US Army Corps of Engineers®
New York District

WESTCHESTER COUNTY STREAMS, BYRAM RIVER BASIN

FLOOD RISK MANAGEMENT FEASIBILITY STUDY

FAIRFIELD COUNTY, CONNECTICUT AND WESTCHESTER COUNTY, NEW YORK

FINAL INTEGRATED FEASIBILITY REPORT & ENVIRONMENTAL IMPACT STATEMENT

APPENDIX D:

Economic Analysis

1. INTRODUCTION

The Byram River flows from the Byram Lake Reservoir, north of Armonk, New York, for approximately 20 miles in both New York and Connecticut to then discharge into Long Island Sound at Port Chester Harbor. This study focuses on the flood prone areas of Greenwich, CT in Fairfield County and Port Chester, NY in Westchester County. Fairfield County is the only county of the Bridgeport-Stamford-Norwalk, CT Metropolitan Statistical Area. Westchester County is in the New York-Newark-Jersey City, NY-NJ-PA Metropolitan Statistical Area. Byram River has a history of substantial flooding including floods in October 1955, during a nor'easter in April 2007, and in October 2012 during Superstorm Sandy. The Town of Greenwich had mandatory evacuations during Superstorm Sandy, including areas along the Byram River. Greenwich established two emergency shelters for evacuees. The results of the feasibility analysis of flood damage and the evaluation of considered plans to reduce these are presented in this appendix.

2. ECONOMIC PARAMETERS

The methods for the economic analysis were completed in accordance with ER 1105-2-100. Monetary values in the tables are in October 2018, Fiscal Year (FY) 2019, price levels and the FY 2019 Federal discount rate of 2.875% was applied to cost and benefits calculations; these values were updated to October 2019, FY 2020 price levels and the FY 2020 Federal discount rate of 2.75%. The base year of the economic analysis, the year when the proposed project is expected to be operational, is 2023 and the period of analysis is 50 years from 2023 to 2072.

3. EXTENT AND CHARACTER OF THE PROJECT AREA

The Byram River watershed is approximately 29 square miles and is located in southwestern Connecticut and Westchester County New York. It flows from Byram Lake Reservoir generally south to Long Island Sound. Byram River defines the boundary for Greenwich and Port Chester and for the states for a distance before its mouth. Several tributaries flow into Byram River along its route, contributing to its flow during rainfall. The project area is about 25 miles northeast of New York City. The project area is the area delineated by the 0.2%-chance (500-year) floodplain from just south of U.S. Route 1 to north of Bailiwick Road. The majority of the project area is in Greenwich but extends into Port Chester at the southern end. A project area reach map is provided below as Figure 1. A table of project area reaches is provided as Table 1.

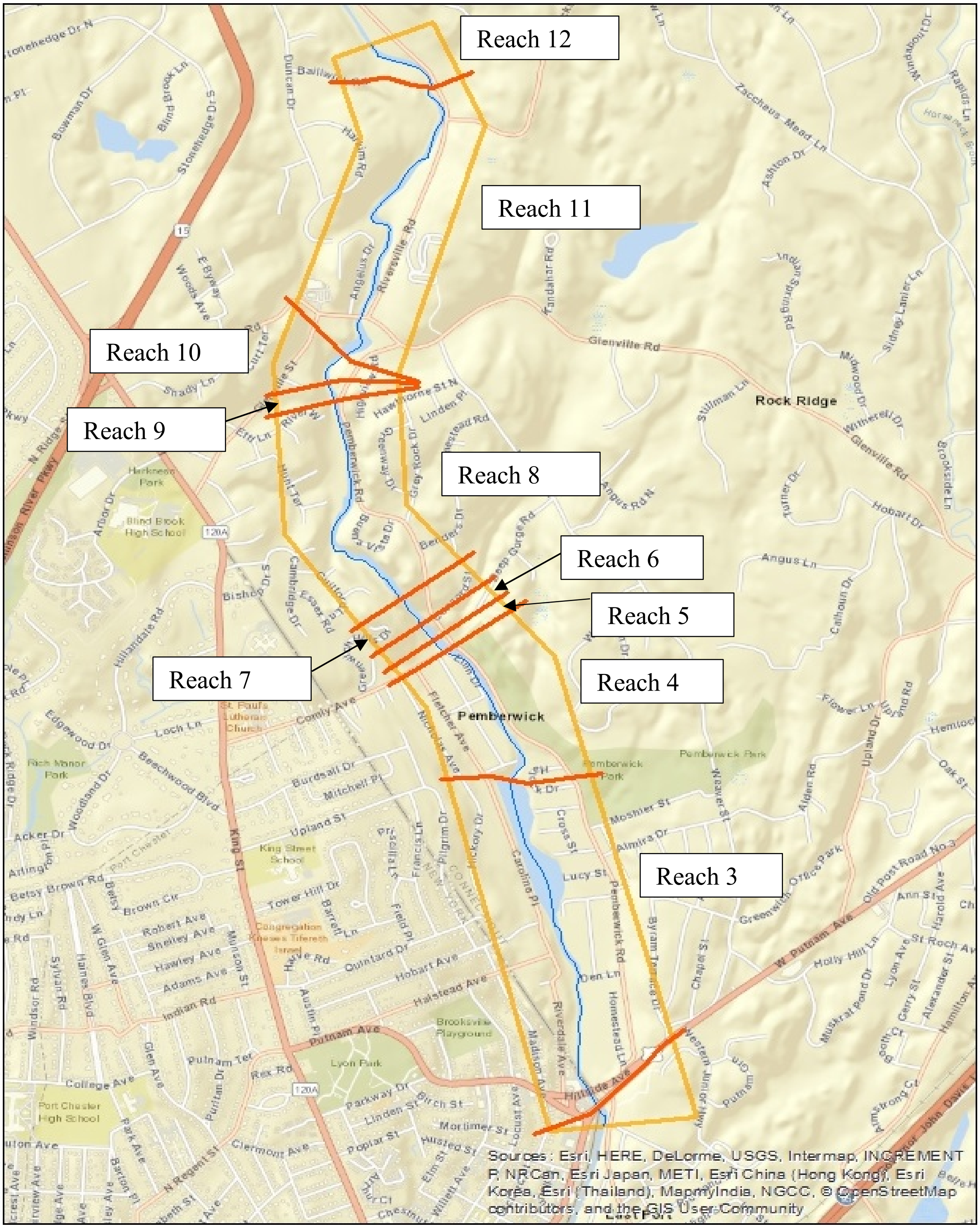

Figure 1: Project Area Reach Map

Table 1: Stream Reach Locations

Reach	Description	Beginning Station	Ending Station
3	Hillside Ave/Rt 1 to north end of Caroline Place Pond	9,230.4	13,544.3
4	North end of Caroline Place Pond to Comly Ave	13,544.3	15,401.2
5	Comly Ave to Footbridge	15,401.2	15,562.2
6	Footbridge to Footbridge	15,562.2	15,813.1
7	Footbridge to Pemberwick Dam	15,813.1	16,211.1
8	Pemberwick Dam to Utility Line Crossing	16,211.1	19,098.9
9	Utility Line Crossing to Dam near Sioux Place	19,098.9	19,330.5
10	Dam near Sioux Place to American Felt Dam	19,330.5	19,750.6
11	American Felt Dam to Bailiwick Rd	19,750.6	23,650.8
12	Bailiwick Rd to Footbridge	23,650.8	28,169.9

There is considerable fluctuation in the topography of the project area. The upper and lower portions of the stream within the project area are relatively flat, while the rest of the stream is fairly steep. A 0.7 mile length of stream in the upper reaches has more than a 2% slope. Overall, there is a total of almost six stream miles that have more than a 1% slope.

Ground elevations at the structures within the project area range from about 8' to 202' msl. There is an average 1.5% slope in grade between the structures at those elevations. The typical nature of flooding in the project area is best described as flash flooding. Flood waters from the stream can rise rapidly and have high velocities. The April 2007 flood caused stone facing of the Bailiwick Road Bridge in Greenwich to be stripped off by high velocity flows.

The floodplain is highly developed with primarily residential structures along with some commercial and public facilities. The amount of development and hydrologic characteristics of the watershed are not expected to significantly change in the future in the absence of a Federal water resources project. Expected depths of flooding on first floors of structures for the without project condition 0.2%-chance event range up to 11.2'. The difference in stages of flooding between the 10%-chance (10-year) and 1%-chance (100-year) events ranges between 1.5' and 7.2' and averages 6.0' for all structures in the study structure inventory. The highest concentration of flood-prone structures in the project area are in reaches 3 and 4. The average difference for these events in reaches 3 and 4 is 6.2' and 3.3', respectively.

4. SOCIO-ECONOMICS

4.1 General Data

Greenwich and Port Chester are both very viable, thriving communities. The population of Greenwich increased 2.6% from 2010 to 2017, to 62,782. Its median household income increased 2.9% from the year 2010 to 2017, to $138,180. Although employment in Greenwich declined from 2000 to 2010, it increased by 4.8% from 2010 to 2017.

The population of Port Chester increased 2.3% from 2010 to 2017, to 29,623, which is slightly above the percentage increase of New York state overall. Port Chester's median household income increased by 24.6% from 2000 to 2010 and then by 6.2% from 2010 to 2017, to $60,041 per household. Employment in Port Chester increased by 16.3% from 2000 to 2010 and then was flat from 2010 to 2017. The resulting percentage increase from 2000 to 2017 is 16.3%. This was a greater percent increase for employment than the 10.9% increase for Westchester County or the 12.9% increase for the State of New York for the same time period. Socio-economic statistics are presented in Tables 2, 3, and 4.

Table 2: Area Population

	Population				
	Total Population			Percent Change	
	2000	2010	2017[1]	2000 to 2010	2010 to 2017
Greenwich CT	61,101	61,171	62,782	0.1%	2.6%
Fairfield Co. CT	882,567	916,829	947,328	3.9%	3.3%
State of Connecticut	3,405,565	3,574,097	3,594,478	4.9%	0.6%
Port Chester NY	27,867	28,967	29,623	3.9%	2.3%
Westchester County NY	923,459	949,113	975,321	2.8%	2.8%
State of New York	18,976,457	19,378,102	19,798,228	2.1%	2.2%

Source: U.S. Census Bureau's American FactFinder at factfinder.census.gov

[1] American Community Survey 5-Year estimate.

Table 3: Area Income

	Income				
	Median Household Income			Percent Change	
	2000[1]	2010	2017	2000 to 2010	2010 to 2017
Greenwich CT	99,086	134,223	138,180	35.5%	2.9%
Fairfield Co. CT	65,249	86,670	89,773	32.8%	3.6%
State of Connecticut	53,935	71,755	73,781	33.0%	2.8%
Port Chester NY	45,381	56,524	60,041	24.6%	6.2%
Westchester County NY	63,582	86,226	89,968	35.6%	4.3%
State of New York	43,393	60,741	62,765	40.0%	3.3%

Source: U.S. Census Bureau's American FactFinder at factfinder.census.gov

[1]Income in 1999 reported in 2000 census.

Note: American Community Survey estimates for 2017 income are unavailable.

Table 4: Area Employment

	Employment				
	Employed			Percent Change	
	2000	2010[1]	2017[1]	2000 to 2010	2010 to 2017
Greenwich CT	28,081	27,067	28,375	-3.6%	4.8%
Fairfield Co. CT	426,638	439,341	474,458	3.0%	8.0%
State of Connecticut	1,664,440	1,765,549	1,805,086	6.1%	2.2%
Port Chester NY	13,452	15,640	15,642	16.3%	0.0%
Westchester County NY	432,600	451,799	479,696	4.4%	6.2%
State of New York	8,382,988	9,045,999	9,467,631	7.9%	4.7%

Source: U.S. Census Bureau's American FactFinder at factfinder.census.gov

[1] American Community Survey 5-Year estimate.

4.2 Social Vulnerability

Although the entire population that lives and works in the floodplain is vulnerable and at risk of flooding and harm, case studies have shown that certain sub-populations are more susceptible to harm from flooding. These "socially vulnerable groups" are typically children, the elderly, those disabled, low income, minorities and female head of households. Some of these have impediments to evacuating and therefore have a higher potential for loss of life. Others have a lack of resources or have special needs that may also inhibit preparing for an impending flood or evacuating. Tables 5 and 6 provide indicating statistics of social vulnerability.

Table 5: Greenwich, CT Social Vulnerability Data

Greenwich CT				Percent of Total			Percent Change	
	2000	2010	2017[1]	2000	2010	2017	2000 to 2010	2010 to 2017
Total Population	61,101	61,171	62,782	NA	NA	NA	0.1%	2.6%
Under 5 Years	4,294	3,721	4,121	7.0%	6.1%	6.6%	-13.3%	10.7%
5 Years thru 17 Years	11,250	12,617	12,062	18.4%	20.6%	19.2%	12.2%	-4.4%
65 Years and Over	9,716	10,068	10,596	15.9%	16.5%	16.9%	3.6%	5.2%
Black or African American	1,017	1,314	2,045	1.7%	2.1%	3.3%	29.2%	55.6%
American Indian and Alaska Native	52	84	76	0.1%	0.1%	0.1%	61.5%	-9.5%
Asian	3,165	4,039	4,886	5.2%	6.6%	7.8%	27.6%	21.0%
Native Hawaiian and Other Pacific Islander	16	14	18	0.03%	0.02%	0.03%	-12.5%	28.6%
Hispanic or Latino (of any race)	3,846	5,964	7,994	6.3%	9.7%	12.7%	55.1%	34.0%
Individuals Below Poverty Level	2,436	NA	4,144	4.0%	NA	6.6%	NA	NA
Disabled	NA	NA	5,093	NA	NA	8.1%	NA	NA
Total Households	23,230	23,076	NA	NA	NA	NA	-0.7%	NA
Female householder, no husband present	1,869	2,123	NA	8.0%	9.2%	NA	13.6%	NA

Source: U.S. Census Bureau's American FactFinder at factfinder.census.gov.

[1] American Community Survey 5-Year estimate.

Table 6: Port Chester, NY Social Vulnerability Data

Port Chester NY				Percent of Total			Percent Change	
	2000	2010	2017[1]	2000	2010	2017	2000 to 2010	2010 to 2017
Total Population	27,867	28,967	29,623	NA	NA	NA	3.9%	2.3%
Under 5 Years	1,947	1,998	1,947	7.0%	6.9%	6.6%	2.6%	-2.6%
5 Years thru 17 Years	4,320	4,547	5,126	15.5%	15.7%	17.3%	5.3%	12.7%
65 Years and Over	3,603	3,082	3,298	12.9%	10.6%	11.1%	-14.5%	7.0%
Black or African American	1,949	1,876	1,384	7.0%	6.5%	4.7%	-3.7%	-26.2%
American Indian and Alaska Native	112	271	420	0.4%	0.9%	1.4%	142.0%	55.0%
Asian	573	596	451	2.1%	2.1%	1.5%	4.0%	-24.3%
Native Hawaiian and Other Pacific Islander	11	11	8	0.04%	0.04%	0.03%	0.0%	-27.3%
Hispanic or Latino (of any race)	12,884	17,193	19,183	46.2%	59.4%	64.8%	33.4%	11.6%
Individuals Below Poverty Level	3,591	NA	3,673	12.9%	NA	12.4%	NA	NA
Disabled	NA	NA	2,790	NA	NA	9.4%	NA	NA
Total Households	9,531	9,240	NA	NA	NA	NA	-3.1%	NA
Female householder, no husband present	1,299	1,320	NA	13.6%	14.3%	NA	1.6%	NA

Source: U.S. Census Bureau's American FactFinder at factfinder.census.gov

[1] American Community Survey 5-Year estimate.

4.3 Transportation

Transportation in and around the project area is primarily via roadways and the roadway system is certainly adequate. U.S. Route 1 crosses Byram River at the southern end of the project area. U.S. Route 1 is a major U.S. highway north-south vehicular travel along the entire east coast. It begins and ends at Fort Kent, Maine at the U.S.-Canada border and at Key West, Florida and provides travel among most major east coast cities including Boston, New York, Philadelphia, Baltimore, and Washington D.C. Although it is a north-south highway, it is oriented in a northeast-southwest direction at the Byram River. It is also named West Putnam Avenue in the project area. Other roads in and around the project area provide adequate capacity for normal traffic flow. Pemberwick Road, Comly Avenue, Glenville Road, and Riversville Road are arterial roads and the remaining roadways are secondary.

5. EXISTING FLOOD REDUCTION FEATURES

A Federal flood risk management project was constructed on the Byram River in the Pemberwick neighborhood of Greenwich and was completed in 1959. The Design Memorandum for the project states that the project would confine stream flows equal to the October 1955 flood, the flood of record, to the improved channel. The project included channel realignment, deepening, reshaping and riprap for 2,400 feet of the stream channel. It also included construction of a levee along the left bank from Rex Road and upstream for approximately 800 feet.

6. FLOOD DAMAGE ANALYSIS

6.1 Risk-Based Model

It is USACE policy to perform analyses to assess existing flood damage and estimate potential benefits of flood reduction measures using risk-based methodology. This requirement is made in both ER 1105-2-100, Planning Guidance Notebook, and ER 1105-2-101, Risk Assessment for Flood Risk Management Studies, revised in July 2017. Such an analysis includes the likelihood, or probabilities, of various flood events occurring and the ability to include arrays of potential values of input parameters and produce estimates of impacts in probabilistic terms. The economic analysis of the Byram River study has been conducted as a risk-based assessment.

The U.S. Army Corps of Engineers' (USACE) Hydrologic Engineering Center Flood Damage Analysis (HEC-FDA) computer model, version 1.4.2 was used to estimate without project flood damage along with benefits of potential flood reduction measures in formulation of the National Economic Development (NED) plan. HEC-FDA integrates hydrologic, hydraulic and economic data. The model has the capability to apply risk-based analysis procedures consistent with both ER 1105-2-101 and EM 1110-2-1619. This capability includes accounting for uncertainties in economic and hydrologic and hydraulic (H&H) inputs. This is done with the use of statistical distributions and standard deviations as measurements of error for primary input variables required to model flooding in a floodplain. The program performs several thousand iterations of Monte Carlo simulation to select values of input variables based on the distributions and standard deviations of error specified by the uncertainty inputs in each iteration.

Ranges of possible values in the most significant input variables were applied in the model. These are described by probability distributions and standard deviations of error. Variables with estimated uncertainties are typically those that have the greatest effect on expected annual damage for the condition/plan being evaluated. These are the variables used to develop stage-damage functions such as first floor elevations, percent-depth damage functions, structure and content values, discharge exceedance probabilities, and stage-discharge functions.

6.2 Structure Inventory

In order to assess potential damage from flooding under current conditions and potential benefits of proposed flood reduction alternatives, a database of structures within the project area was prepared. The Byram River structure inventory was developed for use in HEC-FDA. Structure characteristics such as type of construction, number of stories, foundation type, etc. were determined utilizing both internet "street view" technology and site visits. First floor elevations and foundation heights of structures within the project area were estimated using topography and spot elevations of contour mapping during site visits. Elevation vertical datum is the same as that of the study water surface profiles (WSPs) and is North American Vertical Datum of 1988 (NAVD88). The uncertainty in structure first floor elevations was described as having a normal distribution and a standard deviation of error of 0.6 feet. This value is based on the accuracy of

2-foot contour topographic maps, as presented in EM 1110-2-1619.

The Marshall & Swift (M&S) Residential Cost Handbook and Marshall Valuation Service were used to estimate depreciated replacement values of the study structures to the FY 2019 price level. Values are for structures only; land is not included. Garages associated with residential structures are included in valuation but sheds and any other outbuildings are not. Estimates of error of structure values were based on what is thought to be a typical range when obtaining depreciated replacement values with M&S services. It was assumed that the percent standard deviation of error associated with structure value uncertainty is 10%.

The value of the contents of each structure is based on the content-to-structure-value ratio (CSVR) for the occupancy type (damage function) for each structure type. Occupancy types that were developed during the North Atlantic Coast Comprehensive Study (NACCS) were applied in the economic modeling of the Byram River study for both residential and non-residential structures. The NACCS occupancy types were developed by expert elicitation and focused on the region affected by Superstorm Sandy, which includes the Byram River project area. However, CSVRs were not developed during the NACCS expert elicitation for the NACCS damage functions. The CSVRs of the Passaic River Basin regional damage functions were therefore applied to the NACCS functions. These were originally developed using empirical data and documented in the Passaic River Basin, New Jersey and New York, Phase I General Design Memorandum, dated December 1987 and then updated in the Computation of Flood Damage Survey Data for the Passaic River Basin, dated January 1995. The later report states that content damages were calculated as a percent of structure value. A 100% CSVR was therefore applied to the NACCS damage functions for all structures in the Byram River project area. Flooding of basements of both residential and non-residential structures modeled to only result from overland flow entering structures at ground level and not from sewer backup or leaks in foundations caused by hydrostatic pressure.

Estimates of flood damage to automobiles were made with the HEC-FDA model. Automobile data was included in the structure inventory in order to model these. Occupancy types that were developed by the U.S. Army Corps of Engineers' (USACE) Institute for Water Resources (IWR) and were presented in EGM 09-04, Generic Depth-Damage Relationships for Vehicles were applied to estimate flood damage to vehicles.

All occupancy types that were used in the Byram River study include measures of uncertainty in the form of standard deviations of error of the percent damage estimates for each flood depth in the function.

6.3 Hydrology and Hydraulics

6.3.1 General

Hydrologic engineering inputs are required for eight flood frequency events to adequately define the stage-probability function of the stream within HEC-FDA. Byram River water surface profiles were imported to HEC-FDA with hydrologic and hydraulic data that were generated with a HEC-RAS model for each stream reach and condition/flood risk reduction measure. The water surface profiles include estimated stream discharges/flows from watershed runoff and water surface elevations for each of the eight flood events along with stream invert stages at each modeled cross-section. The water surface profiles that were modeled for Byram River are those of the 50%-chance (2-year), 20%- (5-year), 10%- (10-year), 4%- (25-year), 2%- (50-year), 1%-

(100-year), 0.5%- (200-year) and 0.2%-chance (500-year) flood events. Uncertainties in the discharge-exceedance probability functions were computed with HEC-FDA using analytical statistics and the equivalent record length of the gage, which is 30 years for Byram River, to fit the relationships for each reach to a Log Pearson Type III distribution. The hydraulic stage-discharge uncertainty was estimated to have a standard deviation of error separately for each reach but was not less than 0.7'.

6.3.2 Sea Level Change

The Byram River flows into Long Island Sound. Tidal fluctuations influence approximately 1.3 miles of the lower portion of the river. This tidal area extends to only a small part of the project area. The impacts of three different projections of Sea Level Change (SLC) were evaluated in the study, in accordance with ER 1100-2-8162, Incorporating Sea Level Change in Civil Works Programs. Low, Intermediate, and High scenarios were evaluated. Intermediate SLC is considered to be the expected scenario. Unless otherwise noted, results are presented for Intermediate SLC scenario. Project performance sensitivity to SLC is presented in the results of this report. See Appendix B2 – Hydraulics for a detailed description of the SLC analysis.

6.4 Flood Damage Estimates

6.4.1 General

Physical damages within the 0.2%-chance floodplain were classified as residential, commercial, public facilities, utilities, damage to automobiles, and cleanup costs, which are classified as emergency costs. Commercial structures in the project area include offices, retail stores, restaurants, health clubs, service and entertainment establishments. The primary public facility in the project area is a fire station, which is a critical facility during floods for both fire and flood fighting. The numbers of structures for Without Project Conditions were developed from HEC-FDA output and are shown in Table 7 by reach and category based on elevations of beginning flood damage to structures. This count includes structures which have flood water on and around them below the first floor, as well as structures with first floor flooding. The estimated total value of these properties, including contents, is $175 million within the 0.2%-chance floodplain in FY 2019 price levels, $180 million in FY 2020 price levels. This value of development is detailed by reach and category in Table 8. Figure 2 is a schematic which depicts without project condition WSPs within the project area for the most frequent, least frequent and an intermediate flood event. It also shows locations relative to the WSPs of primary streets, dams, study reaches, structures and stream thalweg, or stream bed.

Table 7: Without Project Condition Number of Structures Flooded by Event and Category
(Based on Intermediate SLC & Beginning Damage)

	Flood Event by Chance of Occurrence							
Reach/Category	**50%**	**20%**	**10%**	**4%**	**2%**	**1%**	**0.5%**	**0.2%**
Reach 3								
Residential	5	14	30	89	116	146	170	204
Commercial	0	1	1	2	2	2	4	5
Public	0	0	0	1	1	1	1	1
Total	5	15	31	92	119	149	175	210
Reach 4								
Residential	0	1	1	2	4	10	15	28
Commercial	0	0	0	0	0	0	0	1
Public	0	0	0	0	0	0	0	0
Total	0	1	1	2	4	10	15	29
Reach 5								
Residential	0	0	0	0	1	2	3	3
Commercial	0	0	0	0	0	0	0	0
Public	0	0	0	0	0	0	0	0
Total	0	0	0	0	1	2	3	3
Reach 6								
Residential	0	0	0	1	1	1	2	3
Commercial	0	0	0	0	0	0	0	0
Public	0	0	0	0	0	0	0	0
Total	0	0	0	1	1	1	2	3

Table 7: Without Project Condition Number of Structures Flooded by Event (Cont.)

	Flood Event by Chance of Occurrence							
Reach/Category	**50%**	**20%**	**10%**	**4%**	**2%**	**1%**	**0.5%**	**0.2%**
Reach 7								
Residential	0	0	0	0	0	0	0	0
Commercial	0	0	1	1	1	1	1	1
Public	0	0	0	0	0	0	0	0
Total	0	0	1	1	1	1	1	1
Reach 8								
Residential	0	0	0	0	0	0	0	0
Commercial	0	0	0	0	0	0	0	0
Public	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0
Reach 9								
Residential	0	0	0	0	0	0	0	0
Commercial	0	0	0	0	0	0	0	0
Public	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0
Reach 10								
Residential	0	0	0	0	0	0	0	0
Commercial	0	0	0	0	0	0	0	0
Public	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0
Reach 11								
Residential	0	0	0	1	2	8	10	12
Commercial	0	0	0	0	0	0	1	2
Public	0	0	0	0	0	0	0	0
Total	0	0	0	1	2	8	11	14

Table 7: Without Project Condition Number of Structures Flooded by Event (Cont.)

	Flood Event by Chance of Occurrence							
Reach/Category	**50%**	**20%**	**10%**	**4%**	**2%**	**1%**	**0.5%**	**0.2%**
Reach 12								
Residential	0	0	0	1	1	1	2	2
Commercial	0	0	0	0	0	0	0	0
Public	0	0	0	0	0	0	0	0
Total	0	0	0	1	1	1	2	2
Study Totals								
Residential	5	15	31	94	125	168	202	252
Commercial	0	1	2	3	3	3	6	9
Public	0	0	0	1	1	1	1	1
Study Total	5	16	33	98	129	172	209	262

Table 8: Without Project Condition Value of Development by Event and Category

(Based on Intermediate SLC & Beginning Damage; FY19 Price Level; in $1,000s)

	Flood Event by Chance of Occurrence							
Reach/Category	**50%**	**20%**	**10%**	**4%**	**2%**	**1%**	**0.5%**	**0.2%**
Reach 3								
Residential	2,379.5	6,093.2	14,707.8	46,889.6	61,253.5	79,030.0	92,119.3	196,696.2
Commercial	0.0	24755.7	24,755.7	29,972.7	29,972.7	29,972.7	30,835.3	31,088.5
Public	0.0	0.0	0.0	69.3	69.3	69.3	69.3	69.3
Total	2,458.0	30,794.9	39,463.4	76,931.6	91,295.5	109,071.9	123,023.9	140,854.0
Reach 4								
Residential	0.0	344.5	344.5	735.3	1,417.3	4,184.9	6,455.1	12,143.1
Commercial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	661.3
Public	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	0.0	0.0	0.0	735.3	1,417.3	4,184.9	6,455.1	12,804.4
Reach 5								
Residential	0.0	0.0	0.0	0.0	400.0	985.2	1,580.2	1,580.2
Commercial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Public	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	0.0	0.0	0.0	0.0	400.0	985.2	1,580.2	1,580.2
Reach 6								
Residential	0.0	0.0	0.0	681.2	681.2	681.2	1,156.1	1,911.5
Commercial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Public	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	0.0	0.0	0.0	681.2	681.2	681.2	1,156.1	1,911.5

Table 8: Without Project Condition Value of Development by Event (Cont.)

	Flood Event by Chance of Occurrence							
Reach/Category	**50%**	**20%**	**10%**	**4%**	**2%**	**1%**	**0.5%**	**0.2%**
Reach 7								
Residential	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Commercial	0.0	0.0	5,737.3	5,737.3	5,737.3	5,737.3	5,737.3	5,737.3
Public	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	0.0	0.0	5,737.3	5,737.3	5,737.3	5,737.3	5,737.3	5,737.3
Reach 8								
Residential	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Commercial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Public	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Reach 9								
Residential	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Commercial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Public	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Reach 10								
Residential	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Commercial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Public	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Reach 11								
Residential	0.0	0.0	0.0	1,281.0	1,691.3	4,335.0	7,264.3	9,062.0
Commercial	0.0	0.0	0.0	0.0	0.0	0.0	1,079.7	1,403.6
Public	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	0.0	0.0	0.0	1,281.0	1,691.3	4,335.0	8,344.0	10,465.6

Table 8: Without Project Condition Value of Development by Event (Cont.)

	Flood Event by Chance of Occurrence							
Reach/Category	**50%**	**20%**	**10%**	**4%**	**2%**	**1%**	**0.5%**	**0.2%**
Reach 12								
Residential	0.0	0.0	0.0	929.2	929.2	929.2	2,020.4	2,020.4
Commercial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Public	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	0.0	0.0	0.0	929.2	929.2	929.2	2,020.4	2,020.4
Study Totals								
Residential	2,458.0	6,383.7	15,052.3	50,516.3	66,372.5	90,145.4	108,133.7	132,657.3
Commercial	0.0	0.0	30,493.0	35,710.0	35,710.0	35,710.0	28,899.2	30,253.4
Public	0.0	0.0	0.0	69.3	69.3	69.3	69.3	69.3
Study Total	2,458.0	6,383.7	45,545.3	86,295.6	102,151.8	125,924.7	148,316.9	175,373.2

Note: Values include both structures and contents.

6.4.2 Automobile Damage

Automobile damage was modeled to occur only at residences in the project area. The 777 West Putnam office building is the only non-residential facility that currently has a substantial number of vehicles that might not be able to be moved in a timely manner following flood warnings. However, it is understood that many of these vehicles are part of a local car dealership's inventory and that storage of these at this location is temporary. U.S. Census Bureau data shows that in 2017 64.9% of Greenwich occupied housing units had two or more vehicles and that 41.8% of Port Chester occupied housing units did as well. It is thought that some residents could evacuate with all their vehicles, some perhaps with only one, and some might not try to evacuate until it is too late to move vehicles. It was therefore assumed that there would be one vehicle per residence during potential flooding and that these would be at the ground elevation at each structure, which is normally also the elevation of any associated garage. Although EGM 09-04 provides damage functions for sedans, sports cars, mini-vans, pickups and SUVs, a distribution of these vehicle types within the project area was not available. The sedan automobile occupancy type was therefore applied for estimates of flood damage for all vehicles. The average value per vehicle is based on an USA Today article entitled "Used-car prices hit a 13-year high as more late-model cars come off lease", dated 15 June 2018. Factors contributing to increased prices are the generally newer vehicles in the market due to off-lease cars; a shift in consumer preference to larger vehicles (SUVs and pickups); strong demand resulting from a strong economy, and people replacing vehicles due to recent hurricanes. The average used car price of $19,657 presented in the article was therefore assumed for all automobiles in the Byram

River FY19 HEC-FDA modeling.

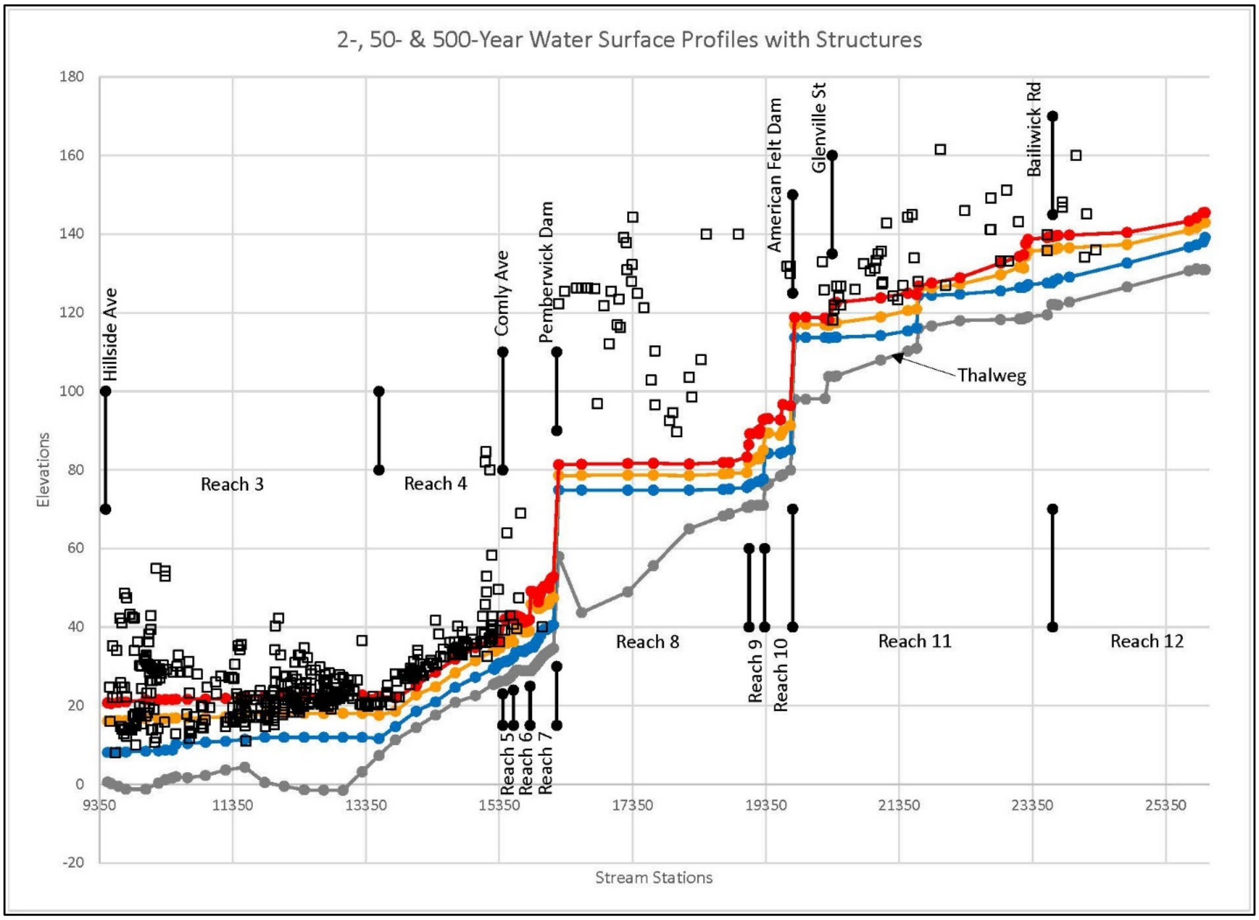

Figure 2: Representation of Structures with Select Existing Condition Water Surface Profiles

6.4.3 Emergency Costs

Emergency costs is a non-physical damage category that can typically include several types of costs, such as flood fighting, evacuations, shelters to provide mass care, assistance to families, and cleanup of debris removal and disposal costs. Estimates of debris costs reduction were made and included as benefits for the Recommended Plan. The estimation of debris costs utilized methodology presented in the NACCS Emergency Costs Report, which incorporates a matrix developed by the FEMA Modeling Task Force.

Another form of Emergency Costs are clean-up costs of structure interiors. Flood waters leave debris, sediment, salts and, at times, hazardous material that cause dangers of disease throughout flooded structures, making the cleaning of these structures a necessary post-flood activity. Clean-up costs for the extraction of flood waters, dry-out, and decontamination vary significantly based upon various factors, including depth of flooding. Studies conducted by both Sacramento and New Orleans Districts indicate a maximum value of ten dollars per square foot for such clean-up costs. This maximum per square foot cost covers clean-up costs associated with mold and mildew abatement, which entails having professional firms apply fans, chemicals, and other techniques to eliminate and prevent mold/mildew in inundated areas. The maximum clean-up cost of $10 per square foot was used for this analysis and applied for flood depths equal to and exceeding five feet, with damage percentages scaled down for depths between zero and five feet.

6.4.4 Utilities

Utility flood damages that have been included represent damage potential to the natural gas service in project area. Damage estimates are for fluvial flooding only; they do not include tidal surge/saltwater impacts. They included costs to investigate and assess damage, turn off meters in the flood area, evaluate and restore service to customers after waters recede, replace pressure regulators that were flooded, coordinate with local officials, provide office support for field operations, and to cut and cap service when access to meters is not possible. Estimates were based on knowledge of historic flood events and were projected for hypothetical, more severe events, such as the 0.2%-chance flood.

The majority of the without project condition damages for all categories and frequency events occur in Reach 3. A 1%-chance (100-year) flood is estimated to cause $46 million in total damage in the project area in FY 2019 price levels, $47 million in FY 2020 price levels; 85% of this would occur in Reach 3. For the project area overall, almost 50% of the damage caused by a 1%-chance flood is to residential structures, 41% is to commercial and 8% is to automobiles. Table 9 presents estimated flood damage by magnitude of flood event, reach and category.

Table 9: Without Project Condition Flood Damage by Reach, Category, and Event
(Intermediate SLC; FY19 Price Level; in $1,000s)

	Flood Event by Chance of Occurrence							
Reach/Category	**50%**	**20%**	**10%**	**4%**	**2%**	**1%**	**0.5%**	**0.2%**
Reach 3								
Residential	135.7	594.0	1,757.5	6,495.0	12,024.7	19,236.0	26,808.2	34,555.3
Commercial	29.4	1,154.3	5,645.2	11,125.0	13,920.1	16,061.5	19,070.3	22,400.4
Public	0.3	1.0	2.6	10.6	20.2	32.5	45.6	57.8
Autos	22.1	95.1	273.4	1,071.8	2,028.9	3,213.7	4,421.6	5,639.2
Emergency Costs	3.5	50.3	226.4	488.3	664.2	848.8	1,077.7	1,316.5
Utilities	0.1	3.4	16.6	31.6	37.9	42.4	49.9	58.2
Total	191.1	1,898.0	7,921.6	19,222.1	28,696.1	39,434.7	51,473.3	64,027.4
Reach 4								
Residential	1.3	14.6	25.7	90.0	315.2	594.1	1,176.6	2,304.7
Commercial	0.0	0.2	0.3	1.2	4.2	7.9	15.7	30.8
Public	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Autos	0.3	3.2	5.7	19.9	69.6	131.1	259.7	508.7
Emergency Costs	0.0	0.1	0.2	0.9	2.8	5.3	10.5	20.5
Utilities	0.0	0.1	0.2	0.7	2.3	4.3	8.6	16.9
Total	1.7	18.3	32.2	112.6	394.1	742.8	1,471.1	2,881.6
Reach 5								
Residential	0.0	0.0	0.0	2.0	37.5	215.9	450.8	677.4
Commercial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Public	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Autos	0.0	0.0	0.0	0.2	3.7	21.3	44.4	66.7
Emergency Costs	0.0	0.0	0.0	0.0	0.8	4.7	9.9	14.8
Utilities	0.0	0.0	0.0	0.0	0.1	0.8	1.7	2.6
Total	0.0	0.0	0.0	2.2	42.1	242.7	506.8	761.6
Reach 6								
Residential	0.0	0.0	2.1	81.2	117.2	212.6	344.2	600.6
Commercial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Public	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Autos	0.0	0.0	0.2	7.6	11.0	20.0	32.3	56.4
Emergency Costs	0.0	0.0	0.0	0.8	1.2	2.2	3.4	5.9
Utilities	0.0	0.0	0.0	0.2	0.2	0.4	0.7	1.3
Total	0.0	0.0	2.3	89.8	129.6	235.1	380.6	664.1

Table 9: Without Project Condition Flood Damage by Reach, Category, and Event (Cont.)

	Flood Event by Chance of Occurrence							
Reach/Category	**50%**	**20%**	**10%**	**4%**	**2%**	**1%**	**0.5%**	**0.2%**
Reach 7								
Residential	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Commercial	0.1	269.0	1,257.3	2,091.5	2,536.2	2,890.7	3,172.1	4,178.9
Public	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Autos	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Emergency Costs	0.0	18.2	85.0	141.4	171.5	195.5	224.5	282.6
Utilities	0.0	0.0	0.1	0.1	0.2	0.2	0.2	0.2
Total	0.1	287.2	1,342.4	2,233.0	2,707.8	3,086.3	3,386.8	4,461.7
Reach 8								
Residential	0.0	0.0	0.0	0.0	0.0	0.0	0.0	23.1
Commercial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Public	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Autos	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.7
Emergency Costs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Utilities	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26.8
Reach 9								
Residential	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Commercial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Public	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Autos	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Emergency Costs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Utilities	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Reach 10								
Residential	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Commercial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Public	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Autos	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Emergency Costs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Utilities	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 9: Without Project Condition Flood Damage by Reach, Category, and Event (Cont.)

	Flood Event by Chance of Occurrence							
Reach/Category	**50%**	**20%**	**10%**	**4%**	**2%**	**1%**	**0.5%**	**0.2%**
Reach 11								
Residential	0.0	11.0	76.3	293.4	759.9	1,412.8	2,396.6	3,056.3
Commercial	0.0	1.6	10.9	41.7	108.0	200.9	340.8	434.5
Public	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Autos	0.0	1.2	8.1	31.3	81.1	150.7	255.7	326.1
Emergency Costs	0.0	0.2	1.4	5.3	13.8	25.7	43.6	55.6
Utilities	0.0	0.0	0.3	1.2	3.1	5.7	9.7	12.3
Total	0.0	14.0	97.0	373.0	965.8	1,795.8	3,046.4	3,884.9
Reach 12								
Residential	0.0	13.7	150.1	320.5	417.5	570.6	750.7	1,289.6
Commercial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Public	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Autos	0.0	0.4	4.0	8.5	11.1	15.2	20.0	34.3
Emergency Costs	0.0	0.6	6.7	14.2	18.5	25.3	33.2	57.1
Utilities	0.0	0.0	0.2	0.3	0.4	0.6	0.8	1.3
Total	0.0	14.7	160.9	343.5	447.5	611.7	804.7	1,382.3
Study Totals								
Residential	137.1	633.3	2,011.8	7,282.1	13,671.9	22,242.0	31,927.1	42,507.1
Commercial	29.6	1,425.1	6,913.7	13,259.3	16,568.5	19,160.9	22,598.9	27,044.6
Public	0.3	1.0	2.6	10.6	20.2	32.5	45.6	57.8
Autos	22.4	99.8	291.4	1,139.3	2,205.4	3,551.9	5,033.7	6,635.2
Emergency Costs	3.6	69.5	319.7	650.9	872.8	1,107.3	1,392.8	1,753.0
Utilities	0.1	3.5	17.3	34.0	44.2	54.4	71.6	92.8
Study Total	192.9	2,232.2	9,556.4	22,376.2	33,383.1	46,149.1	61,069.6	78,090.4

Note: Totals may appear to be incorrect due to mathematical rounding.

6.5 Expected Annual Damage

Damage-probability functions are developed in HEC-FDA that are then used to develop expected annual damage. Expected annual damage (EAD) is the probability-weighted average damage of all possible peak annual damages. It is calculated by numerical integration of the damage-probability function. In risk-based analysis it is equal to the average or mean of all possible values of damage determined by exhaustive Monte Carlo sampling of discharge-exceedance probability, stage-discharge, and stage-damage relationships and their associated uncertainties.

The major variables for which uncertainties are estimated include discharges and stages of flooding, structure first floor elevations, structure values, structure-to-content value ratios and depth-damage functions. HEC-FDA performs many iterations of damage estimates by randomly picking values for these variables with uncertainties described by the type of and error in distributions. Iterations of this procedure are made for each reach until the change in the mean of the damage estimate derived in this manner is minimal. The mean damage estimated in this way is the expected annual damage. Index points in each damage reach are used as points to aggregate stage-damage for that reach.

HEC-FDA has the capability to account for a changed condition for a future year during the period of analysis. The changed condition could be due to changes in the hydrologic and hydraulic estimates in flood characteristics or in economic conditions, or both. Conditions and development of the Byram River project area are not expected to significantly change during the period of analysis. Therefore, annualized damage calculated by HEC-FDA in this analysis is based on the damage-probability functions and is expected annual damage instead of equivalent annual damage.

The without-project condition EAD for the project area, accounting for uncertainties with HEC-FDA, are shown by reach and category in Table 10. More than half of the without-project EAD is to commercial facilities and approximately 36% is to residential structures. Approximately 85% of the without-project EAD occurs in Reach 3.

Table 10: Without Project Condition Expected Annual Damage by Reach and Category

(Intermediate SLC; FY19 Price Level; in $1,000s)

Category / Expected Annual Damage							
Reach	Residential	Commercial	Public	Autos	Emergency Costs	Utilities	Reach Total
3	983	1,430	2	161	65	4	2,645
4	28	1	0	6	0	0	35
5	6	0	0	1	0	0	7
6	9	0	0	1	0	0	10
7	0	283	0	0	19	0	302
8	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0
11	51	7	0	6	1	0	65
12	39	0	0	1	2	0	42
Total (FY19)	1,116	1,721	2	175	88	5	3,106
Total (FY20)	1,143	1,762	2	179	90	5	3,181

Note: Totals may appear to be incorrect due to mathematical rounding.

7. FLOOD RISK REDUCTION ALTERNATIVES

Several individual components and combinations of alternatives were evaluated during this study. These include both structural and non-structural measures that were developed over the different phases of study. The Initial Array of alternatives included non-structural plans with wet and dry floodproofing, ringwalls, raising of structures, and acquisition within both the 10% and 1%-chance floodplains. Structural alternatives of the Initial Array included levees, floodwalls, and channel modification. A list of the Initial Array of screened alternatives evaluated is presented in Table 11. The Final Array of alternatives included expanded stand-alone non-structural analyses and replacement of the U.S. Route 1 bridges, with and without non-structural measures. A list of the Final Array of screened alternatives evaluated is presented in Table 12. Detailed descriptions of these plans and the formulation process are provided in the Main Report.

Table 11: Initial Array of Alternatives

Alternative	Description
1	No action
2 –10%	Non-structural features in 10%-chance floodplain
2 – 1%	Non-structural features in 1%-chance floodplain
3	Levees, floodwalls & channel modifications (update of 1977 plan)
4	Smaller levees & floodwalls with channel widening

Table 12: Final Array of Alternatives

Alternative	Description
1	No action
2a	Non-structural features in 10%-chance floodplain
2b	Non-structural features in 4%-chance floodplain
2c	Non-structural features in 2%-chance floodplain
2d	Non-structural features in 1%-chance floodplain
5	Replacement of U.S. Route 1 bridges
5a	Alt 5 + non-structural features in 10%-chance floodplain
5b	Alt 5 + non-structural features in 4%-chance floodplain
5c	Alt 5 + non-structural features in 2%-chance floodplain
5d	Alt 5 + non-structural features in 1%-chance floodplain

8. WITH PROJECT DAMAGE AND BENEFIT ESTIMATION

8.1 Flood Damage Analysis Model

Each alternative plan was modeled within HEC-FDA in order to calculate residual damage with each plan in order to compare flood risk reduction projects. Modifications to the base condition were made in the model, appropriate for each alternative. Channel modifications and bridge replacements required water surface profiles reflecting hydrology and hydraulics changes. Levees and floodwalls were configured to model truncation of damage in the reaches where these were proposed. The base condition structure inventory was used to prepare structure modules reflecting changes in first floor elevations and beginning damage stages for the non-structural plans under consideration.

Inundation reduction benefits are computed as the difference between with- and without-project condition damage and costs. With-project damage and EAD (i.e. residual damage) were developed in the same manner as without-project damage and EAD, described above. Expected annual benefits of proposed alternatives are equal to the amount which these alternatives reduce the expected annual damage and costs of the without-project condition. Estimates of benefits for structures and their contents and for automobiles were made in this way with HEC-FDA.

8.2 Advanced Bridge Replacement Benefits

Replacement of the two U.S. Route 1 bridges was considered as a potential flood risk reduction measure, which is Alternative 5. There are two bridges because the U.S. Route 1 highway is divided at the Byram River, with two separate roadways that have two lanes each. The existing bridges restrict stream flows. The Hydraulics appendix of this report indicates that flood stages would be reduced with this plan by four feet for the 2%-chance flood event just upstream of the north bridge and by almost that much for the 1%-chance flood event. It has been estimated that the existing bridges would need to be replaced within the next 11 to 25 years, with a mid-point of that range of 18 years. That is the without project condition in regards to bridge replacement. The advanced bridge replacement benefit is the extension of the serviceable life of the bridges and the subsequent postponement of the without project condition bridge replacements by 11 to 25 years. Since the costs of the new bridges are included in the first costs of the project, a credit is needed on the benefit side, which is accomplished by the advanced bridge replacement benefit calculation.

The cost of the new bridge is multiplied by the capital recovery factor to obtain the annual cost of the new bridge over 50 years at the FY 2020 Federal discount rate of 2.75%. The credit is a constant annuity in years 19-50 of the period of analysis. The present worth of the credit is brought to year 18 by multiplying the amount of the annual annuity by the present worth of an annuity factor for 32 years. The present worth of the credit is then brought to the base year of the period of analysis with the single payment, present worth factor for 18 years.

Current annual Operation and Maintenance (O&M) costs are about $25,000 per year. These have been conservatively estimated to continue even with the replaced bridges. It is anticipated that periodic major rehabilitation will be needed until the bridges are replaced, which would be eliminated with new bridges. Rehabilitation is to fix the concrete arches of the bridges, which have exposed and corroding rebar. It is anticipated that the rehabilitation will be needed in five years (in 2024) and will cost $2 million per bridge. It is estimated this type of rehabilitation will need to occur every 10 years until the bridges are replaced. The major rehabilitation costs were annualized with life cycle analysis and included in the Advanced Bridge Replacement calculation.

The project costs available for use in the Advanced Bridge Replacement calculation included costs for Flood Risk Management (FRM) features. There are two primary changes from the current design of the bridges for FRM. These are raising the bridge decks by three feet and eliminating the middle support piers of both bridges. It is thought that the net change in total cost of the bridge replacements will be negligible. It is also reasonable to assume that, since the flooding problem will continue in the future without project condition and because no other alternative is cost justified, the bridges would be replaced in such a way as to minimize flow constrictions in the future even in the absence of a Federal project.

8.3 Plan Evaluation Results

Evaluation of the economic feasibility of the alternatives leading to identification of the Recommended Plan was conducted in phases that occurred over a period of years. Evaluation of the Initial Array alternatives was completed in FY 2016. Evaluation of the Final Array of alternatives was included in the Draft Integrated Feasibility Report in FY 2018. Summaries of economic results of these arrays are presented below in their original price levels. These include estimates of expected annual benefits, first and annualized costs, computed over a 50-year period of analysis, along with benefit-cost ratios and net benefits. Annualized costs include interest during construction calculations and annual operations and maintenance (O&M) costs. The NED plan is defined as the plan which reasonably maximizes net benefits consistent with the Federal objective. The Byram River Recommended and NED plan was determined to be Alternative 5, replacements of U.S. Route 1 bridges.

Some benefit categories were not included within the scope of the screening of alternatives. These include reduction in emergency response costs, traffic delays and diversions, damage to outside property and landscaping, and damage to roads, bridges, and other infrastructure. The benefits presented are therefore considered to be conservative.

Table 13: Economic Summary of Initial Array Plans

(FY16 Price Level; in $1,000s; 3.125% Federal discount rate)

ALTERNATIVE	ANNUAL BENEFITS	TOTAL FIRST COST	TOTAL ANNUAL COST	NET BENEFITS	BENEFIT COST RATIO
1 – No Action	$0	$0	$0	$0	
2 – 10%	$851	$19,170	$799	$52	1.07
2 – 1%	$1,050	$33,169	$1,382	($332)	0.76
3	$2,467	$98,896	$4,328	($1,861)	0.57
4*	$2,601	$101,646	$4,236	($1,635)	0.61

Table 14: Economic Summary of Final Array Plans

(FY18 Price Level; in $1,000s; 2.75% Federal discount rate)

ALTERNATIVE	ANNUAL BENEFITS	TOTAL FIRST COST	TOTAL ANNUAL COST	NET BENEFITS	BENEFIT COST RATIO
No Action	$0	$0	$0	$0	
2a	$434	$18,444	$701	($267)	0.62
2b	$559	$29,745	$1,131	($572)	0.49
2c	$1,337	$36,962	$1,405	($68)	0.95
2d	$1,358	$42,605	$1,620	($262)	0.84
5*	$1,071	$24,302	$949	$122	1.13
5a*	$1,305	$42,877	$1,715	($410)	0.76
5b*	$1,325	$46,749	$1,862	($537)	0.71
5c*	$1,339	$52,502	$2,081	($742)	0.64
5d*	$1,355	$58,319	$2,302	($947)	0.59

* All bridge replacement alternatives include annual advanced bridge replacement benefits of $303k.

9. RECOMMENDED PLAN

Alternative 5 is the Recommended Plan because it is the plan which reasonably maximizes net benefits. It is the replacement of both U.S. Route 1 bridges. The existing bridges have wide stone piers in their center, which restricts stream flow. New bridges will eliminate the center piers and have raised bridge decks to allow more stream flow and reduce trapped debris during high stream flow events.

9.1 Residual Damage

Although the Recommended Plan reduces flood risk in damage centers of the project area, it does not completely eliminate these and there is remaining residual, with-project damage. Reach 3 has the greatest reduction in flood stages with the Recommended Plan. The Recommended Plan causes reductions in flood stages upstream of the bridges almost thru Reach 6. The plan reduces water surface profiles for all modeled flood events for almost 0.9 mile upstream of the north U.S. Route 1 bridge. The greatest reduction of the 1%-chance flood event stage occurs about 50 feet upstream of that bridge with a reduction of 3.83’. The 2%-chance flood event has a 3.98’ reduction and the 50%-chance event has a 0.14’ reduction at the same location. Figure 3 is a map depicting the approximate 1%-chance inundation both without and with the Recommended Plan. The risk of flooding and consequent damage are reduced for the majority of structures in this area and flooding is eliminated by the Recommended Plan for 33 structures, or 19%, in the 1%-chance floodplain based on flooding at beginning damage elevations. Flooding on first floors of structures by the without-project condition 1%-chance event is eliminated for 43 structures, or 64%, by the Recommended Plan. Table 15 presents numbers of structures flooded by the eight modeled flood events under the with-project condition by reach and damage category. Residual flood damages with the Recommended Plan are shown by category and reach for these flood frequencies in Table 16. Expected annual damage with the Recommended Plan is presented by reach and category in Table 17. The Recommended Plan reduces expected annual flood damage overall by 29% and reduces 34% of the annual damage of Reach 3. The with-project, residual, EAD is $2,197,000 in the FY 2019 price levels and $2,225,000 in the FY 2020 price levels.

9.2 Traffic impacts

A temporary impact of the Recommended Plan is to vehicular traffic during construction. Construction is expected to occur during two consecutive construction seasons. Only one bridge will be replaced at a time and traffic will be diverted to the other bridge during that time, leaving one lane open in each direction. There are also other potential diversion routes around the U.S. Route 1 bridges altogether.

A feasibility level traffic analysis was conducted to assess construction impacts associated with roadway closures during the bridge replacement and is detailed in Appendix A10 of this report. Results of the traffic analysis were used to estimate the monetary impact of the traffic delays during construction. The traffic analysis provided amount of increases in travel times during construction. Methodology for estimating the value of time is presented in Appendix D of ER 1105-2-100, specifically Table D-4, was employed in estimating traffic impacts. This was done for both automobiles and trucks. A percentage of truck traffic for U.S. Route 1 of 3.8% was obtained from the New York Department of Transportation Traffic Volume Report dated November 2017. The traffic impacts were annualized over the 50-year economic period of analysis. The annual value of this impact is $176,000. Annual benefits of the bridge replacement plan are reduced by this amount. A detailed description of the traffic impact calculation is provided as Attachment A.

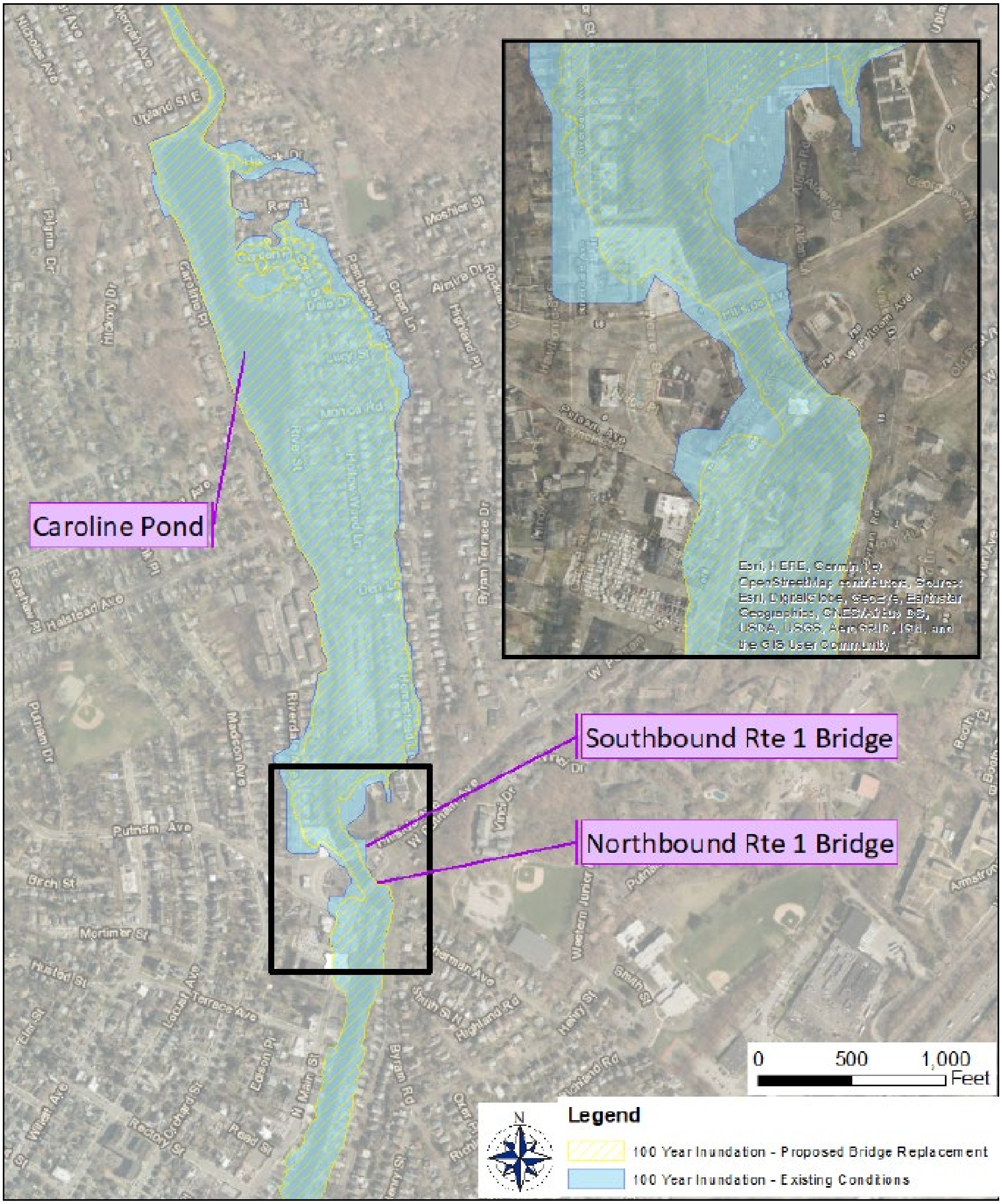

Figure 3: 1%-Chance Flood Inundation Areas for Without- and With-Project Conditions

Table 15: Recommended Plan Number of Structures Flooded

(Intermediate SLC; Based on Beginning Damage)

	Flood Event by Chance of Occurrence							
Reach/Category	**50%**	**20%**	**10%**	**4%**	**2%**	**1%**	**0.5%**	**0.2%**
Reach 3								
Residential	5	13	28	57	85	114	144	194
Commercial	0	0	1	1	1	2	2	5
Public	0	0	0	0	1	1	1	1
Total	5	13	29	58	87	117	147	200
Reach 4								
Residential	0	1	1	2	4	10	14	28
Commercial	0	0	0	0	0	0	0	1
Public	0	0	0	0	0	0	0	0
Total	0	1	1	2	4	10	14	29
Reach 5								
Residential	0	0	0	0	1	2	3	3
Commercial	0	0	0	0	0	0	0	0
Public	0	0	0	0	0	0	0	0
Total	0	0	0	0	1	2	3	3
Reach 6								
Residential	0	0	0	1	1	1	2	3
Commercial	0	0	0	0	0	0	0	0
Public	0	0	0	0	0	0	0	0
Total	0	0	0	1	1	1	2	3
Reach 7								
Residential	0	0	0	0	0	0	0	0
Commercial	0	0	1	1	1	1	1	1
Public	0	0	0	0	0	0	0	0
Total	0	0	1	1	1	1	1	1
Reach 8								
Residential	0	0	0	0	0	0	0	0
Commercial	0	0	0	0	0	0	0	0
Public	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0

Table 15: Recommended Plan Number of Structures Flooded (Cont.)

	Flood Event by Chance of Occurrence							
Reach/Category	**50%**	**20%**	**10%**	**4%**	**2%**	**1%**	**0.5%**	**0.2%**
Reach 9								
Residential	0	0	0	0	0	0	0	0
Commercial	0	0	0	0	0	0	0	0
Public	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0
Reach 10								
Residential	0	0	0	0	0	0	0	0
Commercial	0	0	0	0	0	0	0	0
Public	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0
Reach 11								
Residential	0	0	0	1	2	8	10	12
Commercial	0	0	0	0	0	0	1	2
Public	0	0	0	0	0	0	0	0
Total	0	0	0	1	2	8	11	14
Reach 12								
Residential	0	0	0	1	1	1	2	2
Commercial	0	0	0	0	0	0	0	0
Public	0	0	0	0	0	0	0	0
Total	0	0	0	1	1	1	2	2
Study Totals								
Residential	5	14	29	62	94	136	175	242
Commercial	0	0	2	2	2	3	4	9
Public	0	0	0	0	1	1	1	1
Study Total	5	14	31	64	97	140	180	252

Table 16: Recommended Plan Flood Damage by Reach, Category and Event
(Intermediate SLC; FY19 Price Level; in $1,000s)

	Flood Event by Chance of Occurrence							
Reach/Category	**50%**	**20%**	**10%**	**4%**	**2%**	**1%**	**0.5%**	**0.2%**
Reach 3								
Residential	131.0	497.0	1,178.3	3,222.5	6,149.9	12,479.6	22,062.6	30,692.9
Commercial	25.1	518.0	3,169.2	7,148.6	9,678.4	12,731.0	15,469.1	19,489.7
Public	0.2	0.6	1.2	3.4	7.0	13.7	23.7	32.7
Autos	23.6	89.3	202.8	558.6	1,089.4	2,288.0	4,058.3	5,583.8
Emergency Costs	3.1	25.0	122.1	285.5	414.9	602.0	827.4	1,087.9
Utilities	0.1	1.7	10.6	23.9	32.1	40.6	47.2	59.2
Total	182.9	1,131.6	4,684.0	11,242.5	17,371.6	28,154.8	42,488.4	56,946.2
Reach 4								
Residential	1.3	14.5	25.5	87.0	294.3	533.1	1,080.0	2,234.4
Commercial	0.0	0.2	0.4	1.2	4.2	7.5	15.2	31.5
Public	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Autos	0.3	3.3	5.9	20.0	67.7	122.7	248.5	514.2
Emergency Costs	0.0	0.1	0.2	0.8	2.6	4.7	9.5	19.7
Utilities	0.0	0.1	0.2	0.7	2.3	4.1	8.3	17.3
Total	1.6	18.2	32.2	109.7	371.0	672.1	1,361.6	2,817.1
Reach 5								
Residential	0.0	0.0	0.0	2.0	37.5	215.9	450.8	677.4
Commercial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Public	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Autos	0.0	0.0	0.0	0.2	3.7	21.3	44.4	66.7
Emergency Costs	0.0	0.0	0.0	0.0	0.8	4.7	9.9	14.8
Utilities	0.0	0.0	0.0	0.0	0.1	0.8	1.7	2.6
Total	0.0	0.0	0.0	2.2	42.1	242.7	506.8	761.6
Reach 6								
Residential	0.0	0.0	2.1	81.2	117.2	212.6	344.2	600.6
Commercial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Public	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Autos	0.0	0.0	0.2	7.6	11.0	20.0	32.3	56.4
Emergency Costs	0.0	0.0	0.0	0.8	1.2	2.1	3.4	5.9
Utilities	0.0	0.0	0.0	0.2	0.2	0.4	0.7	1.3
Total	0.0	0.0	2.3	89.8	129.6	235.1	380.6	664.1

Table 16: Recommended Plan Flood Damage by Flood Event (Cont.)

Reach/Category	50%	20%	10%	4%	2%	1%	0.5%	0.2%
	Flood Event by Chance of Occurrence							
Reach 7								
Residential	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Commercial	0.1	269.0	1,257.3	2,091.5	2,536.2	2,890.7	3,172.1	4,178.9
Public	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Autos	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Emergency Costs	0.0	18.2	85.0	141.4	171.5	195.5	214.5	282.6
Utilities	0.0	0.0	0.1	0.1	0.2	0.2	0.2	0.2
Total	0.1	287.2	1,342.4	2,233.0	2,707.8	3,086.3	3,386.8	4,461.7
Reach 8								
Residential	0.0	0.0	0.0	0.0	0.0	0.0	0.0	23.1
Commercial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Public	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Autos	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.7
Emergency Costs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Utilities	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26.8
Reach 9								
Residential	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Commercial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Public	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Autos	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Emergency Costs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Utilities	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Reach 10								
Residential	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Commercial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Public	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Autos	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Emergency Costs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Utilities	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 16: Recommended Plan Flood Damage by Flood Event (Cont.)

	Flood Event by Chance of Occurrence							
Reach/Category	**50%**	**20%**	**10%**	**4%**	**2%**	**1%**	**0.5%**	**0.2%**
Reach 11								
Residential	0.0	11.0	76.3	293.4	759.9	1,412.8	2,396.6	3,056.3
Commercial	0.0	1.6	10.8	41.7	108.0	200.9	340.8	434.5
Public	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Autos	0.0	1.2	8.1	31.3	81.1	150.7	255.7	326.1
Emergency Costs	0.0	0.2	1.5	5.3	13.8	25.7	43.6	55.6
Utilities	0.0	0.0	0.3	1.2	3.1	5.7	9.7	12.3
Total	0.0	14.0	97.0	373.3	965.8	1,795.8	3,046.4	3,884.9
Reach 12								
Residential	0.0	13.7	150.1	320.5	417.5	570.6	750.7	1,289.6
Commercial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Public	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Autos	0.0	0.4	4.0	8.5	11.1	15.2	20.0	34.3
Emergency Costs	0.0	0.6	6.7	14.2	18.5	25.3	33.2	57.1
Utilities	0.0	0.0	0.2	0.3	0.4	0.6	0.8	1.3
Total	0.0	14.7	160.9	343.5	447.5	611.7	804.7	1,382.3
Study Totals								
Residential	132.3	536.2	1,432.3	4,006.5	7,776.2	15,424.6	27,084.9	38,574.4
Commercial	25.2	788.7	4,437.7	9,283.0	12,326.8	15,830.0	18,997.3	24,134.6
Public	0.2	0.6	1.2	3.4	7.0	13.7	23.7	32.7
Autos	23.8	94.2	220.9	626.3	1,264.0	2,617.8	4,659.2	6,585.1
Emergency Costs	3.1	44.1	215.4	448.0	623.3	860.0	1,141.5	1,523.6
Utilities	0.1	1.9	11.3	26.4	38.4	52.4	68.6	94.2
Study Total	184.7	1,465.7	6,318.8	14,393.7	22,035.6	34,798.5	51,975.2	70,944.7

Note: Totals may appear to be incorrect due to mathematical rounding.

Table 17: Recommended Plan Expected Annual Residual Damage

(Intermediate SLC; FY19 Price Level; in $1,000s)

Reach	Residential	Commercial	Public	Autos	Emergency Costs	Utilities	Reach Total
3	662	914	1	118	40	3	1,739
4	26	0	0	6	0	0	33
5	6	0	0	1	0	0	7
6	9	0	0	1	0	0	10
7	0	283	0	0	19	0	302
8	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0
11	51	7	0	5	1	0	65
12	39	0	0	1	2	1	42
Totals	794	1,205	1	132	65	4	2,197

Category / Expected Annual Damage

Note: Totals may appear to be incorrect due to mathematical rounding.

Table 18: Expected Annual Damage Reduced and Distributed by Reach

(Intermediate SLC; FY19 Price Level; in $1,000s)

	Expected Annual Damage			Probability Damage Reduced Exceeds Indicated Values		
Reach	Without Project	With Recommended Plan	Reduced	0.75	0.5	0.25
3	2,645.0	1737.8	907.2	634.6	869.7	1,141.9
4	34.9	33.3	1.6	0.6	1.2	2.1
5	6.5	6.5	0.0	0.0	0.0	0.0
6	10.3	10.3	0.0	0.0	0.0	0.0
7	302.2	302.2	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0
11	65.1	65.1	0.0	0.0	0.0	0.0
12	42.0	42.0	0.0	0.0	0.0	0.0
Total	3,106.0	2,197.2	908.8	635.2	871.0	1,144.0
Total (FY20)	3,180.5	2,249.9	930.6	650.4	891.9	1,171.5

9.3 Net Benefit Calculations

Annualized costs were subtracted from total average annual benefits to compute net benefits. Interest during construction (IDC) was added to first construction costs to obtain investment costs. IDC was calculated at both the FY 2019 Federal discount rate of 2.875% and at 7% interest over a 25 month total construction period. To make this calculation, costs were spread among estimated months of expenditure and end of month payments were assumed. The total expenditure for each month was multiplied by the monthly IDC factor for the period and interest rate, producing monthly IDC. The monthly IDC factor is equivalent to 1 plus the interest rate, raised to the period in months divided by 12, minus 1. The sum of the monthly IDC yields the total IDC for the construction period. The investment cost was then annualized at the discount rate over the 50 year economic life of the project. Annual operation, maintenance and major replacement costs were then added to obtain total annualized costs. An example of IDC calculation is presented in Table 19.

The calculation of Advanced Bridge Replacement benefits with an 18 year remaining useful life, at the FY 2020 Federal discount rate of 2.75% is presented in Table 20. The calculation of net benefits for the Recommended Plan with Intermediate SLC and an 18-year remaining useful life of the existing bridges is presented in Tables 21 and 22. A summary with all scenarios is presented in Table 23. Net benefits for the plan are $358,000 and the benefit-to-cost ratio is 1.3.

Table 19: Interest During Construction Calculation

Project: **Byram River Route 1 Bridge Replacements**
Location: **Greenwich, CT**

The blue fields are the user input parameters

Interest During Construction Calculator

Yearly interest rate: 0.02750
Monthly interest factor: 1.00226 (calculated value)

Construction Value $ 29,405,000
Construction Duration 25.00 month(s)

Period								
IDC	**$**	**812,653**						
1.00	$	1,176,200.00	$	1,241,780.50	$	65,580.50		
2.00	$	1,176,200.00	$	1,238,976.35	$	62,776.35		
3.00	$	1,176,200.00	$	1,236,178.53	$	59,978.53		
4.00	$	1,176,200.00	$	1,233,387.03	$	57,187.03		
5.00	$	1,176,200.00	$	1,230,601.84	$	54,401.84		
6.00	$	1,176,200.00	$	1,227,822.93	$	51,622.93		
7.00	$	1,176,200.00	$	1,225,050.30	$	48,850.30		
8.00	$	1,176,200.00	$	1,222,283.93	$	46,083.93		
9.00	$	1,176,200.00	$	1,219,523.81	$	43,323.81		
10.00	$	1,176,200.00	$	1,216,769.92	$	40,569.92		
11.00	$	1,176,200.00	$	1,214,022.24	$	37,822.24		
12.00	$	1,176,200.00	$	1,211,280.78	$	35,080.78		
13.00	$	1,176,200.00	$	1,208,545.50	$	32,345.50		
14.00	$	1,176,200.00	$	1,205,816.40	$	29,616.40		
15.00	$	1,176,200.00	$	1,203,093.46	$	26,893.46		
16.00	$	1,176,200.00	$	1,200,376.68	$	24,176.68		
17.00	$	1,176,200.00	$	1,197,666.02	$	21,466.02		
18.00	$	1,176,200.00	$	1,194,961.49	$	18,761.49		
19.00	$	1,176,200.00	$	1,192,263.07	$	16,063.07		
20.00	$	1,176,200.00	$	1,189,570.73	$	13,370.73		
21.00	$	1,176,200.00	$	1,186,884.48	$	10,684.48		
22.00	$	1,176,200.00	$	1,184,204.30	$	8,004.30		
23.00	$	1,176,200.00	$	1,181,530.16	$	5,330.16		
24.00	$	1,176,200.00	$	1,178,862.07	$	2,662.07		
25.00	$	1,176,200.00	$	1,176,200.00	$	-	$	812,652.52

Table 20: Advanced Bridge Replacement Benefits

(18 Year Remaining Bridge Life; FY20 Price Level; in $1,000s)

Description	Values
Cost of new bridge	$29,405
Life of new bridge (years)	50
Remaining useful life of existing bridge (years)	18
Extension of bridge life (years)	0.32
Annual O&M and Major Rehab of existing bridge	$459
Annual O&M of new bridge	$25
Interest rate	2.75%
Capital recovery factor	0.037041
Annual cost of new bridge	$1,089
Present worth of annuity factor for extended life	21.10033
Benefits credited to bridge life extension	$22,982
Single payment present worth for remaining useful life of existing bridge	0.61366
Present worth in year 1 of bridge extension	$14,103
Annual O&M savings	$434
Present worth of annuity factor for remaining useful life of existing bridge	14.04877
Present worth in year 1 of O&M savings	$6,098
Present worth of total credit	$20,202
Average annual benefits	$748

Table 21: Net Benefit Calculation @2.75%

(Intermediate SLC; FY19 Price Level; in $1,000s)

<u>Project Cost</u>	
Construction First Cost	$29,405
Interest During Construction	$813
Total Investment Cost	$30,218
<u>Annual Charges</u>	
Interest & Amortization	$1,119
Operation & Maintenance	$25
Total Average Annual Charges	$1,144
<u>Annual Benefits</u>	
Physical Damage Reduction	$905
Emergency Costs Reduction	$26
Advanced Bridge Replacement	$748
Traffic Impacts	($176)
Total Annual Benefits	$1,503
Net Benefits	$358
Benefit vs. Cost Ratio	1.3

Table 22: Net Benefit Calculation @7%

(Intermediate SLC; FY19 Price Level; in $1,000s)

Project Cost	
Construction First Cost	$29,405
Interest During Construction	$2,084
Total Investment Cost	$31,490
Annual Charges	
Interest & Amortization	$2,282
Operation & Maintenance	$25
Total Average Annual Charges	$2,307
Annual Benefits	
Physical Damage Reduction	$905
Emergency Costs Reduction	$26
Advanced Bridge Replacement	$885
Traffic Impacts	($345)
Total Annual Benefits	$1,471
Net Benefits	($836)
Benefit vs. Cost Ratio	0.64

Table 23: Economic Summary

(FY20 Price Level; 2.75%; in $1,000s)

SEA LEVEL CHANGE SCENARIO		25-YEAR REMAINING BRIDGE LIFE: $667,000	18-YEAR REMAINING BRIDGE LIFE: $748,000	11-YEAR REMAINING BRIDGE LIFE: $839,000
LOW	Annual Benefits	$1,100,000	$1,182,000	$1,272,000
	Net Benefits	$44,000	$38,000	$128,000
	Benefit Cost Ratio	0.96	1.03	1.11
INTERMEDIATE	Annual Benefits	$1,421,000	$1,503,000	$1,593,000
	Net Benefits	$277,000	$358,000	$449,000
	Benefit Cost Ratio	1.24	1.31	1.39
HIGH	Annual Benefits	$1,907,000	$1,989,000	$2,079,000
	Net Benefits	$763,000	$845,000	$935,000
	Benefit Cost Ratio	1.67	1.74	1.82

9.4 Risk Analysis

Because uncertainty has been defined for key input parameters in the economic analysis, uncertainty in the expected benefits may be calculated. HEC-FDA calculates the distribution of expected annual damage reduced by plan in terms of the probability that the damage reduced exceeds certain values of probabilities, (e.g. .75, .50, and .25). For example, there is a .75 probability that the expected annual benefits of Alternative 5 exceeds $1,222,000, a .50 probability that they exceed $1,464,000, and a .25 probability they exceed $1,743,000. Table 24 presents the distribution of expected annual benefits for Alternative 5, the Recommended Plan, along with the distribution of net benefits and benefit-to-cost ratios.

Table 24: Economic Summary of Recommended Plan with Uncertainty

(FY20 Price Level; in $1,000s)

	Annual Benefits	Annual Cost	Net Benefits	BCR	Probability Distribution Quartiles		
					0.75	0.5	0.25
Mean	$1,503	$1,144	$358	1.3			
EAB					$1,222	$1,464	$1,743
ENB					$78	$320	$599
BCR					1.07	1.28	1.52

Dollar values are in $1,000s. EAB = Expected Annual Benefits; ENB = Expected Net Benefits; BCR = Benefit-to-Cost Ratio. Annual costs include interest during construction at FY19 Federal discount rate of 2.875%. The 0.50 quartile is the median estimate; it differs from the mean when the probability distribution is asymmetrical. EABs include advanced bridge replacement benefits of $748,000 and emergency cost reduction benefits of $26,000. These benefits are reduced by $176,000 due to the cost of traffic delays during construction.

The hydrologic and hydraulic performance of a project may be described by annual exceedance probability, long-term risk and assurance, or conditional non-exceedance probabilities. Annual exceedance probability is the probability that flooding will occur at a given location in any given year considering the full range of possible annual floods and project performance; the target stage is defined as the water surface elevation that results in significant damages, usually considered 5% damages. Long-term risk is the probability of a target stage, which is typically the start of without project condition significant damage, being exceeded within the 10-, 30-, and 50-year timeframes. Conditional non-exceedance probabilities represent the chance of containing specific flood events within the target stage. Reach 3 of the Byram River economic analysis was further divided into sub-reaches and left- and right-stream bank. Table 25 presents the annual exceedance probability and Table 26 presents both long-term risk and assurance for the Recommended Plan.

Table 25: Annual Exceedance Probability

		Annual Exceedance Probability	
Reach	Target Stage [ft]	Without-Project Condition	Recommended Plan
31 Left Bank	10.03	22%	18%
31 Right Bank	12.34	8%	5%
32 Left Bank	14.04	16%	16%
32 Right Bank	21.70	0.6%	0.4%
33 Left Bank	18.98	2%	1%
33 Right Bank	21.80	0.6%	0.4%
4	22.84	13%	13%
5	36.13	3%	3%
6	37.08	9%	9%
7	41.15	22%	22%
8	81.60	0.4%	0.4%
9	88.80	0.6%	0.6%
10	92.4	0.4%	0.4%
11	125.14	18%	18%
12	140.16	17%	17%

Table 26: Project Performance

	Long Term Risk			Conditional Non-Exceedance Probability by Events					
Reach	10 Years	30 Years	50 Years	10.0%	4.0%	2.0%	1.0%	0.4%	0.2%
31 Left Bank	86%	100%	100%	22%	2%	0%	0%	0%	0%
31 Right Bank	38%	76%	91%	93%	51%	20%	6%	1%	0%
32 Left Bank	82%	99%	100%	28%	4%	1%	0%	0%	0%
32 Right Bank	4%	11%	18%	100%	100%	98%	90%	70%	55%
33 Left Bank	11%	29%	44%	100%	97%	84%	59%	27%	12%
33 Right Bank	4%	11%	18%	100%	100%	97%	89%	69%	53%
4	75%	98%	100%	45%	11%	3%	1%	0%	0%
5	28%	62%	80%	98%	71%	38%	16%	4%	1%
6	60%	94%	99%	66%	14%	2%	0%	0%	0%
7	91%	100%	100%	10%	1%	0%	0%	0%	0%
8	3%	10%	16%	100%	100%	97%	90%	74%	63%
9	6%	16%	25%	100%	100%	95%	82%	56%	36%
10	4%	12%	19%	100%	100%	97%	88%	67%	53%
11	87%	100%	100%	47%	26%	15%	8%	4%	2%
12	85%	100%	100%	21%	2%	0%	0%	0%	0%

ATTACHMENT A – TRAFFIC IMPACT CALCULATION

This Attachment provides a detailed description of calculations to estimate the temporary impact to traffic of the Recommended Plan during construction. Construction is expected to occur during two consecutive construction seasons. Only one bridge will be replaced at a time and traffic will be diverted to the other bridge during that time, leaving one lane open in each direction.

Projections of the traffic delays at modeled intersections were provided by the traffic analysis presented in Appendix A10 of this report. Five bridge closure scenarios were evaluated in that analysis. The results of closures of the North Bridge and of the South Bridge were presented as Scenarios 1 and 2, respectively. Delays in travel times (in seconds) during construction were presented as Table C1 in Appendix A10 and are provided for reference in Table A1, below.

Table A1: Microsimulation Capacity Analysis – Existing Conditions, Scenario 1, and Scenario 2

		Existing Conditions				Scenario 1				Scenario 2			
		Weekday A.M. Peak		**Weekday P.M. Peak**		**Weekday A.M. Peak**		**Weekday P.M. Peak**		**Weekday A.M. Peak**		**Weekday P.M. Peak**	
Intersection	**Lane Group**	**Delay**	**LOS**	**Delay**	**LOS**	**Delay**	**LOS**	**Delay**	**LOS**	**Delay**	**LOS**	**Delay**	**LOS**
Hillside Avenue / Byram Traffic Circle East	WB Hillside Avenue	10.3	B	2.9	A	-	-	-	-	0.2	A	0.3	A
	EB Hillside Avenue	-	-	-	-	-	-	-	-	0.5	A	279.5	F
	NB Byram Road	58.8	F	8.5	A	-	-	-	-	84.1	F	6.0	A
Hillside Avenue / Byram Traffic Circle West	WB Hillside Avenue	-	-	-	-	-	-	-	-	0.2	A	0.8	A
	WBL Hillside Avenue	193.3	F	27.1	D	-	-	-	-	0.4	A	3.1	A
	EB Hillside Avenue	-	-	-	-	-	-	-	-	1.1	A	23.3	C
	NB Byram Circle	-	-	-	-	-	-	-	-	47.8	E	280.2	F
Putnam Avenue / Byram Traffic Circle West	EB Putnam Avenue	87.1	F	1.7	A	14.6	B	308.4	F	2.1	A	2.2	A
	SB Byram Circle	244.1	F	64.3	F	-	-	-	-	5.7	A	5.9	A
	NB Main Street	-	-	-	-	-	-	-	-	16.7	B	103.8	F
Putnam Avenue / North Main Street	EBR Putnam Avenue	1.0	A	1.2	A	-	-	-	-	-	-	-	-
	EBL Putnam Avenue	19.3	C	10.8	B	25.6	D	444.5	F	-	-	-	-
	NB Main Street	0.3	A	0.2	A	0.9	A	33.8	D	-	-	-	-
	SB Main Street	-	-	-	-	1.3	A	4.8	A	-	-	-	-
West Putnam Avenue / Byram Road	EB Putnam Avenue	5.3	A	2.2	A	0.6	A	0.5	A	0.9	A	0.4	A
	WB Putnam Avenue	-	-	-	-	26.2	D	1.6	A	-	-	-	-
	NB Byram Road	1051.0	F	194.5	F	-	-	-	-	-	-	-	-
	NBR Byram Road	986.2	F	141.2	F	1716.7	F	386.5	F	1111.7	F	355.1	F
	NBL Byram Road	-	-	-	-	1942.1	F	429.6	F	1232.4	F	386.5	F

* Under Scenario 1, this approach consists of one shared right and left turn lane.

Note: Delay units are seconds.

The differences in delays under each Scenario and for each intersection and lane group were obtained by subtracting the Scenario delay from the Existing Condition delay. Negative delays indicate there is less delay with the scenario versus under Existing Conditions. These differences in traffic times were converted from seconds to minutes. The resulting losses and savings in travel times in minutes are presented in Table A2.

Table A2: Difference in Delays by Scenario (Scenario less Existing; in minutes)

Intersection	Lane Group	Existing Conditions / Scenario 1 Weekday A.M. Peak Delay	Scenario 1 Weekday P.M. Peak Delay	Scenario 2 Weekday A.M. Peak c	Scenario 2 Weekday P.M. Peak Delay
Hillside Avenue / Byram Traffic Circle East	WB Hillside Avenue	-	-	-0.17	-0.04
	EB Hillside Avenue	-	-		
	NB Byram Road	-	-	0.42	-0.04
Hillside Avenue / Byram Traffic Circle West	WB Hillside Avenue	-	-	0.00	0.01
	WBL Hillside Avenue	-	-	-3.22	-0.40
	EB Hillside Avenue	-	-		
	NB Byram Circle	-	-	0.80	4.67
Putnam Avenue / Byram Traffic Circle West	EB Putnam Avenue	-1.21	5.11	-1.42	0.01
	SB Byram Circle	-	-	-3.97	-0.97
	NB Main Street	-	-	0.28	1.73
Putnam Avenue / North Main Street	EBR Putnam Avenue	-	-	-	-
	EBL Putnam Avenue	0.11	7.23	-	-
	NB Main Street	0.01	0.56	-	-
	SB Main Street	0.02	0.08	-	-
West Putnam Avenue / Byram Road	EB Putnam Avenue	-0.08	-0.03	-0.07	-0.03
	WB Putnam Avenue	0.44	0.03	-	-
	NB Byram Road	-	-	-	-
	NBR Byram Road	12.18	4.09	2.09	3.57
	NBL Byram Road	32.37	7.16	20.54	6.44

The Planning Guidance Notebook, ER 1105-2-100, provides guidance on placing values on the opportunity cost of time. The methodology is the same for both time saved and lost. It specifies the use of percentages presented in its Table D-4, Value of Time Saved by Trip Length and Purpose, in such valuations. Table D-4 is provided for reference as Table A3 of this attachment.

Table A3: Value of Time Saved by Trip Length and Purpose

(ER1105-2-100, Table D-4)

Table D- 4: Value of Time Saved by Trip Length and Purpose

	VALUE OF TIME SAVED ADJUSTED TO HOURLY BASIS ($/HOUR)	VALUE OF TIME SAVED ADJUSTED TO HOURLY BASIS (% OF HOURLY FAMILY INCOME OF DRIVER)
LOW TIME SAVINGS (O-5 MINUTES)		
WORK TRIPS	$0.99	6.4%
SOCIAL / RECREATION TRIPS	0.20	1.3%
OTHER TRIPS	0.01	0.1%
MEDIUM TIME SAVINGS (6-15 MINUTES)		
WORK TRIPS	4.99	32.2%
SOCIAL / RECREATION TRIPS	3.58	23.1%
OTHER TRIPS	2.24	14.5%
HIGH TIME SAVINGS (OVER 15 MINUTES)		
WORK TRIPS	8.33	53.8%
SOCIAL / RECREATION TRIPS	9.29	60.0%
OTHER TRIPS	9.98	64.5%
VACATION		
ALL TIME SAVINGS	11.63	75.1%

Note: Work trip is on per person basis while all other trip purposes are on a per vehicle basis.

The table provides percentages of median family income that vary by purpose of the trip and amount of time. The traffic capacity analysis evaluated and provides changes in travel times for weekday AM and PM peak hour (i.e. “rush hour”) conditions. Value of time percentages of Table D-4 for work trips were therefore applied in estimating traffic impacts. 6.4% was applied to delays up to 5 minutes, 32.2% was applied to delays between 6 and 15 minutes, and 53.8% was applied to delays over 15 minutes. Resulting percentages by intersection, lane group, scenario, and rush hour are shown in Table A4.

Table A4: Percent of Hourly Income per Length of Delay

Intersection	Existing Conditions Lane Group	Scenario 1 Weekday A.M. Peak %	Weekday P.M. Peak %	Scenario 2 Weekday A.M. Peak %	Weekday P.M. Peak %
Hillside Avenue / Byram Traffic Circle East	WB Hillside Avenue	-	-	6.4%	6.4%
	EB Hillside Avenue	-	-		
	NB Byram Road	-	-	6.4%	6.4%
Hillside Avenue / Byram Traffic Circle West	WB Hillside Avenue	-	-	6.4%	6.4%
	WBL Hillside Avenue	-	-	6.4%	6.4%
	EB Hillside Avenue	-	-		
	NB Byram Circle	-	-	6.4%	6.4%
Putnam Avenue / Byram Traffic Circle West	EB Putnam Avenue	6.4%	32.2%	6.4%	6.4%
	SB Byram Circle	-	-	6.4%	6.4%
	NB Main Street	-	-	6.4%	6.4%
Putnam Avenue / North Main Street	EBR Putnam Avenue	-	-	-	-
	EBL Putnam Avenue	6.4%	32.2%	-	-
	NB Main Street	6.4%	6.4%	-	-
	SB Main Street	6.4%	6.4%	-	-
West Putnam Avenue / Byram Road	EB Putnam Avenue	6.4%	6.4%	6.4%	6.4%
	WB Putnam Avenue	6.4%	6.4%	-	-
	NB Byram Road	-	-	-	-
	NBR Byram Road	32.2%	6.4%	6.4%	6.4%
	NBL Byram Road	53.8%	32.2%	53.8%	32.2%

Peak hour traffic volumes, shown by Scenario, intersection, lane group, and rush hour in figures 3 and 4 of the Traffic Analysis are also shown in Table A5.

Table A5: Peak Hour Traffic Volumes

	Existing Conditions	Scenario 1		Scenario 2	
Intersection	Lane Group	Weekday A.M. Peak Volume	Weekday P.M. Peak Volume	Weekday A.M. Peak Volume	Weekday P.M. Peak Volume
Hillside Avenue / Byram Traffic Circle East	WB Hillside Avenue	-	-	418	516
	EB Hillside Avenue	-	-		
	NB Byram Road	-	-	418	516
Hillside Avenue / Byram Traffic Circle West	WB Hillside Avenue	-	-	418	516
	WBL Hillside Avenue	-	-	44	70
	EB Hillside Avenue	-	-		
	NB Byram Circle	-	-	418	516
Putnam Avenue / Byram Traffic Circle West	EB Putnam Avenue	737	568	737	568
	SB Byram Circle	-	-	418	516
	NB Main Street	-	-	462	586
Putnam Avenue / North Main Street	EBR Putnam Avenue	-	-	-	-
	EBL Putnam Avenue	68	57	-	-
	NB Main Street	737	568	-	-
	SB Main Street	2	22	-	-
West Putnam Avenue / Byram Road	EB Putnam Avenue	744	623	744	623
	WB Putnam Avenue	418	516	-	-
	NB Byram Road	-	-	-	-
	NBR Byram Road	42	30	42	30
	NBL Byram Road	695	538	695	538

* Volumes from Figures 3 & 4 of Appx A10.

Peak hour traffic volumes for passenger vehicles and commercial trucks were estimated using these total traffic volumes. A percentage of truck traffic for U.S. Route 1 between Putnam Avenue and the Connecticut state line of 3.8% was obtained from the New York Department of Transportation Traffic Volume Report dated November 2017 was applied to make the volume estimates. (ref. https://www.dot.ny.gov/divisions/engineering/technical-services/hds-respository/NYSDOT_2016TrafficVolumeReport-Routes.pdf). The 2017 U.S. Census Bureau median hourly household income of $89,773 for Fairfield County, CT and $89,968 for Westchester County, NY was averaged and divided by 2080 hours to obtain an average hourly household income of $43.21. ER 1105-2-100 guidance states "The value of time savings for work trips is on a per vehicle-occupant basis. Therefore, to calculate the total value of work time saved per vehicle requires multiplication by the adults per vehicle." Vehicle occupancy rates for both AM and PM peak driving times were obtained from the Vehicle Occupancy Ratios on Connecticut State Roads 1999 and 2000 report (ref. http://www.ct.gov/dot/lib/dot/Documents/dcptc/cpt2001/VEHICLE_OCCUPANCY_RATIOS_ON_CONNECTICUT_HIGHWAYS.pdf). The vehicle occupancy ratios for Southwestern Connecticut of 1.228 during AM peak and 1.419 during PM peak were applied.

The value of time lost for vehicles is presented in Table A6. These were estimated by taking the differences in delays by scenario in hours times the traffic volume for vehicles times the average hourly household income times the percent of hourly income per length of delay (Table A4) times the peak vehicle occupancy rate.

Table A6: Hourly Value of Time Lost for Vehicles

	Existing Conditions	Scenario 1		Scenario 2	
Intersection	Lane Group	Weekday A.M. Peak Delay	Weekday P.M. Peak Delay	Weekday A.M. Peak Delay	Weekday P.M. Peak Delay
Hillside Avenue / Byram Traffic Circle East	WB Hillside Avenue	-	-	-$3.83	-$1.41
	EB Hillside Avenue	-	-		
	NB Byram Road	-	-	$9.59	-$1.35
Hillside Avenue / Byram Traffic Circle West	WB Hillside Avenue	-	-	$0.08	$0.43
	WBL Hillside Avenue	-	-	-$7.64	-$1.75
	EB Hillside Avenue	-	-		
	NB Byram Circle	-	-	$18.13	$151.48
Putnam Avenue / Byram Traffic Circle West	EB Putnam Avenue	-$48.49	$918.32	-$56.85	$0.30
	SB Byram Circle	-	-	-$90.40	-$31.57
	NB Main Street	-	-	$6.99	$63.81
Putnam Avenue / North Main Street	EBR Putnam Avenue	-	-	-	-
	EBL Putnam Avenue	$0.39	$130.81	-	-
	NB Main Street	$0.40	$20.00	-	-
	SB Main Street	$0.00	$0.11	-	-
West Putnam Avenue / Byram Road	EB Putnam Avenue	-$3.17	-$1.11	-$2.97	-$1.18
	WB Putnam Avenue	$9.93	$0.86	-	-
	NB Byram Road	-	-	-	-
	NBR Byram Road	$138.67	$7.75	$4.74	$6.76
	NBL Byram Road	$10,302.19	$1,220.35	$6,537.47	$1,097.92
Totals		$10,399.93	$2,297.10	$6,415.31	$1,283.44

The value of time lost for trucks was made in a similar manner as that of passenger vehicles. The average hourly wage of Connecticut truck drivers was obtained with the Connecticut Occupational Employment & Wages Statewide 2011 (ref. https://www1.ctdol.state.ct.us/lmi/wages/oes_statewide.pdf). Average hourly wages of $16.48 for Industrial Truck and Tractor Operators, $21.21 for Truck Drivers, Heavy and Tractor-Trailer, and $16.22 for Truck Drivers, Light or Delivery Services were averaged to obtain $17.97 per hour. This was rounded to $18 per hour and multiplied by the differences in delays by scenario in hours and then multiplied by traffic volume for trucks. The resulting product is the hourly value of time lost for trucks, presented in Table A7.

Table A7: Hourly Value of Time Lost for Trucks

	Existing Conditions	Scenario 1		Scenario 2	
Intersection	Lane Group	Weekday A.M. Peak Delay	Weekday P.M. Peak Delay	Weekday A.M. Peak Delay	Weekday P.M. Peak Delay
Hillside Avenue / Byram Traffic Circle East	WB Hillside Avenue	-	-	-$0.81	-$0.26
	EB Hillside Avenue	-	-		
	NB Byram Road	-	-	$2.02	-$0.25
Hillside Avenue / Byram Traffic Circle West	WB Hillside Avenue	-	-	$0.02	$0.08
	WBL Hillside Avenue	-	-	-$1.93	-$0.36
	EB Hillside Avenue	-	-		
	NB Byram Circle	-	-	$3.82	$28.02
Putnam Avenue / Byram Traffic Circle West	EB Putnam Avenue	-$10.15	$33.74	-$11.90	$0.06
	SB Byram Circle	-	-	-$19.07	-$5.84
	NB Main Street	-	-	$1.50	$11.42
Putnam Avenue / North Main Street	EBR Putnam Avenue	-	-	-	-
	EBL Putnam Avenue	$0.09	$4.34	-	-
	NB Main Street	$0.08	$3.70	-	-
	SB Main Street	$0.00	$0.02	-	-
West Putnam Avenue / Byram Road	EB Putnam Avenue	-$0.66	-$0.20	-$0.62	-$0.22
	WB Putnam Avenue	$2.10	$0.16	-	-
	NB Byram Road	-	-	-	-
	NBR Byram Road	$7.31	$1.23	$1.26	$1.07
	NBL Byram Road	$252.47	$42.96	$160.21	$38.65
Totals		$251.24	$85.94	$134.51	$72.37

The hourly values of time lost for AM and PM peak hours for vehicles and then trucks for each scenario were summed and multiplied by 222 work days per year. Work days exclude weekends and ten national holidays. (Example Scenario 1 vehicles calculation: ($10,399.93 + $2,297.10) x 222 = $2,818,739.66). This was repeated for trucks and for Scenario 2. Resulting values of time lost due to traffic delays per scenario are presented in Table A8.

Table A8: Value of Time Lost by Scenario

	Annual Value of Time Lost	
	Scenario 1	Scenario 2
Vehicles	$2,818,739.66	$1,709,122.35
Trucks	$74,854.18	$45,926.36
Total	$2,893,593.84	$1,755,048.71

The values of time lost were annualized by applying a mid-year present worth factor for 2.75% of 1.042 for the first year of construction to the Scenario 2 cost of $1,755,048.71 and a factor of 1.014 for the second year of construction to the Scenario 1 cost of $2,893,593.84. The resulting sum of $4,761,050 of the present worth values was amortized at 2.75% over the 50-year economic period of analysis to obtain the annualized full traffic impact during construction of $176,354.