Westchester County Streams,
Byram River Basin
Flood Risk Management
Fairfield County, Connecticut and
Westchester County, New York

Draft Integrated Feasibility Report &
Environmental Impact Statement

Appendix D – Economic Analysis

Byram River Basin Flood Risk Management Study
Connecticut and New York

Appendix D: Economic Analysis

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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 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 will be shown in this appendix.

2. Economic Parameters

The methods for the economic analysis were completed in accordance with ER 1105-2-100. Monetary values are in October 2017, Fiscal Year (FY) 2018, price levels and the FY 2018 Federal discount rate of 2.75% was applied to cost and benefits calculations. The base year 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 delimited 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.

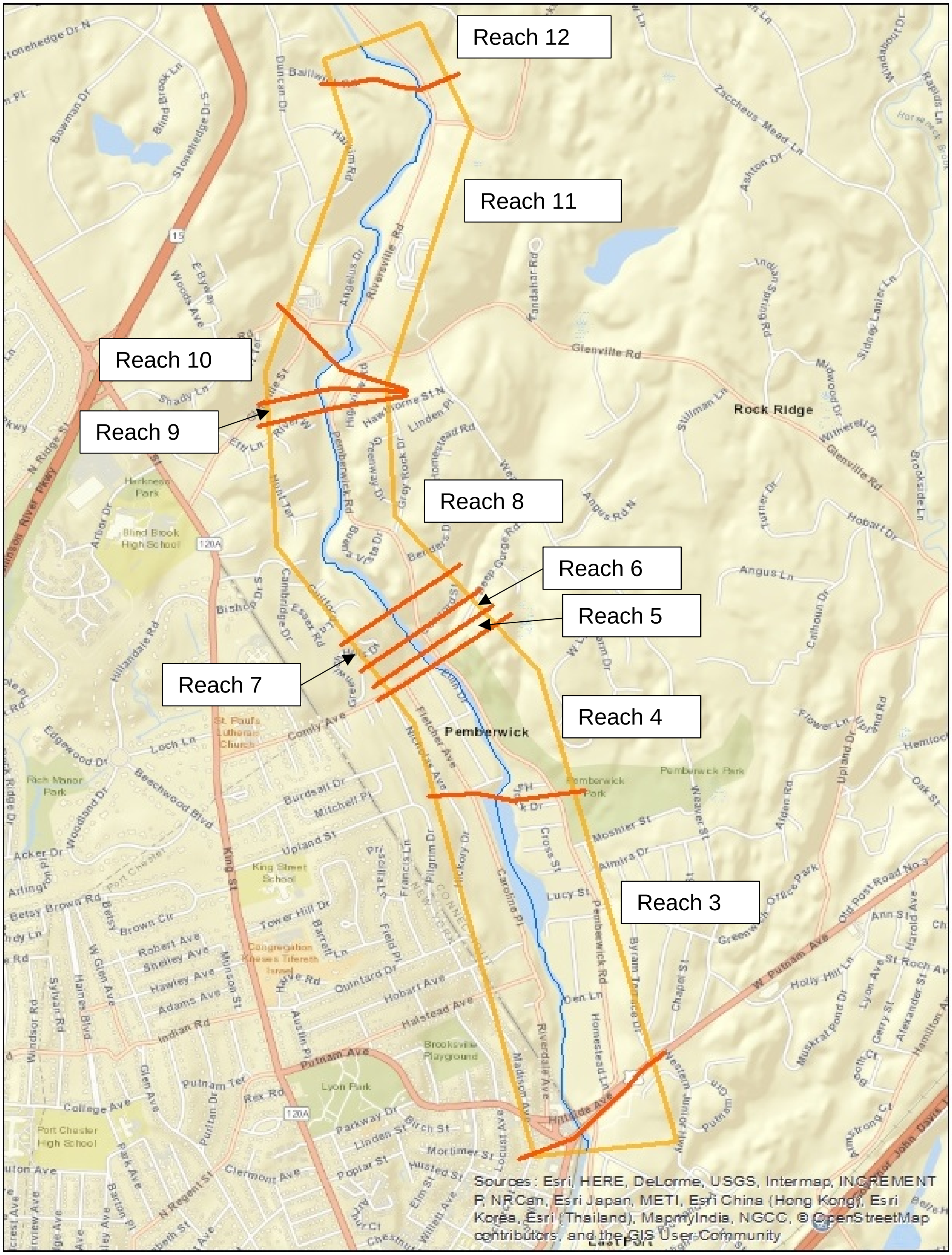

Figure 1: Project Area Reach Map

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 12.8'. The difference in stages of flooding between the 10%-chance (10-year) and 1%-chance (100-year) events ranges between 1.4' and 7.4' and averages 4.8' 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 5.8' and 3.0', respectively.

4. Socio-Economics

4.1 General Data

Greenwich and Port Chester are both very viable, thriving communities. The population of Greenwich increased 2.0% from 2010 to 2016 to 62,418. Its median household income increased 35.5% from the year 2000 to 2010 to $134,223. Although employment in Greenwich declined from 2000 to 2010, it increased by 4.4% from 2010 to 2016.

The population of Port Chester increased 1.6% from 2010 to 2016 to 29,417, the same percentage increase as New York state overall. Port Chester's median household income increased by 24.6% from 2000 to 2010 to $56,524 per household. Employment in Port Chester increased by 16.3% from 2000 to 2010 and then declined slightly from 2010 to 2016. The resulting percentage increase from 2000 to 2016 is 15.9%. This was a greater percent increase for employment than the 8.8% increase for Westchester County or the 11.04% 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	2016[1]	2000 to 2010	2010 to 2016
Greenwich CT	61,101	61,171	62,418	0.1%	2.0%
Fairfield Co. CT	882,567	916,829	941,618	3.9%	2.7%
State of Connecticut	3,405,565	3,574,097	3,588,570	4.9%	0.4%
Port Chester NY	27,867	28,967	29,417	3.9%	1.6%
Westchester County NY	923,459	949,113	969,229	2.8%	2.1%
State of New York	18,976,457	19,378,102	19,697,457	2.1%	1.6%

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	2000 to 2010
Greenwich CT	99,086	134,223	35.5%
Fairfield Co. CT	65,249	86,670	32.8%
State of Connecticut	53,935	71,755	33.0%
Port Chester NY	45,381	56,524	24.6%
Westchester County NY	63,582	86,226	35.6%
State of New York	43,393	60,741	40.0%

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 2016 income are unavailable.

Table 4: Area Employment

	Employment				
	Employed			Percent Change	
	2000	2010[1]	2016[1]	2000 to 2010	2010 to 2016
Greenwich CT	28,081	27,067	28,254	-3.6%	4.4%
Fairfield Co. CT	426,638	439,341	468,570	3.0%	6.7%
State of Connecticut	1,664,440	1,765,549	1,793,688	6.1%	1.6%
Port Chester NY	13,452	15,640	15,591	16.3%	-0.3%
Westchester County NY	432,600	451,799	470,856	4.4%	4.2%
State of New York	8,382,988	9,045,999	9,340,878	7.9%	3.3%

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	2016[1]	2000	2010	2016	2000 to 2010	2010 to 2016
Total Population	61,101	61,171	62,418	NA	NA	NA	0.1%	2.0%
Under 5 Years	4,294	3,721	4,284	7.0%	6.1%	6.9%	-13.3%	15.1%
5 Years thru 17 Years	11,250	12,617	11,588	18.4%	20.6%	18.6%	12.2%	-8.2%
65 Years and Over	9,716	10,068	10,320	15.9%	16.5%	16.5%	3.6%	2.5%
Black or African American	1,017	1,314	1,726	1.7%	2.1%	2.8%	29.2%	31.4%
American Indian and Alaska Native	52	84	116	0.1%	0.1%	0.2%	61.5%	38.1%
Asian	3,165	4,039	5,117	5.2%	6.6%	8.2%	27.6%	26.7%
Native Hawaiian and Other Pacific Islander	16	14	23	0.03%	0.02%	0.04%	-12.5%	64.3%
Hispanic or Latino (of any race)	3,846	5,964	7,521	6.3%	9.7%	12.0%	55.1%	26.1%
Individuals Below Poverty Level	2,436	NA	3,932	4.0%	NA	6.3%	NA	NA
Disabled	NA	NA	5,188	NA	NA	8.3%	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	2016[1]	2000	2010	2016	2000 to 2010	2010 to 2016
Total Population	27,867	28,967	29,417	NA	NA	NA	3.9%	1.6%
Under 5 Years	1,947	1,998	1,842	7.0%	6.9%	6.3%	2.6%	-7.8%
5 Years thru 17 Years	4,320	4,547	4,859	15.5%	15.7%	16.5%	5.3%	6.9%
65 Years and Over	3,603	3,082	3,252	12.9%	10.6%	11.1%	-14.5%	5.5%
Black or African American	1,949	1,876	1,796	7.0%	6.5%	6.1%	-3.7%	-4.3%
American Indian and Alaska Native	112	271	310	0.4%	0.9%	1.1%	142.0%	14.4%
Asian	573	596	486	2.1%	2.1%	1.7%	4.0%	18.5%
Native Hawaiian and Other Pacific Islander	11	11	13	0.04%	0.04%	0.04%	0.0%	18.2%
Hispanic or Latino (of any race)	12,884	17,193	18,429	46.2%	59.4%	62.6%	33.4%	7.2%
Individuals Below Poverty Level	3,591	NA	3,795	12.9%	NA	12.9%	NA	NA
Disabled	NA	NA	2,772	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 at 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 on 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 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 probability, 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 fiscal year (FY) 2018 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 20%.

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. Residential occupancy types applied in this study were developed by the USACE Institute for Water Resources (IWR), presented in Economic Guidance Memorandum (EGM) 04-01, Generic Depth-Damage Relationships for Residential Structures with Basements. These were designed in such a way as to have content damage be based on the full depreciated replacement values of the structures. The CSVR for all residences in the project area is therefore 100%.

Non-residential occupancy types applied in this study were developed utilizing expert elicitation during a joint effort of IWR and FEMA, as presented in the Non-Residential Flood Depth-Damage Functions Derived from Expert Elicitation draft report, first completed in 2009 and revised in 2013. All structure occupancy types also have corresponding damage functions for contents. 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.

Non-residential occupancy types applied in this study have CSVRs ranging from 54.4% to 169.7%. CSVRs applied to non-residential occupancies were developed by the New Orleans district. These were based on the on-site interviews conducted as part of the Jefferson-Orleans, Donaldsonville to the Gulf, and Morganza to the Gulf evaluations. These interviews were conducted with the owners of a sample of structures from each of the eight non-residential content categories from each of the three evaluation areas. Thus, a total of 210 non-residential structures were used to determine the CSVRs for each of the non-residential categories. Since only a limited number of property owners participated in the field surveys and the participants were not randomly selected, statistical bootstrapping was performed to address the potential sampling error in estimating the mean and standard deviation of the CSVR values. Statistical bootstrapping is a method that uses re-sampling with replacement to improve the estimate of a population statistic when the sample size is insufficient for straightforward statistical inference. The bootstrapping method has the effect of increasing the sample size. Thus, bootstrapping provides a way to account for the distortions caused by the specific sample that may not be fully representative of the population.

Automobile occupancy types were also developed by IWR and were presented in EGM 09-04, Generic Depth-Damage Relationships for 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

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 50 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 of 0.5' throughout the function.

6.4 Flood Damage Estimates

Physical damages within the 0.2%-chance floodplain were classified as residential, commercial, public facilities and damage to automobiles. 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 nearly $163 million within the 0.2%-chance floodplain in FY 2018 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 (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	30	89	116	148	173	205
Commercial	0	0	1	1	2	2	4	5
Public	0	0	0	1	1	1	1	1
Total	5	13	31	91	119	151	178	211
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	9	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	10	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	2	2	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	2	2	2	2
Study Totals								
Residential	5	14	31	94	126	171	204	253
Commercial	0	0	2	2	3	3	6	9
Public	0	0	0	1	1	1	1	1
Study Total	5	14	33	97	130	175	211	263

Table 8: Without Project Condition Value of Development by Event

(Based on Beginning Damage; FY18 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	5,571.7	14,371.8	45,391.7	59,296.7	77,729.8	90,938.4	106,793.7
Commercial	0.0	0.0	18,341.1	18,341.1	22,229.5	22,229.5	23,251.2	23,438.8
Public	0.0	0.0	0.0	51.6	51.6	51.6	51.6	51.6
Total	2,379.5	5,571.7	32,712.9	63,784.4	81,577.9	100,011.0	114,241.2	130,284.2
Reach 4								
Residential	0.0	333.5	333.5	711.8	1,372.0	4,051.2	6,248.8	11,755.2
Commercial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	855.8
Public	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	0.0	0.0	0.0	711.8	1,372.0	4,051.2	6,248.8	12,610.9
Reach 5								
Residential	0.0	0.0	0.0	0.0	387.2	953.7	1,529.7	1,529.7
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	387.24	953.68	1529.68	1529.68
Reach 6								
Residential	0.0	0.0	0.0	659.4	659.4	659.4	1,119.2	1,850.4
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	659.4	659.4	659.4	1,119.2	1,850.4

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	4,250.7	4,250.7	4,250.7	4,250.7	4,250.7	4,250.7
Public	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	0.0	0.0	4,250.7	4,250.7	4,250.7	4,250.7	4,250.7	4,250.7
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	1,240.1	1,637.2	6,028.8	6,341.9	8,772.5
Commercial	0.0	0.0	0.0	0.0	0.0	0.0	1,397.3	1,708.2
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	1,637.2	6,028.8	7,739.2	10,480.7

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	899.5	1,955.8	1,955.8	1,955.8	1,955.8
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	899.5	1,955.8	1,955.8	1,955.8	1,955.8
Study Totals								
Residential	2,379.5	5,905.2	14,705.3	48,902.5	65,308.4	91,378.7	108,133.7	132,657.3
Commercial	0.0	0.0	22,591.7	22,591.7	26,480.2	26,480.2	28,899.2	30,253.4
Public	0.0	0.0	0.0	51.6	51.6	51.6	51.6	51.6
Study Total	2,379.5	5,905.2	37,297.0	71,545.9	91,840.3	117,910.6	137,084.6	162,962.4

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 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 2016 64.5% of Greenwich occupied housing units had two or more vehicles and that 43.6% 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 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. An August 2017 Bloomberg article titled Your Car is now Worth Less Than You Think states that "the average used car lost 17 percent of its value in the past 12 months, dropping from $18,400 to $15,300 …". The value of $15,300 was therefore assumed for all automobiles in the Byram River FDA model.

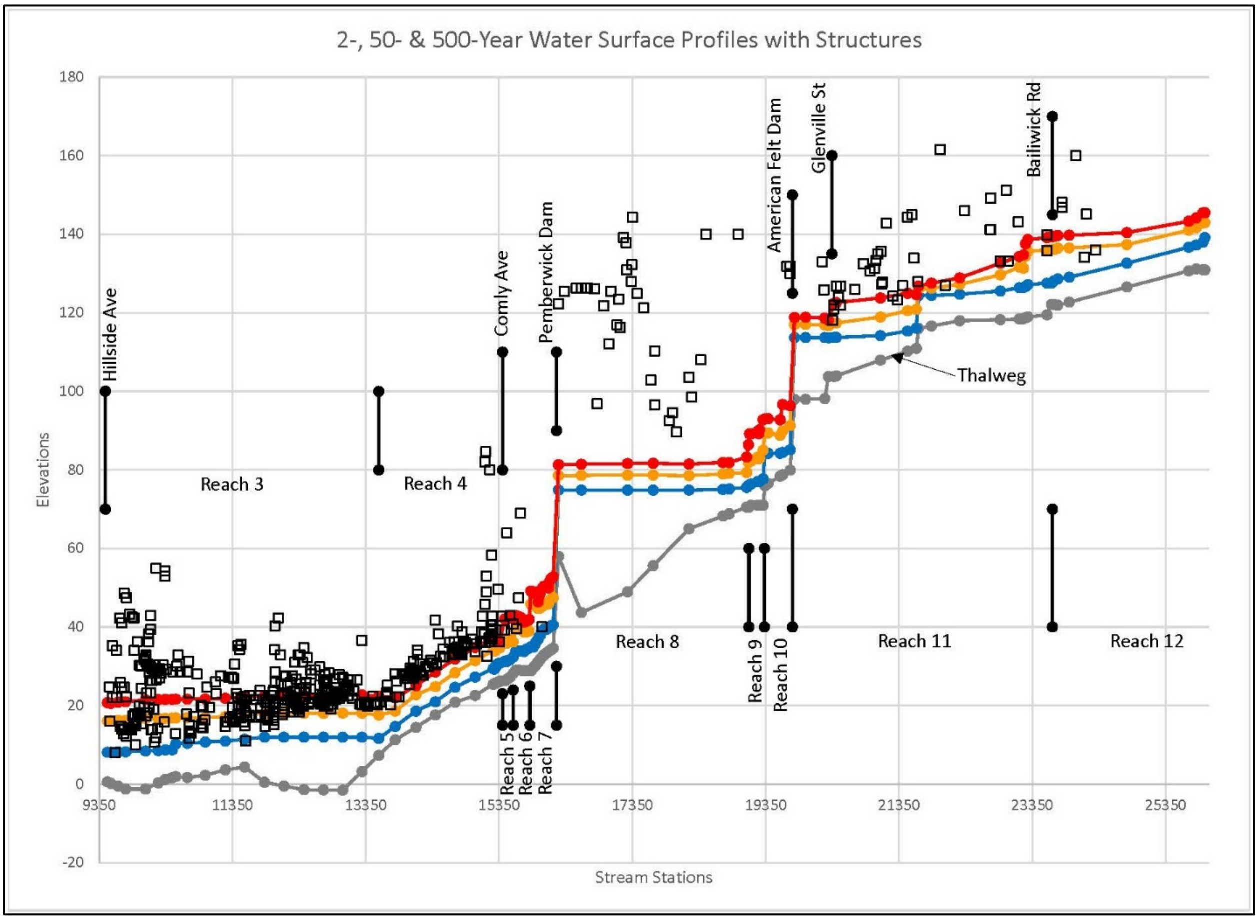

Figure 2: Representation of Structures with Select Existing Condition Water Surface Profiles

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 over $35 million in total damage in the project area in FY 2018 price levels; almost 87% of this would occur in Reach 3. For the project area overall, about 50% of the damage caused by a 1%-chance flood is to commercial structures, 43% is to residential and 7% 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 Flood Event

(FY18 Price Level; in $1,000s)

Reach/Category	Flood Event by Chance of Occurrence							
	50%	20%	10%	4%	2%	1%	0.5%	0.2%
Reach 3								
Residential	119.4	414.8	1,221.2	4,605.1	8,376.2	13,219.2	18,107.9	22,843.3
Commercial	41.0	439.8	3,374.3	8,373.6	11,849.2	14,590.7	20,151.2	24,558.2
Public	0.2	0.7	1.7	7.0	12.6	19.8	26.9	32.7
Autos	22.7	82.2	250.7	949.2	1,737.5	2,674.7	3,619.0	4,560.3
Total	183.3	937.4	4,848.0	13,934.8	21,975.4	30,504.3	41,905.0	51,994.5
Reach 4								
Residential	0.3	8.5	16.0	66.2	217.0	431.4	910.7	1,784.8
Commercial	0.0	0.2	0.4	1.6	5.3	10.6	22.4	43.9
Public	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Autos	0.1	2.1	3.8	15.9	52.1	103.6	218.6	428.4
Total	0.1	10.8	20.2	83.7	274.4	545.6	1,151.7	2,257.1
Reach 5								
Residential	0.2	0.4	0.4	1.7	37.4	164.7	291.9	378.7
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	0.1	0.2	4.3	18.7	33.2	43.1
Total	0.3	0.4	0.5	1.9	41.6	183.5	325.1	421.8
Reach 6								
Residential	5.8	9.3	10.4	76.4	106.1	169.1	225.3	284.7
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	0.5	0.8	0.9	6.6	9.2	14.6	19.4	24.6
Total	6.3	10.1	11.3	83.0	115.3	183.7	244.7	309.3

Table 9: Without Project Condition 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 7								
Residential	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Commercial	39.9	127.8	744.6	1,456.5	2,001.5	2,549.4	3,030.9	4,747.7
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
Total	39.9	127.8	744.6	1,456.5	2,001.5	2,549.4	3,030.9	4,747.7
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
Autos	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
Autos	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
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 Flood Event (Cont.)

	Flood Event by Chance of Occurrence							
Reach/Category	**50%**	**20%**	**10%**	**4%**	**2%**	**1%**	**0.5%**	**0.2%**
Reach 11								
Residential	2.4	3.8	34.7	232.3	498.7	846.7	1,249.5	3,165.9
Commercial	0.5	0.8	7.3	48.6	104.4	177.2	261.5	662.6
Public	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Autos	0.2	0.3	2.9	19.5	41.9	71.2	105.0	266.0
Total	3.1	5.0	44.9	300.4	644.9	1,095.1	1,616.0	4,094.5
Reach 12								
Residential	13.9	22.3	113.6	199.1	276.0	352.9	392.6	690.1
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	0.5	0.8	4.0	7.1	9.8	12.5	13.9	24.4
Total	14.4	23.1	117.6	206.2	285.7	365.4	406.5	714.5
Study Totals								
Residential	142.0	459.2	1,396.3	5,180.8	9,511.3	15,184.1	21,177.8	29,147.4
Commercial	81.5	568.5	4,126.6	9,880.3	13,960.3	17,327.9	23,466.0	30,012.3
Public	0.2	0.7	1.7	7.0	12.6	19.8	26.9	32.7
Autos	24.0	86.2	262.5	998.4	1,854.6	2,895.2	4,009.1	5,346.9
Study Total	247.7	1,114.6	5,787.1	16,066.5	25,338.9	35,426.9	48,679.7	64,539.3

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 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 86% of the without-project EAD occurs in Reach 3.

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

(FY18 Price Level; in $1,000s)

	Category / EAD				
Reach	**Residential**	**Commercial**	**Public**	**Autos**	**Total**
3	691	1,010	1	140	1,842
4	19	0	0	5	24
5	4	0	0	0	4
6	8	0	0	1	9
7	0	193	0	0	193
8	0	0	0	0	0
9	0	0	0	0	0
10	0	0	0	0	0
11	35	7	0	3	45
12	25	0	0	1	26
Totals	782	1,210	1	150	2,143

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. A list of the alternatives evaluated with basic descriptions is presented in Table 11. Detailed descriptions of these plans and the formulation process are provided in the Main Report.

Table 11: Evaluated 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
3	Levees, floodwalls & channel modifications (update of 1977 plan)
4	Smaller levees & floodwalls with channel widening
5	Replacement of 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. 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 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 measures, which is Alternative 5. There are two bridges because the 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 in 25 years if a Federal project is not implemented that requires replacement of the bridges. This is the without project condition in regards to bridge replacement. The benefit is the extension of the serviceable life of the bridges and the subsequent postponement of the bridge replacements by 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. Table 12 presents the calculation for the Advanced Bridge Replacement benefits.

Table 12: Advanced Bridge Replacement Benefits

(FY18 Price Level; in $1,000s)

Description	Values
Cost of new bridge	$24,302
Life of new bridge (years)	50
Remaining useful life of existing bridge (years)	25
Extension of bridge life (years)	25
Annual O&M of existing bridge	$25
Annual O&M of new bridge	$25
Interest rate	2.75%
Capital recovery factor	0.0370
Annual cost of new bridge	$900
Present worth of annuity factor for extended life	17.9083
Benefits credited to bridge life extension	$16,117
Single payment present worth for remaining useful life of existing bridge	0.5075
Present worth in year 1 of bridge extension	$8,180
Annual O&M savings	$0
Present worth of annuity factor for remaing useful life of existing bridge	17.9083
Present worth in year 1 of O&M savings	$0
Present worth of total credit	$8,180
Average annual benefits	$303

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 2018 Federal discount rate of 2.75%. The credit is a constant annuity in years 26-50 of the period of analysis. The present worth of the credit is brought to year 25 by multiplying the amount of the annual annuity by the present worth of an annuity factor for 25 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 25 years. If there is a reduction in the annual Operation and Maintenance (O&M) costs with the new bridges, then there would be benefits due to that reduction. However, annual O&M is not estimated to change in this analysis.

The project costs available for use in the Advanced Bridge Replacement calculation included costs with 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 a way to minimize flow constrictions in the future even in the absence of a Federal project.

8.3 Plan Evaluation Results

A summary of economic results of the screening of alternatives leading to the recommended National Economic Development (NED) plan is presented in Table 13. This summary includes estimates of expected annual benefits, first and annualized costs, computed at the FY 2018 Federal discount rate, 2.75%, for 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 tentatively selected NED plan is therefore Alternative 5, replacements of U.S. Route 1 bridges.

It should be noted that there are several benefit categories that were not included in the scope of this analysis. These include reduction in emergency response costs and traffic delays and diversions, damage to outside property and landscaping, cleanup, damage to roads, bridges, utilities (e.g. power lines, gas lines and meters, water lines) and damage to other infrastructure. The presented benefits are therefore considered to be conservative.

Table 13: Economic Summary of Evaluated Plans

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

Alt.	Expected Annual Flood Damage		Annual Benefits	Total First Cost	Total Annual Cost	Net Benefits	BCR
	Without Project	With Project					
2a	$2,143	$1,709	$434	$18,444	$701	($267)	0.62
2b	$2,143	$1,584	$559	$29,745	$1,131	($572)	0.49
2c	$2,143	$806	$1,337	$36,962	$1,405	($68)	0.95
2d	$2,143	$785	$1,358	$42,605	$1,620	($262)	0.84
3	$2,143	$577	$1,566	$90,327	$3,939	($2,373)	0.40
4*	$2,143	$369	$2,069	$112,479	$4,905	($2,836)	0.42
5*	$2,143	$1,375	$1,071	$24,302	$949	$122	1.13
5a*	$2,143	$1,133	$1,313	$42,877	$1,715	($402)	0.77
5b*	$2,143	$1,112	$1,333	$46,749	$1,862	($529)	0.72
5c*	$2,143	$1,098	$1,347	$52,502	$2,081	($734)	0.65
5d*	$2,143	$1,083	$1,363	$58,319	$2,302	($939)	0.59

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

FY 2018 price level in $1,000s; 2.75% Federal Discount Rate

9. Tentatively Selected Plan

Alternative 5 is the Tentatively Selected Plan (TSP) because it is the plan which reasonably maximizes net benefits. It is the replacement of both 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 TSP 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 TSP. The TSP 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 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 4.65’. The 40%-chance flood event has a 3.25’ reduction and the 50%-chance event has a 0.15’ reduction at the same location. Figure 3 is a map depicting the 1%-chance inundation both without and with the TSP. The risk of flooding and consequent damage are reduced for the majority of structures in this area and flooding is eliminated by the TSP for 41 structures, or 23%, based on flooding at beginning damage elevations. Flooding on first floors of structures in the without-project condition is eliminated for 45 structures, or 66%, by the TSP. Table 14 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 TSP are shown by category and reach for these flood frequencies in Table 15. Expected annual damage with the TSP is presented by reach and category in Table 16. The TSP reduces expected annual flood damage by 36%. The with-project, residual, EAD is $1,375,000.

A temporary impact of the TSP is to vehicular traffic during construction. Construction will only occur during the warmer months of 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 Route 1 bridges altogether. The impact to traffic will accessed during TSP optimization.

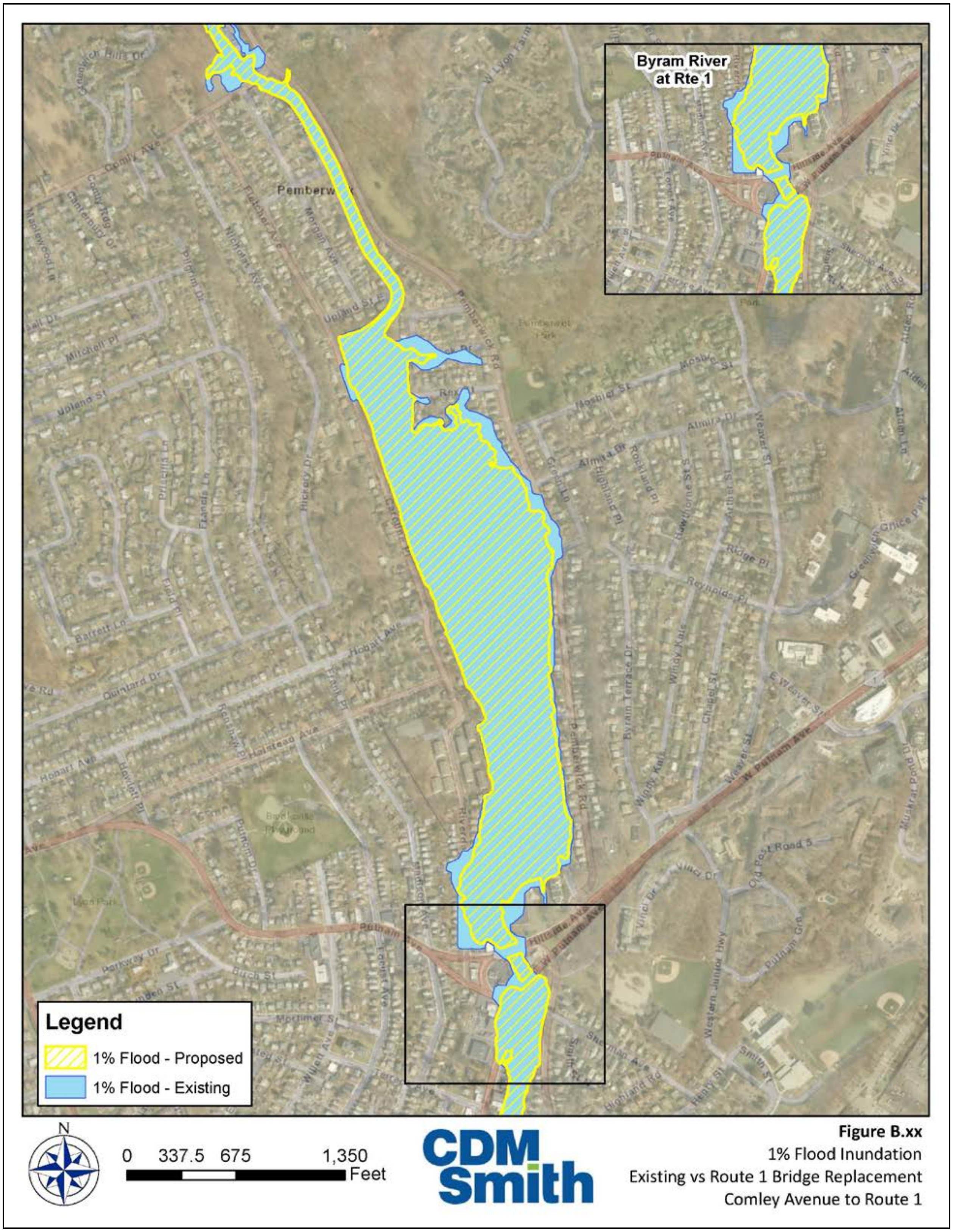

Figure 3: 1%-Chance Flood Inundation Areas for Without- and With-Project Conditions

Table 14: Tentatively Selected Plan Number of Structures Flooded

(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	56	86	108	133	154
Commercial	0	0	1	1	1	1	1	3
Public	0	0	0	0	1	1	1	1
Total	5	13	29	57	88	110	135	158
Reach 4								
Residential	0	1	1	2	4	10	14	26
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	27
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

Table 14: Tentatively Selected Plan Number of Structures Flooded (Cont.)

Reach/Category	Flood Event by Chance of Occurrence 50%	20%	10%	4%	2%	1%	0.5%	0.2%
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	9	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	10	14
Reach 12								
Residential	0	0	0	1	2	2	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	2	2	2	2

Table 14: Tentatively Selected Plan Number of Structures Flooded (Cont.)

	Flood Event by Chance of Occurrence							
Reach/Category	**50%**	**20%**	**10%**	**4%**	**2%**	**1%**	**0.5%**	**0.2%**
Study Totals								
Residential	5	14	29	61	96	131	163	200
Commercial	0	0	2	2	2	2	3	7
Public	0	0	0	0	1	1	1	1
Study Total	5	14	31	63	99	134	167	208

Table 15: Tentatively Selected Plan Flood Damage by Reach, Category and Event

(FY18 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	113.4	364.5	881.8	2,370.9	4,217.8	6,695.3	10,066.3	13,967.0
Commercial	32.5	113.6	1,885.1	4,442.1	6,260.8	8,108.0	10,188.6	15,998.4
Public	0.1	0.4	0.7	1.9	3.6	5.9	8.4	10.8
Autos	22.7	76.3	210.2	564.1	1,005.5	1,596.5	2,388.8	3,303.9
Total	168.7	554.8	2,977.8	7,379.0	11,487.6	16,405.7	22,652.1	33,280.1
Reach 4								
Residentmial	0.3	8.4	15.7	63.3	192.8	373.2	777.9	1,606.4
Commercial	0.0	0.2	0.4	1.6	5.3	10.2	21.3	43.9
Public	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Autos	0.1	2.1	3.8	15.9	50.1	97.0	202.2	417.6
Total	0.4	10.7	19.9	80.9	248.2	480.4	1,001.4	2,067.8

Table 15: Tentatively Selected 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 5								
Residential	0.2	0.3	0.4	1.7	37.4	164.7	291.9	378.7
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	0.1	0.2	4.3	18.7	33.2	43.1
Total	0.3	0.3	0.5	1.9	41.6	183.5	325.1	421.8
Reach 6								
Residential	5.8	9.3	10.4	76.4	106.1	169.1	225.3	284.7
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	0.5	0.8	0.9	6.6	9.2	14.6	19.4	24.6
Total	6.3	10.1	11.3	83.0	115.3	183.7	244.7	309.3
Reach 7								
Residential	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Commercial	39.9	127.8	744.6	1,456.5	2,001.5	2,549.4	3,030.9	4,747.7
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
Total	39.9	127.8	744.6	1,456.5	2,001.5	2,549.4	3,030.9	4,747.7
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
Autos	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 15: Tentatively Selected 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 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
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
Total	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Reach 11								
Residential	2.4	3.8	34.7	232.3	498.7	846.7	1,249.5	3,165.9
Commercial	0.5	0.8	7.3	48.6	104.4	177.2	261.5	662.6
Public	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Autos	0.2	0.3	2.9	19.5	41.9	71.2	105.0	266.0
Total	3.1	5.0	44.9	300.4	644.9	1,095.1	1,616.0	4,094.5
Reach 12								
Residential	13.9	22.3	113.6	199.1	276.0	352.9	392.6	690.1
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	0.5	0.8	4.0	7.1	9.8	12.5	13.9	24.4
Total	14.4	23.1	117.6	206.2	285.7	365.4	406.5	714.5

Table 15: Tentatively Selected 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%**
Study Totals								
Residential	136.1	408.6	1,056.6	2,943.7	5,328.7	8,602.0	13,003.5	20,092.7
Commercial	72.9	242.4	2,637.3	5,948.8	8,371.9	10,844.8	13,502.2	21,452.6
Public	0.1	0.4	0.7	1.9	3.6	5.9	8.4	10.8
Autos	24.0	80.3	222.0	613.3	1,120.7	1,810.5	2,762.5	4,079.6
Study Total	233.1	731.6	3,916.5	9,507.7	14,824.8	21,263.1	29,276.6	45,635.6

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

Table 16: Tentatively Selected Plan Expected Annual Damage by Reach and Category

(FY18 Price Level; in $1,000s)

	Category / EAD				
Reach	**Residential**	**Commercial**	**Public**	**Autos**	**Total**
3	424	551	0	101	1,076
4	17	0	0	4	22
5	4	0	0	0	4
6	8	0	0	1	9
7	0	193	0	0	193
8	0	0	0	0	0
9	0	0	0	0	0
10	0	0	0	0	0
11	35	7	0	3	45
12	25	0	0	1	26
Totals	513	751	0	110	1,375

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

9.2 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 $771,000, a .50 probability that they exceed $994,000 and a .25 probability they exceed $1,284,000. Table 17 presents the distribution of expected annual benefits for Alternative 5, the Tentatively Selected Plan, along with the distribution of net benefits and benefit-to-cost ratios.

Table 17: Economic Summary of Tentatively Selected Plan with Uncertainty

(FY18 Price Level; in $1,000s)

	Annual Benefits	Annual Cost	Net Benefits	BCR	Probability Distribution Quartiles		
					0.75	0.5	0.25
Mean	$1,071	$949	$122	1.13			
EAB					$771	$994	$1,284
ENB					($178)	$45	$335
BCR					0.81	1.05	1.35

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 FY18 Federal discount rate of 2.75%. The 0.50 quartile is the median estimate; it differs from the mean when the probability distribution is asymmetrical. EABs include $303k in Advance Bridge Replacement benefits.