Rio Grande de Manati

Flood Risk Reduction Study

Ciales, Puerto Rico

Feasibility Report

Appendix C – Economic Analysis

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Flood Risk Management Analysis

1 Introduction

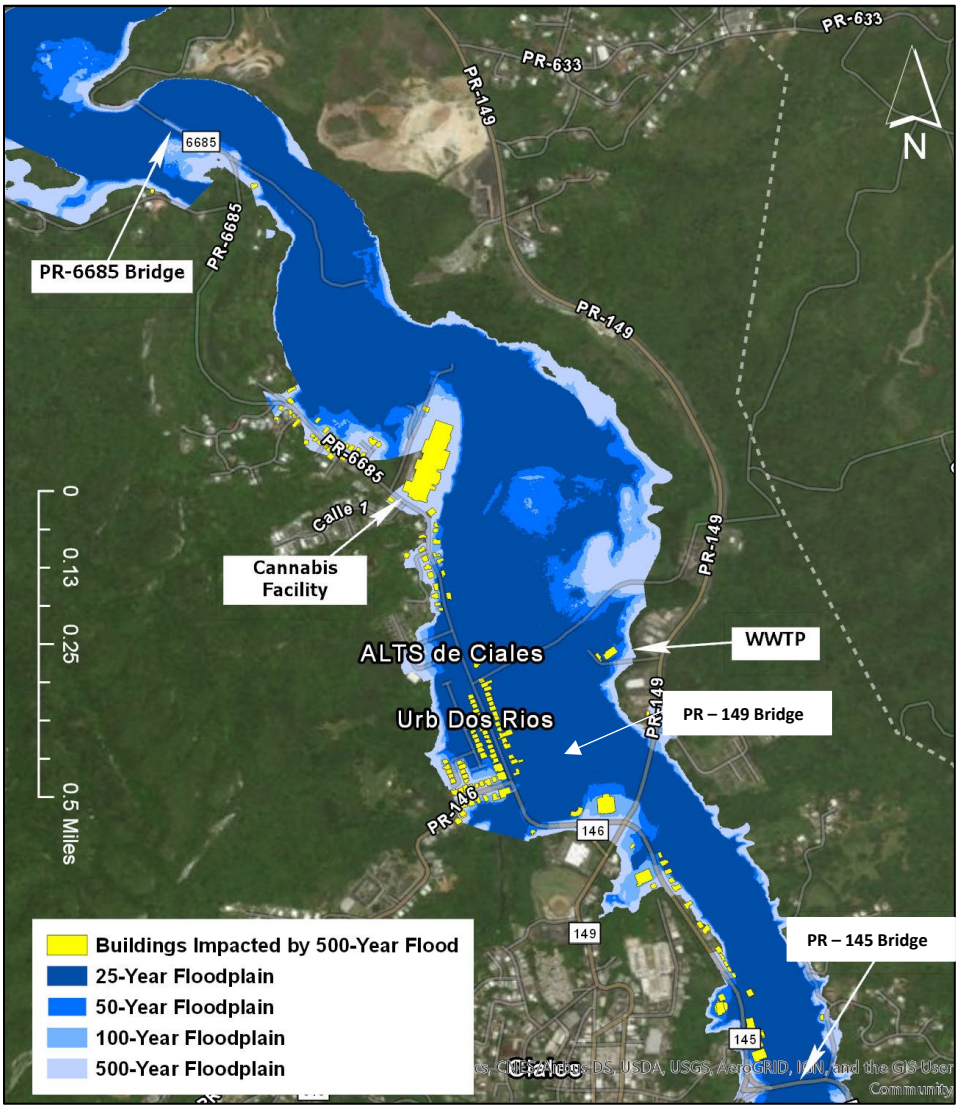
This appendix details the economic analyses that were developed for the Rio Grande de Manati Feasibility Study located in Ciales, Puerto Rico. In 2017, the majority of the structures and infrastructure in the study area were impacted by Hurricane Maria. Many of the residences and businesses were severely damaged, and the PR-145 Bridge deck was destroyed. Critical infrastructure and many structures in Ciales, PR are severely at-risk for potential damage due to regularly recurring flooding and hurricanes. This study's purpose is to determine a holistic solution that mitigates the flood risk that severely impacts this community.

1.1 Project Area

The project area includes the portion of Ciales that is located both within the 500-year floodplain and is between bridge PR-149 and bridge PR-6685. The project area is approximately 2.5 river miles long. There are no levees, floodwalls, or channel improvement projects within the study area. The entire study area is within the Rio Grande de Manati subwatershed (Hydrologic Unit Code 210100020210).

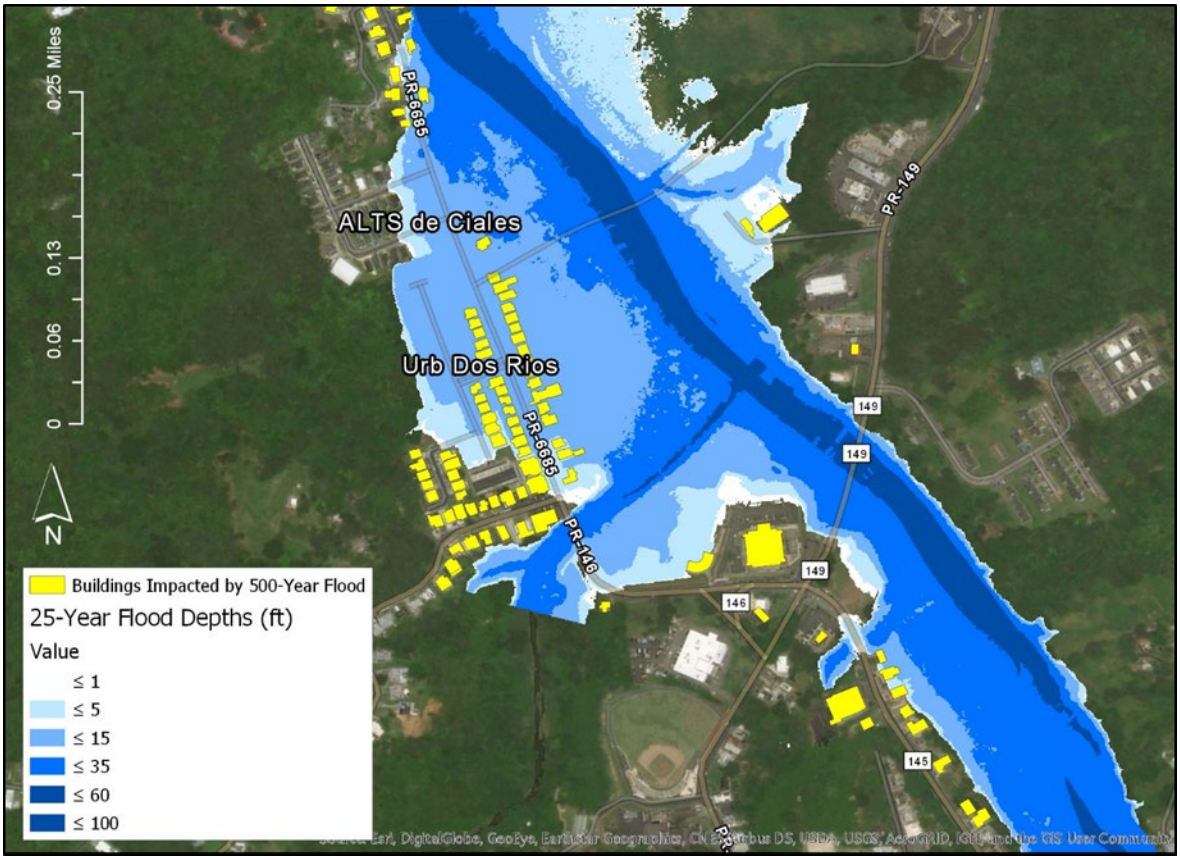
The vast majority of the structures in the study area are residential. There are some commercial, industrial, and public structures; notably there is a cannibas processing facility and a wastewater treatment plant (WWTP) in the study area. Figure 1 shows the extents of the study area and the structures impacted by the 0.002 annual chance exceedence (ACE) event, also known as the 500-year flood event; the figure also highlights the WWTP and cannabis processing facility. As shown in the figure, the WWTP is within the 0.04 ACE floodplain (25-year floodplain) and the cannabis processing facility is within the 500-year floodplain.

Figure 1. Rio Grande de Manati Study Area



The figure below shows the flood depths of a 0.04 ACE (25-year) event for Reaches A, B, and C; Reach D is not shown because no structures in this reach are impacted by the 25-year event. As shown in the figure, the inundated structures in Dos Rios experience flood depths ranging from 3 feet to 16 feet during this flood event. The yellow structures in Figure 2 are all of the structures in the study area (500-year floodplain). The vast majority of the structures in Dos Rios are within the 25-year floodplain, indicating this area is severely at-risk of flood impacts. Overall, it is estimated that 58 structures are within the 25-year floodplain; the estimated population at risk (PAR) for the 25-year event is 170.

Figure 2. Estimated Flood Depths for 0.04 ACE event – Reaches A, B, & C



1.2 Economic Analyses: Purpose and Methodology

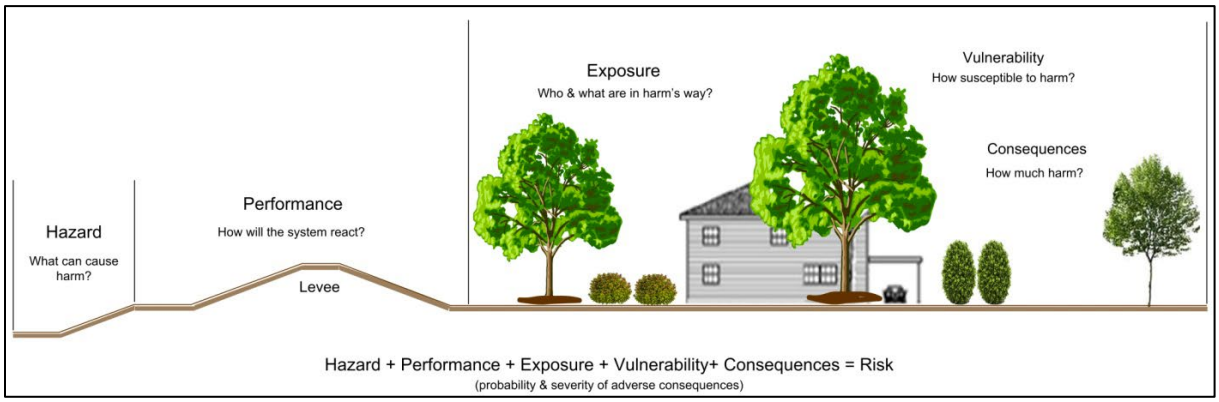
The analyses described in the following sections are used to evaluate the effectiveness and efficiency of potential flood risk reduction measures under consideration for federal investment. The U.S. Army Corps of Engineers (USACE) follows a conceptual flood risk model which is a function of the hazard, performance, and consequences.

The hazard, or potential cause for harm, for this study refers to a flood originating from the Rio Grande de Manati. The performance refers to the system's reaction to the hazard, however, there are no flood control systems in place in the study area; performance is only evaluated for structural alternatives. Finally, the consequences refer to the potential economic and/or non-economic harm that result from a single occurrence of the hazard. There are several different types of consequences that are considered in this study. The consequences of greatest concern are property damage and life safety impacts. Each of these terms are discussed more completely in ER 1105-2-101 *Risk Assessment for Flood Risk Management Studies.*

The National Economic Development (NED) Plan will be determined by calculating flood risk management (FRM) benefits for each alternative. These benefits are determined by calculating the expected annual damages (EAD) reduced, which are found by utilizing Hydrologic Engineering Center

(HEC)-Flood Damage Analysis (FDA). The alternative that maximizes net FRM benefits is the NED Plan for the Rio Grande de Manati study.

Figure 3. Flood Risk Conceptualized



The hazard and performance inputs used in the economic analyses were developed by the Project Delivery Team's (PDT) hydraulic engineer, geotechnical engineer, structural engineer, and civil engineer. These inputs are briefly discussed in this appendix; additional information can be found in the Engineering Appendix.

The majority of this appendix is focused on the development of the economic consequence information, including the application of the hazard and performance inputs to quantify the overall flood risk to structures, critical infrastructure, and the people of Ciales. The following section describes in detail the economic assumptions associated with quantifying the flood risk reduction measures. These assumptions were discussed at length with the PDT, district economists, the vertical team, and the district quality control reviewers.

Assumptions used in the evaluation of alternatives:

1) All costs and benefits are in Fiscal Year (FY) 2020 price levels.
2) The project period of evaluation is estimated to be 50 years, which includes costs associated with operation, maintenance, repair, replacement, and rehabilitation activities.
3) The FY20 federal discount rate of 2.75 is used to evaluate the NED benefits and costs (unless otherwise noted).
4) All computations including structures are based on depreciated replacement values (DRVs) developed by a USACE Real Estate appraisal team.
    a. The appraisal team developed DRVs for 40 structures, which was a representative sample of the structures located within the 0.04 ACE floodplain. Industrial, commercial, and multiple types of residential structures were included in the DRV analysis.
    b. The 40 DRVs provided by real estate were used to estimate a DRV for the structures not included in the original DRV analysis. The remaining DRVs were calculated using the average DRV per square foot and multiplying it by the structure's square footage.
5) All annualized costs were finalized by using middle of year discounting and include interest during construction.

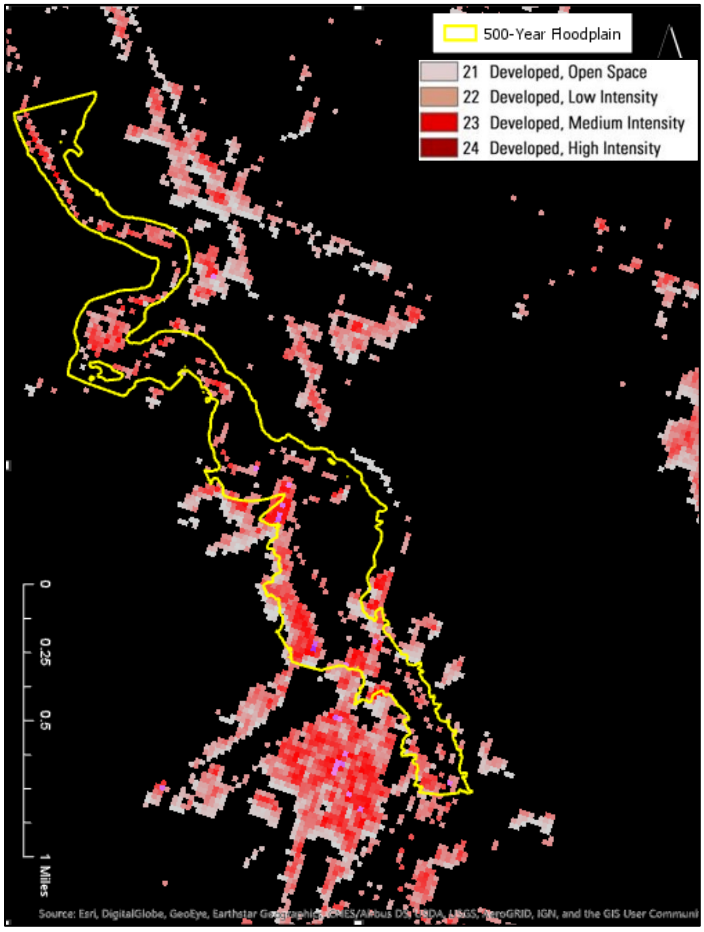
6) The project area is fully developed given the terrain, frequent flooding in the area, and the lack of undeveloped land; it will stay fully developed throughout the period of analysis.
7) All economic damages and benefits shown reflect the best estimate case (unless otherwise noted).

2. Future Without Project Condition

According to the Planning Guidance Notebook (ER 1105-2-100), potential project alternatives are to be compared to the future without project (FWOP) condition. For the purpose of this analysis, the FWOP is assumed to resemble the existing condition. The FWOP will be compared against the formulated alternatives in order to determine the NED Plan.

The National Land Cover Database shows that most of the livable space within the 500-year floodplain, has already been developed (see below in Figure 4). The project area has undeveloped land, but much of this land is considered mountainous and structures could not be built in these areas. Therefore, any flood reducing measures would not lead to an increase in development in the study area. Development in the FWOP condition would remain unchanged.

Figure 4. Impervious Land Cover Layer within the Study Area - National Land Cover Database (2001)



2.1 Hazard

The Municipality of Ciales, Puerto Rico has a long history of flooding during severe storm and hurricane events. Based on historic United States Geological Survey (USGS) gauge data, Rio Grande de Manati has exceeded flood stage 35 times within the past 50 years; the largest flood event within this time period was due to Hurricane Maria in 2017. It is estimated that Hurricane Maria produced somewhere between a 100-year and 500-year flood event in the study area. Other major flood events (stage height is greater than 16 feet) occurred in 1969, 1970, 1975, 1985, 1996, 1998, 2011, and 2012. There were also 15 moderate flood events (stage height is greater than 12 feet) and 10 flood stage events (stage height is greater than 10 feet). The stage height for each flood event can be found below in Table 1. It should be noted that throughout the study area's history of severe flooding, there have been no recorded fatalities.

Table 1. Historic Crests from the 'Rio Grande de Manati near Ciales' Gauge (1968-2018, USGS)

Major Floods[1]	
Stage Height (feet)	Year
28.33	2017
25.20	1996
24.00	1970
22.38	1998
19.75	1985
19.62	1985
18.39	1975
17.97	2011
16.37	2012
16.22	1969

Moderate Floods[2]	
Stage Height (feet)	Year
15.77	2007
14.76	2010
14.41	1992
14.13	1987
14.08	1972
14.01	1965
13.31	2014
13.03	1979
12.74	1983
12.50	1999
12.49	2005
12.20	1989
12.18	2009
12.16	2012
12.15	1981

Flood Stage[3]	
Stage Height (feet)	Year
11.92	1987
11.81	2004
11.81	1973
11.43	1979
10.83	1999
10.74	1969
10.58	2015
10.43	1984
10.35	2002
10.19	2003

[1]USGS defines a Major Flood as the stage height exceeding 16 feet
[2]USGS defines a Moderate Flood as the stage height exceeding 12 feet and less than 16 feet
[3]USGS defines a Flood Stage event as the stage height exceeding 10 feet and less than 12 feet

The Rio Grande de Manati water surface profiles (WSPs) for the economic analysis were developed by the PDT's hydraulic engineer using the HEC-River Analysis System (RAS) software. The values in Table 2 represent the mean WSPs for a given exceedance probability at various stations. The exceedance probabilities below can also be referred to as annual chance exceedance (ACE), referring to the chance, or probability, for which a given stage is anticipated to be met or exceeded each year.

Table 2. Future Without Project Condition Water Surface Profiles

Reach		**Stage by Annual Chance Exceedance[1]**

	River Station	0.5	0.2	0.1	0.04	0.02	0.01	0.005	0.002
Northern edge of Dos Rios to Route 6885 (Reach D)	**29914.84**	84.41	91.52	97.33	106.72	112.57	119.68	127.39	139.68
	29965.48	85.48	93.46	99.83	109.02	117.3	123.01	130.34	140.55
	30282.54	89.65	98.11	104.72	114.79	122.68	128.52	135.7	146.15
	30450.28	90.62	99.39	106.15	116.42	124.18	130.36	137.79	148.63
	30753	91.66	100.42	107.09	117.36	125.05	131.42	139.07	150.29
	31041.5	92.72	101.63	108.6	118.67	125.88	132.23	139.85	151.1
	31444.64	94.89	102.68	108.8	117.74	124.94	131.17	138.81	150.06
	31723.61	98.34	105.71	111.95	121.41	128.01	134.36	141.81	152.85
	32235.51	105.77	110.79	113.89	120.91	127.87	134.61	142.29	153.52
Northern edge of Dos Rios to baseball field upstream of Dos Rios (Reaches B and C)	**32325.2**	106.91	113.02	117.41	125.88	130.72	136.56	143.66	154.49
	32455.27	108.33	115.2	120.1	128.29	132.58	137.96	144.68	155.23
	32740.16	111.94	119.65	125.13	132.24	136.01	140.89	147	156.92
	32918.2	114.76	122.44	127.26	133.95	137.66	142.39	148.19	158.29
	32988.5	115.61	123.71	128.29	134.82	138.51	143.36	149.29	158.42
Baseball field upstream of Dos Rios to Bridge PR-145 (Reach A)	**33153.54**	118.59	125.67	129.8	135.76	139.15	143.62	149.43	158.29
	33200.01	118.79	125.81	129.88	135.9	139.77	146.84	153.07	160.86
	33357.12	120.12	127.27	131.83	138.7	142.95	148.78	154.77	162.7
	33597.73	122.34	129.51	134.29	141.58	145.91	151.52	157.16	164.62
	33704.47	123.37	130.52	135.28	142.57	146.91	152.48	158.05	165.46
	33860.74	124.39	131.59	136.27	143.71	148.27	154.24	160.39	168.81
	34115.96	126.05	133.39	138.32	145.75	149.85	155.38	161.36	169.75
	34155.99	128.9	138.67	142.25	150.36	154.53	159.6	164.67	171.61
	34233.57	129.87	139.51	143.44	151.87	155.56	160.24	165.07	171.73

[1] *Mean modeled river stages in feet Mean Sea Level (PRVD 02)*

For example, a 0.5 ACE event is estimated to result in a mean stage of 84.41 at the most downstream station within Reach D (river station 29914.84). The HEC-RAS model results for the study area are listed in Table 1, above. A complete explanation of the HEC-RAS model development and results can be found in Engineering Appendix

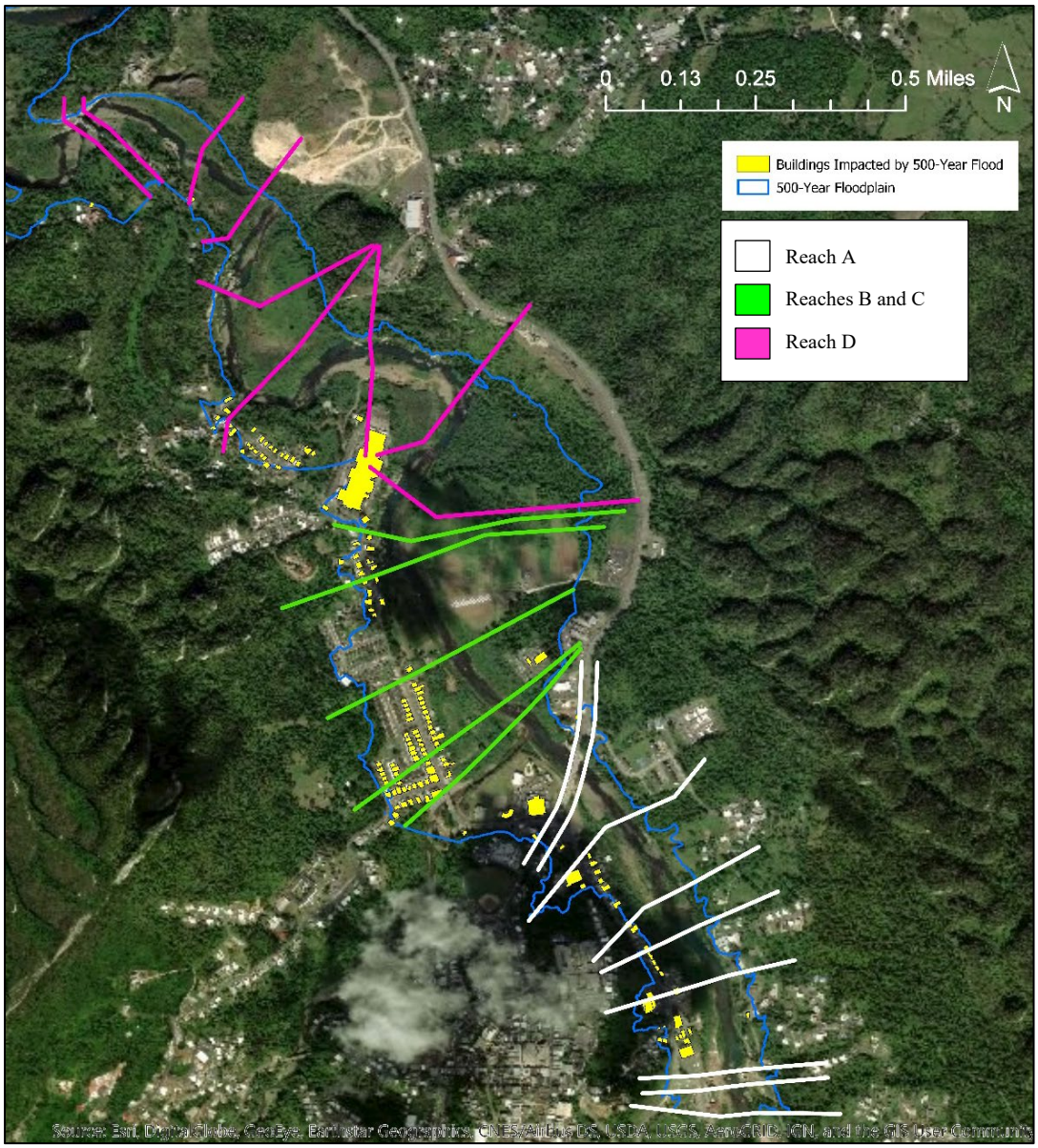
The uncertainty associated with the hydrology (flows) was based on a 54 year gage record, while the uncertainty associated with the rating curve stages was estimated to have a normal distribution with a standard deviation of 1.4 feet (Engineering Appendix). These estimates were derived in accordance with EM 1110-2-1619 "Risk-Based Analysis for Flood Damage Reduction Studies" dated 1 August 1996.

2.1.1 River Reaches in HEC-FDA

To calculate estimated property damages, a HEC-FDA model was built. As shown in Table 2, the hydraulic data used in HEC-FDA is separated into four reaches. The reaches were divided based on where a levee or floodwall was considered, or based on where the river characteristics (i.e. roughness coefficient) significantly change. Reaches B and C contain the same cross sections, or river stations, but Reach B represents the left bank and Reach C represents the right bank. The reaches are separated this way due to various management measures (i.e. floodwalls or levees) that would be implemented on either

side of the bank in this area. Figure 5 shows the location of the cross sections and reaches used in the HEC-FDA model.

Figure 5. River Stations and Reaches Used in the HEC-FDA Model



2.2 Performance

Within the vicinity of the study area, there is no infrastructure in place to reduce flooding. Therefore, the performance of a flood control structure could not be analyzed and is not included in the FWOP condition discussion.

2.3 Consequences

As discussed in section 1.2, the consequences are defined as a product of hazard, performance, exposure, and vulnerability. The following sections discuss how the consequence information was developed and utilized in the comparison and evaluation of potential alternatives. The consequences discussed below include flood damage reduction benefits and life safety risk impacts.

2.3.1 Structure Inventory

The structure inventory provides the economic basis for damage estimation and alternative evaluation. The inventory includes damages to structures, contents, and vehicles incurred during a flood event. The structure inventory developed for this study was used to evaluate flood damage reduction benefits specifically.

Emergency costs can also be included in the flood damage estimates, but there was no readily available data about emergency costs following a flooding event in Ciales, PR. Similarly, road and bridge costs can be included in flood damage estimates, however, no readily available data for road and bridge depreciated replacement values were available. The flood damage reduction benefits are somewhat underestimated due to the exclusion of these damages categories.

2.3.1.1 Methodology

In this section of the analysis, the methodology used to compile an inventory of the residential, commercial, and industrial structures in the study area will be discussed. Additionally, the methods used in the valuation of these structures, contents, and the vehicles associated with these structures will be presented. Finally, the procedures used to assign elevations to the structures, contents, and vehicles will be provided. The uncertainty inherent in the methods used to estimate each of these economic variables is addressed by the risk-based analysis included in this appendix.

2.3.1.2 Available Data

The structure inventory developed for this study relied heavily on information and pictures collected by the Real Estate (RE) appraisal team, Geospatial Information System (GIS) data, and aerial imagery. The most current tax assessor data is missing key information, such as the time of data collection, assessed values for all commercial and industrial structures, outdated assessed values, underestimated assessed values for residential homes. Additionally, it would be inaccurate to index the best available assessor data to current year prices due to hurricane and flooding impacts that occurred following the most recent assessment. The flooding impacts would result in lower appraised values.

Due to the lack of details in the tax assessor data, a RE appraisal team from USACE traveled to the study area to estimate depreciated replacement values (DRV) for a sample of structures in the study area. The ground elevations of structures and vehicles were found by utilizing the LIDAR data used in the HEC-RAS model. The foundation heights were estimated using the photographs taken by the appraisal team; the step counting method was utilized when possible (one step is equal to approximately 8 inches).

2.3.1.3 Structure Depreciated Replacement Values (DRVs)

According to Engineering Regulation 1105-2-100 (D-15), building values should be evaluated as an estimate of DRV of the structure. While neither RS Means nor Marshall & Swift estimation software packages were used to develop DRVs, an appraisal team conducted a DRV analysis within the study area.

This team has conducted several appraisals within Puerto Rico for other supplemental studies; they are accustomed to valuing structures in this region. Due to schedules and funding, the team conducted the DRV analysis on a representative sample of the structures in the study area. The entire structure inventory consists of 158 structures; 40 structures were included in the DRV sample.

This RE team also developed a Rough Order of Magnitude (ROM) cost analysis to estimate the market value and acquisition costs for structures in the study area. In conjunction with the ROM analysis, the majority of structures in the study area were photographed. As previously mentioned, these pictures were utilized to estimate the foundation height and structure type (i.e. one-story residential home, apartment building, warehouse, etc.) of each building, which are key data inputs in HEC-FDA. Some structures were not photographed due to time constraints or lack of accessibility. In these scenarios, it was assumed that the structure in question was similar to adjacent structures.

In addition to providing a DRV for each structure in the sample, the team also estimated each structure's square footage. Because the DRV and square footage was provided for each sampled structure, a representative DRV per square foot was calculated for both residential and commercial structures. The median DRV unit price (dollar per square foot) resulting from the RE analysis was used to develop DRVs for the remaining structures in the inventory. The median DRV per square foot was found to be more appropriate than the DRV per square foot due to outliers in the relatively small dataset. Table 3 shows the details of the structures sampled in the DRV analysis, including the median DRV per square foot by structure type.

Table 3. Structures Included in Real Estate's Depreciated Replacement Value Analysis

Category	Number of Structures	Median DRV ($1,000)	Median DRV/sq. ft.
Residential	33	$78	$71.15
Commercial	5	$321	$48.15
Industrial/Utility	2	$738	$97.39

For the remaining structures outside of the sample, a square footage estimate was done by utilizing the measuring tool in either Google Earth or ArcGIS. The square footage estimates for the non-sampled structures were calibrated based on the square footage estimates in the DRV sample. The square footage estimates provided by RE were also confirmed using a measuring tool; the RE estimate was consistently within 100 feet of the tool's estimate. A Building Footprints layer by Microsoft was also used to calibrate the square footage estimates of the non-sampled structures. Utilizing this layer was more accurate than using aerial imagery alone; it accurately depicts the length and width of all structures in the study area. The square footage estimates for the non-sampled structures are reasonable and align with the estimates in the RE sample.

A final DRV for each structure was then found by multiplying the appropriate DRV per square foot ratio by the structure's estimated square footage. All residential structures utilized the median residential DRV

per square foot ratio; almost all commercial, public, and industrial buildings utilized the median commercial DRV per square foot ratio. The exception is the WWTP—the methodology for the calculating the WWTP DRV can found in Section 2.3.1.3.2. The DRV sample included two structures that are part of the WWTP facility, which are two of the three industrial/utility structures shown in Table 4.

Aside from the WWTP structures, the cannabis processing plant is the only industrial facility in the study area. The estimated DRVs for the industrial structures were estimated with significant uncertainty and are only representative of WWTP structures. The median industrial/utility DRV is not representative of the cannabis processing plant. The median commercial DRV per square foot ratio was utilized for the industrial plant, which is likely a conservative estimate, however, it is the best available data. As previously mentioned, the cannabis processing plant is only impacted by larger flood events (0.002 ACE and less frequent); the estimated flood damages reductions to this structure do not significantly contribute to the overall FRM benefits for this study.

Additionally, the DRV sample did not include public buildings (i.e. churches), however, the commercial and public structures in the study area have similar construction types. Therefore, the median commercial DRV per square foot ratio was utilized to calculate the public structures' DRV. Table 4 shows a summary of the final structure values that have been incorporated into HEC-FDA.

Table 4. Rio Grande de Manati Structure Inventory

Category	Number of Structures	Average DRV ($1,000)	Total DRV[1] ($1,000)
Residential	135	$120	$16,162
Commercial	15	$229	$3,439
Industrial/Utility	3	$9,426	$28,277
Public	5	$318	$1,589
Total	**158**	**-**	**$49,467**

[1]Depreciated replacement values (DRVs) presented at FY2020 price levels

The main report lists the total number of structures in the study area as 159 and this economic appendix will state the total number of structures is 158. Following the gross appraisal (May 2020), it was determined that what was thought to be a single structure is actually two smaller structures on the same parcel. The HEC-FDA modeling was not re-done because the structure values in the model inventory would not change. As discussed above, the structure DRVs were determined based on square footage, therefore, the square footage would remain the same regardless of it is accounted for as one or two structures. The main report lists the total structure count as 159 in order to align with what is reported in the gross appraisal and the real estate plan. However, the difference in structures does not impact the structure inventory's DRVs.

2.3.1.3.1 Structure Value Uncertainty

Within the DRV analysis report, the RE appraisal team reported an uncertainty of 25% "in either direction" for the DRVs. Following discussions with the RE team, it was determined that a normal distribution with a 25% standard deviation best represented the appraisal values. Because all structure

values utilize the DRVs from the RE analysis and the structures in the study area are similar to the sampled structures in terms of construction type, age, and size, the uncertainty associated with each structure value was estimated using a normal distribution with a standard deviation of 25%.

The RE appraisal team has best professional judgment regarding the valuation uncertainty, therefore, these values are considered reasonable estimates. Additionally, the chosen distribution allows for more uncertainty regarding their estimate, especially because many of these structures have been inundated several times in the past 50 years, which may lead to inaccuracies in some DRV estimates.

2.3.1.3.2 Wastewater Treatment Plant (WWTP) Depreciated Replacement Value

The RE team also provided an estimated DRV for the WWTP, however, the team notated that they, and all appraisal teams in their USACE division, have limited experience estimating the value of WWTPs. The team's market value estimate for the WWTP was $2.0 million with a depreciation percentage of 45%, resulting in a $1.1 million DRV. Re-constructing the WWTP to current conditions would involve technical construction work, expensive materials, and rebuilding items unique to WWTPs. The DRV provided by RE is underestimated.

Better data became available following additional research. A 1978 study conducted by the U.S. Environmental Protection Agency (EPA) compiled the construction costs of all WWTPs within the U.S. The report separated construction costs based on the type of treatment plant and flow capacity. Based on an EPA fact sheet, the Ciales WWTP is a secondary treatment plant and has a flow capacity of 1.5 millions of gallons per day (MGD). The figure below is a table shown in the EPA report that shows the construction costs of secondary treatment WWTP at various design flow capacities in 1978 dollars.

Figure 6. Construction Costs of Secondary Treatment Plants in 1978 Dollars - EPA Technical Report: Construction Costs for Municipal Wastewater Treatment Plants (1973-1978)

TABLE 3.5

TOTAL PROJECT COSTS - SECONDARY TREATMENT

	Design Flow (mgd)		
	1.0	10.0	20.0
Total Construction Costs	$2,240,000	$12,030,000	$19,953,000
Step III Nonconstruction Costs (20%)*	448,000	2,406,000	3,991,000
Step I Costs (2.33%)	52,000	280,000	465,000
Step II Costs (5.55%)	124,000	668,000	1,107,000
TOTAL PROJECT COSTS	$2,864,000	$15,384,000	$25,516,000

A graph within the EPA report shows how to accurately increase construction costs as the design flow increases. Based on this graph, the construction cost (in 1978 dollars) for a 1.5 MGD WWTP is estimated to be $2.75 million. An Engineering News-Record Construction Economics construction cost index of 4.0426 was used to update the construction cost to FY2020 values: $11.1 million. This figure represents a new construction cost, not the DRV. To get this value, the RE team's estimated depreciation percentage

(45%) was used. Although the RE team underestimated the market value of the WWTP, the team still has best professional judgment when estimating depreciation percentages. The depreciation percentage estimated for the WWTP aligns with other deprecation percentages, and therefore is considered a reasonable estimate. The final DRV for the WWTP used in the economic analysis is $6.1 million.

2.3.1.4 Structure Content Values

Structure contents are defined as everything within the structure that is not permanently installed, such as rugs, appliances, and store or warehouse inventories. For the majority of residential structures, the generic depth damage curves were utilized. The residential content-to-structure-value-ratio (CSVR) damages are provided within the generic curves provided by the Corps' Institute for Water Resources (Economic Guidance Memorandum 01-03). These content-damage functions are based on the structure value and vary by structure type. For all residential structures, the content-to-structure-value-ratio is estimated at 100 percent. Each of these curves were developed to estimate content damages based on the structure value (discussed further in section 2.5). The uncertainty associated with residential content values is captured in each depth-damage function in accordance with Economic Guidance Memorandum (EGM) 01-03 (4.c.3).

All non-residential structures utilized the CSVRs from the 2009 Analysis of Non-Residential Content-to-Structure Ratios and Depth-Damage Functions for Flood Damage Reduction Studies, which was conducted by the Sacramento District. These depth damage functions and CSRVs were used in other ongoing flood risk management studies located in Puerto Rico and are deemed appropriate based on the similarities between structures in Sacramento and Puerto Rico. The 2009 analysis also calculated uncertainty for each CSVR, which has been incorporated into the economic modeling.

A few residential structures were better represented by utilizing depth damage curves and occupancy types from the North Atlantic Coastal Comprehensive Study (NACCS). There are 32 structures in the inventory that are built on either an open pile foundation or an enclosed pile foundation. These exact occupancy types are a part of the NACCS and have corresponding depth-damage functions. The study does not include a content to structure value ratio (CSVR). An estimate was made using best available data, best professional judgment, and knowledge about region; the CSRV for both of these occupancy types are 70% with uncertainty estimated with a normal distribution using a standard deviation of 25%. This CSRV may seem high, but is appropriate given the unique circumstances surrounding the residents of Puerto Rico.

The Merchant Marine Act of 1920 (also known as the Jones Act) directly impacts the cost of goods in Puerto Rico. The Jones Act bars foreign vessels from shipping goods between United States ports, which increases the cost of goods due to the increased shipping costs. The Federal Reserve Bank of New York estimates the shipping costs from the U.S. east coast to Puerto Rico are double what they are to nearby Dominican Republic, which is mostly due to the Jones Act.

The consumer is directly impacted by the increased shipping cost by paying more for goods ranging from food to large appliances. A large portion of the 3.2 million Puerto Ricans obtain their goods by way of container ships from the continental United States, which indicates the content values of homes in Puerto Rico are relatively higher. It would be more expensive to replace the same contents of a home in Puerto Rico compared to a home in the mainland. Additionally, it is likely that most of the appliances in these structures are relatively new given the severe flood impacts from recent hurricanes and flood events. The

appliances were recently replaced. This is why the 32 structures built on pile foundation have a relatively higher CSRV.

2.3.1.5 Inventory of Vehicles

The United States Census Bureau estimates that there are two vehicles per household in Puerto Rico, on average. Based on the photographs from the RE team, this aligns with the study area. In order to take into account potential evacuations, or people at work, each residential structure, with the exception of a single structure, was estimated to have one vehicle at the residence during the time of flooding. The single residential structure that does not have a vehicle assigned to it may be abandoned, so a vehicle was assumed to not be at the residence. Commercial, public, and industrial structures were estimated to have zero vehicles at the structure at time of flooding; it is assumed that businesses and churches would close if a hurricane or riverine flooding were forecasted.

Based on the photographs, the vehicles in the study area are relatively older vehicles. It is estimated that most vehicles are somewhere between 2005 and 2015 models. To get an estimate of used vehicle values, two used car websites based in Puerto Rico were used to sample vehicle prices. The majority of the vehicles were being sold from Ciales, PR. The sample includes 65 cars, which consists of a wide range of models, manufacturers, and age were in order to obtain a representative sample. However, luxury vehicle brands such as BMW, Lexus, and Mercedes were not used given the socioeconomic class of the population in the study area, and because these types of vehicles were not included in the photographs.

Based on this method, the average used car price in Ciales, PR is $10,161, which was applied to all vehicles in the study area. All vehicles utilized the 'Non Surveyed-Auto' occupancy type from the *Analysis of Non-Residential Content-to-Structure Ratios and Depth-Damage Functions for Flood Damage Reduction Studies.* The default uncertainty is a standard deviation of 82%, which is appropriate given the uncertainty associated with amount of vehicles in the study area, vehicle DRVs, and vehicle types.

2.3.1.6 Structure and Vehicle Elevation Estimates

No physical elevation surveys were completed as a part of this analysis. Instead, these estimates reflect the best available information, which includes photographs, LIDAR data, and aerial imagery. The ground elevation was found by using the LIDAR data that was used in the HEC-RAS model. The ground elevation for each structure represents the lowest ground elevation found for each structure using the LIDAR data. Many of the structures were built on slab and were assumed to have a foundation height of 0.5 feet, which may be considered conservative.

Other structures were built on piers; these foundation heights were estimated by using the pictures and utilizing other objects in the picture, such as vehicles and stairs, as references. Other structures were built on open or enclosed piles; these foundation heights are assumed to be 9 feet. This assumption is based on step counting, pictures, and the NACCS assumptions. In many instances, a car or SUV was parked underneath the structure. This indicates that the foundation height was at least 6 to 7 feet tall, and there was generally at least two feet between the top of the car and the first floor.

Uncertainty for both the foundation heights and ground elevations were incorporated into the HEC-FDA model. Table 9.1 in the HEC-FDA 1.4.2 User Manual provides a standard deviation for the ground elevation based on the LIDAR resolution. The LIDAR used in the hydraulic model has a resolution of one meter (3.28 feet), which indicates a standard deviation of 0.6 feet should be used for the ground elevation

of all structures. Table 9.1 in the model's User Manual lists different standard deviations that correspond to aerial surveys with various contour intervals. The table lists a 2-foot contour interval standard deviation and a 5-foot contour interval, and the study's 3.28-foot contour interval is near the middle of these two intervals. The team's hydraulic engineer and economist decided to use the more conservative standard deviation (5-foot contour interval) because the LIDAR used to estimate the structures' ground elevation was surveyed prior to Hurricane Maria. The study area was significantly impacted by Hurricane Maria, which indicates the terrain has changed since the last LIDAR survey. Opting to use the higher standard deviation in the HEC-FDA model accounts for a portion of the uncertainty associated with using the pre-Hurricane Maria LIDAR data.

The uncertainty surrounding foundation heights was based on best professional judgment and the availability of data. The uncertainty varied based on the type of foundation (slab, piers, or piles) and how easily the foundation height could be determined in pictures. For residential, commercial, and public structures built on slab, the standard deviation was estimated to be 0.3 feet. It is likely that a portion of the structures have a foundation height of 0 feet; conversely, some portion of the foundation heights are likely more than 0.5 feet, but not over one foot, so this level of uncertainty is appropriate.

For industrial structures, the foundation height uncertainty was more conservative (standard deviation of 0.7 feet). The pictures of the few industrial structures in the study area did not clearly show the foundation height, but it is known that these structures are built on slab. The slightly higher standard deviation aligns with the higher uncertainty associated with the industrial structures.

The first floor elevation uncertainty for a structure is based on both the ground elevation standard deviation and foundation height standard deviation. In order to get the first floor elevation standard deviation, these two standard deviations need to be combined. However, it would be statistically inaccurate to add the standard deviations. To find the first floor elevation standard deviation, each standard deviation (ground elevation and foundation height) must be squared, those values are then added to produce the sum of squares, or sum of variances. The square root of the sum of squares then produces the first floor elevation standard deviation. The calculations for each structure category and foundation type can be found in the table below.

Table 5. First Floor Elevation Uncertainty by Category and Foundation Type

	Residential			**Commercial**	**Public**	**Industrial**
Foundation Type	Pier	Slab	Piles	Slab	Slab	Slab
Ground elevation std. dev.	0.60	0.60	0.60	0.60	0.60	0.60
Ground elevation std. dev. squared	0.36	0.36	0.36	0.36	0.36	0.36
Foundation Height std. dev.	1.18	0.30	1.0	0.30	0.30	0.70
Foundation Height std. dev. squared	1.39	0.09	1.0	0.09	0.09	0.49
Sum of Squares (Sum of Variances)	1.75	0.45	1.36	0.45	0.45	0.85
Square Root of Sum of Squares (First Floor Elevation std. dev.)	**1.32**	**0.67**	**1.17**	**0.67**	**0.67**	**0.92**

Each residential structure has a single vehicle assigned to it. The vehicle has the same stationing and ground elevation as the structure. Many of the homes have carports or driveways. If a home does not have a carport or driveway, it unknown where exactly their vehicle would be parked; however, using the ground elevation of the structure is the best available data. The vehicles do not have foundation heights, only a ground elevation with uncertainty.

2.3.1.7 Structure Inventory by River Reach

As previously stated, within the HEC-FDA model there are four river reaches. Each of these reaches were separated based on the potential for a structural management measure (i.e. floodwall or levee) to be implemented. Theses reaches were developed with the team's hydraulic engineer, and it was determined that the reaches did not have to be further separated based on hydrologic and/or hydraulic factors. The table below shows the number of structures, types of structures, and total DRV for each reach used in HEC-FDA. For reference, the reaches are shown in Figure 5, which is in Section 2.1.1.

Reach A primarily consists of residential structures. There are also several commercial structures in this reach. This includes five restaurants, a cockfighting ring, and a pet store. There are also three public structures: one church, and two public recreational facilities. Within Reach A, there are 15 structures in the 0.04 ACE floodplain.

Reach B also primarily consists of residential structures, most of which are located in Urb Dos Rios, which is a neighborhood within the Municipality of Ciales, PR. This is area is mostly low-income houses. About half of the residential structures in Dos Rios are public housing; the public housing authority in this region is in the process of purchasing these structures and removing the families from the floodplain. Therefore, the public housing structures were not included in the study's structure inventory. The handful of commercial structures consist of three grocery store structures, one restaurant, and on gas station. There are also two churches (public) and one small industrial structure. Of the 85 structures, 43 are within the 0.04 ACE floodplain.

Reach C contains the same river stations as Reach B, but only consists of structures on the right bank. There are only two structures in this reach; both are associated with the WWTP. The commercial structure is the WWTP office building. The industrial/utility structure is the WWTP. Both of the structures in this reach are within the 0.04 ACE floodplain.

Reach D is primarily consists of residential structures; none of these structures are within Urb Dos Rios. Additionally within this reach there is one restaurant and the cannabis processing plant, which employs 75 people. None of the structures in this reach are within the 0.04 ACE floodplain; the cannabis processing plant is within the 0.002 ACE floodplain.

Table 6. Structure Inventory by River Reach

River Reach	Number of Structures					Number of Vehicles	Total DRV ($1,000s)
	Residential	Commercial	Public	Industrial / Utility	Total		
Reach A	28	8	3	0	39	28	$6,586
Reach B	77	5	2	1	85	77	$12,101
Reach C	0	1	0	1	2	0	$6,576

Reach D	30	1	0	1	32	30	$25,920
Total	135	15	5	3	158	135	$51,183

2.3.1.8 Depth-Damage Functions

As mentioned in the previous sections, depth-damage functions from three various sources were utilized. Generic Depth Damage Curves for Residential Structures with Basements (EGM 04-01) was utilized for residential structures built on either slab or piers. The NACCS depth-damage functions were utilized only for residential structures built on either open or enclosed pile foundations.

Finally, the depth-damage functions that were developed in the 2009 Analysis of Non-Residential Content-to-Structure Ratios and Depth-Damage Functions for Flood Damage Reduction Studies, which was conducted by Sacramento District (USACE), were utilized for all commercial, industrial, and public structures, as well as all vehicles. There are very few structures (23 of 157) in the study area that utilize these depth-damage functions. These non-residential depth-damage functions were used in other ongoing flood risk management studies located in Puerto Rico, and the vertical team preferred to have the studies use the same curves when applicable. There are limited depth-damage functions for commercial, industrial, and public structures available for areas in the continental United States, and there are none available for Puerto Rico specifically. Ciales, PR is in north-central Puerto Rico and is not a coastal city. Additionally, the Rio Grande de Manati consists primarily of freshwater due to surface water runoff. Sacramento flooding is also primarily freshwater instead of salt water, which indicates the type of flooding is similar in these two areas.

Due to the lack of depth-damage functions that are applicable to Puerto Rico, the Sacramento non-residential functions are deemed appropriate by the PDT and vertical team. The majority of the commercial and public structures in the study area that are masonry, concrete, or are reinforced with concrete. The three industrial structures are steel, which generally aligns with the construction type used for industrial buildings in the continental United States, including Sacramento. Additionally, the Sacramento study contains depth-damage functions for specific occupancy types (i.e. Non-Surveyed Commercial Restaurants 1-Story), which shows it is also the best available data for this study. Table 6 shows the occupancy types, occupancy descriptions, identifies the corresponding depth-damage function source, and shows how many structures are identified as that specific occupancy type.

Table 7. Occupancy Types and Occupancy Descriptions used in HEC-FDA

Category Name	Occupancy Name	Occupancy Description	Source	Number of Structures
RES	1SNB-P	One Story, No Basement, Built on Piers	1	16
	1SNB-S	One Story, No Basement, Built on Slab	1	78
	2SNB-P	Two Stories, No Basement, Built on Piers	1	3
	2SNB-S	Two Stories, No Basement, Built on Slab	1	6
	RES-OP	One or More Stories, Built on Open Pile Foundation	2	8
	RES-EP	One or More Stories, Built on Pile Foundation with Enclosure	2	24
COM	NS-C-GROC1	Non-Surveyed Commercial Food Retail, 1-Story	3	3
	NS-C-OFF1	Non-Surveyed Commercial Office, 1-Story	3	1

	NS-C-REST1	Non-Surveyed Commercial Restaurants 1-Story	3	7
	NS-C-RET1	Non-Surveyed Retail Store 1-Story	3	3
	NS-C-SERV1	Non-Surveyed Commercial Service-Auto 1-Story	3	1
IND	NS-I-HV1	Non-Surveyed Industrial Heavy Manufacture 1-Story	3	1
	NS-I-LT1	Non-Surveyed Industrial Light, Small, 1-Story	3	2
PUB	NS-P-CH1	Non-Surveyed Public Church, 1-Story	3	2
	NS-P-CH2	Non-Surveyed Public Church, 2-Story	3	1
	NS-P-REC1	Non-Surveyed Public Recreation/Assembly, 1-Story	3	2
AUTO	NS-Auto	Non-Surveyed Automobile	3	135 Autos

[1] *EGM 04-01, Generic Depth-Damage Relationships for Residential Structures with Basements*
[2] *North Atlantic Coastal Comprehensive Study (NACCS)*
[3] *Analysis of Non-Residential Content-to-Structure Ratios and Depth-Damage Functions for Flood Damage Reduction Studies (2009)*

2.3.4 FWOP Damage Estimates

As stated previously, the estimation of the FWOP damages is required as the effectiveness for all potential alternatives are to be measured against the FWOP condition. The following sections provide a discussion of the FWOP damages by event and how these estimates were developed.

2.3.5 Stage-Damage

In order to calculate the damages from the inundation of structures (and associated contents) that would occur at each stage, two types of relationships were developed: the stage-damage relationship and the stage-frequency relationship. The stage-damage relationship is the estimated amount of damage that will occur to structures (and associated contents) as the elevation of the water (or stage) rises. The stage-frequency relationship is the probability of the stage reaching various levels for each hydrologic reach.

The uncertainties associated with the development of these relationships are addressed by risk-based analysis. A range of possible values, either with maximum and minimum values, or standard deviations, was calculated for each economic variable (structure and content values, first floor elevation, and stage-damage relationships). These statistics were entered into HEC-FDA version 1.4.2 to calculate the uncertainty or error surrounding each input. The program also used the number of years that stages were recorded at a given gage to determine the hydrologic uncertainty surrounding the stage-frequency curves. The possible occurrences of each variable were derived through Monte Carlo simulations.

The sum of all sampled values, divided by the number of samples, yielded the expected value, or mean. This process was conducted simultaneously for each economic and hydrologic variable. The resulting mean and probability distributions formed a comprehensive picture of all possible outcomes.

Table 8. FWOP Aggregated Stage-Damage Function (Reach A)

Approximate ACE	**River Stage**	**Damages by Category ($1,000s)[1]**			**Total**
		Structures & Contents		**Other Damages**	
		Residential	**Non-Residential**	**Vehicles**	

Ranges from 0.5 to 0.2	120	-	-	-	-
	125	-	-	-	-
Ranges from 0.2 to 0.01	130	-	-	-	-
	135	75.2	-	6.2	81.4
	140	394.0	155.1	32.9	582.0
	145	784.2	415.8	68.9	1,268.9
Ranges from 0.04 to 0.005	150	1,091.3	1,226.6	96.8	2,414.7
	155	1,546.9	1,704.5	134.0	3,385.4
	160	2,112.3	2,335.4	153.1	4,600.8
Ranges from 0.005 to 0.002	165	2,651.4	2,986.5	201.3	5,839.3
	170	3,429.5	3,109.5	240.8	6,779.8
	175	3,962.0	3,475.9	268.7	7,706.5
Less frequent than 0.002	180	4,297.4	3,520.3	286.9	8,104.6
	185	4,413.0	3,530.0	289.4	8,232.3

[1]*Damages are presented in FY2020 price levels*

Table 9. FWOP Aggregated Stage-Damage Function (Reach B)

Approximate ACE	River Stage	Damages by Category ($1,000s)[1]			Total
		Structures & Contents		Other Damages	
		Residential	Non-Residential	Vehicles	
Ranges from 0.2 to 0.1	120	21.1	1.0	2.8	24.9
	125	503.0	512.5	82.5	1,098.0
Ranges from 0.04 to 0.02	130	1,855.8	754.0	307.8	2,917.6
	135	3,736.6	2,110.9	406.3	6,253.8
Ranges from 0.02 to 0.005	140	4,925.4	2,855.6	451.2	8,232.3
	145	5,737.5	3,097.5	524.4	9,359.4
Ranges from 0.005 to 0.002	150	7,828.3	3,163.6	619.3	11,611.2
	155	9,047.6	3,177.5	675.2	12,900.3
	160	9,672.9	3,182.3	697.7	13,552.9
Less frequent than 0.002	165	9,948.2	3,182.3	708.3	13,838.8
	170	10,026.3	3,182.3	709.4	13,918.0

[1]*Damages are presented in FY2020 price levels*

Table 10. FWOP Aggregated Stage-Damage Function (Reach C)

Approximate ACE	River Stage	Damages by Category ($1,000s)[1]		Total
		Structures & Contents	Other Damages	

		Residential	Non-Residential	Vehicles	
Ranges from 0.2 to 0.1	120	-	-	-	-
	125	-	-	-	-
Ranges from 0.04 to 0.02	130	-	2.3	-	2.3
	135	-	1,770.2	-	1,770.2
Ranges from 0.02 to 0.005	140	-	4,397.9	-	4,397.9
	145	-	4,906.2	-	4,906.2
Ranges from 0.005 to 0.002	150	-	5,085.1	-	5,085.1
	155	-	5,086.8	-	5,086.8
	160	-	5,086.8	-	5,086.8
Less frequent than 0.002	165	-	5,086.8	-	5,086.8
	170	-	5,086.8	-	5,086.8

[1]*Damages are presented in FY2020 price levels*

Table 11. FWOP Aggregated Stage-Damage Function (Reach D)

Approximate ACE	River Stage	Damages by Category ($1,000s)[1]			Total
		Structures & Contents		Other Damages	
		Residential	Non-Residential	Vehicles	
Ranges from 0.04 to 0.01	120	-	-	-	-
	125	-	-	-	-
Ranges from 0.01 to 0.005	130	88.0	-	15.9	103.9
	135	349.5	-	72.1	421.6
Ranges from 0.005 to 0.002	140	1,059.3	-	131.4	1,190.7
	145	2,263.1	24,895.9	249.5	27,408.5
	150	3,500.7	50,887.6	338.4	54,726.7
	155	4,939.0	52,913.4	404.3	58,256.7
Less frequent than 0.002	160	5,942.0	53,490.6	435.4	59,868.0
	165	6,636.6	53,497.1	435.8	60,569.5

[1]*Damages are presented in FY2020 price levels*

3. Structural Alternatives

Potential project alternatives are to be compared to the FWOP condition (ER 1105-2-100). For the purpose of this analysis, the FWOP is assumed to be essentially the same as the existing condition (see Section 2). The PDT developed three structural alternatives to be considered in this study. The following alternatives considered modification to the channel, the streambanks, and/or the implementation of flood

control structures (i.e. a levee or floodwall). Each of the following alternatives were modeled in HEC-RAS and HEC-FDA; the subsequent sections describe the results of those modeling efforts.

Alternative 1. Levee/Floodwall System: This alternative incorporates the original, locally-developed flood protection works plan and specifications and a floodwall around the wastewater treatment plant.

Alternative 2. Channel Modification: This alternative includes excavation and construction of a meandering low flow channel with increased capacity and improved hydraulic conductivity. Alternative 2 also incorporates a floodwall around the wastewater treatment plant.

Alternative 4. Channelization: Channelization involves construction of a concrete-lined channel designed to increase capacity and improve hydraulic conductivity. The channel was designed to contain a 0.04 AEP event. Designing the channel to contain larger storm events was not feasible given existing channel dimensions and without the need to significantly alter existing public and provide infrastructure.

3.1 Hazard

In each alternative, the characteristics of the river channel would change and/or a flood control structure (i.e. floodwall or levee) would be constructed. Due to both of these measures, each of the structural alternatives has a unique WSP. As stated in Section 2.1, the values show in the tables below represent the mean WSPs for a given exceedance probability, or also known as ACE, at various stations.

Table 12. Alternative 1 (Levee/Floodwall System) Water Surface Profiles

Reach	River Station	Stage by Annual Chance Exceedance[1]							
		0.5	0.2	0.1	0.04	0.02	0.01	0.005	0.002
Northern edge of Dos Rios to Route 6885 (Reach D)	**29914.84**	84.41	91.52	97.33	106.72	112.57	119.68	127.39	139.68
	29965.48	85.48	93.46	98.83	109.02	117.3	123.01	130.34	140.55
	30282.54	89.65	98.11	104.72	114.79	122.68	128.52	135.7	146.15
	30450.28	90.62	99.39	106.15	116.42	124.18	130.36	137.79	148.63
	30753	91.66	100.42	107.09	117.36	125.05	131.42	139.07	150.29
	31041.5	92.72	101.63	108.6	118.67	125.88	132.23	139.85	151.1
	31444.64	95.1	102.87	108.96	117.88	125.01	131.21	138.83	150.05
	31723.61	99.81	106.42	112.26	121.53	128.09	134.43	141.87	152.89
	32235.51	105.79	109.98	113.32	120.5	127.63	134.39	142.09	153.29
Northern edge of Dos Rios to baseball field upstream of Dos Rios (Reaches B and C)	**32325.2**	106.83	112.49	117.15	125.48	130.36	136.1	143.12	153.91
	32455.27	107.17	113.23	118.19	126.71	131.55	137.21	144.07	154.7
	32740.16	106.42	112.07	117.21	126.31	131.13	137.24	144.77	155.39
	32918.2	111.34	118.26	123.07	130.62	135.22	140.35	145.95	156.66
	32988.5	112.05	119.14	124.56	131.8	136.21	141.19	147.12	156.85
Baseball field upstream of Dos Rios to Bridge PR-145 (Reach A)	**33153.54**	116.41	123.19	127.3	133.37	137.24	141.75	147.36	156.72
	33200.01	116.88	123.53	127.6	133.58	141.15	145.01	151.71	160.08
	33357.12	118.47	125.27	129.73	136.58	143.24	146.85	152.9	161.11
	33597.73	120.93	127.65	132.26	139.49	145.54	149.64	155.33	163.06
	33704.47	122.47	128.97	133.44	140.55	146.32	150.51	156.1	163.71
	33860.74	123.92	130.49	134.84	141.8	147.56	152.14	158.18	166.67

	34115.96	125.73	132.69	137.4	144.81	149.37	153.76	159.43	167.79
	34155.99	128.9	135.22	141.56	149.87	154.31	158.99	164.02	170.84
	34233.57	129.87	136.63	142.87	151.52	155.4	159.71	164.48	171.01

[1] *Mean modeled river stages in feet Datum Mean Sea Level (PRVD 02)*

Table 13. Alternative 2 (Channel Modification) Water Surface Profiles

Reach	River Station	Stage by Annual Chance Exceedance[1]							
		0.5	**0.2**	**0.1**	**0.04**	**0.02**	**0.01**	**0.005**	**0.002**
Northern edge of Dos Rios to Route 6885 (Reach D)	**29914.84**	84.41	91.52	97.33	106.72	112.57	119.68	127.39	139.68
	29965.48	85.48	93.46	99.83	109.02	117.3	123.01	130.34	140.55
	30282.54	89.65	98.11	104.72	114.79	122.68	128.52	135.7	146.15
	30450.28	90.62	99.39	106.15	116.42	124.18	130.36	137.79	148.63
	30753	91.66	100.42	107.09	117.36	125.05	131.42	139.07	150.29
	31041.5	92.35	101.43	108.44	118.61	125.87	132.24	139.88	151.15
	31444.64	92.72	101.8	108.67	118.46	125.51	131.68	139.13	150.15
	31723.61	93.18	102.31	109.42	119.65	126.85	133.35	141.06	152.41
	32235.51	96.71	104.6	110.45	119.77	126.79	133.3	141.07	152.49
Northern edge of Dos Rios to baseball field upstream of Dos Rios (Reaches B and C)	**32325.2**	97.5	105.25	111.07	120.42	127.32	133.82	141.54	152.88
	32455.27	98.53	106.16	111.91	121.09	127.78	134.2	141.81	153.1
	32740.16	105.15	110.39	115.26	123.53	130.02	136.29	143.56	154.52
	32918.2	113.91	121.14	125.72	131	134.45	139.22	145.41	155.48
	32988.5	114.94	122.75	127.23	132.47	135.88	140.62	146.81	156.99
Baseball field upstream of Dos Rios to Bridge PR-145 (Reach A)	**33153.54**	118.23	125.21	129.1	134.8	137.17	141.32	147.2	156.93
	33200.01	118.51	125.41	129.27	134.25	141.14	144.55	151.61	160.21
	33357.12	119.64	126.63	130.93	137	143.24	146.57	152.81	161.22
	33597.73	121.55	128.5	133.05	139.76	145.53	149.45	155.27	163.15
	33704.47	122.83	129.57	134.07	140.78	146.32	150.35	156.05	163.79
	33860.74	124.16	130.92	135.29	142.01	147.55	152	158.14	166.74
	34115.96	125.91	132.95	137.69	144.89	149.37	153.66	159.39	167.85
	34155.99	128.9	135.32	141.78	149.9	154.31	158.96	163.99	170.89
	34233.57	129.87	136.71	143.05	151.54	155.41	159.68	164.45	171.06

[1] *Mean modeled river stages in feet Datum Mean Sea Level (PRVD 02)*

Table 14. Alternative 4 (Channelization) Water Surface Profiles

Reach	River Station	Stage by Annual Chance Exceedance[1]							
		0.5	**0.2**	**0.1**	**0.04**	**0.02**	**0.01**	**0.005**	**0.002**
Northern edge of Dos Rios to	**29914.84**	84.41	91.52	97.33	106.72	112.57	119.68	127.39	139.68
	29965.48	85.48	93.46	99.83	109.02	117.3	123.01	130.34	140.55
	30282.54	89.65	98.11	104.72	114.79	122.68	128.52	135.7	146.15

Route 6885 (Reach D)	**30450.28**	90.62	99.39	106.15	116.42	124.18	130.36	137.79	148.63
	30753	90.56	99.01	105.43	115.24	123.13	129.15	136.5	147.22
	31041.5	90.73	99.34	106.12	116.81	124.65	131.03	138.62	149.74
	31444.64	90.7	99.2	105.79	115.71	123.05	128.52	135.06	144.47
	31723.61	88.11	97.95	105.17	116.42	124.64	131.3	139.27	150.99
	32235.51	92.62	96.53	99.77	105.15	120.23	125.69	133.77	145.84
Northern edge of Dos Rios to baseball field upstream of Dos Rios (Reaches B and C)	**32325.2**	91.97	96.2	99.55	105.08	120.28	125.69	134.56	147.04
	32455.27	91.35	95.75	99.19	104.91	109.41	125.31	134.72	147.88
	32740.16	104.85	110.24	113.93	120.78	126.1	132.3	138.21	145.93
	32918.2	106.22	112.02	116.21	125.13	129.23	138.3	146.07	158.88
	32988.5	108.09	114.79	119.97	129.77	134.28	140.79	148.55	159.13
Baseball field upstream of Dos Rios to Bridge PR-145 (Reach A)	**33153.54**	108.8	115.3	121.15	130.04	134.33	140.5	148.03	158.36
	33200.01	109.41	116.09	122.27	131.6	141.14	142.11	150.96	161.13
	33357.12	110.32	116.76	122.47	131.33	140.57	140.94	148.98	158.19
	33597.73	111.95	117.5	122.33	131.09	140.71	141.29	149.05	157.24
	33704.47	115.44	121.5	125.86	133.63	141.73	144.12	151.47	160.55
	33860.74	117.45	123.68	128.26	135.72	144.2	149.51	158.14	169.55
	34115.96	123.42	129.54	134.18	141.45	147.09	151.74	159.31	170.41
	34155.99	128.9	132.85	142.02	148.09	153.28	158.26	163.96	171.98
	34233.57	129.87	134.98	143.25	150.25	154.72	159.1	164.43	172.09

[1] *Mean modeled river stages in feet Datum Mean Sea Level (PRVD 02)*

3.2 Performance

The performance of a system or structure is not applicable in the FWOP condition; as stated previously, there are no flood control systems or structures in place within the vicinity of the study area. The proposed flood control structures (i.e. floodwall or levee) would be built to current standards, which would essentially eliminate the risk of breaching. This near-zero risk of failure is included in HEC-FDA as a levee that will not breach prior to overtopping. However, the residual risk of flooding due to an event that exceeds the crest elevation (overtopping) remains.

3.3 Consequences

These alternatives do not directly alter the consequences, as such the economic inputs for these alternatives remain the same as the FWOP condition (see Section 2.3). However, because the hazard changes under each alternative, both life safety risk and depth of flooding are altered.

3.3.1 Structure Inventory

The structure inventory for all structural alternatives remains the same as the FWOP condition (see Section 2.3.1).

3.3.2 Life Safety Risk

As shown in the WSPs tables under Section 3.1, each of the structural alternatives defined in Section 3 results in relatively lower WSPs. For example, during the 0.01 ACE event under the FWOP condition, the

stage is 143.62 feet at river station 33153.54 (Reach A). Under Alternative 4 (Channelization), the stage at the same river station is 140.5 feet. The decrease in WSPs results in lower depths on structures, which results in decreased life safety risk.

3.3.3.1 Depth of Flooding

The estimated inundation boundary and flood depths would be altered following the implementation of each structural alternative. To illustrate the changes in flood depths on the most at-risk structures, the figures below show the 0.04 ACE (25-year event) flood depths within Reaches A, B, and C; Reach D is not shown in the figures below because there are no structures impacted by the 25-year event. Figure 2 in Section 1.1 shows the estimated 0.04 ACE flood depths under the FWOP condition.

As shown in the figures below, Alternative 1 (Figure 7) reduces the most flooding with the implementation of the levee surrounding Dos Rios and the floodwall around the WWTP. It is estimated that this alternative results in a PAR of 20 for a 0.04 ACE event, which is a PAR reduction of 150. Alternative 2 (Figure 8) does not considerably reduce the inundation boundary, but there is a significant reduction in flood depths. The PAR for a 0.04 ACE event is essentially unchanged; it is estimated the channel modification alternative reduces PAR by six. Alternative 4 (Figure 9) also significantly reduces flood depths due to the increased channel capacity. Under this alternative PAR for the 0.04 ACE event is reduced by about 70. For alternatives, it is estimated that life loss is 0. There have been 10 major floods (Table 2) within the past 50 years, and there have been zero flood induced fatalities.

Figure 7. Alt. 1 (Levee/Floodwall System) 0.04 ACE Flood Depths – Reaches A, B, & C

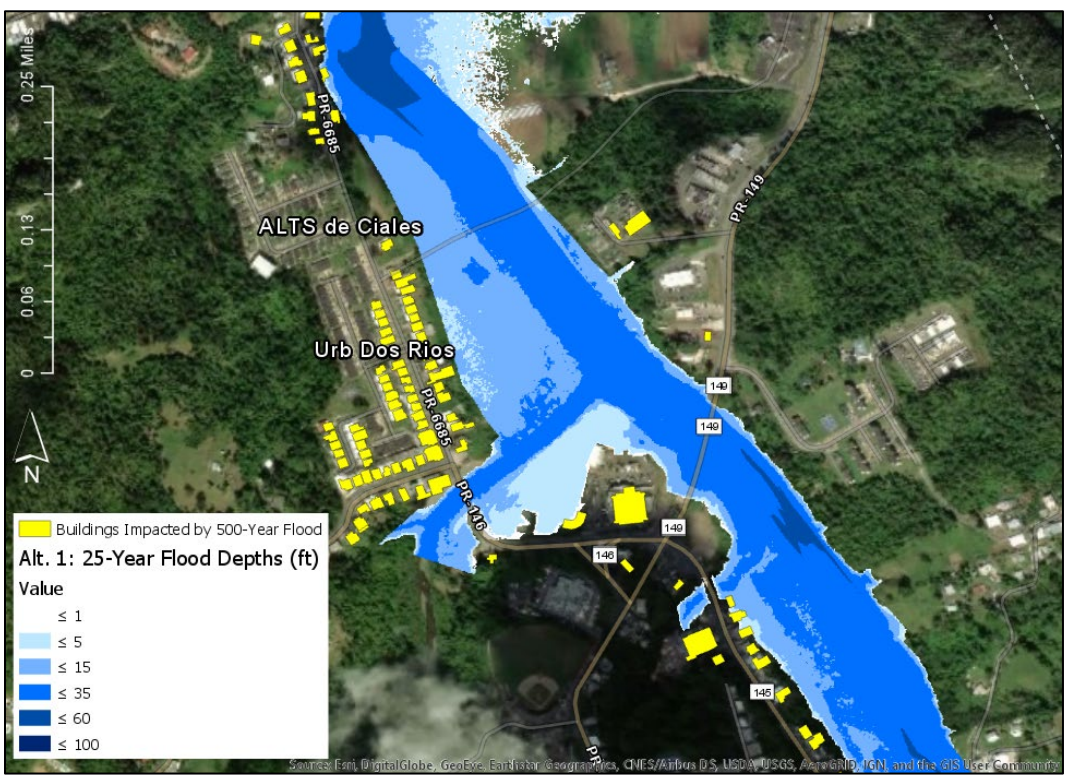


Figure 8. Alt. 2 (Channel Modification) 0.04 ACE Flood Depths – Reaches A, B, & C

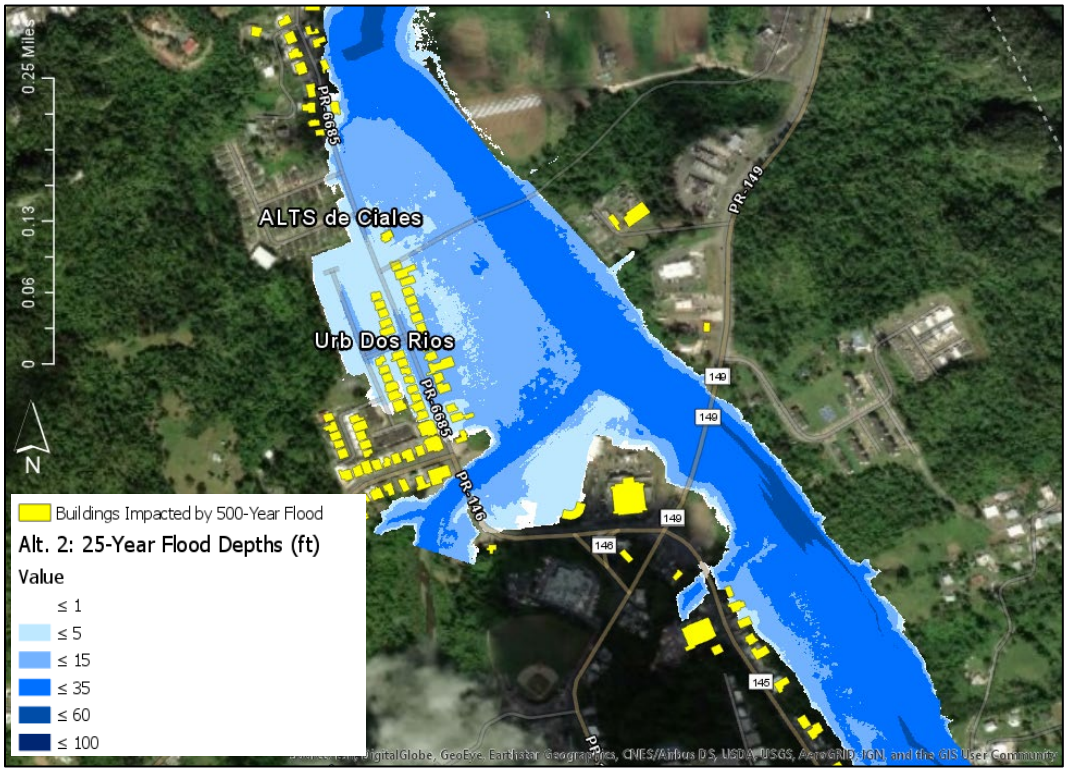


Figure 9. Alt. 4 (Channelization) 0.04 ACE Flood Depths – Reaches A, B, & C

3.3.4 Stage Damage

In order to calculate the damages from the inundation of structures (and associated contents) that would occur at each stage, two types of relationships were developed: the depth-damage relationship and the stage-frequency relationship. The depth-damage relationship is the estimated amount of damage that will occur to structures (and associated contents) as the elevation of the water (or stage) rises. The stage-frequency relationship is the probability of the stage reaching various levels for each hydrologic reach. Refer to section 3.1 in order to relate the river stages shown in the tables below to an ACE.

3.3.4.1 Alternative 1 (Levee/Floodwall System) Stage Damage Functions

*Table 15. **Alt. 1** Aggregated Stage-Damage Function (Reach A)*

Approximate ACE	River Stage	Damages by Category ($1,000s)[1]			Total
		Structures & Contents		Other Damages	
		Residential	Non-Residential	Vehicles	
Ranges from 0.5 to 0.2	120	-	-	-	-
	125	-	-	-	-
Ranges from 0.2 to 0.04	130	-	-	-	-
	135	134.7	-	9.6	144.3
Ranges from 0.04 to 0.01	140	452.6	222.3	37.9	712.8
	145	731.4	370.4	61.9	1,163.7
Ranges from 0.01 to 0.005	150	988.6	833.0	84.6	1,906.3
	155	1,571.7	2,047.4	134.8	3,753.9
0.002	160	2,035.9	2,463.3	149.7	4,648.9
	165	2,546.2	2,995.6	191.7	5,733.5
Less Frequent than 0.002	170	3,320.4	3,103.7	236.5	6,660.6
	175	3,877.2	3,442.5	263.4	7,583.1

[1]Damages are presented in FY2020 price levels

*Table 16. **Alt. 1** Aggregated Stage-Damage Function (Reach B)*

Approximate ACE	River Stage	Damages by Category ($1,000s)[1]			Total
		Structures & Contents		Other Damages	
		Residential	Non-Residential	Vehicles	
Ranges from 0.1 to 0.04	120	36.5	109.9	6.3	152.7
	125	310.1	428.9	61.6	800.5
	130	1,643.5	741.3	283.3	2,668.1
	135	3,600.3	2,127.0	413.5	6,140.9

Ranges from 0.04 to 0.01	140	4,961.5	2,853.1	451.4	8,266.0
0.005	145	5,832.7	3,099.5	530.3	9,462.5
	150	7,859.8	3,163.0	618.8	11,641.7
0.0002	155	9,059.9	3,177.3	675.1	12,912.3
More frequent than 0.002	160	9,676.1	3,182.4	697.8	13,556.3
	165	9,948.2	3,182.3	708.2	13,838.8
[1]Damages are presented in FY2020 price levels					

Table 17. ***Alt. 1*** *Aggregated Stage-Damage Function (Reach C)*

Approximate ACE	River Stage	Damages by Category ($1,000s)[1]			Total
		Structures & Contents		Other Damages	
		Residential	Non-Residential	Vehicles	
Ranges from 0.1 to 0.04	120	-	-	-	-
	125	-	-	-	-
	130	-	2.3	-	2.3
Ranges from 0.04 to 0.01	135	-	1,770.0	-	1,770.0
	140	-	4,397.8	-	4,397.8
0.005	145	-	4,906.1	-	4,906.1
	150	-	5,085.1	-	5,085.1
0.0002	155	-	5,086.8	-	5,086.8
More frequent than 0.002	160	-	5,086.8	-	5,086.8
	165	-	5,086.8	-	5,086.8
[1]Damages are presented in FY2020 price levels					

Table 18. ***Alt. 1*** *Aggregated Stage-Damage Function (Reach D)*

Approximate ACE	River Stage	Damages by Category ($1,000s)[1]			Total
		Structures & Contents		Other Damages	
		Residential	Non-Residential	Vehicles	
Ranges from 0.04 to 0.01	120	-	-	-	-
	125	-	-	-	-
Ranges from 0.01 to 0.005	130	111.6	-	18.5	130.1
	135	363.1	-	73.8	437.0
	140	1,107.3	-	139.4	1,246.7
	145	2,371.8	31,097.2	260.6	33,729.7

Ranges from 0.005 to 0.002	150	3,609.6	51,488.8	347.2	55,445.5
	155	5,040.9	53,011.6	408.1	58,460.5
Less frequent than 0.002	160	6,008.1	53,493.1	437.1	59,938.3
	165	6,668.7	53,497.1	440.7	60,606.4
[1]Damages are presented in FY2020 price levels					

3.3.4.2 Alternative 2 (Channel Modification) Stage Damage Function

*Table 19. **Alt. 2** Aggregated Stage-Damage Function (Reach A)*

Approximate ACE	River Stage	Damages by Category ($1,000s)[1]			Total
		Structures & Contents		Other Damages	
		Residential	Non-Residential	Vehicles	
Ranges from 0.5 to 0.2	120	-	-	-	-
	125	-	-	-	-
Ranges from 0.2 to 0.04	130	-	-	-	-
	135	166.9	0.2	13.2	180.3
Ranges from 0.1 to 0.01	140	496.7	249.8	42.0	788.5
	145	754.8	380.6	65.6	1,201.0
Ranges from 0.04 to 0.005	150	1,022.1	997.6	88.7	2,108.4
	155	1,578.4	1,743.7	135.3	3,457.4
Ranges from 0.005 to 0.002	160	2,027.2	2,200.5	149.8	4,377.5
	165	2,551.2	2,893.2	192.1	5,636.5
	170	3,332.1	3,106.6	237.3	6,676.0
Less frequent than 0.002	175	3,891.7	3,444.1	264.3	7,600.1
	180	4,267.4	3,518.5	285.5	8,071.4
[1]Damages are presented in FY2020 price levels					

*Table 20. **Alt. 2** Aggregated Stage-Damage Function (Reach B)*

Approximate ACE	River Stage	Damages by Category ($1,000s)[1]			Total
		Structures & Contents		Other Damages	
		Residential	Non-Residential	Vehicles	
Ranges from 0.2 to 0.04	120	-	-	-	-
	125	211.5	-	45.8	257.3
Ranges from 0.02 to 0.01	130	1,178.2	600.4	217.6	1,996.2
	135	3,530.6	2,174.0	399.8	6,104.3

Ranges from 0.01 to 0.005	140	4,910.2	2,874.0	453.8	8,237.9
	145	5,798.2	3,104.4	527.5	9,430.1
0.002	150	7,910.3	3,166.2	621.9	11,698.4
	155	9,100.4	3,179.4	681.9	12,961.7
Less frequent than 0.002	160	9,686.2	3,182.3	697.8	13,566.3
	165	9,949.2	3,182.3	708.2	13,839.8
[1]*Damages are presented in FY2020 price levels*					

Table 21. ***Alt. 2*** *Aggregated Stage-Damage Function (Reach C)*

Approximate ACE	River Stage	Damages by Category ($1,000s)[1]			Total
		Structures & Contents		Other Damages	
		Residential	Non-Residential	Vehicles	
Ranges from 0.2 to 0.04	120	-	-	-	-
	125	-	-	-	-
Ranges from 0.02 to 0.01	130	-	1,701.6	-	1,701.6
	135	-	4,380.5	-	4,380.5
Ranges from 0.01 to 0.005	140	-	4,901.5	-	4,901.5
	145	-	5,084.3	-	5,084.3
0.002	150	-	5,086.8	-	5,086.8
	155	-	5,086.8	-	5,086.8
Less frequent than 0.002	160	-	5,086.8	-	5,086.8
	165	-	5,086.8	-	5,086.8
[1]*Damages are presented in FY2020 price levels*					

Table 22. ***Alt. 2*** *Aggregated Stage-Damage Function (Reach D)*

Approximate ACE	River Stage	Damages by Category ($1,000s)[1]			Total
		Structures & Contents		Other Damages	
		Residential	Non-Residential	Vehicles	
Ranges from 0.04 to 0.01	120	-	-	-	-
	125	6.6	-	-	-
Ranges from 0.01 to 0.005	130	240.1	-	0.3	7.0
	135	466.8	-	37.0	277.1
Ranges from 0.005 to 0.002	140	1,278.1	1,521.5	87.2	553.9
	145	2,657.0	42,608.5	170.3	2,970.0

0.002	150	3,851.1	52,129.8	285.6	45,551.1
Less frequent than 0.002	155	5,228.1	53,194.6	362.5	56,343.5
	160	6,122.8	53,494.5	414.1	58,836.8
[1]*Damages are presented in FY2020 price levels*					

3.3.4.3 Alternative 4 (Channelization) Stage Damage Function

Table 23. ***Alt. 4*** *Aggregated Stage-Damage Function (Reach A)*

Approximate ACE	River Stage	Damages by Category ($1,000s)[1]			Total
		Structures & Contents		Other Damages	
		Residential	Non-Residential	Vehicles	
Ranges from 0.5 to 0.1	120	-	-	-	-
	125	-	-	-	-
Ranges from 0.1 to 0.02	130	-	-	-	-
	135	33.2	-	2.0	35.2
Ranges from 0.1 to 0.01	140	222.9	-	15.2	238.1
	145	454.3	6.0	36.7	497.0
Ranges from 0.04 to 0.005	150	826.1	488.8	66.4	1,381.2
	155	1,444.8	1,714.8	126.5	3,286.2
Ranges from 0.005 to 0.002	160	1,654.0	2,107.2	139.7	3,900.8
	165	2,212.1	2,692.5	168.6	5,073.2
	170	2,916.7	3,062.3	216.4	6,195.3
Less frequent than 0.002	175	3,409.6	3,471.1	243.4	7,124.1
	180	3,930.0	3,520.4	271.4	7,721.9
[1]*Damages are presented in FY2020 price levels*					

Table 24. ***Alt. 4*** *Aggregated Stage-Damage Function (Reach B)*

Approximate ACE	River Stage	Damages by Category ($1,000s)[1]			Total
		Structures & Contents		Other Damages	
		Residential	Non-Residential	Vehicles	
Ranges from 0.1 to 0.01	120	1.9	-	0.2	2.1
	125	277.6	42.2	54.1	373.8
Ranges from 0.04 to 0.02	130	1,666.6	904.4	284.2	2,855.2
	135	3,438.0	2,429.6	391.0	6,258.6
Ranges from 0.01 to 0.005	140	4,616.3	2,915.1	432.4	7,963.9
	145	5,727.9	3,123.0	518.6	9,369.5

0.002	150	7,616.1	3,168.0	604.7	11,388.7
	155	8,807.4	3,178.4	673.3	12,659.1
	160	9,573.7	3,182.3	697.8	13,453.7
Less frequent than 0.002	165	9,926.3	3,182.3	708.2	13,816.9
	170	10,025.3	3,182.3	709.4	13,917.0
[1]*Damages are presented in FY2020 price levels*					

Table 25. ***Alt. 4*** *Aggregated Stage-Damage Function (Reach C)*

Approximate ACE	River Stage	Damages by Category ($1,000s)[1]			Total
		Structures & Contents		Other Damages	
		Residential	Non-Residential	Vehicles	
Ranges from 0.1 to 0.01	120	-	-	-	-
	125	-	-	-	-
Ranges from 0.04 to 0.02	130	-	2.3	-	2.3
	135	-	1,770.2	-	1,770.2
Ranges from 0.01 to 0.005	140	-	4,397.9	-	4,397.9
	145	-	4,906.2	-	4,906.2
0.002	150	-	2,076.3	-	2,076.3
	155	-	5,086.8	-	5,086.8
	160	-	5,086.8	-	5,086.8
Less frequent than 0.002	165	-	5,086.8	-	5,086.8
	170	-	5,086.8	-	5,086.8
[1]*Damages are presented in FY2020 price levels*					

Table 26. ***Alt. 4*** *Aggregated Stage-Damage Function (Reach D)*

Approximate ACE	River Stage	Damages by Category ($1,000s)[1]			Total
		Structures & Contents		Other Damages	
		Residential	Non-Residential	Vehicles	
Ranges from 0.02 to 0.01	120	43.4	-	2.8	46.1
	125	266.2	-	34.1	300.3
Ranges from 0.01 to 0.005	130	472.1	-	70.7	542.8
	135	867.9	-	150.3	1,018.2
Ranges from 0.005 to 0.002	140	1,973.1	12,465.9	242.1	14,681.1
	145	3,260.2	44,612.6	324.9	48,197.7

0.002	150	4,510.8	52,191.2	385.2	57,087.2
Less frequent than 0.002	155	5,593.7	53,229.8	430.0	59,253.4
	160	6,410.9	53,497.0	440.5	60,348.4
[1]*Damages are presented in FY2020 price levels*					

3.3.5 Damages Reduced By Reach

The tables below display the expected annual damages and expected annual damages reduced for each of the structural alternatives. As shown in Table 27, there are negative damages reduced, or damage inducements under Alternative 1. This is due to modeling uncertainties and roughness coefficients, as well as the implementation of the levee floodwall in Reaches B and C. A small amount of risk is transferred to Reach D. These inducements may be reduced with model refinement. Additionally, these tables show that Alternative 4 reduces the most annual flood damages relative to the other structural alternatives.

Table 27. ***Alt. 1*** *(Levee/Floodwall System) Estimated Damages Reduced*

HEC-FDA Reach	Annual Damages[1] Without Project ($1,000s)	Annual Damages[1] With Project ($1,000s)	Expected Annual Damages Reduced[1] ($1,000s)
Reach A	394.9	344.0	50.9
Reach B	667.2	95.4	571.8
Reach C	168.6	86.6	82.0
Reach D	412.5	413.8	(1.2)
Total	**1,643.2**	**939.8**	**703.5**
[1]*Damages are presented in FY2020 price levels*			

Table 28. ***Alt. 2*** *(Channel Modification) Estimated Damages Reduced*

HEC-FDA Reach	Annual Damages[1] Without Project ($1,000s)	Annual Damage[1] With Project ($1,000s)	Expected Annual Damages Reduced[1] ($1,000s)
Reach A	394.9	365.4	29.6
Reach B	667.2	388.6	278.5
Reach C	168.6	77.2	91.4
Reach D	412.5	406.4	6.1
Total	**1,643.2**	**1,237.6**	**405.6**
[1]*Damages are presented in FY2020 price levels*			

*Table 29. **Alt. 4** (Channelization) Estimated Damages Reduced*

HEC-FDA Reach	Annual Damages[1] Without Project ($1,000s)	Annual Damage[1] With Project ($1,000s)	Expected Annual Damages Reduced[1] ($1,000s)
Reach A	394.9	215.7	179.2
Reach B	667.2	225.8	441.4
Reach C	168.6	77.0	91.6
Reach D	412.5	276.8	135.7
Total	**1,643.2**	**795.3**	**847.9**

[1]*Damages are presented in FY2020 price levels*

4. Non-Structural Alternatives

The following alternative focuses on non-structural measures. It also includes structural measures, however, the most impactful measure on flood risk management is the non-structural relocations. As opposed to the structural alternatives, which only alters the hazard, this non-structural measure directly alters the consequences as well as the hazard. The following alternative was modeled in both HEC-RAS and HEC-FDA. The results of those modeling efforts are discussed in the subsequent sections.

Alternative 3: Non-Structural Relocations and WWTP Floodwall: Structures within the 0.04 AEP floodplain would be acquired and demolished. Residents would be relocated outside of the floodplain (Fig. 3-5 in the main report). The 0.04 AEP floodplain was selected to include those structures with the majority of recurring flood damages, as well as those with the greatest life and safety risk during major flood events. Alternative 3 also incorporates a floodwall around the wastewater treatment plant, as described under Alternatives 1 and 2 (Fig. 3-5 in the main report).

4.1 Hazard

This alternative's main objective is altering the consequences with non-structural relocations. In addition to altering the consequences, the hazard is slightly altered under this alternative due to the implementation of the floodwall surrounding the WWTP and the acquisition and relocation of 58 structures. Alternative 3's estimated WSP can be found in the table below.

Table 30. Alternative 3 (Non-Structural Relocations & WWTP Floodwall) Water Surface Profiles

Reach	River Station	Stage by Annual Chance Exceedance[1]							
		0.5	0.2	0.1	0.04	0.02	0.01	0.005	0.002
Northern edge of Dos Rios to Route 6885 (Reach D)	**29914.84**	84.41	91.52	97.33	106.72	112.57	119.68	127.39	139.68
	29965.48	85.48	93.46	99.83	109.02	117.3	123.01	130.34	140.55
	30282.54	89.65	98.11	104.72	114.79	122.68	128.52	135.7	146.15
	30450.28	90.62	99.39	106.15	116.42	124.18	130.36	137.79	148.63
	30753	91.66	100.42	107.09	117.36	125.05	131.42	139.07	150.29
	31041.5	92.72	101.63	108.6	118.67	125.88	132.23	139.85	151.1
	31444.64	95.1	102.87	108.96	117.88	125.01	131.21	138.83	150.05

	31723.61	99.81	106.42	112.26	121.53	128.09	134.43	141.87	152.89
	32235.51	105.79	109.98	113.32	120.5	127.63	134.39	142.09	153.29
Northern edge of Dos Rios to baseball field upstream of Dos Rios (Reaches B and C)	**32325.2**	106.98	112.6	117.16	125.52	130.43	136.34	143.49	154.38
	32455.27	108.24	114.53	119.3	127.26	131.73	137.26	144.14	154.86
	32740.16	111.71	119.11	124.5	131.79	135.58	140.5	146.6	156.6
	32918.2	114.6	122.22	127.02	133.83	137.35	142.08	147.86	158.01
	32988.5	115.48	123.54	128.11	134.7	138.25	143.11	149	158.15
Baseball field upstream of Dos Rios to Bridge PR-145 (Reach A)	**33153.54**	118.43	125.55	129.66	135.69	138.99	143.48	149.23	158.08
	33200.01	118.7	125.74	129.8	135.82	139.76	146.85	153.06	160.87
	33357.12	119.78	126.89	131.33	138.05	142.2	148.11	154.06	161.82
	33597.73	121.63	128.68	133.34	140.49	144.81	150.5	156.19	163.62
	33704.47	122.88	129.7	134.3	141.4	145.67	151.28	156.88	164.22
	33860.74	124.2	131.01	135.47	142.54	146.99	152.81	158.85	167.09
	34115.96	125.93	133.01	137.8	145.12	149.02	154.24	160	168.17
	34155.99	128.9	135.35	141.86	150.03	154.16	159.18	164.19	170.99
	34233.57	129.87	136.73	143.12	151.63	155.3	159.87	164.63	171.16

[1] *Mean modeled river stages in feet Datum Mean Sea Level (PRVD 02)*

4.2 Performance

Since this alternative still deals with the construction of a floodwall around the WWTP, the performance is expected to improve as compared to the without project condition. It is assumed that the construction of the floodwall, to current standards, would significantly reduce flood damages associated with the WWTP. This near-zero risk of failure is analyzed in HEC-FDA as a floodwall that will not breach prior to overtopping. However, the residual risk of flooding due to an event that exceeds the crest elevation (overtopping) remains. This improvement in performance only impacts the WWTP.

4.3 Consequences

Unlike structural alternatives, non-structural alternatives are developed as a way to directly reduce potential consequences, rather than altering the hazard or performance. As a result, there would be less structures and people potentially impacted by future flood events, which positively impacts life safety risk and property damage.

4.3.1 Structure Inventory

Alternative 3 includes the non-structural measure of buying-out and relocating several residential and non-residential structures. This management measure results in direct changes in consequences by removing part of the population at risk from the floodplain. This non-structural measure results in fewer structures in the study area. The structure inventory associated with this alternative is summarized below in Tables 31 and 32

Table 31. Structure Inventory for Alternative 3 (Non-Structural Relocations & WWTP Floodwall)

Category	Structures	Average DRV ($1,000)	Total DRV[1] ($1,000)
Residential	84	$128	$10,768
Commercial	8	$172	$1,374
Public	5	$318	$1,589
Industrial	3	$9,426	$28,277
Total[2]	**100**	**-**	**$42,008**

[1]Depreciated replacement values (DRVs) presented at FY2020 price levels
[2]All counts and values represent the entire study area (Reaches A, B, C, & D)

Additionally, fewer vehicles will be permanently located within the study area as residences would be bought out. Table 32 estimates the number and value of vehicles exposed to potential flooding under this alternative.

Table 32. Vehicle Inventory for Alternative 3 (Non-Structural Relocations & WWTP Floodwall)

Category	Vehicles	Average DRV ($1,000)	Total DRV[1] ($1,000)
Vehicles	84	$10	$843
Total[2]	**84**	**-**	**$843**

[1]Depreciated replacement values (DRVs) presented at FY2020 price levels
[2]All counts and values represent the entire study area (Reaches A, B, C, & D)

4.3.2 Life Safety

This non-structural alternative affects overall life safety impacts by removing structures through buyouts. The buyouts will reduce the population at risk in the areas anticipated to receive the highest depths of flooding. Therefore, the population at risk for the majority of flood events and/or hurricanes decreases, which would also decrease the chance for life loss to occur in the study area.

4.3.2.1 Depth of Flooding

Under this alternative, only the WWTP would experience a change in flood depths. This WWTP floodwall does not transfer risk to other parts of the study area, therefore the change in flood depths on the remaining structures in the floodplain is insignificant.

4.3.3 Stage-Damage

The non-structural relocation of 58 structures results in a reduction of potential damages as compared to the without project condition. For example, the river stage reached 150 feet in Reach B, the total damages are estimated to be $11,611,200 in the FWOP condition. If the same stage is reached in Reach B under Alternative 3, total damages decrease to an estimated $5,058,400. The tables below show the aggregated stage-damage functions of each hydrologic reach under Alternative 3. Refer to section 4.1 in order to relate the river stages shown in the tables below to an ACE.

*Table 33. **Alt. 3**: Aggregated Stage-Damage Function (Reach A)*

Approximate ACE	River Stage	Damages by Category ($1,000s)[1]			Total
		Structures & Contents		Other Damages	
		Residential	Non-Residential	Vehicles	
Ranges from 0.5 to 0.2	120	-	-	-	-
	125	-	-	-	-
Ranges from 0.5 to 0.04	130	-	-	-	-
	135	-	-	-	-
Ranges from 0.1 to 0.02	140	-	-	-	-
	145	-	8.3	-	8.3
Ranges from 0.04 to 0.005	150	3.3	484.5	0.2	488.0
	155	100.4	808.1	16.0	924.5
Ranges from 0.01 to 0.002	160	301.9	1,414.3	33.4	1,749.7
	165	762.8	2,054.8	71.6	2,889.2
0.002	170	1,366.7	2,266.7	110.3	3,743.6
Less frequent than 0.002	175	1,882.9	2,565.0	136.8	4,584.7
	180	2,244.8	2,626.8	157.2	5,028.7

[1]*Damages are presented in FY2020 price levels.*

Table 34. ***Alt. 3****: Aggregated Stage-Damage Function (Reach B)*

Approximate ACE	River Stage	Damages by Category ($1,000s)[1]			Total
		Structures & Contents		Other Damages	
		Residential	Non-Residential	Vehicles	
Ranges from 0.2 to 0.04	120	-	-	-	-
	125	-	124.8	-	124.8
Ranges from 0.1 to 0.02	130	-	234.9	2.0	255.9
	135	19.0	242.7	32.5	443.6
Ranges from 0.02 to 0.005	140	168.4	597.1	104.7	1,394.2
	145	692.3	787.5	200.1	3,727.5
Ranges from 0.005 to 0.002	150	2,739.9	840.4	256.0	5,058.4
	155	3,961.9	854.3	278.6	5,722.0
0.002	160	4,589.1	859.2	289.1	6,012.9
Less frequent than 0.002	165	4,864.6	859.2	290.2	6,092.1
	170	4,942.7	859.2	290.2	6,107.6

[1]*Damages are presented in FY2020 price levels.*

*Table 35. **Alt. 3**: Aggregated Stage-Damage Function (Reach C)*

Approximate ACE	River Stage	Damages by Category ($1,000s)[1]			Total
		Structures & Contents		Other Damages	
		Residential	Non-Residential	Vehicles	
Ranges from 0.2 to 0.04	120	-	-	-	-
	125	-	-	-	-
Ranges from 0.1 to 0.02	130	-	2.3	-	2.3
	135	-	1,770.2	-	1,770.2
Ranges from 0.02 to 0.005	140	-	4,402.5	-	4,402.5
	145	-	4,907.1	-	4,907.1
Ranges from 0.005 to 0.002	150	-	5,085.1	-	5,085.1
	155	-	5,086.8	-	5,086.8
0.002	160	-	5,086.8	-	5,086.8
Less frequent than 0.002	165	-	5,086.8	-	5,086.8
	170	-	5,086.8	-	5,086.8

[1]Damages are presented in FY2020 price levels.

*Table 36. **Alt. 3**: Aggregated Stage-Damage Function (Reach D)*

Approximate ACE	River Stage	Damages by Category ($1,000s)[1]			Total
		Structures & Contents		Other Damages	
		Residential	Non-Residential	Vehicles	
Ranges from 0.04 to 0.01	120	-	-	-	-
	125	-	-	-	-
Ranges from 0.02 to 0.005	130	107.6	-	18.0	125.6
	135	356.8	-	73.1	429.9
Ranges from 0.01 to 0.002	140	1,077.0	-	134.4	1,211.4
	145	2,296.4	26,967.2	253.0	29,516.6
0.002	150	3,528.2	51,063.0	340.5	54,931.7
	155	4,958.0	52,929.9	405.1	58,293.0
Less frequent than 0.002	160	5,954.8	53,491.3	436.1	59,882.2
	165	6,643.1	53,497.0	440.6	60,580.7

[1]Damages are presented in FY2020 price levels.

3.3.4.1 Damages Reduced By Reach

Table 35 displays the expected annual damages and expected annual damages reduced for Alternative 3. The table shows there are negative damages reduced, or damage inducements, in Reach D. This is due to both uncertainty in the HEC-RAS model regarding cross sections, channel geometry, and roughness coefficients, as well as the implementation of the floodwall around the WWTP, which transfers a small portion of Reach C's risk to Reach D. The damage inducements are minimal (less than $1,000), and they may be reduced with model refinements.

*Table 37. **Alt. 3** Expected Annual Damages & Damages Reduced by Reach*

HEC-FDA Reach	Annual Damages[1] Without Project ($1,000s)	Annual Damage[1] With Project ($1,000s)	Expected Annual Damaged Reduced[1] ($1,000s)
Reach A	394.9	83.0	311.9
Reach B	667.2	86.5	580.7
Reach C	168.6	113.3	55.3
Reach D	412.5	413.8	(1.3)
Total	**1,643.2**	**696.6**	**946.6**

[1]*Damages are presented in FY2020 price levels.*

5. Alternative Evaluation and Comparison

The alternative evaluation and comparison planning steps require an examination of the potential risk across several categories (economic, engineering, environmental, etc.). The following sections describe the alternative impacts based on monetary damages and damage reductions, while other impacts are discussed in the main report and/or the subject's corresponding appendix.

5.1 Preliminary Benefit-Cost Analysis

The benefit-cost analysis is completed to assist in the identification of the recommended plan. The primary selection criteria is for the recommended plan to "reasonably maximize net benefits" (ER 1105-2-100). The economic evaluation is not the sole metric to be used in plan selection, so this final decision is documented in the main report. The following sections outline the estimates used for the economic evaluation of alternatives, including the amortization of project costs and benefits.

5.1.2 Preliminary Project Benefits

The project benefits were estimated using the previously discussed inputs and software. Table 36 shows expected annual damages (EAD) for the without project condition, EAD for the with project condition for each alternative, the damages reduced by alternative, and the probability distribution of damages reduced by alternative.

For example, the average without project damages for Reach A were estimated to be $394,900 while Alternative 4 would be expected to reduce these damages by $179,200. The next columns on the right side show our confidence levels (i.e. 75%, 50%, or 25%) of exceeding specified values. For example, we

have a confidence level of 75% that the EAD reduced by Alternative 4 in Reach A exceeds $134,700. Based on the economic information outlined in Table 38, Alternative 3 reduces the most damages overall.

Table 38. Expected Annual Damages by Alternative

Rio Grande de Manati Study Alternative Evaluation							
(EAD in $1,000)					Probability Damage Reduced Exceeds Indicated Values		
Alternative Description	**Damage Reach Description**	**Total Without Project**	**Total With Project**	**Damage Reduced**	**0.75**	**0.5**	**0.25**
Alternative 1: Levee / Floodwall System	*Reach A:*	394.9	344.0	50.9	37.1	48.3	62.6
	Reach B	667.2	95.4	571.8	396.3	565.9	729.3
	Reach C	168.6	86.6	82.0	44.5	77.6	117.4
	Reach D	412.5	413.8	(1.2)	(1.2)	(2.2)	(2.3)
	Total	1,643.2	939.8	703.5	476.7	689.6	907.0
Alternative 2: Channel Modification and WWTP Floodwall	*Reach A:*	394.9	365.4	29.6	19.3	27.1	37.5
	Reach B	667.2	388.6	278.5	219.5	280.9	338.2
	Reach C	168.6	77.2	91.4	48.6	85.6	129.1
	Reach D	412.5	406.4	6.1	1.5	3.8	8.7
	Total	1,643.2	1,237.6	405.6	288.9	397.4	513.5
Alternative 3: Non-Structural Relocations and WWTP Floodwall	*Reach A:*	394.9	83.0	311.9	222.6	299.8	389.9
	Reach B	667.2	86.5	580.7	381.6	556.4	750.0
	Reach C	168.6	113.3	55.3	33.7	55.5	75.8
	Reach D	412.5	413.8	(1.3)	(0.5)	(1.3)	(2.5)
	Total	1,643.2	696.6	946.6	637.3	910.4	1,213.2
Alternative 4: Channelization	*Reach A:*	394.9	215.7	179.2	134.7	172.2	218.1
	Reach B	667.2	225.8	441.4	333.3	442.5	550.1
	Reach C	168.6	77.0	91.6	48.4	85.3	128.3
	Reach D	412.5	276.8	135.7	44.6	99.7	214.9
	Total	1,643.2	795.3	847.9	561.0	799.7	1,111.4
[1]*Damages are presented in FY2020 price levels.*							

5.1.3 Preliminary Project Costs

The PDT's cost and civil engineers developed quantities and cost estimates for each of the potential alternatives, outlined in the tables below. These cost estimates also have varying construction schedules. The estimated construction cost for each alternative is displayed below in Table 39. The base construction estimate, engineering and design, and construction management costs account for the work necessary to design and build each alternative. The RE estimate accounts for the costs associated with the lands, easements, rights of way, relocations, and disposal (LERRDs) costs. The interest during construction (IDC) accounts for the time value of money, based on the construction schedule and federal discount rate (FDR). The IDC calculations can be found in Table 40 below. The total investment cost is found by

summing the total first cost and IDC. This value is then annualized using the FY20 FDR (2.75) over a 50-year period of analysis to develop the annualized first cost.

The annual OMRR&R costs for the FRM measures in Alternative 1 include inspections of both the levee and WWTP floodwall (about $2,000). There would also be annual repairs, surveys, landscaping, and vermin control (about $14,000). The annual OMRR&R costs associated with Alternative 2's FRM measures include the annual inspection and repairs of the WWTP floodwall (about $2,000). Additionally, the OMRR&R for the channels and slopes (channel improvement area) under Alternative 2 include annual inspection, debris removal, mowing and clearing, and 5% riprap repair/replacement ($293,000). Alternative 3's annul OMRR&R costs consist of the annual inspection and repairs of the WWTP floodwall ($2,000). Finally, Alternative 4's OMRR&R costs include the annual inspection, debris removal and concrete repair of the channel ($93,000).

Table 39. Preliminary Construction Schedule for FRM Components

	Estimated Costs ($1,000s)[a]			
	Alt. 1[b]	**Alt. 2[c]**	**Alt. 3[d]**	**Alt. 4[e]**
Construction	$23,813	$83,674	$6,591	$100,128
Planning, Engineering and Design (17%)	$4,048	$14,225	$1,120	$17,022
Construction Management (8%)	$1,905	$6,695	$527	$8,011
LERRDs	N/A[f]	N/A[f]	$11,293	N/A[f]
Total First Costs	$29,766	$104,592	$19,531	$125,161
Interest During Construction	$1,068	$3,258	$133	$4,194
Total Investment Cost	$30,834	$107,850	$19,664	$129,355
Annualized First Costs	$1,142	$3,995	$728	$4,791
Annual OMRR&R	$16	$295	$2	$93
Average Annual Cost	$1,158	$4,290	$730	$4,884

[a] Costs are presented in FY2020 price levels
[b] Contingency of 40% included
[c] Contingency of 41% included
[d] Contingency of 39% included
[e] Contingency of 42% included
[f] LERRDs costs were not estimated for Alternatives 1, 2, or 4 due to low BCRs

Table 40. Initial Alternatives Interest During Construction (FRM Measures)

	FRM Management Measures Interest During Construction[1]			
	Alt. 1	**Alt. 2**	**Alt. 3**	**Alt. 4**
Total First Costs ($1,000s)	$29,766	$104,592	$19,531	$125,161

Construction Schedule (Months)	31	27	6	29
Federal Discount Rate	2.75%	2.75%	2.75%	2.75%
Interest During Construction ($1,000s)	$1,068	$3,258	$133	$4,194
[1]*Costs are presented in FY2020 price levels.*				

5.1.5 Preliminary National Economic Development Plan

The table below shows the estimated annual benefits, costs, and net benefits. Alternatives 1, 2, and 4 are estimated to incur negative net benefits. Alternative 3 is the only plan that results in positive net benefits, and therefore a BCR greater than one. The preliminary NED plan is Alternative 3, which consists of non-structural relocations (58 structures) and the construction of a floodwall protecting the WWTP.

Table 41. Preliminary Construction Schedule for FRM Components

	Alt. 1	**Alt. 2**	**Alt. 3**	**Alt. 4**
Average Annual Benefits ($1,000s)[1]	$703	$406	$947	$848
Average Annual Costs ($1,000s)[1]	$1,158	$4,290	$728	$4,884
Average Annual Net Benefits ($1,000s)[1]	($454)	($3,884)	$217	($4,036)
Benefit-to-Cost Ratio	0.6	0.1	1.3	0.2
[1]*Damages and costs are presented in FY2020 price levels*				

5.1.4 Evaluation of Life Safety Impacts

This study is not being justified based on a potential reduction in life safety risk. One of the four alternatives, Alternative 3, is economically justified; the benefit-to-cost ratios (BCR) for the other three alternatives are less than 1.0. The one economically justified alternative does not involve construction of a levee or floodwall, therefore there is no residual or transferred risk in the study area. This alternative is strictly non-structural and effectively removes 58 structures (estimated 170 people) out of the floodplain. This results in a reduction of population at risk of 170 people; these people are most at-risk because they are located in the 0.04 ACE floodplain.

A HEC-LifeSim model was not run for this study due to Alternative 3 being the only economically justified and feasible alternative. This is also the most effective alternative at reducing life safety risk. A HEC-LifeSim model would only confirm this. Additionally, the study area has historically been impacted by hurricanes and riverine flooding; there have been zero flooding related fatalities.

6. Alternative 3 Optimization

As discussed above, Alternative 3 was initially selected as the recommended plan. This resulted in additional analysis of this alternative to optimize net benefits. The estimated annual cost of the WWTP floodwall significantly outweighs the estimated annual benefits. The benefit to cost ratio for the WWTP floodwall is approximately 0.25 (Table 42), which is not economically justified. Further analysis by the technical team determined that additional costs associated with altering the height and type of floodwall would not be justified by the minimal increases in benefits. For these reasons, the floodwall was not carried forward and was removed from the recommended plan.

Table 42. Alternative 3's Separable Flood Risk Management Measures

	Estimated Costs and Benefits ($1,000s)[a]	
Item	**NS Relocations**	**Floodwall**
Investment Cost		
Total Project First Cost	$13,771	$5,760
Interest During Construction	$47[b]	$39[c]
Total Investment Cost	$13,817	$5,799
Annual Cost		
Annualized first cost [d]	$512	$215
Estimated Annual OMRR&R	$0	$2
Total Average Annual Cost (Rounded)	$512	$217
Annual Benefits	$891	$55
Net Annual Benefits	$380	($161)
Benefit Cost Ratio	1.7	0.3

[a] Contingency of 44% is included
[b] Interest during construction is calculated at 2.75% over a 3 month construction period
[c] Interest during construction is calculated at 2.75% over a 6 month construction period
[d] Costs were annualized over a 50-year period of analysis

The optimized and updated Alternative 3, hereafter referred to as Alternative 3B, consists only of the non-structural relocation of 58 structures. As described above, to ensure the maximization of net benefits, the floodwall was removed from this optimized alternative. Alternative 3B was analyzed in both HEC-RAS and HEC-FDA to produce an estimate of annual damages reduced. The following sections discuss the results of those modeling efforts.

6.1 Hazard

The hazard for Alternative 3B is slightly different than the FWOP condition due to the removal of several structures. Because this alternative does not include the implementation of a flood control structure, the WSP does not change as drastically as the other alternatives. The WSP for Alternative 3B can be found in the table below.

Table 43. Alternative 3B (Non-Structural Relocations) Water Surface Profile

Reach	**River Station**	**Stage by Annual Chance Exceedance[1]**							
		0.5	**0.2**	**0.1**	**0.04**	**0.02**	**0.01**	**0.005**	**0.002**
	29914.84	84.41	91.25	97.33	106.72	112.57	119.68	127.39	139.68

Northern edge of Dos Rios to Route 6885 (Reach D)	**29965.48**	85.48	93.46	99.83	109.02	117.3	123.01	130.34	140.55
	30282.54	89.65	98.11	104.72	114.79	122.68	128.52	135.7	146.15
	30450.28	90.62	99.39	106.15	116.42	124.18	130.36	137.79	148.63
	30753	91.66	100.42	107.09	117.36	125.05	131.42	139.07	150.29
	31041.5	92.72	101.63	108.6	118.67	125.88	132.23	139.85	151.1
	31444.64	95.1	102.87	108.96	117.88	125.01	131.21	138.83	150.05
	31723.61	99.81	106.42	112.26	121.53	128.09	134.43	141.87	152.89
	32235.51	105.79	109.98	113.32	120.5	127.63	134.3	142.09	153.29
Northern edge of Dos Rios to baseball field upstream of Dos Rios (Reaches B and C)	**32325.2**	106.98	112.6	117.16	125.52	130.43	136.34	143.49	154.38
	32455.27	108.24	114.53	119.3	127.26	131.73	137.26	144.14	154.86
	32740.16	111.71	119.11	124.49	131.79	135.58	140.5	146.6	156.6
	32918.2	114.6	122.2	126.91	133.63	137.34	142.08	147.86	158.01
	32988.5	115.48	123.53	128.03	134.55	138.23	143.08	148.98	158.14
Baseball field upstream of Dos Rios to Bridge PR-145 (Reach A)	**33153.54**	118.43	125.54	129.6	135.57	138.97	143.46	149.2	158.07
	33200.01	118.7	125.73	129.74	135.7	139.73	146.82	153.04	160.87
	33357.12	119.78	126.88	131.29	137.97	142.18	148.09	154.04	161.82
	33597.73	121.63	128.68	133.31	140.44	144.8	150.48	156.18	163.62
	33704.47	122.88	129.7	134.27	141.35	145.66	151.26	156.87	164.22
	33860.74	124.2	131.01	135.45	142.5	146.98	152.79	158.84	167.09
	34115.96	125.93	133.01	137.79	145.1	149.01	154.23	159.99	168.17
	34155.99	128.9	135.35	141.85	150.02	154.15	159.17	164.18	170.99
	34233.57	129.87	136.73	143.11	151.62	155.29	159.86	164.62	171.16

[1] *Mean modeled river stages in feet Datum Mean Sea Level (PRVD 02)*

6.2 Performance

Alternative 3B does not include the construction of a flood control structure. Therefore, performance was not considered for this alternative.

6.3 Consequences

Unlike structural alternatives, non-structural alternatives are developed as a way to directly reduce potential consequences, rather than altering the hazard or performance. As a result, there would be less structures and people inundated by future flood events, which positively impacts life safety risk and property damage.

6.3.1 Structure Inventory

The structure inventory for Alternative 3B remains unchanged from Alternative 3. Refer to Tables 29 and 30 for a summary of the structure and vehicle inventory.

6.3.1.1 Life Safety

Life safety impacts are comparable to Alternative 3. However, the removal of 58 structures paired with the WWTP floodwall effectively eliminates the life safety risk associated with the 0.04 ACE event. Life

safety risk still exists for less frequent events. As previously stated, the study area has experienced 10 major floods in the past 50 years and there have been zero fatalities.

6.3.1.1.1 Depth of Flooding

This alternative does not consider structural measures therefore, the depth of flooding is minimally changed. The removal of 58 structures would minimally impact the depth flooding; it would essentially remain unchanged compared to the FWOP condition.

6.3.2 Stage-Damage

Alternative 3B incurs more damages than Alternative 3 due to more impacts occurring at the WWTP. The stage-damage functions for Alternative 3B can be found in the tables below. Refer to section 6.1 in order to relate the river stages shown in the tables below to an ACE.

*Table 44. **Alt. 3B**: Aggregated Stage-Damage Function (Reach A)*

Approximate ACE	River Stage	Damages by Category in Thousands			Total
		Structures & Contents		Other Damages	
		Residential	Non-Residential	Vehicles	
Ranges from 0.5 to 0.2	120	-	-	-	-
	125	-	-	-	-
Ranges from 0.5 to 0.04	130	-	-	-	-
	135	-	-	-	-
Ranges from 0.1 to 0.01	140		-	-	-
	145	-	5.1	-	5.1
Ranges from 0.04 to 0.005	150	3.3	475.5	0.2	479.0
	155	111.0	835.2	17.3	963.6
Ranges from 0.01 to 0.002	160	314.9	1,442.6	35.1	1,792.6
	165	789.9	2,093.3	73.7	2,957.0
0.002	170	1,404.8	2,216.3	112.2	3,733.3
Less frequent than 0.002	175	1,929.1	2,582.6	140.1	4,651.9
	180	2,264.6	2,627.1	158.3	5,049.9

[1]Damages are presented in FY2020 price levels.

*Table 45. **Alt. 3B**: Aggregated Stage-Damage Function (Reach B)*

Approximate ACE	River Stage	Damages by Category in Thousands			Total
		Structures & Contents		Other Damages	
		Residential	Non-Residential	Vehicles	
Ranges from 0.2 to 0.1	120	-	-	-	-

Ranges from 0.1 to 0.02	125	-	140.5		140.5
	130	-	236.0		236.0
Ranges from 0.04 to 0.01	135	30.9	242.8	3.7	277.5
	140	171.7	595.1	32.2	799.0
0.005	145	688.1	786.6	105.0	1,579.6
Ranges from 0.005 to 0.002	150	2,745.9	840.4	199.6	3,785.9
	155	3,964.1	854.3	255.3	5,073.6
Less frequent than 0.002	160	4,589.3	859.1	277.8	5,726.2
	165	4,864.6	859.1	288.2	6,012.0
[1]*Damages are presented in FY2020 price levels.*					

Table 46. ***Alt. 3B****: Aggregated Stage-Damage Function (Reach C)*

Approximate ACE	River Stage	Damages by Category in Thousands			Total
		Structures & Contents		Other Damages	
		Residential	Non-Residential	Vehicles	
Ranges from 0.2 to 0.1	120	-	-	-	-
Ranges from 0.1 to 0.02	125	-	-	-	-
	130	-	2.4	-	2.4
Ranges from 0.04 to 0.01	135	-	1,770.2	-	1,770.2
	140	-	4,397.9	-	4,397.9
0.005	145	-	4,906.2	-	4,906.2
Ranges from 0.005 to 0.002	150	-	5,085.2	-	5,085.2
	155	-	5,086.8	-	5,086.8
Less frequent than 0.002	160	-	5,086.8	-	5,086.8
	165	-	5,086.8	-	5,086.8
[1]*Damages are presented in FY2020 price levels.*					

Table 47. ***Alt. 3B:*** *Aggregated Stage-Damage Function (Reach D)*

Approximate ACE	River Stage	Damages by Category in Thousands			Total
		Structures & Contents		Other Damages	
		Residential	Non-Residential	Vehicles	
Ranges from 0.04 to 0.01	120	-	-	-	-
	125	-	-	-	-
	130	88.0	-	15.9	103.9

Ranges from 0.02 to 0.005	135	349.6	-	71.9	421.5
Ranges from 0.005 to 0.002	140	1,059.3	-	131.0	1,190.3
	145	2,263.1	24,894.8	248.8	27,406.7
0.002	150	3,500.7	50,887.8	337.4	54,725.9
	155	4,939.0	52,913.5	403.1	58,255.6
Less frequent than 0.002	160	5,942.0	53,490.9	434.5	59,867.4
	165	6,636.6	53,497.1	439.3	60,573.0
[1]*Damages are presented in FY2020 price levels.*					

6.3.2.1 Damages Reduced by Reach

The table below displays the expected annual damages and expected annual damages reduced for Alternative 3B.

*Table 48. **Alt. 3B** Expected Annual Damages & Damages Reduced by Reach*

HEC-FDA Reach	Expected Annual Damages ($1,000s)[1]			Probability Damage Reduced Exceeds Indicated Values ($1000s)		
	Without Project	With Project	Damages Reduced[1]	0.75	0.5	0.25
Reach A	394.9	87.6	307.3	220.4	296.0	383.7
Reach B	667.2	91.1	576.1	378.3	552.0	744.2
Reach C	168.6	168.6	0.0	0.0	0.0	0.0
Reach D	412.5	412.5	0.0	0.0	0.0	0.0
Total	**1,643.2**	**759.8**	**883.4**	**598.7**	**848.0**	**1,127.9**
[1]*Damages are presented in FY2020 price levels*						

6.4 Project Costs

The project costs for Alternatives 3 and 3B are shown in the tables below. These cost estimates also have varying construction schedules. The interest during construction (IDC) accounts for the time value of money, based on the construction schedule and federal discount rate (FDR); the inputs for the IDC calculation is displayed in Table 49, and the IDC calculations for the optimized plan are shown in Table 50. The estimated construction costs for alternatives 3 and 3B are displayed below in Table 51. The base construction estimate, engineering and design, and construction management costs account for the work necessary to design and build each alternative. The RE estimate accounts for the costs associated with the lands, easements, rights of way, relocations, and disposal (LERRDs) costs. The total investment cost is found by summing the total first cost and IDC. This value is then annualized using the FY20 FDR (2.75%) over a 50-year period of analysis to develop the annualized first cost. The annual OMRR&R for Alternative 3B is zero because it only consists of non-structural relocations, which does not require annual maintenance or inspections.

Table 49. Interest During Construction – Alternatives 3 & 3B

	FRM Measures – Interest During Construction ($1,000s)[1]	
	Alt. 3	**Alt. 3B**
Total First Costs	$19,531	$13,860
Construction Schedule (Months)	6	3
Federal Discount Rate	2.75%	2.75%
Interest During Construction	$133	$47

[1]Costs presented in October 2020 price level

Table 50. Optimized Plan Interest During Construction Calculation

Alternative 3B Interest During Construction Calculations		
	Year[1]	2022
	Federal Interest Rate	2.75%
	Monthly Present Worth (PW) Factor[2]	1.00226
Alt. 3B ($1,000s)	**Total Construction Cost[3]**	**$13,860**
	Middle of the Month Uniform Payment[4]	$4,620
	Month 1 PW Cost	$4,646
	Month 2 PW Cost	$4,636
	Month 3 PW Cost	$4,625
	Total PW Cost	**$13,907**
	IDC	**$47**

[1] Year refers to the year in which project costs occur
[2] The present worth factor is derived using middle of year compounding and the current federal discount rate
[3]Costs presented in October 2020 price level
[4]3 month construction period

Table 51. Cost Estimates – Alternatives 3 & 3B

	Rio Grande de Manati Cost Estimates ($1,000s)[a]	
	Alt. 3[b]	**Alt. 3B[c]**
Construction	$6,591	$2,053
Planning, Engineering and Design (17%)	$1,120	$349
Construction Management (8%)	$527	$164

LERRDs	$11,293	$11,293
Total First Costs	$19,531	$13,860
Interest During Construction	$133	$47
Total Investment Cost	$19,664	$13,907
Annualized First Costs	$728	$515
Annual OMRR&R	$2	$0
Average Annual Cost	$730	$515

[a] *Costs presented in FY2020 price levels*
[b] *Contingency of 39% included*
[c] *Contingency of 44% included*

6.5 The National Economic Development (NED) Plan

The NED plan is determined by comparing average annual net benefits (AANB), the difference between average annual benefits (AAB) and average annual costs (AAC). Based on the economic criteria, the NED plan is Alternative 3B. Prior to optimization, Alternative 3 would have been the NED plan because it was the only alternatives with positive net benefits. However, as stated previously, the WWTP floodwall is not economically justified as a separable element. Therefore, this management measure was removed, which maximized net benefits (Table 52).

Table 52. Net Benefits – Alternatives 3 & 3B

	Estimated Costs ($1,000s)	
	Alt. 3	**Alt. 3B**
Average Annual Benefits[1]	$947	$883
Average Annual Costs[1]	$730	$515
Average Annual Net Benefits	$217	$368

[1]*Benefits and costs are presented in FY2020 price levels*

6.5.1 Recommended Plan BCR

Plan selection is based on optimizing net benefits, but budgetary decisions typically rely on an estimate of the return on investment, or the BCR. To estimate the BCR associated with the recommended plan, the annualized benefits are divided by the annualized costs. Since the same economic evaluation analyses were used in the plan formulation phase, the benefit estimates displayed below remain unchanged. The table below displays the BCR for the recommended plan as a single point estimate. This BCR is based on the average annual benefit and the average annual cost.

Table 53. Recommended Plan BCR

Recommended Plan					
Alternative Name	**Alternative Description**	**Average Annual Benefits**	**Average Annual Costs**	**Average Annual**	**BCR**

		($1,000s)	($1,000s)	Net Benefits ($1,000s)	
Alt. 3B	Non-Structural Relocations	$883	$515	$368	1.7
2.75% Federal Discount Rate for FY2020; 50 year period of analysis					

6.5.2 Project Performance: HEC-FDA Outputs

ER 1105-2-100 requires the reporting of project performance data, which is an output from HEC-FDA. The tables below show the data (ACE, long-term risk, and assurance by event). Table 54 shows the FWOP condition's target stage, target ACE, and long-term risk by damage reach. Table 55 shows the FWOP condition's assurance by event. Tables 56 and 57 show the same data categories for Alternative 3B.

Table 54. FWOP Condition's Target Stage, Target Stage ACE, and Long-Term Risk

HEC-FDA Reach	Target Stage	Target Stage ACE		Long-Term Risk		
		Mean	Expected	10 years	30 years	50 years
Reach A	136.93	0.25	0.25	0.94	1.0	1.0
Reach B	121.93	0.21	0.21	0.90	1.0	1.0
Reach C	130.65	0.06	0.06	0.49	0.86	0.96
Reach D	126.59	0.04	0.04	0.33	0.69	0.86

Table 55. FWOP Assurance by Event

HEC-FDA Reach	Conditional Non-Exceedance Probability by Event					
	0.1	0.04	0.02	0.01	0.004	0.002
Reach A	0.013	0.001	0.000	0.000	0.000	0.000
Reach B	0.047	0.002	0.000	0.000	0.000	0.000
Reach C	0.860	0.245	0.084	0.050	0.009	0.002
Reach D	0.985	0.552	0.289	0.140	0.033	0.008

Table 56. Alternative 3B's Target Stage, Target Stage ACE, and Long-Term Risk

HEC-FDA Reach	Target Stage	Target Stage ACE		Long-Term Risk		
		Mean	Expected	10 years	30 years	50 years
Reach A	136.93	0.20	0.20	0.89	1.0	1.0
Reach B	121.93	0.21	0.20	0.90	1.0	1.0
Reach C	130.65	0.06	0.06	0.48	0.86	0.96
Reach D	126.59	0.03	0.04	0.32	0.68	0.85

Table 57. Alternative 3B's Assurance by Event

HEC-FDA Reach	Conditional Non-Exceedance Probability by Event					
	0.1	**0.04**	**0.02**	**0.01**	**0.004**	**0.002**
Reach A	0.061	0.003	0.000	0.000	0.000	0.000
Reach B	0.054	0.002	0.000	0.000	0.000	0.000
Reach C	0.871	0.258	0.091	0.052	0.009	0.002
Reach D	0.988	0.575	0.307	0.149	0.036	0.009