TAYLOR ENGINEERING, INC.

Task 3.2 Technical Memorandum: Expected Annual Damage and Benefit Cost Calculations

C-8 and C-9 Watersheds Flood Protection Level of Service Adaptation Planning and Mitigation Projects Study

Deliverable 3.2
CONTRACT 4600004085
Work Order 05

South Florida Water Management District
3301 Gun Club Road
West Palm Beach, Florida 33406

Revised Submitted 4/14/2023
Draft

14499 N. Dale Mabry Hwy, Suite 290,
Tampa, Florida 33618
813-963-6469 | www.taylorengineering.com

Task 3.2 Technical Memorandum
Expected Annual Damage and Benefit Cost Calculations

C-8 and C-9 Watersheds Flood Protection Level of Service Adaptation Planning and Mitigation Projects Study

Deliverable 3.2
CONTRACT 4600004085
Work Order 05

Draft

South Florida Water Management District
3301 Gun Club Road
West Palm Beach, Florida 33406

by

Taylor Engineering, Inc.
10199 Southside Blvd, Suite 310
Jacksonville, FL 32256

April 14, 2023

Taylor Project Number: C2021-033

TABLE OF CONTENTS

List of Figures

List of Tables

1.0 INTRODUCTION

The South Florida Water Management District (SFWMD or District) is conducting a system-wide review of the regional water management infrastructure to determine which mitigation projects would maintain or improve the current flood protection level of service (FPLOS). The FPLOS Phase 1 Study describes the level of protection provided by the water management facilities within a watershed considering sea level rise (SLR), future development, and known water management issues in each watershed. This study is part of the FPLOS Phase 2 for the C-8 and C-9 basins. The District's objective of the Phase 2 studies is to identify mitigation activities that will reduce flooding impacts and can show demonstrable reductions in economic consequences. This technical memorandum is Deliverable 3.2 of Task 3 Flood Damage Assessment.

This memorandum details the methodology of flood damage calculations in the SFWMD Flood Impact Assessment Tool (SFWMD-FIAT) to evaluate expected annual damages (EAD) and the benefit-cost ratio (BCR) for the various mitigation strategies.

2.0 GENERAL ECONOMIC DAMAGES APPROACH AND THE SFWMD-FIAT

The general approach to calculate economic damages of flooding requires an understanding of the risk and knowledge of the infrastructure (buildings, roads, etc.) exposed to the risk. The Hazard Data in this case is flooding. The infrastructure database is called Exposure Data and contains data on building type, finished floor elevation, and road elevations. Once those are established, applying relationships between the risk (depth of flooding) and the damage to a building or road (called Depth Damage Functions, or DDFs) allows the calculation of the economic damage. Standard practice is to calculate the economic damage over a range of flooding events, in this case 5-, 10-, 25-, and 100-yr, and integrate the results to determine an estimated annual damage, or EAD. This allows water resource managers and community officials to understand the estimated value of damages predicted yearly. Of course, in reality, flooding is episodic, and some years will have extensive flood damage consequences and while other years will have little. It is important to remember this is a probabilistic average of damages.

Figure 2.1 illustrates the process and data used to calculate the EADs.

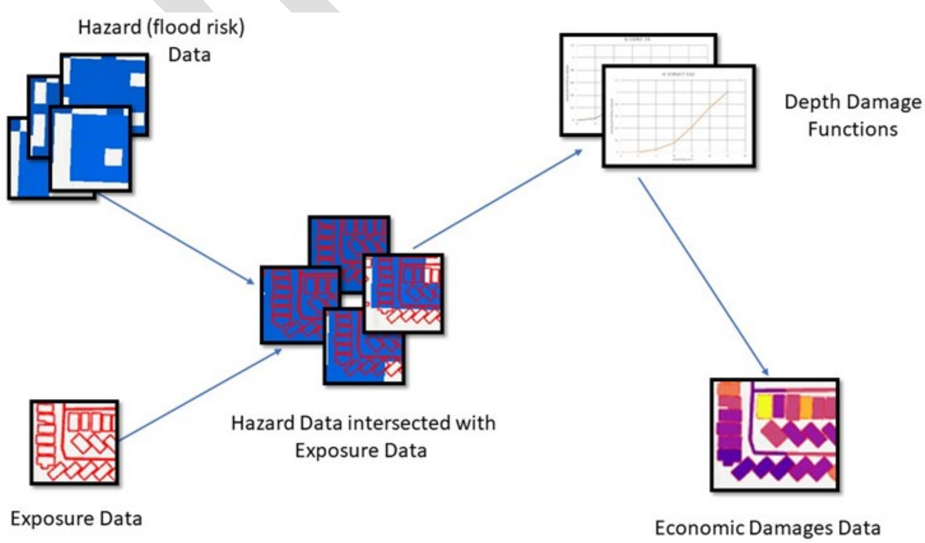


Figure 2.1: Calculation of Expected Annual Damages

Designed specifically for the District, the SFWMD-FIAT provides a user-friendly platform to expeditiously estimate economic damages from flooding due to rainfall runoff and sea level rise to support their FPLOS and resiliency efforts (Deltares). The tool allows for multiple scenarios to run simultaneously and allows for easy comparison between mitigation scenarios. SFWMD-FIAT uses three datasets: depth damage functions (DDF), exposure data, and flood (or water depth) hazard data to calculate economic damages.

2.1.1 Depth Damage Functions (DDFs)

Because this study is one of the first applications of the District's FIAT tool, the team evaluated external sources for DDFs and compared them to the FIAT tool. Sources included Federal Emergency Management Agency (FEMA) Hazard US (HAZUS) Inventory Technical Manual, United States Army Corps of Engineers' North Atlantic Coast Comprehensive Study (USACE NACCS) Physical Depth Damage Function Summary Report, and the South Atlantic Coastal Study (USACE SACS) Tier 2 Economic Risk Assessment.

Depth Damage Functions are typically decided by committees of experts who assess many building types and the hazard exposure. These experts develop DDFs for many building types and allow practitioners a range of functions to choose from. Often, however, suitable DDFs have not been developed for a specific exposure data class – such as roads or water control structures.

The District developed DDFs for roads and water control structures specifically for south Florida. The District compiled the DDFs from multiple sources including the Institute of Water Resources (USACE-IWR), FEMA expert elicitation curves, and existing HAZUS inventory, supplying the SFWMD-FIAT a comprehensive collection of functions.

DDFs apply the depth of flood water at a structure's location to estimate economic damage. A key element of that calculation is the finished floor elevation. The exposure database, developed by the SFWMD, within the FIAT tool for this project estimates the finished floor elevation by adding one foot to the mean ground elevation of the structure.

Before finalizing EAD estimates for this study, ESP Associates, Inc. conducted an audit to compare annualized loss estimate results from SFWMD-FIAT tool with annualized loss estimates using their own in-house methods (ESP, 2022). Their method of damage calculation calculates EADs by using the Average Annualized Loss (AAL) calculation model from the Hazus Flood Technical Manual (FEMA, 2022). To replicate SFWMD-FIAT calculations, damage values were calculated using a sample of residential buildings from the District's exposure database and DDFs provided by the District. The ESP audit results conclude that the calculated EAD from the SFWMD-FIAT tool corresponds closely with HAZUS AAL results.

2.1.2 Exposure Data

In order to build sufficient exposure data, the District gathered various GIS data and other spatial information from stakeholders and partners throughout the study area. Once collected, District staff used a suite of GIS models with ESRI's Model Builder tool to combine the data into one exposure database. The exposure database consists of two parts: a shapefile representing the spatial locations of structures and roads, and a CSV file with tabular attributes for each structure or road. The collected exposure data aids in identifying the spatial location as well as the maximum damage potential of individual structures or road sections within the interested area to evaluate damage using hazard data and damage functions

(Deltares). **Table 2.1** provides the sources for the different layers compiled for the exposure database. The Delft-FIAT interface overlays the various exposure data and hazard data to establish inundation depths at each structure or road section. The DDFs provide calculations to evaluate economic damage from flood depths.

Table 2.1 Layers Compiled for SFWMD-FIAT

Category	Source
Street Data - Line Data	NavTeq/HERE
County Boundaries - Polygon Data	Navteq/HERE
Topo-Bathymetric - Raster	SFWMD Enterprise
LandUse data – Polygon Data	SFWMD Enterprise
Parcels – Polygon Data	SFWMD Enterprise
Census Blocks and Tracts – Polygon Data	US CENSUS Bureau
2018 Social Vulnerability Index	Centers for Disease Control (CDC)
Building Footprints – Polygon Data	Miami-Dade and Broward Counties

2.1.3 Hazard (flood risk) Data

The FIAT tool can use two types of hazard data– flood depth and water surface elevation (WSEL) data. These data are typically provided as model data output in raster format. This study applied the flood depth raster model results as input for the hazard data.

An in-depth discussion of the hydrology and hydraulics applied in the groundwater and surface water integrated model is presented in the FPLOS Phase I study and in Task 2 of this FPLOS Phase 2 study. This detailed model generated the hazard data applied in this economic damage assessment. The modeling applied three forcing functions of note: rainfall, storm surge, and, for future conditions, sea level rise. The modeling focused on four storm events: the 5-, 10-, 25-, and 100-yr return periods.

Important flood risk considerations for the FPLOS studies are SLR projections. The SLR projections used in the analysis of this project are the Southeast Florida Regional Climate Change Compact's (SEFLRC) Unified Sea Level Rise Projection (2019), which has the following characteristics:

- Estimates future local SLR using the Key West NOAA Tide Gauge water level trends, and
- Recommends using one of the following SLR scenarios for estimating flood risk:
    - For non-critical, low risk projects with less than a 50-year design life, use the Intergovernmental Panel on Climate Change Fifth Assessment Report 2013 (IPCC AR5) Median curve, or
    - For non-critical infrastructure with design life estimated to end prior to or after 2070, use the NOAA 2017 Intermediate-High curve, or
    - For critical high-risk infrastructure with design life ending after 2070, use the NOAA 2017 High SLR curve.

For the mitigation projects evaluated in this study, it is recommended to use the NOAA 2017 Intermediate-High SLR projection. This is the SLR projection favored by the FL Department of Environmental Protection for its state-funded studies, such as the Sea Level Impact Projection (SLIP) Tool and vulnerability assessments. Additionally, this scenario is recommended because the District has adopted the SEFLRC Unified SLR Projection, of which this SLR curve is the moderate of the three, as noted above.

A few disclaimers are needed for using this SLR projection, however. These unified projections are slightly outdated since both IPCC and NOAA updated their SLR projections in 2022. The updated SLR projections for both agencies tend to be lower in the near term as there is higher confidence in short term SLR not being affected by ice sheet dynamics. Another note is the use of the NOAA tide gage in Key West rather than the closer Virginia Key gage for localizing the SLR trend. The differences between these two gages are minor, as both the Key West and Virginia Key gages show similar MSL datums and sea level rise trends. Virginia Key's local SLR is estimated to be only one inch lower in 2100 compared to Key West. A final note is that the SEFLRC projections use a five-year average when moving the datum to the year 2000 rather than a nineteen-year moving average, as recommended by NOAA due to the 18.6-year lunar cycle. Both a timeframe longer than a five-year average, as well as a moving average instead of a basic average, provides a more precise, continually updated MSL at which to start the projections.

For this Phase 2 FPLOS study, a separate task, Task 2, produced 32 hazard datasets. The team evaluated the following mitigation scenarios' performance at current sea level as well as three future sea levels, SLR1, SLR2, SLR3, adding one, two, and three feet of SLR respectively to the current sea level (Taylor Engineering, 2022). The "Current Sea Level" is a number based on the assumed tidal boundary condition. This model applied 2017 data at the boundary conditions at S28 and S29. The mitigation strategies assessed include the following:

- M0: Current Conditions, no change to existing flood protection infrastructure or regulations; as well as no change in mitigation improvements within the basins.
- M1: Local mitigation strategies applied within the secondary and tertiary flood control systems
- M2: Regional mitigation strategies implemented to the primary flood control system; uses distributed storage, as well as hardens and elevates tidal structures to provide flood relief within the basin during peak runoff and to discharge to tide during flood conditions associated with SLR.
  - M2A: Addresses near term SLR; 1550 cubic feet per second (CFS) pump implemented
  - M2B: Addressed far term SLR; raises banks and drainage improvements to accommodate raised banks; implements a 2550 CFS pump
  - M2C: Raises and widens canal banks to eliminate bank exceedance and improve conveyance; and internal drainage improvements to accommodate the bank changes; accounts for a 3550 CFS pump
- M3: Land-use mitigation strategies applied across the basins, i.e., seawall/floodwall height changes, administrative and regulatory changes for building codes; changes implemented across both local and regional scales
  - M3(1): Raises all structure and road elevations by one foot
  - M3(2): Raises all structure and road elevations by two feet
  - M3(3): Raising all structure and road elevations by three feet

To complete the scenario runs for M3(1), M3(2), and M3(3); the team added one, two, and three feet of elevation to the ground elevation column in the preliminary exposure datasets. By saving these new files in the exposure folder in the tool's database; they were available as new exposure datasets.

3.0 TOOL IMPLEMENTATION

While setting up the tool, users have two options for how they would like to run their hazard scenarios. The event mode focuses on a specific flood event and the economic damages caused; whereas the risk mode calculates the damages from multiple return periods specified by the user and produces expected annual damages (EAD) (Deltares) (**Figure** 3.1).

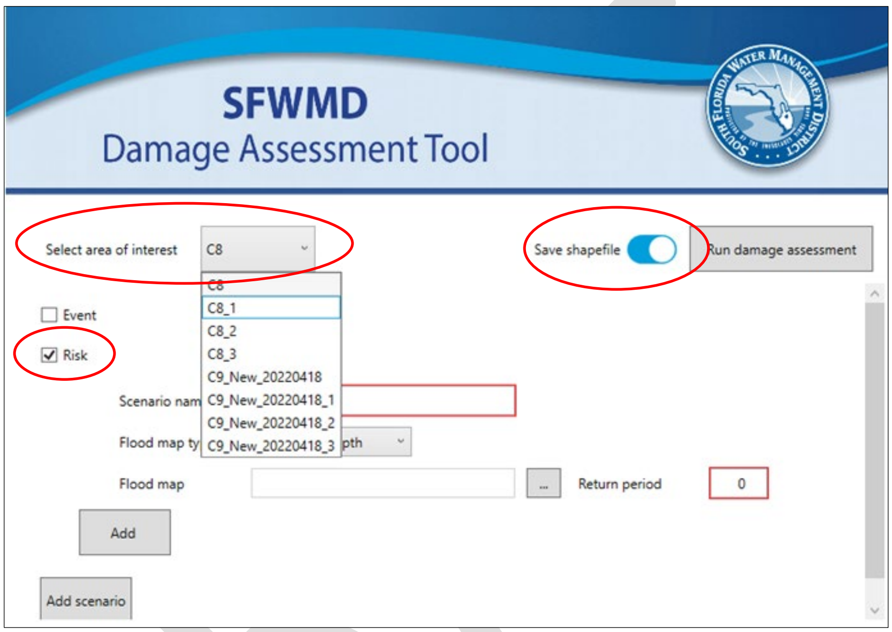


Figure 3.1 SFWMD-FIAT Setup
(The three red circles highlight the initial parameters for the tool.)

Using similar naming conventions throughout all scenarios, the 32 model results were organized for input as flood depth rasters with hazard data from 5-, 10-, 25-, and 100-year storm events as outlined in the scope (**Figure 3.2**).

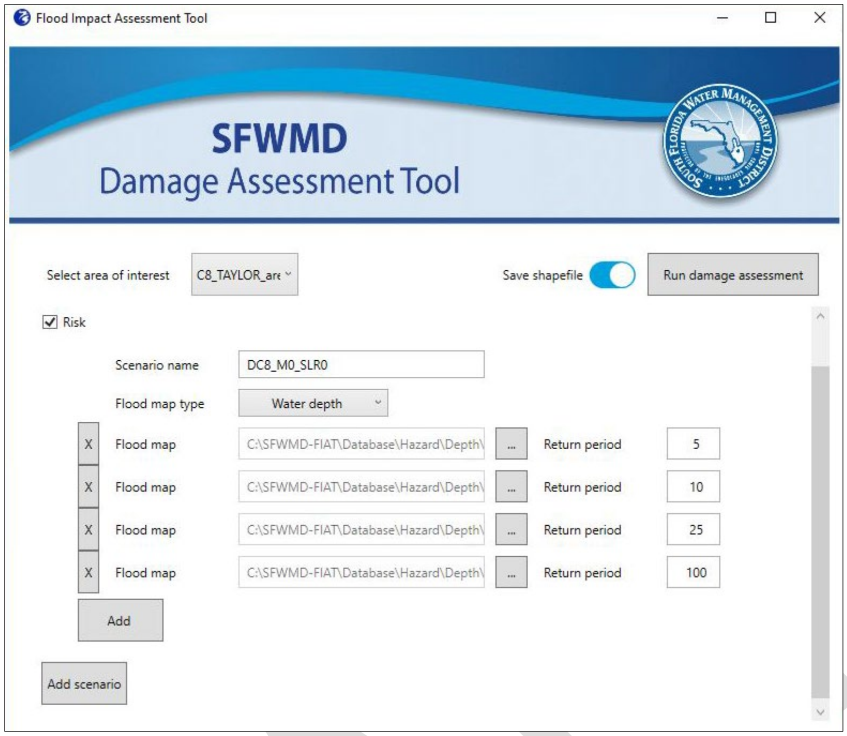


Figure 3.2 An Example Scenario Configuration

The interface of SFWMD-FIAT made it possible for the team to run multiple scenarios in the same basin, at the same time, running the four SLR scenarios for a mitigation strategy in the same run.

Once a scenario ran, the tool created a folder containing four different files:

1. Configuration CSV: Details the user's chosen inputs
2. Aggregated CSV: Aggregated damage costs via various categories, including land use, subbasins, and tax use
3. Social Vulnerability Index (SVI) Piechart: Visualizes the damage allocation between different social vulnerability classes
4. Shapefile: (Optional) A polygon shapefile that details the damage calculations for each structure or road within the area of interest.

The configuration CSV provides a record for all the input information. This spreadsheet provides the user with a convenient document to double-check their inputs to ensure accuracy.

The aggregated data allows the user to have a quick overview of summarized data. The global overview tab displays a total EAD for the scenario; while the global details separate structure and road damage calculations not only by EAD, but by the different return periods as well. The other tabs provide information about specific spatial classifications of the data.

The optional shapefile of economic losses provides damage and spatial location attributes for each structure and road. This option provides an added level of analysis of the different damage functions as well as the SVI (Deltares).

Table 3.1 identifies how structures are classified within the exposure databases. The land-use classes provide a detailed description of the HAZUS damage code that defines each classification within the exposure database. To assist in summarizing damage totals, the maximum damage/ft^2 are multiplied by the total area of each structure for each HAZUS damage code. The HAZUS damage codes also provide an avenue to identify DDF needed to calculate damage based on water depth.

Table 3.1 Data Structure Explained

Damage Category	LandUse Classes	HAZUS Damage Code	Maximum Damage (HAZUS) (\$/ft²) (2021 Prices)
Residential	Single Family, 1 Story No Basement	RES1-1SNB	$126
	Single Family, 2 Story No Basement	RES1-2SNB	$133
	Single Family, 3 Story No Basement	RES1-3SNB	$138
	Mobile Home	RES2	$51
	Condominium; Living Area on Multiple Floors	RES3C	$217
	Condominium; Living Area on Multiple Floors	RES3E	$204
	Average Hotel & Motel	RES4	$197
	Institutional Dormitory	RES5	$216
	Nursing Home	RES6	$233
Offices	Average Professional & Technical Services	COM4	$190
Institutions	Average School	EDU1	$218
	Average College/University	EDU2	$185
	Average Government Services	GOV1	$162
	Church	REL1	$206
Industry	Average Heavy Industrial	IND1	$144
	Average Light Industrial	IND2	$130
	Average Wholesale		
	Average Food/Drug/Chemical,	IND3	$195
	Food Processor – Structure Only		
	Average Metals/Minerals Processing	IND4	$195
	Average High Technology	IND5	$195
Commercial	Average Retail – Structure Only	COM1	$124

Damage Category	LandUse Classes	HAZUS Damage Code	Maximum Damage (HAZUS) ($/ft²) (2021 Prices)
	Restaurant		
	Auto Junk Yard – Structure	COM2	$130
	Average Wholesale, Structure Only		
	Average Personal & Repair Services	COM3	$151
	Airport,	COM4	$151
	Average Personal & Repair Services, Utility Company		
	Bank	COM5	$282
	Hospital	COM6	$326
	Average Entertainment/Recreation, Average Recreation Facility, Bowling Alley, Skating Rink	COM8	$246
	Pool Hall, Enclosed Arena, Golf Courses		
	Average Theatre	COM9	$206
	Garage	COM10	$87
Agriculture	Average Agriculture – Contents Only,	AGR1	$130
	Average Agriculture – Structure Only		
Road	Major Roads	ROAD	$265
	Street	ROAD	$265
Utility	Water Control Structure	UTILITY	$1,949,346
	Medium Voltage (230 KV) Substation	ESSM	$24,874,478
	Medium Wastewater Treatment Plant (50-200 MGD)	WWTM	$117,686,816

4.0 SFWMD-FIAT RESULTS (C-8)

The aggregated summary of total damages (EAD) produced for each scenario for the four return periods exhibit varying degrees of economic impact. **Figure 4.1** represents economic damages for four return periods with current sea level compared to the three sea level rise scenarios modeled in the C-8 basin.

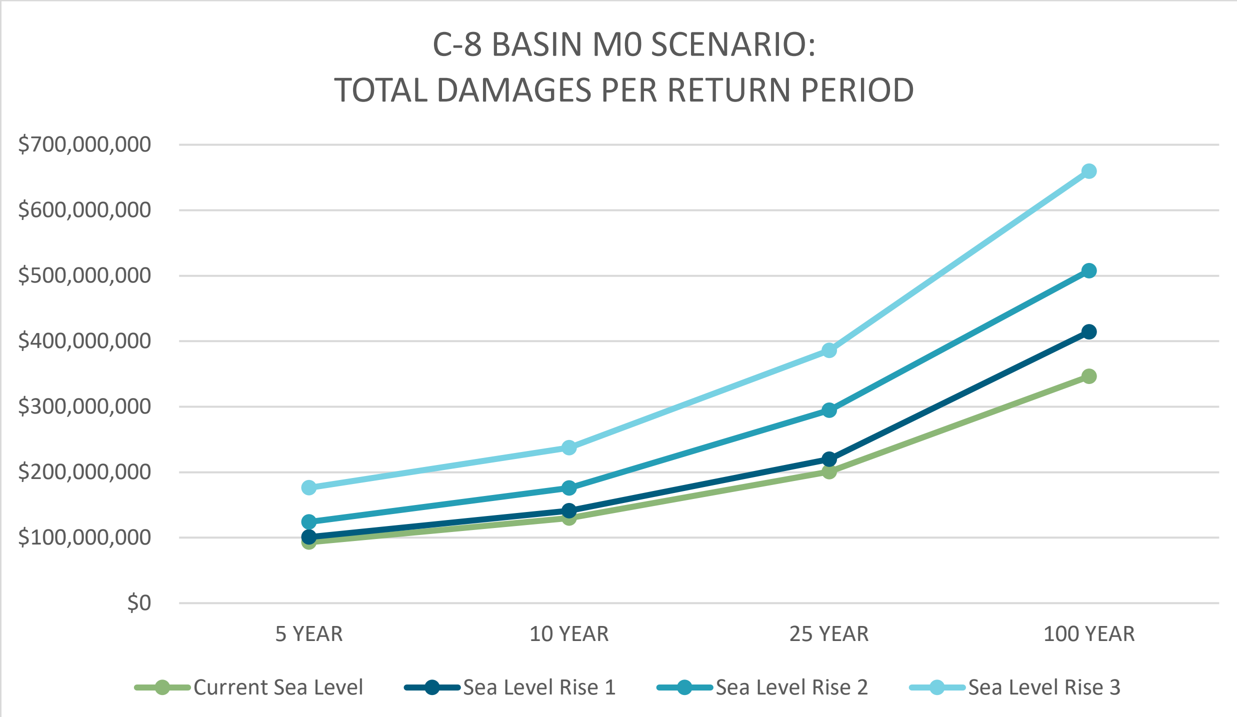


Figure 4.1 Economic Impacts for M0 (no mitigation) in the C-8 Basin

As expected, the current level of service is not viable when evaluated with future storm events and projected sea level rise. The graph in **Figure 4.1** envisions the estimated economic loss the area will endure if mitigation investments are not made to adapt to future conditions.

Table 4.1 below provides the total damages represented in **Figure 4.1** and includes the EAD for current conditions (CSL) and the three SLR scenarios the C-8 basin.

Table 4.1 C-8 Total Expected Annual Damages Represented in Figure 4.1

Scenario	5 Year	10 Year	25 Year	100 Year	EAD
Current Sea Level	$93,027,100	$129,968,000	$200,705,500	$346,200,200	$31,710,700
Sea Level Rise 1	$100,873,200	$141,284,200	$219,588,600	$414,289,800	$35,340,600
Sea Level Rise 2	$124,018,000	$175,585,200	$294,525,400	$507,820,600	$44,641,800
Sea Level Rise 3	$176,195,800	$237,599,300	$385,761,200	$659,630,300	$59,720,100

Table 4.2 identifies the percent change in EAD when comparing current conditions (CSL) to the three different SLR scenarios. With current infrastructure within the C-8 basin without mitigation efforts, and sea level rising by three feet; there would be an 88% increase in EAD.

Table 4.2 C-8 Percent Change Comparing CSL to the Three SLR Scenarios for M0 EADs

Damage Category	CSL (M0)	SLR1 (M0)	SLR2 (M0)	SLR3 (M0)
Residential	$13,041,400	$16,052,800	$22,515,600	$34,033,400
Offices	$143,500	$213,700	$351,800	$566,200
Institutions	$370,900	$427,200	$584,800	$1,052,800
Industry	$1,587,300	$1,845,400	$2,161,000	$2,562,200
Commercial	$301,400	$368,800	$569,600	$1,116,900
Utilities	$0	$358,900	$1,085,900	$1,085,900
Water Control Structure	$0	$0	$0	$0
Agriculture	$34,400	$74,400	$88,400	$105,500
Roads	$16,231,800	$15,999,400	$17,284,900	$19,197,300
TOTAL	**$31,710,700**	**$35,340,600**	**$44,641,800**	**$59,720,100**
Percent Change		**11%**	**41%**	**88%**

In **Table 4.3** the EADs from M1, local mitigation strategy efforts, are compared to the current conditions (CSL). Alone, these local strategies show an immediate benefit, bringing the annual damage costs down eleven percent. However, with only local scale mitigation efforts, the rise in sea level still produces similar damages, lowering the total EAD by an estimated $10.5 million with a three-foot SLR.

Table 4.3 C-8 M1 Storm Events Compared to the Present-Day Scenario EADs

Damage Category	CSL (M0)	CSL (M1)	SLR1 (M1)	SLR2 (M1)	SLR3 (M1)
Residential	$13,041,400	$12,448,600	$15,308,600	$21,440,000	$21,440,000
Offices	$143,500	$134,900	$191,400	$336,500	$336,500
Institutions	$370,900	$347,200	$400,500	$538,100	$538,100
Industry	$1,587,300	$1,480,000	$1,738,900	$2,054,600	$2,054,600
Commercial	$301,400	$248,600	$308,800	$427,800	$427,800
Utilities	$0	$0	$358,900	$1,085,900	$1,085,900
Water Control Structure	$0	$0	$0	$0	$0
Agriculture	$34,400	$35,000	$75,700	$90,600	$90,600
Roads	$16,231,800	$15,212,300	$14,955,900	$16,235,800	$16,235,800
TOTAL	**$31,710,700**	**$29,906,700**	**$33,338,600**	**$42,209,400**	**$42,209,400**
Percent Change		**-6%**	**5%**	**33%**	**33%**

Table 4.4 presents the detailed EADs from the M2A scenarios. It shows the percent change from the four SLR scenarios in comparison to the current conditions. The percent change identifies the benefits which could result from immediate implementation of M2A strategies across the basin. The mitigation strategies are beneficial at the highest rise in sea level. There is still a significant increase in the percentage of EAD, 34%; although that increase is less than EADs with no mitigation strategy.

Table 4.4 C-8 Percent Change of the M2A Storm Events Compared to the Present-Day Scenario EADs

Damage Category	CSL (M0)	CSL (M2A)	SLR1 (M2A)	SLR2 (M2A)	SLR3 (M2A)
Residential	$13,041,400	$12,105,200	$13,974,900	$16,758,200	$20,739,600
Offices	$143,500	$126,900	$146,800	$210,900	$276,600
Institutions	$370,900	$370,700	$399,400	$453,500	$565,500
Industry	$1,587,300	$1,479,700	$1,644,000	$1,859,300	$2,121,800
Commercial	$301,400	$275,700	$316,100	$387,600	$503,100
Utilities	$0	$358,900	$358,900	$358,900	$1,085,900
Water Control Structure	$0	$0	$0	$0	$0
Agriculture	$34,400	$63,000	$67,600	$76,300	$89,900
Roads	$16,231,800	$15,063,500	$15,458,600	$16,090,600	$16,955,600
TOTAL	**$31,710,700**	**$29,843,600**	**$32,366,300**	**$36,195,300**	**$42,337,900**
Percent Change		**-6%**	**2%**	**14%**	**34%**

M2B, the scenario in **Table 4.5**, indicates the percent change in EADs from CSL compared to the three sea level rise scenarios. When looking at the potential for the mitigation strategies implemented, it should be noted that M2B results in reduced risk across all sea level scenarios, bringing the total damage reduction to 22% with three feet of SLR.

Table 4.5 C-8 M2B Scenario Percent Change Compared to Present-Day Conditions

Damage Category	CSL (M0)	CSL (M2B)	SLR1 (M2B)	SLR2 (M2B)	SLR3 (M2B)
Residential	$13,041,400	$11,139,600	$12,589,300	$14,720,000	$18,501,900
Offices	$143,500	$117,600	$137,200	$193,700	$250,800
Institutions	$370,900	$337,000	$353,400	$375,600	$431,800
Industry	$1,587,300	$1,456,000	$1,594,700	$1,818,600	$2,086,200
Commercial	$301,400	$249,600	$280,800	$333,100	$428,000
Utilities	$0	$358,900	$358,900	$358,900	$1,085,900
Water Control Structure	$0	$0	$0	$0	$0
Agriculture	$34,400	$61,900	$66,300	$74,000	$87,700
Roads	$16,231,800	$14,217,700	$14,505,600	$15,025,600	$15,947,900
TOTAL	**$31,710,700**	**$27,938,300**	**$29,886,200**	**$32,899,600**	**$38,820,300**
Percent Change		**-12%**	**-6%**	**4%**	**22%**

In **Table 4.6**, the EADs of mitigation strategy M2C, are shown in comparison to current conditions. As demonstrated at the bottom of the table, the strategies implemented in the M2C model runs provide a considerable reduction of annual damages throughout all but one of the sea level rise scenarios. Notably, when comparing EAD from CSL M0 to EAD from SLR2 there is a $125,000 decrease in damages observed.

Table 4.6 C-8 Percent Change Between M2C and Current Conditions

Damage Category	CSL (M0)	CSL (M2C)	SLR1 (M2C)	SLR2 (M2C)	SLR3 (M2C)
Residential	$13,041,400	$10,691,500	$11,876,600	$13,840,400	$16,810,000
Offices	$143,500	$105,600	$120,700	$171,100	$227,600
Institutions	$370,900	$332,100	$345,400	$363,300	$396,700
Industry	$1,587,300	$1,341,800	$1,445,700	$1,684,400	$1,973,400
Commercial	$301,400	$227,200	$249,100	$299,500	$363,500
Utilities	$0	$358,900	$358,900	$358,900	$1,085,900
Water Control Structure	$0	$0	$0	$0	$0
Agriculture	$34,400	$59,300	$63,600	$70,800	$83,400
Roads	$16,231,800	$14,098,700	$14,284,300	$14,797,500	$15,502,500
TOTAL	**$31,710,700**	**$27,215,100**	**$28,744,200**	**$31,585,800**	**$36,443,200**
Percent Change		**-14%**	**-9%**	**0%**	**15%**

Below are the EAD totals for the M3 scenarios, which raises structure and road elevations, rather than implement standard mitigation construction projects throughout the basin. The decrease in total damage is significant due to the drastic approach. **Table 4.7** identifies the EADs from a one-foot increase in structure and road elevations compared to current conditions. These M3 scenarios are intended to show planners the advantage of requiring, say, building code or land use policies that would require new construction or rebuilding to elevate at 1, 2, or 3 ft above the current elevation. Elevating all the buildings and roads in a basin by these elevations is not considered to be practical in a short-term sense but something planners and communities should aim for over a long period of time.

Table 4.7 C-8 Comparison Between M3(1ft) and Current Conditions

Damage Category	CSL (M0)	CSL M3(1ft)	SLR1 M3(1ft)	SLR2 M3(1ft)	SLR3 M3(1ft)
Residential	$13,041,400	$4,062,200	$5,324,600	$7,409,700	$11,204,600
Offices	$143,500	$13,800	$23,600	$65,200	$149,200
Institutions	$370,900	$177,500	$189,700	$210,400	$273,000
Industry	$1,587,300	$531,600	$798,100	$1,057,300	$1,297,400
Commercial	$301,400	$15,300	$31,600	$31,100	$62,600
Utilities	$0	$0	$0	$0	$0
Water Control Structure	$0	$0	$0	$0	$0
Agriculture	$34,400	$5,900	$20,700	$28,500	$39,300
Roads	$16,231,800	$1,511,000	$1,461,200	$2,076,600	$3,072,300
TOTAL	**$31,710,700**	**$6,317,400**	**$7,849,500**	**$10,878,900**	**$16,098,400**
Percent Change		**-80%**	**-75%**	**-66%**	**-49%**

Table 4.8 shows the percent change in EAD between current conditions and two-foot increases in structure and road elevations.

Table 4.8 C-8 M3(2ft) SLR Scenarios Compared to Current Conditions

Damage Category	CSL (M0)	CSL M3(2ft)	SLR1 M3(2ft)	SLR2 M3(2ft)	SLR3 M3(2ft)
Residential	$13,041,400	$1,058,800	$1,487,900	$2,219,100	$3,482,900
Offices	$143,500	$0	$2,300	$7,000	$21,900
Institutions	$370,900	$131,300	$141,500	$149,900	$167,000
Industry	$1,587,300	$140,400	$287,600	$595,500	$759,200
Commercial	$301,400	$3,100	$5,500	$9,700	$18,300
Utilities	$0	$0	$0	$0	$0
Water Control Structure	$0	$0	$0	$0	$0
Agriculture	$34,400	$1,400	$4,000	$7,000	$11,700
Roads	$16,231,800	$357,100	$376,100	$550,100	$909,600
TOTAL	**$31,710,700**	**$1,692,100**	**$2,305,000**	**$3,538,400**	**$5,370,600**
Percent Change		**-95%**	**-93%**	**-89%**	**-83%**

Table 4.9 shows the percent change in EAD between current conditions and three-foot increases in structure and road elevations.

Table 4.9 C-8 Percent Change Between M3(3ft) and M0, Current Conditions

Damage Category	CSL (M0)	SLR3 M3(3ft)	SLR1 M3(3ft)	SLR2 M3(3ft)	SLR3 M3(3ft)
Residential	$13,041,400	$206,500	$313,000	$510,900	$844,100
Offices	$143,500	$0	$0	$0	$0
Institutions	$370,900	$78,700	$88,000	$97,900	$117,500
Industry	$1,587,300	$27,000	$41,400	$105,900	$232,800
Commercial	$301,400	$1,300	$1,800	$2,500	$5,500
Utilities	$0	$0	$0	$0	$0
Water Control Structure	$0	$0	$0	$0	$0
Agriculture	$34,400	$300	$600	$1,300	$2,700
Roads	$16,231,800	$55,800	$85,400	$163,600	$291,500
TOTAL	**$31,710,700**	**$369,600**	**$530,200**	**$882,200**	**$1,494,100**
Percent Change		**-99%**	**-98%**	**-97%**	**-95%**

The SFWMD-FIAT provides road damages per road segment in polygon format. To extract miles of road damage, the team extracted the polygons from each tool run output with EAD greater than zero. These polygons were used to clip a combined feature class of all road centerlines. Miles of clipped road centerlines were summarized by each scenario and used for reporting purposes.

Table 4.10 identifies the miles of damaged road segments in the C-8 basin when estimating EADs. Based off the information in the table, the expected annual damage estimates average $82,800 per mile.

Table 4.10 C-8 Cost of Road Damages per Mile Segment Summary

Scenario	CSL (2021)	Cost Per Mile	SLR1	Cost Per Mile	SLR2	Cost Per Mile	SLR3	Cost Per Mile
M0	196 mi	**$82,800**	196 mi	**$81,900**	208 mi	**$83,300**	221 mi	**$86,800**
M1	187 mi	**$81,500**	185 mi	**$81,000**	199 mi	**$81,700**	213 mi	**$84,900**
M2A	182 mi	**$82,600**	189 mi	**$81,800**	196 mi	**$82,000**	204 mi	**$83,300**
M2B	172 mi	**$82,500**	176 mi	**$82,300**	183 mi	**$82,100**	191 mi	**$83,700**
M2C	170 mi	**$82,700**	173 mi	**$82,700**	179 mi	**$82,800**	184 mi	**$84,200**

5.0 SFWMD-FIAT RESULTS (C-9)

Each of the scenarios for the C-8 and C-9 basins were processed separately in the SFWMD-FIAT. **Figure 5.1** represents economic damages for four return periods with current sea level compared to the three sea level rise scenarios modeled in the C-9 basin.

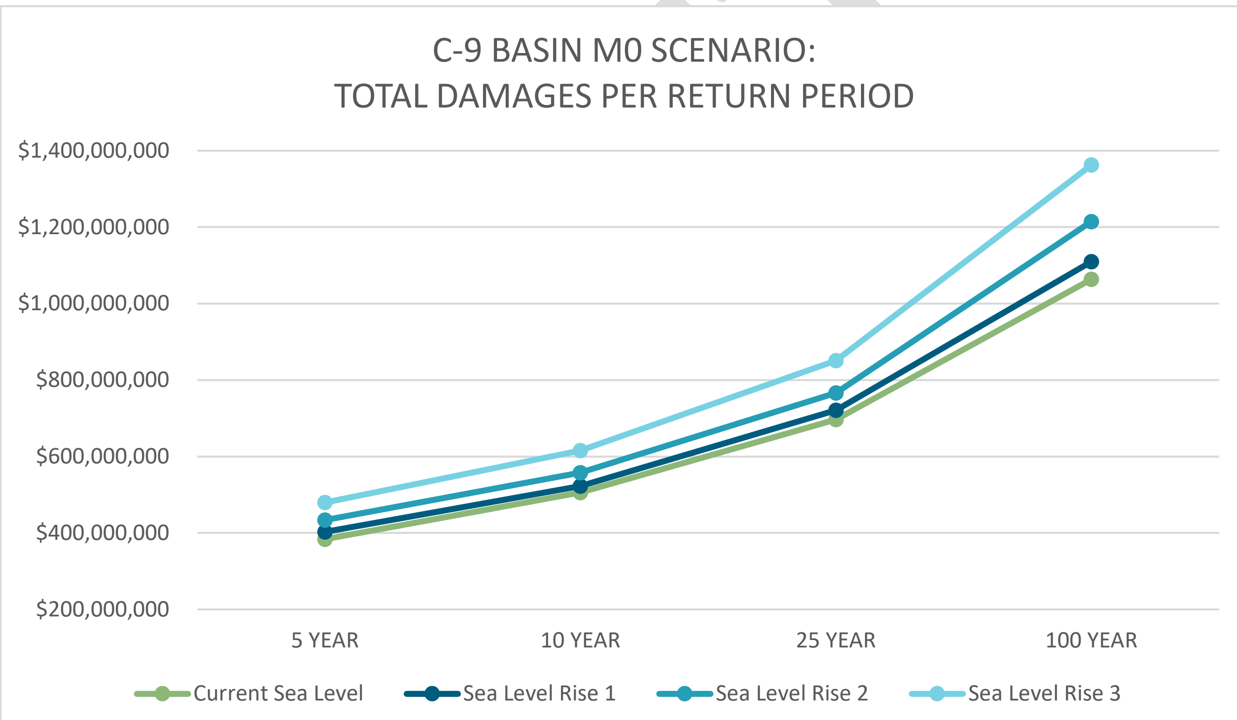


Figure 5.1 Economic Impacts for M0 (no mitigation) in the C-9 Basin

Table 5.1 provides the total damages represented in **Figure 5.1** and includes the EAD for current conditions (CSL) and the three SLR scenarios the C-9 basin. Although the rise is not as drastic as C-8's 456% increase in damages; the C-9 water basin does have a substantial increase in EAD with three-feet of SLR. The difference in percent change of total EADs between the C-8 and C-9 basins (88% vs. 24%) is largely due to the C9 basin having significantly larger storage and is mainly drained by pump stations. The C8 basin is mostly drained by gravity, which allows elevated stages to propagate upstream into the secondary/tertiary systems. The C9 basin benefits from its ability to drain via pump stations coupled with the ability to block elevated stages from propagating upstream into the secondary/tertiary systems. .

Table 5.1 C-9 Percent Change Comparing M0 Damages

Damage Category	CSL (M0)	SLR1 (M0)	SLR2 (M0)	SLR3 (M0)
Residential	$65,647,200	$68,642,500	$74,076,100	$82,741,000
Offices	$645,000	$674,000	$803,400	$1,043,500
Institutions	$1,932,100	$2,099,900	$2,275,000	$2,685,800
Industry	$1,175,600	$1,300,800	$1,567,600	$2,157,400
Commercial	$1,410,300	$1,530,600	$1,826,400	$2,369,400
Utilities	$0	$0	$391,500	$391,500
Water Control Structure	$74,100	$255,800	$485,300	$758,800
Agriculture	$223,800	$225,700	$232,100	$245,500
Roads	$43,654,600	$44,556,300	$46,334,600	$49,588,900
TOTAL	**$114,762,700**	**$119,285,700**	**$127,991,900**	**$141,981,900**
Percent Change		**4%**	**12%**	**24%**

In **Table 5.2**, the EADs from M1, local mitigation strategy efforts, are compared to current conditions (CSL) in the C-9 basin. The local mitigation strategies in this run provide an estimated benefit of ~$100,000 for each rise in sea level when compared to the EAD at all sea levels with no mitigation.

Table 5.2 C-9 M1 Storm Events Compared to M0, Current Conditions

Damage Category	CSL (M0)	CSL (M1)	SLR1 (M1)	SLR2 (M1)	SLR3 (M1)
Residential	$65,647,200	$64,844,800	$67,787,600	$73,042,600	$81,273,500
Offices	$645,000	$652,400	$681,500	$805,600	$1,035,900
Institutions	$1,932,100	$1,929,800	$2,097,600	$2,272,600	$2,683,200
Industry	$1,175,600	$1,157,100	$1,283,400	$1,550,200	$2,140,100
Commercial	$1,410,300	$1,344,500	$1,463,900	$1,756,900	$2,290,800
Utilities	$0	$0	$0	$391,500	$391,500
Water Control Structure	$74,100	$74,100	$255,800	$485,300	$758,800
Agriculture	$223,800	$155,800	$157,700	$163,700	$176,000
Roads	$43,654,600	$42,706,400	$43,553,000	$45,278,500	$48,426,200
TOTAL	**$114,762,700**	**$112,865,000**	**$117,280,500**	**$125,746,900**	**$139,176,000**
Percent Change		**-2%**	**2%**	**10%**	**21%**

Table 5.3 presents the M2A scenario EADs. It compares the percent change from the four SLR scenarios to the M0 scenario with current conditions. The percent change indicates the benefits of the regional mitigation strategies. This mitigation strategy offers benefits throughout all SLR scenarios; observing only 14% increase in damages with three-feet of SLR, better than the 24% increase with two-foot SLR with the current mitigation activities.

Table 5.3 C-9 Percent Change of M2A Compared to Present-Day Scenario

Damage Category	CSL (M0)	CSL (M2A)	SLR1 (M2A)	SLR2 (M2A)	SLR3 (M2A)
Residential	$65,647,200	$63,787,900	$66,467,800	$70,643,900	$76,195,000
Offices	$645,000	$615,600	$633,200	$691,000	$800,600
Institutions	$1,932,100	$1,977,200	$2,025,600	$2,121,500	$2,290,000

Damage Category	CSL (M0)	CSL (M2A)	SLR1 (M2A)	SLR2 (M2A)	SLR3 (M2A)
Industry	$1,175,600	$1,155,600	$1,234,000	$1,396,000	$1,695,700
Commercial	$1,410,300	$1,388,800	$1,495,300	$1,754,200	$2,098,900
Utilities	$0	$0	$0	$0	$391,500
Water Control Structure	$74,100	$29,600	$61,600	$99,200	$159,200
Agriculture	$223,800	$222,400	$224,500	$229,000	$236,600
Roads	$43,654,600	$43,349,300	$43,910,600	$45,087,600	$46,961,200
TOTAL	**$114,762,700**	**$112,526,400**	**$116,052,600**	**$122,022,300**	**$130,828,800**
Percent Change		**-2%**	**1%**	**6%**	**14%**

Table 5.4 compares EADs from M2B to the current condition EADs. Note that M2B results in reduced risk across all sea level scenarios when compared to no mitigation or M2A. With 3' of SLR, M2B reduces the total EADs by $3.5 million when compared to M2A.

Table 5.4 C-9 M2B Scenarios Percent Change Compared to M0

Damage Category	CSL (M0)	CSL (M2B)	SLR1 (M2B)	SLR2 (M2B)	SLR3 (M2B)
Residential	$65,647,200	$62,305,900	$64,884,300	$68,981,600	$74,583,200
Offices	$645,000	$604,900	$617,900	$672,700	$753,000
Institutions	$1,932,100	$1,965,700	$2,011,600	$2,094,800	$2,271,800
Industry	$1,175,600	$1,074,700	$1,092,000	$1,168,300	$1,361,200
Commercial	$1,410,300	$1,298,400	$1,397,600	$1,662,600	$2,013,400
Utilities	$0	$0	$0	$0	$0
Water Control Structure	$74,100	$42,200	$61,600	$159,200	$159,200
Agriculture	$223,800	$222,200	$224,300	$228,800	$236,300
Roads	$43,654,600	$42,626,200	$43,136,100	$44,169,900	$45,949,600
TOTAL	**$114,762,700**	**$110,140,100**	**$113,425,300**	**$119,137,900**	**$127,327,700**
Percent Change		**-4%**	**-1%**	**4%**	**11%**

Table 5.5 identifies the EAD of M2C compared to current conditions. This strategy delivers a substantial decrease in damages from current conditions through the first two feet of SLR, where M2C mitigation provides nominal changes in total damages when compared to current conditions. Compared to M2B, the savings nominally increase, at three feet of sea level rise the decrease between strategies is approximately $2.2 million.

Table 5.5 C-9 Percent Change Comparison of M2C and Current Conditions

Damage Category	CSL (M0)	CSL (M2C)	SLR1 (M2C)	SLR2 (M2C)	SLR3 (M2C)
Residential	$65,647,200	$61,707,600	$64,045,600	$68,121,700	$73,186,300

Damage Category	CSL (M0)	CSL (M2C)	SLR1 (M2C)	SLR2 (M2C)	SLR3 (M2C)
Offices	$645,000	$604,200	$614,500	$658,000	$730,100
Institutions	$1,932,100	$1,955,900	$2,001,500	$2,072,500	$2,207,400
Industry	$1,175,600	$1,071,800	$1,086,200	$1,131,900	$1,247,200
Commercial	$1,410,300	$1,284,200	$1,384,200	$1,645,100	$1,970,900
Utilities	$0	$0	$0	$0	$0
Water Control Structure	$74,100	$29,600	$49,000	$99,200	$159,200
Agriculture	$223,800	$221,500	$223,600	$228,200	$235,000
Roads	$43,654,600	$42,428,400	$42,856,000	$43,830,000	$45,348,100
TOTAL	**$114,762,700**	**$109,303,300**	**$112,260,500**	**$117,786,700**	**$125,084,300**
Percent Change		**-5%**	**-2%**	**3%**	**9%**

Below are the EAD totals for the M3 scenarios for the C-9 basin, which raises structure and road elevations rather than implement standard mitigation construction projects throughout the basin. The decrease in total damages is significant due to the drastic approach. **Table 5.6** identifies the EADs from a one-foot increase in structure and road elevations compared to current conditions.

Table 5.6 C-9 M3(1ft) Comparison to M0 Damages

Damage Category	CSL (M0)	CSL M3(1ft)	SLR1 M3(1ft)	SLR2 M3(1ft)	SLR3 M3(1ft)
Residential	$65,647,200	$28,578,900	$30,662,200	$33,902,800	$38,107,100
Offices	$645,000	$35,300	$43,400	$59,700	$125,300
Institutions	$1,932,100	$519,600	$629,700	$690,700	$803,800
Industry	$1,175,600	$119,400	$139,400	$174,200	$247,500
Commercial	$1,410,300	$264,700	$265,300	$349,200	$558,700
Utilities	$0	$0	$0	$0	$0
Water Control Structure	$74,100	$0	$31,900	$218,500	$281,200
Agriculture	$223,800	$12,800	$13,200	$14,400	$16,600
Roads	$43,654,600	$4,520,100	$4,831,900	$5,422,500	$6,270,500
TOTAL	**$114,762,700**	**$34,051,000**	**$36,617,000**	**$40,832,000**	**$46,410,800**
Percent Change		**-70%**	**-68%**	**-64%**	**-60%**

Table 5.7 shows the percent change in EAD between current conditions and a two foot increase in structure and road elevations. The benefits from the structural code and land use change are apparent in the results below.

Table 5.7 C-9 Percent Change Comparison of M3(2ft) and M0

Damage Category	CSL (M0)	CSL M3(2ft)	SLR1 M3(2ft)	SLR2 M3(2ft)	SLR3 M3(2ft)
Residential	$65,647,200	$9,868,000	$11,087,800	$13,033,600	$15,522,100
Offices	$645,000	$0	$0	$500	$4,800
Institutions	$1,932,100	$100,300	$154,400	$170,700	$208,200
Industry	$1,175,600	$17,700	$19,600	$24,300	$33,700
Commercial	$1,410,300	$63,400	$74,900	$91,800	$126,100
Utilities	$0	$0	$0	$0	$0
Water Control Structure	$74,100	$0	$0	$0	$42,200
Agriculture	$223,800	$500	$500	$600	$800
Roads	$43,654,600	$1,781,600	$2,063,600	$2,313,500	$2,717,900
TOTAL	**$114,762,700**	**$11,831,400**	**$13,400,700**	**$15,634,900**	**$18,655,700**
Percent Change		**-90%**	**-88%**	**-86%**	**-84%**

Table 5.8 shows the percent change in EAD between current conditions and a three foot increase in structure and road elevations.

Table 5.8 C-9 Percent Change of M3(3ft) and M0

Damage Category	CSL (M0)	CSL M3(3ft)	SLR1 M3(3ft)	SLR2 M3(3ft)	SLR3 M3(3ft)
Residential	$65,647,200	$2,025,900	$2,402,300	$2,948,900	$3,974,200
Offices	$645,000	$0	$0	$0	$0
Institutions	$1,932,100	$39,000	$52,600	$53,300	$83,400
Industry	$1,175,600	$800	$900	$1,200	$2,400
Commercial	$1,410,300	$15,000	$20,600	$26,200	$28,200
Utilities	$0	$0	$0	$0	$0
Water Control Structure	$74,100	$0	$0	$0	$0
Agriculture	$223,800	$0	$0	$0	$0
Roads	$43,654,600	$672,400	$843,500	$1,037,400	$1,211,000
TOTAL	**$114,762,700**	**$2,753,100**	**$3,320,000**	**$4,067,000**	**$5,299,100**
Percent Change		**-98%**	**-97%**	**-96%**	**-95%**

Table 5.9 identifies the miles of damaged road segments in the C-9 basin when estimating EADs. Based off the information in the table, the expected annual damage estimates average around $78,000 throughout all sea level scenarios. According to these results, the damage estimates are steady regardless of storm events, averaging around $78,000, annually.

Table 5.9 C-9 Summary of the Cost of Road Damages Per Mile Segment

Scenario	CSL (2021)	Cost Per Mile	SLR1	Cost Per Mile	SLR2	Cost Per Mile	SLR3	Cost Per Mile
M0	564 mi	**$ 77,300**	577 mi	**$ 77,200**	599 mi	**$ 77,300**	626 mi	**$ 79,200**
M1	552 mi	**$ 77,400**	564 mi	**$ 77,200**	586 mi	**$ 77,200**	613 mi	**$ 79,000**
M2A	556 mi	**$ 78,000**	566 mi	**$ 77,600**	583 mi	**$ 77,300**	607 mi	**$ 77,400**
M2B	546 mi	**$ 78,100**	555 mi	**$ 77,700**	572 mi	**$ 77,300**	595 mi	**$ 77,200**
M2C	541 mi	**$ 78,400**	548 mi	**$ 78,200**	563 mi	**$ 77,800**	584 mi	**$ 77,700**

6.0 EAD SUMMARY

As shown in the snapshot of **Figure 6.1** all four of the mitigation strategies modeled can provide benefits for the C-8 basin. The implementation of local mitigation projects in M1 provides nominal benefits when compared to the current mitigation activities in the C-8 basin. However, when various combinations of regional strategies are implemented, the highest annual damage estimates fall from roughly $60 million to $42 million with the mitigation scenario of M2A and with a three-foot rise in sea level, the M2C scenario is estimated to reduce damages by approximately around $36 million dollars annually.

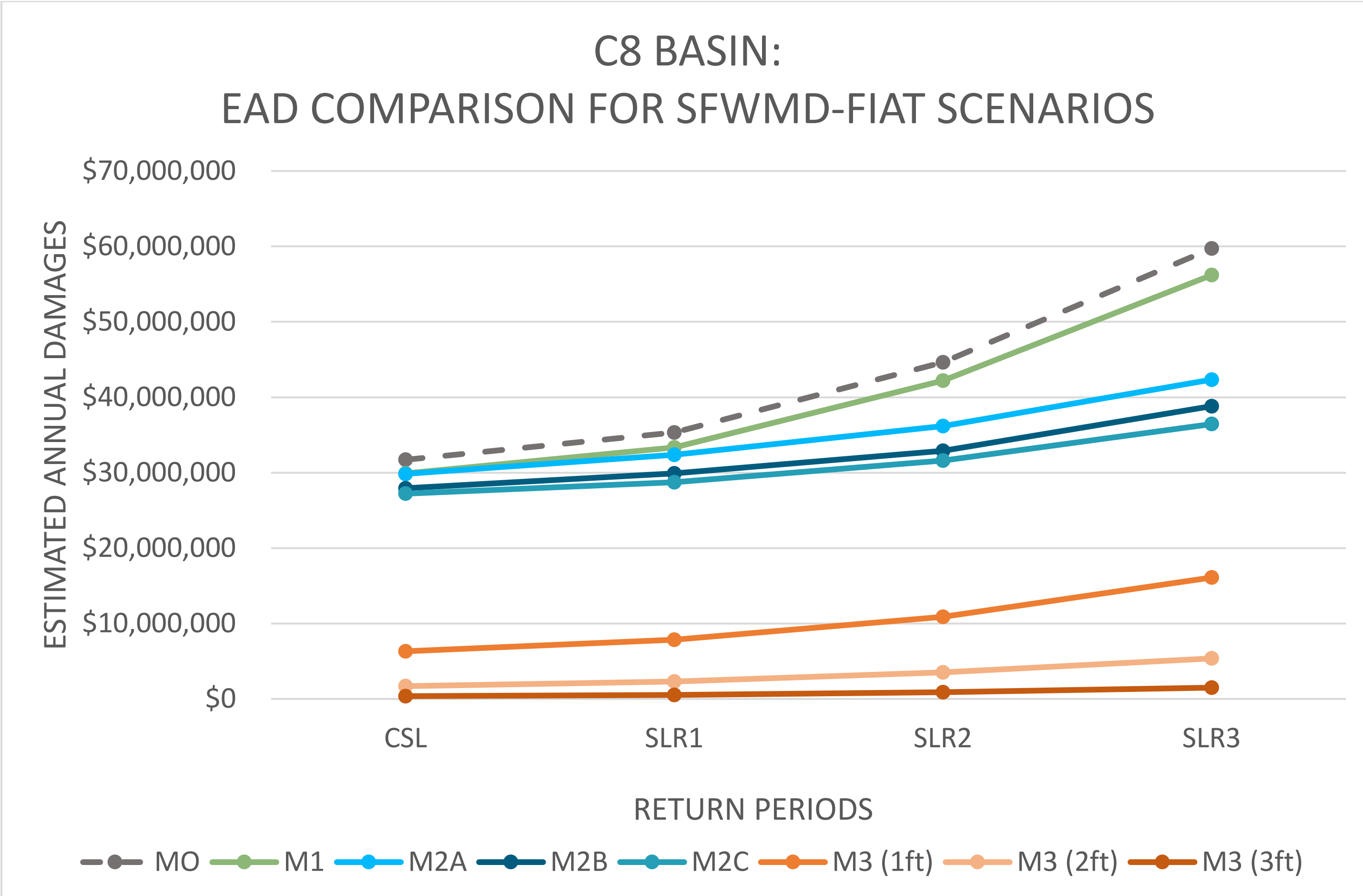


Figure 6.1 C-8 Basin - EAD Comparison for SFWMD-FIAT Scenarios

Corresponding with the C-8 calculations, the C-9 water basin provided similar damage benefits. M1 follows the current conditions closely with negligible benefits throughout the SLR scenarios and the different M2x scenarios provide significant benefits shown below in **Figure 6.2.**

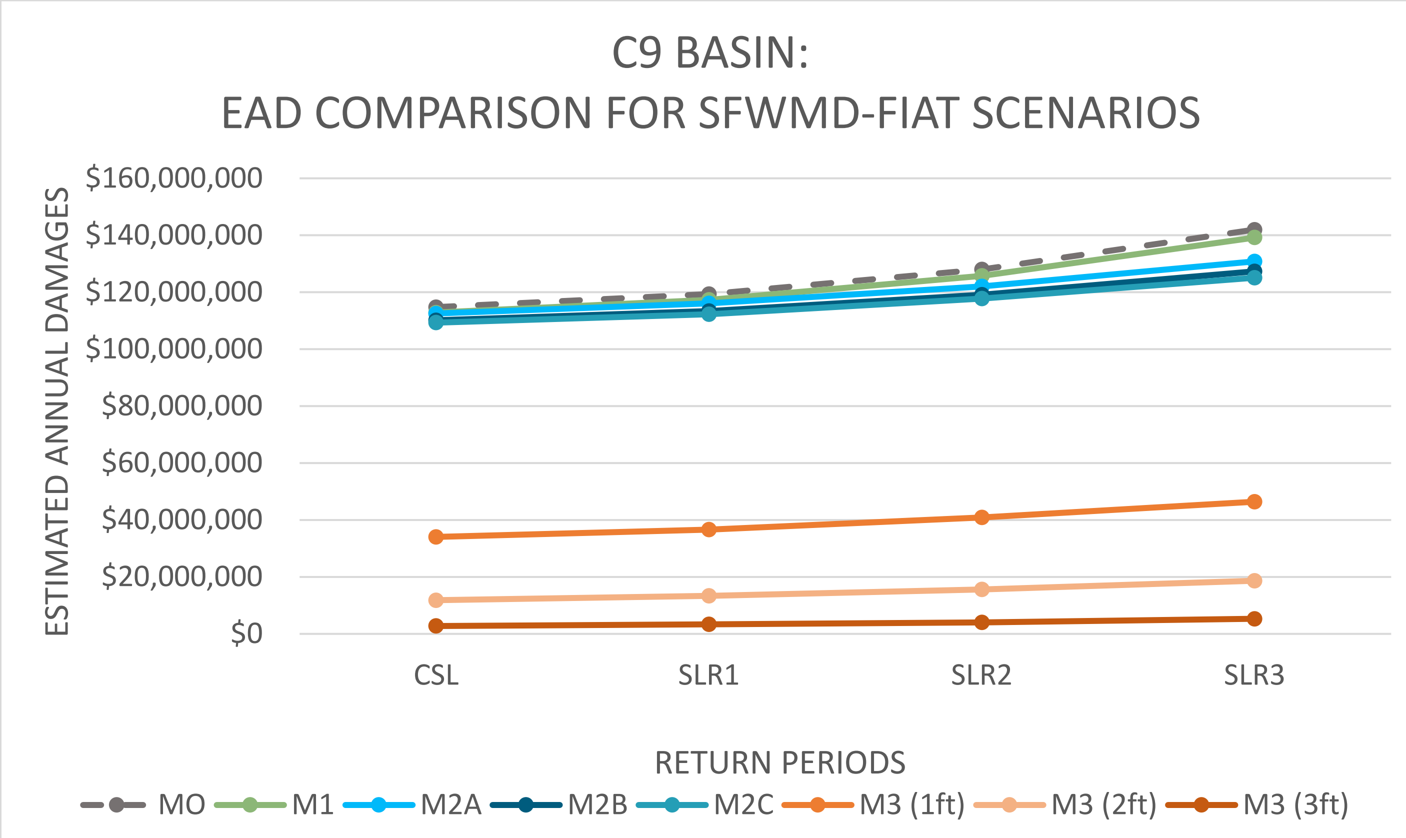


Figure 6.2 C-9 Basin - EAD Comparison for SFWMD-FIAT Scenarios

The two graphs above provide an overview of the EAD results from the different mitigation scenarios applied in the two basins. Initially all mitigation scenarios provide benefits across the basin for current conditions with no sea level rise. As SLR increases so do damages. The mitigation activities show increasing benefits as SLR progresses from 1 to 3 ft, but none of them completely mitigate SLR3.

- M1 projects show that these small-scale projects will benefit the communities in the near future and should be implemented. The communities will have to adapt these mitigation activities as sea level rise progresses.
    - M1 projects reduced SLR3 EADs from 88% with no mitigation to 33%
- M2A, B, and C projects show that regional scale mitigation strategies will have a large benefit to reducing the consequences of flooding and sea level rise. These strategies progressed the forward pump sizes from 1550 (M2A), 2550 (M2B), and finally 3550 (M2C) cfs. The projects included hardening the pump station, raising the banks near the pump station, and for M2C raised interior canal banks to reduce overland flooding.
- A helpful way to think about the mitigation projects and their effectiveness is to revuew the amount they reduce EADs with respect to no mitigation action.
- For the C-8 Basin under SLR3 and no mitigation, the EADs would increase by 88% with respect to current conditions:
    - M2A projects reduced SLR3 EADs from 88% with no mitigation to 34%

  - M2B projects reduced SLR3 EADs from 88% with no mitigation to 22%
  - M2C projects reduced SLR3 EADs from 88% with no mitigation to 15%

- For the C-9 Basin under SLR3 and no mitigation, the EADs would increase by 24% with respect to current conditions:
  - M2A projects reduced SLR3 EADs from 24% with no mitigation to 21%
  - M2B projects reduced SLR3 EADs from 24% with no mitigation to 11%
  - M2C projects reduced SLR3 EADs from 24% with no mitigation to 9%

This summary is one way to see the impact of mitigation activities with respect to reducing the EADs and shows that the District's FIAT tool is valuable to water resources managers and communities in helping quantify the benefits of mitigation activities. The detailed risk analysis provided in Task 2 is used in conjunction with detailed exposure data (building stock and road information) to calculate expected annual damages. These EADs tell part, but not all, of the risk analysis and are a useful metric in mitigation analysis.

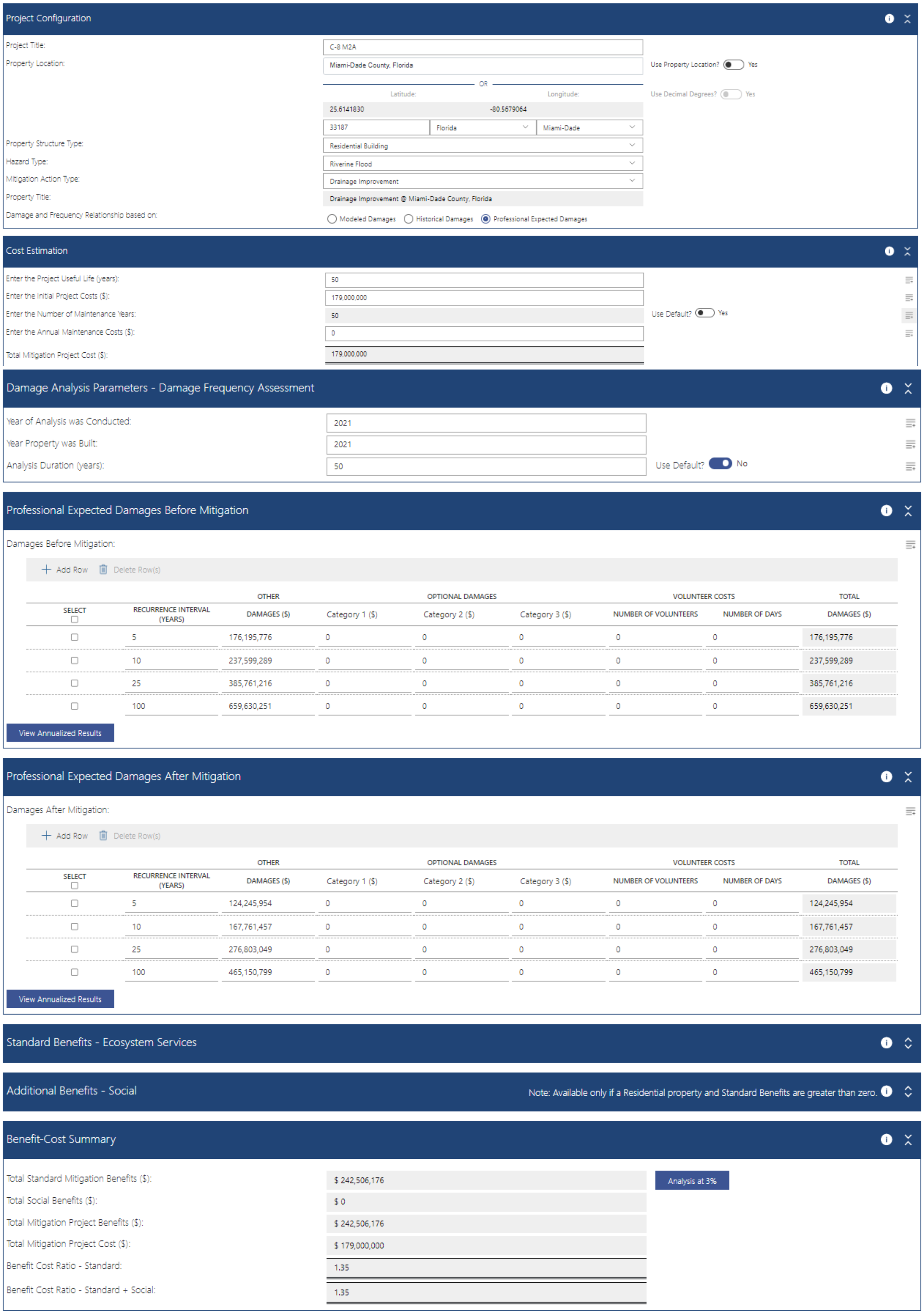
The next step in understanding the benefits of the mitigation activities is to understand the cost associated with the projects and then calculate the benefits of them. This is the strength of the EAD analysis because it gives water resources managers the tools to calculate how the benefits we see in the EADs relate to the approximate costs of the projects using benefit-cost ratios, presented in the following section.

7.0 CALCULATION OF BENEFIT-COST RATIO

The application of benefit-cost ratio (BCR) calculations allows the user to compare the costs and benefits of the various mitigation projects. An industry-standard tool in the development of BCRs is FEMA's BCA Toolkit. This approach assumes mitigation projects with equal design lives and applies a discount rate to account for the time value of money. The result is a ratio that is less than or greater than one indicating whether the project has a net cost or positive benefit, respectively. This section presents the approach and assumptions applied to calculating the BCR.

7.1 Benefit-Cost Approach and Procedure

The value proposition of each mitigation project is that the benefits, or damage costs avoided, will exceed the cost to construct the mitigation option. The C-8 and C-9 FPLOS Phase 2, Task 2 technical memorandum outlined the cost to construct each mitigation project. These costs are estimated in 2021 values. To assess the benefits of each mitigation option, this study calculated the total damage caused by four storm events (5-year, 10-year, 25-year, and 100-year) with and without the mitigation project. The before and after mitigation damages utilized the worst-case SLR condition expected during the life of the project, SLR3. The FEMA BCA toolkit utilized these damages and the initial project costs to calculate a benefit and cost in 2021 dollars for both a 3% and 7% discount rate. Essentially, the toolkit calculated the expected reduction in damages and compared it to the mitigation project costs to develop the BCR for each project. An example FEMA BCA Toolkit dashboard is provided below in **Figure 7.1** for mitigation project M2A in the C-8 Basin



Project Configuration

Project Title:	C-8 M2A
Property Location:	Miami-Dade County, Florida — Use Property Location? Yes
	OR
Latitude: / Longitude:	25.6141830 / -80.5679064 — Use Decimal Degrees? Yes
	33187 / Florida / Miami-Dade
Property Structure Type:	Residential Building
Hazard Type:	Riverine Flood
Mitigation Action Type:	Drainage Improvement
Property Title:	Drainage Improvement @ Miami-Dade County, Florida
Damage and Frequency Relationship based on:	Modeled Damages / Historical Damages / (selected) Professional Expected Damages

Cost Estimation

Enter the Project Useful Life (years):	50
Enter the Initial Project Costs ($):	179,000,000
Enter the Number of Maintenance Years:	50 — Use Default? Yes
Enter the Annual Maintenance Costs ($):	0
Total Mitigation Project Cost ($):	179,000,000

Damage Analysis Parameters - Damage Frequency Assessment

Year of Analysis was Conducted:	2021
Year Property was Built:	2021
Analysis Duration (years):	50 — Use Default? No

Professional Expected Damages Before Mitigation

Damages Before Mitigation:

Add Row Delete Row(s)

		OTHER	OPTIONAL DAMAGES			VOLUNTEER COSTS		TOTAL
SELECT	RECURRENCE INTERVAL (YEARS)	DAMAGES ($)	Category 1 ($)	Category 2 ($)	Category 3 ($)	NUMBER OF VOLUNTEERS	NUMBER OF DAYS	DAMAGES ($)
☐	5	176,195,776	0	0	0	0	0	176,195,776
☐	10	237,599,289	0	0	0	0	0	237,599,289
☐	25	385,761,216	0	0	0	0	0	385,761,216
☐	100	659,630,251	0	0	0	0	0	659,630,251

View Annualized Results

Professional Expected Damages After Mitigation

Damages After Mitigation:

Add Row Delete Row(s)

		OTHER	OPTIONAL DAMAGES			VOLUNTEER COSTS		TOTAL
SELECT	RECURRENCE INTERVAL (YEARS)	DAMAGES ($)	Category 1 ($)	Category 2 ($)	Category 3 ($)	NUMBER OF VOLUNTEERS	NUMBER OF DAYS	DAMAGES ($)
☐	5	124,245,954	0	0	0	0	0	124,245,954
☐	10	167,761,457	0	0	0	0	0	167,761,457
☐	25	276,803,049	0	0	0	0	0	276,803,049
☐	100	465,150,799	0	0	0	0	0	465,150,799

View Annualized Results

Standard Benefits - Ecosystem Services

Additional Benefits - Social — Note: Available only if a Residential property and Standard Benefits are greater than zero.

Benefit-Cost Summary

Total Standard Mitigation Benefits ($):	$ 242,506,176 — Analysis at 3%
Total Social Benefits ($):	$ 0
Total Mitigation Project Benefits ($):	$ 242,506,176
Total Mitigation Project Cost ($):	$ 179,000,000
Benefit Cost Ratio - Standard:	1.35
Benefit Cost Ratio - Standard + Social:	1.35

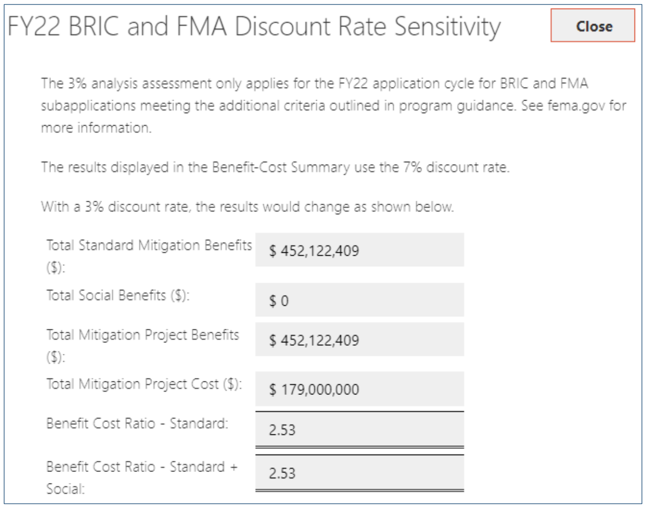


Figure 7.1 FEMA BCA Toolkit Example

The dashboard is separated into several subsections, each of which is described below:

- Project Configuration: lists the project name, type, and location. This subsection includes the option to use professional expected damages as is used in this type of future damage analysis.
- Cost Estimation: lists the initial project costs and design life. Maintenance life is shown in this subsection, but no maintenance costs are used in this calculation.
- Damage Analysis Parameters: lists the year of the analysis and duration of analysis.
- Professional Estimated Damages Before Mitigation: lists the total damages calculated for each return period prior to any mitigation efforts.
- Professional Estimated Damages After Mitigation: lists the total damages calculated for each return period following the implementation of a mitigation project.
- Standards Benefits and Additional Benefits: list ecosystem and social improvements from the mitigation projects. These benefits were not included in any of the project BCR calculations.
- Benefit-Cost Summary: lists the results of the analysis, including Total Mitigation Benefits, Total Project Cost, and Benefit Cost Ratio based on a 7% discount rate. This subsection includes the "Analysis at 3%" option for using a 3% discount rate. This option opens the FY22 BRIC and FMA Discount Rate Sensitivity subsection.
- FY22 BRIC and FMA Discount Rate Sensitivity: lists the results of the analysis, including Total Mitigation Benefits, Total Project Cost, and Benefit Cost Ratio based on a 3% discount rate.

For this analysis of each mitigation alternative, the benefit-cost ratio (BCR) is the ratio between total damages mitigated over a 50-year design life and the 2021 costs, or:

$$BCR_{Mx} = \left(\frac{TMB_{Mx}}{C_{Mx}}\right)$$

Where,

- TMB_{Mx} = Total Mitigation Benefit (expected damage reduction from mitigation activity x)
- C_{Mx} = total cost of the mitigation activity *x*

7.1.1 Assumptions and limitations

- To allow comparisons between BCR results, this study assumes each project has a 50-year design life, with a SLR3 condition.
- The BCR analysis requires a cost estimate for each mitigation project. These cost estimates, presented in Task 2 technical memorandum, are assumed to start at year 0. This negates the fact that each project may take several years to build; realistically, not all of the projects will likely be built simultaneously at year 0, nor it is advantageous to build them all now.
- This BCR analysis does not consider the increase of the building stock over time, nor does it consider an increase in construction costs for each mitigation project.
- Only the initial cost of the mitigation project is included in this calculation, not periodic operations and maintenance.
- This study applied discount rates of 3% and 7%, as per the U.S. Office of Management and Budget (OMB) for federal public investments.

7.2 Results

The following tables (**Table 7.1** - **Table 7.2**) and graphs **(Figure 7.1** - **Figure 7.2**) present the results of the BCR analysis. A BCR result above one indicates a favorable benefit to cost ratio and vice versa. The table presents the results of all projects under SLR 3 conditions, with and without mitigation conditions. Values in the tables are shown in millions. The graphs exclude the extreme results from the M3 projects since their implementation is not practical as an immediate mitigation measure.

Table 7.1 Benefit-Cost Ratio Table for the C-8 Basin

Benefit-Cost Ratio for C-8 Basin (2021 Dollars)

	M0	**M1**	**M2A**	**M2B**	**M2C**	**M3(1ft)**	**M3(2ft)**	**M3(3ft)**
	SLR3	SLR3	SLR3	SLR3	SLR3	SLR3	SLR3	SLR3
Discount Rate 3%:								
Benefits [M$]	-1553	92	452	543	605	1135	1414	1515
Costs [M$]	0	20	179	228	298	179	281	436
BCR	--	4.60	2.52	2.39	2.03	6.34	5.03	3.48
Discount Rate 7%:								
Benefits [M$]	-833	49	243	291	324	609	759	812
Costs [M$]	0	20	179	228	298	179	281	436
BCR	--	2.45	1.36	1.28	1.09	3.40	2.70	1.86

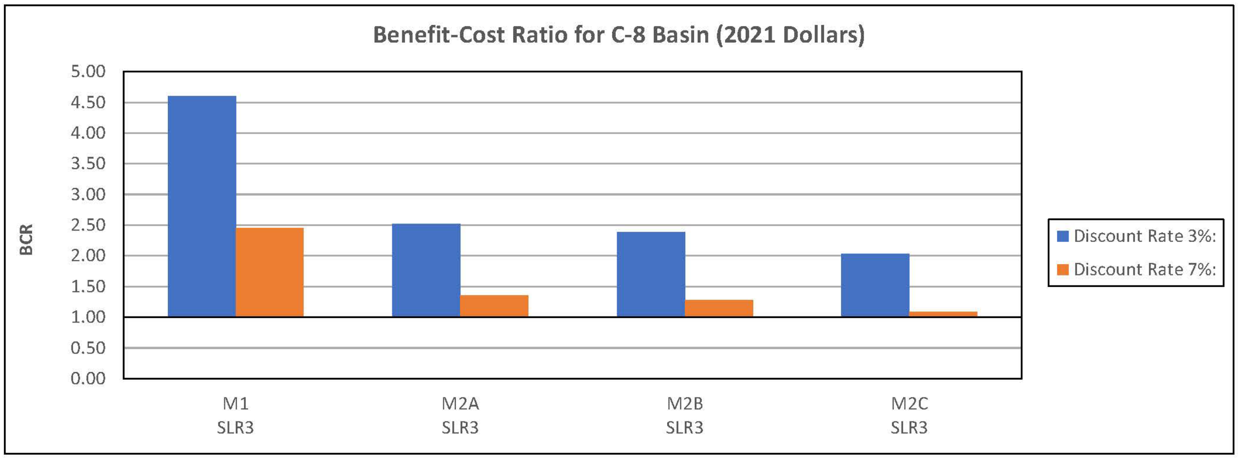


Figure 7.2 Benefit-Cost Ratio Graph for the C-8 Basin

Table 7.2 Benefit-Cost Ratio Table for the C-9 Basin

Benefit-Cost Ratio for C-9 Basin (2021 Dollars)

	M0 SLR3	M1 SLR3	M2A SLR3	M2B SLR3	M2C SLR3	M3(1ft) SLR3	M3(2ft) SLR3	M3(3ft) SLR3
Discount Rate 3%:								
Benefits [M$]	-3967	73	290	382	440	2489	3212	3560
Costs [M$]	0	37	194	236	394	264	372	549
BCR	--	1.97	1.50	1.62	1.12	9.42	8.65	6.48
Discount Rate 7%:								
Benefits [M$]	-1983	39	156	205	236	1335	1723	1909
Costs [M$]	0	37	194	236	394	264	372	549
BCR	--	1.05	0.81	0.87	0.60	5.05	4.64	3.47

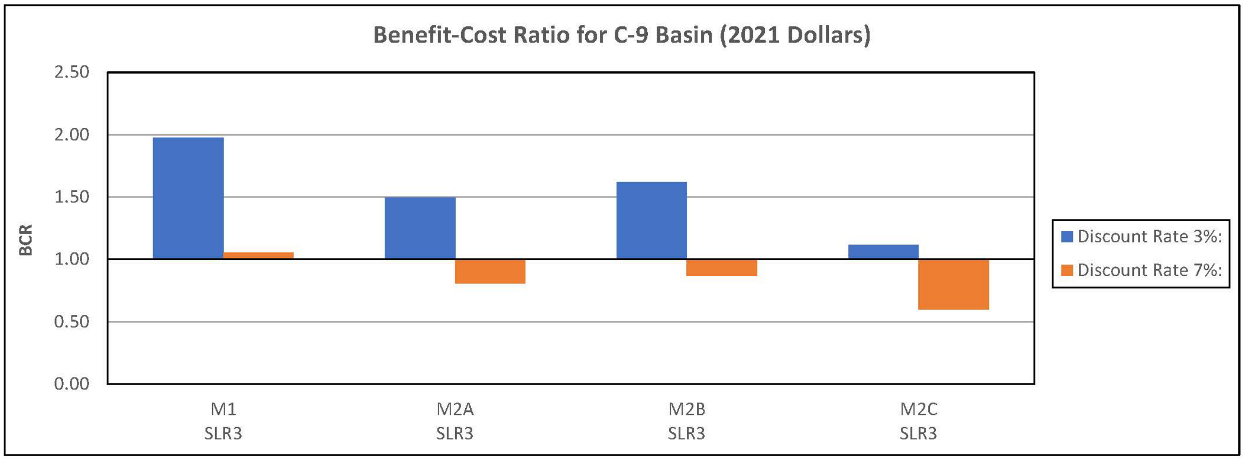


Figure 7.3 Benefit-Cost Ratio Graph for the C-9 Basin

The results indicate that for the C-8 basin, all projects achieved a favorable result at both discount rates (BCR>1). And for the C-9 basin all the projects achieved favorable results at a 3% discount rate and only the M-1 projects achieved a favorable result for the 7% discount rate. . The M3 projects however depict extremely low costs for the resultant benefits under both discount rates.

7.2.1 M0 Projects

These results are based on no mitigation projects (existing conditions) under the SLR3 scenario over a period of 50 years. They provide a baseline for comparison of the mitigation activities.

7.2.2 M1 Projects

These projects are micro or local-scale projects that have great benefit at a small scale. Communities are using these projects to address specific flooding issues and can see benefits that are not easily modeled or calculated at basin scale. For the FPLOS Phase 2 study these projects were identified through input from communities, but most do not have sufficient detail to apply their costs and benefits in this analysis with great certainty. As such, the basin-wide BCR analysis presented here may overestimate the costs and underestimate the benefits. As communities continue to define these projects, they apply small scale modeling and economic analysis to better understand the true BCR results.

7.2.3 M2 Projects

This category of mitigation projects includes M2A, M2B, and M2C under SLR3 conditions. **Table 7.1** and **Table 7.2** show that these mitigation activities provide substantial benefits with BCRs greater than two under all scenarios for the C-8 basin at a 3% discount rate. And, the M2 projects all achieve over 1 BCR for all SLRs's with the 7% discount rate. While the BCR results for the C-8 basin decline from M2A to M2C, all the M2 projects provide BCRs greater than one. Within the C-9 basin the M2A, M2B, and M2C achieve over 1 BCRs for 3% discount rate but only the M1 projects achieve BCR >1 for the 7% discount rate.

These are very good results and should give water managers confidence to move forward with the mitigation projects.

7.2.4 M3 Projects

The M3 projects are planning level projects that help managers understand the costs and benefits of raising all the buildings and roads above flooding and sea level rise impacts. For consistency with previous efforts, the costs associated with these efforts followed the approach and values presented in Deltares 2018. These costs, and therefore the resulting BCRs, have large uncertainty.

As stated above, all M3 projects achieve extremely favorable BCRs due to the high benefits of this type of mitigation strategy. The M3 mitigation activities show large benefits by design since we have elevated all structures above the flooding, thus avoiding damages.

However, these projects are only conceptual in this project. It is very difficult to imagine raising all the houses and roads in the basins. In fact, recent efforts by communities to raise roads and homes has found the unintended consequences of ponding and flooding. These issues will have to be considered carefully by the communities as they look to reduce the flood risks in a basin.

7.2.5 Benefit-Cost Ratio Conclusions

The BCR results shown here are based on multiple estimates and assumptions, each with its own significant amount of uncertainty. The total uncertainty is hard to quantify and, while it could be done, would not shed any significant light on the results. In fact, uncertainty in a planning level document is expected and should be considered in next steps. These BCRs and especially the graphic representation of the EAD results via maps, can help managers further design and refine mitigation activities with more focused BCR and EAD analysis.

7.2.6 Indirect Impact to Benefit-Cost Ratios

The previous analysis is based on reducing the direct costs of flooding impacts to infrastructure. However, there are other indirect costs that should be considered.

Floods can have indirect impacts on a community that extend beyond the physical damage to property and infrastructure. Some examples of indirect impacts of floods on a community include:

- Disruption of social networks: Floods can displace individuals and families, disrupting their social networks and support systems. This can lead to feelings of isolation and loneliness, which can have long-term mental health impacts.
- Loss of economic activity: Floods can disrupt economic activity, especially if businesses are damaged or forced to close. This can result in job losses and reduced economic growth in the affected community.
- Increased healthcare costs: Floods can lead to increased healthcare costs due to injuries, waterborne illnesses, and mental health issues related to the flood. This can strain the resources of local healthcare providers and lead to increased costs for individuals and the community.
- Environmental impacts: Floods can have environmental impacts, such as soil erosion, water pollution, and habitat destruction. These impacts can affect local ecosystems and wildlife populations, as well as the long-term health of the community.

- Displacement of vulnerable populations: Floods can disproportionately affect vulnerable populations, such as low-income households, elderly individuals, and people with disabilities. Displacement can be particularly challenging for these populations, who may have limited resources and support systems.

Overall, the indirect impacts of floods on a community can be far-reaching and long-lasting. It is important to consider these impacts when assessing the full extent of the economic and social costs of a flood.

8.0 CONCLUSIONS

This technical memorandum has presented the calculation of expected annual damages and resulting net present value calculations based on modeled flood hazard risks and mitigation scenarios.

Expected annual damages are calculated using the District's FIAT tool. This tool intersects GIS databases of hazards (flood risks) and exposure data (buildings and roads) with depth damage functions to calculate the economic damages for multiple event frequencies. These multiple frequencies are integrated to calculate an expected annual damage for each time frame (such as current conditions or a future SLR) and mitigation scenario.

This study examined four mitigation scenarios – current conditions with no mitigation (M0), local (or micro) mitigation projects (M1), regional scale mitigation projects (M2), and policy and land use mitigation projects (M3). Regional scale mitigation projects, evaluated and modified with increasing ability to reduce flooding in the primary canals, addressed sea level rise scenarios 1, 2, and 3 via mitigation projects M2A, M2B, and M2C. All EAD calculations compared future sea level conditions and mitigation projects to current conditions.

The C-8 basin experiences increases in flood damages of 43% for SLR1, 168% for SLR2, and 465% for SLR3. By comparison, the C-9 basin experiences increases in flood damages of 5% for SLR1, 18% for SLR2, and 40% for SLR3. The difference in percent change of total EADs between the C-8 and C-9 basins is largely due to the C9 basin having significantly larger storage and is mainly drained by pump stations. The C8 basin is mostly drained by gravity, which allows elevated stages to propagate upstream into the secondary/tertiary systems. A majority of the drainage areas within the C9 basin benefit from its existing ability to drain via pump stations coupled with the ability to block elevated stages from propagating upstream into the secondary/tertiary systems. Therefore, the C9 basin does not experience as much of an increase in flood damage due to elevated stages caused by sea level rise. Ultimately the M2 mitigation projects have less of an impact on flood reduction in many parts of the C9 basin compared with the C8 basin.

The BCR analysis found many favorable projects, especially if interest rates trend closer to 3%. Ultimately the M1 projects showed the most favorable results. Water managers should keep in mind that those results are based on simple analytic solutions and should undergo more rigorous analyses. And communities should be encouraged to move forward with all local scale projects.

The regional scale projects, M2A, M2B, and M2C , showed the very good results and within the C-8 basin and M2B showed the most favorable BCR within the C-9 basin.

The BCR analysis is one metric that water managers can use to narrow down the options in mitigation activities. This metric, a very valuable one, gives some clarity on which projects would be financially reasonable – is the project cost recouped over time by reduced damages? Other elements that should be considered in selecting mitigation alternatives are:

- Impacts to downstream estuaries
- Impacts to water quality issues
- Understanding of project sequencing and adaptive management
- And many other socio-economic factors

These issues and final mitigation project alternatives are the focus of an upcoming task in this project. Task 5 will provide an overall summary of the project and clear mitigation selection.

REFERENCES

Deltares USA. (2022). *South Florida Water Management District Flood Impact Assessment Tool User Manual.*

ESP Associates. (2022). *Flood Damage Assessment Data Review for Wo5 C-8 and C-9 Watershed Flood Protection Level of Service Adaptation Planning and Mitigation Projects Study.* Prepared for Taylor Engineering, Project #JR32.400.

Federal Emergency Management Administration. (2022). Hazus Flood Technical Manual.

Taylor Engineering. (2022). *Flood Protection Level of Service Provided by Potential Mitigation Projects for Current and Future Sea Level Conditions in the C8 and C9 Watersheds.* Prepared for SFWMD C8 C9 Phase II, Deliverable 2.2.