APPENDIX C – ECONOMIC ANALYSES

For

RIO GUAYANILLA, GUAYANILLA, PR

2018 SUPPLEMENTAL APPROPRIATIONS

FLOOD RISK MANAGEMENT STUDY

GOBIERNO DE PUERTO RICO
DRNA
DEPARTAMENTO DE RECURSOS NATURALES Y AMBIENTALES

March 2020

US Army Corps of Engineers®
Chicago District

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1.0 Purpose and Overview

The purpose of this economic analysis is to evaluate the benefits and costs of the recommended project to National Economic Development (NED), as well as consider other social effects (OSE) that have socio-economic impacts on individuals in the study area.[1] This analysis estimates economic benefits and costs consistent with ER 1105-2-100 *Planning Guidance Notebook* and the scope and intent of a feasibility study. This appendix details the economic methodology used to evaluate the final array of alternatives for the Rio Guayanilla Feasibility Study, and determines the NED plan.

The purpose of the study is to evaluate flood risk within the Rio Guayanilla Watershed. The study area experienced devastating flooding in 2017 during Hurricane Maria, and under current channel (without project) conditions, nearly 9,000 people and 1,665 structures are at risk within the 0.002 annual exceedance probability (AEP) floodplain.[2] In the absence of a flood risk management project, it is estimated that average annual damages would total more than $19.8 million, including structures and structure contents, and vehicle, emergency, cleanup and agricultural damages. Implementing Alternative 3 would result in estimated average annual benefits of $20 million, and implementing Alternative 6 would result in estimated average annual benefits of $20.3 million.

This study finds that the NED plan provides average annual net benefits of approximately $14 million, and has a benefit-to-cost ratio (BCR) of 3.3 at the current Fiscal Year 2020 (FY20) 2.75 percent discount rate. At the 7 percent federal discount rate, the NED plan provides average annual net benefits of $7.2 million and has a BCR of 1.6.

1.1 Problems and Opportunities

Risk of property damage and loss of life due to inundation has been recorded in the study area since the 1800s. Heavy rainfall combined with steep slopes as the river leaves the mountains and runs towards its intersection with the Caribbean Sea produces high peak discharges in short periods of time. River discharge can exceed 30,000 – 40,000 cubic feet per second (cfs) in the study area. The central part of the town of Guayanilla is located next to a bend in the river, and due to the proximity of the river, structures, vehicles, and utilities are affected by inundation and individuals are at risk of life loss. This study aims to reduce risks to property, infrastructure, and human lives by reducing the probability and severity of inundation in the floodplain area.

According to the Flood Control Act of 1936, flood risk management projects are in the federal interest if the estimated average annual benefits over the period of analysis exceed the average annual costs (i.e., a BCR greater than 1.0), and if the lives and security of people would otherwise be adversely affected. The *Reconnaissance Report, Rio Guayanilla at Guayanilla, Puerto Rico* (1990 Recon Report) identified a recommended plan for which federal interest was determined. The recommended plan from the Recon Study combined 6.5 kilometers (4 miles) of earthen levee, 3.6 kilometers (2.25 miles) of trapezoidal channel improvements (stream channelization), 1.3 kilometers (0.8) miles of trapezoidal channel diversion, 300 meters (984 feet) of rectangular concrete channels, and the replacement of three bridges. Total first costs for the recommended plan were $12.5 million and average annual costs were $1.2 million in FY1990 price levels. Average annual benefits were $2.5 million with a benefit cost ratio of 2.1.

[1] Regional Economic Development (RED) analysis was not completed due to the lack of functionality for PR in RECONS Software. Environmental Quality (EQ) is discussed in the Main Report, Section 3.
[2] The 0.002 annual exceedance probability refers to the 500-year flood event, or a flood event that would have a 0.2 percent chance of occurring in any given year.

1.2 Historical Flood Events

Significant flood events occurred in the Rio Guayanilla floodplain in: 1975, 1979, 1982, 1985, 1996, 1998, 2004, 2008, 2012, and 2017. The 1975 flood, caused by Hurricane Eloise, caused over $1.7 million in damages in FY1990 price levels. Several hundred residents were forced from their homes as 99 houses were destroyed and 276 additional houses were damaged. Fatalities were reported in the 1975, 1979, 1985, 1998, and 2012 floods. In addition to the damaged structures and lives lost, flood-induced waters and sediment (rock and silt) deposits induced closures of major area roadways and impeded access to critical facilities. These facilities include a regional hospital and the local fire, emergency services, and police stations. In 2017, Hurricane Maria caused significant overtopping of the Rio Guayanilla and the floodwaters washed out a portion of a major bridge, and caused significant damage to the supermarket, a pharmacy, a bakery, and more than 106 homes. Several other critical public structures were inundated, banana crops were destroyed, and the area was left without electricity and telecommunications for months.

1.3 Study Authority

In 1990, the U.S. Army Corps of Engineers (USACE) published the *Reconnaissance Report, Rio Guayanilla at Guayanilla* (Recon Report). This study was conducted under the authority of Section 722 of Public Law (PL) 99-662, the Water Resources Development Act of 1986. The purpose was to investigate flooding problems associated with the overflow of the Rio Guayanilla, in the Town of Guayanilla, Puerto Rico, and identify measures within the Federal interest. Although a federal interest was determined, the non-Federal sponsor opted out of moving into the Feasibility Phase and independently implemented a portion of the project recommended in the Recon Study.

In August 2018, the Bipartisan Budget Act of 2018 (PL 115-123) provided supplemental appropriations for investigations. In order for USACE to request these supplemental appropriates the study must have been or must currently be federally authorized in order to be eligible. PL 115-123 did not provide authority for USACE to undertake a study that was not otherwise authorized; However, the Rio Guayanilla study area had previous authorizations under the Water Resources Development Act of 1986 (PL 99-662) Sec 722, and was therefore qualified to receive investigation funds. A Feasibility Cost Sharing Agreement (FCSA) was signed by the DNER on 6 September 2018.

1.4 Methodology

Methodology used in the economic analysis described in this Appendix is in accordance with ER 1105-2-100 and a risk-based analysis in accordance with ER 1005-2-101 was conducted. Benefits were computed at Fiscal Year (FY) 2020 price levels. The analysis uses the current federal discount rate for FY 2020 of 2.75 percent. The period of analysis is 50 years, with a project Base Year of 2026, and a construction period of 4 years.

2.0 Study Area

2.1 Location

The Rio Guayanilla floodplain lies in the Municipality of Guayanilla, on the southwest coast of Puerto Rico, beginning just north of the PR-2 highway and continuing south until the river's confluence with the Caribbean Sea (see Figure 1). The watershed is bordered on the west by the Rio Yauco and on the east by Rio Tallaboa. The watershed is approximately 96 square kilometers (37 square miles), and the total length of the river channel is approximately 23 kilometers (13.9 miles). There is potential for Rio Macaná, which lies to the east of the Rio Guayanilla watershed, to overflow into the lower basin of the Rio Guayanilla. The study area encompasses the entire floodplain of the lower Rio Guayanilla, including the Town of Guayanilla, and the coastal settlements Playita and El Faro.

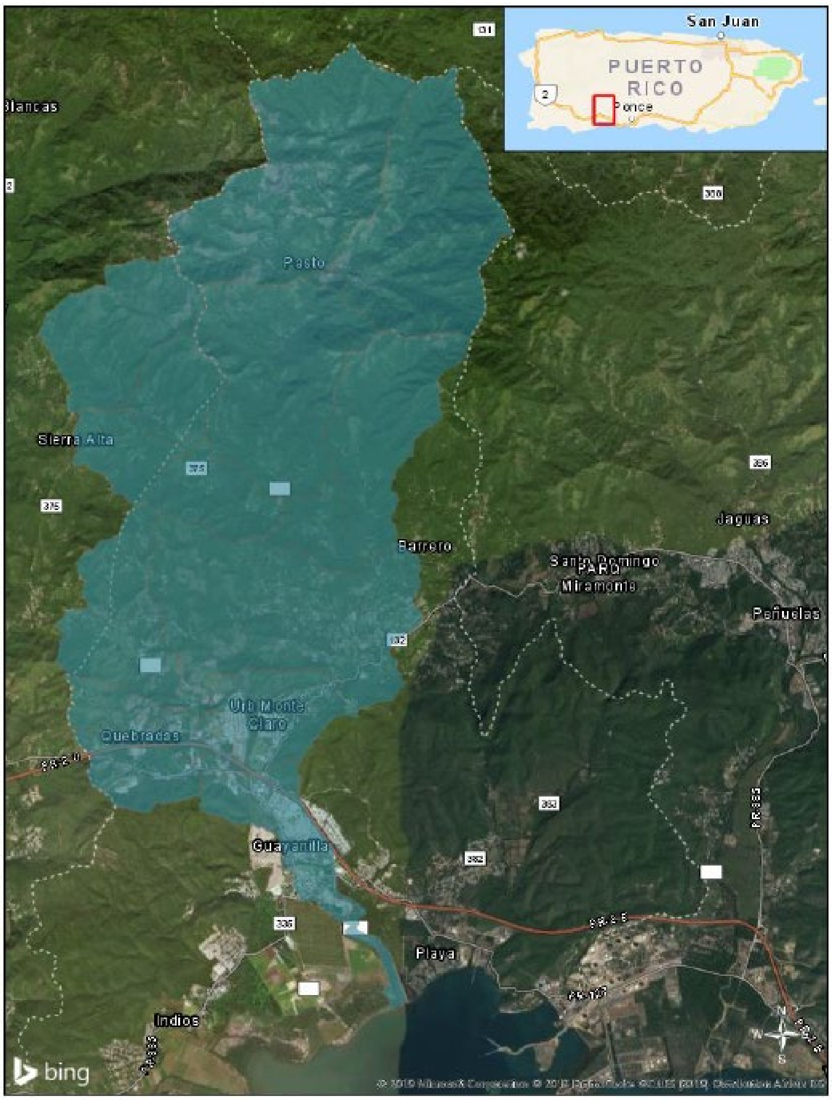

Figure 1. Rio Guayanilla Watershed

2.2 Floodplain Delineation

The 0.002 ACE (500-year event) floodplain and corresponding census tracts are shown below in Figure 2. A total of four census tracts intersect the 0.002 ACE floodplain; however, two census tracts contain the population at risk: tract 7403 and tract 7404. Census tract 7404 extends beyond the 0.002 ACE floodplain; however, since this tract is primarily rural and only two small neighborhoods exists outside of the floodplain extent, population estimates for the entire tract are included in demographics tables below.

Figure 2. 500-year Floodplain and Census Tracts

2.3 Reach Delineation

For purposes of the hydraulic and economic analysis, the study area is divided into eight damages reaches (1L, 1R, 2L, 2R, 3L, 3R, 4L, and 4R). Additional detail on the delineation of the reaches can be found in the H&H appendix. Reaches are depicted in Figure 3. Since no structures are located in reach 1R, this reach is eliminated in the FDA analysis and damage and benefit tables in the report.

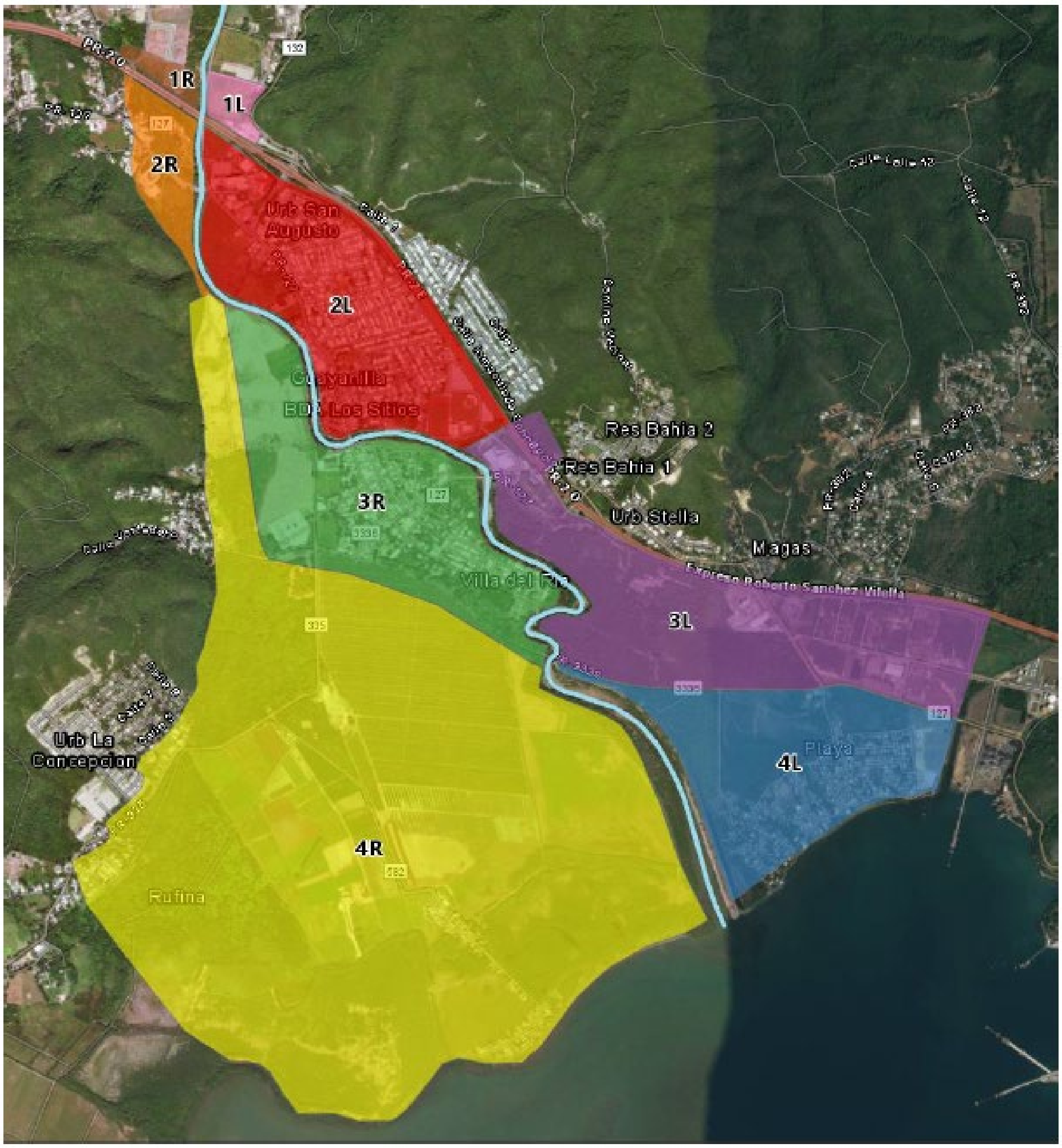

Figure 3. Damage Reaches

The channel within the study area varies by reach in construction material and geometry. The following types of channel are found in the study area:

1. Natural channel that has earthen sides and bottom
2. Leveed channel that has earthen berms along the channel

3. Riprap lined channel with earthen bottom (Phase 1 previously completed by DNER).

2.4 Socio-Economics

This section presents data on the socio-economic characteristics of the population within the floodplain. The data describes the population at risk and highlights the social vulnerability of the study area. Data is shown for the 0.002 ACE floodplain. Because data is shown at the census tract level, estimates were calculated using the entire census tracts of 7403 and 7404. Tracts 7402 and 740102 are not included in the estimates below.

2.4.1 Population

Figure 4 displays the study area population by census tract. Census tract 7403 includes Reach 2L, and portions of Reaches 3L and 3R. Census tract 7404 includes Reach 2R, the remainder of 3L and 3R, and all of 4L and 4R. Population estimates are taken from the 2017 American Community Survey (ACS) 5-year estimates available at census.gov.

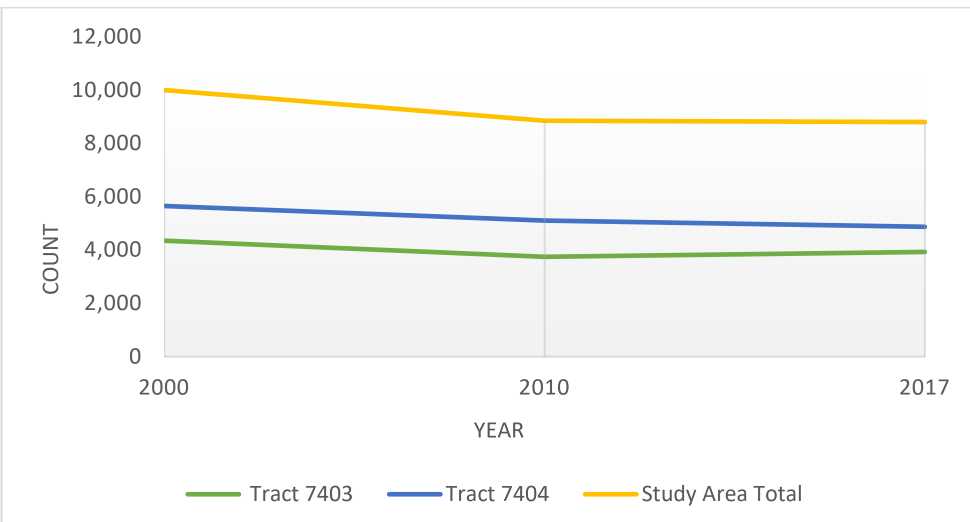

Figure 4. Study Area Population 2000 - 2017
Source: 2017 American Community Survey 5-year estimates

The total population in the study area declined from 10,000 in the year 2000 to 8,850 in 2010. The 2017 5-year estimate population is 8,800. Based on historical population data, it is estimated that the population will stay constant or experience a slight decline over the life of the project. It is not expected that there will be significant land use changes due to population growth in the study area.

Figure 5 shows the population count by age group for 2010 and 2017. The graph shows that between 2010 and 2017, there was a slight increase in the number of individuals aged 20-24 years, 35-44 years, and above 60 years. All other age groups experienced a decrease in population count. The largest decrease in an age-group since 2010 occurred in those aged 45-54 years, which decreased by about 300 individuals.

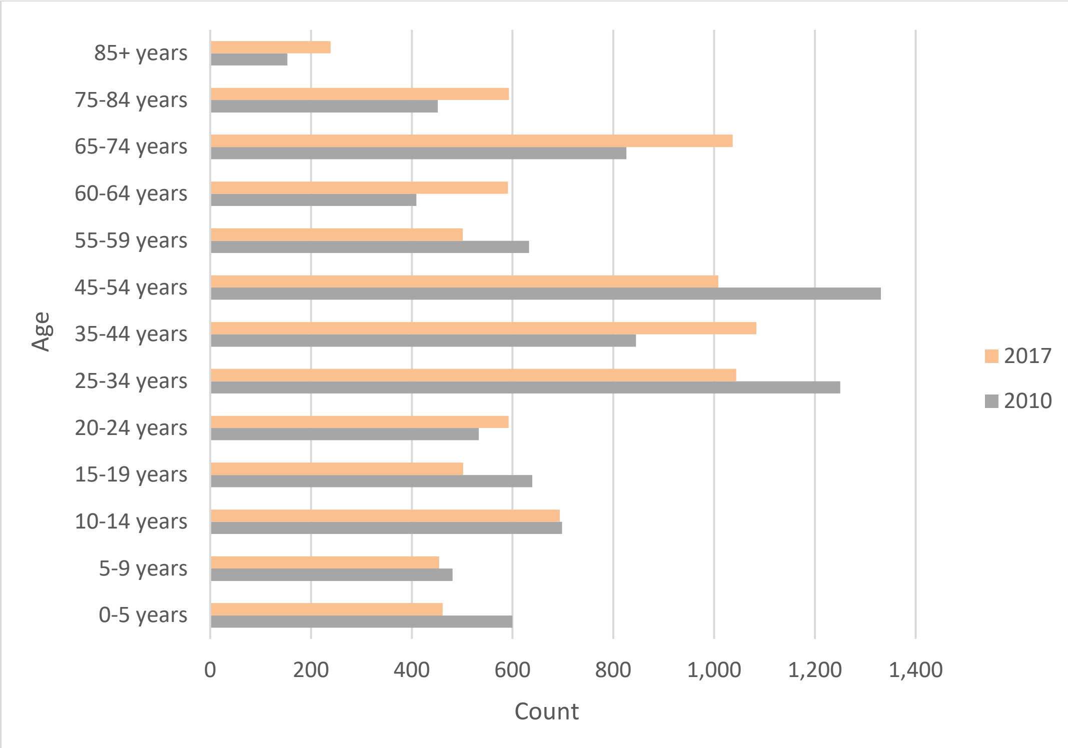

Figure 5. Study Area Population Distribution by Age
Source: 2017 American Community Survey 5-year estimates

2.4.2 Demographics

Poverty, financial, and housing unit characteristics help identify the vulnerability of the population at risk in the event of a 0.002 ACE flood. The tables and figures below describe these characteristics, and data includes estimates of income and poverty, unemployment, and average household size and home value.

Table 1. Income Comparison

	Mean Income	Per Capita Income	% Population Below Poverty Line
Study Area	$20,994	$8,214	57
Puerto Rico	$31,672	$12,081	45
United States	$81,283	$31,177	15

Source: 2017 ACS 5-year Estimates at factfinder.census.gov

Table 1 displays mean income for the study area, all of Puerto Rico, and the United States, based on 2017 5-year ACS estimates. Both mean and per-capita income in the entire US is nearly four times that of the study area. The poverty rate in the study area is also nearly four times as great as that of the entire US.

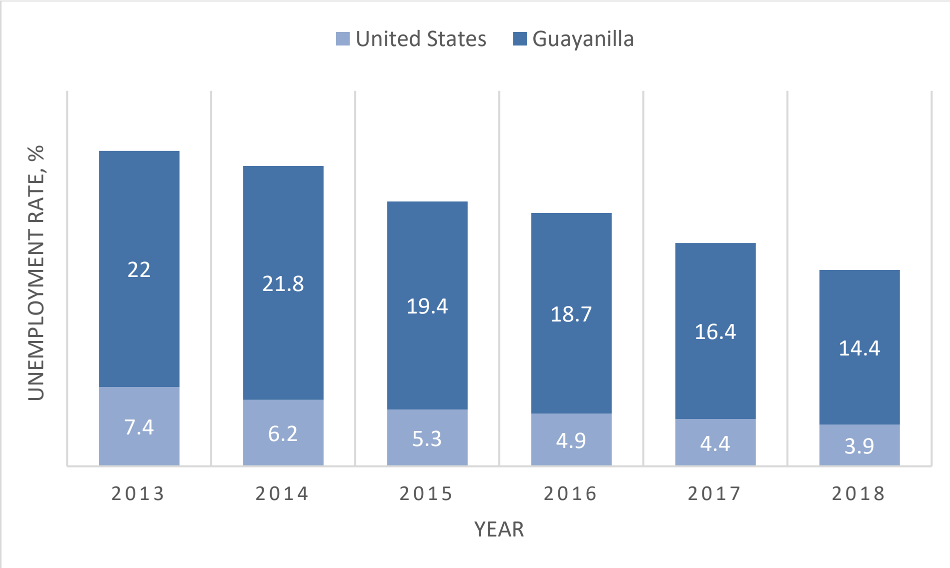

Figure 6. Unadjusted Annual Unemployment Rate, %
Source: Federal Reserve Bank of St. Louis

Figure 6 displays the annual unemployment rate for the United States and the Municipality of Guayanilla for 2013 through 2018. The municipality of Guayanilla encompasses the entire study area, and has a current unemployment rate of 14.4 percent, which is nearly four times the national unemployment rate. The 2017 ACS 5-year estimates available at census.gov show the unemployment rate by census tract, which is 39.6 percent for Census Tract 7403, and 14 percent for Census Tract 7404. Substantial and persistent unemployment exists in the study area, as defined in ER 1105-2-100, Appendix D, which states that substantial and persistent unemployment exists when the current rate of unemployment for the most recent 12 consecutive months is six percent or more, has been at least 50 percent above the national average for three of the preceding four calendar years, and has averaged at least 6 percent during this time period. Unemployed and underemployed labor resources as an NED benefit are discussed below in Section 5.

Table 2. Demographic Housing Characteristics

Location	Median Income	Median Home Value	Home Value to Income Ratio	Average Household Size	% of Housing Units Owner Occupied	% of Housing Units Renter Occupied
Study Area	$14,679	$82,300	5.6	2.5	73	27
Puerto Rico	$19,775	$115,300	5.8	2.5	67	31
United States	$57,652	$193,500	3.4	2.5	64	36

Source: 2017 ACS 5-year Estimates at facfinder.census.gov

Table 2 compares median income and home values, household size, and occupancy type for the study area, all of Puerto Rico, and all of the U.S. The average home to value income ratio for all of the U.S. is 3.4, while the home value to income ratio is 5.6 in the study area. The average household size is 2.5 across all geographies in the table, and the share of owner vs. renter occupied housing units between geographies is also similar. The average home value to income ratio is significantly higher for the study area than for the rest of the U.S.

2.5 Structures and Land Use

The study area floodplain is moderately populated and surrounded by rural and agricultural land. The 0.002 ACE floodplain contains 1,665 residential, public, and commercial structures, and approximately 420 acres of productive agricultural land. The following map shows these structures by structure type.

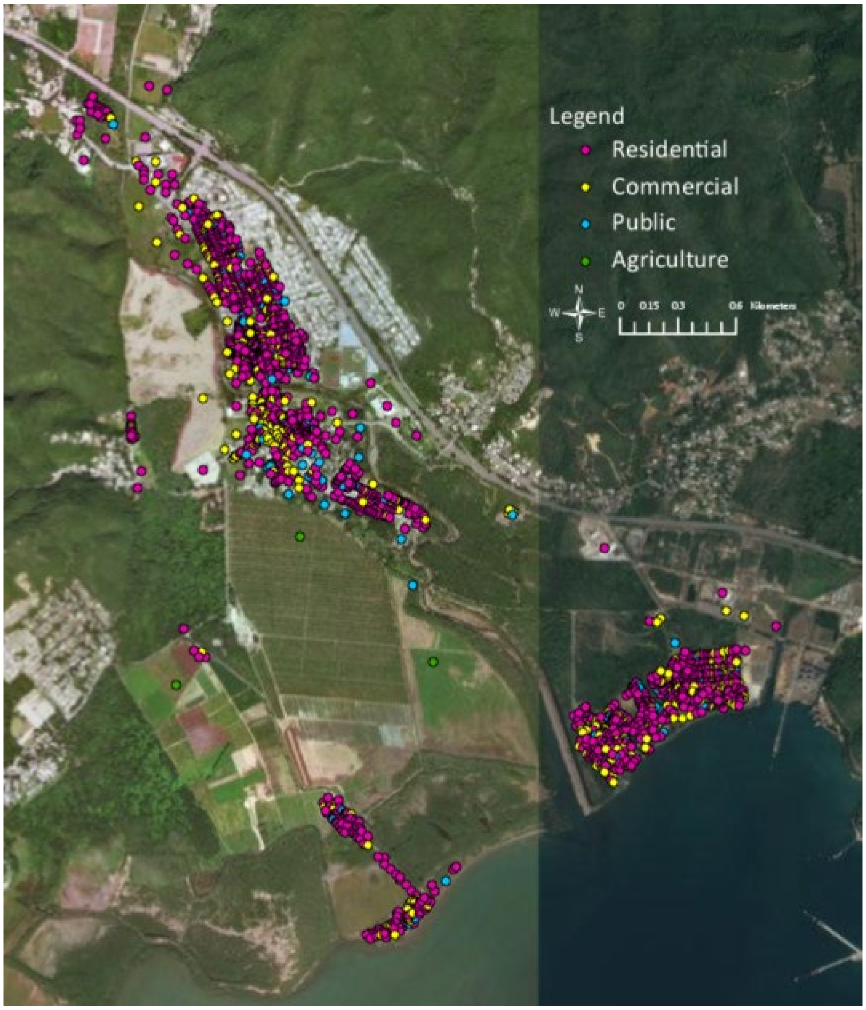

Figure 7. Structure Inventory by Structure Type

Table 3 shows the structure count by structure type, and gives depreciated structure and content values by structure type.

Table 3. Structure Count and Depreciated Replacement Values, FY 2020 PL ($000)

Structure Type	Structure Count	Depreciated Structure Value	Depreciated Content Value	Total Value
Residential	1,246	256,645	256,637	513,282
Commercial	320	110,674	96,283	206,957
Public	99	37,171	6,311	43,482
Floodplain Total	1,665	404,490	359,231	763,720

Residential structures account for 75 percent of structures in the floodplain, and commercial and public structures account for 20 and 5 percent, respectively. Total structure and structure content in the floodplain exceeds $760 million. Structure value accounts for approximately $400 million of this sum, and content values account for over $350 million.

Table 4. Structure and Content Values by Reach, FY 2020 PL ($000)

Reach	Depreciated Structure Value	Depreciated Content Value	Total Value	% of Floodplain Total
1L	448	448	897	0.12
2R	10,363	10,220	20,583	3
2L	133,275	122,506	255,782	33
3R	136,541	109,608	246,149	32
3L	22,501	22,330	44,831	6
4R	24,763	22,440	47,203	6
4L	76,598	71,678	148,277	19
Total	404,490	359,231	763,720	100

Table 4 displays depreciated structure and content values by reach. Reaches 2L and 3R contain the largest portions of structure and content value in the floodplain, accounting for $256 million and $246 million in structure and content value, respectively. Structure and content values in Reach 4L total to $148 million, and account for nearly 20 percent of total structure and content values.

2.6 Future Without Project Conditions

Based on the slightly negative population growth rate over the last two decades shown in Figure 4, it is estimated that future without project conditions will maintain current or slightly lower than current population levels. Additionally, no new development is expected to occur that would significantly alter the future without project condition, nor are any laws expected to be passed that would change the future without project condition.

3.0 Methodology

This section describes the methodology used to develop the Hydrologic Engineering Center – Flood Damage Reduction Analysis (HEC-FDA) analysis used for calculating with project benefits, discusses uncertainty, and describes how the structure inventory and structure values were developed. It also describes sources for depth-damage functions used in the calculation of economic damages, and describes national flood insurance benefits, and Other Social Effects.

3.1 HEC-FDA Analysis

The random and unpredictable nature of flood events means that future flood damage is uncertain and is best represented by a range of possible damage values and their likelihood of occurring, represented by a probability distribution. The USACE Hydrologic Engineering Center developed HEC-FDA 1.4.2, which uses Monte Carlo simulation to obtain a random sample of the contributing relationships and compute stage-damage functions, exceedance probability discharge curves, and conditional stage-discharge relationships, in order to generate expected annual damage (EAD) values. EAD estimates capture the mean of the probability distribution of annual damage, and are the basis for calculating equivalent annual damages and benefits. Uncertainty is incorporated into EAD estimates using Monte Carlo simulation: each iteration of a simulation randomly samples the uncertainty distributions, and the resulting values are used to transform the flow and stage distributions to a damage distribution. The area under the curve of the distribution is integrated to compute EAD. Thousands of iterations of this process are repeated to infer the EAD distribution and estimate EAD as the probability weighted average of all possible peak annual damages, where damage is a continuous random variable.[3]

In order to compute the EAD values, HEC-FDA requires the following data:

1. **Structure Inventory Data –** This includes a structure identification number, a use category (industrial, commercial, single family residence, etc.), stream location identified by cross sectional or grid data, first floor elevation, and depreciated structure and content values. This data was compiled using ArcGIS 10.3.1, and Microsoft Excel, and imported into Geospatial Process for Flood Damage Reduction Analysis (GEO-FDA) and HEC-FDA.
2. **Hydrologic and Hydraulic Data** – This data includes water surface profiles, exceedance probability discharge relationships, stage/discharge relationships, and levee fragility curves. Water surface profiles were developed in Hydrologic Engineering Center River Analysis System (HEC-RAS), processed in GEO-FDA to combine with the structure inventory, and then imported into the HEC-FDA program. Different than traditional cross-sectional analysis which uses only HEC-FDA, GEO-FDA generates a station number and calculates a water-surface profile at each structure location (rather than only at river index stations), based on gridded (2D) HEC-RAS data, for all eight events. The program also assigns each structure to a study reach based on geographic location. GEO-FDA then generates an output file containing all pertinent study data required for import into HEC-FDA.
3. **Depth/Damage Functions for Structures and Structure Contents –** Depth-damage relationships for residential structures were taken from Economic Guidance Memorandum (EGM) 01-03: Generic Depth-Damage Relationships, and depth-damage functions for non-residential structures were obtained from the Sacramento District's expert elicitation report,

[3] This process is described in more detail in the HEC-FDA User's Manual Version 1.4.1 available at http://www.hec.usace.army.mil/software/hec-fda/documentation/CPD-72_V1.4.1.pdf

Technical Report: Content Valuation and Depth-Damage Curves for Non-residential Structures. These depth-damage functions were used due to the similarities between the Guayanilla floodplain and floodplains in California.

4. **Risk and Uncertainty Parameters –** Uncertainty parameters discussed in section 3.2 of this report were also entered into HEC-FDA.

Discharge-exceedance probability, stage-discharge, and damage-stage functions derived at a damage reach index location are used to compute the damage-exceedance probability function. Monte Carlo simulation is a computationally efficient method of obtaining the damage-exceedance probability function due to uncertainty in input parameters. This numerical integration process requires all these relationships, and risk and uncertainty parameters to be input into HEC-FDA. Expected annual damage values are obtained from the cumulative distribution function produced in successive iterations of the Monte Carlo process.

3.2 Primary Sources of Uncertainty

There are many sources of uncertainty when estimating flood risk and associated damages. These uncertainties are accounted for in the HEC-RAS model (see H&H Appendix), and in the HEC-FDA portion of the analysis. The primary sources of uncertainty present in the calculation of economic damages include: storm water discharge, water surface elevations, levee performance, structure elevations, structure and structure content values, and depth-damage relationships. These are described in more detail in this section.

1. **Levels of Storm Water Discharge –** The amount of rainfall from storm events with equal probabilities can vary by location throughout the watershed. Variability in storm intensity, elapsed time during rainfall, ground permeability, soil, ambient temperature, and other physical factors can also cause variation in the location and timing of rainwater entering the channel. This variation causes uncertainty in the level of storm water discharge at any location along the river.

   In addition to natural variation arising from physical factors, there is uncertainty in the modeling of water discharges for a storm event due to limited historical meteorological and stream gauge data. This data can often be incomplete or limited in sample size (length of record for time-series data). Discharge-probability distributions in this study were computed using the graphical method and were based on a period of record length of 30 years. HEC-FDA calculates 95 percent confidence intervals for storm discharges that are used in economic computations.

2. **Water Surface Elevation –** The shape of the riverbed, water temperature, location and amount of debris, and obstructions in the channel can affect the water surface elevation for a specific location along the river. When the water surface elevation exceeds the top of the levee elevation, water flows onto the floodplain. Thus uncertainty affects water surface elevations in the floodplain and in the channel. To address this uncertainty, a standard deviation with standard normal distributions were input into HEC-FDA for water surface elevations. For the without project condition, a standard deviation of 1.0 feet, held constant at the 0.2 ACE was used; a standard deviation of 0.75 feet was used for both the minimum and maximum project alternatives, becoming constant at the 0.1 ACE and 0.02 ACE, respectively.

3. **Levee Performance –** There is uncertainty about how an existing levee will perform under certain water surface elevations, how interior water-control facilities will perform, and the thoroughness of closures or openings in an existing levee. For this analysis, a geotechnical failure function was assigned to Reach 3R, based on recent and historical earthen levee failure. For all

other reaches, top of bank elevations were entered, and it is assumed that the there is no breach prior to overtopping.[4]

4. **Structure Elevations –** Structure elevation is key in determining the depth of flooding inside of a structure during a flood event. First floor structure elevation is the aggregate of topographical elevation and foundation height. Both of these elevations are prone to uncertainty; topographical elevation uncertainty stems from the level of detail of the survey used to develop the data, while foundation height uncertainty is caused by assigning a standard foundation height by structure type based on sample statistics, rather than surveying each individual structure. Structures were sampled and surveyed by strata, as outlined in Section 3.4. Structure elevations were determined by taking the sum of the foundation height and corresponding topographical elevation based on structure location. Statistical uncertainty was determined by referencing the standard deviation estimates contained in USACE Engineering Manual 1110-1-1619, which presents standard deviation of error estimates for various measurement methods, based on Institute for Water Resources (IWR) research. Ground elevations were derived from topographical LIDAR data, and were assigned standard deviations of error ranging from 0.60 feet to three feet, based on the engineering manual cited above. Since additional stairs are typically required when a structure's doorway is six or more inches above the ground or last stair, it was assumed that (1) 98 percent of the data would be accurate within 0.50 feet, and (2) a standard deviation of error in the first floor elevation estimate would be no greater than 0.25 feet. Thus, standard deviation of error estimates between 0.85 and 3.25 were assigned to the joint ground and first floor elevation data. It is assumed that joint distribution error and corresponding probability distribution functions are normally distributed with a mean error of zero.

5. **Depreciated Structure and Content Replacement Values –** The depreciated replacement values for structures and contents are used to determine economic damages in the floodplain and are a function of structure type, condition, and size. Since surveying every structure in the floodplain was not feasible for this study, uncertainty arises in these values. Field surveys were based on a randomized stratified sample of floodplain structures, and were used to determine structure type, condition, square footage, and foundation height, as outlined in Section 3.3. *Marshall & Swift* multiplier values per square foot and uncertainties for structure condition and corresponding estimates of depreciation were used to calculate the structure and content value for each structure. Errors for structure value estimates are assumed to be normally distributed with a mean error of zero, and standard deviations range from 10 to 15 percent of mean structure value. Structure content values are estimated as a percentage of the structure value, based on structure type and the depth-damage function.

6. **Depth-Damage Relationships** – Depth-damage functions are used to calculate the percent damage a structure will incur at a specific water elevation in a flood event. This is another calculation that is subject to variation between structure and flood event. The methodology used to construct depth-damage relationships for non-residential structures was developed by an expert-opinion elicitation process, conducted by USACE Sacramento District and published in *Technical Report: Content Valuation and Depth Damage Curves for Nonresidential Structures, May 2007.* This report provides non-residential depth-damage curves for structure contents by structure type, as well as content-to-structure value ratios and associated standard errors. The use of these depth-damage relationships and associated uncertainty is appropriate for the Rio Guayanilla floodplain, since floodwaters rapidly inundate areas with minimal warning in both geographic locations, where the rivers flow at high velocities from the mountains to the ocean.

[4] Levee fragility parameters used in the current analysis were estimates provided in May 2019. If further refinements are made to geotechnical functions and/or levee heights, economic damage estimates may be impacted.

Non-residential depth-damage functions and structure-content ratios used from the referenced report are provided in Addendum A.

Depth-damage functions and associated standard errors for residential structures and their contents were developed by the Institute for Water Resources (IWR) and published in *Economic Guidance Memorandum 04-01: Generic Depth-Damage Relationships for Residential Structures with Basements, October 2003.*The depth-damage functions and standard error estimates are based upon previous damages that occurred during flood events in the United States.

Depth damage functions for other damage categories are described in the discussion of damages by category in the following sections.

3.3 Engineering Inputs

3.3.1 Hydraulic and Hydrologic Inputs

Hydraulic and Hydrologic inputs including water surface profiles and corresponding relationships were used to compute expected annual damages through Monte Carlo sampling of discharge-exceedance probability relationships, stage-discharge relationships, and stage-damage relationships and their uncertainties. Uncertainty parameters for the exceedance-probability relationship and stage-discharge relationship were developed by H&H engineers. For the exceedance-probability relationship, uncertainty is based on an Equivalent Record Length (N) of 30 year gage record for all project conditions and reaches. The probability – stage curve for the without project condition is included in Addendum A of this report. For the stage-discharge relationship, uncertainty is as follows:

<u>Without / Existing Project Condition</u>
Normal Distribution with a standard deviation of 1 foot, becoming constant at the 5 year profile.

<u>Alternative 3 and Alternative 6</u>
Normal Distribution with a standard deviation of 0.75 feet, becoming constant at the 10 year profile.

These values are based on how river stages within the channel react to various flows and is not expected to change during the period of analysis. Additional detail regarding the estimation of these parameters can be found in the H&H Appendix.

Hydraulic and Hydrologic Inputs were developed for the without project condition, and for Alternatives 3 and 6, for both current and future years. Future year without project and with project conditions incorporate a sea level rise of 3 feet. For additional information on incorporating sea level rise, see the H&H Appendix.

3.3.2 Geotechnical Inputs

Levee fragility curves were developed by geotechnical engineers to address potential levee failure in Reach 3R. In addition to overtopping, the bank could fail in this impact area, as it did during the2017 Hurricane Maria flood event. Levee failure increases flow outside of the channel and damage to structures. Under the without-project condition, there is a 15 percent chance of levee failure at the probable no-failure point (PNP), and an 85 percent chance of levee failure at the probable failure point (PFP) elevation. The geotechnical function for Reach 3R was input into FDA using corresponding PNP and PFP elevations. The Geotechnical function for Reach 3R is shown in the table below. For methodology, see the Geotechnical Appendix.

Table 5. Geotechnical Functions

Reach	Probable No-Failure Point Elevation (PNP)	Probability of Failure at PNP	Probable Failure Point Elevation (PFP)	Probability of Failure at PFP	Levee Crest Elevation	Probability of Failure at Crest
3R	25.7	0.15	33.6	0.85	33.6	1

3.4 Damages to Structures and Structure Contents

Residential, commercial, industrial, and public structures in the floodplain are at risk of being damaged when flood events occur that exceed the system capacity. To value economic loss resulting from these damages, an inventory of structures within the floodplain was developed. Depreciated replacement costs of these structures and their contents were then calculated and flood damages for varying probabilistic events were estimated. This section describes the methodology used to create the structure inventory.

3.4.1 Structure Inventory

Structures in the study area vary greatly in construction type, size, condition, and quality. In the center of town behind the commercial area, many residential structures are smaller wood structures that vary in condition. The community of El Faro contains both wood and concrete structures. The rest of the study area typically contains tropical-type concrete structures that vary in size and condition. Below are pictures of typical residential structures in the floodplain.

Figure 8. Typical Residential Structure in Guayanilla

Figure 9. Typical Residential Structure in Guayanilla

Figure 10. Typical Residential Structure in Guayanilla

Figure 11. Typical Residential Structure in Guayanilla

Figure 12. Typical Residential Structure in Guayanilla

Figure 13. Typical Residential Structure in Guayanilla

Figure 14. Typical Residential Structure in Guayanilla

Structure inventory for the feasibility study was developed using Puerto Rico Tax Collection Agency (CRIM) data, and a randomized survey of structures within the Rio Guayanilla floodplain. CRIM data obtained from the local government included a shapefile of geo-referenced parcel locations. Centroids were calculated based on the center of the parcel location using ArcGIS 10.3. A ten percent sample of structures within the 500-year floodplain was then randomly assigned and stratified across census tracts in Stata. Sampled structures were then surveyed using a windshield-method by District economists to obtain first floor elevations and Marshall & Swift classifications for structure type, construction quality, and condition. Survey statistics were randomly applied to all structures in the floodplain.

Square footage for all parcels in the floodplain was calculated manually in ArcGIS Pro using aerial imagery and the measurement tool. It should be noted that some parcels include multiple structures, and therefore the replacement values shown in FDA are not representative of average structure value. Additional structures not included in the CRIM dataset were identified during this exercise, and added to the structure inventory. Sample statistics from the windshield survey including structure type, quality, and condition were then applied to these structures.

Separately, a contractor carried out a field survey to obtain first floor elevations and square footage for structures. The goal of this additional survey was to verify the ArcGIS square footage measurements and the windshield surveyed first floor elevations. A shapefile was given to the contractor containing the randomly assigned stratified sample of structures, and the same structures were surveyed to verify first floor elevation. A subset of this shapefile was randomly assigned in Stata to include 50 structures that were then surveyed by the contractor to verify square footage measurements. The subset was surveyed since budget and time constraints prevented the contractor from surveying the entire original sample. First floor elevations from the contractor survey were applied to the original randomized sample, and then randomly applied to the entire inventory. The sub-sample of 50 structures was used to compute an adjustment ratio and adjust the square footage of the structure inventory for measurement error in original ArcGIS measurements.

Depreciated structure replacement values were calculated using Marshall & Swift costs per square foot. Structure type, condition, inflation index, and location multiplier values were obtained from Marshall & Swift and used to calculate the depreciated replacement value. Values were obtained in February 2019, and structure values and corresponding damages were calculated in FY (Fiscal Year) 2019 price levels in FDA, and updated to FY20 price levels at the beginning of FY20[5]. Structure inventory data was projected to NAD 1983 State Plane Puerto Rico Virgin Islands FIPS 5200 Feet, to maintain consistency with the H&H data.

Per Marshall & Swift Manual Section 99 Page 1, following natural disasters, labor and material shortage result in increased rebuilding costs, which should be reflected in depreciated replacement values by adjusting the Location Index Adjuster up to 50 percent. Based on a conversation with a local contractor who has been doing much of the structural repair work since Hurricane Maria in Guayanilla, material prices have been at least 30 percent higher since the hurricane. As a result, the Location Index Adjuster was increased by 30 percent for each structure class. The Location Index Adjuster in Marshall and Swift is higher for geographic areas where building materials and costs are higher. Due to the geographic location of Puerto Rico and the wait-time to receive materials, post-disaster material and labor shortages can turn into persistent long-term shortages, particularly following a catastrophic event. Therefore, the 30

[5] Damages were updated to FY20 price levels using the Civil Works Construction Cost Index System (CCWIS) composite index (weighted average) from FY19 Q1 and FY20 Q1.

percent adjustment to the Location Index Adjuster is representative of longer-term shortages in labor and materials, rather than a temporary phenomenon. The Location Index Adjuster is multiplied by the inflation index and unadjusted per square foot cost to obtain the depreciated replacement value per square foot. For example, with the 30 percent location index adjuster increase, the depreciated replacement value per square foot for a single family residence in average condition would be $153.14. This same value without the 30 percent index increase would be $118.10. Therefore, the location index increase results in a depreciated replacement cost increase of about 22 percent. This is conservative based on actual construction costs in Guayanilla since Hurricane Maria.

The structure inventory and HEC-RAS output files, including water surface profiles for eight hydrologic events, were imported in GEO-FDA. LIDAR data was used to assign a ground elevation to each structure location in GEO-FDA, and each structure was also assigned a reach based on geographic location. A water surface profile was created for each structure location from the corresponding 2D grid cell in the HEC-RAS data. Structures and water surface profiles were then imported into HEC-FDA for analysis.

3.4.2 Structures Built After 1991

According to the Water Resources Development Act of 1990 (WRDA90) Section 308, new or improved structures built within the 100-year (0.01 ACE) floodplain after July 1, 1991 should be excluded from the structures used to calculate NED benefits for flood damage reduction projects. CRIM data is incomplete in that it doesn't include all structures, nor the year each structure was built. Additionally, Google Earth Pro historical imagery only dates to October 1993, although imagery from this date shows similar development that exists today in the 100-year floodplain. Based on the windshield survey and Google Earth imagery it is estimated that all structures in the 100 year floodplain were built prior to 1991. In addition, flooding in the community has prevented development, and it is unlikely that additional structures have been built in the floodplain due to the frequent flooding that has caused significant economic loss.

3.5 Other Damage Categories

In addition to damages to structures and their contents, various other damages may occur in a flood event, including cleanup costs, other public assistance, and damages to vehicles. This section explains these categories in more detail and justifies them as flood damage reduction categories that should be included in the calculation of with-project benefits.

3.5.1 Cleanup Costs

ER 1105-2-100 provides for emergency expenses, which include hazardous and toxic waste cleanup, to be included in damage estimates for flood events. Structures that are inundated in a flood event require post-flood cleanup in order to remove floodwater, sediment, debris, mold, mildew, and toxins. These cleanup costs are considered a damage category in the calculation of with-project benefits and can vary based on the depth of flooding. A depth-damage curve is used to estimate the cost incurred for a given level of inundation in a structure. Depth-damage functions for cleanup costs come from USACE Sacramento District's *Technical Report: Content Valuation and Depth Damage Curves for Nonresidential Structures, May 2007.*

Cleanup costs for the structure inventory were based on actual insurance claims for flood damages in Guayanilla following Hurricane Maria in 2017 and non-public debris removal. Insurance claim documents were provided by the Guayanilla Mayor's office, and include mold abatement/mitigation, the application of anti-microbial agents to surface area, air movers, and dehumidifiers. Non-public debris removal costs were taken from the New Orleans District "Development of Depth-Emergency Cost and Infrastructure Damage Relationships" report from 2012. The maximum cleanup cost, including mold abatement and residential debris removal is $5.99 per square foot. The maximum value is applied when water surface elevation reaches three feet, and a portion of this value is applied for water surface elevations below three feet, per the depth-damage function.

3.5.2 Vehicle Damages

This economic analysis includes vehicle damages for vehicles at residential structures. Historical floods, including Hurricane Maria, inundated vehicles with mud and water, and floodwaters carried enough force to physically move cars significant distances, causing damage. Automobile damages were calculated as a function of the number of vehicles per residence, estimated average value per vehicle, and the depth of flooding above the ground elevation. Damages to autos in commercial, industrial, and public parking lots are not included in the analysis.

To obtain the vehicle replacement amount, the average number of available vehicles per household in Puerto Rico was taken from the 2017 American Community Survey estimates at census.gov. A weight was then calculated based on the percent of population with either 0, 1, 2, or 3 cars. The weighted average of total cars per household was calculated to be 1.35. Average vehicle cost was calculated based on the average cost of cars posted on Clasificados Online (a local version of Craigslist) in February 2019, where both new and used cars are posted for sale. Due to the limited number of vehicles for sale in the rural municipality of Guayanilla, and due to the close proximity of Guayanilla to the urban area of Ponce, the average value of vehicles was based on postings from both Guayanilla and Ponce. A histogram of the sample was calculated and values were run through @Risk software to calculate the average value of a vehicle in the study area to be $16,874. Multiplied by the number of vehicles per household, the vehicle replacement cost for vehicles at residences used in the analysis is $22,768. It is important to note that used and new vehicle values in Puerto Rico are higher than in the mainland U.S., due to a steep excise tax that the Puerto Rican government levies on each vehicle imported to the island, whether by a dealer or a third party. For example, a car with a retail value of $25,000 in the U.S. will retail for about $42,000 on the island. Based on this, the average value of vehicles in the study area is a reasonable estimate.

Depth-damage functions for auto damages come from USACE Sacramento District's *Technical Report: Content Valuation and Depth Damage Curves for Nonresidential Structures, May 2007.* The maximum damage value for vehicles is applied when water surface elevations reach nine feet.

3.5.3 Other Emergency Costs

Other emergency costs incurred in flood events come from FEMA's Individuals and Households Program (IHP) and include the following: Public Assistance (PA) to aid in public debris removal, emergency protective measures, and to repair roads, bridges, water facilities, public buildings, utilities, and public parks and recreation facilities; and Other Needs Assistance (ONA), which includes aid to replace essential household items, and moving, storage, medical, dental, and funeral expenses caused by the flood. Housing assistance is not included in the analysis.

For emergency costs in this analysis, actual PA and ONA claims data from Hurricane Maria for the Municipality of Guayanilla was gathered from FEMA's website and used to calculate maximum emergency cost values.[6] PA per household was calculated by taking the total sum of public assistance and dividing it by the number of Individual Assistance Applications approved. As of January 2019, nearly

[6] Data was retrieved on January 18, 2019. Any additional claims for the 2017 flood event that may have been added after this date were not included in the analysis.

$5.4 billion in public assistance grants had been obligated and 467,407 individual assistance applications had been approved for IHP. This resulted in a PA per household amount of $11,533. Other needs assistance for the Municipality of Guayanilla totaled $2.77 million as of January 2019, and was based on 2,286 approved claims. Therefore, average ONA per household was calculated to be $1,209. This was added to the PA per household amount for a maximum emergency cost amount of $12,743.

Emergency costs are also assigned a depth-damage function that associates a specific depth of flooding to a percentage of the emergency costs in HEC-FDA. Fifty percent of the total value of emergency costs are incurred when water surface elevations are greater than 0.5 feet, while water surface elevations of one foot or greater incur 100 percent of the emergency cost value. This is based on the assumption that households must incur a depth of flooding greater than zero to be eligible to file a claim. Thus structures which are inundated one foot or more above the first floor elevation would incur public and other needs assistance related costs as reflected in the FEMA claims data.

3.6 Agricultural Damages

There are approximately 420 acres of productive agricultural land used for banana farming in Reach 4R, west of the existing channel. Valuation of agricultural crops was calculated based on average production per acre per year, and the current average cost per pound of bananas, taken from the Puerto Rico Department of Agriculture's website. Because HAZUS agriculture curves are only calculated for agricultural structures, a depth-damage curve was created that estimated 25 percent damage at 0.5 feet flood depths, 50 percent damage at 1 foot flood depths, and 100 percent damage at 2 foot flood depths. This was based on industry research and historical flood damages that have previously occurred in Puerto Rico, and is a conservative estimate. Growing season coincides with rainy season in Puerto Rico, and banana plants are known to have fragile roots that don't survive short-duration flood events. Agricultural land was divided into three parcels and a centroid of each parcel was calculated. Total agricultural crop value is $2.5 million. Agricultural damages were calculated in FDA as an individual damage category.

3.7 National Flood Insurance Program Operating Costs

EGM 06-04 provides guidance on including the reduction in flood insurance program operating costs as a benefit to the project, as a result of fewer structures at risk of flooding in the 100-year event. With either Alternative 3 or Alternative 6, the number of structures in the 100-year floodplain would be reduced from 1,439 to 24. The flood insurance cost benefit is calculated by multiplying the number of structures in the floodplain under each project condition by the average price of operating costs per policy, and subtracting the product for the with project condition from the without project condition. This methodology assumes that each structure in the 100-year floodplain represents one household that carries a flood insurance policy. The price per policy was taken from EGM 06-04, and represents an estimated average cost per policy for administration of the National Flood Insurance Program. The most recent flood insurance policy cost of $192 is used in this analysis, and was estimated in EGM 06-04 *National Flood Insurance Program Operating Costs, Fiscal Year 2006.* This benefit category is included with other benefits in the tables below, and accounts for a very small portion of overall project benefits.

3.8 Other Social Effects

3.8.1 Life Safety

In accordance with ER 1105-2-101, life loss qualifies as an OSE (Other Social Effects) damage category. A life safety analysis includes the estimation of the population at risk and associated statistical parameters for life loss. For this analysis, life loss was calculated using LifeSim 2.0 for the future without project

(FWOP) condition and future with project (FWP) condition. This software uses Monte Carlo simulation to estimate the number of individuals at risk of life loss by probabilistic event for nighttime and daytime populations. The results of the FWOP and FWP conditions were compared to estimate residual life loss after the project is implemented, and to assess life safety risk during flood events at various flood frequencies.

The latest version of the National Structure Inventory (NSI) and associated population parameters were used for the life loss analysis.[7] This data, along with terrain, arrival time and depth grids, and impact area data were loaded into the LifeSim 2.0 software, and the structure inventory was calibrated to ensure no structures were located within the channel. Default uncertainty parameters and depth-damage functions developed for the NSI data were used for life loss calculations.

Public warning issuance is a key factor in determining life loss estimates. Hazard communication delay was calculated using a uniform distribution with a minimum of six minutes and maximum of 30 minutes. A triangular distribution was used for warning time, with 99 percent of the population being warned of the hazard within 50 minutes and 100 percent of the population being warned within 90 minutes. Life loss estimates are shown below for the 0.01 and 0.002 ACE events for the daytime population.

Table 6. Life Loss Estimates 0.01 ACE

Reach	PAR Daytime	Without Project	Alternative 3	Life Loss Reduced
1L	0	0	0	0
1R	0	0	0	0
2L	1,525	6	0	6
2R	53	2	0	2
3L	0	0	0	0
3R	898	0	0	0
4L	1,116	0	0	0
4R	199	0	0	0
Total	3,791	8	0	8

Note: PAR is Population at Risk within the 0.01 ACE floodplain.

Table 6 shows that the estimated daytime population for the 0.01 ACE is nearly 3,800. Reach 2L has the highest population at risk and the highest life loss estimates. Under FWOP conditions, it is estimated that life loss would be 8 for all reaches combined. Life loss for the 0.01 ACE frequency event would be eliminated under Alternative 3.[8]

[7] NSI population estimates differ from ACS 2017 population estimates for the study area, and thus population at risk in LifeSim is likely underestimated.

[8] Life loss modeling was only undertaken for Alternative 3, due to the fact that Alternative 6 was the non-NED plan. However, since hydrologic and hydraulic models were nearly identical for both alternatives, life loss estimates for Alternative 6 would likely be similar to the estimates shown here.

Table 7. Life Loss Estimates 0.002 ACE

Reach	PAR Daytime	Without Project	Alternative 3	Life Loss Reduced
1L	2	0	0	0
1R	0	0	0	0
2L	1,886	25	1	24
2R	67	1	0	1
3L	16	0	0	0
3R	1,149	1	0	1
4L	1,167	2	0	1
4R	199	1	0	1
Total	4,486	29	1	28

Note: PAR is Population at Risk within the 0.002 ACE floodplain.

Table 7 describes life loss estimates for the 0.002 ACE, and shows that the daytime population at risk for a 500-year flood event is nearly 4,500. Under FWOP, life loss is estimated to be 29. This number is reduced to 1 under Alternative 3. For additional life loss scenarios, refer to the Risk Appendix.

3.8.2 Social Vulnerability

The socio-economics of the study area presented in Section 2.4 show that the population in the study area is particularly economically and socially vulnerable when flood events occur. Unemployment in the study area is 3.7 times that of the U.S. average. The poverty rate in the study area is nearly four times the U.S. average, and is 12 percent higher than the average rate in Puerto Rico. Average income in the study area is 75 percent lower than the U.S. average and 35 percent lower than the average income in Puerto Rico as a whole. These factors can increase the community's propensity to suffer mentally and financially in the event of a flood.

In addition to the demographic data provided in Section 2.4, this analysis uses the Center for Disease Control's Social Vulnerability Index (CDC SVI) tool to estimate social vulnerability. The SVI compares municipalities in Puerto Rico by ranking demographic variables from zero to one, sums all the variables, and then ranks the sum from zero to one, with one being the most socially vulnerable. The ranking represents the percentile of the municipality relative to the other municipalities, so if a municipality has a score of 0.31, the municipality is more socially vulnerable than 31 percent of municipalities. There are fifteen census attributes across four themes that form the base of the SVI. These four themes are: 1) socioeconomic status, 2) household composition and disability, 3) minority status and language, and 4) housing and transportation.[9] The SVI scores in these areas for the Municipality of Guayanilla are shown in the table below.

[9] See https://svi.cdc.gov/Documents/Data/A%20Social%20Vulnerability%20Index%20for%20Disaster%20Management.pdf for data and methodology.

Table 8. Guayanilla Social Vulnerability Index

Category	Ranking
Socioeconomic Status	0.78
Household Composition and Disability	0.52
Minority Status and Language	0.65
Housing and Transportation	0.04
Composite Ranking	0.47

Source: svi.cdc.gov

Guayanilla is 78 percent more socially vulnerable than all other municipalities in Puerto Rico in terms of socioeconomic status. The municipality scored the highest in housing and transportation, and is only 4 percent more vulnerable than the rest of the 77 municipalities. Considering all categories, Guayanilla is 47 percent more socially vulnerable than all other municipalities.

With low income levels and a high poverty rate, even a small flood event can have significant economic and social impacts for the community of Guayanilla. Historically, individuals in the study area have suffered greater economic and social damages than what can be fully quantified in this analysis. During the public meeting held in Guayanilla in November 2018, testimonies given by the public included accounts of economic, social, and psychological impacts of flooding in the community. These impacts include: flood events causing businesses to close to remove debris and floodwaters; businesses experiencing a loss in total income, and the closures resulting in lost wages for local employees; schools closing and impacts on educational outcomes; and the psychological impacts of additional financial and emotional stress from loss of property, and in some cases loss of life. One account given by a 19-year old mentioned the impacts of loss of property in relaying that some children don't have more than one or two pairs of clothes and one pair of shoes for school, and when clothing is destroyed by mud and water in a flood event, there often is no money to buy new clothes. Additionally, following Hurricane Maria, the only supermarket in Guayanilla closed due to floodwater damages, and remains closed. Individuals now have to travel to the neighboring municipality of Yauco to go to the supermarket, and a car is required to get there. Lastly, several individuals mentioned that there was a sentiment that the community cannot grow economically because businesses are aware of the flooding problem, and have left Guayanilla, or will not start a business in Guayanilla, due to the significant risk of suffering economic damages caused by inundation. The high social vulnerability of Guayanilla is exacerbated by flood events, which have negative economic and social impacts.

4.0 Without Project Damages

This section describes the analysis of damages that are expected to occur in the absence of a Federal project to address flood risks in the study area. These damages include damages to structure and structure contents, and other damages, which include damages to agriculture, vehicle damages, and cleanup and emergency costs associated with flooding. Without project flooding also impacts Other Social Effects, which includes loss of life and is quantified in this section. Damages are calculated using a 50-year period of analysis, with a base year of 2026.

HEC-FDA software was used to calculate economic damages for this study. Expected and equivalent annual flood damages are the basis for calculating with-project benefits, and are crucial to the evaluation of the project. Expected annual damages are equal to the mean of all possible values of damage that are derived through Monte Carlo sampling of discharge-exceedance probability relationships, stage-discharge relationships, and stage-damage relationships and their uncertainties. Expected annual damages are calculated for the base and future years, and used to calculate equivalent annual damages. Equivalent annual damages are equal to expected annual damages that have been discounted to present values and annualized. Equivalent annual damages are calculated for the base and future years, and interpolated for in-between years. This section presents expected and equivalent annual damages, and as the result of time-dependent variance in hydrologic, hydraulic, and economic data, the values presented are estimates only. Uncertainty parameters for the exceedance-probability relationship and stage-discharge relationship were developed by H&H engineers as detailed in Section 3.3.1.

4.1 Current and Future Expected Annual Damages

Hydrologic models for current project and future project conditions were developed. The hydrologic model for future project conditions added a sea level rise of three feet to the base water level at the downstream boundary in both without and with project future conditions model runs. The increased water surface elevation had no impact on future damages, since the project is outside of tidal influence. For this reason, there is no difference between without/with current and without/with future project damages. Therefore, expected annual damages are equal to equivalent annual damage estimates shown below. For detailed information regarding current and future project conditions, refer to the H&H appendix.

4.2 Without Project Equivalent Annual Damage Estimates

Equivalent annual damage is the mean damage for each damage reach, obtained by integrating the damage exceedance probability curve and discounting estimates to present values at the current FY20 discount rate of 2.75 percent. Without project equivalent annual damages are the averages of flood damages caused by flood events with a given probability of occurrence in any given year in the absence of the project. These estimates are shown in the tables by reach and use type in the tables below.[10]

Structure and structure contents include the cost of the damage to the physical structure and the contents inside it, based on a depth-percent damaged relationship as previously described. Structure and structure contents include damages to residential, public, and commercial structures. Other related flood damages include damages to agricultural, residential vehicles, and emergency and cleanup costs. Values are shown in FY 2020 price levels.

[10] Damage estimates by probabilistic event are displayed in Table 12.

Table 9. Without Project Equivalent Annual Damages, FY 2020 PL ($000)

Reach	Residential	Commercial	Public	Total
1L	43	0	0	43
2R	59	43	6	108
2L	1,904	1,840	76	3,820
3R	2,833	2,286	279	5,397
3L	67	6	0	74
4R	3,537	1,694	76	5,306
4L	1,377	745	57	2,179
Total	9,820	6,613	493	16,927

Note: Cost and benefits are displayed in FY2020 price levels and discounted using the FY20 federal discount rate of 2.75% over a 50 year period of analysis.

Table 9 displays damages to structures and structure contents under the without project condition. Annual damages total nearly $17 million. The largest portion of damages comes from residential structures and contents, which accounts for 60 percent of structural damages and totals more than $9 million in average annual damages. Reach 3R and 4R combined account for two-thirds of structural damages, and Reach 2L accounts for 23 percent of structural damages.

Table 10. Other Without Project Equivalent Annual Damages, FY 2020 PL ($000)

Reach	Auto	Cleanup	Emergency	Agricultural	Total
1L	4	2	4	0	10
2R	4	5	5	0	14
2L	172	192	202	0	567
3R	112	229	176	0	517
3L	0	3	0	0	4
4R	371	252	543	134	1,300
4L	179	131	197	0	507
Total	841	815	1,127	134	2,918

Note: Cost and benefits are displayed in FY20 price levels and discounted using the FY20 federal discount rate of 2.75% over a 50 year period of analysis.

Table 10 shows damages to agricultural crops, vehicles, and cleanup and emergency costs. Emergency costs account for 40 percent of Other without project damages and totals $1 million. Reach 4R accounts for the highest portion of Other damages, and total $1.3 million in annual damages. Reach 4R is also the only reach with damages to agricultural crops.

Table 11. Total Without Project Damages, FY 2020 PL ($000)

Reach	Structure and Structure Contents	Other Related Flood Damage Categories	Total
1L	43	10	52
2R	108	14	122
2L	3,820	567	4,387
3R	5,397	517	5,915
3L	74	4	77
4R	5,306	1,300	6,605
4L	2,179	507	2,686
Total	16,927	2,918	19,844

Table 11 shows total without project damages, which total over $19 million in average annual damages. Reaches 4R and 3R account for the highest portions of without project damages, followed by Reach 2L.

Table 12. Without Project Damages by Flood Event, FY 2020 PL ($000)

	0.1 ACE		0.02 ACE		0.01 ACE		0.002 ACE	
Reach	Structures Damaged	Total Damage	Structures Damaged	Total Damage	Structures Damaged	Total Damage	Structures Damaged	Total Damage
1L	2	175	2	461	2	493	2	499
2R	6	179	10	966	12	1,269	19	4,706
2L	71	7,430	298	32,723	497	57,416	594	101,585
3R	180	14,681	310	49,712	329	65,933	350	88,169
3L	0	0	0	0	4	39	6	4,116
4R	114	6,251	128	11,801	136	14,147	143	18,785
4L	241	7,444	419	25,504	459	34,838	484	59,974
Total	614	36,161	1,167	121,167	1,439	174,135	1,598	277,834

Table 12 displays structure and content damages by flood event and reach. For the 0.002 ACE (500-year) event, 2L has the highest numbers of structures damaged and total damage. Reaches 3R and 4L also have high structure counts and total damage values for the 0.002 ACE event. It should be noted that Reach 4R has much more frequent flood events than other reaches, and begins flooding at the 1-year event. For this reason, EAD estimates show that 4R has higher structure and content damages than other reaches, although the damages in 4R for less frequent events are lower than other reaches.

4.3 Without Project Performance

Without project performance statistics help inform the risk of a flood event of a specific frequency. Three components are indicators of project performance: the annual exceedance probability (AEP) is the likelihood flooding occurs in any given year; the long-term risk is the probability that flooding occurs in a period of 10, 30, or 50 years; and the assurance is the probability that flooding doesn't occur, conditional on a flood event of 0.02, 0.01 and 0.002 frequency occurring. The table below displays these statistics by reach for the without project condition.

Table 13. Without Project Performance, Base Year

		Long Term Risk[2]			Assurance[3]		
Reach	AEP[1]	10 year	30 year	50 year	2.00%	1.00%	0.20%
1L	99.9	99.00	99.00	99.00	1.00	1.00	1.00
2L	99.9	99.00	99.00	99.00	1.00	1.00	1.00
2R	99.9	99.00	99.00	99.00	1.00	1.00	1.00
3L	20.67	89.97	99.00	99.00	2.28	1.77	1.00
3R	66.77	99.00	99.00	99.00	1.00	1.00	1.00
4L	1.56	42.97	81.46	93.97	51.28	38.79	4.92
4R	99.9	99.00	99.00	99.00	1.00	1.00	1.00

1Probability that flooding will occur in any given year

[2]Probability the target stage is exceeded during the period of time listed below

[3]Probability that no flooding occurs, given that a flood event of the frequency listed has occurred

Table 13 shows that there is a high probability that flooding will occur in reaches 1L, 2L, 2R, 3R, and 4R in any given year in the absence of a project. Reaches 3L and 4L have lower chances of flooding in any given year. The probability that the banks are overtopped in all reaches for the 10, 30 and 50 year events is above 89 percent, except in reach 4L. Reach 4L does have a 94 percent chance of overtopping within 50 years. Correspondingly, the assurance is low in all reaches except for 4L. Given that a 0.02, 0.01, or 0.002 ACE flood event occurs, the probability that no flooding occurs is almost zero for reaches other than 4L. These statistics are consistent with historical floods and anecdotal accounts gathered from the community members; reports of annual flooding are high under the current channel conditions. Note that 4L is included in the phase 1 levee that was constructed by Puerto Rico's Department of Natural and Environmental Resources (DNER), and the lowest top of levee elevation for 4L is higher than that of Reach 4R.

5.0 With Project Benefits

With-project benefits are defined as the difference between without project damages and with project damages computed in HEC-FDA, and other NED benefit categories including underemployed labor resource benefits and national flood insurance program benefits. These are the benefits achieved by taking action as opposed to the study area remaining in its current state. To calculate with-project benefits, hydrologic and hydraulic data were developed for Alternatives 3 and 6.

Alternative 3 includes construction of an 8,550 foot long, engineered diversion channel, beginning approximately 1,500 feet downstream of PR-127. A diversion structure would be constructed across the river channel to split flows and send the majority of flood waters to the diversion channel, but maintain some flow in the main channel to maintain riverine ecology. The channel would be an engineered trapezoidal channel and have levees on the east side of the channel. The west side of the channel would remain at grade and allow certain magnitudes of flooding to spread to the west into non-developed and agricultural lands.

Alternative 6 includes the construction of the diversion channel in Alternative 3, but it would be a terraced greenway channel, and allow channel morphology to be formed by flood pulses.
This alternative would also have levees on the east side of the channel only. The channel would be very wide in certain sections, and at certain locations three times as wide as Alternative 3, to ensure hydraulic forces don't degrade the integrity of the levee and terraces.

The alignment for both alternatives directs flood water away from the center of town and to the west along the confining mountain valley wall, through existing banana fields, to join downstream with the constructed Phase I project near PR-3336. The diversion channel alignment is depicted below in Figure 8

Alternative 1, which is a nonstructural alternative and includes implementing a flood warning system and maintaining normal conveyance in the natural channel, was combined with Alternative 3, once Alternative 3 was identified as the TSP. Although Alternative 1 doesn't reduce physical damages, it was included to help reduce risk of life loss.

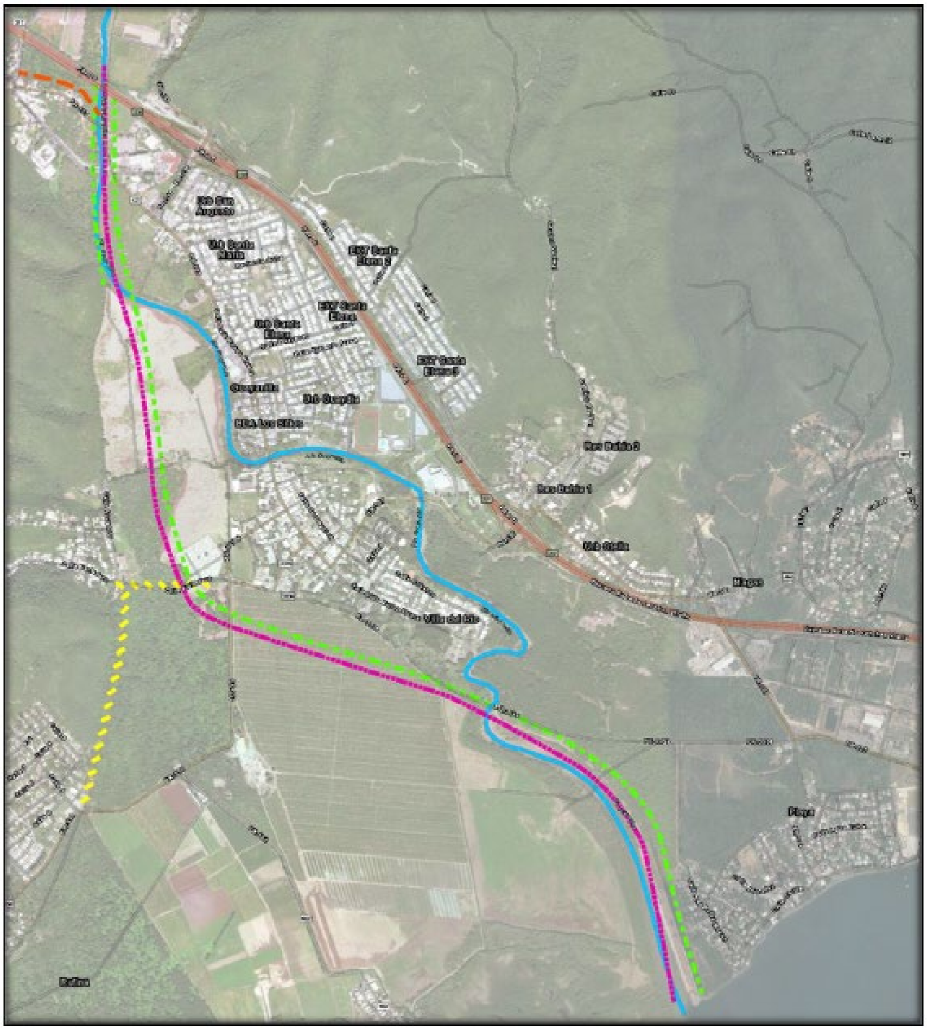

Figure 15. Diversion Channel Alignment and Levee Locations

This section analyzes the with-project conditions under Alternatives 3 and 6, and estimates with-project benefits.

5.1 Unemployed Labor Resource Benefits

ER 1105-2-100 Appendix D details the evaluation procedures for unemployed or underemployed labor resources during project construction as a national economic development (NED) benefit. The justification for including unemployed labor which is employed in project construction as an NED benefit is that the social cost of a project is less than the market contract cost. Rather than adjust construction costs directly, ER 1105-2-100 provides guidance on making adjustments to the social cost of a project when the area has substantial and persistent unemployment by adjusting the NED benefits. The guidance defines substantial and persistent unemployment in an area as the following:

(a) The current rate of unemployment, as determined by appropriate annual statistics for the most recent 12 consecutive months, is 6 percent or more and has averaged at least 6 percent for the qualifying time periods specified in subparagraph (b) below and:

(b) The annual average rate of unemployment has been at least: (a) 50 percent above the national average for three of the preceding four calendar years, or (b) 75 percent above the national average for two of the preceding three calendar years, or (c) 100 percent above the national average for one of the preceding two calendar years.

The following table shows that the project area, which is fully encompassed within the municipality of Guayanilla, has experienced substantial and persistent unemployment consistent with ER 1105-2-100. Table 14 shows yearly unemployment rates for the municipality of Guayanilla from 2013-2018.

Table 14. Unemployment Rate Comparison

Year	Guayanilla Unemployment Rate (%)	U.S. Unemployment Rate (%)	Percent Higher than National Unemployment (%)
2013	22	7.4	197
2014	21.8	6.2	252
2015	19.4	5.3	266
2016	18.7	4.9	282
2017	16.4	4.4	273
2018	14.4	3.9	269

Source: Federal Reserve Bank of St. Louis

Current unemployment is 14.4 percent in Guayanilla and 3.9 percent nationally. For each of the last five years, unemployment in the study area has been more than 100 percent above the national unemployment rate.

Table 15 displays employment characteristics for the municipalities of Guayanilla and Yauco. Yauco lies immediately to the West of Guayanilla and the study area, and is economically integrated with Guayanilla. For example, the closest supermarket for residents of Guayanilla is in Yauco, and many individuals who reside in Guayanilla work in Yauco. Due to the rural location and population size of Guayanilla, it is expected that unemployed labor from Guayanilla and Yauco would be utilized to construct the project.

Table 15. Study Area Employment Characteristics

	Guayanilla	Yauco
Population Count	16,000	31,000
Labor Force Participation Rate	38%	38%
Labor Force Count	6,000	12,000
Unemployment Rate[11]	24%	24%
Number of Unemployed Individuals	1,400	2,800
Percent Employed in Construction and Extraction	6%	5%
Unemployment Pool Construction and Extraction Workers	84	140
Total Number of Unemployed Construction workers		224

Source: ACS 2017 5-year Estimates

Unemployment characteristics are nearly identical between Guayanilla and Yauco. The estimated unemployment pool of construction workers is 84 individuals in Guayanilla and 140 in Yauco, for a total of 224 unemployed construction workers.

Table 16 displays the labor requirements of each alternative, by skilled and unskilled labor. Labor requirements were provided by LRC Cost Engineering.

Table 16. Project Labor Requirements

Labor Requirements by Worker Type		
	Alternative 3	Alternative 6
Unskilled Labor		
Truck Drivers	39	64
Laborers	27	24
Skilled Labor		
Operators	19	42
Carpenters	7	6
Ironworkers	7	6
Total Number of Required Workers	98	141

The table shows that Alternative 3 requires 98 laborers, and Alternative 6 requires 141 laborers. Since the pool of unemployed construction workers in the study area is 224, unemployed labor is sufficient to fulfill either of these labor requirements. This estimate is conservative, since unskilled labor jobs could potentially be filled by unemployed individuals who lack construction experience but could enter the construction workforce if jobs became available.

[11] Unemployment rates are taken from ACE 5-year estimates (in order to compare with other employment characteristics), and thus differ from Federal Reserve and Bureau of Labor Statistics unemployment rates shown above.

The following two tables show the underemployed resource benefits for Alternatives 3 and 6 for a four year construction schedule. Direct costs and labor allocation was provided by LRC Cost Engineering, and provides a more accurate estimate of construction costs than estimating the wage bill for unskilled and skilled laborers. Therefore, the portion of direct costs that was allocated to labor is used as a basis for estimating labor resource benefits. All estimates are shown in FY 2020 price levels.

Table 17. Alternative 3 Underemployed and Unemployed Labor Resource Benefits ($)

Total Costs		
Total Project First Cost		154,341,000
Direct Cost (Includes Labor, Equipment, and Material)		54,500,000
Direct Cost Percent Allocated to Labor		24%
On-Site Labor Cost		13,000,000
Allocation of On-site Labor Cost		
Unskilled Labor	Percent Allocation of Labor Cost	Labor Cost (Wages)
Truck Drivers	40%	5,200,000
Laborers	27%	3,500,000
Skilled Labor		
Operators	19%	2,500,000
Carpenters	7%	900,000
Ironworkers	7%	900,000
Total Wages Allocated to Locally Unemployed Labor		13,000,000
Average Annual Underemployed Labor Resource Benefits at 2.75%		500,000

Total on-site labor cost for Alternative 3 is $13 million. Of this, $8.7 million is allocated to unskilled labor, and $4.3 million is allocated to skilled labor. Skilled and unskilled labor categories were determined by ER 1105-2-100, Appendix D, Table D-7. It is estimated that the full amount of labor will be fulfilled by the local unemployment pool of construction workers. The total amount of wages going to locally unemployed labor, $13 million, was annualized over a 50 year period at a discount rate of 2.75% and results in an average annual underemployed labor resource benefit of $500,000.

Table 18 displays the underemployed labor resource benefits for Alternative 6.

Table 18. Alternative 6 Underemployed and Unemployed Labor Resource Benefits ($)

Total Costs		
Total Project First Cost		230,403,000
Direct Cost (Includes Labor, Equipment, and Material)		72,300,000
Direct Cost Percent Allocated to Labor		26%
On Site Labor Cost		18,800,000
Allocation of On-site Labor Cost		
Unskilled Labor	Percent Allocation of Labor Cost	Labor Cost (Wages)
Truck Drivers	45%	8,500,000
Laborers	30%	5,600,000
Skilled Labor		
Operators	17%	3,200,000
Carpenters	4%	800,000
Ironworkers	4%	800,000
Total Wages Allocated to Locally Unemployed Labor		18,800,000
Average Annual Underemployed Labor Resource Benefits at 2.75%		700,000

The table shows that total wages allocated to unskilled labor is $14 million, and wages allocated to skilled labor total $4.8 million. Twenty-six percent of direct costs are allocated to labor for Alternative 6, and total wages going to locally unemployed labor is $18.8 million. This is annualized at the 2.75 percent discount rate for a period of 50 years, which results in an annual underemployed resource benefit of $700,000. This benefit is higher than that of Alternative 3, since more workers are required to complete the project, and thus more employment benefits are realized.

5.2 With-Project Annual Benefit Summaries

The table below displays the with-project benefits associated with Alternative 3. Structure and structure contents and other related flood damage categories were calculated in HEC-FDA. National flood insurance program and underemployed labor resource benefits were calculated as described above.

Table 19. With Project Benefits Alternative 3, FY 2020 PL ($000)

Reach	Structure and Structure Contents	Other Related Flood Damage Categories	National Flood Insurance Program	Underemployed Labor Resources[12]	Total Average Annual Benefits
1L	16	3	0	-	19
2R	93	11	1	-	106
2L	3,546	532	94	-	4,172
3R	5,346	512	63	-	5,921
3L	74	4	1	-	78
4R	5,180	1,262	25	-	6,466
4L	2,179	507	88	-	2,774
Total	16,434	2,832	272	485	20,022

Table 19 shows that total average annual benefits for Alternative 3 are $20 million. Structure contents and other related flood damages account for $19 million of this total, while flood insurance benefits account for $272,000 and labor resources benefits account for nearly $500,000 annually.

Table 20. With Project Benefits Alternative 6, FY 2020 PL ($000)

Reach	Structure and Structure Contents	Other Related Flood Damage Categories	National Flood Insurance Program	Underemployed Labor Resources	Total Average Annual Benefits
1L	16	4	0	-	20
2R	93	11	1	-	106
2L	3,541	531	94	-	4,166
3R	5,341	512	63	-	5,916
3L	74	4	1	-	78
4R	5,231	1,267	25	-	6,523
4L	2,168	505	88	-	2,761
Total	16,464	2,833	272	696	20,265

Table 20 displays with project benefits for Alternative 6. Underemployed labor resource benefits are $700,000 annually, for a total of $20.3 million in average annual benefits.[13]

5.3 Probabilistic Expected Annual Damages

ER 1105-2-101 Appendix A sets forth requirements for a risk-based analysis to be conducted for flood damage reduction studies. The guidance concludes that probabilistic values of EAD reduced should be included in the analysis, since uncertainty is inherent in the inputs used to estimate economic damages.

[12] The BCR excluding underemployed labor resource benefits is greater than unity. Underemployed labor resource benefits do not impact NED plan selection.
[13] See Table 21 for EAD by probabilistic flood event.

The table below displays without and with project expected annual damage, and the damage reduced by probabilistic value.

Table 21. Probabilistic Damage Reduced Alternative 3, FY 2020 PL ($000)

Reach	Without Project EAD	Alt 3 EAD	Damage Reduced	Probability Damage Reduced Exceeds Indicated Value		
				0.75	0.50	0.25
1L	52	33	19	11	19	27
2R	122	17	105	45	85	143
2L	4,387	309	4,078	1,831	3,516	5,635
3R	5,915	56	5,859	2,755	4,970	8,007
3L	77	0	77	6	19	86
4R	6,605	164	6,442	4,846	6,358	7,890
4L	2,686	0	2,686	275	852	2,913
Total	19,844	579	19,265	9,769	15,818	24,702

Note: Excludes flood insurance benefits and unemployed resource benefits

Table 21 shows that there is a 75 percent chance that damage reduced with Alternative 3 implemented exceeds $9.7 million, there is a 50 percent chance that damage reduced exceeds $15.8 million, and a 25 percent chance that damage reduced exceeds $24.7 million. The significant reduction in damages can be attributed to containing the most frequent flood events within the diversion channel, and thus only incurring minimal damages from breakouts that occur during the 100, 200, and 500-year events. Damages shown include structure and structure content damages and other flood related damages, as described in Section 4.1.

Table 22. Probabilistic Damage Reduced Alternative 6, FY 2020 PL ($000)

Reach	Without Project EAD	Alt 6 EAD	Damage Reduced	Probability Damage Reduced Exceeds Indicated Value		
				0.75	0.50	0.25
1L	52	33	20	11	19	27
2R	122	17	104	45	85	144
2L	4,387	315	4,071	1,830	3,511	5,625
3R	5,915	62	5,853	2,757	4,972	8,019
3L	77	0	77	6	19	86
4R	6,605	107	6,498	4,796	6,305	7,869
4L	2,686	13	2,673	309	888	2,950
Total	19,844	548	19,297	9,754	15,799	24,720

Table 22 shows probabilistic benefits for Alternative 6. The table shows there is a 75 percent chance damage reduced under this alternative exceeds $9.7 million annually, a 50 percent chance damage reduced exceeds $15.8 million, and a 25 percent chance damage reduced exceeds $24 million. There is a very minimal difference in annual damaged reduced between Alternatives 3 and 6, as both alternatives are designed to provide nearly the same level of risk reduction.

5.4 Expected Annual Damages by Annual Chance Event

In addition to viewing probability distributions of damage reduced, it is also helpful to see damages by flood event. The table below compares expected annual damages for the without and with project conditions, by percent annual chance event and impact area, for the 0.1, 0.02, 0.01, and 0.002 annual chance events. Only estimates for structure and structure contents, and other related flood damages are included.

Table 23. Expected Annual Damages by Flood Event, FY 2020 Price Levels ($000)

Reach	0.1 ACE			0.02 ACE			0.01 ACE			0.002 ACE		
	Without	Alt 3	Alt 6	Without	Alt 3	Alt 6	Without	Alt 3	Alt 6	Without	Alt 3	Alt 6
1L	175	39	58	461	376	509	493	461	581	499	499	731
2R	179	0	0	966	7	75	1,269	254	833	4,706	1,266	1,936
2L	7,430	0	0	32,723	0	11	57,416	6	12,245	101,585	28,084	43,995
3R	14,681	0	0	49,712	0	0	65,933	68	0	88,169	17,418	14,442
3L	0	0	0	0	0	0	39	0	0	4,116	0	0
4R	6,251	0	0	11,801	0	174	14,147	44	2,554	18,785	9,739	19,867
4L	7,444	0	0	25,504	0	0	34,838	0	0	59,974	19,588	0
Total	36,161	39	58	121,167	383	770	174,135	833	16,213	277,834	76,595	80,972

Note: Alt 3 and Alt 6 reflect with-project conditions for Alternatives 3 and 6, respectively

The 0.002 ACE, or the 500-year event, is the lowest frequency event analyzed, and would cause the highest expected economic damages in the floodplain, while the 0.1 ACE is a more frequent event and would result in the lowest expected annual damages for the events displayed above. For the 0.002 ACE event, estimated damages in the absence of a Federal project are estimated to be more than $277 million. This decreases to $77 million under the Alternative 3, and $81 million under Alternative 6. The 0.1 ACE results in expected annual damages totaling $36 million for the without project condition, and $39,000 and $58,000 for Alternatives 3 and 6, respectively.

5.5 With Project Performance

HEC-FDA software calculates reliability statistics for the project. Table 24 shows with project performance statistics for Alternative 3 and Table 25 shows these statistics for Alternative 6.

Table 24. With Project Performance Alternative 3

Reach	AEP[1]	Long Term Risk[2]			Assurance[3]		
		10 year	30 year	50 year	2.00%	1.00%	0.20%
1L	21.35	90.97	99.99	99.00	1.00	1.00	1.00
2L	99.90	99.00	99.00	99.00	1.00	1.00	1.00
2R	17.81	86.48	99.75	99.99	2.00	2.00	1.00
3L	0.29	3.50	10.01	16.12	99.29	94.09	44.18
3R	0.22	2.19	6.43	10.49	99.95	98.44	57.99
4L	0.01	0.10	0.30	0.50	99.99	99.97	99.96
4R	7.33	61.13	94.13	99.11	13.52	8.77	3.34

1Probability that flooding will occur in any given year

[2]Probability the target stage is exceeded during the period of time listed below

[3]Probability that no flooding occurs, given that a flood event of the frequency listed has occurred

Since project performance statistics target a levee or top of bank stage, performance isn't accurately reflected in reaches 1L, 2L, and 2R, which have lower discharges and stages, and lower damages due to the construction of a diversion channel, but not significantly higher levee and top of bank stages in the original channel. Downstream of the diversion structure, reaches 3L, 3R, and 4L performance statistics show lower long-term risk and higher assurance under the with project condition. In Reach 4R, without project damages are significantly reduced, particularly for the more frequent events (in which there is significant without project flooding), but performance statistics for the less frequent events still show low assurance. However, the annual exceedance probability (AEP) for this reach decreases from 99.9 percent under the without project condition to 7.33 percent under the with project condition.

Table 25. With Project Performance Alternative 6

		Long Term Risk[2]			Assurance[3]		
Reach	AEP[1]	10 year	30 year	50 year	2.00%	1.00%	0.20%
1L	17.42	86.39	99.75	99.00	1.30	1.04	0.18
2L	99.90	99.00	99.00	99.00	1.00	1.00	1.00
2R	14.56	81.30	99.35	99.98	2.39	1.77	0.44
3L	0.31	3.64	10.53	16.93	99.75	95.80	36.49
3R	0.24	2.32	6.81	11.09	99.98	99.42	48.19
4L	0.01	0.90	2.67	4.42	98.55	96.76	94.61
4R	5.43	47.55	85.57	96.03	19.97	12.17	4.11

1Probability that flooding will occur in any given year

[2]Probability the target stage is exceeded during the period of time listed below

[3]Probability that no flooding occurs, given that a flood event of the frequency listed has occurred

Project performance statistics for Alternative 6 follow the same trends as project performance for Alternative 3. The most notable difference between alternatives is AEP in Reach 4R, which is 14 percent under Alternative 3, and 5 percent under Alternative 6. In this reach, long term risk is also lower under Alternative 6, and Assurance is higher. However, residual flooding in 4R under both alternatives floods wetlands and a small portion of agricultural land, rather than structures, which is why equivalent annual damages under either alternative are nearly completely eliminated.

5.6 Residual Damages

Residual damages are damages to structures and contents, and other related flood damages, that are estimated to occur under the with project condition. The tables below show residual damages for both alternatives, by reach.

Table 26. Residual Equivalent Annual Damages Alternative 3, FY 2020 PL ($000)

Reach	Structure and Structure Contents	Other Related Flood Damage Categories	Total
1L	27	6	33
2R	15	2	17
2L	274	35	309
3R	51	5	56
3L	0	0	0
4R	126	38	164
4L	0	0	0
Total	493	86	579

Table 26 shows that with the construction of Alternative 3, there would be an estimated $579,000 in average annual damage remaining. Of this, $493,000 is composed of structure and structure content damages, and $86,000 is other related flood damage categories, including damages to vehicles, emergency and cleanup costs, and agricultural damages.

Table 27 displays residual damages for Alternative 6, and shows that annual residual damages under this alternative are approximately $548,000.

Table 27. Residual Equivalent Annual Damages Alternative 6, FY 2020 PL ($000)

Reach	Structure and Structure Contents	Other Related Flood Damage Categories	Total
1L	27	6	33
2R	15	2	17
2L	279	36	315
3R	57	5	62
3L	0	0	0
4R	75	33	107
4L	11	2	13
Total	463	85	548

Table 28 displays residual expected annual damage estimates by exceedance probability and reach, for Alternative 3, which is identified as the recommended plan in Section 8.

Table 28. Residual Expected Annual Damages by Flood Event and Reach, Alternative 3

	Expected Annual Damage ($000) by ACE Probability							
Reach	0.5	0.2	0.1	0.04	0.02	0.01	0.004	0.002
1L	0	0	39	273	376	461	495	499
2R	0	0	0	0	7	254	692	1,266
2L	0	0	0	0	0	6	6,166	28,084
3R	0	0	0	0	0	68	1,086	17,464
3L	0	0	0	0	0	0	0	0
4R	0	0	0	0	0	44	2,548	9,739
4L	0	0	0	0	0	0	2,745	19,588
Total	0	0	39	273	383	833	13,732	76,641

Alternative 3 reduces expected annual damages to zero in all reaches for the most frequent events, and reduces nearly all flooding up to the 0.01 ACE event. Residual expected annual damages for the 100 year event total are estimated to be $833,000 annually. This estimate increases to $13.7 million for the 250-year event and nearly $77 million for the 500-year event.

6.0 Costs

Costs for Alternative 3 and Alternative 6 are used to calculate net benefits and the benefit-cost ratio, in order to identify the national economic development (NED) plan. Costs are presented in this section, and include construction costs, interest during construction, contingency costs, operation and maintenance, and lands, easements, rights of way and relocations (LERRDs). Table 29 shows project first costs for Alternatives 3 and 6.

Table 29. Project First Costs by Alternative, FY 2020 PL ($000)

	Alternative 3	Alternative 6
Construction Cost	119,594	179,983
Relocations (Utilities)	5,773	5,945
Roads & Bridges	13,997	13,997
Channels and Canals	53,189	109,526
Levees and Floodwalls	44,017	47,897
Flood Control & Diversions Structure	2,619	2,619
Lands and Damages	6,045	7,224
PED	19,135	28,797
Construction Management	9,568	14,399
Total First Costs	154,341	230,403

Alternative 3 project first costs amount to $154.3 million, and first costs for Alternative 6 are approximately $230.4 million. Channel and canal improvements are roughly one-third of costs for Alternative 3, but make up nearly half of project first costs for Alternative 6.

Tables 30 and 31 display investment costs for each project alternative, including interest during construction (IDC) and annualized investment costs. Annualized investment costs are calculated at the current 2.75 percent discount rate, and the federal 7 percent discount rate, using a 50-year period of analysis. The period of construction used to calculate IDC is four years.

Table 30. Investment Costs by Alternative, 2.75% ($000)

	Alternative 3	Alternative 6
Investment Cost		
Construction Cost	128,526	203,258
LERRDs	25,815	27,145
Subtotal First Cost	154,341	230,403
Interest During Construction	8,501	12,691
Total Gross Investment	162,843	243,094
Annual Cost	6,032	9,004
OMRR&R	39	340
Average Annual Cost	6,071	9,344

Table 30 shows that average annual costs are $6 million for Alternative 3 and $9.3 million for Alternative 6 at 2.75 percent. Since project first costs are higher for Alternative 6, so is interest during construction. Interest during construction is $8.5 million for Alternative 3 and $12.7 million for Alternative 6. Operations and maintenance costs are $39,000 annually for Alternative 3, and $340,000 annually for Alternative 6.

Table 31. Investment Costs by Alternative, 7% ($000)

	Alternative 3	Alternative 6
Investment Cost		
Construction Cost	128,526	203,258
LERRDs	25,815	27,145
Subtotal First Cost	154,341	230,403
Interest During Construction	22,405	33,446
Total Gross Investment	176,746	263,849
Annual Cost	12,807	19,118
OMRR&R	39	340
Average Annual Cost	12,846	19,458

Table 31 displays investment costs for both alternatives, calculated at the federal discount rate of 7 percent. Average annual costs are $12.8 million for Alternative 3 and $19.5 million for Alternative 6. Interest during construction is $22.4 million for Alternative 3 and $33.4 million for Alternative 6.

7.0 Benefit-Cost Analysis

7.1 Benefit Cost Comparison

In order to identify the NED plan, net annual benefits were calculated for Alternative 3 and Alternative 6. Net annual benefits are shown in FY 2020 price levels at the current discount rate of 2.75 percent. Benefits are equivalent at the 2.75 and 7 percent discount rates, since future project conditions result in the same benefit estimates as existing project conditions.

Table 32. Net Benefit Comparison, FY 2020 PL 2.75% ($000)

Category	Alternative 3, 2.75%	Alternative 6, 2.75%
Annual Benefits	20,022	20,265
Structure and Structure Contents	16,434	16,464
Other Related Categories	2,832	2,833
Flood Insurance Program	272	272
Underemployed Labor Resource	485	696
Annual Costs	6,071	9,344
Net Annual Benefits	13,951	10,921

Table 32 shows that Alternative 3 results in net annual benefits of $14 million, compared to Alternative 6 which has net annual benefits of $11 million. The average annual cost of Alternative 3 is $6 million and the annual cost of Alternative 6 is $9.3 million. Average annual benefits are $20 million for Alternative 3 and $20.3 million for Alternative 6. Although Alternative 6 has slightly higher average annual benefits than Alternative 3, the difference in costs results in Alternative 3 having higher annual net benefits. As a result, Alternative 3 is the NED plan.

Table 33. Net Benefit Comparison, FY 2020 PL 7% ($000)

Category	Alternative 3, 7%	Alternative 6, 7%
Annual Benefits	20,022	20,265
Structure and Structure Contents	16,434	16,464
Other Related Categories	2,832	2,833
Flood Insurance Program	272	272
Underemployed Labor Resource	485	696
Annual Costs	12,846	19,458
Net Annual Benefits	7,176	806

Table 33 displays the same information as above at the federal discount rate of 7 percent. Annual costs are $12.8 million for Alternative 3 and $19.5 million for Alternative 6. Net annual benefits are $7.2 million for Alternative 3, and $806,000 for Alternative 6. The difference in annual costs between the estimates at the current and federal discount rates can be attributed to a substantial increase in interest during construction under the 7 percent discount rate.

Table 34. Benefit Cost Analysis, 2.75% ($000)

	Alternative 3	Alternative 6
Annual Cost	6,071	9,344
Annual Benefits	20,022	20,265
Net Annual Benefits	13,951	10,921
Benefit to Cost Ratio	3.3	2.2

Note: Cost and benefits are displayed in FY2020 Price Levels and discounted at 2.75% over a 50 year period of analysis

Table 34 displays annual average costs and benefits and the benefit to cost ratio. The benefit-cost ratio (BCR) for Alternative 3 is 3.3 at a discount rate of 2.75 percent, and is 2.2 for Alternative 6 at the same discount rate. The NED plan, Alternative 3, therefore maximizes net benefits, has the highest BCR, and is economically justified at the current discount rate.

Table 35. Benefit Cost Analysis, 7% ($000)

	Alternative 3	Alternative 6
Annual Cost	12,846	19,458
Annual Benefits	20,022	20,265
Net Annual Benefits	7,176	806
Benefit to Cost Ratio	1.6	1.0

Note: Cost and benefits are displayed in FY2020 Price Levels and discounted at 2.75% over a 50 year period of analysis

Table 35 summarizes benefits and costs at the 7 percent discount rate. The NED plan has a BCR of 1.6 at the federal discount rate of 7 percent, and is economically justified. For this plan, annual costs are $12.8 million, and annual benefits are $20 million. Annual net benefits for the NED plan are seven times the annual net benefits of Alternative 6. Alternative 6 has a BCR of 1.0 at 7 percent.

7.2 Benefit and Cost Distributions

In accordance with ER 1105-2-101 Appendix A, probabilistic benefit cost ratios are included in this section. Benefit distributions were calculated in FDA. Cost distributions were calculated in @Risk Software in Excel using a Weibull distribution.

Table 36. Probabilistic Benefit Cost Analysis Alternative 3, 2.75% ($000)

Category	Benefits	Probability Value Indicated is Exceeded		
		0.75	0.50	0.25
Average Annual Benefits	20,022	10,526	16,575	25,458
Average Annual Costs	6,071	4,987	5,388	5,858
Net Annual Benefits	13,951	5,538	11,187	19,600
Benefit-Cost Ratio	3.3	2.1	3.1	4.3

Note: NFIP and Underemployed Labor Resource Benefits are static.

Table 36 shows benefit, cost, and BCR distributions for Alternative 3 at 2.75 percent. The table shows that there is a 75 percent chance that net annual benefits exceed $5.5 million, and the same probability that the BCR will exceed 2.1. Thus 25 percent of values in the distribution are below this estimate. There is a 50 percent chance that net annual benefits will exceed $11.2 million and that the BCR will exceed 3.1, and there is a 25 percent chance that net benefits will exceed $19.6 million annually and that the BCR will exceed 4.3.

Table 37. Probabilistic Benefit Cost Analysis Alternative 3, 7% ($000)

Category	Benefits	Probability Value Indicated is Exceeded		
		0.75	0.50	0.25
Average Annual Benefits	20,022	10,526	16,575	25,458
Average Annual Costs	12,846	10,531	11,422	12,433
Net Annual Benefits	7,176	-6	5,153	13,026
Benefit-Cost Ratio	1.6	1.0	1.5	2.0

Note: NFIP and Underemployed Labor Resource Benefits are static.

Table 37 displays the distribution of benefits and costs for Alternative 3 at 7 percent. There is a 75 percent chance that the BCR will exceed 1.0, a 50 percent chance that it will exceed 1.5, and a 25 percent chance that the BCR will exceed 2.0.

Tables 38 and 39 describe the same information as the tables above, for Alternative 6, at the 2.75 and 7 percent discount rates, respectively.

Table 38. Probabilistic Benefit Cost Analysis Alternative 6, 2.75% ($000)

Category	Benefits	Probability Value Indicated is Exceeded		
		0.75	0.50	0.25
Average Annual Benefits	20,265	10,737	16,786	25,669
Average Annual Costs	9,344	7,659	8,279	9,028
Net Annual Benefits	10,920	3,077	8,507	16,642
Benefit-Cost Ratio	2.2	1.4	2.0	2.8

Note: NFIP and Underemployed Labor Resource Benefits are static.

For Alternative 6, there is a 75 percent chance that net annual benefits will exceed $3 million, a 50 percent chance that they will exceed $8.5 million, and a 25 percent chance that they will exceed $16.6 million. There is a 75 percent chance that the BCR will exceed 1.4, a 50 percent chance that it will exceed 2.0, and a 25 percent chance that it will exceed 2.8, at a discount rate of 2.75 percent.

Table 39. Probabilistic Benefit Cost Analysis Alternative 6, 7% ($000)

Category	Benefits	Probability Value Indicated is Exceeded		
		0.75	0.50	0.25
Average Annual Benefits	20,265	10,737	16,786	25,669
Average Annual Costs	19,458	15,945	17,248	18,752
Net Annual Benefits	806	-5,209	-462	6,918

Benefit-Cost Ratio	1.0	0.7	1.0	1.4

Note: NFIP and Underemployed Labor Resource Benefits are static.

At the 7 percent discount rate under Alternative 6, there is a 25 percent chance that the BCR will be less than 0.7. There is a 50 percent chance that the BCR will be greater than 1.0, and a 25 percent chance that the BCR will be greater than 1.4.

7.3 Conclusion

The purpose of this study is to evaluate flood risk within the Rio Guayanilla Watershed. Under the without project condition, it is estimated that nearly 9,000 people and 1,665 structures are at risk of inundation. In the absence of a flood risk management project, it is estimated that average annual damages would total $19.8 million, including structures and structure contents, and vehicle, emergency, cleanup and agricultural damages. Implementing Alternative 3 would result in estimated average annual benefits of $20 million, and implementing Alternative 6 would result in estimated average annual benefits of $20.3 million.

This study identified Alternative 3 as the NED plan, because it maximizes annual net benefits. With a four year construction schedule, the NED plan would cost $6 million annually and accumulate estimated annual net benefits of $14 million at the current discount rate of 2.75 percent. At the 7 percent discount rate, the NED plan would cost $12.8 million annually and have annual net benefits of $7.2 million. The BCR for the NED plan is 3.3 at 2.75 percent, and 1.6 at 7 percent. The NED plan is economically justified.

Addendum A

Additional Tables

Table 1. Content to Structure Ratios

Use Category	Content to Structure Ratio					
	n	Mean	Standard Deviation	Coefficient of Variation	Min	Max
Commercial						
C-AUTO1	21	62%	0.07	12%	0.52	0.79
C-DEAL1	29	69%	0.15	22%	0.47	1.22
C-FOOD1	320	42%	0.07	16%	0.25	0.61
C-FOOD2	20	43%	0.06	14%	0.24	0.53
C-FURN1	20	55%	0.14	26%	0.32	0.87
C-FURN2	1	36%	-	-	0.36	0.36
C-GROC1	33	106%	0.18	16%	0.78	1.53
C-HOS1	1	92%	-	-	0.92	0.92
C-HOS2	23	87%	0.37	42%	0.53	1.94
C-HOTEL2	15	69%	0.13	19%	0.53	0.95
C-MED1	242	148%	0.25	17%	0.84	2.03
C-MED2	85	121%	0.30	24%	0.74	2.03
C-OFF1	825	34%	0.09	27%	0.17	0.80
C-OFF2	772	28%	0.09	31%	0.13	0.63
C-REST1	393	134%	0.35	26%	0.00	2.83
C-REST2	93	118%	0.29	25%	0.00	1.92
C-RESTFF1	136	42%	0.08	20%	0.28	0.76
C-RET1	1374	51%	0.13	25%	0.00	1.30
C-RET2	225	47%	0.13	27%	0.13	1.04
C-SERV1	593	193%	0.46	24%	0.00	4.71
C-SERV2	10	193%	0.29	15%	1.53	2.52
C-SHOP1	63	67%	0.11	17%	0.54	1.00
C-SHOP2	17	54%	0.01	3%	0.51	0.57
Industrial						
I-HV1	95	31%	0.09	30%	0.16	0.69
I-HV2	22	20%	0.04	22%	0.14	0.31
I-LT1	568	188%	0.55	29%	0.91	4.09
I-LT2	70	126%	0.47	37%	0.00	2.61
I-WH1	1168	89%	0.25	28%	0.00	2.36
I-WH2	34	85%	0.27	31%	0.04	1.29
Public						
P-CH1	356	20%	0.05	23%	0.08	0.39
P-CH2	99	17%	0.05	28%	0.10	0.32
P-GOV1	161	35%	0.08	24%	0.22	0.60
P-GOV2	162	26%	0.07	28%	0.14	0.60
P-REC1	149	132%	3.56	269%	0.36	2.56
P-REC2	48	58%	0.15	26%	0.31	0.91
P-SCH1	267	38%	0.11	29%	0.00	1.75
P-SCH2	52	32%	0.09	29%	0.00	0.52

Table 2. Frequency – Stage Curve, Without Project Current Condition

Annual Exceedance Probability	Reach 1	Reach 2L	Reach 2R	Reach 3L	Reach 3R	Reach 4L	Reach 4R
0.5	67.69	42.5	51.14	16.6	16.6	6.37	6.37
0.2	72.16	45.45	54.22	19.24	19.24	7.87	7.87
0.1	74.35	47.11	55.92	20.24	20.24	8.48	8.48
0.04	78.87	49.46	58.48	21.35	21.35	9.09	9.09
0.02	82.84	51.19	60.15	21.87	21.87	9.33	9.33
0.01	85.38	53.41	62.45	22.56	22.56	9.61	9.61
0.005	87.99	54.84	64.01	23.04	23.04	9.95	9.95
0.002	91.8	56.83	66.27	23.78	23.78	10.7	10.7

Note: Water Surface Elevations are shown in feet and are for the index station stage only and include terrain elevation.