TAYLOR ENGINEERING, INC.

Task 5.0 Comprehensive Final Report

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

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South Florida Water Management District

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Final Report

Prepared for

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EXECUTIVE SUMMARY

The Flood Protection Level of Service Adaptation Planning and Mitigation Projects Study conducted for the C-8 and C-9 Watersheds in south Broward and northern Miami-Dade Counties has assessed the future conditions of the watersheds in relation to flooding and sea level rise (SLR). The study aimed to develop basin-wide adaptation strategies to address the deficiencies identified during the Assessment Study and to identify flood mitigation projects required in the C-8 and C-9 watersheds to maintain or improve the level of flood protection provided by the District's flood control infrastructure under current conditions and in anticipation of future sea level rise conditions, groundwater level, and land use changes.

The comprehensive mitigation strategies evaluated encompassed the primary, secondary, and tertiary flood control systems and were assessed with respect to the following aspects:

- Hydrologic and hydraulic modeling assessment for different strategies in terms of lower the peak stage profiles along the primary canal and/or reduce the basin-wide flooding depths and durations for different storm events under future sea level rise conditions
    - The modeling included evaluation of existing conditions and future conditions with four simulated four rainfall events, namely the 72-hour duration, 5-year, 10-year, 25-year, and 100-year recurrence frequency design storms. Future conditions include three sea level rise scenarios – 1ft, 2 ft, and 3ft
- Benefit-Cost ratios of the projects, comparing construction costs to losses avoided
- Impacts to downstream flooding
- Impacts to downstream water quality
- An optimized project implementation sequence through a systematic Dynamic Adaptation Policy Pathway approach to adapt to sea level rise

Stakeholder Engagement

The project commenced with a workshop involving local stakeholders and an interactive website utilized for the collection of ongoing or planned mitigation activities. Effective collaboration is vital for the successful implementation of mitigation projects, and as such, the District proactively engaged local stakeholders early on in the project and conducted regular bi-weekly meetings to foster communication and facilitate project progress.

The project concluded with another workshop in Miami Dade County, where the final proposed mitigation strategies were presented, designed to enable the C-8 and C-9 watersheds to adapt to the rising sea levels.

Mitigation Strategies

The study investigated a range of mitigation strategies that included local, regional, and planning-scale projects. The local scale projects denoted as M1, encompassed various initiatives such as stormwater systems, local pump stations, and other small-scale projects.

The regional scale projects, identified as M2, included the installation of forward pumps at S-28 and S-29, improvements to salinity control structures that addressed overtopping from storm surge, improved bank elevations, and enhanced canal conveyance.

The planning scale projects, categorized as M3, incorporated 'what-if' scenarios to evaluate the efficacy of elevating all buildings and roads by 1, 2, and 3 feet to mitigate the effects of sea-level rise. The assessment of these strategies considered a wide range of factors, including efficiency in address flooding, their potential benefit-cost effectiveness, ability to reduce losses, downstream flooding impacts, and downstream water quality implications.

Hydrologic and Hydraulic modeling simulated four rainfall events, namely the 72-hour duration, 5-year, 10-year, 25-year, and 100-year recurrence frequency design storms.

Local Scale Projects (M1)

Local scale projects are characterized as smaller infrastructure additions or modifications to the secondary and/or tertiary canal systems, with expected impacts on a local scale. Typically, these projects are owned by the local municipalities, partner communities, or local drainage districts. In this study, the local scale mitigation projects assessed include:

- the Pembroke Pines three-basin interconnect at Century Village,
- injection well construction,
- upgrades to SBDD B-1/B-2 Pump Stations,
- interconnects for SBDD Basin 3/Basin 7 at Country Club Ranches,
- addition of operable structures (e.g., gates/pumps) to confluency of primary/secondary canals,
- and storage addition to non-pumped drainage areas.

In addition, this study also recommended three local level pump stations in Broward County and three local level pump stations in northern Miami Dade County.

Analytic solutions, based on the estimated area of influence and flood benefit, were utilized to assess the effectiveness of these local scale projects. These estimates are used in subsequent tasks of economic damages to assess benefits.

Regional Scale Projects (M2)

Regional-scale projects refer to larger infrastructure modifications to the primary canal system that have anticipated impacts on a regional scale beyond the immediate project area. These projects are typically considered South Florida Water Management District (SFWMD) projects. This study evaluated the following regional-scale mitigation projects:

- Dredging the C-8 Canal
- Dredging the C-9 Canal
- S-28 Improvements – such as adding a pump station, higher platform and gates, tieback levees/floodwalls
- S-29 Improvements – such as adding a pump station, higher platform and gates, tieback levees/floodwalls
- North Lake Belt Storage Area Improvements- using the western mine pits as storage
- Floodwalls and Storm Surge Barriers downstream of S-28 / S-29
- Raise embankments along S-28 Canal (separate from tieback levee/floodwall)
- Raise embankments along S-29 Canal (separate from tieback levee/floodwall)

These regional scale projects were modeled with an integrated surface water and groundwater model, MIKESHE/MIKE HYDRO RIVER, and the model output (2-D surfaces) were used in the flood damage reduction assessment to quantify the benefits of different mitigation strategies.

Planning Scale Projects (M3)

In light of changing sea levels, communities and decision-makers explored policy and land use modifications to promote the development of resilient infrastructure. As a component of this strategy, the present study conducted assessments of hypothetical scenarios wherein all buildings and roads were elevated by 1, 2, and 3 ft. These planning-level exercises facilitate decision-making regarding the optimal approach for relocating properties from flood-prone areas.

Hydrologic and Hydraulic Modeling and Assessment

The M1 mitigation projects, which were either proposed by stakeholders or identified through a vulnerability assessment in the Phase I study, were evaluated to assess their potential benefits. M1 projects include stormwater swale and infrastructure improvements, as well as drainage system enhancements. However, the basin wide hydrologic and hydraulic model used in this study applied a basin-wide scale that was not conducive to modeling these small-scale projects. Therefore, these small scale projects were not included in the detailed H&H modeling. To overcome this limitation, the team developed an approximation approach that estimated the overall benefits, area of impact, and costs of these projects for subsequent tasks in calculating the expected annual damages (EADs) associated with M1 mitigation activities.

The M2 regional scale projects encompassed a range of activities such as large-scale pumps, levee improvements, canal enhancements, and surface water storage at a significant scale. These undertakings formed the core of the hydrologic and hydraulic modeling and were assessed through the established Flood Protection Level of Service (FPLOS) performance metrics (PM), PM#1 and PM#5, specifically the peak stage profiles along the primary canals (PM#1) and flood depth at urban regions (PM#5). The employment of performance metrics facilitated the iterative refinement of M2 projects through numerous modeling efforts. These regional level projects had progressed through various stages, with M2A aiming to achieve a FPLOS that is equal to or higher than the 25-year existing conditions FPLOS under future scenarios such as SLR1, M2B targeting SLR2, and M2C focusing on SLR3. Initial modeling and screening of mitigation projects used the 25-yr event as preliminary analysis. The 25-yr event is a good indicator of how mitigation projects will perform for a “medium” sized event. Once the project progressed in analysis, the team modeled the full suite of storm events (5-, 10-, 25-, and 100-yr) for each mitigation activity.

While FPLOS performance metrics PM#1 and PM#5 continuously proved effective in quantifying potential flood reduction effectiveness, it is important to note that a comprehensive analysis of these benefits will require consideration of other factors, including expected annual damages (EADs), benefit/cost calculations (or net present value), and downstream impacts on water quality and flooding. These additional factors will enable a more comprehensive assessment of the overall effectiveness and feasibility of the proposed mitigation activities. In this study, M2 mitigation projects include:

- M2A: S-28 and S-29 forward pumps (1,550 cfs); Gate improvements (increased overtopping elevation); Tieback levees/floodwalls; Total of 500 ac-ft distributed storge; Optimized gate/pump controls for SLR

- M2B: S-28 and S-29 forward pumps (2,550 cfs); Gate improvements (increased overtopping elevation); Tieback levees/floodwalls; Total of 500 ac-ft distributed storge; Primary canal improvements; Optimized gate/pump controls for SLR; addition of internal drainage system
- M2C: S-28 and S-29 forward pumps (3,550 cfs); Gate improvements (increased overtopping elevation); Tieback levees/floodwalls; Total of 500 ac-ft distributed storge; Primary canal widening; Optimized gate/pump controls for SLR; addition of internal drainage system

The M3 mitigation activities, which are of a planning nature, involved an examination of the possibility of raising all buildings and roads in a watershed by +1, +2, and +3 ft in the SLR1, SL2, and SLR3 scenarios, respectively. While there is no modeling associated with these activities, the study team conducted an assessment of the estimated cost for these proposed measures. The benefits of these projects were calculated in the expected annual damage (EAD) task.

The M2 mitigation activities provided an opportunity to compare the achieved FPLOS metrics PM#1 and PM#5. The key findings related to these activities and the corresponding metrics were as follows:

- The primary hydraulic objective of M2 projects (M2A, M2B, and M2C) was to attain a PM#1 maximum peak stage profile and PM#5 flood depths that were equal to or lower than the 25-year existing conditions for the respective SLR1, SLR2, and SLR3 storm events.
    - M2A
        - Mitigation M2A, while not completely meeting the goals set for the 25-year SLR1 event, was projected to be highly effective in mitigating the adverse effects of a 1-foot sea level rise in both the C-8 and C-9 Watersheds.
        - Under SLR2 and SLR3, Mitigation M2A was predicted to fall short of achieving canal stages and flood levels equal to or lower than the existing conditions. However, it is still expected to provide significant improvements compared to no mitigation.
    - M2B
        - Mitigation M2B, despite not fully achieving the goals set for the 25-year SLR2 event, is predicted to be highly effective in mitigating the negative impacts of a 2-foot sea level rise in both watersheds.
        - Under SLR1, Mitigation M2B is expected to meet the goals set for Mitigation M2A and demonstrate substantial improvements. Mitigation M2B is projected to achieve canal stages and flood levels equal to or lower than the existing conditions for all simulated rainfall events.
        - Under SLR3, Mitigation M2B is anticipated to provide significant improvements compared to no mitigation.
    - M2C
        - Mitigation M2C, although not fully meeting the goals set for the 25-year SLR3 event, is predicted to be highly effective in mitigating the adverse effects of a 3-foot sea level rise in both watersheds.
        - Under the SLR1 scenario, Mitigation M2C is expected to achieve canal stages and flood levels equal to or lower than the existing conditions for all simulated rainfall events.
        - Under SLR2, Mitigation M2C is projected to largely achieve canal stages and flood levels equal to or lower than the existing conditions for all simulated rainfall events.

- Under SLR3, Mitigation M2C is anticipated to provide significant improvements compared to no mitigation.

These comparisons to the FPLOS metrics provided valuable insights from the hydrology and hydraulic perspective. A more comprehensive understanding of the mitigation activities' economic consequences was also derived from the calculated EADs.

Regarding the impacts of increasing pump sizes on water quality and downstream flooding, minimal impacts have been observed except in cases involving the largest pump sizes of 3,550 cfs. It was recommended that the District explore additional green infrastructure techniques to minimize these impacts.

Flood Damage Assessment

This task aimed to evaluate the economic damages of flooding due to rainfall runoff and sea level rise and assessed the effectiveness of four mitigation scenarios in terms of damage reduction. The South Florida Water Management District Flood Impact Analysis Tool (SFWMD-FIAT) was used to estimate the economic damages from flooding using three datasets, including depth damage functions (DDFs), exposure data, and flood hazard data.

The study compared the estimated annual damages (EADs) for future sea level conditions and mitigation projects to those of current conditions. Three sea level rise scenarios (SLR1, SLR2, and SLR3) were evaluated to provide a comprehensive understanding of the potential impacts of flooding on the C-8 and C-9 basins.

Without implementing any flood mitigation projects, the results showed a significant increase in flood damages in the C-8 basin, ranging from 43% for SLR1 to 465% for SLR3. However, in the C-9 basin, the increase in flood damages was comparatively lesser, ranging from 5% for SLR1 to 40% for SLR3. This disparity in the percent change of total EADs was mainly due to the C-9 basin's larger storage capacity and its reliance on pump stations for drainage, which prevented elevated stages from propagating upstream into the secondary/tertiary systems.

The assessment revealed that regional scale mitigation projects (M2), specifically M2A, M2B, and M2C, were effective in reducing flood damages in the C-8 basin. Although the impact was relatively less in the C-9 basin, it is worth noting that the pump stations in the basin are efficient in draining floodwaters. The benefit-cost assessment, along with the downstream flooding impact assessment and water quality impact assessment, further justified the effectiveness of different strategies.

Benefit-Cost Ratio Analysis

This task aimed to evaluate the economic damages of flooding due to rainfall runoff and sea level rise and assessed the effectiveness of four mitigation scenarios in terms of damage reduction. The South Florida Water Management District Flood Impact Analysis Tool (SFWMD-FIAT) was used to estimate the economic damages from flooding using three datasets, including depth damage functions (DDFs), exposure data, and flood hazard data.

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Dynamic Adaptive Policy Pathways (DAPP)

The Dynamic Adaptive Policy Pathways (DAPP) was developed as an analytical framework that facilitates decision-making under deep uncertainty. Given the uncertainties that exist with future sea level rise, future development and land use conditions, and future water management constraints, the FPLOS studies are suited to the use of DAPP to develop plausible mitigation scenarios. Potential actions are visually depicted with an Adaptations **Pathway** Map that indicates the effectiveness of the action to achieve the desired performance level. For the C-8 and C-9 watersheds, the DAPP analysis included these inputs:

- Sea level rise (SLR) curves
- Estimated Annual Damages (EAD)
- Thresholds and Tipping Points

Two SLR curves were used for the DAPP analysis: (1) the NOAA 2017 Intermediate High; and (2) the NOAA 2017 High. They were interpolated for 2021 start year to estimate a rise of 1-, 2-, and 3-ft. The EAD's have been developed using the Districts' Flood Impact Assessment Tool (FIAT). The threshold amounts are determined by the current conditions economic damages assessment. Because the DAPP analysis incorporates two SLR curves (the NOAA 2017 Intermediate High and the NOAA 2017 High), the timing of the tipping point of threshold exceedance varies. It will also vary based on the mitigation strategy being implemented. The tipping point indicates that the strategy exceeds the current level of damages, suggesting the strategy is not performing, or has exceeded its capacity to accommodate additional flooding, and additional flood mitigation measures are needed.

The DAPP for the C-8 and the C-9 watersheds presented the capacity of the proposed mitigation projects to accommodate amounts of sea level rise and/or the time associated with that level of sea level rise. For example, if a mitigation project can reduce the sea level rise impacts by 2.0 ft that would give the basin until the year 2060 to be at the same level of service as current conditions. The results for the two basins are highlighted in the bullets below.

1. M1: It can accommodate up to 0.5-ft SLR to year 2032 (NOAA Intermediate High) or to year 2030 (NOAA High).
2. M2A: It can accommodate up to 0.8-ft SLR to year 2038 (NOAA Intermediate High) or to year 2035 (NOAA High).
3. M2B: It can accommodate up to 1.7-ft SLR to year 2054 (NOAA Intermediate High) or to year 2048 (NOAA High).

4. M2C: It can accommodate up to 2 -ft SLR by 2060 (NOAA Intermediate High) or to year 2053 (NOAA High).

The adaptation pathways for C-9 indicated that all strategies accommodated some degree of SLR, with M2B and M2C providing long-term risk reduction, though less than in C-8.

1. M1: It can accommodate up to 0.4-ft SLR to year 2030 (NOAA Intermediate High) or to year 2029 (NOAA High).
2. M2A: It can accommodate up to 0.7-ft SLR to year 2036 (NOAA Intermediate High) or to year 2033 (NOAA High).
3. M2B: It can accommodate up to 1.3-ft SLR to year 2048 (NOAA Intermediate High) or to year 2043 (NOAA High).
4. M2C: It can accommodate up to 1.5-ft SLR by 2052 (NOAA Intermediate High) or to year 2046 (NOAA High).

The DAPP results can help water managers understand the benefits, with respect to addressing sea level rise, of each mitigation project. Both basins would benefit from all of the projects, with the larger scale projects giving the most time, as would be expected. The key takeaway from this analysis would point to the benefit of a progressing mitigation strategy that includes M1 projects immediately and then progresses from M2A, to M2B, and finally M2C. Water managers could continue to assess the actual rate of SLR and the ability of the basins to respond to mitigation activities to decide on timing of the progression to each activity. Clearly, it would be advantageous to begin with M2A right away and then assess when the next activities are required.

One of the strengths of using the DAPP framework is the level of transparency available to decision-makers. The DAPP process does not result in an exclusive answer; it does not determine which pathways are optimal. It serves to clarify the anticipated performance of mitigation options for decision-makers to be more informed and to indicate alternative adaptation planning strategies to accommodate funding restrictions, stakeholder preferences, etc., as viable. The data can be viewed with different time scales, varied geographic or jurisdictional boundaries, or different SLR projections. Each lens can yield valuable information on the anticipated impact and duration of the mitigation actions.

Impacts on Downstream Water Levels from S-28 and S-29 Structure Outflows

The FPLOS modeling was limited in resolving water levels downstream of the S-28 and S-29 structures as the FPLOS model did not include the storage of Biscayne Bay and its multiple connections to the Atlantic Ocean. Thus, additional modeling was required to evaluate the downstream effects of the S-28 and S-29 structures gate and pump outflows on water levels in the urban areas downstream of these coastal structures during normal tides and 10-yr surge event conditions.

This task employed a state-of-the-art 2D numerical model—the Biscayne Bay Model (BBM)—to evaluate water levels downstream of S-28 and S-29 with FPLOS outflows. The BBM leveraged an existing MIKE21 hydrodynamic model for Bakers Haulover Inlet, Biscayne Bay, and Intracoastal Waterway (IWW). MIKE SHE is an integrated hydrological modeling software used for analyzing groundwater, surface water, recharge, and evapotranspiration processes. MIKE 21 simulates processes with surface water flows, waves, sediments and ecology in rivers, lakes, estuaries, bays, coastal areas, and seas. Because of these functionalities, this tool can achieve the objective of this task. The BBM also leveraged ADCIRC+SWAN model data and output to expand the model to include upstream areas to the bay that may be inundated with a 10-yr surge flood event. Data collection and field measurements provided the input data for the

BBM validation. The existing MIKD21 and the ADCIRC+SWAN models provided the boundary conditions for normal tides and 10-yr surge event conditions BBM production runs.

Model results showed the effects of FPLOS structure outflows were limited to water depths in the downstream areas near the structures and maximum water depths in the main Biscayne Bay area were not substantially affected by the FPLOS S-28 and S-29 structure outflows, as expected. Model results also indicated rising sea levels generally decreased the effect of the FPLOS S-28 and S-29 structure outflows on normal tides and 10-yr surge maximum water depths (or water levels). In addition to the net differences in terms of flood depth, our simulations have indicated that Scenarios M2A and M2B resulted in little to no increase in the peak stage profiles for the canal segment downstream of the tidal structures, thereby preserving the conveyance from the secondary and tertiary systems to the primary system. However, it must be noted that Scenario M2C has the potential to negatively impact the downstream urban areas by increasing flood risks. If the proposed M2C is advanced to the implementation phase, it is crucial that additional mitigation and adaptation strategies be developed to address the downstream impacts.

Potential Water Quality Impacts to North Biscayne Bay

Canal discharges, as a result of non-profit pollution carried over from upstream areas and secondary and tertiary systems into the primary system, may affect the water quality in Biscayne Bay. Phase II included the evaluation of water quality impacts resulting from the proposed mitigation strategies and the ability to meet existing water quality standards within the Biscayne Bay Aquatic Preserve. The study area is North Biscayne Bay, which is part of the Biscayne Bay Aquatic Preserve and designated as Outstanding Florida Waters (OFW). The purpose of this analysis was to evaluate potential changes in water quality (WQ) to downstream receiving water bodies (Biscayne Bay) that could potentially result from proposed mitigation projects in the C-8 and C-9 canals and flows at the outfall structures. Potential environmental impacts pertaining to marine life and seagrass were evaluated. Some general conclusions of the water quality analysis for each watershed are summarized below.

Note that the terms ‘positive’ and ‘negative’ in the context of the correlation/regression analysis results refer to the direction of correlation (proportional or inversely proportional, respectively) and do not refer to WQ benefits or negative impacts.

<u>C-9 Watershed</u>

- Constituent of Concern (COC’s)
    - Chlorophyll a, TN, DO, and copper. In addition, salinity, TP, and turbidity were identified for further analysis.
- Correlation/regression analyses results:
    - Salinity
        - A <u>moderate negative</u> association exists between cumulative volume inputs from the S-29 and salinity concentrations at BB02.
    - Chlorophyll *a*
        - A <u>moderate positive</u> association exists between cumulative volume inputs from the S-29 and chlorophyll *a* concentrations at BB02.
    - TN
        - <u>No statistically significant</u> association exists between cumulative volume inputs from the S-29 and TN concentrations at BB02.
    - TP

        - No statistically significant association exists between cumulative volume inputs from the S-29 and TP concentrations at BB02 in the Pearson coefficient. Hence, regression analyses could not be performed.
    - DO
        - A weak negative association exists between cumulative volume inputs from the S-29 and DO concentrations at BB02.
    - Turbidity
        - A weak positive association exists between cumulative volume inputs from the S-29 and turbidity concentrations at BB02. A regression analysis could not be performed due to the statistically significant accumulation period not matching the modeling data time window.
    - Copper
        - No statistically significant association exists between cumulative volume inputs from the S-29 and copper concentrations at BB02.

- WQ Impacts:
    - Cumulative volume discharges from the C-9 were shown to be lower for all scenarios across all return periods compared to existing conditions (M0-SLR0) except for scenario M2C-SLR1 and M2C-SLR2. Hence, WQ conditions may be maintained or improved under most scenarios
        - M2C scenarios are associated with more frequent short term negative or uncertain impacts, while M2A scenarios are associated with less frequent negative impacts.

- Mitigation scenario impacts to marine life and seagrass were evaluated
    - The 100-year return period storm for the M2A, M2B, and M2C scenarios is anticipated to violate the salinity tolerances of American Oyster and Johnson's Seagrass, two indicator species for NNB-A. Only scenario M2C-SLR1 is anticipated to lead to lower salinities compared to existing conditions (M0-SLR0). Regarding TN loads, only scenario M2C-SLR1 would result in increased TN loads compared to M0-SLR0 for all return periods.

C-8 Watershed

- COCs identified:
    - Chlorophyll a, TN, TP, DO, and turbidity. In addition, salinity was identified for further analysis.
- Correlation/regression analyses results:
    - Salinity
        - A weak to moderate negative association exists between cumulative volume inputs from the S-28 and salinity concentrations at BB09.
    - Chlorophyll a
        - A moderate positive association exists between cumulative volume inputs from the S-28 and Chlorophyll a concentrations at BB09.
    - TN
        - A moderate to strong positive association exists between cumulative volume inputs from the S-28 and TN concentrations at BS01.
    - TP
        - Correlation/regression analyses could not be performed due to data deficiencies. See *Appendix B* for further details.

    - DO
        - A weak negative association exists between cumulative volume inputs from the S-28 and DO concentrations at BB09.
    - Turbidity
        - No statistically significant association exists between cumulative volume inputs from the S-28 and turbidity concentrations at BB09.
    - WQ Impacts:
        - Cumulative volume discharges from the C-8 were shown to be higher for M2C scenarios for the 100-year storm compared to existing conditions (M0-SLR0). Hence, short term negative WQ conditions may result from M2C mitigation compared to existing conditions for higher return period storms. For the 100-year storm, scenario M2B-SLR1 all M2C scenarios are projected to result in short term negative WQ conditions.
            - M2C scenarios are associated with more frequent short term negative or uncertain impacts.

- Mitigation scenario impacts to marine life and seagrass were estimated
    - Projected salinities are not anticipated to violate the tolerances of any NNB-B indicator species. All M2C scenarios may cause higher TN loads for this same return period. For the 10- and 25-year return period storms, only M2C-SLR1 and M2C-SLR2 are anticipated to cause higher TN loads.

Conclusions and Recommendations

The Flood Protection Level of Service Adaptation Planning and Mitigation Projects Study conducted for the C-8 and C-9 Watersheds in south Broward and northern Miami-Dade Counties assessed the future conditions of the watersheds in relation to flooding and sea level rise. This study assessed basin-wide adaptation strategies to address the deficiencies identified during the Assessment Study and to identify flood mitigation projects required in the C-8 and C-9 watersheds to maintain or improve the level of flood protection provided by the District's flood control infrastructure under current conditions and in anticipation of future sea level rise conditions, groundwater level, and land use changes. The assessment covered the effects of flooding, such as canal peak stage profile and basin-wide flood depth, as well as their economic implications, including expected annual damages, benefit-cost ratios, dynamic adaptive policy pathway, downstream flood impact, and the downstream water quality impact. In summary, this study recommended the following comprehensive strategies:

- County, municipalities, and local water control districts should continue to develop and implement local scale flood mitigation projects, including grey and green mitigation solutions
- The SFWMD should continue to pursue the development of regional scale mitigation projects starting with immediate implementation of M2A projects or, preferably, the larger M2B strategy.
    - Implementation of M2A for both the C-8 and C-9 watersheds will:
        - Have a positive BC ratio
        - Have little to no increase in downstream water levels and associated flood risks
        - Have little to no negative impact to WQ in Biscayne Bay
        - Can accommodate up to 0.8 ft SLR in the C-8 and 0.7 ft SLR in the C-9 watersheds. For the C-8 watershed that would be extending LOS until 2038 or 2035 (depending on SLR curve, NOAA Intermediate High or High, respectively).

        For the C-9 watershed that would extend the LOS until 2036 or 2033 (depending on SLR curve, NOAA Intermediate High or High, respectively).
    - As the District moves forward with M2A, it should be built with additional space, land, and bays for additional pumps. The structure itself could be enlarged, and additional pumps, needed to achieve M2B and M2C, could be added later.
        - This approach allows for adaptive management and does not tie the SFWMD into addressing future conditions that may or may not occur.
    - While the M2A mitigation project is the first phase of this mitigation strategy, the District should expect to quickly move to strategies M2B and M2C.
        - M2B will provide a much longer time horizon for level of service within both basins. For the C-8 watershed, the M2B strategy provides 1.7 ft accommodation for SLR or to 2054, looking at the NOAA Intermediate High curve. For the C-9 watershed, the M2B strategy accommodates 1.3 ft of SLR, or 2048 looking at the NOAA Intermediate High curve.
        - M2B has some impacts on WQ in the C-8 watershed. Therefore, additional water quality analyses and mitigation measures to modify that impact need further investigation.
        - Due to the opportunity to provide co-benefits (social environmental and water quality) along with flood risk reduction, some project components of M2B and M2C scenarios might be recommended for earlier opportunistic implementation.
        - .
    - All of the M2 mitigation strategies showed that the key component to these projects are the hardening of the control structure to withstand storm surge events and adding in a forward pump. Without these elements none of the mitigation strategies are able to minimize the affects of SLR.
        - The forward pump is critical to an overall, basin-wide flood control strategy. Without the ability to reduce peak flood stages in the primary canal, secondary and tertiary mitigation activities are not possible since there will be no capacity "downstream."
- The SFWMD should continue to investigate additional storage strategies within the basins. The addition of storage can reduce peak floods, increase infiltration and aquifer recharge, have benefits to water quality, and provide communities with the added benefits of associated green infrastructures.
    - This should include additional investigations into the mining pits in the western part of both watersheds. The larger mine-pits are in the C-9 watershed but area also available to the C-8 watershed.
- The SFWMD should continue to promote and optimize the pre-storm drawdown operations within the watersheds, along with increased inter-basin connectivity. These operational plans should also consider how to adjust gate operations for future conditions.
- Communities should continue to discuss policy and planning approaches to mitigate flooding – such as the M3 options of elevating buildings and roads throughout the watershed, especially in areas with residual flood risk.

1.0 INTRODUCTION

The South Florida Water Management District (SFWMD or District) conducted 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 Vulnerability Assessment (Phase I) 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. Flood Protection Level of Service Mitigation and Adaptation Planning (FPLOS Phase II) Studies focus on identifying mitigation and adaptation projects that will reduce flooding impacts and can show demonstrable reductions in economic consequences. Further, Phase II studies aim to understand other impacts of mitigation and adaptation projects, such as water quality and water surface elevation changes (flooding) in downstream areas. Additionally, Phase II studies aim to understand benefit-cost ratios and address dynamic adaptation policy pathway (DAPP).

This report documents the assessments and the results of each task within the overall project (**Figure 1.1**). Separate technical memorandums are available for the majority of the sections discussed below. These separate technical memorandums were included as Appendices of this report.

- Hydrologic and hydraulic modeling – Flood Reduction ***(APPENDIX D***)
- Economic flood damages reduction assessment (***APPENDIX F*)**
- Benefit/Cost assessment (***APPENDIX F***)
- Downstream impact of recommended mitigation and adaptation projects ***(APPENDIX E***)
- Water quality impact of recommended mitigation and adaptation projects (***APPENDIX H***)
- Project sequencing using Dynamic Adaptation Policy Pathway Approach (DAPP) (***APPENDIX H***)

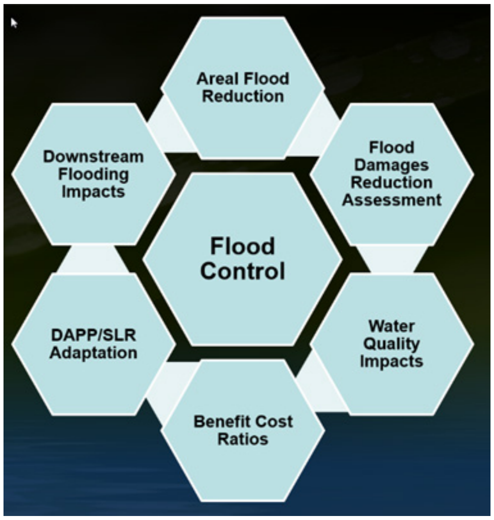


Figure 1.1 The District FPLOS Studies Focus on Systematic Approach to Ensure Infrastructure Readiness

Each element of these FPLOS Phase II studies contributed to the understanding of and selection of a final mitigation strategy. These strategies develop a progressive and adaptive solution that can evolve as managers assess the progress of predicted climate changes such as sea level rise. The focus of this study are two watersheds, the C-8 and C-9 watersheds in southern Broward and northern Miami-Dade Counties. The watersheds are shown in **Figure 1.2**.

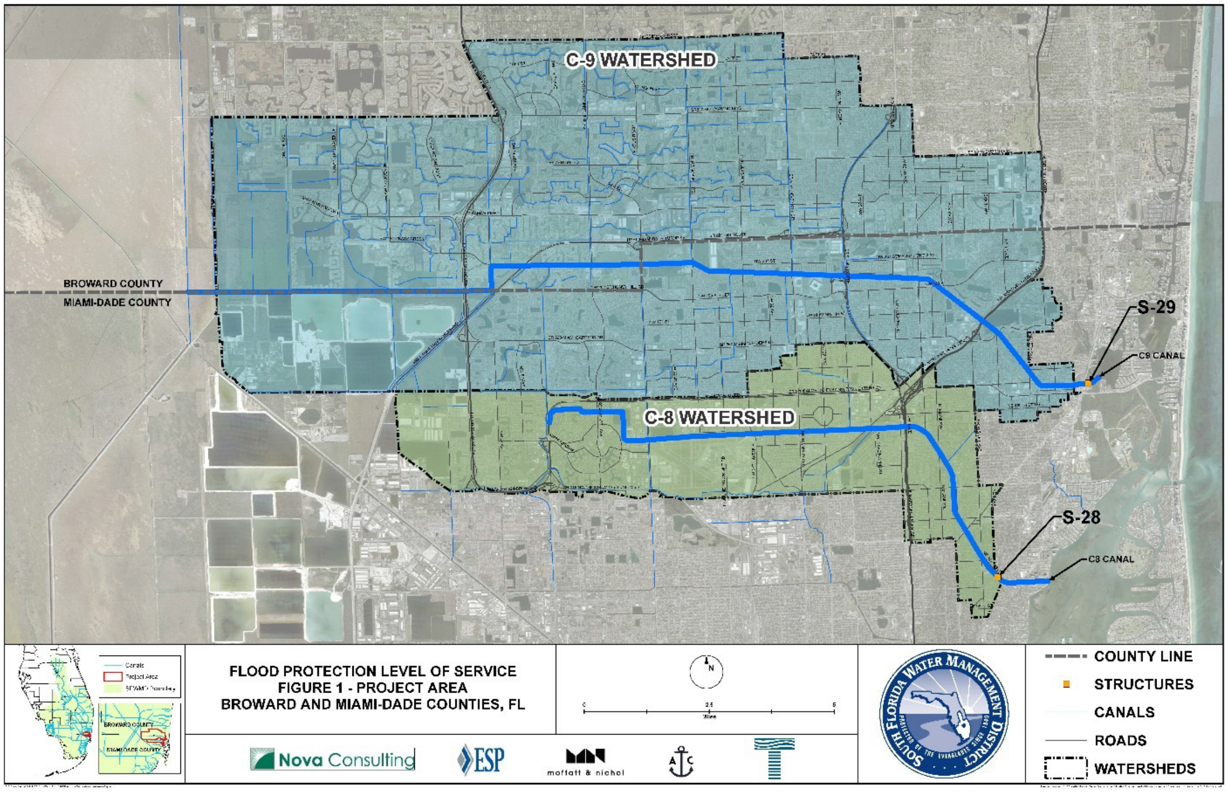


Figure 1.2 Location Map for C-8 and C-9 Watersheds in Southeast Florida

The subsequent sections of this report presents stakeholder involvement to help develop mitigation projects in **Section 2.0**; an overview of the mitigation strategies developed in **Section 3.0**; **Section 4.0** presents a high level review of the hydrologic and hydraulic modeling applied to evaluate efficacy of the mitigation projects; **Section 1.0** highlights the overall approach to calculate the Expected Annual Damages, the economics of flood damages; **Section 6.0** presents standard evaluation of the benefit cost ratios of the mitigation projects using the Federal Emergency Management Agency's (FEMA) methodology and tools; Dynamic Adaptation Policy Pathway and sea level rise assumptions are presented in **Section 7.0**; **Section 8.0** discusses the effects of mitigation projects on water levels downstream of the S-28 and S-29 structures and within Biscayne Bay; **Section 9.0** discusses the approach and methodology of a water quality analysis; and **Section 10.0** highlights the recommendations for mitigation and adaptation projects.

2.0 STAKEHOLDER WORKSHOPS

The development of mitigation strategies within the C-8 and C-9 watersheds relies on the interconnectedness of the multiple layers of flood control managed by county, municipalities, and Special 298 Districts (so called after the Florida Statue Chapter 298 that defines designated water control districts). Each partner in this overall system is responsible for elements of flood control that are influenced by other partners; nobody can work in isolation. Therefore, a key element of FPLOS Phase II studies is the active engagement and participation of stakeholders. ***APPENDIX B*** presents the stakeholder meetings and kickoff workshop.

The District engaged the stakeholders throughout this Phase II study by:

- Holding kickoff workshop asking for input and information on mitigation and adaptation projects (on August 3, 2021)
- Developing an interactive website where stakeholders could submit mitigation projects
- C-8 C-9 Basins FPLOS (buildcommunityresilience.com)
- Reviewing existing mitigation project lists such as the Local Mitigation Strategy (LMS) reports and Capital Improvement Projects (CIPs)
- Conducting 41 bi-weekly team meetings with active participation from Miami Dade, Broward County, Municipalities, and 298 Districts
- These meetings presented approaches, methodologies, assumptions, data, results, and conclusions of technical work
- A final workshop, held in Doral on April 18th, 2023, presented key study elements and conclusions (on April 18th, 2023)

The District would like to thank, in particular, the following stakeholders for their involvement in and contribution to this project:

- Kevin Hart – South Broward Drainage District
- Greg Mount – Broward County
- Susan Bodmann – Broward County
- Michael Zygnerski – Broward County
- Rajendra Sishodia – Broward County
- Alberto Pisani – Miami-Dade County
- Karina Cordero – Miami-Dade County
- Pamala Sweeney – Miami-Dade County
- Valentina Caccia – Miami-Dade County

Many others attended and participated in stakeholder meetings, but these individuals exhibited exceptional dedication, for which the team is sincerely appreciative.

3.0 MITIGATION PROJECTS (NGVD29 TO NAVD88 CONVERSION = -1.57FT)

The C-8 and C-9 watersheds comprise a network of flood control systems ranging from roadside swales and stormwater ponds to large sluice gates and pump stations capable of moving several thousand cubic feet/second of water. The system can be defined as primary, secondary, and tertiary systems (**Figure 3.1**), much like the dendritic flow of a riverine system with increasing size from river to creek to stream. Correspondingly, when defining mitigation projects, the projects can be categorized as those that affect flood control at a local scale, regional scale, or basin-wide scale. For this study, we have defined projects that impact local scale as M1 projects, regional scale as M2 projects, and basin-wide scale as M3 projects. All the projects are critical to the overall performance of the system and are dependent on each other to make the whole system work. For example, an M1 project requires that the downstream system have adequate capacity to receive the flood flows. Without the secondary systems function, a tertiary system cannot work, and so on.

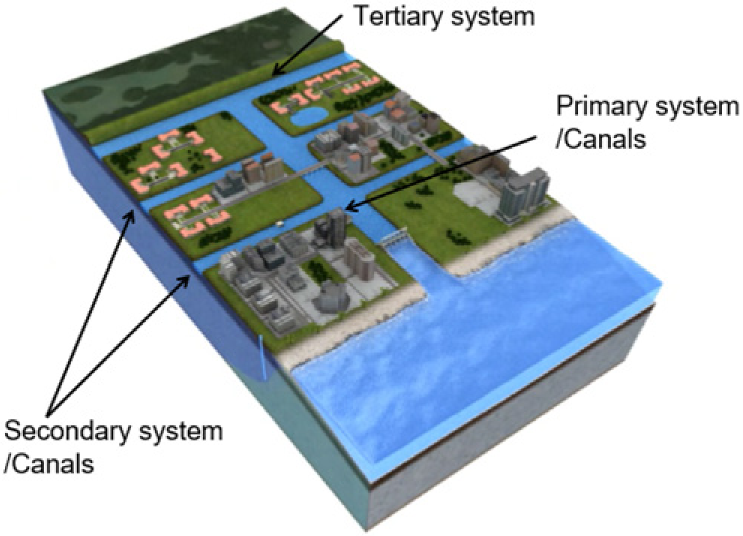


Figure 3.1 A SFWMD Depiction of Typical Flood Control Systems in South Florida (Image courtesy of the SFWMD)

An important first step in developing mitigation strategies is defining success. Mitigation and adaptation projects in the two watersheds, C-8 and C-9, are focused on 1) reducing peak water surface elevations in the primary canals during storm events (PM#1) and 2) reducing overland flooding (PM#5) – both with respect to three sea level rise scenarios. Both metrics are measured by comparing current condition with future (sea level rise) conditions with and without mitigation projects. In addition, these flood control metrics are balanced with other critical concerns such as water quality in Biscayne Bay and flooding risks downstream of the water control structures S-28 and S-29.

The SFWMD has identified standard performance metrics (PMs) to evaluate flood protection level of service (Flood Protection Level of Service Provided by Potential Mitigation Projects for Current and Future Sea Level Conditions in the C-8 and C-9 Watersheds Report, Deliverable 2.2.). For this study, PM#1 and PM#5 are two essential metrics to evaluate success. PM#1 looks at the peak water surface elevations in the primary canals and PM#5 looks at overland flooding. PM#1 plays a crucial role in the development of mitigation projects as it provides valuable insights into areas where canal banks are exceeded and require modifications. Additionally, it assesses the system's capacity to accommodate flows from secondary and tertiary systems, as previously discussed. Equally, PM#5 is critical because it identifies overland flooding and allows calculation of the economic damages from that flooding (that work is detailed in **Section 1.0** of this report).

The formulation of the outlined mitigation strategies acknowledges the interconnectedness of each proposed project and recognizes the collaborative efforts between the District and stakeholders to adapt projects and timelines in response to evolving climatological conditions. This approach allows for flexible implementation, where certain projects can be promptly executed while others can be adjusted based on the pace of sea level changes, either faster or slower than initially projected.

In this study, the term Current Conditions (or M0) is the baseline conditions for comparison to future and with/without projects. This current condition assumes no changes to existing flood protection infrastructure or regulations.

This study developed the mitigation projects that follow through a series of analyses that included, as discussed in Section 1 of this report, hydrologic and hydraulic modeling, economic analysis, adaptation pathway planning, downstream flooding assessment, and water quality analyses.

All elevations in this report are referenced to NGVD29. The NGVD29 to NAVD88 Conversion is -1.57 ft.

3.1 M1 Projects – Local Scale

M1 projects are intended to address local flooding issues, ranging from small scale stormwater projects to more substantial sluice gates and smaller pump stations. M1 projects were not included in the final modeled mitigation strategies due to scale and resolution of the model, and the assumptions adopted for the assessment (mainly the simulation of rainfall events occurring simultaneously throughout the basins). This study estimated the impact M1 local scale projects would have on reducing flooding by using analytic solutions, as opposed to hydraulic modeling as was done with regional mitigation projects.

It is important to note that local scale projects are critical to reducing flooding in secondary and tertiary systems. But, their ability to function is often predicated on the ability of the projects to discharge downstream to primary systems. So, for example, the local scale project is only effective if the receiving canal system has capacity to receive the water. Therefore, these projects must be developed in concert with larger regional scale projects that ensure the downstream systems can handle to discharges.

Local scale projects are smaller magnitude projects that have anticipated impacts on a local scale, or an area larger than the immediate project area but not to the same extent as a regional scale project. These projects are more likely to be smaller infrastructure additions or modifications to the secondary and/or tertiary canal systems. This project will evaluate the following list of local scale mitigation projects:

- Micro stormwater improvements – swales, French drains, stormwater systems and improvements
- Sluice gates – particularly on secondary canals
- Small pump stations – conceptual locations for pumps to help relieve overland flooding

The team developed M1 projects through review of mitigation projects presented in community local mitigation strategy reports, projects identified by stormwater master plans, and input from the communities themselves. Many of these projects had very limited information – often just a general location and comment of “stormwater improvements.” Other projects listed the location of pumps, which we assumed were small, local drainage improvement pumps, or the locations of sluice gates. All of the projects had assigned locations, so the team was able to estimate the area of impact based on visual assessment of the area and probable drainage patterns.

To delineate the extent of project impact on water surface elevations during different storm events, Taylor relied on a set of assumptions. In the absence of comprehensive modeling outcomes and construction plans for most projects, Taylor made a reasonable estimate that suggests a general improvement of 0.25 ft in water surface levels across all projects and storm events. Based on our knowledge, project scope, and previous experience with similar endeavors, we found this estimate to be consistent with the typical outcomes of drainage infrastructure projects.

Furthermore, the collected local level projects did not include major stormwater impoundment projects that could result in a widespread reduction of water surface elevations. The available plans for the projects indicated relatively modest enhancements. For instance, projects involving exfiltration systems, which rely solely on infiltration into the groundwater table without any direct positive outfall, would likely contribute only minor improvements to peak water surface elevations. Similarly, larger projects like pump stations and sluice gates, while capable of impacting larger areas, are expected to yield relatively minor improvements when assessed within a regional context.

The M1 projects included some general locations for pumps that could improve local drainage issues identified in Phase I. These locations of overland flooding appeared to be suitable candidates for pump stations that could move overland flooding to nearby canals. These projects are beneficial to reduce local flooding and need to be examined beyond this planning level analysis.

The M1 projects are shown in **Figure 3.2** and

. Note that the “other influence areas” were not used in calculations of EADs.

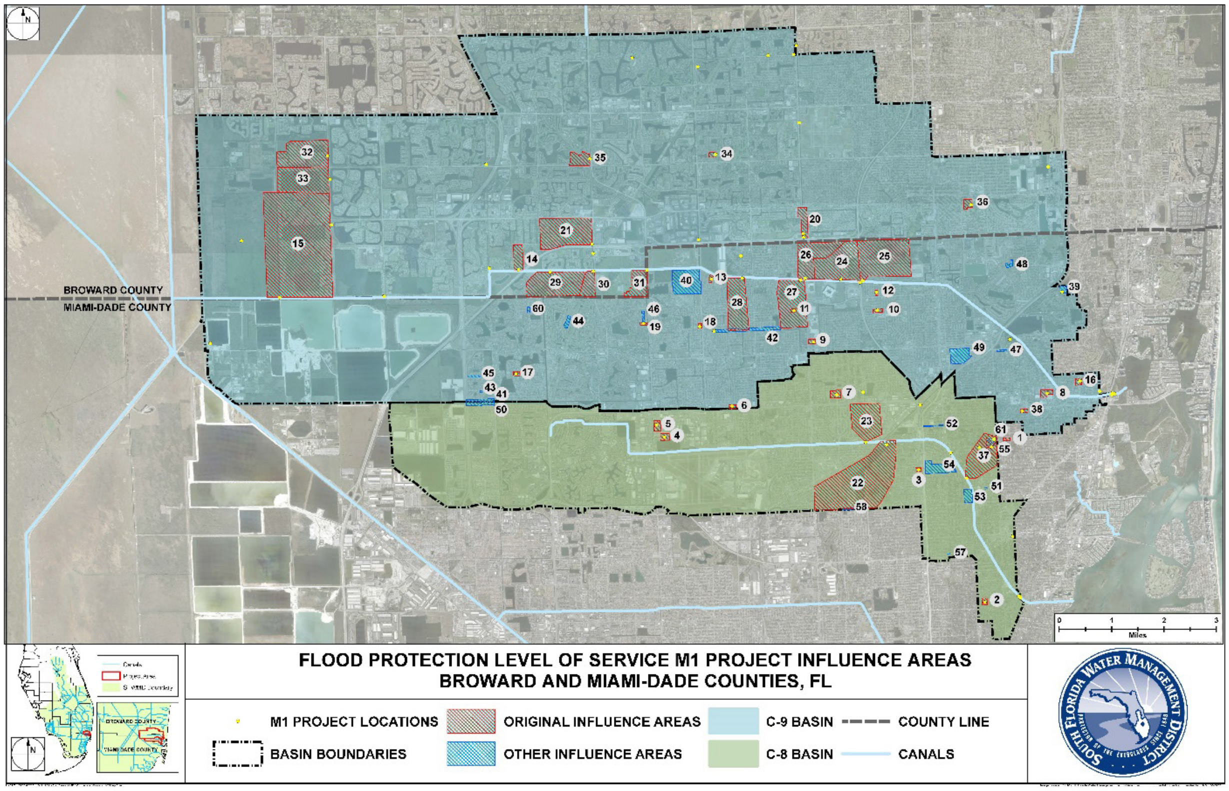


Figure 3.2 **M1 Projects Shown in C8 and C9 Watersheds**

Table 3.1 M1 Project ID, Name, and Basin

ID	PROJECT NAME	BASIN	COUNTY
1	NE 154 Street NE 7 Avenue	C-9	Miami-Dade
2	105 Street Drainage Pump Station	C-8	Miami-Dade
3	NW 146 Street and NW 7 Avenue (east end of street)	C-8	Miami-Dade
4	NW 159 Street Stormwater Drainage Project	C-8	Miami-Dade
5	NW 163 Street Drainage Improvement Project	C-8	Miami-Dade
6	NW 42 Avenue and NW 167 Terrace	C-9	Miami-Dade
7	Drainage Improvements NW 170 Street (west of 22 Ave)	C-8	Miami-Dade
8	NE 167 Street and NE 14 Avenue	C-9	Miami-Dade
9	NW 191 Street-196 Terrace	C-9	Miami-Dade
10	NW 195 Street West of NW 12 Avenue	C-9	Miami-Dade
11	Leslie Estates #4 Road and Drainage Improvements	C-9	Miami-Dade
12	20021 to 20081 NW 13 Avenue	C-9	Miami-Dade
13	20601 NW 44 Court	C-9	Miami-Dade
14	Emergency Sluice Gate into the C-9 Canal	C-9	Broward
15	Emergency Discharge Sluice Gate	C-9	Broward
16	Injection Well Construction	C-9	Miami-Dade
17	NW 178 Street and NW 82 Avenue	C-9	Miami-Dade
18	Drainage Improvements Multiple Sites	C-9	Miami-Dade
19	NW 57 PL from NW 194 St to NW 198 Terrace	C-9	Miami-Dade
20	Sluice Gate at the S-1 Pump Station	C-9	Broward
21	Interconnect at County Club Ranches	C-9	Broward
22	Potential Future Pump	C-9	Miami-Dade
23	Potential Future Pump	C-8	Miami-Dade
24	Potential Future Pump	C-9	Miami-Dade
25	Potential Future Pump	C-9	Miami-Dade
26	Potential Future Pump	C-9	Miami-Dade
27	Potential Future Pump	C-9	Miami-Dade
28	Potential Future Pump	C-9	Miami-Dade
29	Potential Future Control Structure	C-9	Broward
30	Potential Future Control Structure	C-9	Broward
31	Potential Future Control Structure	C-9	Broward
32	Encantada Sluice Gate	C-9	Broward

ID	PROJECT NAME	BASIN	COUNTY
33	Harbour Lake Estates Sluice Gate	C-9	Broward
34	Lakeside Key Storm Drainage System	C-9	Broward
35	Pembroke Pines Three Basin Interconnect	C-9	Broward
36	Pembroke Park SW 52nd Avenue Drainage	C-9	Broward
37	Potential Future Pump	C-8	Miami-Dade
38	NE 10th Avenue/NE 159th Street and NMB Boulevard	C-9	Miami-Dade
39	40 NE 197 Street NE 17 Avenue	C-9	Miami-Dade
40	Construct a wet detention pond from C-9 Canal to NW 203 Terrace From NW 47 Avenue to NW 52 Avenue	C-9	Miami-Dade
41	General drainage improvements mitigation of flood complaints at NW 169 Terrace to NW 170 St between NW 87 Avenue and I-75 Ext	C-9, C-8	Miami-Dade
42	General drainage improvements at NW 191 Street between NW 32 Avenue and NW 47 Avenue	C-9	Miami-Dade
43	General drainage improvements mitigation of flood complaints at 8907 NW 173 Terrace	C-9	Miami-Dade
44	General drainage improvements mitigation of flood complaints at E Oakmont Dr BTW N Oakmont Dr & Cul-De-Sac - 19501 E Oakmont Dr	C-9	Miami-Dade
45	General drainage improvements mitigation of flood complaints at NW 178 Street from NW 89 Avenue To NW 91 Ct (South Swale)	C-9	Miami-Dade
46	19551 NW 57 Place	C-9	Miami-Dade
47	Roadway Drainage general drainage improvements mitigation of flood complaints	C-9	Miami-Dade
48	945 NE 207 Terrace	C-9	Miami-Dade
49	NE 179 Street from NW Miami Court to End of Road Drainage Improvements Project	C-9	Miami-Dade
50	NW 169 Terrace to NW 170 Street between NW 87 Avenue and I-75 Ext	C-9, C-8	Miami-Dade
51	General drainage improvements at NE 4th Avenue and NE	C-8	Miami-Dade
52	General drainage improvements mitigation of flood	C-8	Miami-Dade
53	NE Miami Ct from NE 135 Street to South Biscayne River	C-8	Miami-Dade
54	NE 164 St to Spur #4 Canal between N Biscayne Dr A	C-8	Miami-Dade
55	CRS North Mitigation of Repetitive Losses	C-8	Miami-Dade
56	NE 154 Street and NE 5 Court	C-8	Miami-Dade
57	General drainage improvements at NW 2 Avenue and NW 120 Street	C-8	Miami-Dade

ID	PROJECT NAME	BASIN	COUNTY
58	General drainage improvements at NW 20 Avenue to NW 22 Avenue from NW 133 Street to NW 135 Street	C-7	Miami-Dade
59	NE 154 Street and NE 5 Court	C-8	Miami-Dade
60	NW 79 Avenue from NW 197 Street to NW 199 Terrace Drainage Improvements Project	C-9	Miami-Dade
61	71 NE 154 Street NE 5 Court	C-8	Miami-Dade

Once the flood reduction was estimated (0.25 ft) the team proceeded to apply that reduction to an area of influence for the project. It is important to note that as these projects move from conceptual to draft and final designs, thorough data collection and modeling would be conducted to understand the flood control benefits and resulting floodplain maps. In lieu of that data, the team reviewed the projects and their location to estimate the area of influence. Aerial interpretation of hydraulic flow paths and typical municipal storm sewer layout lead to the areas depicted. Projects such as exfiltration systems would typically affect 1-10 acres by at least 0.25 ft., while projects such as pump stations or sluice gates would be expected to affect 10-100s of acres by the same amount. Taylor limited the influence areas at physical termination points such as major culvert crossings, edges of developments, or crowns of roads.

The application of this analytical approach yielded a significant outcome whereby the estimated flood benefits resulting from these mitigation projects will be incorporated into the calculations of expected annual damages. This integration allows the District to gain a quantitative understanding of the tangible advantages these local projects offer in terms of reducing the financial ramifications of flooding. By considering the flood benefits in these calculations, a comprehensive evaluation of the projects' overall effectiveness and cost-efficiency can be achieved. These M1 projects were analyzed separately from the following M2 projects and were not included in the M2 hydrologic and hydraulic modeling.

3.2 M2 Projects – Regional Scale

Regional-scale projects are larger magnitude projects that have anticipated impacts on a regional scale. These projects are often major infrastructure additions or modifications to the primary canal system. The M2 projects focused on addressing the two objectives mentioned earlier – reducing the peak stages in the canals and reducing overland flooding. These objectives could be met in several ways including:

- using pumps to draw down the canals and improve conveyance capacity
- using the PM#1and PM#5 metrics to identify areas where the canal banks were exceeded during floods and areas with flooding vulnerability
- finding areas of storage of peak flows within the watersheds. These storage areas could incorporate nature-based solutions and green infrastructure alternatives.

As the projects developed and evolved, it was clear that addressing SLR1, SLR2, and SLR3 would take progressively more aggressive solutions. So, the natural progression developed M2 projects that increased in ability to tackle increased SLR scenarios. For example, M2A projects are intended to address regional flooding issues and attempt to keep the C-8 and C-9 Canals and watersheds flood elevations at or below 25-year existing condition levels for SLR1. M2B mitigation projects enhance those in M2A and try to achieve flood elevations at or below 25-year existing condition levels for SLR2. M2C mitigation projects enhance those in M2B and try to achieve flood elevations at or below 25-year existing condition levels for SLR3.

3.2.1 Forward Pump Stations and Structure Hardening at S-28 and S-29

The C-8 and C-9 canals are designed to drain the basins through gravity-fed outfalls at S-28 and S-29. This dependence on a head differential between upstream and downstream sides of the structures is critical to understanding the impact sea level rise (SLR) can have on the overall system. Even slight raises in SLR on the downstream end of the structure can impact the ability of the system to drain. For this reason, one of the first regional scale projects that should be implemented in these systems is the addition of forward pumps at the S-28 (**Figure 3.3**) and S-29 (**Figure 3.4**) locations. The benefits of these pumps can be seen in the PM#1 metric and show great ability to reduce or maintain peak canal flood elevations.

Figure 3.3 Generalized Schematic of Tie-back Levees at S-28

Figure 3.4 Locations of S-29 Improvements and Potential Oleta River Surge Barrier

3.2.1.1 Hardening Control Structures

The existing S-28 and S-29 tidal structures are gravity-dependent sluice gates, which regulate the canal discharges in the C-8 and C-9 watersheds, respectively. To prevent saltwater intrusion, the gates are required to close whenever the headwater becomes less than 0.1 ft greater than the tailwater, causing a complete shutdown of the discharge out of the watershed during storm surge or even high-tide, increasing the potential for inland flooding during rainfall events. Given the future sea level rise scenarios of 1 ft, 2 ft, and 3 ft, the existing gated structures are not only expected to be 100% ineffective at discharging during peak storm surge events, but are also expected to be overtopped, allowing storm surge to bypass the structure. Therefore, the first mitigation component proposed is an overhaul to the tidal structure, composed of three key parts:

- raised gate overtopping elevation,
- tieback levees and/or floodwalls, and
- forward pump station.

For simplicity, this study applied just one raised gate overtopping elevation for all mitigation scenarios, with a proposed elevation of 9.0 ft NGVD29. The team chose this elevation as a conservative estimate that is higher than the peak surge elevation of the 100-year SLR3 event. It is important to note that this elevation does not include freeboard or an analysis of construction feasibility. Similarly, tieback levees and/or floodwalls were conceptually represented by raising cross-sections and topography as needed, with a matching elevation of 9.0 ft NGVD29. Both the raised gates and the tieback levees/floodwalls were assumed to fully block storm surge for the purposes of adding a forward pump station. Without blocking storm surge, the benefits of a pump station would be greatly reduced. Therefore, as the gravity structure is assumed to be either modified or rebuilt, pump stations were proposed that discharge to tide whenever the gravity structure is unable to discharge. Essentially, the proposed pump stations supplement discharge from the gravity structure rather than replace it.

3.2.1.2 Developing Pump Sizes

Developing pump sizes required extensive model runs and evaluation. This study, as will be discussed later in this report, modeled storm events of 5, 10, 25, and 100-year return periods. Starting with the 5-year SLR1 event, modelers used an iterative approach, starting with 500 cfs, to determine approximately what pump capacity is required to reduce the PM#1 peak stage profile to a level equal to or lower than existing conditions. Once the modelers determined a pump capacity for a specific storm event that achieved this goal, they simulated the next storm event in increasing order of rainfall magnitude, starting the iterative process with the pump capacity from the previous storm event. Once all four rainfall events (5, 10, 25, and 100-year) for a given sea level rise scenario were completed, the iterative process was repeated for the next sea level rise scenario.

During pump iteration testing, the team identified two issues: first, even with the pumps lowering canal water levels (compared to existing conditions), there were still instances of bank exceedance, and second, the limited ability of pumps to create drawdown in the upstream portions of the canal. As pumping capacity increased, the benefits beyond a certain point upstream of the pump stations decreased. Essentially, at some discharge rate, the pumps only draw down the water in the canal segment immediately upstream of the structure and there are minimal or no real improvements further upstream. These two issues are addressed in the following mitigation activities.

3.2.2 Raised Canal Embankments

When the C-8 or C-9 canals overtop their canal embankments, the watershed can experience extensive overland flooding. Extensive modeling of the storm events and good model detail on the bank elevations allow mitigation and adaptation projects that can identify areas of overtopping and raise canal embankments to reduce or eliminate them. This planning level analysis only identified the areas that require modification and did not address the construction feasibility or property acquisition challenges of this approach.

3.2.3 Conveyance Improvements

Adding pump capacity at the downstream end of the systems, at S-28 and S-29, can only do so much to affect the water surface elevations in the upstream portion of the canal. A larger pump can provide significant or even too much drawdown immediately upstream of the pump station but be unable to reduce elevations further upstream, simply due to canals ability to move water. The canal's conveyance capacity can limit the benefits of larger pumps.

Therefore, the more aggressive mitigation strategy, M2C, required modification of the canal to increase conveyance capacity. This strategy widened the eastern segment of the C-8 Canal by 100 ft, from Interstate 95 to Structure S-28. The conveyance improvements include dredging, widening, and re-grading of the side slopes. Again, the study did not consider legal and administrative issues concerning land availability and acquisition.

This conveyance capacity improvement lowered the water levels in the section upstream of the improvement and raised the levels in the improved section. Essentially, widening eliminated a chocking point in the C-8 Canal and allowed for it to flow more efficiently, shifting some of the water that stacked in the upstream section to the downstream section. The upstream section of the canal still has a larger maximum water elevation. The raised water levels are easily mitigated in the improved section by further increasing the pump capacity. In some instances, the "increase" in downstream water levels would still be lower than existing conditions as the pump station draws it down, so no additional pump capacity was necessarily required. Although no iteration testing on widening of the C-9 Canal was done, it was included as part of one of the M2C mitigation strategy.

3.2.4 Storage Area Identification

Mitigation Strategies M2A, M2B, and M2C included the conceptual storage/removal of a total of 500 acre-feet of runoff combined between the C-8 and C-9 Watersheds as a project element. This project element was more about the actual volume of storage rather than the particular location of where that storage occurred. Although 500 acres were arbitrarily assigned (assuming 1 ft of flood storage per acre), Taylor did a preliminary investigation to find areas that could potentially be used to store flood water. This was a cursory analysis and will need further investigation. **Figure 3.5** depicts a conceptual detail for the surface water storage areas.

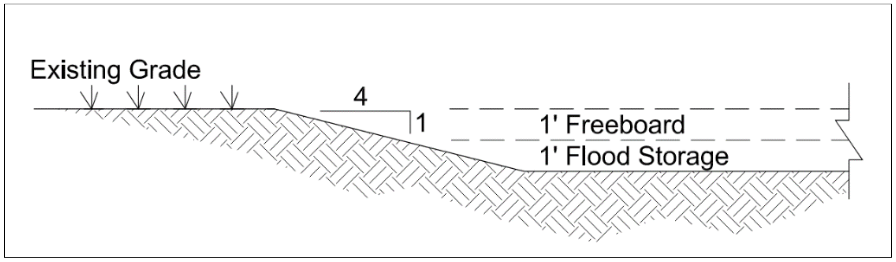
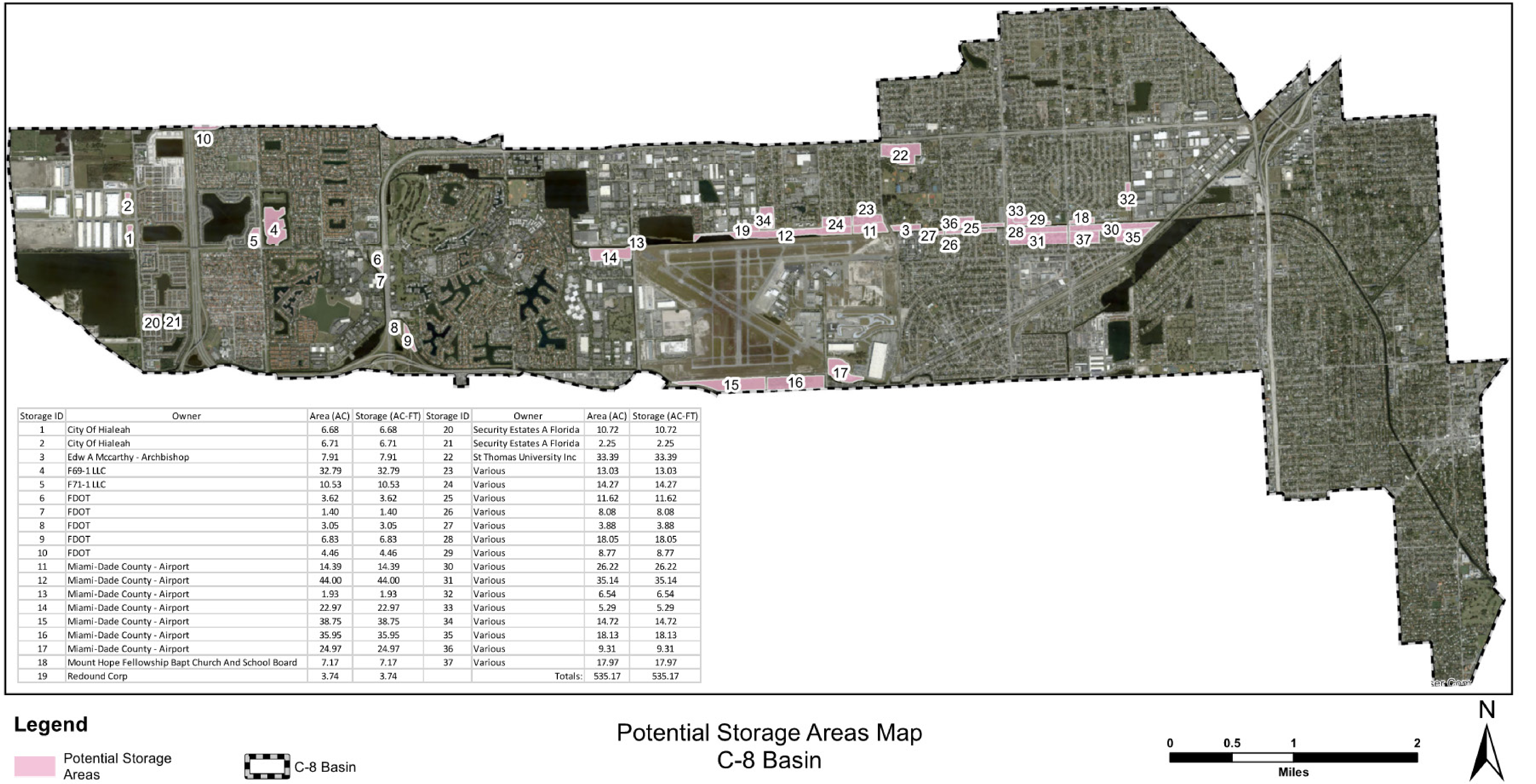


Figure 3.5 Storage Area Concept

To facilitate the planning of aboveground flood mitigation, the study analyzed the C-8 and C-9 Watersheds and located at least 500 acres of land using aerial photography and property appraiser maps to identify the locations. The following ranking methodology identified and prioritized these locations, with the most significant factors at the top of the list:

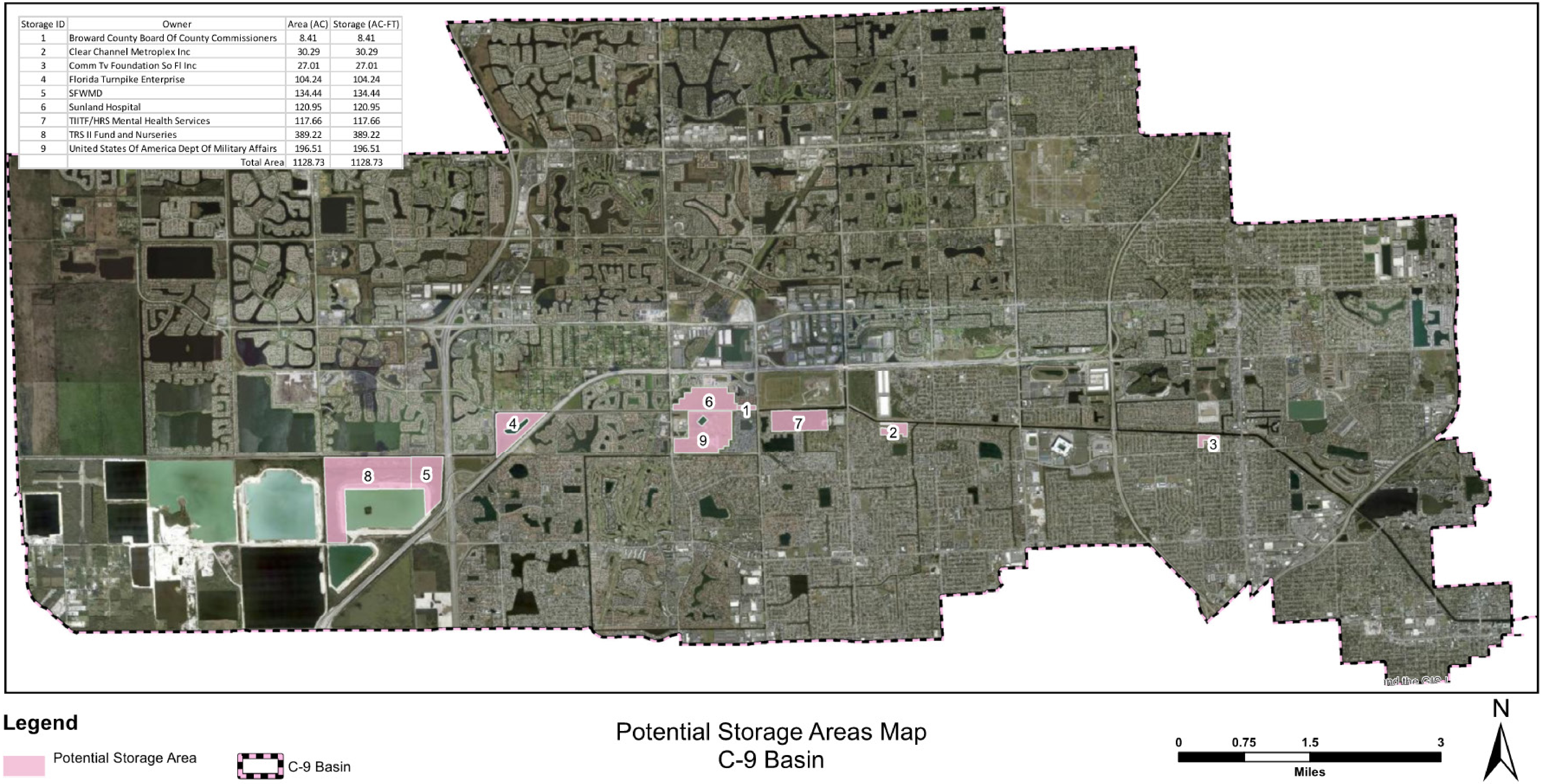
1. District/FDEP/FDOT (or TIITF (Board of Trustees of the Internal Improvement Trust Fund of the State of Florida))- owned land
2. Other government-owned land
3. Vacant land/Underutilized
4. Tracts of land larger than approximately 5 acres

Based on these criteria, **Figure 3.6** and **Figure 3.7** identified locations for potential surface water storage in the C-8 and C-9 Watersheds, respectively. Please note that this preliminary investigation did not consider the elevation of the identified lands and it is likely that many may have an existing grade that would inhibit gravity-driven transfer of flood waters. The C-9 Watershed contains many large government-owned tracts of land, many of which appear to be underutilized. Hundreds of acres are potentially available beyond the target 500 acres within the C-9 Watershed. Conversely, the C-8 Watershed has limited space available, with most of the open space identified near the Miami-Opa Locka Executive Airport. Beyond the Miami-Dade-owned airport land, there are privately-owned lands to meet the 500-acre target. Ultimately the open space in C-8 was limited. Properties in locations that suffer from repetitive losses would be an ideal place for storage, as it eliminates future repetitive loss to a structure and provides storage. However, without access to repetitive loss data, this was excluded from further consideration. A more detailed and in-depth review of these properties is warranted if the benefits of these projects show promising results.



Storage ID	Owner	Area (AC)	Storage (AC-FT)	Storage ID	Owner	Area (AC)	Storage (AC-FT)
1	City Of Hialeah	6.68	6.68	20	Security Estates A Florida	10.72	10.72
2	City Of Hialeah	6.71	6.71	21	Security Estates A Florida	2.25	2.25
3	Edw A Mccarthy - Archbishop	7.91	7.91	22	St Thomas University Inc	33.39	33.39
4	F69-1 LLC	32.79	32.79	23	Various	13.03	13.03
5	F71-1 LLC	10.53	10.53	24	Various	14.27	14.27
6	FDOT	3.62	3.62	25	Various	11.62	11.62
7	FDOT	1.40	1.40	26	Various	8.08	8.08
8	FDOT	3.05	3.05	27	Various	3.88	3.88
9	FDOT	6.83	6.83	28	Various	18.05	18.05
10	FDOT	4.46	4.46	29	Various	8.77	8.77
11	Miami-Dade County - Airport	14.39	14.39	30	Various	26.22	26.22
12	Miami-Dade County - Airport	44.00	44.00	31	Various	35.14	35.14
13	Miami-Dade County - Airport	1.93	1.93	32	Various	6.54	6.54
14	Miami-Dade County - Airport	22.97	22.97	33	Various	5.29	5.29
15	Miami-Dade County - Airport	38.75	38.75	34	Various	14.72	14.72
16	Miami-Dade County - Airport	35.95	35.95	35	Various	18.13	18.13
17	Miami-Dade County - Airport	24.97	24.97	36	Various	9.31	9.31
18	Mount Hope Fellowship Bapt Church And School Board	7.17	7.17	37	Various	17.97	17.97
19	Redound Corp	3.74	3.74		Totals:	535.17	535.17

Figure 3.6 Potential Storage Locations – C-8 Watershed



Storage ID	Owner	Area (AC)	Storage (AC-FT)
1	Broward County Board Of County Commissioners	8.41	8.41
2	Clear Channel Metroplex Inc	30.29	30.29
3	Comm Tv Foundation So Fl Inc	27.01	27.01
4	Florida Turnpike Enterprise	104.24	104.24
5	SFWMD	134.44	134.44
6	Sunland Hospital	120.95	120.95
7	TIITF/HRS Mental Health Services	117.66	117.66
8	TRS II Fund and Nurseries	389.22	389.22
9	United States Of America Dept Of Military Affairs	196.51	196.51
	Total Area	1128.73	1128.73

Figure 3.7 Potential Storage Locations – C-9 Watershed

3.2.5 Green Infrastructure Storage Options

The previous section presented a general understanding of open space availability in the C-8 and C-9 Watersheds. These spaces could be used as floodplain or surface water storage. This section discusses how green infrastructure could be implemented as an enhancement to generic surface water storage. Green infrastructure refers to the strategic incorporation of natural and semi-natural elements, such as green roofs, rain gardens, and wetlands, into urban planning and development, aiming to effectively manage stormwater, improve water quality, and enhance overall water resilience. In general, green infrastructure is ideal for small scale peak reduction and water quality improvements in urban environments. For the largest impact, small scale green infrastructure, such as green roofs, downspout disconnection, rainwater harvesting, and planter boxes, could be implemented as a condition of development or redevelopment within the C-8 and C-9 Watersheds. Communities are encouraged to promote these projects and remember that each additional reduction in stormwater runoff helps. These types of projects can be promoted by local communities and even put into local ordinances to maximize their use.

For very large conversion of land to floodplain storage, communities can think of using the open space for storage and for community use. Flood mitigation storage by its nature is only required intermittently and much of the lifespan of a retention system would be spent dry and unused for storing floodwaters. For this reason, storage areas make ideal multi-use facilities and 95% (or more) of the year can serve as a recreation area (parks and athletic fields), parking, or community gathering facilities for the local community. Below are several examples of green infrastructure that could be implemented in a multi-use flood mitigation facility:

- Permeable pavement parking lots.
- Bioswales for onsite access drives, parking lots, or for surrounding urban areas.
- Urban Tree Canopy expansion along the banks of the storage area or within the storage area using flood-resistant tree species.
- Land Conservation of natural areas is possible if flood storage can still be provided. Creating berms around natural areas could allow for intermittent flood mitigation while still preserving natural areas.
- Rain Gardens/Green Roofs/Downspout Disconnection/Rainwater Harvesting for onsite restroom or maintenance facilities.
- Converting repetitive flood loss properties into green space

Of all these options, the expansion of tree canopy may be the easiest method, largely because it is simply dependent on planting more trees, but depending on the alternate-use of the area, there is potential for many combinations of green infrastructure.

Green features and natural-based solutions should be incorporated into and further promoted/enhanced in the project design phase.

An example of a bioretention facility is shown in **Figure 3.8.**

Figure 3.8 An Example of a Road Median Stormwater Bioretention Facility
(from USEPA Stormwater Best Management Practice, Office of Water, 4203M – photo credit Montgomery County, MD Department of Environmental Protection)

Urban tree canopies have been shown to have multiple benefits in the community. Broward County stated that tree canopies increase property values, help protect water quality, help groundwater recharge, and prevent erosion (refer to link below).

https://www.broward.org/NaturalResources/LandStewardship/UrbanForest/Pages/TreeCanopyCoverage.aspx

If areas presented in **Figure 3.6** and **Figure 3.7** are used as storage, it would benefit the community to plant native tree species that can provide tree canopies. Adding trees to the open spaces would have minimal impact on floodplain storage but would greatly enhance the property for the reasons previously mentioned. An example of different types of tree canopy are shown in **Figure 3.9.**

Figure 3.9 Examples of Urban Forest

(From Left to Right and Top to Bottom: Urban Street Trees, Park Trees, Residential Trees, and Trees Along a trail in a Nature Preserve. Credit: Drew C. McLean, UF/IFAS) (Image from https://edis.ifas.ufl.edu/publication/EP595)

Floodplain managers agree that converting repetitive loss properties to floodplain storage can have many benefits (see Floods.org and FEMA.gov). The Federal Emergency Management Agency (FEMA) provides Community Rating System (CRS) program credits to communities that address repetitive loss properties. Both Miami-Dade and Broward County participate in FEMA's CRS program and address repetitive loss properties. Repetitive loss properties can be bought by local governments and converted into floodplain storage. An example of this conversion is shown in **Figure 3.10**.

Figure 3.10 Example of Repetitive Loss Property Replaced with Green Space

(Mecklenburg County, North Carolina, https://www.pewtrusts.org/en/research-and-analysis/articles/2022/04/01/property-buyouts-can-reduce-flood-impacts-but-funding-planning-hurdles-limit-their-reach)

3.3 M3 Projects – Planning Scale

As communities lean into adapting to sea level rise scenarios and plan for the future, they are setting local and county-wide land use policies. Ideally, communities would begin implementing zoning and land use policies that would elevate buildings and roads to mitigate future flooding. This study performed a planning exercise to elevate all the buildings and roads in the C-8 and C-9 watersheds.

For example, Miami-Dade has enacted Chapter 11C of the Code of Miami-Dade County which tackles new and replacement developments and substantial improvements to existing developments. This ordinance says, "Establishing such new and higher regulatory standards for the design and construction of projects in Miami-Dade County supports the County's efforts to increase resilience and reduce future risks from projected increases in sea level rise." (Miami-Dade County Memorandum, October 18, 2022, see also "Water Control Map and County Flood Criteria Update - Miami-Dade County (miamidade.gov) ")

The long-term effect of these type planning policies are examined in this study by modeling the economic benefits of removing all buildings and roads from flooding. The mitigations strategies are identified as:

- 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

3.4 Mitigation Strategy Summary

In summary, improving tidal structures to block storm surge and adding forward pumping capacity will offer the largest flood protection level of service benefits. The District already uses pump stations to supplement gravity discharge in other watersheds, such as Structure S-26 in the C-6 Watershed and S-13 in the C-11 East Watershed. Without these core projects, blocking surge and adding forward pumping capacity, nearly all of the other tested or identified potential mitigation projects were shown or predicted to provide little to no benefit. In the absence of components to lower peak stages in the primary canals, mitigation projects aiming to move more water from the secondary/tertiary system to the primary canal by gravity would be ineffective in many of the future condition sea level rise scenarios due to elevated canal stages from storm surge.

Therefore, the focus of the mitigation strategies revolves around improving the primary canal system. After testing various mitigation projects and then focusing on the pump stations in combination with other mitigation projects such as raising canal banks, widening the canals, and distributed storage it was evident a progressive solution could meet the mitigation objectives.

The team ran dozens of simulations, testing different pump on/off protocols in combination with the gate protocols to allow for continuous discharge out of the watershed, while minimizing pumping while the gravity structure was operable.

Many of the iteration runs focused on the establishment of optimal operational pump on/off water levels and the corresponding discharge rates, or basically how the pump discharge ramps up. To avoid pumping while the gravity structure is discharging while also preventing a stoppage in discharge as one structure turns on or opens while the other turns off or closes, additional testing was done to find an appropriate water level differential for pump-off conditions, given an assumed gate-close differential.

The product of these iteration runs is three mitigation strategies, M2A, M2B, and M2C, which rather than being thought of as three separate alternatives can be thought of as one progressive mitigation strategy. Mitigation M2A is the least involved of the three projects and could be implemented to address near-term sea level rise. Mitigation M2A can be expanded into M2B/M2C as sea level rise increases and progressively more aggressive forms of mitigation are required. The physical structures needed for these pumps could be built to handle increasing pump sizes as needed. Ideally, adding pumps as needed, would be the best adaptation strategy, but recent design considerations are pointing to lower flexibility in adding pumps. More recent findings estimate that the pump associated buildings and canal diversion represent ~85% of the total costs; adding pumps later will only reduce 15% of the total cost needed for the project. It will be very important to have a starting point for the pump size and given the 50-yr life expectancy, the pump size should be at least to address 50-year SLR conditions and bring back to 25 LOS.

Like all planning studies, there are limits to the amount of mitigation projects that can be investigated. Limits due to modeling scales, modeling run times, available data, and other factors weigh on mitigation activities that can be examined. The following mitigation projects present the collective team and stakeholders planning level results but additional work could certainly be valuable to advancing other mitigation activities.”

A summary of the mitigation projects is presented in **Table 3.2**. A full discussion of the mitigation activities is provided in ***APPENDIX D.***

Table 3.2 Summary of Mitigation Strategies for both C-8 and C-9 Watersheds

Scenario	Distributed Storage	Pumps & Structural Improvements	Canal Improvements & Drainage Changes
Current Conditions	N/A	N/A	N/A
M1 (Local)	11-acres	Stormwater projects, sluice gates, and pump stations	Reduces overland flooding by 0.25 ft in area of influence
M2A	500 ac-ft	1550 cfs harden and elevate downstream structure	N/A
M2B	500 ac-ft	2550 cfs harden and elevate downstream structure	Improved geometry and raised banks Internal drainage to accommodate raised banks
M2C	500 ac-ft	3550 cfs harden and elevate downstream structure	Improved geometry, raised banks, and widened banks. Internal drainage to accommodate raised banks
M3	N/A	Planning analysis of raising all buildings and roads above: SLR1 = + 1 ft SLR2 = + 2 ft SLR3 = + 3 ft	N/A

4.0 HYDROLOGIC AND HYDRAULIC ANALYSIS AND MODELING

The hydraulic modeling has been detailed in depth in Flood Protection Level of Service Provided by existing Infrastructure for Current and Future Sea Level conditions in the C-8 and C-9 Watersheds Final Comprehensive Report (Taylor, 2021) and in ***APPENDIX C*** and ***APPENDIX D***.

Taylor Engineering developed an integrated groundwater and surface water model of the C-8 and C-9 watersheds, using MIKE SHE and MIKE HYDRO, to analyze the benefits of various potential mitigation projects within the C-8 and C-9 Watersheds. To accurately estimate the benefits of the various potential mitigation projects, a LOS performance baseline was established for existing infrastructure under current sea level (SLR0) as well as existing infrastructure without mitigation under future conditions for three sea level rise scenarios. Some elements of the model include:

- Physics-based spatially distributed model tools
- Overland flow, Unsaturated flow, Groundwater flow, and fully dynamic channel flow
- Model was calibrated and validated in Phase I FPLOS
- Current Condition and Future without projects Simulation completed in Phase I
- 4 rainfall events paired with surge and different sea level rise conditions – SLR1, SLR2, and SLR3
- Future with mitigation projects M2A, M2B, and M2C

The objective of this modeling was to find mitigation projects that would:

- lower the peak stage profiles at the primary canal and
- reduce flood inundation area, depth, and duration basin-wide

In line with District FPLOS approaches, this study examined two primary Performance Metrics – PM#1 and PM#5. These are defined as follows:

- PM#1 – Maximum Stage in Primary Canals – This is the peak stage profile in the primary canal system. The profile is developed for the 72-hour duration, 5-year, 10-year, 25-year, and 100-year recurrence frequency design storms. The largest design storm that stays within the canal banks establishes the FPLOS of the primary canal system as measured by this metric.
- PM#5 – Frequency of Flooding – In this metric, the flood elevations or depths of overland flooding are evaluated for the 72-hour duration, 5-year, 10-year, 25-year, and 100-year recurrence frequency design storms. These flood depths/elevations can then be compared with elevations of built features such as buildings and roadways, where such information exists. For the purposes of this C-8 C-9 FPLOS evaluation, flood inundation maps were developed from the model output for each storm event.

The following subsections provide a high-level review of the model setup for existing conditions, future conditions without mitigation, and future conditions with mitigation.

4.1 General Model Setup

4.1.1 Tidal Boundary Conditions

It is important to understand the downstream boundary conditions used in modeling because the addition of a storm surge at the structure is crucial to the ability of the system to discharge during rainfall and storm surge events.

On the east side of the model, the tailwater stage at the primary canal outfall structures were forced as a user-specified boundary condition based on District provided year 2017 tidal boundary data at the S-28 and S-29 structures, which included storm surge effects for the design storms of interest. The dates of the District provided time series data were relative for the purposes of design storms. Therefore, for each boundary condition using SFWMD-provided data, the dates were adjusted so that the peak stages occur at the same time as the peak rainfall, as prescribed by the District. The 1D tidal boundaries, which force the tailwater at structures S-28 and S-29 were set up to use the SFWMD provided design storm stages. The design storm tidal boundaries for current sea level (CSL) are shown in the following two figures (**Figure 4.1** and **Figure 4.2**).

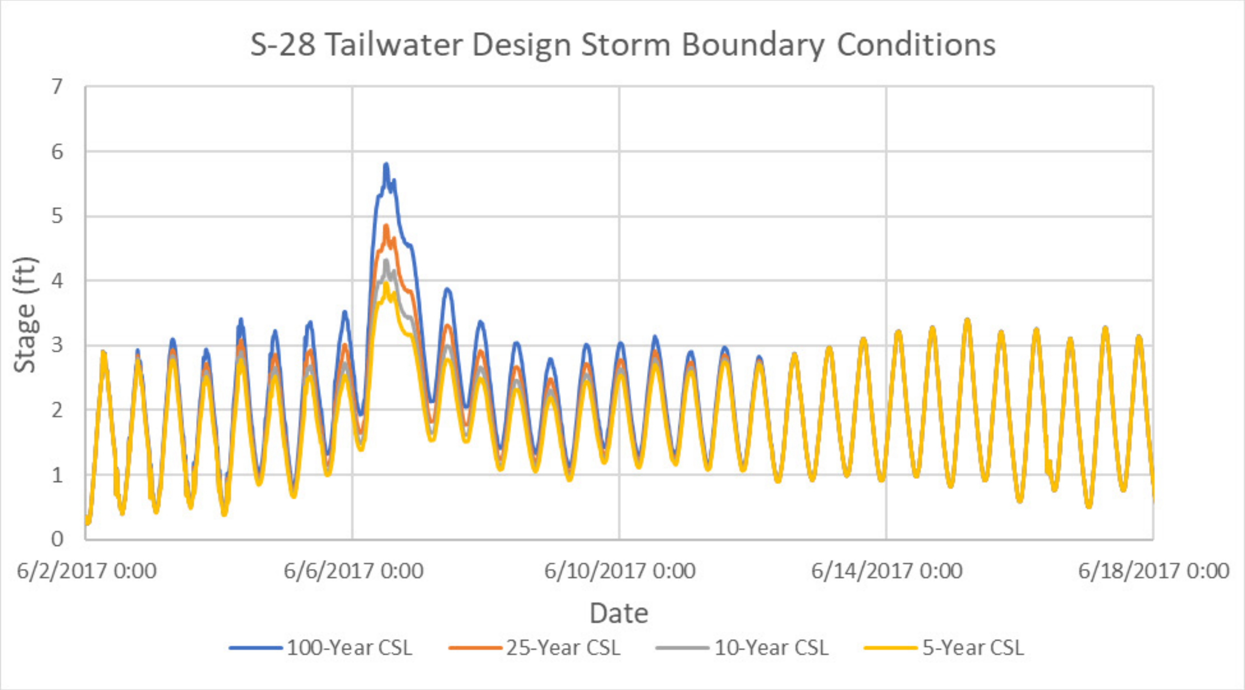


Figure 4.1 Storm Surge Boundary Condition Applied at S-28

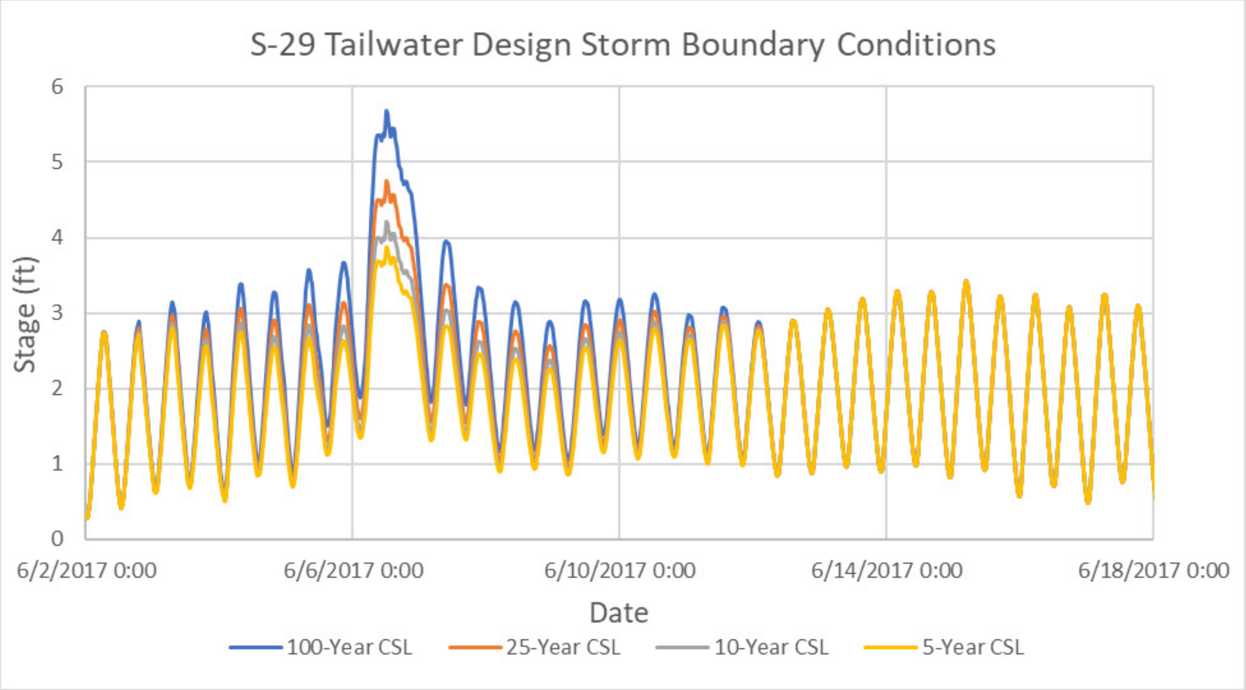


Figure 4.2 Storm Surge Boundary Condition Applied at S-29

The model boundary conditions are adjusted for sea level rise conditions 1, 2, and 3 – which add 1 ft, 2 ft, and 3 ft to the boundary conditions shown above – for each design storm. So, for example, the future 25-year storm event with sea level rise at S-28 would be as shown in **Figure 4.3**. This condition was repeated for all four rainfall events for all three SLR conditions.

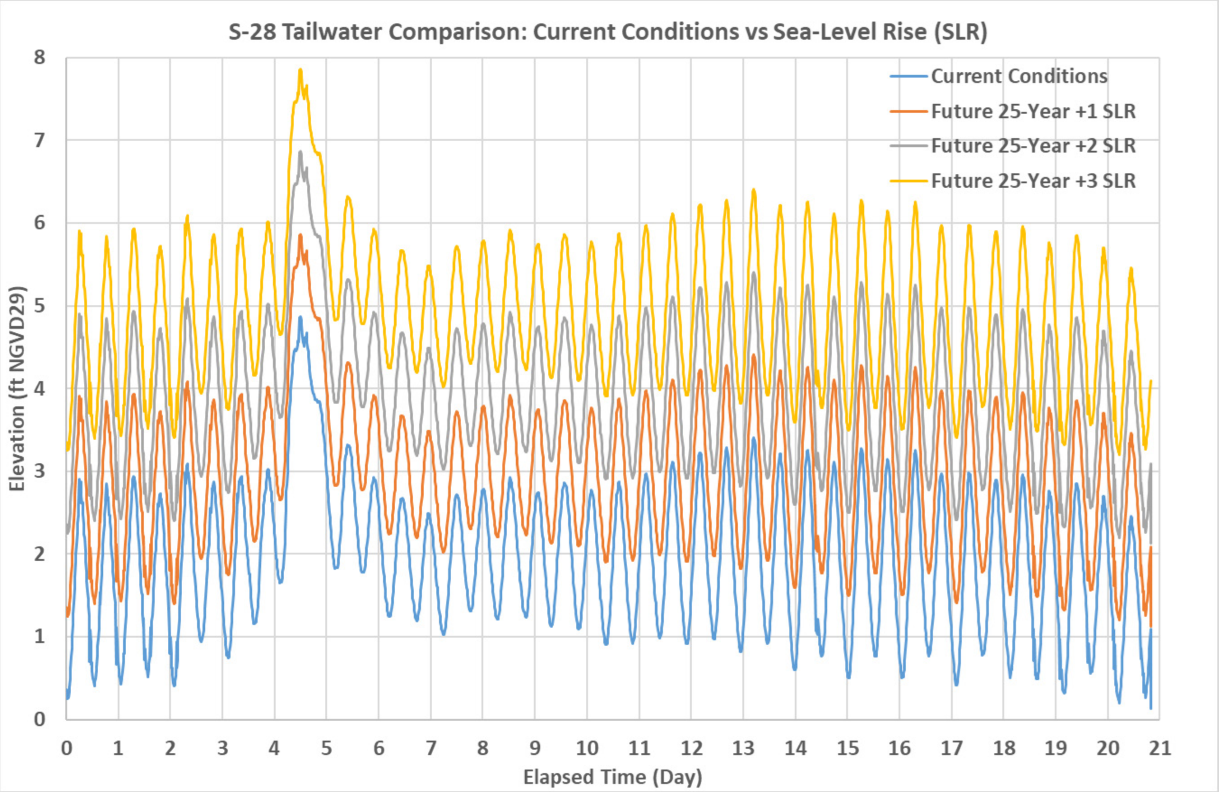


Figure 4.3 Example of 25-Year Storm Surge Boundary Condition Applied at S-28 for 3 SLR Conditions

4.2 Review of Model Setup for Existing Conditions and Future Conditions Without Mitigation

The existing conditions model was developed in Phase I of the C-8 C-9 FPLOS Assessment but was revised during the Phase II assessment to accommodate the comparison of particular mitigation strategies that required modifications to the baseline model, new data that was previously unavailable, and other changes that improved the performance and reliability of the C-8 and C-9 FPLOS Model. Please refer to the SFWMD *Flood Protection Level of Service Provided by Existing Infrastructure for Current and Future Sea Level Conditions in the C8 and C9 Watersheds Final Comprehensive Report* (Taylor Engineering, 2021) for a detailed description of the existing conditions model setup. Please refer to the SFWMD *Flood Protection Level of Service Provided by Potential Mitigation Projects for Current and Future Sea Level Conditions in the C8 and C9 Watersheds Final Report (Revised)* (Taylor Engineering, 2022) for a detailed description of the changes made to existing conditions and future conditions without mitigation as well as the reasons for those changes. The following list serves as a high-level overview of the changes made to existing conditions and future conditions without mitigation model setup for the Phase II assessment:

- The C-7 Canal boundary condition, which represents the southern model boundary, was updated to provide a more realistic approximation that was more consistent with other assumptions built into the model.
- The northern boundary condition was replaced with simulated data from a more recently developed model that had more similarly aligned assumptions and was believed to provide a more realistic approximation.
- The model was updated to explicitly represent “Lake Ojus”, also known as “East” and “West” Lake, to capture how it interacts with the C-9 Canal in the baseline results before adding mitigation projects in the area.
- One specific flood code was updated in a localized area to remove an instability.
- The bank elevations in the Opa Locka Canal were updated in the 1D model to better match the topography for overbank spilling purposes and to eliminate artifacts in the flood inundation maps.
- The initial water levels were increased for the SLR3 scenario to better align with other modeling assumptions.
- The tidal structure operational rules were updated to have more detailed salinity control protocols, which changes how or when the structure closes rather than affecting how it opens.

Additionally, as discussed in the FPLOS Phase I project for these watersheds, the “future conditions” assumed that the C-9 impoundment on the west side of the C-9 Watershed has been constructed. The C-9 Impoundment was modeled having a storage capacity of 3,500 ac-ft (about 50% of its intended design) that was filled by a 1,000 cfs pump pulling from the C-9 Canal. This impoundment had significant benefits to the system and showed reduced peak water levels in the canal and reduced total discharge volumes at the tidal structures.

4.3 Model Setup for Future Conditions With Mitigation

The future conditions with mitigation model were developed as part of this Phase II assessment of the C-8 and C-9 Watersheds. Starting with the updated future conditions without mitigation model described in the previous section, various model setup changes were applied to represent the various mitigation projects. Please refer to the SFWMD *Flood Protection Level of Service Provided by Potential Mitigation Projects for Current and Future Sea Level Conditions in the C8 and C9 Watersheds Final Report (Revised)* (Taylor Engineering, 2022) for a detailed description of the specific changes made to each model component to represent the various mitigation projects. The following list serves as a high-level overview of the model changes made to represent the various mitigation projects.

- Raising the gate overtopping elevation was done by simply increasing the height of the S-28 and S-29 Sluice Gates within the MIKE HYDRO model.
- Tieback levees / floodwalls were represented by increasing cross section bank elevations in the 1D MIKE HYDRO model as well as raising the topography in areas where surge could bypass the tidal structure within the 2D overland flow portion of the MIKE SHE model.
- Forward pump stations were represented by adding a discharge structure to the 1D MIKE HYDRO model, along with necessary operational rules.
- New and updated operational rules were applied to the operation structures within MIKE HYDRO, specifically the S-28 and S-29 sluice gates and pump stations. These rules were developed to combine the full use of the pumps as well as the maximum practical use of the sluice gates, while minimizing both features operating concurrently.
- Conceptual storage was added to the model by removing a total 500 ac-ft of water from 17 locations distributed across the gravity-driven drainage areas of the C-8 and C-9 Watersheds. This was conceptually represented through internal boundary conditions, which simply removed water at a set rate for a set duration at a set time based on when model-wide water levels are at their highest.
- Initial canal elevation changes were applied within the 1D MIKE HYDRO model to represent the assumed increase in water control elevations due to sea level rise.
- Canal improvements were represented by modifying the cross sections within the 1D MIKE HYDRO model. This includes improved geometry (features such as side slope, removing irregularities, increasing the cross-sectional area within the existing canal width), and/or raising the canal bank elevations.
- An internal drainage system along the primary canals was represented through a system of "dummy" canals and one-way culverts to allow water to continue to drain directly overland to the C-8 and C-9 Canal from surrounding areas for scenarios where the canal bank elevations were increased.
- Canal widening was represented separately from other general canal improvements and was represented within MIKE HYDRO by widening the actual spatial extent that the canal occupies. The differentiator here is that this form of canal improvement required extending the width of the cross section whereas the other improvements were represented within the existing width.

Pump sizes used in the M2 mitigation projects were developed using many model iterations. The objective of the pump sizes developed was to mitigate the impacts of SLR1, 2, and 3 on each basin. Hundreds of model iterations were simulated to determine the pump capacity required to bring canal elevations back to current condition levels. Examining pump sizes started with modeling the 5-year SLR1 event with a 500 cfs pump to determine approximately what pump capacity is required to reduce the peak stage profile to a level equal to or lower than existing conditions. Once the modelers determined a pump capacity for a specific storm event that achieved this goal, they simulated the next storm event in increasing order of rainfall magnitude, starting the iterative process with the pump capacity from the previous storm event. Once all four rainfall events for a given sea level rise scenario were completed, the iterative process was repeated for the next sea level rise scenario. For example, a model run would test 1,500 cfs at S-28 and 1,500 cfs at S-29. After reviewing the results, the modelers would change pump sizes to, say for example, 2,000 cfs and 1,500 cfs, respectively. This continued until the "best" (smallest size that could achieve the goal) forward pump size was determined for each location, rounded to the nearest 50 cfs.

Like all planning studies, there are limits to the amount of mitigation projects that can be investigated. Limits due to modeling scales, modeling run times, available data, and other factors weigh on the number of mitigation activities that can be examined. The following mitigation projects present the collective team and stakeholders planning level efforts and numerous model runs but additional work could certainly be valuable to advancing other mitigation activities and more comprehensively evaluating tradeoffs between measures.

4.3.1 Mitigation M2A Model Setup

Mitigation Strategy M2A has two main elements that aim to reduce flood levels by improving the performance of the tidal structure and storing excess flood water. For Mitigation M2A, the forward pump station has a maximum capacity of 1,550 cfs in each coastal structure. The following list describes the individual components of mitigation strategy M2A:

- S-28 and S-29 forward pumps (1550 cfs)
- S-28 and S-29 gate improvement – raised overtopping elevation to 9.0 ft NGVD29
- Tieback levees/floodwalls (conceptually represented with elevation of 9.0 ft NGVD29)
    - S-28: approximately 600 ft length for the north bank and 700 ft length for south bank
    - S-29: approximately 250 ft length for the north bank and 425 ft length for south bank
- Total of 500 ac-ft distributed storage across both C-8 and C-9 combined
    - conceptually represented – gravity-driven drainage areas only
    - refer to **Figure 3.6** and **Figure 3.7** for the potential storage locations
    - important to note that no specific locations are recommended, rather this study analyzed the benefit of the volume of storage, not the specific location of storage
- Optimized S-28 and S-29 operational controls for SLR1, SLR2, and SLR3 for the M2A scenario

4.3.2 Mitigation M2B Model Setup

Mitigation Strategy M2B has three main elements that aim to reduce flood levels by improving the performance of the tidal structure, storing excess flood water, and preventing bank exceedances in the C-8 and C-9 Canals. The first two elements are the same as Mitigation M2A (improving the performance of the tidal structure and storing excess flood water). For Mitigation M2B, the forward pump station has a maximum capacity of 2,550 cfs in each coastal structure. The third element, preventing bank exceedances in the C-8 and C-9 Canals, consist of two main components that work together to prevent the primary canals from spilling out into the watershed while simultaneously allowing the watershed to drain to the primary canal. The following list clearly describes the individual components of mitigation strategy M2B:

- S-28 and S-29 forward pumps (2550 cfs)
- S-28 and S-29 gate improvement – raised overtopping elevation to 9.0 ft NGVD29
- Tieback levees/floodwalls (conceptually represented with elevation of 9.0 ft NGVD29)
    - S-28: approximately 600 ft length for the north bank and 700 ft length for south bank
    - S-29: approximately 250 ft length for the north bank and 425 ft length for south bank
- Total of 500 ac-ft distributed storage across both C-8 and C-9 combined
    - conceptually represented – gravity-driven drainage areas only
    - refer to **Figure 3.6** and **Figure 3.7** for the potential storage locations
    - important to note that no specific locations are recommended, rather this study analyzed the benefit of the volume of storage, not the specific location of storage

- Primary canal improvements
    - improved geometry (cross-section features such as side slope, removing irregularities in channel bottom, and increasing cross-sectional area within the existing width of canal banks) as deemed appropriate along entire C-8 and C-9 Canal
    - raised bank elevations to elevation 7.5 ft NGVD29 anywhere banks are currently lower than 7.5 ft NGVD29 (this does not include freeboard)
- Internal drainage system along primary canals to drain water through raised banks
    - System of “dummy” canals and one-way culverts along the perimeter of the C-8 and C-9 Canals to allow water to drain into the C-8 and C-9 Canals from the surrounding area
    - Can only discharge if C-8 and C-9 Canal elevations are lower than water elevation in the surrounding floodplain (the same way as if the raised banks weren’t there)
- Optimized S-28 and S-29 operational controls for SLR1, SLR2, and SLR3 for M2A scenario

4.3.3 Mitigation M2C Model Setup

Mitigation Strategy M2C has four main elements that aim to reduce flood levels by: (1) improving the performance of the tidal structure, (2) storing excess flood water, (3) preventing bank exceedances in the C-8 and C-9 Canals, and (4) improving the performance of the primary canals. The first two elements are the same as Mitigation M2A and M2B. The third element is the same as Mitigation M2B. For Mitigation M2C, the forward pump station has a maximum capacity of 3,550 cfs in each coastal structure. The fourth element, improving the performance of the primary canals, consists of widening the C-8 and C-9 Canals and optimizing channel geometry (including dredging and re-grading). The locations where the C-8 and C-9 Canal were widened in the MIKE HYDRO model was chosen largely based on areas needing improvement or areas where it looked possible based on aerial imagery. It is important to note that no feasibility study was completed, nor is Taylor Engineering recommending these locations for widening. Rather, this mitigation strategy is simply intended to serve as a “what if” analysis.

The following list describes the individual components of mitigation strategy M2C:

- S-28 and S-29 forward pumps (3550 cfs)
- S-28 and S-29 gate improvement – raised overtopping elevation to 9.0 ft NGVD29
- Tieback levees/floodwalls (conceptually represented with elevation of 9.0 ft NGVD29)
    - S-28: approximately 600 ft length for the north bank and 700 ft length for south bank
    - S-29: approximately 250 ft length for the north bank and 425 ft length for south bank
- Total of 500 ac-ft distributed storage across both C-8 and C-9 combined
    - conceptually represented – gravity-driven drainage areas only
    - refer to **Figure 3.6** and **Figure 3.7** for the potential storage locations
    - important to note that no specific locations are recommended, rather this study analyzed the benefit of the volume of storage, not the specific location of storage
- Primary canal improvements
    - improved geometry (cross-section features such as side slope, removing irregularities in channel bottom, and increasing cross-sectional area within the existing width of canal banks) as deemed appropriate in locations where the C-8 and C-9 Canal were not widened
    - widened cross sections (refer to **Figure 4.4** Location of Canal Segment with Widened Cross Sections)
        - C-8 Canal widened along approximately 20,000 ft by a width of 100 ft from Interstate 95 to Structure S-28, to a total width of approximately 240 feet.

    - C-9 Canal widened within the existing footprint of the canal embankments along approximately 79,000 ft of canal from the west side of the South Broward Drainage District to Interstate 95. The total width between embankments did not change, however, the "wetted area" was increased by an average of approximately 75 feet.
  - raised bank elevations to elevation 7.5 ft NGVD29 anywhere banks are currently lower than 7.5 ft NGVD29 (this does not include freeboard)
- Internal drainage system along primary canals to drain water through raised banks
  - System of "dummy" canals and one-way culverts along the perimeter of the C-8 and C-9 Canals to allow water to drain into the C-8 and C-9 Canals from the surrounding area
  - Can only discharge if C-8 and C-9 Canal elevations are lower than water elevation in the surrounding floodplain
- Optimized S-28 and S-29 operational controls for SLR1, SLR2, and SLR3 for M2B scenario

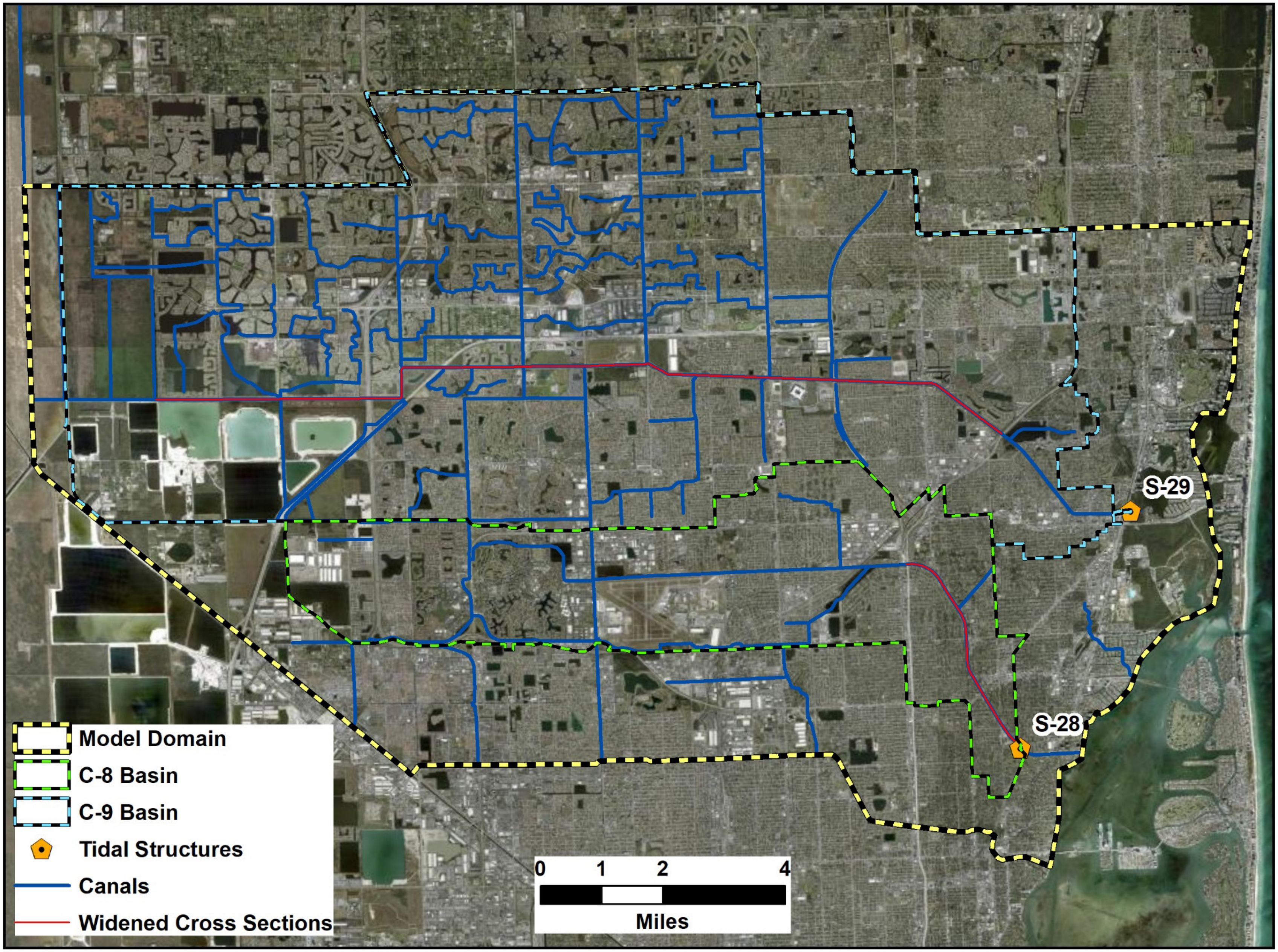


Figure 4.4 Location of Canal Segment with Widened Cross Sections under Mitigation Strategy M2C

For the C-8 Canal, widening was limited to the section of canal between Interstate 95 and Structure S-28. This approximately 20,000 ft long section of C-8 Canal was widened in the MIKE HYDRO model by 100 ft to increase the conveyance capacity of the canal, lower upstream water levels, and allow the C-8 system to handle a larger pump capacity. For the C-8 Canal, land availability is minimal and land acquisition would be required to achieve what was represented in the model.

For the C-9 Canal, widening was implemented in the MIKE HYDRO model wherever there was land availability, strictly based on aerial imagery and not based on ownership or usage rights, which was essentially limited to western two-thirds of the canal. This approximately 79,000 ft long section of C-9 Canal between the west side of South Broward Drainage District to Interstate 95 was widened in the MIKE HYDRO model by an average of approximately 75 ft. The intention of this change was to increase the conveyance capacity of the canal, provide additional relief to the C-8 Watershed by lowering upstream water levels, and allow the C-9 system to handle a larger pump capacity. Unlike the C-8 Canal, the C-9 Canal was not predicted to have level of service deficiencies directly related to elevated stages at the west side of the watershed under future sea level rise scenarios as the C-9 Impoundment was providing relief by lowering water levels through its removal of 1,000 cfs from the C-9 Canal. Therefore, as the C-8 and C-9 Watersheds share several basin-interconnects and the C-8 Watershed was predicted to have level of service deficiencies directly related to elevated stages at the west side of the watershed, providing additional conveyance capacity in the C-9 Canal is believed to contribute to the reduced stages in the C-8 Watershed to some degree. This effect needs further examination.

For both the C-8 and C-9 Canals, conveyance capacity was not just improved by widening the canals, but also by optimizing channel geometry. In areas where the C-8 and C-9 Canals were widened in MIKE HYDRO, changes were made to the channel geometry to represent a more typical trapezoidal channel, increasing conveyance capacity. In areas where the C-8 and C-9 Canals were not widened, the cross sections were changed to increase conveyance capacity within the existing levee banks and also represent a more typical trapezoidal channel.

4.4 Model Results

The Phase I FPLOS Assessment analyzed the model results to identify deficiencies in the system and to provide a level of service rating. The level of service rating assigned to the C-8 and C-9 Watersheds in the Phase I FPLOS Assessment described what frequency storm event the watershed's existing infrastructure is predicted to handle, both under current and future sea level rise scenarios. For this Phase II FPLOS Assessment, a level of service rating was not assigned since the objective was to examine figure FPLOS with respect to future conditions and SLR. Therefore, instead of pointing out deficiencies of the system, this Phase II Assessment, focused on mitigation and adaptation planning strategies, identified improvements and compared the different strategies against each other and against both existing conditions and future conditions without mitigation.

Modeling events included the 5-, 10-, 25-, and 100-yr events for each basin for current conditions, SLR1, SLR2, and SLR3. This modeling looked at existing conditions, future conditions, and with/without mitigation projects. The complexity of comparison between events and mitigation projects becomes overwhelming and does not allow for an "easy" comparison of results. To simplify the comparisons of initial results the Team chose to run the 25-yr events are part of the iterative process and to screen mitigation projects. Additionally, this report presents results for the 25-yr event as only a subset of all the model runs performed. The full set of model runs are presented in Appendix D.

Mitigation Scenario M2A was designed with the goal of providing a LOS under the 25-year SLR1 scenario that is equal to or greater than the 25-year current conditions LOS, specifically the maximum water surface profile and the maximum overland depths.

For the C-8 Watershed:

- Mitigation M2A is predicted to reduce the maximum water levels in the C-8 Canal to a level equal to or lower than existing conditions for the 5-year and 10-year SLR1 scenarios.
- It is also predicted to be nearly equal to or, in some cases lower than current conditions for the 25-year and 100-year SLR1 scenarios.

For the C-9 Watershed:

- Mitigation M2A is predicted to reduce the maximum water levels in the C-9 Canal to a level equal to or lower than existing conditions for the 5, 10, 25, and 100-year SLR1 scenarios.

Mitigation Scenario M2A improvements are predicted to lower the maximum canal profile across all rainfall events for all three sea level rise scenarios simulated. However, the performance of Mitigation Scenario M2A is really only an improvement compared to existing conditions for up to one foot of sea level rise.

Mitigation Scenario M2B was designed with the goal of providing a LOS under the 25-year SLR2 event that is equal to or greater than the 25-year current conditions LOS, specifically the maximum water surface profile and the maximum overland depths.

For the C-8 Watershed:

- Mitigation M2B is predicted to reduce the maximum water levels in the C-8 Canal to a level lower than existing conditions for the 5, 10, and 25-year SLR1 scenarios.
- It is also nearly equal to or, in some cases lower than current conditions for the 100-year SLR1 scenario.

For the C-9 Watershed:

- Mitigation M2B is predicted to reduce the maximum water levels in the C-9 Canal to a level lower than existing conditions for the 5, 10, 25, and 100-year SLR1 scenarios.

As for the SLR2 Scenario:

- For both C-8 and C-9, Mitigation M2B was unable to reduce the overall maximum canal stages to a level equal to or lower than current conditions.
- However, a critical component of Mitigation Scenario M2B is raised canal bank elevations, which eliminates bank exceedances.

Like Mitigation M2A, Mitigation Scenario M2B improvements are predicted to lower the maximum canal profile across all rainfall events for all three sea level rise scenarios simulated. However, when compared to existing conditions, the performance of Mitigation Scenario M2B is really only an improvement for up to more than one foot of sea level rise but less than two feet of sea level rise.

So, although Mitigation M2B is unable to achieve maximum canal stages under 2 feet or more of sea level rise that are comparable to existing conditions, it does provide a significant level of performance compared to future conditions without mitigation across all return period and sea level rise scenarios.

Mitigation Scenario M2C was designed with the goal of providing a LOS under the 25-year SLR3 event that is equal to or greater than the 25-year current conditions LOS, specifically the maximum water surface profile and the maximum overland depths.

For both the C-8 and C-9 Watersheds:

- Mitigation M2C could reduce the maximum water levels in the primary canals to a level approximately equal to or lower than existing conditions for the 10, 25, and 100-year SLR2 scenarios.

As sea level rise increases:

- It becomes increasingly more challenging to get back to current condition flood levels for the smaller return period events compared to larger rainfall events.
- Antecedent conditions under SLR3 conditions are almost as high or higher than the peak rainfall-induced flooding under current conditions before any rainfall even occurs.
- This makes it extremely difficult or, in some cases, impossible to mitigate flooding to a level comparable to current conditions.

However, under larger return period events such as the 25-year or 100-year event:

- Rainfall-induced flooding under current conditions is higher than the assumed antecedent conditions under SLR3, allowing the system a fighting chance to maintain or reduce flood levels through aggressive means of mitigation, such as large forward pump stations.

Model results indicate that even Mitigation M2C would be unable to achieve flood levels comparable to existing conditions under SLR3.

- For both the C-8 and C-9 Watersheds, Mitigation M2C is able to, in most instances, reduce the maximum water levels in the primary canals to a level approximately equal to or lower than existing conditions for SLR1 and SLR2.
- Like Mitigation M2B, Mitigation M2C has raised canal bank elevations, which eliminates bank exceedances, but elevated stages under SLR3 conditions still inhibit gravity-driven drainage from the secondary/tertiary systems, leading to increased flooding compared to existing conditions.

However, compared to future conditions without mitigation, Mitigation M2C significantly reduces the maximum canal levels and the overland flooding in all return period and sea level rise scenarios.

From the modeling side of this FPLOS analysis, the two most important components examined when trying to understand and interpret the results are the maximum water levels in the primary canals and the overland flooding which is depicted through inundation maps. Respectively, these components are the Performance Metrics #1 and #5 of the FPLOS analysis.

PM#1 is relatively straightforward and easy to understand, as it is simply a comparison of maximum water levels in the primary canal, compared with the canals bank elevations and other maximum water levels based on different rainfall return periods or sea level rise scenarios. Looking at the maximum water surface profiles is a quick and simple way to identify basic trends across the watershed. For instance, if the maximum water surface profile shows several instances where the maximum water level is higher than the canal banks, then it is easy to identify locations that are likely to have flooding. Similarly, if the maximum water surface profile shows areas where the maximum water level is lower than the canal banks or is lower in one scenario than another, then it is easy to identify areas that are less likely to have flooding or see locations that have benefited from whatever changes were being analyzed. What the PM#1 maximum water surface profiles do not show is that just because a canal segment may not be exceeding bank elevations, doesn't mean the water level isn't high enough to inhibit drainage from the secondary/tertiary systems. Therefore, just because PM#1 results indicate that a canal segment may or may not have flooding based on elevations above or below canal banks, the reality of it is that it is just one of many tools that needs to be analyzed before drawing conclusions. So, how can the maximum water surface profiles be used? The PM#1 maximum water surface profiles should be used to:

1. identify locations with bank exceedances,
2. identify canal segments with significant head loss,
3. identify areas prone to flooding due to primary system elevations,
4. identify locations that could potentially handle additional inflow,
5. compare the performance of the system to other scenarios such as mitigation and adaptation projects, and
6. be used in direct connection with flood inundation maps or inundation difference maps

The PM#5 flood inundation maps were not as straightforward as the PM#1 maximum canal flood profiles. Although the flood inundation maps showed directly where there is flooding, it doesn't necessarily indicate the source of that flooding, whether it be excess rainfall, elevated groundwater, or bank exceedances. Nevertheless, the PM#5 flood inundation maps were extremely useful in showing location of flooding and severity of flooding in terms of water depths. In conjunction with the PM#1 maximum water surface profiles, the PM#5 results can be used to decipher whether flood inundation along the primary canal is a result of bank exceedances or something else such as insufficient drainage capacity in the secondary/tertiary systems. Likewise, the flood inundation maps can be used to decipher whether instances of bank exceedance result in flood inundation of developed areas or if the bank exceedance occurs in undeveloped or natural areas.

When used together, the PM#5 flood inundation maps can be used to determine locations that could benefit from drainage improvements or added pumping capacity, while the PM#1 maximum water surface profiles could be used as a quick check if the primary canal system can handle the additional discharge. For instance, maximum water surface profiles could indicate that a particular segment of the primary canal is already peaking higher than the canal bank elevation, which would likely indicate that no additional capacity is available through that segment. On the other hand, a maximum water surface profile that is well below the canal bank elevation could indicate that it has the capacity to handle additional discharge. However, when exploring this result, the flood inundation maps should be looked at through the form of flood elevations rather than flood depths, which is just the flood depth map added to the base topography. The reason for this is that it is possible for the primary canal elevation to be well below the canal bank elevation but still be higher than the flood elevation in the flooded areas draining to it. In this case, although the primary canal system appears to have capacity when compared to bank elevations, the area draining to it would be unable to as the downstream water level is higher than it, which inhibits gravity-driven discharge. Now, if this particular area is drained by pump stations, then the relative difference in elevations of the flooded areas and the downstream discharge location becomes less significant.

What are the potential applications of PM#5 flood inundation/flood elevation maps? The PM#5 flood inundation maps should be used to

1. identify locations with flooding,

2. identify location of flooding contributed by bank exceedances,
3. identify areas prone to flooding due to primary system elevations,
4. identify locations that could benefit from additional drainage capacity,
5. compare the performance of the system to other scenarios such as mitigation and adaptation projects, and
6. be used in direct connection with maximum water surface profiles

Although the performance of the mitigation scenarios in terms of flood protection is very important, it is not the only factor that should be considered. Just because a mitigation scenario is predicted to have significant flood reduction doesn't mean that it is economically viable. For instance, from an economic standpoint, it wouldn't make sense to implement a $100 million mitigation scenario if it would only prevent $20 million in damages over the course of the project lifespan. Or, perhaps it would make sense to implement a mitigation scenario or mitigation project that doesn't have major regional impacts to flood reduction, but they prevent more in damages than the cost of the project. This is where the flood damage assessment in terms of expected annual damages becomes a "performance metric" or success indicator. Using the model results, specifically the flood inundation maps, an analysis of the expected annual damages can be evaluated. Predicting the expected annual damages under both future conditions without mitigation and future conditions with mitigation allows for the prediction of annual avoided damages, which allows for a benefit-cost analysis to be completed, which will provide additional insight on the performance of a mitigation strategy but from an economic perspective. Together, a comprehensive flood damage assessment that evaluates the performance of the system in terms of flooding level of service protection, expected annual damages, and benefit vs. costs analysis, that is coupled with adaptation pathway planning, allows for a no-regret decision to be made when deciding on which mitigation scenario(s) to implement and when. Although these are the main components of a comprehensive flood damage assessment, other important factors to consider include downstream impacts and water quality.

4.4.1 Summary of Model Results for the C-8 Watershed

The following subsections highlight the results of the 25-year storm events for each of the M2A, M2B, and M2C mitigation strategies for PM#1 and PM#5 for the C-8 Watershed (**Figure 4.5** through **Figure 4.10**).

4.4.1.1 Summary of Model Results For the C-8 Watershed for each Mitigation Strategy

4.4.1.1.1 Mitigation Strategy M2A

- Significantly reduce the impact of sea level rise
- M2A 25-yr SLR1 canal peak stage profile is lower than M0 25-yr SLR1
- M2A 25-yr SLR1 canal peak stage profile is lowered to approximately the same level as M0 25-yr SLR0
- M2A 25-yr SLR2 canal peak stage profile is lower than M0-25 yr SLR2
- M2A 25-yr SLR3 canal peak stage profile is lower than M0 25-yr SLR2
- Significantly less flood inundation for the M2A 25-year SLR1 event than the 25-year SLR1 event without mitigation
- With M2A, the system can maintain current LOS under 1 ft SLR.

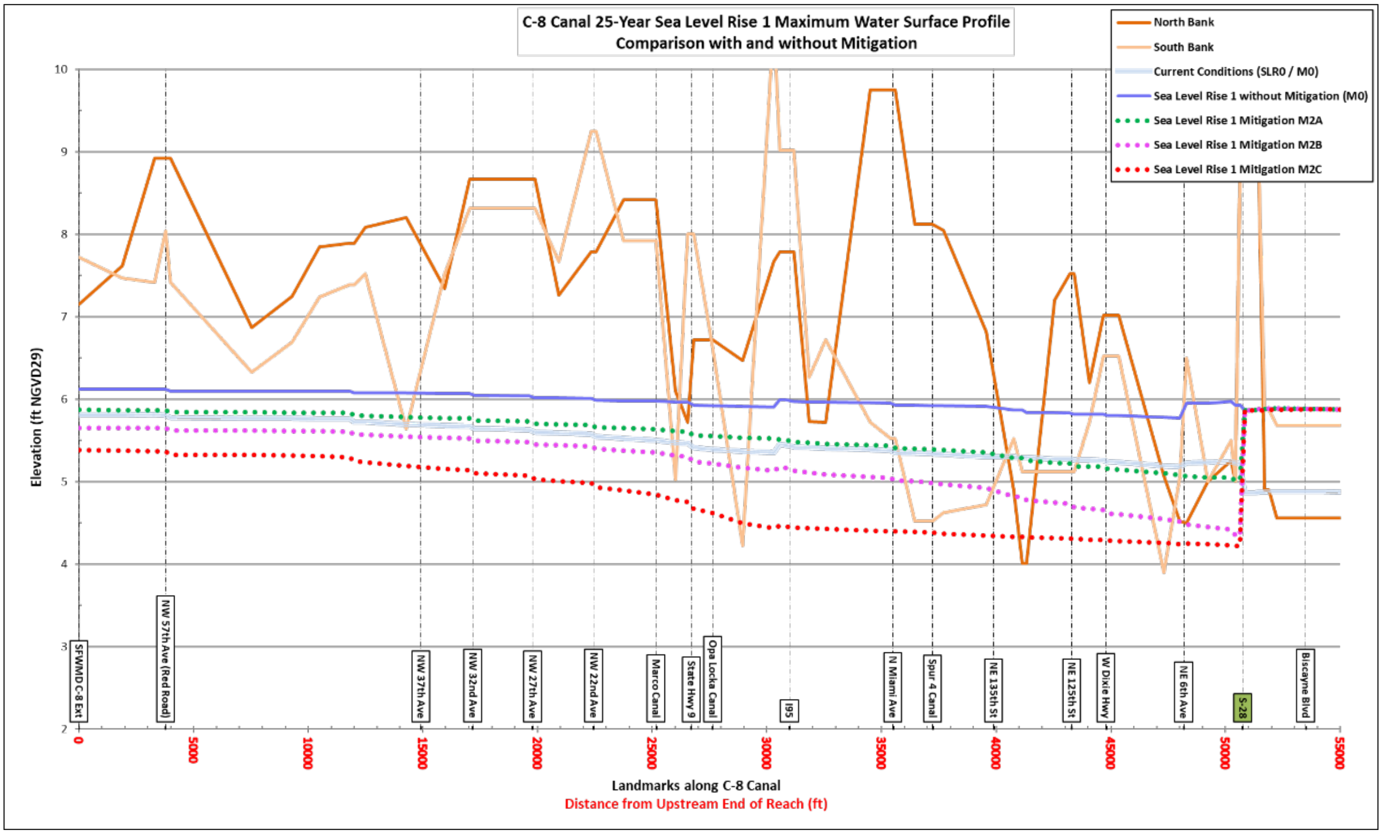


Figure 4.5 C-8 Canal Peak Stage Profiles for 25-Year Sea Level Rise 1 Design Storm with and without Mitigation

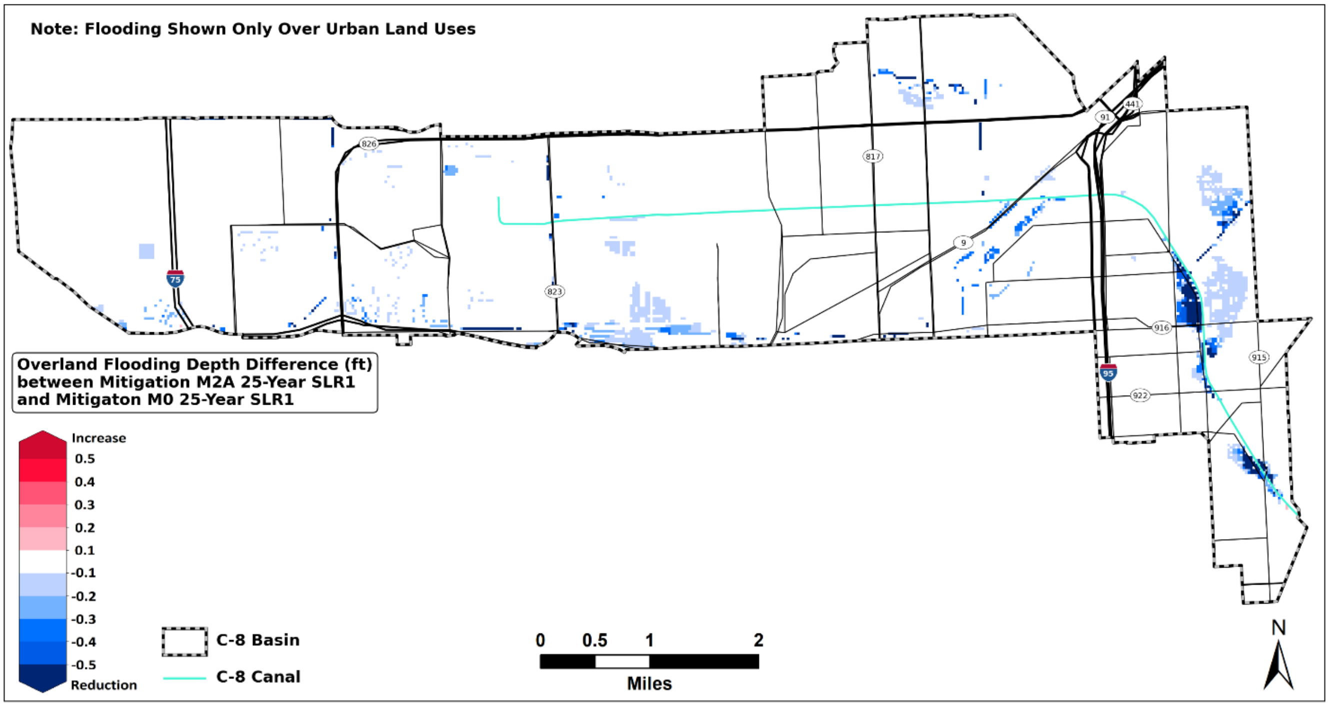


Figure 4.6 C-8 Basin Flood Inundation Difference Map for Mitigation M2A 25-Year Sea Level Rise 1 Versus Future Conditions without Mitigation (M0) 25-Year SLR1 in Urban Land Use Areas

4.4.1.1.2 Mitigation Strategy M2B

- reduce the 5, 10, 25, and 100-yr SLR1 peak stage profile equal to or below the existing conditions
- reduce the 25-yr SLR2 peak elevations by 0.5 ~ 1.9 ft, or an average of 0.92 ft compared to future without mitigation
- significantly less flood inundation for the M2B 25-year SLR1 event than the 25-year SLR1 event without mitigation
- significantly reduce the impact of sea level rise
- with M2B, the current LOS can be maintained under 2 ft SLR.

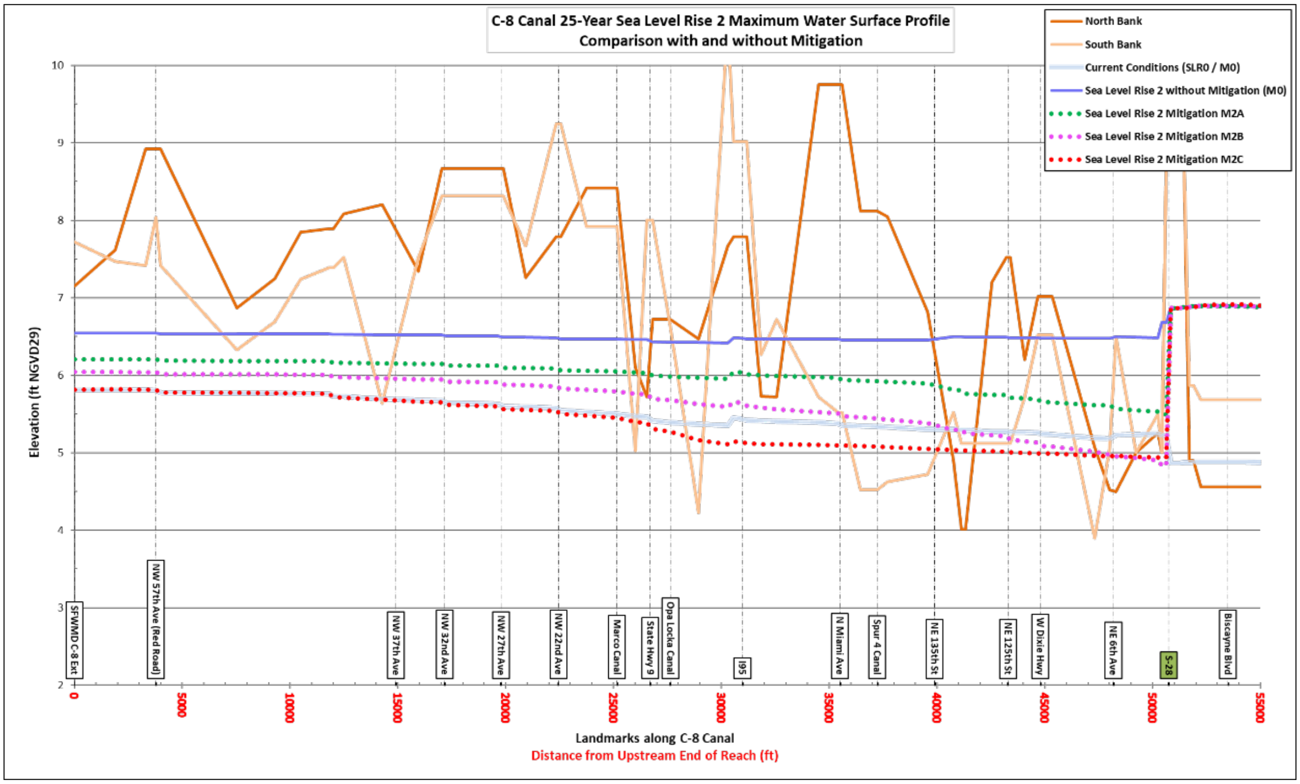


Figure 4.7 C-8 Canal Peak Stage Profiles for 25-Year Sea Level Rise 2 with and without Mitigation

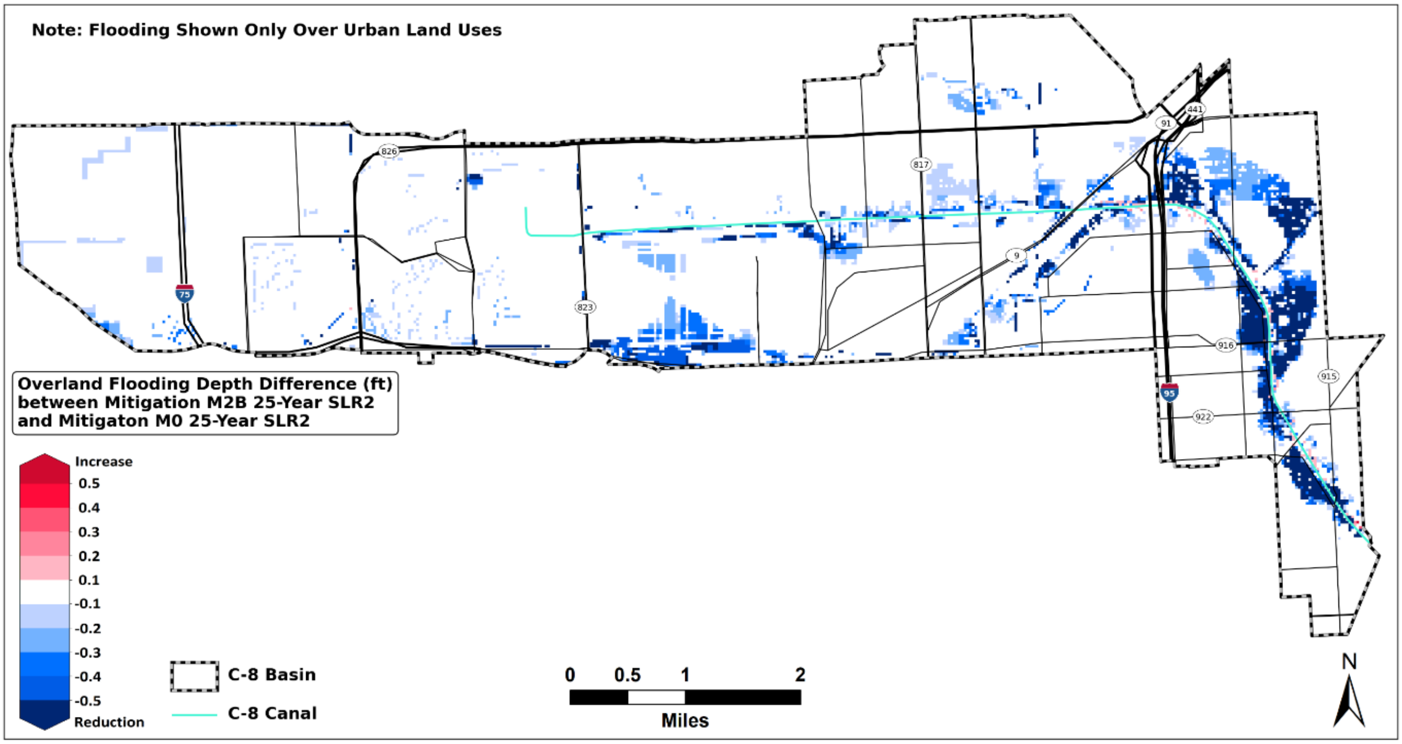


Figure 4.8 C-8 Basin Flood Inundation Difference Map for Mitigation M2B 25-Year Sea Level Rise 2 Versus Future Conditions without Mitigation (M0) 25-Year SLR2 in Urban Land Use Areas

4.4.1.1.3 Mitigation Strategy M2C

- will not reduce the peak stage profile to a level equal to or below the existing conditions
- reduce the 25-yr SLR3 peak elevations by 0.7 ~ 1.9 ft, compared to future without mitigation
- 25-year SLR3: maintain approximately the same level of flood inundation as current conditions
- 25-year SLR3 event: significantly less flood inundation compared to future without mitigation
- significantly reduce the impact of sea level rise

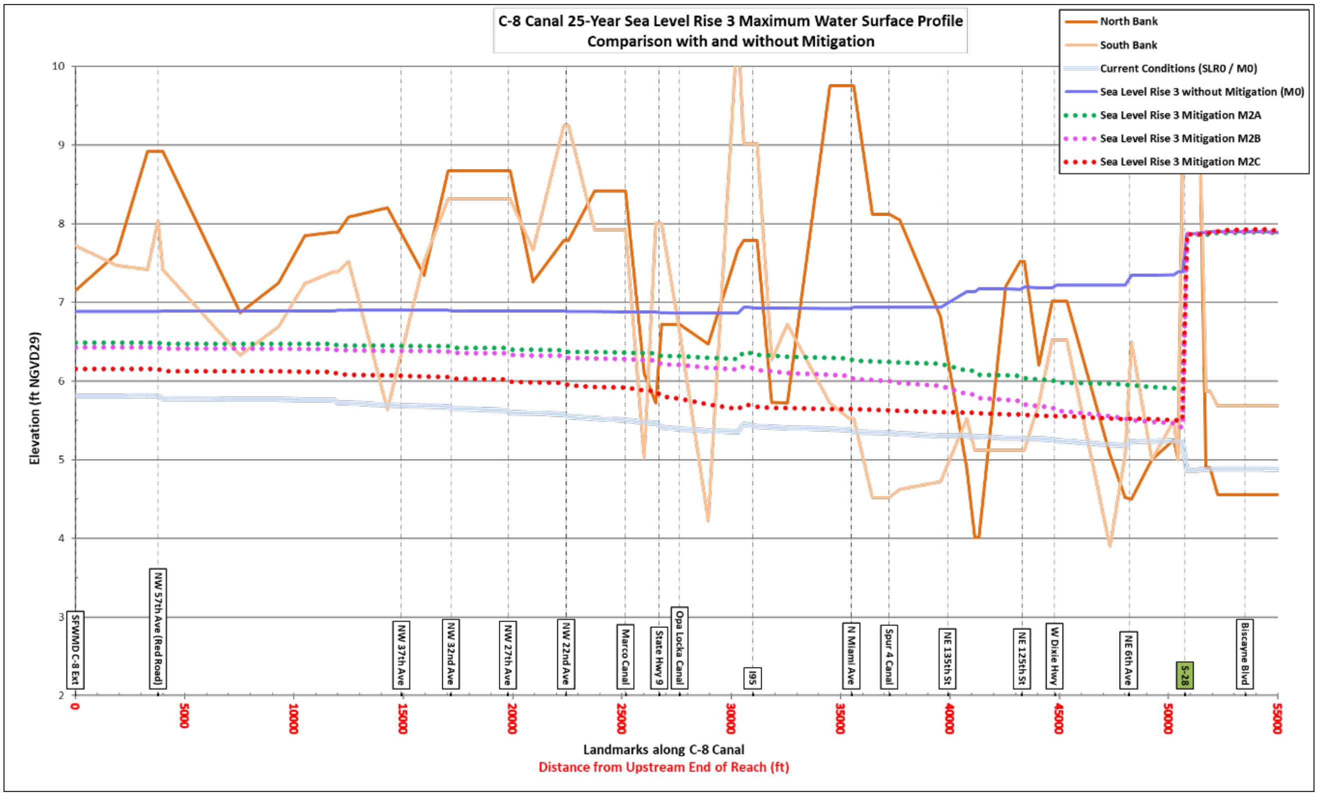


Figure 4.9 C-8 Canal Peak Stage Profiles for 25-Year Sea Level Rise with and without Mitigation

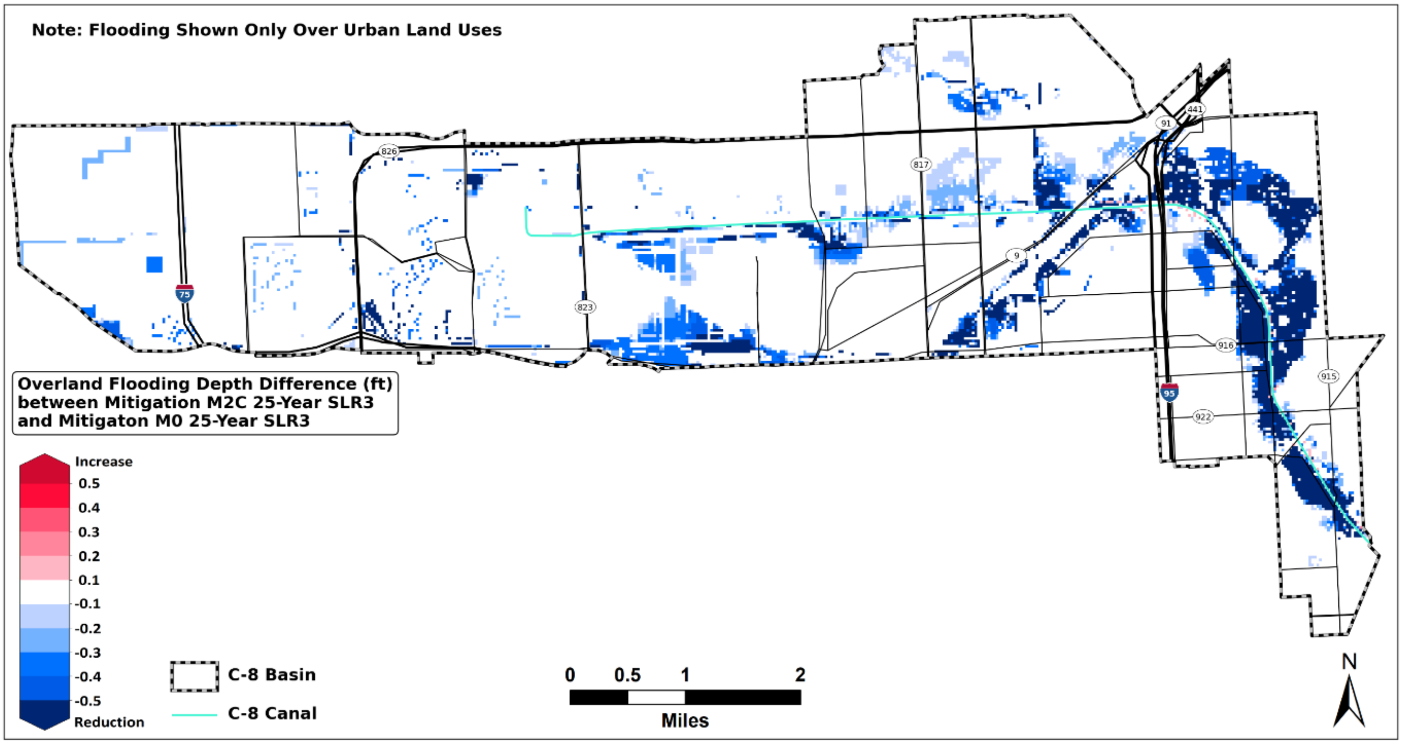


Figure 4.10 C-8 Basin Flood Inundation Difference Map for Mitigation M2C 25-Year Sea Level Rise 3 versus Future Conditions without mitigation (M0) 25-Year SLR3 in Urban Land Use Areas

4.4.1.2 PM#1 Summary for the C-8 Watershed for each Mitigation Strategy

4.4.1.2.1 Mitigation Strategy M2A

- Mitigation M2A should eliminate bank exceedance for the 5-year SLR1 event and greatly reduce the elevation above bank for the 10-year SLR1 event
- The M2A 5, 10, and 25-year SLR1 maximum water surface profiles are nearly equal to or below existing conditions (M0 5, 10, 25-year, respectively)
    - Mostly achieves the goal of M2A
    - There are still LOS deficiencies due to bank exceedances and/or elevated stages
- Mitigation M2A should lower the maximum canal profile across all sea level rise scenarios, effectively removing the effect of one foot of sea level rise
    - M2A 25-year SLR3 canal elevations are lower than M0 25-year SLR2
    - M2A 10-year SLR2 canal elevations are lower than M0 10-year SLR1
- Mitigation M2A did not show significant improvement in the C-8 Watershed's LOS compared to existing conditions
- Mitigation M2A showed significant improvement in the C-8 Watershed's LOS compared to future conditions without mitigation
- Mitigation M2A will significantly reduce the impact of sea level rise for SLR1

4.4.1.2.2 Mitigation Strategy M2B

- Although M2B has an additional 1,000 cfs pumping capacity compared to M2A, model results showed it did not contain the canal within bank by itself; therefore the bank elevations were increased
    - Raised bank elevations reduce floodplain storage and increase the maximum water level in the C-8 Canal
    - Raised bank elevations prevent overland drainage to the C-8 Canal
    - Internal drainage system required to drain water "across" the raised banks
    - The 1,000 cfs pump capacity helps offset the reduced floodplain storage and/or the increased stages due to improved overland drainage
- Mitigation M2B was unable to reduce the 25-year SLR2 maximum surface profile to a level equal to or below the 25-year existing conditions SLR0 profile
    - Mitigation M2B is able to reduce the 5, 10, 25, and 100-year SLR1 maximum water levels appropriately equal to or below the existing conditions maximum water levels
    - Mitigation M2B is predicted to reduce the 25-year SLR2 maximum elevations in the C-8 Canal by 0.5 ft to 1.9 ft, or an average of 0.92 ft compared to future conditions without mitigation
- Mitigation M2B showed it was able lower the maximum canal profile across all sea level rise scenarios, effectively removing the effect of one foot of sea level rise
    - M2B 25-year SLR3 canal elevations are lower than M0 25-year SLR2
    - M2B 10-year SLR2 canal elevations are lower than M0 10-year SLR1
- Mitigation M2B will likely not significantly improve the C-8 Watershed's LOS compared to existing conditions
- Mitigation M2B did show substantial improvement the C-8 Watershed's LOS compared to future conditions without mitigation
- Mitigation M2B will significantly reduce the impact of sea level rise

4.4.1.2.3 Mitigation Strategy M2C

- Diminishing returns at the point where the pumping capacity becomes greater than the conveyance capacity of the canal.
    - Diminishing returns became more obvious for the C-8 Canal around the 2,550 cfs capacity under Mitigation Scenario M2B
    - The 3,550 cfs pump capacity alone had minimal improvement compared to 2,550 cfs
    - So, to get the benefit of the larger pump. This strategy requires increased canal conveyance capacity
- Increased canal conveyance capacity through widening MIKE HYDRO cross sections downstream of I-95
- Mitigation M2C was unable to reduce the 25-year SLR3 maximum surface profile to a level equal to or below the 25-year existing conditions SLR0 profile
    - Mitigation M2C is able to reduce the 25-year and 100-year SLR2 maximum water levels equal to or below the existing conditions maximum water levels
    - Mitigation M2C is predicted to reduce the 25-year SLR3 maximum elevations in the C-8 Canal by 0.7 ft to 1.9 ft compared to future conditions without mitigation
- Mitigation M2C is predicted to lower the maximum canal profile across all sea level rise scenarios, effectively removing the effect of up to two feet of sea level rise
    - M2C 25-year SLR3 canal elevations are lower than M0 25-year SLR1
    - M2C 5-year SLR2 canal elevations are lower than M0 5-year SLR1
- Mitigation M2C is not predicted to significantly improve the C-8 Watershed’s LOS compared to existing conditions
- Mitigation M2C will significantly improve the C-8 Watershed’s LOS compared to future conditions without mitigation, reducing the impact of sea level rise

Table 4.1 shows PM#1 Summary for the C-8 Canal.

Table 4.1 PM#1 Summary for the C-8 Canal

Rainfall Return Period	Sea Level Rise Scenario	Mitigation M2A		Mitigation M2B		Mitigation M2C	
		Peak Stage Profile with Mitigation lower than Existing Conditions	Eliminates Bank Exceedance	Peak Stage Profile with Mitigation lower than Existing Conditions	Eliminates Bank Exceedance	Peak Stage Profile with Mitigation lower than Existing Conditions	Eliminates Bank Exceedance
5-year	SLR1	yes	yes	yes	yes	yes	yes
	SLR2	no	no	no	yes	no	yes
	SLR3	no	no	no	yes	no	yes
10-year	SLR1	yes	reduces	yes	yes	yes	yes
	SLR2	no	no	no	yes	Yes (half)	yes
	SLR3	no	no	no	yes	no	yes
25-year	SLR1	No, but within 0.1 ft on average	reduces some instances	yes	yes	yes	yes
	SLR2	no	no	no	yes	yes	yes
	SLR3	no	no	no	yes	no	yes
100-year	SLR1	No, but within 0.1 ft on average	slight reduction in some locations	yes	yes	yes	yes
	SLR2	no	no	no	yes	yes	yes
	SLR3	no	no	no	yes	no	yes

4.4.1.3 PM#5 Summary for the C-8 Watershed for each Mitigation Strategy

4.4.1.3.1 Mitigation Strategy M2A

- Even with Mitigation M2A, there are areas with higher levels of overland flooding compared to existing conditions. However, there are also areas with lower levels of overland flooding
- Overall, the M2A 25-year SLR1 flood inundation shows similar flooding to existing conditions
- Overall, PM#5 showed there will be substantially less flood inundation for the M2A 25-year SLR1 event than the 25-year SLR1 event without mitigation

4.4.1.3.2 Mitigation Strategy M2B

- Overall, the M2B 25-year SLR2 flood inundation shows similar flooding to existing conditions
- There exist widespread areas with both increases and decreases in flooding
- Many of the areas predicted to have an increase in flooding compared to existing conditions occur in low-lying areas, where the groundwater elevation peaks are higher than the elevation of the land surface. This results in an increase in flood depths that are difficult to fully mitigate.
- Overall, model results show that there will be substantially less flood inundation for the M2B 25-year SLR2 event than the 25-year SLR2 event without mitigation

4.4.1.3.3 Mitigation Strategy M2C

- Overall, the M2C 25-year SLR3 flood inundation shows similar flooding to existing conditions
    - There exist widespread areas with both increases and decreases in flooding
    - Many of the areas predicted to have an increase in flooding compared to existing conditions occur in low-lying areas, where the groundwater elevation peaks are higher than the elevation of the land surface. This results in an increase in flood depths that are difficult and potentially infeasible to fully mitigate.
- Overall, PM#5 shows that there will be substantially less flood inundation for the M2C 25-year SLR3 event than the 25-year SLR3 event without mitigation

4.4.2 Summary of Model Results for the C-9 Watershed

The following subsections highlight the results of the 25-year storm events for each of the M2A, M2B, and M2C mitigation strategies for PM#1 and PM#5 for the C-9 Watershed (**Figure 4.11** through **Figure 4.16**).

4.4.2.1 Summary of Model Results for the C-9 Watershed for each Mitigation Strategy

4.4.2.1.1 Mitigation Strategy M2A

- Remove the effect of SLR by about 1 ft
- M2A 25-yr SLR3 peak stage profile: lower than M0 25-yr SLR2
- M2A 10-yr SLR2 peak stage profile: lower than M0 10-yr SLR1
- M2A 25-year SLR1 flood inundation is expected to maintain a comparable level of impact to the existing conditions, without indicating any substantial improvement or worsening
- M2A 25-year SLR1 flood inundation is less than the M0 25-year SLR1 event

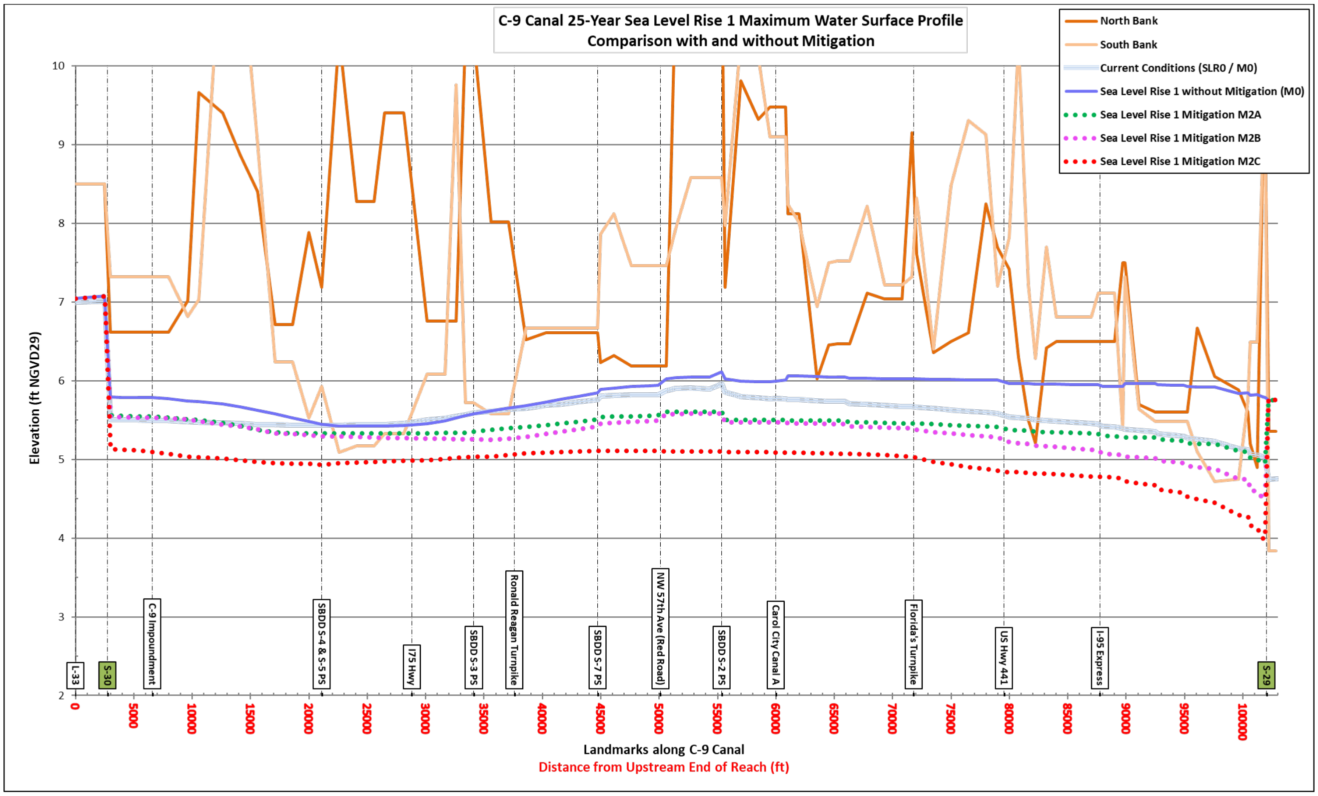


Figure 4.11 C-9 Canal Peak Stage Profiles for 25-Year Sea Level Rise 1 with and without Mitigation

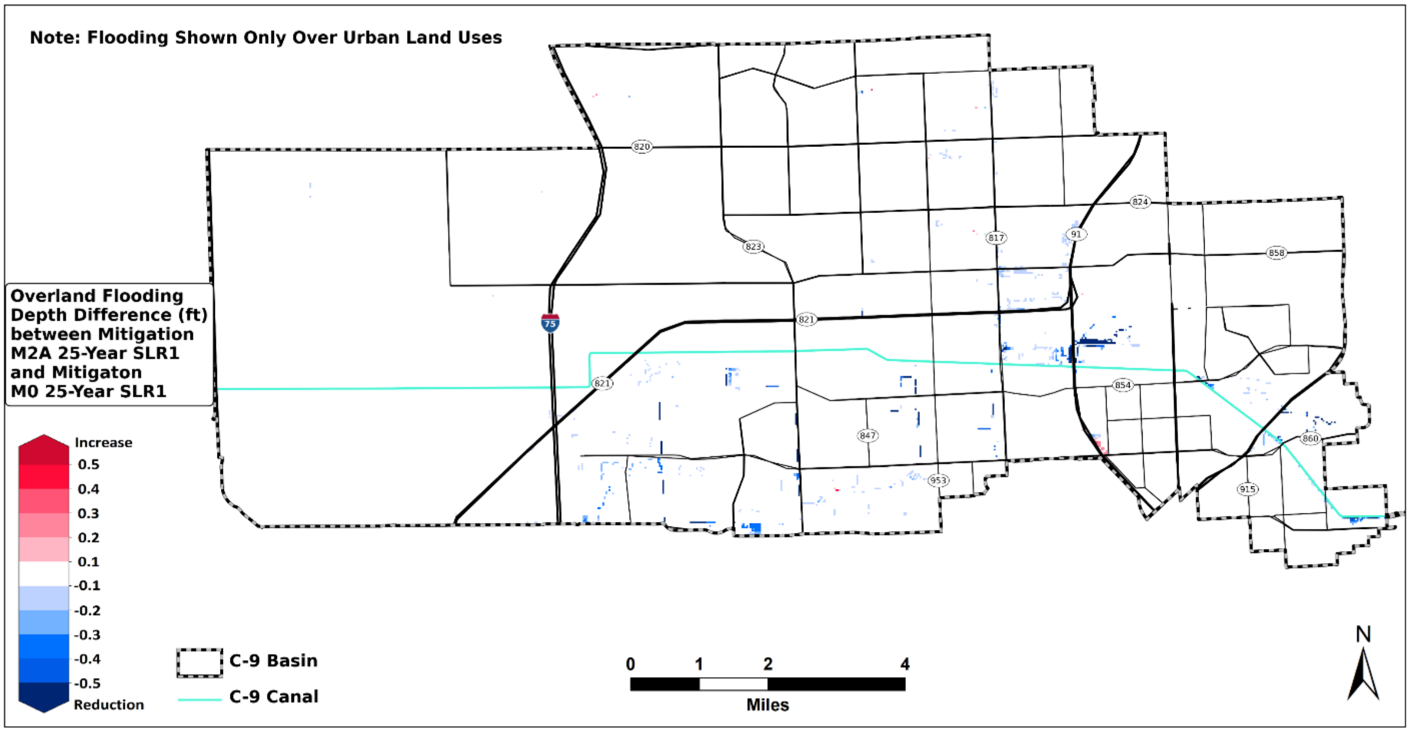


Figure 4.12 C-9 Basin Flood Inundation Difference Map for Mitigation M2A 25-Year Sea Level Rise 1 Versus Future Conditions without Mitigation (M0) 25-Year SLR1 in Urban Land Use Areas

4.4.2.1.2 Mitigation Strategy M2B

- reduce the 5, 10, 25, and 100-yr SLR1 peak stage profile equal to or below the existing conditions
- reduce the 25-yr SLR2 peak elevations by 0.2 ~ 1.4 ft, or an average of 0.56 ft compared to future without mitigation
- With M2B, can maintain current LOS under SLR2 conditions
- Substantially less flood inundation for the M2B 25-yr SLR2 event than the 25-yr SLR2 event without mitigation, reducing the impact of sea level rise

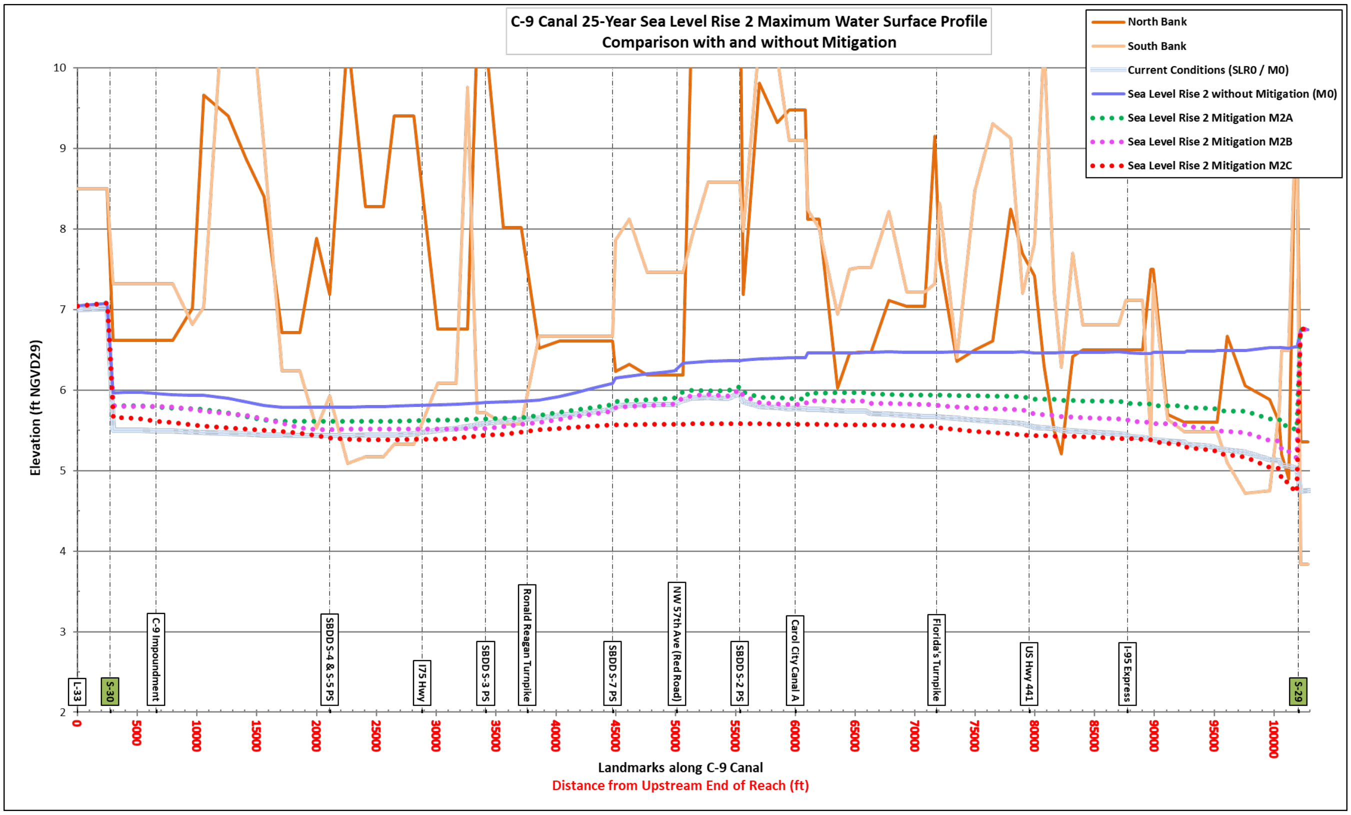


Figure 4.13 C-9 Canal Peak Stage Profiles for 25-Year Sea Level Rise 2 with and without Mitigation

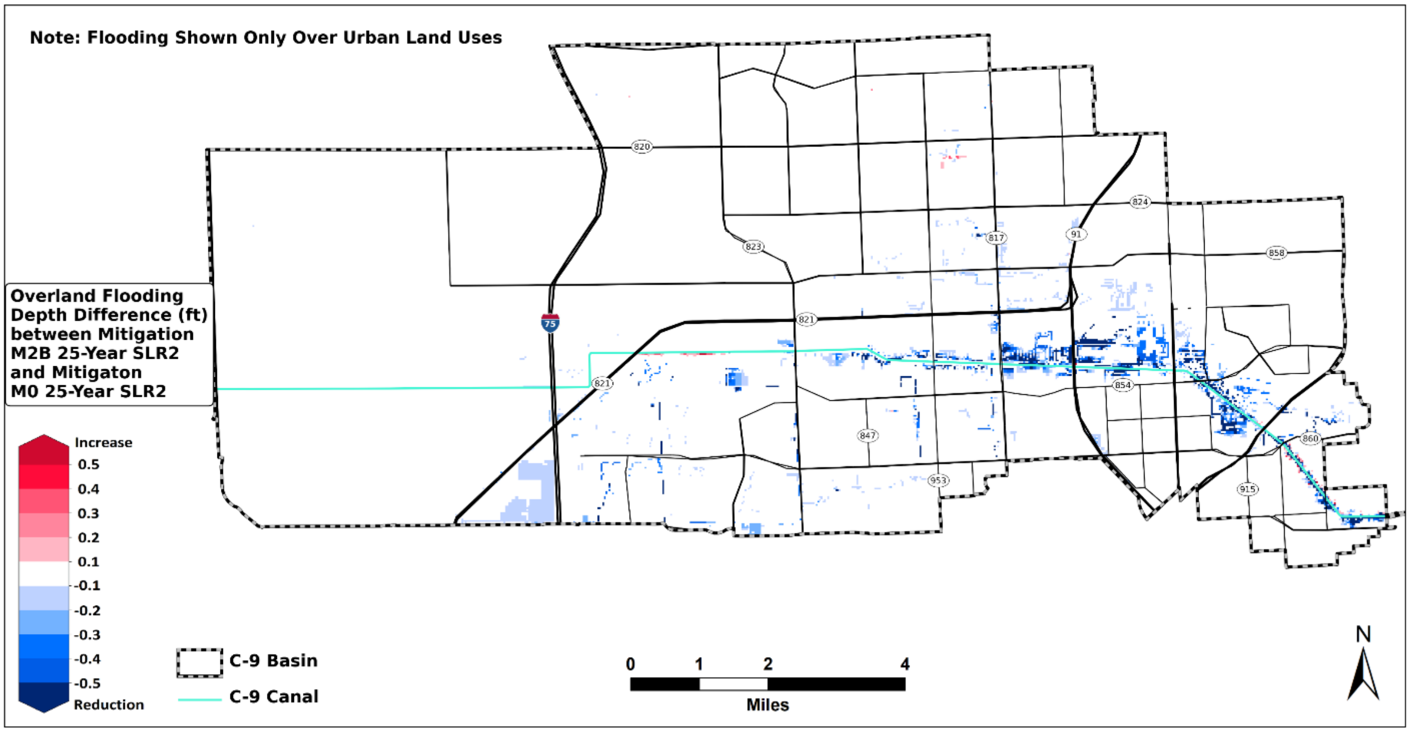


Figure 4.14 C-9 Basin Flood Inundation Difference Map for Mitigation M2B 25-Year Sea Level Rise 2 Versus Future Conditions without Mitigation (M0) 25-Year SLR2 in Urban Land Use Areas

4.4.2.1.3 Mitigation Strategy M2C

- reduce the 25 and 100-yr SLR2 peak stage profile equal to or below the existing conditions
- reduce the 25-yr SLR3 peak elevations by 0.1 ~ 1.9 ft, or an average of 0.67 ft compared to future without mitigation
- With M2C, maintain current LOS under SLR3 conditions
- substantially less flood inundation for the M2C 25-yr SLR3 event than the 25-yr SLR3 event without mitigation
- significantly reduce the impact of sea level rise

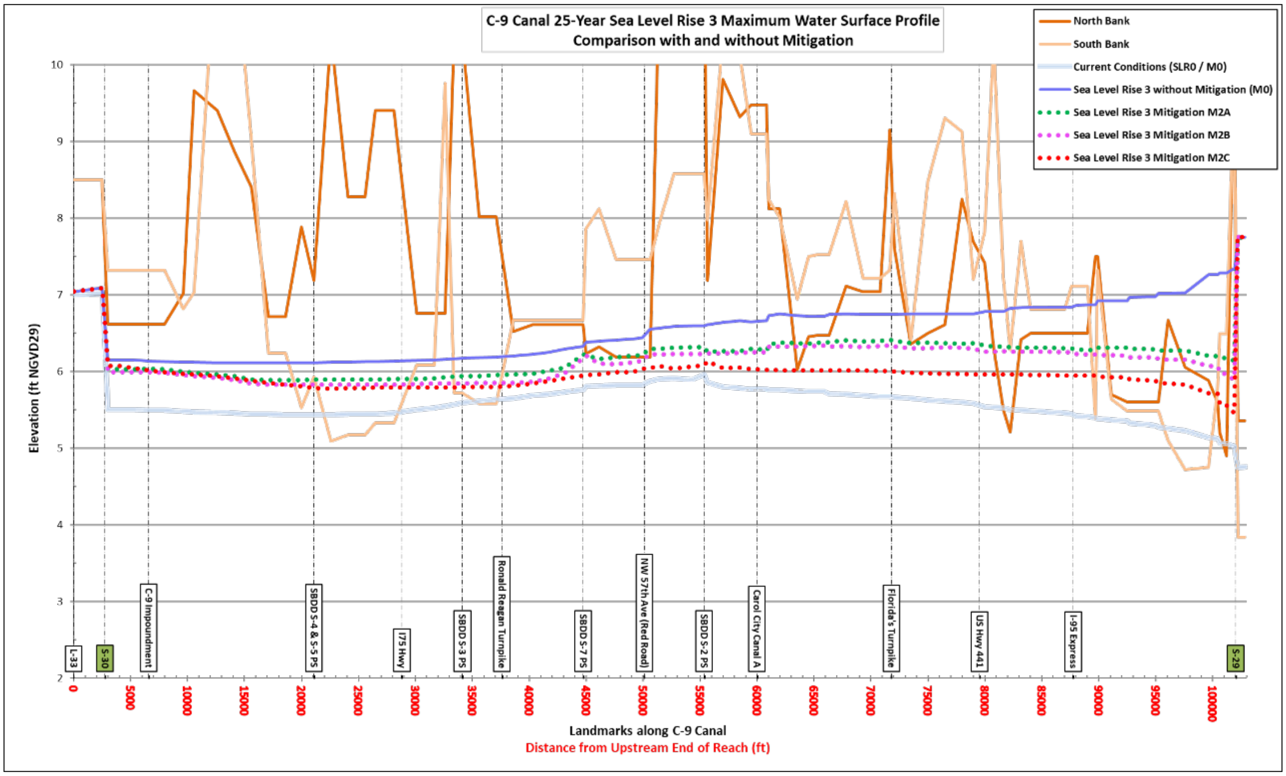


Figure 4.15 C-9 Canal Peak Stage Profiles for 25-Year Sea Level Rise 3 with and without Mitigation

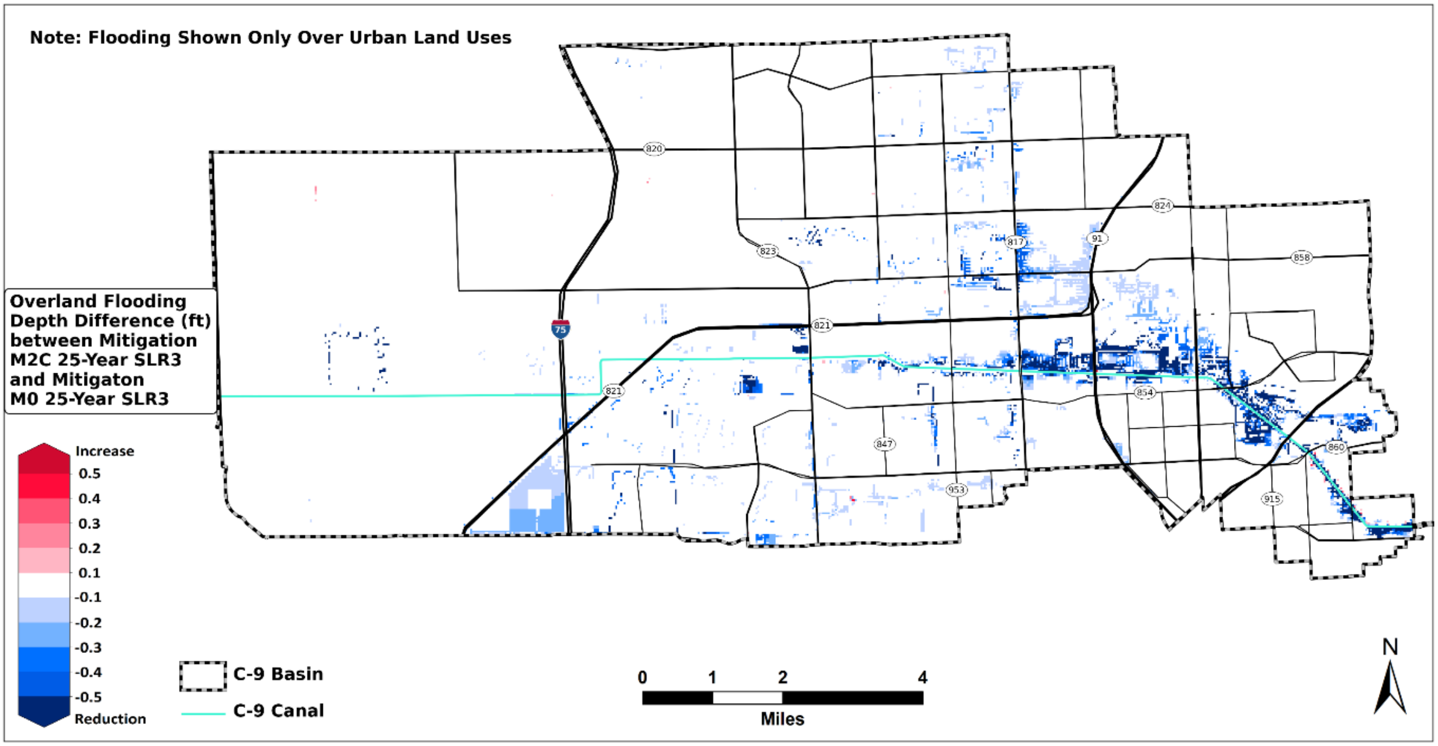


Figure 4.16 C-9 Basin Flood Inundation Difference Map for Mitigation M2C 25-Year Sea Level Rise 3 Versus Future Conditions without Mitigation (M0) 25-Year SLR3 in Urban Land Use Areas

4.4.2.2 PM#1 Summary for the C-9 Watershed for each Mitigation Strategy

4.4.2.2.1 Mitigation Strategy M2A

- Mitigation M2A is able to achieve a maximum water surface profile that is lower than existing conditions for eliminating bank exceedance for the 5, 10, 25, and 100-year SLR1 event
- Although Mitigation M2A is not able to eliminate bank exceedances under the 25-year SLR1 storm event, model results show it is able to reduce the level of exceedance
- Mitigation M2A is able to lower the maximum canal profile across all sea level rise scenarios, effectively removing the effect of about one foot of sea level rise
    - M2A 25-year SLR3 canal elevations are lower than M0 25-year SLR2
    - M2A 10-year SLR2 canal elevations are lower than M0 10-year SLR1
- Mitigation M2A is not able to significantly improve the C-9 Watershed's provided LOS compared to existing conditions
- Mitigation M2A is able to substantially improve the C-9 Watershed's LOS provided compared to future conditions without mitigation, reducing the impact of sea level rise

4.4.2.2.2 Mitigation Strategy M2B

- Although M2B has an additional 1,000 cfs pumping capacity compared to M2A, it is not able contain the canal within bank; therefore, the bank elevations were increased for the eastern canal segment (western bank exceedances are in an undeveloped area and act as storage areas)
    - Raised bank elevations reduce floodplain storage and increase the maximum water level in the C-9 Canal
    - Raised bank elevations prevents overland drainage to the C-9 Canal
    - Internal drainage system required to drain water through the raised banks
    - The additional 1,000 cfs pump capacity helps offset the reduced floodplain storage and/or the increased stages due to improved overland drainage
- Mitigation M2B was unable to reduce the 25-year SLR2 maximum surface profile to a level equal to or below the 25-year existing conditions SLR0 profile
    - Mitigation M2B is able to reduce the 5, 10, 25, and 100-year SLR1 maximum water levels equal to or below the existing conditions maximum water levels
    - Mitigation M2B is able to reduce the 25-year SLR2 maximum elevations in the C-9 Canal by 0.2 ft to 1.4 ft, with an average reduction of 0.56 ft compared to future conditions without mitigation
- Mitigation M2B is able to lower the maximum canal profile across all sea level rise scenarios, effectively removing the effect of one foot of sea level rise
    - M2B 25-year SLR3 canal elevations are lower than M0 25-year SLR2
    - M2B 10-year SLR2 canal elevations are lower than M0 10-year SLR1
- Mitigation M2B is not able to significantly improve the C-9 Watershed's provided LOS compared to existing conditions
- Mitigation M2B is able to substantially improve the C-9 Watershed's LOS provided compared to future conditions without mitigation, reducing the impact of sea level rise

4.4.2.2.3 Mitigation Strategy M2C

- Increased canal conveyance capacity through widening MIKE HYDRO cross sections along approximately 79,000 linear ft of C-9 Canal

  - Not necessarily needed due to canal conveyance limitations, rather to help reduce water levels in both C-9 and in the interconnected C-8 Watershed
- Increased pump capacity (additional 1,000 cfs over M2B) to help offset the increased water levels in the eastern portion of the C-9 Canal due to the increased conveyance capacity
- Mitigation M2C was unable to reduce the 25-year SLR3 maximum surface profile to a level equal to or below the 25-year existing conditions SLR0 profile
  - Mitigation M2C is able to reduce the 25-year and 100-year SLR2 maximum water levels equal to or below the existing conditions maximum water levels
  - Mitigation M2C is able to reduce the 25-year SLR3 maximum elevations in the C-9 Canal by 0.1 ft to 1.9 ft, with an average reduction of 0.67 ft, compared to future conditions without mitigation
- Mitigation M2C is able to lower the maximum canal profile across all sea level rise scenarios, effectively removing the effect of up to two feet of sea level rise
  - M2C 25-year SLR3 canal elevations are lower than M0 25-year SLR1
  - M2C 10-year SLR2 canal elevations are lower than M0 10-year SLR1 and almost as low as existing conditions
- Mitigation M2C is not able to significantly improve the C-9 Watershed's provided LOS compared to existing conditions
- Mitigation M2C is able to substantially improve the C-9 Watershed's LOS provided compared to future conditions without mitigation, reducing the impact of sea level rise

Table 4.2 shows PM#1 Summary for the C-9 Canal.

Table 4.2 PM#1 Summary for the C-9 Canal

Rainfall Return Period	Sea Level Rise Scenario	Mitigation M2A		Mitigation M2B		Mitigation M2C	
		Peak Stage Profile with Mitigation lower than Existing Conditions	Eliminates Bank Exceedance	Peak Stage Profile with Mitigation lower than Existing Conditions	Eliminates Bank Exceedance	Peak Stage Profile with Mitigation lower than Existing Conditions	Eliminates Bank Exceedance
5-year	SLR1	yes	N/A (none)	yes	yes	yes	yes
	SLR2	no	yes	no	yes	no	yes
	SLR3	no	reduces	no	yes	no	yes
10-year	SLR1	yes	N/A (none)	yes	yes	yes	yes
	SLR2	no	no	no	yes	almost	yes
	SLR3	no	no	no	yes	no	yes
25-year	SLR1	yes	reduces	yes	yes	yes	yes
	SLR2	no	no	almost	yes	yes	yes
	SLR3	no	no	no	yes	no	yes
100-year	SLR1	yes	reduces	yes	yes	yes	yes
	SLR2	no	no	almost	yes	yes	yes
	SLR3	no	no	no	yes	no	yes

4.4.2.3 PM#5 Summary for the C-9 Watershed for each Mitigation Strategy

4.4.2.3.1 Mitigation Strategy M2A

- In general, for all events, strategy M2A shows some changes in flooding areas but overall shows similar flood inundation to current conditions without mitigation
- For the M2A 25-year SLR1 event PM#5 shows less flooding than without mitigation.

4.4.2.3.2 Mitigation Strategy M2B

- Overall, the M2B 25-year SLR2 flood inundation is similar to existing conditions
    - PM#5 shows that there will be widespread areas with an increase in flooding as well as widespread areas with a decrease in flooding
    - Many of the areas that will have an increase in flooding compared to existing conditions occur in low-lying areas, where the groundwater elevation peaks are higher than the elevation of the land surface. This results in an increase in flood depths that are difficult and potentially infeasible to fully mitigate.
- Overall, it is predicted that there will be substantially less flood inundation for the M2B 25-year SLR2 event than the 25-year SLR2 event without mitigation

4.4.2.3.3 Mitigation Strategy M2C

- Overall, the M2C 25-year SLR3 flood inundation is similar to existing conditions
    - PM#5 shows that there will be widespread areas with an increase in flooding as well as widespread areas with a decrease in flooding
    - Many of the areas predicted to have an increase in flooding compared to existing conditions occur in low-lying areas, where the groundwater elevation peaks higher than the elevation of the land surface. This results in an increase in flood depths that are difficult and potentially infeasible to fully mitigate.
- Overall, PM#5 shows that there will be substantially less flood inundation for the M2C 25-year SLR3 event than the 25-year SLR3 event without mitigation

5.0 FLOOD DAMAGE ASSESSMENT – EXPECTED ANNUAL DAMAGES

The general approach to calculate economic damages of flooding required an understanding of the risk and knowledge of the infrastructure (buildings, roads, etc.) exposed to the risk. The Hazard Data in this case is depth of 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-year, 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 damage predicted yearly.

In practice, flooding occurs in episodic events, with certain years experiencing extensive damage consequences, while others may have minimal impact. It is important to keep in mind that the estimations presented reflect a probabilistic average of damage, considering the inherent variability in flood events over time. This process is shown in **Figure 5.1**. The full report explores the details of each of these elements and can be found in ***APPENDIX F***.

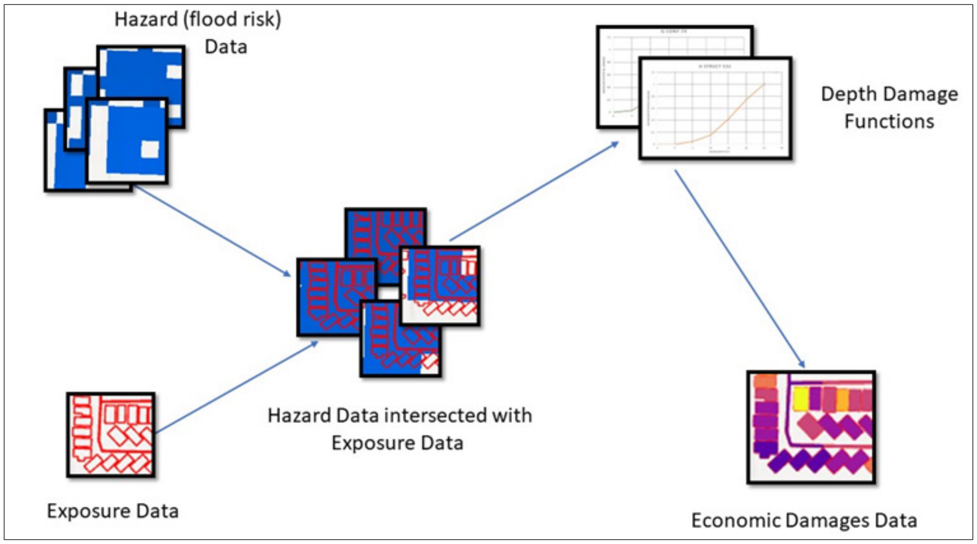


Figure 5.1 Schematic of Economic Damage Calculation

The value of calculating EAD's is not in trying to understand the actual dollar amount of damages, but the relative reduction in damages with respect to mitigation and adaptation projects. The EAD results can be plotted with respect to current sea level (CSL), SLR 1, 2 and 3 for each of the mitigation strategies and compared to existing conditions (M0). The following two graphs present the final comparisons for the C-8 and C-9 watersheds (**Figure 5.2** and **Figure 5.3**). The M0 curve shows the existing conditions economic damages estimated for each SLR scenario. The curves for each project are below the M0 curve, indicating the reduction in economic damages. The curves also show a slope up and to the right indicating the increased in economic damages as sea level elevations increase.

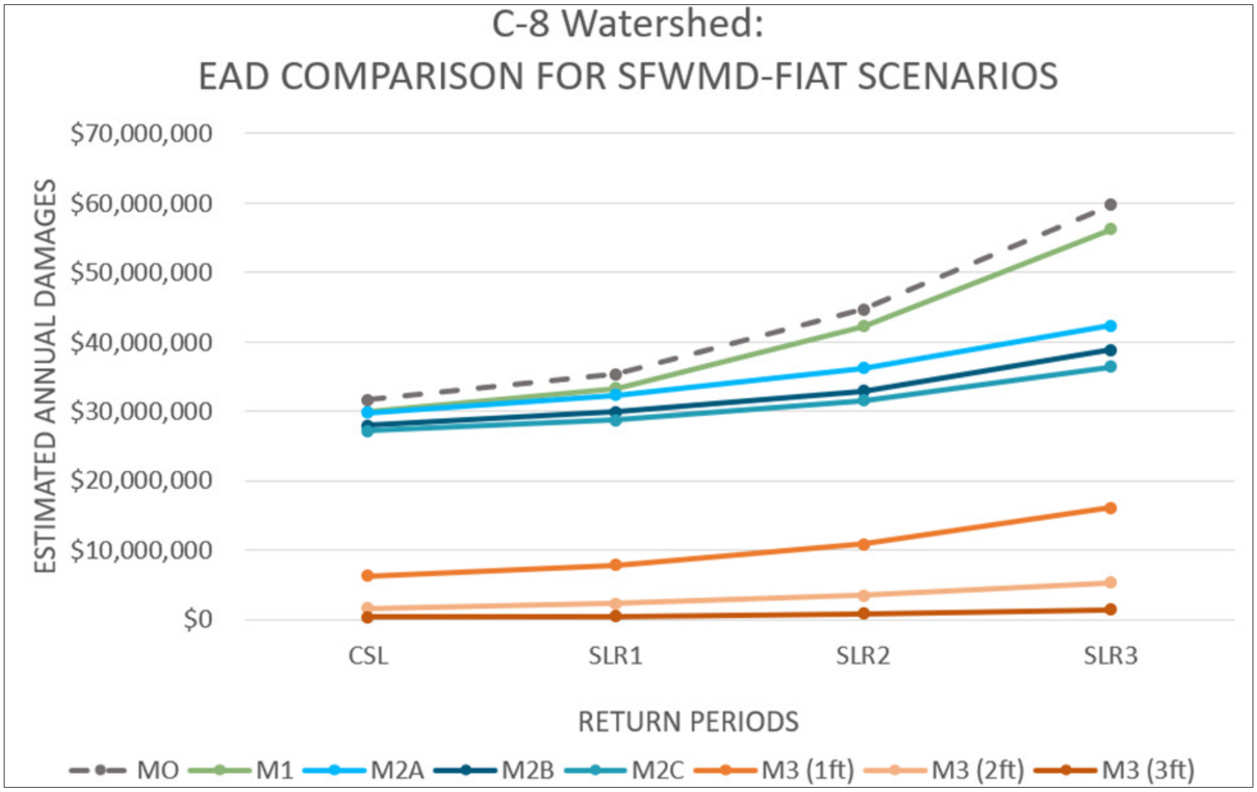


Figure 5.2 C-8 Watershed – EAD Comparison for SFWMD-FIAT Scenarios

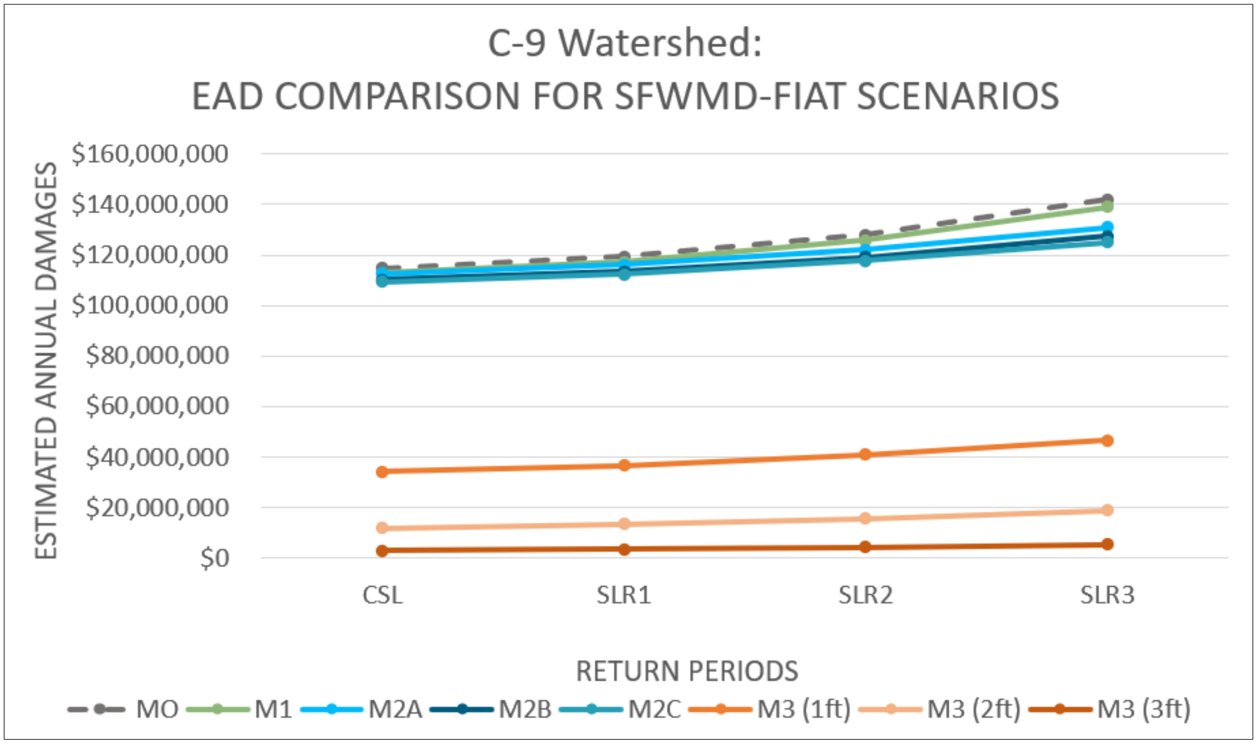


Figure 5.3 C-9 Watershed – EAD Comparison for SFWMD-FIAT Scenarios

In Summary:

- M1 projects show that small-scale projects will benefit the communities in the near future and should be implemented. However, the analytic approach used to define the benefits of M1 projects do not vary with SLR and, therefore, the M1 projects simply track the increasing damages of SLR.
- 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 results show that the C-8 Watershed has a significantly larger beneficial response to the mitigation projects than does the C-9 Watershed.
- A helpful way to think about the mitigation projects and their effectiveness is to review the amount they reduce EADs with respect to no mitigation action.
- For the C-8 Watershed 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 Watershed 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 and adaptation projects 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 and adaptation projects. The detailed risk analysis provided by hydrologic and hydraulic modeling 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 and adaptation projects 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.

6.0 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 Benefit Cost Approach (BCA)Toolkit (FEMA 2023). 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.

6.1 Mitigation Project Cost Estimates

This planning study required a rough order of magnitude costs for mitigation projects to calculate benefit-cost ratios (BCRs). The M1 and M3 projects are based on very limited project information. M1 projects included generic items such as "drainage improvements" or approximate pump locations with no sizing. M3 projects are estimating the cost to elevate all roads and buildings within the basin – it is quite difficult to develop costs for such an activity. However, it is possible to make educated and informed estimates based on industry standards and practice. The cost estimates for the M1 and M3 projects are approximate and gross in nature, but certainly help in this planning study.

M2 mitigation projects are based on much more detailed cost assumptions than the M1 and M3 mitigation projects and allowed a more detailed cost estimate. However, these are still planning level estimates and will need considerable updates as the project designs advance.

M2 projects costs are largely based on prior estimates from the SFMWD on similar projects. In particular, the District's Coastal Resiliency Program had developed costs for similar projects in the same area. For this study, then, the team was able to apply these unit costs and scale them appropriately for the mitigation projects identified in M2A, M2B, and M2C.

Details on the assumptions and data used to calculate mitigation project costs are outlined in ***APPENDIX A***. These costs are estimated in 2021 values.

6.2 Benefit-Cost Approach and Procedure

The value proposition of each mitigation project is that the benefits, or economic damage avoided, will exceed the cost to construct the mitigation option. 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.

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:

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

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

Where,

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

6.2.1 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 (***APPENDIX C***), 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 is it 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.

6.3 Benefit-Cost Analysis Results

Table 6.1 and **Table 6.2** 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 SLR3 conditions, with and without mitigation conditions. Values in the tables are shown in millions. The graphs (**Figure 6.1** and **Figure 6.2**) exclude the extreme results from the M3 projects since their implementation is not practical as an immediate mitigation measure.

Table 6.1 Benefit-Cost Ratio Table for the C-8 Watershed

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

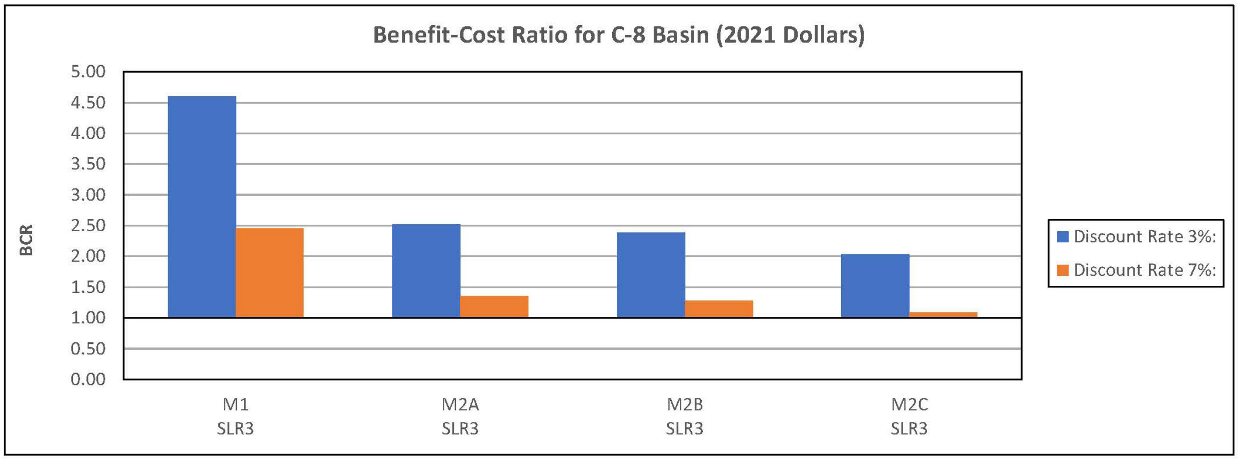


Figure 6.1 Benefit-Cost Ratio Graph for the C-8 Watershed

Table 6.2 Benefit-Cost Ratio Table for the C-9 Watershed

Benefit-Cost Ratio for C-9 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$)	-3967	73	290	382	440	2489	3212	3560
Costs (M$)	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

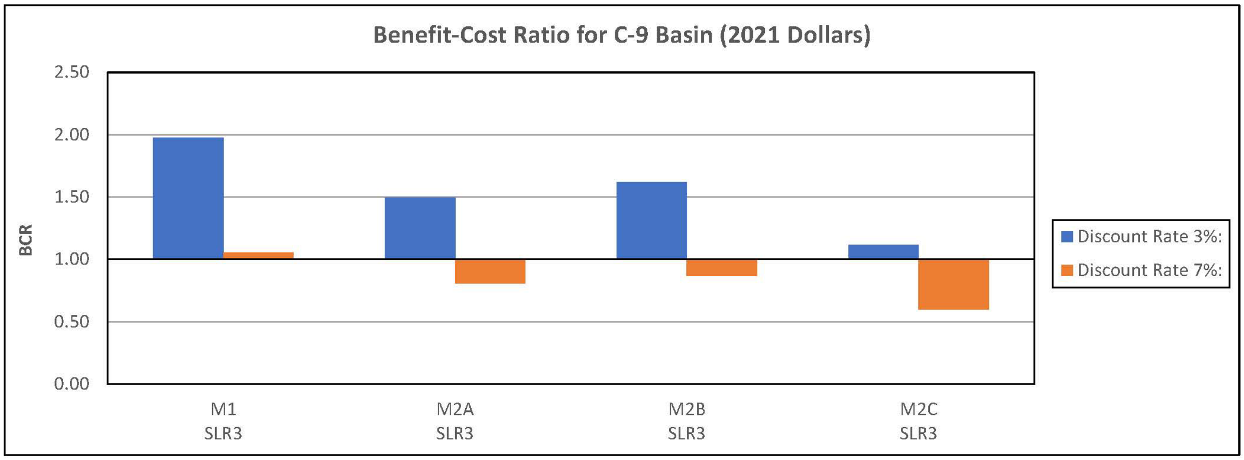


Figure 6.2 Benefit-Cost Ratio Graph for the C-9 Watershed

The results indicated 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 achieved very high BCRs, as expected for the planning exercise. However, this may be partially due to the difficulty in developing a cost for these projects. These results have a high uncertainty.

6.3.1 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 and adaptation projects.

6.3.2 M1 Projects

These projects are micro or local-scale projects that have great benefit on 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 II 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 communities continue to define these projects, they apply small scale modeling and economic analysis to better understand the true BCR results. The M1 projects had high BC ratios for both the C-8 and C-9 watersheds. The M1 projects were studied with analytic solutions and not included in the modeling applied for the M2 projects that follow.

6.3.3 M2 Projects

This category of mitigation projects included M2A, M2B, and M2C under SLR3 conditions. **Table 6.1** and **Table 6.2** show that these mitigation and adaptation projects provided substantial benefits with BCRs greater than two under all scenarios for the C-8 basin at a 3% discount rate. The M2 projects all achieved over 1 BCR for all SLR scenarios with the 7% discount rate. While the BCR results for the C-8 basin declined from M2A to M2C, all the M2 projects provided BCRs greater than one. Within the C-9 basin the M2A, M2B, and M2C achieved over 1 BCRs for 3% discount rate but only the M1 projects achieved 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.

6.3.4 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 and adaptation projects 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 watersheds. In fact, recent efforts by communities to raise roads and homes have 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 watershed.

6.3.5 *Benefit-Cost Ratio Conclusions*

The results of the Benefit-Cost Ratio (BCR) analysis provide planners, water managers, and decision makers with confidence to proceed with both M1 and M2 projects. The analysis suggested favorable projects under all different regional-level strategies, particularly considering the potential impact of lower interest rates trending closer to 3%.

The evaluation of regional-scale projects, specifically M2A, M2B, and M2C, has yielded highly favorable BCRs, particularly within the C-8 basin for both 3% and 7% discount rates. In C-9 Basin, regional-scale projects, under M2A, M2B, and M2C demonstrated favorable BCRs under 3% discount rate and the most advantageous Benefit-Cost Ratio for M2B under 7% discount rate.

6.3.6 *Indirect Impact to Benefit-Cost Ratios*

The previous analysis was based on reducing the direct costs of flooding impacts to infrastructure. However, there are other indirect impacts from flooding 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.

The indirect consequences of floods on a community can have wide-ranging and enduring effects. It is essential to take into account these impacts when comprehensively evaluating the complete scope of economic and social costs associated with a flood event. By acknowledging and considering these indirect ramifications, a more accurate understanding of the comprehensive implications of floods can be attained.

7.0 DYNAMIC ADAPTIVE PLANNING PATHWAYS (DAPP)

The Dynamic Adaptive Policy Pathways (DAPP) was developed as an analytical framework that facilitates decision-making under deep uncertainty (***APPENDIX G***). Given the uncertainties that exist with future sea level rise, future development and land use conditions, and future water management constraints, the FPLOS studies are suited to the use of DAPP to develop plausible mitigation scenarios. Potential actions are visually depicted with an Adaptations Pathway Map (**Figure 7.1**) that indicates the effectiveness of the action to achieve the desired performance level.

DAPP relies on a few key concepts:

- Thresholds: A pre-specified minimum performance level. In this study, the threshold is determined by the expected annual flood damage (EAD), further discussed in this report.
- Adaptation Tipping Points (ATP): The point at which the proposed action exceeds the threshold. This means that the performance of that action fails to meet the objective. In this study, with the threshold represented as a level of EAD; reaching the tipping point indicates higher estimated annual damages.
- Pathways: Any proposed action or sequence of actions that form a roadmap for future are known as a pathway on the Adaptations Pathway Map.

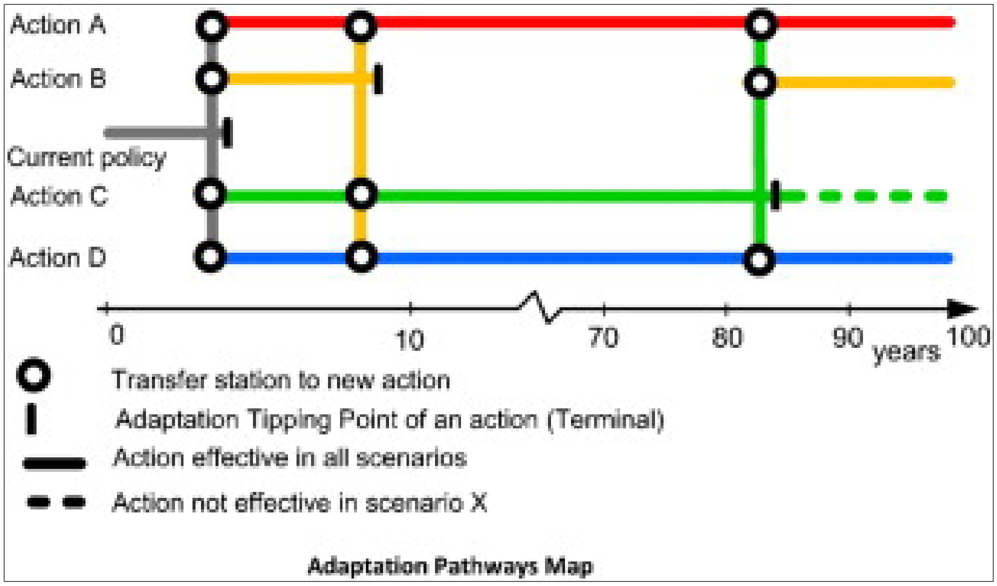


Figure 7.1 Example of an Adaptations Pathway Map

Adaptation pathways can represent multiple sequences of adaptation measures to adjust to changing conditions. In **Figure 7.1**, the example depicts that Action B is effective for almost 10 years. At this tipping point, other actions would need to be taken for the objectives to be met. This approach does not dictate a fixed way to respond. A pathway map shows all the potential options and their combinations. Different maps allow for examining these adaptation decisions under different assumptions about timing and or physical conditions. Thereby, the map shows how far one option (or sequence of options) can perform.

7.1 C-8 & C-9 DAPP Framework

For the C-8 and C-9 study, the DAPP analyzed how much sea level rise can be accommodated by each of the mitigation measures (or sequence of measures) based on the threshold (the pre-specified minimum performance level performance criteria). For example, how long will an action last (e.g., 10 years or 20 years) until it does not function anymore, at which time another action must be implemented. This allows decision-makers to determine the functional lifetime of different mitigation scenarios based on the assumptions about the rate of sea level rise. Demonstrating the potential timing of options can allow decision makers the ability to develop an adaptation plan. By examining the path dependency, it is possible to see which short-term actions are needed to keep long-term options open. The plan also indicates which triggers should be monitored to determine the appropriate timing to implement different actions. In this case, triggers could be, for example, a change in the rate of sea level rise.

For the C-8 and C-9 Watershed study, the DAPP analysis included these inputs:

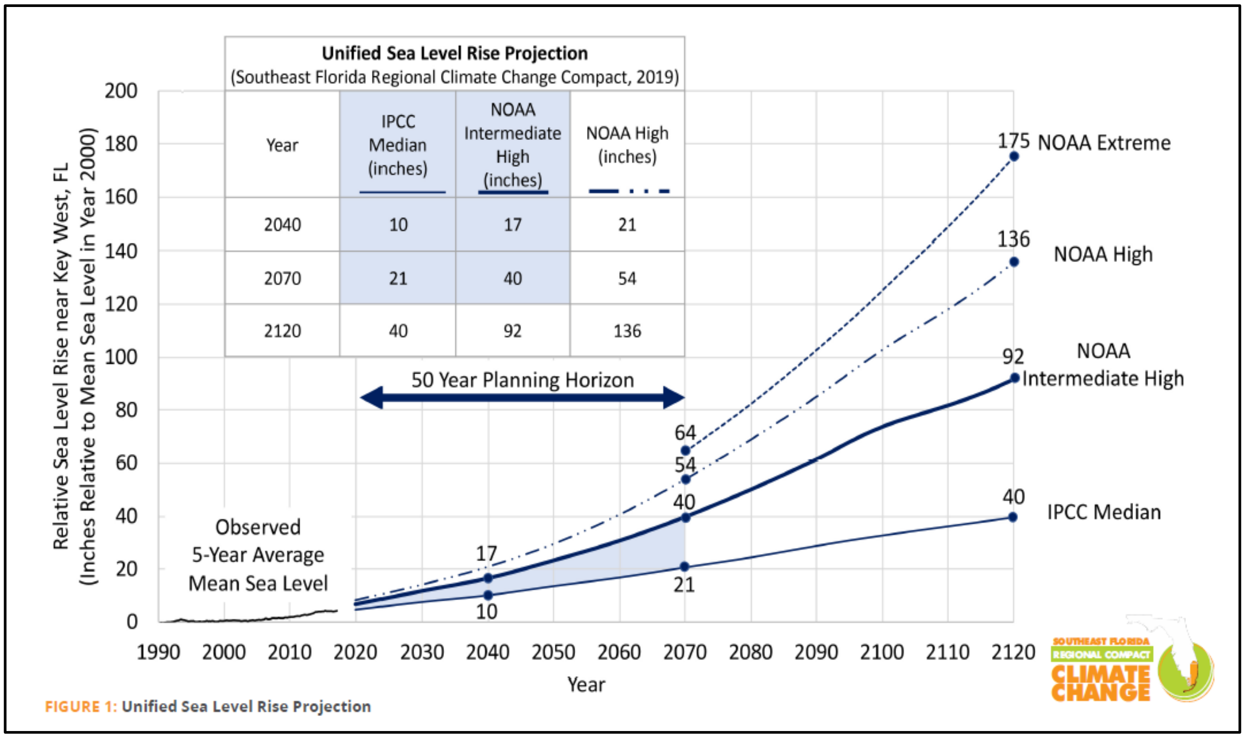
- Sea level rise (SLR) curves
- Estimated Annual Damages (EAD)
- Thresholds and Tipping Points

7.2 Sea Level Rise Curves

The SLR projections (**Figure 7.2**) are derived from the Unified Sea Level Rise Projection: 2019 Update, by the Southeast Florida Regional Climate Change Compact Sea Level Rise Work Group (2020). The SLR curves have 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.

Two SLR curves were used for the DAPP analysis: (1) the NOAA 2017 Intermediate High; and (2) the NOAA 2017 High. They were interpolated for 2021 start year to estimate a rise of 1-, 2-, and 3-ft (**Figure 7.2**).



Unified Sea Level Rise Projection
(Southeast Florida Regional Climate Change Compact, 2019)

Year	IPCC Median (inches)	NOAA Intermediate High (inches)	NOAA High (inches)
2040	10	17	21
2070	21	40	54
2120	40	92	136

FIGURE 1: Unified Sea Level Rise Projection

Figure 7.2 Southeast Florida Regional Climate Change Compact (2020) Unified Sea Level Rise Projection: 2019 Update

7.3 Estimated Annual Damages (EAD)

The EADs used for the DAPP analyses were derived from the SFWMD Flood Impact Assessment Tool (SFWMD-FIAT). 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. 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, exposure data, and flood (or water depth) hazard data to calculate economic damages. The approach is described more fully in the Task 3.2 *Technical Memorandum: Expected Annual Damage and Benefit Cost Calculations* (***APPENDIX F***).

7.3.1 C-8 and C-9 Thresholds and Tipping Points

For each watershed, thresholds were set to the EAD from the M0 scenario. By using the current conditions under current sea level rise conditions, with no mitigation, we can compare the anticipated effectiveness of the mitigation strategies. So, the threshold is presenting the expected annual damage for current conditions and allows comparisons between existing conditions and various mitigation strategies. The thresholds used for the C-8 and C-9 Watersheds, shown as a dashed line in **Figure 7.3** and **Figure 7.4**, respectively, are:

- C-8 Watershed Threshold: $31.7 million EAD, and,
- C-9 Watershed Threshold: $114.8 million EAD.

As an example of how to use these figures, examine M0 for the C-8 watershed. It crosses the y-axis as $31.7M in expected annual damages at current conditions. So, if, say, mitigation project M2C were in place in current conditions, the Expected Annual Damages would be reduced to about $27M. This makes sense in that the M2C projects would certainly mitigate the flooding and reduce the amount of property damaged.

The figures also spotlight that the M3 strategies do not pass the threshold even with 3-ft SLR, and are, therefore, not included in the adaptive pathways analysis, as previously mentioned. In other words, the M3 scenarios reduced risk well and can accommodate the SLR under each elevation scenario M3(1ft), M3(2ft), and M3(3ft) for both C-8 and C-9 watershed-wide. Uncertainties associated with M3 scenario were not considered as part of this analysis.

Because the DAPP analysis incorporated two SLR curves (the NOAA Intermediate High and the NOAA High), the timing of the tipping point of threshold exceedance varied. It will also vary based on the mitigation strategy being implemented. The tipping point indicated that the strategy exceeded the current level of damages, suggesting the strategy is not performing, or has exceeded its capacity to accommodate additional flooding, and additional flood mitigation measures are needed.

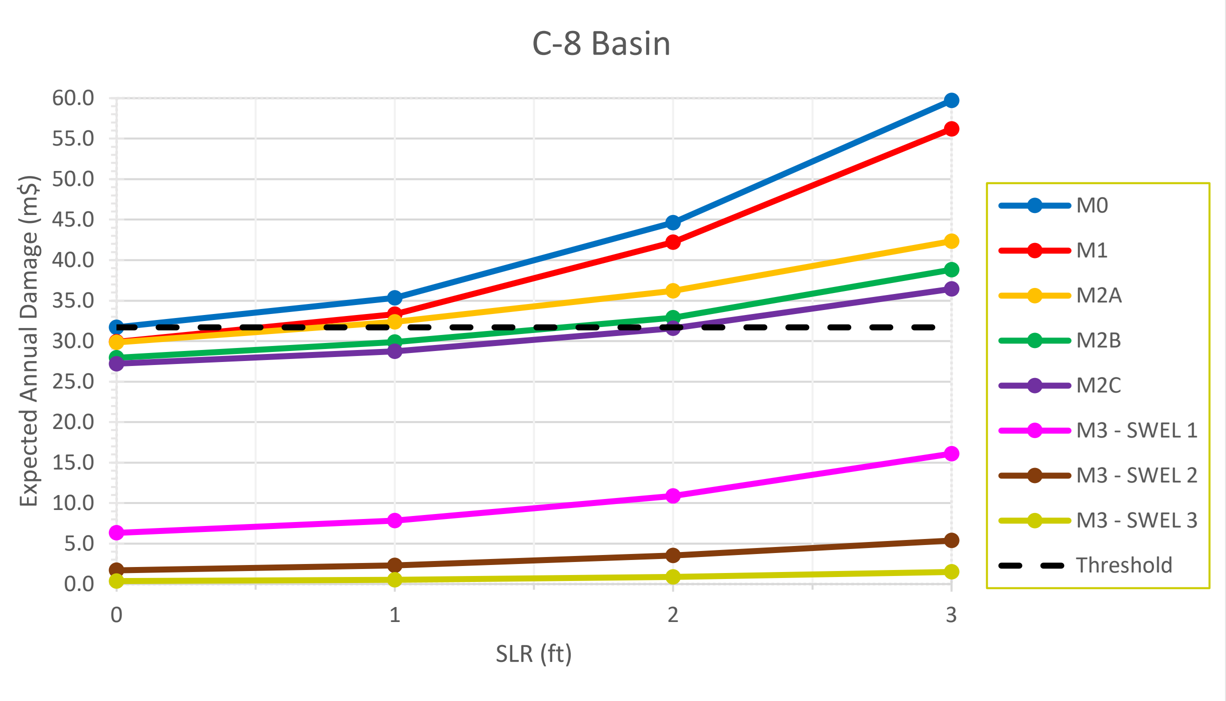


Figure 7.3 C-8 Watershed Estimated Annual Damages for Flood Mitigation Strategies With 1-, 2-, 3-ft Sea Level Rise (ft, msl)

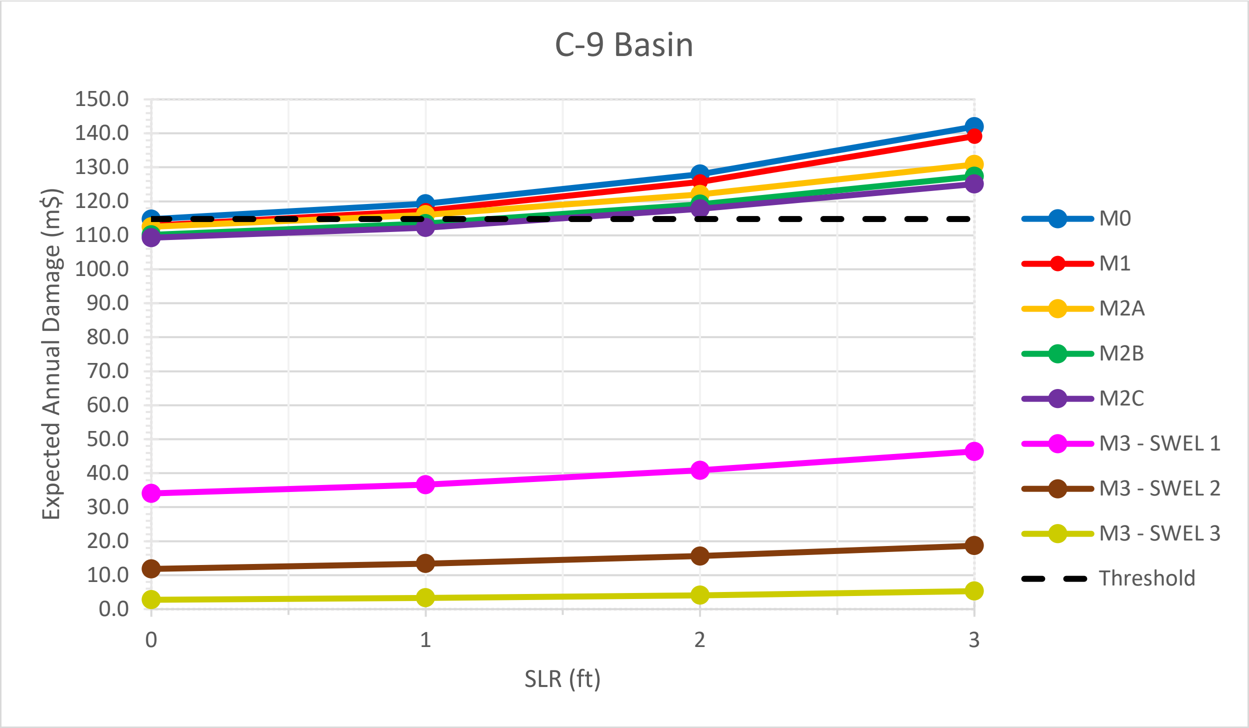


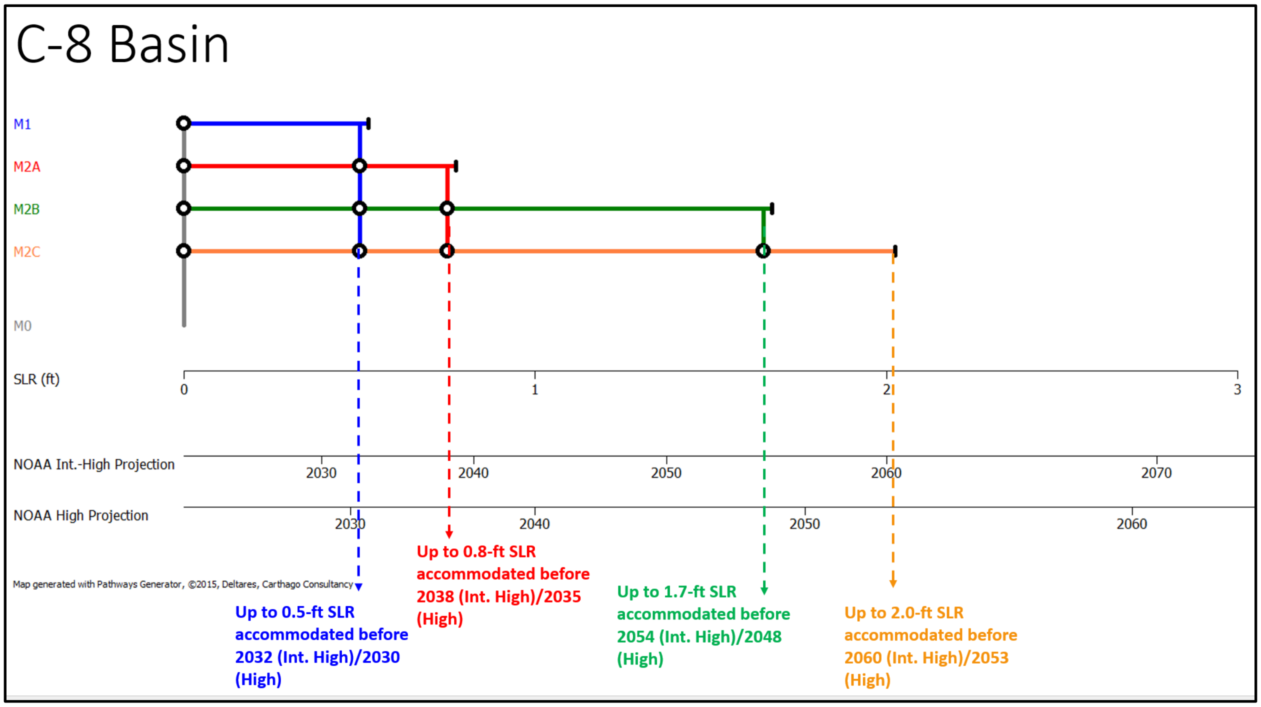
Figure 7.4 C-9 Watershed Estimated Annual Damages for Flood Mitigation Strategies With 1-, 2-, 3-ft Sea Level Rise (ft, msl)

7.4 DAPP Results

7.4.1 Results for C-8 Watershed

As shown in **Figure 7.5**:

- M1: It can accommodate up to 0.5 ft SLR
  - As early as 2030 based on NOAA High and as late as 2032 based on Intermediate High
- M2A: It can accommodate up to 0.8 ft SLR
  - As early as 2035 based on NOAA High and as late as 2038 based on Intermediate High
- M2B: It can accommodate up to 1.7 ft SLR
  - As early as 2048 based on NOAA High and as late as 2054 based on Intermediate High
- M2C: It can accommodate up to 2.0 ft SLR
  - As early as 2053 based on NOAA High and as late as 2060 based on Intermediate High



Up to 0.5-ft SLR accommodated before 2032 (Int. High)/2030 (High)

Up to 0.8-ft SLR accommodated before 2038 (Int. High)/2035 (High)

Up to 1.7-ft SLR accommodated before 2054 (Int. High)/2048 (High)

Up to 2.0-ft SLR accommodated before 2060 (Int. High)/2053 (High)

Figure 7.5 DAPP Analysis Results for C-8 Watershed

7.4.2 Results for C-9 Watershed

As shown in **Figure 7.6**:

- M1: It can accommodate up to 0.4 ft SLR
  - As early as 2029 based on NOAA High and as late as 2030 based on Intermediate High
- M2A: It can accommodate up to 0.7 ft SLR
  - As early as 2033 based on NOAA High and as late as 2036 based on Intermediate High
- M2B: It can accommodate up to 1.3 ft SLR
  - As early as 2043 based on NOAA High and as late as 2048 based on Intermediate High
- M2C: It can accommodate up to 1.5 ft SLR
  - As early as 2046 based on NOAA High and as late as 2052 based on Intermediate High

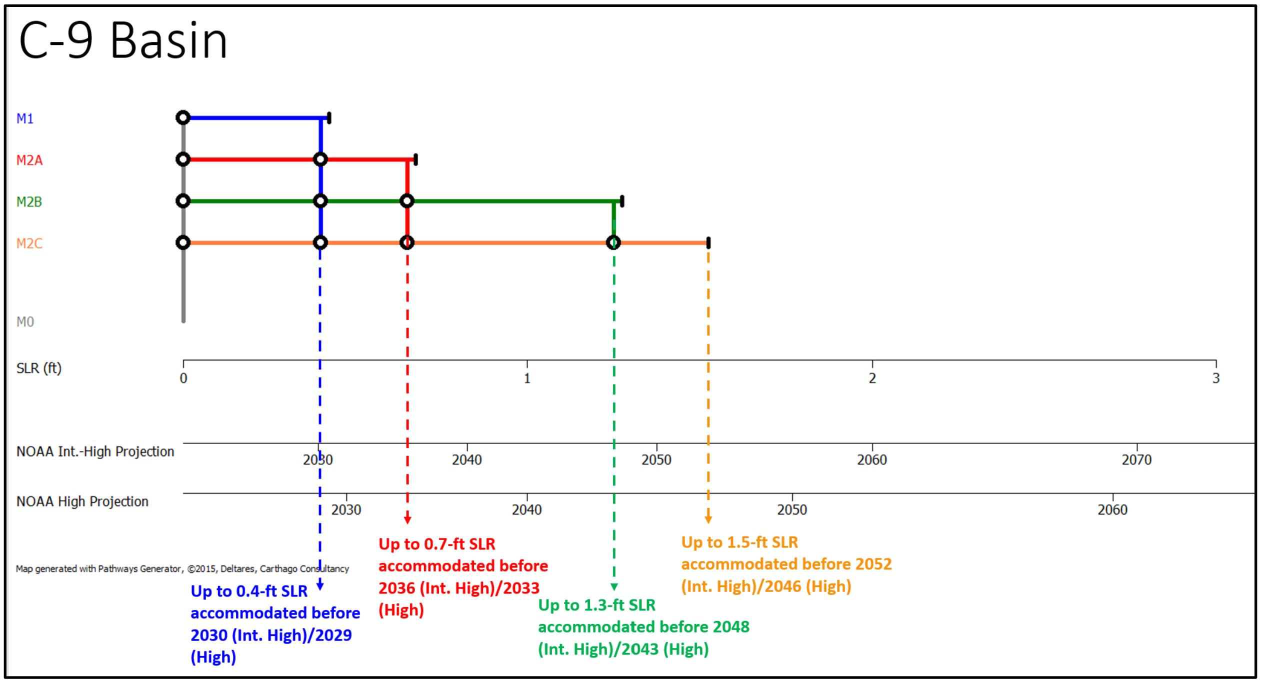


Figure 7.6 DAPP Analysis Results for C-9 Watershed

8.0 IMPACTS OF MITIGATION ON WATER SURFACE ELEVATIONS IN DOWNSTREAM AREAS

The District wanted to understand the potential impact of forward pump stations at S-28 and S-29 on the downstream water surface elevations at urban areas. Thus, the SFWMD requested Taylor Engineering evaluate the downstream effects of the S-28 and S-29 structures gate and pump outflows on water levels in the urban areas of C8 and C9 basins during normal tides and 10-yr surge event conditions. The full report presents an in-depth discuss of the modeling approach, data, and results. See: *Effects on Downstream Areas Water Levels from Floodplain Level of Service (FPLOS) Model S-28 and S-29 Structures Outflows*.

8.1 Model Setup

This study employed a state-of-the-art 2D numerical model—the Biscayne Bay Model (BBM)—to evaluate water levels downstream of S-28 and S-29 with FPLOS outflows. In developing the BBM, Taylor Engineering leveraged an existing Florida Inland Navigation District (FIND) MIKE21 hydrodynamic model (henceforth called "BHIM" in this study) for Bakers Haulover Inlet, Biscayne Bay, and Intracoastal Waterway (IWW). MIKE SHE is integrated hydrological modelling software for analyzing groundwater, surface water, recharge, and evapotranspiration processes. MIKE 21 simulates processes with surface water flows, waves, sediments and ecology in rivers, lakes, estuaries, bays, coastal areas, and seas. Because of these functionalities, this tool can achieve the objective of this task. Taylor Engineering also leveraged ADCIRC+SWAN model data and output sourced from effective Federal Emergency Management Agency (FEMA) modeling (FEMA, 2021) to expand the BHIM to include upstream areas that may be inundated with a 10-yr surge flood event. Data collection and field measurements provided the input data for the BBM validation. The BHIM and the ADCIRC+SWAN model also provided the boundary conditions for normal tides and 10-yr surge event conditions BBM production runs. **Figure 8.1** presents the model domain.

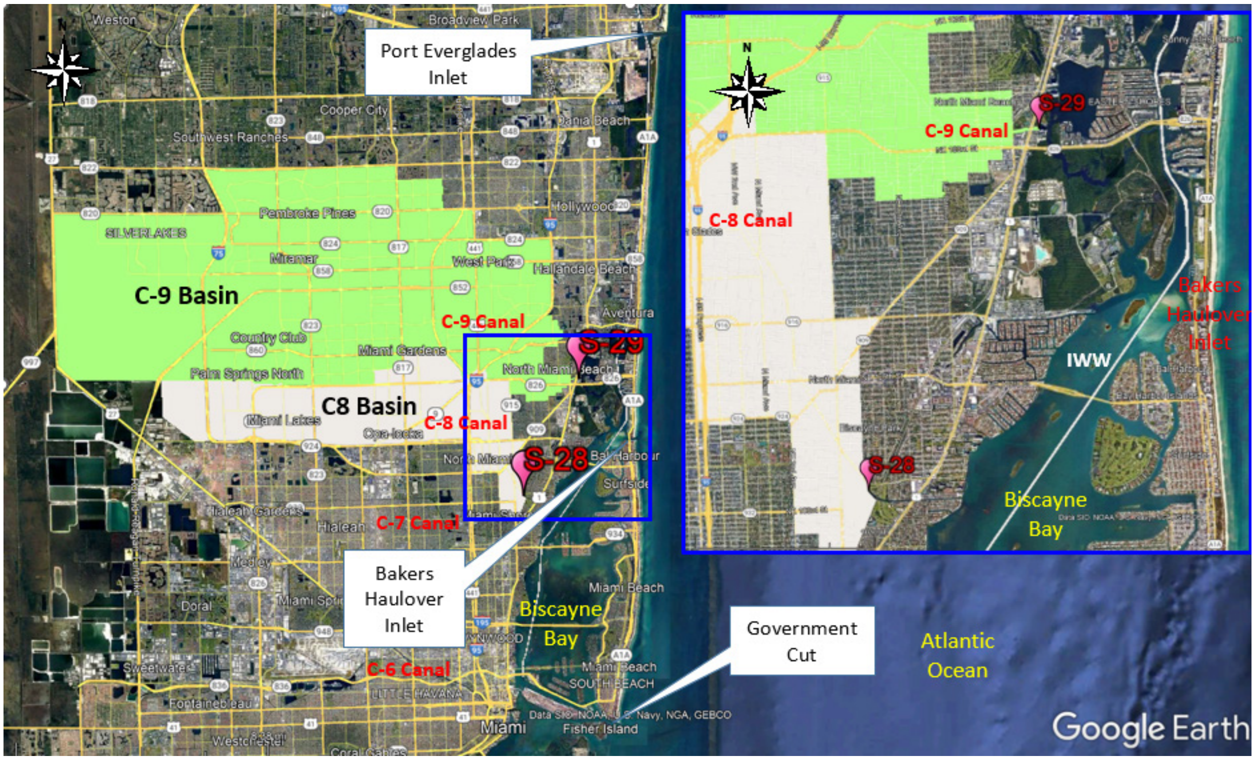


Figure 8.1 Locations of C-8 and C-9 Basins and S-28 and S-29 Structures West of Biscayne Bay

A full discussion of model setup, boundary conditions, and validations can be found in the full report for this task.

8.2 Model Scenarios

This study applied the BBM model for the M2A, M2B, and M2C mitigation strategies under the following scenarios:

- Normal Tides Conditions
    - Effects on Normal Tides with No Sea Level Rise
    - Effects on Normal Tides with 1-, 2-, and 3-ft Sea Level Rises
- 10-year Surge Event Conditions
    - Effect of M2C S-28 and S-29 Structures Outflows with No SLR on 10-yr Surge Highwater Levels
    - Effect of M2C S-28 and S-29 Structures Outflows with SLR on 10-yr Surge Highwater Levels
    - Effect of M2A S-28 and S-29 Structures Outflows with 1-ft SLR on 10-yr Surge Highwater Levels
    - Effect of M2B S-28 and S-29 Structures Outflows with 2-ft SLR on 10-yr Surge Highwater Levels

8.3 Results and Conclusions

This study developed the BBM—a two-dimensional depth-averaged hydrodynamic model—to evaluate the effects on downstream water levels of FPLOS outflows at S-28 and S-29 structures. The BBM mesh development takes advantage of an existing FIND MIKE21 hydrodynamic model and existing FEMA South Florida ADCIRC+SWAN model Version 11 meshes. The BBM applies time-varying elevation boundary conditions at the mouth of Bakers Haulover Inlet, IWW North (adjacent to Whiskey Creek South Entrance near NOAA 8722971), and IWW South (San Marino Island near NOAA 8723156) model boundaries. The S-28 and S-29 outflows are specified in the BBM as time-varying flow sources at locations downstream of these structures. The BBM was successfully validated through visual and statistical comparisons of modeled water level with measured data at select locations in Biscayne Bay. Based on favorable comparison of statistics and very good visual comparisons of the model and measured water levels, this study deemed the BBM well validated to estimate water levels and water depths in the urban areas downstream of coastal structures and connected waterways.

Comparison of the calculated maximum modeled water depths for each model element for baseline (no flood mitigation alternatives) conditions and with flood mitigation alternatives (i.e., M2C with 1-ft, 2-ft, and 3-ft sea level rise; M2A with 1-ft sea level rise; and M2B with 2-ft sea level rise) provided estimates of the effect of C-8 and C-9 basins flood mitigation alternatives outflows at S-28 and S-29 on downstream maximum water depths.

Table 8.1 summarizes the effects of the S-28 and S-29 structures outflows on downstream maximum water depths.

Alternative M2C can cause larger peak depth increases downstream of S-28 structure than downstream of S-29 structure. In contrast to Alternative M2C-SLR1 conditions, Alternative M2A-SLR1 decreases maximum water depths downstream of S-28 structure and has smaller maximum water depth increase downstream of S-29 structure when compared with M2C-SLR1 results. Alternative M2B-SLR2 has smaller maximum water depth increases downstream of S-28 and S-29 structures when compared with M2C-SLR2 results.

Model results showed the effects of FPLOS structure outflows were limited to water depths in the downstream areas near the structures and maximum water depths in the main Biscayne Bay area were not substantially affected by the FPLOS S-28 and S-29 structure outflows. Model results also indicated rising sea levels generally decreased the effect of the FPLOS S-28 and S-29 structure outflows on normal tides and 10-yr surge maximum water depths (or water levels). In addition to the net differences in terms of flood depth, our simulations have indicated that Scenarios 2A and 2B will result in little to no increase in the peak stage profiles for the canal segment downstream of the tidal structures, thereby preserving the conveyance from the secondary and tertiary systems to the primary system. However, it must be noted that Scenario 2C has the potential to negatively impact the downstream urban areas. If the proposed M2C is advanced to the implementation phase, it is crucial that additional mitigation strategies be developed to address the downstream impacts.

Including the effect of rainfall-induced flooding is extremely critical in characterizing the flood risk across South Florida and was the focus of the work done for the FPLOS study. This is reflected in the different return frequencies applied in that study. For determining the potential impact of proposed course of action or adaptation measures downstream of the coastal structures, a parsimonious strategy was employed that started with a simple representation and gradually introduced complexity as needed. This initial analysis excluded rainfall in the area downstream of the structures, but included surge, to understand the impact on canal stages and tailwater conditions. The result in this case indicates de-minimis changes in tailwater conditions and supports the conclusion that no adverse impact will result in the ability of these basins to discharge due to implementing the study recommended measures in M2A and 2B. This suggests that while additional modeling to include rainfall in tidal basins would be important to quantify extent of flooding, it would not change the conclusion that the recommended measures would not cause elevated tailwater conditions. This conclusion may not apply to all projects or basins, or even different recommended measures within the same basin. We consider the application as described in the report sufficiently demonstrates that the recommended measures from this study will not raise tailwater levels and cause adverse downstream flooding.

Table 8.1 Summary of Effects of FPLOS Outflows at S-28 and S-29 Structures on Normal Tides and 10-Year Surge Maximum Water Depths

Conditions	Flood Mitigation Alternative	Sea Level Rise (ft)	Effect on Downstream Water Depths		Notes
			S-28 (ft)	S-29 (ft)	
Normal Tides	M2C-SLR0	0	+0.25 to +1.0	up to +0.25	larger increases at S-28
Normal Tides	M2C-SLR1	1	+0.5 to +1.0	up to +0.25	larger increases at S-28
Normal Tides	M2C-SLR2	2	+0.1 to +1.0	up to +0.25	slightly larger area downstream of S-28 structure (compared to M2C-SLR1)
Normal Tides	M2C-SLR3	3	+0.1 to +1.0	up to +0.1	slightly larger area downstream of S-28 structure (compared to M2C-SLR1)
10-yr Surge	M2C-SLR0	0	+0.25 to +1.5	up to +0.1	larger increases at S-28
10-yr Surge	M2C-SLR1	1	+0.5 to +1.5	+0.1 to +0.25	larger increases at S-28
10-yr Surge	M2C-SLR2	2	+0.25 to +1.0	0.0	same area downstream of S-28 structure (compared to M2C-SLR1)
10-yr Surge	M2C-SLR3	3	0.1 to +0.5	0.0	a slightly larger area downstream of S-28 structure (compared to 10-yr M2C-SLR1 and 10-yr M2C-SLR2)
10-yr Surge	M2A-SLR1	1	0.0 to -1.5	0.0 to +0.25	decrease maximum depths downstream of S-28
10-yr Surge	M2B-SLR2	2	+0.1 to +0.25	0.0	smaller area downstream of S-28 (compared to 10-yr M2C SLR1, SLR2, and SLR3)

9.0 WATER QUALITY ANALYSIS IN BISCAYNE BAY

Phase II includes the evaluation of water quality impacts resulting from these mitigation strategies and the ability to meet existing water quality standards within the Biscayne Bay Aquatic Preserve. The study area is North Biscayne Bay, which is part of the Biscayne Bay Aquatic Preserve and designated as Outstanding Florida Waters (OFW) under Chapter 62- 302.700, Florida Administrative Code (FAC). The purpose of this study is to evaluate potential changes in water quality (WQ) to downstream receiving water bodies (Biscayne Bay) that could potentially result from proposed FPLOS changes in water management of the C-8 and C-9 canals and flows at the outfall structures. Potential environmental impacts pertaining to marine life and seagrass were also evaluated.

The full report presents data, methodology, and results in ***APPENDIX H*** – Task 4B Water Quality Analysis.

This effort included the following tasks:

- Collect readily available WQ data from the study area (North Biscayne Bay) from publicly available databases, including Miami-Dade County and the SFWMD. Review existing studies relevant to North Biscayne Bay.
- Review existing WQ datasets and determine ambient background concentrations and contaminants of concern (COCs), if any, in the C-8 and C-9 canals and in North Biscayne Bay.
- Provide time-series plots of these COCs showing historical data and note changes in concentrations.
- Evaluate existing flows and, where possible, contaminant mass loading rates from the C- 8 and C-9 canals into North Biscayne Bay and assess any discernable peaks. Assess the statistical significance of any correlation between canal discharges and COC concentrations in the Bay.
- Perform regression analyses for each COC exhibiting a statistically significant correlation with canal discharges.
- Based on existing WQ data and proposed changes in flowrates resulting from the implementation of selected flood adaptation strategies and mitigation project(s), make qualitative assessments of the potential effects of the implementation of FPLOS projects on water quality. This will include assessing potential environmental impacts pertaining to marine life and seagrass using established relations between contaminant concentrations/loads and marine life degradation.
- For each canal, up to forty (52) flow scenarios will be utilized for these assessments. This totals eighty (104) scenarios for both the C-8 and C-9 canals. Note that this analysis will consider the C-8 and C-9 canal basins separately to assess their individual influence on bay WQ.

The study area and location of water quality samples are shown in **Figure 9.1**.

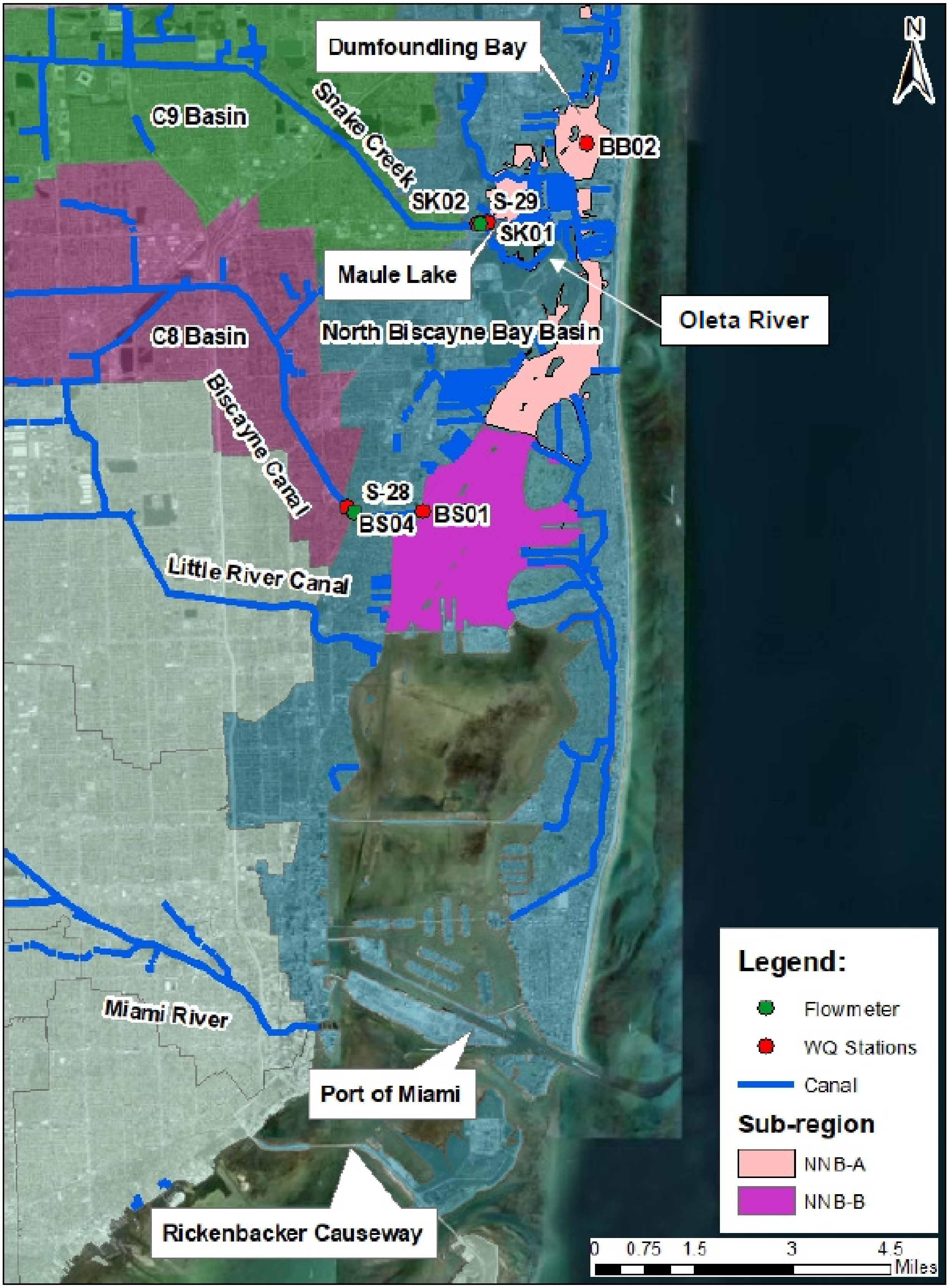


Figure 9.1 Water Quality Sample Locations

9.1 Data Collection

To support this WQ data analysis, the following data/information was obtained:

- Historical reports and literature sources concerning WQ near the project site were obtained from the SFWMD, MDC, and other sources. (See the References.)
- Historical WQ data was provided by MDC.
- Historical flow data was consolidated from the SFWMD's DBHYDRO.
- Proposed changes in flow rates based on the FPLOS modeling scenarios were provided by Taylor Engineering (Flood Protection Level of Service Provided by Potential Mitigation Projects for Current and Future Sea Level Conditions in the C-8 and C-9 Watersheds, 2022).

Table 9.1 summarizes the list of Flowmeters and WQ Stations Associated with the C-8 and C-9 Canals and Watersheds.

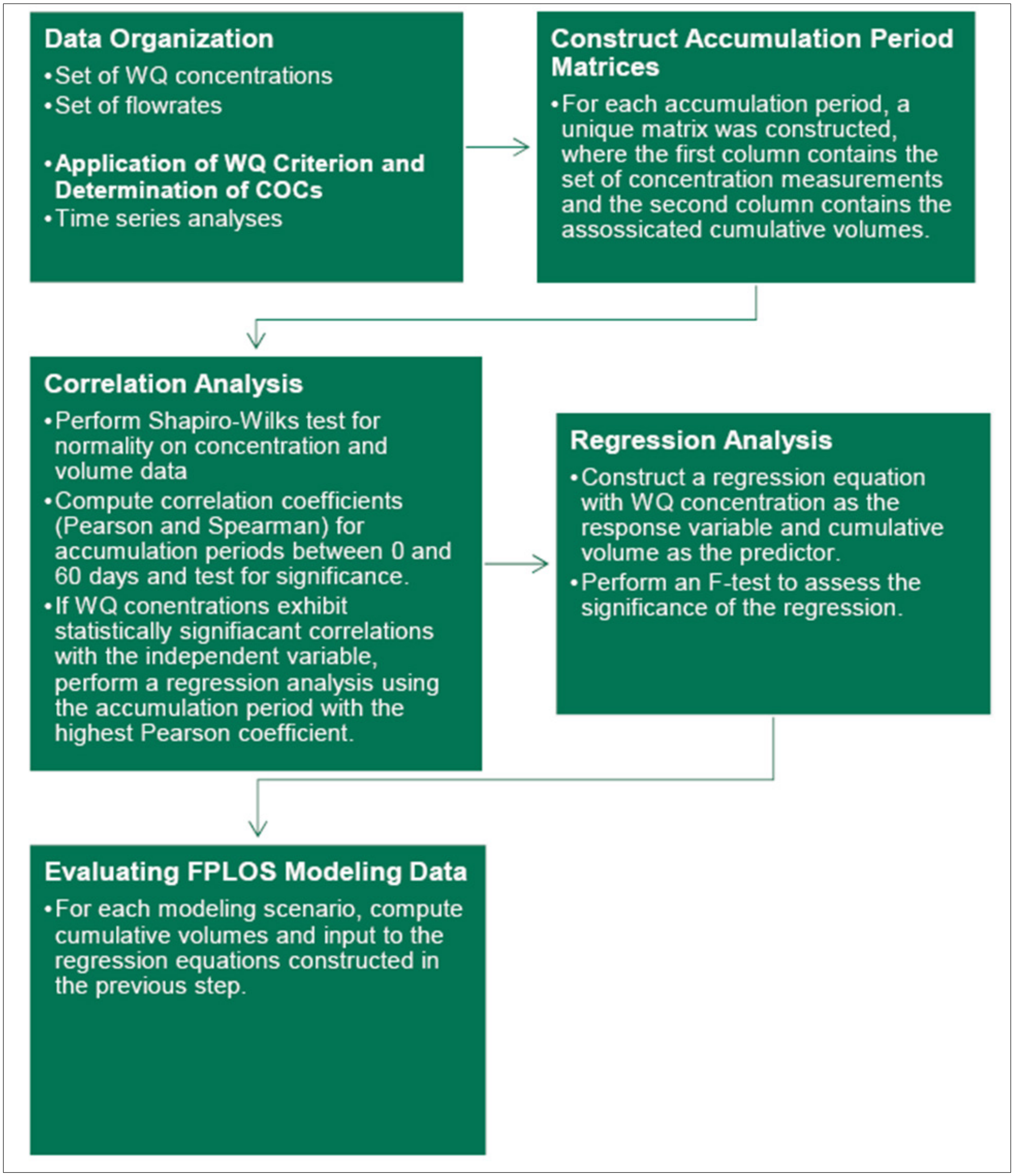
Where available, data were collected and analyzed for the period 1996 – 2022.

Table 9.1 List of Flowmeters and WQ Stations Associated with the C-8 and C-9 Canals and Watersheds

Station ID	Data Type	Associated Watershed
BS04	WQ Concentrations	C-8
BS01	WQ Concentrations	C-8
BB09	WQ Concentrations	C-8
S28_S	Flowrates	C-8
SK01	WQ Concentrations	C-9
SK02	WQ Concentrations	C-9
BB02	WQ Concentrations	C-9
S29_S	Flowrates	C-9

9.2 Methodology

To investigate the relationship between discharges at the S-28 and S-29 and WQ variable concentrations measured in the bay, analyses were conducted using cumulative volume data derived from the flow stations listed in **Table 9.1. Figure 9.2** describes the general steps taken to assess the impact of proposed FPLOS scenarios on each WQ variable at North Biscayne Bay; for the full analysis, see Nova Consulting (2023).



Data Organization

- Set of WQ concentrations
- Set of flowrates

- **Application of WQ Criterion and Determination of COCs**
- Time series analyses

Construct Accumulation Period Matrices

- For each accumulation period, a unique matrix was constructed, where the first column contains the set of concentration measurements and the second column contains the assossicated cumulative volumes.

Correlation Analysis

- Perform Shapiro-Wilks test for normality on concentration and volume data
- Compute correlation coefficients (Pearson and Spearman) for accumulation periods between 0 and 60 days and test for significance.
- If WQ conentrations exhibit statistically signifiacant correlations with the independent variable, perform a regression analysis using the accumulation period with the highest Pearson coefficient.

Regression Analysis

- Construct a regression equation with WQ concentration as the response variable and cumulative volume as the predictor.
- Perform an F-test to assess the significance of the regression.

Evaluating FPLOS Modeling Data

- For each modeling scenario, compute cumulative volumes and input to the regression equations constructed in the previous step.

Figure 9.2 Flowchart of Methodology Used for the Cumulative Volume Analysis

This methodology resulted in the development of regression equations for Salinity, Chlorophyll a, TN (C-8 watershed only), and Dissolved Oxygen. **Table 9.2** and **Table 9.3** present the resulting regression equations for the C-8 and C-9 watersheds, respectively.

Table 9.2 Regression Equations Developed for C-8 Watershed

WQ Variable	Regression Equation	R^2	Statistical Significance	Calibration Accumulation Period (Days)
Salinity	$y = -0.0004 * V + 33.6384 \pm 2.10$	0.09	$p < 0.05$	5
Chlorophyll *a*	$y = 0.0002 * V + 1.612 \pm 1.39$	0.19	$p < 0.05$	13
TN	$y = 3.33 * 10^{-5} * V + 0.3597 \pm 0.16$	0.31	$p < 0.05$	15
Dissolved Oxygen	$y = -9.54 * 10^{-5} * V + 6.3797 \pm 1.20$	0.10	$p < 0.05$	15

Table 9.3 Regression Equations Developed for C-9 Watershed

WQ Variable	Regression Equation	R^2	Statistical Significance	Calibration Accumulation Period (Days)
Salinity	$y = -0.0008 * V + 31.1496 \pm 5.92$	0.17	$p < 0.05$	5
Chlorophyll *a*	$y = 0.0001 * V + 3.0079 \pm 2.22$	0.21	$p < 0.05$	15
Dissolved Oxygen	$y = -2 * 10^{-5} * V + 5.8336 \pm 1.23$	0.03	$p < 0.05$	15

9.3 Water Quality Analysis Results

9.3.1 C-8 Watershed Water Quality Analysis Results

- M2A: Doesn't present negative impact on WQ compared to existing conditions and M2C scenarios
- M2B: negative impact on Chlorophyll a; negative impact on TN for 10-yr & 100-yr events
- M2C: negative impact on Chlorophyll a, TN, and/or DO for different events

Table 9.4 summarizes the results for the 25-yr storm in NNB-B and **Table 9.5** summarizes the results for the 100-yr storm in NNB-B.

Table 9.4 Summary of Results for the 25-yr Storm in NNB-B

	Percent Change Relative to Existing Conditions (M0-SLR0)											
Variable	**M0-SLR1**	**M0-SLR2**	**M0-SLR3**	**M2A-SLR1**	**M2A-SLR2**	**M2A-SLR3**	**M2B-SLR1**	**M2B-SLR2**	**M2B-SLR3**	**M2C-SLR1**	**M2C-SLR2**	**M2C-SLR3**
Salinity	**1.2**	**2.4**	**4.3**	**0.5**	**1.1**	**3.0**	**-1.2**	**-0.5**	**1.8**	**-4.2**	**-3.6**	**-2.8**
Chlorophyll a	**-5.1**	**-14.3**	**-30.2**	**-2.4**	**-7.0**	**-16.0**	**2.8**	**-3.8**	**-14.2**	**10.2**	**3.6**	**-1.3**
TN	**-4.9**	**-13.2**	**-24.6**	**-2.7**	**-7.0**	**-15.4**	**2.0**	**-4.2**	**-13.9**	**8.4**	**2.4**	**-2.8**
DO	**3.5**	**9.4**	**17.4**	**1.9**	**4.9**	**10.9**	**-1.4**	**2.9**	**9.8**	**-5.9**	**-1.7**	**2.0**

Table 9.5 Summary of Results for the 100-yr Storm in NNB-B

	Percent Change Relative to Existing Conditions (M0-SLR0)											
Variable	**M0-SLR1**	**M0-SLR2**	**M0-SLR3**	**M2A-SLR1**	**M2A-SLR2**	**M2A-SLR3**	**M2B-SLR1**	**M2B-SLR2**	**M2B-SLR3**	**M2C-SLR1**	**M2C-SLR2**	**M2C-SLR3**
Salinity	**1.0**	**1.8**	**3.9**	**0.4**	**0.8**	**3.2**	**-1.9**	**-1.6**	**0.6**	**-7.1**	**-6.8**	**-5.4**
Chlorophyll a	**-3.4**	**-11.0**	**-25.8**	**0.6**	**-3.4**	**-11.3**	**5.8**	**0.3**	**-7.6**	**16.5**	**10.9**	**5.7**
TN	**-3.4**	**-10.2**	**-19.2**	**0.2**	**-3.7**	**-11.2**	**5.0**	**-0.4**	**-8.0**	**14.3**	**9.0**	**3.9**
DO	**3.2**	**9.7**	**18.3**	**-0.2**	**3.5**	**10.7**	**-4.7**	**0.4**	**7.7**	**-13.7**	**-8.6**	**-3.7**

9.3.2 C-9 Watershed Water Quality Analysis Results

- M2A: Doesn't present negative impact on WQ compared to existing conditions and M2C scenarios
- M2B: Doesn't present negative impact on WQ compared to existing conditions and M2C scenarios
- M2C: negative impact to Chlorophyll a

Table 9.6 summarizes the results for the 25-yr storm in NNB-A and **Table 9.7** summarizes the results for the 100-yr storm in NNB-A.

Table 9.6 Summary of Results for the 25-yr Storm in NNB-A

	Percent Change Relative to Existing Conditions (M0-SLR0)											
Variable	**M0-SLR1**	**M0-SLR2**	**M0-SLR3**	**M2A-SLR1**	**M2A-SLR2**	**M2A-SLR3**	**M2B-SLR1**	**M2B-SLR2**	**M2B-SLR3**	**M2C-SLR1**	**M2C-SLR2**	**M2C-SLR3**
Salinity	**23.5**	**48.7**	**83.4**	**23.5**	**43.6**	**70.6**	**10.6**	**29.1**	**59.1**	**-17.3**	**5.5**	**39.0**
Chlorophyll a	**-8.0**	**-17.6**	**-28.6**	**-5.2**	**-11.2**	**-19.7**	**-2.5**	**-8.3**	**-17.8**	**3.9**	**-2.8**	**-11.7**
DO	**2.3**	**5.1**	**9.6**	**1.5**	**3.2**	**5.5**	**0.1**	**1.7**	**4.5**	**-1.1**	**0.8**	**3.4**

Table 9.7 Summary of Results for the 100-yr Storm in NNB-A

	Percent Change Relative to Existing Conditions (M0-SLR0)											
Variable	**M0-SLR1**	**M0-SLR2**	**M0-SLR3**	**M2A-SLR1**	**M2A-SLR2**	**M2A-SLR3**	**M2B-SLR1**	**M2B-SLR2**	**M2B-SLR3**	**M2C-SLR1**	**M2C-SLR2**	**M2C-SLR3**
Salinity	**51.7**	**118.8**	**233.1**	**60.7**	**113.6**	**176.5**	**30.4**	**71.2**	**139.2**	**-59.6**	**-11.0**	**62.0**
Chlorophyll a	**-8.2**	**-17.9**	**-28.1**	**-4.8**	**-10.6**	**-17.6**	**-2.0**	**-7.0**	**-15.0**	**5.5**	**-0.3**	**-7.6**
DO	**2.8**	**6.4**	**11.7**	**1.7**	**3.7**	**6.0**	**-0.2**	**1.5**	**4.3**	**-1.9**	**0.1**	**2.6**

9.4 Water Quality Conclusions

This section comprised an analysis of potential WQ impacts to the regions NNB-A (associated with the C-9 basin) and NNB-B (associated with the C-8 basin) of North Biscayne Bay using the proposed implementation of FPLOS scenarios. To this end, WQ data was gathered from databases affiliated with MDC, the SFWMD, and other sources. This data was utilized to identify COCs, for which time series plots were constructed and correlation/regression analyses were performed. A total of eighty (80) scenarios were assessed for both the C-8 and C-9 canals based on the results of the regression analyses. This assessment suggested statistically significant changes in COCs concentrations resulting from future conditions (i.e., combinations of sea level rise and FPLOS mitigation projects). Potential environmental impacts pertaining to marine life and seagrass were estimated using established relations between contaminant concentrations/loads and marine life degradation.

The following are the conclusions of these analyses.

C-8 Basin (NNB-B)

- COCs identified:
  - Chlorophyll a, TN, TP, DO, and turbidity. In addition, salinity was identified for further analysis.
- Correlation/regression analyses results:
  - Salinity
    - A weak to moderate negative association exists between cumulative volume inputs from the S-28 and salinity concentrations at BB09.
  - Chlorophyll a
    - A moderate positive association exists between cumulative volume inputs from the S-28 and Chlorophyll a concentrations at BB09.
  - TN
    - A moderate to strong positive association exists between cumulative volume inputs from the S-28 and TN concentrations at BS01.
  - TP
    - Correlation/regression analyses could not be performed due to data deficiencies.
  - DO
    - A weak negative association exists between cumulative volume inputs from the S-28 and DO concentrations at BB09.
  - Turbidity
    - No statistically significant association exists between cumulative volume inputs from the S-28 and turbidity concentrations at BB09.
- Cumulative volume discharges from the C-8 were shown to be higher for M2C scenarios for the 100-year storm compared to existing conditions (M0-SLR0). Hence, short term negative WQ conditions may result from M2C mitigation compared to existing conditions for higher return period storms. For the 100-year storm, scenario M2A-SLR1 is projected to result in short term negative WQ conditions.
  - M2C scenarios are associated with more frequent short term negative or uncertain impacts, while M2A scenarios are associated with less frequent negative impacts.
- FPLOS impacts to marine life and seagrass were estimated

- Projected salinities are not anticipated to violate the tolerances of any NNB-B indicator species. All M2C scenarios may cause higher TN loads for this same return period. For the 10- and 25-year return period storms, only M2C-SLR1 and M2C-SLR2 are anticipated to cause higher TN loads.

<u>C-9 Basin (NNB-A)</u>

- COCs identified:
    - Chlorophyll a, TN, DO, and copper. In addition, salinity, TP, and turbidity were identified for further analysis.
- Correlation/regression analyses results:
    - Salinity
        - A moderate negative association exists between cumulative volume inputs from the S-29 and salinity concentrations at BB02.
    - Chlorophyll a
        - A moderate positive association exists between cumulative volume inputs from the S-29 and chlorophyll a concentrations at BB02.
    - TN
        - No statistically significant association exists between cumulative volume inputs from the S-29 and TN concentrations at BB02.
    - TP
        - No statistically significant association exists between cumulative volume inputs from the S-29 and TP concentrations at BB02 in the Pearson coefficient. Hence, regression analyses could not be performed.
    - DO
        - A weak negative association exists between cumulative volume inputs from the S-29 and DO concentrations at BB02.
    - Turbidity
        - A weak positive association exists between cumulative volume inputs from the S-29 and turbidity concentrations at BB02. A regression analysis could not be performed due to the statistically significant accumulation period not matching the modeling data time window.
    - Copper
        - No statistically significant association exists between cumulative volume inputs from the S-29 and copper concentrations at BB02.
- Cumulative volume discharges from the C-9 were shown to be lower for all scenarios across all return periods compared to existing conditions (M0-SLR0) except for scenario M2C-SLR1 and M2C-SLR2. Hence, WQ conditions may be maintained or improved under most scenarios
    - M2C scenarios are associated with more frequent short term negative or uncertain impacts, while M2A scenarios are associated with less frequent negative impacts.
- Mitigation projects and changing SLR conditions could impact marine life and seagrass
    - Two indicator species, American Oysters and Johnson's Seagrass, can be used to speak to the impact of mitigation projects to the ecology in Biscayne Bay by reviewing changes in salinity.
    - It is important for American Oysters that salinity does not drop below or exceed certain thresholds. Existing data show that these thresholds are often exceeded under existing conditions (examining data from 1996 to 2022).

  - Because mitigation activities that would help remove flood waters from the watersheds would put more water into the Bay, the study looked at the potential impacts of increased freshwater in the Bay.
    - Existing conditions with SLR0 keeps salinity above the minimum threshold for the 5-yr event but drops below the minimum threshold for the 10-, 25-, and 100-yr events.
      - So, any mitigation activity that increases the minimum threshold for more than just the 5-yr event would be seen as an improvement.
    - Mitigation Activity M2A for SLR1 and SLR2 improves the minimum for the 5-yr and 10-yr events.
    - Mitigation Activity M2A for SLR3 improves the minimum for the 5-, 10, and 25-yr events.
    - Mitigation Activity M2B for SLR1 achieves the same minimums as existing conditions, only the 5-yr event.
    - Mitigation Activity M2B for SLR2 improves the minimum for the 5-yr and 10-yr events.
    - Mitigation Activity M2B for SLR3 improves the minimum for the 5-, 10, and 25-yr events.
    - Mitigation Activity M2C for SLR1 achieves the same minimums as existing conditions, only the 5-yr event.
    - Mitigation Activity M2C for SLR2 and SLR3 improves the minimum for the 5-yr and 10-yr events.
- Regarding TN loads, only scenario M2C-SLR1 would result in increased TN loads compared to M0-SLR0 for all return periods.

10.0 CONCLUSIONS AND RECOMMENDATIONS

The Flood Protection Level of Service Adaptation Planning and Mitigation Projects Study conducted for the C-8 and C-9 Watersheds in south Broward and northern Miami-Dade Counties has assessed the future conditions of the watersheds in relation to flooding and sea level rise (SLR). The study aimed to develop basin-wide adaptation strategies to address the deficiencies identified during the Assessment Study and to identify flood mitigation projects required in the C-8 and C-9 watersheds to maintain or improve the level of flood protection provided by the District's flood control infrastructure under current conditions and in anticipation of future sea level rise conditions, groundwater level, and land use changes.

The comprehensive mitigation strategies evaluated encompassed the primary, secondary, and tertiary flood control systems and were assessed with the following methods:

- Hydrologic and hydraulic modeling for different mitigation strategies aimed at lowering the peak stage profiles along the primary canal and/or reduce the basin-wide flooding depths and durations for different storm events under future sea level rise conditions
- Calculation of economic impacts (expected annual damages) of SLR with and without mitigation activities
- Evaluation of Benefit-Cost ratios of the projects, comparing construction costs to losses avoided
- Hydrodynamic modeling of coastal areas to assess impacts to downstream flooding
- Analytic analysis of water quality in Biscayne Bay
- An optimized project implementation sequence through a systematic Dynamic Adaptation Policy Pathway approach to adapt to sea level rise

Stakeholder input was critical to the development of the mitigation activities. The project started and ended with stakeholder workshops and stakeholders were included in over 40 bi-weekly meetings. Watershed-wide coordination is imperative because of the interdependencies of the mitigation solutions.

10.1 Mitigation Strategies

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, could address sea level rise scenarios 1 ft, 2ft, and 3ft via mitigation projects M2A, M2B, and M2C. All comparisons included relative changes from future sea level conditions and mitigation projects to current conditions.

10.1.1 M1 Projects – Local Scale

In this study, the following local scale mitigation projects (M1) were assessed using analytic solutions. This study also recommended three local level pump stations in Broward County and three local level pump stations in northern Miami Dade County.

- the Pembroke Pines three-basin interconnect at Century Village,
- injection well construction,
- upgrades to SBDD B-1/B-2 Pump Stations,
- interconnects for SBDD Basin 3/Basin 7 at Country Club Ranches,
- addition of operable structures (e.g., gates/pumps) to confluency of primary/secondary canals,

- and storage addition to non-pumped drainage areas.

The M1 projects included some general locations for pumps that could improve local drainage issues. These locations of overland flooding appeared to be suitable candidates for pump stations that could move overland flooding to nearby canals. These projects are beneficial to reduce local flooding and need to be examined beyond this planning level analysis.

10.1.2 M2 Projects – Regional Scale

The C-8 and C-9 canals are designed to drain the basins through gravity fed outfalls at S-28 and S-29. This dependance on a head differential between upstream and downstream sides of the structures is critical to understanding the impact sea level rise (SLR) can have on the overall system. Even slight raises in SLR on the downstream end of the structure can impact the ability of the system to drain. For this reason, one of the first regional scale projects that should be implemented in these systems is the addition of forward pumps at the S-28 and S-29 locations. These pumps show great ability to reduce, or maintain, peak canal flood elevations.

Therefore, the first mitigation component proposed is an overhaul to the tidal structures, composed of three key parts:

- raise gate overtopping elevations,
- create tieback levees and/or floodwalls, and
- add forward pumps

This study used a single raised gate overtopping elevation of 9.0 ft NGVD29 for all mitigation scenarios, chosen as a conservative estimate exceeding the peak surge elevation of the 100-year SLR3 event. It is important to note that this elevation lacks freeboard and construction feasibility analysis. Tieback levees and/or floodwalls were conceptually represented at the same 9.0 ft NGVD29 elevation by raising cross-sections and topography as needed. Both raised gates and tieback levees/floodwalls were assumed to fully block storm surge to justify the inclusion of a forward pump station. Pump stations were proposed as supplements to discharge from the gravity structure, discharging to tide when the gravity structure is unable to do so.

Not surprisingly, increasing sea level at the downstream boundary required mitigation projects with larger pump sizes at S-28 and S-29. This study determined pump sizes required at each basin through multiple model runs. The model independently simulated various pump sizes, at 500 cfs increments, for 5-, 10-, 25-, and 100-yr events under SLR 1, SLR 2, and SLR3 scenarios. As a result, there are multiple pump sizes to mitigate SLR under various events. To narrow the pump size selection, this project set a goal of maintaining or improving the existing level of service (LOS) under future SLR scenarios for the 25-yr event.

With a goal of achieving a maintenance or reduction in the 25-yr event LOS for three SLR scenarios, the study found that both basins would require the same pump sizes for the progressive mitigation activities – M2A, M2B, and M2C. M2A's goal was to mitigate SLR1, M2B's goal was to mitigate SLR2, and M2C's goal was to mitigate SLR3 for the 25-yr event.

The assessment concluded with the following regional Scale Projects (M2) projects. These strategies are adaptable to different sea level rises and are evolvable and can be implemented incrementally.

- M2A: S-28 and S-29 forward pumps (1,550 cfs); Gate improvements (increased overtopping elevation); Tieback levees/floodwalls; Total of 500 ac-ft distributed storge; Optimized gate/pump controls for SLR
- M2B: S-28 and S-29 forward pumps (2,550 cfs); Gate improvements (increased overtopping elevation); Tieback levees/floodwalls; Total of 500 ac-ft distributed storge; Primary canal improvements; Optimized gate/pump controls for SLR; addition of internal drainage system
- M2C: S-28 and S-29 forward pumps (3,550 cfs); Gate improvements (increased overtopping elevation); Tieback levees/floodwalls; Total of 500 ac-ft distributed storge; Primary canal widening; Optimized gate/pump controls for SLR; addition of internal drainage system

The mitigation strategies above include a generic 500 ac-ft distributed storage. This project element was more about the volume of storage (distributed between both basins) rather than the particular location of where that storage occurred. This study conducted a review of potentially available land that could hold 1 ft of storage with 1 ft of freeboard and found that between both basins there seems to be locations that could be further investigated. Some benefits of these types of storage areas could include:

- Green infrastructure storage options such as permeable pavement, bioswales
- Land conservation
- Conversion of repetitive loss properties to green spaces
- Multi-use of space such as athletic fields and floodplain storage

A more detailed and in-depth review of these properties is warranted if the benefits of these projects show promising results.

10.1.3 M3 Projects – Planning Scale

As communities embrace the challenges posed by rising sea levels and strategize for the future, they are formulating land use policies at both local and county levels. Ideally, these communities would proactively enforce zoning regulations and land use policies that raise the elevation of buildings and roads to effectively counter future instances of flooding. In this study, a planning exercise was conducted to ascertain the feasibility of elevating all buildings and roads within the C-8 and C-9 watersheds.

The long-term effect of these type planning policies are examined in this study by modeling the economic benefits of removing all buildings and roads from flooding. The mitigations strategies are identified as:

- 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

A summary of the mitigation strategies is shown in **Table 10.1.**

Table 10.1 Summary of Mitigation Strategies for both C-8 and C-9 Watersheds

Summary of Mitigation Strategies			
Scenario	**Distributed Storage**	**Pumps & Structural Improvements**	**Canal Improvements & Drainage Changes**
M0 (Current Conditions)	None	None	None
M1 (Local)	11-acres	Stormwater projects, sluice gates and pump stations	Reduces flooding by 0.25 ft
M2A	500 ac-ft	1550 cfs harden and elevate downstream structure	None
M2B	500 ac-ft	2550 cfs harden and elevate downstream structure	Improved geometry, raised banks Internal drainage to accommodate raised banks
M2C	500 ac-ft	3550 cfs harden and elevate downstream structure	Improved geometry, raised banks, and widened banks Internal drainage to accommodate raised banks

10.2 Hydrologic and Hydraulic Modeling Assessment

This project applied analytic procedures to evaluate the M1 Local Scale and M3 Planning Scale strategies. These procedures were aimed at giving some reasonable hydraulic benefit of the mitigation efforts for use in the subsequent expected annual damages assessment.

The modeling platform applied in this study used an integrated surface water and groundwater model, MIKESHE. The model applied four rainfall events (5-, 10-, 25-, and 100-yr) for four sea level rise (SLR) scenarios (current conditions, +1 ft, +2 ft, and +3 ft). The modeling examined existing conditions, future conditions, and future conditions with and without mitigation strategies.

The M2 Regional Scale mitigation activities provided an opportunity to compare the achieved FPLOS metrics PM1 and PM5 using detailed hydrologic and hydraulic (H&H) modeling. The key findings related to these activities and the corresponding metrics were as follows:

M2A

- Mitigation M2A, while not completely meeting the goals set for the 25-year SLR1 event, is predicted to be highly effective in mitigating the adverse effects of a 1-foot sea level rise in both the C-8 and C-9 Watersheds.
- Under SLR2 and SLR3, Mitigation M2A will fall short of achieving canal stages and flood levels equal to or lower than the existing conditions. However, it is still expected to provide significant improvements compared to no mitigation.

M2B

- Mitigation M2B, despite not fully achieving the goals set for the 25-year SLR2 event, is predicted to be highly effective in mitigating the negative impacts of a 2-foot sea level rise in both watersheds.
- Under SLR1, Mitigation M2B is expected to meet the goals set for Mitigation M2A and demonstrate substantial improvements. Mitigation M2B is projected to achieve canal stages and flood levels equal to or lower than the existing conditions for all simulated rainfall events.
- Under SLR3, Mitigation M2B is anticipated to provide significant improvements compared to no mitigation.

M2C

- Mitigation M2C, although not fully meeting the goals set for the 25-year SLR3 event, is predicted to be highly effective in mitigating the adverse effects of a 3-foot sea level rise in both watersheds.
- Under the SLR1 scenario, Mitigation M2C is expected to achieve canal stages and flood levels equal to or lower than the existing conditions for all simulated rainfall events.
- Under SLR2, Mitigation M2C is projected to largely achieve canal stages and flood levels equal to or lower than the existing conditions for all simulated rainfall events.
- Under SLR3, Mitigation M2C is anticipated to provide significant improvements compared to no mitigation.

It is important to note that all of the M2 mitigation strategies showed that the key component to these projects are the hardening of the control structure to withstand storm surge events and adding in a forward pump. Without these elements none of the mitigation strategies are able to minimize the affects of SLR.

The forward pump is critical to an overall, basin-wide flood control strategy. Without the ability to reduce peak flood stages in the primary canal, secondary and tertiary mitigation activities are not possible since there will be no capacity “downstream.”

10.3 Flood Damage Assessment – Expected Annual Damages (EADs)

This study compared expected annual damages (EADs) for future sea level conditions and mitigation projects to those of current conditions. Three sea level rise scenarios (SLR1, SLR2, and SLR3) were evaluated to provide a comprehensive understanding of the potential impacts of flooding on the C-8 and C-9 basins.

EAD’s are calculated using flood hazard data (from the H&H modeling), building and infrastructure data, and depth damage functions that relate the damage costs to the depth of flooding. The resulting economic damages for each flood event (5-, 10-, 25-, 100-yr) are used to calculate the expected annual damage. In this way, managers can compare the economic benefits of mitigation strategies across multiple storm events and sea level rise scenarios.

The assessment revealed that local scale mitigation projects (M1) show, as expected, great benefits at the local level – when examined at, say, census tract scale. These projects are very beneficial to the local flooding issues and should be encouraged. The M3 projects, which are for planning purposes only, simply used buildings and roads elevated above current levels by 1, 2, and 3 ft (to match SLR). Of course, this showed that the damages would be minimal in the basin if this could be achieved.

The assessment revealed that regional scale mitigation projects (M2), specifically M2A, M2B, and M2C, were effective in reducing flood damages in the C-8 basin. Although the impact was relatively less in the C-9 basin, it is worth noting that the pump stations in the basin are efficient in draining floodwaters. The benefit-cost assessment, along with the downstream flooding impact assessment and water quality impact assessment, further justified the effectiveness of different strategies.

10.4 Benefit-Cost Ratios (BCRs)

The expected annual damages provide the estimated benefits for each mitigation strategy. The costs were developed using, as much as possible, standard District costs for similar mitigation projects. For example, the District has recently developed costs for pump station modification at S-28 and this project leveraged those costs for the M2 series mitigation projects. The costs are for planning purposes only and would require further modification as the projects are refined. This study applied standard FEMA methodologies to calculate the BC ratios. This approach applies discount rates of 3% and 7%. The benefits only applied expected annual damages and didn't account for many other benefits such as environmental or socio-economic benefits, which would further enhance the "plus side" of the equation.

The evaluation of regional-scale projects, specifically M2A, M2B, and M2C, yielded highly favorable BCRs, particularly within the C-8 basin for both 3% and 7% discount rates. In C-9 Basin, regional-scale projects, under M2A, M2B, and M2C demonstrated favorable BCRs under 3% discount rate and the most advantageous Benefit-Cost Ratio for M2B under 7% discount rate. The assessment revealed that regional scale mitigation projects (M2), specifically M2A, M2B, and M2C, were effective in reducing flood damages in the C-8 basin. Although the impact was relatively less in the C-9 basin, it is worth noting that the pump stations in the basin are efficient in draining floodwaters under high tail water conditions. The benefit-cost assessment, along with the downstream flooding impact assessment and water quality impact assessment, further justified the effectiveness of different strategies.

10.5 Dynamic Adaptive Policy Pathways (DAPP)

The DAPP assesses the sea level rise accommodation capacity of mitigation measures in the C-8 and C-9 study. It considers the minimum performance level criteria to determine how long each action can function until it requires replacement. For example, how long will an action last (e.g., 10 years or 20 years) until it does not function anymore, at which time another action must be implemented. Decision-makers can use this information to determine the lifespan of different mitigation scenarios based on sea level rise assumptions. By understanding the timing of options, decision-makers can develop an adaptation plan and identify short-term actions needed to maintain long-term options. The plan also identifies triggers, such as changes in the sea level rise rate, that indicate when different actions should be implemented. For the C-8 and C-9 Basin study, the DAPP analysis includes these inputs:

- Sea level rise (SLR) curves
- Estimated Annual Damages (EAD)
- Thresholds and Tipping Points

For the C-8 watershed, the DAPP results indicate:

- M1: It can accommodate up to 0.5-ft SLR to year 2032 (NOAA Intermediate High) or to year 2030 (NOAA High).

- M2A: It can accommodate up to 0.8-ft SLR to year 2038 (NOAA Intermediate High) or to year 2035 (NOAA High).
- M2B: It can accommodate up to 1.7-ft SLR to year 2054 (NOAA Intermediate High) or to year 2048 (NOAA High).
- M2C: It can accommodate up to 2 -ft SLR by 2060 (NOAA Intermediate High) or to year 2053 (NOAA High).

For the C-9 watershed, the DAPP results indicate:

- M1: It can accommodate up to 0.4-ft SLR to year 2030 (NOAA Intermediate High) or to year 2029 (NOAA High).
- M2A: It can accommodate up to 0.7-ft SLR to year 2036 (NOAA Intermediate High) or to year 2033 (NOAA High).
- M2B: It can accommodate up to 1.3-ft SLR to year 2048 (NOAA Intermediate High) or to year 2043 (NOAA High).
- M2C: It can accommodate up to 1.5-ft SLR by 2052 (NOAA Intermediate High) or to year 2046 (NOAA High).

10.6 Impacts on Downstream Water Levels from S-28 and S-29 Structure Outflows

A stakeholder concern of the M2 series mitigation projects is the potential for the forward pumps to impact water surface elevations downstream of the pumps. To evaluate the downstream effects of the S-28 and S-29 structures gate and pump outflows on water levels in Biscayne Bay during normal tides and 10-yr surge event conditions, this study simulated dynamic water surface elevations with a detailed 2-D model that incorporated freshwater inflows and tidal conditions in the Bay.

Model results show the effects of FPLOS structure outflows are limited to water depths in the downstream areas near the structures and maximum water depths in the main Biscayne Bay area are not substantially affected by the S-28 and S-29 structure outflows. Model results also indicate rising sea levels generally decrease the effect of the S-28 and S-29 structure outflows on normal tides and 10-yr surge maximum water depths (or water levels). In addition to the net differences in terms of flood depth, our simulations have indicated that Scenarios 2A and 2B will result in little to no increase in the peak stage profiles' for the canal segment downstream of the tidal structures, thereby preserving the conveyance from the secondary and tertiary systems to the primary system. However, it must be noted that Scenario 2C has the potential to negatively impact the downstream urban areas. If the proposed M2C is advanced to the implementation phase, it is crucial that additional mitigation strategies be developed to address the downstream impacts.

10.7 Potential Water Quality Impacts to Northern Biscayne Bay

This study developed a regression model to compare water quality data with expected changes in freshwater discharge due to the M2 mitigation strategies. In summary, results showed:

For the C-8 watershed:

- WQ Impacts:
    - Cumulative volume discharges from the C-8 were shown to be higher for M2C scenarios for the 100-year storm compared to existing conditions (M0-SLR0). Hence, short term

    negative WQ conditions may result from M2 mitigation compared to existing conditions for higher return period storms (Section 8.4).

  - M2B-SLR1 all M2C scenarios are projected to result in short term negative WQ conditions.
    - M2C scenarios are associated with more frequent short term negative or uncertain impacts.

- Marine life and seagrass Impacts:
  - Projected salinities are not anticipated to violate the tolerances of any indicator species. All M2C scenarios may cause higher TN loads for this same return period. For the 10- and 25-year return period storms, only M2C-SLR1 and M2C-SLR2 are anticipated to cause higher TN loads.

For the C-9 watershed:

- WQ Impacts:
  - Cumulative volume discharges from the C-9 were shown to be lower for all mitigation scenarios across all return periods compared to existing conditions (M0-SLR0) except for scenario M2C-SLR1 and M2C-SLR2. Hence, WQ conditions may be maintained or improved under most scenarios.
    - M2C scenarios are associated with more frequent short term negative or uncertain impacts, while M2A scenarios are associated with less frequent negative impacts.
- Marine life and seagrass Impacts:
  - The 100-year return period storm for the M2A, M2B, and M2C scenarios is anticipated to violate the salinity tolerances of American Oyster and Johnson's Seagrass, two indicator species for NNB-A. Only scenario M2C-SLR1 is anticipated to lead to lower salinities compared to existing conditions (M0-SLR0). Regarding TN loads, only scenario M2C-SLR1 would result in increased TN loads compared to M0-SLR0 for all return periods.

10.8 Recommendations for Mitigation Strategies

The mitigation strategies presented are shown to be effective in mitigating the impacts of sea level rise to flood protection level of service. This study recommends the following actions:

- County, municipalities, and local water control districts continue to develop and implement local scale flood mitigation projects
- The SFWMD should continue to pursue the development of regional scale mitigation projects starting with immediate implementation of M2A projects
  - Implementation of M2A for both the C-8 and C-9 watersheds will:
    - Have a positive BC ratio
    - Have little to no increase in downstream flood elevations
    - Have little to no negative impact to WQ in Biscayne Bay
    - Can accommodate up to 0.8 ft SLR in the C-8 and 0.7 ft SLR in the C-9 watersheds

  - M2A should be built with additional space and bays for additional pumps or reserve additional land. The structure itself could be enlarged and additional pumps, needed to achieve M2B and M2C, could be added later.
    - This approach allows for adaptive management and does not tie the SFWMD into addressing future conditions that may or may not occur.
    - Opportunities to implement other features of the M2B and M2C mitigation projects should be explored. This could include raising canal banks and/or widening the canals.
    - The construction of pump stations at S-28 and S-29 requires considerable engineering and design that has not been accounted for in this study. The cost of construction for the M2A and M2B strategies should be investigated and evaluated to understand the relative benefits of achieving a longer lifespan with respect to SLR.
    - The S-29 structure has recently received a FEMA BRIC grant for construction of an additional pump. This project should be considered in advancing a mitigation strategy for this basin.
    - Both M2A and M2B achieve positive BCRs but M2A will have a much shorter lifespan with respect to achieving reductions in SLR. Therefore, it may be beneficial to go straight to M2B.
    - M2B mitigation strategies showed a slight impact to WQ conditions for SLR1 scenarios. This warrants further investigation and would require additional mitigation features that could minimize or remove this impact.

The District, stakeholders and water managers have additional facets to consider when implementing these strategies.

- The SFWMD should continue to investigate additional storage features within the basin. The addition of storage can reduce peak floods, have benefits to water quality, and provide communities with the added benefits of green infrastructures.
  - This should include additional investigations into the mining pits in the western part of the basin.
  - This should also include the evaluation of potential storage areas identified in this study.
- The SFWMD should continue to promote and optimize the pre-storm drawdown operations within the watersheds. These operational plans should also consider how to adjust gate operations for future conditions.
- The C-8 and C-9 Watersheds share several basin-interconnects and the C-8 Watershed was predicted to have level of service deficiencies directly related to elevated stages at the west side of the watershed, providing additional conveyance capacity in the C-9 Canal is believed to contribute to the reduced stages in the C-8 Watershed to some degree. This effect needs further examination.
- Communities should continue to discuss policy and planning approaches to mitigate flooding – such as the M3 options of elevating buildings and roads throughout the watershed.

10.9 Mitigation Strategy Progression

The three major mitigation strategies (M2A, M2B, and M2C) evaluated in this FPLOS assessment are built progressively. M2B included all components of M2A and added pumping capacity, raised canal banks, and drainage adjustments. M2C included everything in M2B along with additional pumping capacity and widened canals.

The results of the FPLOS Phase II Assessment indicated that there is no one-size-fits-all scenario to solve all problems across all sea level rise scenarios. Each of the M2A, M2B, and M2C scenarios has its own advantages and disadvantages. M2A is the least expensive but effective only for up to one foot of sea level rise. M2C is the most expensive but has the longest effectiveness duration. M2B falls in the middle in terms of cost and effectiveness.

Both M2B and M2C are effective for sea level rise up to around two feet, with M2C reducing flooding to a level lower than current conditions under most SLR1 and SLR2 scenarios. M2B returns to current condition levels but does not surpass them greatly.

For planning purposes, it is recommended to adopt a progressive approach to mitigation, starting with M2A and considering the installation of the required number of pump bays for M2C. This allows for a transition to M2B or M2C by adding pumps to the existing pump bays. The transition would mainly involve upstream projects such as canal modifications and storage areas.

This approach enables water managers to adapt to sea level rise as it occurs, avoiding the need for immediate investment in M2C. Instead, starting with M2A and assessing system performance and sea level rise progression, they can gradually scale up to M2C if necessary.

The details of progressing from each mitigation activity would require further analysis and a detailed construction sequencing – including a cost evaluation of designing a pump station size that would allow pump size increases (i.e., having a footprint big enough to accommodate future pump size increases), reviewing canal bank elevations and how they are sequenced with pumps, and so on. This planning level study only identified the mitigation projects but did not detail construction protocols.

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APPENDIX A

Supporting Documentation For Cost Estimation

APPENDIX B

Task 1 Summary Memorandum: Desktop Review, Website Project Viewer, and Partner Workshop on the Adaptation Planning and Mitigation Projects

APPENDIX C

Task 2.1 Technical Memorandum: Develop Mitigation Efficiency Criteria, Mitigation Projects for Modeling, and Project Plan (Revised)

APPENDIX D

Task 2.2 Flood Protection Level of Service Provided by Potential Mitigation Projects for Current and Future Sea Level Conditions in the C-8 And C-9 Watersheds Report

APPENDIX E

Task 2B Hydrodynamic Modeling to Evaluate Downstream Coastal Area Water Levels Prepared for SFWMD C-8 C-9 Phase II

APPENDIX F

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

APPENDIX G

Task 4.1 Technical Memorandum: Adaptation Planning Report C-8 And C-9 Watersheds Flood Protection Level of Service Adaptation Planning and Mitigation Projects Study

APPENDIX H

Task 4B – Water Quality Impact Analysis of Mitigation Strategies on North Biscayne Bay