas/Rio Saliente	Gage data
17315	Rio Cayaguas	Gage data
13347, 13406	Rio Cibuco	Gage data
3810, 3955	Rio Coamo	Gage data and FIS flows

HEC-RAS Model Streamid	Flooding Source Name	Method of Flow Adjustment
7132, 7143	Rio Culebrinas	Gage data and FIS flows
15363, 15382,15385	Rio De Bayamon	Gage data
14093	Rio De La Plata	Gage data
13251, 13252	Rio Duguao	FIS flows
16857, 16860	Rio Espiritu Santo	Gage data
16941	Rio Grande	Gage data
12119	Rio Grande de Manati	Gage data
6353, 6359, 6362	Rio Guamani	FIS flows
2498	Rio Guanajibo	Gage data and FIS flows
8407	Rio Guayanes	FIS flows
1552	Rio Guayanilla	Gage data
17805	Rio Gurabo	Gage data and FIS flows
9741	Rio Humacao	Gage data and FIS flows
7002	Rio Jacaboa	FIS flows
3504	Rio Jacaguas	FIS flows
4878	Rio Lapa	Gage data
4771	Rio Majada-Nagua at Coco	Gage data and FIS flows
16599	Rio Mameyes	Gage data and FIS flows
7690	Rio Manubo	Gage data
6558	Rio Nigua at Arroyo and Pitahaya	FIS flows
2166	Rio Portugues	Gage data
11940, 11954	Rio Santiago	FIS flows
7989	Rio Tanama	Gage data
3382	Rio Toa Vaca and Jacaguas	FIS flows
17465	Rio Turabo	Gage data and FIS flows
17970	Rio Valenciano	Gage data

The spatial files developed are described in the table below.

Table 3-5: Spatial Files and Related Data for Final Peak Flows Adjusted for High Drainage Area and Regulation by Large Dams

File Name	Type	Description
***_adj_streams.shp**	polyline	Polylines showing where regulated flow adjustments were made for large dams
***_gage_*.shp**	point	Shapefile with the gage PEAKFQ frequency flows and/or FIS flows. The ending digits of the filename correspond to the streamid.
***_adj_stream_regress_eqs_*.shp**	polyline	Shape file with the regression results for each return period using the gage and/flow data and the

File Name	Type	Description
		drainage area. The last digits in the file name correspond to the return period.
***_Q10_final.tif**	grid	Final peak streamflows with gage and FIS flow adjustments for the 10-year event
***_Q25_final.tif**	grid	Final peak streamflows with gage and FIS flow adjustments for the 25-year event
***_Q50_final.tif**	grid	Final peak streamflows with gage and FIS flow adjustments for the 50-year event
***_Q100_final.tif**	grid	Final peak streamflows with gage and FIS flow adjustments for the 1-percent annual chance event
***_Q100_plus1_final.tif**	grid	Final peak streamflows with gage and FIS flow adjustments for the 1-percent annual chance plus event
***_Q500_final.tif**	grid	Final peak streamflows with gage and FIS flow adjustments for the 500-year event

3.1.2.5 Flow Comparisons

The computed flows were compared to selected gage analyses and FIS flows as described in the sections below. Shapefiles with the comparisons are included with the electronic data.

3.1.2.5.1 HUC 2101000202 – Rio Cibuco Watershed

Two gages on Rio Cibuco were used to adjust the regression flows for Rio Cibuco and Rio De Los Negros using the methodology described above. The table below shows that the 1-percent annual chance gage flow and the 1-percent annual chance flow used in this study concur.

Gage	Flooding Source Name	1-Percent Annual Chance Gage Flow (cfs)	1-Percent Annual Chance BLE Flow (cfs)
50038320	Rio Cibuco	27,200	27,345
50039500	Rio Cibuco	67,920	63,260

The computed 1-percent annual chance flows and FIS flows for those streams not part of the gage adjustment above, were similar on Quebrada Hondo. There appeared to be a unit conversion issue or typo for the FIS flows on Rio Morovis and Rio De Los Negros and the results were not comparable. The computed 1-percent annual chance regression flow on Rio Indio was higher than the FIS flow. Since ABFEs were being developed, the higher, more conservative flow was used in this study.

3.1.2.5.2 HUC 2101000202 – Rio Grande de Manati Watersheds

Three gages on Rio Grande de Manati were used to adjust the regression flows on this river for drainage areas less than 50 square miles. The table below shows that the 1-percent annual chance gage flow and the 1-percent annual chance flow used in this study concur. The 1-percent annual chance regression flow and the gage flow on Rio Orocovis were within 7-percent, so the regression flows were not adjusted. The 1-percent annual chance regression flow was less than the gage flow on Rio Bauta. However, the flows were not adjusted because Rio Bauta was not modeled in this study.

Gage	Flooding Source Name	1-Percent Annual Chance Gage Flow (cfs)	1-Percent Annual Chance BLE Flow (cfs)
50031200	Rio Grande de Manati	77,290	76,415
50035000	Rio Grande de Manati	151,000	160,701
50038100	Rio Grande de Manati	227,800	208,769
50030460	Rio Orocovis	10,690	9,935
50038100	Rio Bauta	35,450	28,632

The computed flows on Rio Grande de Manati were less than the FIS flows. However, the flows match the gage data and no further refinements were made. The computed flows on Rio Orocovis were higher than the FIS flows, but agreed with gage data. Therefore, no adjustments were made.

3.1.2.5.3 HUC 2101000204 – Rio Grande de Arecibo

A comparison of the gage flows and the computed final flows is included in the table below. Flows were adjusted with gage data upstream of Lake Caonillas. Regression flows were higher but within 20-percent for Rio Limon and Rio Tanama, so no adjustments were made.

Gage	Flooding Source Name	1-Percent Annual Chance Gage Flow (cfs)	1-Percent Annual Chance BLE Flow (cfs)
50025155	Rio Saliente	35,580	35,673
50026025	Rio Caonillas	59,030	58,996
50038100	Rio Limon	40,540	47,465
50030460	Rio Tanama	17,250	19,211

The regression flows were compared to the FIS flows downstream of Lake Dos Bocas. The 1-percent annual chance regression flows were within 10-percent of the FIS flows, so no adjustments were made.

3.1.2.5.4 HUC 2101000205 – Quebrada Los Cedros to Rio Camuy

The flows on Rio Camuy were adjusted with gage data where there were longer gage records. The flow comparison is shown in the table below.

Gage	Flooding Source Name	1-Percent Annual Chance Gage Flow (cfs)	1-Percent Annual Chance BLE Flow (cfs)
50014800	Rio Camuy	13,460	13,460
50015700	Rio Camuy	14,950	14,950

The regression flow was somewhat higher, but similar to the gage flow at the mouth. No further adjustments to the flows were made.

3.1.2.5.5 HUC 2101000301 – Rio Culebrinas

The flows on Rio Culebrinas were adjusted with one gage (see table below) and with FIS flows. The computed flows were within 5-percent of the FIS flows on this stream.

Gage	Flooding Source Name	1-Percent Annual Chance Gage Flow (cfs)	1-Percent Annual Chance BLE Flow (cfs)
50047800	Rio Culebrinas	46,850	54,309

Regression flows along the tributaries were higher than the FIS flows. The more conservative regression flows were used.

3.1.2.5.6 HUC 2101000302 – Rio Grande de Anasco

A comparison of the computed flows and the gage flows is displayed in the table below. The regression flows were somewhat higher, but within 15-percent of the FIS flows and similar to the gage on Rio Grande De Anasco, so no adjustments were made.

Gage	Flooding Source Name	1-Percent Annual Chance Gage Flow (cfs)	1-Percent Annual Chance BLE Flow (cfs)
50141000	Rio Blanco	18,000	26,182
50144000	Rio Grande de Anasco	161,300	160,860

3.1.2.5.7 HUC 2101000303 – Rio Yaguez

There were no gages with a long period of record in this watershed. The regression flow and the FIS flow were similar, so no adjustments were made.

3.1.2.5.8 HUC 2101000304 – Rio Guanajibo

A comparison of the computed flows and the gage flows is shown in the table below.

The flows on Rio Guanajibo were adjusted based on the two gages listed below and FIS flows at the mouth, near PR-347, at PR 2, and the upstream limit of study.

The flows on Rio Guanjibo were not adjusted because the flows decreased with drainage area. The higher regression flows were used.

Gage	Flooding Source Name	1-Percent Annual Chance Gage Flow (cfs)	1-Percent Annual Chance BLE Flow (cfs)
50131990	Rio Guanajibo	59,620	59,278
50138000	Rio Guanajibo	138,800	139,250
50136000	Rio Rosario	27,320	31,243
50136400	Rio Rosario	18,440	32,547

The FIS and regression flows differed on the small streams, generally within the backwater of Rio Guanajibo. The flows were not adjusted at these locations.

3.1.2.5.9 HUC 2101000401 – Quebrada Boqueron to Rio Loco

There were no gages with a long period of record in this watershed. The regression flow and the FIS flows were similar on Rio Loco, upstream of the confluence with Canal Este De Drenaje Del

Valle de Lajas. The drainage area for the canal (~ 50 square miles) was used in the regression flow approach. The regression flows were higher than the FIS flows downstream of the confluence. No adjustments were made to the flow and the floodplains were not significantly different.

3.1.2.5.10 HUC 2101000402 – Rio Yuaco to Rio Tallaboa

A comparison of the computed flows and the gage flows are shown in the table below.

The flows on Rio Guyanilla were adjusted based on the two gages listed.

The flows on Rio Tallaboa were not adjusted to the gage because the computed flow was similar to the FIS flow at this location. The computed flows were higher than the FIS flows downstream of the gage. To be conservative, the flows were not adjusted.

Gage	Flooding Source Name	1-Percent Annual Chance Gage Flow (cfs)	1-Percent Annual Chance BLE Flow (cfs)
50124200	Rio Guayanilla	34,910	34,731
50124500	Rio Guayanilla	46,970	42,614
50121000	Rio Tallaboa	42,320	36.455

Though there were some differences between the FIS and regression flows at other locations, adjustments were not made because the differences should not result in noticeably different floodplains.

3.1.2.5.11 HUC 2101000403 – Rio Matilde to Rio Descalabrado

A comparison of the computed flows and the gage flows are shown in the table below.

The flows on Rio Portugues were adjusted based on gage flows. Since the gage regression was weighted by the period of record, the flows more closely match gage 50115000.

Flows on Rio Jacaguas were adjusted based on FIS flows.

Flows on Rio Bucana were adjusted downstream of the Lake Cerrillos based on gage data.

Gage	Flooding Source Name	1-Percent Annual Chance Gage Flow (cfs)	1-Percent Annual Chance BLE Flow (cfs)
50108000	Rio Descalabrado	25,930	19,355
50110900	Rio Toa Vaca	15,070	22,999
50112500	Rio Inabon	11,990	17,095
50113800	Rio Cerrillos	18,480	20,850
50114000	Rio Cerrillos	31,290	15,486
50114390	Rio Bucana	20,010	19,831
50114900	Rio Portugues	7,784	12,350
50115000	Rio Portugues	19,840	14,586
50115900	Rio Portugues	26,280	28,832

It was attempted to adjust the flows on Rio Descalabrado based upon the gage above and other nearby gages. The gage analysis results were unreasonable, so no adjustment was made and the regression flow used.

The more conservative regression flows were used on Rio Toa Vaca.

The regression FIS flows for Rio Inabon were reasonable, so no adjustments were made.

Gage 50113800 on Rio Cerrillos was upstream of Lake Cerrillos, and the differences between the gage and regression flows were small. Gage 50114000 was below Lake Cerrillos, and the gage record reflected flows prior to the construction of the dam. Therefore, flow adjustments were not made to this gage.

For the remaining streams the generally higher, more conservative, regression flows were used.

3.1.2.5.12 HUC 2101000404 – Rio Coamo to Rio Seco

A comparison of the computed flows and the gage flows are shown in the table below.

The flows on Rio Coamo were adjusted based on both gage and FIS flows. Gage 50106500 was not used because the 1-percent annual chance flow decreased with drainage area.

Flows on Rio Lapa were adjusted based on gage data.

Flows on Rio Majada and Rio Nigua were adjusted based on both gage and FIS flows.

Gage	Flooding Source Name	1-Percent Annual Chance Gage Flow (cfs)	1-Percent Annual Chance BLE Flow (cfs)
501002000	Rio Lapa	23,210	23,319
50100450	Rio Majada	42,120	40,741
50106100	Rio Coamo	91,740	91,811
50106500	Rio Coamo	62,590	94,834

3.1.2.5.13 HUC 2101000405 – Rio Guamani to Rio Jacaboa

There was only one gage (see following table) in this watershed that had a long period of record. The gage and regression flows were within 2-percent, so the regression flows were not adjusted.

Gage	Flooding Source Name	1-Percent Annual Chance Gage Flow (cfs)	1-Percent Annual Chance BLE Flow (cfs)
50092000	Rio Grande de Patillas	29,330	28,815

Rio Guamani, Rio Jacaboa, and Rio Nigua were adjusted based on the FIS flows.

3.1.2.5.14 HUC 2101000501 – Rio Maunabo to Rio Humacao

A comparison of the computed flows and the gage flows are shown in the table below.

The flows on Rio Humacao were adjusted based on both gage and FIS flows.

Flows on Rio Maunabo were adjusted based on gage data.

Gage	Flooding Source Name	1-Percent Annual Chance Gage Flow (cfs)	1-Percent Annual Chance BLE Flow (cfs)
50081000	Rio Humacao	17,130	19,181
50090500	Rio Maunabo	17,630	17,407
50091000	RioMaunabo	34,900	35,039

Flows on Rio Guayanes were adjusted based on FIS flows.

There were differences in the regression and FIS flows for the remaining streams with small drainage areas. The differences in the FIS and regression flows should not noticeably affect the floodplain delineations.

3.1.2.5.15 HUC 2101000502 – Rio Anton Ruiz to Rio Fajardo

There was one gage on a modeled stream that had a long period of record: Gage 5007100 on Rio Fajardo. The 1-percent annual chance gage flow was 26,080 cfs and the regression flow was 31,280 cfs. The more conservative regression flow was used.

The flows on Rio Daguao and Rio Santiago were adjusted based on FIS flows.

There were differences in the regression and FIS flows for the remaining streams with small drainage areas. The differences in the FIS and regression flows should not noticeably affect the floodplain delineations.

3.1.2.5.16 HUC 2101000503 – Rio Herrera to Las Cabezas de San Juan

A comparison of the computed flows and the gage flows are shown in the table below.

The flows on Rio Espiritu Santo and Rio Grande were adjusted based on the gage data only. Flows on Rio Mameyes were adjusted based on both gage and FIS data. Flows were not adjusted on Rio Sabana because the gage and regression flows were similar.

Gage	Flooding Source Name	1-Percent Annual Chance Gage Flow (cfs)	1-Percent Annual Chance BLE Flow (cfs)
50063300	Rio Espiritu Santo	13,550	13,608
50063800	Rio Espiritu Santo	25,880	26,562
50064200	Rio Grande	28,190	24,532
50062500	Rio Herrara	5,446	7,908
50065700	Rio Mameyes	46,710	43,263
50065500	Rio Mameyes	26,720	26,477
50067000	Rio Sabana	12,380	10,771

In general, the regression flows were higher than the FIS. To be more conservative, the regression flows were used.

3.1.2.5.17 HUC 2101000504 – Rio Grande de Loiza

A comparison of the computed flows and the gage flows is displayed in the table below.

Gage data were used to adjust the flows for Quebrada Blanca, Quebrada Salvatierra, Rio Cayaguas, and Rio Valenciano.

Gage data and FIS flows were used to adjust the flows for Rio Gurabo, Rio Turabo, and Rio Caguitas.

Since the gage and regression flows on Rio Canovanas were similar, no adjustments were made.

The regression flows closely match the FIS flows on Rio Grande De Loiza. Therefore, no adjustments were made to the gage data.

Gage	Flooding Source Name	1-Percent Annual Chance Gage Flow (cfs)	1-Percent Annual Chance BLE Flow (cfs)
50051150	Quebrada Blanca	13,240	15,008
50051180	Quebrada Salvatierra	18,170	16,309
50055225	Rio Caguitas	32,700	29,864
50062500	Rio Canas	8,646	13,515
50065700	Rio Canovanas	23,610	25,451
50065500	Rio Cayaguas	26,440	26,952
50055000	Rio Grande de Loiza	80,460	114,240
50051800	Rio Grande de Loiza	67,620	62,957
50050900	Rio Grande de Loiza	36,830	12,779
50057000	Rio Gurabo	115,200	114,954
50053025	Rio Turabo	18,780	19,004
50056400	Rio Valenciano	44,530	44,173

FIS flows were used to adjust the flows on Rio Bairoa.

In general, the FIS flows and the computed flows were in fair agreement except at a couple smaller streams where the backwater from the main stem dominated. The effects on the floodplain should be small.

3.1.2.5.18 HUC 2101000505 – San Juan Bay Estuary

There were no gages with long periods of record in this watershed.

The flows on Rio Quebrada Margarita were adjusted based on FIS flows.

The differences in the regression and FIS flows were not large and no further adjustments were made.

3.1.2.5.19 HUC 2101000507 – Rio de Bayamon to Rio Hondo

A comparison of the computed flows and the gage flows are displayed in the table below.

The gage data were used to adjust the flows on Rio De Bayamon.

Gage	Flooding Source Name	1-Percent Annual Chance Gage Flow (cfs)	1-Percent Annual Chance BLE Flow (cfs)
50047535	Rio de Bayamon	2,025	2,198
50047560	Rio de Bayamon	30,050	18,461
50047850	Rio de Bayamon	49,300	58,337
50048000	Rio de Bayamon	91,450	86,876

The FIS and regression flows were similar for the other reaches.

3.1.2.5.20 HUC 2101000506 – Rio de La Plata

A comparison of the computed flows and the gage flows are shown in the table below.

The gage data were used to adjust the flows on Rio de La Plata. There was not sufficient gage data downstream of the reservoir to adjust the flows. The computed flows were conservative and show the effect of what would happen if the reservoir were at capacity during flood conditions.

Gage	Flooding Source Name	1-Percent Annual Chance Gage Flow (cfs)	1-Percent Annual Chance BLE Flow (cfs)
50043000	Rio de La Plata	127,200	133,921
50043800	Rio de La Plata	229,900	200,048
50045010	Rio de La Plata	247,700	265,806

The differences between the FIS flows and regression flows in the tributaries were reasonable.

3.1.3 Hydraulic Analyses

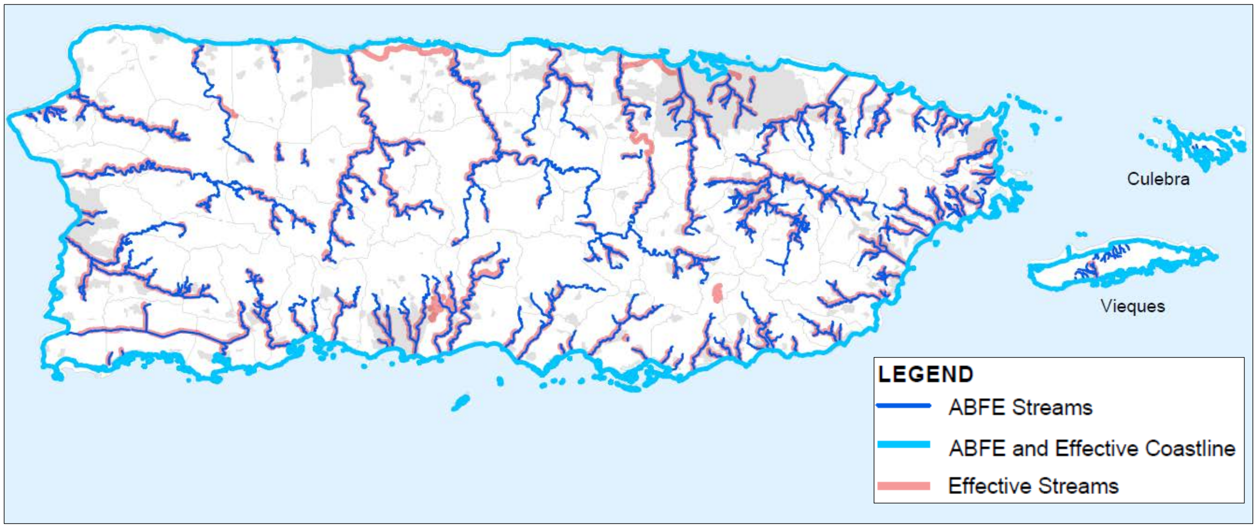
The scope for the hydraulic analyses was to develop non-regulatory flood hazard information (i.e., Base Level Engineering) for 950 miles of existing CNMS stream mileage, as well as an additional 500 miles of unmapped areas. A stream network was developed by leveraging FEMA's CNMS centerlines and NHD high- to medium-resolution data for unmapped areas. **Figure 3-2** provides spatial location of the BLE analysis of 1,400 miles. **Appendix A** provides the list of streams where the hydraulic analysis was completed along with HEC-RAS model naming convention. The final mileage was slightly less than the original proposed scope due to various factors outlined below:

1. Partially or completely influenced by coastal in the following HUC-10s:
    - 2101000507 - Rio de la Plata Watershed
    - 2101000505 - San Juan Bay Estuary Watershed
    - 2101000203 - Cano Tiburones Coastal Watershed
    - 2101000502 - Rio Anton Ruiz to Rio Fajardo Watersheds
    - 2101000503 - Rio Herrera to Las Cabezas de San Juan Coastal Watersheds
2. Unable to locate clear flow paths from LiDAR or aerial photography at the upstream segments of proposed streams in the following HUC-10s:
    - 2101000403 - Rio Matilde to Rio Descalabrado Watersheds

- 2101000504 - Rio Grande de Loiza Watershed
  - 2101000506 - Rio de Bayamon to Rio Hondo Watersheds

3. Stream centerlines adjusted to better fit the LiDAR data or aerials from original source of CNMS database or NHD stream centerlines.

Figure 3-2: Spatial Location of Hydraulic Analysis



Steady flow hydraulic (“HEC-RAS”) models were developed for the 10-percent, 4-percent, 2-percent, 1-percent, 1-percent plus, and 0.2-percent annual chance flood events. The 1-percent plus flood event was included to be consistent with upcoming BLE guidance to support FEMA’s future CNMS validation process. Model geometry and mapping were developed automatically using GIS tools and scripts and then refined as needed. A common modeling practice that was not considered included in this analysis, was the inclusion of survey data for bridges, culverts, levees. However, hydraulic structures (such as bridges and culverts) were included using the National Bridge Inventory (“NBI”). Spit flow analysis was also not included.

The NHD high-definition streamlines were used to create the initial hydraulic centerlines for the models. These lines were then reviewed and modified to more closely follow the thalweg of the stream. A single conveyance area was used for each cross-section, e.g. bank stations were set at the outer limits of the cross-section. This method was found to give good results, especially when Manning’s n-values were set based on land use coverage.

No supercritical flows were permitted in the models, so the lowest possible water surface elevation for any cross-section was critical depth.

After automated hydraulic models were developed, the floodplains and cross-sections were visually reviewed. Cross sections with unusual changes in hydraulic parameters (water surface and energy grade slopes, water surface elevations, and velocity) were examined. In numerous cases, cross-sections were deleted or modified, to improve the quality of the hydraulic model.

Water surface grids and floodplains (0.2-percent and 1-percent annual chance flood events) were processed once the models were finalized.

3.1.3.1 Discharges

Discharges for all events were imported into HEC-RAS using automated tools. A corresponding computed USGS rural regression discharge was assigned for each cross-section location. Details of the discharge computation are provided in section 3.1.2.

3.1.3.2 Boundary Conditions

The downstream boundary condition for almost all models was set at critical depth. For areas of interest where the streamline did not terminate at a confluence with another river, the reach was extended by approximately 3,200 feet downstream. This allowed the water surface to stabilize, and ensured that the area of interest was outside the influence of the downstream limit of the model. In the model extensions downstream of confluences, the discharge applied was not increased to represent the increased discharge computed for the main channel, instead the highest computed discharge upstream of the confluence was used. This process allowed for a smooth transition in water surface elevation and thus floodplains between tributaries and main channels.

“Normal” depth is typically used in hydraulic models as the downstream boundary condition. However, the use of normal depth required an estimate of the “normal slope,” which depended on the method used to estimate it. Fully automated methods to estimate the normal slope for large numbers of reaches were not completely reliable. In particular, there was a risk that the slope would be estimated too low, which would have caused a significant and unrealistic backwater condition at the start of the model, which could perpetuate for a long distance upstream. When critical depth is used, the models will typically stabilize to a “normal” depth within just a few cross-sections.

The only circumstance in which the model results in this stabilization region were used was when the downstream end of a reach was in the confluence area with another modeled stream. For most confluences, the downstream main channel was modeled as well. Typically the higher water surface elevation (backwater) of the main channel would govern when the water surface grids and floodplains were merged, negating any inaccuracies associated with the critical depth boundary condition on the tributary stream.

Additional sensitivity analysis was completed to evaluate the above assumption for those streams joining the ocean if the Mean Higher High Water (“MHHW”) elevation was higher. BLE riverine elevations were developed using a critical elevation start assumption. This may not have been an appropriate assumption for those streams joining the ocean, if the MHHW elevation had been higher. In order to verify whether the critical depth assumption was valid as a boundary condition, the starting elevations of the streams joining the ocean were compared with the MHHW elevation. 92 streams were reviewed because they emptied into the ocean. NOAA’s VDATUM website was used to obtain the MHHW elevations.

Two tasks were conducted for this evaluation:

1. **TASK 1:** Estimated the MHHW elevation for streams that joined the ocean and determined whether this elevation was lower than the 1-percent annual chance elevation computed for the most downstream cross section (RAS Start elevation).

    - The downstream cross-section locations for the 92 streams were extracted from the stream shapefile for the study. The streams emptying to the ocean and the most downstream locations are shown in **Figure 3-3**.

    - The MHHW elevation for each downstream cross stream location was estimated using https://vdatum.noaa.gov/vdatumweb/.

    - The estimated MHHW elevation was compared to the 1-percent annual chance elevation of the most downstream cross section. The comparison results are summarized in **Appendix B**.

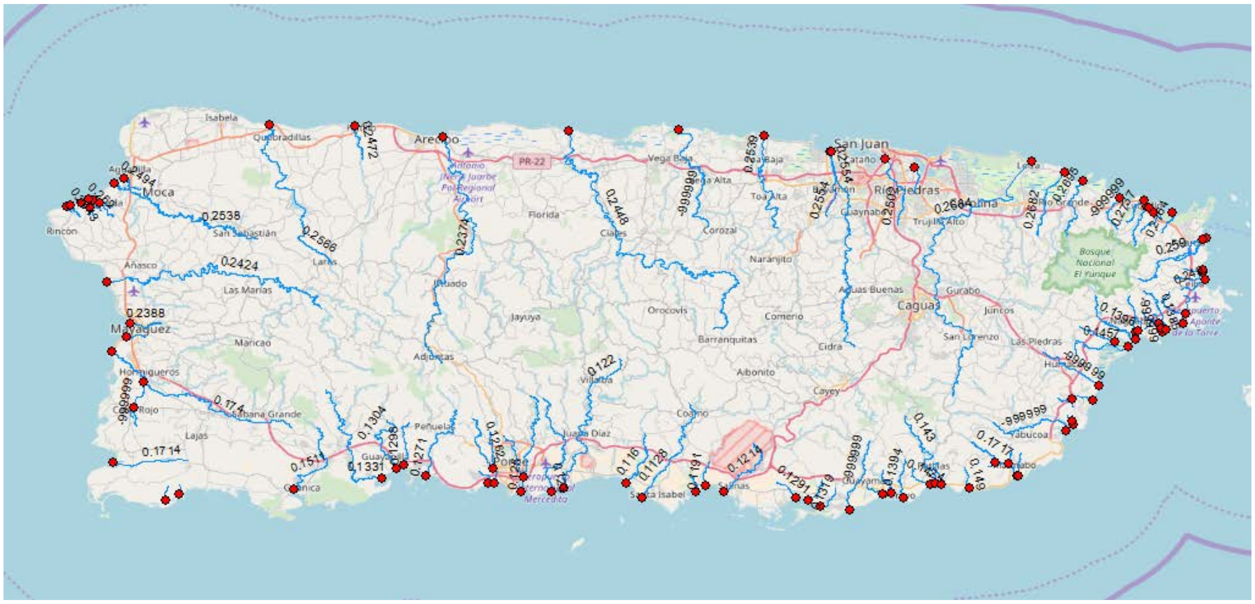
2. **TASK 2:** For those streams in which the MHHW was higher than the RAS start elevation, determined the upstream cross section with elevation equal to or larger than (= or >) the MHHW.

    - Find the RAS cross section upstream, where the 1-percent annual chance flood elevation is = or > MHHW.

    - If the 1-percent annual chance flood elevation of the most downstream cross section is lower than the estimated MHHW, the cross section upstream where the 1-percent annual chance elevation is = or > MHHW is located.

    - There is only one stream, Río Sin Nombre (Modelo núm. 189), stream ID = 40100189, that has a water surface elevation at downstream end below the MHHW. The next XS on this stream above MHHW is XS_ID = 40100037.

Figure 3-3: Streams Joining Ocean and the Most Downstream Locations



The sensitivity test indicated that critical depth start assumption was appropriate for all study streams, except for one - Rio sin Nombre. Normal depth was used for Rio sin Nombre.

3.1.3.3 Cross Sections

Although some cross sections were edited manually, cross section placement was primarily automated. Cross sections were placed perpendicular to the direction of flow. Cross section spacing was typically at 250 feet or less. Cross section geometries were obtained by overlaying the cross section on the DEM topography.

After automated placement, a series of checks was performed to look for unusual changes in water surface elevation, slope, or velocity between cross-sections for the water surface profile of the 1-percent plus annual chance exceedance event. Places flagged as exhibiting unusual behavior were examined, and cross sections were sometimes modified (or deleted) in these areas. This process resulted in the final cross section location and orientation, however the cross-section extent or width was determined using a separate process based on the estimated limits of effective flow.

3.1.3.4 Ineffective Areas

Ineffective flow limits were not used. Instead, cross-sections were trimmed back to the extent of the estimated effective flow region. The cross-section extents were determined first using the 1-percent plus event such that under normal conditions, the cross-section would be wide enough to contain the determined discharge for that cross-section. In some cases, the cross-section width was limited based on an estimation of the allowable change in cross-section width for contraction or expansion of effective top width. Allowable ratios for flow contraction and expansion were set at 1:1 and 4:1, respectively.

The determined final cross-section orientation and width from review and hydraulic analysis using the 1-percent plus event were applied for all other events with the exception of the 10-percent annual chance event. For the 10-percent annual chance event, a second pass was completed to decrease the effective top width of cross-sections. This forced the flow to be contained mostly within the low flow channel, if it had significant capacity to allow it. Because the previously determined cross-sections from the 1-percent plus event were used as the input sections for this process, the cross-sections for the 10-perecent annual chance event can only be shorter and must be a section of the cross-section created from the 1-percent plus hydraulic model.

3.1.3.5 Channel Roughness Values

Manning's n values were assigned to each class in the National Land Cover Database 2011 ("NLCD") found at (http://www.mrlc.gov/nlcd11_data.php). The correlation between land use codes and Manning's n-values are provided in **Appendix C**. For each model cross-section, a single n-value was computed by compositing the land cover Manning's n values along a cross section using the Lotter method (Chow, 1959, p. 136-137). This included an estimate of the 1-percent plus water surface elevation, and allowed for the wetted extents to be used to perform the compositing. Because of this method, Manning's n-values varied significantly from cross-section to cross-section depending on the land use in the vicinity. The compositing was done by each cross-section using the 1-percent plus discharges and estimated wetted extents. These composite n-values were then used for all other event simulations, including the 10-percent for which shorter cross sections are used to limit conveyance to the smallest overall width that may provide containment.

3.1.3.6 Expansion and Contraction

Default contraction and expansion coefficients (0.1 and 0.3) were used, for river cross-sections. In areas where the change in effective cross-section area was abrupt (e.g., at bridges), contraction and expansion coefficients of 0.3 and 0.5 were used.

3.1.3.7 Special Issues

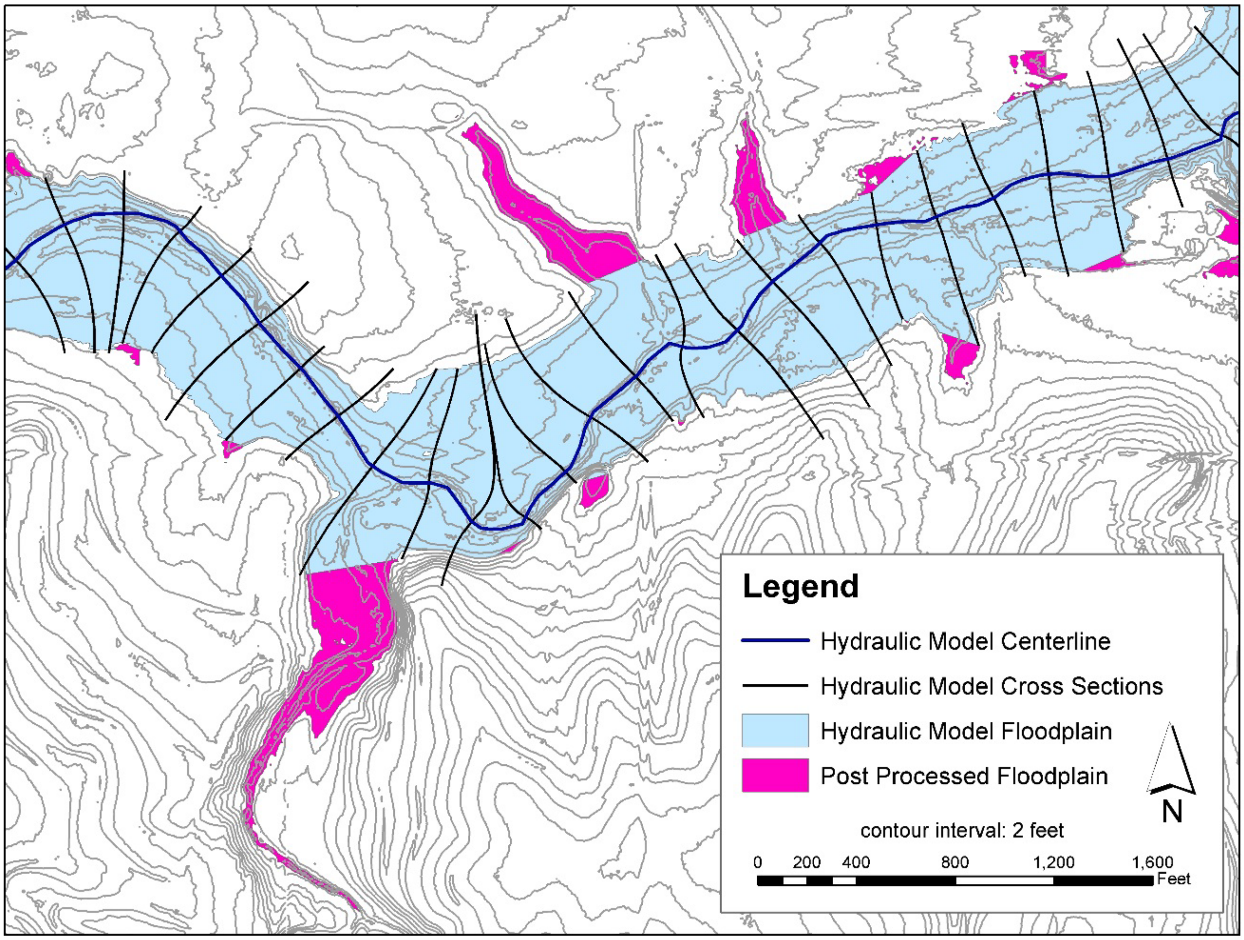
Flow was not decreased due to model breakouts, nor were models modified to take them into account.

3.1.4 Floodplain Mapping and Water Surface Elevation Grids

Floodplains were generated for the 1-percent and 0.2-percent annual chance exceedance events for the hydraulic model reaches. **Appendix A** provides the list of the streams where the floodplains and water surface elevations grids were developed. These floodplains were utilized to determine if the hydraulic model results looked reasonable, and if the models needed adjustment.

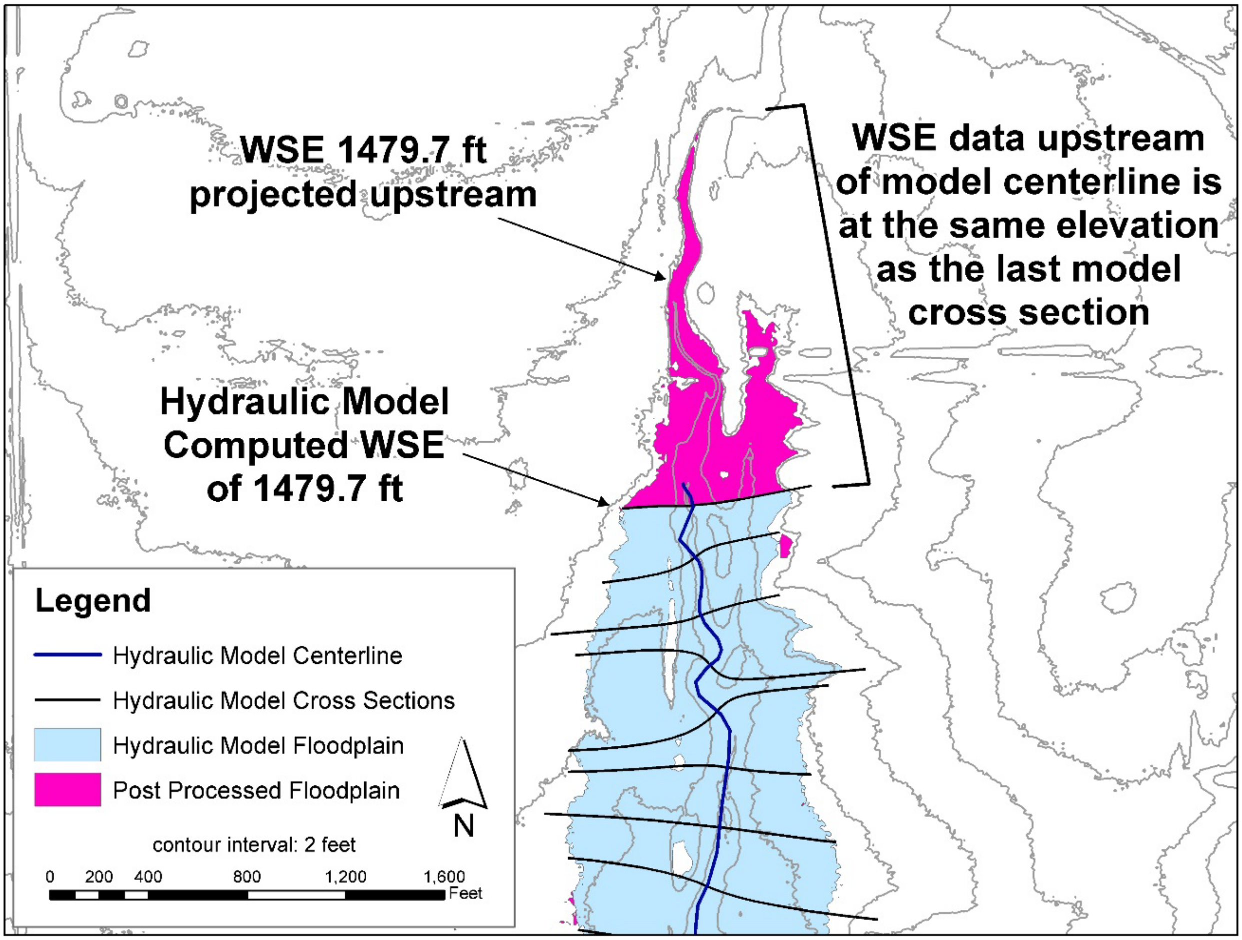
The floodplains were based on water surfaces interpolated from the hydraulic model cross-sections. In most locations where flow containment was lost at the limits of the models, backwater conditions were considered and the floodplains adjusted with an automated post-processing step to include additional backwater areas. **Figure 3-4** shows backwater that was added beyond the limits of the hydraulic model. **Figure 3-5** shows an example of backwater that required additional area because the water surface elevations extend upstream beyond the upstream limits of most models.

Figure 3-4: Post Processed Floodplain



The post processing of floodplains adds backwater areas along a modeled reach that would be flooded but were not reflected in the hydraulic model; typically; these occur as small tributaries join a larger reach.

Figure 3-5: Post Processed Floodplain



The post processing of floodplains also adds backwater areas upstream of the hydraulic model; these areas have the projected water surface from the most upstream cross section.

For locations where the models overlap (e.g. at confluences), the highest water surface elevation across all models dominated and resulted in the largest delineated floodplain by definition.

Dams and reservoirs were accounted for by simply placing a model cross-section along the upstream face of the dam at the same elevation as the emergency spillway.

Special consideration was provided to eliminate the crossing profiles for only the 1-percent and 0.2-percent annual chance events.

3.1.5 1-Percent Riverine Floodplain Product Limitations / Assumptions

The 1-percent data produced by this effort should provide a useful resource in support of residential areas subject to riverine hazards within the 1-percent floodplain. The data were subject to internal team and independent review to identify and correct issues and ensure overall product quality. The product is subject to the following limitations/assumptions due to inherent error in the data resources and the production approach:

1. Hydrologic Analyses

   - The recording of the peak discharges at stream gages was interrupted by gage failures during Hurricanes Irma and Maria. USGS is currently working to develop estimates using all available data. Once the USGS estimates are published, the stream gage analyses may produce different results than those estimated by this study.
   - The peak flows estimated for 1-percent chance event (and those of more frequent events) did not use the effective 1999 USGS regression equation. However, the 1979 regression equation estimates compared well with the statistically derived peak flows at stream gage locations.
   - Impact of storage was not considered for un-gaged stream reaches downstream of regulated and unregulated dams. The peak flows estimated for these reaches are likely to be larger when compared with the estimates that reflect flow regulation and storage.
   - Weighting of the stream gage analysis result with the regression estimate was conducted using a procedure developed for this study. The procedure recommended by the USGS in the 1999 regression equation report did not provide reliable results.

2. Hydraulic Analyses

   - Underwater cross sections are not based on ground survey. This may result in the channel invert of the stream to be at a higher elevation.
   - Channel bank stations were set at the outer limit of cross sections. The high flow channel is not identified in the cross section geometry used by the hydraulic model. However, significant adverse effects of this assumption is mitigated to some extent by the use of single composite Manning's roughness coefficient.
   - Ineffective flow modeling is generally not incorporated and/ or refined.
   - Floodplains extend landward beyond all levees; Levees are not modeled as features restricting the flow to stay within the river or as providing protection.
   - Split flows were not modeled separately.
   - Structure modeling:
     - Only hydraulic structures included in the NBI are reflected in hydraulic models
     - Impact of these structures on floodplain was modeled without any surveyed data.

3. Floodplain Delineation, Flood Elevation Labeling, and Tie-in with Coastal Floodplain

   - FIRM-type Base Flood Elevations were not developed. Modeled cross sections were clipped to the floodplain boundary extents wherever possible, and used as proxies to represent the water surface elevations.
   - Minimal cleanup of floodplain mapping was performed based on visual inspection.

3.2 Coastal Advisory Data Development

Final coastal advisory data development deliverables include:

1. A GIS line shapefile representing the 1-percent annual chance boundary delineated with the new USGS 2017 LiDAR, as well as GIS polygons covering the 1-percent annual chance floodplain. These products will also be accompanied by a new 1-percent Total Stillwater Elevation ("SWEL") raster that includes wave setup.

2. A GIS line shapefile representing the Limit of Moderate Wave Action ("LiMWA") as well as a GIS polygon shapefile identifying the "Coastal A" zone or Moderate Wave Action ("MoWA") area for both the 1-percent and 0.2-percent flood levels. Accompanying these will be a GIS point shapefile showing the locations of the LiMWA from the Wave Height Analysis for Flood Insurance Studies ("WHAFIS") model output.

3. A GIS polygon shapefile that provides digital cartography for whole-foot levels with zone delineations and floodplain boundaries for the 0.2-percent wave hazard.

4. A GIS polygon shapefile identifying areas subject to 30- and 60-year erosion. GIS polyline shapefile of erosion analysis transects attributed with long-term shoreline change rates and assessed error.

5. GIS polygon shapefiles representing the storm-induced erosion, including areas identified from the erosion analysis supporting the 1-percent and 2-percent wave hazard modeling as well as the visual analysis of the post-storm imagery.

These products are intended for digital delivery and dissemination for desktop GIS and/or Web-GIS platforms. The following sections provide information on data sources and limitations, production procedures, and guidance on usability for each of the coastal advisory data deliverables.

3.2.1 Terrain Processing

The updated flood hazard analysis modeling in this study was based on newly acquired high resolution topographic Light Detection and Ranging (LIDAR) data. This data was transformed into the project coordinate system and then combined with the bathymetric data from the existing study. A newly updated seamless topobathy DEM surface, to be used as the basis of the subsequent flood hazard modeling and mapping, was created.

3.2.1.1 Coordinate Systems and Unit Conversions

The two data sources used for the updated seamless topobathy DEM were the existing study topobathy DEM and new 2017 USGS topographic LIDAR data. Neither of these data sources were provided in the project coordinate system, units, and resolution. Therefore, the data sources were re-projected, re-sampled, and converted into the target coordinate systems and units. Coordinate system re-projections were carried out using the ESRI Project Raster tool, while conversions from meters to feet were performed using the standard definition of 1 meter being equal to exactly 3.28084 feet. The specifics of the source data and target coordinate systems and units can be seen in **Table 3-6**.

Table 3-6: Resolution, Vertical Datum, and Coordinate Systems Associated with Each Data Source and Final Topobathy DEM

Raster Data	Resolution	Vertical Datum	Coordinate System
Existing Study	25 feet	feet, LMSL	NAD_1983_StatePlane_Puerto_Rico_Virgin_Islands_FIP_5200_feet
2017 USGS LiDAR	1 meter	meters, PRVD02	NAD_1983_StatePlane_Puerto_Rico_Virgin_Islands_FIP_5200_feet
Updated Project DEM	10 feet	feet, PRVD02	NAD_1983_StatePlane_Puerto_Rico_Virgin_Islands_FIP_5200_feet

3.2.1.1.1 Conversion Surface Creation

In order to convert the existing study data from a Local Mean Sea Level (LMSL) vertical datum to PRVD02, a raster conversion surface covering the entire study area was created using the NOAA software, VDATUM. The process through which this surface was created is described below.

The first step in the process was to create a polygon shapefile mask covering the study. This mask was given an attribute “MSL” with a value of 0. The polygon mask was then converted to a raster GeoTIFF with a uniform value of 0 from the “MSL” attribute and with a cell size of 300 feet. The GeoTIFF raster was then re-projected from the project coordinate system, to WGS84, and converted to an ASCII raster in order to work with the VDATUM software.

The uniform ASCII raster file was then converted from LMSL to PRVD02 by the VDATUM software. This resulted in an ASCII raster conversion surface which could be used to convert vertical data from units of feet above LMSL, to feet PRVD02 by simply adding the conversion raster to the raster data file in feet above LMSL. The newly created conversion surface was then converted from WGS84 to Puerto Rico State Plane coordinates and from ASCII raster format to GeoTIFF.

Although a conversion from LMSL to PRVD02 was required for the entire inland areas of Puerto Rico, Vieques, and Culebra, this conversion did not actually exist for all of the inland areas. In order to convert data between the two vertical datums in areas where a standard conversion is non-existent, the existing conversion data was interpolated across these areas using an IDW interpolation. In order to accomplish this, the GeoTIFF raster file in Puerto Rico State Plane coordinates was converted to points. These points were then used with the ArcGIS IDW tool to create a raster conversion raster file with full coverage of the study area. This surface was subjected to a Quality Control Check (QC) and once found acceptable used for all vertical datum transformations in the rest of the study data.

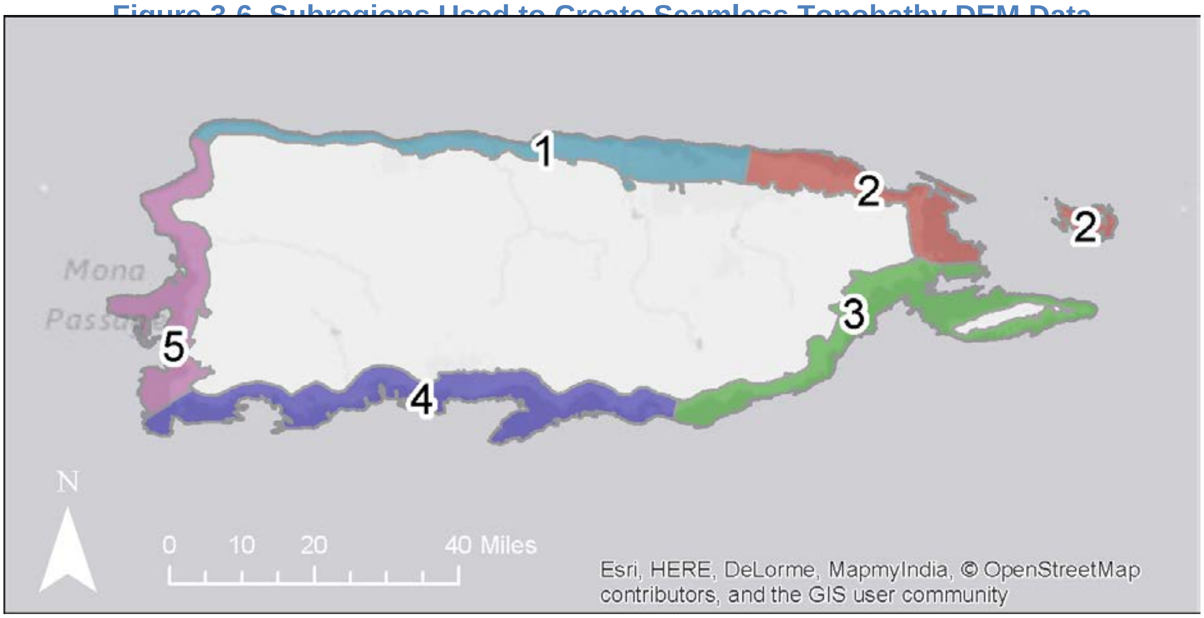
3.2.1.2 Shoreline Delineation

A new 0 foot PRVD02 shoreline was delineated in order to clip the new topographic LiDAR data. The ArcGIS Contour List tool was used to extract a 0 foot PRVD02 shoreline. This shoreline was then visually inspected, disconnected contours were removed, and overly complex sections of shoreline were manually redrawn. The edited shoreline was smoothed at a 20 foot tolerance using the PAEK algorithm in the ArcGIS Smooth Polyline tool. The smoothed shoreline was simplified at a 5 foot tolerance using the ArcGIS Simplify Geometry tool. This shoreline then went through internal QC and any revisions, if needed, were made.

3.2.1.3 Data Masks

The existing study seamless topobathy DEM is broken up into five subregions (see **Figure 3-6**) including the Islands of Puerto Rico, Vieques, and Culebra. These five separate topobathy DEMs were converted to polygons, using the ArcGIS raster to polygon tool, to create masks for extracting updated topographic data. The full topobathy mask for each region was then split into separate topographic and bathymetric data masks using the newly delineated 0 foot PRVD02 shoreline. The new 2017 USGS topographic LiDAR data was clipped to the topographic mask for each region, while the existing study data was clipped using the bathymetric masks.

Figure 3-6 Subregions Used to Create Seamless Topobathy DEM Data



Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

3.2.1.4 Bathy Terrain

The bathymetric data was converted to a terrain in order to ensure a smooth transition between the new 2017 USGS topographic LiDAR data and the existing bathymetric data. This was done by first converting the clipped bathymetric raster data to points. All points with positive elevations near the shoreline that were not attributable to exposed rocks or other geomorphic features visible in aerial imagery were removed. The remaining points for each region were then imported into an ESRI File Geodatabase along with the bathymetric data mask for that region and the new shoreline, which was used as a hard break-line with an elevation of 0-feet PRVD02. A new bathymetric terrain was built using this data and then reviewed through an internal QC process. If any erroneous data points were found during the QC process, such as points representing unrealistically deep data, they were individually removed from the set of bathymetric points and the terrain was rebuilt. The final ESRI Terrain was converted to an ESRI floating point raster in the project coordinate system.

3.2.1.5 Mosaicked Topobathy DEM

The final step in the seamless topobathy DEM creation process was to combine the topographic and bathymetric data rasters into a single raster file using the ESRI Mosaic to New Raster tool. This combined, seamless, topobathy raster file was then reviewed through an internal QC process. If any discontinuities or quality issues were found in the data, the source of each issue was addressed and the updated surface reviewed once more. The final seamless topobathy DEM for each region was saved in raster GeoTIFF format.

3.2.2 Redelineation of the 1-Percent Annual Chance Floodplain Boundary

The effective analysis did not include the current practice of performing 2D wave modeling along with the surge analysis. As a result, wave setup was only calculated at each transect using the USACE's Shore Protection Manual formula. This means that the 1-percent SWEL raster developed for the previous study did not include wave setup and could not be used to create a floodplain boundary directly. The following sections describe the production procedure for developing the new 1-percent SWEL raster including wave setup, the updated 1-percent annual chance floodplain boundary, and floodplain polygons.

3.2.2.1 Wave Setup Extraction

Wave setup associated with the 1-percent level was extracted from the previous WHAFIS modeling at each transect through the following process:

1. A script was used to extract the total 1-percent SWEL elevations (including wave setup) from the effective WHAFIS modeling output files (WHAFIS PART 4). Transects from the effective modeling PDGB were used as an input to the script. The tool output was a transect station shapefile with the total 1-percent level value at each station.

2. Extract Values to Points was used to extract the 1-percent stillwater elevation ("SWEL") (not including wave setup) from the original study SWEL rasters to each point in the station shapefile.

3. The wave setup component at each transect station was calculated by taking the difference between the total SWEL 1-percent level from the WHAFIS files and the 1-percent SWEL values from the original study SWEL rasters. Note that the wave setup value is datumless, since both the original total 1-percent level and the 1-percent SWEL are both referenced to feet above MSL.

4. For transects where surge stays constant across the transect, as indicated by no data in the WHAFIS text output files (WHAFIS PART 4), the wave setup value documented in the effective study FIS (See Table 7 in the effective FIS) was assumed to remain constant

across the length of the transect. A point was added to the station shapefile at the zero station (shoreline) with the correct wave setup value.

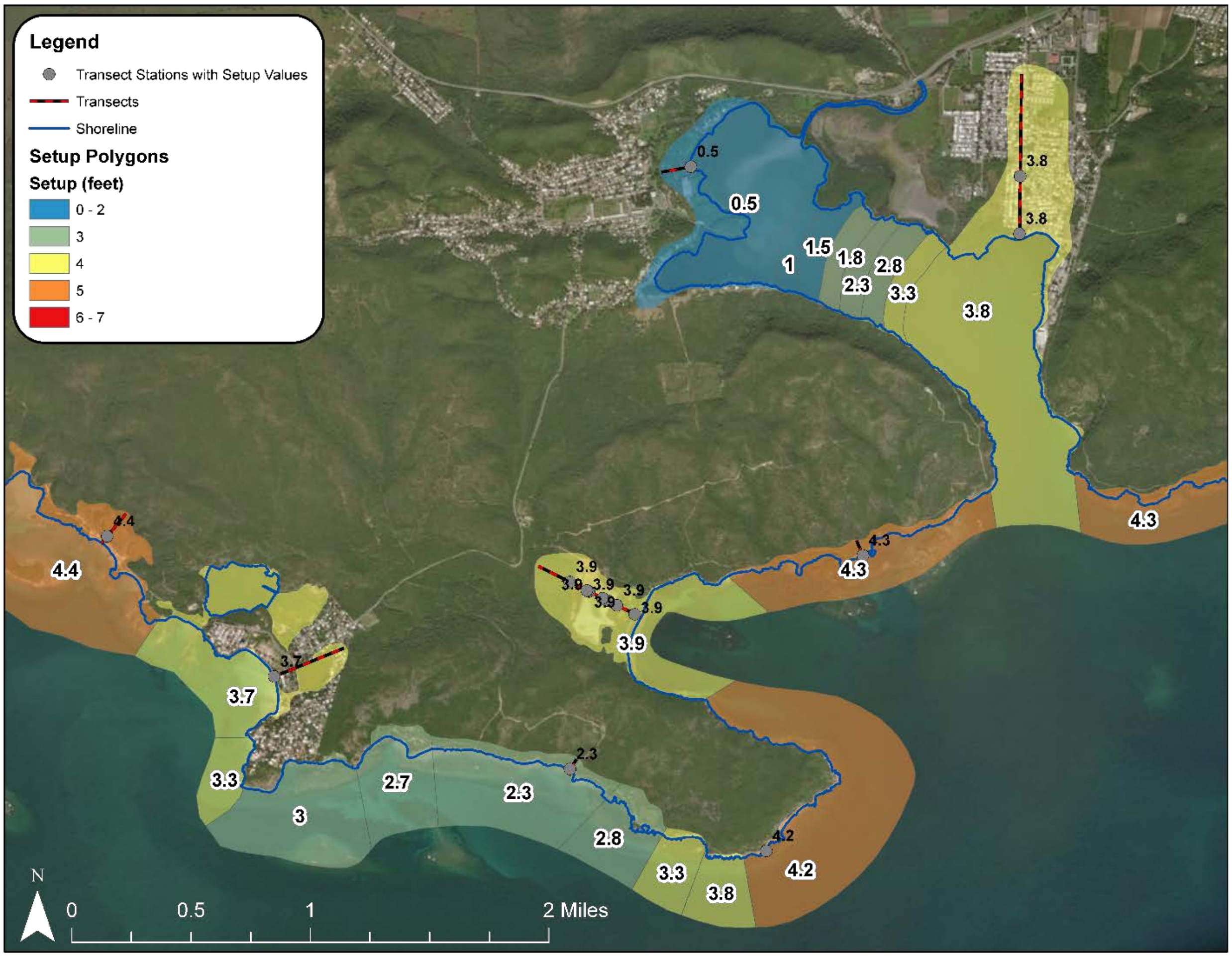
5. There were several transects with very small negative values oscillating around zero toward the landward extent of the transect. These negative values were converted with the assumption that wave setup was completely reduced by that point inland. There were also several transects that showed small oscillations or even slight regeneration over land. These values were also converted to zero landward of the initial wave setup reduction, since wave setup is an open ocean process and should not be regenerated over land. The small oscillations in the WHAFIS calculations were likely residuals from rounding and raster interpolation.

3.2.2.2 Interpolation and Setup Surface

Wave Setup values at the transect stations were manually interpolated between transects as was originally done in the effective coastal analysis. The effective flood hazard polygons and their associated BFEs were used as the basis for the interpolation since these zones already reflected the original analysts' interpretation of wave setup transitions between the transects. Topographic contours at a 2-foot interval used in conjunction with the effective zone breaks and BFEs were used as a guide to adjust a polygon coverage for wave setup values. Boundaries were established to follow wave setup differences between adjacent transects and reflect the inland extent of wave setup. Transition zones were added to ensure differences between adjacent wave setup polygons varied by less than ½ foot. An aerial basemap was also used to guide the interpolation to ensure that land use and vegetation were considered. **Figure 3-7** shows the wave setup polygons in an example area.

The wave setup polygon was converted to a raster (25-foot cell size) and then to points. An Inverse Distance Weighting (IDW) interpolation was used to interpolate the setup points to match the extent of the effective SWEL surface. This was done to ensure the new 1-percent annual chance floodplain boundary was not cut off too soon inland. The interpolation was confined to a polygon that represented stretches of advisory shoreline.

Figure 3-7: Wave Setup Interpolation Polygon



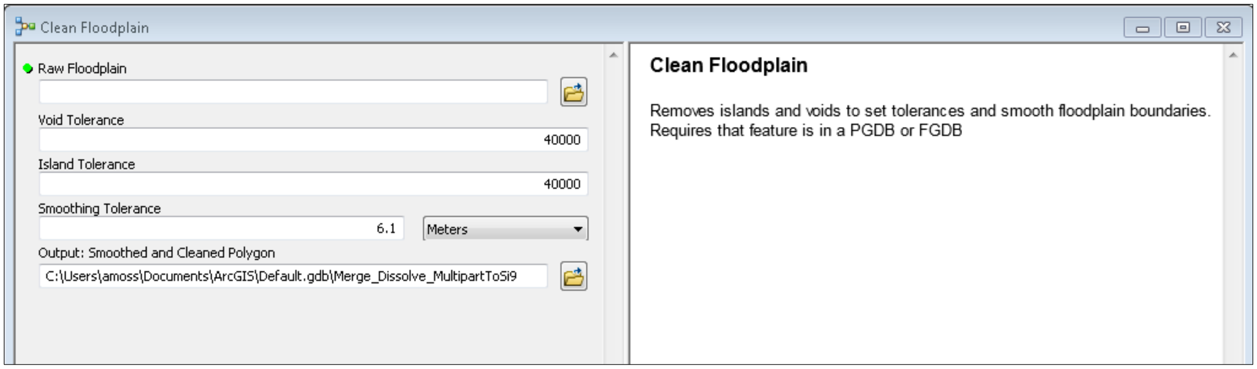
3.2.2.3 New Total SWEL Raster

The original 1-percent SWEL surface was converted from MSL to PRVD02 using the conversion surface created for this project using NOAA's VDATUM tool. The wave setup surface was added to the original 1-percent SWEL surface (PRVD02) to derive a new total 1-percent SWEL raster that included wave setup.

3.2.2.4 Floodplain Creation

The new total SWEL raster was intersected with the 2017 USGS LiDAR to create a new 1-percent annual chance floodplain boundary and polygon. A floodplain cleaning tool was used on the raw floodplain to remove islands and voids and smooth floodplain boundaries. Tolerances used in the tool are shown in **Figure 3-8**.

Figure 3-8: Floodplain Cleaning Tool



Raw Floodplain

Void Tolerance
40000

Island Tolerance
40000

Smoothing Tolerance
6.1 Meters

Output: Smoothed and Cleaned Polygon
C:\Users\amoss\Documents\ArcGIS\Default.gdb\Merge_Dissolve_MultipartToSi9

Clean Floodplain

Removes islands and voids to set tolerances and smooth floodplain boundaries. Requires that feature is in a PGDB or FGDB

3.2.2.5 1-Percent Floodplain Product Limitations/Assumptions

The 1-percent products produced by this effort should provide a useful resource in support of residential areas subject to coastal hazards within the 1-percent floodplain. The data were subject to internal team and independent review to identify and correct issues and ensure overall product quality. The product was subject to the following limitations/assumptions due to inherent error in the data resources and the production approach:

1. In order to keep a 1-percent boundary product that was as continuous as possible (without small sections with gaps in between), it was necessary to generate a continuous SWEL delineation across/between WHAFIS controlled zones.

    - For shorelines with very large stretches of Runup, the 1-percent total SWEL floodplain boundary was removed.

    - In some areas, where dune removal erosion was applied in the effective study and the updated mapping polygon was not connected to the flooding behind a ridge, there were gaps in the new floodplain. These gaps had to be filled, assuming the dune ridge would erode as was applied in the effective study. In areas where the updated topographic information showed a high ridge or dune feature with high elevations that would prevent water from passing, the gaps in the floodplain were left in. Many of these types of areas are shown in the effective as retreat erosion cases. For the final product, the effective will be merged with the new 1-percent boundary so that areas where the floodplain was extended to the landward limit of the primary frontal dune will be filled in as it is shown in the effective mapping.

2. The 1-percent boundary may not always follow the SWEL + wave setup value indicated by the effective study mapping notes or modeling results.

    - The scope of this product did not include wave setup reduction calculations, therefore the following assumptions were used:

    - Where the new 1-percent floodplain boundary increased, the wave setup value at the landward limit of the modeling transect would continue to the extent of the new 1-percent floodplain.
    - For areas where the effective mapping notes indicated delineation without wave setup, the original SWEL without wave setup was used.

3. Because the effective 1-percent boundary was used to delineate 1-percent LiMWA product, there are times where it is shown outside of the updated 1-percent boundary.

    - In order to alleviate this, the effective 1-percent boundary was used in the merged product for areas where the updated 1-percent boundary has been reduced. This eliminated any areas of overlaps and crossovers of the LiMWA and the 1-percent boundary for the final product.

3.2.3 LiMWA Mapping

The LiMWA was mapped in accordance with the WHAFIS Part 2 modeling results from the effective 1-percent coastal overland modeling output and the new 0.2-percent coastal overland modeling output. The LIMWA mapping methodology was in accordance with Operating Guidance No. 13-13 (FEMA 2013b).

The study team used the effective 1-percent coastal overland modeling data and new 0.2-percent coastal modeling results to generate fully model-derived 1-percent and 0.2-percent LiMWA lines and “Coastal A” zone polygons. The 1-percent LiMWA line represented the location where coastal wave heights equaled 1.5 feet under base flood condition. The 0.2-percent LiMWA represented the location where coastal wave heights equaled 1.5 feet under the 0.2-percent recurrence condition. The effective study performed the overland wave propagation analysis using WHAFIS at each transect. The 0.2-percent overland wave modeling was performed using WHAFIS on the effective FIS transects. These modeling results were used to delineate 1-percent and 0.2-percent LiMWA lines, respectively, through the following process:

1. A script was developed to identify the locations where wave heights equaled 1.5 feet along each WHAFIS transect. The script used the transect station (point) shapefile as the input, and exacted wave height from the WHAFIS model results at each station. The locations where wave heights equaled 1.5 feet were found by linear interpolation between adjacent stations with wave heights that bound 1.5 feet. The tool output is a point shapefile that contained 1.5 foot wave height locations with ground elevation, wave height, and wave crest elevations as the attributes.

2. Along each study transect, the location with 1.5 foot wave heights immediately landward of the effective VE zone was selected as the LiMWA location per FEMA Guidance for Flood Risk Analysis and Mapping – Coastal Floodplain Mapping (FEMA, 2015). A line that followed the contour of the ground elevation at the location with 1.5 feet wave height was used as a guide to delineate the LiMWA line between the transects, as well as the zone mapping and the land use characteristics. Areas without modeling transects were inferred from adjacent areas with similar shoreline features and ground elevation.

3. Laterally, the 1-percent and 0.2-percent LiMWA lines were tied to the boundary of the floodplain or Runup/PFD VE zone.

Once LiMWA lines were delineated, “Coastal A” zone polygons associated with 1-percent LiMWA line were generated with the following steps:

1. AE zone polygons from the effective map database were selected and merged in GIS using the merge analysis.
2. Polygons without a LiMWA line inside were identified and checked to determine if the LiMWA line was either missing or intentionally omitted because the area did not support LiMWA line delineation.
3. The remaining polygons were split by the LiMWA lines, and the landward portion from the LiMWA lines were deleted, which resulted in the “Coastal A” zone polygon.

3.2.4 0.2-Percent Coastal Modeling and Mapping

Overland wave height analysis was conducted and applied to the effective FIS modeling transects to generate 0.2-percent annual chance ABFEs. The methodologies used for the 0.2-pecent modeling followed closely to the methodologies used in the effective 1-percent modeling to maintain consistency between the 1-percent and 0.2-percent mapping. This was done using the Wave Height Analysis for Flood Insurance Studies (“WHAFIS”) model. The WHAFIS model was incorporated into the Coastal Hazard Analysis Modeling Program (“CHAMP”), and the model input and output is contained in a CHAMP database format.

A FIRM-like floodplain polygon layer, covering areas with overland flooding only, with flood extent and ABFEs was generated using standard FIS modeling and mapping procedures. Flood hazard mapping was completed and attributed with 0.2-percent ABFEs from WHAFIS model outputs. The production procedure was comprised of multiple tasks, which are explained in the following sections.

3.2.4.1 0.2-Percent Starting Wave Conditions

Offshore wave characteristics representing a 0.2-percent annual chance storm were developed using the Shore Protection Manual (USACE, 1984) equations (equations 3-59 and 3-60) for slowly moving hurricanes in a similar manor that was done in the effective study. The variables required for these equations were hurricane central pressure P_O, radius of maximum wind R and forward speed V_F for each storm. Their values were obtained from the Hurricane Database (“HURDAT”) developed by NOAA (P_O is from HURDAT directly; V_F is computed using spatial change of HURDAT data points given every 6 hours; R is calculated using wind speed and latitude value of HURDAT data points).

A total of 37 storms (**Table 3-7**) were selected from HURDAT to represent the range of different storm magnitudes impacting the study area. Storms were selected using the following criteria: The event must have passed within a 250 mile radius of Puerto Rico; the duration of the storm within this radius must have been longer than 6 hours (so there would be at least two data points in HURDAT for this storm in order to calculate the forward speed); and been classified as a category 1-5 hurricane that may have caused damage to the island.

Table 3-7: List of Hurricanes Selected for Offshore Starting Wave Condition Calculation

Name of Storm	Year	Name of Storm	Year
UNNAMED_1867	1867	EDITH	1963
UNNAMED_1871	1871	FLORA	1963
UNNAMED_1876	1876	CLEO	1964
UNNAMED_1899	1899	INEZ	1966
UNNAMED_1921	1921	FAITH	1966
UNNAMED_1924	1924	BEULAH	1967
UNNAMED_1928	1928	DAVID	1979
UNNAMED_1931	1931	HUGO	1989
UNNAMED_1932	1932	MARILYN	1995
DOG	1950	BERTHA	1996
BAKER	1950	HORTENSE	1996
CHARLIE	1951	GEORGES	1998
CAROL	1953	LENNY	1999
CONNIE	1955	DEBBY	2000
BETSY	1956	JEANNE	2004
ELLA	1958	OMAR	2008
FIFI	1958	EARL	2010
ABBY	1960	IRENE	2011
DONNA	1960		

Summary statistics for their forward velocity, radius to maximum wind, and central pressure were calculated to create a range of variable combinations. For all the combinations and for each variable, offshore wave parameters were computed with this range. After performing statistical analysis on these results, a lognormal distribution was selected to predict the return periods of wave parameters (details of the methodology and program to calculate the wave condition statistics are supplied in the technical analysis files). This methodology provided the following values:

Deepwater Significant Wave Height = 31.54 feet;
Deepwater Significant Wave Period = 12.01 seconds

For harbors and other land-sheltered areas, a limited fetch analysis was performed using ACES's Wave Prediction Technique to determine the starting wave conditions for the associated transects and wave parameters. **Table 3-8** lists the starting wave conditions for the transects with limited fetches.

Table 3-8: Offshore Starting Wave Condition for Transects with Limited Fetch

Transect No.	Fetch Length (mi)	Wave Height (ft)	Wave Period (sec)	Wave Breaking Depth (ft)
44	2.47	5.81	3.75	7.4
45	3.87	7.27	4.36	9.3
46	3.63	7.04	4.27	9.0
47	2.07	5.32	3.54	6.8
48	2.17	5.44	3.60	7.0
49	1.61	4.69	3.26	6.0
180	3.81	7.21	4.34	9.2
194	1.6	4.67	3.25	6.0

3.2.4.2 0.2-Percent Wave Setup Calculations

The Puerto Rico islands, due to their high cliffs and exposure to ocean waves, are subject to larger waves than eastern Atlantic coasts, and nearshore wave-induced processes (such as wave Runup and wave setup) constitute a greater part of the combined wave envelope than storm surge.

For this particular environment, wave setup on an open coast was calculated following the Atlantic Ocean and Gulf of Mexico Draft Coastal Guideline (FEMA, 2006). The guidelines established the Direct Integrated Method (DIM) to be utilized to determine static wave setup along the coastline.

The variables required for this calculation were deepwater significant wave height, wavelength, and the profile slope. The slope was determined from the location of the breaking depth of deepwater significant wave height, or of the limited-fetch significant wave height, to an onshore elevation defined by the 0.2-percent SWEL.

For coastal areas protected by reefs, a localized variation in wave setup values was induced. A modified wave setup approach was applied in those locations where reefs extended above the breaking depth of incident wave height. The method proposed for the determination of wave setup on reefs was based on the methodology outlined by Gourlay M.R. (1996) titled: "Wave set-up on coral reef 2. Set-up on reefs with various profiles", Coastal Engineering Journal, Vol. 28. Figure 12 of the above-mentioned paper used two curves to determine wave setup on reefs. Curve A was suggested for reefs where the water, pumped through the setup process, escaped over the leeward edge of the reef. Curve B was suggested for reefs where the absence of a channel allowed the water to pile on shore and eventually flow back over the seaward edge of the reef.

The variables required for this reef wave setup calculation were deepwater wave conditions (the paper suggests for irregular waves to substitute H_o - deepwater wave height with H_{orms} - deepwater room mean square wave height) and the reef submergence (reef depth + 0.2-percent SWEL). The computation assumed a known wave setup value, since the wave setup variable appeared in both parameters on the graph (Curve A or B). An iterative solution was required until convergence of the two parameters was reached.

If the reef plateaus to the mainland (Curve B), waves would dissipate the majority of their energy through wave breaking at the reef crest where the maximum wave setup would occur.

For instances where the reef was detached from the mainland through a deep channel (Curve A), waves would not only break on the reef, but would be transmitted, regenerated, and eventually broken onshore at a depth related to the maximum wave height capable of traveling above the reef. In this situation the computation of a second wave set-up component was required. The significant wave height (capable of traveling in a water depth described as the reef crest depth + 0.2-percent SWEL) and described in terms of deep water would be used to graph a new setup curve following the DIM Method. The wave setup value on shore would be determined by entering the curve with a slope value measured between the breaking depth of the wave traveling onshore past the reef and an inland elevation defined by the 0.2-percent SWEL + the wave setup on the reef previously determined. The final wave setup value, associated to that particular profile, would be given by the sum of the wave setup on the reef and the wave setup onshore.

Wave setup values for all transects are listed in **Appendix D.**

Note that not all transects listed in **Appendix D** were used to model the 0.2-percent event with WHAFIS.

3.2.4.3 New Total 0.2-Percent SWEL Surface

As with the 1-percent wave setup values, the 0.2-percent wave setup values needed to be interpolated between the transect locations. The wave setup polygons developed for the 1-percent SWEL surface were used as a starting point to ensure consistency between interpolation techniques for the 1-percent and 0.2-percent wave setup surfaces. The polygons were updated for the 0.2-percent wave setup calculations calculated by the advisory effort at the transect locations. Next, values were transitioned between the transects in a consistent manner as the 1-percent surface. Additional transition zones were added, where needed, to ensure differences between adjacent wave setup polygons varied by less than ½ foot.

The effective study 0.2-percent SWEL surface was clipped to an extent terminating just beyond the effective coastal flood hazard area. To ensure the new SWEL surface extended far enough inland to capture potentially expanded 0.2-percent floodplain areas, the original 1-percent SWEL surface was interpolated to match the extent of the effective 1-percent SWEL surface (between 1-3 miles inland from the shoreline). The interpolated 0.2-percent surface was then converted from MSL to PRVD02 using the conversion surface created for this project using NOAA's VDATUM tool.

The 0.2-percent wave setup polygons were converted to a raster (25 foot cell size) and then to a point coverage. An IDW interpolation was used to interpolate the wave setup points to match the extent of the extended 0.2-percent SWEL surface (described above). The wave setup surface was added to the original (extended) 0.2-percent SWEL surface to derive a new total SWEL raster including wave setup.

3.2.4.4 0.2-Percent Storm Erosion Analysis

Erosion assessments were undertaken in order to determine beach erosion during a 0.2-percent hurricane along the coastline of Puerto Rico. Sandy beaches characterized by dunes, were analyzed to determine the Primary Frontal Dune ("PFD") feature using standard FEMA methodology. A recent procedure memorandum from FEMA superseded the original guidance on the input water surface elevation. Operating Guidance No. 15-13 states that the total stillwater (surge + wave setup) should be used in dune erosion models (FEMA 2013d). FEMA's standard erosion methodology allows the dune cross-sectional area to be evaluated against a 1030-square foot criteria for the 0.2-percent flood level. If the frontal dune reservoir was less than 1030 square feet in cross-sectional area, the feature would be removed from the profile, known as dune removal; if the dune cross-sectional area was greater than 1030 square feet, the feature would have 1030 square feet of the dune eroded, known as dune retreat.

A non-standard erosion methodology was also applied to determine beach erosion in sandy beaches characterized by a veneer of sand overlaying rocky ledges. Through examination of pre- and post-storm photographs, it has been determined that a portion of this sand veneer (0.3-1 meter) was removed by wave action to expose the rocky ledge beneath. This assumption was verified by review of available literature during the effective study such as, Hubbard (1991), conversations with specialists in the field (Dr. Dennis Hubbard, November, 4, 2002), and site investigation (August, 2002). The assumption was further verified by comparing the pre- and post-Maria imagery. **Appendix E** provides details of the non-standard erosion methodology applied to each transect in the study area.

3.2.4.5 Obstruction Review and Update

Land use information from the effective Puerto Rico Flood insurance study was used to create parameters for obstructions and open-fetch areas for the overland wave propagation modeling using WHAFIS. The approach was to review the obstruction polygons in a GIS environment to consistently code representative land cover. Obstruction carding was added in areas where the WHAFIS transects were extended to encompass the 0.2 percent annual-chance floodplain. This land use data included representative values for the vegetation and building parameters that was verified along the existing overland wave modeling transects through field reconnaissance that occurred during the effective flood insurance study and/or was interpreted from aerial imagery where field reconnaissance data was not available. Areas where land use appeared to change significantly since the effective study were updated to represent current conditions.

Transects originating along any open coast shoreline of Puerto Rico were coded as ("OF") to reflect the default WHAFIS wind speed of 100 mph for wave growth for the 0.2-percent event. The OF card was maintained except in building ("BU"), vegetation ("VE"), or marsh ("VH") obstruction areas or areas where the ground topography exceeded the total still water elevation (0.2-percent surge plus wave setup) resulting in an above surge (AS) card. OF cards were used to represent areas directly exposed to high winds coming onshore, where wind wave regeneration would not be impeded. Puerto Rico's coastal floodplain had direct exposure to high winds coming off the Caribbean Sea and the Atlantic Ocean from tropical storms. Every Puerto Rico study transect originated from the Caribbean or Atlantic shoreline or from an exposed coastal embayment. Consequently, no wind sheltered areas were identified, warranting use of IF (75 mph wind) cards.

3.2.4.5.1 Buildings

In addition to the information collected during field reconnaissance, imagery was used for obtaining building obstruction information for the coastal WHAFIS modeling. These data sources were used to digitize polygons around areas of relatively uniform building density. Building to open space ratio (open space in feet/total length in feet) and number of building rows were obtained primarily from aerial imagery and notes from the field during the reconnaissance completed during the effective coastal flood hazard study. The presence of elevated structures was reviewed for 0.2-percent modeling along the Puerto Rico shoreline. The treatment of elevated structures in overland modeling is based on their foundation. If the structure was elevated on open foundation (piles, piers m columns, etc.), it was removed from the obstructions and treated as open space since the open foundation allowed wave passing underneath the structure unobstructed; if the structure was elevated on closed foundation (fill, crawlspace, stem wall, etc.), it was treated as an obstruction. Although there were structures that were found to be elevated it was determined (after review of effective field recon notes and Google street view) that the majority of homes along the open coast do not contain continuous elevated structures or where structures were elevated they have significant enclosures (non-breakaway) at ground level and therefore were treated as obstructions within the WHAFIS model.

3.2.4.5.2 Vegetation and Marsh

In locations where rigid vegetation was present, polygons were attributed using various combinations of the height, diameter, and spacing parameters for vegetation areas (VE cards), mainly taken from the effective field reconnaissance notes and pictures. Mangrove height, diameter, and spacing parameters were recorded during field reconnaissance phase. Those parameters were added to the VE cards to ensure the mangroves were captured in the wave modeling. The primary region used for VH cards was the South Florida region and the primary marsh type was medium saltmeadow cordgrass. Marsh grass parameters were noted during the field reconnaissance and matched closely with the default values provided by the WHAFIS model, therefore the defaults were used in the VH/MG cards in WHAFIS.

3.2.4.6 0.2-Percent WHAFIS Modeling

General guidance provided by FEMA G&S, specifically related to overland wave propagation, was used to calculate overland wave heights.

Overland wave height analysis was conducted with the WHAFIS model. The WHAFIS model was incorporated into the Coastal Hazard Analysis Modeling Program (“CHAMP”), and the model input and output is contained in a CHAMP database format.

The digital CHAMP database and related WHAFIS input/output digital files are available as part of the submittal.

3.2.4.7 WHAFIS Zone Stationing Extraction

The WHAFIS output defines the zone designation and wave height transformation along each transect. The WHAFIS output was provided as stationing along each transect; these data points were converted to geographic coordinates so they could be used with GIS software. These extracted station points were used to delineate the coastal flood zones and ABFEs (described in the section below).

The 0.2-percent annual chance floodplain boundary was generated using GIS utilities to find the intersection of the SWEL raster surface with the topography. The resulting floodplain boundary was smoothed to create a cleaner line without the noise associated with the fine-resolution topography data. The boundary was then edited to remove low-lying areas that were not hydraulically connected to the areas of coastal flooding and to remove above-surge features too small for the map scale.

3.2.4.8 0.2-Percent Flood Zones

Coastal ABFEs were based on a combination of the 0.2-percent annual chance SWEL including wave setup and the wave crests from the WHAFIS modeling.

Coastal flood zones and ABFEs were separated by drawing gutter lines delineating the interpolation of the output elevation points between transects and are based on ground elevation, surge surface changes, and land use.

Areas flooded by the 0.2-percent annual chance-event were mapped in one of two zones: VE or AE. Zone VE (high velocity zone) represented areas where the controlling wave height is greater than or equal to 3 feet. The elevation of the wave crest relative to the total SWEL was 70-percent of the controlling wave height. Consequently, in Zone VE, the ABFE was at least 2.1 feet higher than the total SWEL. Zone AE represents areas where the controlling wave height is less 3 feet.

The transect baseline for the WHAFIS analyses represented the 0-foot contour referenced to PRVD02 as derived from the seamless topography/bathymetric DEM.

The WHAFIS output defined the zone designation and wave height transformation along each transect. The WHAFIS output was provided as stationing along each transect; these data points were converted to geographic coordinates so they could be used with GIS software. The zones and ABFEs were separated by drawing gutter lines delineating the interpolation of the output elevation points between transects based on ground elevation, surge surface changes, and land use.

The minimum zone width used was 70 feet, and any narrower zone would usually be merged into an adjacent zone with a higher ABFE. There is one exception to this rule; in locations where the break between Zones VE and AE would be changed by following this rule, narrow AE zones were merged with other narrow AE zones to preserve the Zone VE/AE boundary. For example, if the overland modeling produces a 20 foot-wide AE12 between a 200 foot-wide VE13 and a 150 foot-wide AE11, the AE12 were merged into the AE11 to preserve the Zone AE designation to more accurately represent the wave hazard. The Letter of Map Amendment process does not allow building owners to remove the structure from VE to AE; therefore, careful attention was paid to areas with structures, and zones as small as 25 feet wide may have been mapped to allow the proper designation at a structure location.

3.2.4.9 0.2-Percent Floodplain Product Limitations/Assumptions

The 0.2-percent product developed by this effort will provide a useful resource for identifying critical facilities subject to coastal hazards within the 0.2-percent floodplain. The data was subject to internal team and independent review, in order to identify and correct issues and ensure overall product quality. The product was subject to the following limitations/assumptions due to inherent errors in the data resources and the production approach:

1. Use of a single calculated starting deepwater wave height and wave period was used for all exposed transects following the methodology used in the effective study. The following assumptions were made:
    - The deepwater wave height was at a significant distance offshore and very little sheltering would influence it.
    - During the passage of a tropical storm, at some point during the passage, the wind direction would be such that would drive the wave onshore.
    - WHAFIS modeling was not sensitive to these deepwater wave conditions. Input as the depth at the shoreline limited the wave height propagated along the transect in WHAFIS.
2. The 0.2-percent modeling obstruction carding methodology followed the methods used in the effective study. The following may be noted in the modeling:
    - OF cards were captured during WHAFIS modeling in between BU cards in well developed areas.
    - VE cards were at times misplaced in urbanized areas. However, it was determined that the schema did not significantly affect the results or mapping.
    - Use of DU card in areas of PFD. Since the effective study did not utilize the DU card it was not used as part of this modeling for consistency.
3. Erosion methods were adopted from the effective study with the exception of increased erosion criteria from 540 square feet to 1,030 square feet, per guidelines for 0.2-percent modeling and mapping.
4. The topographic data used in the effective modeling and mapping for Puerto Rico was much less detailed than what was used to produce these advisory products. As a result, there may be discrepancies between the 1-percent and 0.2-percent mapping. Areas may be within the 1-percent Special Flood Hazard Area (“SFHA”) floodplain but outside of the 0.2-percent floodplain. The new 1-percent floodplain boundary was merged with the effective so that only increased areas of floodplain are shown. In areas where the effective 1-percent boundary, delineated on the original study topography, is further landward than the new 1-percent boundary, delineated on the new 2017 topography, it is possible that the 0.2-percent boundary, also delineated to the new 2017 topography, is seaward of the

effective 1-percent boundary. *For example,* areas that are AE within the 1-percent floodplain may be Zone X based on the 0.2-percent mapping. The 1-percent advisory data will be used to support residential areas and the 0.2-percent will be used to support critical facilities.

5. Due to the lack of densely spaced transects in the effective study (and limited to use of these transects for this product), the mapping in these areas relied heavily on topography, stillwater elevations (model based), and land use data.

6. Runup dominated areas in 0.2-percent product were not scoped to be modeled. Therefore the following method was used to map areas of 0.2% Runup (rather than leaving the areas blank).

    - Adoption of the 0.2-percent maximum wave crest elevation from the adjacent 0.2-percent modeled WHAFIS transects.
    - The boundary in the Runup areas were then mapped to the 0.2-percent wave crest elevation and the ABFE assigned this elevation as a VE zone.

3.2.5 Long-Term Shoreline Change

Long-term shoreline change was examined for Puerto Rico, Culebra, and the north shore of Vieques for a 16-year period spanning 2000-2016. The analysis leveraged LiDAR-based shoreline proxies to establish the annual rate of shoreline change, and produced projected areas subject to coastal erosion in the next 30-60 years. These products will inform recovery efforts to potential long-term coastal erosion hazards.

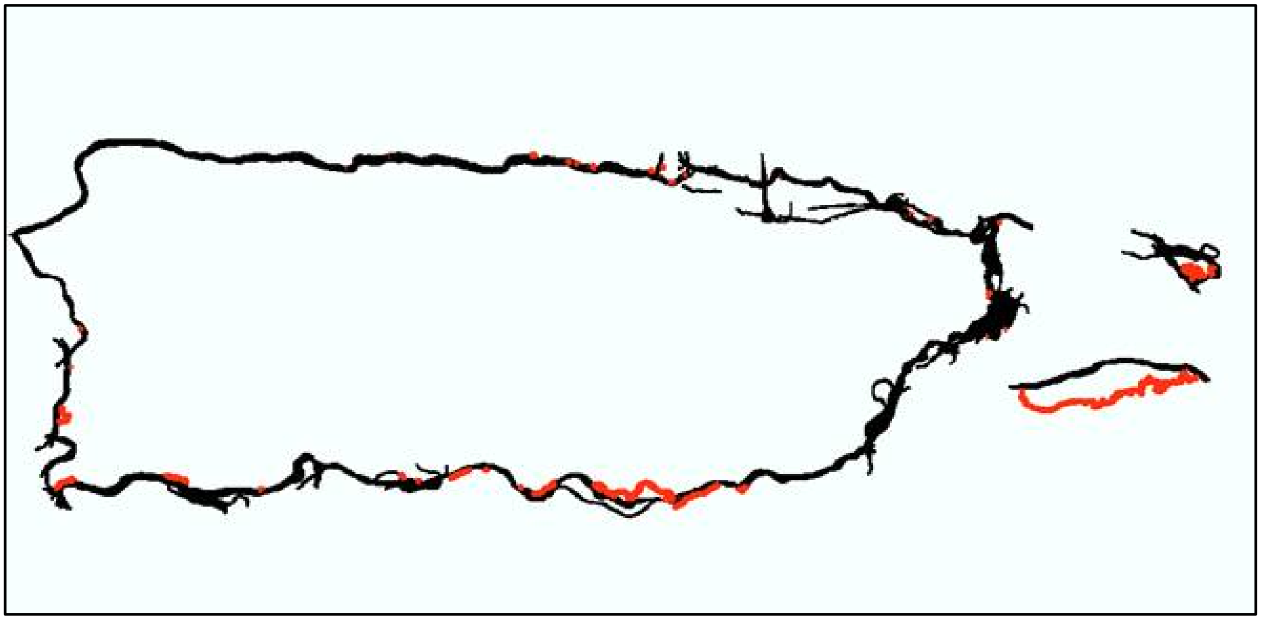
The recovery necessitated an approach that could provide reasonably accurate change rates within a 1-month production timeframe. This precluded the time-consuming collection and rectification of historical aerials and subsequent digitization of shoreline vectors. LiDAR-derived shorelines have become increasingly used for shoreline change analysis and provided an objective proxy for traditional, visually identified high water lines (Morton et al., 2004). A description of the data resources and approach for the long-term erosion analysis are provided in the following sub-sections.

3.2.5.1 Base Topography

The shoreline change analysis leveraged the 2016 USGS LiDAR topography, the base topography utilized for the advisory data, in addition to a 2000 USGS/NASA LiDAR topography. A USGS/NASA Airborne LiDAR Assessment was undertaken in December 2000 in an effort to map beach topography and coastal elevations in mainland Puerto Rico, Culebra, and Vieques. Both datasets were relative to the PRVD02 vertical datum. The coverage was limited to a swath along the shoreline for the island of Puerto Rico, Culebra, and the north shore of Vieques (**Figure 3-9**).

The 2000 USGS LiDAR was utilized over other existing data, such as the effective FIS topography, as it provided near-full coverage of the islands from a single high-quality dataset. For example, the effective FIS topography was a composite of 2003 U.S. Army Corps of Engineers topography, aerial photogrammetric topography from 1996-1998, and USGS National Elevation Data from the 1970s and 1980s.

Figure 3-9: Extent of 2000 USGS/NASA DEM (areas missing shoreline coverage are shown in red)



3.2.5.2 Shoreline Delineation

A shoreline is defined as the boundary where a body of water comes in contact with dry land. Changing conditions in the marine and terrestrial environments modify the shoreline position in time spans from seconds to centuries, resulting in numerous fluctuations from inches to hundreds of feet. To accurately compare successive shoreline positions at a site, a consistent shoreline definition must be established (Kraus and Rosati 1997).

Shoreline delineation for this effort was initially approached using the tidal water datum MHHW, which is defined by NOAA as the “average of the higher high water height of each tidal day” (NOAA 2000). In other words, MHHW represents the higher of the daily tide elevations. The NOAA vertical software package, VDATUM, was used in conjunction with a regularly spaced grid generated in the ESRI GIS ArcMap to create a tidal elevation surface across the study area. The surface was then used to generate shorelines along the intersection of the MHHW elevation with each DEM. The resultant shorelines were compared visually against aerial imagery to ensure their location appeared as expected based on the visually apparent tidal wet/dry line. The review found that the MHHW shorelines were unexpectedly seaward of their expected location. Calculations, datums, and units of the data sources were reviewed and found to be correct and consistent across the datasets.

Given the poor quality of the results, it was decided to base the shoreline elevation on a sampling of berm crest elevations. The berm crest marks the general upper limit of wave uprush on a beach, and is a transition point to the flatter berm. The berm crest can be used as a proxy for the high water line, a common shoreline indicator for shoreline change analysis. This interpretation is not to be confused with the “wet/dry” or water-saturated zone, which occurs close to the water line (Leatherman 2003). To assess a representative berm height across Puerto Rico, 93 elevation cross-sections were visually reviewed at 12 locations around the study area. The average berm elevation was 1.97 feet PRVD02 – this value was then rounded to 2.0 feet for application. Representative shorelines were then extracted from each DEM as the 2 feet elevation contour from the 2000 and 2016 DEMs.

Shorelines were again visually reviewed for consistency with the expected position on the aerial photographs. The review did find some locations where the shoreline from the 2000 LiDAR was located further seaward than expected. These instances were found to be a result of the vegetation present in the 2000 LiDAR (not bare earth). Areas of mangroves, or with sporadic vegetation or trees at the shoreline were found to be biased by the additional high elevations introduced into the DEM by those features. These areas were identified and excluded from the change rate analysis. In some cases where the shoreline was only periodically influenced by these features, additional care was taken to appropriately locate analysis transects where the shoreline was not affected. The placement of the 2000 shoreline was also reviewed against historical imagery in Google Earth in areas showing larger amounts of change. This review mostly corroborated the shoreline placement; however, in a few instances it flagged a reach of shoreline for exclusion. Overall, the location was found to be improved over the MHHW approach and suitable for change analysis.

3.2.5.3 Change Rate Analysis

Change rate analysis was completed at transect locations across the three islands. The transect layout, rate calculations, associated error, and classification of transects based on shoreline change trends and relative degree of erosion risk were completed and are described in the following text.

3.2.5.3.1 Transect Layout

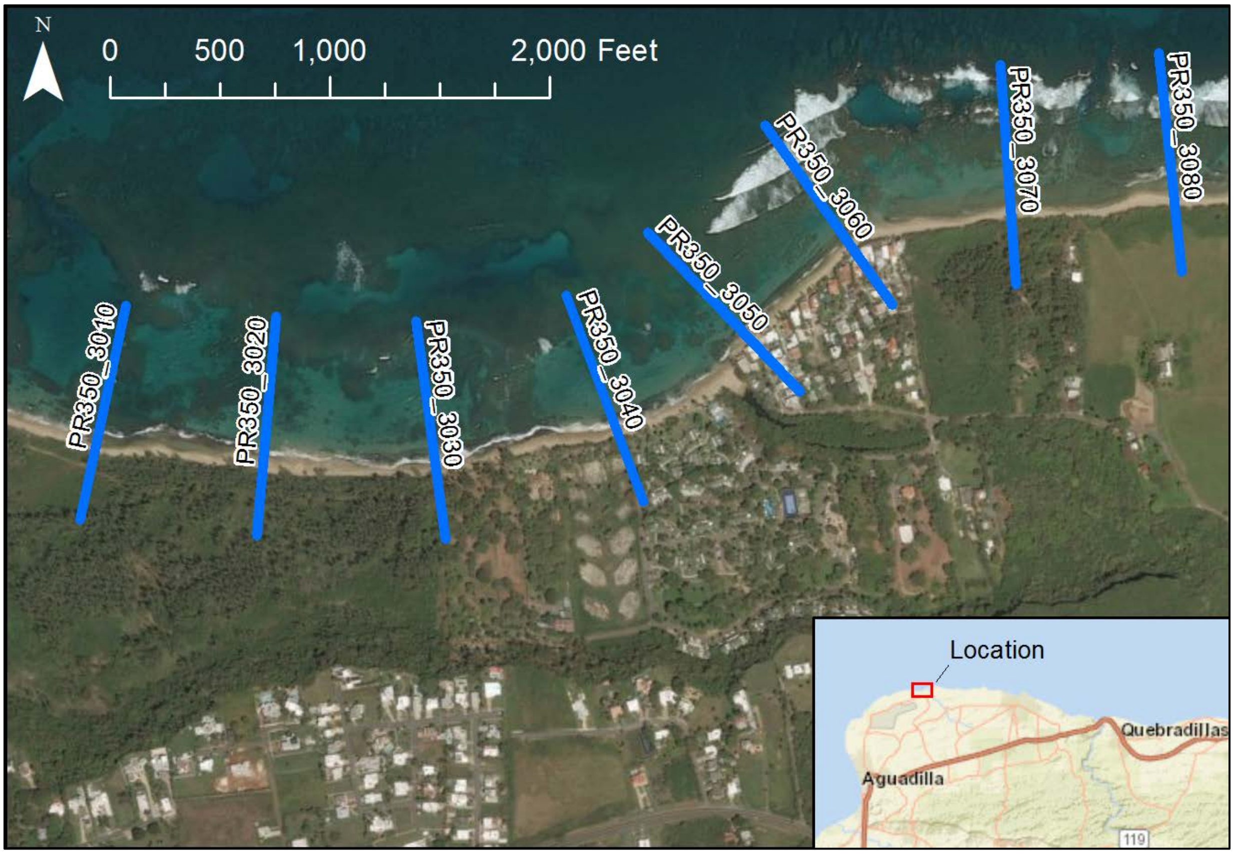
The shoreline positions were sampled for change rate analysis at shore-perpendicular transects. An initial total of 2,296 transects were spaced at a 750 feet (229 meters) interval along a baseline around the three islands (**Figure 3-10**). The baseline was established from a simplified version of the 2016 shoreline. Transect IDs were assigned in clockwise ascending numbers around each of the three islands. Initial transect placement was accomplished via an automated tool. The transects were then reviewed and adjusted to achieve an acceptable placement. This review included:

1. Perpendicular placement of the transects to the two shorelines and general orientation of the coast;
2. Located a representative shoreline location suitable for shoreline change analysis. For example, not located immediately adjacent to the mouth of a river;
3. Transect placement avoided suspect areas in the shoreline, i.e., not located on an apparent artifact from the LiDAR, especially the 2000 DEM that included vegetation and;

4. Transect placement avoided areas with highly complicated shoreline geometry that would result in multiple intersections of the transect with the shorelines.
5. Transect placement on visibly rocky or stabilized coastlines. Transects were reviewed for placement on non-erodible shorelines. In general, imagery quality available from ESRI or Google Earth allowed for this classification and removal of transects. In cases where shore protection structures consisted of ad-hoc rip-rap or debris placed on the shoreline, transects were not removed in order to convey the potential erosion hazard.

The final count of transects after this review process was 1,669.

Figure 3-10: Example of Transect Placement and Spacing



3.2.5.3.2 Change Rate Calculations

Shoreline change rates were calculated by sampling the location of each shoreline along each transect. The distance between the two shorelines was then divided by the time interval between the collection of the two DEMs to derive the raw change rate. Each LiDAR collection occurred over multiple days. The mid-point of the data collection was used as the representative date for shoreline change analysis. Collection dates and representative dates are provided in the table below:

Table 3-9: Collection Information

LiDAR Dataset	Collection Timeframe	Representative Date
2000	2000-12-01 to 2000-12-08	2000-12-04
2016 – Western Collection Area	2016-01-26 to 2016-05-15	2016-03-21
2016 – Eastern Collection Area	2016-12-08 to 2017-03-16	2017-01-26

3.2.5.3.3 Change Rate Error

The Root Mean Square Error ("RMSE") of the shoreline change rates was estimated by compiling the error values associated with the horizontal accuracy of shoreline placement. Such error values were compiled separately for the 2000 and 2016 DEMs and then summed to represent total error within the change rate. The potential sources of error in the rate change calculation included:

1. Horizontal accuracy of each DEM – provided by DEM metadata and quantified at the time of data collection.
2. Shoreline vector extraction error – introduced by variance in ESRI geospatial extraction algorithm. Estimated by extracting the shoreline contour with 3 different geospatial extents. Measured spread in shoreline position from the 3 extracted contours at 20 locations and tabulated the average error. The average error was 1.4 feet. This value was used for both DEMs given their identical cell size and use of the same extraction process.
3. Horizontal positioning error due to vertical accuracy – estimated by reviewing slopes in the DEM at 25 randomly selected locations across the 3 islands within the average vertical error tolerance of the two DEMs (+/-0.4 feet). For the contour elevation of 2 feet, the location of the 1.5 feet and 2.5 feet elevations were identified. The distance between the two elevations represented the potential uncertainty. The sampled values were averaged for a single representative number for both DEMs, and the error was included for each shoreline date. This average error for this item was 10.4 feet.

Error components were combined in quadrature to provide a measure of the total position error for the shoreline position $(\in)$ as:

$$\in = \sqrt{\epsilon_1^2 + \epsilon_2^2 + \epsilon_3^2}$$

Where:

$\varepsilon =$ total horizontal position shoreline recession error

$\varepsilon_1 =$ horizontal accuracy of DEM

$\varepsilon_2 =$ shoreline vector extraction error

$\varepsilon_3 =$ horizonal position error due to vertical accuracy

The total position error was then divided by the interval of each change analysis for the study area to provide the rate error (ϵ_R):

$$\epsilon_R = \frac{\epsilon_{\text{Shoreline 1}} + \epsilon_{\text{Shoreline 2}}}{\text{time interval between shorelines, yr}}$$

Based on this approach, the rate change error was estimated at 1.3 feet/year. Given the results of the error analysis, it was decided to round the raw change rate to the nearest integer to remove un-warranted precision from the results.

3.2.5.3.4 Change Rate Classifications

Two types of rate classification were performed, one intended for simple classification and the other to reflect erosion risk. Both classifications were based on the rounded change rates and reflected the assessed change rate error.

The first general categorization was intended to provide a simple assessment of shoreline change directions around the three islands, as shown in **Table 3-10**:

Table 3-10: General Status Classification for Shoreline Change Transects.

Classification	Included Rounded Change Rates	Description	Percent of Transects
Accretion	>1 ft/yr	Shoreline gaining sediment and advancing	10
Stable	0 ft/yr	No or low amount of change	38
Erosion	<-1 ft/yr	Shoreline losing sediment and receding	52

A second schema focused on the recovery effort and classified the change rates into 5 relative erosion risk categories, as shown in **Table 3-11**. The intention in this exercise was to conservatively communicate the degree of risk of each location to shoreline recession:

Table 3-11: Erosion Risk Classification Schema for Shoreline Change Transects

Erosion Risk Classification	Included Rounded Change Rates	Description	Percent of Transects
Negligible Risk	>1 ft/yr	No risk of erosion given change rate error	20
Low Risk	0 ft/yr	Minimal risk of erosion, but listed as low due to change rate error. No	28

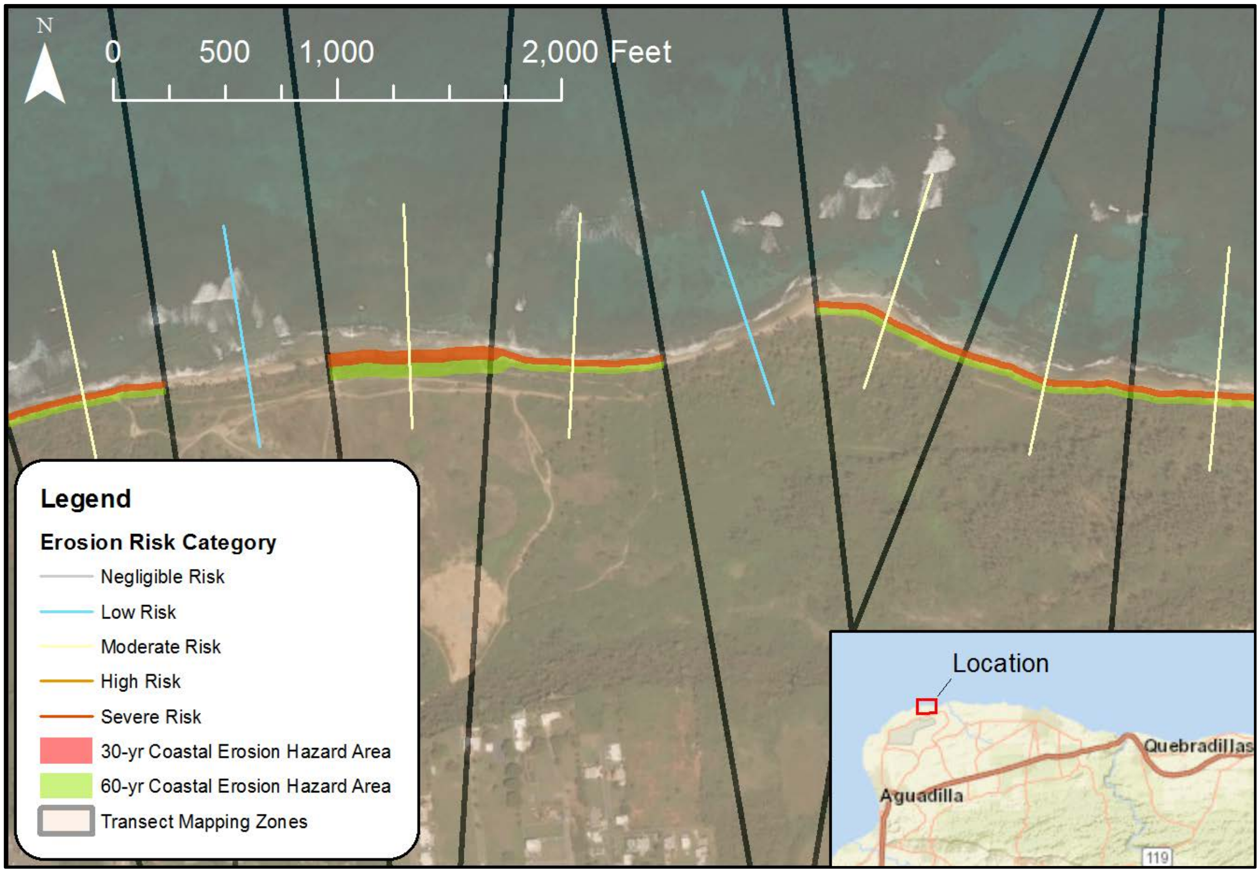
		erosion hazard polygon mapped.	
Moderate Risk	-1 ft/yr to -3 ft/yr	Based on error and distribution of change rates. Erosion hazard polygon mapped.	48
High Risk	-4 ft/yr to -5 ft/yr	Based on error and distribution of change rates. Erosion hazard polygon mapped.	3
Severe Risk	<-5 ft/yr	Based on error and distribution of change rates. Erosion hazard polygon mapped.	1

3.2.5.4 Projected Future Erosion Hazard Area Polygons

To ease the use of the change analysis in Hurricane Maria and Irma recovery effort, erosion hazard area polygons were generated. These polygons represented areas projected to be subject to erosion in the next 30 and 60 years. Such areas should either be protected, or have recovery activities sited outside of the indicated hazard area based on their lifecycle. Polygons were created for areas having a rounded shoreline change rate equal to or greater than -1 foot/year. This criterion was assigned to generate polygons for areas having significant erosion trends for rates approximate to the calculated RMSE. It should be noted that the projections are based on the approximate 16-year period of analysis provided by this effort and are subject to the inherent limitations of that limited period of record.

The polygons were generated from setback distances calculated at each transect by multiplying the rounded change rate to the setback period (30 or 60 years) for transects in the Moderate, High, and Severe Risk categories. The rounded rate was used to reflect the inherent error in the rate calculations. The first step in the process was to establish “Transect Mapping Zones.” These zones defined the mid-point between the transects. This simplification was required to produce the polygon layers for the entirety of the three islands within the production window. The Transect Mapping Zones were applied to the 2016 shoreline to divide it into segments, each of which were used for the buffering process to create the projected erosion hazard zones. The setback distance for each future timeframe was then applied as a buffer to each shoreline segment to generate the polygons. The edges of buffered areas were rounded to improve the cartographic aesthetics of the final product. A visual review and additional editing were performed to remove awkward transitions and artifacts, or clip the polygons to applicable reaches of coast. An example of the Transect Mapping Zones and coastal erosion hazard area polygons is provided in **Figure 3-11.**

Figure 3-11: Projected Coastal Erosion Hazard Areas Mapped with "Transect Mapping Zone" (an area that provided coverage to the approximate mid-points between transects)



3.2.5.5 Comparison to Existing Data

A review of existing studies during the scoping phase of this effort did not identify any other modern, island-wide studies of shoreline change for Puerto Rico. During the initial execution of the technical scope, FEMA was notified that an island-wide study, "Assessment of Beach Morphology at Puerto Rico Island" (Barreto, et al. 2017) had been recently completed by the Puerto Rico and Caribbean Beach Network Planning School, University of Puerto Rico. The study offered analysis completed by a research entity familiar with Puerto Rico, and for a longer period of record (1977 to 2016). Other notable differences from this, to the Barreto-led effort include:

1. Use of a visually-identified and digitized shoreline indicator – the "wet/dry" line
2. Spacing of transects at a 20 meter (~65 feet) interval

Efforts were made to acquire and utilize data generated from Barreto study for the recovery effort; however, the change rate data were not made available to FEMA. Towards the end of the advisory mapping effort, limited data included shoreline classifications were made available in a spreadsheet with geographic locations, but the specific change rate values were excluded.

A comparison was made between the shoreline change rates calculated by the advisory and Barreto studies. This was accomplished by the following steps:

1. Re-assigning change rate values at the provided point locations to each of the classifications provided by Barreto using their report documentation.
2. Performing a spatial join between point locations from Barreto to the advisory shoreline change transects.
3. Comparing the range of Barreto values, based on classification, to the nearest advisory transect.
4. Assessing and compiling minimum difference values based on the ranges at each advisory transect.

Overall, the comparison found that 80-percent of the values calculated by the advisory effort were in agreement with Barreto. The count of transects and minimum difference are presented in **Table 3-12**. 62-percent of transects had a minimum difference of "0", whereas another 18-percent had a minimum difference of 1 foot. We also considered the additional 18-percent to indicate agreement, given associated rate errors from this and the Barreto studies. From this comparison, we can conclude that the advisory change rates are in agreement with Barreto.

Table 3-12: Summary of Comparison of Advisory Effort and Barreto Shoreline Change Rates

Minimum Difference in Change Rate, ft/yr	Count of Transects	Percent of Transects
0	137	62%
1	39	18%
2	12	5%
3	11	5%
4	11	5%
5	2	1%
6	0	0%
7	4	2%
8	1	0%
9	0	0%
10	0	0%
11	2	1%
12	1	0%

3.2.5.6 Long-Term Erosion Product Limitations

The coastal erosion hazard information produced by this effort will provide a useful resource for identifying areas subject to coastal erosion hazards in support of the recovery effort. The data were subject to internal team and independent review to identify and correct issues and ensure overall product quality. The product was subject to the following limitations due to inherent error in the data resources and the production approach:

1. The analysis conducted for long-term shoreline erosion was limited to two shorelines over an approximate 16 year period. The calculated rates and resultant polygons were subject to the limitations of those source data and antecedent conditions that may have influenced shoreline position prior to the data of survey in 2000 and 2016/2017. The analysis here was simplified for the purposes of the recovery effort. The overall accuracy of the rates would be improved if the period of record was longer, or if additional shorelines were included. Ideally, rates would be derived from 4-5 shorelines over a 30-year period to derive a rate linear-regression method that included all shoreline data points for each transect.

2. Change rate transects were removed from areas with apparent non-erodible shorelines, such as those with rock substrates or significant shoreline stabilization structures, such as engineered revetments and seawalls. The quality of the available imagery and production schedule limited a full and detailed review of all areas. As such, polygons may be shown for areas that locals consider stabilized due to the placement of rip-rap or ad-hoc structures consisting large pieces of mixed materials.

3. It is recommended that end-users utilize the rounded, whole-foot value shoreline change rates for recovery purposes – presented as the “Change Rate” in the Transect shapefile. The calculated change rates have an estimated error of 1.3 feet/year. This error reflects the horizontal and vertical error in the source LiDAR topography and error in extracting the shorelines from the topography. As such, presented rates were rounded to the closest whole foot. The raw rates are provided for informational purposes only. Where more accurate and/or precise rates are needed, it is recommended that end-users leverage information from Barreto (2017) or conduct site-specific detailed analysis.

4. The 30-year and 60-year projected Coastal Erosion Hazard Area polygons are not explicit along-shore spatial representations of the extent of the coastal erosion hazard. Polygons were generated to the mid-point between analysis transects. The coverage was not adjusted to the site-specific location of the transition in the shoreline change trend as apparent from the shoreline positions. End-users should review the shoreline positions to identify the full alongshore extent of the erosion hazard, or conduct additional detailed analysis where needed.

5. The landward edge of the polygons of the 30-year and 60-year projected Coastal Erosion Hazard Area polygons were not an explicit representation of potential future erosion hazard. The polygons were generated from the rounded rates to enable end-users to readily identify areas subject to coastal erosion for the purposes of post-Maria recovery. It is not recommended that end-users use the explicit edge of the zones when siting any

structures in the vicinity of polygons. Appropriate caution and additional setback from the edge should be considered for such areas in absence of other shoreline stabilization efforts.

6. The polygons were intended to inform recovery efforts and are not for regulatory use.

3.2.6 Storm Induced Coastal Erosion

Shorelines of Puerto Rico experienced significant erosion from Hurricanes Maria and Irma. Some areas may not have had a significant flooding issue, however due to storm induced erosion, structures experienced foundation damages. To help identify areas from Maria and Irma that experienced erosion, the areas with the most risk to storm induced erosion areas were identified. This product will help identify areas where mitigation projects might be desirable. This task consisted of the below components.

3.2.6.1 Areas of Significant Storm Induced Erosion from Hurricane Maria

Areas of significant storm-induced erosion from Hurricane Maria and Irma were identified from a visual review of post-disaster vertical aerial photographs in comparison with the shoreline delineated from the pre-storm 2017 USGS LiDAR surveys, used in the long-term erosion task, and available pre-storm imagery. Apparent areas of significant storm-induced erosion were captured with a manually drawn polygon bounded by the shoreline and the area subject to erosion. The shoreline was drawn along the wet/dry line in the aerial photographs to provide a consistent delineation of the eroded shoreline. The aerial review polygons do not follow the updated delineated shoreline because the hurricane events altered the shorelines in some areas so drastically that it does not make sense to try to correlate them. Instead, this product aims to highlight areas of significant change based on pre and post imagery. The extents were based on the extent of change from different sources of aerial photography.

The polygons were delineated based on a visual assessment of all data sources. Post-event imagery was sourced from Vexcel and NOAA. Pre-event imagery was sourced from NOAA. Areas of long-term erosion and naturally dynamic areas were disregarded based on indicators of vegetation and soil disturbance, as well as historical imagery from Google Earth Pro. Care was taken to distinguish between deceptive variations in the brightness and saturation of aerial imagery. Furthermore, areas where the tree and shrub canopies were simply stripped, exposing the substrate beneath were evaluated on a case by case basis. These areas may appear to have been eroded, but often times the removal of vegetation simply exposed the existing underlying natural materials.

Three types of coastal erosion processes were collected: erosion, deposition, and overwash. Erosion occurs where sand is removed from the beach system, deposition occurs where sand is transported and stored in new sandbars, and overwash occurs where storm-induced waves and surge transport and deposit sand landward.[1] In instances where erosion processes were occurring near structures, the distance in feet was measured to the nearest at-risk structure.

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[1] USGS St. Petersburg Coastal and Marine Science Center.

3.2.6.2 Areas of Minor and Severe Storm Induced Erosion Potential

The effective FIS study was used to identify areas of storm induced erosion potential. Areas that had no erosion modeled during the effective study were not covered. A polygon coverage was created to identify three areas of erosion severity: retreat, removal, and non-standard. The polygons were bounded by the updated shoreline from this study and the area subject to erosion.

During the effective study, areas of dune retreat and dune removal were identified and delineated following FEMA's standard 540 square feet rule as specified in **Appendix D** of the *Guidelines and Specifications for Flood Hazard Mapping Partners*. For coastal areas where sand veneer overlay rocky ledges, a non-standard erosion methodology was applied and the sandy veneer was removed. **Appendix E** describes the non-standard erosion from the effective coastal study and contains a table which describes the erosion applied to all transect in Puerto Rico. Refer to the effective study for more information on non-standard erosion methodology.

The polygons were delineated landward based on the extent of erosion identified in the effective CHAMP database transects, or documentation from the effective study, and the seaward extent was drawn along the updated shoreline from this study. Along the shore, the polygons were interpolated using primary frontal dune location, shoreline descriptions, and topographic data.

3.2.6.3 Storm Induced Erosion Product Limitations

The coastal storm induced erosion hazard information produced by this effort will provide a useful resource for identifying areas subject to coastal storm erosion in support of the recovery effort. The data were subject to internal team and independent review to identify and correct issues and ensure overall product quality. The product was subject to the following limitations due to inherent error in the data resources and the production approach:

1. The Maria and Irma storm induced erosion areas are solely based on aerial imagery analysis, no ground truthing was performed. The areas that experience erosion from the storms are limited by the observations in the aerial imagery.

2. There is no difference between the Maria and Irma induced storm erosion areas as no aerial imagery was taken between the storms.

3. Areas indicated as experiencing erosion from Maria and Irma, may recover from the erosion as time passes. Sand may be transported back to a beach from offshore deposits. As well as overwash sand removed.

4. The storm erosion potential areas are based on the analysis performed in the effective coastal study; no changes to the erosion type and analysis were made. Current conditions may change the storm erosion evaluation if performed on the most recent topographic information.

5. The storm erosion potential areas are based on the effective study spacing of transects. New areas between the transects were not evaluated for storm erosion in this effort. The current transect data was interpolated to areas between the transects were appropriate.

3.3 Supporting Advisory Products

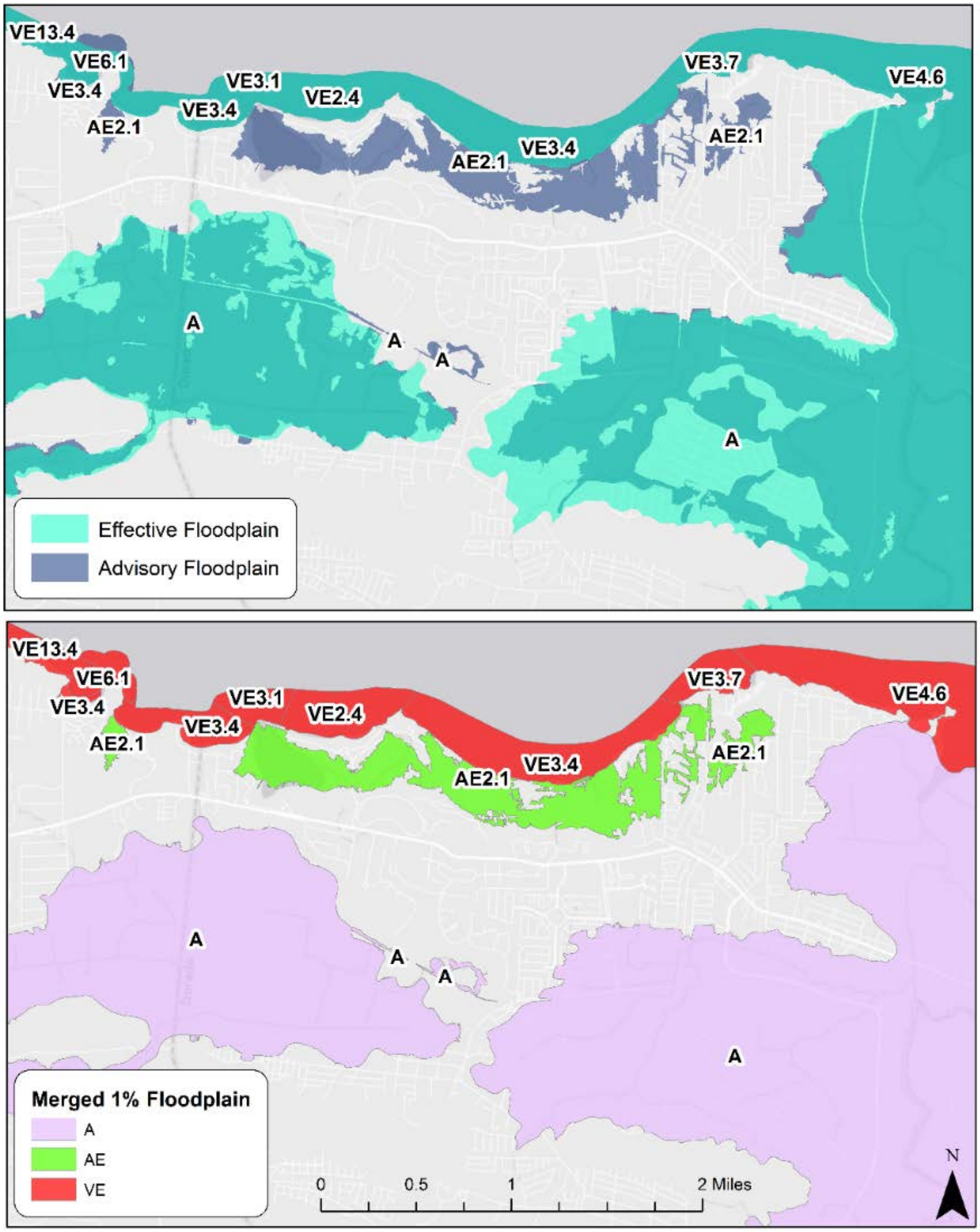
3.3.1 Floodplain Product Development

3.3.1.1 Merged 1-Percent and 0.2-Percent Floodplain Generation Process

In order to show the most conservative picture of flood risk and to generate seamless 1-percent and 0.2-percent floodplain advisory products, the new advisory floodplains were merged with the effective floodplains. The goal of this task was to maintain expansions in the advisory floodplain, but ensure that no areas would be less than the regulatory SFHA. This task was accomplished by performing a merge of the effective and advisory 1-percent and 0.2-percent polygon areas where the most conservative coastal BFE was maintained and attributed to the merged floodplain polygons. Due to the new topographic information being used to map the advisory 0.2-percent floodplain boundaries, there were areas where the advisory 0.2-percent floodplains were less than the effective 1-percent floodplains. In these areas, the effective 1-percent floodplain boundary was utilized as the 0.2-percent floodplain boundary. By doing this, the 0.2-percent floodplain at least covers the area covered by the 1-percent floodplains.

Manual cleanup was performed to remove slivers, dangles, and overlaps of the merged product. Additionally, coastal riverine tie-in areas were revisited to ensure seamless transitions for the merged product. **Figure 3-12** shows an example of the merging process.

Figure 3-12: Merged Floodplain Generation Process Illustration



3.3.1.2 0.2-Percent Fringe Floodplains

For the 1-percent floodplains, a 0.2-percent shaded X Zone fringe was developed, similar to the standard FIRM floodplains. These 0.2-percent fringe areas were also built based on the most conservative floodplain respective to the effective or new advisory 0.2-percent mapping. Due to the new topographic information being used to map the advisory 0.2-percent floodplain boundaries, there were areas where the 0.2-percent floodplains were less than the effective 1-percent floodplains, and, in these areas, no 0.2-percent floodplain fringe was shown. These shaded X Zone fringes were then attached to the 1-percent floodplains. Small areas or slivers less than 900 square feet were removed.

3.3.1.3 Merged Riverine Cross Sections

The Puerto Rico advisory maps contain riverine floodplains developed from multiple models, which utilized effective detailed and advisory BLE methods. In certain areas, water surface elevations existed from both effective and advisory models; therefore, a determination of which flood elevations should be attributed was needed. In an effort to provide a conservative level of risk preparedness, a procedure was developed for selecting which modeled flood elevation would be shown for the advisory maps:

1. The effective and advisory cross sections were combined (maintaining elevation information) into a single “merged cross section” feature.

2. Where advisory cross sections crossed multiple stream reaches, cross sections were clipped to the appropriate stream reach.

3. Effective water surface elevations were converted from MSL to PRVD02 using the conversion surface developed for this project.

4. On the merged cross section dataset, stationing was assigned in the upstream direction of every stream reach. The advisory streamline was used, as it contained all of the streams from the effective and the updated areas included in the advisory.

5. A python script was developed that performed the following procedure on the merged cross section feature (with stream name and station number):

    a. Iterated through the dataset by stream name beginning with the first station (ascending) and testing each cross section. If the water surface elevation (WSE) was less than the previous cross section, the cross section was removed, and then it continued to the next upstream cross section. In this way, where two cross sections exist from differing models, the more conservative WSE was used to determine which should be included in the final mapping product. The resulting shapefile was a complete, blended dataset providing a conservative WSE in areas of conflicting data.

    b. Interpolated frequencies for effective cross sections that only had the 1-percent flood event. In places where the effective cross section showed a higher WSE than the advisory model and was therefore selected for inclusion into the blended shapefile, these effective cross sections only had values for the 1-percent flood event. The advisory cross sections upstream and downstream of these effective cross sections have 5 frequencies. In order to make a uniform product, a linear interpolation was used to populate the remaining frequencies. The methodology for this was as follows: 1) all frequencies were interpolated from the downstream advisory cross sections, 2) the 1-percent WSEs from the interpolated cross section and the effective cross section at this location were used to create a normalization factor, and 3) this normalization factor was applied to all of the frequencies on the effective cross section, resulting in a seamless WSE for the reach, with all frequencies attributed to all of the cross sections.

   c. An interpolation check was performed to identify spaces in between the stationing that may have shown a higher water surface elevation if interpolation was performed on the unmerged, original datasets. In the areas where these interpolations would have resulted in a higher flood elevation, manual edits were made, and BFE lines were brought in from the effective. **Figure 3-13** shows an example of the BFE line selection process.

6. Manual clean up was then performed as follows:

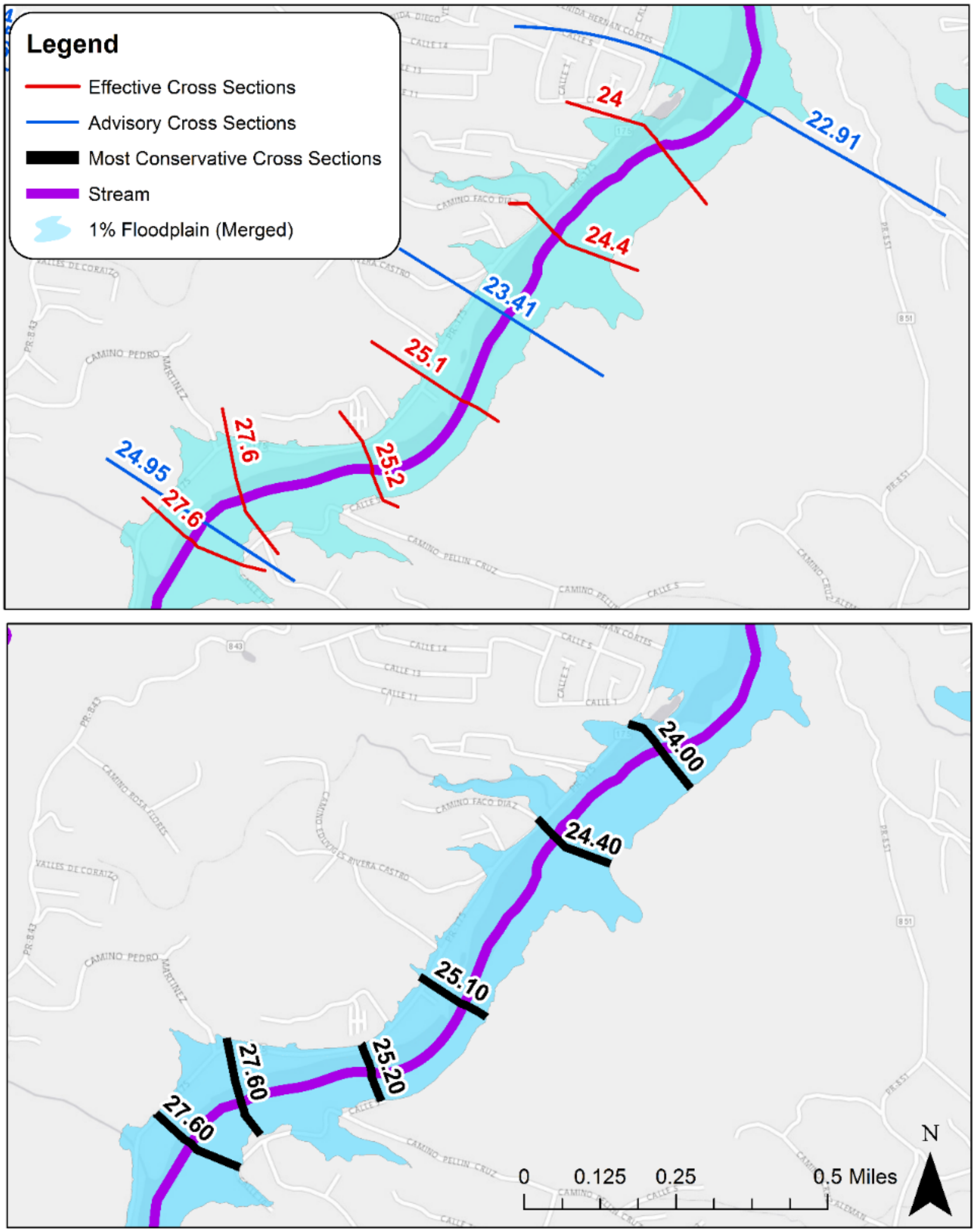
   a. Where cross sections crossed each other, the more conservative cross section was maintained and the less conservative was removed or the cross section orientation was altered to avoid crossings.

   b. The merged floodplain polygon was used to clip the cross sections so cross sections did not exist outside of the floodplain.

   c. Cross sections were extended where necessary to cover the floodplain and re-oriented to avoid cross section overlaps.

7. A quality review was performed on interpolated values, at junctions, at tie-ins, and at randomly sampled locations.

Figure 3-13: Selection of Most Conservative Riverine Water Surface Elevation Process Illustration



Water surface elevations are shown in meters.

3.3.1.4 Final Floodplain Products

Two separate floodplain products resulted from this effort: 1) a 1-percent floodplain product that included the most conservative floodplain from the effective or new advisory mapping, the most conservative riverine BFEs from either the effective or new advisory modeling, effective coastal static BFEs, and 0.2-percent fringe floodplain areas shown as shaded Zone X and 2) a 0.2-percent floodplain product that included the most conservative floodplain from either the effective 0.2-percent, effective 1-percent (if more than the new advisory 0.2-percent mapping) or new advisory 0.2-percent mapping, the most conservative riverine BFEs from the effective or the new advisory modeling, and the new advisory coastal 0.2-percent static BFEs.

3.3.2 Map Change Products

The effective flood hazard data and the advisory 1-percent seamless flood hazard data were compared to analyze the changes in flood hazard zones. The analyses were developed using ESRI's ArcGIS software and its Geoprocessing tools. Spatial overlay tool "Union" was the primary function utilized for this analyses. The union function identified the differences between the effective and advisory flood zone information. This spatial analyses resulted in about 30 zone change (AE to A, VE to AE, A to X, etc.) combinations. To simplify the visualization and comprehension of this product, the change combinations were further grouped into 7 bins, attributed as "Change Description". **Table 3-13** summarizes the zone change combinations and the categories.

Table 3-13: Zone Change Combinations and Categories

Change Description	Zone Change Combination
ShadedX to SFHA	X to A; X to AE; X to AO; X to VE
UnShadedX to SFHA	UX to A; UX to AE; UX to AO; UX to VE
No Change To SFHA	A to A; A to AE; A to AO; A to VE; A99 to A; AE to A; AE to AE; AE to AO; AE to VE; AH to A; AO to A; AO to AE; AO to AO; VE to A; VE to AE; VE to VE
No Change To ShadedX	X to X
SFHA to UnShadedX	AE to UX
UnShadedX to ShadedX	UX to X
ShadedX to UnShadedX	X to UX

The map change product, which was in polygon GIS format, includes the results of the analyses. The dataset was attributed with above described zone change and change descriptions, including the source flood zone attribution from the effective flood zone and 1-percent advisory flood zone layers.

Additionally, a spreadsheet product was developed that included land area summaries that were based on the GIS change product, as the input. The spreadsheet products include the following land area summaries:

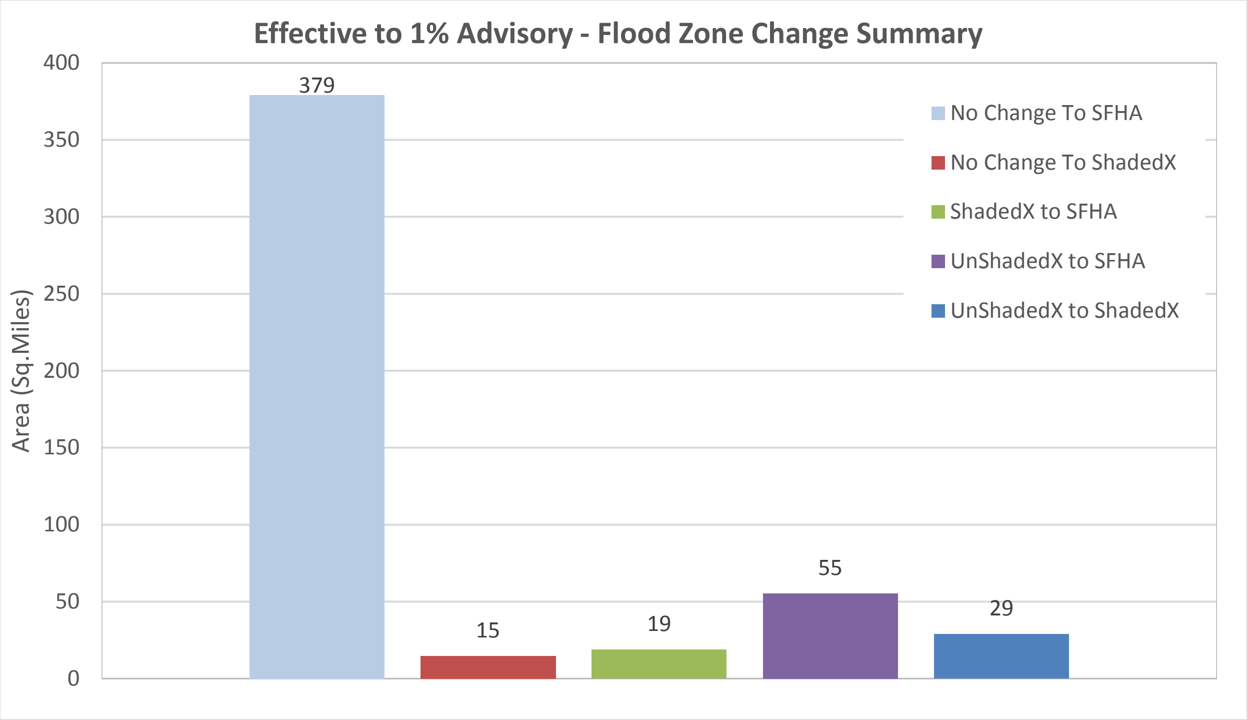
- Summary of Special Flood Hazard Area Change (Worksheet: SFHA_Change)
- Summary of Flood Zone Change, in Square miles (Worksheet: Zone_Change_SqMiles)
- Flood Zone Change summary in Acres (Worksheet: Zone_Change_Acres)

Provided below is a quick summary of the high-level discussion on change statistics (in square miles).

- No decreases to the 1-percent floodplain area, with some notable zone changes
  - Riverine Increase (Coastal to Riverine): 0.1 Sq. miles
    - VE to A: 0.1 Sq. miles
  - Coastal Increase (Riverine to Coastal): 1.3 Sq. miles
    - A to AE: 1.3 Sq. miles
- Total 1-percent Floodplain Area Increase (Newly Added Areas to SFHA): 74 Sq. miles
  - Riverine Increase: 63 Sq. miles
  - Coastal Increase: 11 Sq. miles
    - AE Zone Increase: 9.5 Sq. Miles
    - AO Zone Increase: 0.8 Sq. Miles
    - VE Zone Increase: 0.5 Sq. Miles
- Area changed from UnShadedX to ShadedX: 29 Sq. miles
- Overall Coastal 1-percent floodplain area increase: 12 Sq. Miles
- Overall Riverine 1-percent floodplain area increase: 63 Sq. Miles

A graphical summary of floodplain changes is also provided in **Figure 3-14**.

Figure 3-14: Flood Zone Change Summary



3.3.3 Critical Facility Flood Risk Summaries

A critical facility provides services and functions essential to a community, especially during and after a disaster. *FEMA Fact Sheet: Critical Facilities and Higher Standards* notes that critical facilities can include a variety of facility types, for example police stations, fire stations, critical vehicle and equipment storage facilities, and emergency operations centers. Individual communities typically determine the types of facilities that are considered to be included in such a list of facilities. Puerto Rico has seventy-eight (78) local municipalities or municipios, however the scope of work for this project did not include soliciting responses from each individual municipio to identify their critical facilities.

Rather, the project team utilized the aforementioned fact sheet to determine facility types. Priority was given to capturing individual buildings and data specific to each individual building at critical facility sites across the entirety of Puerto Rico.

Table 3-14 includes the list of priority sites which were considered.

Table 3-14: Priority Sites

Data Type (Point Site Features)	Source	Circa Date	Comment
1. Bank (Financial Institution)	PRPB	2018	Received 02/08/2018
2. Blood Bank	N/A	N/A	No Data Available

Data Type (Point Site Features)	Source	Circa Date	Comment
3. Day Care Center	PRPB Permits	2014	Unknown if permits were approved or just submitted
4. Electric Power Facility	Hazus Util	2014	Stock Hazus Data
5. Emergency Operations Center	Hazus EF	2014	Site points previously updated by RAMPP
6. Equipment Storage Facility	N/A	2018	Visually identified using Street-level service from Google
7. Fire stations	Hazus EF	2014	Site points previously updated by RAMPP
8. Hospitals	DR 4339 AGOL		Used to cross-reference Hazus data
9. Medical Facility	Hazus EF	2014	Site points previously updated by RAMPP
10. Medical Records Facility	N/A	N/A	No Data Available
11. Nursing Home	PRPB	2014	Used as-is
12. Police stations	Hazus EF	2014	Site points previously updated by RAMPP
13. PoliceDeptStatus_20171106	DR 4339 AGOL	2017	Used to cross-reference Hazus data
14. Power Generation Center	PRPB	2014	Puerto Rico Infrastructure Data
15. Public_Schools_2017	DR 4339 AGOL	2017	Used to cross-reference Hazus data
16. School	Hazus EF	2014	Site points previously updated by RAMPP
17. School_Openings_OCT_23_2017	DR 4339 AGOL		Used to cross-reference Hazus data
18. Vehicle Storage Facility	N/A	2018	Visually identified using Street-level service from Google
19. Volatile/Flammable/Explosive/Toxic Facility	Hazus HPLF	2014	Stock Hazus Data
20. Wastewater Treatment Plant	Hazus Util	2014	Stock Hazus Data
21. Wastewater Treatment Plant	PRPB & Util Co.	2014	Puerto Rico Infrastructure Data
22. Water Treatment Plant	Hazus Util	2014	Stock Hazus Data
23. Water Treatment Plant	PRPB & Util Co.	2014	Puerto Rico Infrastructure Data

Point data listed in **Table 3-14** established known available critical facility sites and were utilized to locate site locations. Primary site data resources included various FEMA Hazus-MH facility data (i.e., Hazus-MH Essential Facility Database, Hazus-MH Utility Facility Database), various data available from the Puerto Rico Planning Board (PRPB) and various other GIS thematic data available from the FEMA Disaster Relief (DR) 4339 ArcGIS Online Group (e.g., School Status or Police Department Status).

After sites were identified as being located within the advisory floodplains, an additional 200-foot buffer was added to account for sites that may exists in close proximity. Building footprints were extracted for the site and processed for inclusion. Most facility types defined included a photograph, with a few exceptions. Day care centers did not include photographs because the data utilized to define the facility as a day care was acquired from a PRPB database of permits. There was no clarity as to whether the permit database was one of three possibilities; 1) Applications only, 2) Combination of both applications and approved permitted facilities or 3) Only permitted facilities. Due to the lack of confidence in the day care centers' source data, photographs were not captured. Banks were a second exception due to the volume of sites and the inability to distinguish with certainty between being an actual bank building versus an ATM machine (sometimes located within a larger building, such as an ATM in a convenience store or a bank inside a shopping center). Photos were not captured for bank facilities and the building was analyzed in its entirety as a bank facility. Source images were embedded in the GIS data and source disk paths existed within the attribute table.

Attributes such as name, address, city, and zip were sporadic in the source data. Data were backfilled, within the schedule time constraints, from a variety of sources to include reverse geocoded data utilizing ESRI World Geocoding Service, as well as web-based mapping applications. Latitude and Longitude in decimal degrees existed based on the centroid of the building footprint. Lowest Adjacent Grade (LAG) and Highest Adjacent Grade (HAG) were extracted from new 2017 USGS 1-meter Digital Elevation Model (DEM) along the perimeter of the building footprint. Advisory base flood elevations (1-percent and 0.2-percent annual chance or ABFE100 and ABFE500) represented the maximum elevation from the combination of both the coastal and riverine water surface elevation grids intersecting each building footprint.

The GIS database includes results of a risk analysis that was performed based on the following parameters:

1. Damage percentages were computed based on the maximum depth at each building footprint per the following:

    a. Maximum Advisory Base Flood Elevation within the building footprint and the Lowest Adjacent Grade at each building footprint. The difference between the two elevations established the depth value for each building.

    b. Depth-Damage function selection was based on typical Hazus-MH Flood Model parameters. Based on this, the following were assigned for each respective building:

        i. Occupancy

        ii. Number of Stories

            1. Where 2010 building footprints intersected the critical facility building footprint utilized, the height value was transferred to establish stories assuming a 10-foot ceiling height
            2. All other building heights were assumed to be 1-story
        iii. First-Floor-Height
            1. All buildings were assumed to have a first-floor height of 0.5 feet
        iv. Foundation Type
            1. All buildings were assumed to be Slab-On-Grade
        v. Core Construction Type
            1. All buildings were assumed to be Concrete
    c. In addition, the newly created ABFE Floodplain Zones were utilized to establish whether a building touched a coastal zone and if so, coastal depth-damage functions were applied.

Notably, future building-specific work would benefit from making distinctions in varied occupancies within larger buildings. Since dollar values were not being considered as part of the risk assessment (only estimated damage percentages), the results being produced as part of this project would not be over- or under-stating estimated ($) value. Given this, users of this report would be free to consider building and contents value in light of the estimated maximum damage percentages. Furthermore, additional work efforts at the building-level would benefit from a detailed analysis of the first-floor elevation or height. A cursory review of the difference between the LAG and HAG elevations (from the USGS 1-meter elevation grid of Puerto Rico), showed that, without a detailed analysis, use of the difference value as a proxy for the first-floor height of the building was not feasible given the wide a range of values in the data set. Because of this, a first-floor height of 0.5 feet was assumed for all buildings to be conservative in representing the highest potential risk for each building.

PDF documents represent a handout product that can be provided to operators and includes core recommendations from the most recent FEMA post-event guidance documents, along with key contacts and publications. These documents provide operators with avenues for appropriately considering options. Should additional work be required in the future, each of the elements on the PDF document were drawn from a customized python module that can be executed on a CSV export of the GIS data.

Table 3-15 presents an overall representation of relative risk for all the captured facilities. This table also includes relative risk rank color-coding to help highlight relative risk comparisons between a few key statistics.

Table 3-15: Overall Statistics of Facility Types Generally at Most Risk

Type	Building Count	Mean (AVG) Of All Facilities			
		Building Damage Percent (1%)	Building Damage Percent (0.2%)	Contents Damage Percent (1%)	Contents Damage Percent (0.2%)
Airport	1	1%	7%	1%	10%
Bank	130	11%	19%	62%	86%
Critical Equipment Storage	12	6%	10%	20%	32%
Critical Vehicle Storage	9	7%	16%	25%	48%
Day Care Center	220	5%	9%	24%	39%
Emergency Operations Center	14	16%	23%	39%	63%
Fire Station	21	8%	13%	19%	36%
Government Center	1	8%	13%	58%	77%
Medical Facility	71	9%	22%	11%	32%
Nursing Home	4	16%	24%	49%	60%
Police Station	111	8%	13%	25%	45%
Power Generation Center	29	10%	20%	14%	28%
School	1125	11%	17%	43%	62%
Volatile/Flammable/Explosive/ Toxic Facility	67	22%	28%	38%	48%
Wastewater Treatment Plant	138	19%	28%	25%	36%
Water Treatment Plant	27	11%	23%	15%	30%
TOTAL	**1980**	**11%**	**18%**	**29%**	**46%**

100	Rank Value / Color: High
80	
50	Rank Value / Color: Medium
20	
0	Rank Value / Color: Low

4.0 References

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5.0 Appendices

5.1 Appendix A: Hydraulic Analysis Streams List

HUC-10 / HEC-RAS Model Name	Flooding Source Name	Length (miles)
201/13347	Rio Corozal	2.46
201/13386	Rio de los Negros	1.25
201/13406	Rio Cibuco	17.92
201/13600	Quebrada Honda (Vega Alta Municipio)	5.54
201/13678	Rio Morovis	7.12
201/13716	Rio Indio	8.24
201/13595	Rio sin nombre (Modelo n·m. 13595)	0.22
201/13681	Quebrada Honda (Morovis Municipio)	0.20
205/07878	Rio Camuy (Tramo Arriba)	3.02
205/07919	Rio Criminales	1.21
205/09176	Rio Guajataca	24.47
205/09956	Rio Camuy (Tramo Abajo)	5.71
302/05199	Rio Limani	1.51
302/05238	Rio Blanco (Adjuntas & Lares Municipios)	19.05
302/05289	Rio Guayo (Adjuntas & Lares Municipios)	5.10
302/05321	Rio Cidra	1.53
302/05402	Rio Grande de Anasco	38.59
302/05528	Rio Guaba	6.60
302/05598	Rio Bucarabones (Las Marias Municipio)	2.39
302/05893	Rio Casey	1.96
302/05249	Rio Toro	0.66
303/04217	Rio Yaguez	4.31
401/00152	Rio sin nombre (Modelo n·m. 152)	1.60
401/00189	Rio sin nombre (Modelo n·m. 189)	1.11
401/00286	Rio sin nombre (Modelo n·m. 286)	1.22
401/00691	Canal Este de Drenaje del Valle de Lajas	9.22
401/00708	Quebrada Mamey (Lajas Municipio)	3.84
401/00978	Rio Loco	11.37
402/01253	Rio Yauco	18.20
402/01300	Rio Naranjo	1.25
402/01313	Quebrada Grande (Yauco Municipio)	1.38
402/01375	Quebrada de Quebradas	1.52
402/01386	Quebrada Berrenchin	3.80
402/01552	Rio Guayanilla	9.32
402/01706	Rio Tallaboa	10.53

HUC-10 / HEC-RAS Model Name	Flooding Source Name	Length (miles)
402/01761	Rio Guayanes (Penuelas Municipio)	2.86
402/01938	Rio Macana	6.18
402/01388	Quebrada Berrenchin Afluente N·m. 1	0.82
402/01291	Rio sin nombre (Modelo n·m. 1291)	0.79
405/06362	Rio Guamani	8.57
405/06511	Quebrada Bandera	2.44
405/06558	Rio Nigua (Arroyo Municipio)	4.90
405/06602	Quebrada Caimital	1.56
405/06612	Quebrada Corazon	4.04
405/06662	Quebrada Yaurel	3.51
405/06721	Rio Grande de Patillas	10.48
405/06817	Rio Marin	2.07
405/06869	Rio de Apeadero	1.84
405/06888	Rio Chico	2.97
405/07002	Rio Jacaboa	2.52
405/06367	Quebrada Culebra	0.59
405/06830	Rio sin nombre (Modelo n·m. 6830)	0.56
405/06891	Quebrada Mamey (Patillas Municipio)	0.58
504/17163	Rio Emajagua	2.10
504/17203	Rio Grande de Loiza	40.57
504/17315	Rio Cayaguas	3.16
504/17371	Rio sin nombre (Modelo n·m. 17371)	0.50
504/17380	Rio sin nombre (Modelo n·m. 17380)	1.12
504/17388	Rio sin nombre (Modelo n·m. 17388)	1.89
504/17395	Rio sin nombre (Modelo n·m. 17395)	1.53
504/17397	Rio sin nombre (Modelo n·m. 17397)	1.04
504/17400	Rio sin nombre (Modelo n·m. 17400)	1.24
504/17408	Quebrada Matias	2.85
504/17433	Rio sin nombre (Modelo n·m. 17433)	1.93
504/17439	Quebrada Janer	1.10
504/17465	Rio Turabo	8.02
504/17501	Quebrada Naranjito	1.08
504/17521	Quebrada Beatriz	1.96
504/17551	Quebrada de las Quebradillas	1.78
504/17588	Rio sin nombre (Modelo n·m. 17588)	1.16
504/17602	Quebrada Las Bambuas	2.39
504/17646	Rio Caguitas	6.81
504/17671	Quebrada Algarrobo	1.47
504/17672	Rio sin nombre (Modelo n·m. 17672)	1.60
504/17678	Rio Canaboncito	4.14

HUC-10 / HEC-RAS Model Name	Flooding Source Name	Length (miles)
504/17696	Rio Caguitas Afluente N·m. 1	2.25
504/17698	Rio Caguitas Afluente N·m. 2	0.75
504/17725	Rio Bairoa	10.68
504/17730	Quebrada de los Muertos	1.54
504/17818	Quebrada Honda (Las Piedras Municipio)	4.36
504/17843	Rio Gurabo	17.31
504/17895	Quebrada Arenas (Juncos & Las Piedras Municipios)	3.89
504/17923	Rio sin nombre (Modelo n·m. 17923)	1.22
504/17937	Quebrada Ceiba (Juncos Municipio)	3.33
504/17970	Rio Valenciano	2.94
504/18068	Rio sin nombre (Modelo n·m. 18068)	1.11
504/18089	Rio sin nombre (Modelo n·m. 18089)	2.54
504/18137	Rio sin nombre (Modelo n·m. 18137)	1.91
504/18178	Quebrada Arena (Caguas Municipio)	2.31
504/18193	Rio Canas (Caguas Municipio)	2.50
504/18254	Quebrada Colorada	3.38
504/18261	Quebrada Rohena	1.03
504/18286	Quebrada Grande (Trujillo Alto Municipio)	3.13
504/18370	Quebrada Maracuto	7.06
504/18394	Quebrada Pastrana	4.88
504/18446	Rio Canovanillas	2.66
504/18539	Rio Canovanas	10.62
504/18599	Rio sin nombre (Modelo n·m. 18599)	1.28
504/17417	Rio sin nombre (Modelo n·m. 17417)	0.79
504/17401	Rio sin nombre (Modelo n·m. 17401)	0.41
504/17398	Rio sin nombre (Modelo n·m. 17398)	0.62
504/17386	Rio sin nombre (Modelo n·m. 17386)	0.69
504/17510	Rio sin nombre (Modelo n·m. 17510)	0.92
504/17613	Rio sin nombre (Modelo n·m. 17613)	0.91
504/18057	Rio sin nombre (Modelo n·m. 18057)	0.37
504/18130	Rio sin nombre (Modelo n·m. 18130)	0.78
504/18213	Rio sin nombre (Modelo n·m. 18213)	0.58
504/18501	Quebrada Cambute	0.60
504/18597	Rio sin nombre (Modelo n·m. 18597)	0.96
504/18600	Rio sin nombre (Modelo n·m. 18600)	0.75
505/15937	Rio Piedras	8.46
505/15985	Quebrada Quaracanal	2.45
505/16016	Quebrada Dona Ana	2.23
505/16031	Quebrada Josefina	2.09

HUC-10 / HEC-RAS Model Name	Flooding Source Name	Length (miles)
505/16054	Quebrada Margarita	3.48
505/16165	Quebrada Juan Mendez	3.09
505/16029	Rio sin nombre (Modelo n·m. 16029)	0.34
505/16051	Rio sin nombre (Modelo n·m. 16051)	0.53
202/12188	Rio Orocovis	8.82
20212267	Rio Grande de Manati	56.11
20212494	Rio Toro Negro	20.54
20212496	Rio sin nombre (Modelo n·m. 12496)	0.48
20212582	Rio Matrullas	6.88
40302027	Rio Bucana	12.21
40302166	Rio Portugues	5.50
40302217	Rio Chiquito	3.30
40302249	Quebrada del Agua	1.98
40302300	Rio Matilde	9.11
40302351	Rio Canas (Ponce Municipio)	4.81
40303120	Rio Inabon	13.75
40303211	Rio Guayo (Juana Diaz Municipio)	6.19
40303382	Rio Toa Vaca	6.99
40303504	Rio Jacaguas	22.30
40304379	Rio Descalabrado	7.88
50107690	Rio Maunabo	8.14
50107741	Quebrada Talante	1.93
50107775	Quebrada Arenas (Maunabo Municipio)	2.42
50108407	Rio Guayanes (Yabucoa Municipio)	10.81
50108524	Rio Limones	3.70
50108698	Rio sin nombre (Modelo n·m. 8698)	0.98
50108701	Rio sin nombre (Modelo n·m. 8701)	0.62
50108704	Rio sin nombre (Modelo n·m. 8704)	0.87
50109102	Rio Candelero	4.09
50109111	Rio sin nombre (Modelo n·m. 9111)	0.98
50109116	Rio sin nombre (Modelo n·m. 9116)	1.43
50109119	Quebrada N·m. 2	0.98
50109741	Rio Humacao	6.94
50109783	Quebrada Mariana	4.73
50109801	Quebrada Mariana Afluente	1.68
50109816	Quebrada Mabu	2.64
50109117	Quebrada N·m. 4	0.73
50109112	Quebrada N·m. 1	0.74
50108504	Rio sin nombre (Modelo n·m. 8504)	0.96
50107731	Quebrada de Los Chinos	0.94

HUC-10 / HEC-RAS Model Name	Flooding Source Name	Length (miles)
50211666	Quebrada Collores	1.43
50211669	Rio Anton Ruiz	8.14
50211677	Quebrada Mambiche	2.41
50211714	Quebrada de Las Mulas	4.53
50211785	Rio Blanco (Naguabo Municipio)	9.28
50211856	Quebrada de Pena Pobre	4.50
50211940	Quebrada Grande (Naguabo Municipio)	2.85
50211954	Rio Santiago	4.54
50291954	Rio Santiago (Tramo Lateral)	1.93
50212017	Quebrada Botija	3.63
50212023	Rio sin nombre (Modelo n·m. 12023)	1.36
50212026	Rio sin nombre (Modelo n·m. 12026)	2.17
50213108	Quebrada del Platano	2.29
50213111	Rio sin nombre (Modelo n·m. 13111)	1.00
50213117	Quebrada Palma	6.16
50213252	Rio Daguao	6.41
50213263	Rio sin nombre (Modelo n·m. 13263)	1.75
50213270	Rio sin nombre (Modelo n·m. 13270)	2.36
50215178	Quebrada Aguas Claras	2.91
50215180	Quebrada Aguas Claras Afluente	1.58
50215896	Quebrada Ceiba (Ceiba Municipio)	3.56
50215906	Rio Demajagua	2.54
50216296	Rio Fajardo	12.01
50216338	Quebrada Juan Diego	1.25
50216358	Rio sin nombre (Modelo n·m. 16358)	1.35
50216397	Quebrada Redonda	4.29
50213256	Rio sin nombre (Modelo n·m. 13256)	0.45
50212019	Rio sin nombre (Modelo n·m. 12019)	0.64
50211945	Rio sin nombre (Modelo n·m. 11945)	1.04
50211833	Rio sin nombre (Modelo n·m. 11833)	0.66
50316599	Rio Mameyes	4.41
50316643	Quebrada Tabonuco	1.77
50316656	Quebrada Anon	2.76
50316701	Rio Sabana (Luquillo Municipio)	5.65
50316735	Rio Pitahaya	4.89
50316749	Rio sin nombre (Modelo n·m. 16749)	1.39
50316789	Rio Juan Martin	3.11
50316794	Rio sin nombre (Modelo n·m. 16794)	1.31
50316814	Quebrada Mata de Platano	3.62
50316857	Rio Espiritu Santo	8.27

HUC-10 / HEC-RAS Model Name	Flooding Source Name	Length (miles)
50316941	Rio Grande (Rio Grande Municipio)	5.10
50316979	Rio sin nombre (Modelo n·m. 16979)	2.12
50318726	Rio Herrera	8.29
50316792	Rio sin nombre (Modelo n·m. 16792)	0.65
50794093	Rio de la Plata (Tramo Abajo)	15.25
50784093	Rio de la Plata (Tramo Arriba)	33.49
50714213	Rio Guavate	3.42
50714287	Rio de la Plata Afluente N·m. 1	2.07
50714313	Quebrada Santo Domingo	3.58
50714317	Rio sin nombre (Modelo n·m. 14317)	0.53
50714322	Rio sin nombre (Modelo n·m. 14322)	0.98
50714441	Rio Usabon (Tramo Arriba)	6.92
50714448	Rio sin nombre (Modelo n·m. 14448)	0.95
50714449	Rio sin nombre (Modelo n·m. 14449)	0.53
50714492	Rio de Aibonito	6.62
50714510	Quebrada Serrales	5.53
50714536	Rio de Barranquitas	5.35
50714650	Quebrada Convento	0.68
50714876	Rio Guadiana	3.68
50714988	Rio Bucarabones (Toa Alta Municipio)	5.19
50714993	Rio sin nombre (Modelo n·m. 14993)	0.49
50794492	Rio de Aibonito (Tramo Lateral)	0.26
50794536	Rio Usabon (Tramo Abajo)	4.73
30106632	Rio sin nombre (Modelo n·m. 6632)	0.92
30106641	Rio Grande (Aguada & Rincon Municipios)	2.44
30106678	Cano de Santi Ponce	0.77
30106926	Rio Ingenio	2.97
30106945	Rio sin nombre (Modelo n·m. 6945)	0.94
30106959	Rio Culebra	3.90
30106977	Cano Guayabo	1.61
30106981	Rio Guayabo	2.15
30107132	Rio Culebrinas	28.52
30107217	Rio Culebrinas Afluente	1.50
30107248	Rio Guatemala	2.38
30107548	Quebrada Grande (Moca Municipio)	2.15
30107587	Rio Cano	4.01
30107599	Quebrada El Gallinero	1.02
30107800	Cano Madre Vieja	3.31
30107221	Rio sin nombre (Modelo n·m. 7221)	0.34
30106944	Rio sin nombre (Modelo n·m. 6944)	0.65

HUC-10 / HEC-RAS Model Name	Flooding Source Name	Length (miles)
30106978	Rio sin nombre (Modelo n·m. 6978)	0.48
40403810	Rio Cuyon	6.64
40403955	Rio Coamo	14.04
40404010	Rio sin nombre (Modelo n·m. 4010)	1.60
40404023	Rio de la Mina	1.41
40404078	Rio sin nombre (Modelo n·m. 4078)	4.91
40404095	Rio sin nombre (Modelo n·m. 4095)	1.55
40404577	Rio Cayures	2.12
40404640	Canal de Guamani	0.41
40404771	Rio Jajome	1.44
40404828	Rio Majada	5.86
40404878	Rio Lapa	3.53
40404932	Rio Nigua (Salinas Municipio)	8.22
40405048	Rio Jueyes	2.93
40406117	Quebrada Melania	2.79
40406177	Rio sin nombre (Modelo n·m. 6177)	2.70
40406232	Rio Seco	3.09
20410355	Rio Saliente	3.38
20410395	Rio Caonillas	20.31
20410409	Rio Caricaboa	1.42
20410443	Rio Zamas	1.33
20410614	Rio Limon	5.54
20410675	Rio La Venta	1.09
20410703	Rio Yunes	2.33
20410813	Rio Vacas	5.03
20410829	Rio sin nombre (Modelo n·m. 10829)	1.66
20410883	Rio Saltillo	1.10
20410896	Rio Grande de Arecibo	37.38
20410956	Rio Pellejas	3.84
20410977	Rio sin nombre (Modelo n·m. 10977)	0.35
20411038	Quebrada Arenas (Utuado Municipio)	2.93
20411081	Rio Vivi	6.49
20411111	Rio sin nombre (Modelo n·m. 11111)	2.06
20407989	Rio Tanama	2.58
20408050	Rio sin nombre (Modelo n·m. 8050)	0.66
30402498	Rio Grande (Sabana Grande Municipio)	1.95
30402549	Rio Guanajibo	26.16
30402575	Rio Cruces	3.19
30402587	Rio Flores	1.75
30402597	Rio sin nombre (Modelo n·m. 2597)	2.10

HUC-10 / HEC-RAS Model Name	Flooding Source Name	Length (miles)
30402598	Rio sin nombre (Modelo n·m. 2598)	1.23
30402651	Rio Cain	2.41
30402700	Rio Duey	4.55
30402742	Rio Hoconuco	3.90
30402834	Quebrada Mendoza	5.86
30402838	Rio sin nombre (Modelo n·m. 2838)	1.61
30402923	Rio Maricao	7.04
30402953	Rio Rosario	16.67
30402982	Rio sin nombre (Modelo n·m. 2982)	1.05
30402986	Rio sin nombre (Modelo n·m. 2986)	1.73
30403716	Cano Majagual	2.29
30402527	Rio sin nombre (Modelo n·m. 2527)	0.89
50615203	Quebrada Gordo	1.85
50615221	Rio Hondo	7.07
50615242	Quebrada Santa Catalina	2.41
50615363	Rio Sabana (Cidra Municipio)	2.24
50615382	Rio de Bayamon	28.17
50615395	Quebrada Prieta	1.73
50615526	Quebrada Santa Olaya	2.59
50615565	Rio Minillas	2.86
50615603	Rio Guaynabo	8.00
50615667	Quebrada Frailes	1.41
60100150	Rio sin nombre (Modelo n·m. Vieques-150)	1.12
60100151	Rio sin nombre (Modelo n·m. Vieques-151)	1.04
60100155	Rio sin nombre (Modelo n·m. Vieques-155)	1.62
60100157	Rio sin nombre (Modelo n·m. Vieques-157)	1.29
60100160	Quebrada Cofi	1.69
60100176	Rio sin nombre (Modelo n·m. Vieques-176)	2.42
60100177	Quebrada Cofresi	1.19
60100195	Rio sin nombre (Modelo n·m. Vieques-195)	1.79
60100196	Rio sin nombre (Modelo n·m. Vieques-196)	0.92
60100199	Rio sin nombre (Modelo n·m. Vieques-199)	1.28
60100156	Rio sin nombre (Modelo n·m. Vieques-156)	0.81
60100031	Rio sin nombre (Modelo n·m. Vieques-31)	0.63
60100043	Quebrada Urbano	2.23
60100055	Quebrada La Perla	1.39
60100061	Quebrada Pilon	2.51
60100064	Rio sin nombre (Modelo n·m. Vieques-64)	2.02
60100066	Quebrada La Mina Afluente	0.54
60100067	Quebrada La Mina	2.70

HUC-10 / HEC-RAS Model Name	Flooding Source Name	Length (miles)
60200016	Rio sin nombre (Modelo n·m. Culebra-16)	1.01
60200020	Rio sin nombre (Modelo n·m. Culebra-20)	0.74
60200004	Rio sin nombre (Modelo n·m. Culebra-4)	0.67
60200007	Rio sin nombre (Modelo n·m. Culebra-7)	0.80
60200009	Rio sin nombre (Modelo n·m. Culebra-9)	0.48

5.2 Appendix B: Comparison Between MHHW and the Most Downstream Water Surface Elevation for Streams Joining the Ocean

HUC-10 Stream ID	Flooding Source Name	Latitude	Longitude	1-Percent Annual Chance Elevation at Downstream Cross Section (meters)	MHHW Elevation (meters)	Delta (meters)
20113406	Río Cibuco	18.482729	-66.3768286	1.42	N/A	N/A
20212267	Río Grande de Manati	18.4816023	-66.5332247	4.69	0.24	4.45
20410896	Río Grande de Arecibo	18.4726645	-66.7105715	4.19	0.24	3.95
20509176	Río Guajataca	18.4891751	-66.9573998	3.08	0.26	2.82
20509956	Río Camuy (Tramo Abajo)	18.4873909	-66.8364045	2.38	0.25	2.13
30106632	Río sin nombre (Modelo núm. 6632)	18.3736597	-67.2452584	2.43	0.26	2.17
30106641	Río Grande (Aguada & Rincón Municipios)	18.3758912	-67.2388227	2.35	0.26	2.09
30106678	Caño de Santi Ponce	18.3792053	-67.2243607	2.3	0.26	2.04
30106926	Río Ingenio	18.3821116	-67.2078586	2.53	N/A	N/A
30106945	Río sin nombre (Modelo núm. 6945)	18.3719948	-67.2120742	4.32	N/A	N/A
30106959	Río Culebra	18.3817611	-67.2070479	2.23	N/A	N/A
30106977	Caño Guayabo	18.3788743	-67.1985653	1.43	N/A	N/A
30106981	Río Guayabo	18.3837332	-67.2139691	1.28	0.26	1.02

HUC-10 Stream ID	Flooding Source Name	Latitude	Longitude	1-Percent Annual Chance Elevation at Downstream Cross Section (meters)	MHHW Elevation (meters)	Delta (meters)
30107132	Río Culebrinas	18.4058429	-67.1771594	2.93	0.25	2.68
30107800	Caño Madre Vieja	18.413047	-67.1624456	2.02	0.25	1.77
30205402	Río Grande de Añasco	18.2665938	-67.1879132	2.12	0.24	1.88
30304217	Río Yagüez	18.2080362	-67.154816	1.54	0.24	1.30
30402549	Río Guanajibo	18.1679414	-67.1809094	2.51	0.17	2.34
30402834	Quebrada Mendoza	18.1248964	-67.1353952	8.46	N/A	N/A
30402838	Río sin nombre (Modelo núm. 2838)	18.087226	-67.1485764	14.95	N/A	N/A
30403716	Caño Majagual	18.1891019	-67.1605531	1.12	0.22	0.90
40100152	Río sin nombre (Modelo núm. 152)	17.9559751	-67.105194	1.49	N/A	N/A
40100189	Río sin nombre (Modelo núm. 189)	17.9644648	-67.0847443	0.05	0.17	-0.12
40100286	Río sin nombre (Modelo núm. 286)	18.0094749	-67.1783019	0.78	0.17	0.61
40100978	Río Loco	17.971146	-66.9218124	0.62	0.15	0.47
40201253	Río Yauco	17.9872193	-66.7974034	0.59	0.13	0.46
40201552	Río Guayanilla	18.0009906	-66.7765918	0.58	0.13	0.45

HUC-10 Stream ID	Flooding Source Name	Latitude	Longitude	1-Percent Annual Chance Elevation at Downstream Cross Section (meters)	MHHW Elevation (meters)	Delta (meters)
40201706	Río Tallaboa	17.990077	-66.7355041	0.5	0.13	0.37
40201938	Río Macaná	18.0061143	-66.7671252	0.26	0.13	0.13
40302027	Río Bucaná	17.9687838	-66.5997077	1.29	0.13	1.17
40302166	Río Portugués	17.9898608	-66.5969817	1.2	N/A	N/A
40302249	Quebrada del Agua	17.9803203	-66.6473275	1.1	0.13	0.97
40302300	Río Matilde	17.9813163	-66.6378207	1.57	0.13	1.44
40302351	Río Cañas (Ponce Municipio)	18.0018589	-66.640215	5.68	N/A	N/A
40303120	Río Inabón	17.9689277	-66.5575841	1.57	0.12	1.45
40303504	Río Jacaguas	17.9743205	-66.5399129	1.05	0.12	0.93
40304379	Río Descalabrado	17.9811499	-66.4506751	1.28	0.12	1.16
40403955	Río Coamo	17.9598375	-66.4292827	0.95	0.11	0.84
40404577	Río Cayures	17.9684485	-66.352121	0.88	0.12	0.76
40404932	Río Nigua (Salinas Municipio)	17.9685905	-66.312484	1.41	0.12	1.29
40405048	Río Jueyes	17.9765384	-66.3381575	1.66	0.12	1.54
40406117	Quebrada Melanía	17.947512	-66.1751838	0.28	0.13	0.15
40406177	Río sin nombre (Modelo núm. 6177)	17.9603754	-66.2108419	0.34	0.13	0.21
40406232	Río Seco	17.9555735	-66.1928797	0.54	0.13	0.41
40506362	Río Guamaní	17.9430667	-66.1339112	1.77	N/A	N/A

HUC-10 Stream ID	Flooding Source Name	Latitude	Longitude	1-Percent Annual Chance Elevation at Downstream Cross Section (meters)	MHHW Elevation (meters)	Delta (meters)
40506511	Quebrada Bandera	17.9645791	-66.0869803	1.94	0.14	1.80
40506558	Río Nigua (Arroyo Municipio)	17.9594965	-66.0582963	1.21	0.14	1.07
40506612	Quebrada Corazon	17.9658703	-66.0750407	1.99	0.14	1.85
40506662	Quebrada Yaurel	17.9785172	-66.0200504	1.84	0.14	1.70
40506721	Río Grande de Patillas	17.9803854	-66.0129838	1.45	0.14	1.31
40506888	Río Chico	17.9786412	-66.0050568	1.3	0.14	1.16
40507002	Río Jacaboa	17.9737489	-65.9645671	2.17	0.15	2.02
50107690	Río Maunabo	17.9905793	-65.8968434	1.49	0.17	1.32
50107731	Quebrada de Los Chinos	18.0106749	-65.9286168	13.52	N/A	N/A
50107741	Quebrada Talante	18.0083528	-65.9097368	6.12	N/A	N/A
50107775	Quebrada Arenas (Maunabo Municipio)	17.9911771	-65.8955448	2.39	0.17	2.22
50108407	Río Guayanés (Yabucoa Municipio)	18.0553882	-65.827472	2.41	N/A	N/A
50108698	Río sin nombre (Modelo núm. 8698)	18.0636048	-65.8167903	1.93	0.20	1.73

HUC-10 Stream ID	Flooding Source Name	Latitude	Longitude	1-Percent Annual Chance Elevation at Downstream Cross Section (meters)	MHHW Elevation (meters)	Delta (meters)
50108704	Río sin nombre (Modelo núm. 8704)	18.0692593	-65.8183371	1.93	N/A	N/A
50109102	Río Candelero	18.0985712	-65.7899995	2.34	N/A	N/A
50109111	Río sin nombre (Modelo núm. 9111)	18.0999816	-65.818274	14.05	N/A	N/A
50109741	Río Humacao	18.1197172	-65.781	2.13	N/A	N/A
50211669	Río Antón Ruiz	18.1743074	-65.7390178	1.08	0.15	0.93
50211714	Quebrada de Las Mulas	18.1807513	-65.7580831	0.58	N/A	N/A
50211785	Río Blanco (Naguabo Municipio)	18.1853731	-65.7284815	1.36	0.14	1.22
50211954	Río Santiago	18.1960614	-65.729611	2.78	N/A	N/A
50212017	Quebrada Botija	18.1951023	-65.6905308	0.55	0.14	0.41
50212023	Río sin nombre (Modelo núm. 12023)	18.2068025	-65.6957181	1.16	N/A	N/A
50212026	Río sin nombre (Modelo núm. 12026)	18.2000802	-65.6922798	0.46	N/A	N/A
50213117	Quebrada Palma	18.1986874	-65.68538	0.58	0.14	0.44
50213252	Río Daguao	18.2073953	-65.6614328	0.7	N/A	N/A

HUC-10 Stream ID	Flooding Source Name	Latitude	Longitude	1-Percent Annual Chance Elevation at Downstream Cross Section (meters)	MHHW Elevation (meters)	Delta (meters)
50213270	Río sin nombre (Modelo núm. 13270)	18.2221471	-65.6575916	1.21	N/A	N/A
50215178	Quebrada Aguas Claras	18.2696282	-65.6309769	1.03	0.25	0.78
50215896	Quebrada Ceiba (Ceiba Municipio)	18.280634	-65.6329535	0.77	0.25	0.52
50215906	Río Demajagua	18.2839819	-65.6344462	1.12	0.25	0.87
50216296	Río Fajardo	18.3279892	-65.6279294	1.04	0.26	0.78
50216397	Quebrada Redonda	18.3265753	-65.6339531	0.89	N/A	N/A
50291954	Río Santiago (Tramo Lateral)	18.1967579	-65.7249948	2.14	N/A	N/A
50316599	Río Mameyes	18.3857411	-65.7509212	2.25	N/A	N/A
50316701	Río Sabana (Luquillo Municipio)	18.3742754	-65.7126196	2.1	N/A	N/A
50316735	Río Pitahaya	18.3722852	-65.7097481	2.12	N/A	N/A
50316749	Río sin nombre (Modelo núm. 16749)	18.3656964	-65.7036483	1.84	N/A	N/A
50316789	Río Juan Martín	18.3647302	-65.6777557	1.87	0.28	1.59
50316814	Quebrada Mata de Plátano	18.3816463	-65.7169211	1.79	0.27	1.52

HUC-10 Stream ID	Flooding Source Name	Latitude	Longitude	1-Percent Annual Chance Elevation at Downstream Cross Section (meters)	MHHW Elevation (meters)	Delta (meters)
50316857	Río Espíritu Santo	18.4105654	-65.8034563	2.15	0.27	1.88
50318726	Río Herrera	18.4227672	-65.8290535	2.42	0.27	2.15
50417203	Río Grande de Loíza	18.4384785	-65.8767116	2.94	0.27	2.67
50515937	Río Piedras	18.4412724	-66.0848925	2	0.25	1.75
50516165	Quebrada Juan Mendez	18.4287151	-66.0419742	1.34	N/A	N/A
50615221	Río Hondo	18.451542	-66.1626685	1.51	0.26	1.25
50615382	Río de Bayamón	18.4517835	-66.1609999	1.79	0.26	1.53
50794093	Río de la Plata (Tramo Abajo)	18.4735914	-66.2552348	3	0.25	2.75

5.3 Appendix C: Manning's n Values

NLCD 2011 Land Use Code	Description	Range of n Values in Literature	Utilized n-Value
Water			
11	Open Water - areas of open water, generally with less than 25% cover of vegetation or soil.	0.001 - 0.06	0.013
12	Perennial Ice/Snow - areas characterized by a perennial cover of ice and/or snow, generally greater than 25% of total cover.	.01 - 0.027	0.020
Developed			
21	Developed, Open Space - areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.	0.01 -0.048	0.040
22	Developed, Low Intensity - areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units.	0.01 - 0.12	0.060
23	Developed, Medium Intensity – areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.	0.01 - 0.1	0.075
24	Developed High Intensity -highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover.	0.01 - 0.12	0.100
Barren			
31	Barren Land (Rock/Sand/Clay) - areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.	0.011 - 0.09	0.030
Forest			

NLCD 2011 Land Use Code	Description	Range of n Values in Literature	Utilized n-Value
41	Deciduous Forest - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.	0.07 - 0.36	0.120
42	Evergreen Forest - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.	0.07 - 0.32	0.120
43	Mixed Forest - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.	0.1 - 0.4	0.120
Shrubland			
51	Dwarf Scrub - Alaska only areas dominated by shrubs less than 20 centimeters tall with shrub canopy typically greater than 20% of total vegetation. This type is often co-associated with grasses, sedges, herbs, and non-vascular vegetation.	0.04	0.040
52	Shrub/Scrub - areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.	0.035 - 0.4	0.055
Herbaceous			
71	Grassland/Herbaceous - areas dominated by gramanoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.	0.022 - 0.36	0.040
72	Sedge/Herbaceous - Alaska only areas dominated by sedges and forbs, generally greater than 80% of total vegetation. This type can occur with significant other grasses or other grass like plants, and includes sedge tundra, and sedge tussock tundra.	0.03	0.040
73	Lichens - Alaska only areas dominated by fruticose or foliose lichens generally greater than 80% of total vegetation.	0.027	0.035

NLCD 2011 Land Use Code	Description	Range of n Values in Literature	Utilized n-Value
74	Moss - Alaska only areas dominated by mosses, generally greater than 80% of total vegetation.	0.025	0.030
Planted/Cultivated			
81	Pasture/Hay – areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.	0.033 - 0.325	0.040
82	Cultivated Crops – areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled.	0.035 - 0.04	0.040
Wetlands			
90	Woody Wetlands - areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.	0.037 - 0.14	0.090
95	Emergent Herbaceous Wetlands - Areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.	0.045	0.045

5.4 Appendix D: Wave Setup

Transect No.	Setup Method	Wave Setup (ft)	0.2% SWEL (ft)	Total SWEL (ft)	Wave Period (sec)	Wave Height (ft)	Note
Island of Puerto Rico							
1	DIM	4.56	7.39	11.96	12.0	31.5	
2	DIM	4.69	7.36	12.04	12.0	31.5	
3	Gourlay	4.40	7.66	12.05	12.0	31.5	Reef
4	Gourlay	3.84	8.01	11.85	12.0	31.5	Reef
5	Gourlay	3.92	7.94	11.86	12.0	31.5	Reef
6	DIM	4.93	7.91	12.84	12.0	31.5	
7	DIM	5.08	8.00	13.08	12.0	31.5	
8	DIM	4.98	8.07	13.04	12.0	31.5	
9	DIM	4.51	8.06	12.58	12.0	31.5	
10	DIM	4.61	8.07	12.67	12.0	31.5	
11	DIM	5.70	7.91	13.61	12.0	31.5	
12	DIM	4.72	8.13	12.86	12.0	31.5	
13	DIM	5.53	7.72	13.24	12.0	31.5	
14	Gourlay	4.81	7.55	12.36	12.0	31.5	Reef
15	DIM	5.40	7.48	12.88	12.0	31.5	
16	DIM	4.84	7.56	12.39	12.0	31.5	
17	Gourlay	3.62	7.40	11.02	12.0	31.5	Reef
18	DIM	4.79	6.89	11.68	12.0	31.5	
19	DIM	4.88	7.17	12.05	12.0	31.5	
20	DIM	4.51	6.41	10.92	12.0	31.5	
21	DIM	4.89	6.79	11.68	12.0	31.5	
22	DIM	5.18	6.24	11.42	12.0	31.5	
23	Gourlay	3.05	7.05	10.10	12.0	31.5	Reef
24	DIM	4.76	6.20	10.96	12.0	31.5	
25	DIM	4.40	6.69	11.09	12.0	31.5	
26	DIM	4.83	6.72	11.55	12.0	31.5	

Transect No.	Setup Method	Wave Setup (ft)	0.2% SWEL (ft)	Total SWEL (ft)	Wave Period (sec)	Wave Height (ft)	Note
27	DIM	6.25	6.30	12.55	12.0	31.5	
28	DIM	4.69	6.78	11.47	12.0	31.5	
29	Gourlay	4.48	5.13	9.61	12.0	31.5	Reef
30	Gourlay	4.41	5.48	9.89	12.0	31.5	Reef
31	Gourlay	4.32	6.10	10.42	12.0	31.5	Reef
32	Gourlay	4.23	5.58	9.81	12.0	31.5	Reef
33	Gourlay	2.99	5.31	8.29	12.0	31.5	Reef
34	DIM	4.41	6.84	11.25	12.0	31.5	
35	Gourlay	6.88	5.51	12.39	12.0	31.5	Reef
36	Gourlay	5.04	6.00	11.04	12.0	31.5	Reef
37	Gourlay	3.48	6.63	10.11	12.0	31.5	Reef
38	Gourlay	2.04	8.84	10.88	12.0	31.5	Reef
39	Gourlay	1.64	7.83	9.47	12.0	31.5	Reef
40	Gourlay	3.32	6.45	9.77	12.0	31.5	Reef
41	Gourlay	5.79	5.45	11.24	12.0	31.5	Reef
42	DIM	3.83	8.66	12.49	12.0	31.5	
43	DIM	4.23	7.63	11.87	12.0	31.5	
44	DIM	1.26	7.70	8.97	3.8	5.8	
45	DIM	1.28	6.76	8.03	4.4	7.3	
46	DIM	1.24	6.73	7.97	4.3	7.0	
47	DIM	1.27	5.13	6.40	3.5	5.3	
48	DIM	1.27	4.93	6.19	3.6	5.4	
49	DIM	4.18	5.10	9.28	3.3	4.7	
50	DIM	5.86	5.04	10.90	12.0	31.5	
51	Gourlay	7.38	4.15	11.53	12.0	31.5	Reef
52	Gourlay	3.48	5.64	9.12	12.0	31.5	Reef
53	Gourlay	3.56	5.74	9.30	12.0	31.5	Reef
54	Gourlay	4.04	5.63	9.67	12.0	31.5	Reef
55	Gourlay	4.02	7.53	11.55	12.0	31.5	Reef

Transect No.	Setup Method	Wave Setup (ft)	0.2% SWEL (ft)	Total SWEL (ft)	Wave Period (sec)	Wave Height (ft)	Note
56	Gourlay	4.34	6.53	10.88	12.0	31.5	Reef
57	Gourlay	3.23	6.00	9.23	12.0	31.5	Reef
58	Gourlay	3.30	4.40	7.70	12.0	31.5	Reef
59	DIM	5.13	4.14	9.27	12.0	31.5	
60	Gourlay	3.48	4.72	8.20	12.0	31.5	Reef
61	Gourlay	3.69	5.54	9.23	12.0	31.5	Reef
62	Gourlay	4.16	4.84	9.01	12.0	31.5	Reef
63	Gourlay	3.98	6.22	10.20	12.0	31.5	Reef
64	Gourlay	4.17	5.68	9.85	12.0	31.5	Reef
65	Gourlay	4.17	7.17	11.34	12.0	31.5	Reef
66	Gourlay	4.35	7.30	11.64	12.0	31.5	Reef
67	Gourlay	3.65	7.00	10.65	12.0	31.5	Reef
68	Gourlay	2.94	7.14	10.08	12.0	31.5	Reef
69	DIM	3.89	7.28	11.17	12.0	31.5	
70	Gourlay	3.17	6.56	9.72	12.0	31.5	Reef
71	Gourlay	3.14	6.65	9.79	12.0	31.5	Reef
72	DIM	4.34	6.56	10.90	12.0	31.5	
73	Gourlay	7.24	5.24	12.48	12.0	31.5	Reef
74	Gourlay	4.06	7.55	11.61	12.0	31.5	Reef
75	Gourlay	7.38	4.95	12.33	12.0	31.5	Reef
76	DIM	4.77	5.00	9.77	12.0	31.5	
77	Gourlay	7.00	6.75	13.75	12.0	31.5	Reef
78	Gourlay	4.55	9.06	13.61	12.0	31.5	Reef
79	DIM	4.97	9.84	14.81	12.0	31.5	
80	DIM	4.33	11.07	15.40	12.0	31.5	
81	DIM	4.84	10.61	15.45	12.0	31.5	
82	DIM	4.89	11.13	16.03	12.0	31.5	
83	DIM	4.85	11.59	16.44	12.0	31.5	
84	DIM	5.04	12.00	17.03	12.0	31.5	

Transect No.	Setup Method	Wave Setup (ft)	0.2% SWEL (ft)	Total SWEL (ft)	Wave Period (sec)	Wave Height (ft)	Note
85	DIM	4.52	13.46	17.98	12.0	31.5	
86	DIM	4.21	13.71	17.92	12.0	31.5	
87	DIM	4.17	13.77	17.94	12.0	31.5	
88	DIM	3.55	15.11	18.66	12.0	31.5	
89	DIM	4.07	14.07	18.14	12.0	31.5	
90	DIM	4.25	12.68	16.93	12.0	31.5	
91	DIM	4.32	12.87	17.19	12.0	31.5	
92	DIM	5.33	10.40	15.72	12.0	31.5	
93	DIM	5.72	11.15	16.88	12.0	31.5	
94	DIM	4.26	11.86	16.12	12.0	31.5	
95	DIM	5.77	10.99	16.76	12.0	31.5	
96	DIM	4.58	12.68	17.27	12.0	31.5	
97	DIM	4.22	8.43	12.65	12.0	31.5	
98	DIM	3.95	9.44	13.39	12.0	31.5	
99	DIM	3.85	12.61	16.46	12.0	31.5	
100	DIM	3.90	12.49	16.40	12.0	31.5	
101	DIM	3.38	14.25	17.64	12.0	31.5	
102	DIM	3.74	9.15	12.89	12.0	31.5	
103	DIM	3.72	10.06	13.78	12.0	31.5	
104	DIM	3.64	11.13	14.77	12.0	31.5	
105	DIM	4.07	11.75	15.82	12.0	31.5	
106	DIM	3.77	13.09	16.86	12.0	31.5	
107	DIM	4.11	14.33	18.44	12.0	31.5	
108	DIM	3.87	12.02	15.88	12.0	31.5	
109	DIM	3.49	14.11	17.60	12.0	31.5	
110	DIM	3.62	13.83	17.45	12.0	31.5	
111	DIM	3.59	14.10	17.69	12.0	31.5	
112	DIM	3.98	10.67	14.65	12.0	31.5	
113	Gourlay	2.93	11.68	14.61	12.0	31.5	Reef

Transect No.	Setup Method	Wave Setup (ft)	0.2% SWEL (ft)	Total SWEL (ft)	Wave Period (sec)	Wave Height (ft)	Note
114	DIM	3.80	9.12	12.92	12.0	31.5	
115	DIM	4.41	9.79	14.20	12.0	31.5	
116	DIM	4.44	8.65	13.09	12.0	31.5	
117	Gourlay	4.97	7.26	12.23	12.0	31.5	Reef
118	Gourlay	3.36	9.45	12.81	12.0	31.5	Reef
119	DIM	5.08	9.38	14.46	12.0	31.5	
120	DIM	5.84	9.64	15.48	12.0	31.5	
121	Gourlay	4.12	9.38	13.50	12.0	31.5	Reef
122	DIM	4.68	8.33	13.02	12.0	31.5	
123	DIM	4.54	7.14	11.68	12.0	31.5	
124	Gourlay	3.28	7.73	11.01	12.0	31.5	Reef
125	Gourlay	3.26	8.35	11.61	12.0	31.5	Reef
126	Gourlay	3.90	8.10	11.99	12.0	31.5	Reef
127	Gourlay	3.13	7.94	11.07	12.0	31.5	Reef
128	DIM	5.24	7.84	13.08	12.0	31.5	
129	DIM	4.58	7.93	12.51	12.0	31.5	
130	DIM	5.11	7.87	12.98	12.0	31.5	
131	Gourlay	5.54	7.97	13.51	12.0	31.5	Reef
132	DIM	4.30	8.07	12.37	12.0	31.5	
133	DIM	4.22	8.07	12.29	12.0	31.5	
134	Gourlay	5.85	8.08	13.93	12.0	31.5	Reef
135	DIM	4.00	9.20	13.20	12.0	31.5	
136	DIM	3.70	8.53	12.23	12.0	31.5	
137	DIM	4.71	8.19	12.90	12.0	31.5	
138	Gourlay	4.99	7.83	12.82	12.0	31.5	Reef
139	DIM	3.90	8.79	12.70	12.0	31.5	
140	DIM	3.85	9.25	13.10	12.0	31.5	
141	DIM	4.09	9.25	13.34	12.0	31.5	
142	DIM	3.81	8.53	12.34	12.0	31.5	

Transect No.	Setup Method	Wave Setup (ft)	0.2% SWEL (ft)	Total SWEL (ft)	Wave Period (sec)	Wave Height (ft)	Note
143	DIM	3.99	8.11	12.10	12.0	31.5	
144	DIM	3.53	7.27	10.79	12.0	31.5	
145	DIM	6.10	7.49	13.59	12.0	31.5	
146	DIM	4.10	7.20	11.30	12.0	31.5	
147	DIM	3.98	7.31	11.30	12.0	31.5	
148	DIM	3.91	9.00	12.91	12.0	31.5	
149	Gourlay	2.35	7.15	9.50	12.0	31.5	Reef
150	DIM	3.91	8.16	12.07	12.0	31.5	
151	DIM	3.85	10.00	13.85	12.0	31.5	
152	DIM	3.63	8.39	12.02	12.0	31.5	
153	DIM	3.27	8.80	12.08	12.0	31.5	
154	DIM	3.65	7.21	10.86	12.0	31.5	
155	DIM	3.82	7.09	10.91	12.0	31.5	
156	Gourlay	3.29	6.71	10.00	12.0	31.5	Reef
157	Gourlay	3.21	5.47	8.68	12.0	31.5	Reef
158	DIM	3.29	7.20	10.48	12.0	31.5	
159	Gourlay	2.60	7.83	10.43	12.0	31.5	Reef
160	DIM	3.62	8.08	11.69	12.0	31.5	
161	DIM	3.48	10.06	13.53	12.0	31.5	
162	DIM	3.47	9.66	13.13	12.0	31.5	
163	DIM	3.22	10.19	13.41	12.0	31.5	
164	DIM	3.52	8.82	12.34	12.0	31.5	
165	DIM	3.53	7.26	10.79	12.0	31.5	
166	DIM	4.12	6.40	10.53	12.0	31.5	
167	DIM	4.45	4.70	9.15	12.0	31.5	
168	DIM	4.22	6.05	10.27	12.0	31.5	
169	DIM	4.58	5.29	9.87	12.0	31.5	
170	DIM	4.75	5.71	10.46	12.0	31.5	
171	DIM	3.80	6.54	10.34	12.0	31.5	

Transect No.	Setup Method	Wave Setup (ft)	0.2% SWEL (ft)	Total SWEL (ft)	Wave Period (sec)	Wave Height (ft)	Note
172	DIM	4.08	5.42	9.49	12.0	31.5	
173	DIM	4.48	4.74	9.22	12.0	31.5	
174	DIM	4.70	3.67	8.37	12.0	31.5	
175	Gourlay	2.79	5.57	8.36	12.0	31.5	Reef
176	DIM	4.84	5.10	9.94	12.0	31.5	
177	Gourlay	5.73	5.28	11.01	12.0	31.5	Reef
178	DIM	5.42	4.82	10.24	12.0	31.5	
179	DIM	1.04	5.85	6.89	4.3	7.2	
180	DIM	4.27	5.49	9.77	12.0	31.5	
181	DIM	4.49	3.90	8.39	12.0	31.5	
182	Gourlay	7.35	3.51	10.86	12.0	31.5	Reef
183	DIM	4.31	3.65	7.96	12.0	31.5	
184	DIM	4.14	3.31	7.45	12.0	31.5	
185	DIM	3.85	3.77	7.63	12.0	31.5	
186	Gourlay	5.50	4.14	9.63	12.0	31.5	Reef
187	Gourlay	5.50	5.09	10.59	12.0	31.5	Reef
188	DIM	4.38	4.50	8.87	12.0	31.5	
189	DIM	0.65	4.66	5.30	3.3	4.7	
190	DIM	5.04	3.35	8.39	12.0	31.5	
191	Gourlay	4.50	4.36	8.86	12.0	31.5	Reef
192	DIM	4.94	2.51	7.45	12.0	31.5	
193	Gourlay	2.72	3.21	5.93	12.0	31.5	Reef
194	DIM	3.98	5.19	9.17	12.0	31.5	
195	Gourlay	4.87	5.06	9.93	12.0	31.5	Reef
196	DIM	4.91	5.76	10.67	12.0	31.5	
197	Gourlay	2.68	7.09	9.77	12.0	31.5	Reef
198	Gourlay	3.99	5.51	9.50	12.0	31.5	Reef
199	Gourlay	3.68	5.12	8.80	12.0	31.5	Reef
200	DIM	3.68	4.62	8.30	12.0	31.5	

Transect No.	Setup Method	Wave Setup (ft)	0.2% SWEL (ft)	Total SWEL (ft)	Wave Period (sec)	Wave Height (ft)	Note
201	DIM	4.35	5.09	9.45	12.0	31.5	
202	DIM	3.96	3.22	7.18	12.0	31.5	
203	DIM	3.64	5.49	9.13	12.0	31.5	
204	DIM	3.71	4.77	8.47	12.0	31.5	
205	DIM	4.55	6.65	11.19	12.0	31.5	
206	DIM	5.04	10.88	15.93	12.0	31.5	
207	DIM	3.71	11.36	15.07	12.0	31.5	
208	DIM	4.33	8.79	13.12	12.0	31.5	
209	DIM	4.49	7.72	12.21	12.0	31.5	
210	DIM	4.36	8.51	12.88	12.0	31.5	
211	DIM	4.01	9.01	13.01	12.0	31.5	
212	DIM	3.81	10.23	14.04	12.0	31.5	
213	DIM	3.47	8.74	12.21	12.0	31.5	
214	DIM	3.60	9.80	13.41	12.0	31.5	
215	DIM	3.41	10.30	13.70	12.0	31.5	
216	DIM	3.98	10.84	14.82	12.0	31.5	
217	DIM	3.71	8.94	12.65	12.0	31.5	
218	DIM	4.85	9.39	14.24	12.0	31.5	
219	Gourlay	3.21	10.10	13.31	12.0	31.5	Reef
220	Gourlay	3.76	10.43	14.19	12.0	31.5	Reef
221	DIM	3.93	8.02	11.95	12.0	31.5	
222	DIM	3.70	7.47	11.17	12.0	31.5	
223	DIM	3.75	7.33	11.09	12.0	31.5	
224	DIM	3.88	6.69	10.57	12.0	31.5	
225	DIM	3.97	7.28	11.26	12.0	31.5	
226	DIM	4.60	6.20	10.79	12.0	31.5	
227	DIM	4.70	4.51	9.21	12.0	31.5	Reef
228	DIM	4.95	5.36	10.31	12.0	31.5	
229	Gourlay	4.91	6.15	11.06	12.0	31.5	Reef

Transect No.	Setup Method	Wave Setup (ft)	0.2% SWEL (ft)	Total SWEL (ft)	Wave Period (sec)	Wave Height (ft)	Note
230	DIM	4.55	6.07	10.62	12.0	31.5	
231	Gourlay	4.85	6.33	11.18	12.0	31.5	Reef
232	DIM	4.73	6.47	11.21	12.0	31.5	
233	Gourlay	5.27	6.96	12.23	12.0	31.5	Reef
234	DIM	4.49	6.97	11.46	12.0	31.5	
235	DIM	4.55	6.88	11.43	12.0	31.5	
236	DIM	4.71	7.87	12.58	12.0	31.5	
237	DIM	5.06	7.56	12.62	12.0	31.5	
238	DIM	5.52	7.83	13.35	12.0	31.5	
239	DIM	5.20	7.33	12.53	12.0	31.5	
ISLAND of VIEQUES							
V1	DIM	3.96	4.36	8.32	11.2	31.5	
V2	DIM	3.86	11.47	15.33	11.2	31.5	
V3	Gourlay	3.67	11.48	15.15	11.2	31.5	Reef
V4	Gourlay	2.87	11.44	14.31	11.2	31.5	Reef
V5	DIM	4.01	10.78	14.79	11.2	31.5	
V6	Gourlay	6.73	10.50	17.23	11.2	31.5	Reef
V7	DIM	5.51	9.85	15.37	11.2	31.5	
V8	Gourlay	3.26	10.03	13.28	11.2	31.5	Reef
V9	Gourlay	3.54	9.20	12.74	11.2	31.5	Reef
V10	Gourlay	5.32	6.44	11.76	11.2	31.5	Reef
V11	Gourlay	3.09	5.62	8.71	11.2	31.5	Reef
V12	DIM	4.23	5.34	9.57	11.2	31.5	
V13	Gourlay	2.80	7.10	9.89	11.2	31.5	Reef
V14	DIM	4.40	6.75	11.15	11.2	31.5	
V15	DIM	4.28	5.29	9.57	11.2	31.5	
V16	DIM	4.15	5.18	9.33	11.2	31.5	
V17	Gourlay	4.02	5.74	9.76	11.2	31.5	Reef
V18	Gourlay	3.65	5.12	8.77	11.2	31.5	Reef

Transect No.	Setup Method	Wave Setup (ft)	0.2% SWEL (ft)	Total SWEL (ft)	Wave Period (sec)	Wave Height (ft)	Note
ISLAND of CULEBRA							
C1	Gourlay	3.01	6.27	9.29	11.2	31.5	Reef
C2	DIM	6.55	5.75	12.30	11.2	31.5	
C3	Gourlay	3.75	6.44	10.19	11.2	31.5	Reef
C4	DIM	4.62	8.54	13.16	11.2	31.5	
C5	DIM	5.04	5.72	10.76	11.2	31.5	
C6	DIM	5.67	4.20	9.87	11.2	31.5	

5.5 Appendix E: Puerto Rico Non-Standard Erosion Methodology

5.5.1 General Overview

The non-standard erosion methodology applied to the beaches of Puerto Rico was the same one applied to the beaches of St. Croix. The following appendix originated from a St. Croix Coastal Study memo dated November 18, 2002.

5.5.2 Introduction

The sandy beaches of St. Croix were characterized by 1-3 foot veneer of sand overlaying rocky ledges. Through examination of pre- and post-storm photographs, it was determined that a portion of this sand veneer was removed by wave action to expose the rocky ledge beneath.

This assumption was verified by a review of available literature (Hubbard, D. K., et al, 1991, “The Effects of Hurricane Hugo on the Reefs and Associated Environments of St. Croix, U.S. Virgin Islands – A preliminary Assessment,” Journal of Coastal Research, Vol. 8, pp 33-48), conversations with specialists in the field (Dr. Dennis Hubbard, November, 4, 2002), and site investigation (August, 2002). The erosion module of the CHAMP database did not have the capabilities to account for this type of storm-induced erosion. It was therefore determined that a non-standard approach to erosion modeling must be applied to the sandy beaches of St. Croix. The following is a brief description of the proposed methodology to model erosion on the sandy beaches of St. Croix:

5.5.3 Methodology

1. It was assumed that the mean amount removed from the sand veneer would be 2 feet along the beach, the mean value of the veneer depth. To model this, 1 foot would be removed from the 2 feet elevations and 2 feet would be removed from the landward elevations. The shoreline (0 foot station) would be preserved. Erosion modeling would stop at the first obstruction, defined as the limit of substantial vegetation or development, or where the eroded slope intersected the existing profile.

2. Elevation changes would be applied to the Adjusted Transect within CHAMP, thereby leaving the original Transect unchanged for comparison.

3. The limit of vegetation or development would be determined by examination of aerial imagery and photographs taken during site investigation. Consideration would be given to the type and amount of vegetation as it affected its ability to withstand erosion.

4. If the first obstruction occurred within 50 feet of a station, that station would be the extent of the erosion. If the distance between the first obstruction and the previous station was greater than 50 feet, a station would be added to the Adjusted Transect, at the location of the obstruction, to define the extent of storm-induced erosion.

The table below describes the type of storm induced erosion applied to the Transects of Puerto Rico in the effective coastal study.

Transect No.	Description
PUERTO RICO	
1	Rocky cliff, no vegetation.
2	Sandy beach, non-standard erosion used. Station 105 used as limit of erosion. The point at elevation 2’ eroded to 1’, elevation 4’ eroded to 2’, elevation 6’ eroded to 4’.
3	Sandy beach: PFD area, standard erosion used.
4	Sandy beach: PFD area, standard erosion used.
5	Sandy beach: PFD area, standard erosion used.
6	Sandy beach: PFD area, standard erosion used.
7	Rocky cliff, no vegetation.
8	Rocky cliff, no vegetation.
9	Sandy beach: PFD area, standard erosion used. Transect was moved west from original location after field survey.
10	Sandy beach non-standard erosion used. Transect slightly moved west of its original location. 2’ to 1’, 4’ to 2’, 6’ to 4’, 8’ to 6’, 10’ to 8’, 12’ to 10’, Station 238 used as limit of erosion.
11	Rocky cliff, no vegetation.
12	Rocky cliff, no vegetation.
13	Sandy beach : 2’ to 1’, 5’ to 3’, Station 58 used as limit of erosion.
14	High bluff with rocky beach at its base.
15	Sandy beach: PFD area, standard erosion used.
16	Rocky bluff.
17	Bluff protected by riprap.
18	Sandy beach, non-standard erosion used.
19	Sandy beach: PFD area, standard erosion used.
20	Sandy beach: non-standard erosion used. 2’ to 1’, 5.3’ to 3.3’, 8.8’ to 6.8’, Station 70 used as limit of erosion.
21	Sandy beach: PFD area, standard erosion used.
22	Sandy beach: PFD area, standard erosion used. Transect moved east of its original location after field survey.
23	Sandy beach, non-standard erosion applicable. No erosion was performed because vegetation starts at station 75 and elevation is zero from shoreline to station 75.

Transect No.	Description
24	Sandy beach, non-standard erosion used. 2’ to 1’, 4.2’ to 2.2’, 7.6’ to 5.6’, Station 130 used as limit of erosion.
25	River estuary, no erosion necessary.
26	Sandy beach. Non-standard erosion applied, 2’ to 1’, Station 89 used as limit of erosion.
27	Rocky cliff, no vegetation.
28	Sandy beach: PFD area, standard erosion used.
29	Rocky cliff, no vegetation.
30	Sandy beach, non-standard erosion applicable but not performed because first obstruction is located at first station very close (28.5 ft) from shoreline.
31	No erosion performed, start of transect exposed underlying rock. Exposed rock at beach and vegetation begins within 20’.
32	Sandy beach, non standard erosion used. Adjusted 2’ to 1’, 4’ to 2’, Station 50 used as limit of erosion due to bulkhead.
33	Sandy beach, non standard erosion used. Adjusted 2’ to 1’, 4.6’ to 2.6, Station 50 used as limit of erosion due to vegetation.
34	Rocky bluff.
35	Exposed rocks at beginning of transect, sandy beach starts at Station 380 limit of erosion at Station 410. 2’ Point added at elevation 2’. Elevation 2’ eroded to 1’ at back beach.
36	Sandy beach: PFD area, standard erosion used.
37	Sandy beach: PFD area, standard erosion used.
38	Sandy beach: PFD area, standard erosion used.
39	Sandy beach: PFD area, standard erosion used.
40	Seawall/revetment, no erosion.
41	Sandy beach: non-standard erosion used. Points added at elevations 2’ and 4’, eroded to 1’ and 2’ respectively. Limit of erosion at Station 60 due to vegetation.
42	Partially dismantled riprap: cobblers mixed to sand. No need to erode.
43	No erosion, bulkhead/revetment.
44	No erosion, bulkhead/revetment.
45	No erosion, mangrove.
46	No erosion, mangrove.
47	No erosion, bulkhead/revetment.

Transect No.	Description
48	No erosion, bulkhead/revetment.
49	No erosion, bulkhead/revetment.
50	No erosion, bulkhead/revetment.
51	Sandy beach: non-standard erosion method used. Point added at elevation 2’ reduced to 1’. Adjusted 5’ to 3’ and 6.5’ to 4.5’. Station 80 used as limit of erosion due to vegetation.
52	Short sandy beach, non-standard erosion applicable but not used. First obstruction at Station 18, no erosion performed.
53	Sandy beach: non-standard erosion used. Point added at elevation 2’ reduced to 1’. Adjusted 4’ to 2’, 6’ to 4’, and 8’ to 6’. Station 130 used as limit of erosion due to vegetation and bulkhead.
54	Sandy beach: non-standard erosion used. Point added at elevation 2’ reduced to 1’. Adjusted 4’ to 2’. Station 80 used as limit of erosion due to bulkhead.
55	Sandy beach: non-standard erosion method used. Point added at elevation 2’ reduced to 1’. Adjusted 4’ to 2’. Station 60 used as limit of erosion due to vegetation.
56	Sandy beach: non-standard erosion used. Point added at elevation 2’ reduced to 1’. Adjusted 4’ to 2’ and 6’ to 4’. Station 100 used as limit of erosion due to vegetation.
57	Sandy beach: non-standard erosion used. Point added at elevation 2’ reduced to 1’. Adjusted 4’ to 2’, 8’ to 6’, 9’ to 7’, and 8.5’ to 6.5’. Station 240 used as limit of erosion due to roadway.
58	Sandy beach: non-standard erosion applicable but not used. No erosion performed, vegetation at shoreline.
60	Sandy beach: PFD area, standard erosion used.
61	Sandy beach: PFD area, standard erosion used.
62	Sandy beach: PFD area, standard erosion used.
63	Sandy beach. Area has been developed from how it looks in the aerial. No PFD is present. Non-standard erosion used. Station 75 used as limit of erosion. Elevation 6’ eroded to 4’; elevation 4’ eroded to 2’; elevation 2’ eroded to 1’.
64	Sandy beach. PFD area, standard erosion suggested.
65	Sandy beach: non-standard erosion used. Station 71 used as limit of erosion. Elevation 4 eroded to 2’; elevation 2’ eroded to 1.
66	Sandy beach. Non-standard erosion applicable but not performed because first obstruction occurs too close to shoreline.

Transect No.	Description
67	Sandy beach. Non-standard erosion applicable but not performed first obstruction occurs at shoreline.
68	Sandy beach, non-standard erosion performed. Station 21 used as limit of erosion. Elevation 3’ eroded to 1’.
69	Sandy beach, Non-standard erosion applicable but not performed first obstruction occurs at shoreline.
70	Sandy beach, non-standard erosion applicable. Station 91’ represents the limit of erosion. Elevation 4’ eroded to 2’ and elevation 2’ eroded to 1’.
71	Sandy beach: non-standard erosion used. Station 100 used as limit of erosion. Elevation 6’ eroded to 4’; elevation 4’ eroded to 2’ and elevation 2’ eroded to 1’.
72	Sandy beach: PFD area, standard erosion used.
73	Sandy beach, non-standard erosion applicable but not performed because first obstruction occurs too close to shoreline.
74	Non-standard erosion applicable but not performed. Vegetation starts at the shoreline.
75	Short sandy beach. Non-standard erosion applicable but not performed because first obstruction occurs too close to shoreline.
77	Non-standard erosion applicable but not performed, first obstruction occurs at shoreline.
78	Sandy beach: non-standard erosion applicable but not performed, first obstruction occurs at shoreline.
79	Rocky cliff, no vegetation.
80	Non-standard erosion applicable but not performed, first obstruction occurs at shoreline.
81	Rocky Cliff, no erosion.
82	Short Sandy beach, non-standard erosion applicable but not performed because first obstruction occurs too close to shoreline.
83	Short sandy beach, non-standard erosion applicable but not performed because first obstruction occurs too close to shoreline.
86	No erosion, vegetation starts very close to shoreline.
87	No erosion, mangroves at coastline.
88	Non-standard erosion applicable but not performed: vegetation starts at shoreline.
89	No erosion, mangrove at shoreline.
91	No erosion, mangrove at shoreline.

Transect No.	Description
93	Rocky bluff, no erosion, rip rap protecting shoreline.
95	No erosion, bulkhead/revetment.
96	No erosion, mangroves at coastline.
97	Rocky Cliff, no erosion.
98	Rocky Cliff, no erosion.
99	No erosion, mangroves at coastline.
100	Rocky Cliff, no erosion.
101	No erosion, mangroves at coastline.
103	No erosion, mangroves at coastline.
104	Non standard erosion does not apply: different beach type.
105	No erosion, bulkheaded at shoreline.
106	Vegetated cliff, no erosion.
107	Short beach, then rip rap: non-standard erosion does not apply.
108	Short beach, then rip rap: non-standard erosion does not apply.
109	Non-standard erosion used. Station 71 used as limit of erosion, elevation 4' eroded to 2' and elevation 2' eroded to 1'.
110	Sandy beach, non-standard erosion applicable but not performed because first obstruction is very close to shoreline.
111	Sandy beach: non-standard erosion used. Station 30 used as limit of erosion, elevation 4' eroded to 2' and elevation 2' eroded to 1'.
112	Vegetated cliff, no erosion.
113	Sandy beach: non-standard erosion used. Station 40 used as limit of erosion, elevation 4' eroded to 2' and elevation 2' eroded to 1'.
114	Sandy beach: non-standard erosion used. Station 50 used as limit of erosion, elevation 4' eroded to 2' and elevation 2' eroded to 1'.
115	Offshore breakwater, boat dock and riprap protecting marina.
118	Sandy beach: non-standard erosion used. Station 50 used as limit of erosion. Elevation 4' eroded to 2' and elevation 2' eroded to 1'.
119	River estuary: no erosion.
120	Vegetated shoreline.
121	Sandy beach, non-standard erosion applicable but not performed because first obstruction is very close to shoreline.

Transect No.	Description
129	Non-standard erosion applicable but not performed, obstructions start close to shoreline.
130	Non-standard erosion applicable but not performed because the first obstruction starts close to shoreline.
131	Non-standard erosion applicable but not performed because the first obstruction starts close to shoreline.
132	Non standard erosion applicable but not performed because buildings start right on the coast.
133	Sandy beach: non-standard erosion not applicable. Rocky layer disappears in the area, proved both by field reconnaissance pictures and location of bathy contours (waves do not break offshore). Non-standard erosion not applicable.
134	Sandy beach. Standard erosion used, in isolated PFD area, removal case.
135	Non-standard erosion applicable but not performed due to vegetation starting at the shoreline and parts of shoreline has bulkhead.
136	Used non-standard erosion methodology. Vegetation starts at 5.6 feet elevation. Elevation 4’ eroded to 2 ’and elevation 2’ eroded to 1’.
137	Sandy Beach. Non-standard erosion applicable but not performed because obstruction starts very close to the shoreline.
138	Sandy beach. Non-standard erosion applicable but not performed because vegetation starts too close to shoreline.
139	Non-standard erosion applicable but not performed because vegetation starts too close to shoreline.
140	Non-standard erosion applicable but not performed. Transect has rocky ground already exposed or protected with bulkheads.
141	Mangroves area. Non-standard erosion method not applicable.
145	Sandy beach. Non-standard erosion performed. Vegetation starts at 5 feet elevation. Elevation 4’ have eroded to 2’ and 2 feet elevation has eroded to 1 foot.
146	No erosion has been applied due to partially protected coast.
147	Sandy Beach. PFD area, standard erosion used.
148	Sandy Beach. PFD area, standard erosion used. Note that field reconnaissance pictures refers to the back bay coastline.
149	No erosion has been applied due to concrete bulkhead at shoreline.
150	Mangroves area. Non-standard erosion method not applicable.
151	Mangroves area. Non-standard erosion method not applicable.

Transect No.	Description
152	Mangroves area and buildings close to shoreline. Non-standard erosion method not applicable.
153	No erosion has been applied due to the revetment at shoreline.
155	Sandy Beach. Non-standard applicable. Vegetation starts at 5.5 feet elevation. Elevation 4’ eroded to 2’ and elevation 2’ eroded to 1 ’.
156	Non-standard erosion applicable but not performed because vegetation and buildings starts at the shoreline.
157	Mangroves area. Non-standard erosion method not applicable.
158	Mangroves area. Non-standard erosion method not applicable.
159	Mangroves area. Non-standard erosion method not applicable. Transect moved southwest of its original location.
160	No erosion has been applied due to the concrete seawall.
161	Mangroves area. Non-standard erosion method not applicable.
162	Non-standard erosion applicable but not performed due to the buildings starting at the shoreline.
163	Mangroves area. Non-standard erosion method not applicable.
164	No evidence of beachrock layer in area.
165	No erosion has been applied: partially protected coast with buildings starts too close to the shoreline.
166	Mangroves area. Non-standard erosion method not applicable.
167	Mangroves area. Non-standard erosion method not applicable.
168	Mangroves area. Non-standard erosion method not applicable.
169	Mangroves area. Non-standard erosion method not applicable
171	No erosion has been applied due to the revetment at shoreline. Transect slightly moved northwest of its original location.
172	No erosion has been applied due to the revetment at shoreline.
174	Mangroves area. Non-standard erosion method not applicable.
175	Mangroves area. Non-standard erosion method not applicable.
177	Mangroves area. Non-standard erosion method not applicable.
178	Mangroves area. Non-standard erosion method not applicable. Transect moved south of its original location.
179	Mangroves area. Non-standard erosion method not applicable.
181	Alluvional environment: non-standard erosion not applicable.

Transect No.	Description
182	Non-standard erosion not applicable due to presence of mud flat.
184	Non-standard erosion not applicable: cliff.
185	Sandy Beach. PFD area, standard erosion used.
188	Mangroves area. Non-standard erosion method not applicable.
190	Sandy Beach. Used non-standard erosion methodology. Vegetation starts at 3.5 feet elevation. Elevation 2' eroded to 1'.
192	Seawall.
196	Sandy Beach, PFD area, standard erosion approach used.
201	Sandy Beach. Used non-standard erosion methodology. Vegetation starts at 4.1 feet elevation. Elevation 2' eroded to 1'.
203	Sandy Beach. Used non-standard erosion methodology. Vegetation starts at 4.8 feet elevation. Elevation 2' eroded to 1'.
204	Cliff.
206	Mangroves area. Non-standard erosion method not applicable.
208	Mangroves area. Non-standard erosion method not applicable. Field reconnaissance picture taken slightly west of transect location, at village's marina.
209	Bulkhead.
212	Mangroves area. Non-standard erosion method not applicable.
214	Sandy beach and PFD fronting mangroves area, standard erosion used.
2144 (214b)	Cliff. Transect added following field survey.
215	Sandy beach, Non-standard erosion applicable but not performed because vegetation starts very close to the shoreline.
217	Non-standard erosion applicable but not performed. Buildings start at shoreline.
219	No erosion has been applied due to the vegetated shoreline.
220	Shoreline protected by bulkhead.
223	Non-standard erosion applicable but not performed. But no erosion was applied because vegetation starts too close to the shoreline.
224	No erosion has been applied due to vegetation and buildings too close to shoreline.
225	No erosion has been applied due to bulkhead.
226	No erosion has been applied due to the vegetated shoreline. Transect moved northeast of its original location.
227	No erosion has been applied due to the vegetated shoreline.

Transect No.	Description
229	Non-standard erosion applicable but not performed. Vegetation starts too close to the shoreline. Transect moved south of its original location.
231	Sandy beach, Non-standard erosion applicable but not performed because vegetation starts very close to the shoreline.
233	Mangroves area. Non-standard erosion method not applicable.
234	Shoreline protected by revetment.
236	Non-standard erosion applicable but not performed. Vegetation starts very close to the shoreline.
237	Non-standard erosion applicable but not performed. Vegetation starts very close to the shoreline.
238	Non-standard erosion applicable but not performed. Vegetation starts very close to the shoreline.
239	Sandy Beach. Non-standard erosion applied. Vegetation starts at 4.1 feet elevation. Elevation 2' eroded to 1'.
249	Sandy beach. Non-standard erosion performed. Vegetation starts at elevation 8.6 ft. Elevation 6' eroded to 4', elevation 4' eroded to 2' and elevation 2' eroded to 1'.
250	Shoreline protected by revetment.
251	Non-standard erosion applicable but not performed: shoreline is too close to seawall.
252	Rocky shoreline.
VIEQUES	
1001	Sandy Beach. Used non-standard erosion methodology. Vegetation starts at 6.5 feet elevation. Elevation 4' eroded to 2' and elevation 2' eroded to 1'.
1002	Non-standard erosion method applicable but not performed: obstruction (vegetation) starts at shoreline.
1006	Sandy Beach. Non-standard erosion applicable but not performed. Vegetation starts very close to shoreline.
1008	Sandy Beach. Non-standard erosion applicable but not performed. Vegetation starts very close to shoreline.
1010	Sandy Beach. Used non-standard erosion methodology. Vegetation starts at 7.6 feet elevation. Elevation 6' eroded to 4', elevation 4' eroded to 2' and elevation 2' eroded to 1'.
1013	Mangrove shoreline. Non-standard method not applicable.

Transect No.	Description
1014	Sandy Beach. Used non-standard erosion methodology. Vegetation starts at 7.5 feet elevation. Elevation 6’ eroded to 4’, elevation 4’ eroded to 2’and elevation 2’ eroded to 1’.
1015	Sandy Beach with PFD. Standard erosion used, removal case.
1017	Sandy Beach. Used non-standard erosion methodology. Vegetation starts at 9.5 feet elevation. Elevation 8’ eroded to 6’, elevation 6’ eroded to 4’, elevation 4’ eroded to 2’and elevation 2’ eroded to 1’.