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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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***)

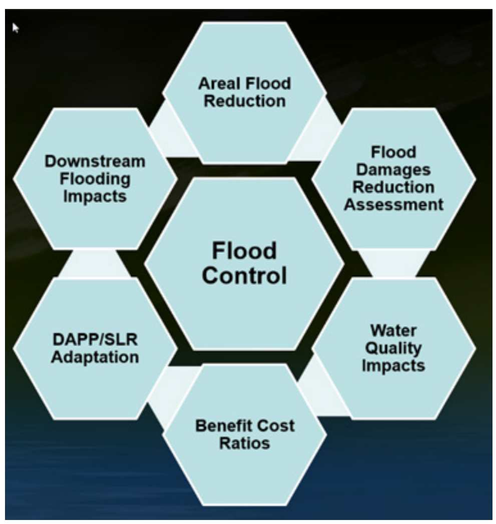


Figure 1.1 The District FPLOS Studies Focus on Systematic Approach to Ensure Infrastructure Readiness

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**.

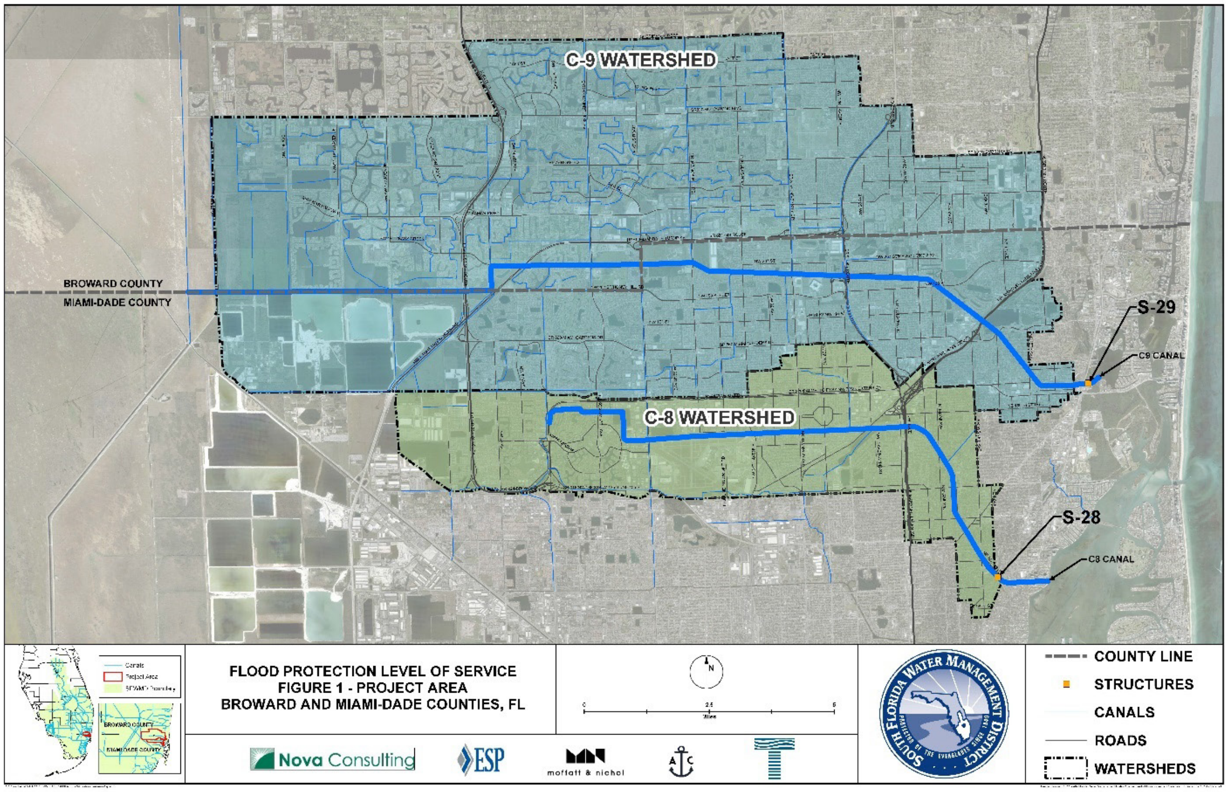


Figure 1.2 Location Map for C-8 and C-9 Watersheds in Southeast Florida

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 5.0** 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.

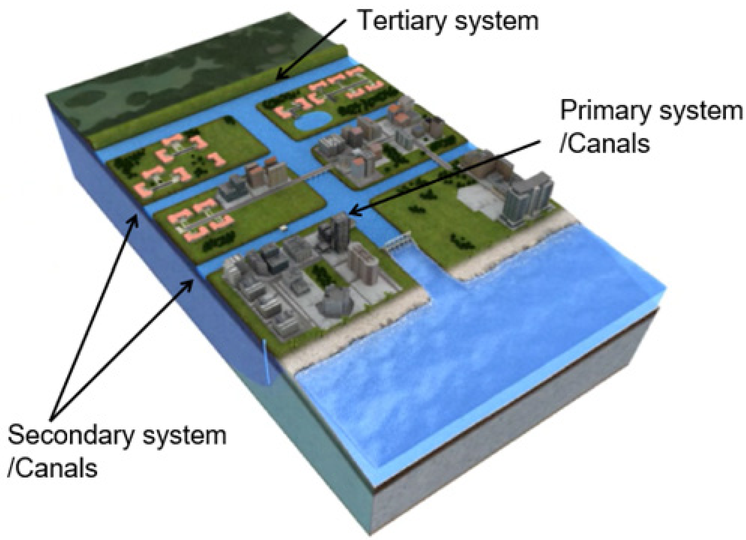


Figure 3.1 A SFWMD Depiction of Typical Flood Control Systems in South Florida (Image courtesy of the SFWMD)

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 5.0** 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 **Table 3.1**. Note that the “other influence areas” were not used in calculations of EADs.

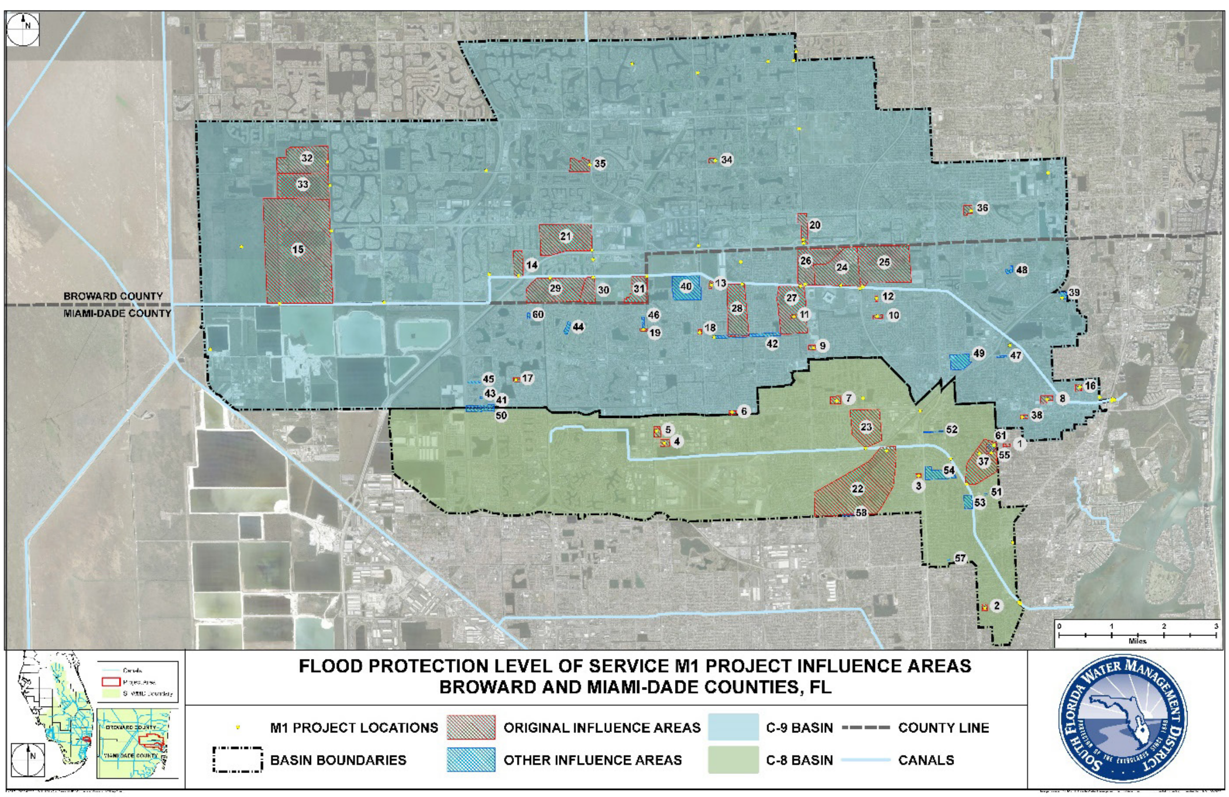


Figure 3.2 M1 Projects Shown in C8 and C9 Watersheds

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.

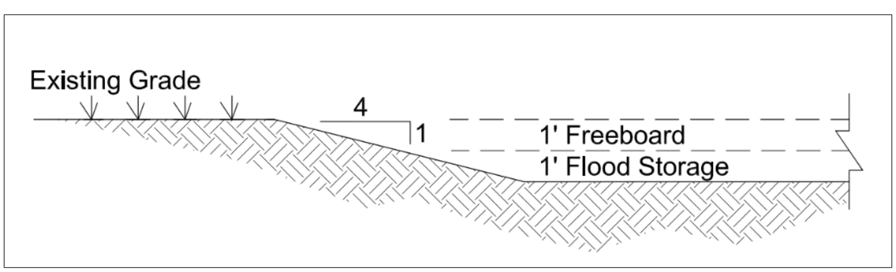
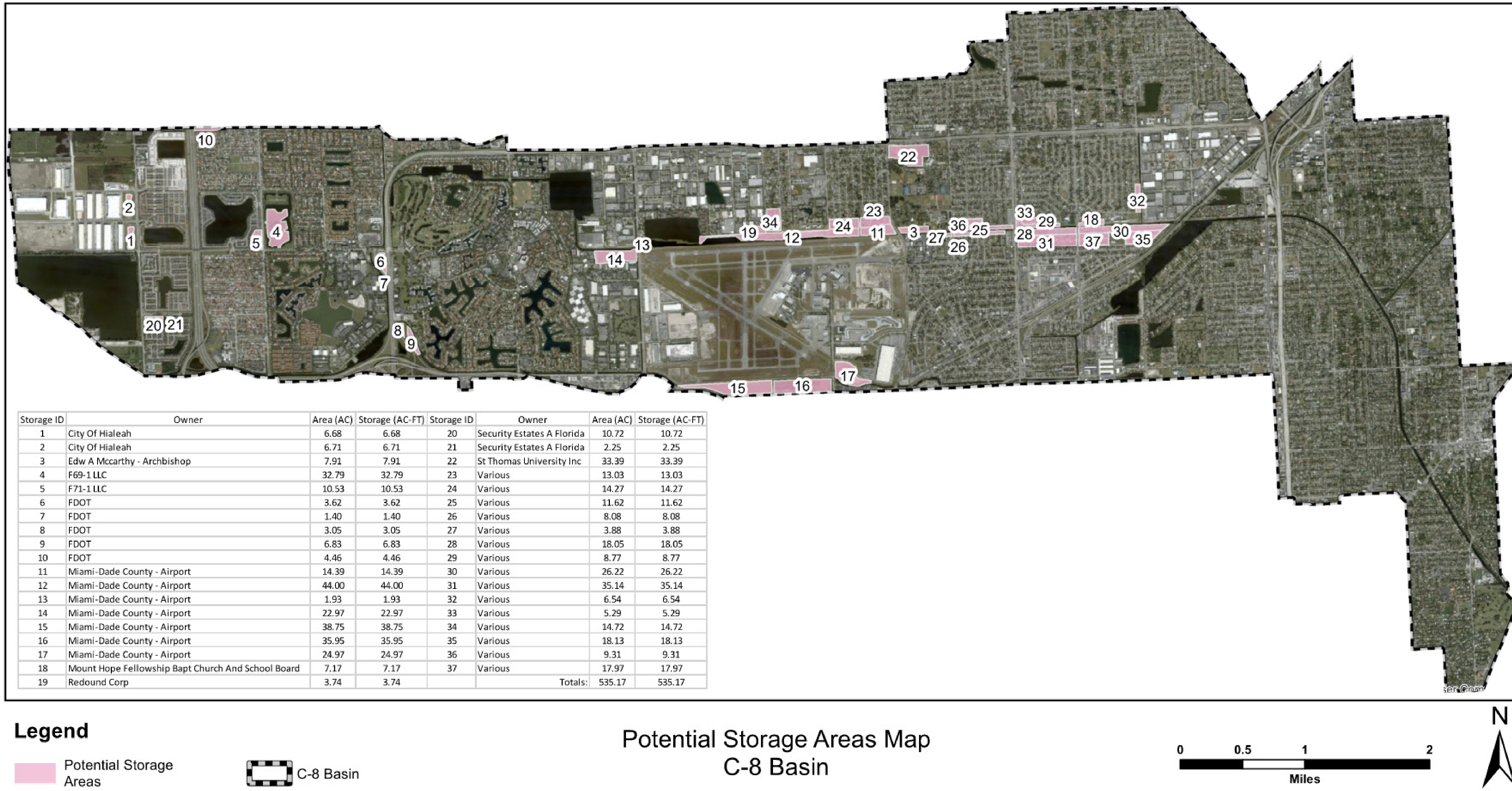


Figure 3.5 Storage Area Concept

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:

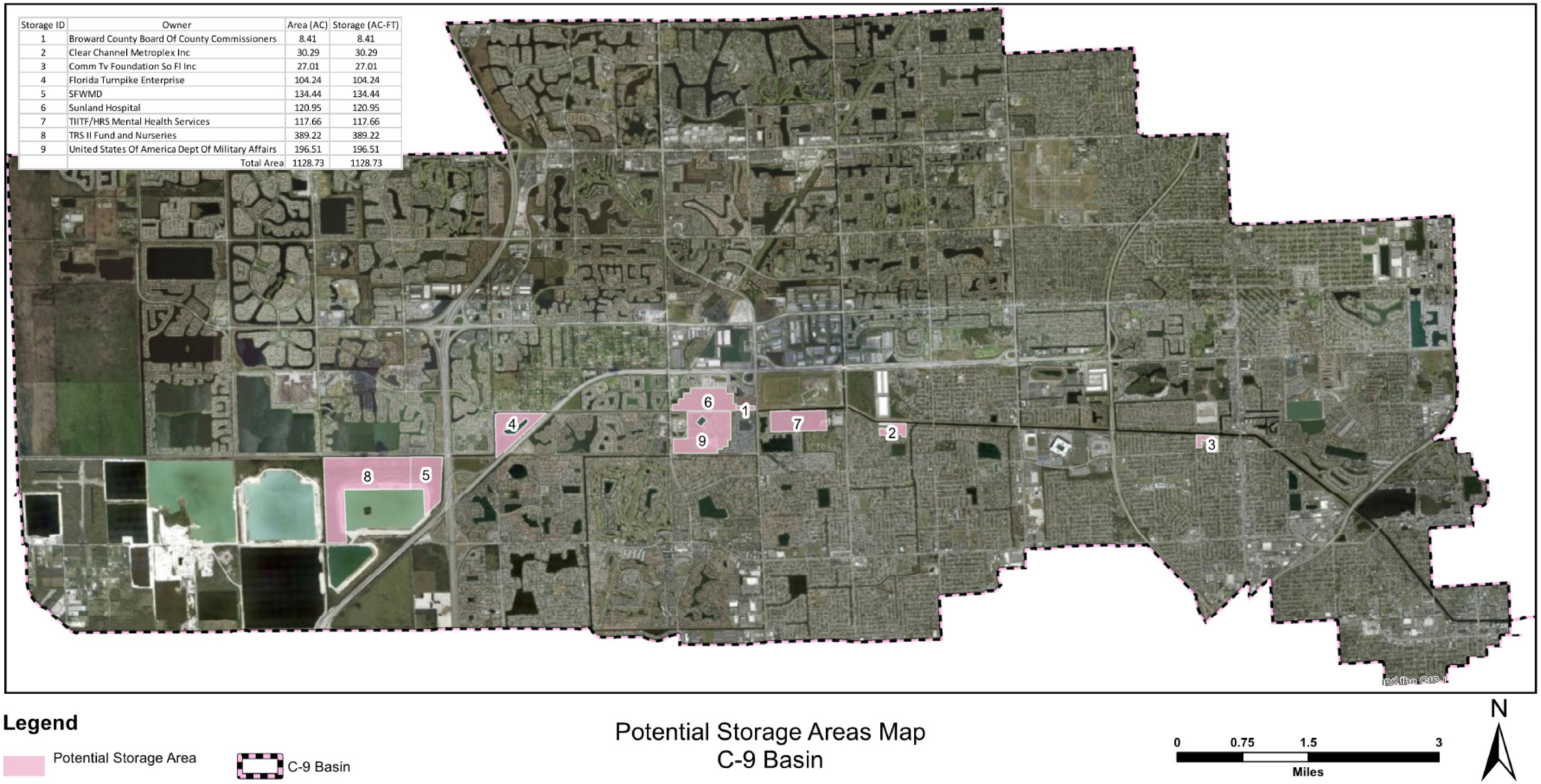
1. District/FDEP/FDOT (or TIITF (Board of Trustees of the Internal Improvement Trust Fund of the State of Florida))- owned land
2. Other government-owned land
3. Vacant land/Underutilized
4. Tracts of land larger than approximately 5 acres

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**).

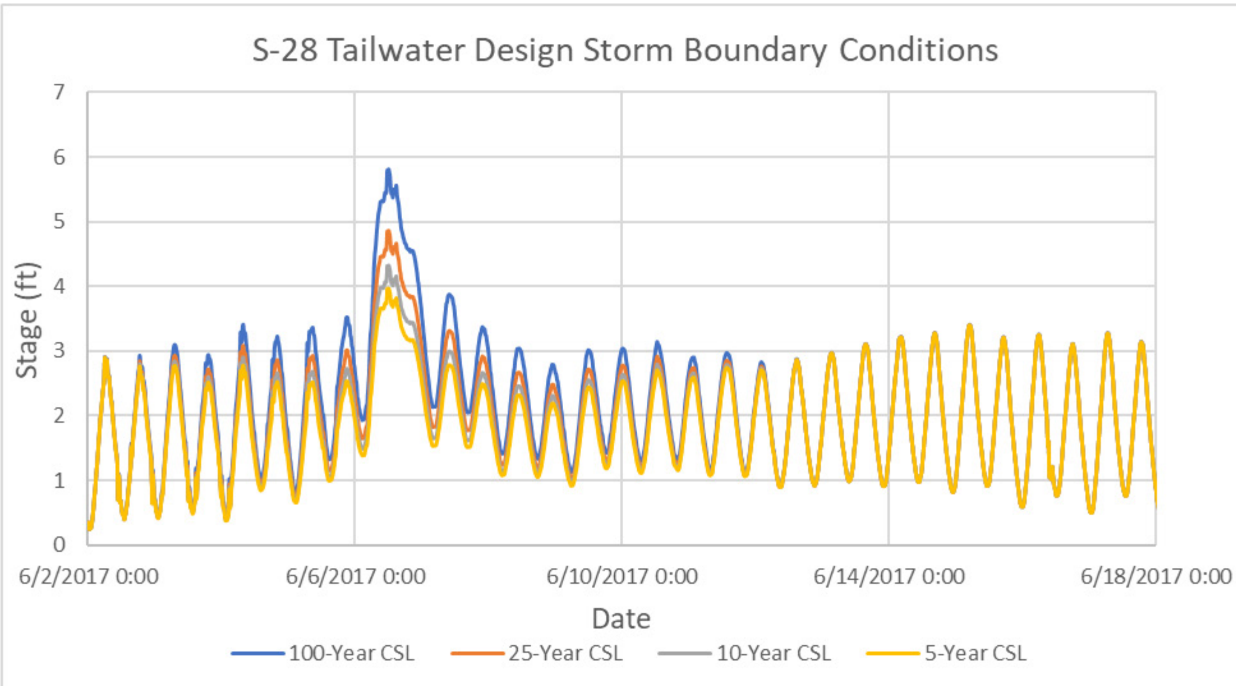


Figure 4.1 Storm Surge Boundary Condition Applied at S-28

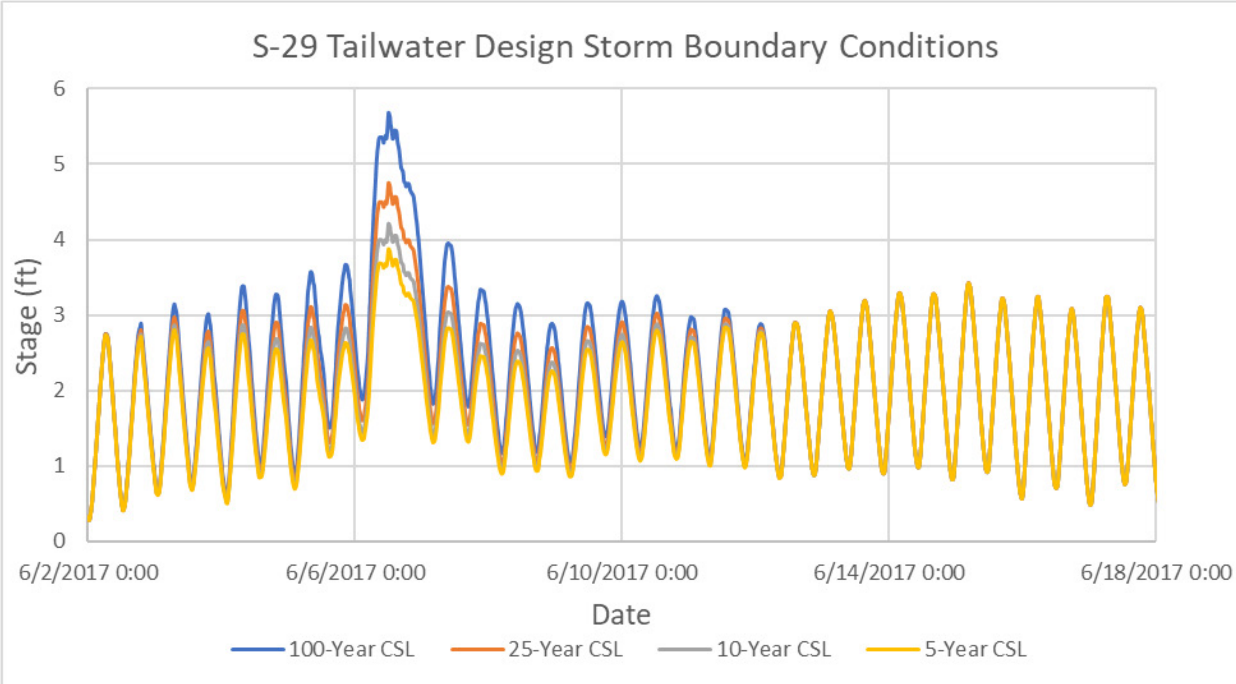


Figure 4.2 Storm Surge Boundary Condition Applied at S-29

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.

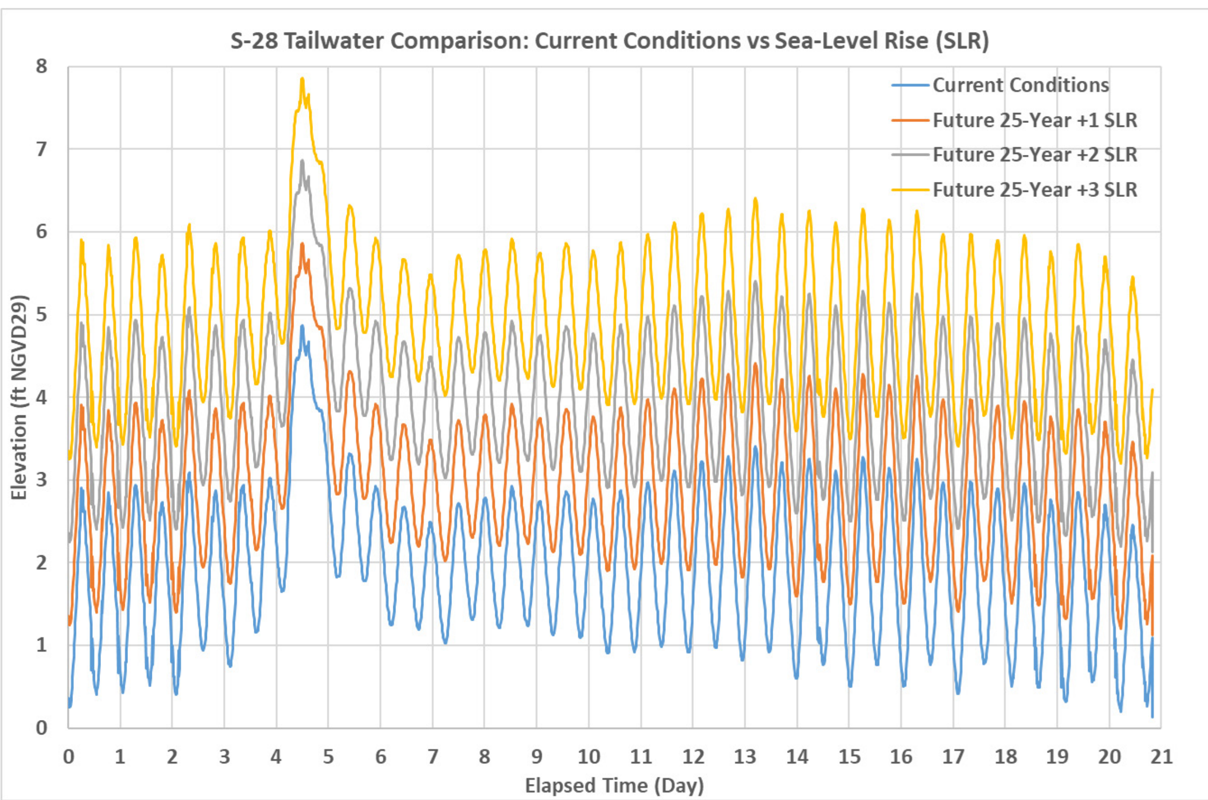


Figure 4.3 Example of 25-Year Storm Surge Boundary Condition Applied at S-28 for 3 SLR Conditions

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

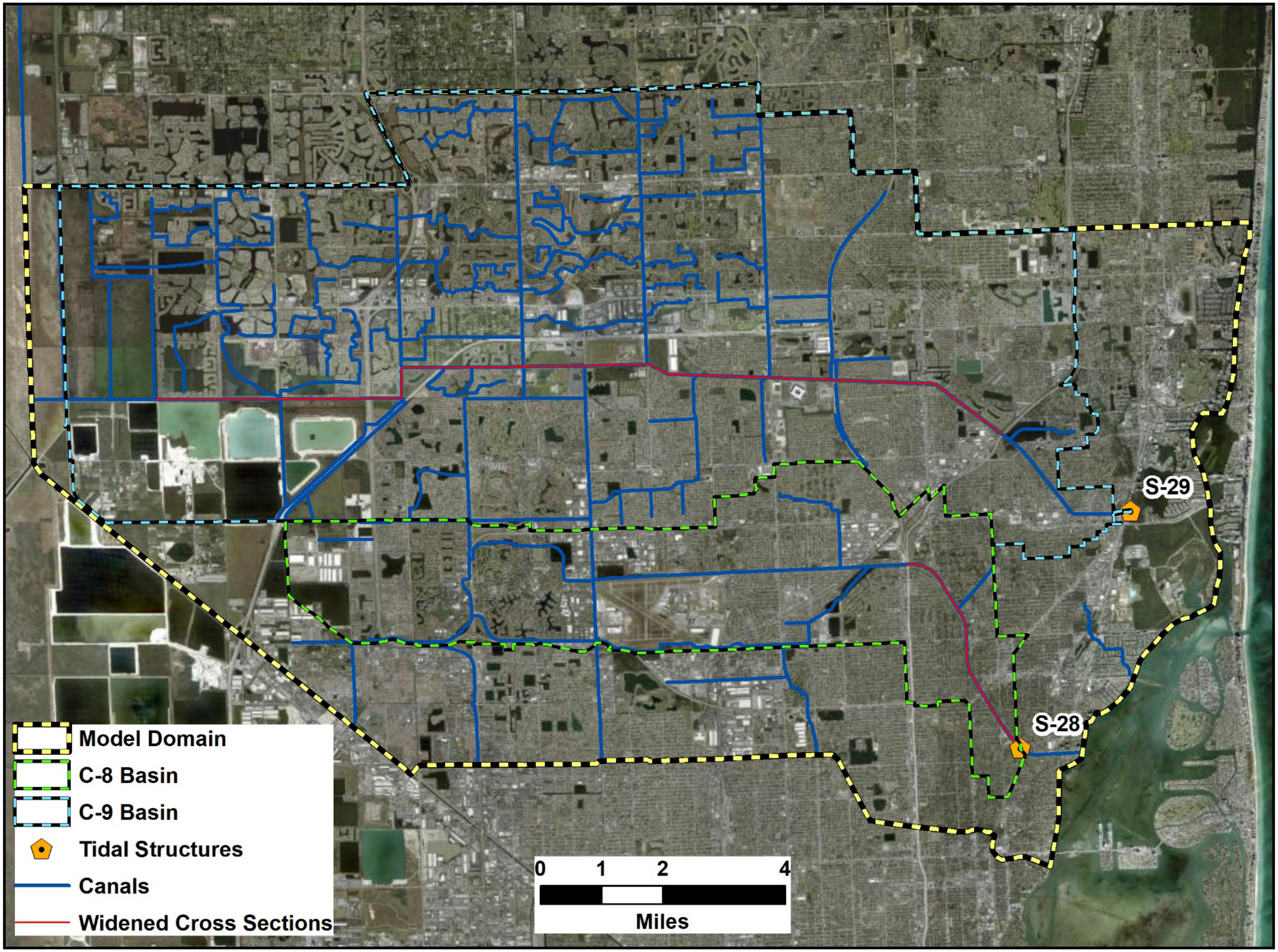


Figure 4.4 Location of Canal Segment with Widened Cross Sections under Mitigation Strategy M2C

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 <u>Summary of Model Results For the C-8 Watershed for each Mitigation Strategy</u>

4.4.1.1.1 <u>Mitigation Strategy M2A</u>

- 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.

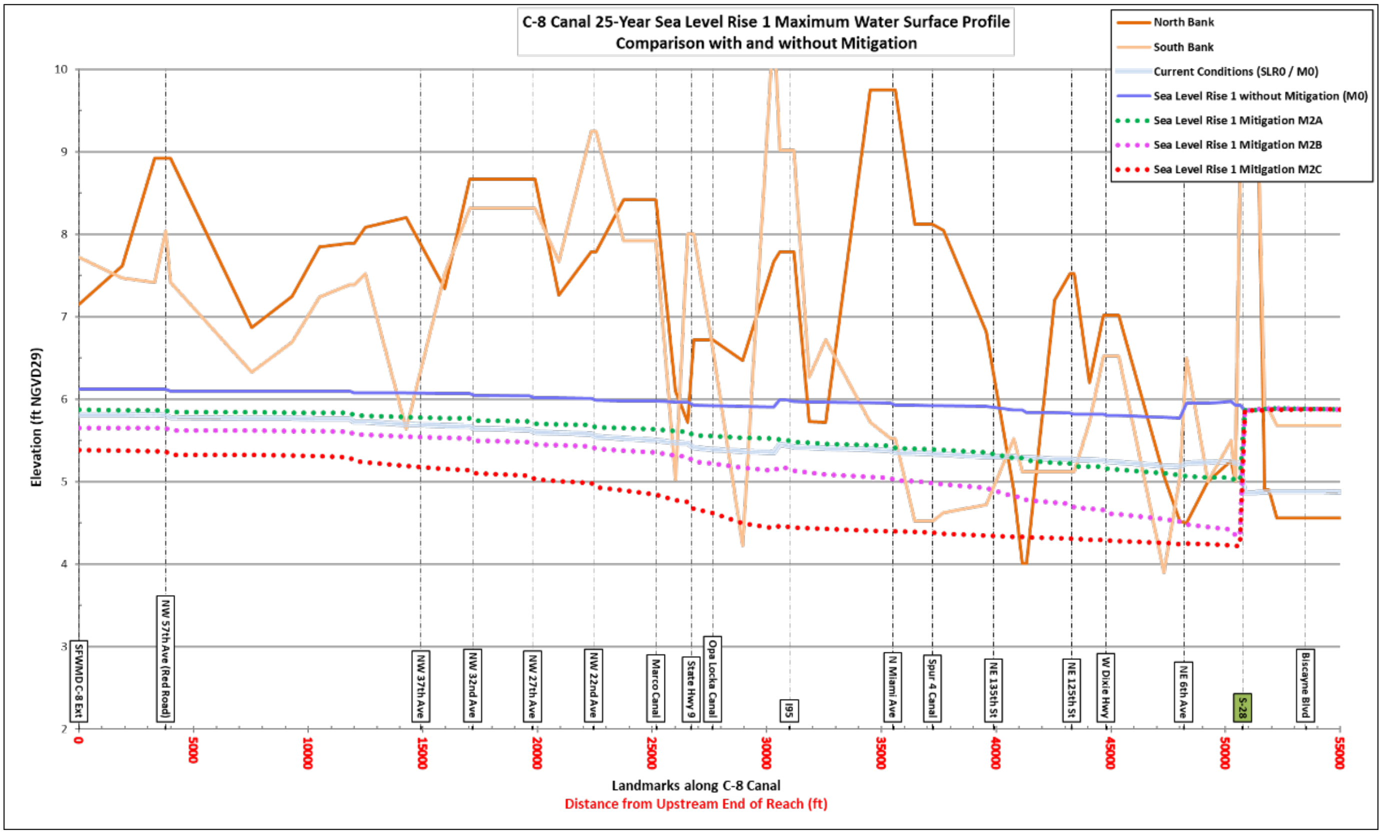


Figure 4.5 C-8 Canal Peak Stage Profiles for 25-Year Sea Level Rise 1 Design Storm with and without Mitigation

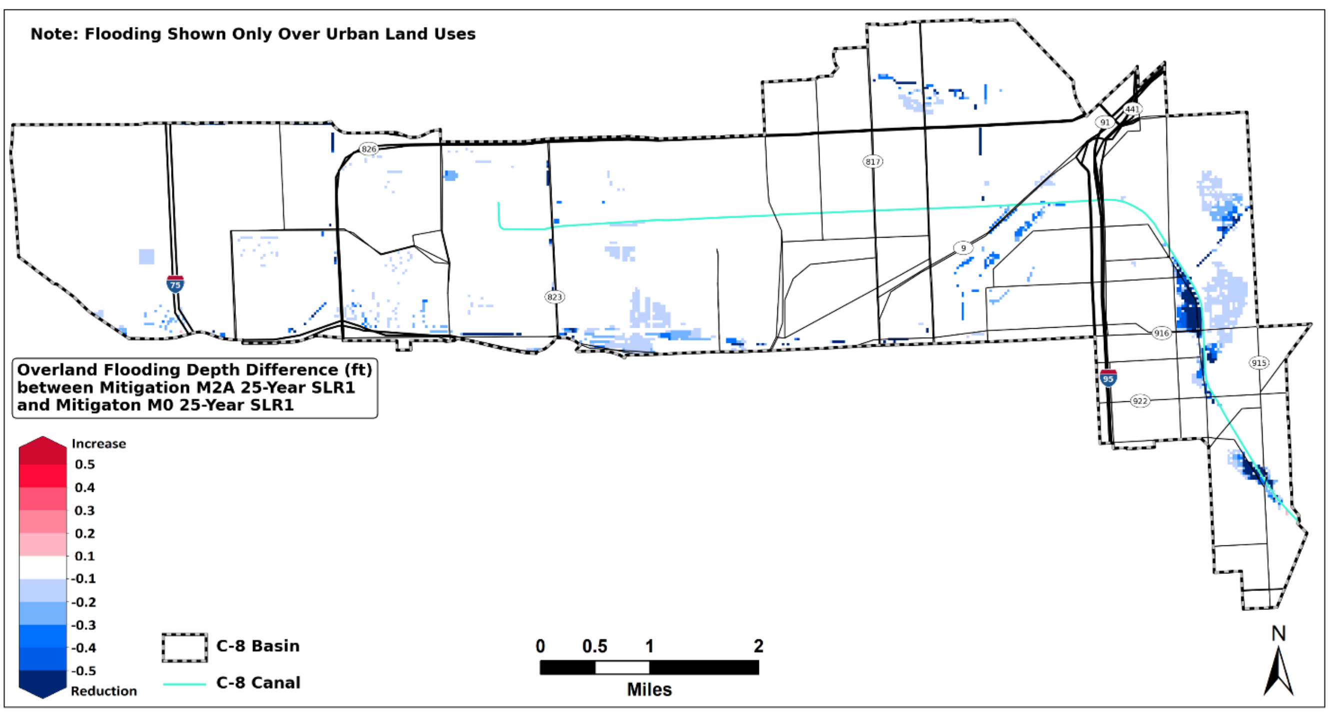


Figure 4.6 C-8 Basin Flood Inundation Difference Map for Mitigation M2A 25-Year Sea Level Rise 1 Versus Future Conditions without Mitigation (M0) 25-Year SLR1 in Urban Land Use Areas

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.

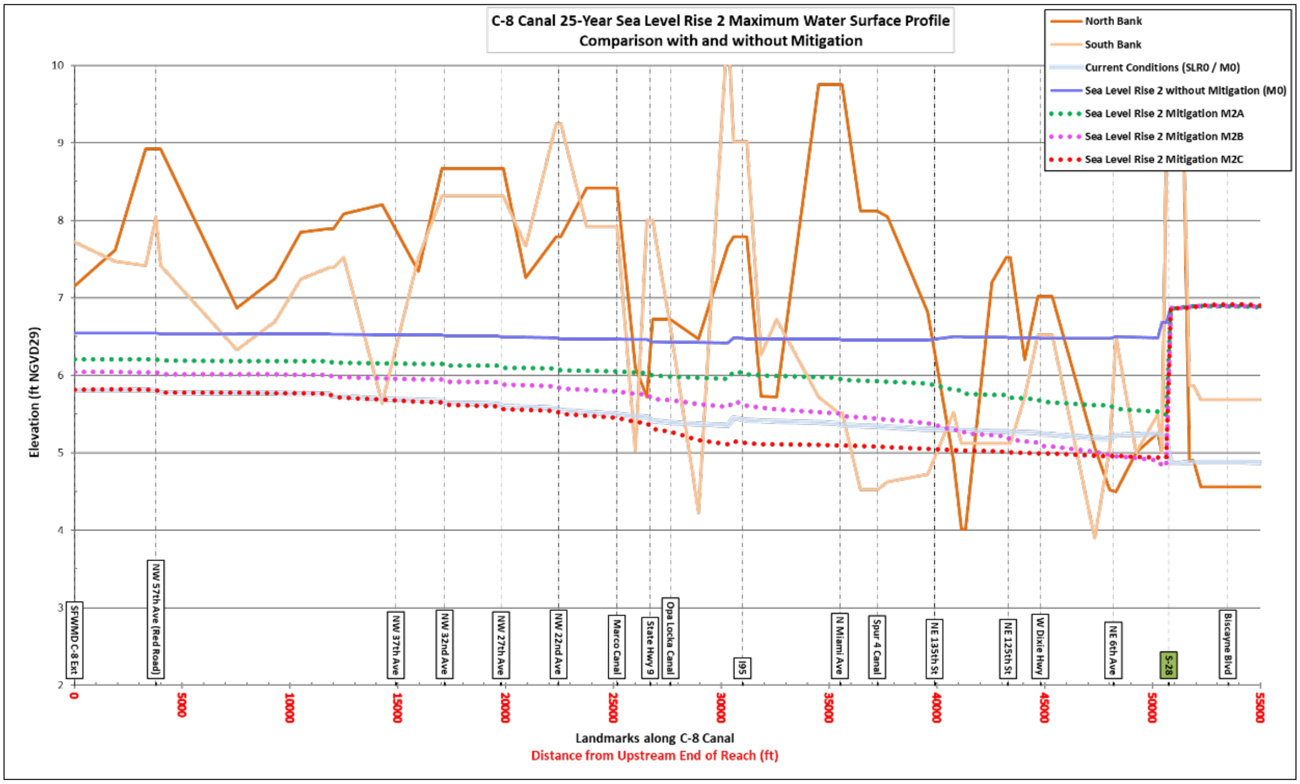


Figure 4.7 C-8 Canal Peak Stage Profiles for 25-Year Sea Level Rise 2 with and without Mitigation

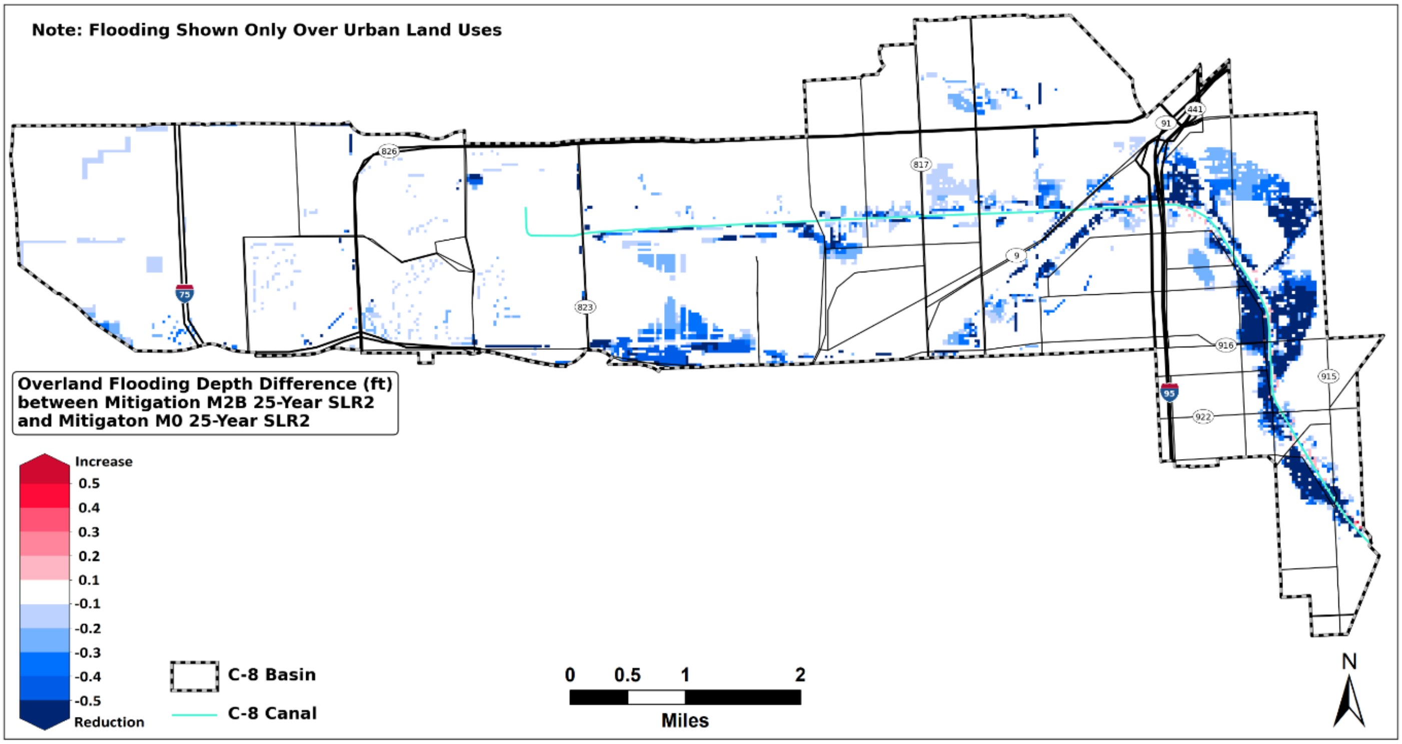


Figure 4.8 C-8 Basin Flood Inundation Difference Map for Mitigation M2B 25-Year Sea Level Rise 2 Versus Future Conditions without Mitigation (M0) 25-Year SLR2 in Urban Land Use Areas

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

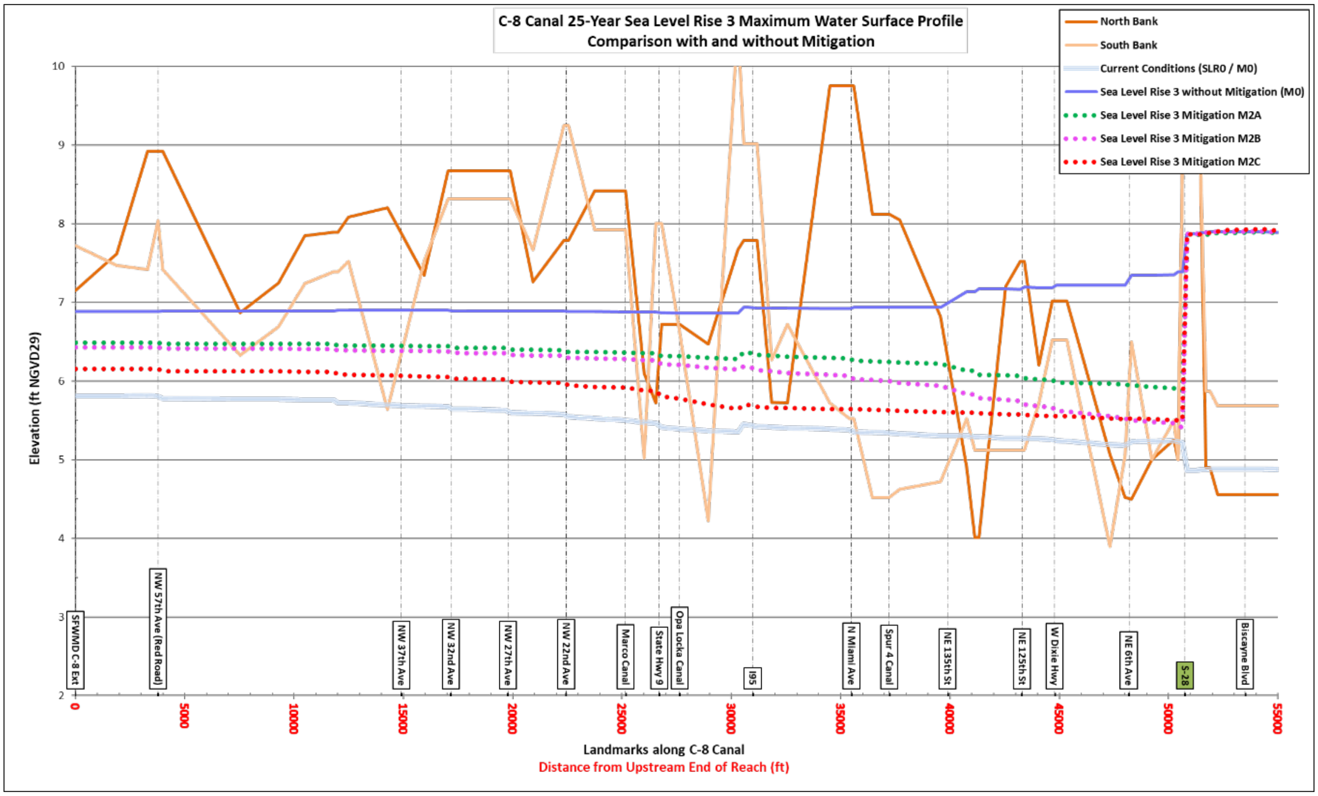


Figure 4.9 C-8 Canal Peak Stage Profiles for 25-Year Sea Level Rise with and without Mitigation

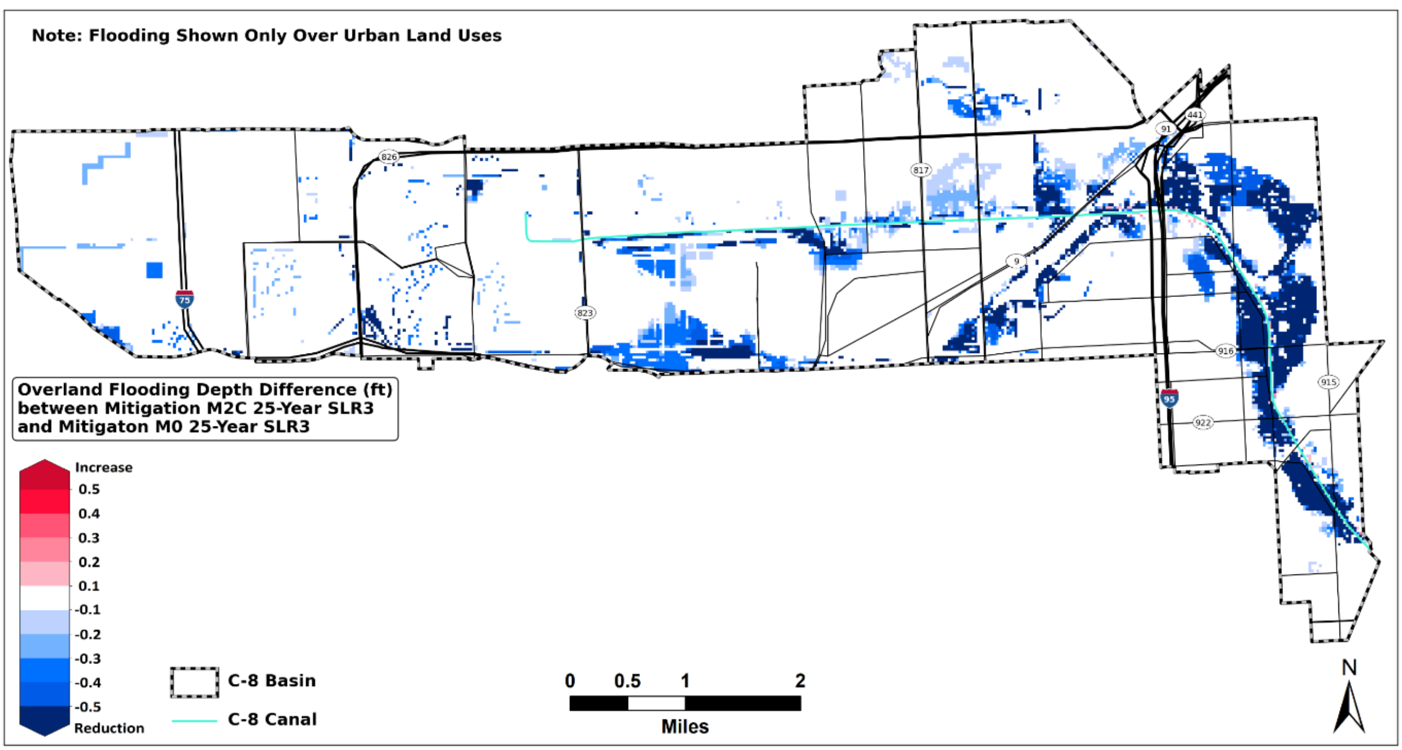


Figure 4.10 C-8 Basin Flood Inundation Difference Map for Mitigation M2C 25-Year Sea Level Rise 3 versus Future Conditions without mitigation (M0) 25-Year SLR3 in Urban Land Use Areas

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

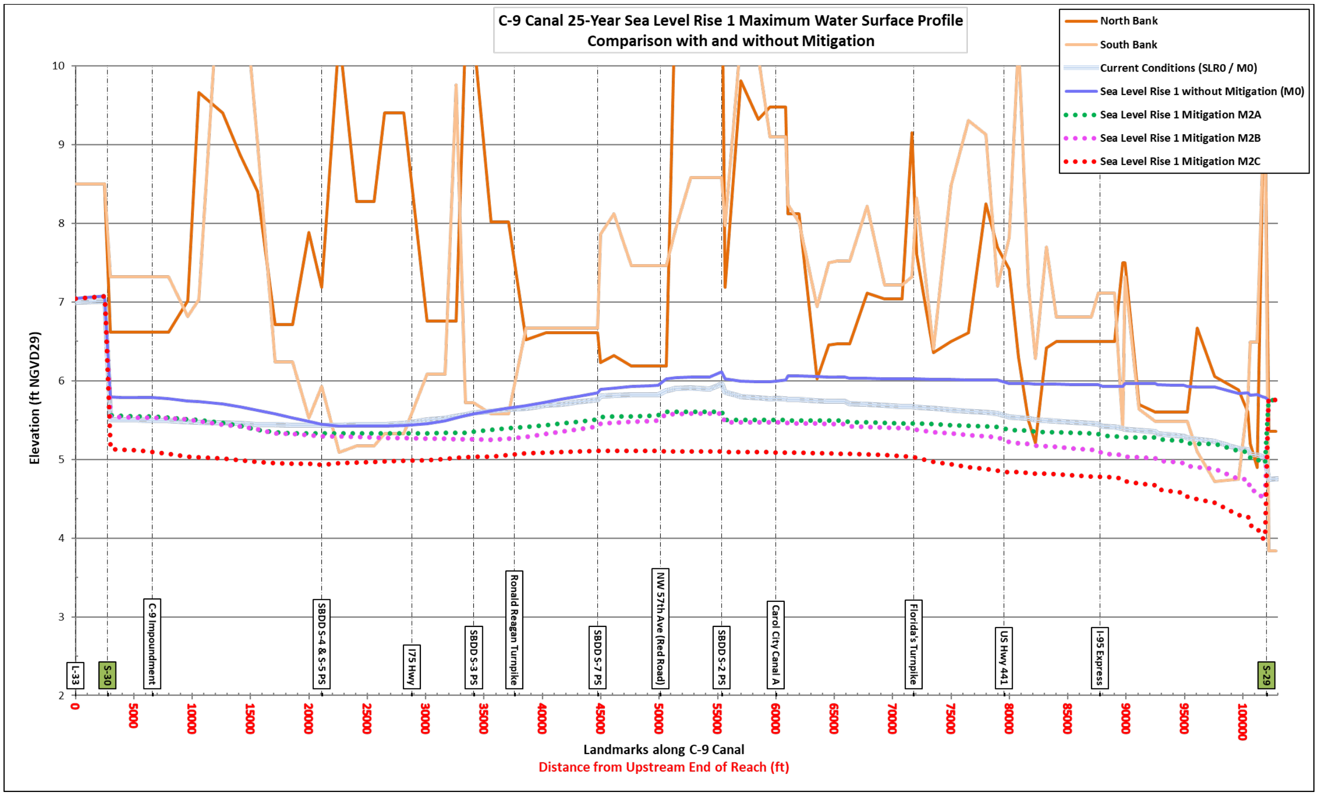


Figure 4.11 C-9 Canal Peak Stage Profiles for 25-Year Sea Level Rise 1 with and without Mitigation

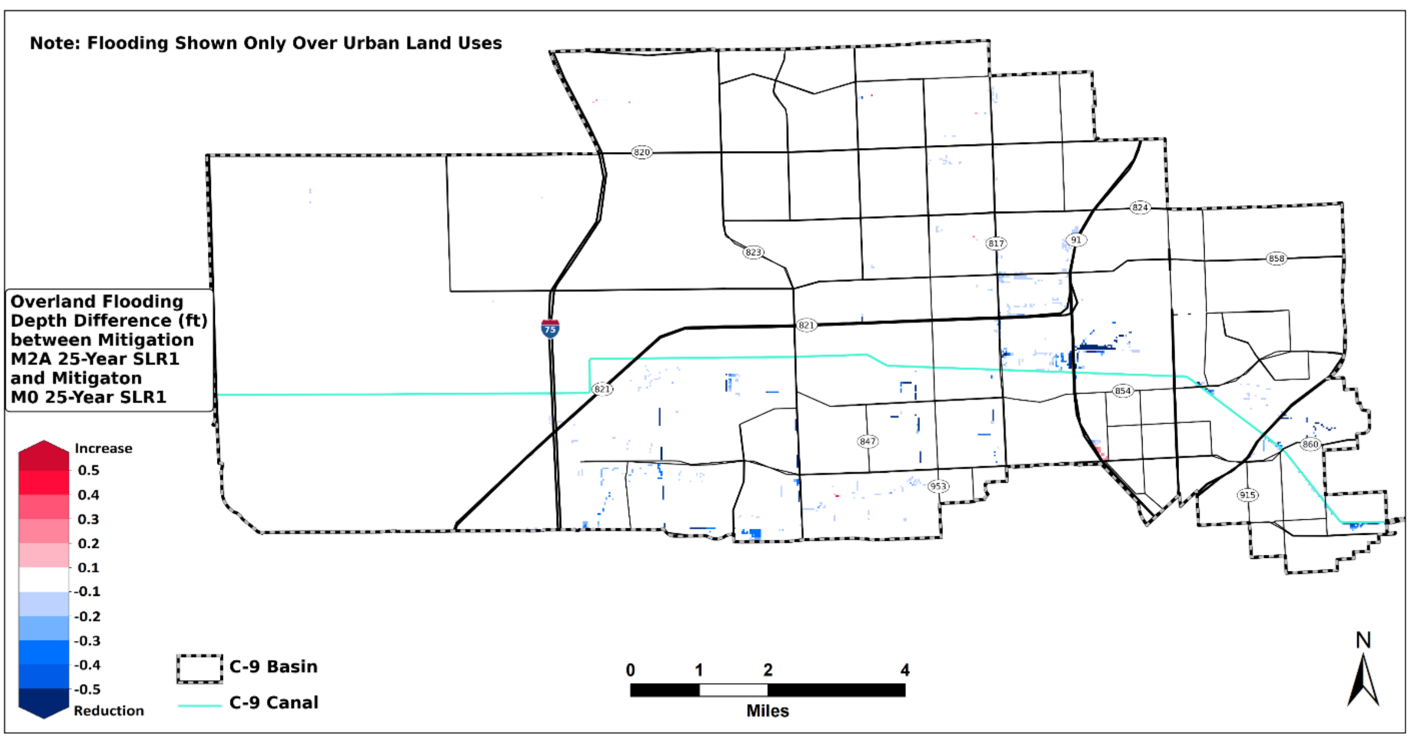


Figure 4.12 C-9 Basin Flood Inundation Difference Map for Mitigation M2A 25-Year Sea Level Rise 1 Versus Future Conditions without Mitigation (M0) 25-Year SLR1 in Urban Land Use Areas

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

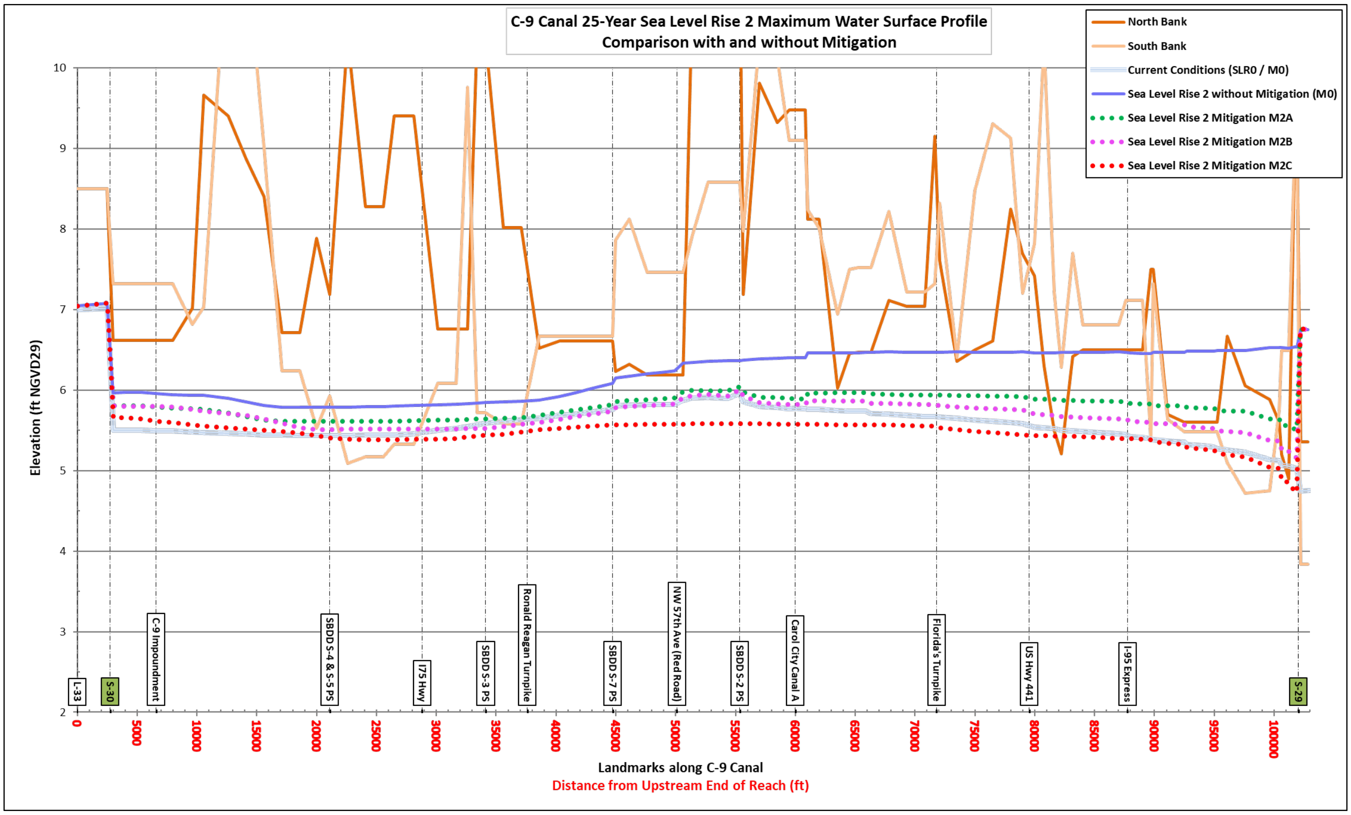


Figure 4.13 C-9 Canal Peak Stage Profiles for 25-Year Sea Level Rise 2 with and without Mitigation

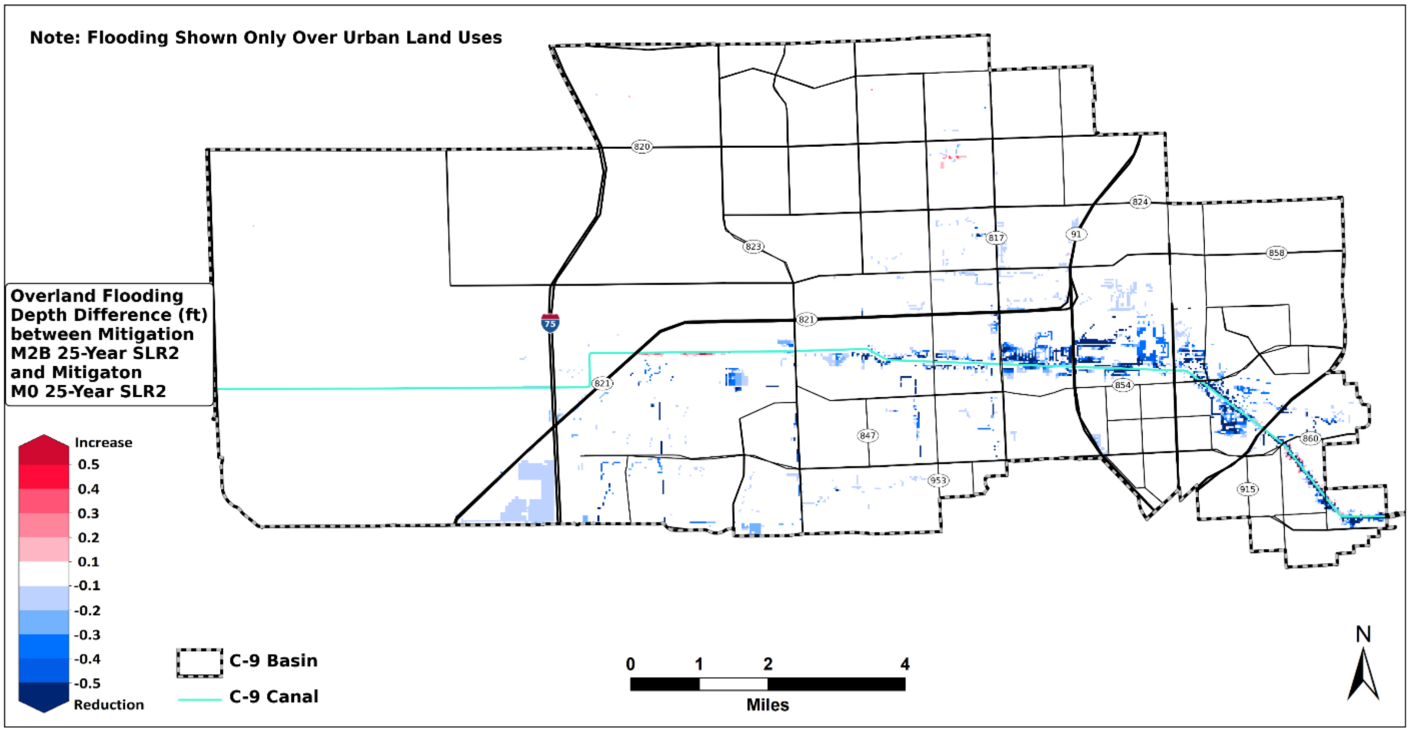


Figure 4.14 C-9 Basin Flood Inundation Difference Map for Mitigation M2B 25-Year Sea Level Rise 2 Versus Future Conditions without Mitigation (M0) 25-Year SLR2 in Urban Land Use Areas

4.4.2.1.3 <u>Mitigation Strategy M2C</u>

- 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

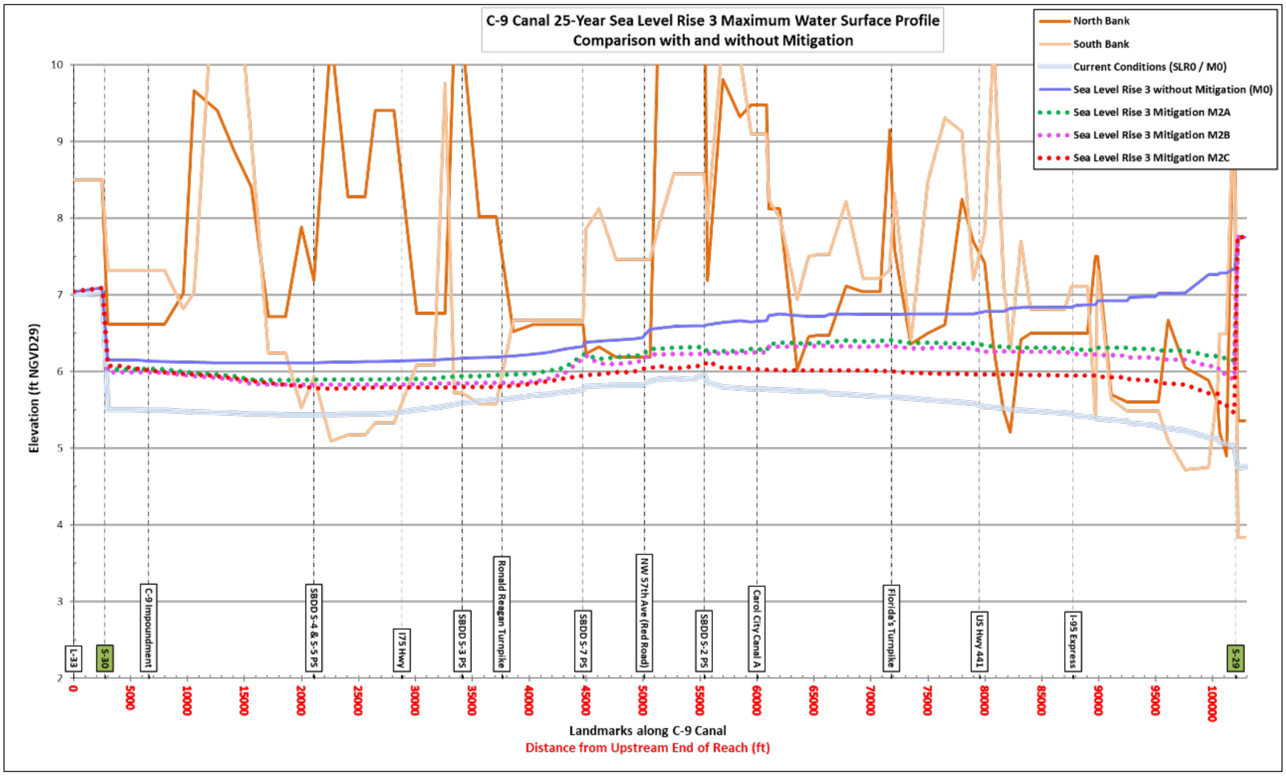


Figure 4.15 C-9 Canal Peak Stage Profiles for 25-Year Sea Level Rise 3 with and without Mitigation

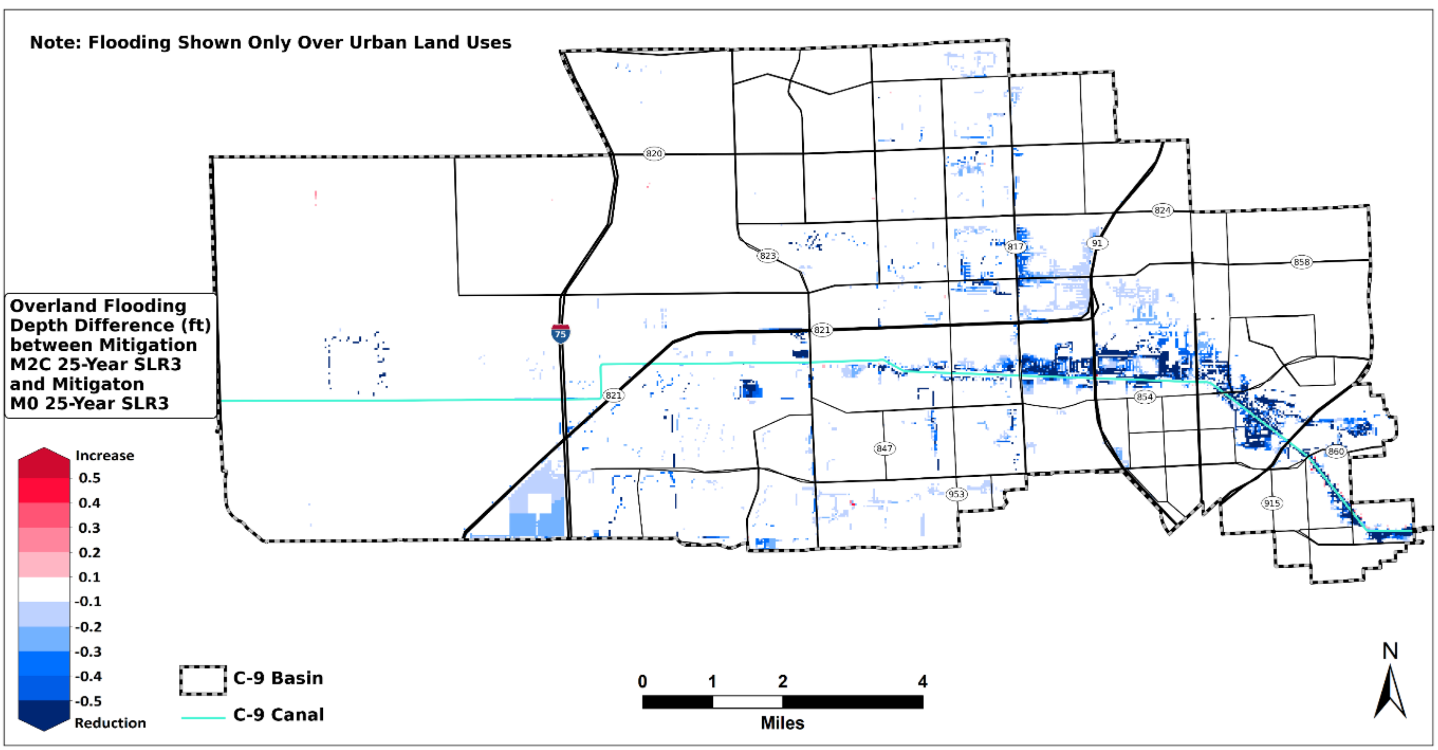


Figure 4.16 C-9 Basin Flood Inundation Difference Map for Mitigation M2C 25-Year Sea Level Rise 3 Versus Future Conditions without Mitigation (M0) 25-Year SLR3 in Urban Land Use Areas

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***.

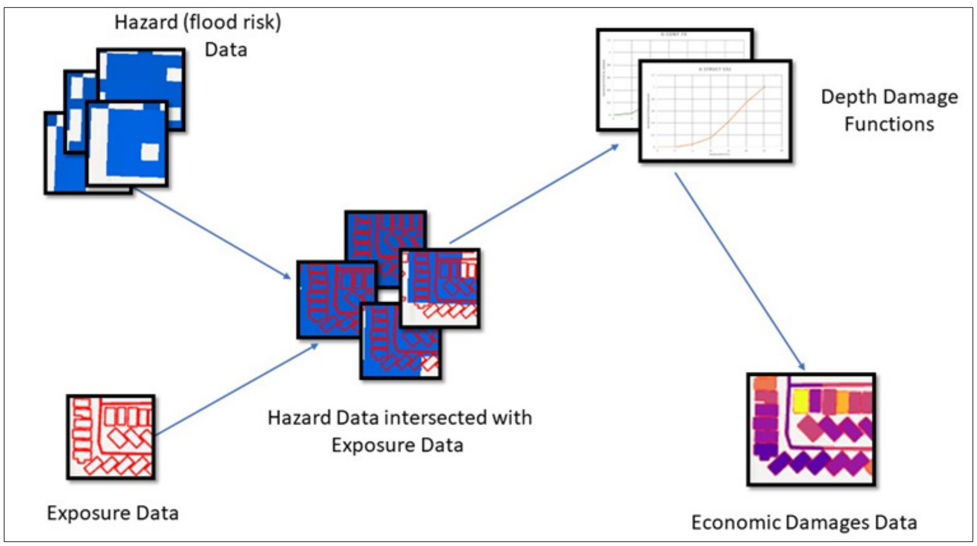


Figure 5.1 Schematic of Economic Damage Calculation

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.

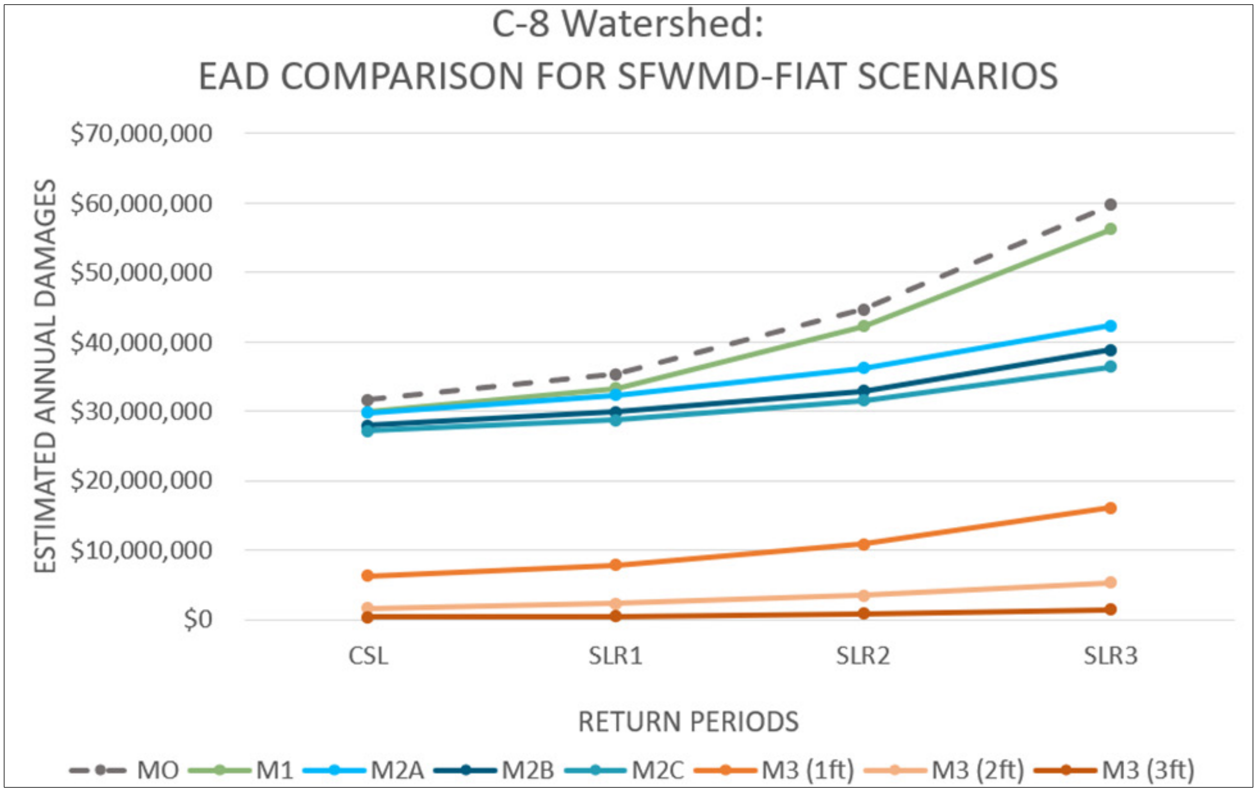


Figure 5.2 C-8 Watershed – EAD Comparison for SFWMD-FIAT Scenarios

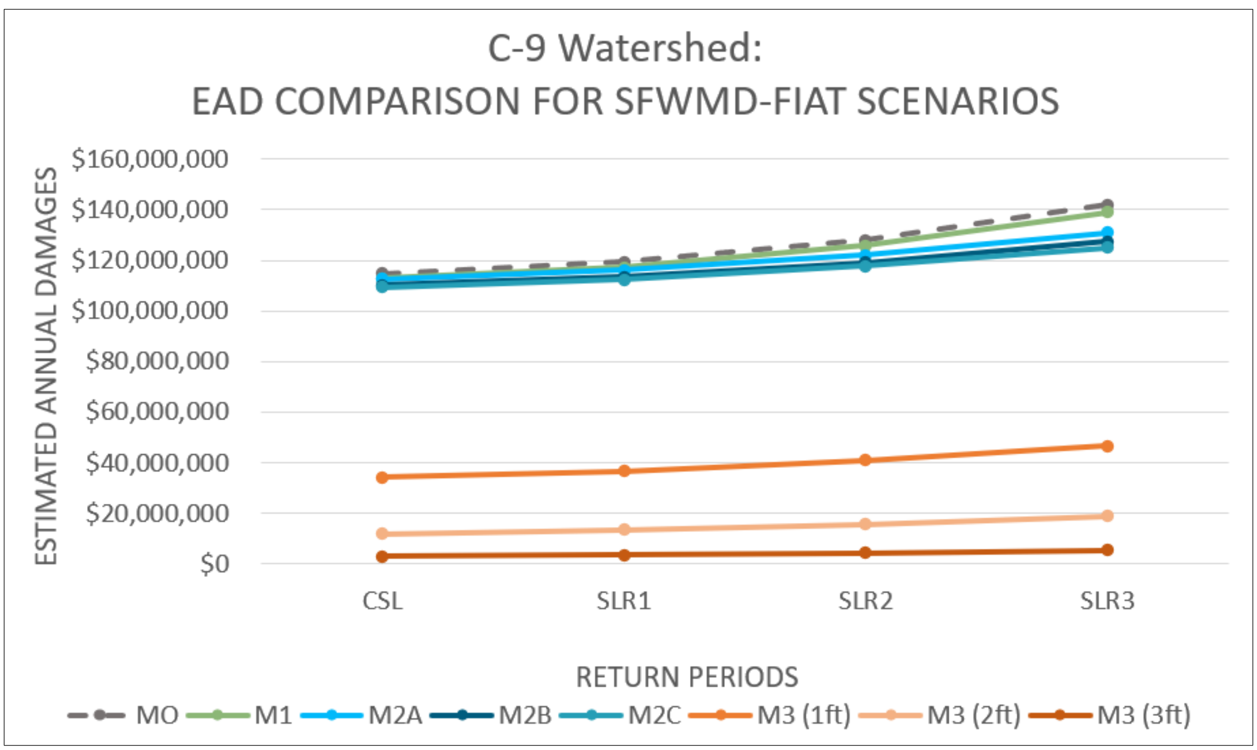


Figure 5.3 C-9 Watershed – EAD Comparison for SFWMD-FIAT Scenarios

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

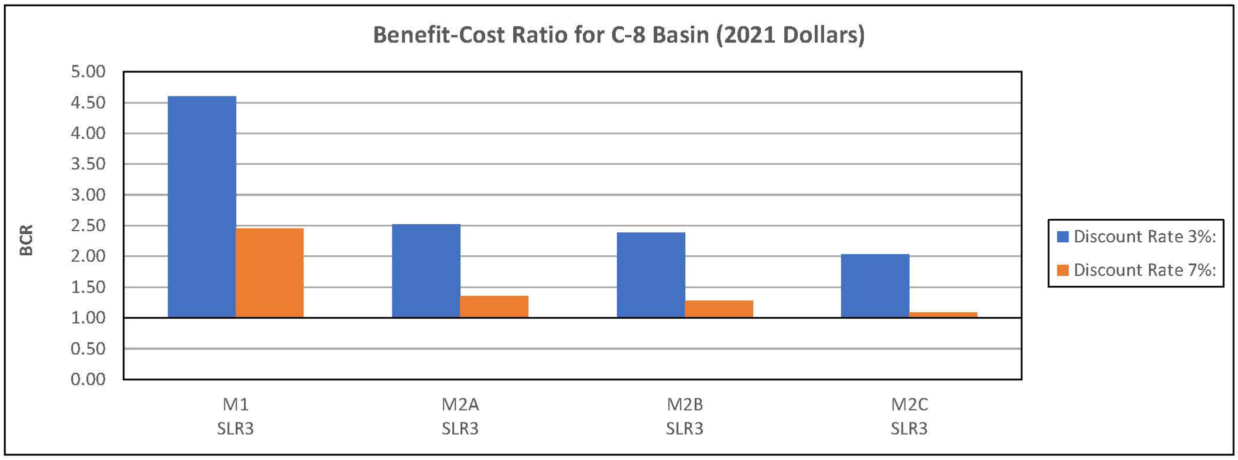


Figure 6.1 Benefit-Cost Ratio Graph for the C-8 Watershed

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

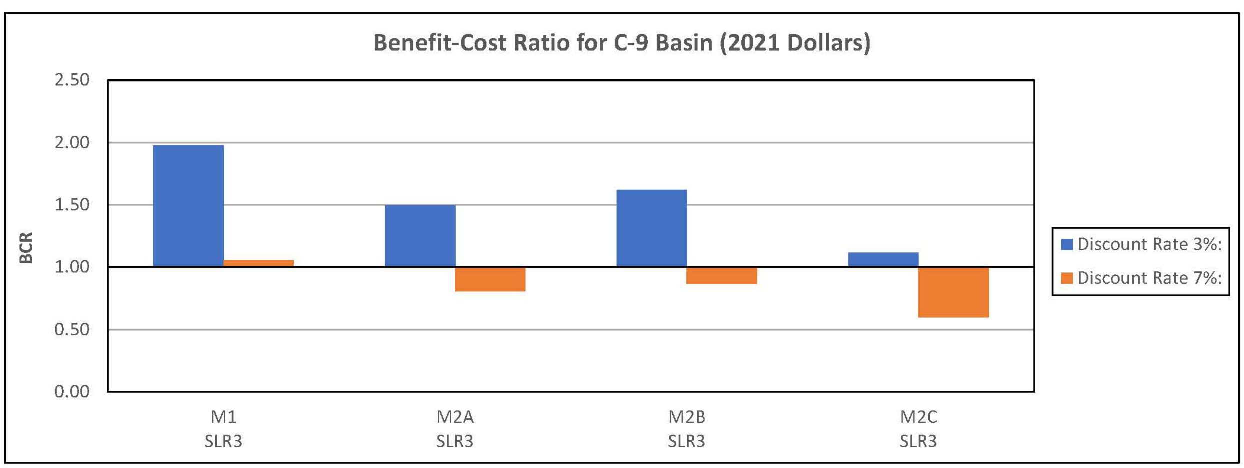


Figure 6.2 Benefit-Cost Ratio Graph for the C-9 Watershed

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.

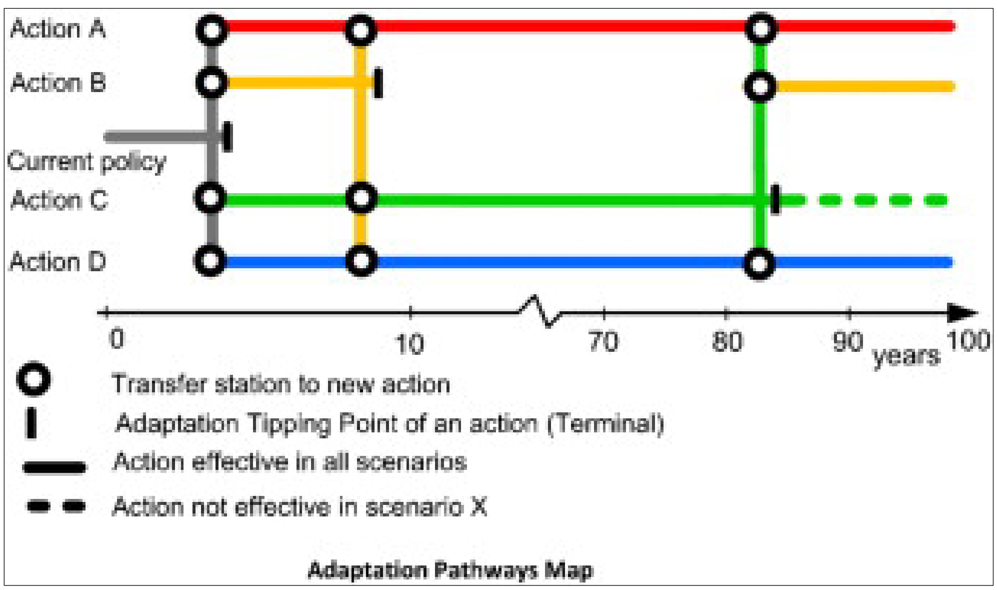


Figure 7.1 Example of an Adaptations Pathway Map

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**).

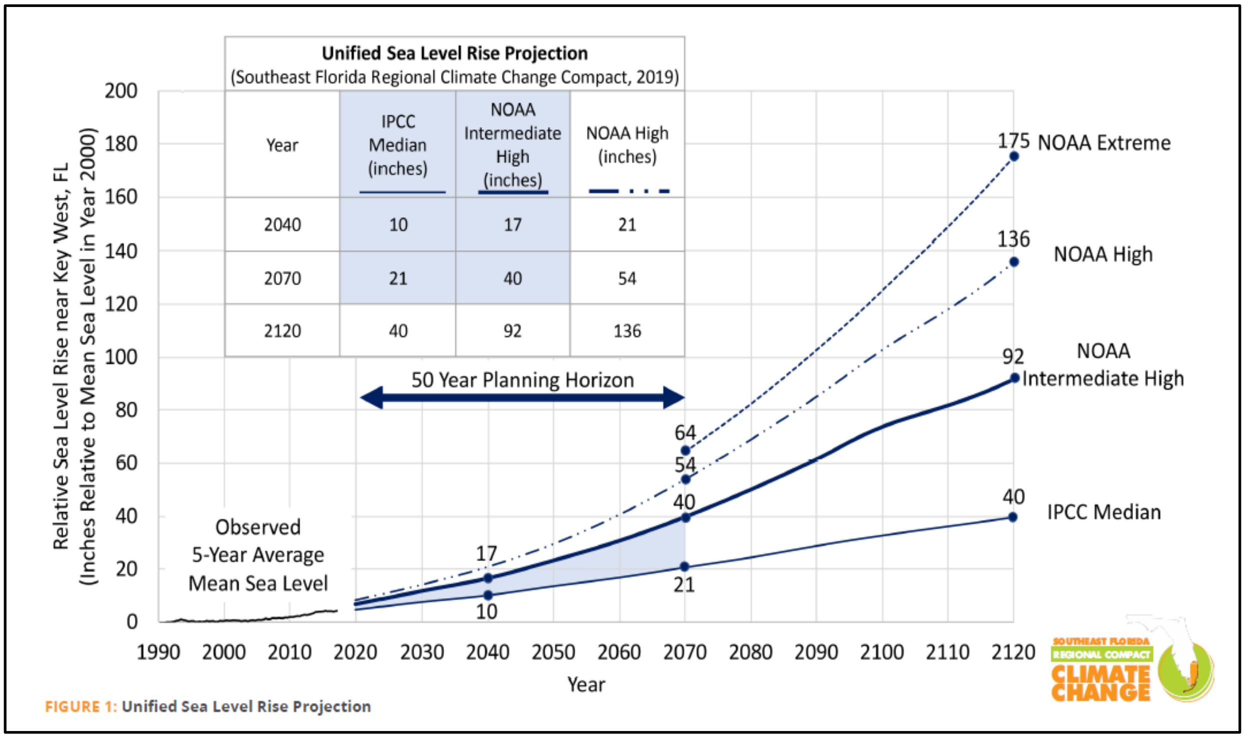


Figure 7.2 Southeast Florida Regional Climate Change Compact (2020) Unified Sea Level Rise Projection: 2019 Update

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.

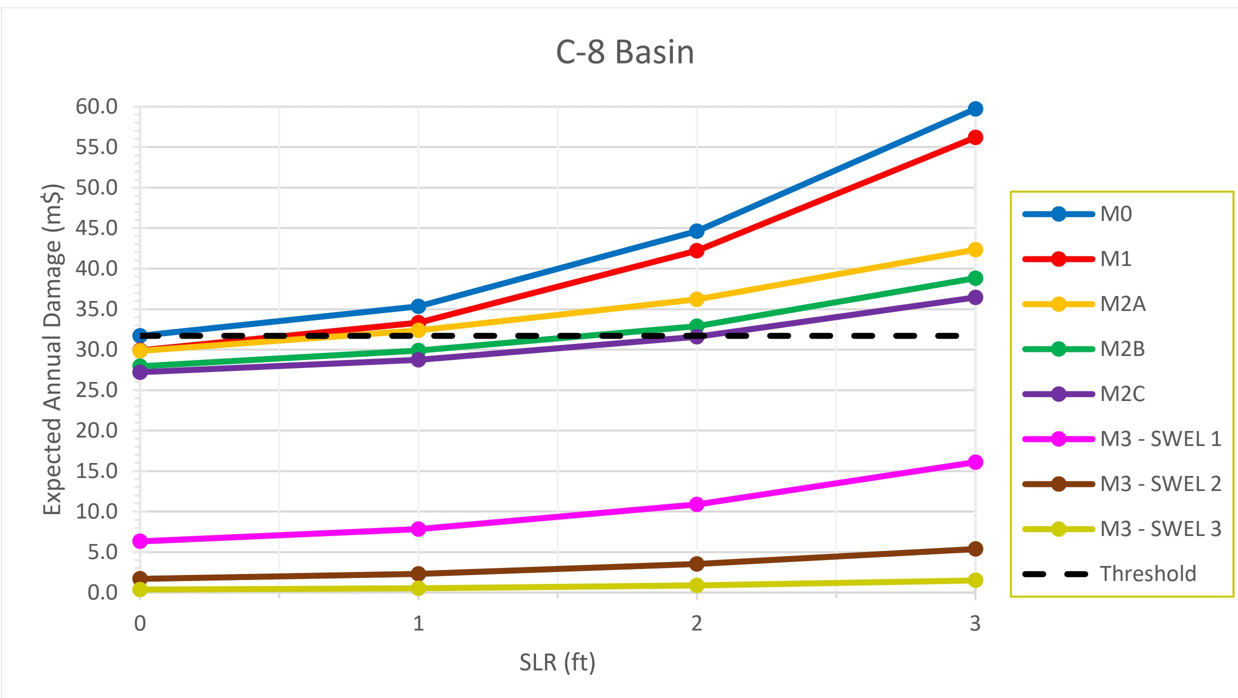


Figure 7.3 C-8 Watershed Estimated Annual Damages for Flood Mitigation Strategies With 1-, 2-, 3-ft Sea Level Rise (ft, msl)

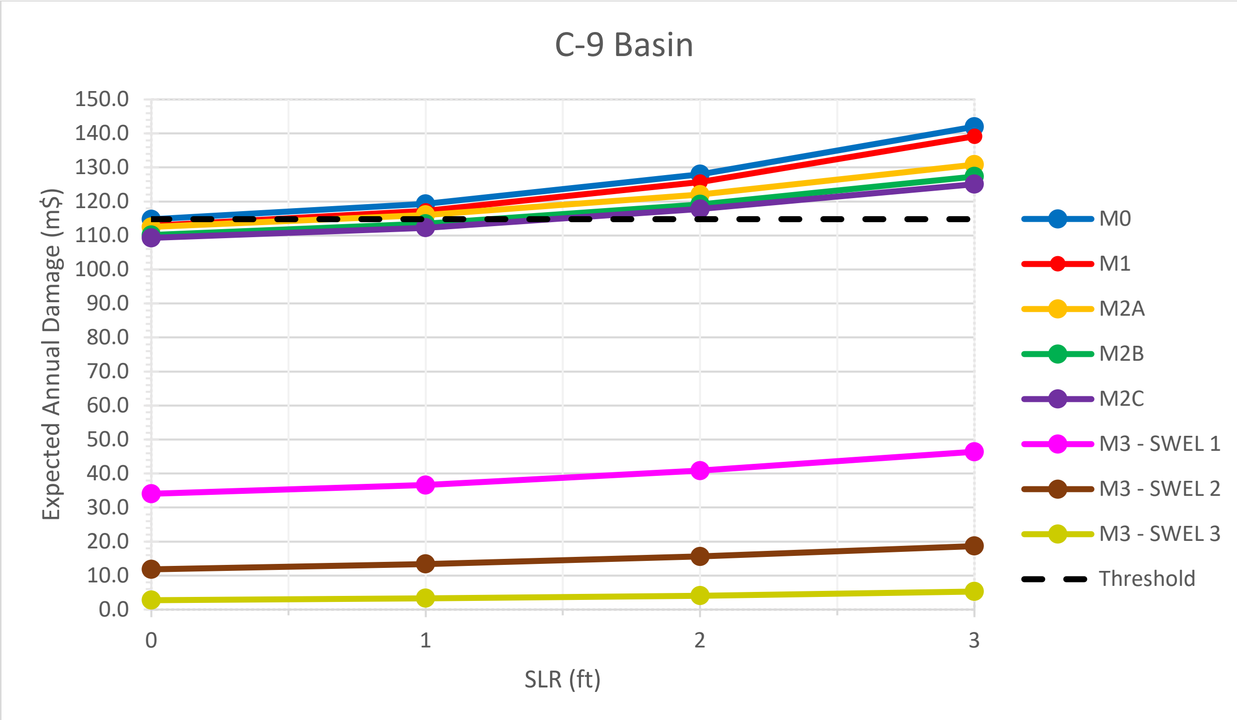


Figure 7.4 C-9 Watershed Estimated Annual Damages for Flood Mitigation Strategies With 1-, 2-, 3-ft Sea Level Rise (ft, msl)

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

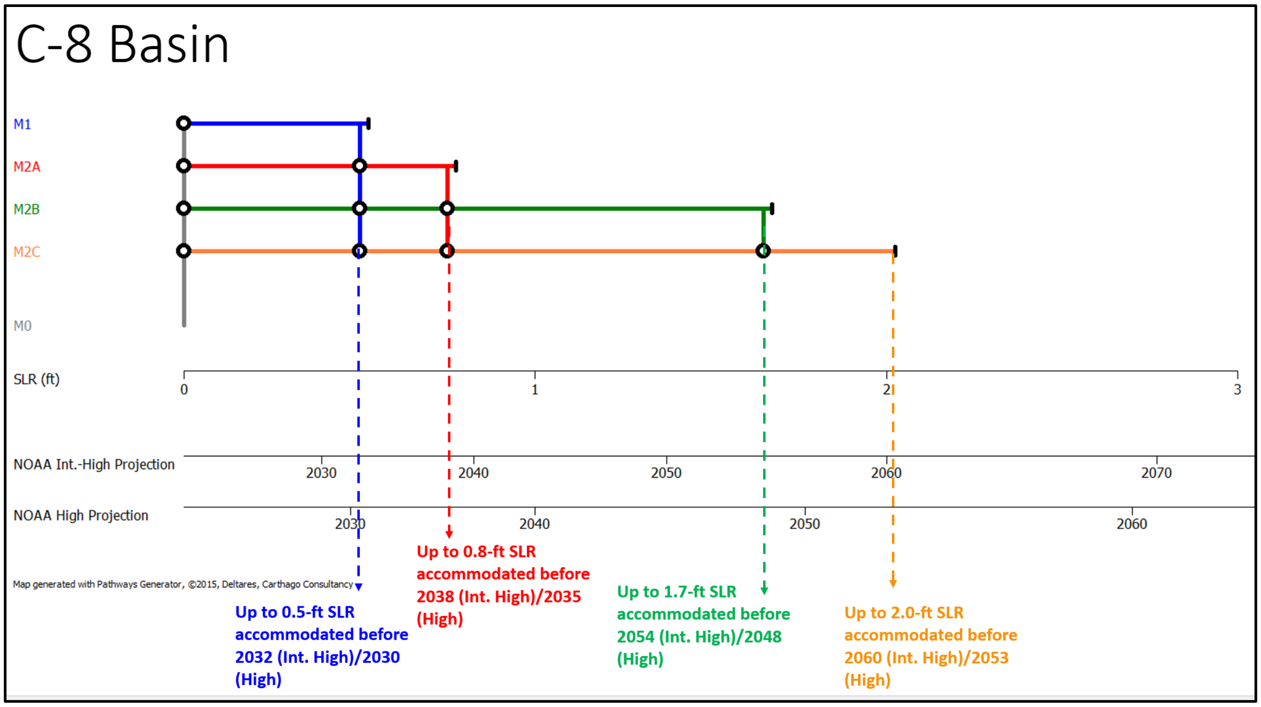


Figure 7.5 DAPP Analysis Results for C-8 Watershed

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

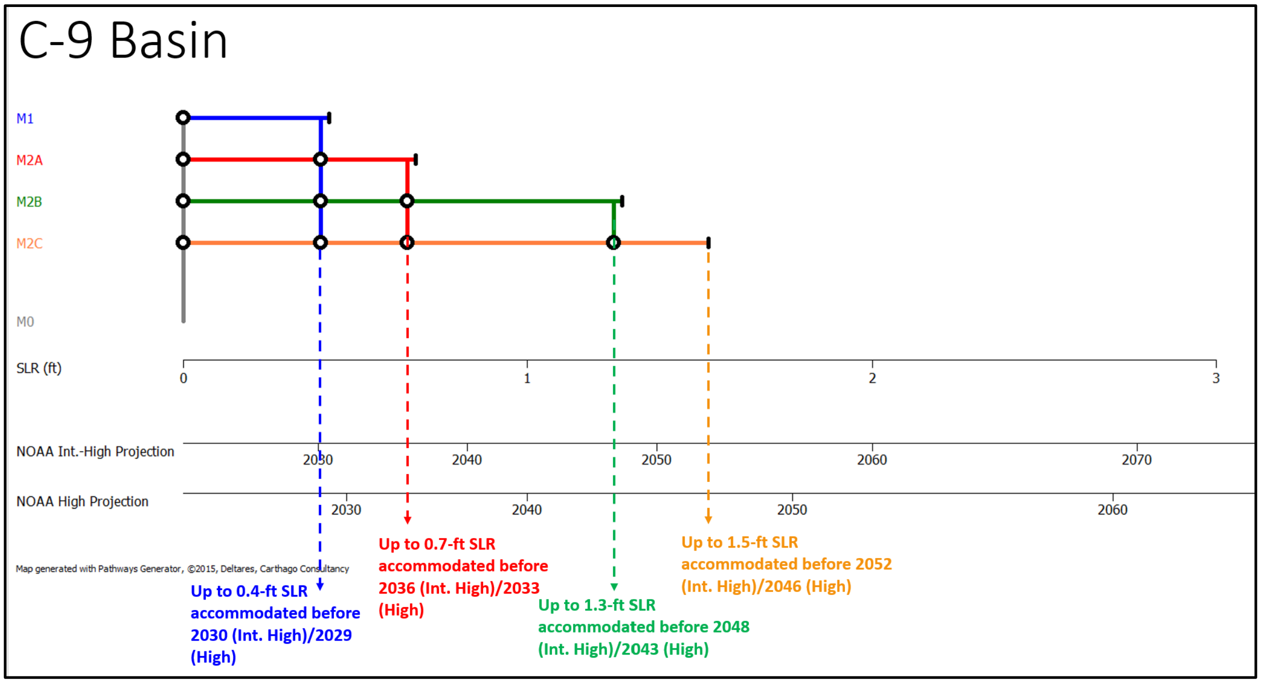


Figure 7.6 DAPP Analysis Results for C-9 Watershed

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.

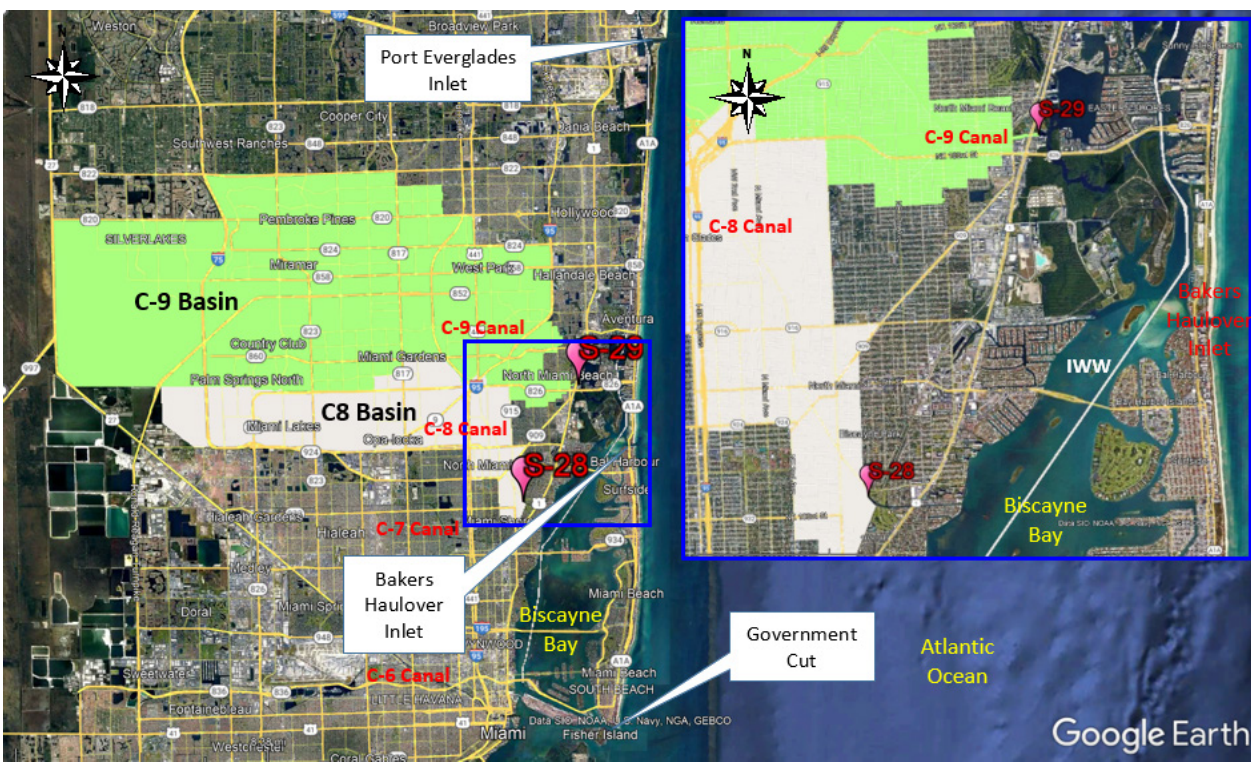


Figure 8.1 Locations of C-8 and C-9 Basins and S-28 and S-29 Structures West of Biscayne Bay

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**.

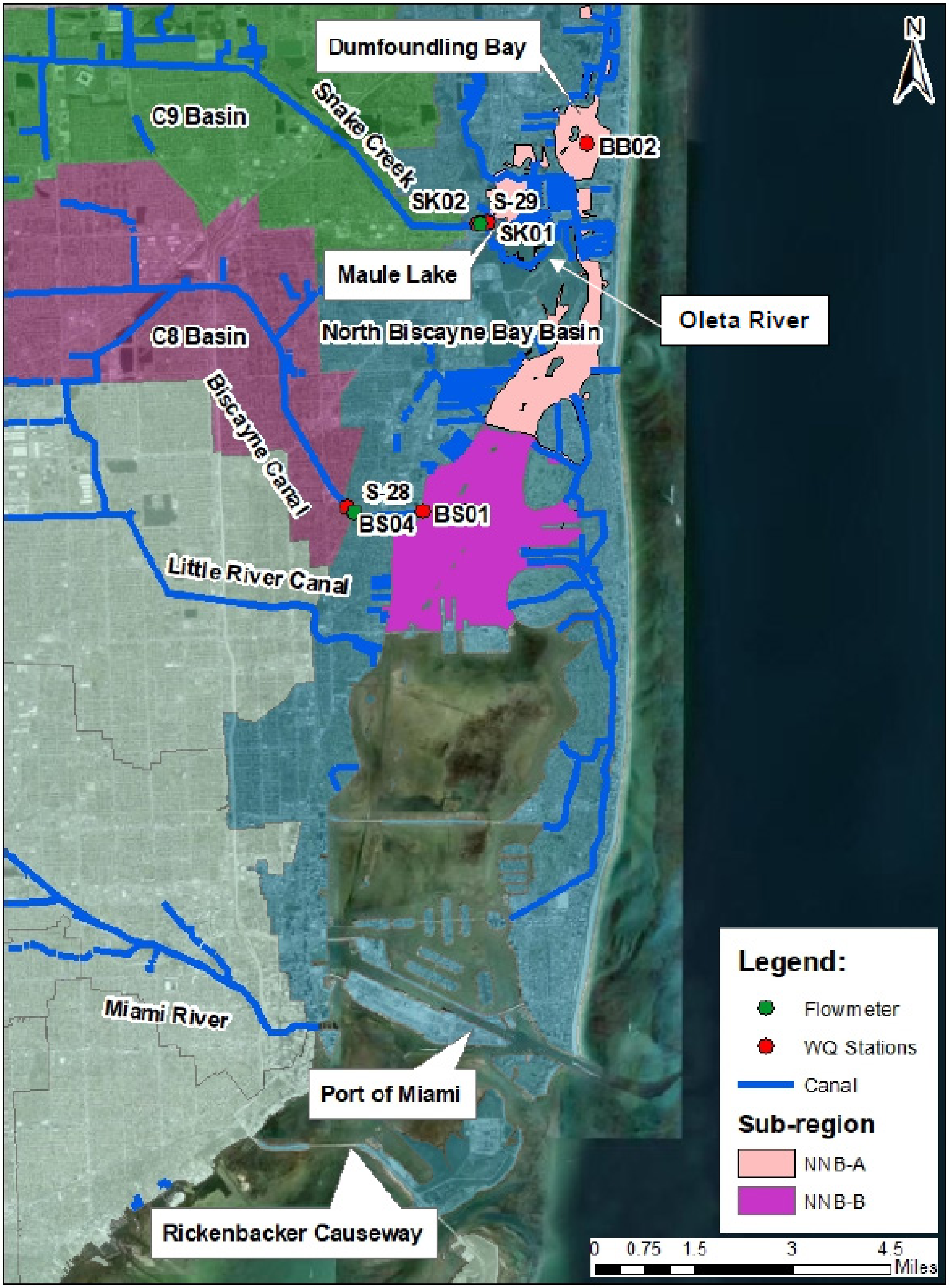


Figure 9.1 Water Quality Sample Locations

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).

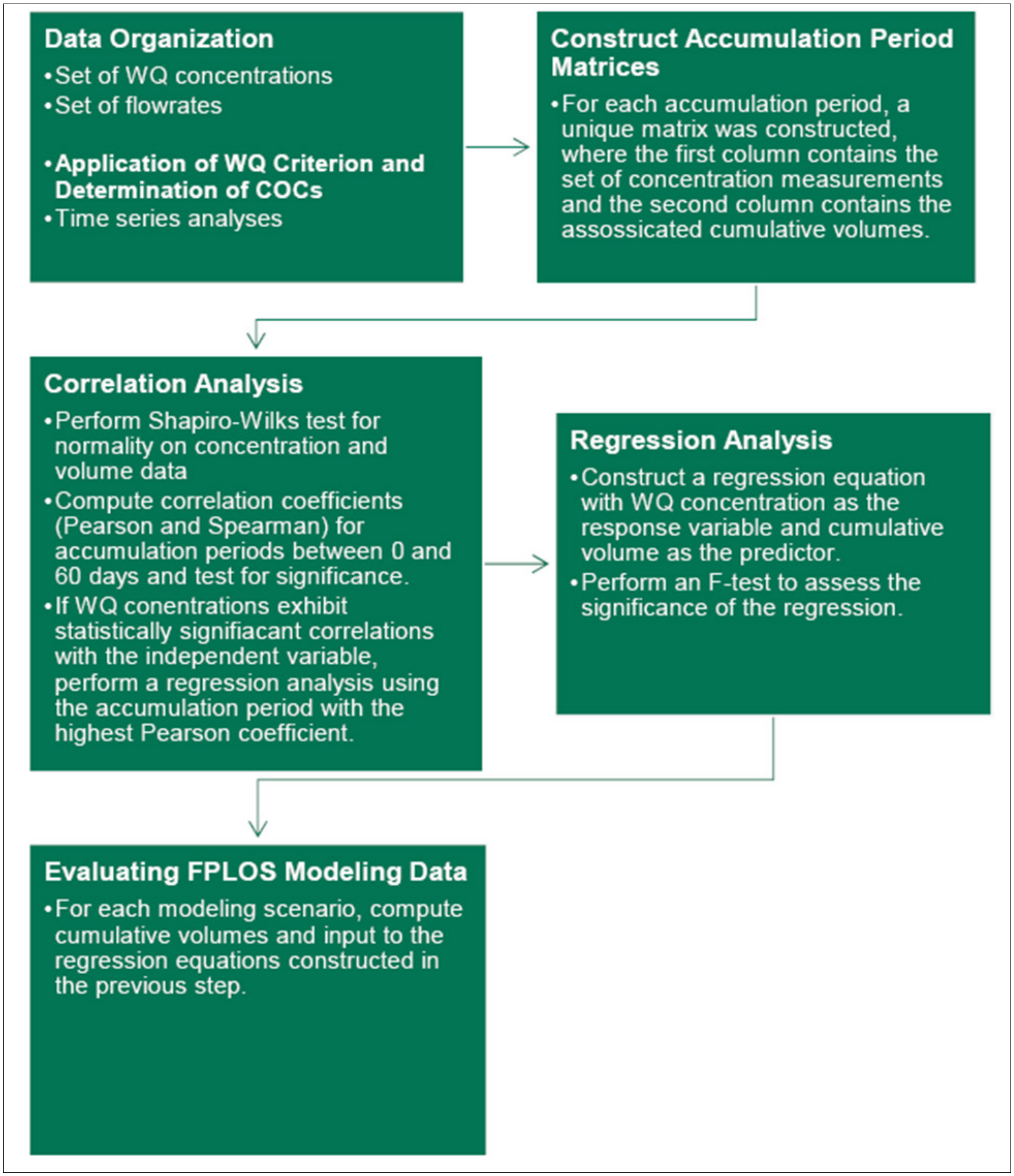


Figure 9.2 Flowchart of Methodology Used for the Cumulative Volume Analysis

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.

C-9 Basin (NNB-A)

- 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.

11.0 REFERENCES

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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

Appendix A
Supporting Documentation for Cost Estimation

To understand the relative benefit of a mitigation activity with respect to its cost, this study developed planning level cost estimates. The mitigation activities identified through the study are conceptual and will undergo further refinement and development. At this stage of development, it is only possible to estimate rough order of magnitude costs for each of the mitigation projects. The team used the best available data and engineering judgment to quantify the costs. Unless specifically mentioned, all cost estimates provided in this study exclude the costs of real estate acquisition and operation/maintenance.

1.1 M1 Projects

M1 projects would benefit local drainage areas and are small-scale efforts.

1.1.1 Cost Estimation Methodology

The M1 projects provided the limited project information used in the cost estimates. Approximately 15% of the projects within the project list included cost estimates. Approximately 10% of the projects had construction plan sets. These plan sets allowed development of a general understanding of the type of projects being considered in the C-8 and C-9 Watersheds. The team applied this understanding and the project name/description to categorize most of the projects into one of the following categories:

- Drainage Improvements (typically exfiltration systems)
- Sluice Gate Construction (operational canal controls)
- Pump Station Construction (Levels 1 and 2)

Many of the M1 projects identified by partner communities address maintenance of systems. This study assumes systems are fully operational and maintained. Maintenance is critical to good flood control but is not “new” to the system and, therefore, was not included.

Applying the limited cost estimates provided, the team calculated an average project cost for the drainage improvements and sluice gate construction projects. There are several pump stations identified only by location as mitigation projects. Based on the locations of the pump station projects, the team assigned a reasonable pump station size of either 25 cfs or 100 cfs. With this size, this study assigned each a cost proportional to the SFWMD Coastal Resiliency Program (SFWMD, 2022) that applied a typical cost of $55,000 per cfs. This rule of thumb cost gave the following unit costs for the two levels:

- Level 1-Neighborhood Pump Station-Level 1 $1,375,000 Based on 25 CFS @ $55,000/CFS
- Level 2-Tributary Canal Pump Station-Level 2 $5,500,000 Based on 100 CFS @ $55,000/CFS

These planning level costs apply appropriate assumptions and are in line with typical engineering projects of similar size and type **Table A- 1** presents the project costs for M1 projects. These costs can be updated as the M1 projects are refined and as unit costs for similar projects are developed.

Table A- 1: C-8 M1 Projects Cost Estimate

M1 Projects Cost Estimate - C-8 Basin		
Project Type	**Unit Cost**	**Total Cost**
Drainage Improvements	$ 542,000	$ 2,350,000
Pump Station - Level 1	$ 1,375,000	$ 1,375,000
Pump Station - Level 2	$ 5,500,000	$ 16,500,000
Total Projects Cost		$ 20,225,000
M1 Projects Cost Estimate - C-9 Basin		
Project Type	**Unit Cost**	**Total Cost**
Drainage Improvements	$ 542,000	$ 7,948,000
Sluice Gate	$ 108,000	$ 1,080,000
Pump Station - Level 2	$ 5,500,000	$ 27,500,000
Total Projects Cost		$ 36,528,000

1.2 M2 Projects (NGVD29 to NAVD88 Conversion = -1.57 ft)

1.2.1 Cost Estimation Methodology

Cost estimates for the M2 projects (M2A, M2B, and M2C) are based largely on prior cost estimates from SFWMD. SFWMD provided cost estimates from the Coastal Resiliency Program which were updated to represent the improvement strategies identified by the modeling team. This mainly involved modifying the pump and generator size, spillway elevation, tie-back levee elevation, and associated costs. Specifically, SFWMD provided the structure replacement costs with a 5 ft increase in spillway elevation.

Taylor developed all other pump station costs based on the cost estimates provided by SFWMD, as part of the Coastal Resiliency Program (SFWMD, 2022). Furthermore, Taylor proportionally modified (scaled up or down) the pump system items (pumps, generators, and associated control systems/structures) to develop the costs for the range of pump sizes used in the M2 projects. Based on the Coastal Resiliency Program cost estimates, Taylor used 15% of the construction costs for design and construction management. Please see **Table A- 14** through **Table A- 16** for the M2 projects cost estimates with references depicting the source of the item costs. In addition, Taylor developed the costs for expanding surface storage of floodwaters assuming a total of 500 acres of land is available across both watersheds combined, or 250 acres in each of the C—8 and C-9 Watersheds. Taylor also assumed each storage area would provide 1 ft of storage depth with the goal of providing 500 ac-ft of storage within the watersheds. This estimate excluded the real estate costs of these storage areas. While some of the areas identified are SFWMD or FDEP-owned, most would require purchasing the land or other intergovernmental agreements. These cost estimates are very general in nature and cannot increase in specificity until a project location and size is determined. Each site will have its unique challenges that will greatly influence the construction costs.

To develop these general costs, the team used the FDOT Historical Costs Database and considered the following factors:

- Clearing
- Erosion Control
- Excavation
- Final Grade and Sod
- Bonds and Insurance 1.5%
- Profit 10%
- Overhead 6%
- Contingency 30%

Taylor also prepared costs for canal improvements including raising the canal banks to elevation 7.5 ft NGVD29 for M2B and M2C and widening the C-8 and C-9 Canals for M2C. **Table A- 2** through **Table A- 7** depict the overall cost estimates for the M2A, M2B, and M2C projects.

Table A- 2: Mitigation Project M2A Cost Estimate For C-8 Watershed

Pump Station		
Structure Replacement	$	19,057,000
Forward Pump (1550 cfs)	$	79,639,000
Forward Pump Backup Generator Facility	$	9,086,000
Structure Tie Back (Flood Barrier)	$	2,987,000
Design & Construction Management	$	16,615,000
Real Estate	$	7,000,000
Total Pump Station Cost	**$**	**134,384,000**
Storage		
Distributed Storage (~250 Ac-Ft)	$	38,860,000
Design & Construction Management	$	5,829,000
Total Storage Cost	**$**	**44,689,000**
Total Cost of Mitigation M2A for C-8 Watershed	**$**	**179,073,000**

Table A- 3: Mitigation Project M2A Cost Estimate For C-9 Watershed

Pump Station		
Structure Replacement	$	19,057,000
Forward Pump (1550 cfs)	$	84,291,000
Forward Pump Backup Generator Facility	$	9,618,000
Structure Tie Back (Flood Barrier)	$	2,769,000
Design & Construction Management	$	17,360,000
Real Estate	$	16,000,000
Total Pump Station Cost	**$**	**149,095,000**
Storage		
Distributed Storage (~250 Ac-Ft)	$	38,860,000
Design & Construction Management	$	5,829,000
Total Storage Cost	**$**	**44,689,000**
Total Cost of Mitigation M2A for C-9 Watershed	**$**	**193,784,000**

Table A- 4: Mitigation Project M2B Cost Estimate For C-8 Watershed

Pump Station		
Structure Replacement	$	19,057,000
Forward Pump (2550 cfs)	$	107,002,000
Forward Pump Backup Generator Facility	$	11,440,000
Structure Tie Back (Flood Barrier)	$	2,987,000
Design & Construction Management	$	21,073,000
Real Estate	$	7,000,000
Total Pump Station Cost	**$**	**168,559,000**
Storage		
Distributed Storage (~250 Ac-Ft)	$	38,860,000
Design & Construction Management	$	5,829,000
Total Storage Cost	**$**	**44,689,000**
Canal Improvements		
Raise Canal Banks (to 7.5 ft NGVD29)	$	12,413,000
Design & Construction Management	$	1,862,000
Total Canal Improvements Cost	**$**	**14,274,000**
Total Cost of Mitigation M2B for C-8 Watershed	**$**	**227,522,000**

Table A- 5: Mitigation Project M2B Cost Estimate For C-9 Watershed

Pump Station		
Structure Replacement	$	19,057,000
Forward Pump (2550 cfs)	$	111,669,000
Forward Pump Backup Generator Facility	$	11,919,000
Structure Tie Back (Flood Barrier)	$	2,769,000
Design & Construction Management	$	21,812,000
Real Estate	$	16,000,000
Total Pump Station Cost	**$**	**183,226,000**
Storage		
Distributed Storage (~250 Ac-Ft)	$	38,860,000
Design & Construction Management	$	5,829,000
Total Storage Cost	**$**	**44,689,000**
Canal Improvements		
Raise Canal Banks (to 7.5 ft)	$	7,119,000
Design & Construction Management	$	1,068,000
Total Canal Improvements Cost	**$**	**8,186,000**
Total Cost of Mitigation M2B for C-9 Watershed	**$**	**236,101,000**

Table A- 6: Mitigation Project M2C Cost Estimate For C-8 Watershed

Pump Station		
Structure Replacement	$	19,057,000
Forward Pump (3550 cfs)	$	134,482,000
Forward Pump Backup Generator Facility	$	13,792,000
Structure Tie Back (Flood Barrier)	$	2,987,000
Design & Construction Management	$	25,548,000
Real Estate	$	7,000,000
Total Pump Station Cost	**$**	**202,866,000**
Storage		
Distributed Storage (~250 Ac-Ft)	$	38,860,000
Design & Construction Management	$	5,829,000
Total Storage Cost	**$**	**44,689,000**
Canal Improvements		
Raise Canal Banks (to 7.5 ft NGVD29)	$	12,412,000
Widen Canal (approx. 20,000 linear ft by 100 ft)	$	31,619,000
Design & Construction Management	$	6,605,000
Total Canal Improvements Cost	**$**	**50,636,000**
Total Cost of Mitigation M2C for C-8 Watershed	**$**	**298,191,000**

Table A- 7: Mitigation Project M2C Cost Estimate For C-9 Watershed

Pump Station		
Structure Replacement	$	19,057,000
Forward Pump (3550 cfs)	$	139,006,000
Forward Pump Backup Generator Facility	$	14,217,000
Structure Tie Back (Flood Barrier)	$	2,769,000
Design & Construction Management	$	26,257,000
Real Estate	$	16,000,000
Total Pump Station Cost	**$**	**217,306,000**
Storage		
Distributed Storage (~250 Ac-Ft)	$	38,860,000
Design & Construction Management	$	5,829,000
Total Storage Cost	**$**	**44,689,000**
Canal Improvements		
Raise Canal Banks (to 7.5 ft NGVD29)	$	7,119,000
Widen Canal (approx. 79,000 linear ft by ~75 ft)	$	107,725,000
Design & Construction Management	$	17,227,000
Total Canal Improvements Cost	**$**	**132,070,000**
Total C-9 Cost	**$**	**394,065,000**

1.3 M3 Projects

1.3.1 Cost Estimation Methodology

This study followed the approach applied by Deltares (2018) to estimate the cost of raising buildings and roads. For buildings, Deltares used estimates by FEMA (2019) and Aerts et al (2013) to estimate a unit cost of raising a residential building by 2 to 6 ft. This unit cost is very general and only provides a gross estimate of what the possible costs could be. As communities work to mitigate buildings and roads on a basin-wide scale, these unit costs can be refined as the true cost of the activities are developed. To identify the number of buildings that need to be elevated, the team used MIKE SHE model results for existing conditions and added 1, 2, and 3 ft, and added the number of buildings in each flood layer.

Estimates to elevate roads follow a similar approach and use a unit cost per ft of road based on road costs values provided by Miami-Dade. The values provided by Miami-Dade included an average for elevating a 2-lane road in 50 ft of right-of-way. This study applies the average of elevating roads 1, 2, and 3 ft for a unit cost of $673, $892, and $1,111 per linear foot, respectively. The M3 Cost Estimates are presented in

Table A- 8 through **Table A- 13**. Please note that the units EA and LF stand for "each" and "linear feet," respectively.

Table A- 8: C-8 Watershed Cost Estimate of Mitigation M3 (1 ft)

Type	Unit Costs	Units	Value	Total Costs
Buildings	$ 55,386	EA	1,648	$ 91,300,000
Roads	$ 673	LF	130,416	$ 87,800,000
			Total	$ 179,100,000

Table A- 9: C-8 Watershed Cost Estimate of Mitigation M3 (2 ft)

Type	Unit Costs	Units	Value	Total Costs
Buildings	$ 55,386	EA	2,255	$ 124,900,000
Roads	$ 892	LF	175,296	$ 156,300,000
			Total	$ 281,200,000

Table A- 10: C-8 Watershed Cost Estimate of Mitigation M3 (3 ft)

Type	Unit Costs	Units	Value	Total Costs
Buildings	$ 55,386	EA	3,193	$ 176,800,000
Roads	$ 1,111	LF	232,848	$ 258,700,000
			Total	$ 435,500,000

Table A- 11: C-9 Watershed Cost Estimate of Mitigation M3 (1 ft)

Type	Unit Costs	Units	Value	Total Costs
Buildings	$ 55,386	EA	1,064	$ 58,900,000
Roads	$ 673	LF	304,656	$ 205,200,000
			Total	$ 264,100,000

Table A- 12: C-9 Watershed Cost Estimate of Mitigation M3 (2 ft)

Type	Unit Costs	Units	Value	Total Costs
Buildings	$ 55,386	EA	1,225	$ 67,800,000
Roads	$ 892	LF	340,560	$ 303,700,000
			Total	$ 371,500,000

Table A- 13: C-9 Watershed Cost Estimate of Mitigation M3 (3 ft)

Type	Unit Costs	Units	Value	Total Costs
Buildings	$ 55,386	EA	1,616	$ 89,500,000
Roads	$ 1,111	LF	413,952	$ 459,900,000
			Total	$ 549,400,000

Table A- 14: M2A Cost Estimation

M2A for 25-Year SLR1		
C-8/S-28 Cost Estimate		
Pump Station	**Costs**	**References/Notes**
Structure Replacement	$19,056,898	S28 Costs from SFWMD PDF Costs (Assumed 250' DS; raise spillway by 5')
Forward Pump (1550 cfs)	$79,639,466	S28 Costs from SFWMD's XLS Costs (S28:AN271)
Forward Pump Backup Generator Facility	$9,085,601	S28 Costs from SFWMD's XLS Costs (S28:BH118)
Structure Tie Back (Flood Barrier)	$2,987,463	S28 Costs from SFWMD's XLS Costs (raise berm by 3'x250') (S28:AX47)
Design & Construction Management	$16,615,414	S28 Costs from SFWMD's XLS Costs (15% of costs excluding real estate)
Real Estate	$7,000,000	S28 Costs from SFWMD's XLS Costs (S28:BR10)
Total Pump Station Cost	**$134,384,842**	
Storage		
Distributed Storage (500 Ac-Ft)	$38,859,600	Real estate costs excluded
Design & Construction Management	$5,828,940	15% of costs excluding real estate
Total Storage Cost	**$44,688,540**	
Total C-8 Cost	**$179,073,382**	
C-9/S-29 Cost Estimate		
Pump Station		
Structure Replacement	$19,056,898	S28 Costs from SFWMD's PDF Costs (raise spillway by 5') at minimum
Forward Pump (1550 cfs)	$84,291,017	S29 Costs from SFWMD's XLS Costs Modified to 1500 CFS Pump (S29:J9)
Forward Pump Backup Generator Facility	$9,618,145	S29 Costs from SFWMD's XLS Costs (S29:J10)
Structure Tie Back (Flood Barrier)	$2,769,122	S29 Costs from SFWMD's XLS Costs (raise berm by 3') (S29:J11)
Design & Construction Management	$17,360,277	S29 Costs from SFWMD's XLS Costs (15% of costs excluding real estate)
Real Estate	$16,000,000	S29 Costs from SFWMD's XLS Costs (S29:J13)
Total Pump Station Cost	**$149,095,459**	
Storage		
Distributed Storage (500 Ac-Ft)	$38,859,600	Real estate costs excluded
Design & Construction Management	$5,828,940	15% of costs excluding real estate
Total Storage Cost	**$44,688,540**	
Total C-9 Cost	**$193,783,999**	

Table A- 15: M2B Cost Estimation

M2B for 25-Year SLR1		
C-8/S-28 Cost Estimate		
Pump Station	**Costs**	**References/Notes**
Structure Replacement	$19,056,898	S28 Costs from SFWMD's PDF Costs (Assumed 250' DS; raise spillway by 5')
Forward Pump (2550 cfs)	$107,001,675	S28 Costs from SFWMD's XLS Costs scaled to 2500 CFS Pump (S28-M2B:AN271)
Forward Pump Backup Generator Facility	$11,440,141	S28 Costs from SFWMD's XLS Costs, Scaled generator to match pump (S28:BH118)
Structure Tie Back (Flood Barrier)	$2,987,463	S28 Costs from SFWMD's XLS Costs (raise berm by 3'x250') (S28:AX47)
Design & Construction Management	$21,072,927	S28 Costs from SFWMD's XLS Costs (15% of costs excluding real estate)
Real Estate	$7,000,000	S28 Costs from SFWMD's XLS Costs (S28:BR10)
Total Pump Station Cost	**$168,559,105**	
Storage		
Distributed Storage (500 Ac-Ft)	$38,859,600.00	Real estate costs excluded
Design & Construction Management	$5,828,940.00	15% of costs excluding real estate
Total Storage Cost	**$44,688,540.00**	
Canal Improvements		
Raise Canal Banks (to 7.5 ft)	$12,412,542	Costs from SFWMD's email estimate (real estate costs excluded)
Design & Construction Management	$1,861,881	15% of costs excluding real estate
Total Canal Improvements Cost	**$14,274,423**	
Total C-8 Cost	**$227,522,068**	
C-9/S-29 Cost Estimate		
Pump Station		
Structure Replacement	$19,056,898	S28 Costs from SFWMD's PDF Costs (raise spillway by 5') at minimum
Forward Pump (2550 cfs)	$111,668,639	S29 Costs from SFWMD's XLS Costs Scaled to 2500 CFS Pump (S29-M2B:J9)
Forward Pump Backup Generator Facility	$11,918,924	S29 Costs from SFWMD's XLS Costs, Scaled generator to match pump (S29:J10)
Structure Tie Back (Flood Barrier)	$2,769,122	S29 Costs from SFWMD's XLS Costs (raise berm by 3') (S29:J11)
Design & Construction Management	$21,812,037	S29 Costs from SFWMD's XLS Costs (15% of costs excluding real estate)
Real Estate	$16,000,000	S29 Costs from SFWMD's XLS Costs (S29:J13)
Total Pump Station Cost	**$183,225,620**	
Storage		

M2B for 25-Year SLR1		
C-8/S-28 Cost Estimate		
Distributed Storage (500 Ac-Ft)	$38,859,600	Real estate costs excluded
Design & Construction Management	$5,828,940	15% of costs excluding real estate
Total Storage Cost	**$44,688,540**	
Canal Improvements		
Raise Canal Banks (to 7.5 ft)	$7,118,542	Costs from SFWMD's email estimate (real estate costs excluded)
Design & Construction Management	$1,067,781	15% of costs excluding real estate
Total Canal Improvements Cost	**$8,186,323**	
Total C-9 Cost	**$236,100,483**	

Table A- 16: M2C Cost Estimation

M2C for 25-year SLR3		
C-8/S-28 Cost Estimate		
Pump Station	**Costs**	**References/Notes**
Structure Replacement	$19,056,898	S28 Costs from SFWMD's PDF Costs (Assumed 250' DS; raise spillway by 5')
Forward Pump (3550 cfs)	$134,481,716	S28 Costs from SFWMD's XLS Costs scaled to 3500 CFS Pump (S28-M2C:AN271)
Forward Pump Backup Generator Facility	$13,791,922	S28 Costs from SFWMD's XLS Costs, Scaled generator to match pump (S28:BH118)
Structure Tie Back (Flood Barrier)	$2,987,463	S28 Costs from SFWMD's XLS Costs (raise berm by 3'x250') (S28:AX47)
Design & Construction Management	$25,547,700	S28 Costs from SFWMD's XLS Costs (15% of costs excluding real estate)
Real Estate	$7,000,000	S28 Costs from SFWMD's XLS Costs (S28:BR10)
Total Pump Station Cost	**$202,865,699**	
Storage		
Distributed Storage (500 Ac-Ft)	$38,859,600	Real estate costs excluded
Design & Construction Management	$5,828,940	15% of costs excluding real estate
Total Storage Cost	**$44,688,540**	
Canal Improvements		
Raise Canal Banks (to 7.5 ft)	$12,412,542	Raise Tab using SFWMD's email estimate (real estate costs excluded)
Widen Canal (by 100 ft)	$31,618,782	Widen Tab using (real estate costs excluded)
Design & Construction Management	$6,604,699	15% of costs excluding real estate
Total Canal Improvements Cost	**$50,636,022**	
Total C-8 Cost	**$298,190,261**	
C-9/S-29 Cost Estimate		
Pump Station		
Structure Replacement	$19,056,898	S28 Costs from SFWMD's PDF Costs (raise spillway by 5') at minimum
Forward Pump (3550 cfs)	$139,005,527	S29 Costs from SFWMD's XLS Costs Modified to 3500 CFS Pump (S29-M2C:J9)
Forward Pump Backup Generator Facility	$14,217,365	S29 Costs from SFWMD's XLS Costs, Scaled generator to match pump (S29:J10)
Structure Tie Back (Flood Barrier)	$2,769,122	S29 Costs from SFWMD's XLS Costs (raise berm by 3') (S29:J11)
Design & Construction Management	$26,257,337	S29 Costs from SFWMD's XLS Costs (15% of costs excluding real estate)
Real Estate	$16,000,000	S29 Costs from SFWMD's XLS Costs (S29:J13)
Total Pump Station Cost	**$217,306,249**	

M2C for 25-year SLR3		
C-8/S-28 Cost Estimate		
Storage		
Distributed Storage (500 Ac-Ft)	$38,859,600	Real estate costs excluded
Design & Construction Management	$5,828,940	15% of costs excluding real estate
Total Storage Cost	**$44,688,540**	
Canal Improvements		
Raise Canal Banks (to 7.5 ft)	$7,118,542	Costs from SFWMD's email estimate (real estate costs excluded)
Widen Canal (by ~75 ft)	$107,725,296	Widen Tab using (real estate costs excluded)
Design & Construction Management	$17,226,576	15% of costs excluding real estate
Total Canal Improvements Cost	**$132,070,414**	
Total C-9 Cost	**$394,065,203**	

TAYLOR ENGINEERING, INC.

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

Deliverable 1.1.2

CONTRACT 4600004085

Work Order 05

South Florida Water Management District
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November 2021

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

Deliverable 1.1.2
CONTRACT 4600004085
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Prepared for the

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November 2021

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Introduction

The South Florida Water Management District (SFWMD or District) is conducting a system-wide review of the regional water management infrastructure to determine what mitigation projects would maintain or improve the current flood protection level of service (FPLOS). The FPLOS Phase 1 Study describes the level of protection provided by the water management facilities within a watershed considering sea level rise (SLR), future development, and known water management issues in each watershed.

This memorandum details the facilitation of the kickoff workshop for the adaptation planning and mitigation project study within the SFWMD C8 and C9 basins. Specifically, this memorandum details the desktop mitigation project research, the Build Community Resilience Planning for Flood Adaptation Website Viewer, the outcome of the partner user survey, the summary of the Partner Workshop meetings, and the list of mitigation projects. The next phase of the study (Task 2) will identify the framework for the mitigation efficiency criteria used to determine which mitigation projects will be evaluated through explicit modeling or through other approaches.

Pre-Workshop

Summary of Desktop Mitigation Project Research

The local communities and county governments within the C8 and C9 basins plan, fund, and implement flood mitigation and resilience projects; this sub-task sought to capture many of those projects. Typically, flood mitigation projects are documented in either a County's Local Mitigation Strategy (LMS) or a municipality's Capital Improvement Projects (CIP) list; often, flood mitigation and resilience projects are reflected within both. LMS lists consist of a variety of mitigation projects for a wide range of natural hazards, and often contain limited information such as the project's location, cost, and purpose. CIP lists, however, typically contain detailed design information of future public works projects. The specific sources of flood mitigation projects gathered in this sub-task are discussed below. As discussed later, the team also solicited input from partner communities and added those projects to the mitigation list.

LMS efforts gather local officials and technical experts to identify potential projects that would mitigate or reduce flooding or other hazards. These projects undergo a ranking process and are then catalogued and submitted to the State Hazard Mitigation Office (SHMO). The State uses this list to allocate funding in the event of a disaster when Federal Emergency Management Agency (FEMA) funds become available. The projects identified in the LMS have varying degrees of supporting information, from fully developed design drawings to locations where mitigation projects are needed. Communities typically capture flood mitigation projects in the LMS process.

The Miami-Dade and Broward County's extensive LMS lists were shared with the consultant team, who further refined the lists to identify flood mitigation projects for further evaluation in this study. The refining process included the evaluation of the following attributes: project location (i.e. within or adjacent to the C8 or C9 basins), time frame (i.e. has the project already been constructed or planned for the future), cost (i.e. smaller costs indicate micro-scale), and project name/description/type (i.e. regular canal maintenance, ditch improvements, and swale regrading not included, as the model assumes that the canals are operating at their designed capacity).

Miami-Dade County

Two sources provided information about Miami-Dade mitigation projects. The first was the LMS project list, and the other was the CIP project list provided by the Miami-Dade County Department of Transportation and Public Works (DTPW) open platform. This platform provided sufficient project details and location for inclusion in the preliminary mitigation project list. The DTPW list included traffic, roadway, and drainage projects. Only those projects associated with drainage and within the C8 and C9 basins were selected for the initial list of flood mitigation projects. For this task, the team limited the projects included to stormwater/drainage projects with a date range of 2015-2030, assuming that plans before those dates would have been superseded or revised.

Broward County

Broward County's LMS list was not publicly available; however, the District provided a list of potential projects filtered to display only projects from the municipalities within the C9 Basin. These projects did not have location data, so the team identified, to the best extent possible, project location from the given description.

In summary, the review of the County LMS and CIP data helped the team generate an initial list of potential mitigation projects (identified in **Appendix A**) to improve the resilience of the two basins. Many projects on the list contained few details or design information needed for evaluating each project. In post-workshop follow-up meetings, partners were asked to provide construction documents or other substantiating information to help the team evaluate projects for inclusion in the flood mitigation scenario model. This effort is detailed in a future section of this report, ***Partner and Stakeholder Follow-up,*** and within **Appendix B**.

Summary of Website Projects and User Survey

To facilitate the review of potential mitigation projects and enable community partners to add to the list, an interactive web-based map was developed for the C8 and C9 basins that presents the preliminary list of mitigation projects. The website address is the following:

http://www.buildcommunityresilience.com/SFWMD/FPLOS/c8c9/

Using Environmental Systems Research Institute's (ESRI) Experience Builder application, the team created a multi-tabbed map viewer. The map viewer provides a platform for local partners to view the projects identified, submit their own projects, and edit previously identified projects. Phase I result figures from the map tool were incorporated into the PowerPoint presented at the workshop as a deliverable. The reason for showing these results was to inform community partners of projected areas of flooding within their jurisdiction.

The SFWMD uses six (6) performance metrics (PMs) to establish the level of service within each basin studied. The flood depth is one of the six metrics and represents a spatial measure of flood risk based on district modeling assumptions including rainfall frequency, storm surge and sea level rise. These maps are different from and should not be equated to FEMA Zones or other flooding assessment conducted by local governments. Note that this was not the only assessment performed during the FPLOS, but the map viewer was utilized to represent graphically, areas of concern needing solutions. The five tabs in the map viewer provide more details on the Flood Protection Level of Service (FPLOS).

Tab 1: The Overview tab provides a summary of Phase II's project goals and a map of all projects currently identified (**Figure 1**).

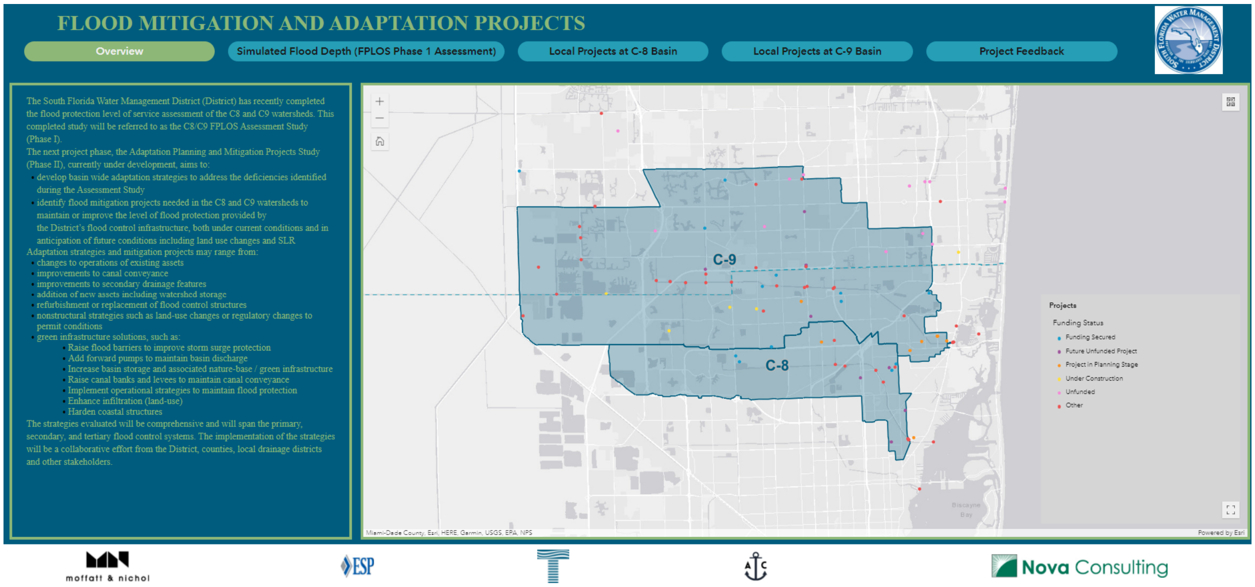

***Figure 1**: Interactive Web-Based Map Viewer – Overview Tab*

Tab 2: The Simulated Flood Depth (FPLOS Phase 1 Assessment) tab includes four maps on separate sub-tabs. Each map contains a different scenario – current conditions, sea level rise (SLR) with 1 foot, SLR with 2 feet, and SLR with 3 feet of flooding; each map displays future 5-, 10-, 25-, and 100-year/72-hour overland flood depth (**Figure 2**).

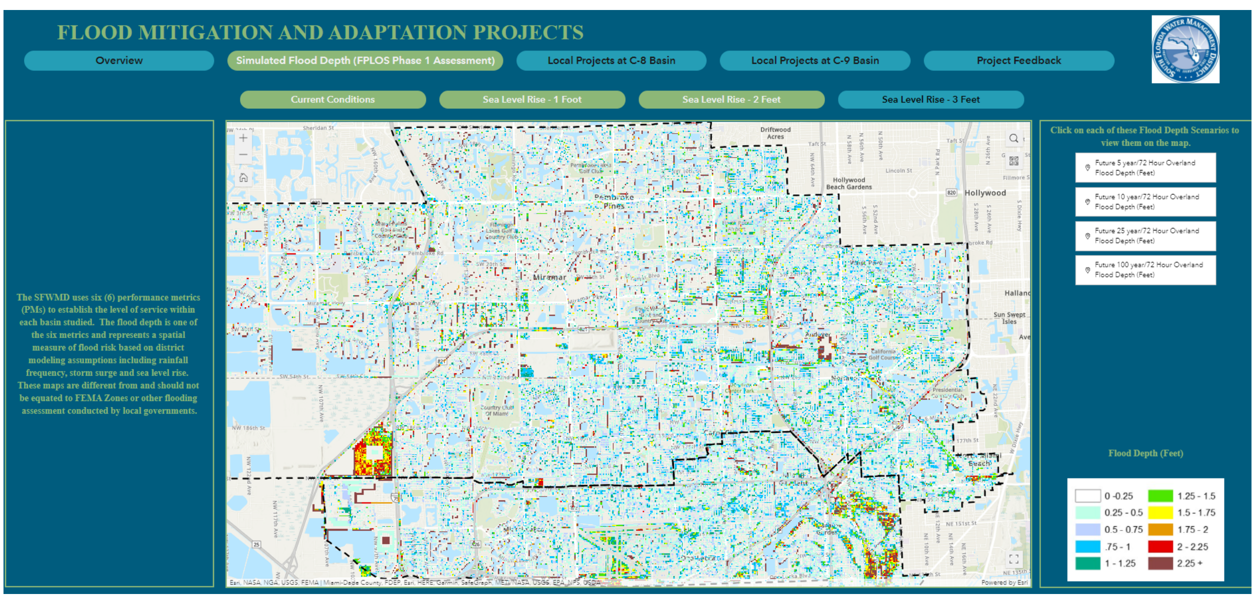

Figure 2: Interactive Web-Based Map Viewer – Simulated Flood Depth Tab

Tabs 3 and 4: Basin C8 and C9 are on individual tabs with pertinent information displayed in two different pop-ups. The bubble appearing on the map provides the project's title, estimated cost, and potential funding sources; the box on the left displays the title, agency responsible for the project, the type, and an estimated completion date range. These tabs provide additional information about the FPLOS study and illustrate the mitigation projects being sought for Phase II's scenario modeling (**Figures 3 and 4**).

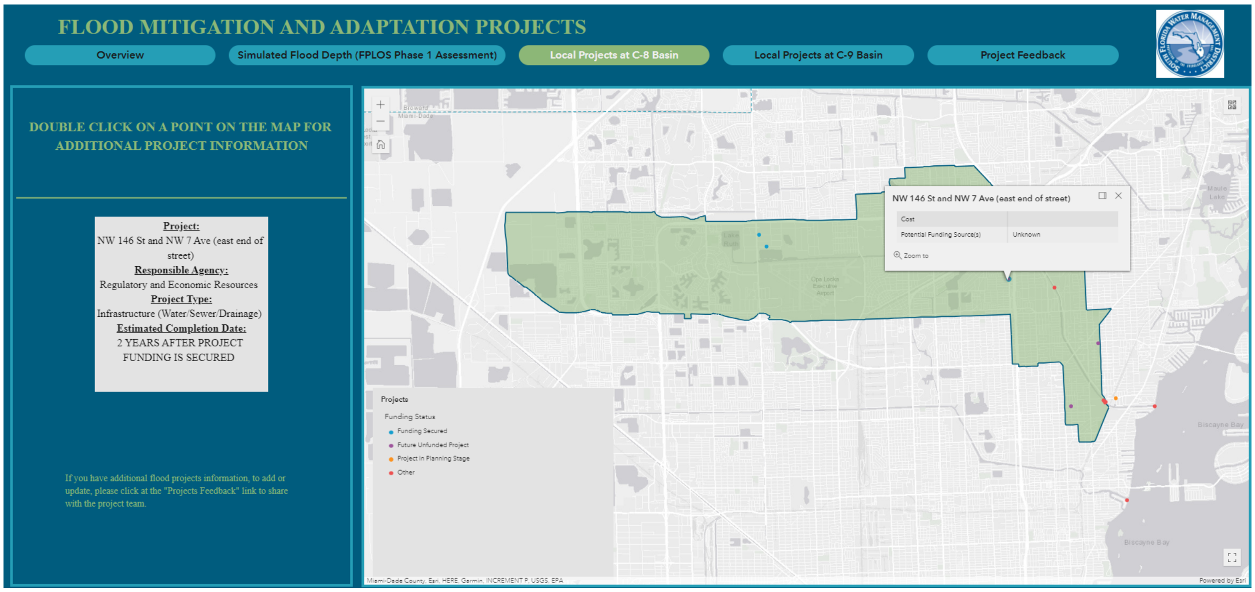

***Figure 3**:* Interactive Web-Based Map Viewer – Local Projects at C-8 Basin Tab

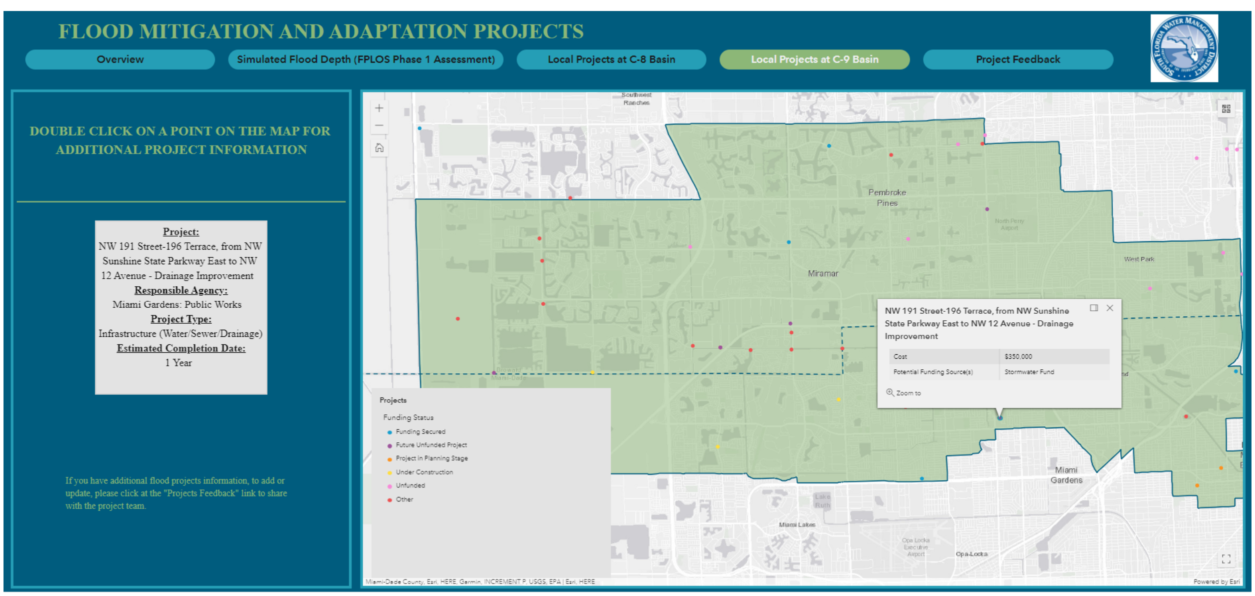

***Figure 4**:* Interactive Web-Based Map Viewer – Local Projects at C-9 Basin Tab

Tab 5: The Project Feedback tab (**Figure 5**) includes a link to the Project Form (**Figure 6**) and a map of the projects submitted through the form which updates each time a form is submitted. Using ESRI's application, Survey123, the team set up a simple form to collect the necessary data shown on previous tabs. In addition, the form collected contact information in case the consulting team should need further discussion.

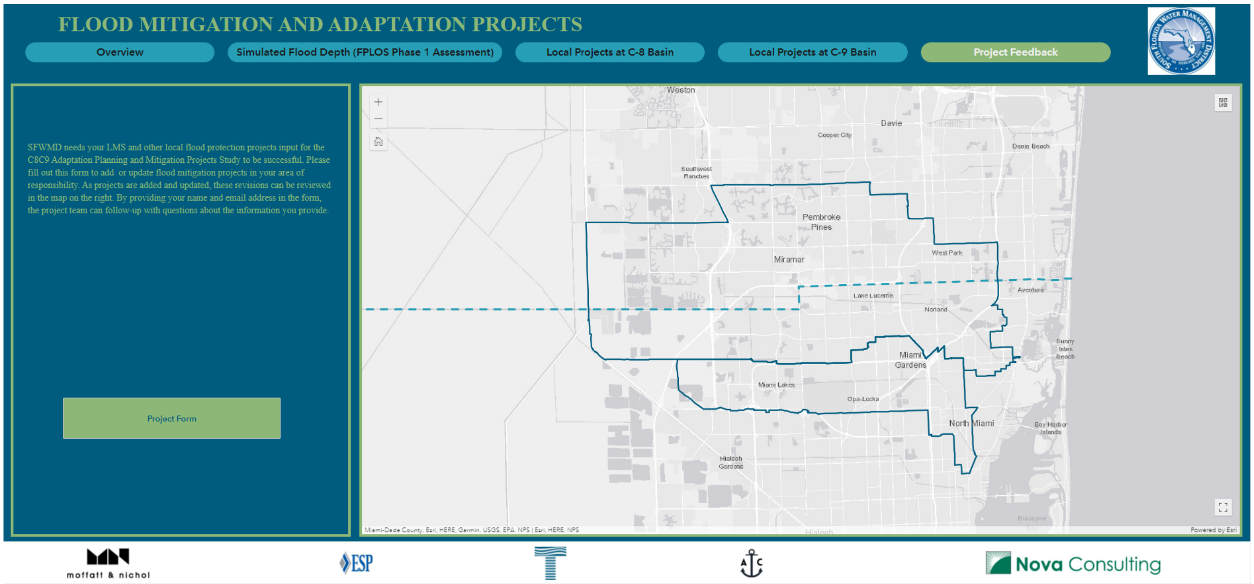

***Figure 5**:* Interactive Web-Based Map Viewer – Project Feedback Tab

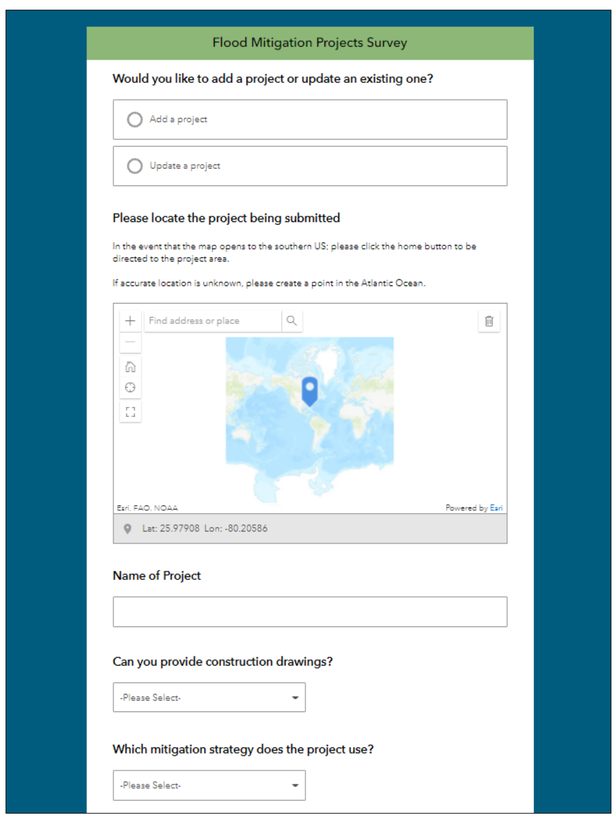

***Figure 6**:* Interactive Web-Based Map Viewer – Project Form Under the Project Feedback Tab

The site provides a simple avenue to share project information and documents. In addition to providing necessary information, the website offers more discretion for mitigation projects which are not yet public. The site hosts the map viewer and relevant project documents, which can be uploaded as needed. The project documents contained on the website will be transferred to the District for possible future hosting on their website at the conclusion of this project.

The team invited partner communities to fill out the Map Viewer questionnaire and submit relevant projects and documents to the website before the workshop. No new projects were received via the Map Viewer website prior to the workshop. An online survey was also deployed prior to the Partner Workshop. The six questions are listed below. The survey received responses from seventeen partners and are included in **Appendix C**.

1. What is your involvement in flood mitigation and adaptation planning?
2. Have you observed significant changes in flooding conditions in the recent 5-10 years? Do you have any documentation?
3. What do you believe are the major limitations of the existing flooding system at C-8 and C-9 Basins? Do you have a plan and preferred actions to address these limitations?
4. How are future conditions (e.g., sea level rise or increased rainfall) considered as part of project planning/design?

Workshop

Summary of Partner Workshop

The objective of the Phase II FPLOS studies for the District is to develop adaptation strategies within the basin that mitigate existing and future floodplain challenges in the communities. To that end, after soliciting input to view the web viewer, the District hosted a workshop to encourage dialogues around these mitigation plans with the communities, local, state, and federal government agencies interested in resiliency within the C8 and C9 basins. In addition to encouraging the discussion around mitigation projects, the District asked the partners to submit any projects they thought would benefit the study. The projects suggested during the workshop are listed in **Appendix A**.

The project team developed a list of partners and invited them to a workshop held on August 3, 2021, at Florida International University's Biscayne Bay Campus in North Miami. The meeting agenda is in **Appendix D**.

The main points presented at the workshop included background of flood protection responsibilities, an overview of District water managements systems, sea level rise (SLR) projections, and an introduction to the FPLOS program and its phases. A summary and background of the Phase I project was presented along with its findings, together with the objective of Phase II, which pertains to future land use and mitigation strategies. The importance of the map viewer and pre-workshop feedback was emphasized as critical in filling data gaps to achieve further progress in Phase II.

Topics of discussion raised by community partners included the mechanisms/functions by which water levels are maintained at the canals and at structures; a discussion of whether the influence of storm surge was accounted for in Phase I; and water quality interests, especially in Biscayne Bay. The Phase I model resolution was also discussed together with the metrics it utilized. More information on these discussions is given in Sections 1 to 5 in the meeting summary included in **Appendix D**.

Following these presentations and discussions, the attendees were broken up into five (5) breakout groups – two (2) in person groups and three (3) virtual groups. The goals of the break-out sessions were as follows:

- Discuss the materials presented prior to the breakout groups (FPLOS Program, C-8/C-9 Phase I results presentation, Phase II Pre-workshop feedback, Map-viewer, etc.)
- To enhance connectivity among the community of practitioners in the C-8/C-9 basins through dialogue
- To share concerns about present and anticipated flooding/drainage problems
- To communicate ideas that the practitioners would like this project to address
- To generate ideas on future projects to be included, how to integrate these ideas into the existing basin configuration, and to develop additional solutions. This includes sharing innovative regulatory/policy ideas associated with planned or existing projects

Each break-out group had a moderator, scribe, and technical assistant that were either District employees or members of the project team. The break-out group instructions that were provided to the moderators are included in **Appendix E**. Following the break-out groups, one (1) member from each group reported out the main topics of their group's discussion. Within the breakout groups, some common points of interest included SLR and climate impact considerations on future projects; water quality considerations; and integration of local and regional projects.

The District, in response to the concerns of community partners, reassured its commitment to coordination efforts across agencies as well as its commitment to current and future system resiliency. It was expressed that flood control considerations are of primary importance, but that water quality improvements can be considered within the framework of successful flood control. In addition to affirming the importance of collaboration and interagency planning in facing flood control issues, partners indicated that there was a lack of awareness about the FPLOS program, and that spreading awareness may help in resolving community partner challenges together with regional flood control challenges.

The workshop concluded with a discussion of the next steps in the FPLOS study. The modeling priorities and the method to categorize projects was introduced and is further discussed in the Post Workshop section of this memorandum. Use of the Dynamic Adaptive Policy Pathways (DAPP) approach in relation to this study was also presented, which aims to support the development of an adaptive plan that is able to deal with conditions of deep uncertainty (e.g., climate change predictions). This approach was developed by Deltares and TU Delft to help specify actions to be taken immediately to be prepared for the near future and actions to be taken now to keep options open to adapt if needed. A monitoring system is used to collect information to get early warning signals (triggers) for implementation of actions or for reassessment of plans. Adaptation pathways are developed that describe a sequence of policy actions or investments in institutions and infrastructure over time to achieve a set of pre-specified objectives (e.g., flood protection) under uncertain and changing conditions (e.g., SLR). An adaptation pathways map (**Figure 7**) provides insight into policy options, the sequencing of actions over time, potential lock-ins, and path dependencies.

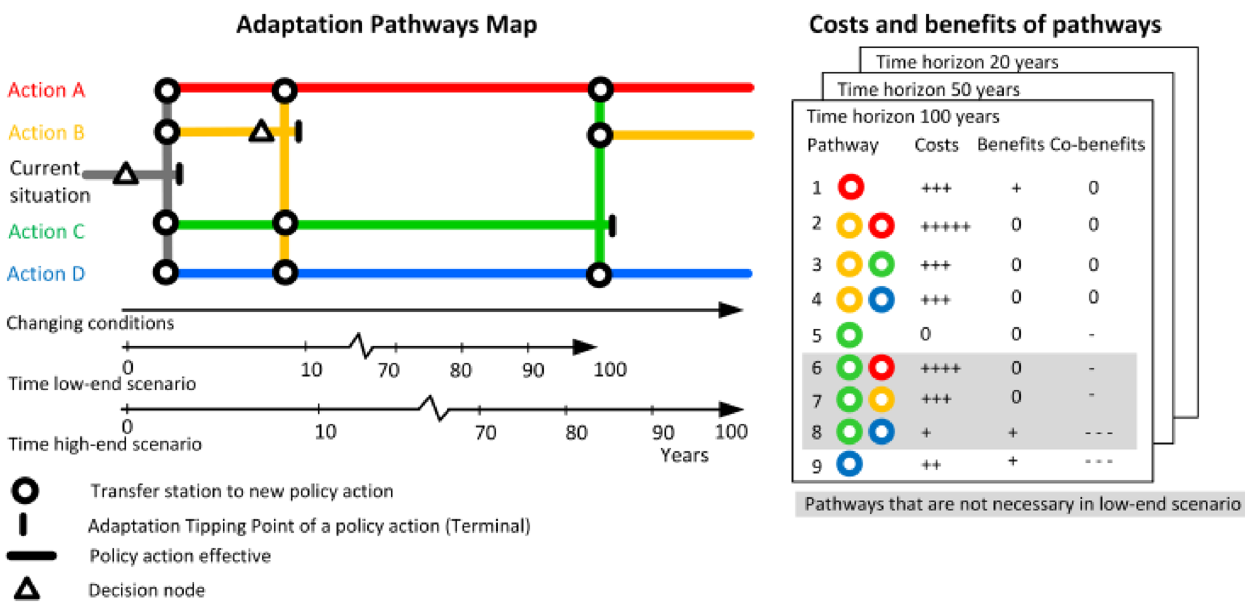

Figure 7: *Example Adaptation Pathways Map*

The full Workshop PowerPoint Presentation and pictures from the in-person workshop can be found in **Appendix F** and **Appendix G**, respectively. A summary of the workshop feedback from the Consultant/SFWMD team is provided in **Appendix H**.

Post-Workshop

Partner and Stakeholder Follow-up

Post-workshop partner and stakeholder meetings took place to follow up on mitigation projects discussed during the workshop. A comprehensive log of these meetings, including dates, involved entities, content, outcomes, and insights can be found in **Appendix E**. The projects suggested during the partner follow-ups are listed in **Appendix A**.

Beginning on 9/14/2021, a request was made to Robin Yang of Miami-Dade County Emergency Management for additional information on the County's LMS Projects. Requested information includes construction drawings; culvert and gate sizes, dimensions, inverts, geometries, and geocoordinates; trigger elevations for gates and pumps; pump station capacities; and anticipated areas of impact. In response to this request, Robin Yang issued requests (via email) to jurisdictions that had submitted LMS projects, which include Miami Gardens, Miami Shores, North Miami, North Miami Beach, the Miami-Dade Public Works Department, and the Miami-Dade Department of Regulatory and Economic Resources.

On 9/22/2021 a meeting was held with the Miami-Dade County Stormwater Department regarding FEMA and Building Resilient Infrastructure and Communities (BRIC) coordination in the C8 basin. The SFWMD gave an overview of how various projects in these basins fit together within a broader resiliency program. Specific BRIC applications to the C8/C9 FPLOS project were addressed. The County was asked to review the Miami-Dade project list to ensure that all of the County's flood mitigation projects have been included; and to remove those projects that should be, in the County's view, excluded.

A meeting was held on 9/29/2021 with the Miami-Dade County Resiliency team. Topics discussed include the identification of potential distributed storage areas and how modeling efforts can help identify a critical storage threshold that makes more of a difference to the overall system. It was noted that water quality benefits may be derived from a more distributed approach to storage, a point to be revisited in future discussions.

On 10/07/2021, Armando Ramirez of the SFWMD hosted the Seminole Trible of Florida to introduce the Tribe to the FPLOS. There are no tribal lands in the C8 /C9 basins. However, for future phases of the FPLOS program, there is potential for there to be some lands, potentially around the Hollywood area. The broader program was discussed as well as the C8/C9 workshop. The parties agreed to continue to share information as the FPLOS program develops and to continue to include the Tribe with information and include feedback.

Preliminary Project Types and Categorization

The South Florida flood control system is an interconnected network of canals that drain from third-order systems (roadway swales and stormwater retention ponds) to second-order canals (systems controlled by local drainage districts and counties with pumps and flood control gates) to primary systems (those controlled by large canals and pumpstations maintained by the SFWMD). This system is truly interconnected, and no single piece can function well without the others. For example, an improvement in neighborhood drainage will require a secondary system to handle the additional flow volumes. And that secondary system requires a primary system that can, in turn, absorb the additional flow volumes. This project will assume that this interconnectedness is effectively addressed for each project. However small or large, each project can have a beneficial impact on the local area it serves. The project aims to allow a systematic approach to categorizing the mitigation projects proposed by each partner and allow further evaluation based on flood control and economic impact to the basin.

To categorize the mitigation projects, the team assessed each with respect to its impact to a tertiary, secondary, or primary system. As noted above, every project will, in some way, impact all three systems. But each project has a *primary* benefit, and the team used that benefit to categorize the projects.

The draft project list generated from the initial review of projects and partner input contained projects such as:

1.0 Stormwater systems, upgrades, or retrofit
2.0 Sluice gates
3.0 Pump stations
4.0 Seepage berms
5.0 Storm surge barriers

6.0 Flood criteria maps
7.0 Canal bank and roadway improvements
8.0 Lake outfall replacement
9.0 Basin interconnects

In addition to these projects, the team wanted to evaluate:

10.0 Green infrastructure projects downstream of the S-28 and S-29 pumps
11.0 Potential surface water storage in upstream areas of the system
12.0 Land use and zoning modifications/changes
13.0 Buyouts of homes or properties
14.0 Potential connection in the basin to move water south, so it discharges in the southern end of Biscayne Bay.

Each of the projects in the collective list (**Appendix A**) will likely have a beneficial impact at reducing flooding in the real-world within the immediate vicinity, with some projects contributing further-reaching impacts. However, in the flood model which will be set up in the next task of this project, a project which is effective in the real-world may show an underestimation of benefits due to the model's scale and design assumptions (i.e., rainfall distribution). The team is developing a scoring system to achieve a better understanding of what the anticipated real-world benefits would be for each project, if any. This scoring system evaluates the flood mitigation efficiencies for each project as well as the scale of the project, such as regional, local, or micro-scale. Use of this scoring allows the consultant and District team to assess which projects to prioritized for inclusion in the flood mitigation scenario models.

Conclusion

The first stage of this project conducted a desktop exercise to collect mitigation projects identified by the communities within the C8 and C9 basins. The team presented these projects in a website viewer and solicited additional input from the communities. The District hosted a workshop inviting all the partners within the basins to understand more about the FPLOS projects and this Phase II study. In addition, the District asked for additional mitigation projects and the team followed up after the workshop leading further conversations with local and regional partners. These partner follow-up conversations provided clarification and substantiating information to help the team evaluate projects for inclusion in the flood mitigation scenario model.

In Task 2, the team is working with the District to evaluate which of the flood mitigation projects presented in this report will be included in the modeling study of the SFWMD C8 and C9 basins. A scoring system is used to assess the mitigation efficiency of each project in order to understand how effective the project will be at reducing flooding within the system. The scale of each project's benefits is also estimated, such as regional, local or micro. The project team and the District will use the results of the mitigation efficiency scoring and project scale to select which projects will be included in the future modeling runs.

APPENDIX A: Pre-Workshop, From-Workshop, and Post-Workshop Project Lists

Pre-Workshop Project List

Basin	County	Source, Date Added	Project Name	Project Location	Responsible Agency	Project Type	Cost	Potential Funding Source(s)	Time Frame	Funding Status
C-9	Broward	Phase I Report, 5/28	Basin S-5 Sluice Gate		South Broward Drainage District	Drainage				Other
C-9	Miami-Dade	Phase I Report, 5/28	Emergency Discharge Sluice Gate		South Broward Drainage District	Drainage	$120,000		>12 Months	Future Unfunded Project
C-9	Broward	Phase I Report, 5/28	Encantada Sluice Gate		South Broward Drainage District	Drainage				Other
C-9	Broward	Phase I Report, 5/28	Harbour Lake Estates Sluice Gate		South Broward Drainage District	Drainage				Other
C-9	Broward	Phase I Report, 5/28	Sunset Lakes Sluice Gate		South Broward Drainage District	Drainage				Other
C-9	Miami-Dade	Phase I Report, 5/28	South Broward Drainage District S4/S5 Pump Station	5400 SW 172nd Avenue Miramar, FL 33029	South Broward Drainage District	Drainage		FEMA	<3 Months	Under Construction
C-9	Miami-Dade	MDC_LMS, 6/1	20021 to 20081 NW 13 Ave-Stormwater Drainage Improvements Project	20021-20081 NW 13 Avenue	Miami Gardens	Infrastructure (Water/Sewer/Drainage)		Stormwater Fund	1 Year	Funding Secured
C-9	Miami-Dade	MDC_LMS, 6/1	20601 NW 44 Court-Stormwater Drainage Improvements Project	20601 NW 44 Court	Miami Gardens	Infrastructure (Water/Sewer/Drainage)		Stormwater Fund	1 Year	Funding Secured
C-9	Miami-Dade	MDC_LMS, 6/1	Injection Well Construction	City-wide	North Miami Beach	Infrastructure (Water/Sewer/Drainage)		Capital Improvement Project	FY19-FY21	Project in Planning Stage
C-9	Miami-Dade	MDC_LMS, 6/1	Kings Gardens #3	18605 NW 27 Avenue	Miami Gardens	Infrastructure (Roadway)		Unidentified funding at this time since it is on private property and the City cannot take over the streets due to the streets being part of the property lines.	Over one year	Other

Pre-Workshop Project List

Basin	County	Source, Date Added	Project Name	Project Location	Responsible Agency	Project Type	Cost	Potential Funding Source(s)	Time Frame	Funding Status
C-9	Miami-Dade	MDC_LMS, 6/1	Leslie Estates #4 Road and Drainage Improvements	Leslie Estates #4	Miami Gardens: Public Works	Infrastructure (Water/Sewer/Drainage)	$1,500,000	Funding with be a combination of CITT, Stormwater, and State Appropriations.	1 Year	Project in Planning Stage
C-9	Miami-Dade	MDC_LMS, 6/1	NE 10th Avenue/NE 159th Street and NMB Boulevard	NE 10th Avenue/NE 159th Street and NMB Boulevard	North Miami Beach	Infrastructure (Roadway)		Capital Improvement Project	FY16 -FY20	Project in Planning Stage
C-9	Miami-Dade	MDC_LMS, 6/1	NE 167 Street and NE 14 Avenue	NE 167 Street and NE 14 Avenue	Miami-Dade County Regulatory and Economic Resources	Infrastructure (Water/Sewer/Drainage)		GOB	2 Years After Project Funding Is Secured	Project in Planning Stage
C-9	Miami-Dade	MDC_LMS, 6/1	NE 197 Terrace and NE 17 Avenue Drainage Improvements	NE 197 Terrace and NE 17 Avenue	Miami-Dade County Regulatory and Economic Resources	Infrastructure (Water/Sewer/Drainage)	$620,000	SWU	2/5/2022	Funding Secured
C-9	Miami-Dade	MDC_LMS, 6/1	NW 191 Street-196 Terrace, from NW Sunshine State Parkway East to NW 12 Avenue - Drainage Improvement	18605 NW 27 Avenue	Miami Gardens: Public Works	Infrastructure (Water/Sewer/Drainage)	$350,000	Stormwater Fund	1 Year	Future Unfunded Project
C-9	Miami-Dade	MDC_LMS, 6/1	NW 42 Avenue and NW 167 Terrace	16760 NW 42 AVE	Miami Gardens	Infrastructure (Water/Sewer/Drainage)		Stormwater Fund	1 Year	Funding Secured
C-8	Miami-Dade	MDC_LMS, 6/1	NW 163 Street Drainage Improvement Project	5501 NW 163 ST	Miami Gardens	Infrastructure (Water/Sewer/Drainage)		Stormwater Fund	6 mos to 1 year	Funding Secured
C-8	Miami-Dade	MDC_LMS, 6/1	NW 159 Street Stormwater Drainage Project	5400 NW 159 ST	Miami Gardens	Infrastructure (Water/Sewer/Drainage)		Stormwater Fund	1 Year	Funding Secured
C-8	Miami-Dade	MDC_LMS, 6/1	Drainage Improvements NW 170 St west of 22 Ave	NW 170 Street and NW 22 Avenue	Miami Gardens: Public Works/Private	Infrastructure (Water/Sewer/Drainage)			> 1 year	Project in Planning Stage
C-8	Miami-Dade	MDC_LMS, 6/1	NW 146 St and NW 7 Ave (east end of street)	NW 146 Street and NW 7 Avenue (east end of street)	Miami Dade County Regulatory and Economic Resources	Infrastructure (Water/Sewer/Drainage)		Unknown	2 Years After Project Funding Is Secured	Future Unfunded Project

Pre-Workshop Project List

Basin	County	Source, Date Added	Project Name	Project Location	Responsible Agency	Project Type	Cost	Potential Funding Source(s)	Time Frame	Funding Status
C-8	Miami-Dade	MDC_LMS, 6/1	Biscayne Gardens Community Rating System Site Mitigation	326 NE 152 Street	Miami Dade County Public Works	Infrastructure (Water/Sewer/Drainage)		SWU, CDBG, FEMA (CRS)	2 Years from acquisition of funding	Future Unfunded Project
C-8	Miami-Dade	MDC_LMS, 6/1	105 Street Drainage Pump Station	10050 NE 2nd Avenue	Miami Shores	Infrastructure (Water/Sewer/Drainage)		Potential future funding	Unknown	Future Unfunded Project
C-8	Miami-Dade	MDC_LMS, 6/1	Biscayne Gardens Stormwater Inspection	NE 150 St & Spur Dr	Miami Dade County Regulatory and Economic Resources	Infrastructure (Water/Sewer/Drainage)	$25,000	SWU	5/4/2021	Funding Secured
C-8	Miami-Dade	MDC_LMS, 6/1	NE 154 Street and NE 5 Court	NE 154 Street and NE 5 Court	Miami Dade County Regulatory and Economic Resources	Infrastructure (Water/Sewer/Drainage)	$182,000	SWU	8/3/2023	Funding Secured
C-8	Miami-Dade	MDC_LMS, 6/1	Correct Water Infiltration at City Hall (EOC) Basement	776 NE 125 ST	North Miami	Infrastructure (Building)		Potential	6 mos to 1 year	Future Unfunded Project
C-9	Miami-Dade	MDC_LMS, 6/1	Storm Water Pump Replacement Program	City-wide	North Miami Beach	Infrastructure (Water/Sewer/Drainage)		Capital Improvement Project	FY16-FY20	Project in Planning Stage
C-9	Miami-Dade	MDC_LMS, 6/1	Vista Verde Phase #4 - Remaining Phase from Snake Creek Canal to NW 41 Ave Rd Community	18605 NW 27 Avenue	Miami Gardens: Public Works	Infrastructure (Water/Sewer/Drainage)		State, Stormwater, CDBG, CITT through each budget cycle	> than one year	Funding Secured
C-9	Miami-Dade	MDC_LMS, 6/1	Well Field Stormwater System Improvement	City-wide	North Miami Beach	Infrastructure (Water/Sewer/Drainage)		Capital Improvement Project	FY16-FY20	Project in Planning Stage
C-9	Miami-Dade	MDC_LMS, 6/1	West Dixie Highway Drainage Improvements	NE 22 Ave and Dixie Hwy	North Miami Beach: Public Works	Infrastructure (Water/Sewer/Drainage)		Stormwater enterprise fund or grant	June 2023	Project in Planning Stage
C-9	Broward	BC_LMS, 6/7	Enlargement of Silver Lake Control Structure		South Broward Drainage District	Flood control/reduction and waterway management - Potential mitigation project for investigation (from Phase I study)			Unknown	Other

Pre-Workshop Project List

Basin	County	Source, Date Added	Project Name	Project Location	Responsible Agency	Project Type	Cost	Potential Funding Source(s)	Time Frame	Funding Status
C-9	Broward	BC_LMS, 6/7	Hollywood Arthur and Cleveland Streets Drainage Improvement		Hollywood: Emergency Management Coordinator	Drainage	$488,000	HMGP/PDM	>12 Months	Unfunded
C-9	Broward	BC_LMS, 6/7	Hollywood North Lake Pump Station and Outfalls		Hollywood: Emergency Management Coordinator	Drainage	$2,234,000	HMGP/PDM	>12 Months	Unfunded
C-9	Broward	BC_LMS, 6/7	Hollywood South Lake Pump Station		Hollywood: Emergency Management Coordinator	Drainage	$2,500,000	HMGP/PDM	<12 Months	Unfunded
C-9	Broward	BC_LMS, 6/7	Hollywood Sunset Golf Course Pump Station Rehabilitation		Hollywood: Emergency Management Coordinator	Drainage	$2,166,000	HMGP/PDM	<12 Months	Unfunded
C-9	Broward	BC_LMS, 6/7	Pembroke Park Carolina Street/Park Road Pump Station		Pembroke Park: Emergency Management Coordinator	Drainage	$2,785,000	HM, PDM, GF	>12 Months	Unfunded
C-9	Broward	BC_LMS, 6/7	Pembroke Park SW 30 Avenue Drainage		Pembroke Park: Emergency Management Coordinator	Drainage	$590,000	HM, PDM, GF	>12 Months	Unfunded
C-9	Broward	BC_LMS, 6/7	Pembroke Park SW 52nd Avenue Drainage		Pembroke Park: Emergency Management Coordinator	Drainage	$500,000	HM, PDM, GF	>12 Months	Unfunded
C-9	Broward	BC_LMS, 6/7	Pembroke Pines Storm Water Project - Lakeside Key Storm Drainage System		Pembroke Pines: Public Services Assistant Director	Drainage Improvement	$100,000	HMGP	>12 Months	Unfunded
C-9	Broward	BC_LMS, 6/7	Pembroke Pines Storm Water Project - Taft St. and 85th Way Culvert Linings		Pembroke Pines: Public Services Assistant Director	Drainage improvement	$150,000	HMGP	>12 Months	Unfunded

Pre-Workshop Project List

Basin	County	Source, Date Added	Project Name	Project Location	Responsible Agency	Project Type	Cost	Potential Funding Source(s)	Time Frame	Funding Status
C-9	Broward	BC_LMS, 6/7	Pembroke Pines Storm Water Project - Taft St. Swale Regrading		Pembroke Pines: Public Services Assistant Director	Drainage Improvement	$357,500	HMGP	>12 Months	Funding Secured
C-9	Broward	BC_LMS, 6/7	Pembroke Pines Three Basin Interconnect at Century Village Project		Pembroke Pines: Public Services Assistant Director	Drainage Improvement	$125,000	HMGP	>12 Months	Funding Secured
C-9	Broward	BC_LMS, 6/7	Pembroke Pines West Communities Pump Station		Pembroke Pines: Public Services Assistant Director	Flood Diversion and Storage	$1,250,000	HMGP, Florida Earmark, Capital Improvement	>12 Months	Funding Secured
C-9	Broward	BC_LMS, 6/7	SBHD Memorial Healthcare System Joe DiMaggio Vertical Expansion Flood Proofing Project		South Broward Hospital District: Safety Director	Flood proofing	$15,031,781	HMGP	>12 Months	Unfunded
C-9	Broward	BC_LMS, 6/7	South Broward Drainage District Basin 3 Emergency Sluice Gate into the C-9 Canal		South Broward Drainage District	Flood control/reduction and waterway management	$120,000	Capital Improvement	>12 Months	Future Unfunded Project
C-9	Broward	BC_LMS, 6/7	South Broward Drainage District Maintenance Dredging of Primary and Secondary Canals (Location #1)		South Broward Drainage District	Flood Control/Reduction and Waterway Management	$300,000	Capital Improvement	>12 Months	Unfunded
C-9	Broward	BC_LMS, 6/7	South Broward Drainage District Maintenance Dredging of Primary and Secondary Canals (Location #2)		South Broward Drainage District	Flood control/reduction and waterway management	$300,000	Capital Improvement	>12 Months	Future Unfunded Project
C-9	Broward	BC_LMS, 6/7	South Broward Drainage District Maintenance Dredging of Primary and Secondary Canals (Location #3)		South Broward Drainage District	Flood control/reduction and waterway management	$300,000	Capital Improvement	>12 Months	Unfunded
C-9	Miami-Dade	BC_LMS, 6/7	South Broward Drainage District S.W. 54th Place/S.W. 164th Terrace Culvert Replacement	S.W. 54th Place and S.W 164th Terrace	South Broward Drainage District	Drainage	$10,000,000	HMGP/PDM	<12 Months	Unfunded

Pre-Workshop Project List

Basin	County	Source, Date Added	Project Name	Project Location	Responsible Agency	Project Type	Cost	Potential Funding Source(s)	Time Frame	Funding Status
C-9	Broward	BC_LMS, 6/7	South Broward Drainage District Seepage Management Storm Water Pump Station		South Broward Drainage District	Flood	$1,250,000	Capital Improvement	>12 Months	Future Unfunded Project
C-9	Broward	BC_LMS, 6/7	West Park Stormwater Vaults along 441/SR7		West Park: Emergency Management Coordinator	Drainage	$500,000	HM, PDM, GF	>12 Months	Unfunded
C-9	Miami-Dade	MDC_CIP, 6/24	Drainage Improvements Multiple Sites		Miami-Dade County Department of Transportation and Public Works	Stormwater				Under Construction
C-9	Miami-Dade	MDC_CIP, 6/24	NW 178 ST and NW 82 AVE		Miami-Dade County Department of Transportation and Public Works	Stormwater				Under Construction
C-9	Miami-Dade	MDC_CIP, 6/24	NW 57 PL from NW 194 ST to NW 198 TR		Miami-Dade County Department of Transportation and Public Works	Stormwater				Under Construction
C-9	Broward	SBDD, 6/28	Basin S-3 Sluice Gate		South Broward Drainage District	Drainage				Other
C-9	Broward	SBDD, 6/28	South Broward Drainage District B-1 Pump Station		South Broward Drainage District	Drainage				Other
C-9	Broward	SBDD, 6/28	South Broward Drainage District B-2 Pump Station		South Broward Drainage District	Drainage				Other
C-9	Broward	SBDD, 6/28	South Broward Drainage District S-7 Pump Station		South Broward Drainage District	Drainage				Other
C-9	Broward	SBDD, 6/28	South Broward Drainage District S-8 Pump Station		South Broward Drainage District	Drainage				Other

Pre-Workshop Project List

Basin	County	Source, Date Added	Project Name	Project Location	Responsible Agency	Project Type	Cost	Potential Funding Source(s)	Time Frame	Funding Status
C-9	Broward	SBDD, 6/28	South Broward Drainage District S-1 Pump Station		South Broward Drainage District	Drainage				Other
C-9	Broward	SBDD, 6/28	South Broward Drainage District S-2 Pump Station		South Broward Drainage District	Drainage				Other
C-9	Broward	SBDD, 6/28	South Broward Drainage District S-3 Pump Station		South Broward Drainage District	Drainage				Other
C-9	Broward	SBDD, 6/29 & Workshop	Rehabilitation of Triple 96" Culverts (CIPP)		South Broward Drainage District	Drainage	$450,000	Capital Improvement/Grant	<12 Months	Future Unfunded Project
C-9	Broward	SBDD, 6/29	South Broward Drainage District Basin 3/Basin 7 Interconnect at County Club Ranches		South Broward Drainage District	Drainage	$75,000	Capital Improvement/Grant	<12 Months	Future Unfunded Project
C-9	Broward	SBDD, 6/29	South Broward Drainage District East By-Pass & Sluice Gate at the S-1 Pump Station		South Broward Drainage District	Drainage	$100,000	Capital Improvement	>12 Months	Funding Secured
C-9	Miami-Dade	Phase I Report, 7/7	North Lake Belt Storage Area Improvements (western mine pits)		US Army Corps of Engineers & South Florida Water Management District	CERP - Potential mitigation project for investigation (from Phase I study)			Unknown	Other
C-9	Miami-Dade	Phase I Report, 7/7	S-28 downstream of tidal structure - floodwalls and storm surge barriers (USACE Back Bay study)		South Florida Water Management District	Infrastructure (Water/Sewer/Drainage) - Potential mitigation project for investigation (from Phase I study)			Unknown	Other

Pre-Workshop Project List

Basin	County	Source, Date Added	Project Name	Project Location	Responsible Agency	Project Type	Cost	Potential Funding Source(s)	Time Frame	Funding Status
C-9	Miami-Dade	Phase I Report, 7/7	S-28 improvements - pump station, higher platform and gates, tieback, levee and floodwall		South Florida Water Management District	Flood control/reduction and waterway management - Potential mitigation project for investigation (from Phase I study)			Unknown	Other
C-9	Miami-Dade	Phase I Report, 7/7	S-28 raise levees along canal and add operable structures to secondary system (gates/pumps) (Figure 3 from Phase I mitigation memo)		South Florida Water Management District	Infrastructure (Water/Sewer/Drainage) - Potential mitigation project for investigation (from Phase I study)			Unknown	Other
C-8	Miami-Dade	Phase I Report, 7/7	Dredging C-8 Canal		South Florida Water Management District	Capital Improvement - Potential mitigation project for investigation (from Phase I study)			Unknown	Other
C-9	Miami-Dade	Phase I Report, 7/7	S-29 improvements include Oleta River surge barrier, tieback levees, and floodwall		South Florida Water Management District	Infrastructure (Water/Sewer/Drainage) - Potential mitigation project for investigation (from Phase I study)			Unknown	Other

From-Workshop Project List

Basin	County	Source, Date Added	Project Name	Project Location	Responsible Agency	Project Type	Cost	Potential Funding Source(s)	Time Frame	Funding Status
C-9	Miami-Dade	Phase I Report, 5/28 & Workshop	South Broward Drainage District S4/S5 Pump Station	5400 SW 172nd Avenue Miramar, FL 33029	South Broward Drainage District	Drainage		FEMA	<3 Months	Under Construction
C-9	Broward	SBDD, 6/28 & Workshop	South Broward Drainage District S-1 Pump Station		South Broward Drainage District	Drainage				Other
C-9	Broward	SBDD, 6/28 & Workshop	South Broward Drainage District S-2 Pump Station		South Broward Drainage District	Drainage				Other
C-9	Broward	SBDD, 6/28 & Workshop	South Broward Drainage District S-3 Pump Station		South Broward Drainage District	Drainage				Other
C-9	Broward	SBDD, 6/29 & Workshop	Rehabilitation of Triple 96" Culverts (CIPP)		South Broward Drainage District: Director	Drainage	$450,000	Capital Improvement/Grant	<12 Months	Future Unfunded Project
C-9	Broward	SBDD, 6/29 & Workshop	South Broward Drainage District Basin 3/Basin 7 Interconnect at County Club Ranches		South Broward Drainage District: Director	Drainage	$75,000	Capital Improvement/Grant	<12 Months	Future Unfunded Project
C-9	Broward	SBDD, 6/29 & Workshop	South Broward Drainage District East By-Pass & Sluice Gate at the S-1 Pump Station		South Broward Drainage District: Director	Drainage	$100,000	Capital Improvement	>12 Months	Funding Secured
C-9	Miami-Dade	Phase I Report, 7/7 & Workshop	S-29 improvements include Oleta River surge barrier, tieback levees, and floodwall		South Florida Water Management District	Infrastructure (Water/Sewer/Drainage) - Potential mitigation project for investigation (from Phase I study)			Unknown	Other
C-9	Broward	Workshop, 8/3	C-9 Impoundment: Seepage Management		South Broward Drainage District	Drainage				Other
C-9	Miami-Dade	Workshop, 8/3	Drainage Improvements for Eastern Shores	Eastern Shores	Judeen Johnson	Drainage				Other

From-Workshop Project List

Basin	County	Source, Date Added	Project Name	Project Location	Responsible Agency	Project Type	Cost	Potential Funding Source(s)	Time Frame	Funding Status
C-9	Miami-Dade	Workshop, 8/3	Outfall Replacement at Pickwick Lake		Judeen Johnson	Pickwick Lake outfall replacement project that may change flow in the eastern lakes.				Other
C-8	Miami-Dade	Workshop, 8/3	Bank stabilization proposed on Marco Canal		Leslie Pettit - Miami Gardens	Drainage; Bank stabilization of canals/concrete mattresses. Raise bank heights ~1.5'. There are issues with property owner buy in. Raising banks impacts drainage on adjacent properties. Sediment buildup due to erosion of banks is an issue.				Other
C-8	Miami-Dade	Workshop, 8/3	C-8 Spur Canal Non-structural Flooding Solutions		Miami-Dade County: Katherine Hagemann	Flood control/reduction and waterway management; Elevating low-lying areas Multiple flooding complaints outstanding				Other
C-8	Miami-Dade	Workshop, 8/3	Miami Dade County Flood Criteria Map		Amy Cook	Updating and improving Flood Criteria Map for Miami Dade County				Other

From-Workshop Project List

Basin	County	Source, Date Added	Project Name	Project Location	Responsible Agency	Project Type	Cost	Potential Funding Source(s)	Time Frame	Funding Status
C-8	Miami-Dade	Workshop, 8/3	Retrofit the Control Structure to Block Surge		Miami-Dade County: Katherine Hagemann	Flood control/reduction and waterway management; System where gate can be closed and keep surge from going upstream. Currently, the gates are open as a hurricane approaches. SFWMD S-28 Tie in to high ground likely necessary. There is high ground nearby.				Other
C-9	Broward	Workshop, 8/3	Stormwater Master Plan		Jeff Jiang	Completed by CDM Smith				Other
	Miami-Dade	Workshop, 8/3	Biscayne Bay and Southeastern Everglades Ecosystem Restoration (BBSEER); BBSEER project		Table 1 and Table 2	Biscayne Bay and Southeastern Everglades Ecosystem Restoration (BBSEER); BBSEER project, a federal/regional collaborating project, is proposing a conveyance route to send water from north to south, such as Model Land				

From-Workshop Project List

Basin	County	Source, Date Added	Project Name	Project Location	Responsible Agency	Project Type	Cost	Potential Funding Source(s)	Time Frame	Funding Status
	Miami-Dade	Workshop, 8/3	Add cut-off wall at impoundment to address seepage issues		Table 1	Add cut-off wall at impoundment. a. Introduce water quality features/components into the pumps. b.Add living shorelines				
	Miami-Dade	Workshop, 8/3	Make sure to consider different perspectives, such as insurance and land use issues		Table 1	Make sure to consider different perspectives, such as insurance and land use issues				
C-8	Miami-Dade	Workshop, 8/3	Canal bank improvement and roadway improvement planned in C8 Basin		Table 2	Canal bank improvement and roadway improvement planned in C8 Basin				
C-9	Miami-Dade	Workshop, 8/3	Lake Belt Storage project		Table 2	Lake Belt Storage project, high conductivity can be a concern. Need more details about this project				

From-Workshop Project List

Basin	County	Source, Date Added	Project Name	Project Location	Responsible Agency	Project Type	Cost	Potential Funding Source(s)	Time Frame	Funding Status
N/A	Miami-Dade	Workshop, 8/3	Good Neighbor Stormwater Park project, City of North Miami		Table 2	Good Neighbor Stormwater Park project, City of North Miami, combines a community park with local flood prevention, addressing repetitive loss properties, bringing awareness of flooding and climate impacts to community, also used for native planting.				
		Workshop, 8/3	An ongoing project to alleviate low-lying area flooding along A1A		James Poole, FDOT, james.poole@dot.state.fl.us	An ongoing project to alleviate low-lying area flooding along A1A. This project involves the operation of small pump stations. Discharges will not exceed pre-project conditions and consideration is being given to WC issues.				

From-Workshop Project List

Basin	County	Source, Date Added	Project Name	Project Location	Responsible Agency	Project Type	Cost	Potential Funding Source(s)	Time Frame	Funding Status
C-8	Miami-Dade	Workshop, 8/3	Regarding the C8 Canal & S28 Structure		Miami-Dade County: Katherine Hagemann	Regarding the C8 Canal & S28 Structure, asked if the gates can be closed as storm approaches. Can the gates be tied by structural modification to higher ground (e.g., the Railroad embankment)?				
C-9	Broward	Workshop, 8/3	Add the conveyance between C9 and C11		SBDD, Kevin Hart	SBDD provided some facts to support this idea.				

Post-Workshop Project List

Basin	County	Source, Date Added	Project Name/Description	Project Limits	Cost Estimate	Funding Year	Funding Status	Project Status	System
C-9 WEST	Miami-Dade	Alberto Pisani, 10/1	Ditch Planned Project improvements	Golden Glades (NW 170 St from NW 117 Ave to NW 137 Ave)	$2,608,315		Unfunded	Survey, Design, & Construction needed	Secondary
C-8	Miami-Dade	Alberto Pisani, 10/1	Ditch Planned Project NW 107 Ave Canal improvements	NW 107 Ave canal improvements NW 107 Ave Between NW 138 St and NW 170 St	$2,622,852	FY19-20	Funded - SWU	Design/Build	Secondary
C-9	Miami-Dade	Alberto Pisani, 10/1	NE 179 Street from NW Miami Court to End of Road Drainage Improvements Project	NE 179 Street from NW Miami Court to End of Road and NE 1 Court from NE 179 Street to NE 181 Street and NE 181 Street from NE 1 Court to End of Road.	$788,357	FY19-20	Funded - SWU	Design	Tertiary
C-8	Miami-Dade	Alberto Pisani, 10/1	Ditch Planned Project NW 97 Ave Canal Improvements	NW 97 Ave Canal improvements - NW 97 Ave between NW 138 St and NW 170 St	$1,100,000		Unfunded	Survey, Design, & Construction needed	Secondary
C-9 WEST, C-8	Miami-Dade	Alberto Pisani, 10/1	Secondary Canal Planned Project improvements	Golden Glades Canal Cross Section Improvements (from NW 82 Ave to NW 87 Ave)	$702,000		Unfunded	Survey, Design, & Construction needed	Secondary
C-8	Miami-Dade	Alberto Pisani, 10/1	General drainage improvements	NE 4th Ave and NE 139 St	$811,000		Unfunded	Survey, Design, & Construction needed	Tertiary

Post-Workshop Project List

Basin	County	Source, Date Added	Project Name/Description	Project Limits	Cost Estimate	Funding Year	Funding Status	Project Status	System
C-9 WEST, C-8	Miami-Dade	Alberto Pisani, 10/1	Secondary Canal Planned Project improvements	Golden Glades Canal Cross Section Improvements (from NW 77 Ct to NW 82 Ave)	$676,000		Unfunded	Survey, Design, & Construction needed	Secondary
C-9	Miami-Dade	Alberto Pisani, 10/1	945 NE 207 TER	NE 9 Place from NE 207 Terrace to NE 205 Street, NE 205 Street from NE 8 Court to NE 9 Place, NE 8 Court from NE 205 Street to NE 205 Terrace	$669,620	FY19-20	Funded - SWU	Construction	Tertiary
C-9	Miami-Dade	Alberto Pisani, 10/1	Mitigation of Repetitive losses and flood complaints	Phase 3: NE 195 Terrace from NE 18 AVE to NE 22 Rd.	$639,721	FY 18-19	Funded - SWU		Tertiary
C-9	Miami-Dade	Alberto Pisani, 10/1	Coventry Drainage Improvements-NE 197 Terrace and NE 17 Avenue Drainage Improvements	NE 197 Terrace and NE 17 Avenue	$620,000	FY20-21	Funded - SWU	60% Design	Tertiary
C-9W	Miami-Dade	Alberto Pisani, 10/1	Ditch Planned Project (No canal reservation exists, land acquisition may be required)	NW 127 Ave from NW 202 St to NW 186 St	$579,296		Unfunded	Survey, Design, & Construction needed	Secondary
C-9	Miami-Dade	Alberto Pisani, 10/1	NW 57 Avenue and NW 186 Street 3-54" Culvert Repair	Culvert is located on NW 186 Street west of NW 57 Avenue	$455,000	FY20-21	Funded - SWU	Bidding	Secondary
C-9 WEST, C-8	Miami-Dade	Alberto Pisani, 10/1	General drainage improvements and mitigation of repetitive losses and flood complaints	NW 169 Terr to NW 170 St between NW 87 Ave and I-75 Ext	$217,000		Unfunded	Survey, Design, & Construction needed	Tertiary

Post-Workshop Project List

Basin	County	Source, Date Added	Project Name/Description	Project Limits	Cost Estimate	Funding Year	Funding Status	Project Status	System
C-9 WEST, C-8	Miami-Dade	Alberto Pisani, 10/1	Secondary Canal Planned Project improvements	Golden Glades Canal Cross Section Improvements (from NW 767 Ave to NW 77 Ct)	$0		Unfunded	Survey, Design, & Construction needed	Secondary
C-8	Miami-Dade	FDOT, 10/14	Golden Glades Interchange Enhancement	Golden Glades Interchange from SR 826/Palmetto Expwy to I-95	$600,000,000	TBD	Federal Funding	~60% Design, has SFWMD Conceptual Permit	

APPENDIX B: Partner/Stakeholder Meeting Notes

Date/Date Initiated	Purpose	Partner Agency	Partners in Attendance/ Correspondence	Project Team	Notes	Additional Information
9/14/2021	Miami-Dade LMS Projects: Request for additional information	Miami-Dade County Emergency Management	Robin Yang	Patrick Lawson (Lead) Others on email chain	Patrick getting additional technical information for projects included in LMS list. Generally requesting: 1.Construction Drawings 2.Culvert and gates: sizes, dimensions, inverts, geometry and locations 3.Trigger elevations for gates and pumps 4.Pump station capacity (CFS) 5.Anticipated area of impact **09/16/2021:** Robin Yang sent email requests to jurisdictions that had submitted projects to LMS. Email went to: Miami Gardens Miami Shores North Miami North Miami Beach Miami-Dade Public Works Miami-Dade Regulatory and Economic Resources **09/23/2021:** Robin sent reminder	**Miami Gardens** Leslie (Les) Pettit lpettit@miamigardens-fl.gov; Bernard Buxton-Tetteh bbuxton-tetteh@miamigardens-fl.gov; Mike Gambino (Miami Gardens) (risingwatersconsulting@gmail.com); **Miami Shores** Scott Davis daviss@msvfl.gov; Chris Miranda mirandac@msvfl.gov; Esmond Scott scotte@msvfl.gov; **North Miami** Wisler Pierre-Louis pwisler@northmiamifl.gov; Thomas Positano tpositano@northmiamifl.gov; Chuks Okereke cokereke@northmiamifl.gov; **North Miami Beach** Ana.Parada@citynmb.com; Tobias,Chidi Chidi.Tobias@citynmb.com; Proffitt, Justin Justin.Proffitt@citynmb.com; **Miami-Dade Public Works** Hildoer, Daryl (DTPW) Daryl.Hildoer@miamidade.gov; Herrera, Liza (DTPW) Liza.Herrera@miamidade.gov; barria@miamidade.gov **Miami-Dade Regulatory and Economic Resources** Dwyer, Cindy (RER) Cindy.Dwyer@miamidade.gov; Brown, Kimberly (RER) Kimberly.Brown@miamidade.gov; Blanco-Pape, Marina (RER) Marina.Blanco-Pape@miamidade.gov; Steelman, Marcia (RER) Marcia.Steelman@miamidade.gov

Date/Date Initiated	Purpose	Partner Agency	Partners in Attendance/ Correspondence	Project Team	Notes	Additional Information
9/17/2021	FPLOS intro: Tribe was not able to make workshop	Seminole Tribe of Florida	Jill Horwitz Alfonso Tigertail Kevin Cunniff Whitney Sapienza Christopher Murphy Stacy Myers	Carolina Maran Hongying Zhao Akin Owosina Armando Ramirez Armando Villaboy Bryan Palacio Michael DelCharco Angela Schedel Joe Wilder Lynette Cardoch	09/17: Carolina requested Tribe availability. 09/20: Jill sent proposed times. Need to confirm if a time was selected. **10/07/2021: Meeting held with the Tribe, with meeting hosted by Armando Ramirez (SFWMD)**	
9/22/2021	C8 Basin FEMA BRIC Coordination	Miami-Dade County Stormwater	Alberto Pisani Marcia Steelman	Carolina Maran David Colangelo Hongying Zhao Angela Schedel Lynette Cardoch	Marina Blanco-Pape (invited) SFWMD gave overview of how the various projects fit together--broader resiliency program, FPLOS C8/C9 project, and specific BRIC applications. **ACTION:** **Miami- Dade to review Miami-Dade project list.** Angela sent Project List via email 09/22/2021. With specific language: *While reviewing it, the FPLOS project team needs the following information:* *1)Are all of the County's flood mitigation projects identified on this list? If one is missing, please add it.* *2)Is there a project on the list that should not be included?* *3)Keep in mind that we will be asking the responsible agency for additional technical details about each project to help us determine the specifics needed for inclusion in the C8C9 basin FPLOS model.*	

Date/Date Initiated	Purpose	Partner Agency	Partners in Attendance/ Correspondence	Project Team	Notes	Additional Information
9/27/2021	Hollywood Drainage Projects	City of Hollywood			09/27/2021: Lynette to ring Hollywood for potential meeting times. 10/11/2021 Carolina Maran followed up with email requesting time.	
9/28/2021	SBDD Project List	South Broward Drainage District	Kevin Hart	Joseph Wilder	The SBDD provided information regarding the purpose and status of projects within the C8/C9 basin. Topics discussed include the following. •Enlargement of the Silver Lake control structure •Basin S-5 emergency sluice gate •Sluice gate at Encantada, Harbour Lake, and Sunset Lake •Basin S-3 emergency sluice gate •S-1, S-2, S-4/5, S-7 pump stations •B-1 and B-2 pump stations •Basin 3/ Basin 7 interconnect •East by-pass and sluice gate at the S-1 pump station	

Date/Date Initiated	Purpose	Partner Agency	Partners in Attendance/ Correspondence	Project Team	Notes	Additional Information
10/14/2021	FDOT Golden Glades Interchange Project Information	FDOT District 6	Amanda Montgomery	Angela Schedel	Emailed Jennifer Carver and Jennifer Green at FDOT. They forwarded the email to the District 6 Drainage Engineer, who forwarded my request to their environmental permits contractor, Amanda Montgomery. Amanda called Angela to discuss the extent, schedule, cost, and potential drainage changes to the area affected by the FDOT Golden Glades Interchange project. She shared information about the permits and emails for the FDOT District 6 Drainage Engineer, Stantec modelers, and EOR's for the project. Email with info about this project sent to SFWMD.	

Log Item 1: Miami-Dade County LMS Projects - Request for Information

From: Chris Miranda <MirandaC@msvfl.gov>
Sent: Friday, September 17, 2021 10:48 AM
To: Yang, Robin (MDFR)
Cc: Patrick Lawson; Michael DelCharco; Joseph Wilder; Esmond K. Scott
Subject: RE: Miami-Dade County LMS Projects - Request for information
Attachments: Figure1.pdf

Good morning,

Here are the responses to the questions asked:

1. Construction Drawings – Working on schematic plans now. Should be completed within 2 weeks. 60% design to follow approximately 2 months after schematic design.
2. Culvert and gates: sizes, dimensions, inverts, geometry and locations – To be determined upon completion of 60% design
3. Trigger elevations for gates and pumps – To be determined upon completion of 60% design
4. Pump station capacity (CFS) – To be determined upon completion of 60% design
5. Anticipated area of impact – Shores Estates Neighborhood (see attached map)

If you need anything additional just let me know.

Thank You and Stay Healthy,
Chris Miranda
Director
Miami Shores Village
Public Works
10050 NE 2nd Avenue
Miami Shores, FL 33138
(305) 795-2210; Fax (305) 795-2213
mirandac@msvfl.gov

From: Yang, Robin (MDFR) <Robin.Yang@miamidade.gov>
Sent: Thursday, September 16, 2021 4:29 PM
To: Yang, Robin (MDFR) <Robin.Yang@miamidade.gov>
Cc: Patrick Lawson <plawson@taylorengineering.com>; Michael DelCharco <mdelcharco@taylorengineering.com>; Joseph Wilder <jwilder@taylorengineering.com>
Subject: Miami-Dade County LMS Projects - Request for information

Good afternoon LMS partners,

As you may be aware, the South Florida Water Management District has contracted Taylor Engineering to conduct a study to model the Flood Protection Level of Service. If you are receiving this email, it is because projects you entered in the LMS list are part of the current study area.

Please respond to Patrick Lawson (plawson@taylorengineering.com) with technical information about your projects not included in the LMS project list. Information they are requesting includes:

1. Construction Drawings
2. Culvert and gates: sizes, dimensions, inverts, geometry and locations
3. Trigger elevations for gates and pumps
4. Pump station capacity (CFS)
5. Anticipated area of impact

The projects in question are in the attached excel sheet.

For your project to be included in this study, information must be submitted to Taylor Engineering by COB 9/24/2021.

Please reach out to Patrick Lawson if you have any questions about this request.

Patrick Lawson, GISP, CFM | **Director of Geospatial Science**
Taylor Engineering, Inc.
10199 Southside Blvd., Suite 310, Jacksonville, FL 32256
Main: 904-731-7040 | Direct: 904-256-1326
www.taylorengineering.com
Destin | Jacksonville | Sarasota | Tampa

Thank you,

Robin Yang
EM Planner, Office of Emergency Management
Miami-Dade Fire Rescue
Office: 305-468-5427
e-mail: robin.yang@miamidade.gov
www.miamidade.gov/oem
"Delivering Excellence Every Day"

|

From: Patrick Lawson
Sent: Monday, September 20, 2021 2:00 PM
To: Herrera, Liza (DTPW); Yang, Robin (MDFR); Blanco-Pape, Marina (RER)
Cc: Molina, Maria (DTPW)
Subject: RE: Miami-Dade County LMS Projects - Request for information

Thank you very much, Ms. Herrera!

Patrick Lawson, GISP, CFM | **Director of Geospatial Science**
Main: 904-731-7040 | Direct: 904-256-1326

From: Herrera, Liza (DTPW) <Liza.Herrera@miamidade.gov>
Sent: Monday, September 20, 2021 1:37 PM
To: Yang, Robin (MDFR) <Robin.Yang@miamidade.gov>; Blanco-Pape, Marina (RER) <Marina.Blanco-Pape@miamidade.gov>
Cc: Patrick Lawson <plawson@taylorengineering.com>; Molina, Maria (DTPW) <Maria.Molina@miamidade.gov>
Subject: RE: Miami-Dade County LMS Projects - Request for information

Good Afternoon,
Please see attached the as built drawings and design plans for the projects requested:

- Coventry-NE 197 Terrace and NE 17 Avenue, currently under design attached are 90% design plans.
- CRS North-As built attached
- NE 167 Street from NE 14 Avenue to 13 Avenue - As built attached
- NW 146 Street and NW 7 Avenue (east end of street)- has not been designed.

Regards,

Liza Herrera, P.E.,ENV SP
Manager, Stormwater Drainage Design Section
Roadway Engineering and Right-of-Way Division
Miami-Dade County Department of Transportation and Public Works
305-375-4526 Phone
305-375-4969 Fax
herrel@miamidade.gov
"Delivering Excellence Every Day"

From: Yang, Robin (MDFR) <Robin.Yang@miamidade.gov>
Sent: Friday, September 17, 2021 2:10 PM
To: Blanco-Pape, Marina (RER) <Marina.Blanco-Pape@miamidade.gov>; Herrera, Liza (DTPW) <Liza.Herrera@miamidade.gov>
Subject: RE: Miami-Dade County LMS Projects - Request for information

Hello Liza and Marina,

Thank you for the update.

Have a great weekend!

Robin Yang
EM Planner, Office of Emergency Management

Miami-Dade Fire Rescue
Office: 305-468-5427
e-mail: robin.yang@miamidade.gov
www.miamidade.gov/oem
"Delivering Excellence Every Day"

Please consider the environment before printing this e-mail.

From: Blanco-Pape, Marina (RER) <Marina.Blanco-Pape@miamidade.gov>
Sent: Thursday, September 16, 2021 5:09 PM
To: Yang, Robin (MDFR) <Robin.Yang@miamidade.gov>; Herrera, Liza (DTPW) <Liza.Herrera@miamidade.gov>
Subject: FW: Miami-Dade County LMS Projects - Request for information

Robin,

Of the five stormwater projects included in the selected for the study, four are funded and in different stages of development. Liza Herrera, will provide the requested information for those projects.

The fifth project (address: NE 150 St & Spur Dr, FID: 1190) is in our unfunded list of projects. Therefore, we do not have the information requested at this time.

Regards,

Liza, for the four funded projects below, please provide the information requested. Thank you. Regards,

2015-60		6036	20190096	NW 146 Street and NW 7 Avenue (east end of street)	NW 146 Street and NW 7 Avenue (east end of street)	Wait updated from Alex Barrios	C-8	SPUR1-E-1,I95-1C8,7AV-1	C-8	2
	CPE316PWDRNG	7927	20140177	NE 167 Street from NE 14 Avenue to 13 Avenue	NE 167 Street & NE 14 Avenue	SWU	C-9	C9-S-43	C9-E	4
2014-41_1	CPE316RDD029	200		CRS North Mitigation of Repetitive Losses	NE 154 ST FROM NE 7 AVE TO NE 8 AVE NE 151 ST FROM NE 6 PL TO NE 8 AVE NE 154 ST AND NE 150 ST FROM NE 5 AVE TO NE 6 AVE	SWU fee increase (FY18-19)towards this project.	C-9EAST,C-7,C-8,NBiscayne Bay - Arch Creek & Little Arch Creek	SPUR4-W-2,SPUR-4	C-9EAST,C-7,C-8,NBiscayne Bay - Arch Creek & Little Arch Creek	2,3,4
2020-844	CPE316RDD059		NE 197 Terrace and NE 17 Avenue Drainage Improvements		NE 197 Terrace and NE 17 Avenue	SWU	C9-E	COVENTRY	C9-E	4

From: Yang, Robin (MDFR)
Sent: Thursday, September 16, 2021 4:28 PM
To: Yang, Robin (MDFR)
Cc: Patrick Lawson; Michael DelCharco; Joseph Wilder
Subject: Miami-Dade County LMS Projects - Request for information

Good afternoon LMS partners,

As you may be aware, the South Florida Water Management District has contracted Taylor Engineering to conduct a study to model the Flood Protection Level of Service. If you are receiving this email, it is because projects you entered in the LMS list are part of the current study area.

Please respond to Patrick Lawson (plawson@taylorengineering.com) with technical information about your projects not included in the LMS project list. Information they are requesting includes:

1. Construction Drawings
2. Culvert and gates: sizes, dimensions, inverts, geometry and locations
3. Trigger elevations for gates and pumps
4. Pump station capacity (CFS)
5. Anticipated area of impact

The projects in question are in the attached excel sheet.

For your project to be included in this study, information must be submitted to Taylor Engineering by COB 9/24/2021.

Please reach out to Patrick if you have any questions about this request.

Patrick Lawson, GISP, CFM | **Director of Geospatial Science**
Taylor Engineering, Inc.
10199 Southside Blvd., Suite 310, Jacksonville, FL 32256
Main: 904-731-7040 | Direct: 904-256-1326
www.taylorengineering.com
Destin | Jacksonville | Sarasota | Tampa

Thank you,

Robin Yang
EM Planner, Office of Emergency Management
Miami-Dade Fire Rescue
Office: 305-468-5427
e-mail: robin.yang@miamidade.gov
www.miamidade.gov/oem
"Delivering Excellence Every Day"
MIAMI-DADE COUNTY EMERGENCY MANAGEMENT

From: Patrick Lawson
Sent: Monday, September 20, 2021 10:48 AM
To: Yang, Robin (MDFR)
Cc: Michael DelCharco; Joseph Wilder
Subject: RE: Miami-Dade County LMS Projects - Request for information

Thanks so much, Robin!

Patrick Lawson, GISP, CFM | **Director of Geospatial Science**
Main: 904-731-7040 | Direct: 904-256-1326

From: Yang, Robin (MDFR) <Robin.Yang@miamidade.gov>
Sent: Friday, September 17, 2021 2:12 PM
To: Yang, Robin (MDFR) <Robin.Yang@miamidade.gov>
Cc: Patrick Lawson <plawson@taylorengineering.com>; Michael DelCharco <mdelcharco@taylorengineering.com>; Joseph Wilder <jwilder@taylorengineering.com>
Subject: RE: Miami-Dade County LMS Projects - Request for information

Hi all,

Our RER department provided the following update:

Of the five stormwater projects included in the selected for the study, four are funded and in different stages of development. RER, will provide the requested information for those projects.

The fifth project (address: NE 150 St & Spur Dr, FID: 1190) is in our unfunded list of projects. Therefore, they do not have the information requested at this time.

RER will be providing the information requested for the projects listed below:

2015-60		6036	20190096	NW 146 Street and NW 7 Avenue (east end of street)	NW 146 Street and NW 7 Avenue (east end of street)	Wait updated from Alex Barrios	C-8	SPUR1-E-1,I95-1C8,7AV-1	C-8	2
	CPE316PWDRNG	7927	20140177	NE 167 Street from NE 14 Avenue to 13 Avenue	NE 167 Street & NE 14 Avenue	SWU	C-9	C9-S-43	C9-E	4
2014-41_1	CPE316RDD029	200		CRS North Mitigation of Repetitive Losses	NE 154 ST FROM NE 7 AVE TO NE 8 AVE NE 151 ST FROM NE 6 PL TO NE 8 AVE NE 154 ST AND NE 150 ST FROM NE 5 AVE TO NE 6 AVE	SWU fee increase (FY18-19)towards this project.	C-9EAST,C-7,C-8,NBiscayne Bay - Arch Creek & Little Arch Creek	SPUR4-W-2,SPUR-4	C-9EAST,C-7,C-8,NBiscayne Bay - Arch Creek & Little Arch Creek	2,3,4
2020-844	CPE316RDD059		NE 197 Terrace and NE 17 Avenue Drainage Improvements		NE 197 Terrace and NE 17 Avenue	SWU	C9-E	COVENTRY	C9-E	4

Regards,

Robin Yang
EM Planner, Office of Emergency Management
Miami-Dade Fire Rescue

Office: 305-468-5427
e-mail: robin.yang@miamidade.gov
www.miamidade.gov/oem
"Delivering Excellence Every Day"

Please consider the environment before printing this e-mail.

From: Yang, Robin (MDFR)
Sent: Thursday, September 16, 2021 4:29 PM
To: Yang, Robin (MDFR) <Robin.Yang@miamidade.gov>
Cc: Patrick Lawson <plawson@taylorengineering.com>; Michael DelCharco <mdelcharco@taylorengineering.com>; Joseph Wilder <jwilder@taylorengineering.com>
Subject: Miami-Dade County LMS Projects - Request for information

Good afternoon LMS partners,

As you may be aware, the South Florida Water Management District has contracted Taylor Engineering to conduct a study to model the Flood Protection Level of Service. If you are receiving this email, it is because projects you entered in the LMS list are part of the current study area.

Please respond to Patrick Lawson (plawson@taylorengineering.com) with technical information about your projects not included in the LMS project list. Information they are requesting includes:

1. Construction Drawings
2. Culvert and gates: sizes, dimensions, inverts, geometry and locations
3. Trigger elevations for gates and pumps
4. Pump station capacity (CFS)
5. Anticipated area of impact

The projects in question are in the attached excel sheet.

For your project to be included in this study, information must be submitted to Taylor Engineering by COB 9/24/2021.

Please reach out to Patrick if you have any questions about this request.

Patrick Lawson, GISP, CFM | **Director of Geospatial Science**
Taylor Engineering, Inc.
10199 Southside Blvd., Suite 310, Jacksonville, FL 32256
Main: 904-731-7040 | Direct: 904-256-1326
www.taylorengineering.com
Destin | Jacksonville | Sarasota | Tampa

Thank you,

Robin Yang
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Miami-Dade Fire Rescue
Office: 305-468-5427
e-mail: robin.yang@miamidade.gov
www.miamidade.gov/oem
"Delivering Excellence Every Day"

From: Tobias,Chidi <Chidi.Tobias@citynmb.com>
Sent: Tuesday, September 21, 2021 4:28 PM
To: Patrick Lawson
Cc: Johnson, Judeen; Adediran, Emmanuel; Christian,Gregory; Yang, Robin (MDFR); Parada,Ana C.
Subject: RE: Miami-Dade County LMS Projects - Request for information
Attachments: PUMP STATION ASBUILT 2020 PDF BINDER rev 07-24-20.pdf; Pump Controls.docx

Good day,

As requested, information for the Pump Station on West Dixie Highway is attached.

The station is capable of managing 9,875 gallons per minute (22 cfs) and is designed for a 25-year 3 day storm.

Regards,

D. Chidi Tobias | *Fields Division Manager*
City of North Miami Beach
Public Works Department
T (305) 948-2904, ext. 4115

1965 NE 151st Street, North Miami Beach, FL 33162 | www.citynmb.com | City NMB on Social Media:

From: Yang, Robin (MDFR) <Robin.Yang@miamidade.gov>
Sent: Thursday, September 16, 2021 4:29 PM
To: Yang, Robin (MDFR) <Robin.Yang@miamidade.gov>
Cc: Patrick Lawson <plawson@taylorengineering.com>; Michael DelCharco <mdelcharco@taylorengineering.com>; Joseph Wilder <jwilder@taylorengineering.com>
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Thank you,

Robin Yang
EM Planner, Office of Emergency Management
Miami-Dade Fire Rescue
Office: 305-468-5427
e-mail: robin.yang@miamidade.gov
www.miamidade.gov/oem
"Delivering Excellence Every Day"

From: Patrick Lawson
Sent: Thursday, September 23, 2021 2:33 PM
To: Herrera, Liza (DTPW); Yang, Robin (MDFR); Blanco-Pape, Marina (RER)
Cc: Molina, Maria (DTPW); Stephanie Massey; Angela Schedel; Michael DelCharco; Joseph Wilder
Subject: RE: Miami-Dade County LMS Projects - Request for information

Good afternoon Ms. Herrera,

The Miami-Dade LMS records do not show a project at CRS North (NE 154th ST/7th Avenue). We can add this to our list of potential mitigation projects but will most likely request additional information.

Do you have any information about the nearby project at NE 154 Street and NE 5 Court?

Thank you!

Patrick Lawson, GISP, CFM | **Director of Geospatial Science**
Main: 904-731-7040 | Direct: 904-256-1326

From: Herrera, Liza (DTPW) <Liza.Herrera@miamidade.gov>
Sent: Monday, September 20, 2021 1:37 PM
To: Yang, Robin (MDFR) <Robin.Yang@miamidade.gov>; Blanco-Pape, Marina (RER) <Marina.Blanco-Pape@miamidade.gov>
Cc: Patrick Lawson <plawson@taylorengineering.com>; Molina, Maria (DTPW) <Maria.Molina@miamidade.gov>
Subject: RE: Miami-Dade County LMS Projects - Request for information

Good Afternoon,
Please see attached the as built drawings and design plans for the projects requested:

- Coventry-NE 197 Terrace and NE 17 Avenue, currently under design attached are 90% design plans.
- CRS North-As built attached
- NE 167 Street from NE 14 Avenue to 13 Avenue - As built attached
- NW 146 Street and NW 7 Avenue (east end of street)- has not been designed.

Regards,

Liza Herrera, P.E.,ENV SP
Manager, Stormwater Drainage Design Section
Roadway Engineering and Right-of-Way Division
Miami-Dade County Department of Transportation and Public Works
305-375-4526 Phone
305-375-4969 Fax
herrel@miamidade.gov
"Delivering Excellence Every Day"

From: Yang, Robin (MDFR) <Robin.Yang@miamidade.gov>
Sent: Friday, September 17, 2021 2:10 PM
To: Blanco-Pape, Marina (RER) <Marina.Blanco-Pape@miamidade.gov>; Herrera, Liza (DTPW) <Liza.Herrera@miamidade.gov>
Subject: RE: Miami-Dade County LMS Projects - Request for information

Hello Liza and Marina,

Thank you for the update.

Have a great weekend!

Robin Yang
EM Planner, Office of Emergency Management
Miami-Dade Fire Rescue
Office: 305-468-5427
e-mail: robin.yang@miamidade.gov
www.miamidade.gov/oem
"Delivering Excellence Every Day"

MIAMI-DADE COUNTY EMERGENCY MANAGEMENT

From: Blanco-Pape, Marina (RER) <Marina.Blanco-Pape@miamidade.gov>
Sent: Thursday, September 16, 2021 5:09 PM
To: Yang, Robin (MDFR) <Robin.Yang@miamidade.gov>; Herrera, Liza (DTPW) <Liza.Herrera@miamidade.gov>
Subject: FW: Miami-Dade County LMS Projects - Request for information

Robin,

Of the five stormwater projects included in the selected for the study, four are funded and in different stages of development. Liza Herrera, will provide the requested information for those projects.

The fifth project (address: NE 150 St & Spur Dr, FID: 1190) is in our unfunded list of projects. Therefore, we do not have the information requested at this time.

Regards,

Liza, for the four funded projects below, please provide the information requested. Thank you. Regards,

2015-60		6036	20190096	NW 146 Street and NW 7 Avenue (east end of street)	NW 146 Street and NW 7 Avenue (east end of street)	Wait updated from Alex Barrios	C-8	SPUR1-E-1,I95-1C8,7AV-1	C-8	2
	CPE316PWDRNG	7927	20140177	NE 167 Street from NE 14 Avenue to 13 Avenue	NE 167 Street & NE 14 Avenue	SWU	C-9	C9-S-43	C9-E	4
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2020-844	CPE316RDD059		NE 197 Terrace and NE 17 Avenue Drainage Improvements		NE 197 Terrace and NE 17 Avenue	SWU	C9-E	COVENTRY	C9-E	4

From: Yang, Robin (MDFR)
Sent: Thursday, September 16, 2021 4:28 PM
To: Yang, Robin (MDFR)

Cc: Patrick Lawson; Michael DelCharco; Joseph Wilder
Subject: Miami-Dade County LMS Projects - Request for information

Good afternoon LMS partners,

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Please respond to Patrick Lawson (plawson@taylorengineering.com) with technical information about your projects not included in the LMS project list. Information they are requesting includes:

1. Construction Drawings
2. Culvert and gates: sizes, dimensions, inverts, geometry and locations
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5. Anticipated area of impact

The projects in question are in the attached excel sheet.

For your project to be included in this study, information must be submitted to Taylor Engineering by COB 9/24/2021.

Please reach out to Patrick if you have any questions about this request.

Patrick Lawson, GISP, CFM | **Director of Geospatial Science**
Taylor Engineering, Inc.
10199 Southside Blvd., Suite 310, Jacksonville, FL 32256
Main: 904-731-7040 | Direct: 904-256-1326
www.taylorengineering.com
Destin | Jacksonville | Sarasota | Tampa

Thank you,

Robin Yang
EM Planner, Office of Emergency Management
Miami-Dade Fire Rescue
Office: 305-468-5427
e-mail: robin.yang@miamidade.gov
www.miamidade.gov/oem
"Delivering Excellence Every Day"
MIAMI-DADE COUNTY EMERGENCY MANAGEMENT

From: Yang, Robin (MDFR) <Robin.Yang@miamidade.gov>
Sent: Thursday, September 23, 2021 4:54 PM
To: Patrick Lawson
Cc: Michael DelCharco; Joseph Wilder; Angela Schedel
Subject: RE: Miami-Dade County LMS Projects - Request for information
Attachments: RE: Miami-Dade County LMS Projects - Request for information

Hi Patrick,

I reached out to all the points of contact for LMS for the agencies listed in the excel sheet with project you provided:

Miami Gardens
Miami Shores
North Miami
North Miami Beach
Public Works
Regulatory and Economic Resources

I've attached the email I sent out… I believe you should be able to see the BCC line this way.

Regards,

Robin Yang
EM Planner, Office of Emergency Management
Miami-Dade Fire Rescue
Office: 305-468-5427
e-mail: robin.yang@miamidade.gov
www.miamidade.gov/oem
"Delivering Excellence Every Day"

From: Patrick Lawson <plawson@taylorengineering.com>
Sent: Thursday, September 23, 2021 4:29 PM
To: Yang, Robin (MDFR) <Robin.Yang@miamidade.gov>
Cc: Michael DelCharco <mdelcharco@taylorengineering.com>; Joseph Wilder <jwilder@taylorengineering.com>; Angela Schedel <aschedel@taylorengineering.com>
Subject: RE: Miami-Dade County LMS Projects - Request for information

EMAIL RECEIVED FROM EXTERNAL SOURCE

Thanks for sending the reminder, Robin!

Would you mind sharing the list of partners that you reached out to? We'd like to document who we've requested data from.

Happy Thursday!

Patrick Lawson, GISP, CFM | **Director of Geospatial Science**
Main: 904-731-7040 | Direct: 904-256-1326

From: Yang, Robin (MDFR) <Robin.Yang@miamidade.gov>
Sent: Thursday, September 23, 2021 4:15 PM
To: Yang, Robin (MDFR) <Robin.Yang@miamidade.gov>
Cc: Patrick Lawson <plawson@taylorengineering.com>; Michael DelCharco <mdelcharco@taylorengineering.com>; Joseph Wilder <jwilder@taylorengineering.com>
Subject: RE: Miami-Dade County LMS Projects - Request for information

Good afternoon LMS partners,

Please see the information request below regarding your LMS flood related projects. Some of you have not yet responded to the request. Please provide a response as soon as possible so this study may be as accurate as possible.

Thank you,

Robin Yang
EM Planner, Office of Emergency Management
Miami-Dade Fire Rescue
Office: 305-468-5427
e-mail: robin.yang@miamidade.gov
www.miamidade.gov/oem
"Delivering Excellence Every Day"

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Sent: Thursday, September 16, 2021 4:29 PM
To: Yang, Robin (MDFR) <Robin.Yang@miamidade.gov>
Cc: Patrick Lawson <plawson@taylorengineering.com>; Michael DelCharco <mdelcharco@taylorengineering.com>; Joseph Wilder

<jwilder@taylorengineering.com>
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Thank you,

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Miami-Dade Fire Rescue
Office: 305-468-5427
e-mail: robin.yang@miamidade.gov
www.miamidade.gov/oem
"Delivering Excellence Every Day"

From: Herrera, Liza (DTPW) <Liza.Herrera@miamidade.gov>
Sent: Friday, September 24, 2021 12:24 PM
To: Patrick Lawson; Yang, Robin (MDFR); Blanco-Pape, Marina (RER)
Cc: Molina, Maria (DTPW); Stephanie Massey; Angela Schedel; Michael DelCharco; Joseph Wilder
Subject: RE: Miami-Dade County LMS Projects - Request for information
Attachments: FINAL PLANS UPDATE NE 154 ST-5 AVE to 5 CT.pdf

Good afternoon Patrick,
See attached plans for the area requested.

Regards,

Liza Herrera, P.E.,ENV SP
Manager, Stormwater Drainage Design Section
Roadway Engineering and Right-of-Way Division
Miami-Dade County Department of Transportation and Public Works
305-375-4526 Phone
305-375-4969 Fax
herrel@miamidade.gov
"Delivering Excellence Every Day"

From: Patrick Lawson <plawson@taylorengineering.com>
Sent: Thursday, September 23, 2021 2:33 PM
To: Herrera, Liza (DTPW) <Liza.Herrera@miamidade.gov>; Yang, Robin (MDFR) <Robin.Yang@miamidade.gov>; Blanco-Pape, Marina (RER) <Marina.Blanco-Pape@miamidade.gov>
Cc: Molina, Maria (DTPW) <Maria.Molina@miamidade.gov>; Stephanie Massey <smassey@taylorengineering.com>; Angela Schedel <aschedel@taylorengineering.com>; Michael DelCharco <mdelcharco@taylorengineering.com>; Joseph Wilder <jwilder@taylorengineering.com>
Subject: RE: Miami-Dade County LMS Projects - Request for information

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Good afternoon Ms. Herrera,

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Do you have any information about the nearby project at NE 154 Street and NE 5 Court?

Thank you!

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Main: 904-731-7040 | Direct: 904-256-1326

From: Herrera, Liza (DTPW) <Liza.Herrera@miamidade.gov>
Sent: Monday, September 20, 2021 1:37 PM
To: Yang, Robin (MDFR) <Robin.Yang@miamidade.gov>; Blanco-Pape, Marina (RER) <Marina.Blanco-Pape@miamidade.gov>
Cc: Patrick Lawson <plawson@taylorengineering.com>; Molina, Maria (DTPW) <Maria.Molina@miamidade.gov>
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Miami-Dade County Department of Transportation and Public Works
305-375-4526 Phone
305-375-4969 Fax
herrel@miamidade.gov
"Delivering Excellence Every Day"

From: Yang, Robin (MDFR) <Robin.Yang@miamidade.gov>
Sent: Friday, September 17, 2021 2:10 PM
To: Blanco-Pape, Marina (RER) <Marina.Blanco-Pape@miamidade.gov>; Herrera, Liza (DTPW) <Liza.Herrera@miamidade.gov>
Subject: RE: Miami-Dade County LMS Projects - Request for information

Hello Liza and Marina,

Thank you for the update.

Have a great weekend!

Robin Yang
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Miami-Dade Fire Rescue
Office: 305-468-5427
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MIAMI-DADE COUNTY
EMERGENCY MANAGEMENT

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Sent: Thursday, September 16, 2021 5:09 PM
To: Yang, Robin (MDFR) <Robin.Yang@miamidade.gov>; Herrera, Liza (DTPW) <Liza.Herrera@miamidade.gov>
Subject: FW: Miami-Dade County LMS Projects - Request for information

Robin,

Of the five stormwater projects included in the selected for the study, four are funded and in different stages of development. Liza Herrera, will provide the requested information for those projects.

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Regards,

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	CPE316PWDRNG	7927	20140177	NE 167 Street from NE 14 Avenue to 13 Avenue	NE 167 Street & NE 14 Avenue	SWU	C-9	C9-S-43	C9-E	4
2014-41_1	CPE316RDD029	200		CRS North Mitigation of Repetitive Losses	NE 154 ST FROM NE 7 AVE TO NE 8 AVE NE 151 ST FROM NE 6 PL TO NE 8 AVE NE 154 ST AND NE 150 ST FROM NE 5 AVE TO NE 6 AVE	SWU fee increase (FY18-19)towards this project.	C-9EAST,C-7,C-8,NBiscayne Bay - Arch Creek & Little Arch Creek	SPUR4-W-2,SPUR-4	C-9EAST,C-7,C-8,NBiscayne Bay - Arch Creek & Little Arch Creek	2,3,4
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From: Yang, Robin (MDFR)
Sent: Thursday, September 16, 2021 4:28 PM
To: Yang, Robin (MDFR)
Cc: Patrick Lawson; Michael DelCharco; Joseph Wilder
Subject: Miami-Dade County LMS Projects - Request for information

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The projects in question are in the attached excel sheet.

For your project to be included in this study, information must be submitted to Taylor Engineering by COB 9/24/2021.

Please reach out to Patrick if you have any questions about this request.

Patrick Lawson, GISP, CFM | Director of Geospatial Science

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10199 Southside Blvd., Suite 310, Jacksonville, FL 32256
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www.taylorengineering.com
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Thank you,

Robin Yang
EM Planner, Office of Emergency Management
Miami-Dade Fire Rescue
Office: 305-468-5427
e-mail: robin.yang@miamidade.gov
www.miamidade.gov/oem
"Delivering Excellence Every Day"
MIAMI-DADE COUNTY EMERGENCY MANAGEMENT

Log Item 3: FEMA BRIC Coordination

From:	Pisani, Alberto (RER) <Alberto.Pisani@miamidade.gov>
Sent:	Friday, October 1, 2021 12:50 PM
To:	Angela Schedel; Blanco-Pape, Marina (RER); Steelman, Marcia (RER)
Cc:	Michael DelCharco; Cardoch, Lynette; Owosina, Akintunde; Zhao, Hongying; Maran, Ana Carolina; Colangelo, David
Subject:	RE: C8 Basin FEMA BRIC Coordination
Attachments:	C8-C9 Projects.pdf

Follow Up Flag:	Follow up
Flag Status:	Completed

Angela:

I am sending you our complete list of funded and unfunded flood mitigation projects for basins C-8 and C-9. See attached.

Thanks

Alberto Pisani, P.E., ENV SP
Sr. Professional Engineer
Department of Regulatory and Economic Resources
Division of Environmental Resources Management
Water Management
701 N.W. 1st Court. 5th Floor
Miami, Florida 33136-3912
(305) 372-6834 (Office)
(786) 493-1439 (Mobile)
alberto.pisani@miamidade.gov

From: Angela Schedel <aschedel@taylorengineering.com>
Sent: Wednesday, September 22, 2021 3:50 PM
To: Blanco-Pape, Marina (RER) <Marina.Blanco-Pape@miamidade.gov>; Pisani, Alberto (RER) <Alberto.Pisani@miamidade.gov>; Steelman, Marcia (RER) <Marcia.Steelman@miamidade.gov>
Cc: Michael DelCharco <mdelcharco@taylorengineering.com>; Cardoch, Lynette <lcardoch@moffattnichol.com>; Owosina, Akintunde <aowosin@sfwmd.gov>; Zhao, Hongying <hzhao@sfwmd.gov>; Maran, Ana Carolina <cmaran@sfwmd.gov>; Colangelo, David <dcolange@sfwmd.gov>
Subject: RE: C8 Basin FEMA BRIC Coordination

Alberto,
As requested during our talk today, I've attached the list of flood mitigation projects we have collected for the C8/C9 basins within Miami-Dade County.

Carolina requested the County's review of the list. While reviewing it, the FPLOS project team needs the following information:

1) Are all of the County's flood mitigation projects identified on this list? If one is missing, please add it.
2) Is there a project on the list that should not be included?

3) Keep in mind that we will be asking the responsible agency for additional technical details about each project to help us determine the specifics needed for inclusion in the C8C9 basin FPLOS model.

Thank you.
Best,
Angela

Angela Schedel, Ph.D., P.E. | **Vice President, Community Resilience**

Taylor Engineering, Inc.
10199 Southside Blvd., Suite 310, Jacksonville, FL 32256
Main: 904-731-7040 | Direct: 904-256-1305
www.taylorengineering.com
Destin | Jacksonville | Sarasota | Tampa

-----Original Appointment-----
From: Maran, Ana Carolina <cmaran@sfwmd.gov>
Sent: Monday, September 20, 2021 10:05 AM
To: Maran, Ana Carolina; Colangelo, David; Zhao, Hongying; Marina Blanco-Pape; Pisani, Alberto (RER); Steelman, Marcia (RER); Michael DelCharco; Owosina, Akintunde; Cardoch, Lynette
Subject: C8 Basin FEMA BRIC Coordination
When: Wednesday, September 22, 2021 3:00 PM-4:00 PM (UTC-05:00) Eastern Time (US & Canada).
Where: Microsoft Teams Meeting

____

Microsoft Teams meeting

Join on your computer or mobile app
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____

Log Item 5: SBDD Project List

From: Joseph Wilder
Sent: Tuesday, September 28, 2021 12:35 PM
To: Kevin Hart
Subject: SBDD Project list

Kevin,

Thanks for providing detail regarding the status and purpose of projects on the SBDD list we have. Here are some notes to summarize our conversation, please feel free to correct or add detail as you see fit.

1. Enlargement of Silver Lake Control Structure:
   - A single 72" culvert already exists that connects C9 to C11 through the SBDD S-5 and S-9 basins
   - SBDD has no immediate plans of enlargement (crosses major road- Pines Blvd)

2. Basin S-5 emergency sluice gate:
   - Proposed project to provide emergency relief of S-5 Basin *with permission* from District.
   - Would *not* have a set trigger elevation that would allow it to start operating automatically. Manually operated.

   Please provide example of emergency sluice gate (geometry, design capacity, etc).

3. Encantada, Harbour Lake and Sunset Lake sluice gate:
   - Fixed crest weirs were replaced with sluice gates.
   - Project already installed, waiting on some final things (this is modellable as is).
   - Used for pre-storm drawdown

   Please provide invert, height, width, and operation criteria (i.e., will they open automatically when HW > 5.0?).

4. Basin S-3 emergency sluice gate:
   - Proposed project to provide emergency relief of S-3 Basin *with permission* from District.
   - Would *not* have a set trigger elevation that would allow it to start operating.

   Same example as Basin S-5 emergency sluice gate.

5. S-1, S-2, S-, S-4/5, S-7, S-7 Pump Stations:
   - These pump stations are at permitted allowance and have backup pumps (could readily increase discharge with permission from District)
   - Resiliency upgrades such as fire suppression systems, upgraded exhaust, concrete roof, etc
   - *No increase* in pump capacity or anything directly affecting discharge

6. B-1 & B-2 Pump Stations:
   - Upgrading from diesel to electric
   - Service area is relatively small, but larger pumps could help reduce flooding
   - If downstream pump station (S-1) is forced to turn off, then B-1 & B-2 would need to be turned off.

   Upgrading from 15k GPM to 25k? These are manually operated, so no set trigger elevation to automatically turn on, right?

7. Basin 3 / Basin 7 interconnect
   - Could help reduce flooding in secondary system when one basin is critical and the other isn't.

   Please provide details. Gate/culvert/gated culvert, dimensions, etc. This would be manually operated, so no set HW/TW trigger?

8. East by-pass & sluice gate at S-1 Pump Station:
   - Proposed operational gate.
   - No increase in permitted allowance, however, it could act as another discharge point and increase capacity if given permission from District.
   - Reduces burden on pump station and could act as a failsafe if pump(s) fail (given HW/TW conditions).

   Please provide some preliminary detail such as gate width or estimated design discharge.

I believe that covers everything we discussed.

Thanks!

Joseph Wilder, E.I. | **Water Resources Engineer**

Taylor Engineering, Inc.
14499 N. Dale Mabry Hwy, Ste 290, Tampa, FL 33618
Main: 813-963-6469 | Direct: 813-343-0817
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Log Item 7: FDOT Golden Glades Drainage Project Information

From:	Montgomery, Amanda <Amanda.Montgomery@dot.state.fl.us>
Sent:	Thursday, October 14, 2021 5:48 PM
To:	Angela Schedel
Cc:	Francis, Manuel; Restrepo, Juan; Pulido, Nathaniel; Dominguez, Mario; Navarro, JuanR; Greg Griffith
Subject:	FW: Drainage Question about Golden Glades Project

Hey Angela,

So nice to 'meet you' and hear about this exciting effort! Thank you for taking the time to chat with me on the phone about the GGI project.

As discussed, there is a SFWMD Conceptual Permit (Permit # 13-06504-P; Application # 180424-511) with information pertaining to the overall drainage condition that you can access through the ePermitting portal. We will be going back to SFWMD to obtain construction permits under the GGI Light scope in January 2022. I am including the master drainage EORs on this response in the event they can provide you with any additional information to assist the Districts mapping/modeling efforts.

Please let me know if I can be of any additional assistance. Best of luck with your endeavors.

Best wishes,
Amanda Montgomery, PWS, WEDG

WGI – Environmental Permits Consultant
Florida Department of Transportation - District VI
1000 NW 111th Avenue - Rm 6211
Miami, Florida 33172

FDOT | Amanda.Montgomery@dot.state.fl.us
WGI | Amanda.Montgomery@WGInc.com
(d) | 786.878.5016

From: Pulido, Nathaniel <Nathaniel.Pulido@dot.state.fl.us>
Sent: Thursday, October 14, 2021 4:02 PM
To: Montgomery, Amanda <Amanda.Montgomery@dot.state.fl.us>
Cc: Dominguez, Mario <Mario.Dominguez@dot.state.fl.us>; Navarro, JuanR <JuanR.Navarro@dot.state.fl.us>
Subject: FW: Drainage Question about Golden Glades Project

Good afternoon Amanda,

Please see request below. Please reach out to EORs if needed to get requested info.

Regards,

Nathan V. Pulido, P.E.
District Drainage Engineer
Florida Department of Transportation - District 6 Adam Leigh Cann Building
1000 NW 111th Avenue - Room 6211
Miami, FL 33172
Office (305)-470-5264
Email: nathaniel.pulido@dot.state.fl.us

From: Green, Jennifer <Jennifer.Green@dot.state.fl.us>
Sent: Thursday, October 14, 2021 2:50 PM
To: Poole, James <James.Poole@dot.state.fl.us>; Pulido, Nathaniel <Nathaniel.Pulido@dot.state.fl.us>
Cc: Carver, Jennifer <Jennifer.Carver@dot.state.fl.us>; Dominguez, Mario <Mario.Dominguez@dot.state.fl.us>
Subject: FW: Drainage Question about Golden Glades Project

James & Nathan,
Can you help Angela with her request below?

Jennifer Green, P.E.
State Drainage Engineer
Phone: (850) 414-4351

From: Angela Schedel <aschedel@taylorengineering.com>
Sent: Thursday, October 14, 2021 1:24 PM
To: Green, Jennifer <Jennifer.Green@dot.state.fl.us>
Cc: Carver, Jennifer <Jennifer.Carver@dot.state.fl.us>
Subject: Drainage Question about Golden Glades Project

EXTERNAL SENDER: Use caution with links and attachments.

Jennifer(s) 😉,
I appreciated your insight when we met last fall while I was working with DEP to define the SLIP tool requirements. I hope you can provide similar perspective on one of FDOT's planned projects – the Golden Glades Interchange Enhancement.

I have a resilience question that is unrelated to SLIP, that I'm asking on behalf of my client SFWMD. I'm working on a project with Dr. Carolina Maran's team where we are researching future flood mitigation projects within the District's C8 and C9 basins. My consulting team is creating hydrologic models of the basins with and without SLR and local partner's projects. More info about our project can be found at our project website:
http://www.buildcommunityresilience.com/SFWMD/FPLOS/c8c9/

During a call with Jim Murley of MDC last week, he mentioned that we should reach out to FDOT to obtain more details on potential drainage changes within the Golden Glades project area. Do you have any preliminary conceptual designs that you can share with our consulting team? This would help us understand the extent of the project and if/how it may affect the C8 and C9 basins' future performance.

Thank you for your advice.
Best,
Angela

Angela Schedel, Ph.D., P.E. | **Vice President, Community Resilience**
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Destin | Jacksonville | Sarasota | Tampa

APPENDIX C: Pre-Workshop Stakeholder Survey Responses

Respondent	What is your involvement in flood mitigation and adaptation planning?	Have you observed significant changes in flooding conditions in the recent 5-10 years? Do you have any documentation?	What do you believe are the major limitations of the existing flooding system at C-8 and C-9 Basins? Do you have a plan and preferred actions to address these limitations?	How are future conditions (e.g. sea level rise or increased rainfall) considered as part of project planning/design?	Please state your name.	Please state your organization.	Please provide your email.	Please provide your phone number.
1	Shareholder	No	No	Respondent skipped this question	NA	NA	NA	NA
2	I am the Floodplain Administrator for the city of Miami Gardens, Hialeah and the Town of Medley	More severe flooding during major events	Gravity flow to the east in advance of flood events is not adequate to create capacity in both C8 and C9, different interests in habit he District from moving water more quickly (ESA, Miccosukee's, Everglades National Park, urban residents, Miami-Dade County residents and governments)	Not adequate currently, but now being considered, which is beneficial	NA	NA	NA	NA
3	State Drainage Engineer for Florida Department of Transportation	Respondent skipped this question	Respondent skipped this question	Sea level rise should be considered for tailwater conditions with appropriate risk tolerance of the agency. Using NOAA Atlas 14 rainfall data and confidence limits should account for future rainfall conditions.	NA	NA	NA	NA
4	Prepare plans and manage flood mitigation	N/A. I have been with the Town only 1 year. No documentation	Town would like better maintenance plan and coordination with FDOT for the C-9 canal	Increased rainfall causes increase lake levels. Outflow is constrained due to limited capacity. Pumps are operating non-stop to maintain lake levels and avoid floods.	NA	NA	NA	NA
5	Project management.	Yes and yes.	Respondent skipped this question	Factored in plans and design.	NA	NA	NA	NA
6	Municipal Public Works staff	Over the past 3 years yes. Do not have sufficient data to compare before that.	Capacity	Future storm drainage improvement projects are being designed with higher capacity than current data requires.	NA	NA	NA	NA
7	I'm the resilience program manager for adaptation in Miami-Dade County's Office of Resilience	I think tide gauge or other observational data support this. We also have photos.	Elevating certain homes/businesses will have to be part of the solution - some areas are just a foot or two above current high tides. It is too difficult to design a whole water management system around these lowest-lying areas. We need to raise the lowest areas.	Sea level rise is reasonable well incorporated into County planning. Changes in precipitation are not yet fully.	NA	NA	NA	NA
8	As the Public Works Director, I am on the high level decision making team for our municipality	We have a sub-division along the C-8 that has experienced a significant increase in flooding over the last 5 years.	I believe the embankment/seawalls need to be raised along the C-8	These conditions should be the driving forces behind project planning/design.	NA	NA	NA	NA

Respondent	What is your involvement in flood mitigation and adaptation planning?	Have you observed significant changes in flooding conditions in the recent 5-10 years? Do you have any documentation?	What do you believe are the major limitations of the existing flooding system at C-8 and C-9 Basins? Do you have a plan and preferred actions to address these limitations?	How are future conditions (e.g. sea level rise or increased rainfall) considered as part of project planning/design?	Please state your name.	Please state your organization.	Please provide your email.	Please provide your phone number.
9	Managers of a secondary canal system located in four N. Broward Water Control Districts	We have observed an increase in storm intensities which overwhelm drainage systems causing localized flooding	We are not familiar with the major limitations of the existing flooding system in C8-C9 basins and have no preferred actions	For N. Broward County, sea level rise and increased rainfall are included as considerations for all planning activities	NA	NA	NA	NA
10	Regulatory (issuance of SWM licenses and delegated ERP)	Respondent skipped this question.	Tidal influence. Pump and gated structures could be overtopped due to low elevation of canal banks on C-9 during storm surge events.	Conveyance capacity of tidal areas downstream of coastal structures serving C9 and C-8 basins must be considered. These areas will experience high tidal surge, and discharge from coastal structure may have to be balanced between the need to continued to provide a flood protection service in wester areas and preventing additional surcharge elevation on the eastern areas resulting from coastal structure discharges.	NA	NA	NA	NA
11	I lead a team at Broward county.	Yes, yes.	Respondent skipped this question	Respondent skipped this question	Gregory Mount	Broward County EPGMD	gmount@broward.ord	954-519-0356
12	Regional Planning Agency providing assistance to local governments.	Respondent skipped this question	Respondent skipped this question	Respondent skipped this question	Isabel Cosio Carballo	South Florida Regional Planning Council	isabelc@sfrpc.com	954-924-3653
13	Flooding inspections, sea level rise, king tide response.	Yes.	Unknown	Sea wall height changes, elevated ground water levels.	Larry Teich	City of Fort Lauderdale	lteich@fortlauderdale.gov	954-828-7844
14	Work with Resource Management Division at the NW FL Water Management District	(I do not have experience in basins C-8 and C-9.)	(Have no information on this topic.)	(Will be interested in learning about this.)	Paul Thorpe	Northwest Florida Water Management District	Paul.Thorpe@nwfwater.com	(850) 539-2643
15	Hydrologic modeling	Yes	Respondent skipped this question	Respondent skipped this question	Michelle Irizarry-Ortiz	USGS	mirizarry-ortiz@usgs.gov	(407) 803-5569
16	Planning activities with the Broward MPO related to resiliency	No documentation/ only anecdotal	No strong opinion/ no plan from the MPO for these systems	Yes, resiliency is a factor in project prioritization	James Cromar	Broward MPO	cromarj@browardmpo.org	954-876-0038
17	Ecosystem restoration projects, i.e., BBSEER	I have not received documents related to specific conditions	Not sure	Projected using relevant sea level curves and modeling	April Patterson	U.S. Army Corps of Engineers	April.N.Patterson@usace.army.mil	904-549-3803

APPENDIX D: Workshop Meeting Agenda and Notes

South Florida Water Management District

AGENDA

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

August 3, 2021
9:00 AM – 12:00 PM
Florida International University
Biscayne Bay Campus
Wolfe University Center (Room 155)
3000 151st Street, North Miami, FL 33181

9:10 – 9:20	Welcome – Drew Bartlett, Executive Director, SFWMD
9:20 – 9:35	Flood Protection Level of Service Program – Akintunde Owosina, PE, H&H Bureau Chief, SFWMD
9:40 – 9:55	Phase I Study Results – Michael DelCharco, PE, Taylor Engineering
10:00 – 10:10	Phase II Pre-Workshop Feedback – Lynette Cardoch, PhD, Moffatt & Nichol
10:15 – 11:00	Breakout Sessions
11:10 – 11:40	Reporting on Breakout Sessions
11:40 – 11:55	Next Steps – Carolina Maran, PhD, PE, District Resiliency Officer, SFWMD
11:55 – 12:00	Closing

South Florida Water Management District

MEETING NOTES

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

August 3, 2021
9:00 AM
Florida International University
Biscayne Bay Campus
Wolfe University Center (Room 155)
3000 NE 151st Street, North Miami, FL 33181

Please find the PowerPoint presentation and all files noted throughout on the project website:
http://www.buildcommunityresilience.com/SFWMD/FPLOS/c8c9/ProjectDocuments.aspx

1. Welcome via video, Drew Bartlett, Executive Director, SFWMD
    a. See the video file "August 3, 2021 Workshop: Welcome Remarks from Drew Bartlett, Executive Director, SFWMD" on the project website.
2. Adam Blalock, Deputy Secretary for Ecosystems Restoration, Florida Department of Environmental Protection (FDEP)
    a. Main Message:
        i. Briefly explained the resiliency grant program.
        ii. See https://floridadep.gov/rcp/florida-resilient-coastlines-program/content/frcp-resilience-grants

3. Flood Protection Level of Service Program (FPLOS) – Akintunde Owosina, PE, H&H Bureau Chief, SFWMD
    a. Main Message:
        i. Background of Flood Protection Responsibilities, the water management systems in the district, and sea level rise (SLR) projections

   ii. An Introduction to the FPLOS program and the different phases
b. Partner Feedback and Questions:
   i. Q: Are there other functions to maintain the water levels?
      A: Yes, there are two aspects – ground storage and the canals, which can move it across the land. Levels are kept high during the dry season to maintain the water system, and low during the wet season to create room and to maintain ground storage for smaller rain events. Gravity structures will eventually need to be raised to adapt to increased water levels.
   ii. Q: Does Phase I account for storm surge?
      A: Yes, it does. We modeled storm surge as a boundary condition. Several factors are involved in a level of service - at least three different SLR scenarios, and four storm surge conditions, and rainfall events.
   iii. Q: Since it is a remodeling job of an old system, there may be missed opportunities of new ideas, such as land acquisition, are not incorporated into the model to deal with the water quality in areas (Biscayne Bay). Pumping more water into it would be against Miami-Dade County's best interest.
      A: Yes, we might come across opportunities that provide both flood protection and water quality aspects. The initial focus is flood protection; but not all solutions will pump to tides. All these things are on the table as we evaluate the flood protection that projects may provide. The District will include water quality as a factor in the mitigation benefits, so that decision makers can make better decisions. Initially, nothing will be left out.

4. Phase I Study Results – Michael DelCharco, PE, Taylor Engineering
   a. Main Message:
      i. Phase I project – Summary/Background, explanation of the six metrics, model selections, and the findings (with example maps of limited results)
      ii. The objective and overview of Phase II – future land use, potential mitigation strategies (examples of them to explain what the consultant team is looking for), and example results
   b. Partner Feedback and Questions:
      i. Q: Has the Phase I model been broken down into level of service? Is the primary system being modeled only?
         A: The whole basin is modeled – so the primary, secondary, and tertiary systems are included. The model resolution comprises 125 square grids. Metrics are analyzed based on district infrastructure and their ability to get water out to tide.
      ii. Q: How is the level of service assessed for a whole system based on individual metrics? How is the return period being assigned?
         A: In giving "summaries" of the overall system we are making general statements primarily about the least efficient parts of the system. There exist different levels of service at different locations. Like a hurricane that can be a 100-year event in one location and a 25-year event in another. So too with the Metrics.

iii. Q: Overbank flooding was looked at, but did the model account for water circumventing the structures?

A: Yes, the surface water model allows the water to flow around a structure. In fact, the model is a fully 3D model containing no artificial barriers so it gets the overland and groundwater flooding that would happen in a flood. We can use the model to put in barriers and see ‘What would happen if…’ a barrier was put here.

iv. Discussion about how it matches to a Federal Emergency Management Agency (FEMA) study and MIKE SHE studies. The current FEMA map for Broward County used the same MIKE SHE model. However, this effort updated the model quite significantly with new channel and structure data. It is not the District’s intention to re-create the FEMA floodplain maps.

v. Q: Since three feet is on low end of SLR projections in 25-50 years, is the future system resilient enough to accommodate/adapt to this?

A: To date there are no agreed upon solutions or mitigation activities. This is the goal of this workshop.

vi. Q: Adaptation strategies include multiple layers. Is this strategy multilayered such that impacts to adjacent communities are accounted for? Is the model wholistic?

A: The model is wholistic and accounts for adjacent communities.

vii. Q: It was mentioned that some options like tieback levees were modeled. Are the results of those modeling efforts available?

A: No, those results were simply preliminary looks at the modeling system. They are neither published nor available, given that the team was just doing some test runs to assess the model’s capability.

viii. Explanation of local mitigation strategies/project ideas that the team is looking at to see how they will work into the next phase. Such as:
1. Implement operational strategies to maintain flood protection
2. Enhance infiltration (land-use)
3. Harden coastal structures
4. Increase basin storage and associated nature-base / green infrastructure

ix. Discussion on use of drainage wells, land-use to store and hold water back, incorporate modeling for Miami-Dade County SLR strategy for structure elevations scenario.

x. There is high uncertainty in which is the correct SLR curve and what period into future should be planned for. The District’s strategy is to ask at what threshold of rise would a structure become critically insufficient. Then the number of years to act is determined. Projects can be sequenced, and the appropriate system components can be addressed in this way and allows for decision makers to not forget about a possible strategy.

5. Phase II Pre-Workshop Feedback – Lynette Cardoch, PhD, Moffatt & Nichol
   a. Main Message:
      i. Explanation of the map viewer; what information the team has collected and uploaded; and how to use the feedback portal/Summary of the pre-meeting survey results
      ii. The data gaps that the team needs partner’s assistance to fill
      iii. Breakout clarification
6. Breakout Sessions: See detailed notes for each group (pp 18-22)

7. Breakout Groups Report-Out
    a. Table 1: Kevin Hart, PE, District Director, South Broward Drainage District (SBDD)
        i. SLR and changes in climate; two of the last four years have seen record high rain fall in Southwest Broward
        ii. Contrast between C-11 (large pump) and C-9 (dependent on gravity)
        iii. Impacts the C-9 deals with – storm surge, high tides, etc.
        iv. Water quality importance in all solutions
        v. Pumps into the C-9/Raising banks/Increasing retention areas and storage basins/land acquisition
        vi. Nature-based solutions, including green infrastructures
        vii. Inter-agency collaboration/Phasing projects versus waiting until down the road
    b. Table 2: Alberto Pisani, PE, Division of Water Management, Miami-Dade County
        i. Integration of local and regional projects
        ii. Combine water quantity and quality
        iii. Identifying storage areas/Repetitive loss properties for storage
        iv. Green infrastructure/Design criteria
        v. Conveyance and increased maintenance
        vi. County/District collaboration; United States Army Corp of Engineers (USACE) coordination as well
    c. Virtual Room 1: Dr. Greg Mount, Water Resource Manager, Broward County
        i. Improving Conveyance (Leslie Pettit, Miami Gardens)
        ii. Herbicides on banks and a greener solution?
        iii. Looked at the map viewer
        iv. Broward County Resilience Dashboard: Citizen Science King Tide reporting program
    d. Virtual Room 2: Katherine Hagemann, Resilience Program Manager for Adaptation, Miami-Dade County
        i. Water quality and the need to consider more than just traditional flood control measures to address it
        ii. Non-structural solutions: smaller projects that may have basin-wide benefits/Elevating areas/Repetitive Loss Areas in the C-8 basin, consider buyouts?
        iii. Rising groundwater: Infiltration into the stormwater system/King Tides are particularly challenging
        iv. FDOT's project at I-95 and the Turnpike's interchange/Consider expanding storage?
    e. Virtual Room 3: Michael DelCharco
        i. Participants happy about what has been collected as well as map viewer
        ii. Discussed future project ideas
        iii. Discussion of the current projects
        iv. Participants happy that the District is looking at all three systems
8. Next Steps – Carolina Maran, PhD, PE, District Resiliency Officer, SFWMD
    a. Main Message:
        i. Reassurance about current/future resiliency and the District's commitment to coordination efforts across agencies
        ii. Modeling priorities proposed by team (three levels)

        iii. The Dynamic Adaptive Policy Pathways/Flood Damage Cost Estimates explanation/Resilient Florida Program
    b. Partner Feedback and Questions:
        i. Q: Have we considered collaborating with developers, updating codes to include rainwater collection for toilet's purposes?

            A: A piece of the solution: example of a regulatory aspects that can be implemented at the local level simultaneously to larger mitigation strategies

9. Closing
    a. Adam Blalock
        i. Belief in collaborative effort/workshop was a great start
    b. Akintunde Owosina
        i. has heard plenty of feedback today/Reassurance that all is being noted for the flood mitigation project considerations

<u>In-Person Table 1 Discussion Notes</u>

Moderator: Lynette Cardoch **Scribe:** **Tech: N/A**

Participants:

- Dr. Tiffany Troxler, FIU
- Ms. Isabel Cosio Carballo, South Florida Regional Planning Council
- Bridget Huston, South Florida Regional Planning Council
- Mr. Karl Kennedy, City of Pembroke Pines
- Mr. James Cromar, Broward MPO
- Mr. Levi Stewart-Figueroa, Broward MPO
- Mr. Kevin Hart, SBDD
- Ms. Eva Velez, U.S. Army Corp of Engineers
- Commissioner Nan Rich, Broward District 1
- Dr. Matahel Ansar, SFWMD
- Mr. David Colangalo, SFWMD

1. Non-structural mitigation
   a. Solutions need to be comprehensive enough to allow for inclusion of natural and nature-based features as well as other non-structural solutions (e.g., elevate structures, buy-outs.
2. Bring holistic ideas together.
3. Concerns with water quality not being fully incorporated into the decision making.
4. Water quality concerns with pumping water:
   a. For example: "Miami Beach" model works well for flood control, but not water quality.
   b. Western pump at the SBDD boundary would bring water quality concerns.
   c. Do you send east to Biscayne Bay/water quality concerns or do you send west/south to the Everglades/water quality concerns.
   d. Impoundments on C-11/Pembroke Pines still must deal with nutrient loads.
   e. S-29 pump = sends more water to Biscayne Bay.
   i. Argued that "more water" is not precisely correct because it is the water that would have been going out. Making up for tide.
   ii. Discharge is accelerated, which can produce different vertical gradients, reduce oxygen, and the physical and temporal variations are important.
5. Recent large events:
   a. SBDD: Record rainfall in the last 4 years.
      i. Also, flow at C-9 and C-11. Recovery at the C-11 was about 2 days, while the C-9 was about 10 days.
      ii. Attributed to pumping capacity. Need additional pumping capacity at other areas.
   b. Tidal influences at western county boundary: even the far west pup stations in the SBDD jurisdiction see the tidal influence with about a 3-hour delay.
   c. During Tropical storm Eta: pre-storm pumping helped. C-11 pumps west and east
6. Flood water, can it be used for beneficial use?
7. Biscayne Bay and Southeastern Everglades Ecosystem Restoration (BBSEER)
   a. western features being contemplated to bring more water into area.
   b. Keep water in the Everglades and continue to move it south
8. Can South Broward area serve as a stormwater treatment area and re-evaluate pump for a dual purpose: water quality and flood control?
9. Seepage issues: Add cut-off wall at impoundment?
10. Flood control versus water quality benefits

   a. The amount of area/volume need to capture water depends on goal: If you are looking for storage as the primary goal, then the area needs to have 15-20 feet of depth. If you are looking for treatment, then the depth would be 2-3 feet.
   b. With substrate being so porous, how does one route the water and new sources of water?
11. Can we build a system that is adaptable and doesn't require re-do of structures in the future?
12. Prevent repetitive losses
13. Cannot allow communities to increase what is beyond their allowable discharges.
14. Some recommendations:
    a. Introduce water quality features/components into the pumps.
    b. Add living shorelines
    c. Make sure to consider different perspectives, such as insurance and land use issues.

    Action Item: Follow-up with Kevin for more information on SBDD's pumps.

    Action Item: Participants' environmental ideas should be noted to identify them in projects as they are collected to promote benefits in flood control as well as water quality.

In-Person Table 2 Discussion Notes

Moderator: Hongying Zhao **Scribe: Nicole Cortez/ Maryam Roostaee** **Tech: N/A**

Participants:

- Alberto Pisani, P.E., Miami-Dade County RER-DERM
- Jason Engle, U.S. Army Corps of Engineers
- Jayantha Obeysekera, FIU
- Christina Miskis, South Florida Regional Planning Council
- Georgio Tachiev, Miami-Dade County RER-DERM
- Myriam Jacques, Town of Pembroke Park
- Juan Prieto, Nova Consulting
- Sashi Nair, SFWMD

1. Mr. Alberto Pisani, P.E., Miami-Dade County RER-DERM, alberto.pisani@miamidade.gov
   a. Canal bank improvement and roadway improvement planned. Some projects are funded, and some projects are not funded.
   b. BBSEER project, a federal/regional collaborating project, is proposing a conveyance route to send water from north to south, such as Model Land
   c. Lake Belt Storage project, high conductivity can be a concern

   Action item: Follow-up with Alberto to get the detailed projects locations in C8 and C9 basins.
2. Dr. Jayantha Obeysekera, FIU, jobeysek@fiu.edu
   a. Need to address water quality concerns. Green infrastructure technology can be an approach for consideration. Some examples. Distributed storage areas throughout the basins, small wetlands retrofit. This will benefit the small events.
   b. Connect exfiltration trenches to the primary system, coupled with forward pump and pre-storm operations, to create additional storage prior to the storm.
   c. ASR Deep injection wells
   d. Allow storages in parks, convert the repetitive loss properties to storage area
   e. Convert parking lot to impervious areas
   f. Police/criteria change such as revisiting the allowable discharge for new development
   g. Clean up the swale to improve efficiency

   Action item: schedule a follow-up meeting with Obey to fine tune these options
3. Ms. Christina Miskis, South Florida Regional Planning Council, cmiskis@sfrpc.com
   a. Good Neighbor Stormwater Park project, City of North Miami, combines a community park with local flood prevention, addressing repetitive loss properties, bringing awareness of flooding and climate impacts to community, also used for native planting. The solution will need collaborations from all tiers. (Totally agree!)

   Action item: Follow-up with Christina to get the detailed project locations
4. Mr. Georgio Tachiev, Miami-Dade County RER-DERM, georgio.tachiev@gmail.com
   a. Dade County has a GIS database about funded and unfunded projects and DOT road information; not sure if golf courses can be used as storage.

   Action item: Schedule a follow up meeting with Georgio to get more details about these projects that are in C8 and C9 basins.
5. Ms. Myriam Jacques, Town of Pembroke Park, mjacques@tppfl.gov
   a. C9, mostly C10, golf course, not enough storage, small municipality.
   b. Requested the website link.

   Action item: Hongying Sent the link to Ms. Ms. Myriam Jacques after the workshop.

Virtual Room 1 Discussion Notes

Moderator: Angela Schedel **Scribe: Carol Ballard** **Tech: Patrick Lawson**

Participants:

- Andrew Wolf, SFWMD
- Bridget Huston, SFRPC
- Bryan Palacio (In-Person), SFWMD
- Camile Campbell, Broward
- Jenny Staletovich, WLRN News
- Karin Smith, SFWMD
- Leslie Pettit, Miami Gardens
- Mitchell Moore, U.S. Army Corp of Engineers
- Rebecca Elliot, FDACS
- Gene Duncan, Miccosukee Tribe
- Christian Avila, SFWMD
- Jeremy McBryan, Palm Beach County
- Maria Del Mar Trejos, Brizaga

1. Leslie Pettit, Miami Gardens, lpettit@miamigardens-fl.gov
   a. Discussed planned projects addressing improvement of banks (bank stabilization, erosion control) and improvement of canal conveyance (removing sediment, vegetation buildup). There is a project located in the Marco Canal area which has funding, but he presented concerns about County requirements which were slowing/stopping the project progress. Apparently to get a permit for bank stabilization would require canal banks to be raised to 100 year elevations. This would add cost to the effort and include encroachment on properties of homeowners. He is looking for some help with solutions for this issue. The area he was talking about was in Miami Gardens around 17th, 18th, 19th, &20th Avenue – chain of lakes including Scott Lake. Note added by Scribe: The group attendees were more heavily Broward County participants so this may need to be communicated to Miami County Partners.
2. Maria Del Mar Trejos, Brizaga, delmartrejos@gmail.com
   a. Would like to see green strategies investigated for cleaning canals (not using herbicides so heavily). Should local universities lead local research effort
   b. Could we do a citizen's crowd sourced to gather information on local areas which flood?
3. Dr. Greg Mount (Broward County) gmount@broward.org
   a. Provided a link to the Broward County Resilience Dashboard which is a web portal that gathers flooding information for and from the communities. There is anecdotal information but also some elevation data. There will be more information at the GIS Expo in Palm Beach County. He also mentioned there are documented flooding problems in Hollywood.
   b. Link: https://www.broward.org/Resilience/Pages/default.aspx

   Action Item: Joe looked at the website to determine what project information could be compiled.
4. Jeremy McBryan, Palm Beach County, Water Resource Manager; JMcBryan@pbcgov.org
   a. Would like a Palm Beach County FPLOS study soon
5. Patrick Lawson presented the map viewer. It was noted several projects were already in the database and were showing on the map.
   a. Discussion about what to call the tool and it was decided to use FPLOS map portal for now.
   b. Who would have access to the tool – if the tool would be available to universities? Partners at this workshop?
   c. Link: http://www.buildcommunityresilience.com/SFWMD/FPLOS/c8c9/

Virtual Room 2 Discussion Notes

Moderator: Ann Springston **Scribe:** **Tech: Peter Sahwell**

Participants:

- Anaily Padron, City of Miami Lakes
- Dorothy Sifuentes, USGS
- Irela Bague, Miami-Dade
- James Poole, FDOT
- Jennifer Green, FDOT
- Katharine Mach, Rosenstiel School of Marine and Atmospheric Science, University of Miami
- Katherine Hagemann, Miami-Dade
- Kimberly Brown, Miami-Dade Long-Range Planning
- Lehar Brion, SFWMD
- Mark Elsner, SFWMD
- Milan Mora, U.S. Army Corp of Engineers
- Omar Santos, City of Miami Lakes
- Pam Sweeney, City of Miami-Dade

1. Irela Bague, Miami-Dade, Irela.Bague@miamidade.gov
   a. Use of drainage wells, land use to store and hold water back, incorporate modeling for MDC SLR strategy for structure elevation scenarios
   b. Would like FPLOS projects to incorporate water quality improvements. Discussed that Phase 1 modeling did not include sediment transport or WC calculations. Why? Can it be included going forward?

   Action Item:
2. James Poole, FDOT, james.poole@dot.state.fl.us
   a. Mentioned an ongoing project to alleviate low-lying area flooding along A1A. This project involves the operation of small pump stations. Discharges will not exceed pre-project conditions and consideration is being given to WC issues.

   Action Item: Schedule a meeting with James to discuss project further
3. Jennifer Green, FDOT, jennifer.green@dot.state.fl.us
   a. Commented that other regional projects include consideration that groundwater infiltration into the drainage system will sometimes allow back flow preventers to open, thus allowing saltwater intrusion and sometimes flood conditions upstream of the BFP. FPLOS project should consider the effects of GW infiltration into the drainage system.

   Action Item:
4. Katherine Hagemann, Miami-Dade, hagemk@miamidade.gov
   a. Mentioned the I95 & Turnpike interchange improvement project and asked if this project could incorporate more storage.
   b. Regarding the C8 Canal & S28 Structure, asked if the gates can be closed as storm approaches. Can the gates be tied by structural modification to higher ground (e.g., the Railroad embankment)?
   c. Regarding the C8 Spur Canal, mentioned that neighborhoods to the north and west of this canal and south of the main C8 canal at the same location are repetitive flooding areas. Can consideration be given to buyouts? Elevations? A note was added to the portal database and Katy agreed to populate her projects after the meeting within a two-week time frame.

Action Item: Contact Katherine to schedule a meeting to discuss the improvement project.

Action Item: Stephanie checks the website regularly and will let the team know when updates occur.

5. Kimberly Brown, Miami-Dade Long-Range Planning, Kimberly.Brown@miamidade.gov
    a. Wanted more details of Future Land Use – response was that Taylor used MD Future Land Use Map and Zoning to develop future conditions model. Requested that she provide more detailed FLU information if available.

Action Item: Check in with Kimberly about FLU information.

6. Pam Sweeney, Miami-Dade, pamela.sweeney@miamidade.gov
    a. Raised concerns regarding the quantity of water that must be dealt with and water quality issues.
    b. Mentioned that flood control projects should be dual purpose (FC and WQ benefits). At a minimum WC must not be degraded.
    c. Suggested the consideration of regulatory and operational means to enhance FC & WC

Action Item: See above

Virtual Room 3 Discussion Notes

Moderator: Joseph Wilder **Scribe: Michael DelCharco** **Tech: Laura Vogel**

Participants:

- Amy Cook, City of Miami-Dade
- Brett Sanders, UCI
- Christopher Miranda, MSV
- Elaine Franklin, City of Hollywood
- Feng (Jeff) Jiang, City of Hollywood
- John Smith, Genterra
- Judeen Johnson, City of North Miami Beach
- Larry Teich,
- Lois Bush, FDOT
- Mario Diaz, Biscayne Park
- Rajendra Sishodia, Broward
- Robin Yang, Miami-Dade Fire Rescue
- Susan Bodmann, Broward
- Tibebe Dessalegne, SFWMD
- Vijay Mishra, SFWMD
- Wisler Pierre-Louis, City of North Miami

1. Amy Cook, Miami-Dade, amy.cook@miamidade.gov
   a. Discussed the need for us to review the Miami Dade Capital Improvement Projects (CIP). They have a list of smaller projects, too, but they are mostly conceptual in nature. They have a "flood criteria map" that is currently being updated and be completed by the end of the year (2021). It requires policy changes. The CIP has some canal cross section improvement projects that would help flooding in C-8/C-9. They are working on updating sea walls in the local ordinance. Something like what Broward County has done.

   Action Item: Reach out to ask for the CIP list to add to the project website.
2. Feng (Jeff) Jiang, City of Hollywood, FJiang@HollywoodFL.org
   a. They are working on a new stormwater master plan for the City of Hollywood. CDM Smith is doing the work.

   Action Item: Perhaps get in touch with Susanne Mechler of CDM Smith?
3. Judeen Johnson, City of North Miami Beach, Judeen.Johnson@citynmb.com
   a. There is a Pickwick Lake outfall replacement project that may change flow in the eastern lakes. Not a big project.

   Action Item: Reach out to Pickwick Lake for more information
4. Lois Bush, FDOT, lois.bush@dot.state.fl.us
   a. Very glad to see we were including policy planning in the mitigation projects.
5. Robin Yang, Office of Emergency Management: Miami-Dade Fire Rescue, EM Planner, Robin.Yang@miamidade.gov
   a. Works with the Emergency Management group and they use the Local Mitigation Strategy list for projects. He said they have a dashboard for the local mitigation strategies (LMS), and we should check that. Many of the LMS projects are not up to date.

Action item: Reach out for the dashboard information. Compare to ensure they projects have been evaluated

6. Susan Bodmann, Broward County, SBODMANN@broward.org
   a. Discussed some connector canals in northern Broward County. Joe was familiar with them, but they are outside of the C-8/C-9 basin and this study.

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Christina Miskis	South Florida Regional Planning Council		
Georgio Tachiev	Miami-Dade County	~~irela.bague@miamidade.gov~~	
Hongying Zhao	SFWMD	hzhao@sfwmd.gov	HZ
Irela Bague	Miami Dade County		
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19549213930				
17868599847				
19543032383				
19049108554				
wuc poly3		**Stakeholders**	**SFWMD**	**Team**
	Totals	69	20	9

APPENDIX E: Group Moderator Instruction Notes

Breakout Groups

Before Participants Breakout

1. Before participants are split into groups, participants (virtual and in-person) will get instructions on what to expect for the breakout sessions during the presentation (see draft slides).
2. Speaker (Lynette) will emphasize the goals of the session, with the slide of the breakout goals and what the group will be addressing (slide text pasted below).

Breakout Groups
Develop and integrate adaptation and mitigation strategies and projects

- Share concerns about present and anticipated flooding/drainage issues
- Enhance connectivity among the community of practitioners in the C-8/C-9 basins through dialogue
- Communicate ideas that the practitioners would like this project to address
- Generate ideas on future projects

3. Speaker will also emphasize that ultimately the collaboration amongst the different regional and local agencies will help all of us formulate projects and policies that can be accomplished by our different agencies. We also want to share the available tools (H&H model resources) and technical assessments that can support local planning projects. It is going to be key that projects get done at the various levels/tiers since not all can be done by the SFWMD.

Breakout Session: Participants in Rooms/Tables

1. Moderator: Tech Information
    a. Virtual Sessions: Give technical instructions before we roll into introductions
        i. The virtual sessions are being recorded for the purposes of note taking. These audios/videos are not going to be kept long term nor posted after the session.
        ii. Turn videos on, if possible.
        iii. Mute your microphone when you are not speaking.
        iv. Use the chat function to ask questions. While we intend this to be interactive, we do not want to lose any ideas that you may have. Please use the chat function liberally.
        v. The chat can also be used to share files, much like you got the workshop packet this AM.

    b. Virtual/In-person: Solicit help for a report-out person. Let them know that we are going to share, in just a few minutes, our highlights with the other groups after the session.
        i. If you do not get someone immediately that agrees to report-out, we can call on one of the participants that we know are quite active (our key people) and ask them.

ii. General time is 5 mins for intros, 35 min discussion, 5 min wrap up.
iii. Moderators ought to use a timer to allow for the 5 mins at the end.

2. Group introduction
   a. Virtual
      i. Moderator has participant list. Use that as a guide for the order. Example: "We are going to do quick introductions. To keep us on track, we have names of anticipated participants on the screen with a number order. We can go down the list. Please share your name, organization, and role." Tech support will pull up map while introductions are going along.

   b. In-Person
      i. Have participants share name, organization, and role.

3. Discussion/Project Area Map as background
   a. Virtual
      i. The project area map will be up as the main screen. This will be used to capture ideas on projects and policies. The map can also be used to document flooding "hot spots" that do not yet have projects planned or in CIPs.

   b. In-person
      i. The maps are on the table. They can be marked up to capture ideas on projects and policies. The map can also be used to document flooding "hot spots" that do not yet have projects planned or in CIPs.

   c. Virtual/In-person
      i. While the intent is to capture as many projects as possible, we want to have discussion on all the topics that were previously mentioned.

      ii. Moderator will need to review the topics again as we start conversation:
         1. Share concerns about present and anticipated flooding/drainage issues
         2. Enhance connectivity among the community of practitioners in the C-8/C-9 basins through dialogue
         3. Communicate ideas that the practitioners would like this project to address
         4. Generate ideas on future projects
         5. Feedback on potential projects for consideration from the Phase I study

      iii. Keep bringing the group back to actionable ideas. For example, ask for more specificity by saying, "What would that look like if we were to consider a project?" or "What information gives you "helpful-help"?

4. Discussion Tips
    a. Successful breakout groups tend to have a clear focus and goal. Our group goals are a bit mix given that we want to have project and policy input (measurable outcome) as well as collaborative dialogue (soft aspects of teambuilding). Keep an eye on the dialogue going too far into futile tones ("We've always flooded and there is nothing we can do") and pivot back to the actionable dialogue of potential solutions that can be explored with this and other projects.

    b. Document issues but stay positive in looking for solutions and next steps.

    c. Encourage participants to share and ask each other questions. Moderators are there to help focus conversation and balance the team; stand back for the participants have their exchange.

    d. Try to balance speaking time amongst participants.
        i. Virtual: take a look at the chat box to capture ideas from the more introverted in the audience.
        ii. In-person: without placing a participant too on-the-spot, you can ask a quiet person to contribute with a broad question that can be answered with whatever areas feels comfortable to them. Example, "Is what you are hearing similar to what your city/agency/area is facing?"

    e. Ideas that are not closely aligned with the FPLOS project will be acknowledged and collected.

5. 5 minutes wrap-up
    a. Group picks top 2-3 items to share with the other groups.
    b. They can share projects, policies, observations, requests for further collaboration, etc.
    c. Send projects through Portal or send to the project team within 2 weeks.

APPENDIX F: Workshop PowerPoint Presentation

SOUTH FLORIDA WATER MANAGEMENT DISTRICT

C-8 and C-9 Basins
Flood Protection Level of Service (FPLOS)

Adaptation and Mitigation Planning Projects Study Workshop

August 3, 2021

sfwmd.gov

1

SOUTH FLORIDA WATER MANAGEMENT DISTRICT

Welcome

Drew Bartlett
Executive Director
South Florida Water Management District

sfwmd.gov

2

2

SOUTH FLORIDA WATER MANAGEMENT DISTRICT

Project Team

SFWMD

- Akintunde Owosina, PE
- Carolina Maran, PhD, PE
- Hongying Zhao, PhD, PE
- Ann Springston, PE
- Nicole Cortez
- Supported by other SFWMD staff

Consultants

- Taylor Engineering
  - Michael DelCharco, PE
  - Angela Schedel, PhD, PE
  - Patrick Lawson
  - Stephanie Massey
- Moffatt and Nichol
  - Lynette Cardoch, PhD
- Nova Consulting
  - Laura Vogel, PhD, PE
  - Peter Sahwell

sfwmd.gov

3

3

SOUTH FLORIDA WATER MANAGEMENT DISTRICT

Context and Big Picture
Flood Protection Level of Service Program

A Systematic Approach to Ensure Infrastructure Readiness

Akintunde Owosina P.E.
Chief, Hydrology and Hydraulics Bureau
South Florida Water Management District

sfwmd.gov

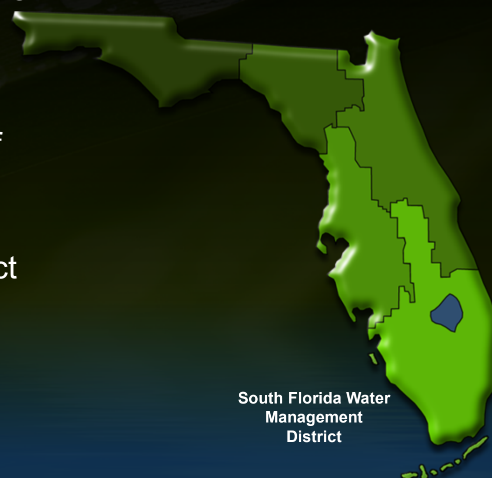
4

SOUTH FLORIDA WATER MANAGEMENT DISTRICT

Who We Are and What We Do

SOUTH FLORIDA WATER MANAGEMENT DISTRICT

- Oldest and largest of the state's five regional water management districts
- Protecting water resources in the southern half of the state since 1949
- Our mission: To safeguard and restore South Florida's water resources and ecosystems, protect our communities from **flooding**, and meet the region's water needs while connecting with the public and stakeholders



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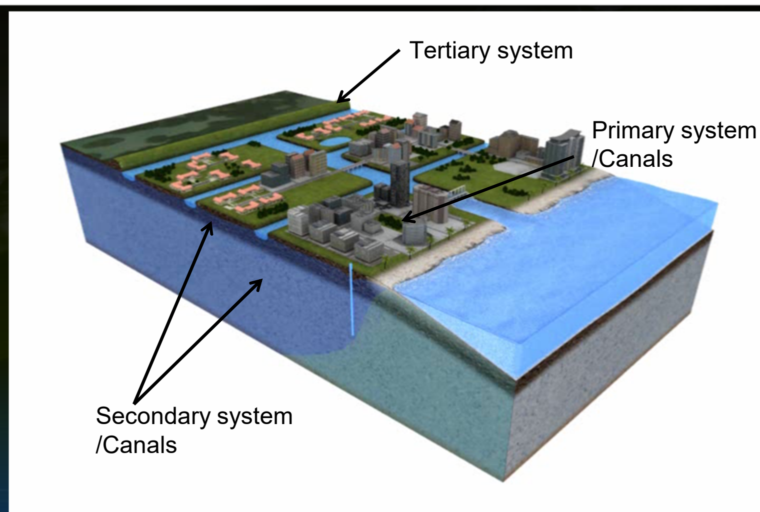
Presenter: Akintunde Owosina 5

5

SOUTH FLORIDA WATER MANAGEMENT DISTRICT

Flood Protection Responsibility

- Primary
  - **USACE**
  - **SFWMD**
- Secondary
  - Local Governments
  - Special Districts
- Tertiary
  - Homeowners Associations
  - Private Land Owners



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Presenter: Akintunde Owosina 6

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SOUTH FLORIDA WATER MANAGEMENT DISTRICT

Water Management System

- 2,060 miles of canals
- 2,028 miles of levees
- 160 major drainage basins
- 1,413 water control **structures**
- 71 pumping stations
- 60,000 acres of regional wetland Stormwater Treatment Areas
- Lake Okeechobee
  - 450,000 acre water storage area
- Water Conservation Areas
  - 959,000 acre water storage

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Presenter: Akintunde Owosina 7

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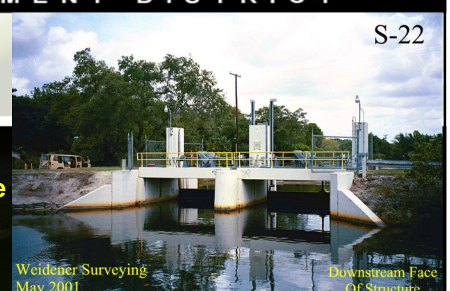
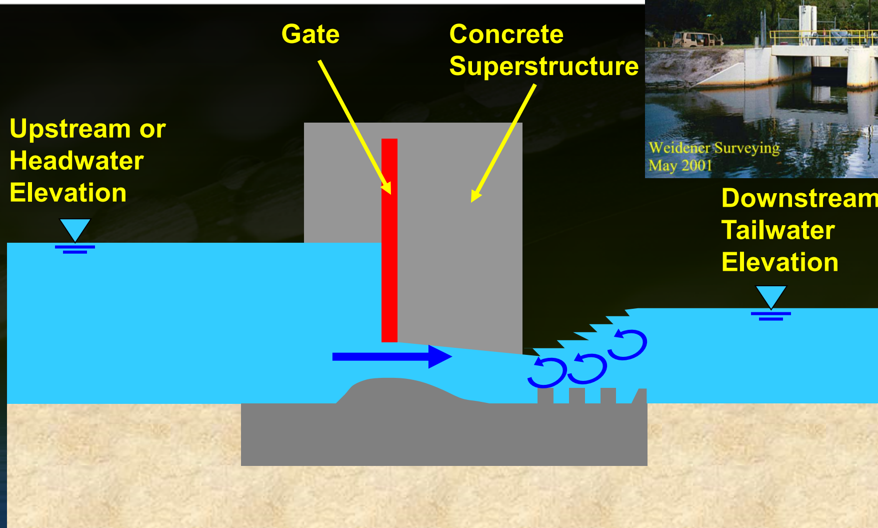
SOUTH FLORIDA WATER MANAGEMENT DISTRICT

Gated Spillway Basics





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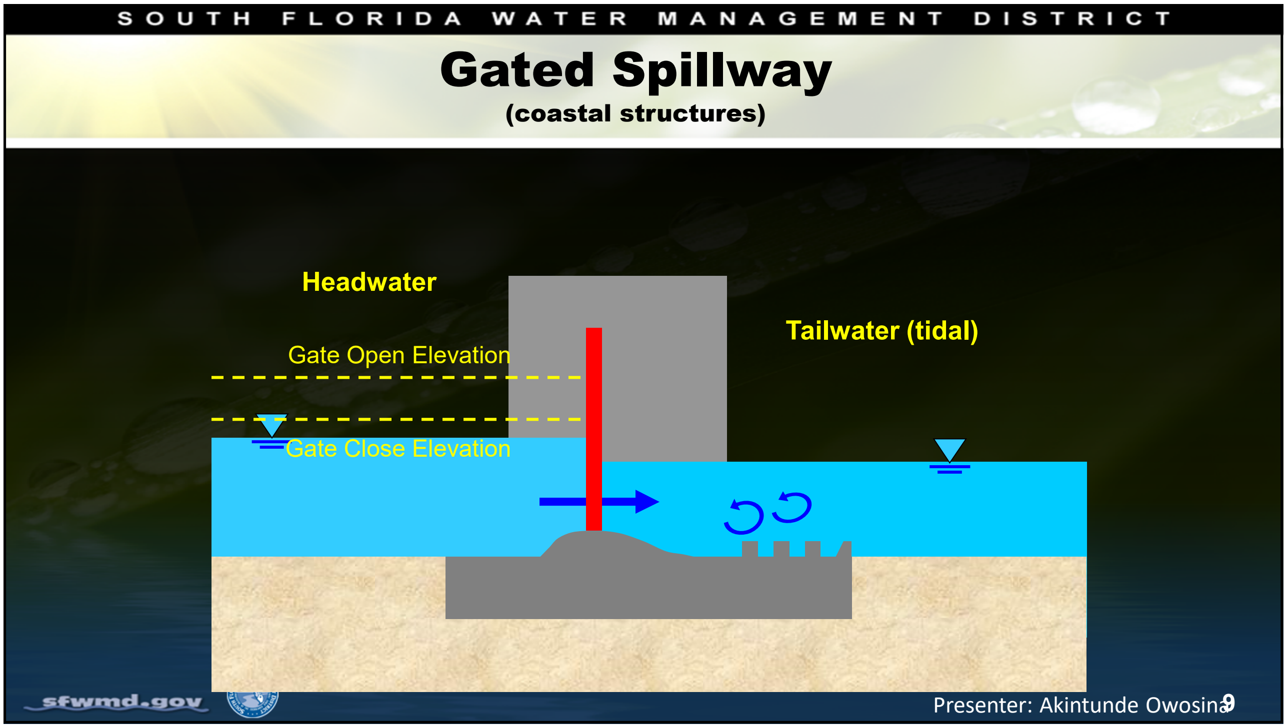
SOUTH FLORIDA WATER MANAGEMENT DISTRICT
Gated Spillway
(coastal structures)
Headwater
Tailwater (tidal)
Gate Open Elevation
Gate Close Elevation
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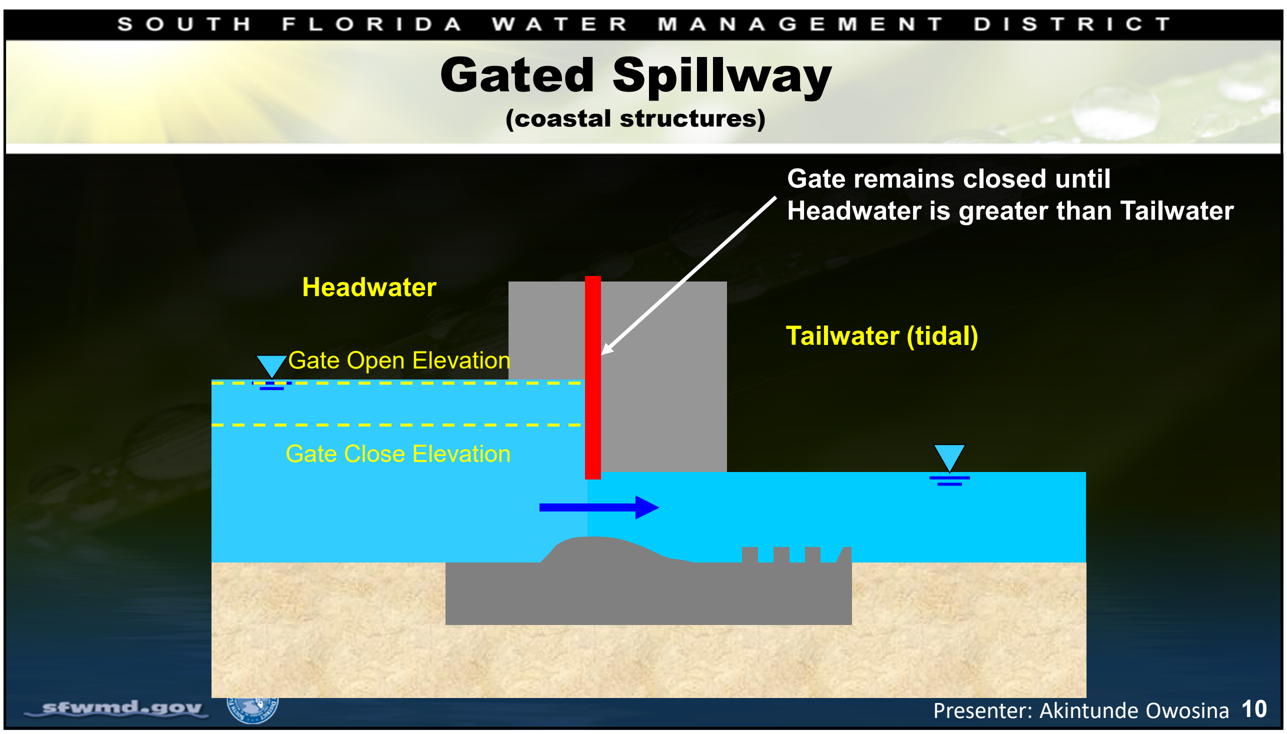
SOUTH FLORIDA WATER MANAGEMENT DISTRICT
Gated Spillway
(coastal structures)
Gate remains closed until
Headwater is greater than Tailwater
Headwater
Tailwater (tidal)
Gate Open Elevation
Gate Close Elevation
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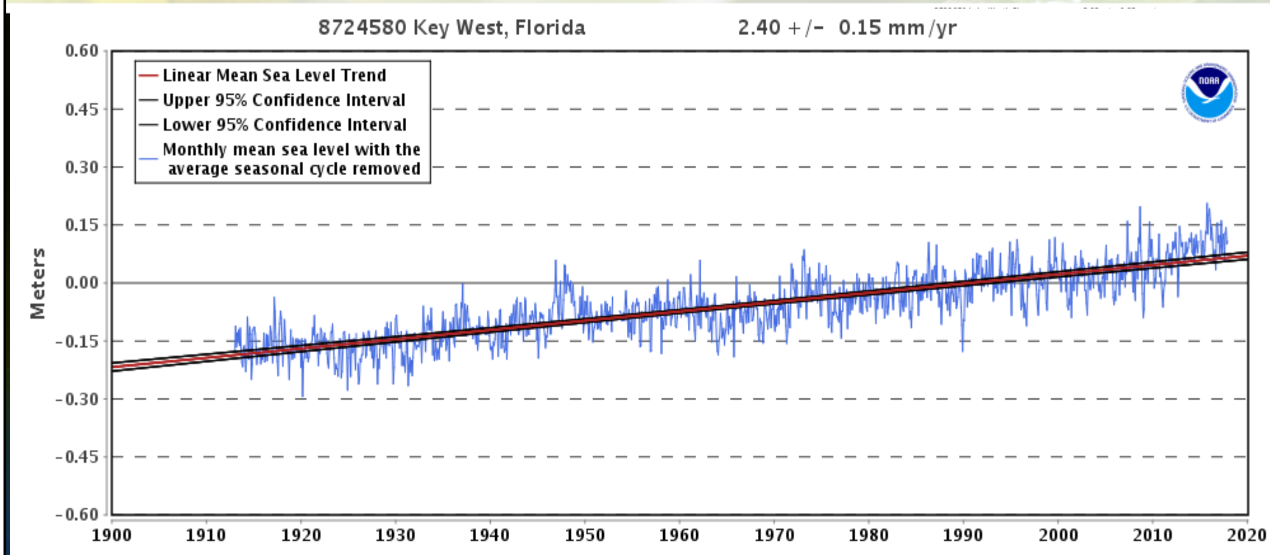
Sea Level Rise Trends in South Florida (NOAA)



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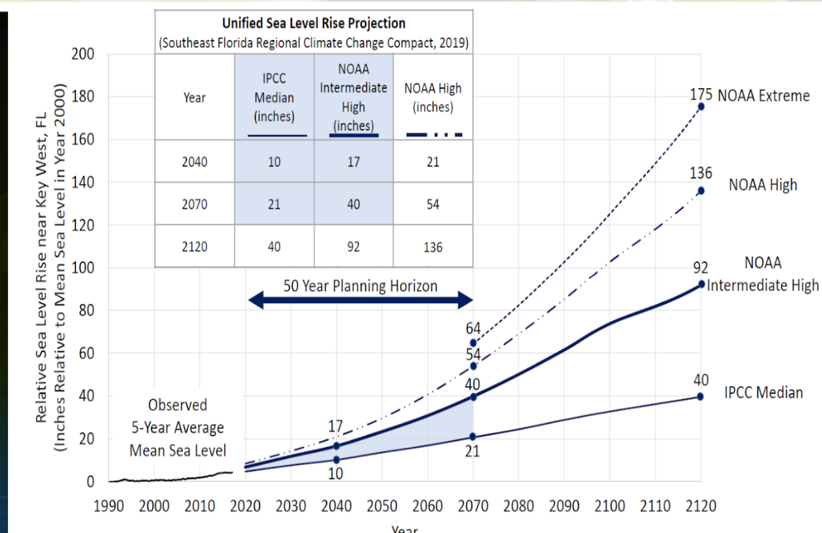
Unified SLR Projections 2019 (Climate Compact)

- Developed by the Four-County Compact
  - Palm Beach
  - Broward
  - Miami Dade
  - Monroe
- SFWMD staff provided technical assistance



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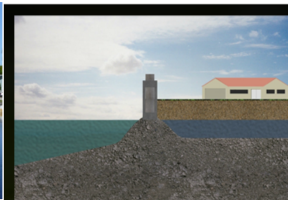
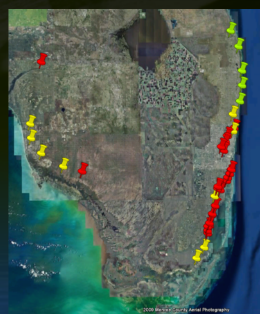
S O U T H   F L O R I D A   W A T E R   M A N A G E M E N T   D I S T R I C T

Coastal Structures and Flood Protection



Potentially impacted gravity coastal structure in Miami-Dade County

Aerial Map of Coastal Miami



- Gravity Coastal structures on primary canals (also known as "Salinity Barriers") showing inefficiency during high tide
  - Designed and built in the 1950s
  - Finding from initial screening: Miami-Dade County most potential to be impacted
- Future potential rise in water table due to sea level rise will further impact flood protection
- Future potential increase in extreme rainfall and the projected increase in intensity and frequency of hurricanes will exacerbate sea level rise impacts

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S O U T H   F L O R I D A   W A T E R   M A N A G E M E N T   D I S T R I C T

… The Manager's Question …

We have the aging infrastructure approaching or past design end of life:

- Do I replace them and if so When do I replace them ?
- What do I replace them with ?
  - In kind - same as it was? or
  - Different to accommodate known changes since design and projected changes?
- Where and how ?
  - What goes first, what happens next?
  - What happens downstream of our current assets?
- What liability or risk am I exposed to – due to action or inaction
- Who pays for the fix ?
- What assurances do I have ? (responsibility to manage public funds) considering high uncertainty

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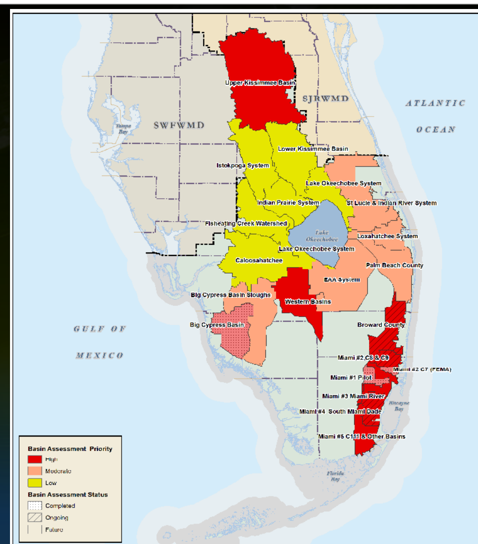
Flood Protection Level of Service Program

How we ensure that our flood control assets are up to the task considering development, land use change, SLR and climate change

- Identify and prioritize long-term District infrastructure needs
- Assess level of flood protection throughout the 16-counties of the SFWMD – relative to design
- Identify at-risk structures and needed improvements to operations, canal conveyance or structures
- Provide a **formal process** to initiate retrofit and adaptation efforts for future infrastructure improvements and/or modification of regulatory criteria
- Incorporate **resilient** design standards and construction
- Coordinated with SFWMD Operations, local government entities, drainage districts and other agencies with flood control or related responsibility



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Three Phases of the FPLOS Program

- FPLOS Assessment:
  - Identify location of potential challenge
  - Identify time horizon of potential challenge
  - Prioritize watersheds for detailed resilience studies
- FPLOS Resilience Study and Adaptation Design
  - Based on findings of assessment
  - Detailed study focused on identifying most cost effective adaptation
  - Involves solution search in all three tiers
  - Identification of uncertainties and time horizon for implementation
  - Culminate with preliminary design sufficient for cost development
- Resilient Infrastructure Implementation
  - Final design, permitting and construction of sequenced adaptation

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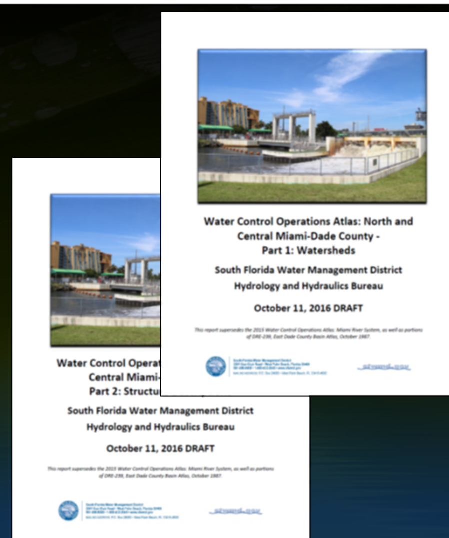
Activities Completed in a Typical FPLOS Assessment

- Focus on primary system
- Compilation and publishing of a multi-volume water control operations atlas of the basin
- Hydraulic and hydrologic model of basin including structures, pumps stations and canals
- Assessment of current conditions using different severity of storm events (rainfall) plus storm surge
- Simulation of future conditions with three different Sea Level Rise projections also with rainfall and storm surge
- Identify underperforming or at-risk segments or components
- Coordination with counterparts in the County
- Activities for the C8/C9 Basin



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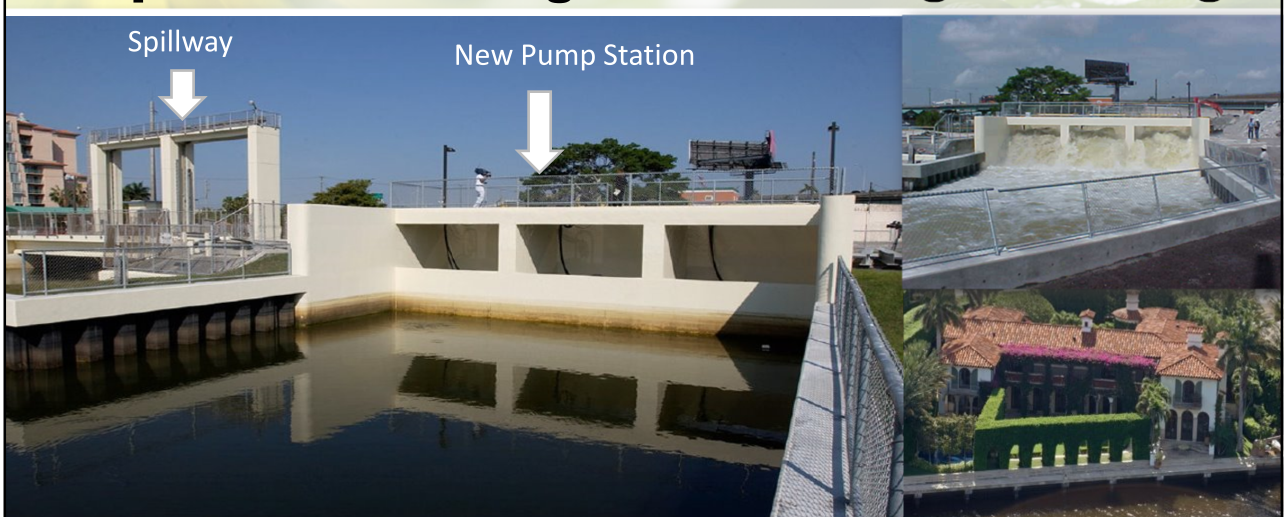
Activities Completed in a Typical FPLOS Adaptation and Mitigation Planning and Design



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Questions?

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Break

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C-8 and C-9 Basins Flood Protection Level of Service

Phase I Study Results

Michael DelCharco, PE
Vice President of Water Resources
Taylor Engineering

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C-8 and C-9 Basins FPLOS Phase 1 Study

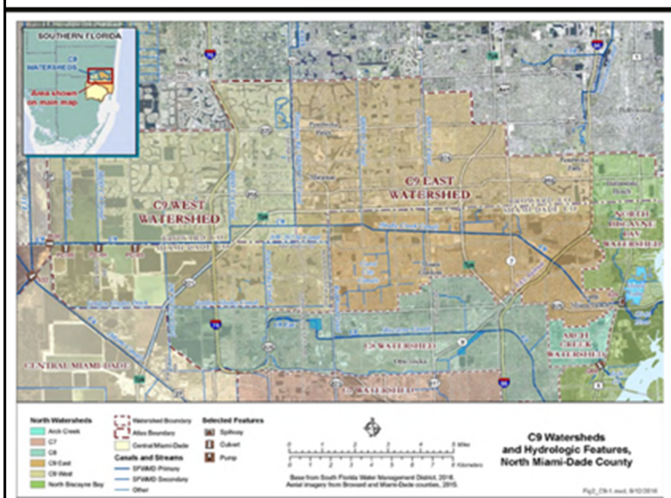

Figure 2. Major features of the C9 East and C9 West Watersheds in Miami-Dade and Broward counties.

- Focus on primary system
- Evaluating effects of changes in SLR, storm surge, and land use on FPLOS
- Model Calibration and Validation
- Current Condition Assessment (4 return periods and storm surge)
- Future Condition Assessment
  - 4 return periods and storm surge
  - Sea level rise (+1, +2, +3 ft)
  - Groundwater level
  - Future land use and project
    - American Dream Mega Mall
    - C9/C11 impoundments (USACE)
    - C-9 Impoundment

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Six FPLOS Performance Metrics

Canal

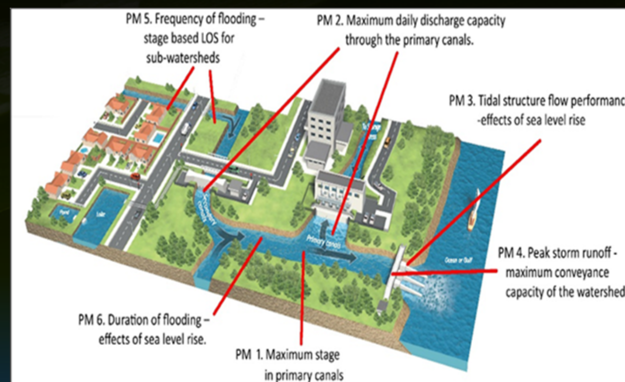
- Maximum stage profiles (PM1)
- Discharge capacity of sub-basins (PM2)

Tidal Structure (Sea Level Rise)

- Structure discharge capacity during surge (PM3)
- Max conveyance capacity at tidal structure caused by surge and SLR (PM4)

Land

- Maximum flood depth map (PM5)
- Flood duration map (PM6)



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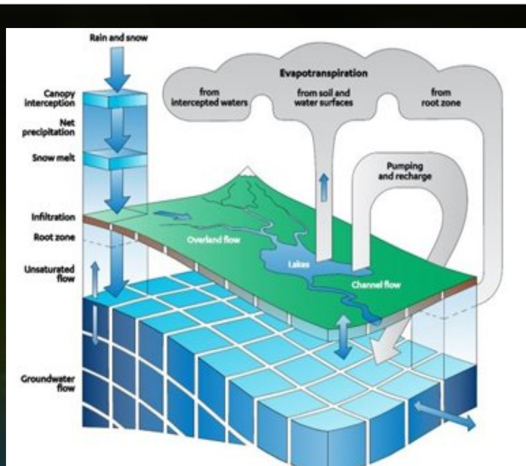
Model Tool Selection



Model Tools Selected for C8 and C9 Basins

- Physics-based spatially distributed model tools
- Simulate
  - Overland flow
  - Unsaturated flow
  - Groundwater flow
  - And fully dynamic channel flow
  - Including all their complex feedbacks and interactions

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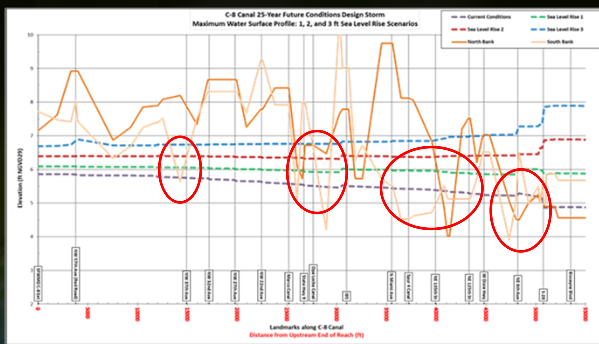
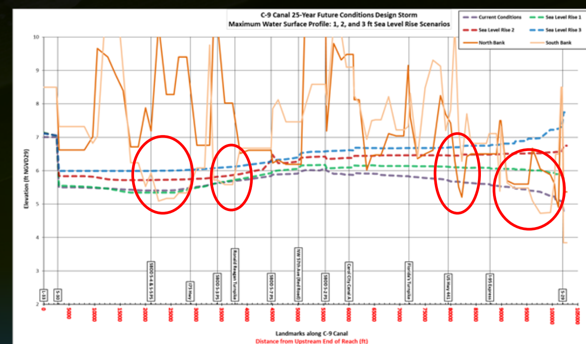
C8 and C9 Basins FPLOS Assessment – PM 1





Examples of 25yr event

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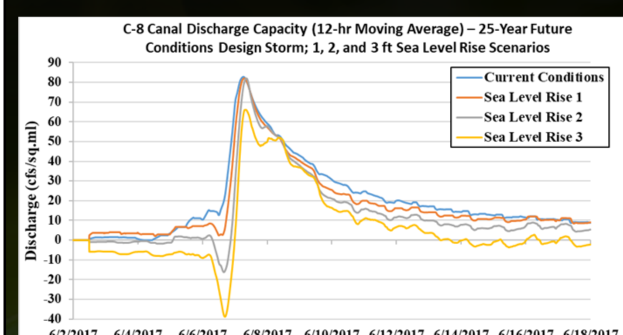
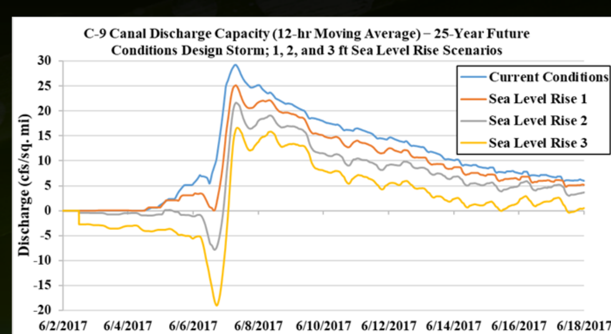
C8 and C9 Basins FPLOS Assessment – PM 2





Examples of 25yr event

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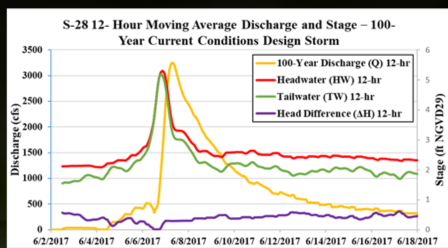
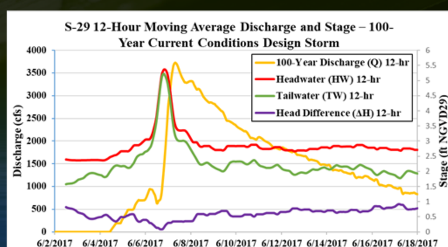
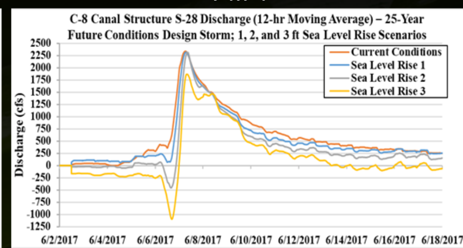
C8 and C9 Basins FPLOS Assessment – PM 3 and PM 4

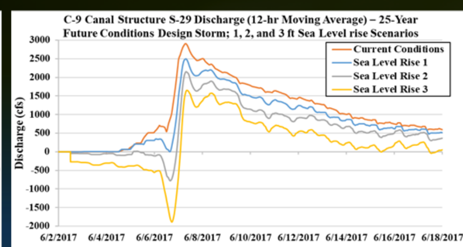
PM 3





PM 4





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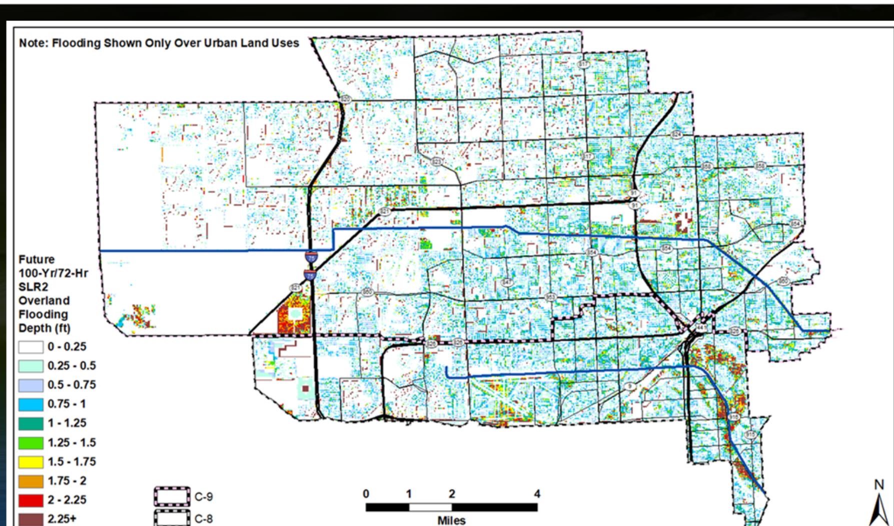
C8 and C9 Basins FPLOS Assessment – PM 5



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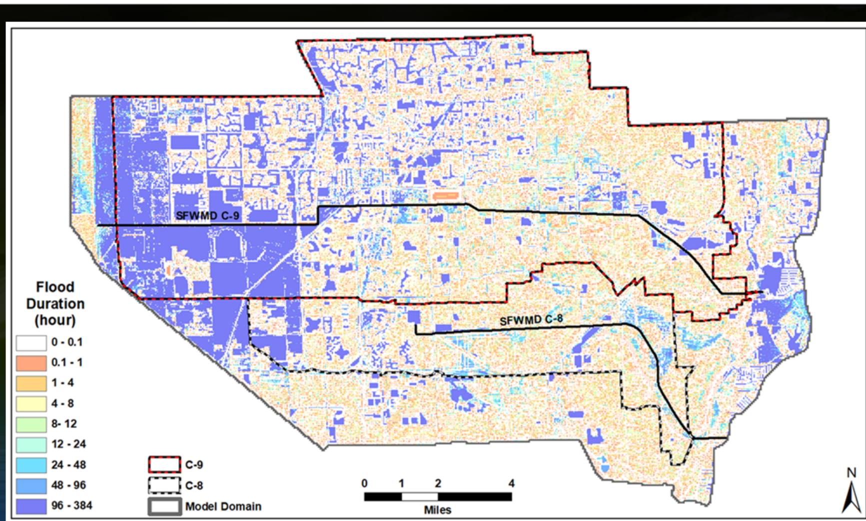
C8 and C9 Basins FPLOS Assessment – PM 6



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C8 FPLOS Phase 1 Assessment Summary

C8 Basin

- Overall, C8 provides about a 10-year FPLOS under current conditions. Western half of C8 performed better than eastern half. Multiple areas in eastern C8 performed poorly.
- Under future 1 ft and 2 ft SLR scenarios, the basin overall provides a 5-yr LOS. For the 3 ft SLR Scenario, portions of the system was overwhelmed even for the 5-yr event.
- Western segment of the C8 performs better than eastern segment, maintain about a 25-yr LOS for current conditions and SLR1.
- Discharge capacity at S28 is reduced dramatically under SLR 3. Reduction ranged from 19% to 28% for different events.

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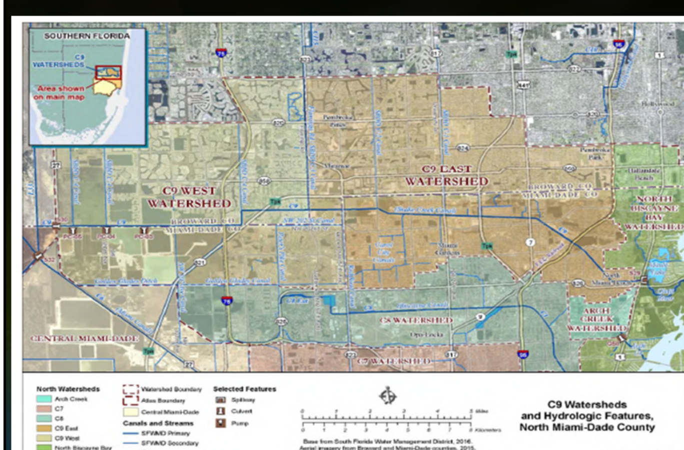
C9 FPLOS Phase 1 Assessment Summary

C9 Basin

- C9 generally functions at about a 25-year FPLOS under current conditions.
- Bank exceedance occurred in several locations under SLR conditions.
- The 12-hour peak discharges at S-29 for all storms are sensitive to all SLR scenarios
- Under future conditions, the C9 generally function at a 10-year or lower FPLOS for the 1 ft and 2 ft SLR scenarios, and a 5-year FPLOS for the 3 ft SLR scenario.
- Widespread bank exceedances, with corresponding flood depths and durations occur for the 25-year event, for all SLR scenarios.
- Western segment performs better than eastern segment.

C-8 and C-9 Basins FPLOS Adaptation and Mitigation Planning Projects Study – Phase II



- Objectives: To develop basin wide flood adaptation strategies and mitigation projects for the C8 and C9 watersheds to maintain or improve the level of flood protection in anticipation of future conditions including SLR, land use changes, and increased ground water.
- The development and implementation of the strategies will be a collaborated effort from the District, USACE, counties, local drainage districts and other stakeholders.

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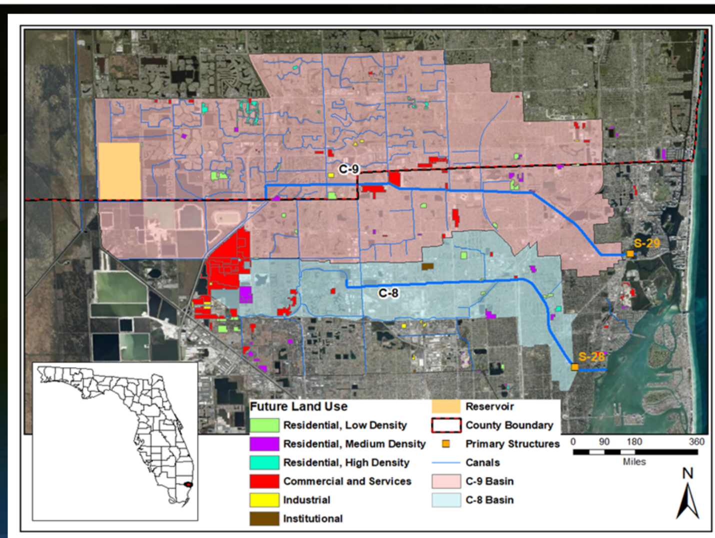
Future Land Use

- Approx. 4,000 acres identified for change
- Parameters affected:
  - OL Manning's Roughness
  - Paved Area Fraction
  - Detention Storage
  - Topography



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Examples of Potential Mitigation Strategies

C8 Basin:

- Canal Conveyance Improvements
- S28 Structure Improvements
- Flood Walls and Surge Barriers
- Raise Levees along C8 Canal and add Gates/Pumps on Secondary Branches

C9 Basin:

- C9 Impoundment
- Connect Western Mine Pits South of C9 to Canal
- S29 Structure Improvements
- Raise Levees along C9 Canal and add Gates/Pumps on Secondary Branches

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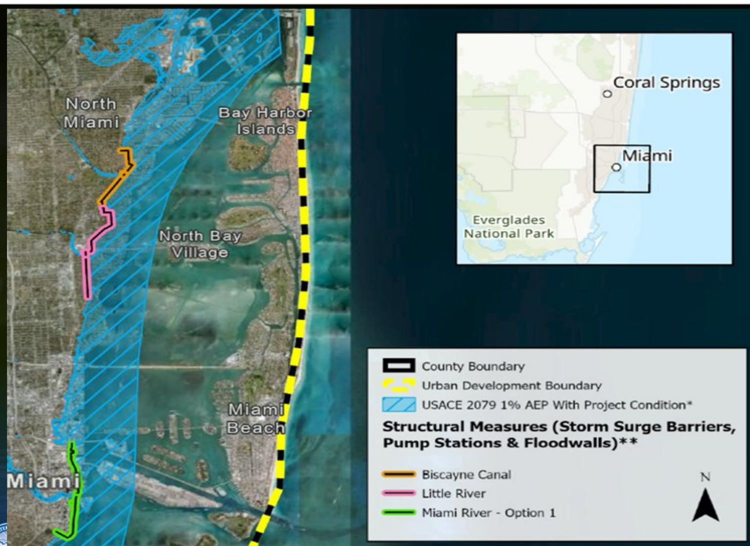
Examples of Potential Mitigation Strategies

C7 Basin:

- Looked at structural changes
- Examined land use building code changes
  - Building codes to elevate roads and buildings
    - Economic review of “what if” elevations at 100-yr with SLR3 in 2065
  - Very effective, but very expensive and slow to implement
  - No hydraulic modeling
  - Included in economic modeling/calculations

S28 Structure Improvements

Surge Barriers and Flood Walls on C8 and C7



(Adapted from USACE, 2020)

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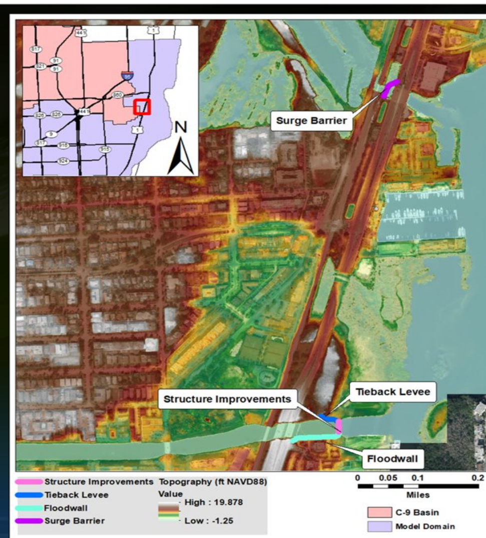
Locations of S29 Improvements and Potential Oleta River Surge Barrier

Example of Mitigation Project at S29

- Add pump
- Add levees
- Add floodwalls and surge barriers
- Tie in to existing topography



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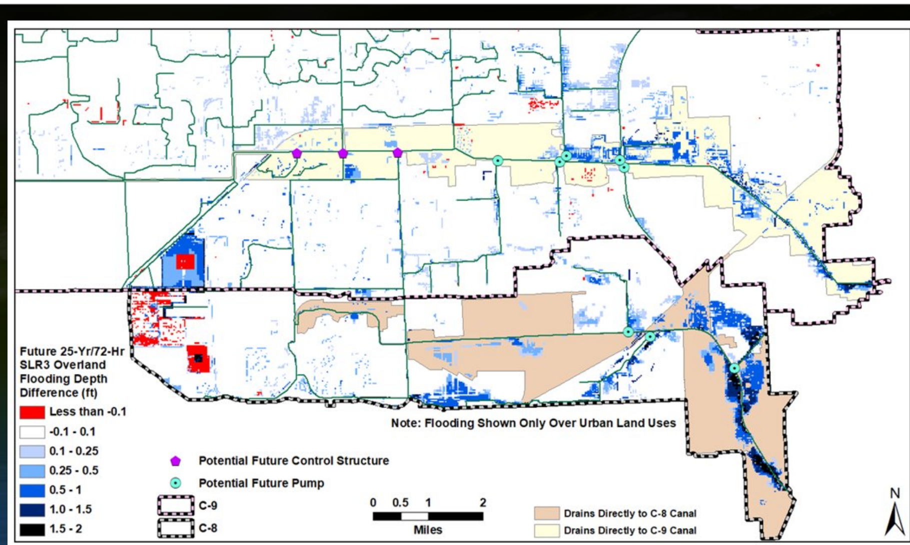
Example of Modeling Results from Structural Mitigation Projects

Flood Difference Map with Possible Locations of Future Control Structures and/or Pump Stations



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Western Mine Pits (a.k.a. North Lake Belt Storage)

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Questions and Comments

Photo: Miamidade.gov

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C-8 and C-9 Basins Flood Protection Level of Service

Phase II Pre-Workshop Survey

Lynette Cardoch, PhD
Director, Resilience & Adaptation
Moffatt & Nichol

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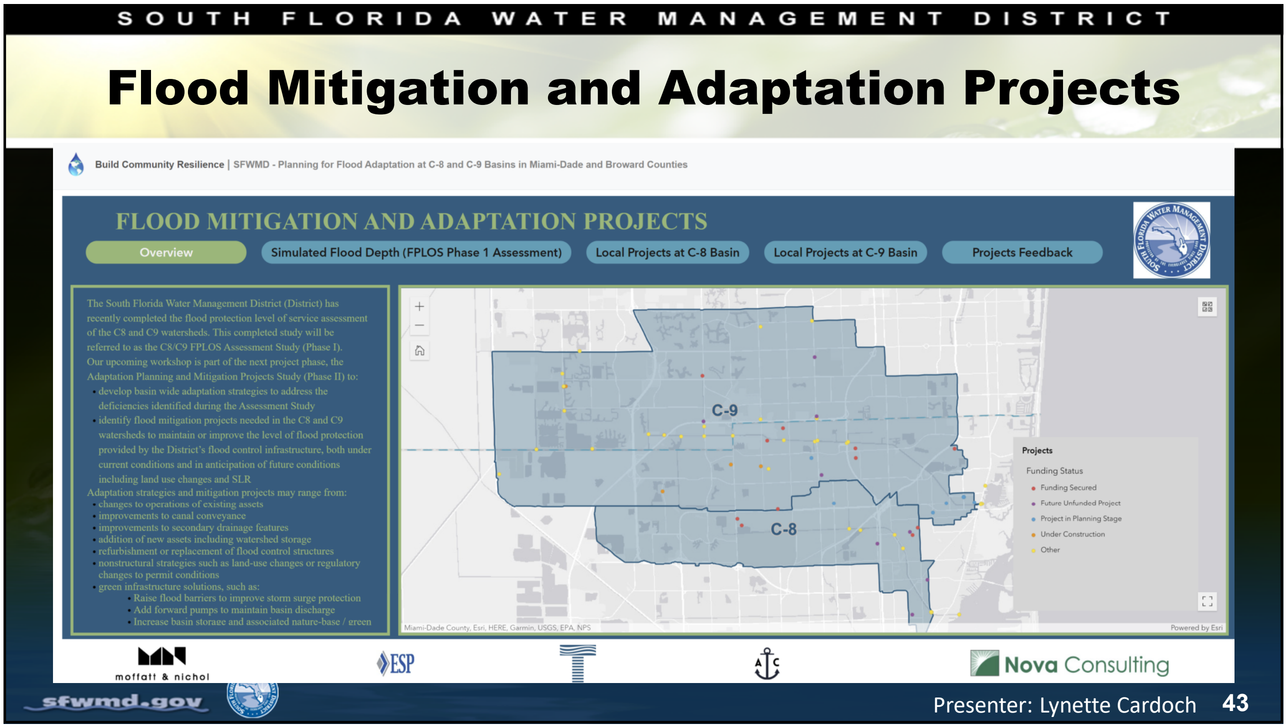

SOUTH FLORIDA WATER MANAGEMENT DISTRICT
Flood Mitigation and Adaptation Projects
Build Community Resilience | SFWMD - Planning for Flood Adaptation at C-8 and C-9 Basins in Miami-Dade and Broward Counties
FLOOD MITIGATION AND ADAPTATION PROJECTS
Overview
Simulated Flood Depth (FPLOS Phase 1 Assessment)
Local Projects at C-8 Basin
Local Projects at C-9 Basin
Projects Feedback
The South Florida Water Management District (District) has recently completed the flood protection level of service assessment of the C8 and C9 watersheds. This completed study will be referred to as the C8/C9 FPLOS Assessment Study (Phase I).
Our upcoming workshop is part of the next project phase, the Adaptation Planning and Mitigation Projects Study (Phase II) to:
• develop basin wide adaptation strategies to address the deficiencies identified during the Assessment Study
• identify flood mitigation projects needed in the C8 and C9 watersheds to maintain or improve the level of flood protection provided by the District's flood control infrastructure, both under current conditions and in anticipation of future conditions including land use changes and SLR
Adaptation strategies and mitigation projects may range from:
• changes to operations of existing assets
• improvements to canal conveyance
• improvements to secondary drainage features
• addition of new assets including watershed storage
• refurbishment or replacement of flood control structures
• nonstructural strategies such as land-use changes or regulatory changes to permit conditions
• green infrastructure solutions, such as:
• Raise flood barriers to improve storm surge protection
• Add forward pumps to maintain basin discharge
• Increase basin storage and associated nature-base / green
C-9
C-8
Projects
Funding Status
Funding Secured
Future Unfunded Project
Project in Planning Stage
Under Construction
Other
Miami-Dade County, Esri, HERE, Garmin, USGS, EPA, NPS
Powered by Esri
moffatt & nichol
ESP
Nova Consulting
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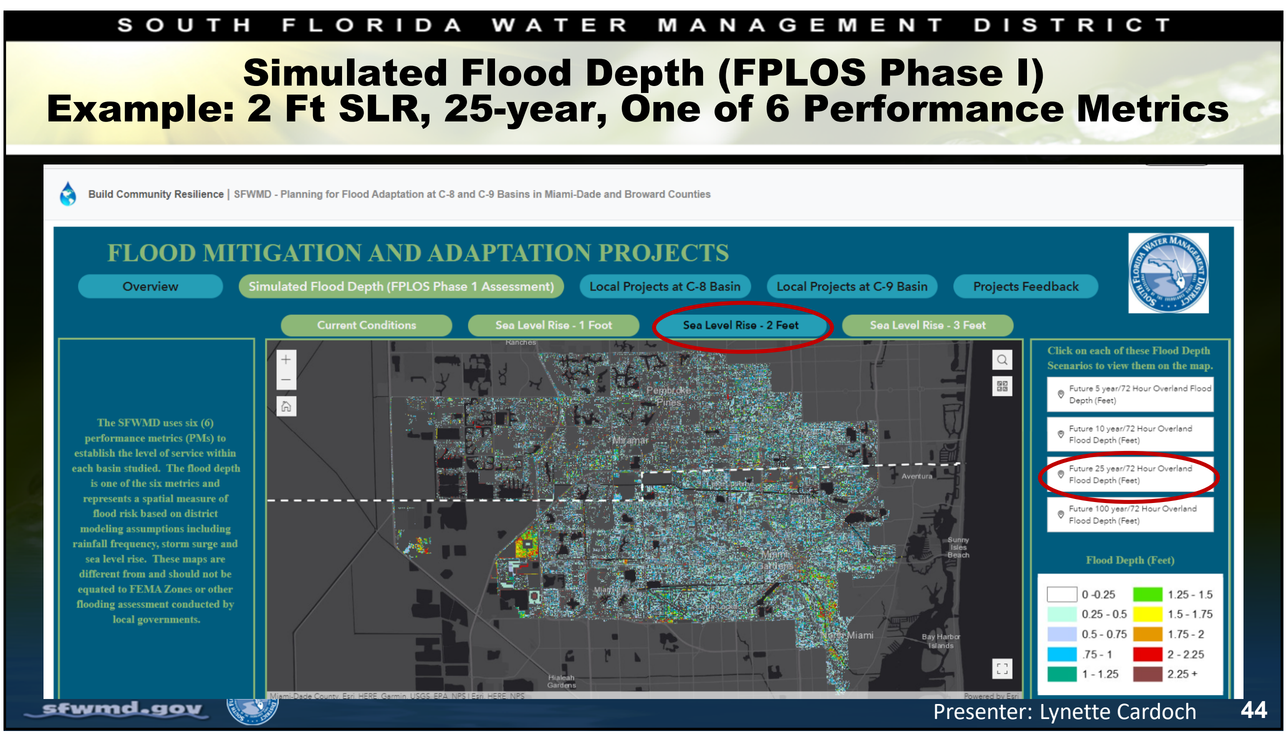

SOUTH FLORIDA WATER MANAGEMENT DISTRICT
Simulated Flood Depth (FPLOS Phase I)
Example: 2 Ft SLR, 25-year, One of 6 Performance Metrics
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FLOOD MITIGATION AND ADAPTATION PROJECTS
Overview
Simulated Flood Depth (FPLOS Phase 1 Assessment)
Local Projects at C-8 Basin
Local Projects at C-9 Basin
Projects Feedback
Current Conditions
Sea Level Rise - 1 Foot
Sea Level Rise - 2 Feet
Sea Level Rise - 3 Feet
The SFWMD uses six (6) performance metrics (PMs) to establish the level of service within each basin studied. The flood depth is one of the six metrics and represents a spatial measure of flood risk based on district modeling assumptions including rainfall frequency, storm surge and sea level rise. These maps are different from and should not be equated to FEMA Zones or other flooding assessment conducted by local governments.
Click on each of these Flood Depth Scenarios to view them on the map.
Future 5 year/72 Hour Overland Flood Depth (Feet)
Future 10 year/72 Hour Overland Flood Depth (Feet)
Future 25 year/72 Hour Overland Flood Depth (Feet)
Future 100 year/72 Hour Overland Flood Depth (Feet)
Flood Depth (Feet)
0 -0.25
0.25 - 0.5
0.5 - 0.75
.75 - 1
1 - 1.25
1.25 - 1.5
1.5 - 1.75
1.75 - 2
2 - 2.25
2.25 +
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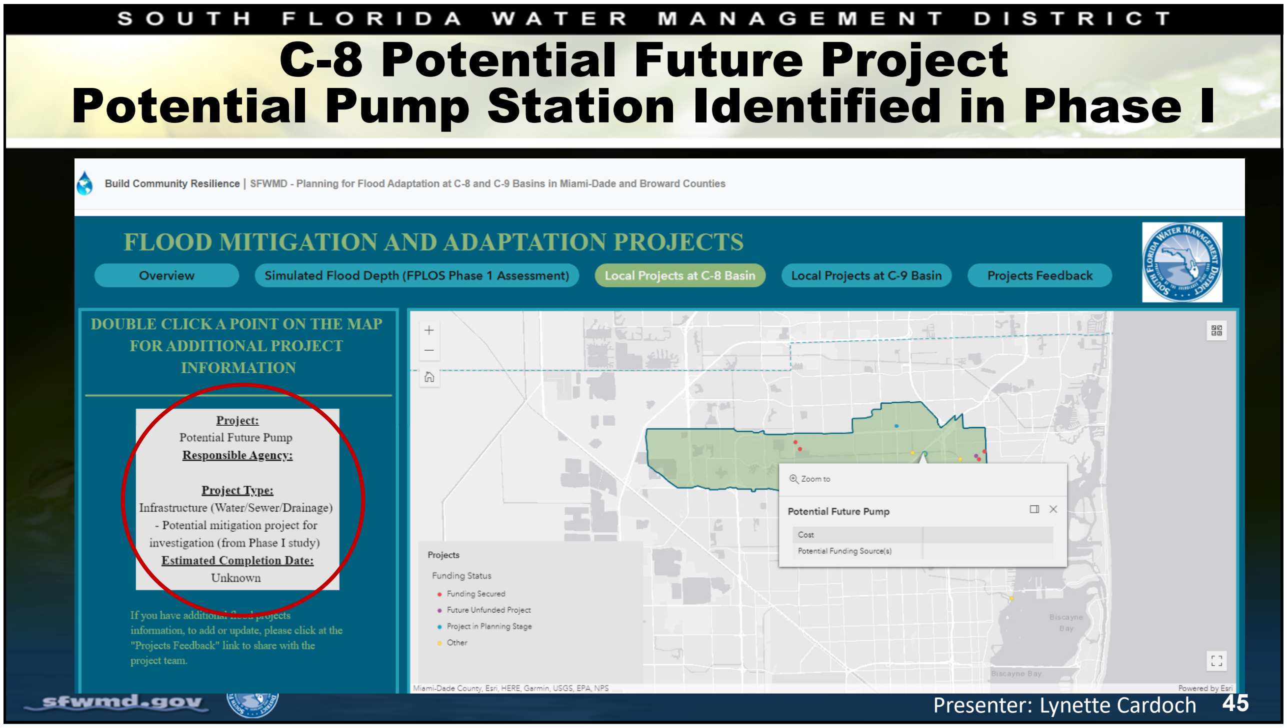
SOUTH FLORIDA WATER MANAGEMENT DISTRICT
C-8 Potential Future Project
Potential Pump Station Identified in Phase I
Build Community Resilience | SFWMD - Planning for Flood Adaptation at C-8 and C-9 Basins in Miami-Dade and Broward Counties
FLOOD MITIGATION AND ADAPTATION PROJECTS
Overview
Simulated Flood Depth (FPLOS Phase 1 Assessment)
Local Projects at C-8 Basin
Local Projects at C-9 Basin
Projects Feedback
DOUBLE CLICK A POINT ON THE MAP FOR ADDITIONAL PROJECT INFORMATION
Project:
Potential Future Pump
Responsible Agency:
Project Type:
Infrastructure (Water/Sewer/Drainage) - Potential mitigation project for investigation (from Phase I study)
Estimated Completion Date:
Unknown
If you have additional flood projects information, to add or update, please click at the "Projects Feedback" link to share with the project team.
Zoom to
Potential Future Pump
Cost
Potential Funding Source(s)
Projects
Funding Status
Funding Secured
Future Unfunded Project
Project in Planning Stage
Other
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Presenter: Lynette Cardoch
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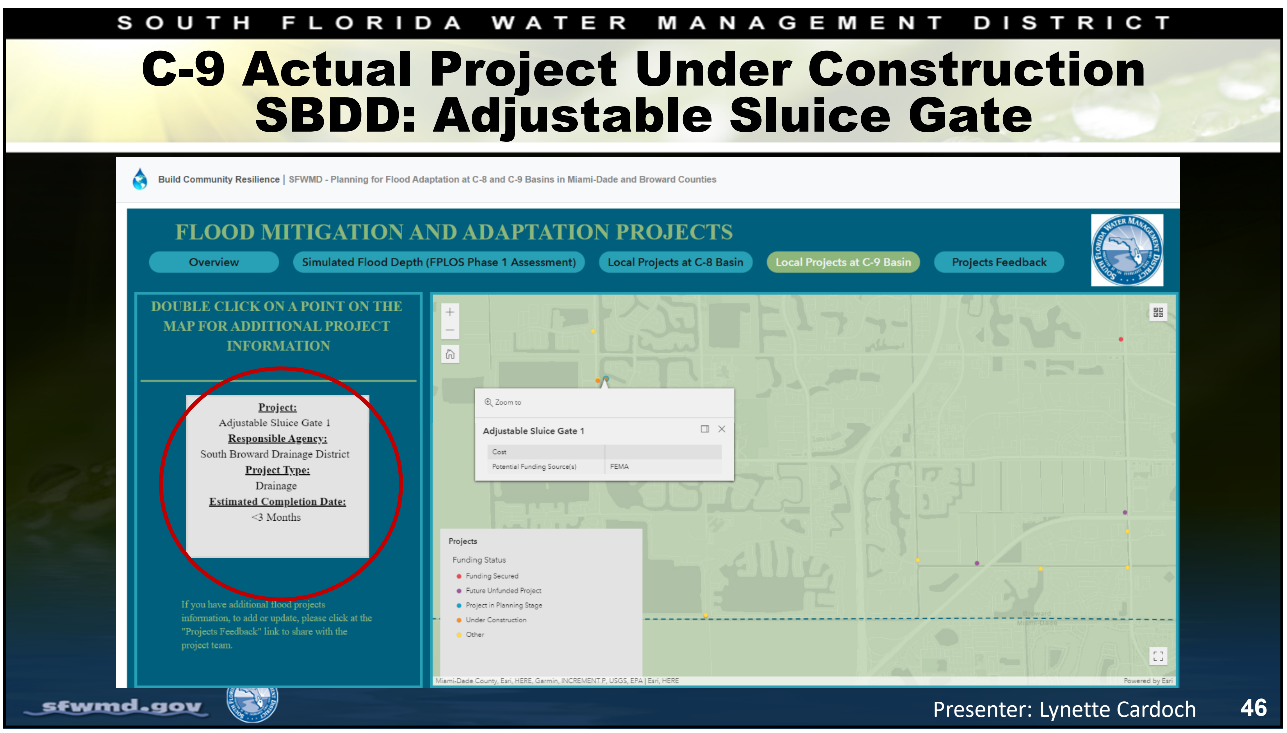
SOUTH FLORIDA WATER MANAGEMENT DISTRICT
C-9 Actual Project Under Construction
SBDD: Adjustable Sluice Gate
Build Community Resilience | SFWMD - Planning for Flood Adaptation at C-8 and C-9 Basins in Miami-Dade and Broward Counties
FLOOD MITIGATION AND ADAPTATION PROJECTS
Overview
Simulated Flood Depth (FPLOS Phase 1 Assessment)
Local Projects at C-8 Basin
Local Projects at C-9 Basin
Projects Feedback
DOUBLE CLICK ON A POINT ON THE MAP FOR ADDITIONAL PROJECT INFORMATION
Project:
Adjustable Sluice Gate 1
Responsible Agency:
South Broward Drainage District
Project Type:
Drainage
Estimated Completion Date:
<3 Months
If you have additional flood projects information, to add or update, please click at the "Projects Feedback" link to share with the project team.
Zoom to
Adjustable Sluice Gate 1
Cost
Potential Funding Source(s)
FEMA
Projects
Funding Status
Funding Secured
Future Unfunded Project
Project in Planning Stage
Under Construction
Other
sfwmd.gov
Presenter: Lynette Cardoch
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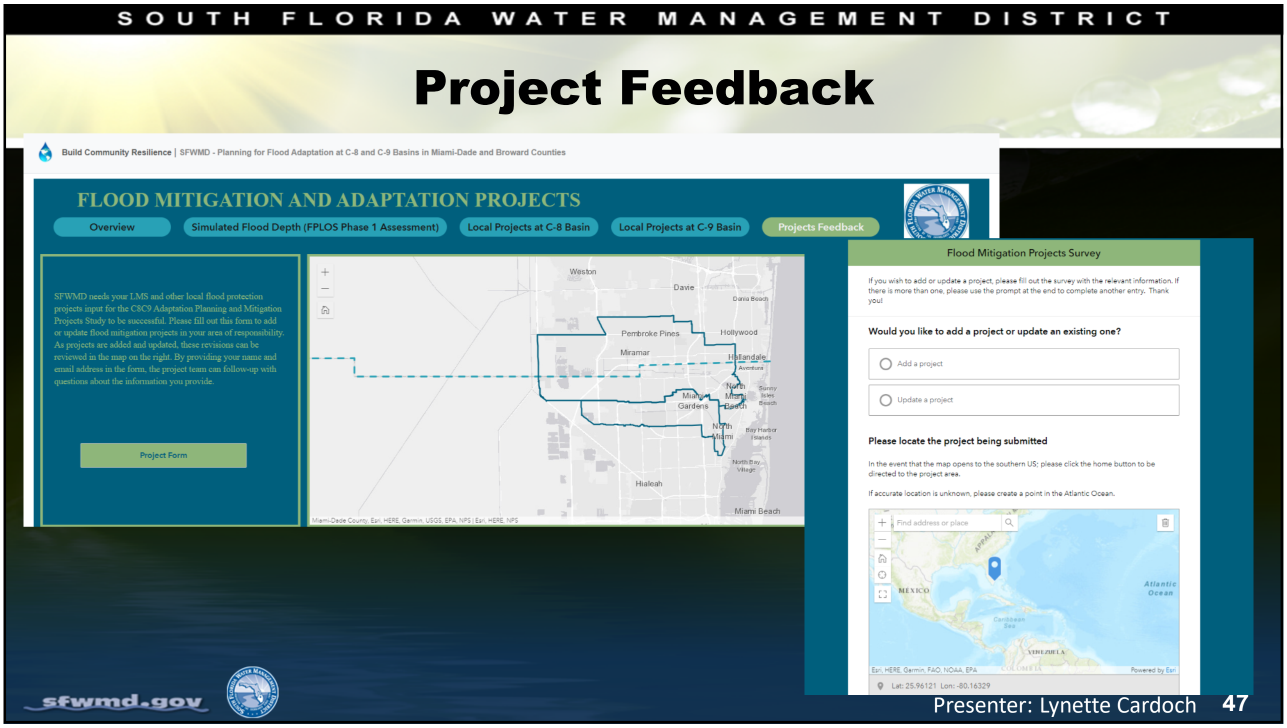
SOUTH FLORIDA WATER MANAGEMENT DISTRICT
Project Feedback
Build Community Resilience | SFWMD - Planning for Flood Adaptation at C-8 and C-9 Basins in Miami-Dade and Broward Counties
FLOOD MITIGATION AND ADAPTATION PROJECTS
Overview
Simulated Flood Depth (FPLOS Phase 1 Assessment)
Local Projects at C-8 Basin
Local Projects at C-9 Basin
Projects Feedback
SFWMD needs your LMS and other local flood protection projects input for the C8C9 Adaptation Planning and Mitigation Projects Study to be successful. Please fill out this form to add or update flood mitigation projects in your area of responsibility. As projects are added and updated, these revisions can be reviewed in the map on the right. By providing your name and email address in the form, the project team can follow-up with questions about the information you provide.
Project Form
Flood Mitigation Projects Survey
If you wish to add or update a project, please fill out the survey with the relevant information. If there is more than one, please use the prompt at the end to complete another entry. Thank you!
Would you like to add a project or update an existing one?
Add a project
Update a project
Please locate the project being submitted
In the event that the map opens to the southern US: please click the home button to be directed to the project area.
If accurate location is unknown, please create a point in the Atlantic Ocean.
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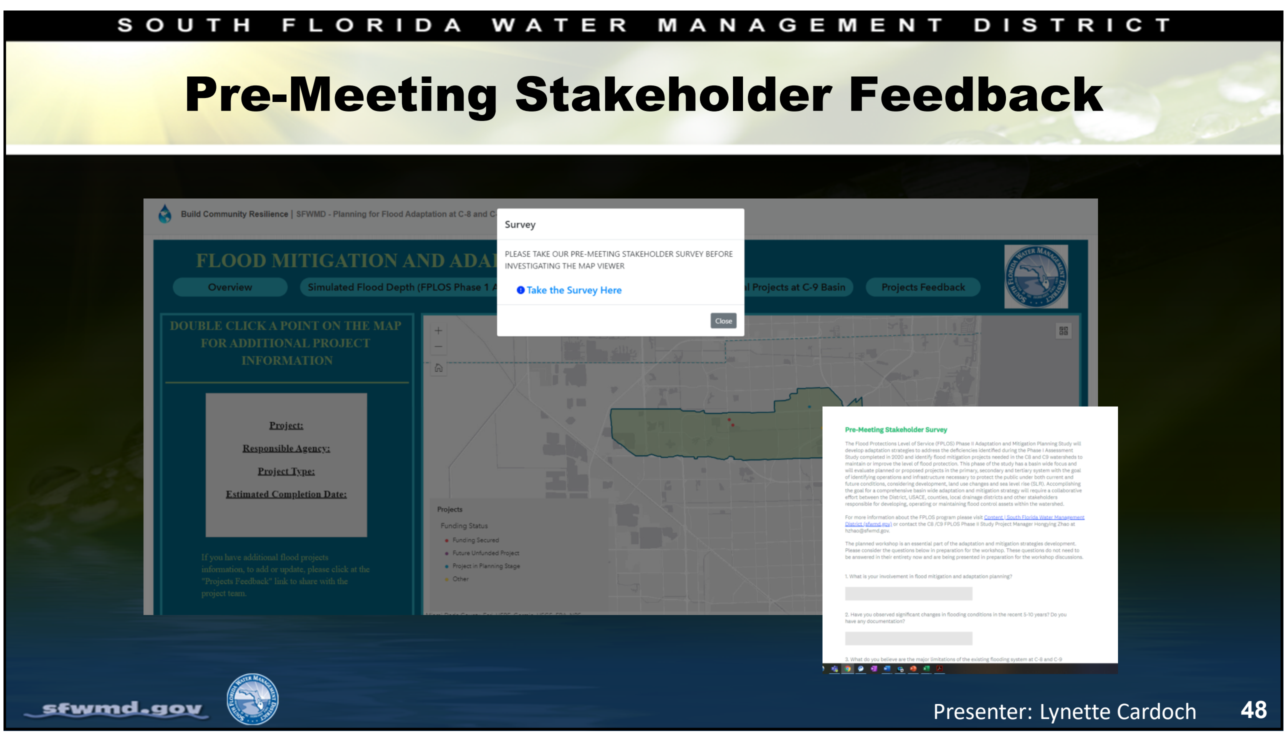
SOUTH FLORIDA WATER MANAGEMENT DISTRICT
Pre-Meeting Stakeholder Feedback
Survey
PLEASE TAKE OUR PRE-MEETING STAKEHOLDER SURVEY BEFORE INVESTIGATING THE MAP VIEWER
Take the Survey Here
Close
DOUBLE CLICK A POINT ON THE MAP FOR ADDITIONAL PROJECT INFORMATION
Project:
Responsible Agency:
Project Type:
Estimated Completion Date:
Projects Feedback
Pre-Meeting Stakeholder Survey
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Pre-Meeting Stakeholder Questions

- What is your involvement in flood mitigation and adaptation planning?
- Have you observed significant changes in flooding conditions in the recent 5-10 years? Do you have any documentation?
- What do you believe are the major limitations of the existing flooding system at C-8 and C-9 Basins? Do you have a plan and preferred actions to address these limitations?
- How are future conditions (e.g. sea level rise or increased rainfall) considered as part of project planning/design?

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Knowledge Gained

- Respondents indicate increased flooding events in past 5-10 years
- Capacity concerns in both basins
- Gravity flow will not accomplish needed drainage
- Uneven consideration of future conditions for rainfall and SLR
  - Not at all → Factored into plans and designs
  - Rain/precipitation changes less understood
- Different conditions in tidal areas versus the western parts of the counties
- Interest in inter-agency and multi-jurisdictional collaboration

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Data Gaps

- Additional feedback on potential mitigation projects at the various levels
- Lacking information on projects that may be more local
- Want more sharing of innovative regulatory/policy ideas
- Integration of new projects and new ideas into the existing basin configuration

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Breakout Groups

Develop and integrate adaptation and mitigation strategies and projects

- Share concerns about present and anticipated flooding/drainage issues
- Enhance connectivity among the community of practitioners in the C-8/C-9 basins through dialogue
- Communicate ideas that the practitioners would like this project to address
- Generate ideas on future projects

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Breakout Topics

- Share any implemented and/or planned specific projects, and innovative regulatory/policy ideas.
- What flood control items do you would like to see assessed in this project to address concerns in your jurisdiction?
- What are the priorities for your region or the broader basin? How can projects be integrated within the region/basin?
- Phase I study put together a list of projects for considerations (reported in the presentation). What do you think about these projects?

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Breakout Group Instructions

- Virtual participants
  - Assigned to a virtual breakout room
  - Zoom platform will automatically take them to correct room
  - More specific platform instructions given in room
- In-person participants
  - Group was designated at check-in
- 45 mins
- Moderator, Scribe, Report-Out

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Questions and Comments

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Breakout Groups Report-Out

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SOUTH FLORIDA WATER MANAGEMENT DISTRICT
Dynamic Adaptation Policy Pathway &
Project Next Steps
Carolina Maran, PhD, PE
District Resiliency Officer
South Florida Water Management District
sfwmd.gov

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SOUTH FLORIDA WATER MANAGEMENT DISTRICT
SFWMD Commitment to Resiliency
Ensuring the Region's Water Resources and Ecosystems Resiliency Now and in the Future
Central and Southern Florida Flood Resiliency Study
Water and Climate Resilience Metrics
Resiliency and Ecosystem Restoration
Resiliency and Water Supply
Resiliency and Flood Protection
As a key part of its resiliency strategy, the District continues assessing the status of its flood control infrastructure and advancing adaption strategies necessary to continue providing primary flood protection for South Florida and other mission critical services.
The Flood Protection Level of Service Program ensures the regional flood control system provides the desired level of flood protection upstream of the tidal structures in place today, and will continue to do so, with consideration for sea level rise, as well as more intense rainfall events.
This effort is integrated into the District's Capital Improvement Program to ensure its structures, pumps, canals -- all of which are critical in keeping South Florida habitable -- are functioning as designed, and will remain
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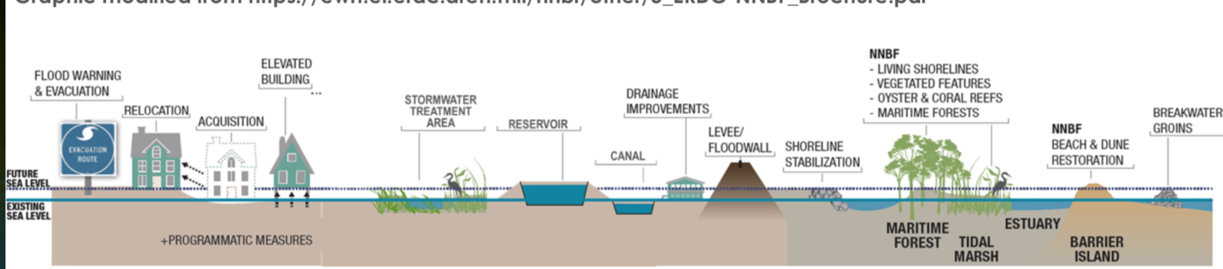
Coordination with Water Managers

Building Resiliency: Integrating Inland and Coastal Flood Mitigation Strategies

POTENTIAL MEASURES TO IMPROVE RESILIENCE AND SUSTAINABILITY
Graphic modified from https://ewn.el.erdc.dren.mil/nnbf/other/5_ERDC-NNBF_Brochure.pdf



Source: USACE

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Modeling Representation Priorities

Category 1- Modeling Priority 1

Modellable and benefits expected under current assumptions

- Has appropriate detail such as geometry, inverts, etc.

Example 1: Add municipal pump at confluence of primary/secondary canal

Reason: There are ways to determine the benefits associated with it (such as reduced stages upstream or reduced overland flooding).

Category 2 – Modeling Priority 2

Modellable and expected benefits underestimated under current assumptions

• Has appropriate detail such as geometry, inverts, etc.

Example 1: Clearing out culverts.

Reason: Model assumes structures are operating at design/maintained condition

Category 3- Not Modeling

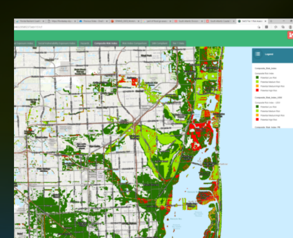
Not modellable / uncertainty to accurately quantify benefits

- Does not have appropriate detail
- Requires modification to modeling assumptions/baseline

Example 1: maintenance dredging in sec. canals

Reason: Too much uncertainty in existing condition cross sections to be able simulate maintenance dredging.

\+ GIS Assessment



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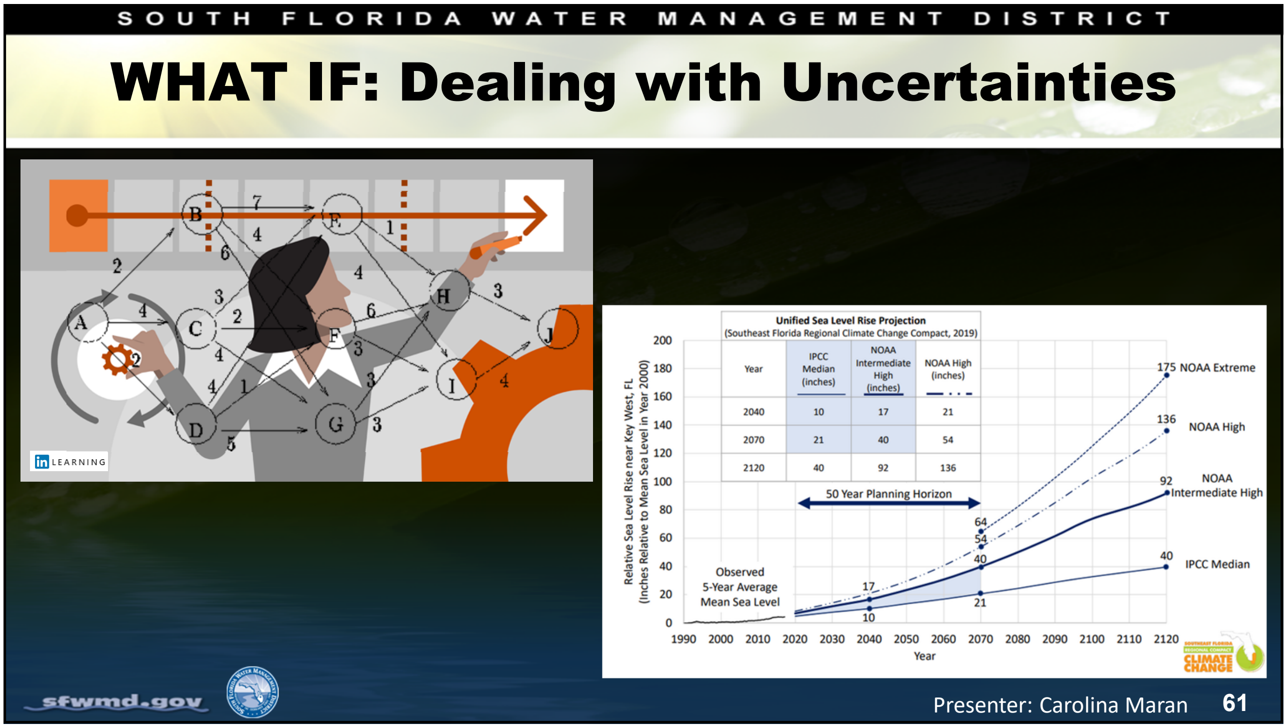
SOUTH FLORIDA WATER MANAGEMENT DISTRICT
WHAT IF: Dealing with Uncertainties
LEARNING
Unified Sea Level Rise Projection
(Southeast Florida Regional Climate Change Compact, 2019)
Year | IPCC Median (inches) | NOAA Intermediate High (inches) | NOAA High (inches)
2040 | 10 | 17 | 21
2070 | 21 | 40 | 54
2120 | 40 | 92 | 136
50 Year Planning Horizon
Relative Sea Level Rise near Key West, FL
(Inches Relative to Mean Sea Level in Year 2000)
Observed 5-Year Average Mean Sea Level
175 NOAA Extreme
136 NOAA High
92 NOAA Intermediate High
40 IPCC Median
Year
CLIMATE CHANGE
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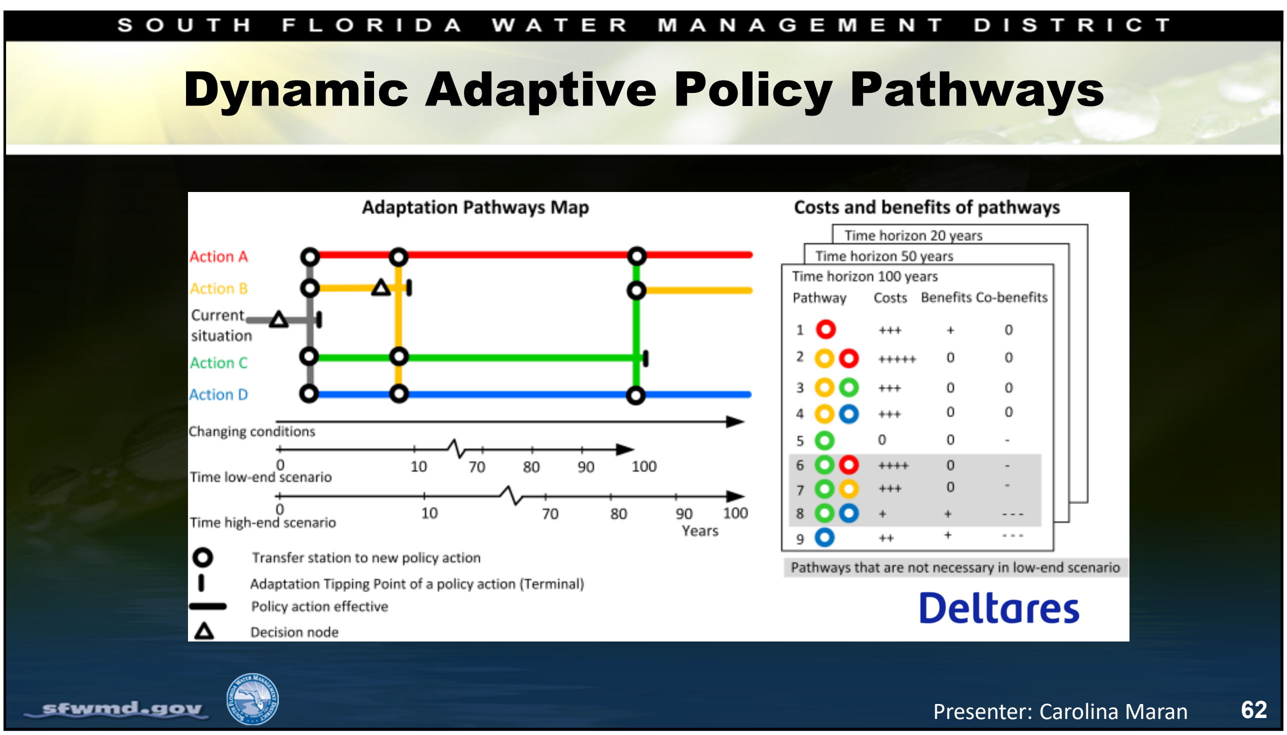
SOUTH FLORIDA WATER MANAGEMENT DISTRICT
Dynamic Adaptive Policy Pathways
Adaptation Pathways Map
Action A
Action B
Current situation
Action C
Action D
Changing conditions
Time low-end scenario
Time high-end scenario
Years
Transfer station to new policy action
Adaptation Tipping Point of a policy action (Terminal)
Policy action effective
Decision node
Costs and benefits of pathways
Time horizon 20 years
Time horizon 50 years
Time horizon 100 years
Pathway | Costs | Benefits | Co-benefits
1 | +++ | + | 0
2 | +++++ | 0 | 0
3 | +++ | 0 | 0
4 | +++ | 0 | 0
5 | 0 | 0 | -
6 | ++++ | 0 | -
7 | +++ | 0 | -
8 | + | + | - - -
9 | ++ | + | - - -
Pathways that are not necessary in low-end scenario
Deltares
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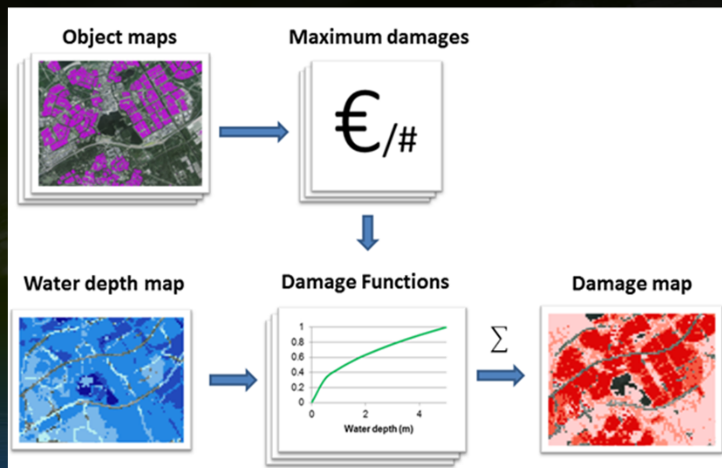
Flood Damage Cost Estimates



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SOUTH FLORIDA WATER MANAGEMENT DISTRICT

Historic and Largest Florida Flooding and Sea Level Rise Resilience Initiative

- SB1954: Resilient Florida Program
- Over $640 million available to support efforts to ensure state and local communities are prepared to deal with the impacts of sea level rise, intensified storms and flooding

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Presenter: Carolina Maran 64

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Collaboration is Key

We count on your continuous engagement throughout the project development, scenarios formulation, review of initial results, etc.

Stakeholder Engagement + Local & Regional Partnerships = Reduced Flood Risks

Source: FEMA BRIC

\+ Maximize Other Associated Benefits

Please reach out to the Project Team if you want to set up a 30-min briefing for elected officials or additional technical staff in your area

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Photo by Miami DDA

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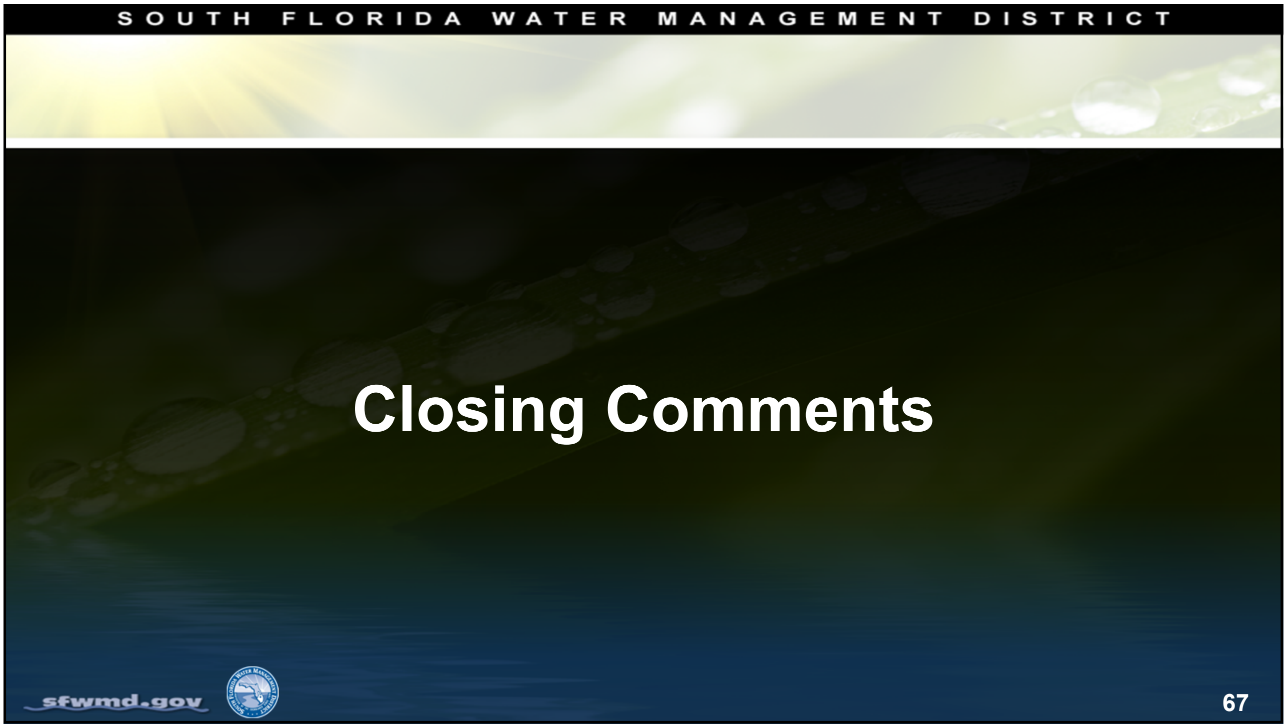
SOUTH FLORIDA WATER MANAGEMENT DISTRICT
Closing Comments
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APPENDIX G: Workshop Pictures

Picture 1: *Date, Time, and Location of the FPLOS Phase II Opening Workshop*

Picture 2: *Report-out Session of the Workshop Break-out Groups*

Picture 3: *Report-out Session of the Workshop Break-out Groups*

Picture 4: *Report-out Session of the Workshop Break-out Groups*

Picture 5: *Presentation by Dr. Carolina Maran*

APPENDIX H: Workshop Feedback

South Florida Water Management District

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

Workshop Feedback (August 3, 2021)

SFWMD Project Team

August 11, 2021

I. **Was the workshop outcome what we planned for?**
   1. Yes, we all agreed that the workshop outcome appears to have met the planned objectives and expectations. Time will confirm how well. The workshop also opened up new avenues for collaboration.
   2. Now we have a bigger commitment to deliver the next project steps.
   3. The virtual breakout session #2 produced a lot of discussion and brought some stakeholders together to discuss different agency projects.

II. **What went well?**
   1. The overall planning went very well.
   2. The stakeholder coordination is very effective.
   3. The pre-survey and the website for collecting information (such as projects and concerns) and sharing information (such as Phase I results and the workshop related message) are very well designed and is a very innovative tool.
   4. The agenda is very well planned.
   5. The presentations are very robust and covered all the critical components.
   6. The breakout groups were very well formulated.

7. The subgroup discussion packet was very well prepared; the discussion topics were very well formulated.
8. The subgroup discussions were very effective.
9. All the subgroup moderators conducted discussions in a very effective way.
10. The breakout group report back truly showed the stakeholder engagement.
11. Uploading all the notes from the discussion groups is also a critical step.
12. The overall workshop moderator led the workshop in a very professional way and the atmosphere was very friendly and encouraging.
13. All four presentations are very robust and delivered a clear message about the FPLOS, resilience, and collaborations.
14. Debriefing and lesson learned allows us to continue to improve in future endeavor.
15. The collaborations from the entire team were the key to success.
16. Outside of the technology challenges, most planed aspects of the event went well.
17. The venue was close to the partners and adequately sized for the in person attendance.
18. Though not planned, the in-person DEP presence was a plus and the flexibility to amend the agenda to accommodate an opening and closing statement by Adam B was excellent.
19. The movement between parts of the event was well planned and nothing was too long, keeping the attendee's attention through the workshop.
20. The pre workshop work including the web tool showed preparation.
21. The mix in the breakout sessions appears to have achieve the desired goal of fostering cross region engagement.
22. The level of stakeholder engagements was encouraging.

23. Level of participation was excellent and only a few communities did not have a participant attending.
24. Participants came ready to share thoughts, ideas and overall project details with the District team. They seemed open to coordinate with us now and in the future (as part of scenario simulations).

25. Materials were super well prepared, the room looked great, the food offer was also very good.

26. The ZOOM breakout session was well thought out. The instructions to the moderators were very helpful and kept the discussion on track.
27. Having a list of attendees assigned to the BO room was essential. Most attendees kept their cameras off.
28. It was key to have a SFWMD FPLOS team member in the BO room to advise of policy and answer specific questions.
29. The event structure (hybrid set-up, group breakouts, venue/space, etc.) and material presented (program wide, study specific, etc.) were well planned, this was apparent to me based on the engagement received in person and online via zoom and the enthusiasm of many of the participants to continue working together to share/learn where improvements are needed between our agencies.
30. The public calendar posting.

III. What could have been better?

1. Some technologies related to the audio and the hybrid type of meetings can be improved.
2. Consider having a website for the project to communicate all the critical milestones.
3. The breakout discussion session can use a little more time.
4. The engagement with elected could have improved. I do not know for example how many elected officials were represented and if there was some way of acknowledging the office to help start the process of finding a couple of champions for the work.
5. We need to have better coordination with Counties. We are not sure yet if all projects were brought to the discussion, via tool or via breakout sessions. Miami Dade County (Marina) mentioned their projects developed as part of the latest XPSWIMM Modeling effort (in our separate coordination meeting) and it seems these projects were not fully incorporated yet as part of the Workshop process.
6. The Counties participation in the Workshop was more on the overall project's aspects and review, and not yet to share project details. I agree that the engagement with elected officials ended up being ineffective.
7. The initial part of the ZOOM meeting audio (while presentations were being made) before the breakout sessions had audio issues.
8. Increasing the participation of elected officials. Internal engagement, I did receive last minute link requests for the meeting link as well as after the workshop from District personnel. Some folks had great input and resources after the fact that would have been helpful. Perhaps an invite to all bureau chiefs or section leads next time.
9. The handling of the audio issues by venue staff could've been improved – e.g. using breaks in the presentation to bring in the soundboard instead of doing so while a presenter was speaking.
10. During Q&A, I find it would've been helpful to allow the more technical members of the consulting team to address the participants, e.g. Joe W. had excellent insights in response to some questions and during the field trip the next day.

IV. What did we learn?

1. In general, I think this is the right direction for conducting an adaptation and mitigation planning projects workshop and to encourage stakeholders' engagement.
2. Three important things.
    - There is stakeholder interest and desire to engage (district interest in local projects).
    - The suite of adaptation strategies is not too different from those we could have anticipated going in.
    - There is a strong local desire to incorporate green and water quality considerations - not news but confirmed.

3. Several projects and willingness to collaborate One Water approach - accounting for Water Quality implications.
4. Stakeholders want to incorporate water quality issues with flood control issues where possible. They want FC projects to improve WC where possible.
5. Folks are interested in collaborating and advancing approaches/projects that address flood issues in additional to providing other beneficial services/outcomes (e.g. community benefits, water quality, etc.).

V. What are our next steps?

1. The next step will be completing the remaining subtasks.
2. Develop a workshop minutes.
3. Summarize all the projects collected through survey and workshop.
4. Fine-tune the criteria and prioritization scheme to select the final M1 projects to be included in subsequent modeling activities.
5. Identify the projects that need follow-up discussions with stakeholders to collect additional information to be able to do the assessment in the next task.
6. Follow-up discussions with stakeholders.
7. Develop Task 1 technical memo.
8. Leverage the engagement and relationships established. Finalize a list of strategies that we know of and determine the feasibility of evaluating with existing tools (with or without modifications).
9. Determine if a new tool is needed to augment the available suite of tools and if it is in or out of scope of the current contracts Take on the WQ challenge I put to the team to develop a metric (monetized) that shows up as a cost under current or no action condition and a cost avoidance under alternative scenarios that improve (or have the potential to improve) WQ Revisit and follow the scope of work for the project. Confirm timelines.
10. Crosswalk between counties and SFWMD models will be a very strategic next step, to get more recognition from our efforts and have the capacity to represent their efforts in an integrated model. Share results along the way to boost engagement, not only next DAPP Workshop.
11. Reconnect with the stakeholders to flesh out projects they submitted or get projects from them that they did not submit at the Workshop.
12. Keep the engagement going through data sharing and follow-up.
13. Somehow address all projects/ideas, if not through modelling, then GIS or other avenues.
14. Engage with any cities/municipalities that were not represented at the workshop.
15. Use of comms news updates.

TAYLOR ENGINEERING, INC.

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

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

Deliverable 2.1

CONTRACT 4600004085

Work Order 05

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

Submitted 2/02/2022

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Tampa, Florida 33618
813-963-6469 | www.taylorengineering.com

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1 INTRODUCTION

The South Florida Water Management District (SFWMD or District) is conducting a system-wide review of the regional water management infrastructure to determine what mitigation projects would maintain or improve the current flood protection level of service (FPLOS). The FPLOS Phase 1 Study describes the level of protection provided by the water management facilities within a watershed considering sea level rise (SLR), future development, and known water management issues in each watershed.

This memorandum details the development of mitigation efficiency criteria, mitigation projects suitable for modeling, and a draft modeling plan for the adaptation planning and mitigation project study within the SFWMD C8 and C9 basins. Specifically, this memorandum details the criteria used to filter through the project list developed in Task 1 (combination of anticipated impacts and project scale), the list of mitigation projects suitable for modeling, and the preliminary approach proposed to determine what suite of projects the team will apply in the final mitigation scenario models.

Task 1 Summary Memorandum (Desktop Review, Website Project Viewer, and Partner Workshop on the Adaptation Planning and Mitigation Projects) details the complete list of projects identified for flood mitigation in the basins.

2 MITIGATION EFFICIENCY CRITERIA

This project compiled 92 proposed mitigation projects from previous work efforts (Phase 1) and partner communities. These proposed projects ranged from fixing damaged culverts to improving local street drainage to adding forward pump stations and floodwalls at the tidal outfalls. However small or large, each project can, and likely will, have a beneficial impact on the local area it serves in real-world events. However, simulating these projects in the hydrologic and hydraulics model of the C8 and C9 basins, several factors such as model scale and design assumptions (i.e., rainfall distribution) can cause what would realistically be a beneficial project to show an underestimation of benefits, if any. Therefore, to assess such a diverse set of projects and project scales, the team developed a scoring to help generate a better understanding of what the anticipated real-world benefits are likely for each project. The scoring process assigned each project a score of 1 to 5 for each category, with 1 being not likely and 5 being very likely, for each of the following categories:

- *Allows operation flexibility* – flood control managers need operational flexibility to accommodate the dynamic and complex nature of real-world flood events.
- *Prevents "high water" from backflowing in* – a system that can provide mitigation against the influx of tidal surge during a tropical storm event is highly advantageous.
- *Increases discharge ability* – some mitigation activities can promote the ability of a system to increase discharges through canals or hydraulic structures.
- *Can alleviate primary system flooding* – the primary system being major canals such as the C8 or C9.
- *Can alleviate secondary system flooding* – the secondary systems being canals such as the Carol City Canal or Red Road Canal
- *Can alleviate tertiary system flooding* – the tertiary systems being stormwater systems such as Pembroke Pines, the large ponds and drainage areas of Miramar, or Miami Lakes.

In addition to these categories, the team wanted to point out the value of water quality and how well developed the project is. For water quality, a simple scale evaluating a neutral impact or positive impact. And for project development, the team thought capturing some level of how well conceived a project is would help the team know the likelihood of its progress and what to expect for design details. It is important to note that these scores are not used to determine what projects are included in the model simulations. Rather, these scores are just a way to assess anticipated real-world impacts and understand what benefits each project could potentially have. It is important to note that the scoring system was not used to rank projects, chose projects for modeling, or make any other decision; it was simply an exercise used to understand each project better

The team developed, modified, and updated the project list and scoring presented in **Appendix A** many times. This version presents only one set of scoring and draft project lists. The project team found the exercise of scoring the projects quite instructive and helped gain an appreciation of the impact each project may have on the system. It became quite clear that the effort to categorize the projects based on the criteria listed above proved problematic since the majority of the impact a project would have on the system was driven by the exact location of the project.

After discussion of the project list and scoring of the results, the team decided to pivot and create a categorization scheme that would better reflect the scale of the mitigation projects. The team evaluated each project in terms of four categories: (1) regional scale, (2) local scale, (3) micro scale, and (4) other. Regional-scale projects have anticipated impacts on a regional scale, or to a much larger extent than the immediate project area. An example of a regional scale project is improvements to the tidal outfall structure, which has anticipated benefits further upstream such as reduced stages. Local-scale projects 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. An example of a local scale project is the addition of a gated structure or pump station on the confluence of the primary and secondary canal system, which has anticipated benefits further upstream such as reduced stages or flood duration, but do not necessarily contribute to flood mitigation downstream. Micro scale projects are those that have anticipated impacts on a small (micro) scale, such as only to the immediate project area, or projects that are so local they fall below the scale and resolution of the model. An example of a micro scale project is the drainage improvement to a specific street, which has anticipated impacts only to the immediate drainage area. Projects classified as "other" are those that are outside of the study areas, already constructed, or do not directly affect flooding or flood mitigation in any way. An example of a project classified as "other" is a fire suppression system at a pump station or stormwater system inspections. These projects classified as "other," although important aspects to everyday real-world safety and maintenance, do not relate to the flood model.

For the purposes of this regional Flood Protection Level of Service project, the team will only evaluate regional and local scale projects in the MIKE SHE / MIKE HYDRO models. Micro scale and "other" projects are known to have some level of benefit for the area they serve but are unable to be adequately represented under the current resolution and scale of the model. Therefore, the micro scale and "other" projects are still recommended to be pursued by partner communities.

Appendix A lists the mitigation projects sorted according to regional, local, micro, or other scale. The scoring in this list is based on engineering judgement and with the limited data collected in Task 1. The primary determination is based largely on the location of each project and its scale, as described in the following sections

2.1 Regional Scale Projects

Regional-scale projects are larger magnitude projects that have anticipated impacts on a regional scale, or to a much larger extent than the immediate project area. These projects are often major infrastructure additions or modifications to the primary canal system and are likely considered SFWMD projects. The following list shows the regional scale mitigation projects that are proposed to be evaluated:

- Dredging the C-8 Canal
- Dredging the C-9 Canal
- S-28 Improvements – such as pump station, higher platform and gates, tieback levees/floodwalls
- S-29 Improvements – such as 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)
- Miami Shores Country Club impoundment

2.2 Local Scale Projects

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. Although SFWMD would lead some of these projects, the local municipalities, partner communities, or local drainage districts would own the majority of local scale projects. This project will evaluate the following list of local scale mitigation projects:

- Pembroke Pines three basin interconnect at Century Village
- Injection Well construction
- SBDD B-1 / B-2 Pump Station upgrades
- SBDD Basin 3 / Basin 7 interconnects at Country Club Ranches
- Add operable structures (gates / pumps) to confluency of primary / secondary canals
- Storage addition to non-pumped drainage areas

2.3 Micro Scale and “Other” Projects

Micro scale projects are small projects that have anticipated impacts on a micro scale, such as only to the immediate project area or projects so local they fall below the scale and resolution of the model. These projects are typically drainage improvements to the tertiary drainage system or beyond. These micro scale projects are anticipated to have some level of benefit for the area they serve but are unable to be adequately represented under the current resolution and scale of the model or model assumptions. Projects classified as “other” are outside of the study areas, already constructed, or do not directly affect flooding or flood mitigation in any way.

3 MITIGATION EFFICIENCY CRITERIA AND MODELING APPROACH

This part of the study, Task 2, involves evaluating and comparing the different mitigation projects proposed in Task 1 to ensure that the current flood control level of service is maintained or improved under future conditions with sea level rise. The project team will evaluate four mitigation strategies across four return interval rainfall events and three sea level rise scenarios, for a total of 48 final model simulations, for use in the flood damage assessment (Task 3 of this project). The four mitigation strategies include (1) Local Mitigation Strategy (M1), (2) Regional Mitigation Strategy for near-term SLR (M2A), (3) Regional Mitigation Strategy for far-term SLR (M2B) and (4) Combination of Mitigation Strategies (MX). Each of the four final mitigation strategies will be simulated using the 5, 10, 25, and 100-year return interval rainfall events with 1, 2, and 3 ft of sea level rise. However, before these 48 final design storm simulations are evaluated, the team will complete a series of iterative model runs to determine what mitigation projects proposed in Task 1 will be included. Or what the specific project details are, such as pump capacity required to achieve a level of service equal to or better than current conditions. Please note that not all projects proposed in Task 1 will be evaluated in the model iterations, specifically the micro scale and "other projects" discussed in **Section 2.3**, rather, just local scale and regional scale projects will be analyzed. Also note that the mitigation efficiency criteria includes PM1 profiles, PM5 flood depths, and PM6 flood durations, as well as qualitative assessment based on the project team's professional judgement. The mitigation efficiency criteria are assessed during the 3-part model iteration process documented in the following subsections and not as part of the 48 final model simulations. The following subsections document the proposed modeling approach that the team will use to select mitigation projects and develop the final four mitigation strategy scenarios' model setup and parameterization.

3.1 Part 1 - Model Setup for M2A and M2B – *Approximating the Tidal Outfall Pump Capacity Required to Achieve a Level of Service Equal to or Greater than Current Conditions for each Return Interval and Sea Level Rise Scenario*

Taylor Engineering proposes to start developing model scenarios by approximating the tidal outfall pump capacity required to achieve a level of service equal to or greater than current conditions for each return interval and sea level rise scenario. To determine if the current level of service provided under current conditions is maintained or improved under future conditions with mitigation, this project will review peak stage profiles. It is important to note that it is possible that regional mitigation strategies alone, specifically the modification of the tidal outfall structure, may not be enough to maintain the current conditions level of service under future sea level rise conditions.

For the Part 1 iteration runs, the team assumed that no other regional or local projects are implemented aside from the pump station and necessary improvements such as raising overtopping elevation of the gate, and conceptually representing tieback levees/floodwalls. This assumption is applied so that the pump station capacity required to achieve a level of service that is equal to or greater than current conditions for each return interval and sea level rise scenario can be determined. At the end of the Part 1 iteration runs, the team can complete the following table for both S-28 and S-29:

Table 3-1: Tidal Outfall Pump Capacity Required to Restore Current Condition (M0) LOS

SLR Condition	Pump Size Required to get Back to M0 Conditions (CFS)			
	5-Year	10-Year	25-Year	100-Year
SLR1				
SLR2				
SLR3				

The following approach is proposed for the Part 1 iteration runs:

1. Start by running the 5-year SLR1 model with the only changes made to SFWMD tidal outfall structure – changes include forward pump, raising gate, and representing a tieback levee/floodwall system.
2. Use an iterative approach to determine approximately what size pump (starting with 500 cfs increments) would be required to reduce 5-year SLR1 peak stage profiles equal to or below the 5-year CSL peak stage profile (M0). This analysis is a PM1 comparison.
3. Repeat step 2 for every rainfall return interval and sea level rise scenario.

This Part 1 iteration runs will provide twelve pump capacities for the S-28 and S-29 structures. The SFWMD will choose two pump capacities from the provided table to be used in the M2 Mitigation Strategies, one pump capacity for M2A and a larger capacity for M2B. The pump size for the M2A scenario will address near-term SLR issues (SLR1 or SLR2) and the pump size for the M2B scenario will address far-term SLR issues (SLR3). Note that the M1 local projects or other M2 regional projects that could increase or decrease the requirement of the District Pumps are not included in this determination of the M2 pump capacity.

3.2 Part 2 - Model Setup for M1 Mitigation Strategy – *Mitigation Efficiency for Local Scale Projects*

This task will evaluate local scale mitigation projects in two separate sets of model iteration scenarios: (A) projects proposed by partner communities that have been categorized as "local scale," and (B) additional projects identified by the consulting team to address local flood vulnerabilities with potential larger regional benefits, not included in the initial list of recommended projects by local partners. Model runs will only apply the 25-yr SLR1 storm event for this part of the study. Subsequent model runs as part of Task 2.2 will apply the full suite of rainfall events and sea level rise scenarios.

The additional projects identified by the consulting team to address local flood vulnerabilities with potential larger regional benefits, grew from a need to take a larger view of the system and propose solutions that address larger scale issues. In Task 1 the team requested mitigation projects from the local communities and partners. However, most of the partner projects are focused on their specific area of interest and do not necessarily contribute to the larger-scale flood protection. The partner projects are still very important to the area they serve and should still be pursued by partner communities and stakeholders. However, for the purposes of this regional-scale model, many of the projects were on such a local scale that they fall below the scale and resolution of the model. Therefore, the team realized the need take a broader view of the area and propose projects that can be explicitly modeled in this regional-scale model and have anticipated benefits that can be quantified through the standard data outputs from the MIKE SHE / MIKE HYDRO model.

The following approach is proposed for the M1 mitigation strategy model setup iteration:

A. Projects Proposed by Partner Communities

1. Start by adding local scale projects proposed by partner communities to the 25-year SLR1 model.
2. Run 25-year SLR1 scenario.
3. Create PM5/PM6 difference maps.
   i. If project has some level of benefit identifiable through model run, it becomes classified as a M1 project to be included in the final M1 model setup.
   ii. If model is unable to show some level of benefit, THEN anticipated real-world impact assessment is used to justify if project is included in final list of recommended projects.

B. Additional Projects Identified by the Consulting Team to Address Local Flood Vulnerabilities

B-1. IF only one proposed option (i.e., only one proposed size culvert for basin interconnect):

1. Start by adding local scale projects identified by the consulting team to the 25-year SLR1 model.
2. Run 25-year SLR1 scenario.
3. Create PM5/PM6 difference maps to determine if/what impact each project has compared to M0.
   i. IF project has some level of benefit identifiable through model run, it becomes classified as a M1 project to be included in the final M1 model setup.
   ii. IF model is unable to show some level of benefit, THEN anticipated real-world impact assessment is used to justify if project is included in final list of recommended projects.

B-2. IF more than one option in the same location (i.e., gate or pump station):

1. Start by adding local scale projects identified by the consulting team to the 25-year SLR1 model.
2. Run 25-year SLR1 scenario for option 1 (i.e., secondary system gate).
3. Create PM5/PM6 difference maps to determine if/what impact each project has compared to M0.
4. Run 25-year SLR1 scenario for option 2 (i.e., secondary system pump)
5. Create PM5/PM6 difference maps to determine if/what impact each project has compared to M0.
6. Create PM5/PM6 difference maps to determine if/what impact each project has compared to proposed Option 1.

Figure 3-1 shows an example of a difference map where two model simulations – with and without mitigation projects – are used to create a difference map. This is an example only and not intended to convey results for this ongoing study.

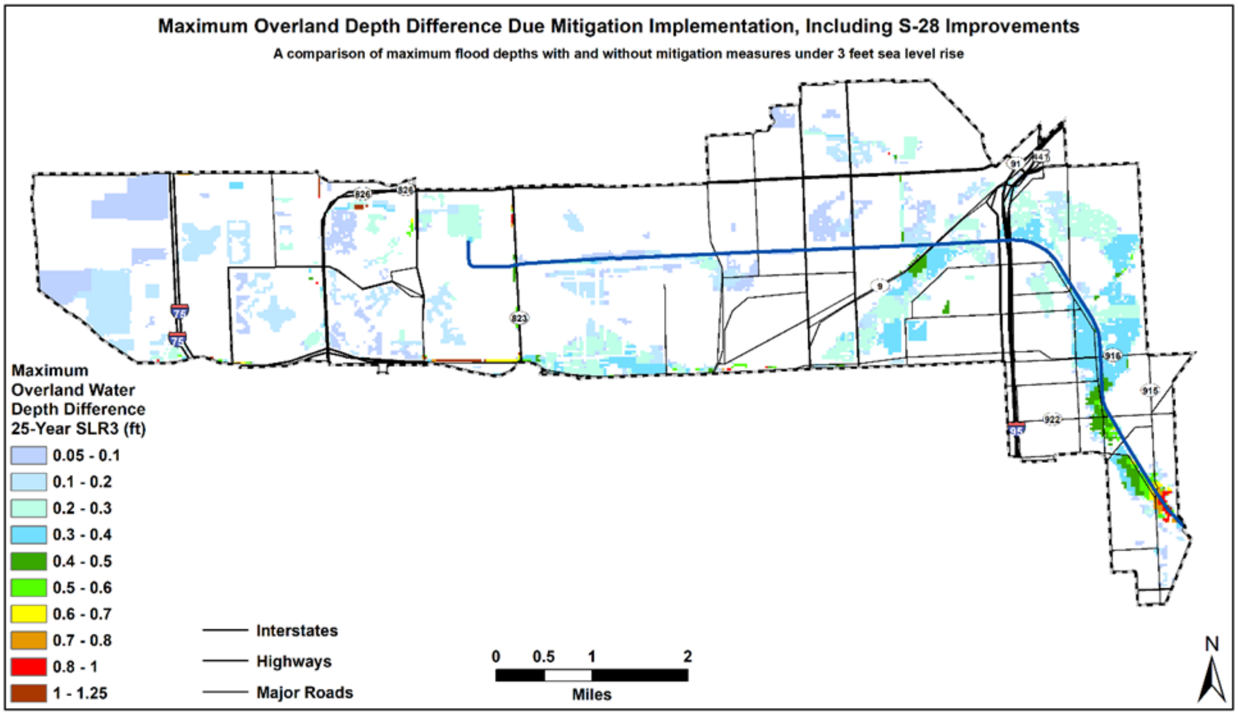

Figure 3-1: Difference Map Showing Example of with and without Mitigation Projects differences.

The team anticipates at least one or two instances of proposing multiple projects in the same general area. The purpose of multiple projects in the same area is that, while pumps may always show a larger benefit, the mitigation projects should not be limited to pumps. This analysis will look at different combinations/placement of gates/pumps and use flood depth/duration difference maps to help the District decide which to include in the final suite of projects to be included in the final M1 model setup.

These iteration runs may show that in the particular area where both a pump station and gated structure are proposed, the pump station has some "X" level of improvement compared to the gated structure. It may be beneficial for the 12 M1 scenarios to use gated structures at these selected secondary system locations instead of pump stations, which would serve as the baseline or minimum level of improvement. Then, as part of the flood damage assessment, a second "back of the envelope" calculation can be performed assuming the same "X" level of improvement to the specific area where the secondary system pump stations were tested, assuming the specific area with some "X" level of benefit could be identified. Essentially, this would allow for an approximation of the cost benefit for a pump instead of just a gated gravity structure in the same location, given there is a set number of final model setups that can be simulated.

3.3 Part 3 - Model Setup for MX Mitigation Strategy – *Approximating Tidal Outfall Capacity Requirements for a Combination of Local and Regional Mitigation Strategies*

Once Parts 1 and 2 are complete, the team will understand what pump capacity is required to maintain or improve the current condition level of flood protection under future conditions assuming no other projects and what local scale projects show a flood mitigation benefit. As M1 local projects or other M2 regional projects could increase or decrease the requirement of the District Pumps, Taylor Engineering proposes to approximate the tidal outfall pump capacity required when these other projects are considered. Therefore, the Part 3 model iteration runs will determine what size tidal outfall pump station the District needs to provide to improve or reestablish a FPLOS comparable to current conditions under future conditions with local and regional mitigation projects in place. For the Part 3 iteration runs the team will analyze PM1, PM5, and PM6 metrics as part of the mitigation efficiency criteria analysis. The following approach is proposed for the Part 3 iteration runs:

1. Start by running 25-year SLR1 model with the final suite of M1 projects and regional projects such as changes to the SFWMD tidal outfall structure – changes include forward pump, raising gate, and representing a tieback levee/floodwall system.
2. Use an iterative approach to determine approximately how much increase in pump capacity (if any) would be required to:
   a. Reduce 25-year SLR1 peak stage profiles equal to or below the 25-year CSL (M0) peak stage profile. This analysis is a PM1 comparison.
   b. Reduce 25-year SLR1 maximum overland flood depths/durations equal to or below the 25-year CSL (M0) maximum overland depths/durations. This analysis is a PM5/PM6 comparison.
   c. Keep S-28/S-29 tidal outfall 12-hour average 25-year SLR1 peak stages and flows at or below the current values for the 25-year CSL (M0). This is a PM3 comparison.

At the end of the Part 3 model runs, the team will have identified a suite of projects and subsequent model parameterization requirements that together meet the flood protection level of service mitigation goals, such as reducing primary canal stages equal to below current conditions, reducing overflood flood depths, and reducing flood duration. Although it is desired that every rainfall storm event and sea level rise scenario modeled will be able to reach a level of service equal to or greater than current conditions, it is likely that this will not be achievable for every scenario. In this event, the final analysis may show that the mitigation can restore or improve the flood protection level of service for some specific storm events while only being able to partially mitigate the effects of sea level rise by some amount for other storm events. It is important to note that a suite of mitigation projects can have a positive cost benefit while not restoring current condition level of service just as a suite of mitigation projects that can restore the current conditions level of service can have a negative cost benefit. As the final suite of projects is determined through the iteration runs, other things besides restoring to current conditions should be considered such as feasibility, as an analysis showing flood reduction back to current conditions that could never feasibly be implemented would not be best use of valuable model runs and analysis.

4 PROJECT PLAN

Section 3 above details the approach used to understand how both local scale and regional scale mitigation projects affect flooding in the C-8 and C-9 Basins, what pumping capacity may be required, and how the model will respond to certain changes. These iteration runs are used to help influence model setup changes including but not limited to what mitigation projects will be implemented, structure operations, and initial conditions. Moving forward, the project plan is to:

- Complete M1 iteration runs to determine final suite of M1 mitigation projects
- Complete MX iteration runs to determine final model setup and parameterization for MX mitigation scenario
- Complete the final M1 Mitigation Strategy modeling (12 events)
    - Postprocess the 12 final model simulations for use in the flood damage assessment
- Complete the final M2A Mitigation Strategy modeling (12 events)
    - Postprocess the 12 final model simulations for use in the flood damage assessment
- Complete the final M2B Mitigation Strategy modeling (12 events)
    - Postprocess the 12 final model simulations for use in the flood damage assessment
- Complete the final MX Mitigation Strategy modeling (12 events)
    - Postprocess the 12 final model simulations for use in the flood damage assessment

Table 4-1 shows the list of 48 final model simulations the team will complete in Task 2.2 to analysis the flood protection level of service under future conditions with mitigation, some of which are required to complete the flood damage assessment. **Table 4-2** shows a breakdown of what data will be generated/postprocessed and provided as part of the project deliverables. It is estimated that it will take 4 to 5 months to fully simulate and postprocess the 48 final model simulations, which cannot start until after the 3-part model iteration process detailed in **Section 3** is completed. In order to make-up time, the project team will provide model results for use in the flood damage assessment in four sets of completed runs instead of waiting until all 48 model scenarios are simulated and postprocessed. Additionally, the project team will enlist additional engineer's familiar with the postprocessing routine to shorten the amount of time required to complete all postprocessing while ensuring a consistent approach.

Table 4-1: List of Final Model Simulations to be Completed in Task 2.2

Design Storm Frequency	Mitigation Scenario											
	M1			M2A			M2B			MX		
	SLR1	SLR2	SLR3	SLR1	SLR2	SLR3	SLR1	SLR2	SLR3	SLR1	SLR2	SLR3
5-Year	5-Yr SLR1 (M1)	5-Yr SLR2 (M1)	5-Yr SLR3 (M1)	5-Yr SLR1 (M2A)	5-Yr SLR2 (M2A)	5-Yr SLR3 (M2A)	5-Yr SLR1 (M2B)	5-Yr SLR2 (M2B)	5-Yr SLR3 (M2B)	5-Yr SLR1 (MX)	5-Yr SLR2 (MX)	5-Yr SLR3 (MX)
10-Year	10-Yr SLR1 (M1)	10-Yr SLR2 (M1)	10-Yr SLR3 (M1)	10-Yr SLR1 (M2A)	10-Yr SLR2 (M2A)	10-Yr SLR3 (M2A)	10-Yr SLR1 (M2B)	10-Yr SLR2 (M2B)	10-Yr SLR3 (M2B)	10-Yr SLR1 (MX)	10-Yr SLR2 (MX)	10-Yr SLR3 (MX)
25-Year	25-Yr SLR1 (M1)	25-Yr SLR2 (M1)	25-Yr SLR3 (M1)	25-Yr SLR1 (M2A)	25-Yr SLR2 (M2A)	25-Yr SLR3 (M2A)	25-Yr SLR1 (M2B)	25-Yr SLR2 (M2B)	25-Yr SLR3 (M2B)	25-Yr SLR1 (MX)	25-Yr SLR2 (MX)	25-Yr SLR3 (MX)
100-Year	100-Yr SLR1 (M1)	100-Yr SLR2 (M1)	100-Yr SLR3 (M1)	100-Yr SLR1 (M2A)	100-Yr SLR2 (M2A)	100-Yr SLR3 (M2A)	100-Yr SLR1 (M2B)	100-Yr SLR2 (M2B)	100-Yr SLR3 (M2B)	100-Yr SLR1 (MX)	100-Yr SLR2 (MX)	100-Yr SLR3 (MX)

Table 4-2: Data Deliverables for C-8 C-9 Task 2 H&H Modeling

C-8 Basin					C-9 Basin				
	Excel files	Figures	GIS Rasters	Data Tables		Excel files	Figures	GIS Rasters	Data Tables
PM1	48	48			**PM1**	48	48		
PM2	48			1 combined table	**PM2**	48			1 combined table
PM5 Max Flood depth (project area)		48	48	4 combined tables	**PM5 Max Flood depth (project area)**		48	48	4 combined tables
PM5 Max Flood depth (urban area)		48	48		**PM5 Max Flood depth (urban area)**		48	48	
PM5 Max Flood elevation (project area)			48		**PM5 Max Flood elevation (project area)**			48	
PM6 Flood Duration (project area)		48	48	4 combined tables	**PM6 Flood Duration (project area)**		48	48	4 combined tables
PM6 Flood Duration (urban area)		48	48		**PM6 Flood Duration (urban area)**		48	48	
Water Budget for 10-yr event				12	**Water Budget for 10-yr event**				12
Summary of peak discharge, peak head water, and peak tail water (instantaneous and 12-hr moving average)				48	**Summary of peak discharge, peak head water, and peak tail water (instantaneous and 12-hr moving average)**				48

Number of data tables are subject to change depending on how the data is organized (i.e., by mitigation scenario, by design storm frequency, or by sea level rise scenario, or any combination thereof
PM2 for C-9 Basin is just for the overall basin, not east/west of Red Road
PM5/PM6 Figures are just flood depth/duration maps, not difference maps

5 CONCLUSIONS

This technical memorandum has outlined the team's process to categorize the mitigation projects identified in Task 1 and developed a modeling approach to examine the projects' efficacy to meet FPLOS mitigation criteria. After several iterations of scoring, the consulting team and District agreed that the scoring system was not intended to be used to rank projects or chose which projects to model. Rather, the scoring system was used as a way to understand potential benefits or lack thereof. Therefore, the process of categorizing mitigation projects hinged primarily on the location and scale of the project. To that end, the team's final project list and categorization is focused on whether the project affects a primary, secondary, or tertiary system. Therefore, the projects were identified as affecting regional, local, or micro scale systems.

As part of the 3-part model iteration process, a limited number of projects will be evaluated based on the project team's understanding of the MIKE SHE/MIKE HYDRO model and its limitations, which are influenced by the proposed project scale and location. During the Task 1 assessment, the proposed projects were ultimately categorized into four categories: regional scale, local scale, micro scale, and "other." The C-8 C-9 MIKE SHE/MIKE HYDRO model is a regional scale model and there are limitations to what can be modeled with respect to the scale and location of the project. For example, projects like the addition of a control structure on a canal is readily modellable and can be modeled explicitly, whereas projects related to improving roadway drainage for a small section of road is not explicitly modellable as the underground storm drains are not explicitly modeled. During current conditions model development, systems that could not be simulated explicitly were conceptually represented through various runoff and routing parameters based on literature values (assuming a well-maintained system) and were refined during model calibration as needed. This was possible since there was observed data to calibrate to, allowing for a measurable level of adjustment to the conceptual representation based on model response in relation to the observed data. With the proposed mitigation projects, there is no basis for determining an appropriate level of adjustment. Therefore, the project team used their professional judgement and knowledge of the C-8 C-9 MIKE SHE/MIKE HYDRO model to filter through the project list to separate out projects that are not of appropriate scale, have already been completed, or do not directly affect flooding or flood mitigation. The project categorization of regional scale, local scale, and micro scale ultimately line up with primary canal systems, secondary systems, and tertiary/beyond systems.

For the 3-part iteration process, the evaluation of projects on flood mitigation will be primary focused on projects in the primary and secondary canal system, due to the scale issues. However, this is not to say that the micro scale and "other" projects are not important or won't have an impact, they are just not compatible with this resolution and scale of the C-8 C-9 MIKE SHE/MIKE HYDRO model. The micro scale and "other" projects proposed by partner communities and stakeholders are known to have some level of benefit for the area they serve but are simply unable to be adequately represented under the current resolution and scale of the model. These projects are still recommended to be pursued by partner communities.

The three primary aspects of mitigation efficiency are (1) reducing peak canal stages equal to or below current conditions, (2) reducing overland flooding equal to or below current conditions, and (3) reduce flood duration equal to or below current conditions. These three mitigation efficiencies will be evaluated through flood protection level of service performance metrics, specially PM1, PM5, and PM6. If a project does not show any benefits through the traditional model outputs, whether due to project scale or due to underlying model assumptions (such as design rainfall everywhere), the project team's qualitative assessment of the project will determine if it is included in the final list of mitigation projects. These mitigation efficiencies are evaluated during the 3-part model iteration process, which is used to understand how the mitigation projects affect flooding, what pumping capacity may be required, and how the model responds to changes such as structure operations. The 3-part model iteration process is used to evaluate the mitigation efficiencies and influence the final four mitigation strategies model setup and parameterization.

At the end of the 3-part model iteration process, the team will have identified a suite of projects and subsequent model parameterization requirements that together meet the flood protection level of service mitigation goals, such as reducing primary canal stages, reducing overflood flood depths, and reducing flood duration, whether equal to or below current conditions or some other acceptable level that is determined once the project team and the District have a better understanding of what is possible. Once the final model setup is configured for each of the four mitigation strategies, the project team will begin to run the final 48 model simulations. Each of the four final mitigation strategies will be simulated using the 5, 10, 25, and 100-year return interval rainfall events with 1, 2, and 3 ft of sea level rise. After all 12 model runs for a mitigation strategy are completed and the data is post processed, data for the flood damage assessment will be provided before moving on to the next mitigation strategy. At the completion of all 48 final simulations across the four mitigation strategies, several flood protection level of service performance metrics will be completed, and all data required for completing the flood damage assessment will be produced. It is estimated the full simulation, evaluation, and post processing of the 48 final model scenarios will take 4 to 5 months, which cannot start until after the 3-part model iteration process detailed in **Section 3** is completed. The next steps are to complete the Part 2 and Part 3 of the 3-part iteration process, determining which mitigation projects and what pump size will be included in the final model setup.

Appendix A Project Categories and Project Scoring System (Incomplete) Used to Understand Potential Benefits of Proposed Mitigation Projects

Tab 1- Regional Scale: Score 1-5, 1 being not likely and 5 being very likely. Score based on anticipated real-world impacts.

Project Name	Comment		Allows Operation Flexibility	Prevents "high water" from back flowing in	Increases discharge ability	Can alleviate primary system flooding	Can alleviate secondary system flooding	Can alleviate tertiary system flooding	Total Score	Improves Water Quality (neutral impact =3, positive impact =5)	How well developed is the project (conceptual = 1, full design=5)	Notes
Dredging C-8 Canal	Doesn't change operation of anything and doesn't prevent high water from backing in. Has the ability to increase discharge by having larger conveyance capacity, possibly keeping pump operating at max capacity longer. Could reduce head loss / lower stages, which could alleviate some flooding in primary, secondar, and tertiary systems.	Regional	1	1	3	3	3	3	13	3		Restore the design capacity.
S-28 improvements - pump station, higher platform and gates, tieback, levee, and floodwall	Allows operation flexibility and can operate when TW is higher than HW. Prevents storm surge from overtopping or flanking structure. Increases discharge capacity when gravity structure would be forced to close otherwise. Can alleviate flooding in primary, secondary, and tertiary systems.	Regional	5	5	5	5	4	3	22	3		Improvement to the primary system.
S-29 improvements include Oleta River surge barrier, tieback levees, and floodwall	Allows operation flexibility and can operate when TW is higher than HW. Prevents storm surge from overtopping or flanking structure. Increases discharge capacity when gravity structure would be forced to close otherwise. Can alleviate flooding in primary, secondary, and tertiary systems.	Regional	5	5	5	5	4	3	22	3		Improvement to the primary system.
North Lake Belt Storage Area Improvements (western mine pits)		Regional	3	1	1	5	4	3	14	5		Improvement to the primary system by adding additional storage. Need more information.
S-28 downstream of tidal structure - floodwalls and storm surge barriers (USACE Back Bay study)		Regional	3	5	1	5	4	3	18	3		Improvement to the primary system.
S-28 raise levees along canal and add operable structures to secondary system (gates/pumps) (Figure 3 from Phase I mitigation memo)	Allows operation flexibility and can operate when TW is higher than HW. Prevents elevated TW from propagating upstream. Pumps would allow discharge when gravity structure would be forced to close otherwise, gravity structure prevents elevated TW from propagating upstream. Higher levees could prevent elevated canal stage from spilling out. Can alleviate flooding in secondary and tertiary systems.	Regional	5	5	3	5	5	4	22	3		Improvement to the primary system.
S-29 raise levees along canal and add operable structures to secondary system (gates/pumps)	Allows operation flexibility and can operate when TW is higher than HW. Prevents elevated TW from propagating upstream. Pumps would allow discharge when gravity structure would be forced to close otherwise, gravity structure prevents elevated TW from propagating upstream. Higher levees could prevent elevated canal stage from spilling out. Can alleviate flooding in secondary and tertiary systems.	Regional	5	5	3	5	5	4	22	3		Improvement to the primary system.

Tab 2- Local Scale: Score 1-5, 1 being not likely and 5 being very likely. Score based on anticipated real-world impacts.

Project Name	Comment		Allows Operation Flexibility	Prevents "high water" from back flowing in	Increases discharge ability	Can alleviate primary system flooding	Can alleviate secondary system flooding	Can alleviate tertiary system flooding	Total Score	Improves Water Quality (neutral impact =3, positive impact =5)		How well developed is the project (conceptual = 1, full design=5)		Notes
Pembroke Pines Three Basin Interconnect at Century Village Project	This project would allow some operational flexibility of the secondary system as it would allow water to be moved from one basin to the other. It does not prevent high water from backing in (may be gated, but water could not transfer between basins w/o project, so this would just be to allow control of when to transfer water). It is not very likely to alleviate primary system flooding as the water is likely still going to be discharged out, just through a different route. It is likely to alleviate some secondary and tertiary flooding by somewhat increasing discharge ability by moving water to another basin with available storage.	Local	3	1	3	2	3	3	12	3	3			Need length, inverts, diameter, type, etc.
South Broward Drainage District Basin 3 Emergency Sluice Gate into the C-9 Canal	Doesn't allow operation flexibility as it would be used for emergency discharge, *after* existing infrastructure is used or at capacity. Could provide some flexibility as a Failsafe in case pump(s) fail. System already in place to prevent water from backing in, so this project doesn't get points for that. This system does increase discharge capacity by providing emergency relief. Does not alleviate primary system flooding as it is a secondary infrastructure designed to add more water to primary. Very likely to alleviate emergency flooding in secondary/tertiary.	Local	3	1	3	1	3	3	11	3	3			working in conjunction with regional pump station. Kevin Hart from SBDD providing example of an emergency sluice gate. No design available.
South Broward Drainage District Maintenance Dredging of Primary and Secondary Canals	Does not allow operation flexibility nor does it prevent high water from backing in. It cannot increase discharge ability in terms of cfs, but it has the potential to increase duration of max discharge by reducing "down time" of pump stations. Unlikely to alleviate primary system flooding as it is not holding water back, may somewhat increase infiltration. Neutral score for alleviating secondary/tertiary system flooding as system is ultimately controlled by secondary system pump station.	Local	1	1	3	1	3	3	11	3	3			Restore the design capacity.
Enlargement of Silver Lake Control Structure	Existing tertiary system project. This could allow some operation flexibility. It does not prevent high water from backing in as it is already prevented with existing control structure. This could increase discharge ability out of the basin. Could potentially alleviate some local primary system flooding by reducing the total discharge out required by pump station. More likely to alleviate flooding in tertiary system, some in secondary.	Local	5	1	5	1	3	5	15		3			Spoke with Kevin Hart, single 72" RCP. No immediate plans of enlargement by SBDD.
Injection Well Construction	More likely to impact duration of flooding instead of flood depth.	Local	2	1	2	2	2	3	10	5	5			Installing stormwater system, including but not limited, to deep-well injection wells to reduce flooding would benefit approximately 30 percent of the City. This type of project is needed where localized flooding is observed.

Project Name	Comment		Allows Operation Flexibility	Prevents "high water" from back flowing in	Increases discharge ability	Can alleviate primary system flooding	Can alleviate secondary system flooding	Can alleviate tertiary system flooding	Total Score	Improves Water Quality (neutral impact =3, positive impact =5)		How well developed is the project (conceptual = 1, full design=5)		Notes
Basin S-5 Emergency Sluice Gate	Doesn't allow operation flexibility as it would be used for emergency discharge, *after* existing infrastructure is used or at capacity. System already in place to prevent water from backing in, so this project doesn't get points for that. This system does increase discharge capacity by providing emergency relief. Does not alleviate primary system flooding as it is a secondary infrastructure designed to add more water to primary. Very likely to alleviate emergency flooding in secondary/tertiary.	Local	3	1	3	1	3	3	11		3			working in conjunction with regional pump station. Kevin Hart from SBDD providing example of an emergency sluice gate. No design available.
South Broward Drainage District B-1 Pump Station	Upgrade to existing tertiary system pumps.	Local	1	1	5	1	1	5	13		3			working in conjunction with regional pump station. Need pump capacity, operation rule. etc.
South Broward Drainage District B-2 Pump Station	Upgrade to existing tertiary system pumps.	Local	1	1	5	1	1	5	13		3			working in conjunction with regional pump station. Need pump capacity, operation rule. etc.
Rehabilitation of Triple 96" Culverts (CIPP)	Does not allow operation flexibility nor does it prevent high water from backing in. Will increase discharge ability in terms of cfs as it is being restored back to design. Will not alleviate flooding in primary system. May alleviate some flooding in secondary/tertiary system if this culvert was chocking the pump station immediate downstream.	Local	1	1	1	1	1	1	5		3			Restore the design capacity.
South Broward Drainage District Basin 3/Basin 7 Interconnect at County Club Ranches	This project would allow some operational flexibility of the secondary system as it would allow water to be moved from one basin to the other. It does not prevent high water from backing in (may be gated, but water could not transfer between basins w/o project, so this would just be to allow control of when to transfer water). Not likely to alleviate flooding in local primary system, as basin pump would probably still be running at max capacity and the transfer water is likely still going to be discharged out, just through a different route. It is likely to alleviate some secondary and tertiary flooding by increasing discharge ability by moving water to another basin with available storage.	Local	2	1	3	1	3	3	11		3			Kevin Hart from SBDD will provide details
South Broward Drainage District East By-Pass & Sluice Gate at the S-1 Pump Station	Proposed operational gate. Same permitted allowance. Allow them to lessen burden on pump station. Failsafe in case pump(s) fail. Can increase discharge ability with permission from District.	Local	3	1	3	1	3	3	11		3			Kevin Hart from SBDD will provide details

Project Name	Comment		Allows Operation Flexibility	Prevents "high water" from back flowing in	Increases discharge ability	Can alleviate primary system flooding	Can alleviate secondary system flooding	Can alleviate tertiary system flooding	Total Score	Improves Water Quality (neutral impact =3, positive impact =5)		How well developed is the project (conceptual = 1, full design=5)		Notes
Bank stabilization proposed on Marco Canal	Bank stabilization may improve conveyance through canal, increasing discharge ability to some degree, which could potentially reduce flooding in the tertiary system.	Local	**1**	**1**	**2**	**1**	**1**	**3**	**8**					Recommended
C-8 Spur Canal Non-structural Flooding Solutions		Local												Need more details
Add the conveyance between C9 and C11		Local	**3**	**1**	**3**	**2**	**3**	**3**	**12**		3			add inter-basin transfer flexibility.
Outfall Replacement at Pickwick Lake		Local												will help restore the design capacity.
South of airport storage area		Local												
Convert golf courses to stormwater park		Local												

Tab 3- Micro Scale: Score 1-5, 1 being not likely and 5 being very likely. Score based on anticipated real-world impacts.

Project Name	Comment		Allows Operation Flexibility	Prevents "high water" from back flowing in	Increases discharge ability	Can alleviate primary system flooding	Can alleviate secondary system flooding	Can alleviate tertiary system flooding	Total Score	Improves Water Quality (neutral impact =3, positive impact =5)		How well developed is the project (conceptual = 1, full design=5)		Notes
Pembroke Park Carolina Street/Park Road Pump Station	This is a very local scale tertiary system project for draining a street. Doesn't provide operation flexibility or prevent high water from back flowing in. It does increase discharge ability of a very small area. Will not alleviate primary or secondary system flooding. Will have some local scale reduction in flooding.	Micro	3	1	3	1	1	5	11					Nowhere near canal system. Draining to a lake so it would not be dependent on regional pump station.
Pembroke Park SW 30 Avenue Drainage	This is a very local scale tertiary system project for some local street drainage. Doesn't provide operation flexibility or prevent high water from backing in. Will have some increase in local drainage. Will not alleviate primary or secondary system flooding. Will have some local scale reduction in flooding	Micro	1	1	3	1	1	5	11					Need more details
Pembroke Park SW 52nd Avenue Drainage	This is a very local scale tertiary system project for some local street drainage. Doesn't provide operation flexibility or prevent high water from backing in. Will have some increase in local drainage. Will not alleviate primary or secondary system flooding. Will have some local scale reduction in flooding	Micro	1	1	3	1	1	5	11					Need more details
Pembroke Pines Storm Water Project - Lakeside Key Storm Drainage System	This is a very local scale tertiary system project for some local drainage. Doesn't provide operation flexibility or prevent high water from backing in. Will have some increase in local drainage ability. Will not alleviate primary or secondary system flooding. Will have some local scale reduction in flooding	Micro	1	1	3	1	1	5	11					Need more details
Pembroke Pines Storm Water Project - Taft St. and 85th Way Culvert Linings	This is a very local scale tertiary system project for a culvert under a road. Replacing culvert linings could reduce friction or prevent degradation and erosion of pipe. Doesn't provide operation flexibility or prevent high water from backing in. Could somewhat increase discharge ability with reduced friction or restoring back to design capacity. Will not alleviate primary or secondary system flooding.	Micro	1	1	3	1	3	5	14		3			Restore the design capacity and reduce frictions

Project Name	Comment		Allows Operation Flexibility	Prevents "high water" from back flowing in	Increases discharge ability	Can alleviate primary system flooding	Can alleviate secondary system flooding	Can alleviate tertiary system flooding	Total Score	Improves Water Quality (neutral impact =3, positive impact =5)		How well developed is the project (conceptual = 1, full design=5)		Notes
Pembroke Pines Storm Water Project - Taft St. Swale Regrading	This is a very local scale tertiary system project for some local drainage. Doesn't provide operation flexibility or prevent high water from backing in. Could have some increase in local drainage ability. Will not alleviate primary or secondary system flooding. Could have some local scale reduction in flooding. Not modellable.	Micro	1	1	3	1	3	5	14		3			Restore the design capacity and improve conveyance
Drainage Improvements Multiple Sites	Drainage improvement doesn't provide operation flexibility or prevent high water from backing in. Will have some increase in local drainage ability. Will not alleviate primary or secondary system flooding. Will have some local scale reduction in flooding	Micro	1	1	3	1	1	5	11					Need more details (25? 26? 27? Relationship? What kind of improvements?
NW 178 ST and NW 82 AVE	This is a very local scale tertiary system project for some local drainage. Doesn't provide operation flexibility or prevent high water from backing in. Will have some increase in local drainage ability. Will not alleviate primary or secondary system flooding. Will have some local scale reduction in flooding	Micro	1	1	3	1	1	5	11					Need more details
NW 57 PL from NW 194 ST to NW 198 TR	This is a very local scale tertiary system project for some local drainage. Doesn't provide operation flexibility or prevent high water from backing in. Will have some increase in local drainage ability. Will not alleviate primary or secondary system flooding. Will have some local scale reduction in flooding	Micro	1	1	3	1	1	5	11					Need more details
105 Street Drainage Pump Station	This is a very local scale tertiary system project for draining streets. Doesn't provide operation flexibility or prevent high water from back flowing in. It does increase discharge ability of a very small area. Will not alleviate primary or secondary system flooding. Will have some local scale reduction in flooding. Downstream of S-28 pump station	Micro	3	1	3	1	1	5	16		3			Need more details. The neighborhood in the vicinity of 104 Street has been experiencing flooding during times of heavy rain especially during high tide and also sunny day flooding in relation to king tides. The drainage pump system will help against this.

Project Name	Comment		Allows Operation Flexibility	Prevents "high water" from back flowing in	Increases discharge ability	Can alleviate primary system flooding	Can alleviate secondary system flooding	Can alleviate tertiary system flooding	Total Score	Improves Water Quality (neutral impact =3, positive impact =5)		How well developed is the project (conceptual = 1, full design=5)		Notes
20021 to 20081 NW 13 Ave-Stormwater Drainage Improvements Project	This is a very local scale tertiary system project for some local drainage. Doesn't provide operation flexibility or prevent high water from backing in. Will have some increase in local drainage ability. Will not alleviate primary or secondary system flooding. Will have some local scale reduction in flooding	Micro	1	1	3	1	1	5	11					Need more details. Stormwater Drainage Project - Flooding Issues in the area.
20601 NW 44 Court-Stormwater Drainage Improvements Project	This is a very local scale tertiary system project for some local drainage. Doesn't provide operation flexibility or prevent high water from backing in. Will have some increase in local drainage ability. Will not alleviate primary or secondary system flooding. Will have some local scale reduction in flooding	Micro	1	1	3	1	1	5	11					Need more details. Drainage Project due to flooding.
Biscayne Gardens Community Rating System site mitigation		Micro	2	1	1	2	2	2	8					Need more details. Mitigate future losses by buying low lying homes and turning them into water retention areas.
Drainage Improvements NW 170 St west of 22 Ave	This is a very local scale tertiary system project for some local drainage. Doesn't provide operation flexibility or prevent high water from backing in. Will have some increase in local drainage ability. Will not alleviate primary or secondary system flooding. Will have some local scale reduction in flooding	Micro	1	1	3	1	1	5	11					Need more details. The following areas have been identified as having severe flooding problems, and the stated improvements will reduce property damage and repetitive losses from future rain events. Two repetitive losses exist in this area. These projects also improve water
Kings Gardens #3		Micro	1	1	3	1	1	5	11					Need more details. through time, the roads and drainage have declined due to a lack of maintenance. The decline is to the extent that the situation is a driving and flooding hazard

Project Name	**Comment**		**Allows Operation Flexibility**	**Prevents "high water" from back flowing in**	**Increases discharge ability**	**Can alleviate primary system flooding**	**Can alleviate secondary system flooding**	**Can alleviate tertiary system flooding**	**Total Score**	**Improves Water Quality (neutral impact =3, positive impact =5)**		**How well developed is the project (conceptual = 1, full design=5)**		**Notes**
Leslie Estates #4 Road and Drainage Improvements	This is a very local scale tertiary system project for some local drainage. Doesn't provide operation flexibility or prevent high water from backing in. Will have some increase in local drainage ability. Will not alleviate primary or secondary system flooding. Will have some local scale reduction in flooding	Micro	**1**	**1**	**3**	**1**	**1**	**5**	**11**					Need more details. This area was assessed of the conditions for acquiring the ROW in order to do road and drainage improvements since the area has private roads without a Homeowners Association.
NE 105 St Pump Station	This is a very local scale tertiary system project for draining a street. Doesn't provide operation flexibility or prevent high water from back flowing in. It does increase discharge ability of a very small area. Will not alleviate primary or secondary system flooding. Will have some local scale reduction in flooding.	Micro	**3**	**1**	**3**	**1**	**1**	**5**	**16**		**3**			Downstream of S-28. Tidally influenced.
NE 10th Avenue/NE 159th Street and NMB Boulevard	This is a very local scale tertiary system project for some local drainage. Doesn't provide operation flexibility or prevent high water from backing in. Will have some increase in local drainage ability. Will not alleviate primary or secondary system flooding. Will have some local scale reduction in flooding	Micro	**1**	**1**	**3**	**1**	**1**	**5**	**11**					Need more details. This project consists of street and Roadway improvements. This will make significant drainage improvements.
NE 154 Street and NE 5 Court	This is a very local scale tertiary system project. Doesn't provide operation flexibility or prevent high water from backing in. Will have some increase in local drainage ability. Will not alleviate primary or secondary system flooding. Will have some local scale reduction in flooding	Micro	**1**	**1**	**3**	**1**	**1**	**5**	**11**					Have some project plans. Roadway Drainage.
NE 167 Street and NE 14 Avenue	This is a very local scale tertiary system project for some local drainage. Doesn't provide operation flexibility or prevent high water from backing in. Will have some increase in local drainage ability. Will not alleviate primary or secondary system flooding. Will have extremely local scale reduction in flooding. ~700 linear ft area of influence	Micro	**1**	**1**	**3**	**1**	**1**	**5**	**11**					Have project plans. General drainage improvements, mitigation of flood complaints.

Project Name	Comment		Allows Operation Flexibility	Prevents "high water" from back flowing in	Increases discharge ability	Can alleviate primary system flooding	Can alleviate secondary system flooding	Can alleviate tertiary system flooding	Total Score	Improves Water Quality (neutral impact =3, positive impact =5)		How well developed is the project (conceptual = 1, full design=5)		Notes
NE 197 Terrace and NE 17 Avenue Drainage Improvements	This is a very local scale tertiary system project. Doesn't provide operation flexibility or prevent high water from backing in. Will increase local drainage ability Will not alleviate primary or secondary system flooding. Will have some local scale reduction in flooding.	Micro	1	1	3	1	1	5	11					Have some project plans. Drainage improvements. The recommended solution is the construction of an exfiltration system to fully retain onsite runoff.
NW 146 St and NW 7 Ave (east end of street)	This is a very local scale tertiary system project for some local drainage. Doesn't provide operation flexibility or prevent high water from backing in. Will have some increase in local drainage ability. Will not alleviate primary or secondary system flooding. Will have some local scale reduction in flooding	Micro	1	1	3	1	1	5	11					Need more details. General drainage improvements, mitigation of flood complaints.
NW 159 Street Stormwater Drainage Project	This is a very local scale tertiary system project for some local drainage. Doesn't provide operation flexibility or prevent high water from backing in. Will have some increase in local drainage ability. Will not alleviate primary or secondary system flooding. Will have some local scale reduction in flooding	Micro	1	1	3	1	1	5	11					Need more details. Drainage Improvement Project - Flooding Issues and Vehicles Hydroplaning through the area that can cause an accident.
NW 163 Street Drainage Improvement Project	This is a very local scale tertiary system project for some local drainage. Doesn't provide operation flexibility or prevent high water from backing in. Will have some increase in local drainage ability. Will not alleviate primary or secondary system flooding. Will have some local scale reduction in flooding	Micro	1	1	3	1	1	5	11					Need more details. Increasing underground drainage capacity due to flooding issues and vehicles hydroplaning causing a possible accident to occur.
NW 191 Street-196 Terrace, from NW Sunshine State Parkway East to NW 12 Avenue - Drainage Improvement	This is a very local scale tertiary system project for some local drainage. Doesn't provide operation flexibility or prevent high water from backing in. Will have some increase in local drainage ability. Will not alleviate primary or secondary system flooding. Will have some local scale reduction in flooding	Micro	1	1	3	1	1	5	11					Need more details. The following areas have been identified as having severe flooding problems, and the stated improvements will reduce property damage and repetitive losses from future rain events. These projects also improve water quality of stormwater runoff.
NW 195 Street West of NW 12 Avenue - Drainage Improvements	This is a very local scale tertiary system project for some local drainage. Doesn't provide operation flexibility or prevent high water from backing in. Will have some increase in local drainage ability. Will not alleviate primary or secondary system flooding. Will have some local scale reduction in flooding	Micro	1	1	3	1	1	5	11					Need more details. The following areas have been identified as having severe flooding problems, and the stated improvements will reduce property damage and repetitive losses from future rain events. These projects also improve water quality of stormwater runoff.

Project Name	Comment		Allows Operation Flexibility	Prevents "high water" from back flowing in	Increases discharge ability	Can alleviate primary system flooding	Can alleviate secondary system flooding	Can alleviate tertiary system flooding	Total Score	Improves Water Quality (neutral impact =3, positive impact =5)		How well developed is the project (conceptual = 1, full design=5)		Notes
NW 42 Avenue and NW 167 Terrace	This is a very local scale tertiary system project for some local drainage. Doesn't provide operation flexibility or prevent high water from backing in. Will have some increase in local drainage ability. Will not alleviate primary or secondary system flooding. Will have some local scale reduction in flooding	Micro	**1**	**1**	**3**	**1**	**1**	**5**	**11**					Need more details. French Drainage Project due to excessive flooding.
Vista Verde Phase #4 - Remaining Phase from Snake Creek Canal to NW 41 Ave Rd Community		Micro	**1**	**1**	**3**	**1**	**1**	**5**	**11**					Sediment removal and canal stabilization and headwall and culvert repairs.
West Dixie Highway Drainage Improvements	This is a very local scale tertiary system project for some local drainage. Doesn't provide operation flexibility or prevent high water from backing in. Will have some increase in local drainage ability. Will not alleviate primary or secondary system flooding. Will have some local scale reduction in flooding. Was built in 2017... conceptually factored into model already?	Micro												Have some project plans. Underground drainage improvement to eliminate flooding after storm events
Well Field Stormwater System Improvement		Micro												In order to protect public water supply wells #13 and #19 from contamination, the City needs to modify the stormwater system previously constructed in the vicinity of the wells. Approximately 300 ft. of 30-inch French drain needs to be removed and replaced

Tab 4- Other Projects: Score 1-5, 1 being not likely and 5 being very likely. Score based on anticipated real-world impacts.

Project Name	Comment		Allows Operation Flexibility	Prevents "high water" from back flowing in	Increases discharge ability	Can alleviate primary system flooding	Can alleviate secondary system flooding	Can alleviate tertiary system flooding	Total Score	Improves Water Quality (neutral impact =3, positive impact =5)		How well developed is the project (conceptual = 1, full design=5)		Notes
Encantada Sluice Gate	Already constructed	Other	5	5	5	1	1	5	17		3			working in conjunction with regional pump station. Kevin Hart from SBDD providing gate details.
Harbour Lake Estates Sluice Gate	Already constructed	Other	5	5	5	1	1	5	17		3			working in conjunction with regional pump station. Kevin Hart from SBDD providing gate details.
Sunset Lakes Sluice Gate	Already constructed	Other	5	5	5	1	1	5	17		3			working in conjunction with regional pump station. Kevin Hart from SBDD providing gate details.
South Broward Drainage District S.W. 54th Place/S.W. 164th Terrace Culvert Replacement	This project is in the C-11 Basin. Remove	Other												Restore the design capacity. Need length, inverts, diameter, type, etc.
South Broward Drainage District Seepage Management Storm Water Pump Station	This project is in the C-11 Basin. Remove	Other												Need pump capacity, operation rule. etc.
Hollywood Arthur and Cleveland Streets Drainage Improvement	This project is outside of model domain. Remove	Other												Need more details
Hollywood North Lake Pump Station and Outfalls	This project is outside of model domain. Remove	Other									3			working in conjunction with regional pump station.
Hollywood South Lake Pump Station	This project is outside of model domain. Remove	Other									3			working in conjunction with regional pump station. Need pump capacity, operation rule. etc.
Hollywood Sunset Golf Course Pump Station Rehabilitation	This project is outside of model domain. Remove	Other									3			Restore the design capacity. Need pump capacity, operation rule. etc.
Pembroke Pines West Communities Pump Station	This project is outside of model domain. Remove	Other									3			working in conjunction with regional pump station.
SBHD Memorial Healthcare System Joe DiMaggio Vertical Expansion Flood Proofing Project	This project is outside of model domain. Remove	Other									3			Damage prevention? Resilience project?
West Park Stormwater Vaults along 441/SR7	This project is outside of model domain. Remove	Other												Need more details

Project Name	Comment		Allows Operation Flexibility	Prevents "high water" from back flowing in	Increases discharge ability	Can alleviate primary system flooding	Can alleviate secondary system flooding	Can alleviate tertiary system flooding	Total Score	Improves Water Quality (neutral impact =3, positive impact =5)		How well developed is the project (conceptual = 1, full design=5)		Notes
Biscayne Gardens Stormwater Inspection		Other												General inspection and assessment of the stormwater pump stations located at NE 150 Street and N. Spur Drive (Biscayne Gardens)
Correct Water Infiltration at City Hall (EOC) Basement		Other												Need more details
Storm Water Pump Replacement Program		Other												The project consist of the replacement of existing storm water pumps on an as needed basis.
Emergency Discharge Sluice Gate	Delete. 51 & 52 refer to same project.	Other												
South Broward Drainage District S4/S5 Pump Station	Fire suppression system for all pumps and upgraded exhaust	Other												Does not affect discharge or operations in any way. Delete
Basin S-3 Sluice Gate	proposed emergency gate for basin 3, same as basin 5. Duplicate as project #5	Other									3			will help restore the design capacity.
South Broward Drainage District S-1 Pump Station	Fire suppression system for all pumps and upgraded exhaust	Other												Does not affect discharge or operations in any way.
South Broward Drainage District S-2 Pump Station	Fire suppression system for all pumps and upgraded exhaust. concrete roof and control panel upgrades	Other												Does not affect discharge or operations in any way.
South Broward Drainage District S-3 Pump Station	Fire suppression system for all pumps and upgraded exhaust	Other												Does not affect discharge or operations in any way.
South Broward Drainage District S-7 Pump Station	Fire suppression system for all pumps and upgraded exhaust	Other												Does not affect discharge or operations in any way.
South Broward Drainage District S-8 Pump Station	Fire suppression system for all pumps and upgraded exhaust	Other												Does not affect discharge or operations in any way.
C-9 Impoundment: Seepage Management		Other									4			Need more details

Project Name	Comment		Allows Operation Flexibility	Prevents "high water" from back flowing in	Increases discharge ability	Can alleviate primary system flooding	Can alleviate secondary system flooding	Can alleviate tertiary system flooding	Total Score	Improves Water Quality (neutral impact =3, positive impact =5)		How well developed is the project (conceptual = 1, full design=5)		Notes
Drainage Improvements for Eastern Shores		Other												Need more details
Miami Dade County Flood Criteria Map		Other												completed by the County
Retrofit the Control Structure to Block Surge		Other	**1**	**5**	**1**	**5**	**4**	**3**	**18**					Improvement to the primary system.
Stormwater Master Plan		Other												Recommended
Biscayne Bay and Southeastern Everglades Ecosystem Restoration (BBSEER); BBSEER project		Other									**4**			Additional conveyance route.
Add cut-off wall at impoundment to address seepage issues		Other									**3**			Model assumes no leakage- conceptually represents seepage collection
Make sure to consider different perspectives, such as insurance and land use issues		Other												none-structure strategy
Lake Belt Storage project		Other												
Good Neighbor Stormwater Park project, City of North Miami		Other									**5**			Need more details
an ongoing project to alleviate low-lying area flooding along A1A		Other									**4**			need more details
Regarding the C8 Canal & S28 Structure		Other												need clarification
Regarding the C9 Canal & S29 Structure		Other												Improvement to the primary system.
Pickwick Lake outfall replacement project		Other												Improvement to the primary system.
Canal bank improvement and roadway improvement planned in C8 Basin		Other												Improvement to the primary system.

TAYLOR ENGINEERING, INC.

Flood Protection Level of Service Provided by Potential Mitigation Projects for Current and Future Sea Level Conditions in the C8 and C9 Watersheds Draft Report

Deliverable 2.2

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Work Order 5

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EXECUTIVE SUMMARY

The South Florida Water Management District's (SFWMD or District) Phase II (2) systematic review of the Flood Protection Level of Service (FPLOS) for the C-8 and C-9 Watersheds focuses on developing mitigation activities that achieve a level of service under future conditions with sea level rise (SLR) that is equal to or greater than existing conditions. This study evaluated the performance of the C-8 and C-9 Watersheds for the 5, 10, 25, and 100-year rainfall events under existing (SLR0) and future conditions (SLR1, SLR2, and SLR3), both with and without mitigation. The model simulations include the effects of future conditions land use, sea level rise, increased groundwater elevations, and tidal storm surge.

Mitigation scenarios developed for this Phase 2 project included conceptual local (or micro-scale) projects developed by stakeholders (called M1), regional-scale projects (called M2), and planning level projects (called M3). These projects are conceptual in nature and will need further development and refinement. This study developed flood risk benefits for each category of project (M1, M2, M3) and an associated rough order-of-magnitude costs. These results are intended for use in future tasks that will calculate the expected annual damages (EADs). EADs are the best way to evaluate the results of these mitigation activities because it combines not only the risk, but also the consequences associated with them (i.e., the impact and costs/loss avoided by each mitigation activity).

M1 local scale projects, provided by stakeholders, have benefits at small scales and could not be included in the existing hydrologic and hydraulic model. Examples include improvement of stormwater swales, stormwater "improvements," and drainage improvements. Most of these projects had little or no details (such as specific location, costs, and/or design) so the team developed rough approximations of overall benefits, area of impact, and costs. These approximations are intended for use in subsequent tasks that will calculate EADs for the entire "M1" mitigation activities.

M2 regional scale projects include activities such as large-scale pumps, levee improvements, canal improvements, and large-scale surface water storage. These projects are the focus of the hydrologic and hydraulic modeling and are evaluated using performance metrics (PM) 1, 2, 5, and 6 to show the benefits to the FPLOS, specifically the maximum flood elevations in both the primary canals and urban areas. Application of the performance metrics allowed the study team to refine M2 projects with each iteration. The "M" series projects progressed from M2A which tried to achieve a FPLOS equal to or greater than the 25-year existing conditions FPLOS for future conditions SLR1, M2B targeted SLR2, and M2C targeted SLR3. The objective of this study, unlike previous Phase 1 FPLOS, was not to assign FPLOS but rather to focus on the benefits provided by the mitigation activities. To that end, the performance metrics are helpful to identify benefits of the projects, but the true analysis will depend on future tasks of EADs and benefit/cost (or net present value) calculations. 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; 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; Internal drainage system

M3 mitigation activities are planning in nature. These activities simply examine the idea of raising all buildings and roads in a watershed by +1, +2, and +3 ft in the SLR1, SL2, and SLR3 scenarios, respectively. There is no modeling associated with these activities; this study simply examined a rough cost to do something along these lines. The benefit of these projects will be calculated in future EAD tasks.

Only the M2 mitigation activities allow comparison to FPLOS Metrics. The key takeaways for these activities with respect to those metrics include:

- One goal of M2 projects (M2A, M2B, and M2C) was to achieve a PM #1 maximum water surface profile and PM #5 flood depths that were equal to or lower than 25-year existing conditions for the 25-year SLR1, SLR2, and SLR3 storm events, respectively.
- Although Mitigation M2A was unable to completely achieve the goals set for the 25-year SLR1 event, it is still predicted to be very effective in reducing negative effects of 1 foot of sea level rise in both the C-8 and C-9 Watersheds.
    - Under SLR2 and SLR3, Mitigation M2A is not predicted to be able to achieve canal stages or flood levels equal to or lower than predicted under existing conditions; however, it is predicted to have significant improvements compared to no mitigation
- Although Mitigation M2B was unable to completely achieve the goals set for the 25-year SLR2 event, it is still predicted to be very effective in reducing negative effects of 2 feet of sea level rise in both the C-8 and C-9 Watersheds.
    - Under SLR1, Mitigation M2B is predicted to be able to achieve canal stages and flood levels equal to or lower than existing conditions for all four rainfall events simulated
    - Overall, Mitigation M2B is predicted to achieve the goals set for Mitigation M2A
    - Mitigation M2B is not predicted to be effective at achieving the goals set for SLR3; however, it is predicted to have significant improvements compared to no mitigation
- Although Mitigation M2C was unable to completely achieve the goals set for the 25-year SLR3 event, it is still predicted to be very effective in reducing negative effects of 3 feet of sea level rise in both the C-8 and C-9 Watersheds.
    - Under SLR1, Mitigation M2C is predicted to be able to achieve canal stages and flood levels equal to or lower than existing conditions for all four rainfall events simulated
    - Under SLR2, Mitigation M2C is predicted to be able to mostly achieve canal stages and flood levels equal to or lower than predicted under existing conditions for all four rainfall events simulated
    - Mitigation M2C is not predicted to be fully effective at achieving the goals set for SLR3

These comparisons to the FPLOS metrics are informative, but the following tasks that calculate Expected Annual Damages will tell a fuller story and allow better decisions based on the economic consequences of the mitigation activities.

Costs developed for mitigation activities M1 and M3 are rough order-of-magnitude estimates that would require more project definition for further refinement. Costs developed for the M2 mitigation activities are based on refined projects and work done by the SFWMD for grant funding and are, therefore, more reliable. Cost estimates will be applied in future tasks to calculate the net present value of the projects.

1 INTRODUCTION

The South Florida Water Management District (SFWMD or District) is conducting a system-wide review of the regional water management infrastructure to determine what mitigation projects would maintain or improve the current flood protection level of service (FPLOS). The FPLOS Phase 1 Study (*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, Deliverables 5.2*, January 2021) describes the level of protection provided by the water management facilities within a watershed considering sea level rise (SLR), future development, and known water management issues in each watershed. This report will refer to that document as the FPLOS Phase 1 Study or Taylor (2021).

For this study, Taylor Engineering, Inc. (or Taylor) analyzed the effects of various potential mitigation projects on the FPLOS within the C-8 and C-9 Watersheds under current and future sea level rise scenarios. This technical report describes the mitigation projects, the results of modeling hydrologic and hydraulic conditions with the various mitigation projects, and the rough order of magnitude (ROM) costs of the projects. Please note that this modeling effort and report references the NGVD29 datum. This study assumes a uniform conversion of +1.57 ft (NAVD88 to NGVD29) for all elevations within the study area.

This technical report, *Flood Protection Level of Service Provided by Potential Mitigation Projects for Current and Future Sea Level Conditions in the C8 and C9 Watersheds Draft Report*, the deliverable for Task 2.2, is part of a larger effort to understand the FPLOS of the C-8 and C-9 Watersheds. As mentioned above, most of the discussion of the current FPLOS of the systems is presented in the Phase 1 Study. The Phase 1 report discusses the data, calibration, validation, current conditions, and future conditions used in the C-8 and C-9 MIKE SHE and MIKE HYDRO model. The FPLOS is defined by six performance metrics (PM), which are discussed in detail in Taylor (2021). In summary, the model examined the 5-, 10-, 25-, and 100-year rainfall events for four sea level scenarios – current sea level (CSL or SLR0) and +1 ft, +2 ft, and +3 ft. This report presents PM #1, #2, #5, and #6 and examines the effect of the respective mitigation projects on each metric. Although model results and post-processed data are available for each of the four rainfall return frequencies analyzed under each of the four sea level scenarios, the focus of the discussion in this report is on the 25-year rainfall event as the goal of the various mitigation projects was to achieve a 25-year level of service for each of the three sea level rise scenarios. Please note that this goal was established for the purposes of this study and may not be how other Phase II studies are conducted. With that said, post-processed model results are included for each rainfall event for PM #1 and PM #2 as they are either directly compared against each other, provide better context, or simply can be presented in just a few tables and figures. For PM #5 and PM #6, tabular data is provided for all rainfall events in one summary table, however, the figures showing spatial data is limited to just the 25-year event as the full set of figures for all rainfall events consist of several hundred pages and are instead presented as an Appendix and included separately with this report.

Critical to understanding the benefits of each mitigation project is the understanding of the costs and benefits of each. That understanding is developed over several steps contained in this Task 2.2 report that identifies the flood risks (hazard analysis) for each mitigation scenario and generates the mitigation project costs, and the draft Task 3.2 technical memorandum (Technical Memorandum: Expected Annual Damage and Net Present Value Calculations, Taylor Engineering, 2022) calculates estimated annual damages (EADs) for the buildings and roads within the watershed. The Task 3.2 technical memorandum will apply the EADs with Net Present Value calculations to determine the cost/benefit ratio of the mitigation projects.

2 MITIGATION SCENARIOS (NGVD29 to NAVD88 Conversion = -1.57 ft)

A significant effort of this Phase 2 FPLOS project developed mitigation plans that met objective criteria (such as lowering the canal flood stages with respect to various SLR scenarios), that were feasible to construct, and that met local partner communities' interests. The Phase 2 study presented the overall development of these mitigation projects in a summary technical memorandum *Task 1 Summary Memorandum: Desktop Review, Website Project Viewer, and Partner Workshop on the Adaptation Planning and Mitigation Projects* (November 2021).

These projects have evolved since their original formulation and are described in the following paragraphs. In general, the mitigation projects are to achieve the following objectives: M1 projects are intended to address local flooding issues in the secondary/tertiary system, ranging from small scale stormwater projects to more substantial sluice gates and smaller pump stations. M1 projects are not included in the final modeled mitigation strategies due to scale and resolution of the model. This study estimated the impact M1 local scale projects would have on reducing flooding using analytic solutions, as described in **Section 3.1** of this report. M2 projects, specially under scenario M2A, 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. This is measured primarily by examining PM #1 and PM #5. 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. M3(x) projects are considered policy changes that would result in the raising of all buildings and roads 1, 2, and 3 ft in the SLR1, SL2, and SLR3 scenarios, respectively. These M3 scenarios are not modeled hydraulically but are used in the calculation of estimated annual damages (EAD), as described in the Task 3.2 deliverable (Technical Memorandum: Expected Annual Damage and Net Present Value Calculations, Taylor Engineering, 2022). The following mitigation projects were evaluated:

<u>*M1 (local scale mitigation projects):*</u>

- Micro Stormwater Improvements
- Sluice Gates
- Small Pump Stations

<u>*M2A (regional scale mitigation projects – level 1, "mildly aggressive mitigation"):*</u>

- 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)
- Total of 500 ac-ft distributed storage (conceptually represented – gravity-driven drainage areas only)
- Optimized S-28 and S-29 operational controls for SLR1, SLR2, and SLR3 for the M2A scenario

M2B (regional scale mitigation projects – level 2, "moderately aggressive mitigation"):

- S-28 and S-29 forward pumps (2550 cfs)
- S-28 and S-29 gate improvement - raised overtopping elevation to 9.0 ft NGVD29 – same as M2A
- Tieback levees/floodwalls (conceptually represented) – same as M2A
- Total of 500 ac-ft distributed storage (conceptually represented – gravity-driven drainage areas only) – same as M2A
- 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) and raised bank elevations
- Internal drainage system along primary canal to drain water through raised banks
- Optimized S-28 and S-29 operational controls for SLR1, SLR2, and SLR3 for M2B scenario

M2C (regional scale mitigation projects – level 3, "aggressive mitigation"):

- S-28 and S-29 forward pumps (3550 cfs)
- S-28 and S-29 gate improvement – raised overtopping elevation to 9.0 ft NGVD29– same as M2A
- Tieback levees/floodwalls (conceptually represented) – same as M2A
- Total of 500 ac-ft distributed storage (conceptually represented – gravity-driven drainage areas only) – same as M2A
- 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), widened cross sections, and raised bank elevations
- Internal drainage system along primary canal to drain water through raised banks– same as M2B
- Optimized S-28 and S-29 operational controls for SLR1, SLR2, and SLR3 for M2C scenario

M3(x) (policy-related changes):

- Land elevation or building finished floor elevation changes (i.e. raising buildings)
- Elevating all roads
- These projects are intended to help policy makers understand the long-term benefits of policy changes – such as requiring all new construction above a certain elevation or providing mitigation grants to elevate homes (such as FEMA's https://www.fema.gov/grants/mitigation/hazard-mitigation/property-owners)

3 M1 MITIGATION PROJECT ANALYSIS AND MODEL ITERATIONS

This section describes the analytic solutions applied for M1 mitigation projects, development of conceptual floodplain storage (500 ac-ft), use of green infrastructure, and model iteration / mitigation implementation and testing of proposed mitigation projects. These local scale projects, developed in conjunction with the local stakeholders, are discussed in *Task 1 Summary Memorandum: Desktop Review, website Project Viewer, and Partner Workshop on the Adaptation Planning and Mitigation Projects*, and can be viewed in an interactive map at: https://buildcommunityresilience.com/sfwmd/fplos/c8c9/

3.1 M1 Mitigation Project Analytic solutions

Communities within the C-8 and C-9 Watersheds are actively addressing flooding issues with ongoing stormwater improvements, upgrading pump stations, modifying canal flows with sluice gates, and many other mitigation activities. These important projects have the intended effect of reducing flooding but are at a scale that does not allow them to be simulated in the hydraulic model used in this study. To ensure this project evaluates the potential impact of these projects on the estimated annual damages, the team developed analytic solutions and estimates of their benefit (how much they would reduce flood elevations) and their areal impact within the watershed.

This study team developed the project list used for 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 provided general locations, so the team was able to estimate the area of impact based on visual assessment of the area and probable drainage patterns.

To estimate the limits of project influence on the water surfaces elevations of various storm events, Taylor made a series of assumptions. Lacking modeling results and construction plans for most projects, Taylor assumed a conservative estimate of 0.25 ft of water surface level improvement for all projects and storm events. Given the information provided, the general scope of the projects, and experience with projects like these, we believe this estimate is in line with typical drainage infrastructure projects.

The estimated 0.25 ft of water surface improvement is a gross assumption of the overall benefit of a project to the entire "area of influence." There is no way to quantify what these projects would actually do to improve the water surface flooding reduction without further investigation. Each individual project would have a larger impact next to the project – say a local pump or improvement of a swale – but that reduction would tail off further from the project. The lists presented in the following figures and tables were simply identified as "potential control structure" or "drainage improvements" and would require much more detailed information to refine the estimates of benefits.

Of course, most projects that move forward with design and consideration would require local scale modeling with actual data – such as topographic data, culvert, swale, pipe size, inverts, and so on. This data is not available and is not within the scope of this project – these projects are purely conceptual at this point.

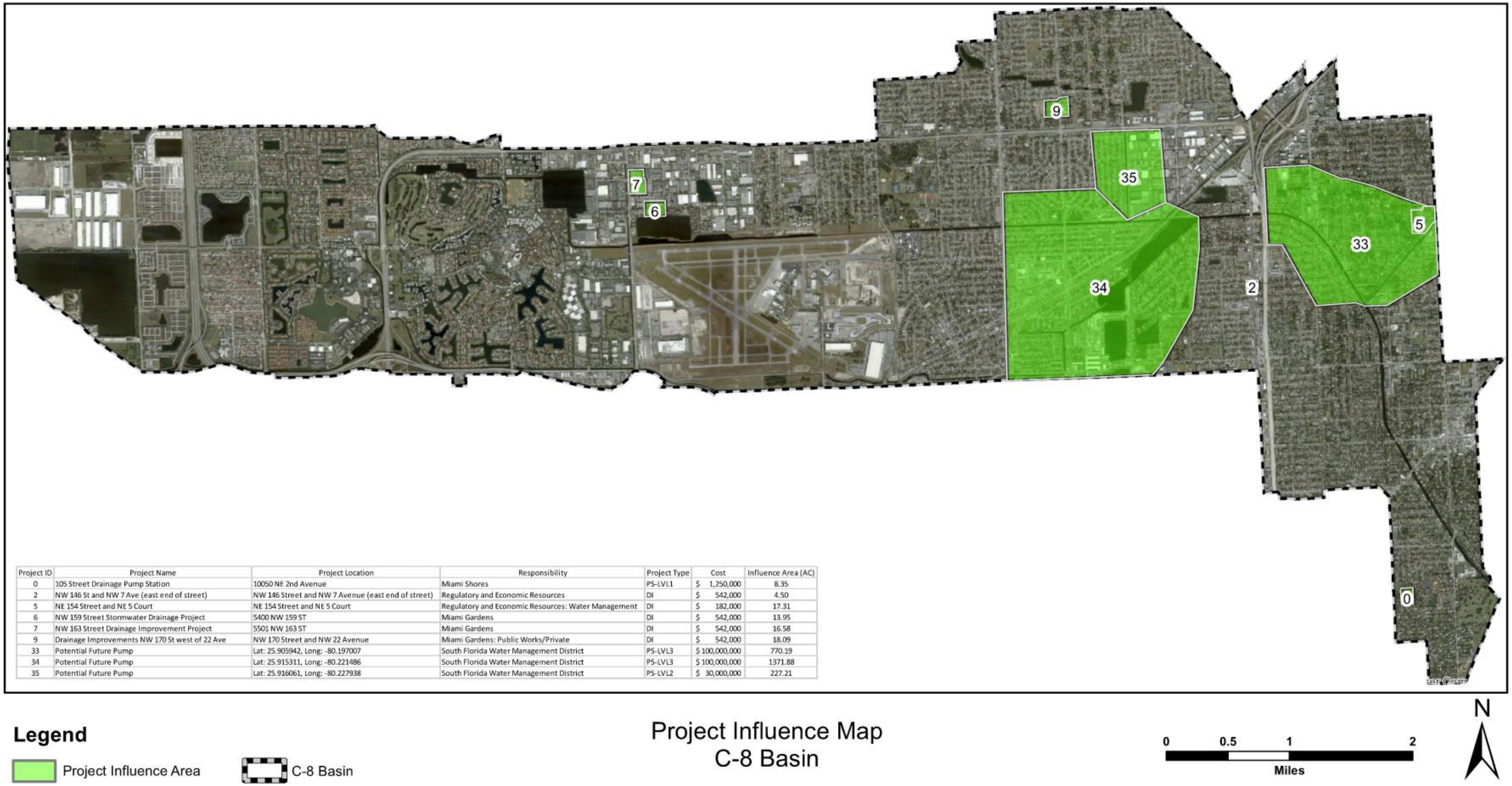
The 0.25 ft improvement estimated for this analysis is gleaned from years of experience working with similar projects and cannot be substantially documented in any meaningful way. But for the purposes of this analyses – which is simply to put a general benefit to these projects and allow managers to understand the relative impact of their benefit to the expected annual damage and net present value - we believe this estimate is wholly adequate.

In an effort to check the “reasonableness” of this 0.25 ft benefit assumption, Taylor Engineering discussed the concept and estimate with Kevin Hart of South Broward Drainage District on June 28, 2022. Mr. Hart has years of experience in water management within the C-9 Watershed and agreed that 0.25 ft reduction seemed like a reasonable assumption.

Taylor also assumed that none of the projects were large stormwater impoundment projects that would result in a widespread reduction in water surface elevations. The projects with available plans depicted somewhat modest improvements. Projects such as exfiltration systems with no positive outfall other than infiltration into the groundwater table would be expected to only provide minor improvements to the peak water surface elevations. Larger projects such as the pump station and sluice gate projects would affect larger areas but also may only produce minor improvements when considered in a regional context.

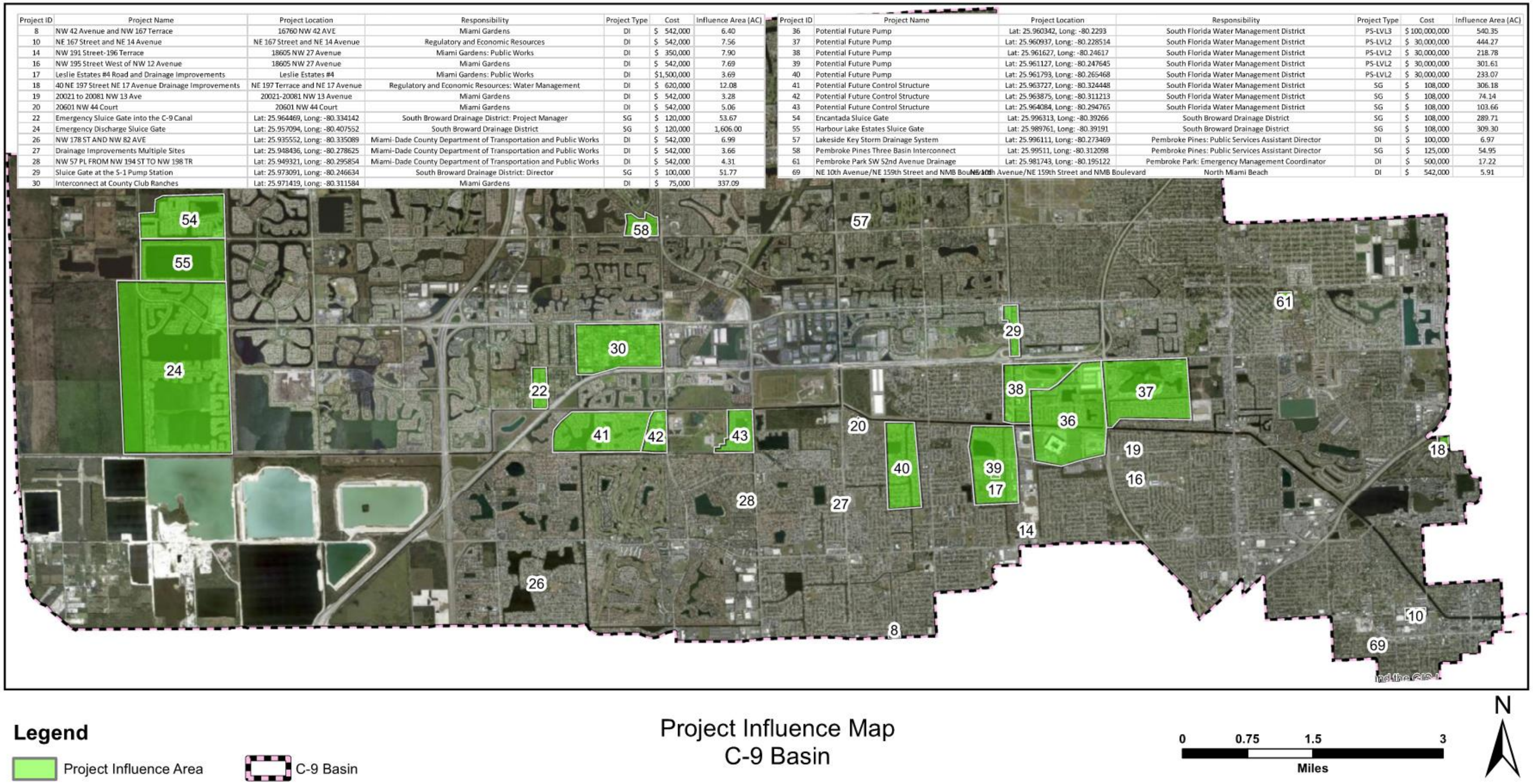
Once the flood reduction has been estimated (0.25 ft) the team needed to apply that reduction to an area of influence for the project. Of course, as these projects move from conceptual to draft and final designs, thorough data collection and modeling would be conducted to understand the flood control 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 logical termination points such as major culvert crossings, edges of developments, or crowns of roads. **Figure 3.1-1** and **Figure 3.1-2** show the area of influence for the M1 projects within the C-8 and C-9 Watersheds, respectively.

The end result of this analytic approach is that these mitigation projects have an estimated flood benefit that will be included in the calculations of expected annual damages, which will be presented in a future task in this project, Task 3. This will allow the District to have a quantitative sense of the benefit of these local projects on reducing the financial impact of flooding.



Project ID	Project Name	Project Location	Responsibility	Project Type	Cost	Influence Area (AC)
0	105 Street Drainage Pump Station	10050 NE 2nd Avenue	Miami Shores	PS-LVL1	$ 1,250,000	8.35
2	NW 146 St and NW 7 Ave (east end of street)	NW 146 Street and NW 7 Avenue (east end of street)	Regulatory and Economic Resources	DI	$ 542,000	4.50
5	NE 154 Street and NE 5 Court	NE 154 Street and NE 5 Court	Regulatory and Economic Resources: Water Management	DI	$ 182,000	17.31
6	NW 159 Street Stormwater Drainage Project	5400 NW 159 ST	Miami Gardens	DI	$ 542,000	13.95
7	NW 163 Street Drainage Improvement Project	5501 NW 163 ST	Miami Gardens	DI	$ 542,000	16.58
9	Drainage Improvements NW 170 St west of 22 Ave	NW 170 Street and NW 22 Avenue	Miami Gardens: Public Works/Private	DI	$ 542,000	18.09
33	Potential Future Pump	Lat: 25.905942, Long: -80.197007	South Florida Water Management District	PS-LVL3	$ 100,000,000	770.19
34	Potential Future Pump	Lat: 25.915311, Long: -80.221486	South Florida Water Management District	PS-LVL3	$ 100,000,000	1371.88
35	Potential Future Pump	Lat: 25.916061, Long: -80.227938	South Florida Water Management District	PS-LVL2	$ 30,000,000	227.21

Figure 3.1-1: C-8 M1 Projects Area of Influence



Project ID	Project Name	Project Location	Responsibility	Project Type	Cost	Influence Area (AC)
8	NW 42 Avenue and NW 167 Terrace	16760 NW 42 AVE	Miami Gardens	DI	$ 542,000	6.40
10	NE 167 Street and NE 14 Avenue	NE 167 Street and NE 14 Avenue	Regulatory and Economic Resources	DI	$ 542,000	7.56
14	NW 191 Street-196 Terrace	18605 NW 27 Avenue	Miami Gardens: Public Works	DI	$ 350,000	7.90
16	NW 195 Street West of NW 12 Avenue	18605 NW 27 Avenue	Miami Gardens	DI	$ 542,000	7.69
17	Leslie Estates #4 Road and Drainage Improvements	Leslie Estates #4	Miami Gardens: Public Works	DI	$1,500,000	3.69
18	40 NE 197 Street NE 17 Avenue Drainage Improvements	NE 197 Terrace and NE 17 Avenue	Regulatory and Economic Resources: Water Management	DI	$ 620,000	12.08
19	20021 to 20081 NW 13 Ave	20021-20081 NW 13 Avenue	Miami Gardens	DI	$ 542,000	3.28
20	20601 NW 44 Court	20601 NW 44 Court	Miami Gardens	DI	$ 542,000	5.06
22	Emergency Sluice Gate into the C-9 Canal	Lat: 25.964469, Long: -80.334142	South Broward Drainage District: Project Manager	SG	$ 120,000	53.67
24	Emergency Discharge Sluice Gate	Lat: 25.957094, Long: -80.407552	South Broward Drainage District	SG	$ 120,000	1,606.00
26	NW 178 ST AND NW 82 AVE	Lat: 25.935552, Long: -80.335089	Miami-Dade County Department of Transportation and Public Works	DI	$ 542,000	6.99
27	Drainage Improvements Multiple Sites	Lat: 25.948436, Long: -80.278625	Miami-Dade County Department of Transportation and Public Works	DI	$ 542,000	3.66
28	NW 57 PL FROM NW 194 ST TO NW 198 TR	Lat: 25.949321, Long: -80.295854	Miami-Dade County Department of Transportation and Public Works	DI	$ 542,000	4.31
29	Sluice Gate at the S-1 Pump Station	Lat: 25.973091, Long: -80.246634	South Broward Drainage District: Director	SG	$ 100,000	51.77
30	Interconnect at County Club Ranches	Lat: 25.971419, Long: -80.311584	Miami Gardens	DI	$ 75,000	337.09

Project ID	Project Name	Project Location	Responsibility	Project Type	Cost	Influence Area (AC)
36	Potential Future Pump	Lat: 25.960342, Long: -80.2293	South Florida Water Management District	PS-LVL3	$ 100,000,000	540.35
37	Potential Future Pump	Lat: 25.960937, Long: -80.228514	South Florida Water Management District	PS-LVL2	$ 30,000,000	444.27
38	Potential Future Pump	Lat: 25.961627, Long: -80.24617	South Florida Water Management District	PS-LVL2	$ 30,000,000	218.78
39	Potential Future Pump	Lat: 25.961127, Long: -80.247645	South Florida Water Management District	PS-LVL2	$ 30,000,000	301.61
40	Potential Future Pump	Lat: 25.961793, Long: -80.265468	South Florida Water Management District	PS-LVL2	$ 30,000,000	233.07
41	Potential Future Control Structure	Lat: 25.963727, Long: -80.324448	South Florida Water Management District	SG	$ 108,000	306.18
42	Potential Future Control Structure	Lat: 25.963875, Long: -80.311213	South Florida Water Management District	SG	$ 108,000	74.14
43	Potential Future Control Structure	Lat: 25.964084, Long: -80.294765	South Florida Water Management District	SG	$ 108,000	103.66
54	Encantada Sluice Gate	Lat: 25.996313, Long: -80.39266	South Broward Drainage District	SG	$ 108,000	289.71
55	Harbour Lake Estates Sluice Gate	Lat: 25.989761, Long: -80.39191	South Broward Drainage District	SG	$ 108,000	309.30
57	Lakeside Key Storm Drainage System	Lat: 25.996111, Long: -80.273469	Pembroke Pines: Public Services Assistant Director	DI	$ 100,000	6.97
58	Pembroke Pines Three Basin Interconnect	Lat: 25.99511, Long: -80.312098	Pembroke Pines: Public Services Assistant Director	SG	$ 125,000	54.95
61	Pembroke Park SW 52nd Avenue Drainage	Lat: 25.981743, Long: -80.195122	Pembroke Park: Emergency Management Coordinator	DI	$ 500,000	17.22
69	NE 10th Avenue/NE 159th Street and NMB Boulevard	NE 10th Avenue/NE 159th Street and NMB Boulevard	North Miami Beach	DI	$ 542,000	5.91

Figure 3.1-2: C-9 M1 Projects Area of Influence

3.2 Storage Area Identification

Mitigation Strategies M2A, M2B, and M2C include the conceptual storage/removal of 500 acre-feet of runoff combined between both 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 was arbitrarily assigned (assuming 1 ft of flood storage per acre), Taylor did a preliminary investigation to find areas that could be used to store flood water. This was a cursory analysis and will need further investigation. **Figure 3.2-1** depicts a conceptual detail for the surface water storage areas.

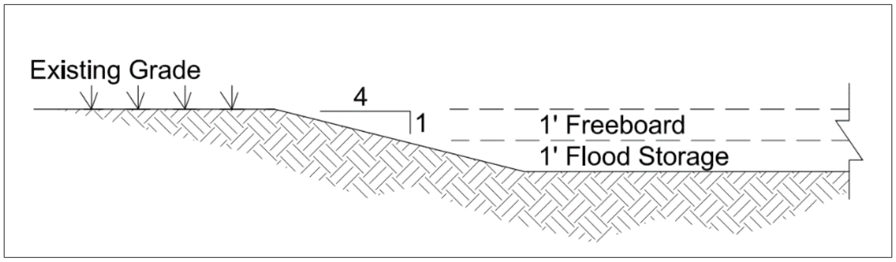
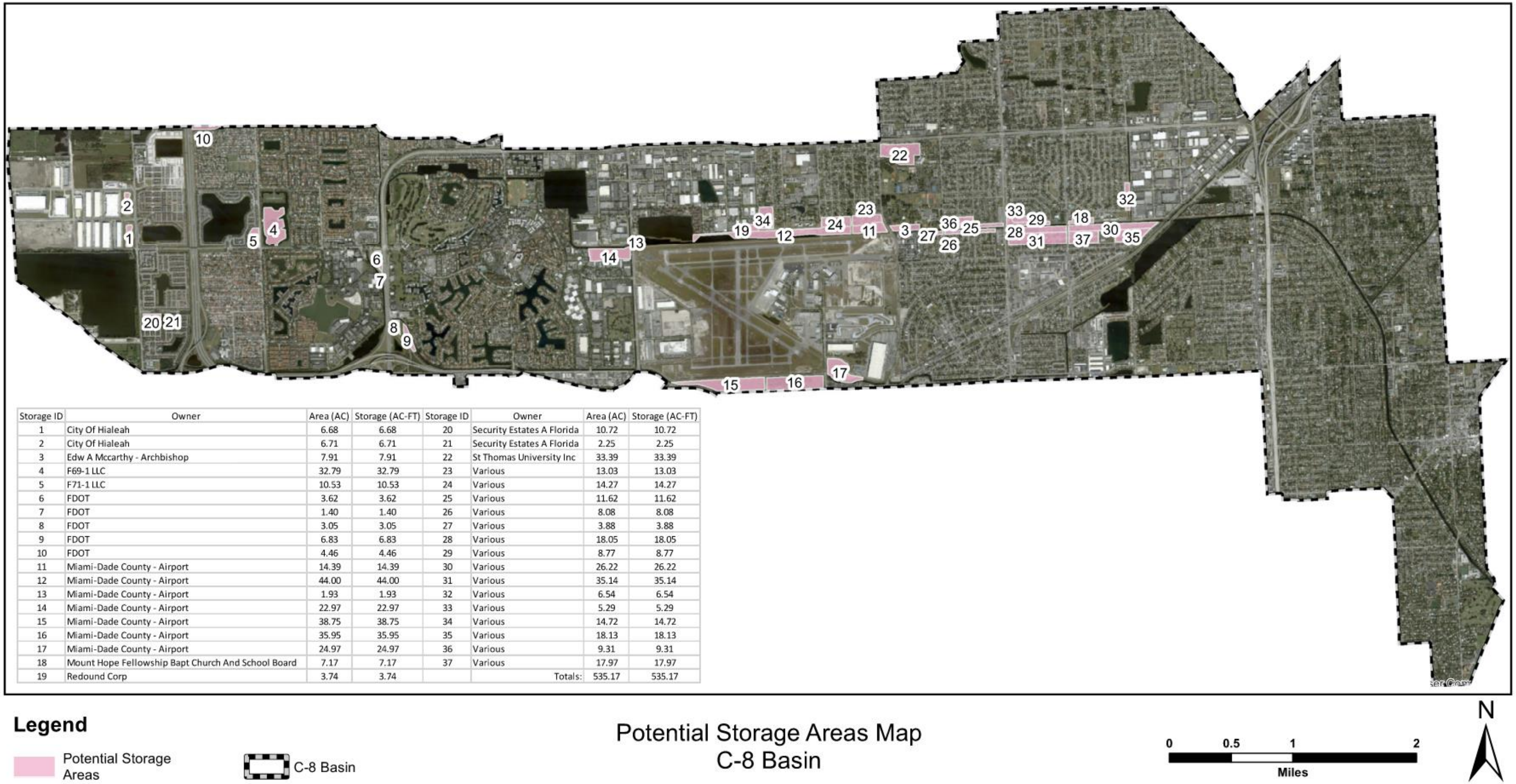


Figure 3.2-1: Storage Area Concept

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 and used 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:

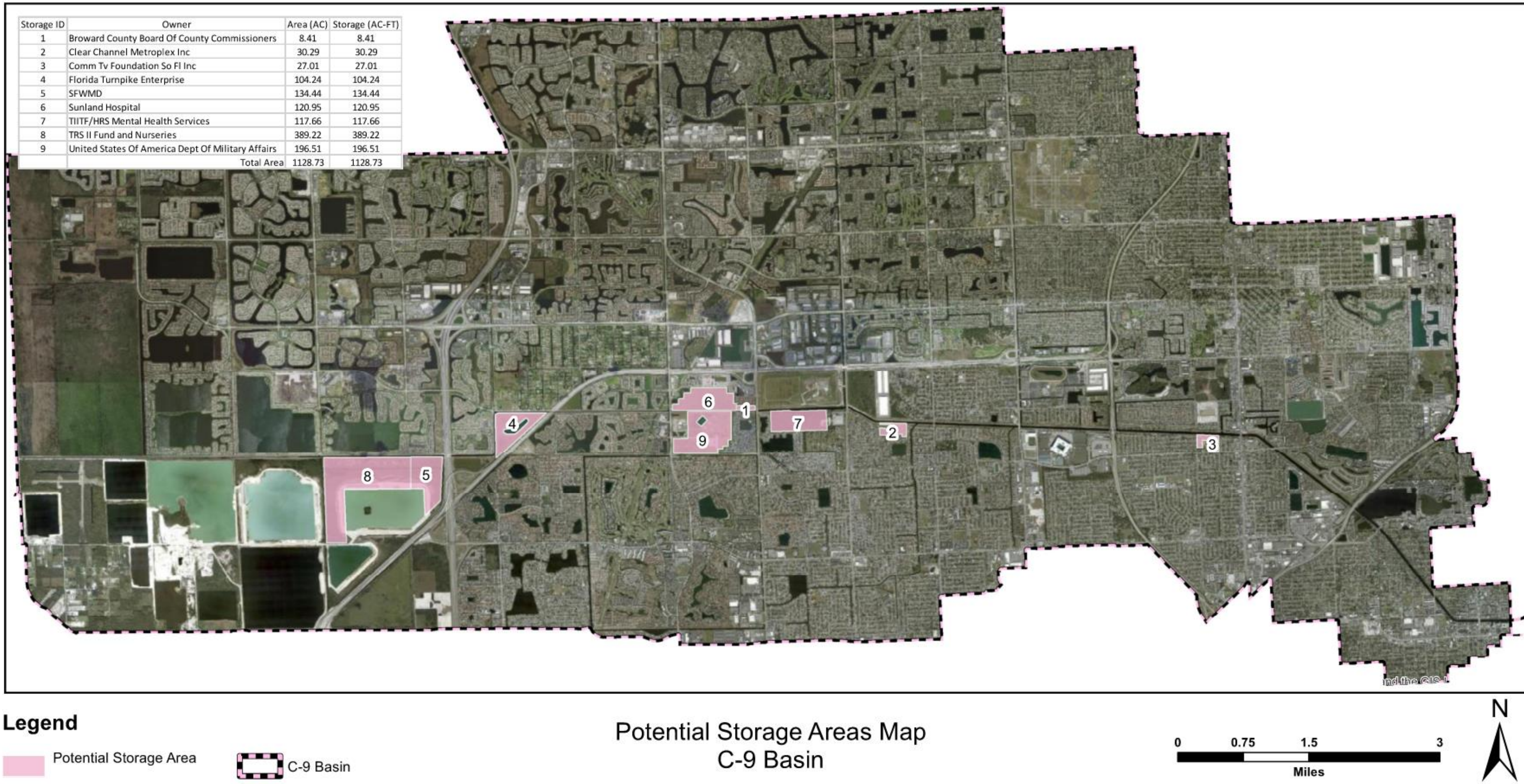
1. District/FDEP/FDOT (Or TIITF) -owned land
2. Other government-owned land
3. Vacant land/Underutilized
4. Tracts of land larger than approximately 5 acres were considered

Based on these criteria, **Figure 3.2-2** and **Figure 3.2-3** identifies 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 are 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 3.2-2: 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 3.2-3: Potential Storage Locations – C-9 Watershed

3.3 Green Infrastructure Storage Options

Section 3.2 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 will discuss how green infrastructure could be implemented as an enhancement to generic surface water storage. 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 most flexible method 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 3.3-1** below.

Figure 3.3-1: 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 3.2-2** and **Figure 3.2-3** 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 3.3-2**.

Figure 3.3-2: 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 credit for 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 3.3-3

Figure 3.3-3: 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)

3.4 Model Iteration, Mitigation Implementation, and Testing of Proposed Mitigation Projects

The Phase 2 Flood Protection Level of Service Study modified the integrated groundwater and surface water MIKE SHE / MIKE HYDRO model, developed in the Phase 1 FPLOS Study, to analyze the benefits of various potential mitigation projects within the C-8 and C-9 Watersheds. These analyses included several hundred model iterations to examine various mitigation activities. These activities range from regional pump stations to local basin-interconnects, with the goal of identifying individual mitigation projects that could be combined into mitigation strategies. The Phase 2 study approach evaluated the mitigation strategies to understand their effectiveness at protecting the C-8 and C-9 system from flooding or reducing the vulnerability of flooding. The following discussion provides a brief overview of the model iteration, mitigation implementation, and testing of the proposed mitigation projects.

During model testing, the modelers discarded many simulations and conducted no further analysis once it was evident that there were negligible benefits, or that the mitigation activity did not “move the needle” for flood control. Although the goal was to achieve a level of service under future condition sea level rise that was equal to or greater than existing conditions, for the purposes of model iteration and mitigation testing, the results were analyzed for any reduction in primary canal stages or decreased overland flood depths. In some instances, if the tested mitigation project did not show favorable results but modelers believed that it should have, they conducted further testing by either adjusting the mitigation project or conducting model runs in combination with another project that could “unlock” some of the benefits.

The mitigation efficiency criteria used to evaluate and select components of the mitigation strategies includes PM #1 profiles, PM #5 flood depths, and PM #6 flood durations, as well as qualitative assessment based on the team’s professional judgement.

The Phase 2 FPLOS study aims to mitigate future flood levels corresponding to three future sea level rise scenarios in the C-8 and C-9 Watersheds. The team proposed, conceptualized, and tested several mitigation projects, along with potential projects proposed by partner communities, with the goal of reducing future flooding to a level equal to or lower than existing conditions. The existing condition flood levels and future conditions without mitigation flood levels have already been established in the Phase 1 FPLOS Study (Taylor, 2021). The final mitigation strategies include different combinations and configurations of blocking storm surge, pumping water out of the canal system to downstream of the salinity control structures (S-28 and S-29), improving canal conveyances, and storing water. Several other mitigation projects tested during model iteration runs are believed to either be infeasible (in terms of constructability or are cost prohibitive), show no benefits due to underlying modeling assumptions, or fall below the scale and resolution of the model.

<u>Raised Structure, Tieback Levees, and Forward Pumps</u> (NGVD29 to NAVD88 Conversion = -1.57 ft)

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, 2, 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: (1) raised gate overtopping elevation, (2) tieback levees and/or floodwalls, and (3) 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.

Pump Sizing Iterations

Starting with the 5-year SLR1 event, the 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 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 is minimal or no real improvements further upstream.

Raised Canal Embankments

To address the first issue, the team simulated raised embankments on the C-8 and C-9 Canals in the MIKE HYDRO model. However, this not only prevents the canal from spilling out into the floodplain, but it also prevents drainage to the canal. Model iteration testing showed an increase in overland (pluvial) flooding, as rainfall runoff stacks along the newly raised canal embankments. To overcome this, the modelers developed an internal drainage system along the primary canal in the MIKE HYDRO model to represent the required drainage infrastructure necessary to allow the watersheds to drain through the raised canal embankments. Through several more rounds of model iteration testing, the team developed a system of "dummy" canals and one-way culverts that allow the C-8 and C-9 Watersheds to drain directly to the C-8 and C-9 Canals when there is positive water level differential. This approach also limits the ability of the C-8 and C-9 Canal to spill back out into the watersheds. The team did not address the construction feasibility or property acquisition challenges of this approach.

Conveyance Improvements

To address the second issue and to extend the benefits of the pump station further upstream and into the watershed, the team conducted additional pump iteration testing on the C-8 Watershed, but this time with the addition of increased canal conveyance. These simulations tested the widening of the eastern segment of the C-8 Canal by 100 ft, from Interstate 95 to Structure S-28. The conveyance improvements modeled 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. 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 were still 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 mitigation strategies.

Potential Storage Projects

The team also evaluated storage as a potential mitigation project, in the form of injection wells and distributed surface storage. In terms of flood mitigation, both potential strategies do the same thing but through different means. Injection wells remove water from canals and pump it underground, whereas surface storage removes water from canals and holds it on the surface. In terms of modeling, the team simulated both injection wells and distributed storage the same way, a simple removal of water through internal boundaries or sinks. Although injection wells would remove water by injecting it into an aquifer, for the sake of preliminary evaluation, the injection wells were conceptually represented as a sink in the model. Using 10 internal boundaries along the upstream portion of the C-8 Canal, a combined rate of 300 cfs was removed from the canal for various lengths of time. When starting to remove water as soon as rainfall starts, the injection wells result in an average reduction in peak stages of approximately 0.15 ft along the entire canal. When only removing water during an 8-hour window during peak stages, the injection wells had an overall negligible benefit in terms of flood reduction.

Preliminary cost estimates from a SFWMD study on Aquifer Storage Recovery (ASR) wells made it obvious that the costs would far outweigh the limited benefits and therefore injection wells were not considered feasible.

The distributed storage testing was completed the same way as the injection wells, using internal boundaries to remove water from the model. This was a conceptual representation to identify any potential benefits from the volume of storage rather than the location of storage. With respect to surface storage, a total of 500 ac-ft of storage distributed across 17 locations in the C-8 and C-9 Watersheds was tested. Although shown to have minimal effects on flooding when viewed on a regional basis, the surface storage construction was estimated to be significantly cheaper than injection wells (land acquisition costs not considered) and could have water quality benefits along with significant local-scale flood benefits. Although neither of these other benefits were quantified, the distributed storage was considered a part of the final mitigation strategies.

North Lake Belt Storage Area

One mitigation project the team anticipated would show great benefit was the North Lake Belt Storage Area Improvements, also known as the western mine-pits. The modeling team, with guidance from SFWMD, evaluated the existing mining pits in the western part of the C-9 Watershed as a potential regional storage facility. In the preliminary analysis, the model was configured to divert water from the C-9 Canal into the mining-pits. However, initial results showed that the diverted canal water rapidly leaked out into the aquifer, making its way back to the surface in the surrounding areas, causing an increase in overland flooding. As the initial mining pit iterations diverted 1,000 cfs from the C-9 Canal, the team performed additional simulations with decreased rates of 500 cfs and 250 cfs, to see if the mining-pits could contain the lower inflow rates.

In all of these iterations, the mining pits could not store flood waters due to the high conductivity of the surrounding limestone formation. Therefore, in the following iterations, the team modeled seepage cut-off walls by reducing the horizontal conductivity of the mining-pits by 90% to 99%. These seepage cut-off walls did not change the outcome. The team further tested the feasibility of the mining pits as a potential means for storage by reducing the vertical conductivity by 99%. Model results indicate that although slowing down the rate at which the diverted water leaked out, the mining pits still seeped into the surrounding areas and caused an increase in water levels. Although it would be expensive, it is possible to construct a seepage cut-off wall surrounding the mine pits. However, it would be practically impossible, or likely too expensive, to cut-off seepage through the bottom of the mining pits through a barrier such as an impervious liner. It is likely that the only practical way the mining-pits could be used for storage is if the bottom of the mining pits are within a confining unit. This was partially tested by reducing the vertical conductivity by 99%. Due to the uncertainties surrounding this potential project and lack of data such as the elevation of the bottom of the mining pits, it was dropped from further consideration in this study. Extensive further studies (beyond the scope of this project) would be needed to establish the engineering feasibility and costs of controlling seepage out of these pits.

<u>Lake Ojus or East and West Lakes</u>

Another storage-related mitigation project proposed by the team was the diversion of C-9 Canal discharge during times of peak stage into Lake Ojus, also known as the East and West Lakes, just east of I95 along the C-9 Canal. This lake is directly connected to the C-9 Canal through a wide opening, more than 1,000 ft in length. When generating ideas for potential mitigation projects, this lake was identified as being in an ideal spot to buffer peak discharge from the tidal structure and reduce peak stages reaching the furthest points downstream in the C-9 Canal, upstream of Structure S-29.

The proposed project included severing the open connection between the lake and the C-9 Canal by adding an embankment between them, along with a gravity-structure, to allow the lake to fill-up only once the C-9 Canal reached a certain elevation. Essentially, instead of the lake filling up as the C-9 Canal stage increases, the proposed mitigation project would block inflow into the lake from the C-9 Canal until a target stage was reached in which the gravity-structure would be opened or overtopped, rapidly filling up the lake, resulting in a decrease in C-9 Canal peak stages and ultimately a decrease in peak discharge from the S-29 sluice gates. Model iterations showed what appeared to be promising results, achieving the desired effect of reduced stages, and decreased peak discharge. However, in the Phase 1 model, this lake was not represented in the 1D MIKE HYDRO River model. Although not explicitly modeled in the river model, it was still represented to some degree in the MIKE SHE 2D model and groundwater model. Therefore, when trying to understand the net benefits of this mitigation project, the team tested the model with the lake explicitly represented without the proposed mitigation projects. Comparisons of model results showed the lake storage and attenuation was not effectively represented in the without-project models, and that nearly all the benefits seen by the potential lake mitigation projects came from better representing the lake storage and allowing the storage to communicate better with the C-9 Canal. Therefore, no mitigation project was assigned to the lake, but all future MIKE HYDRO model simulations include this enhanced representation of the Lake Ojus system. Due to this model setup change, along with other model setup related changes unrelated to mitigation projects, the team re-simulated the without-mitigation models so that there was a consistent comparison to the new and improved with-mitigation models. This is further discussed in **Section 4**.

Exfiltration Trench

To reduce the peak stages and discharge in the C-8 and C-9 Canals, the team analyzed the impact of exfiltration trenches, or increased infiltration, through the conceptual representation of modified ponded drainage runoff coefficients in the urban areas of the C-8 and C-9 Watershed. Within the 2D overland component of the MIKE SHE model, the modelers reduced the ponded drainage runoff coefficients, which can reduce the rate of runoff being routed to the canal system by keeping water on the surface for longer durations, increasing the potential for infiltration. However, under future sea level rise scenarios, the increased groundwater often results in groundwater elevations near or higher than land surface, which limits or prevents infiltration. Ultimately, the reduced runoff coefficients made negligible difference to the model results and as such were not updated to conceptually represent any part of the mitigation strategies.

General Drainage Improvements

To mitigate flooding in urban areas, the team analyzed the impact of generalized drainage improvement through the conceptual representation of increased ponded drainage runoff coefficients. Within the 2D overland component of the MIKE SHE model, modelers increased the runoff coefficients, which can increase the rate of runoff being routed to the canal system and could lead to reduced flood levels in urban areas. However, this adjustment resulted in negligible differences in local flood levels, and worse, increased the stages in the C-8 and C-9 Canals. Essentially, a little reduction in ponded water doesn’t make a big difference for individual areas, but cumulatively, all that extra runoff has a more pronounced effect on the canals with limited capacity.

Local Scale Mitigation Projects

Other mitigation projects were tested that were either identified by partner communities having been categorized as “local scale,” or identified by the team to address local flood vulnerabilities. Unlike the pump iterations which analyzed all rainfall return period and sea level rise scenarios, these M1 iterations focused solely on the 25-year SLR1 storm event. These projects, as listed in the Task 2.1 Technical Memorandum, included ideas such as basin-interconnects, injection wells, general drainage improvements, distributed storage, etc. Most of these M1 projects were not explicitly modellable due to scale, however, the modeling team did iterate through the ones that could be reasonably represented. As predicted, benefits from these local scale mitigation projects were not identifiable in the model results. However, it is important to note that this does not mean the projects are not worth considering. In fact, each of the identified projects brought forward by the partner communities will likely have some level of local impact in real-world situations and are encouraged to be pursued or further evaluated. The team conducted analytic solutions and estimates for these M1 projects for their expected annual damage estimates, as discussed in the Task 3.2 deliverable (Technical Memorandum: Expected Annual Damage and Net Present Value Calculations, Taylor Engineering, 2022).

Conclusions

The tidal structure improvements of blocking storm surge and adding forward pumping capacity offered the largest flood protection level of service benefits. The District 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 this core project, 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, beyond just the limitations of the model due to scale. 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 that most other projects were not going to further contribute to the LOS goal, regardless of if the mitigation project is known to have real-world application and benefits. Therefore, instead of trying to add additional mitigation projects to the mix, the team focused on optimizing the mitigation projects that were predicted to have the most benefit. 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.

4 M0 EXISTING CONDITIONS MODEL UPDATE TO ACCOMMODATE THE COMPARISON OF MITIGATION STRATEGIES MODEL SCENARIOS AND THE NEEDS OF THE PHASE II ASSESSMENT

Due to some model changes identified during the development of the mitigation project scenarios, Taylor Engineering decided to update the current condition model to serve as a baseline for comparison with the mitigation results from this Phase 2 assessment. Under the Phase 1 assessment, the current condition models simulating the 5, 10, 25, and 100-year SLR0 scenarios are referred to as the "current condition models" and these models simulating future sea level rise conditions are referred to as "existing conditions with sea level rise." It is important to note that these results from the Phase 1 assessment are still valid and the model simulations from this Phase 2 assessment do not replace them. Under the Phase 2 assessment, these "current conditions" and "existing conditions with sea level rise" models were updated to reflect some model setup changes that were integrated into the mitigation project models as part of model development rather than as part of mitigation. Therefore, for the purposes of this Phase 2 assessment, the updated "current conditions" and "existing conditions with sea level rise" models are referred to as "Mitigation 0" and represent current sea level (SLR0) and future sea level (SLR1, SLR2, and SLR3). The "Mitigation 0" model is the baseline model for the Phase 2 assessment and will be used for all comparisons with the various mitigation scenarios presented in this report. The model updates applied to form the "Mitigation 0" model (unrelated to any particular mitigation project) are listed below along with the reason for the update:

- C-7 Canal Boundary – Originally this was based on District-provided XP SWMM simulated data at the headwater of Structure S-27 and tailwater of Structure G-72. At that time, there was no simulated data available for future conditions. The S-27 headwater boundary was increased by 1, 2, and 3 ft, but not the G-72 tailwater boundary as it was much further inland. This had an effect on groundwater levels that became more apparent when closely examining the effects of different potential mitigation activities. The solution was to redevelop the G-72 tailwater boundary by increasing the water levels 0.5 ft for every 1 ft of sea level rise. This was approximated by examining the increase in upstream water levels in the C-8 and C-9 Canals with respect to sea level rise. Although not an exact science, this provided a more realistic approximation that was more consistent with other assumptions built into the model.
- Northern Boundary- The northern boundary across the C-9 / C-11 Watershed divide was originally based on the 2019 Broward County Current Conditions Model. This is a time varying and spatial varying boundary based on simulated groundwater elevations. However, the current conditions simulated values were used for all future condition with sea level rise scenarios. Although simulated future conditions were available, the 2019 Broward County Future Conditions Model had increased rainfall, along with other modeling assumptions that did not line up with the approach used in the SFWMD C-8 C-9 FPLOS Model. Additionally, at the time this boundary was developed, the SFWMD Broward FPLOS Model was still under development and no data was available. However, now that data from the SFWMD Broward FPLOS Model is available, the northern boundary condition in the SFWMD C-8 C-9 FPLOS model has been replaced with the simulated groundwater elevations for both current sea level and future sea level rise scenarios. This fixed an artificial groundwater sink in the northeast corner of the model.
- Represent "Lake Ojus" in the 1D model – Also known as "East" and "West" Lake just east of where I-95 crosses the C-9 Canal, this lake was originally not represented in the current conditions 1D model. Although not explicitly modeled in the river model, it was still represented to some degree

in the MIKE SHE 2D model and groundwater model. However, when looking at potentially modifying the lake to be used as a mitigation project, it was determined that much of the lake storage and attenuation was not effectively represented in the without-project models, and that all the benefits seen by the potential lake mitigation projects actually came from better representing the storage and allowing the storage to communicate better with the C-9 Canal. Therefore, no mitigation project was assigned to the lake, rather, the lake was explicitly represented in the MIKE HYDRO 1D model, which connects it directly to the C-9 Canal and responds in a much more realistic way.

- Updated Flood Codes – Removed a few flood code grid cells for one specific flood code in the tertiary system that was causing instability in the water levels in one small area. This was showing up in the flood depth difference maps for only certain rainfall or sea level rise scenarios during model iteration testing. This affects a very small area in the tertiary system and does not appear to change any overland flooding to the surrounding urban areas, just the local lake level itself.
- Bank elevation update – Updated the bank elevations in the Opa Locka Canal near where it discharges to the C-8 Canal. In order for overbank spilling to work properly and not stack water in the canal or on the canal banks, the canal bank elevation and topography of the grid cell along the canal should be a close match. During iteration testing, it was noticed that for certain rainfall or sea level rise scenarios, there were mismatched 1D/2D elevations. Essentially, the 2D overland flood elevations and 1D canal elevations did not match, leading to small artifacts in the PM5 flood inundation maps. This was a minor change.
- Increased initial water levels – For the 3 ft sea level rise scenario, the initial water elevation within the C-8 and C-9 Canal, along with all the gravity-connected tributaries, was increased. Originally, the assumption was that the initial water level under SLR3 would be 3.25 ft NGVD29 and then let the model come to some dynamic equilibrium during the spin up period. During the various iteration runs working out the details of updating the tidal structures, it was decided to increase the initial water level to 3.5 ft NGVD29, allowing the model to reach a more appropriate dynamic equilibrium before rainfall starts. This was a minor change that felt necessary once a better understanding was reached of how SLR, tidal structure improvements, and operational changes affect the relationship between headwater and tailwater.
- Operational Rules – The models were updated to have more detailed salinity control protocols, which were provided during the Phase 2 Study. This change does not appear to change peak discharge or water levels in the Mitigation 0 models as it does not affect how the structure opens, rather it affects how the structure closes. This results in a small difference in total discharge volume as the structure can stay open slightly longer between tide cycles. Doesn't appear to show up in any of the performance metric results and was just updated for consistency and to rule out any possible differences.

5 FLOOD PROTECTION LEVEL OF SERVICE DEFINITIONS

The District relies on six (6) formal performance metrics (PMs) to evaluate the FPLOS provided by the primary water management infrastructure. With respect to the mitigation analysis, only four of these metrics were used to evaluate the system under the various mitigation scenarios. These four metrics, defined briefly in this section, were initially derived from the District publication *Flood Protection LOS Analysis for the C-4 Watershed, Appendix A: LOS Basic Concepts* (SFWMD H&H Bureau, December 29, 2015). The process and data deliverables used to analyze the performance metrics were subsequently refined by Taylor Engineering, in consultation with the District, in previous FPLOS projects. With respect to this analysis, only PM #1, #2, #5, and #6 were evaluated for this study. PM #3 and PM #4 were excluded from this Phase 2 Mitigation Analysis as they show less meaningful data when comparing mitigation vs non mitigation scenarios compared to when they are used to compare existing conditions vs future conditions SLR with no mitigation.

Section 7 of this report provides the results of the FPLOS evaluation for future conditions with mitigation. The remainder of this section describes the four PMs relevant to this Phase 2 Study.

5.1 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.

5.2 PM #2 – Maximum Daily Discharge Capacity through the Primary Canals – This is the maximum discharge capacity throughout the primary canal network. Discharge is calculated as area weighted flow, in units of cubic feet per second per square mile (CSM) of contributing area. Tidal effects are filtered by using a 12-hour moving average of discharge. The discharge capacity of the canal segment is the net discharge corresponding to the largest design flood event that remains within the banks of the canal using the results of the 5-year, 10-year, 25-year, and 100-year events.

5.3 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.

5.4 PM #6 – Duration of Flooding – This metric quantifies the duration of flooding across the entire watershed. For this study, the length of time the flood elevation is projected to be above a threshold depth of 0.25 ft was mapped over the entire study area using the multi-cell gridded model output files for the 2-D overland flow component.

6 M2 MITIGATION PROJECTS

This section details the specific model changes made to represent each mitigation project represented in M2A, M2B, and M2C. For full detail on model development and design storm setup, refer to *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,2021). Please note that this modeling effort and report references NGVD29 datum and all elevations have been documented as such. A conversion factor of -1.57 ft (NGVD29 to NAVD88) is applied throughout this study.

Mitigation M2A, M2B, and M2C each have two of the same elements that aim to reduce flood levels by improving the performance of the tidal structure and storing excess flood water. The first element, improving the performance of the tidal structure, consist of several components that work together to prevent storm surge from getting past the tidal structure while simultaneously act to discharge flood water. To achieve this, the following four distinct components are required and without any one of these components the rest would not be as successful: (1) raised gate overtopping elevation, (2) tieback levees and/or floodwalls, (3) forward pump station, and (4) optimized operational control rules. Figures presenting these components are shown later in this section.

Raised Gate Overtopping Elevation

The first component, raising the gate overtopping elevation to 9.0 ft NGVD29, was the first step at blocking storm surge from flooding areas upstream of the tidal structure. With respect to model changes, this was simply represented by increasing the height of the S-28 and S-29 Sluice Gates in the MIKE HYDRO model.

Tieback Levees and/or Floodwalls

The second component, tieback levees and/or floodwalls, was the second step at blocking storm surge from flooding areas upstream of the tidal structure. Due to the relatively low topography surrounding the existing S-28 and S-29 tidal structures, just raising the elevation of the sluice gates would only block one flow path of high storm surge. Therefore, the elevated S-28 and S-29 structures needed to tie-in to higher ground, to prevent storm surge from flanking the structure. With respect to model changes, these tieback levees/floodwalls were conceptually represented by raising the MIKE HYDRO cross-sections in the proximity of the tidal structure to an elevation of 9.0 ft NGVD29, along with the topography of locations in the proximity of the structure with elevations that could allow storm surge to bypass the structure. This conceptual representation tells MIKE SHE and MIKE HYDRO not to exchange water from river to overland or from overland to river until the water elevation is greater than this elevated cross-sections or topography, fully preventing storm surge from bypassing the tidal structure for all scenarios simulated in this study.

Forward Pump Station

The third component, forward pump station, is solely responsible for removing water from upstream of the tidal structure when the tidal structure is unable to operate due to downstream conditions. During high tide and increasingly more often as sea level rise increases, the water levels downstream of the tidal structure become higher than the upstream water levels, completely stopping gravity-driven discharge. Couple that with additional water volume entering the canal due to rainfall-runoff, water stacks upstream of the tidal structure, causing upstream flooding. Therefore, the forward pump station simply aims to provide relief by allowing the watershed to continue to discharge to tide when the gravity structure is unable to. With respect to model changes, this was represented by adding a direct discharge structure to the MIKE HYDRO model. A direct discharge structure was chosen as it is essentially the same as a pump station, but one that can be controlled with specific rules coded into the model.

Operational Control Rules

The fourth and last component of improving the performance of the tidal structure, optimized operational control rules. Rather than just a simple on or off elevation, a "tuned" set of control rules were developed through several rounds of model iterations to combine both the full use of the pump station as well as the maximum practical use of the sluice gates. It is known that pumping is expensive as pumps require large amounts of electricity or fuel to operate as well as maintenance costs, therefore, it is important to take full advantage of gravity-driven discharge whenever possible, especially when adequate head differential across the structure means potentially much higher discharge rates can be achieved. It was also kept in mind while developing the operational rules that under real-world operation, on-the-fly operational changes are often made to address a range of potential various issues across the watershed. Therefore, there is no such thing as a perfect set of operational rules and the rules were finalized once a satisfactory response was achieved in the model results.

Operational controls with SLR

Although the same set of rules apply for each rainfall event, a set of operational rules were developed for each sea level rise scenario. These operational rules are quite similar, however, they were slightly adjusted for each sea level rise scenario to help meet the goal. The idea behind this is that the SFWMD will likely have a strategic plan and have thought-out how the structures will have to operate differently as sea level rise increases and have years between each sea level rise scenario to plan accordingly. Whereas with rainfall, there is no way to tell if the rainfall event approaching is going to have 5, 10, 25, or 100-year year rainfall totals, which means the operational plan will be the same. It is important to note that the structure operations involving the forward pump station, particularly the scenarios in which the chosen pump capacity exceeds the current capacity of the gravity spillway (just M2C at S-28 in this instance), may lead to unintended effects on the downstream side of the tidal structure and are not evaluated as part of this study. Rather, the effects of increased discharge from the structures will be analyzed in a separate task order following this Task 2.2 report, using the data provided from this study. It is also important to note that although the chosen pump capacity for S-28 under mitigation M2C is higher than the original design capacity (3,550 cfs vs 3,220 cfs), the design discharge of 3,220 cfs is based on very specific headwater and tailwater conditions. Under future conditions without mitigation, as shown in the Phase 1 study (Taylor, 2021), the S-28 sluice gate was predicted to have peak discharge rates that are significantly higher than the design discharge. Therefore, having a pump capacity larger than the design capacity of the gravity structure does not necessarily mean there will be impacts, but as mentioned, it will be evaluated.

Conceptual Storage Modeling

The second element, storing excess flood water, consists of the conceptual storage of flood water by removing a total of 500 ac-ft of water from 17 locations distributed across the gravity-drained portions of the C-8 and C-9 Watershed. With respect to model changes, this water storage was conceptually represented through 17 internal boundary conditions, 14 set with a time-series file to remove water from areas at a rate of 37.8 cfs for 8 hours (25 ac-ft) and 3 at a rate of 75.6 cfs for 8 hours (50 ac-ft). This removal of water from the model over the 8-hour period when model-wide water levels were at their highest was a simplistic way to represent the storage and its possible effect on flood reduction. This conceptual representation of water storage is intended to simulate small-scale distributed impoundments. As previously mentioned, the specific locations of these 17 distributed storage representatives was not the focus of this mitigation project, rather the potential flood reduction and total discharge volume reduction, which could have some secondary benefits related to water quality (not analyzed as part of this study).

Canal Elevations Assumed for Mitigation Projects

For Mitigation M2A, M2B, and M2C, an assumed canal control elevation was chosen for each sea level rise scenario. Although the District has well-defined normal range and low range control operations, the normal range operations have been used in the C8 C9 FPLOS studies as they provide a more conservative estimate by starting the C-8 and C-9 Canal at a higher elevation. Under existing conditions (SLR0) and normal operations, SFWMD controls the S-28 and S-29 structures in a way such that the headwater is maintained at an elevation as high as 2.25 ft NGVD29 and 2.5 ft NGVD29, respectively.

For the purposes of this study, Taylor assumed that both the C-8 and C-9 Watershed would be subject to an increase in water control elevations to a new level of 2.75 ft NGVD29, 3.75 ft NGVD29, and 4.75 ft NGVD29 under SLR1, SLR2, and SLR3, respectively. Please note that this was strictly an assumption made based on other assumptions such as assuming that the SFWMD will choose/need to keep the headwater higher than the average tailwater to protect against saltwater intrusion, or assuming that it is too expensive / infeasible to continually pump to against the higher tailwater conditions that are assumed to seep around the structure over a long-period of time. Assuming an elevated control elevation was also made as it provides a more conservative set of constraints with respect to how the system can operate. It is important to note that there are uncertainties inherent in the assumptions made that can be reduced through additional study. The future study efforts could include longer-term modeling to assess the ability of the pump systems to keep up with the higher groundwater seepage induced by sea level rise (between flood events).

6.1 Mitigation M2A

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. These elements are described in detail in **Section 6**, as these two elements also apply to Mitigation M2B and M2C. For Mitigation M2A, the forward pump station has a maximum capacity of 1,550 cfs. 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 (refer to **Figure 6.1-1**)
  - S-29: approximately 250 ft length for the north bank and 425 ft length for south bank (refer to **Figure 6.1-2**)
- 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 3.2-2** and **Figure 3.2-3** 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

Figure 6.1-1: Potential Alignment of Tie-Back Levees for S-28 structure Improvements

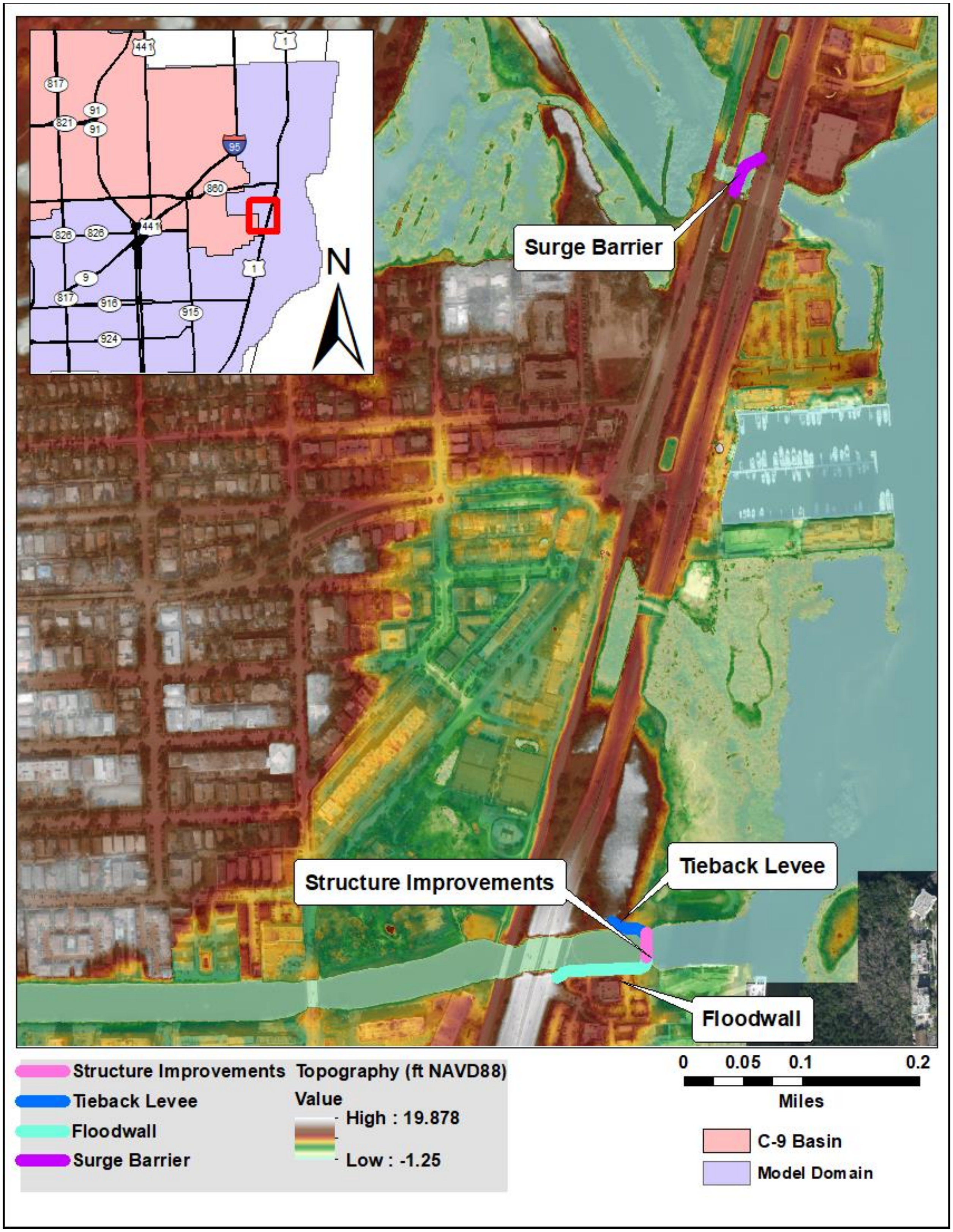


Figure 6.1-2: Locations of S-29 Improvements and Potential Oleta River Surge Barrier (as part surge bypass prevention)

Table 6.1-1 through **Table 6.1-9** detail the control rules for the S-28 and S-29 sluice gates and pump stations. Both S-28 and S-29 have the same operating criteria and rules under Mitigation M2A and change with respect to sea level rise. As sea level rise increases, the open/close and on/off elevations of the gates and pumps also increase to represent the assumed change in antecedent water levels (control elevations), largely for the purposes of protecting against saltwater intrusion. Additionally, as sea level rise increases, the stage/discharge relationship of the pump station changes, becoming increasingly more aggressive in the sense that they ramp up to full capacity with less total change in headwater elevation. Under SLR1, the S-28 and S-29 headwater is required to raise by 0.75 ft before being at full capacity, whereas under SLR2 and SLR3 the headwater is required to raise by 0.5 ft and 0.45 ft, respectively. For the S-28 and S-29 pump station, there are two different pump-on rules. The first pump-on rule establishes how and when the pump can turn on for the first time and the second rule establishes how and when it can pump before turning off. Using SLR1 as an example, the first pump-on rule states that the headwater upstream of the structure must be greater than 2.75 ft NGVD29 AND the head difference between upstream and downstream of the structure is less than 0.25 ft. The first part of this rule establishes that the headwater must be greater than the water control elevation of 2.75 ft NGVD29 before being allowed to start pumping. The second part of this rule ensures that the pump is only active when the gravity structure is unable to discharge due to its operating constraints. The second pump-on rule states that the headwater upstream of the structure must be greater than 2.25 ft NGVD29 AND the head difference between upstream and downstream of the structure is less than 0.25 ft AND the discharge through the pump station is greater than 0 cfs. The rule establishes that the pump can discharge down to a headwater level of 2.25 ft NGVD29, but ONLY if the pump is already on. Essentially, the pump station must first reach its designated control elevation of 2.75 ft NGVD29 before turning on, at which point it is allowed to draw down the canal 0.5 ft to an elevation of 2.25 ft. Together, the two pump-on rules would accomplish the following:

- prevent the pump station from turning on and off repeatedly at the control elevation,
- prevents it from pumping while at an elevation lower than the control elevation unless the water level has already reached control and is being drawn down,
- ensures it stops pumping after the maximum allowed drawdown has been reached, and
- ensures the pump station turns off whenever the established minimum head differential has been reached that allows the sluice gates to operate.

It is important to note that the operational rules for the pump station assumes that there are no elevated tailwater constraints which may be placed by the District to protect downstream property, if needed.

Table 6.1-1: Control Rules for S-28 and S-29 Sluice Gates for SLR1

Rule Priority	Condition	Control
1	Head difference between upstream and downstream of S-28 / S-29 is less than 0.1 ft	Close
2	Head upstream of S-28 / S-29 is greater than 2.75 ft NGVD29 AND head difference between upstream and downstream of S-28 / S-29 is greater than 0.3 ft	Fully open
3	Head upstream of S-28 / S-29 is greater than 2.25 ft	Unchanged
4	Head upstream of S-28 / S-29 is less than 2.25 ft NGVD29	Close

Table 6.1-2: Control Rules for S-28 and S-29 Pump Station for SLR1

Rule Priority	Condition	Control
1	Head difference between upstream and downstream of S-28 / S-29 is greater than 0.25 ft	Off
2	Head upstream of S-28 / S-29 is greater than 2.75 ft NGVD29 AND head difference between upstream and downstream of S-28 / S-29 is less than 0.25 ft	Pump Station On - Tabulated
3	Head upstream of S-28 / S-29 is greater than 2.25 ft AND head difference between upstream and downstream of S-28 / S-29 is less than 0.25 ft AND Discharge of pump station is currently greater than 0 cfs	Pump Station On - Tabulated
4	Head upstream of S-28 / S-29 is less than 2.25 ft NGVD29	Off

Table 6.1-3: Tabulated Control Points for S-28 and S-29 Pump Station for SLR1

Headwater Elevation (NGVD29)	Discharge (ft3/s)
2.25	350
2.75	350
2.95	350
3	700
3.2	700
3.25	1050
3.45	1050
3.5	1550

Table 6.1-4: Control Rules for S-28 and S-29 Sluice Gates for SLR2

Rule Priority	Condition	Control
1	Head difference between upstream and downstream of S-28 / S-29 is less than 0.1 ft	Close
2	Head upstream of S-28 / S-29 is greater than 3.75 ft NGVD29 AND head difference between upstream and downstream of S-28 / S-29 is greater than 0.3 ft	Fully open
3	Head upstream of S-28 / S-29 is greater than 3.25 ft	Unchanged
4	Head upstream of S-28 / S-29 is less than 3.25 ft NGVD29	Close

Table 6.1-5: Control Rules for S-28 and S-29 Pump Station for SLR2

Rule Priority	Condition	Control
1	Head difference between upstream and downstream of S-28 / S-29 is greater than 0.25 ft	Off
2	Head upstream of S-28 / S-29 is greater than 3.75 ft NGVD29 AND head difference between upstream and downstream of S-28 / S-29 is less than 0.25 ft	Pump Station On - Tabulated
3	Head upstream of S-28 / S-29 is greater than 3.25 ft AND head difference between upstream and downstream of S-28 / S-29 is less than 0.25 ft AND Discharge of pump station is currently greater than 0 cfs	Pump Station On - Tabulated
4	Head upstream of S-28 / S-29 is less than 3.25 ft NGVD29	Off

Table 6.1-6: Tabulated Control Points for S-28 and S-29 Pump Station for SLR2

Headwater Elevation (NGVD29)	Discharge (ft3/s)
3.25	350
3.75	350
3.95	350
4	1050
4.2	1050
4.25	1550

Table 6.1-7: Control Rules for S-28 and S-29 Sluice Gates for SLR3

Rule Priority	Condition	Control
1	Head difference between upstream and downstream of S-28 / S-29 is less than 0.1 ft	Close
2	Head upstream of S-28 / S-29 is greater than 4.75 ft NGVD29 AND head difference between upstream and downstream of S-28 / S-29 is greater than 0.3 ft	Fully open
3	Head upstream of S-28 / S-29 is greater than 4.25 ft	Unchanged
4	Head upstream of S-28 / S-29 is less than 4.25 ft NGVD29	Close

Table 6.1-8: Control Rules for S-28 and S-29 Pump Station for SLR3

Rule Priority	Condition	Control
1	Head difference between upstream and downstream of S-28 / S-29 is greater than 0.25 ft	Off
2	Head upstream of S-28 / S-29 is greater than 4.75 ft NGVD29 AND head difference between upstream and downstream of S-28 / S-29 is less than 0.25 ft	Pump Station On - Tabulated
3	Head upstream of S-28 / S-29 is greater than 4.25 ft AND head difference between upstream and downstream of S-28 / S-29 is less than 0.25 ft AND Discharge of pump station is currently greater than 0 cfs	Pump Station On - Tabulated
4	Head upstream of S-28 / S-29 is less than 4.25 ft NGVD29	Off

Table 6.1-9: Tabulated Control Points for S-28 and S-29 Pump Station for SLR3

Headwater Elevation (NGVD29)	Discharge (ft3/s)
4.25	350
4.75	350
4.95	350
5	1050
5.15	1050
5.2	1550

6.2 Mitigation M2B

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 described in detail in **Section 6**, as these two elements also apply to Mitigation M2A and M2C. For Mitigation M2B, the forward pump station has a maximum capacity of 2,550 cfs. 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 (refer to **Figure 6.1-1**)
    - S-29: approximately 250 ft length for the north bank and 425 ft length for south bank (refer to **Figure 6.1-2**)
- 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 3.2-2** and **Figure 3.2-3** 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 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 C8 and C9 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

The first component, preventing bank exceedances in the C-8 and C-9 Canal, was the first step at reducing flood levels in the urban areas along the primary canals. With respect to model changes, this was simply represented by increasing the elevation of the left and right levee bank to 7.5 ft NGVD29 for all applicable C-8 and C-9 cross-sections in the MIKE HYDRO model. This elevation was chosen by Taylor and is just a modeling assumption based on being higher than the maximum simulated water levels under future sea level rise scenarios from the Phase 1 Study. This chosen elevation does not include any freeboard and was not analyzed for feasibility nor does it consider any potential property acquisition that may be required. This representation keeps MIKE SHE and MIKE HYDRO from exchanging water from river to overland or from overland to river until the water elevation is at least 7.5 ft NGVD29, fully preventing the C-8 and C-9 Canal from spilling out onto the floodplain for all scenarios simulated in this study. This leads into the second component, allowing the watershed to drain to the primary canal.

When the C-8 and C-9 levee banks are raised, it not only prevents the canal from spilling out until the water reaches an elevation greater than the levee banks, but it also prevents water from draining to the canal until it reaches an elevation greater than the levee banks. Model iteration testing showed that in some locations or storm scenarios, raising the C-8 or C-9 Canal levee banks alone to prevent bank exceedance may actually result in increased flooding, as rainfall runoff stacks along the newly raised canal embankments. To overcome this, an internal drainage system along the primary canal was included in the MIKE HYDRO model to represent the required drainage infrastructure that would be necessary to allow the watersheds to drain through raised canal embankments. With respect to model changes, this internal drainage system was represented in the MIKE HYDRO model through the addition of hundreds of short canal segments and one-way culverts. This allows the rainfall to runoff towards the C-8 and C-9 Canal like usual, but then the runoff can flow into a “dummy” canal where it then has to ability to drain into the C-8 and C-9 Canals through a one-way culvert whenever the water level in the “dummy” canal is greater than the water level in the C-8 and C-9 Canals. It is possible that if something like this is ever implemented, that the water being collected along the sides of the C-8 and C-9 Canals could be pumped, which would allow them to actively drain throughout the entire storm event and not just when water levels are favorable for gravity-discharge. Please note that this was a very simplistic representation and was not analyzed for feasibility nor does it consider any potential property acquisition that may be required.

Table 6.2-1 through **Table 6.2-9** detail the control rules for the S-28 and S-29 sluice gates and pump stations under Mitigation M2B. Both S-28 and S-29 have the same operating criteria and rules under Mitigation M2B and change with respect to sea level rise. As sea level rise increases, the open/close and on/off elevations of the gates and pumps also increase to represent the assumed change in antecedent water levels (control elevations), largely for the purposes of protecting against saltwater intrusion. Additionally, as sea level rise increases, the stage/discharge relationship of the pump station changes, becoming increasingly more aggressive in the sense that they ramp up to full capacity with less total change in headwater elevation. Under SLR1, the S-28 and S-29 headwater is required to raise by 1.0 ft before being at full capacity, whereas under SLR2 and SLR3 the headwater is required to raise by 0.65 ft. For the S-28 and S-29 pump station, there are two different pump-on rules. The first pump-on rule establishes how and when the pump can turn on for the first time and the second rule establishes how and when it can pump before turning off. Using SLR2 as an example, the first pump-on rule states that the headwater upstream of the structure must be greater than 3.75 ft NGVD29 AND the head difference between upstream and downstream of the structure is less than 0.25 ft. The first part of this rule establishes that the headwater must be greater than the water control elevation of 3.75 ft NGVD29 before being allowed to start pumping. The second part of this rule ensures that the pump is only active when the gravity structure is unable to discharge due to its operating constraints. The second pump-on rule states that the headwater upstream of the structure must be greater than 3.25 ft NGVD29 AND the head difference between upstream and downstream of the structure is less than 0.25 ft AND the discharge through the pump station is greater than 0 cfs. The rule establishes that the pump can discharge down to a headwater level of 3.25 ft NGVD29, but ONLY if the pump is already on. Essentially, the pump station must first reach its designated control elevation of 3.75 ft NGVD29 before turning on, at which point it is allowed to draw down the canal 0.5 ft to an elevation of 3.25 ft. Together, the two pump-on rules would accomplish the following:

- prevent the pump station from turning on and off repeatedly at the control elevation,
- prevents it from pumping while at an elevation lower than the control elevation unless the water level has already reached control and is being drawn down,
- ensures it stops pumping after the maximum allowed drawdown has been reached, and
- ensures the pump station turns off whenever the established minimum head differential has been reached that allows the sluice gates to operate.

It is important to note that the operational rules for the pump station assumes that there are no elevated tailwater constraints which may be placed by the District to protect downstream property, if needed.

Table 6.2-1: Control Rules for S-28 and S-29 Sluice Gates for SLR1

Rule Priority	Condition	Control
1	Head difference between upstream and downstream of S-28 / S-29 is less than 0.1 ft	Close
2	Head upstream of S-28 / S-29 is greater than 2.75 ft NGVD29 AND head difference between upstream and downstream of S-28 / S-29 is greater than 0.3 ft	Fully open
3	Head upstream of S-28 / S-29 is greater than 2.25 ft	Unchanged
4	Head upstream of S-28 / S-29 is less than 2.25 ft NGVD29	Close

Table 6.2-2: Control Rules for S-28 and S-29 Pump Station for SLR1

Rule Priority	Condition	Control
1	Head difference between upstream and downstream of S-28 / S-29 is greater than 0.25 ft	Off
2	Head upstream of S-28 / S-29 is greater than 2.75 ft NGVD29 AND head difference between upstream and downstream of S-28 / S-29 is less than 0.25 ft	Pump Station On - Tabulated
3	Head upstream of S-28 / S-29 is greater than 2.25 ft AND head difference between upstream and downstream of S-28 / S-29 is less than 0.25 ft AND Discharge of pump station is currently greater than 0 cfs	Pump Station On - Tabulated
4	Head upstream of S-28 / S-29 is less than 2.25 ft NGVD29	Off

Table 6.2-3: Tabulated Control Points for S-28 and S-29 Pump Station for SLR1

Headwater Elevation (NGVD29)	Discharge (ft3/s)
2.25	350
2.75	350
2.95	350
3.00	700
3.20	700
3.25	1050
3.45	1050
3.50	1550
3.70	1550
3.75	2550

Table 6.2-4: Control Rules for S-28 and S-29 Sluice Gates for SLR2

Rule Priority	Condition	Control
1	Head difference between upstream and downstream of S-28 / S-29 is less than 0.1 ft	Close
2	Head upstream of S-28 / S-29 is greater than 3.75 ft NGVD29 AND head difference between upstream and downstream of S-28 / S-29 is greater than 0.3 ft	Fully open
3	Head upstream of S-28 / S-29 is greater than 3.25 ft	Unchanged
4	Head upstream of S-28 / S-29 is less than 3.25 ft NGVD29	Close

Table 6.2-5: Control Rules for S-28 and S-29 Pump Station for SLR2

Rule Priority	Condition	Control
1	Head difference between upstream and downstream of S-28 / S-29 is greater than 0.25 ft	Off
2	Head upstream of S-28 / S-29 is greater than 3.75 ft NGVD29 AND head difference between upstream and downstream of S-28 / S-29 is less than 0.25 ft	Pump Station On - Tabulated
3	Head upstream of S-28 / S-29 is greater than 3.25 ft AND head difference between upstream and downstream of S-28 / S-29 is less than 0.25 ft AND Discharge of pump station is currently greater than 0 cfs	Pump Station On - Tabulated
4	Head upstream of S-28 / S-29 is less than 3.25 ft NGVD29	Off

Table 6.2-6: Tabulated Control Points for S-28 and S-29 Pump Station for SLR2

Headwater Elevation (NGVD29)	Discharge (ft3/s)
3.25	350
3.75	350
3.95	350
4.00	1050
4.15	1050
4.20	2050
4.35	2050
4.40	2550

Table 6.2-7: Control Rules for S-28 and S-29 Sluice Gates for SLR3

Rule Priority	Condition	Control
1	Head difference between upstream and downstream of S-28 / S-29 is less than 0.1 ft	Close
2	Head upstream of S-28 / S-29 is greater than 4.75 ft NGVD29 AND head difference between upstream and downstream of S-28 / S-29 is greater than 0.3 ft	Fully open
3	Head upstream of S-28 / S-29 is greater than 4.25 ft	Unchanged
4	Head upstream of S-28 / S-29 is less than 4.25 ft NGVD29	Close

Table 6.2-8: Control Rules for S-28 and S-29 Pump Station for SLR3

Rule Priority	Condition	Control
1	Head difference between upstream and downstream of S-28 / S-29 is greater than 0.25 ft	Off
2	Head upstream of S-28 / S-29 is greater than 4.75 ft NGVD29 AND head difference between upstream and downstream of S-28 / S-29 is less than 0.25 ft	Pump Station On - Tabulated
3	Head upstream of S-28 / S-29 is greater than 4.25 ft AND head difference between upstream and downstream of S-28 / S-29 is less than 0.25 ft AND Discharge of pump station is currently greater than 0 cfs	Pump Station On - Tabulated
4	Head upstream of S-28 / S-29 is less than 4.25 ft NGVD29	Off

Table 6.2-9: Tabulated Control Points for S-28 and S-29 Pump Station for SLR3

Headwater Elevation (NGVD29)	Discharge (ft3/s)
4.25	350
4.75	350
4.95	350
5.00	1050
5.15	1050
5.20	2050
5.35	2050
5.40	2550

6.3 Mitigation M2C

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 described in detail in **Section 6**, as these two elements also apply to Mitigation M2A and M2B. The third element is described in detail in **Section 6.2** as this element is the same as Mitigation M2B. For Mitigation M2C, the forward pump station has a maximum capacity of 3,550 cfs. 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 by Taylor Engineering, 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 (refer to **Figure 6.1-1**)
    - S-29: approximately 250 ft length for the north bank and 425 ft length for south bank (refer to **Figure 6.1-2**)
- 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 3.2-2** and **Figure 3.2-3** 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 6.3-1**)
        - C-8 Canal widened along approximately 20,000 ft by a width of 100 ft from Interstate 95 to Structure S-28
        - C-9 Canal widened along approximately 79,000 ft by an average of approximately 75 ft, from the west side of the South Broward Drainage District to Interstate 95.
    - raised bank elevations to elevation 7.5 ft NGVD29 anywhere 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 C8 and C9 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 M2B scenario

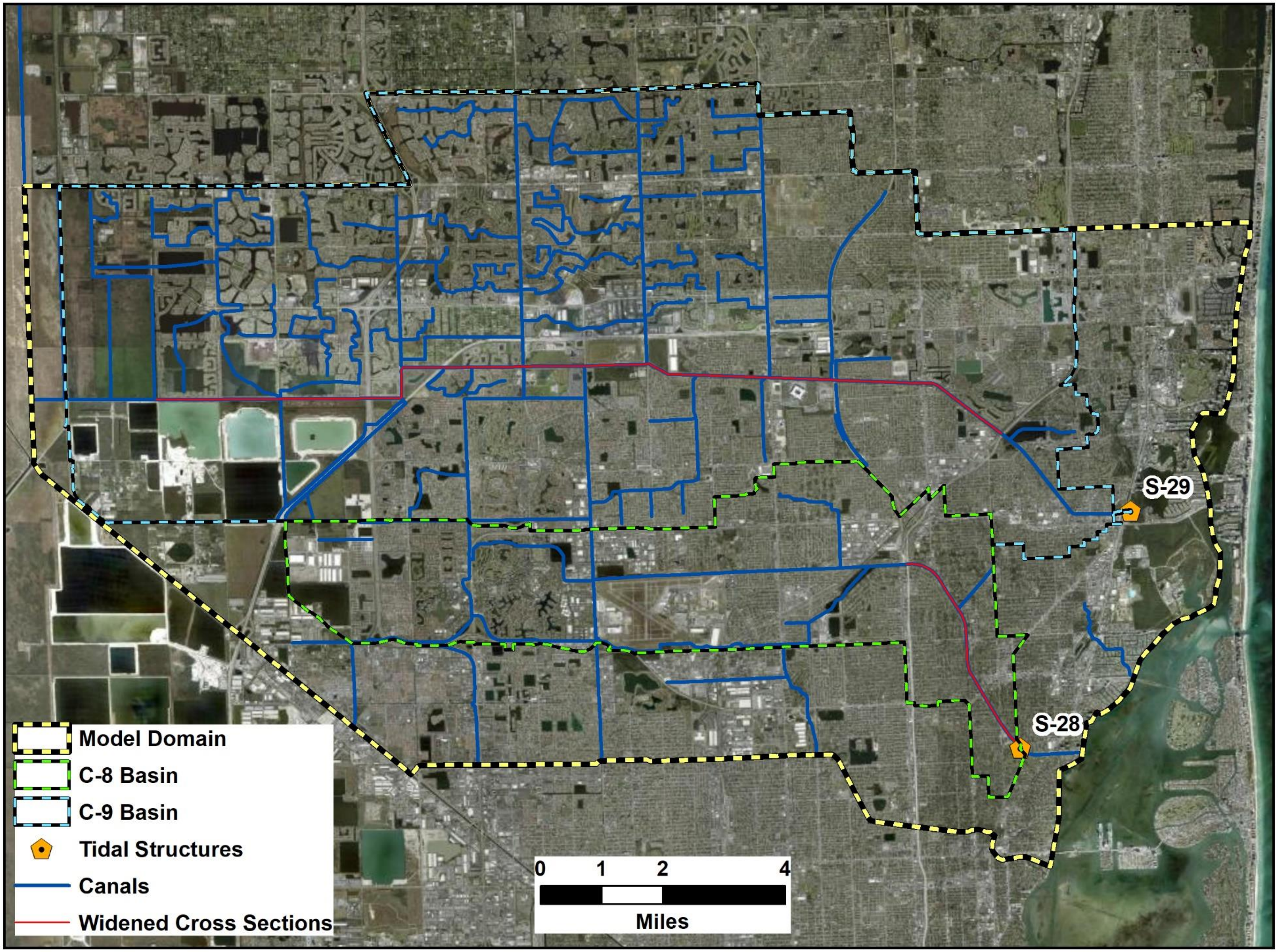


Figure 6.3-1: Location of Canal Segment with Widened Cross Sections

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 ownage 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. It is important to note that this was not independently tested and there were multiple changes made during iteration testing, so this is strictly based on opinion. Essentially, it is believed that the increase in conveyance capacity of the C-9 Canal not only benefits portions of the C-9 Watershed, but also parts of the C-8 Watershed, particularly those in close proximity to the basin-interconnects.

For both the C-8 and C-9 Canal, 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 Canal 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.

Table 6.3-1 through **Table 6.3-9** detail the control rules for the S-28 and S-29 sluice gates and pump stations. Both S-28 and S-29 have the same operating criteria and rules under Mitigation M2C and change with respect to sea level rise. As sea level rise increases, the open/close and on/off elevations of the gates and pumps also increase to represent the assumed change in antecedent water levels (control elevations), largely for the purposes of protecting against saltwater intrusion. Additionally, as sea level rise increases, the stage/discharge relationship of the pump station changes, becoming increasingly more aggressive in the sense that they ramp up to full capacity with less total change in headwater elevation, or have larger increases in discharge earlier on in the ramp-up schedule. Under SLR1, the S-28 and S-29 headwater is required to raise by 1.0 ft before being at full capacity, whereas under SLR2 and SLR3 the headwater is required to raise by 0.65 ft. Under SLR1, the pump station first turns on with a capacity of 350 cfs and then increases another 350 cfs after an additional 0.25 ft of headwater increase, whereas under SLR2 and SLR3, the pump station first turns on with a capacity of 350 cfs and 700 cfs and then increases by another 700 cfs and 850 cfs, respectively. Essentially, as sea level rises, the pump discharge increases by larger amounts for a given increase in headwater.

For the S-28 and S-29 pump station, there are two different pump-on rules. The first pump-on rule establishes how and when the pump can turn on for the first time and the second rule establishes how and when it can pump before turning off. Using SLR3 as an example, the first pump-on rule states that the headwater upstream of the structure must be greater than 4.75 ft NGVD29 AND the head difference between upstream and downstream of the structure is less than 0.25 ft. The first part of this rule establishes that the headwater must be greater than the water control elevation of 4.75 ft NGVD29 before being allowed to start pumping. The second part of this rule ensures that the pump is only active when the gravity structure is unable to discharge due to its operating constraints. The second pump-on rule states that the headwater upstream of the structure must be greater than 4.25 ft NGVD29 AND the head difference between upstream and downstream of the structure is less than 0.25 ft AND the discharge through the pump station is greater than 0 cfs. The rule establishes that the pump can discharge down to a headwater level of 4.25 ft NGVD29, but ONLY if the pump is already on. Essentially, the pump station must first reach its designated control elevation of 4.75 ft NGVD29 before turning on, at which point it is allowed to draw down the canal 0.5 ft to an elevation of 4.25 ft. Together, the two pump-on rules would accomplish the following:

- prevent the pump station from turning on and off repeatedly at the control elevation,
- prevents it from pumping while at an elevation lower than the control elevation unless the water level has already reached control and is being drawn down,
- ensures it stops pumping after the maximum allowed drawdown has been reached, and
- ensures the pump station turns off whenever the established minimum head differential has been reached that allows the sluice gates to operate.

It is important to note that the operational rules for the pump station assumes that there are no elevated tailwater constraints which may be placed by the District to protect downstream property, if needed.

Table 6.3-1: Control Rules for S-28 and S-29 Sluice Gates for SLR1

Rule Priority	Condition	Control
1	Head difference between upstream and downstream of S-28 / S-29 is less than 0.1 ft	Close
2	Head upstream of S-28 / S-29 is greater than 2.75 ft NGVD29 AND head difference between upstream and downstream of S-28 / S-29 is greater than 0.3 ft	Fully open
3	Head upstream of S-28 / S-29 is greater than 2.25 ft	Unchanged
4	Head upstream of S-28 / S-29 is less than 2.25 ft NGVD29	Close

Table 6.3-2: Control Rules for S-28 and S-29 Pump Station for SLR1

Rule Priority	Condition	Control
1	Head difference between upstream and downstream of S-28 / S-29 is greater than 0.25 ft	Off
2	Head upstream of S-28 / S-29 is greater than 2.75 ft NGVD29 AND head difference between upstream and downstream of S-28 / S-29 is less than 0.25 ft	Pump Station On - Tabulated
3	Head upstream of S-28 / S-29 is greater than 2.25 ft AND head difference between upstream and downstream of S-28 / S-29 is less than 0.25 ft AND Discharge of pump station is currently greater than 0 cfs	Pump Station On - Tabulated
4	Head upstream of S-28 / S-29 is less than 2.25 ft NGVD29	Off

Table 6.3-3: Tabulated Control Points for S-28 and S-29 Pump Station for SLR1

Headwater Elevation (NGVD29)	Discharge (ft3/s)
2.25	350
2.75	350
2.95	350
3.00	700
3.20	700
3.25	1550
3.45	1550
3.50	2550
3.70	2550
3.75	3550

Table 6.3-4: Control Rules for S-28 and S-29 Sluice Gates for SLR2

Rule Priority	Condition	Control
1	Head difference between upstream and downstream of S-28 / S-29 is less than 0.1 ft	Close
2	Head upstream of S-28 / S-29 is greater than 3.75 ft NGVD29 AND head difference between upstream and downstream of S-28 / S-29 is greater than 0.3 ft	Fully open
3	Head upstream of S-28 / S-29 is greater than 3.25 ft	Unchanged
4	Head upstream of S-28 / S-29 is less than 3.25 ft NGVD29	Close

Table 6.3-5: Control Rules for S-28 and S-29 Pump Station for SLR2

Rule Priority	Condition	Control
1	Head difference between upstream and downstream of S-28 / S-29 is greater than 0.25 ft	Off
2	Head upstream of S-28 / S-29 is greater than 3.75 ft NGVD29 AND head difference between upstream and downstream of S-28 / S-29 is less than 0.25 ft	Pump Station On - Tabulated
3	Head upstream of S-28 / S-29 is greater than 3.25 ft AND head difference between upstream and downstream of S-28 / S-29 is less than 0.25 ft AND Discharge of pump station is currently greater than 0 cfs	Pump Station On - Tabulated
4	Head upstream of S-28 / S-29 is less than 3.25 ft NGVD29	Off

Table 6.3-6: Tabulated Control Points for S-28 and S-29 Pump Station for SLR2

Headwater Elevation (NGVD29)	Discharge (ft3/s)
3.25	350
3.75	350
3.95	350
4.00	1050
4.15	1050
4.20	2050
4.35	2050
4.40	3550

Table 6.3-7: Control Rules for S-28 and S-29 Sluice Gates for SLR3

Rule Priority	Condition	Control
1	Head difference between upstream and downstream of S-28 / S-29 is less than 0.1 ft	Close
2	Head upstream of S-28 / S-29 is greater than 4.75 ft NGVD29 AND head difference between upstream and downstream of S-28 / S-29 is greater than 0.3 ft	Fully open
3	Head upstream of S-28 / S-29 is greater than 4.25 ft	Unchanged
4	Head upstream of S-28 / S-29 is less than 4.25 ft NGVD29	Close

Table 6.3-8: Control Rules for S-28 and S-29 Pump Station for SLR3

Rule Priority	Condition	Control
1	Head difference between upstream and downstream of S-28 / S-29 is greater than 0.25 ft	Off
2	Head upstream of S-28 / S-29 is greater than 4.75 ft NGVD29 AND head difference between upstream and downstream of S-28 / S-29 is less than 0.25 ft	Pump Station On - Tabulated
3	Head upstream of S-28 / S-29 is greater than 4.25 ft AND head difference between upstream and downstream of S-28 / S-29 is less than 0.25 ft AND Discharge of pump station is currently greater than 0 cfs	Pump Station On - Tabulated
4	Head upstream of S-28 / S-29 is less than 4.25 ft NGVD29	Off

Table 6.3-9: Tabulated Control Points for S-28 and S-29 Pump Station for SLR3

Headwater Elevation (NGVD29)	Discharge (ft3/s)
4.25	700
4.75	700
4.95	700
5.00	1550
5.15	1550
5.20	2550
5.35	2550
5.40	3550

7 FLOOD PROTECTION LEVEL OF SERVICE ASSESSMENT – FUTURE CONDITIONS WITH MITIGATION

7.1 C-8 Watershed Flood Protection Level of Service – Future Conditions with Mitigation

The Phase 1 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 Watershed (**Figure 7.1-1**) in the Phase 1 FPLOS Assessment describes 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 2 FPLOS Assessment, a level of service rating is not assigned, as the overall level of service watershed-wide remains largely unchanged. Therefore, instead of pointing out similar deficiencies of the system, this Phase 2 Assessment identifies improvements and compares the different mitigation strategies against each other and against both existing conditions and future conditions without mitigation.

7.1.1 PM #1 – Maximum Stage in Primary Canal (NGVD29 to NAVD88 Conversion = -1.57 ft)

Section 7.1.1.1 through **Section 7.1.1.3** discusses the PM #1 results for Mitigation Scenarios M2A, M2B, and M2C, respectively. Within each section, four figures are presented that compare the respective mitigation strategy across three sea level rise scenarios with existing conditions (M0 / SLR0) and future conditions without mitigation (M0 / SLR1 / SLR2 / SLR3) for each rainfall return frequency. These figures capture how the maximum water surface profile in the C-8 Canal changes from existing conditions with no sea level rise to future condition sea level rise without mitigation and compares that with the maximum water surface profile under future condition sea level rise with mitigation. **Section 7.1.1.4** presents an alternative assessment by comparing existing condition without sea level rise and future condition sea level rise without mitigation to each of the three mitigation strategies, for each of the twelve different combinations of rainfall return frequency and sea level rise.

7.1.1.1 PM #1 – Mitigation Scenario M2A

The C-8 Canal was assigned a 5-year PM #1 LOS rating for SLR1 and a less-than 5-year LOS rating for SLR2, and SLR3 in the Phase 1 study, due to multiple instances of out of bank exceedance. However, under Mitigation M2A, these bank exceedances were reduced to a level nearly equal to or in some cases lower than current conditions, which was the goal. Due to low bank elevations in several locations along the C-8 Canal, it was known that it would not be possible to increase the level of service "rating", however, the team believed that the Mitigation M2A projects could reduce the predicted flood elevations under sea level rise, which is an improvement to the overall level of service provided by the watershed infrastructure. Under Mitigation Scenario M2A, the improvements are predicted to lower the maximum canal profile across all sea level rise scenarios. Essentially, this mitigation scenario reduces the maximum water surface profile as if it was removing one foot of sea level rise. What that means is, the simulated maximum water surface profile for a 25-year sea level rise 3 event with Mitigation M2A is lower than the 25-year sea level rise 2 event without mitigation. Similarly, the simulated maximum water surface profile for the 5-year sea level rise 2 event with Mitigation M2A is lower than the 5-year sea level rise 1 event without mitigation. This trend is common across most combinations of rainfall and sea level rise scenarios. However, perhaps more importantly, the 25-year SLR1 maximum water surface profile is nearly equal to or below current conditions (SLR0), as are the 5-year and 10-year SLR1 scenarios. Although there are still level of service deficiencies at the corresponding maximum water levels associated with the 25-year SLR0 scenario, getting back down to this condition under sea level rise 1 is an overall improvement compared to no mitigation activities. **Figure 7.1-2** through **Figure 7.1-5** present the C-8 Canal's simulated maximum water levels for Mitigation M2A compared to no mitigation for each rainfall and sea level rise scenario.

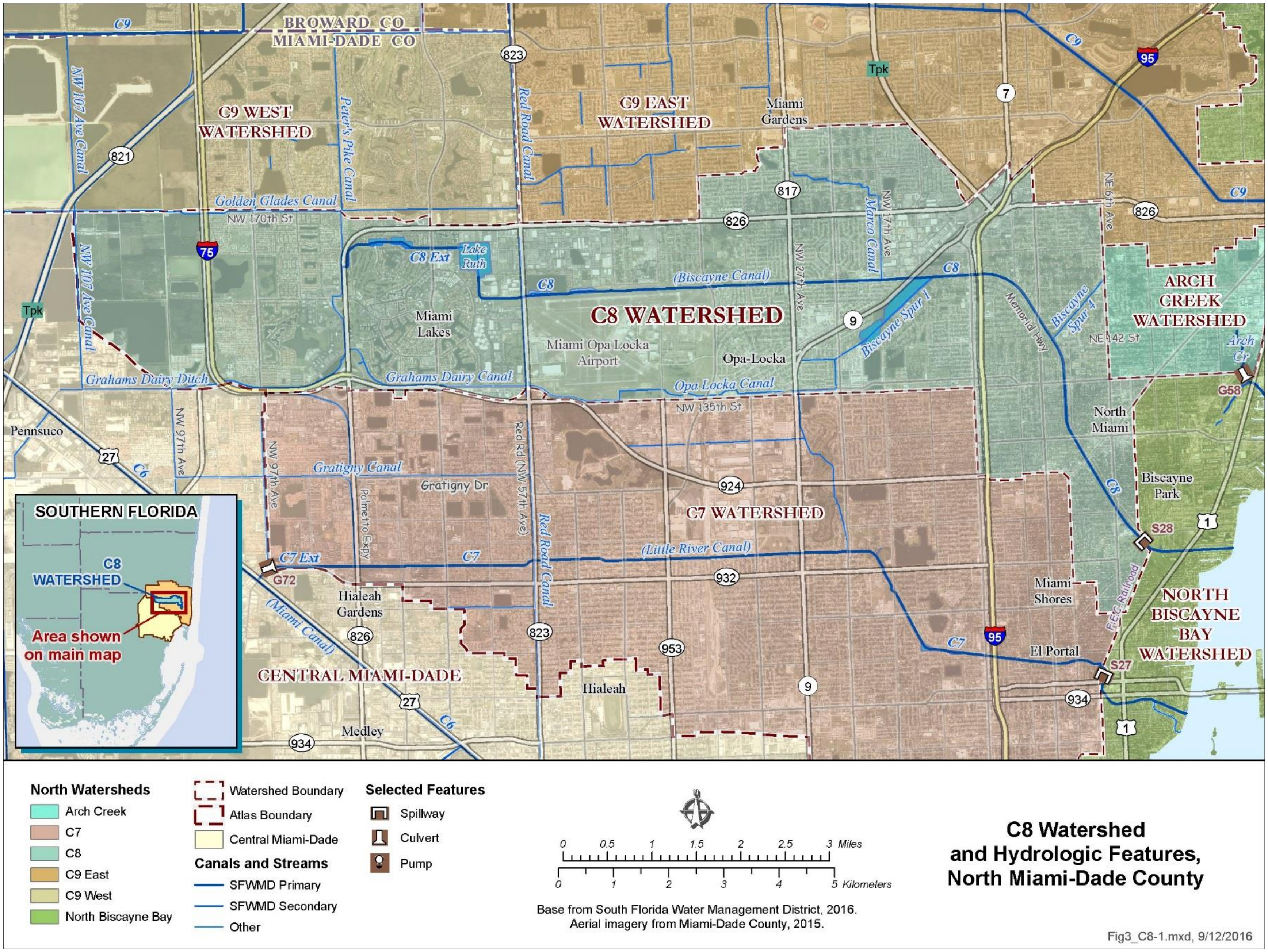


Figure 7.1-1: Map of C-8 Watershed (Figure by SFWMD)

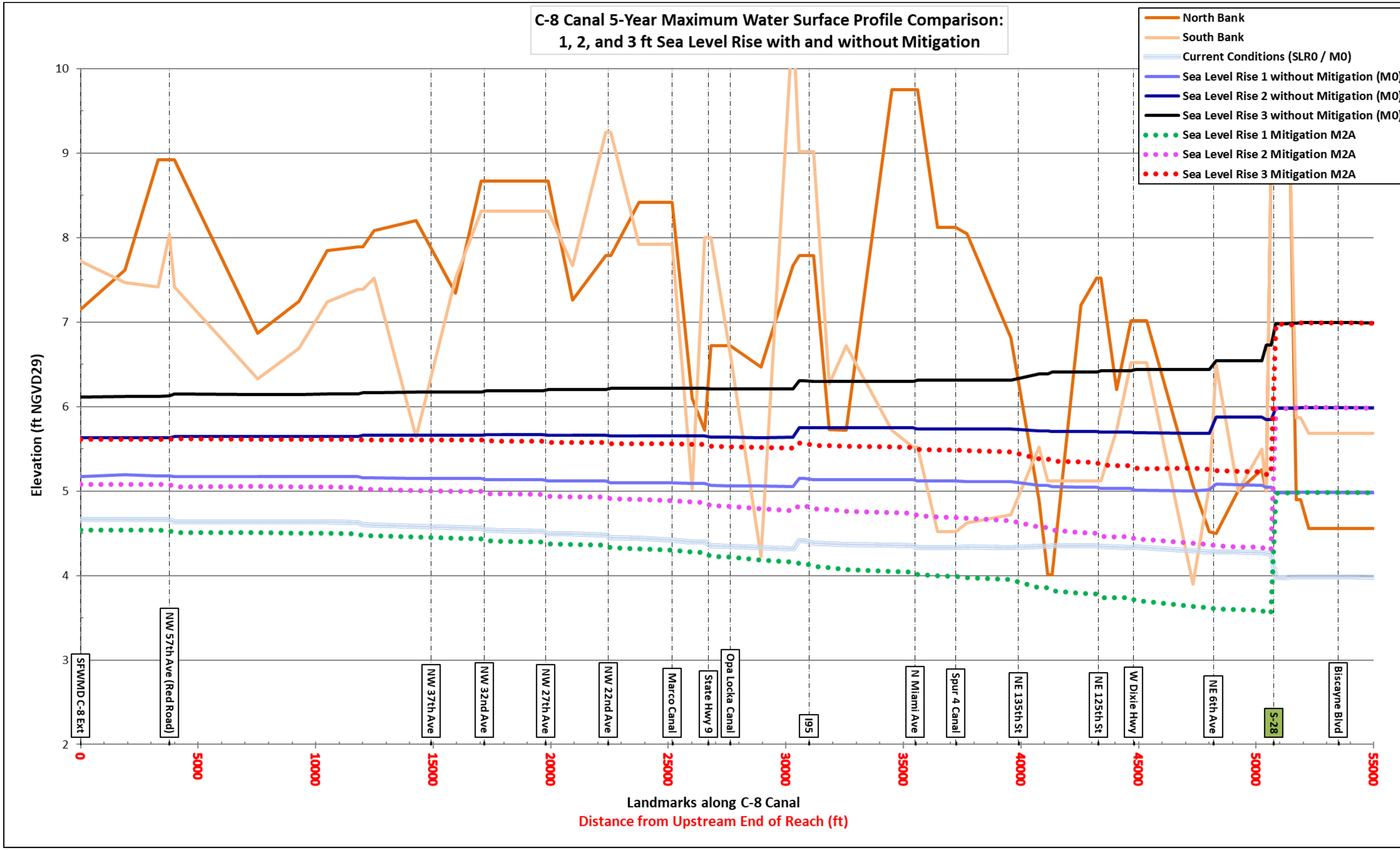


Figure 7.1-2: C-8 Canal Peak Stage Profiles for 5-Year Design Storm with and without Mitigation Scenario M2A – Current vs Future Sea Level Rise Scenarios

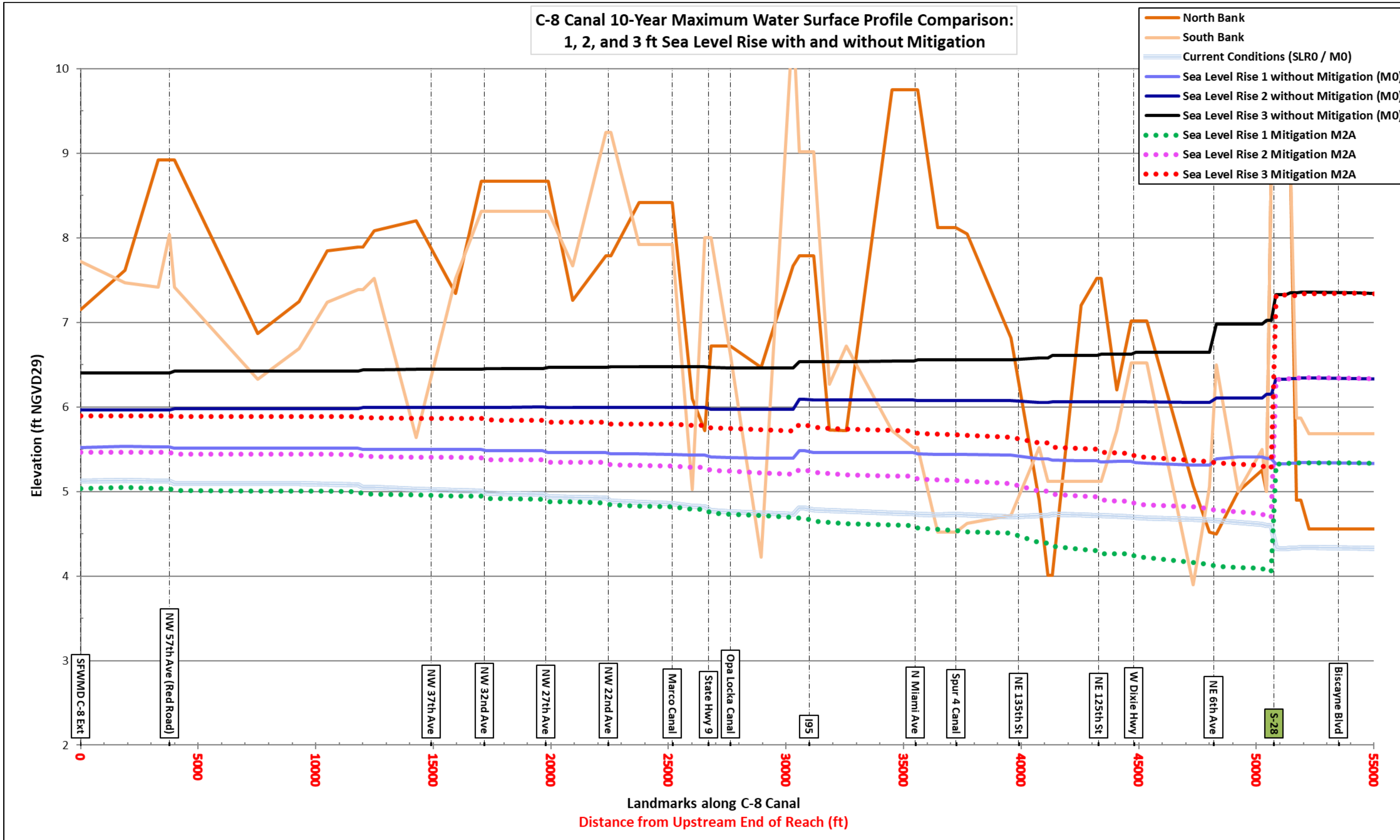


Figure 7.1-3: C-8 Canal Peak Stage Profiles for 10-Year Design Storm with and without Mitigation Scenario M2A – Current vs Future Sea Level Rise Scenarios

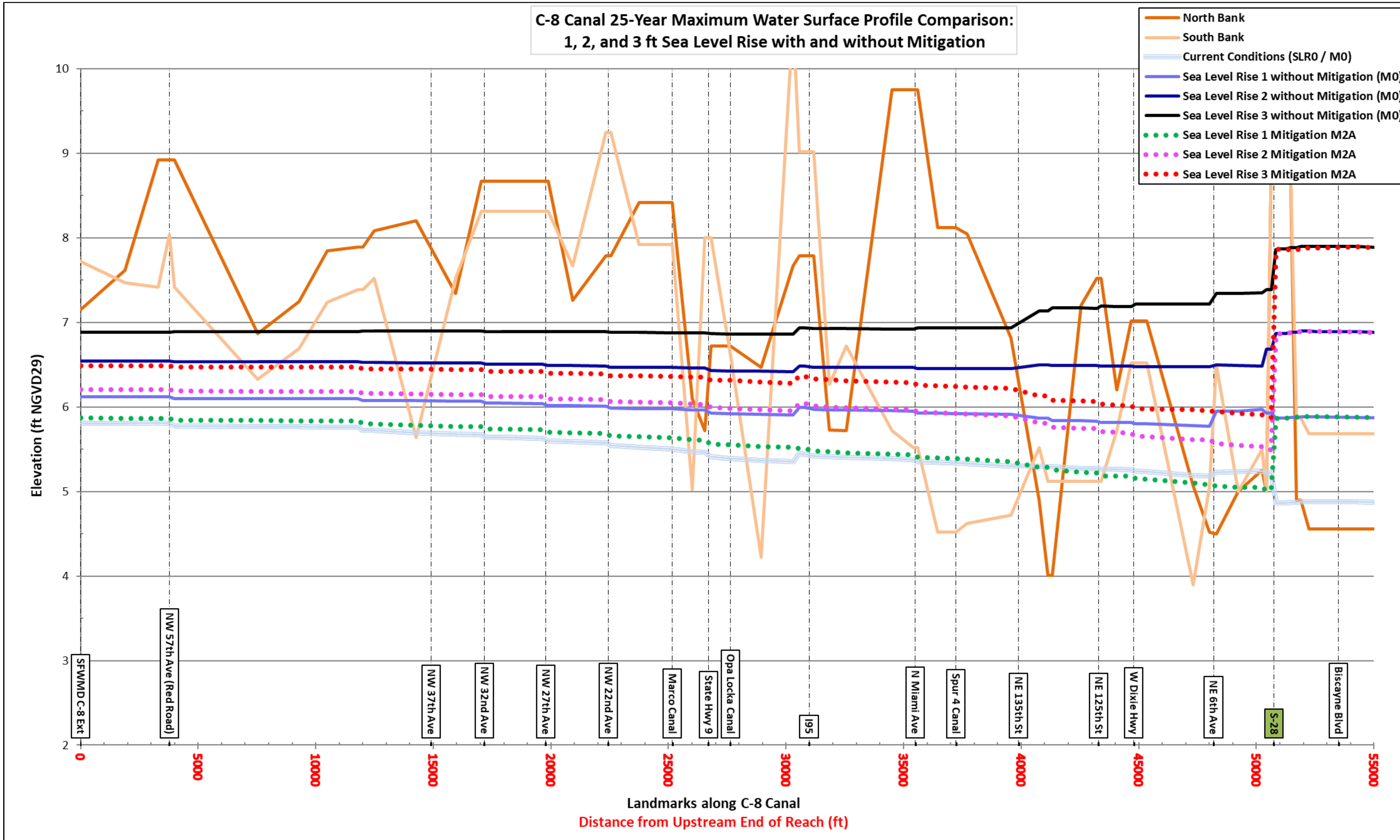


Figure 7.1-4: C-8 Canal Peak Stage Profiles for 25-Year Design Storm with and without Mitigation Scenario M2A – Current vs Future Sea Level Rise Scenarios

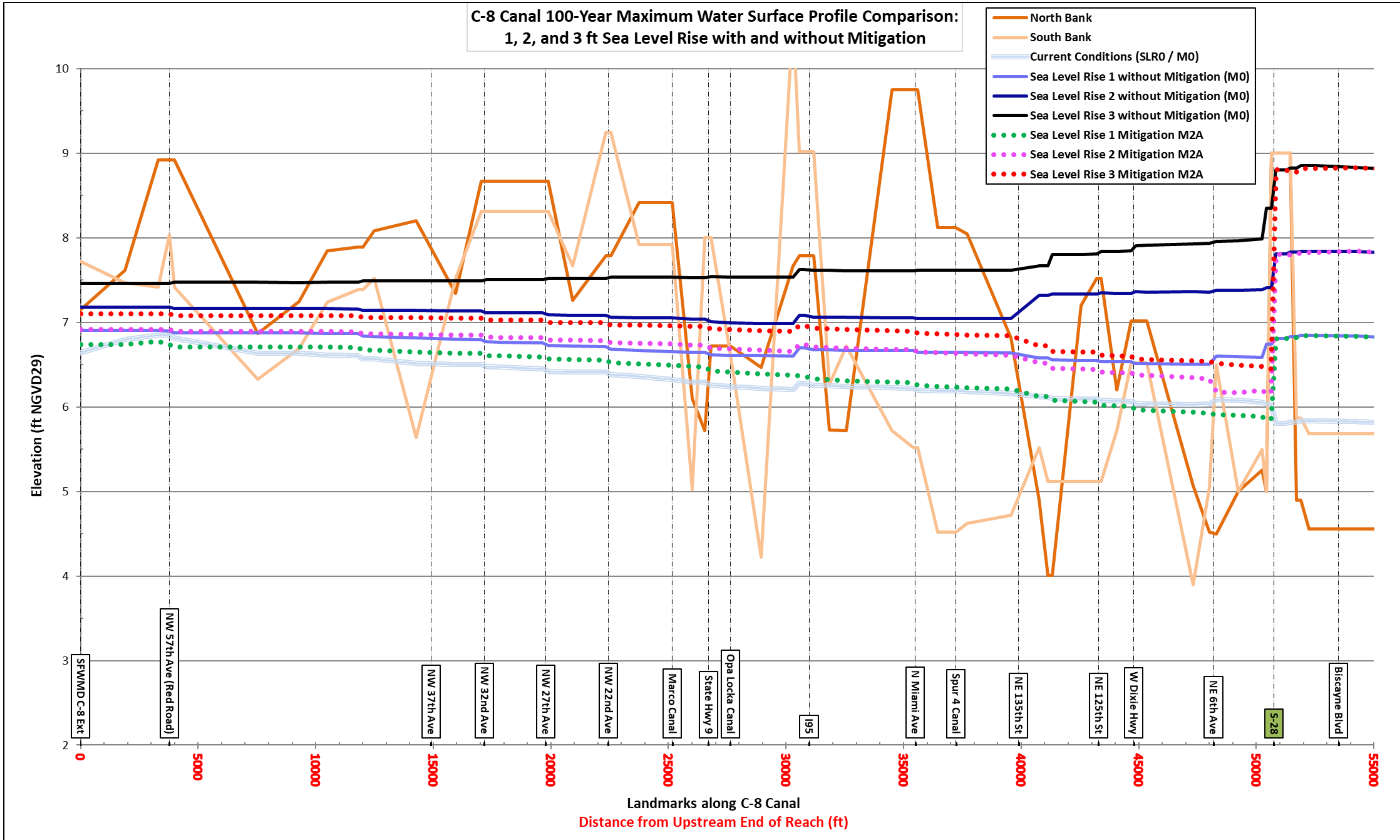


Figure 7.1-5: C-8 Canal Peak Stage Profiles for 100-Year Design Storm with and without Mitigation Scenario M2A – Current vs Future Sea Level Rise Scenarios

7.1.1.2 PM #1 – Mitigation Scenario M2B (NGVD29 to NAVD88 Conversion = -1.57 ft)

Under Mitigation Scenario M2B, the C-8 Canal has a 100-year PM #1 LOS rating for SLR1, SLR2, and SLR3 due to a critical component of the Mitigation M2B project, which includes raising the canal embankments to an elevation of 7.5 ft NGVD29. Although Mitigation Scenario M2B has an additional 1,000 cfs pumping capacity compared to Mitigation M2A, it is important to note that this improvement alone was not enough to keep the C-8 Canal in bank. With this being the case, one may ask why even add additional pumping capacity if the banks are raised under this mitigation strategy and the additional pump capacity alone doesn't keep the C-8 Canal within bank. The reason for this is that the maximum water surface profile, whether completely contained within bank or not, still plays an important role on flooding within the C-8 Watershed, especially since the C-8 Canal has relatively low topography and relies on gravity-driven drainage from the secondary/tertiary systems. As the goal of Mitigation Scenario M2B was to achieve a 25-year current conditions maximum stage profile or better under Sea Level Rise 2, the additional 1,000 cfs pumping capacity along with some tuning adjustments to the operational controls was crucial in lowering the maximum C-8 Canal stage to the minimum desired level.

Although the C-8 Canal has a 100-year PM #1 LOS rating for SLR1, SLR2, and SLR3 under Mitigation Scenario M2B and there is a significant reduction in flooding compared to future sea level rise conditions without mitigation, the C-8 Watershed still has a low overall flood protection level of service. Elevated stages in the C-8 Canal reduce the drainage efficiency of the secondary/tertiary systems which lead to localized flooding, which is further discussed in PM #5.

Under Mitigation Scenario M2B, the improvements led to a shift in the maximum canal profile across all sea level rise scenarios. Essentially, this mitigation scenario reduces the maximum water surface profile as if it was removing at least one foot of sea level rise. What that means is, the maximum surface profile for a 25-year sea level rise 3 event with Mitigation M2B is lower than the 25-year sea level rise 2 event without mitigation. Similarly, the maximum surface profile for the 5-year sea level rise 2 event with Mitigation M2B is lower than the 5-year sea level rise 1 event without mitigation. This trend is common across most combinations of rainfall and sea level rise scenarios. The goal for Mitigation Scenario M2B was to reduce the 25-year SLR2 maximum canal stage profile to a level equal to or lower than the 25-year existing conditions SLR0 scenario. Although close, as shown in **Figure 7.1-8** Mitigation M2B was unable to reduce the 25-year SLR2 maximum surface profile (pink dotted line) to a level equal to or below the 25-year existing conditions SLR0 profile (light blue solid line). However, when compared to the 25-year SLR2 without mitigation maximum water surface profile (dark blue solid line), the significance of this potential mitigation scenario is shown by the significant reduction in water levels, with reductions ranging from 0.5 ft to 1.9 ft, with an average reduction of 0.92 ft. Although there are still level of service deficiencies at the corresponding maximum water levels associated with the 25-year SLR2 Mitigation M2B scenario, getting the system down to this condition is a significant improvement compared to no mitigation activities. Likewise, when compared with the no-mitigation scenarios, Mitigation M2B shows significant improvement across all rainfall and sea level rise events, as shown in **Figure 7.1-6** through **Figure 7.1-9**.

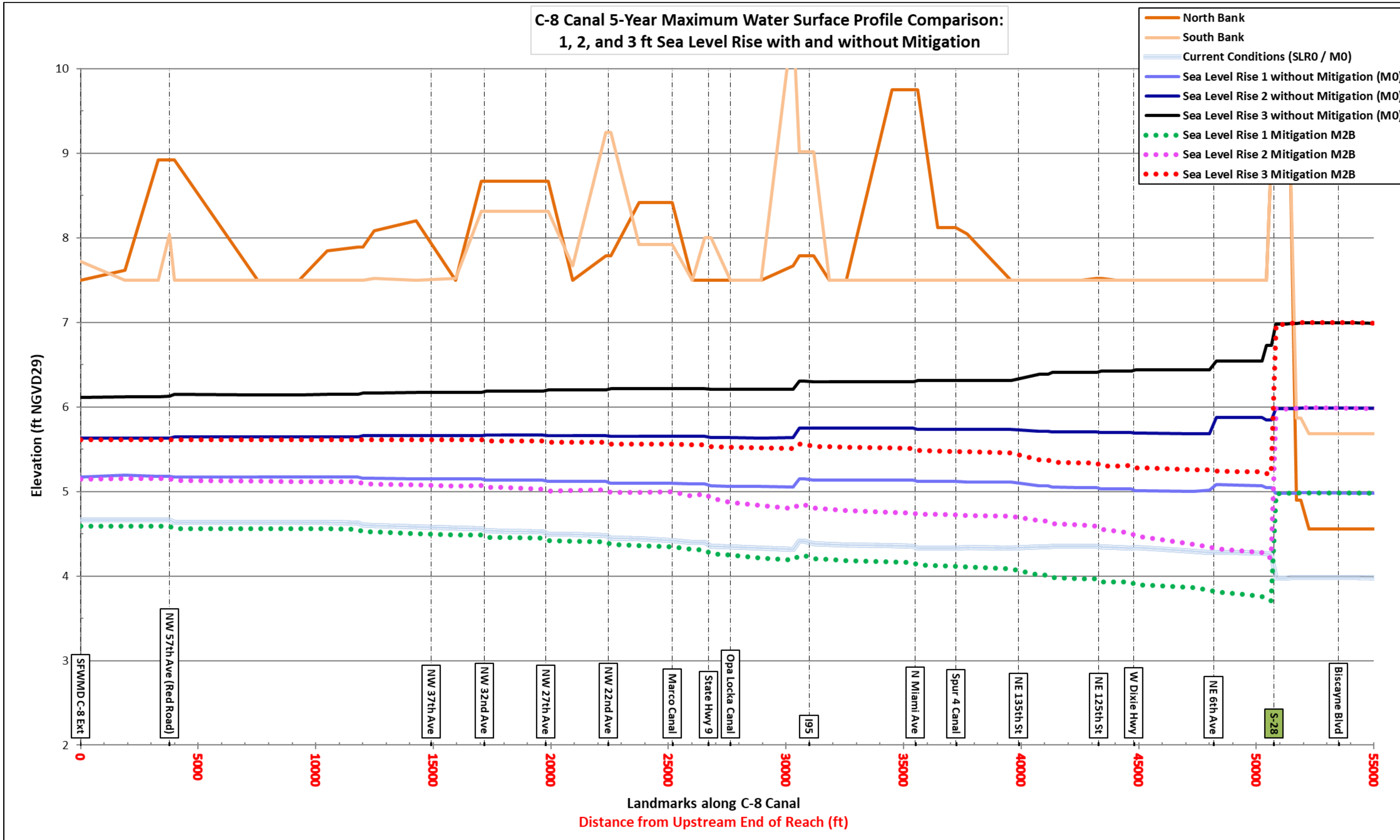


Figure 7.1-6: C-8 Canal Peak Stage Profiles for 5-Year Design Storm with and without Mitigation Scenario M2B – Current vs Future Sea Level Rise Scenarios

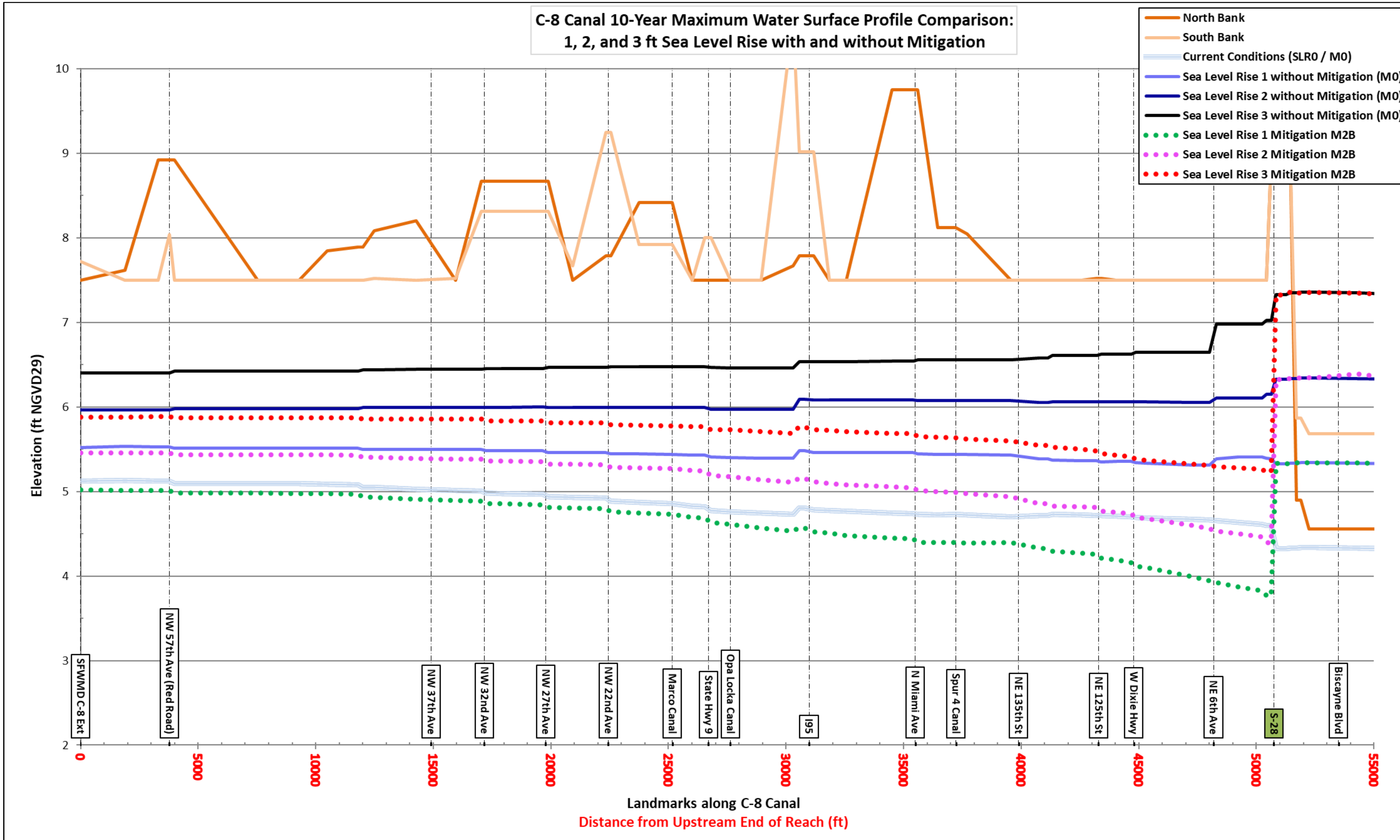


Figure 7.1-7: C-8 Canal Peak Stage Profiles for 10-Year Design Storm with and without Mitigation Scenario M2B – Current vs Future Sea Level Rise Scenarios

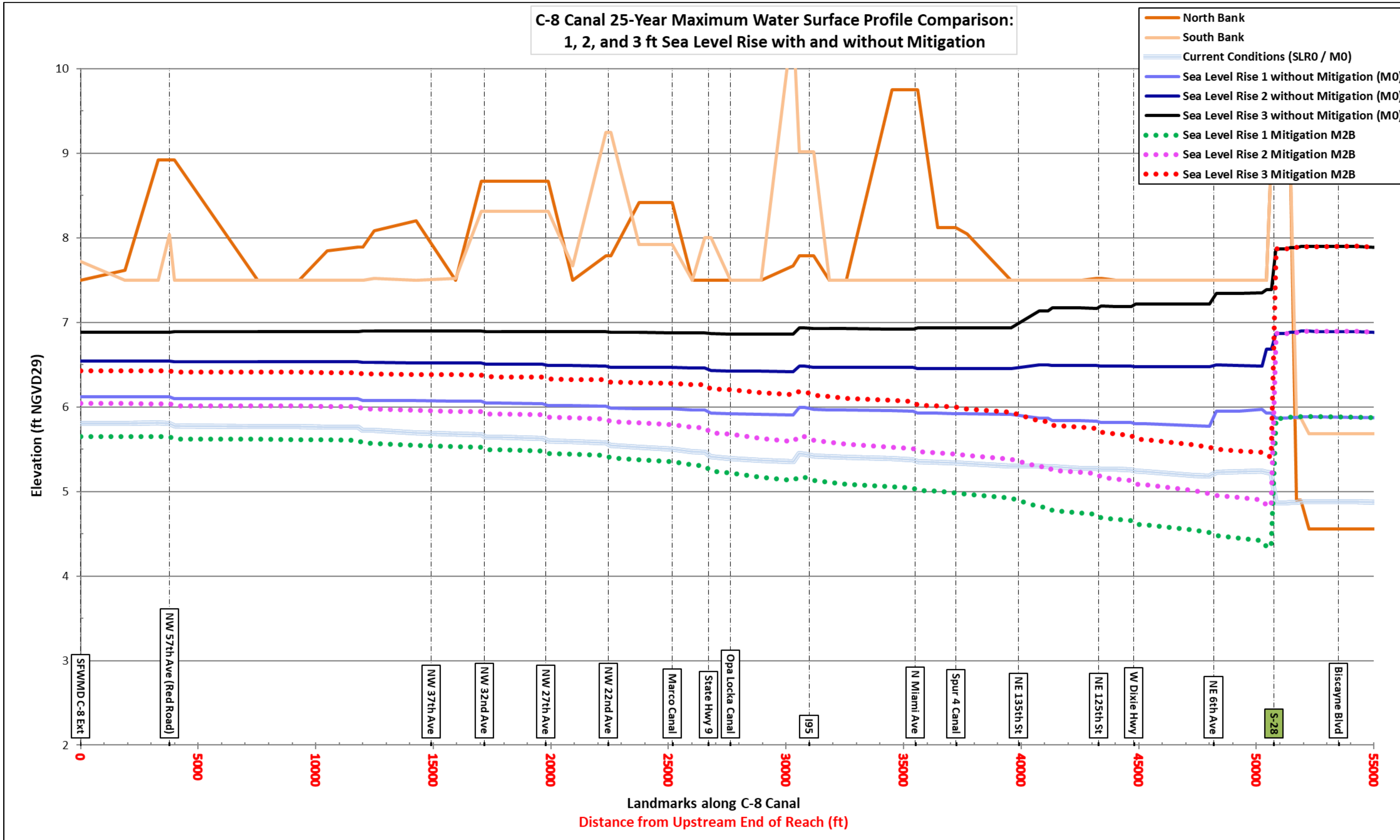


Figure 7.1-8: C-8 Canal Peak Stage Profiles for 25-Year Design Storm with and without Mitigation Scenario M2B – Current vs Future Sea Level Rise Scenarios

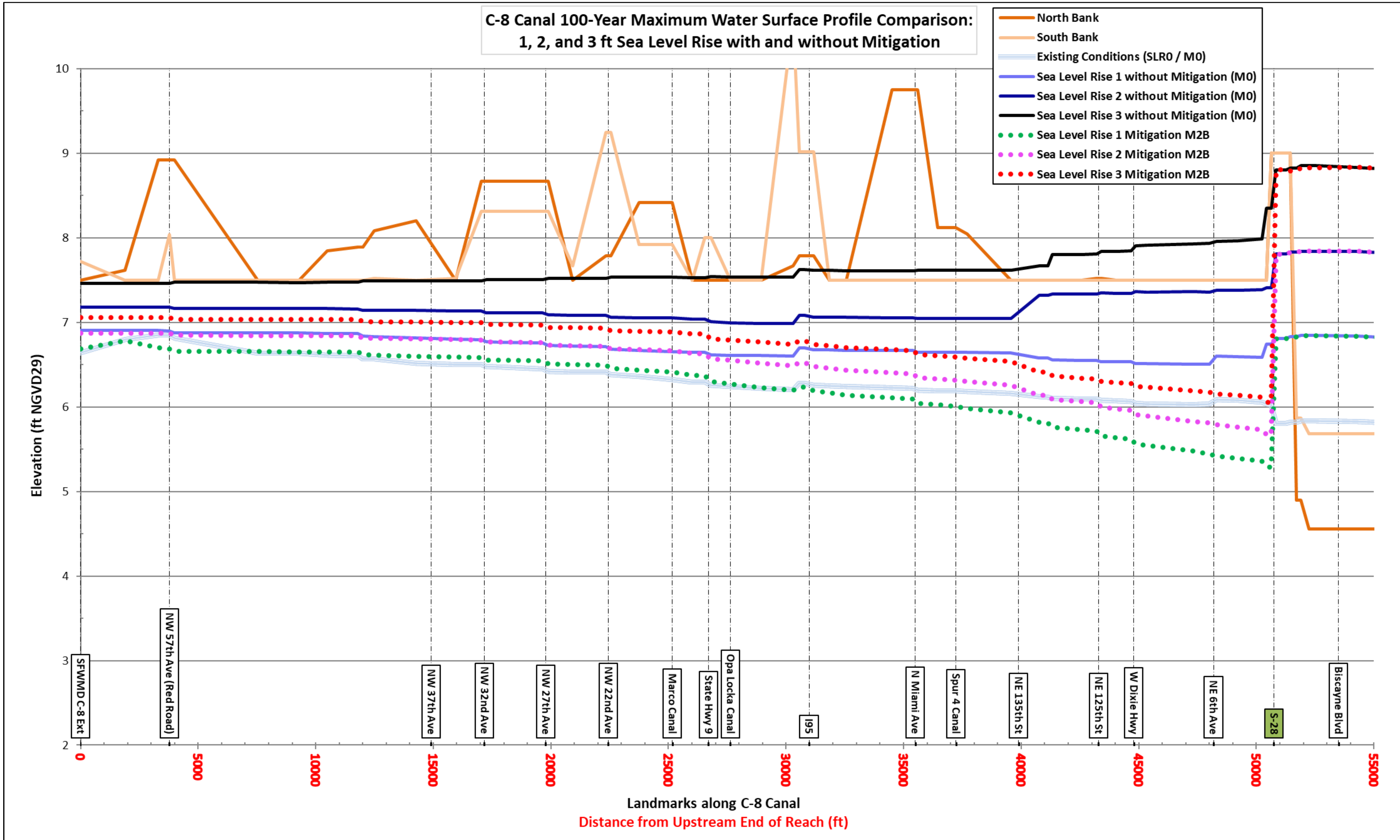


Figure 7.1-9: C-8 Canal Peak Stage Profiles for 100-Year Design Storm with and without Mitigation Scenario M2B – Current vs Future Sea Level Rise Scenarios

7.1.1.3 PM #1 – Mitigation Scenario M2C (NGVD29 to NAVD88 Conversion = -1.57 ft)

Under Mitigation Scenario M2C, the C-8 Canal has a 100-year PM #1 LOS rating for SLR1, SLR2, and SLR3 due to a critical component of both the Mitigation M2B and M2C projects, which includes raising the canal embankments to an elevation of 7.5 ft NGVD29. Mitigation Scenario M2C has an additional 2,000 cfs pumping capacity compared to Mitigation M2A and an additional 1,000 cfs pumping capacity compared to Mitigation M2B. Given that Mitigation Scenario M2B solved the bank exceedance issue by raising the canal banks, the thought of increasing the pump capacity by another 1,000 cfs and widening the canal may seem unnecessary. However, in order to try and achieve a 25-year SLR3 maximum water surface profile equal to or lower than the 25-year current conditions profile, significant changes were required.

When looking at just increasing pumping capacity, there are diminishing returns at the point where the pumping capacity becomes greater than the conveyance capacity of the canal. When that occurs, the localized water levels near the pump are drawn down, but it doesn't extend very far upstream. Therefore, the canal itself becomes the limiting element of the system and not the discharge capacity of the tidal structure. For the C-8 Canal, this point of diminishing returns was very evident with the 2,550 cfs capacity under Mitigation Scenario M2B, where the slope of the instantaneous water surface profile east of Interstate 95 (i95) was sharp and decreased to the point of essentially no slope in the western half of the C-8 Canal. It is important to note that the maximum water levels presented in the maximum surface water profiles do not necessarily occur at the same time; they are the maximum stage at each location regardless of timing. Therefore, the maximum surface profiles do not reflect the instantaneous slope of the canal during peak discharge. By widening the C-8 Canal downstream of i95, significant improvements were achieved in the form of reduced maximum water levels west of i95. To offset the increased water levels in the eastern portion of the C-8 Canal due to the increased conveyance capacity and to try and achieve a 25-year SLR3 maximum water surface profile that was equal to or lower than the 25-year current conditions profile, the pumping capacity was increased by 1,000 cfs for the final total of 3,550 cfs. Again, whether completely contained within bank or not, the water level in the C-8 Canal plays an important role on flooding within the C-8 Watershed, especially since the C-8 Watershed has relatively low topography and relies on gravity-driven drainage from the secondary/tertiary systems. As the goal of Mitigation Scenario M2C was to achieve a 25-year current conditions maximum stage profile or better under Sea Level Rise 3, the additional 1,000 cfs pumping capacity over Mitigation M2B, further tuning adjustments to the operational controls, and increased canal conveyance capacity was crucial in lowering the maximum C-8 Canal stage to the minimum desired level.

Although the C-8 Canal has a 100-year PM #1 LOS rating for SLR1, SLR2, and SLR3 under Mitigation M2C and there is a significant reduction in flooding compared to future sea level rise conditions without mitigation, the C-8 Watershed still would have a low overall flood protection level of service. Elevated stages in the C-8 Canal reduce the drainage efficiency of the secondary/tertiary systems which lead to localized flooding, which is further discussed in PM #5.

Under Mitigation Scenario M2C, the improvements led to a shift in the maximum canal profile across all sea level rise scenarios. Essentially, this mitigation scenario reduces the maximum water surface profile as if it was removing at least one foot of sea level rise and in some instances more than two feet. What that means is, the maximum surface profile for a 25-year sea level rise 3 event with Mitigation M2C is lower than the 25-year sea level rise 1 event without mitigation. Similarly, the maximum surface profile for the 5-year sea level rise 2 event with Mitigation M2C is lower than the 5-year sea level rise 1 event without mitigation. These trends are common across all combinations of rainfall and sea level rise scenarios. The goal for Mitigation Scenario M2C was to reduce the maximum canal stage profile to a level equal to or lower than the 25-year current condition (Mitigation 0) scenario. Although this goal was unable to be achieved as shown in **Figure 7.1-12**, Mitigation M2C was able to reduce the 25-year SLR3 maximum surface profile (red dotted line) to a level between the 25-year current conditions (Mitigation 0) profile (light blue solid line) and the 25-year SLR1 profile (medium blue solid line). When compared with the 25-year SLR3 without mitigation maximum water surface profile (black solid line), the significance of this potential mitigation scenario is shown by the significant reduction, with water level reductions of 0.7 ft to 1.9 ft. Although it is predicted that there will still be level of service deficiencies at the corresponding maximum water levels associated with the 25-year SLR3 Mitigation M2C scenario, getting the system down to this condition is a significant improvement compared to no mitigation activities. Likewise, when compared with the no-mitigation scenario, Mitigation M2C shows significant improvement across all rainfall and sea level rise events, as shown in **Figure 7.1-10** through **Figure 7.1-13**.

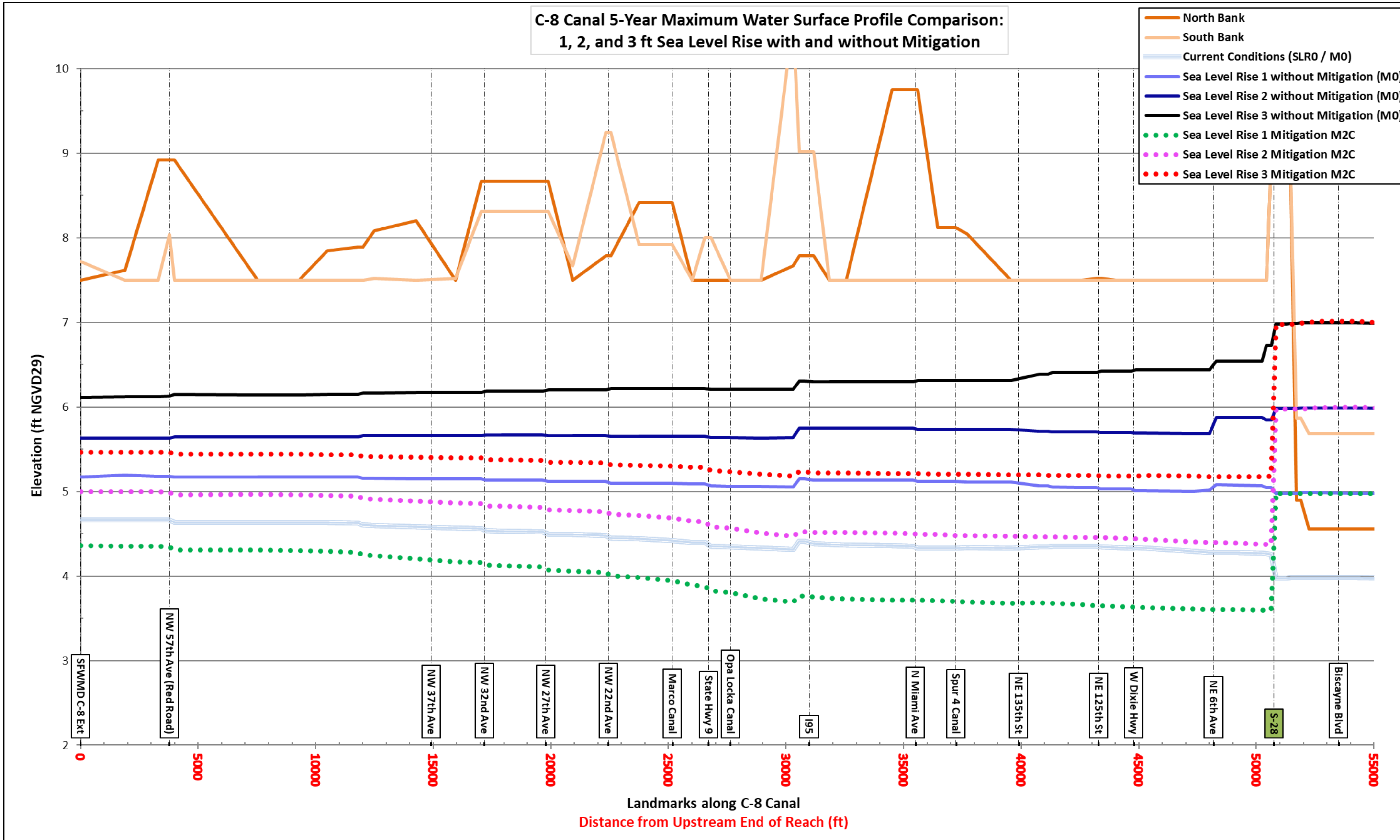


Figure 7.1-10: C-8 Canal Peak Stage Profiles for 5-Year Design Storm with and without Mitigation Scenario M2C – Current vs Future Sea Level Rise Scenarios

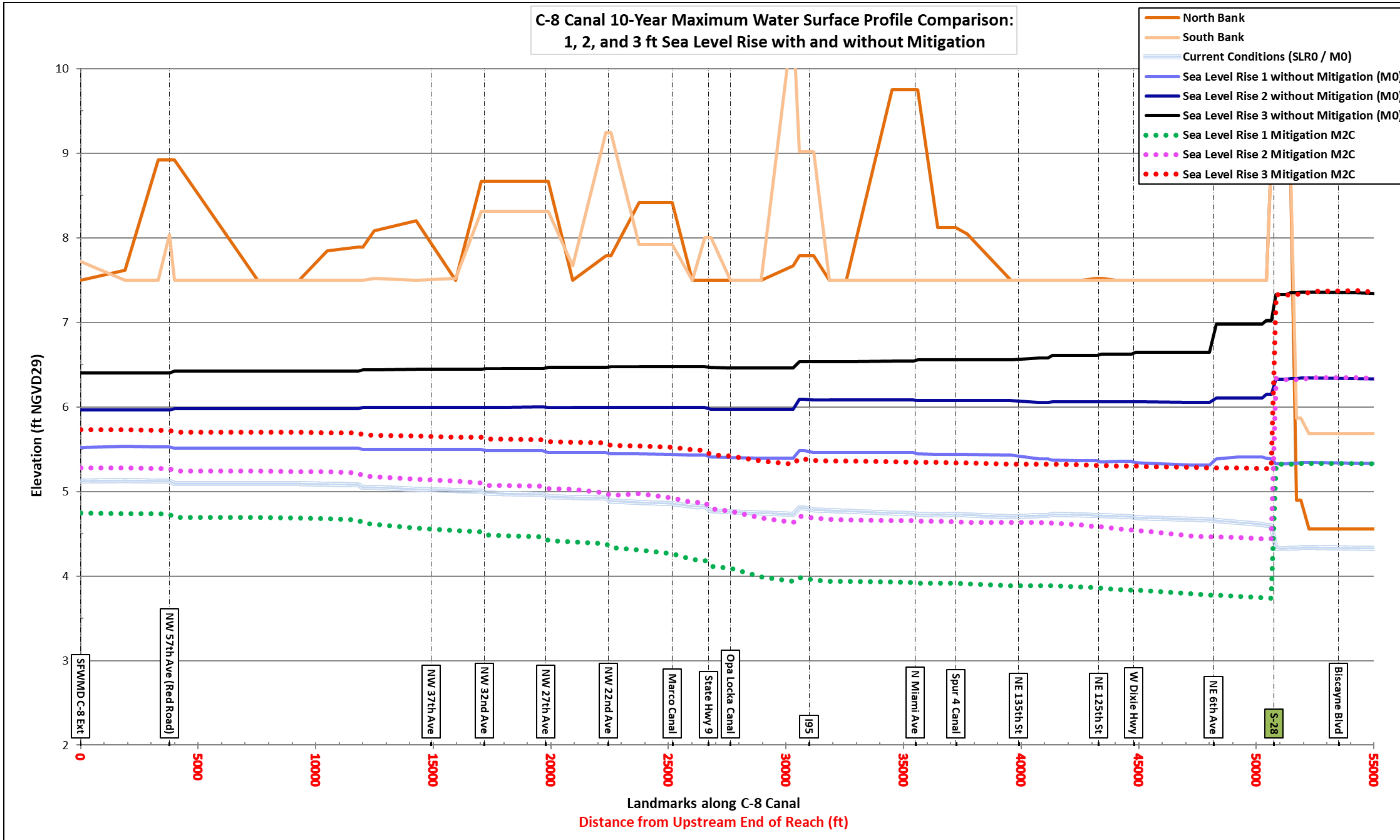


Figure 7.1-11: C-8 Canal Peak Stage Profiles for 10-Year Design Storm with and without Mitigation Scenario M2C – Current vs Future Sea Level Rise Scenarios

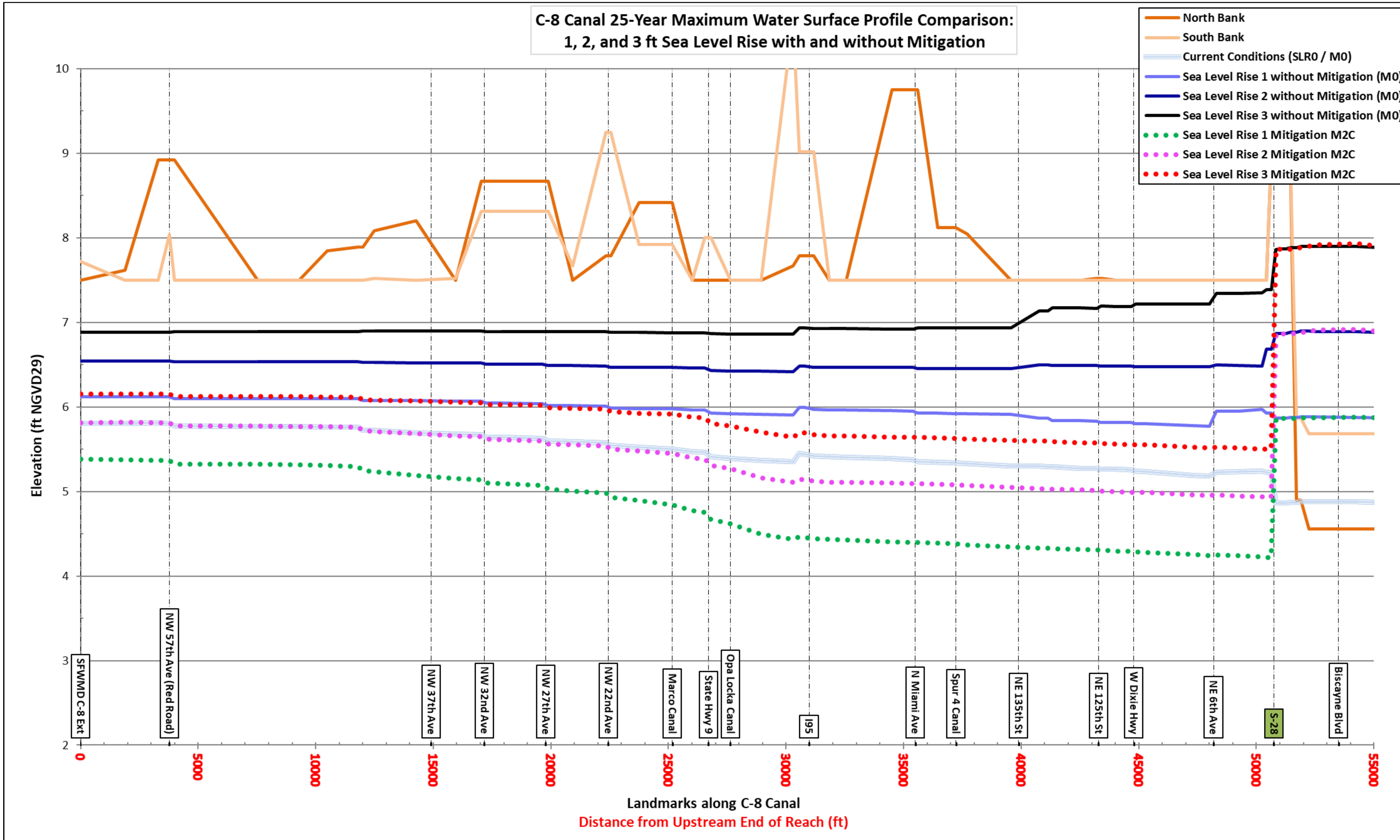


Figure 7.1-12: C-8 Canal Peak Stage Profiles for 25-Year Design Storm with and without Mitigation Scenario M2C – Current vs Future Sea Level Rise Scenarios

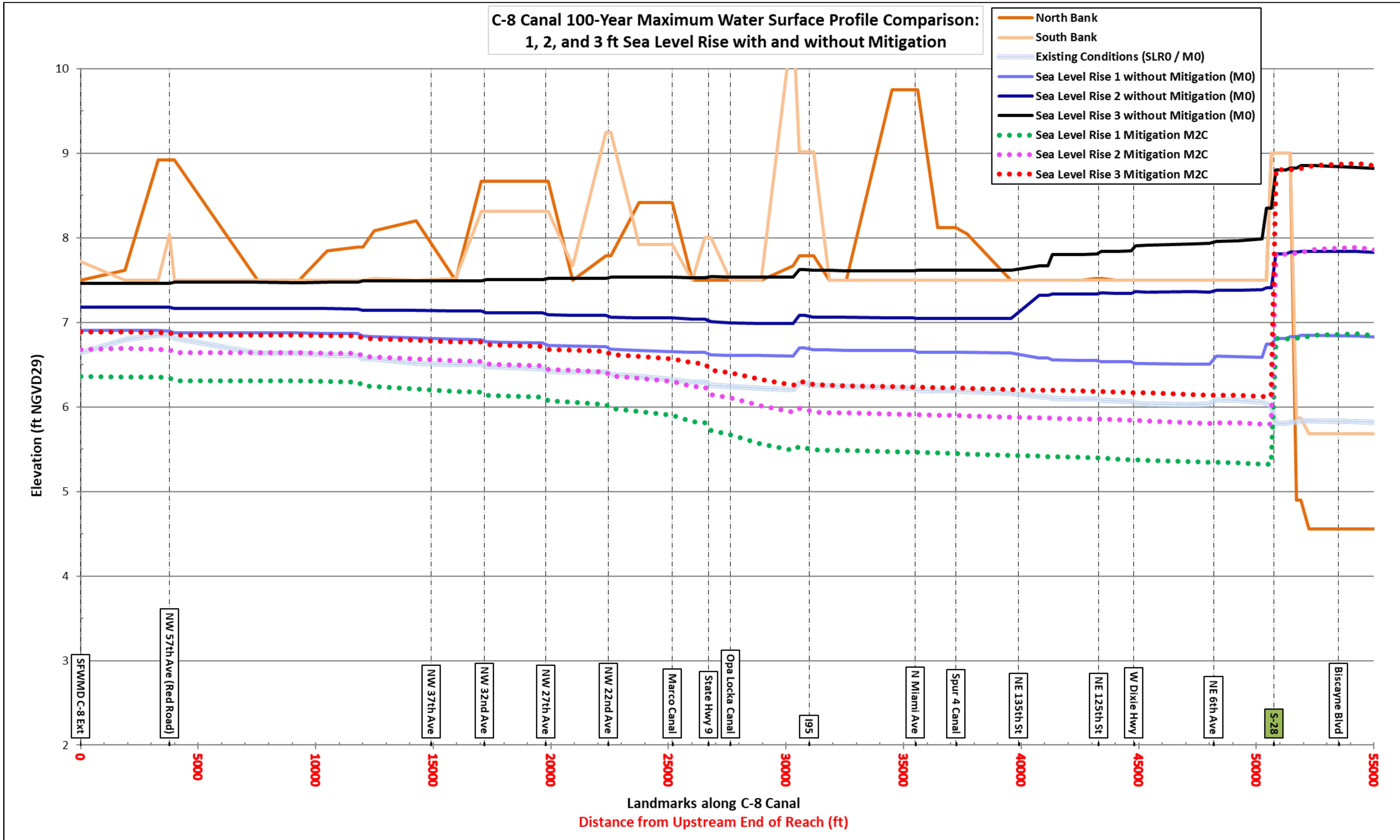


Figure 7.1-13: C-8 Canal Peak Stage Profiles for 100-Year Design Storm with and without Mitigation Scenario M2C – Current vs Future Sea Level Rise Scenarios

7.1.1.4 PM #1 – Alternative Comparison Figures

Section 7.1.1.1 through **Section 7.1.1.3** presents figures that compare the respective mitigation strategy across three sea level rise scenarios with existing conditions (M0 / SLR0) and future conditions without mitigation (M0 / SLR1 / SLR2 / SLR3) for each rainfall return frequency. This section presents the same model simulated water levels but displays them differently as an alternative source of comparison. This section presents an alternative assessment by comparing existing condition without sea level rise and future condition sea level rise without mitigation to each of the three mitigation strategies, for each of the twelve different combinations of rainfall return frequency and sea level rise. These figures provide an alternative way of looking at the model results and provide a direct comparison of what the existing PM #1 level of service is under current conditions, what the PM #1 level of service may be in the future if no mitigation is implemented, and what PM #1 level of service could be under the three different mitigation scenarios, for each combination of rainfall and sea level rise.

It is important to note that the canal embankments were raised in the model setup under Mitigation Scenario M2B and M2C, however, only one set of canal embankments are displayed in **Figure 7.1-14** through **Figure 7.1-25**. Therefore, when comparing Mitigation Scenario M2A, M2B, and M2C in these figures, it will appear that there are out of bank exceedances under Mitigation M2B and M2C, but that is an artifact of showing the original embankments for Mitigation M2A. Please ignore any bank exceedances associated with M2B and M2C in **Figure 7.1-14** through **Figure 7.1-25**.

Although each figure on its own provides valuable information, comparing different figures with each other reveals findings that may otherwise go unnoticed. For instance, **Figure 7.1-21** shows that for the 25-year SLR2 scenario, Mitigation Scenario M2C is able to achieve a maximum water surface profile that is equal to or lower than current conditions. Looking at **Figure 7.1-21** by itself, one would assume that if the 25-year SLR2 profile is equal to or lower than current conditions, than so will the 5-year and 10-year SLR2 profiles. However, when looking at **Figure 7.1-15** and **Figure 7.1-18**, Mitigation Scenario M2C was unable to bring the maximum water surface profile back down to current conditions for the 5-year and 10-year SLR2 scenarios, respectively. In fact, for the 5-year and 10-year rainfall events, only under sea level rise 1 were any of the simulated mitigation strategies able to achieve a PM #1 maximum water surface profile that was equal to or lower than current conditions. This is brought up because this is likely the harsh reality of sea level rise. Even during the model iteration testing, where pump capacities upwards of 5,550 cfs were examined, the 5-year and 10-year rainfall scenarios under future sea level rise scenarios were unable to be consistently brought back to current condition levels. The reason for this is simply the fact that sea level rise will cause water levels on the tailwater side of the tidal structure that are high enough to cause the antecedent upstream water levels to be at an elevation that drastically hinders the ability of the system to not peak higher than it did in the past. In some cases, the new antecedent headwater levels may be nearly equal to or even higher than what the 5-year or 10-year design storm peaked out under existing conditions. . Therefore, if the future condition starting upstream water levels before rainfall are nearly equal to or greater than the existing conditions peak water levels with rainfall, no amount of mitigation will achieve a maximum water surface profile equal to or lower than current conditions. This is less of an issue with the larger 25-year and 100-year rainfall events as the C-8 Canal peaked a lot higher, providing a wider-range of water levels to work with under the mitigation scenarios before exceeding the maximum current condition elevations.

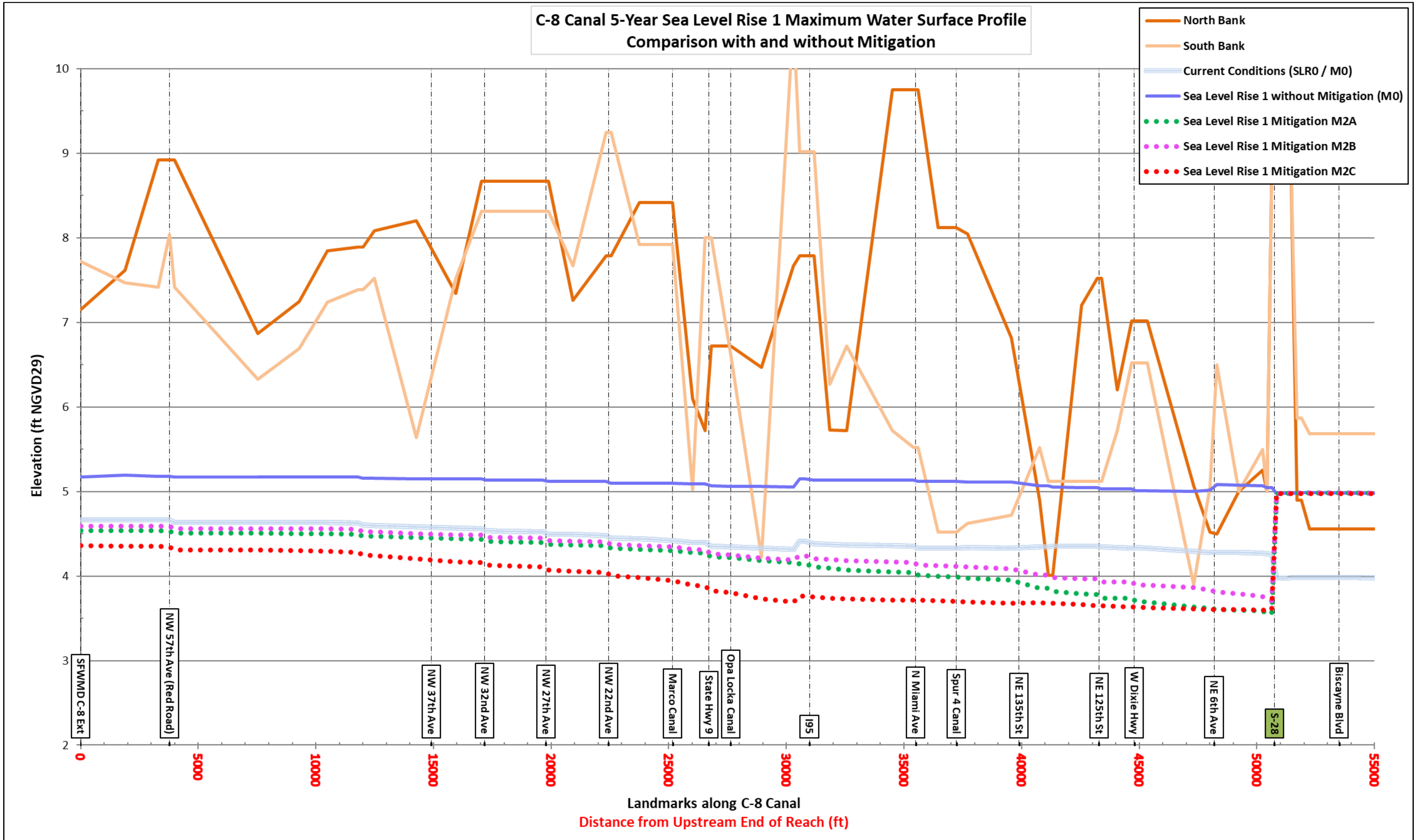


Figure 7.1-14: C-8 Canal Peak Stage Profiles for 5-Year Sea Level Rise 1 Design Storm with and without Mitigation

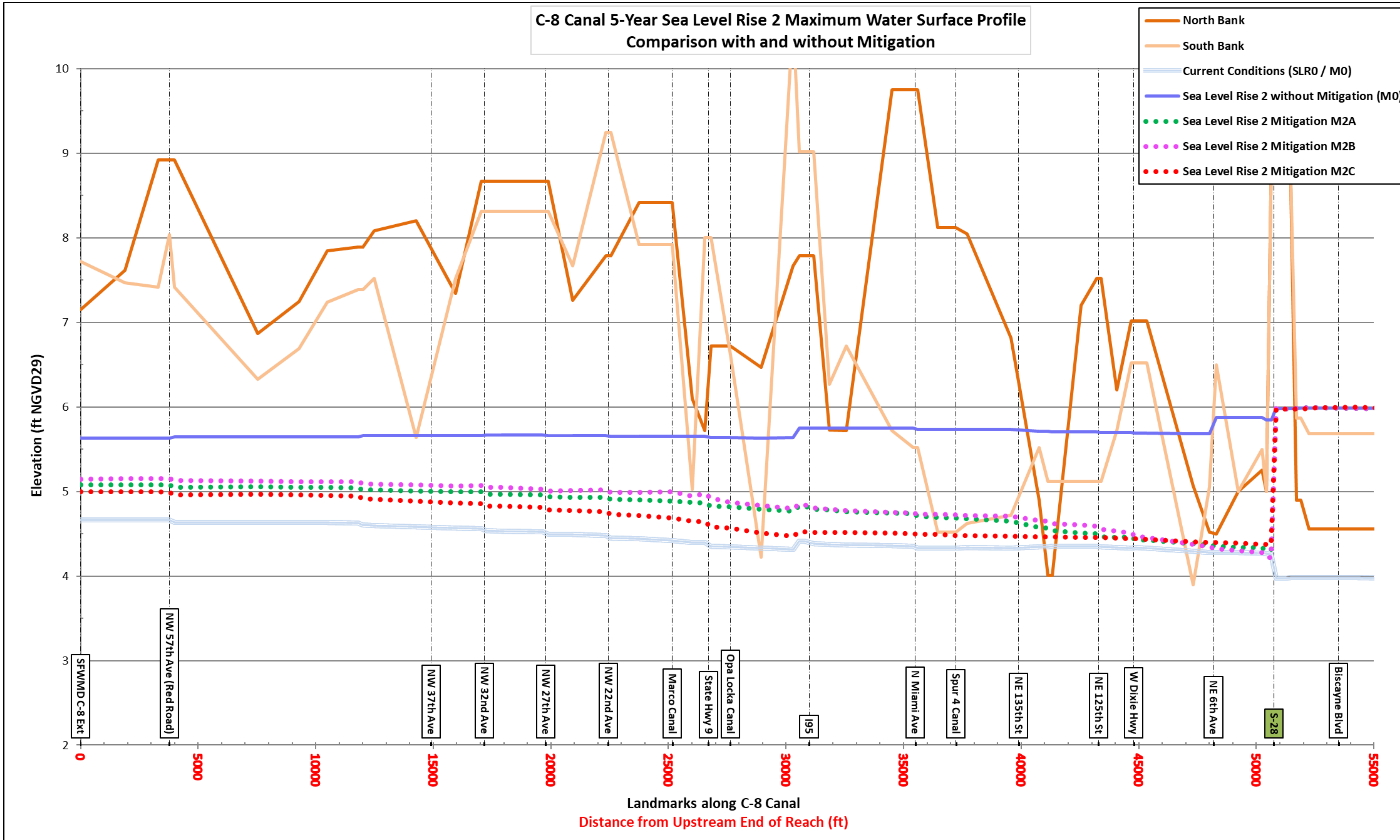


Figure 7.1-15: C-8 Canal Peak Stage Profiles for 5-Year Sea Level Rise 2 Design Storm with and without Mitigation

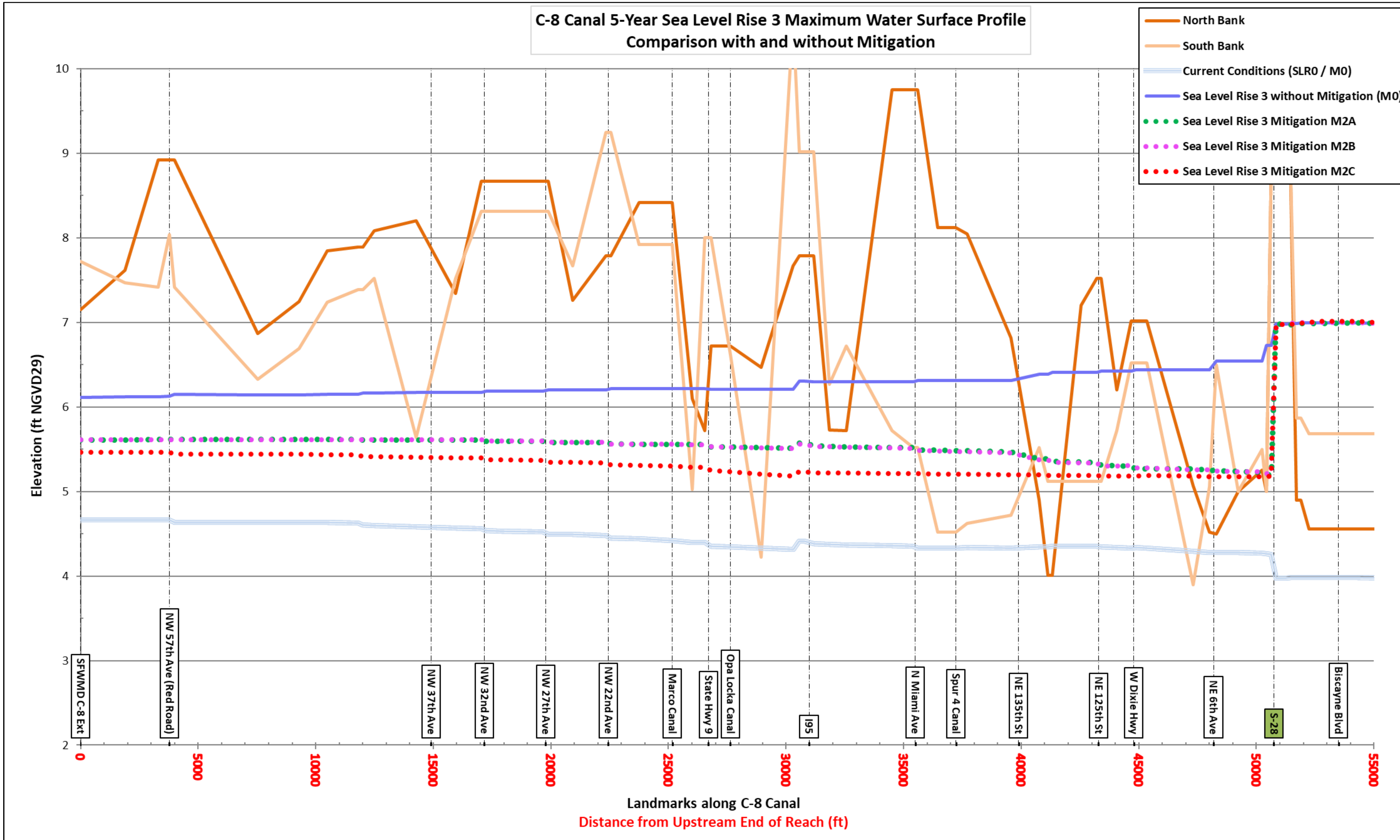


Figure 7.1-16: C-8 Canal Peak Stage Profiles for 5-Year Sea Level Rise 3 Design Storm with and without Mitigation

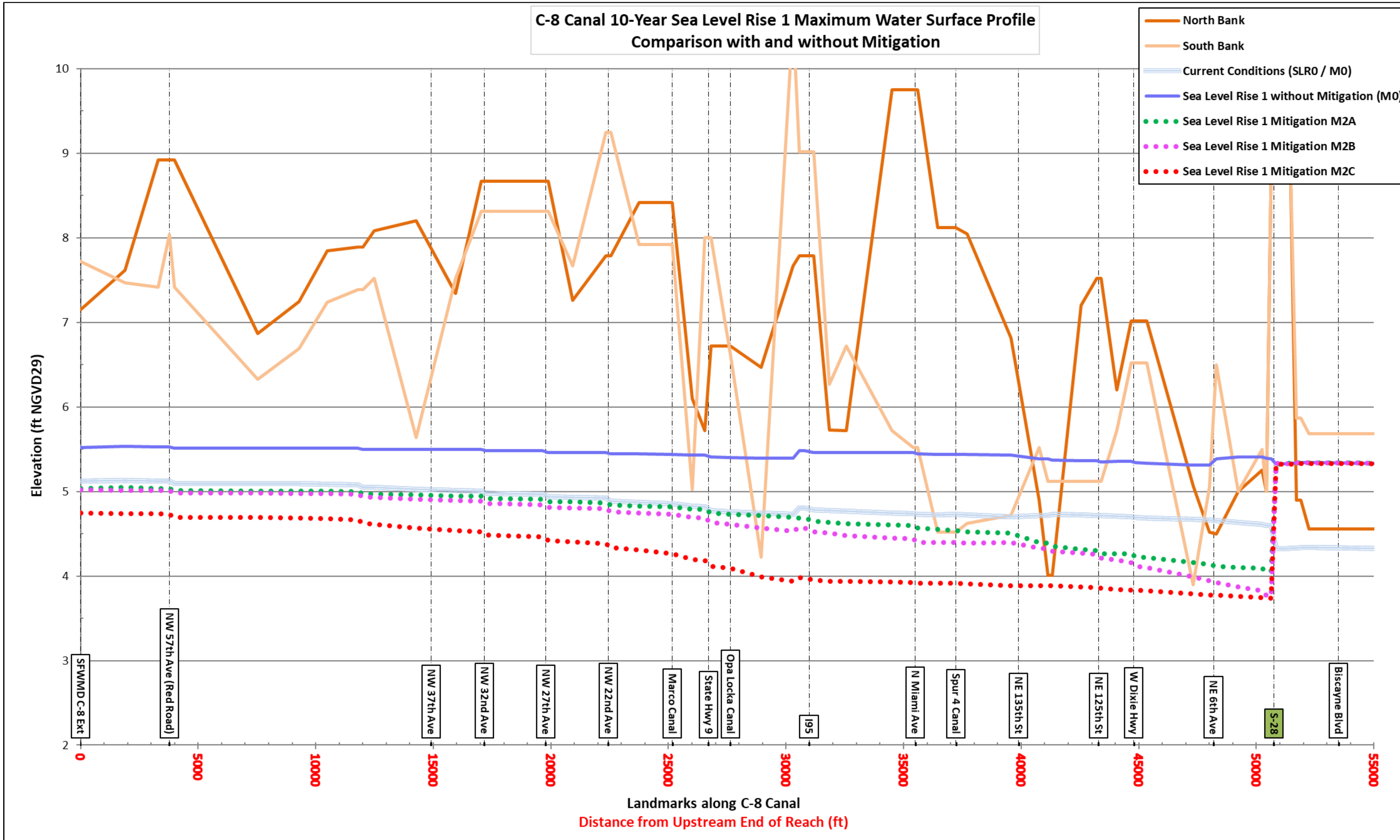


Figure 7.1-17: C-8 Canal Peak Stage Profiles for 10-Year Sea Level Rise 1 Design Storm with and without Mitigation

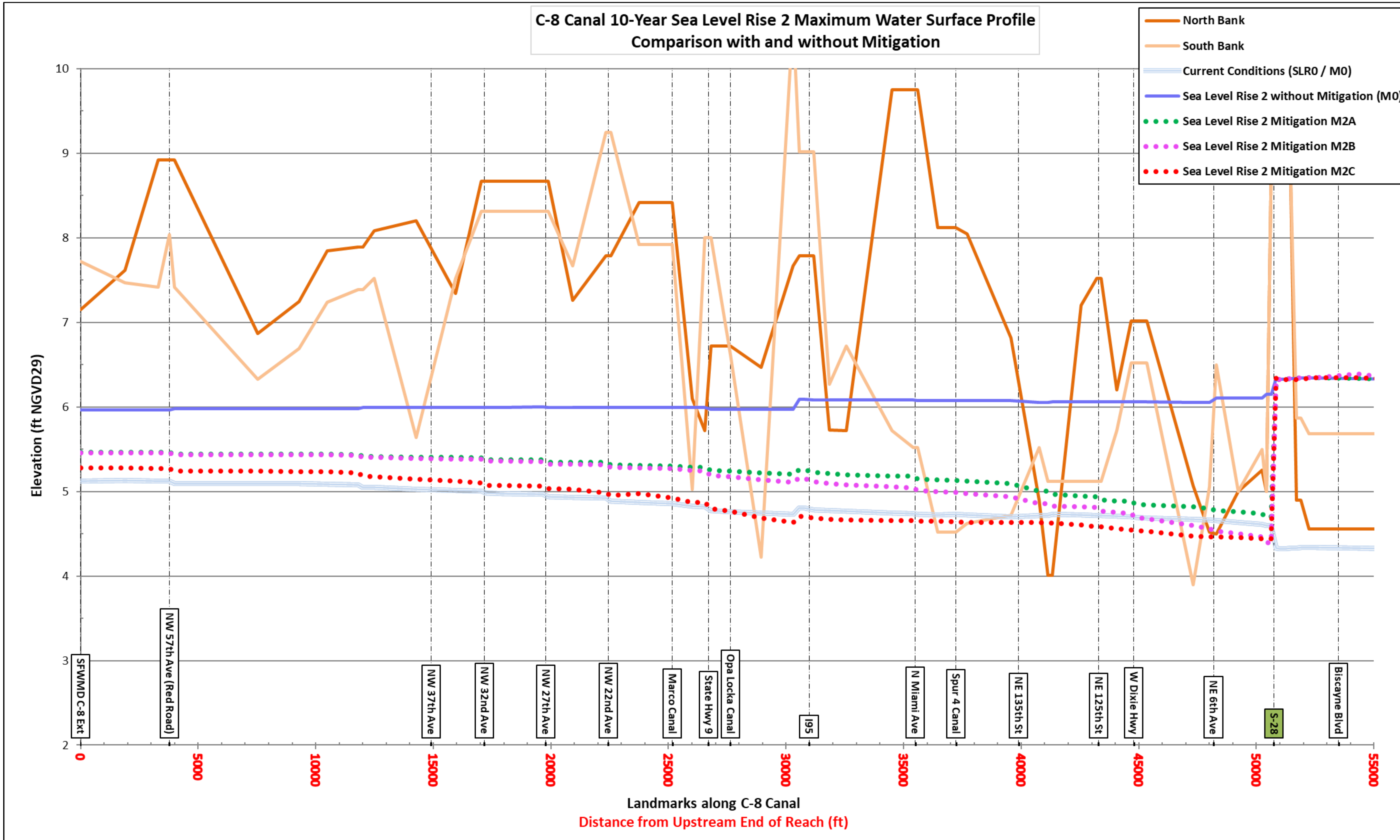


Figure 7.1-18: C-8 Canal Peak Stage Profiles for 10-Year Sea Level Rise 2 Design Storm with and without Mitigation

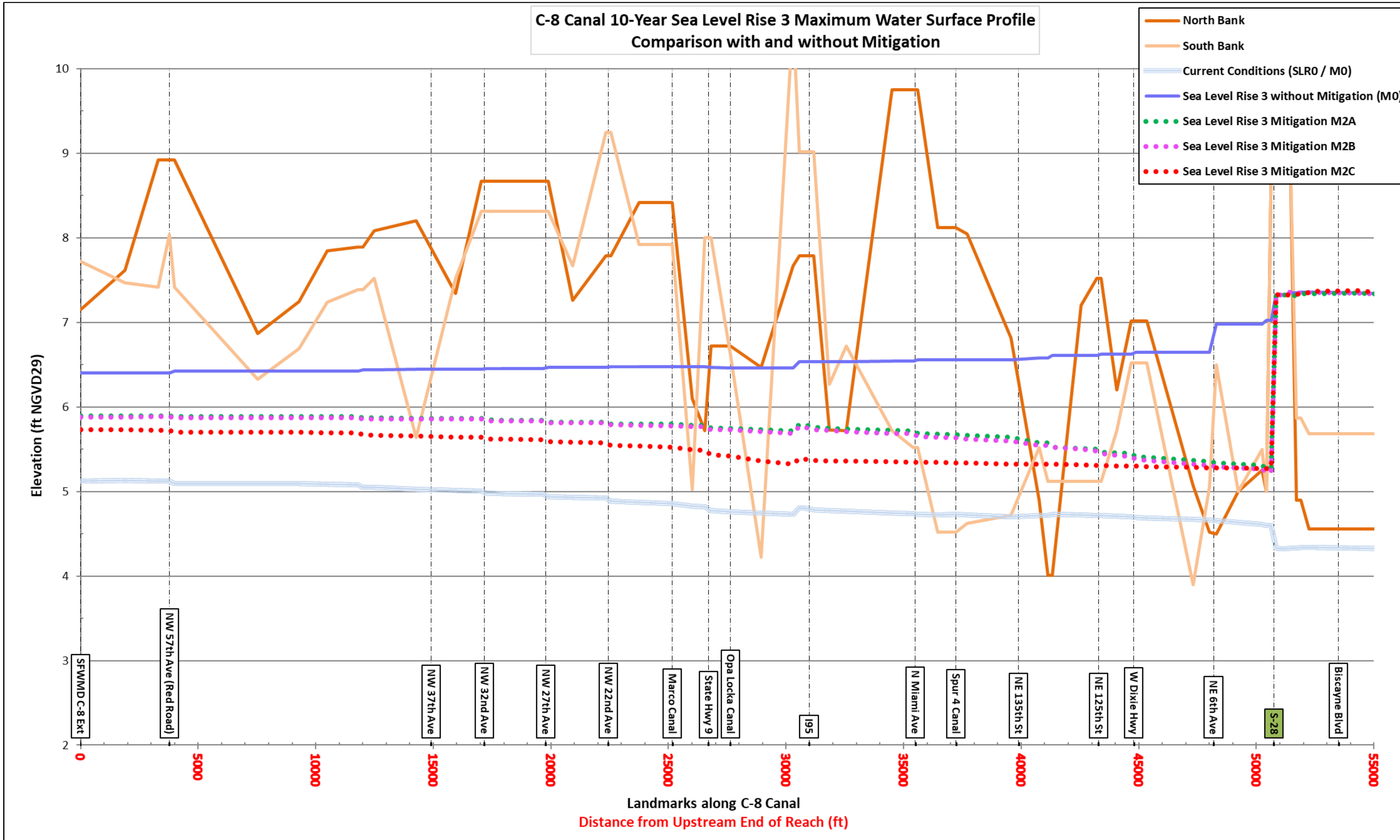


Figure 7.1-19: C-8 Canal Peak Stage Profiles for 10-Year Sea Level Rise 3 Design Storm with and without Mitigation

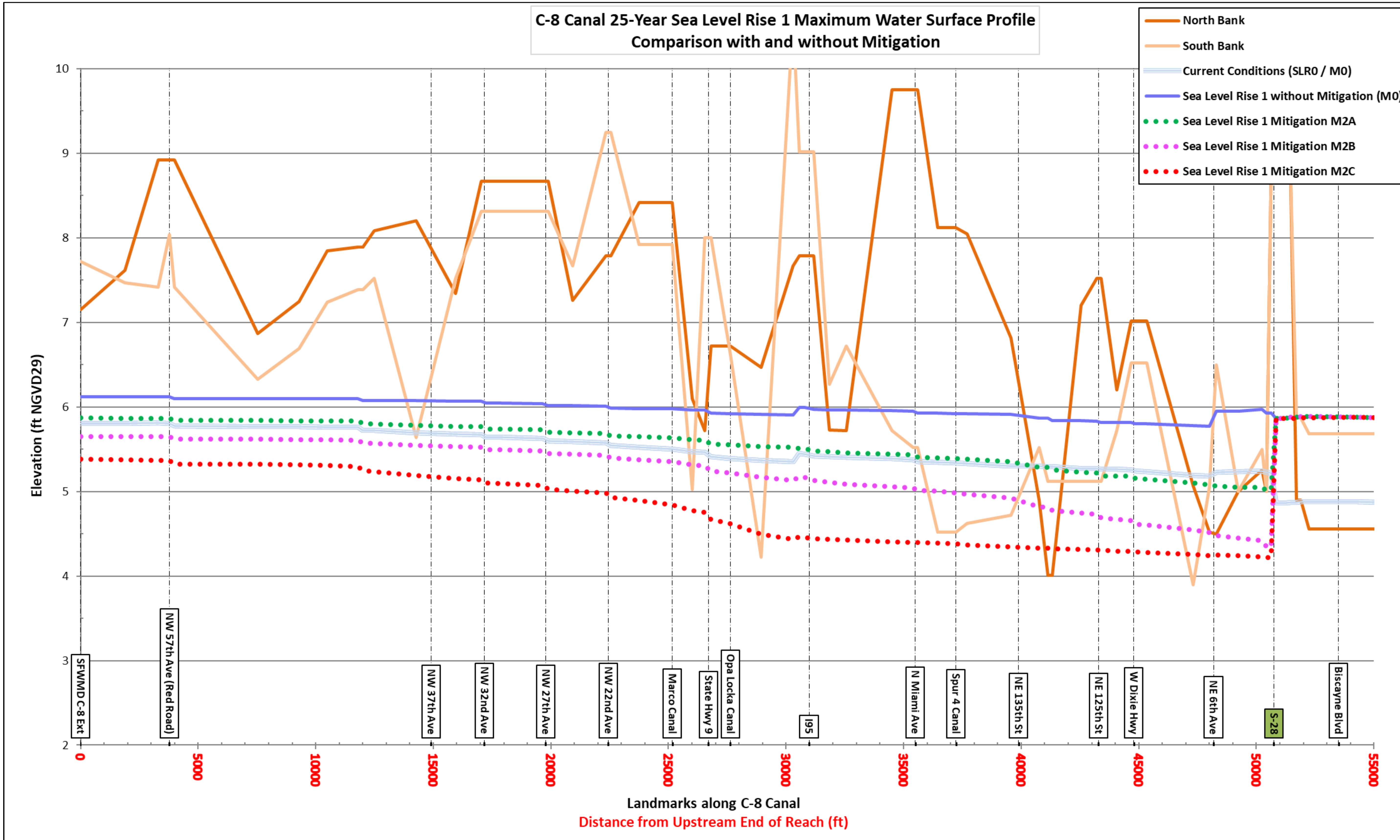


Figure 7.1-20: C-8 Canal Peak Stage Profiles for 25-Year Sea Level Rise 1 Design Storm with and without Mitigation

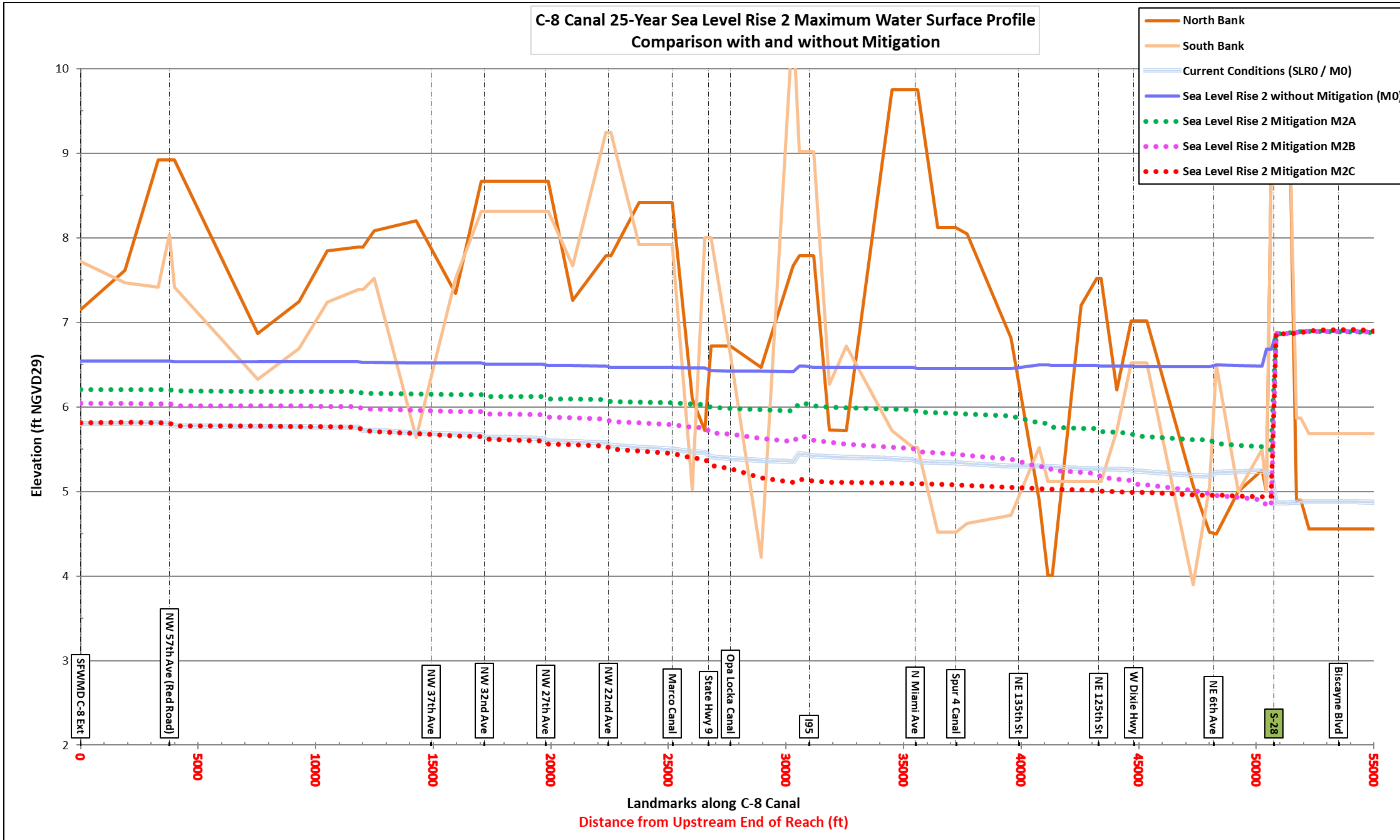


Figure 7.1-21: C-8 Canal Peak Stage Profiles for 25-Year Sea Level Rise 2 Design Storm with and without Mitigation

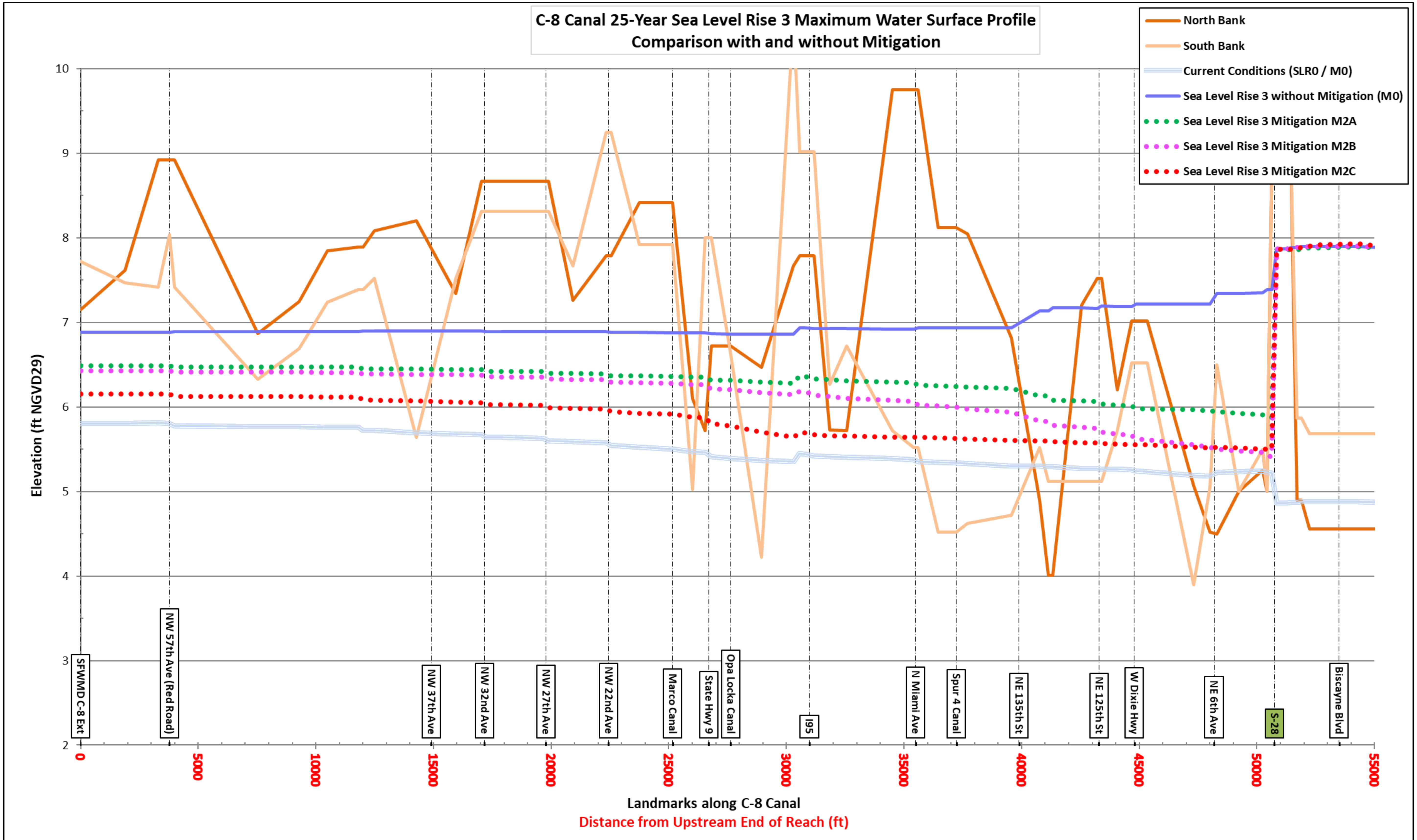


Figure 7.1-22: C-8 Canal Peak Stage Profiles for 25-Year Sea Level Rise 3 Design Storm with and without Mitigation

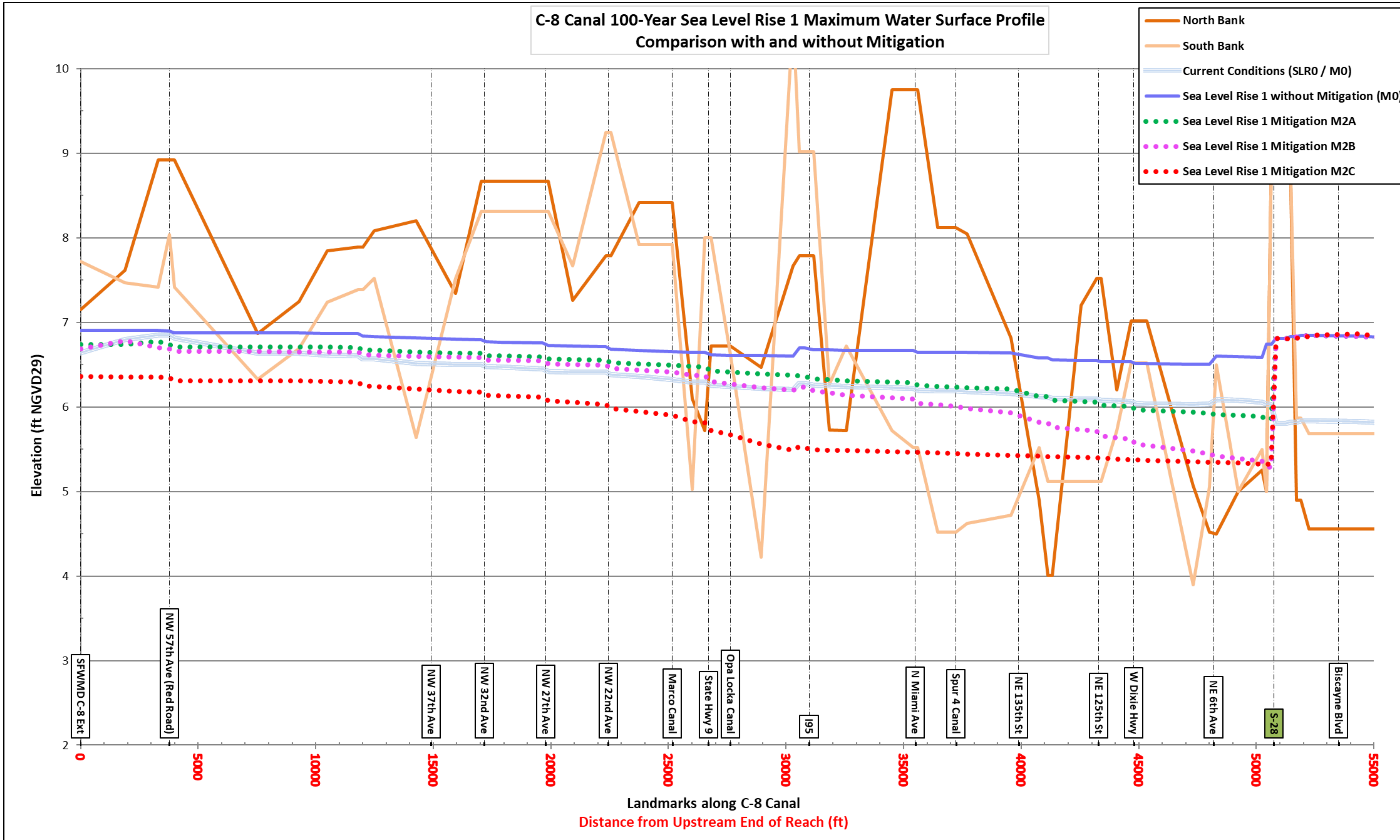


Figure 7.1-23: C-8 Canal Peak Stage Profiles for 100-Year Sea Level Rise 1 Design Storm with and without Mitigation

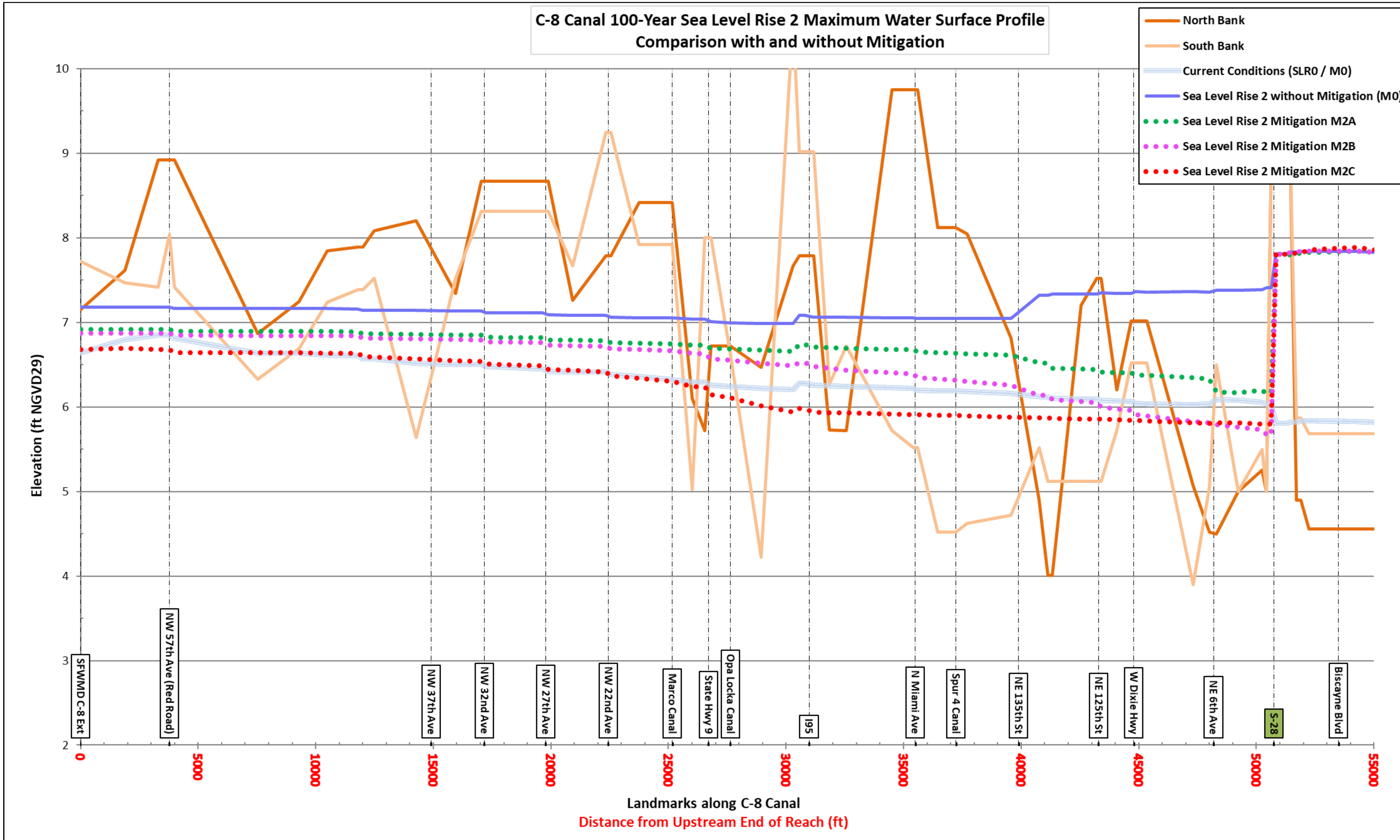


Figure 7.1-24: C-8 Canal Peak Stage Profiles for 100-Year Sea Level Rise 2 Design Storm with and without Mitigation

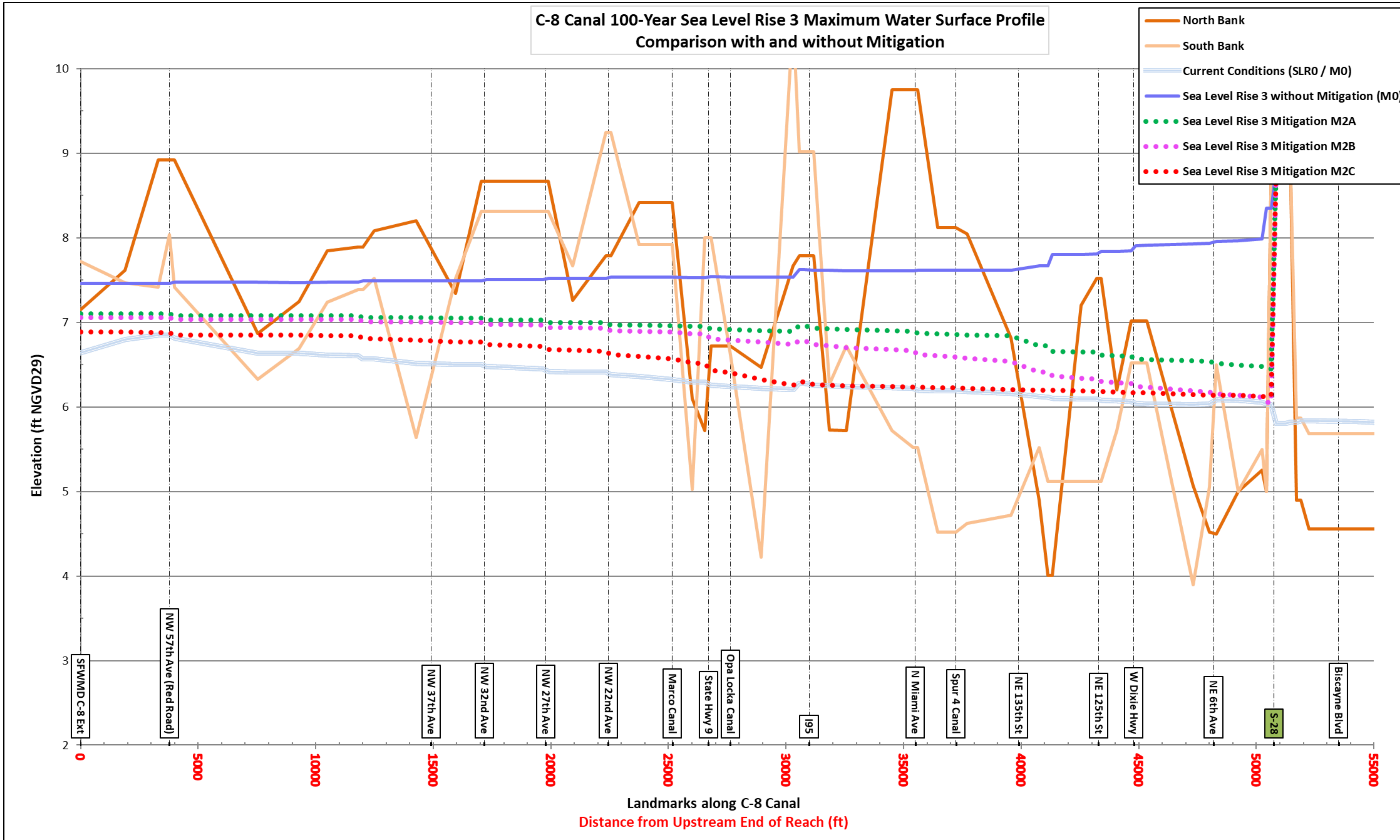


Figure 7.1-25: C-8 Canal Peak Stage Profiles for 100-Year Sea Level Rise 3 Design Storm with and without Mitigation

7.1.1.5 <u>PM #1 – Summary for C-8 Watershed</u>

- Mitigation M2A
  - Mitigation M2A is predicted to 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 is predicted to lower the maximum canal profile across all sea level rise scenarios as if it was 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 is not predicted to significantly improve the C-8 Watershed's provided LOS compared to existing conditions
  - Mitigation M2A is predicted to significantly improve the C-8 Watershed's LOS provided compared to future conditions without mitigation
  - Mitigation M2A is predicted to significantly reduce the impact of sea level rise
- Mitigation M2B
  - Although M2B has an additional 1,000 cfs pumping capacity compared to M2A, it is predicted to 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 prevents 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 is predicted to lower the maximum canal profile across all sea level rise scenarios as if it was 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 predicted to significantly improve the C-8 Watershed's provided LOS compared to existing conditions
  - Mitigation M2B is predicted to significantly improve the C-8 Watershed's LOS provided compared to future conditions without mitigation
  - Mitigation M2B is predicted to significantly reduce the impact of sea level rise
- Mitigation 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
    - Requires increased canal conveyance capacity
  - Increased canal conveyance capacity through widening MIKE HYDRO cross sections downstream of I95
  - 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 as if it was 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 provided LOS compared to existing conditions
  - Mitigation M2C is predicted to significantly improve the C-8 Watershed's LOS provided compared to future conditions without mitigation
  - Mitigation M2C is predicted to significantly reduce the impact of sea level rise

Table 7.1-1: PM #1 Summary for the C-8 Canal

Rainfall Return Period	Sea Level Rise Scenario	Mitigation M2A		Mitigation M2B		Mitigation M2C	
		Canal Elevation with Mitigation lower than Existing Conditions	Eliminates Bank Exceedance	Canal Elevation with Mitigation lower than Existing Conditions	Eliminates Bank Exceedance	Canal Elevation 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

7.1.2 PM #2 – Maximum Daily Discharge Capacity through the Primary Canal

The maximum daily discharge capacity through the C-8 Canal is a function of the drainage from the entire C-8 Watershed. Per the District's ERP Handbook, the C-8 Watershed is allowed "Essentially unlimited inflow by gravity connection", which means there is not a set discharge rate that the simulated data presented in this section can be compared to. Rather, the simulated peak 12-hour moving average discharge from the contributing drainage area in terms of cfs/sq.mi (CSM) are compared across rainfall events, sea level rise scenarios, and mitigation strategies. **Table 7.1-2** summarizes the C-8 Watershed's peak 12-hour moving average discharge per square mile calculated for each design storm event. The peak 12-hour moving average discharge per square mile was calculated by dividing the peak discharge through structure S-28 by the C-8 Canal's contributing drainage area.

Under existing conditions (Mitigation 0), there are two trends that apply to most storm events, with one being an increase in peak discharge as rainfall increases and the other being a decrease in peak discharge as sea level rise increases, which are to be expected. In some instances, for a given rainfall event under the same mitigation strategy, the peak 12-hour average discharge is larger for SLR2 than SLR1, although there is an overall decreasing trend going from SLR0 to SLR3. These exceptions appear to be related to how the pump station turns on and ramps up, as each sea level rise condition has a different set of operational rules. In the instances where the SLR2 peak 12-hour average discharge is larger than the SLR1 discharge, it appears that it is caused by timing of operations and water levels, resulting in a slightly larger head differential across the tidal structure which ultimately means a larger peak discharge by the gravity structure when the pump turns off. The difference in peak 12-hour average discharge between these instances in SLR1 and SLR2 are rather small, which also indicates this is just an artifact of timing in structure operations. Using the 5-year rainfall event under Mitigation M2A as an example, the peak 12-hour average discharge for SLR2 is 0.6 CSM larger than SLR1, however, the total discharge volume for SLR2 is about 10% less than SLR1, indicating that there is an overall decrease in discharge as sea level rise increases.

Using the 25-year rainfall event as an example, **Table 7.1-2** shows structure S-28 had a 25-year simulated peak 12-hour average discharge of 88.8 CSM under existing conditions SLR0, 61.3 CSM for SLR1 under Mitigation M2A, 90.9 CSM for SLR2 under Mitigation M2B, and 113.2 CSM for SLR3 under Mitigation M2C. This makes it appear that the peak 12-hour average discharge is increasing as sea level rise in increasing, but it is actually just that the discharge increases as the mitigation scenario changes. For instance, Mitigation M2A has a 1,550 cfs pump station, whereas Mitigation M2B has a 2,550 cfs pump station and Mitigation M2C has a 3,550 cfs pump station and conveyance improvements.

As simulated, the S-28 pump station is meant to supplement the discharge from the tidal structure whenever the gravity structure is unable to due to operational constraints and has a pumping capacity that is less than the gravity structure's design capacity. Therefore, as sea level rise increases, regardless of the level of mitigation, it is expected that the discharge will decrease, which is what the model results show. These hydrographs show that for mitigation strategy M2A and M2B, there is an overall decrease in discharge volume as sea level rises. For mitigation strategy M2C, although there is an overall increase in discharge volume as sea level rises, the total discharge volume for SLR1 and SLR2 rise is greater than existing conditions (SLR0). For mitigation strategy M2C, the increased conveyance capacity and increased ability to pump to tide is predicted to allow Structure S-28 to exceed the total existing discharge volume under SLR1 and SLR2, but not for SLR3, which indicates the discharge volume is still heavily influenced by gravity discharge of the tidal structure.

Table 7.1-2: C-8 Watershed Peak 12-Hour Average Area-Weighted Discharge Summary

C-8 Watershed Structure S-28				
Rainfall Return Frequency	Peak 12-Hour Moving Average Discharge from the Contributing Drainage Area (cfs/sq.mi)			
	M0	M2A	M2B	M2C
	SLR0			
5-year	58.2	51.9	56.6	72.9
10-year	68.8	62.6	67.9	87.4
25-year	88.8	82.9	90.2	114.3
100-year	118.8	112.3	121.8	156.3
	SLR1			
5-year	57.4	50.9	56.0	71.0
10-year	69.2	61.3	68.4	87.0
25-year	89.8	78.8	91.3	114.4
100-year	120.5	108.9	117.1	156.3
	SLR2			
5-year	57.4	51.5	57.0	72.5
10-year	69.2	60.1	72.0	90.3
25-year	91.6	75.6	90.9	123.1
100-year	111.8	95.6	108.8	154.9
	SLR3			
5-year	52.7	43.7	47.7	65.0
10-year	62.1	56.5	62.1	82.5
25-year	77.1	66.5	80.4	113.2
100-year	90.1	76.8	97.1	143.0

Please note the following important points about **Table 7.1-2**:

- The peak discharges presented in this table are highly sensitive to timing of operations, headwater/tailwater differential, and flow rating.
- A decrease in peak discharge does not necessarily indicate a decrease in performance. There are instances where the peak discharge decreased (see previous point) but the total discharge volume increased (see **Figure 7.2-26** through **Figure 7.2-37**).
- An increase in peak discharge does not necessarily indicate an increase in performance. There are instances where the peak discharge increased (see first point) but the total discharge volume decreased (see **Figure 7.2-26** through **Figure 7.2-37**).
- In most instances, the peak discharge is coming from the gravity structure, as the discharge capacity (regardless of rated design discharge) of the sluice gates far exceed that of the simulated pump stations.
- The impact of the pump station is not apparent in this dataset. The pump station discharges when the gravity structure is unable to, which suppresses the headwater (reduces flooding) and shifts the timing and characteristics of discharge. This often leads to a smaller (or larger)

headwater/tailwater differential and timing change in discharge, which may be reflected as smaller (or larger) peak discharges in this table.

Table 7.1-3 provides a summary of the instantaneous and 12-hour moving average peak discharge, peak headwater, and peak tailwater, for the 25-year rainfall event for all sea level rise combinations for each mitigation strategy. Refer to **Appendix A** for the complete set of summary tables for all rainfall events.

Section 7.1.2.1 through **Section 7.1.2.3** present PM #2 figures for each of the three mitigation strategies. **Figure 7.1-26** through **Figure 7.1-37** presents the 12-hour moving average discharge hydrographs for the C-8 Canal for each rainfall frequency and sea level rise scenario while comparing existing conditions (no mitigation) versus Mitigation M2A, M2B, and M2C.

Table 7.1-3: Summary of Structure S-28 25-Year Simulated Peak Discharge, Peak Headwater, and Peak Tailwater (NGVD29 to NAVD88 Conversion = -1.57 ft)

25-Year Design Storm												
	Summary of the Instantaneous Peak Discharge, Peak Headwater, and Peak Tailwater at Structure S-28 in the C-8 Watershed											
	Existing Conditions (Mitigation 0)			Mitigation M2A			Mitigation M2B			Mitigation M2C		
	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)
SLR0	2833	5.22	4.87	2697	4.32	4.87	2994	4.01	4.87	4031	3.89	4.87
SLR1	2990	5.92	5.87	2726	5.01	5.87	2818	4.34	5.87	3813	4.22	5.87
SLR2	3354	6.68	6.87	2795	5.49	6.87	2813	4.83	6.87	3717	4.93	6.87
SLR3	3442	7.39	7.87	2644	5.87	7.87	2708	5.41	7.87	3990	5.5	7.87
Summary of the 12-Hour Moving Average Peak Discharge, Peak Headwater, and Peak Tailwater at Structure S-28 in the C-8 Watershed												
SLR0	2506	4.45	4.36	2340	4.04	4.36	2546	3.71	4.36	3227	3.70	4.36
SLR1	2535	5.41	5.36	2224	4.68	5.36	2577	3.84	5.36	3227	3.81	5.36
SLR2	2585	6.32	6.36	2135	5.29	6.36	2566	4.49	6.36	3473	4.53	6.36
SLR3	2176	7.14	7.36	1877	5.72	7.36	2269	5.36	7.36	3195	5.39	7.36

7.1.2.1 PM #2 Figures – Mitigation M2A

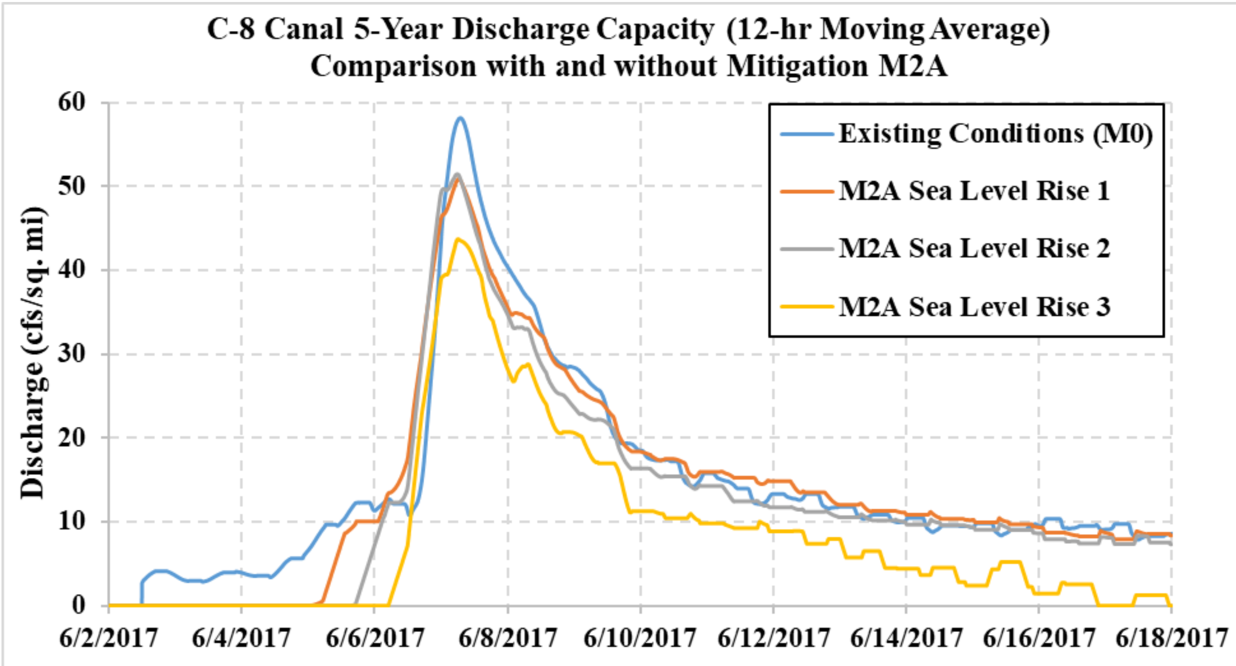


Figure 7.1-26: Mitigation M2A 12-Hour Moving Average Discharge Hydrographs (cfs/sq-mi) for C-8 Canal Structure S-28 for 5-Year Design Storms

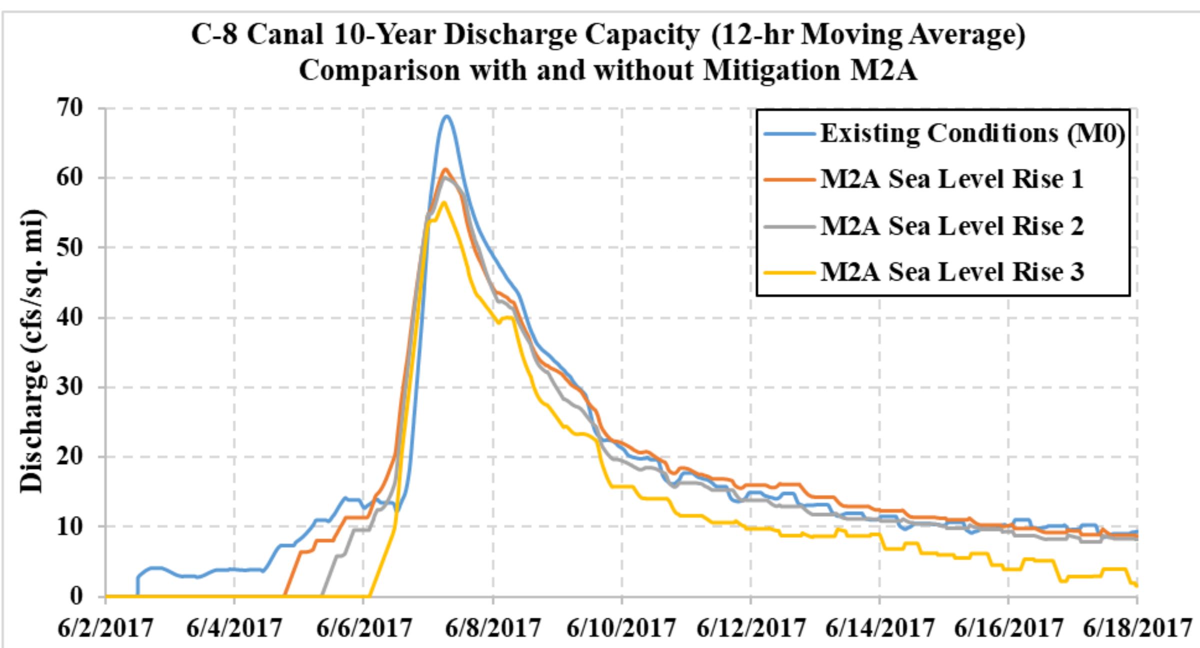


Figure 7.1-27: Mitigation M2A 12-Hour Moving Average Discharge Hydrographs (cfs/sq-mi) for C-8 Canal Structure S-28 for 10-Year Design Storms

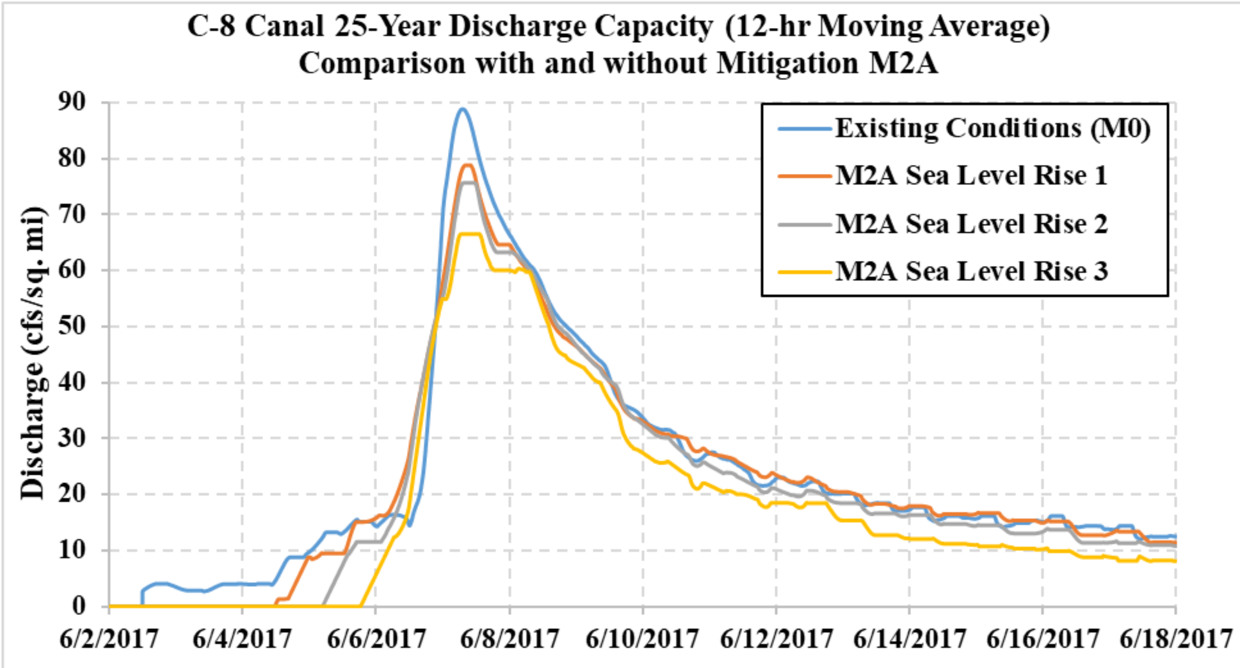


Figure 7.1-28: Mitigation M2A 12-Hour Moving Average Discharge Hydrographs (cfs/sq-mi) for C-8 Canal Structure S-28 for 25-Year Design Storms

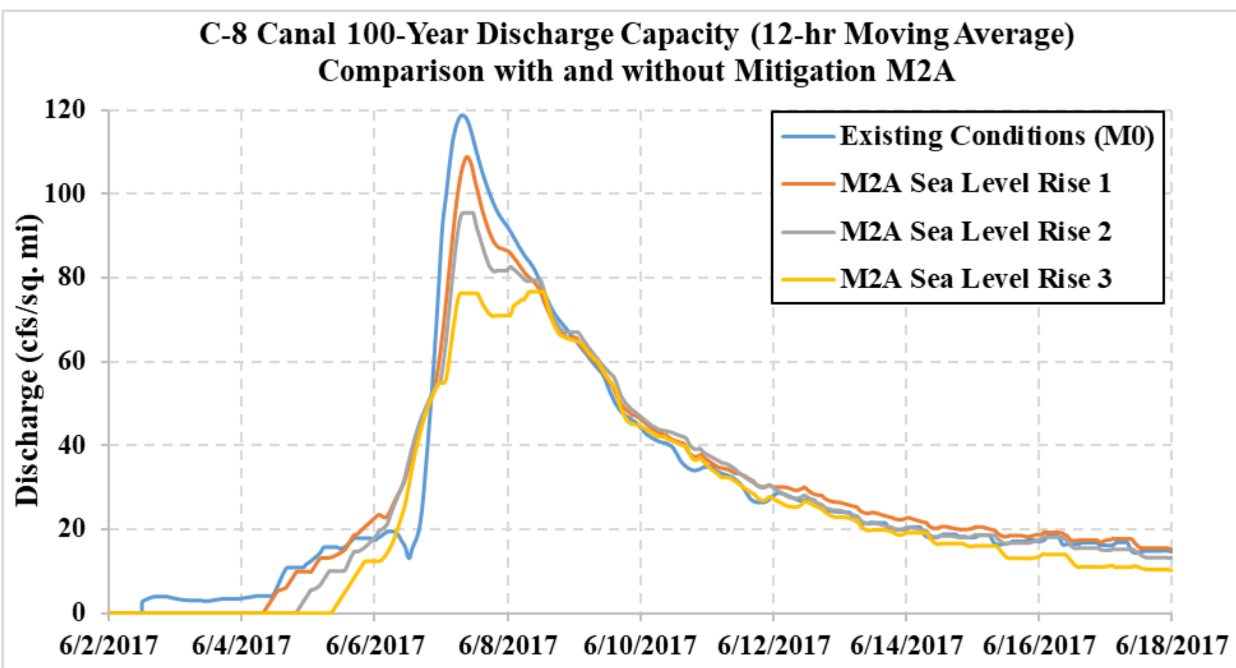


Figure 7.1-29: Mitigation M2A 12-Hour Moving Average Discharge Hydrographs (cfs/sq-mi) for C-8 Canal Structure S-28 for 100-Year Design Storms

7.1.2.2 PM #2 Figures – Mitigation M2B

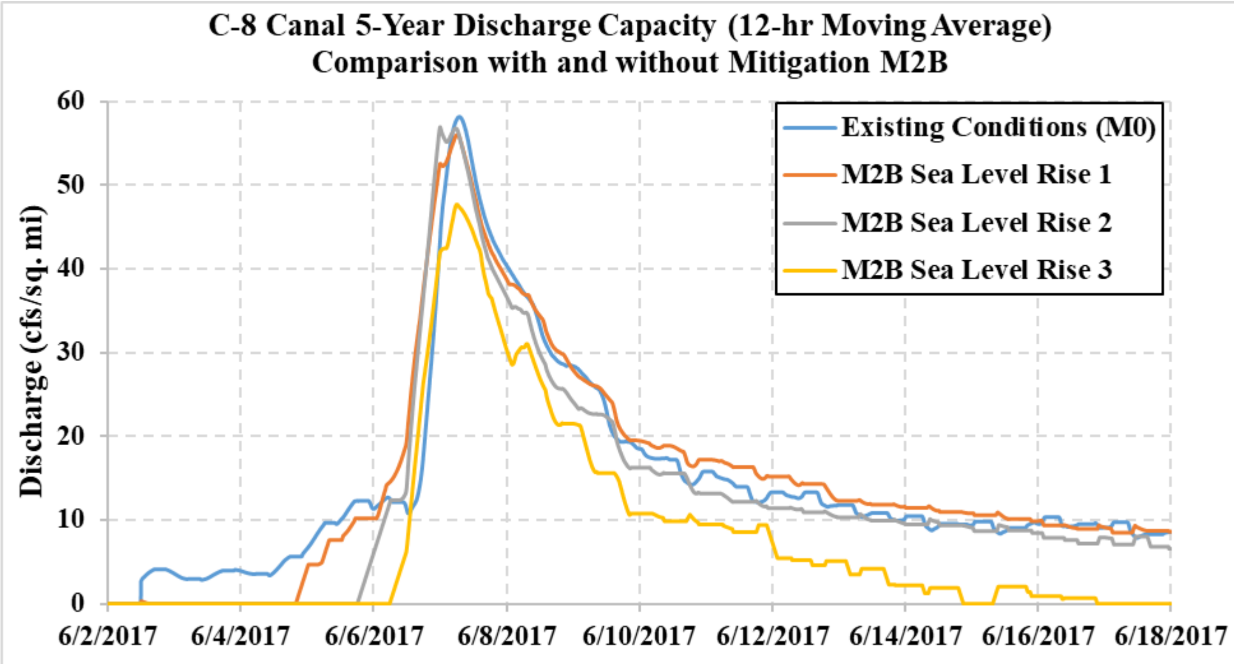


Figure 7.1-30: Mitigation M2B 12-Hour Moving Average Discharge Hydrographs (cfs/sq-mi) for C-8 Canal Structure S-28 for 5-Year Design Storms

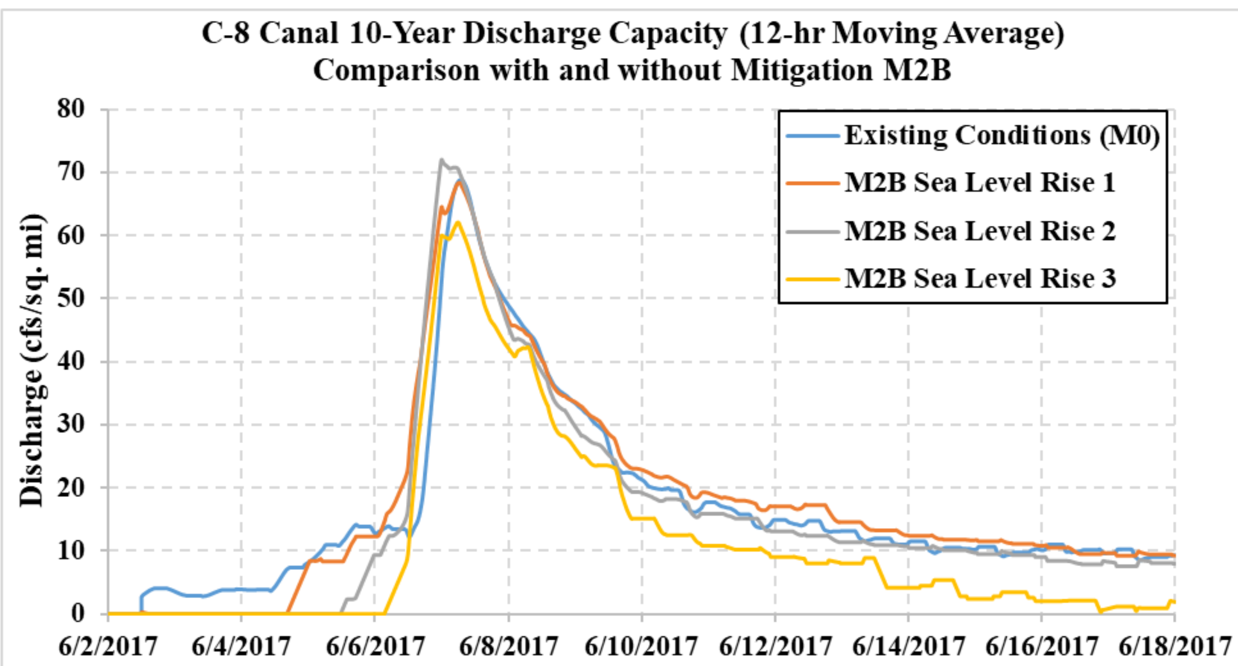


Figure 7.1-31: Mitigation M2B 12-Hour Moving Average Discharge Hydrographs (cfs/sq-mi) for C-8 Canal Structure S-28 for 10-Year Design Storms

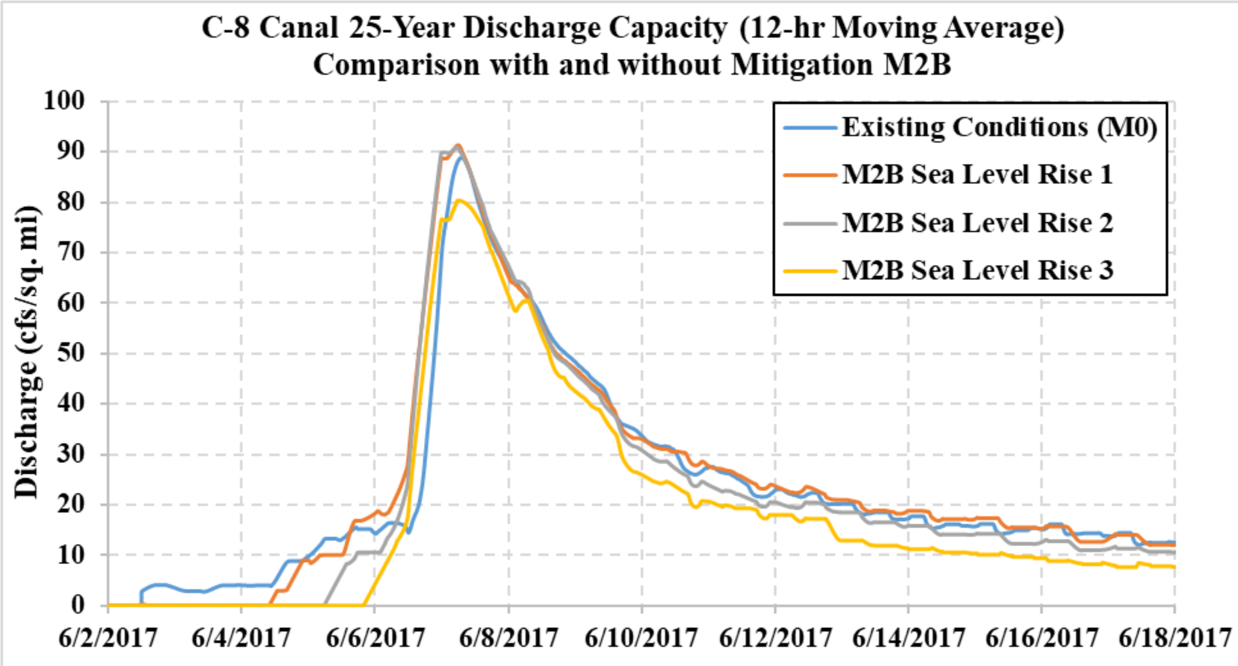


Figure 7.1-32: Mitigation M2B 12-Hour Moving Average Discharge Hydrographs (cfs/sq-mi) for C-8 Canal Structure S-28 for 25-Year Design Storms

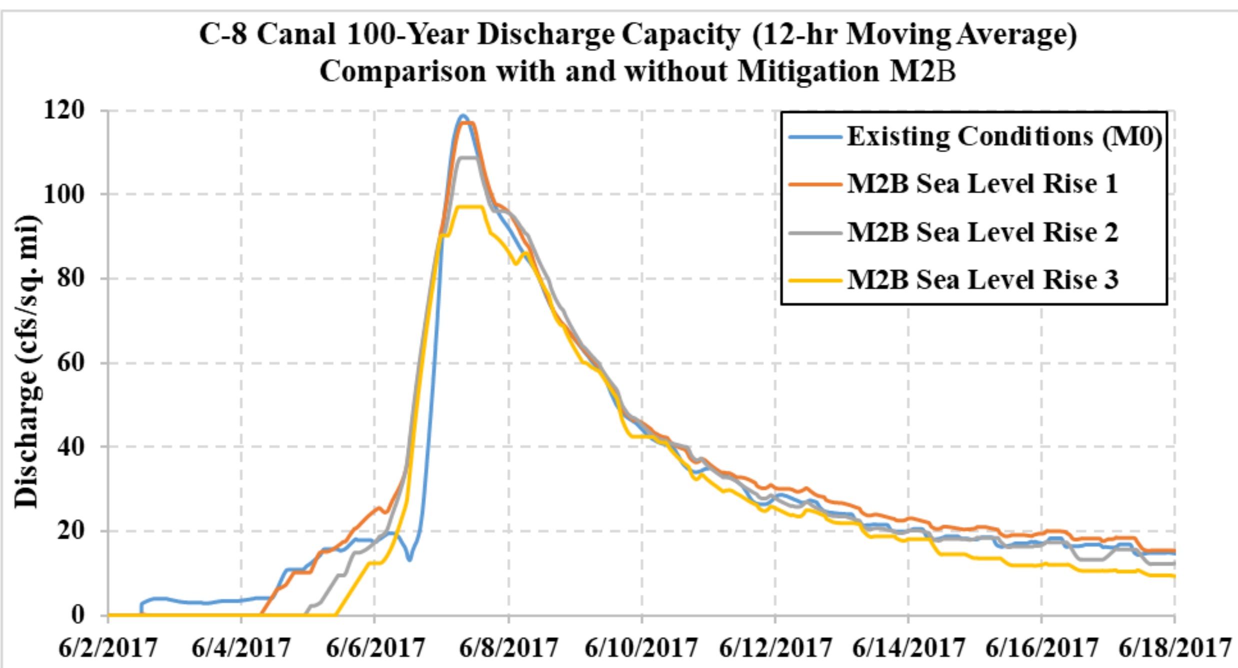


Figure 7.1-33: Mitigation M2B 12-Hour Moving Average Discharge Hydrographs (cfs/sq-mi) for C-8 Canal Structure S-28 for 100-Year Design Storms

7.1.2.3 PM #2 Figures – Mitigation M2C

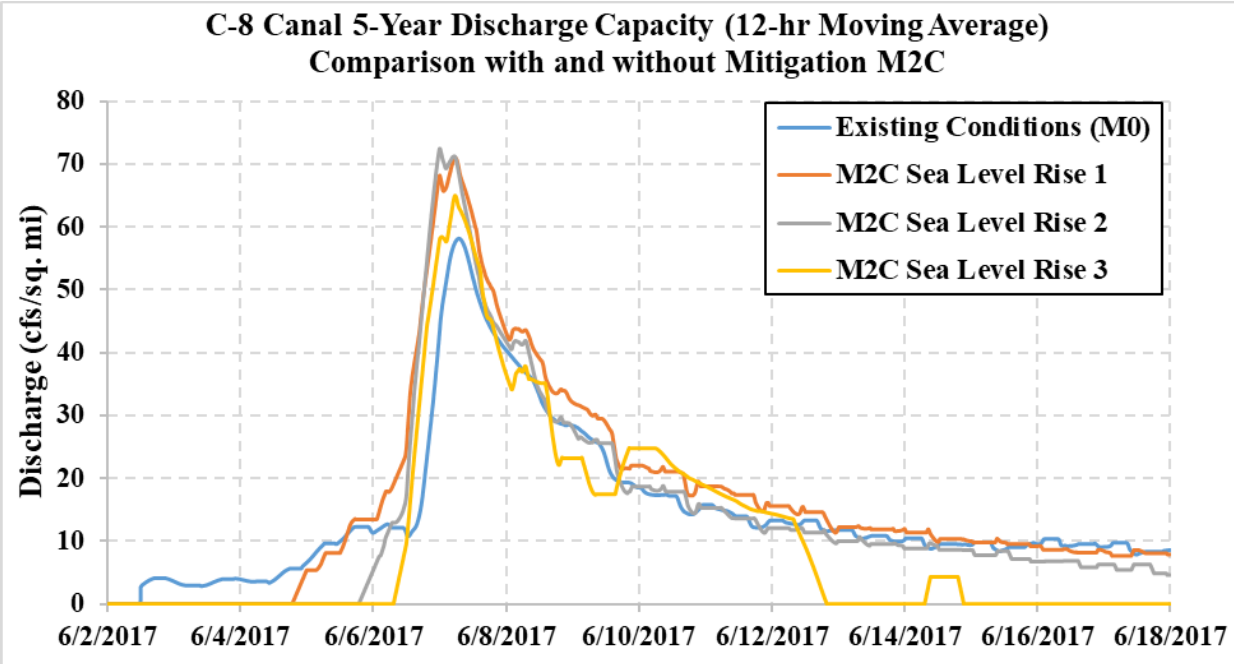


Figure 7.1-34: Mitigation M2C 12-Hour Moving Average Discharge Hydrographs (cfs/sq-mi) for C-8 Canal Structure S-28 for 5-Year Design Storms

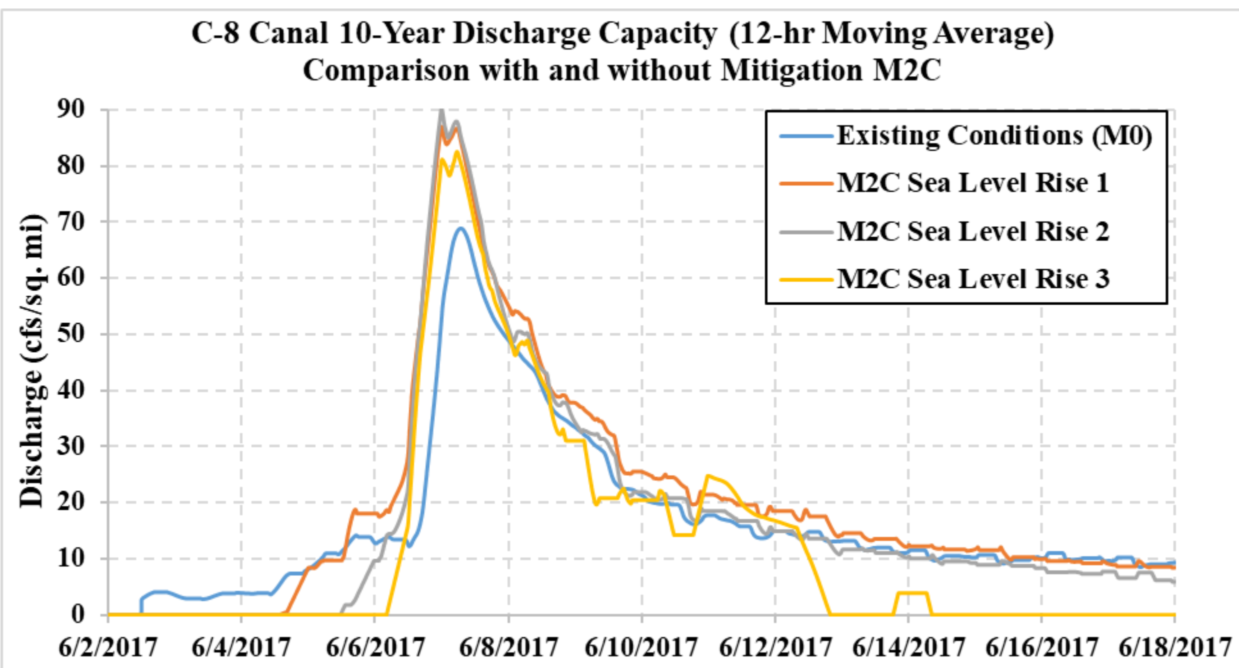


Figure 7.1-35: Mitigation M2C 12-Hour Moving Average Discharge Hydrographs (cfs/sq-mi) for C-8 Canal Structure S-28 for 10-Year Design Storms

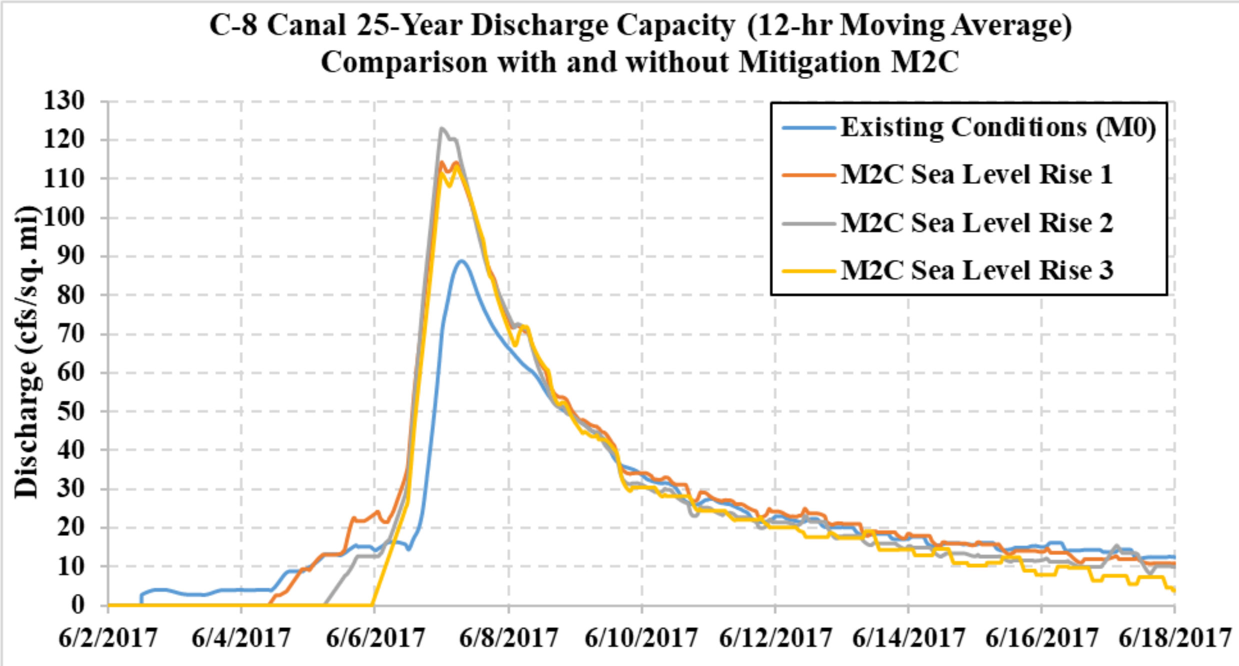


Figure 7.1-36: Mitigation M2C 12-Hour Moving Average Discharge Hydrographs (cfs/sq-mi) for C-8 Canal Structure S-28 for 25-Year Design Storms

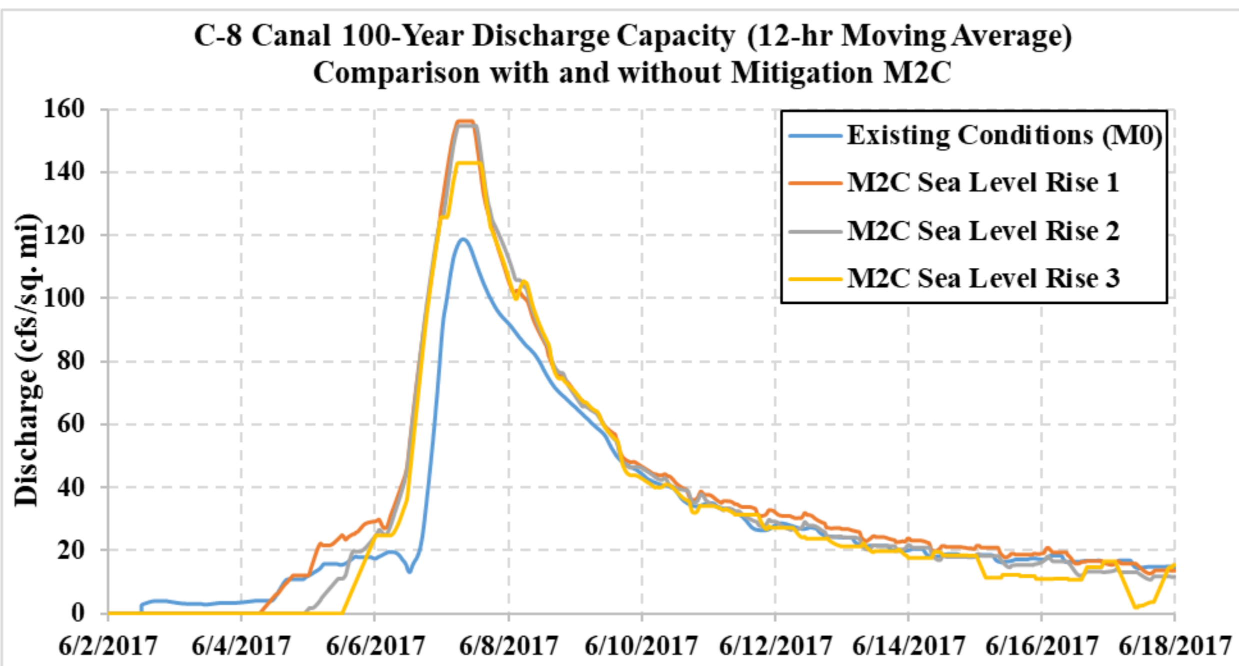


Figure 7.1-37: Mitigation M2C 12-Hour Moving Average Discharge Hydrographs (cfs/sq-mi) for C-8 Canal Structure S-28 for 100-Year Design Storms

7.1.2.4 PM #2 Summary – C-8 Watershed

- M2A
    - Even with 1,550 cfs pump station, there is a decrease in peak discharge as sea level rises
        - This is because the peak discharge is still from the sluice gate and is highly dependent on the headwater and tailwater differential
        - The pump station is actively working to reduce or maintain headwater when tailwater inhibits gravity discharge, which ultimately decreases the headwater and tailwater differential when the gravity structure is able to discharge, resulting in smaller peak discharge
    - Even with 1,550 cfs pump station, there is an overall decrease in discharge volume as sea level rises
        - Total discharge volume should not be used as an indicator of structure performance
            - The raised gate overtopping elevation blocks storm surge, which directly reduces the total discharge volume as there is no reverse flow or structure bypass for the tidal structure to discharge like there is under the without mitigation scenarios.
        - Simulated pump station has a discharge capacity that is less than 50% of the sluice gate design discharge
- M2B
    - Even with 2,550 cfs pump station, there is a decrease in peak discharge as sea level rises
        - This is because the peak discharge is still from the sluice gate and is highly dependent on the headwater and tailwater differential
        - The pump station is actively working to reduce or maintain headwater when tailwater inhibits gravity discharge, which ultimately decreases the headwater and tailwater differential when the gravity structure is able to discharge, resulting in smaller peak discharge
    - Even with 2,550 cfs pump station, there is an overall decrease in discharge volume as sea level rises
        - Total discharge volume should not be used as an indicator of structure performance
            - The raised gate overtopping elevation blocks storm surge, which directly reduces the total discharge volume as there is no reverse flow or structure bypass for the tidal structure to discharge like there is under the without mitigation scenarios.
        - Simulated pump station has a discharge capacity that is about 80% of the sluice gate design discharge

- M2C
  - The peak discharge for all three sea level rise scenarios are greater than the existing conditions (SLR0) peak discharge. However, there is a decrease in peak discharge as sea level rises (SLR1 > SLR2 > SLR3)
    - The peak discharge is still most often from the sluice gate and is highly dependent on the headwater and tailwater differential
    - In some instances, the pump station has enough capacity to suppress headwater elevations enough that they operate infrequently
      - This results in the pump station having larger peak discharge than the gravity structure,
      - The peak discharge capacity of the pump station is 3,550 cfs, which is less than what the gravity structure would otherwise discharge if there wasn't a pump station
  - There is an overall decrease in discharge volume as sea level rise increases (SLR1 > SLR2 > SLR3), however, the total discharge volume for SLR1 and SLR2 is greater than existing conditions (SLR0)
    - This is partially due to increased canal conveyance capacity and pump capacity
    - Total discharge volume should not be used as an indicator of structure performance
      - The raised gate overtopping elevation blocks storm surge, which directly reduces the total discharge volume as there is no reverse flow or structure bypass for the tidal structure to discharge like there is under the without mitigation scenarios.
    - Total discharge volume should not be used as an indicator of structure performance
      - The raised gate overtopping elevation blocks storm surge, which directly reduces the total discharge volume as there is no reverse flow or structure bypass for the tidal structure to discharge like there is under the without mitigation scenarios.
    - Simulated pump station has a discharge capacity that is about 110% of the sluice gate design discharge
      - The design discharge of 3,220 cfs is based on very specific headwater and tailwater conditions. Under future conditions without mitigation, the S-28 sluice gate is predicted to have peak discharge rates of more than 5,000 cfs
      - The pump station allows longer periods of "smaller" discharge rates whereas gravity structure tends to operate in short bursts of "larger" discharge rates

7.1.3 PM #5 – Frequency of Flooding

The Phase 1 FPLOS PM #5 Assessment analyzed overland flooding for the purposes of identifying deficiencies in the system, both those related to or unrelated to PM #1 deficiencies, and to assign an overall level of service rating in conjunction with the results from PM #1. The PM #5 level of service analysis of the C-8 Watershed in the Phase 1 FPLOS Assessment was used as a way to identify areas of flooding due to water levels in the C-8 Canal that may not show up as bank exceedances in PM #1. As a reminder, bank exceedances are just one component of flood protection and just because there are bank exceedances doesn't necessarily mean there will be inundation of urban areas, and likewise, just because there are areas where there are not bank exceedances doesn't necessarily mean there isn't flooding of urban areas. As these bank exceedances and areas of overland flooding were identified in the Phase 1 FPLOS Assessment, the focus of this Phase 2 FPLOS PM #5 assessment is to show how of the flooding compares to both existing conditions and future condition sea level rise with no mitigation. For the purposes of the Phase 2 FPLOS Assessment, the goal was to provide a flood protection level of service equal to or better than the 25-year SLR0 event during a 25-year SLR1 event for Mitigation M2A, 25-year SLR2 event for Mitigation M2B, and 25-year SLR3 event for Mitigation M2C.

Table 7.1-4 through **Table 7.1-7** summarizes the area of flooding for the 5-year, 10-year, 25-year, and 100-year design storm events for SLR0, SLR1, SLR2, and SLR3, under existing conditions (Mitigation 0), Mitigation M2A, Mitigation M2B, and Mitigation M2C, for all land use and urban land use only. Please note that the area with water depth less than 0.25 ft presented in these tables do not include areas with water depth equal to zero. Area of flooding presented in **Table 7.1-4** through **Table 7.1-7** are cumulative in order of decreasing depths (i.e., area greater than 2.5 ft are included in the area greater than 2.25 ft). Depths less than 0.25 ft are not included in the cumulative area calculations.

Section 7.1.3.1 through **Section 7.1.3.3** presents the Phase 2 PM #5 FPLOS Assessment for Mitigation M2A, M2B, and M2C, respectively. Within each section, three figures are presented that show the 25-year flood inundation map for the respective sea level rise scenario, a flood inundation difference map between the 25-year SLR mitigation scenario and the 25-year SLR0 existing conditions scenario, and a flood inundation difference map between the 25-year SLR mitigation scenario and the respective 25-year future sea level rise without mitigation scenario. For instance, **Section 7.1.3.1** presents the 25-year SLR1 flood inundation map under Mitigation M2A, the flood inundation difference map between the M2A 25-year SLR1 event and the existing conditions (M0) 25-year SLR0 event, and the flood inundation difference map between the M2A 25-year SLR1 event and the future conditions without mitigation 25-year SLR1 event. **Section 7.1.3.2** and **Section 7.1.3.3** show the same three figures but for SLR2 for Mitigation M2B and SLR3 for Mitigation M2C, respectively. Please note that some of the areas shown to have a large decrease in flood depths in the comparison between future conditions and existing conditions may correspond to areas where the topography was increased to the FEMA BFE in areas of future land use change during future conditions model development. Refer to **Appendix B** for the complete set of flood inundation maps for the 5-year, 10-year, 25-year, and 100-year design storms for SLR1, SLR2, and SLR3, for all land use and urban land use only, for each of the three mitigation scenarios.

Table 7.1-4: Summary of the PM#5 Flood Inundation Area for the C-8 Watershed 5-Year Design Storm

5-Year Design Storm																
Water Depth (ft)	Area of Flooding within the C-8 Watershed (acres) (C-8 Watershed is approximately 18,060 acres)															
	Mitigation 0 (Existing Conditions)				Mitigation M2A				Mitigation M2B				Mitigation M2C			
	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3
< 0.25	3662	3819	3762	3723	3842	3827	3807	3768	3996	3987	3966	3924	4005	3992	3976	3951
>= 0.25	6579	6552	6730	7001	6460	6511	6584	6730	6306	6343	6416	6571	6294	6329	6397	6514
>= 0.50	3592	3639	3858	4169	3493	3559	3674	3841	3378	3428	3534	3712	3370	3409	3514	3659
>= 0.75	2225	2310	2510	2881	2179	2228	2337	2520	2097	2142	2254	2428	2086	2128	2225	2382
>= 1.00	1662	1788	1964	2305	1684	1722	1813	1975	1635	1668	1756	1922	1622	1657	1738	1876
>= 1.25	1396	1546	1703	1961	1448	1493	1577	1707	1414	1453	1542	1680	1400	1441	1518	1626
>= 1.50	1272	1381	1538	1756	1181	1266	1440	1547	1165	1247	1417	1526	1154	1201	1401	1495
>= 1.75	1189	1190	1357	1638	1090	1163	1201	1433	1077	1146	1189	1418	1015	1127	1178	1395
>= 2.00	1064	1112	1196	1442	945	1080	1132	1215	896	1067	1121	1205	878	974	1117	1186
>= 2.25	839	975	1136	1234	705	859	1029	1148	665	843	1020	1138	601	760	1023	1122
>= 2.50	324	509	859	1169	233	366	630	955	220	352	633	952	211	273	614	905
Area of Flooding in Urban Land Use within the C-8 Watershed (acres) (C-8 Watershed Urban Area by Land Use is approximately 15,760 acres)																
< 0.25	3432	3563	3520	3485	3585	3573	3555	3523	3707	3704	3686	3647	3713	3707	3695	3666
>= 0.25	5062	5024	5163	5401	4952	4990	5044	5160	4830	4855	4910	5036	4821	4845	4894	4991
>= 0.50	2274	2267	2443	2711	2162	2207	2291	2428	2069	2100	2176	2327	2064	2087	2157	2279
>= 0.75	1014	1024	1179	1500	936	969	1039	1183	866	895	962	1107	860	884	943	1065
>= 1.00	516	547	683	968	481	504	565	680	442	459	509	637	435	454	501	598
>= 1.25	301	348	465	668	287	315	366	457	263	286	334	434	260	282	320	388
>= 1.50	210	240	339	504	195	215	269	338	187	204	250	319	183	202	241	296
>= 1.75	159	195	238	421	154	175	203	259	147	166	199	247	142	162	190	233
>= 2.00	126	156	196	307	124	140	164	203	118	132	159	198	114	129	154	192
>= 2.25	85	126	167	222	72	87	138	170	63	83	135	165	54	79	131	157
>= 2.50	50	71	110	182	36	52	76	128	31	48	74	126	27	39	70	113

Area of flooding is cumulative in order of decreasing depths (i.e., area greater than or equal to 2.5 ft are included in the area greater than or equal to 2.25 ft)

Table 7.1-5: Summary of the PM#5 Flood Inundation Area for the C-8 Watershed 10-Year Design Storm

10-Year Design Storm																
Water Depth (ft)	Area of Flooding within the C-8 Watershed (acres) (C-8 Watershed is approximately 18,060 acres)															
	Mitigation 0 (Existing Conditions)				Mitigation M2A				Mitigation M2B				Mitigation M2C			
	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3
< 0.25	3404	3551	3500	3382	3567	3564	3548	3501	3736	3737	3714	3677	3741	3734	3714	3689
>= 0.25	7362	7342	7536	7881	7222	7271	7354	7515	7029	7070	7155	7315	7015	7051	7130	7258
>= 0.50	4359	4341	4600	4953	4179	4258	4365	4549	3999	4063	4171	4375	3983	4037	4133	4292
>= 0.75	2715	2779	3064	3391	2599	2672	2800	2994	2489	2549	2666	2865	2471	2523	2631	2792
>= 1.00	1956	2077	2293	2664	1912	1976	2086	2261	1841	1899	2002	2171	1825	1873	1970	2115
>= 1.25	1601	1741	1932	2273	1609	1667	1756	1912	1565	1614	1700	1858	1555	1594	1674	1800
>= 1.50	1412	1566	1740	1974	1453	1503	1589	1711	1420	1468	1551	1673	1400	1446	1526	1625
>= 1.75	1288	1421	1585	1794	1205	1301	1456	1569	1187	1277	1438	1549	1179	1218	1409	1512
>= 2.00	1220	1213	1381	1662	1148	1175	1221	1453	1129	1155	1203	1434	1050	1148	1189	1404
>= 2.25	1074	1160	1230	1381	1040	1095	1168	1236	1034	1082	1155	1226	945	1017	1116	1207
>= 2.50	910	1092	1194	1272	727	969	1113	1193	714	955	1085	1181	643	851	1050	1164
Area of Flooding in Urban Land Use within the C-8 Watershed (acres) (C-8 Watershed Urban Area by Land Use is approximately 15,760 acres)																
< 0.25	3196	3319	3280	3175	3328	3327	3316	3281	3466	3466	3445	3413	3470	3464	3447	3427
>= 0.25	5773	5749	5911	6224	5658	5694	5755	5886	5504	5533	5598	5733	5494	5519	5579	5680
>= 0.50	2947	2910	3124	3445	2778	2839	2923	3079	2631	2677	2764	2941	2623	2658	2733	2869
>= 0.75	1427	1437	1677	1961	1296	1350	1450	1612	1203	1243	1332	1501	1194	1227	1302	1439
>= 1.00	747	783	958	1289	669	707	786	928	607	640	708	854	598	624	683	803
>= 1.25	447	490	641	937	404	439	495	614	368	393	443	570	362	382	428	518
>= 1.50	300	352	483	675	286	314	362	450	263	286	326	416	256	275	315	376
>= 1.75	217	263	368	524	207	226	273	341	197	215	257	324	192	207	244	296
>= 2.00	174	205	254	431	171	184	213	264	161	173	202	249	159	170	195	237
>= 2.25	138	176	212	324	140	156	179	214	136	149	173	209	132	142	163	200
>= 2.50	101	146	191	238	95	125	152	190	90	118	147	184	71	112	142	173

Area of flooding is cumulative in order of decreasing depths (i.e., area greater than or equal to 2.5 ft are included in the area greater than or equal to 2.25 ft)

Table 7.1-6: Summary of the PM#5 Flood Inundation Area for the C-8 Watershed 25-Year Design Storm

25-Year Design Storm																
Water Depth (ft)	Area of Flooding within the C-8 Watershed (acres) (C-8 Watershed is approximately 18,060 acres)															
	Mitigation 0 (Existing Conditions)				Mitigation M2A				Mitigation M2B				Mitigation M2C			
	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3
< 0.25	3050	3117	3012	2900	3166	3153	3111	3037	3357	3343	3321	3266	3358	3356	3337	3282
>= 0.25	8450	8499	8816	9163	8304	8384	8534	8751	8050	8111	8217	8447	8023	8064	8162	8332
>= 0.50	5455	5440	5761	6242	5199	5282	5477	5712	4959	5029	5172	5403	4921	4981	5101	5288
>= 0.75	3582	3587	3906	4403	3312	3427	3624	3854	3143	3214	3360	3610	3104	3158	3289	3474
>= 1.00	2571	2612	2993	3356	2377	2469	2670	2916	2264	2339	2470	2719	2224	2286	2404	2584
>= 1.25	2014	2099	2448	2782	1903	1989	2150	2352	1833	1884	1995	2207	1797	1844	1937	2102
>= 1.50	1722	1853	2075	2466	1682	1752	1877	2033	1636	1684	1767	1936	1602	1649	1721	1843
>= 1.75	1547	1687	1874	2185	1555	1618	1724	1850	1522	1574	1640	1776	1488	1537	1612	1700
>= 2.00	1413	1561	1740	1953	1430	1503	1596	1710	1405	1466	1544	1646	1355	1420	1513	1593
>= 2.25	1314	1304	1612	1788	1216	1262	1480	1581	1197	1234	1440	1550	1161	1200	1265	1510
>= 2.50	1262	1248	1325	1673	1161	1205	1260	1413	1133	1184	1240	1325	1018	1131	1214	1271
Area of Flooding in Urban Land Use within the C-8 Watershed (acres) (C-8 Watershed Urban Area by Land Use is approximately 15,760 acres)																
< 0.25	2870	2922	2826	2715	2955	2950	2918	2848	3103	3104	3083	3030	3109	3108	3100	3046
>= 0.25	6762	6810	7100	7414	6650	6709	6838	7038	6447	6486	6579	6787	6426	6455	6530	6681
>= 0.50	3930	3923	4204	4641	3719	3786	3946	4153	3520	3578	3694	3900	3489	3538	3632	3798
>= 0.75	2154	2155	2437	2883	1923	2016	2186	2386	1779	1836	1956	2189	1749	1790	1898	2063
>= 1.00	1236	1250	1584	1907	1048	1127	1295	1512	947	1008	1119	1343	922	968	1061	1218
>= 1.25	749	779	1080	1380	616	686	820	992	555	590	685	866	533	567	632	772
>= 1.50	517	567	757	1097	432	480	584	712	391	418	484	630	371	398	444	547
>= 1.75	379	425	586	849	333	371	456	555	305	331	379	493	289	311	358	425
>= 2.00	279	330	477	645	256	288	353	443	242	268	308	387	230	248	288	341
>= 2.25	218	251	375	509	206	228	270	343	196	214	246	319	189	199	226	288
>= 2.50	186	219	267	427	174	194	223	263	166	182	209	246	158	171	197	228

Area of flooding is cumulative in order of decreasing depths (i.e., area greater than or equal to 2.5 ft are included in the area greater than or equal to 2.25 ft)

Table 7.1-7: Summary of the PM#5 Flood Inundation Area for the C-8 Watershed 100-Year Design Storm

100-Year Design Storm																
Water Depth (ft)	Area of Flooding within the C-8 Watershed (acres) (C-8 Watershed is approximately 18,060 acres)															
	Mitigation 0 (Existing Conditions)				Mitigation M2A				Mitigation M2B				Mitigation M2C			
	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3
< 0.25	2526	2514	2454	2307	2630	2575	2519	2472	2855	2810	2766	2702	2873	2851	2801	2762
>= 0.25	10071	10231	10533	10986	9871	10053	10239	10446	9559	9705	9869	10089	9472	9565	9730	9919
>= 0.50	7211	7299	7697	8245	6848	7067	7331	7593	6514	6667	6893	7160	6418	6518	6716	6953
>= 0.75	5043	5099	5584	6155	4641	4878	5138	5447	4392	4557	4762	5048	4293	4398	4604	4817
>= 1.00	3693	3741	4210	4766	3328	3535	3769	4063	3141	3280	3473	3720	3043	3152	3322	3538
>= 1.25	2858	2971	3310	3942	2573	2764	2984	3188	2441	2580	2736	2954	2349	2447	2605	2787
>= 1.50	2369	2485	2813	3306	2133	2290	2510	2723	2036	2162	2315	2513	1955	2038	2199	2356
>= 1.75	2025	2139	2505	2860	1864	2004	2174	2379	1801	1902	2028	2216	1750	1804	1928	2079
>= 2.00	1775	1927	2221	2594	1712	1821	1945	2110	1680	1752	1845	1992	1644	1684	1759	1880
>= 2.25	1614	1795	1993	2364	1618	1688	1804	1916	1593	1646	1724	1831	1560	1599	1662	1739
>= 2.50	1486	1657	1819	2107	1531	1594	1674	1773	1508	1566	1620	1706	1323	1518	1582	1641
Area of Flooding in Urban Land Use within the C-8 Watershed (acres) (C-8 Watershed Urban Area by Land Use is approximately 15,760 acres)																
< 0.25	2383	2360	2312	2168	2462	2415	2362	2323	2640	2609	2574	2513	2657	2638	2602	2576
>= 0.25	8266	8423	8689	9115	8100	8261	8429	8611	7842	7962	8110	8308	7765	7842	7981	8146
>= 0.50	5540	5649	6011	6511	5246	5440	5680	5911	4964	5101	5295	5530	4878	4969	5140	5338
>= 0.75	3473	3538	3978	4498	3141	3342	3576	3850	2931	3074	3258	3503	2841	2931	3116	3300
>= 1.00	2204	2254	2665	3178	1899	2078	2277	2530	1735	1859	2030	2240	1647	1740	1894	2085
>= 1.25	1443	1547	1834	2402	1197	1366	1559	1727	1076	1197	1339	1526	993	1081	1216	1378
>= 1.50	1021	1103	1388	1823	793	933	1130	1306	707	815	951	1127	635	704	848	983
>= 1.75	737	797	1111	1422	564	675	824	1005	505	585	697	859	462	502	605	737
>= 2.00	548	614	859	1191	440	526	628	761	410	461	540	659	379	407	463	564
>= 2.25	421	510	663	990	367	420	517	601	344	380	445	527	323	347	390	448
>= 2.50	325	394	529	772	303	346	406	486	288	322	360	427	258	292	331	369

Area of flooding is cumulative in order of decreasing depths (i.e., area greater than or equal to 2.5 ft are included in the area greater than or equal to 2.25 ft)

7.1.3.1 PM #5 – Mitigation M2A

Mitigation scenario M2A is the least aggressive form of mitigation out of the three mitigation strategies analyzed in this study. Although Mitigation M2A has a relatively large pumping capacity of 1,550 cfs, the C-8 Canal still had several instances of bank exceedances and had high enough water levels to inhibit gravity-driven drainage in the secondary/tertiary system, contributing to overland flooding of urban areas in several locations as shown in **Figure 7.1-38**. Mitigation M2A, although close, was unable to achieve a PM #1 25-year SLR1 maximum water surface profile in the C-8 Canal that was equal to or lower than existing conditions 25-year SLR0 profile. As such, it is no surprise that there are areas of overland flooding during the 25-year SLR1 event under mitigation M2A that is greater than existing conditions, as shown in **Figure 7.1-39**. **Figure 7.1-39** shows a large area near State Road 915 and 916 that is approximately 0.1 to 0.2 ft higher than current conditions. Further south, near where State Road 915 intersects the C-8 Canal, there is a small area with flood depths approximately 0.1 to 0.3 ft lower than current conditions. This is due to the pump station pulling down localized water levels upstream of Structure S-28. During the 25-year SLR1 event, the 1,550 cfs pump station is large enough to draw down C-8 Canal to an elevation lower than existing conditions, but only for about the first two miles upstream of the structure. Please note that some of the areas shown to have a large decrease in flood depths **Figure 7.1-39** correspond to areas where the topography was increased to the FEMA BFE in areas of future land use change during future conditions model development. Although **Figure 7.1-39** doesn't show that Mitigation M2A has significant improvements compared to current conditions, **Figure 7.1-40** shows just how much flooding this mitigation strategy is mitigating compared to future conditions without mitigation.

Figure 7.1-40 presents the flooding depth differences between the 25-year SLR1 event with and without mitigation. Although the goal was to achieve flood protection equal to or better than existing conditions, it was just that- a goal. The reality of it is that sea level rise is going to bring about unprecedented changes in the form of higher tide levels to discharge against, higher antecedent water levels throughout the watershed which effectively removes storage that was once there, and areas with higher groundwater levels which not only removes storage that was once there but can actively rise above land surface further contributing to flooding. Therefore, although achieving flood protection equal to or greater than what is currently provided under existing conditions is an appropriate goal to aim for, this shouldn't limit the success or consideration of mitigation strategies. Therefore, looking at the difference between flooding under a particular mitigation strategy and the flooding that could occur if no mitigation was implemented is what really shows how effective the mitigation strategy is. **Figure 7.1-40** shows a widespread reduction in flooding ranging from 0.1 to more than 0.5 ft (with localized values as high as 1 ft). This figure highlights the areas that are most impacted or benefited by Mitigation M2A.

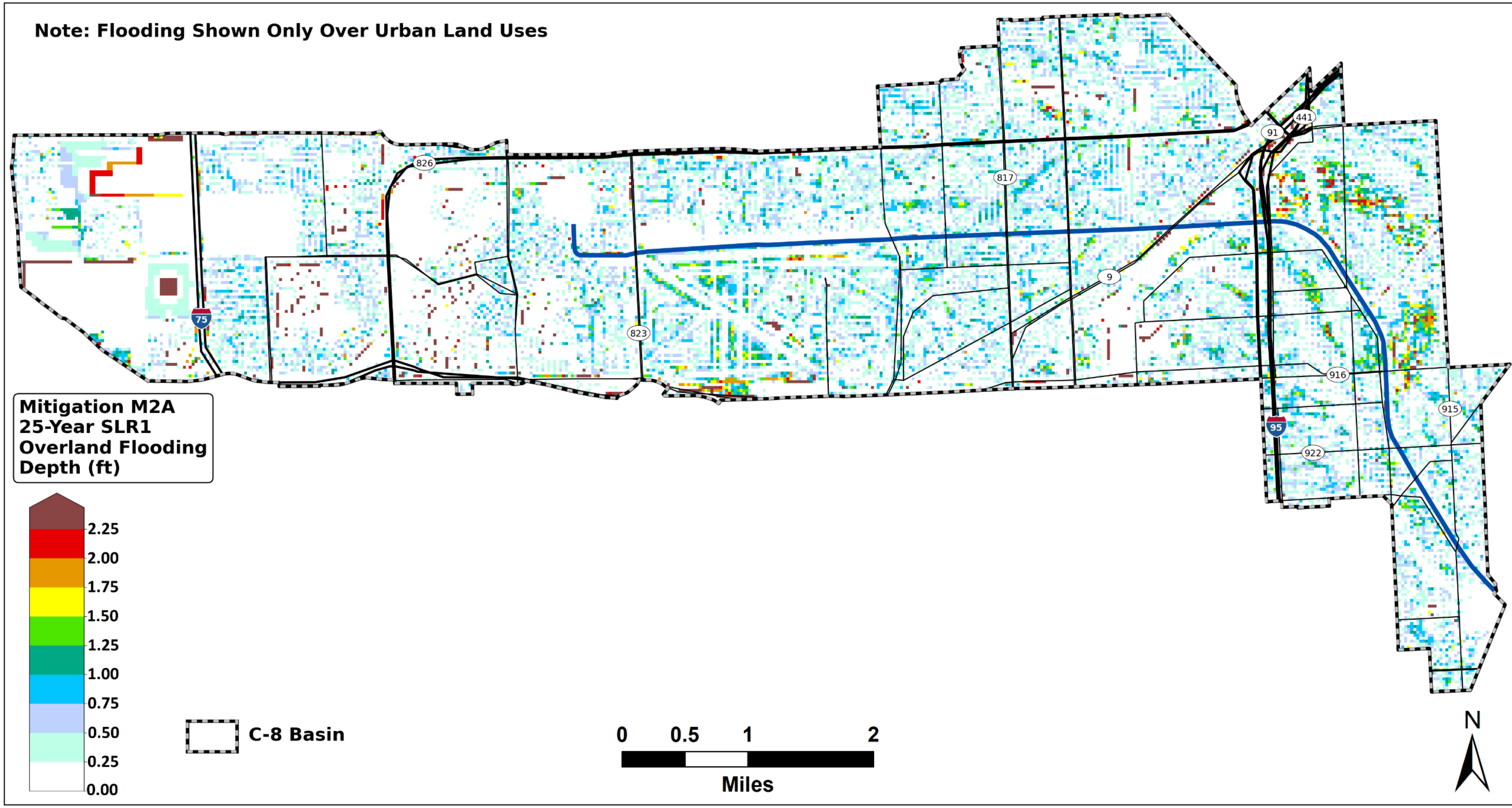


Figure 7.1-38: C-8 Watershed Flood Inundation Map for the Mitigation M2A 25-Year Sea Level Rise 1 Design Storm Event in Urban Land Use Areas

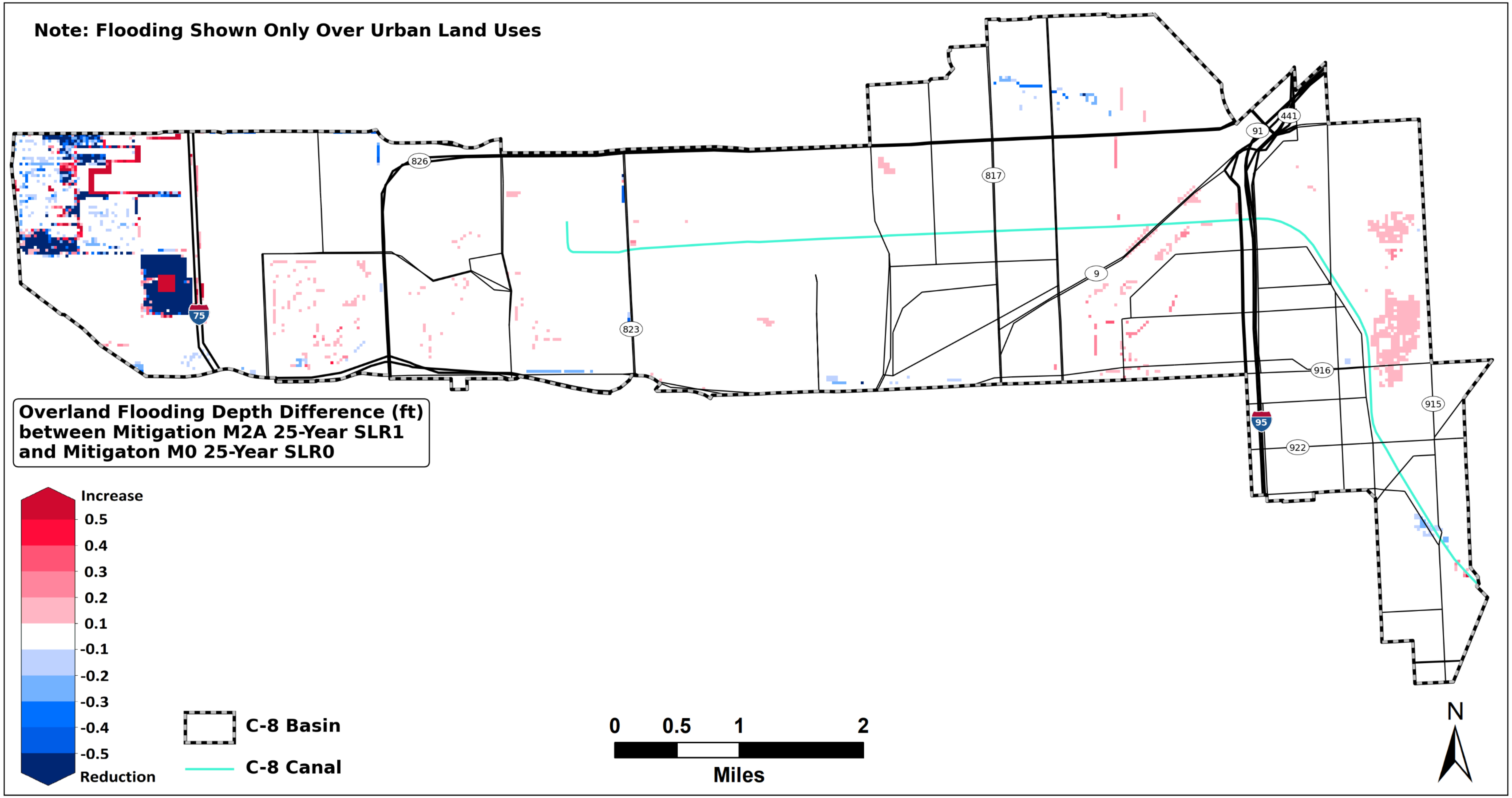


Figure 7.1-39: C-8 Watershed Flood Inundation Difference Map for Mitigation M2A 25-Year Sea Level Rise 1 versus Existing Conditions (M0) 25-Year SLR0 in Urban Land Use Areas

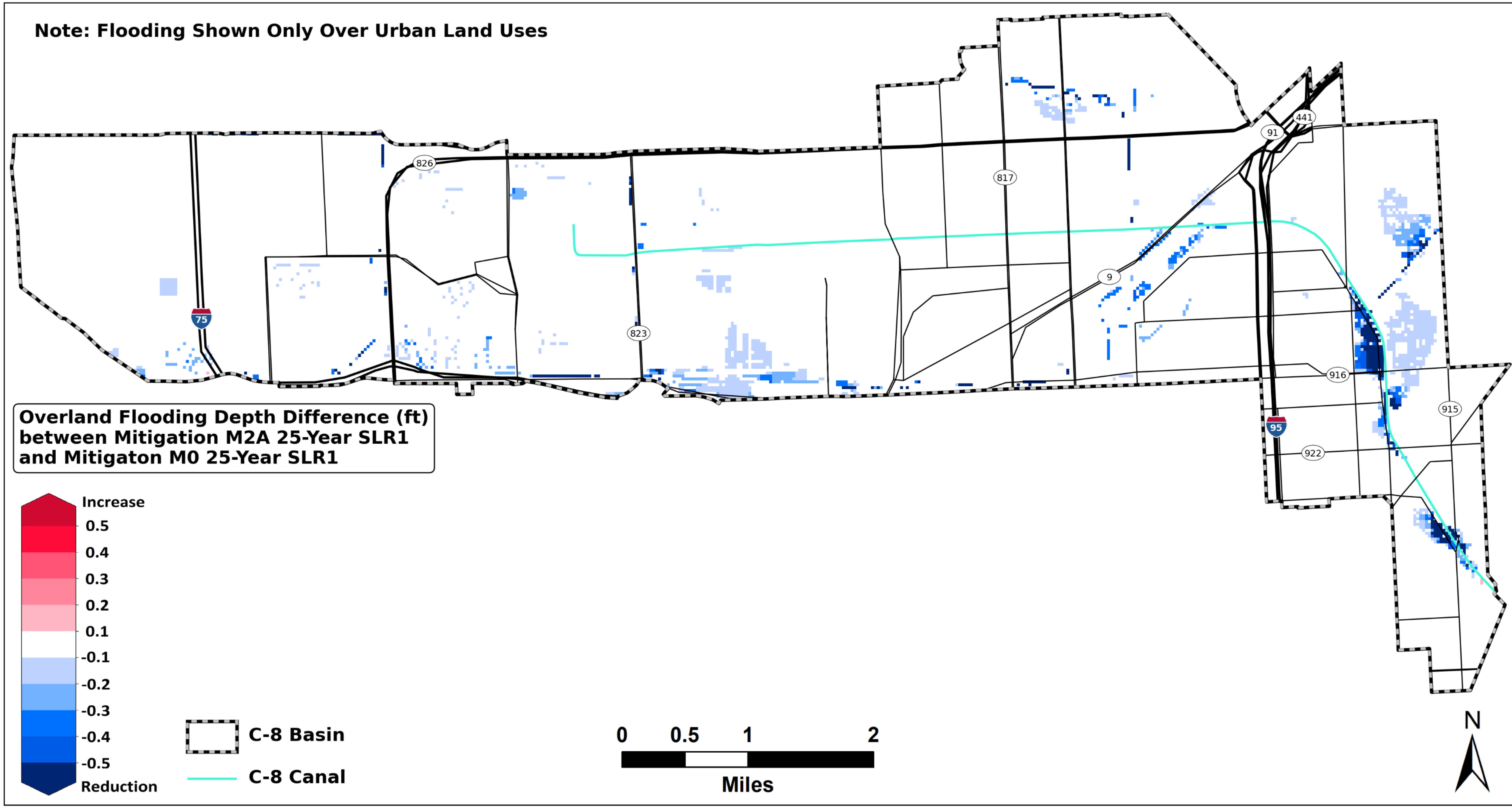


Figure 7.1-40: C-8 Watershed Flood Inundation Difference Map for Mitigation M2A 25-Year Sea Level Rise 1 versus Future Conditions without mitigation (M0) 25-Year SLR1 in Urban Land Use Areas

7.1.3.2 PM #5 – Mitigation M2B

Mitigation scenario M2B is a more aggressive form of mitigation compared to M2A but less aggressive than M2C, making it the middle level of mitigation out of the three mitigation strategies analyzed in this study. Although Mitigation M2B has a large pumping capacity of 2,550 cfs and raised canal embankments which prevents any instance of bank exceedance, the C-8 Canal still had high enough water levels to inhibit gravity-driven drainage in the secondary/tertiary system, contributing to overland flooding of urban areas in several locations as shown in **Figure 7.1-41**. Mitigation M2B, although within about 0.3 ft in any given location, was unable to achieve a PM #1 25-year SLR1 maximum water surface profile in the C-8 Canal that was equal to or lower than the existing conditions 25-year SLR0 profile. As such, it is no surprise that there are areas of overland flooding during the 25-year SLR2 event under mitigation M2B that is greater than existing conditions, as shown in **Figure 7.1-42**. However, there is also a significant amount of area shown in **Figure 7.1-42** that has less flooding during the Mitigation M2B 25-year SLR2 event than under the 25-year SLR0 event without mitigation. Please note that some of the areas shown to have a large decrease in flood depths in **Figure 7.1-42** correspond to areas where the topography was increased to the FEMA BFE in areas of future land use change during future conditions model development. Raising the canal banks alone are not solely responsible for the reduction in flooding along most of the C-8 Canal, as this not only prevents water from spilling out of the canal into the urban areas but also prevents water from draining from urban areas into the canal. A conceptual internal gravity-driven drainage system was added along the C-8 Canal to allow one-way flow from the watershed into the C-8 Canal whenever the water level in the C-8 Canal was lower than the water level in the area draining to it. Without the conceptual drainage system and pump station in place, raising the canal embankments was actually shown to worsen flooding during the iteration testing, as all the rainfall would stack along the canal banks and would be unable to drain either due to the raised canal banks (without the internal drainage system) or due to elevated canal stages (without the pump station).

Like Mitigation M2A, the 2,550 cfs pump station is large enough to draw down C-8 Canal to an elevation lower than existing conditions, but only for about the first two miles upstream of the structure under the 25-year SLR2 scenario. Although 1,000 cfs larger than the pump capacity under Mitigation M2A, the reason the C-8 Canal water levels aren't pulled down further is a result of the increase in sea level rise reducing S-28 gravity discharge, reduced floodplain storage from the C-8 Canal staying within bank, and increased flow to the C-8 Canal due to the internal drainage system.

Some of the increased flooding shown in **Figure 7.1-42** is related to higher groundwater elevations. As sea level rise increases, the antecedent groundwater elevations are predicted to increase. In some areas, the maximum groundwater elevation is higher than the land surface elevation, which results in an increase in flood depths that are difficult and potentially infeasible to fully mitigate. **Figure 7.1-43** presents the flooding depth differences between the 25-year SLR2 event with and without mitigation. Although the goal was to achieve flood protection equal to or better than existing conditions, it was just that, a goal. Therefore, although achieving flood protection equal to or greater than what is currently provided under existing conditions is a great goal to aim for, this shouldn't limit the success or consideration of mitigation strategies. Therefore, looking at the difference between flooding under a particular mitigation strategy and the flooding that could occur if no mitigation was implemented is what really shows how effective the mitigation strategy is. **Figure 7.1-43** shows a widespread reduction in flooding ranging from 0.1 to more than 0.5 ft (up to 2 ft). This figure highlights the areas that are most impacted or benefited by Mitigation M2B.

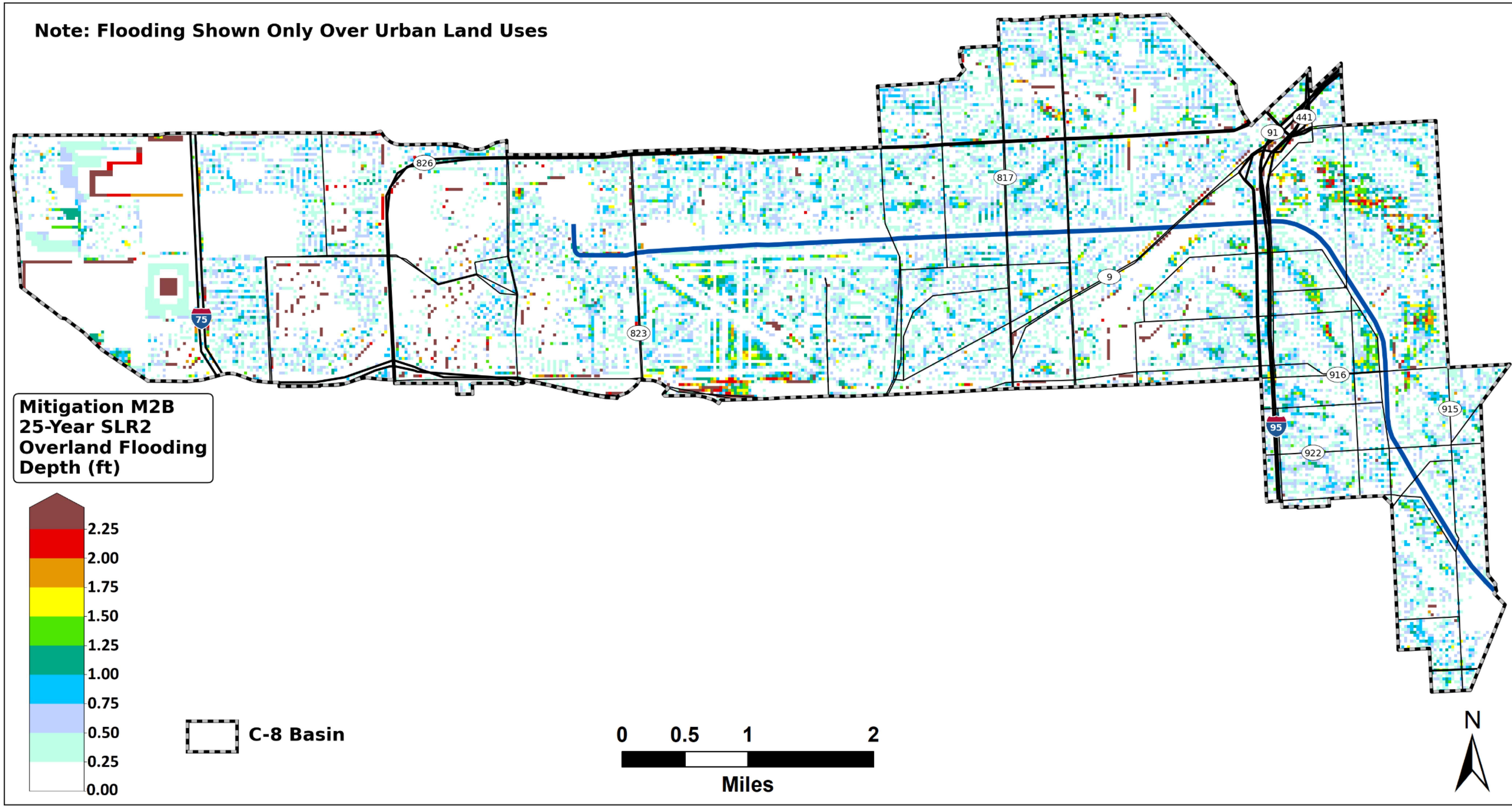


Figure 7.1-41: C-8 Watershed Flood Inundation Map for the Mitigation M2B 25-Year Sea Level Rise 2 Design Storm Event in Urban Land Use Areas

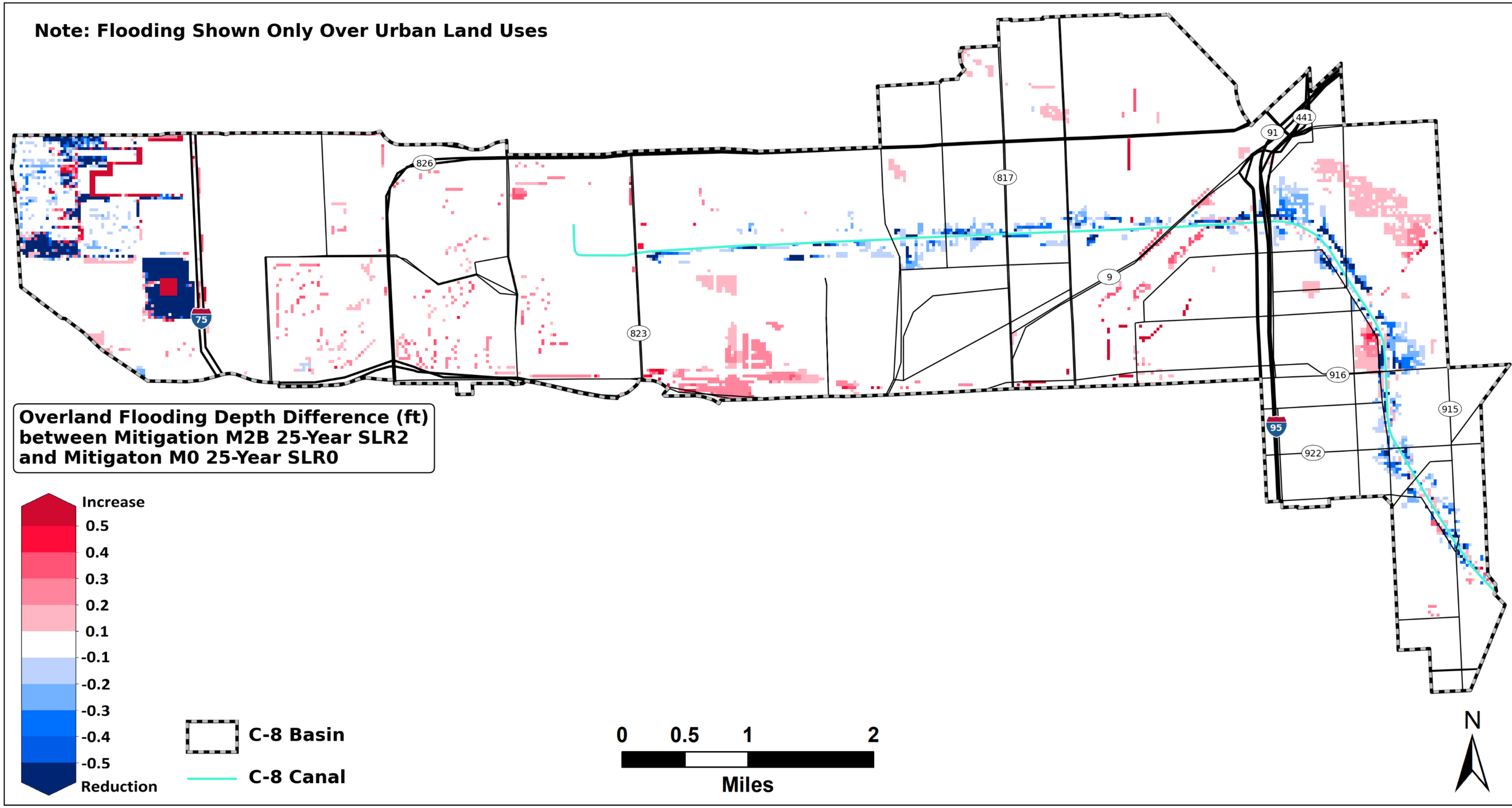


Figure 7.1-42: C-8 Watershed Flood Inundation Difference Map for Mitigation M2B 25-Year Sea Level Rise 2 versus Existing Conditions (M0) 25-Year SLR0 in Urban Land Use Areas

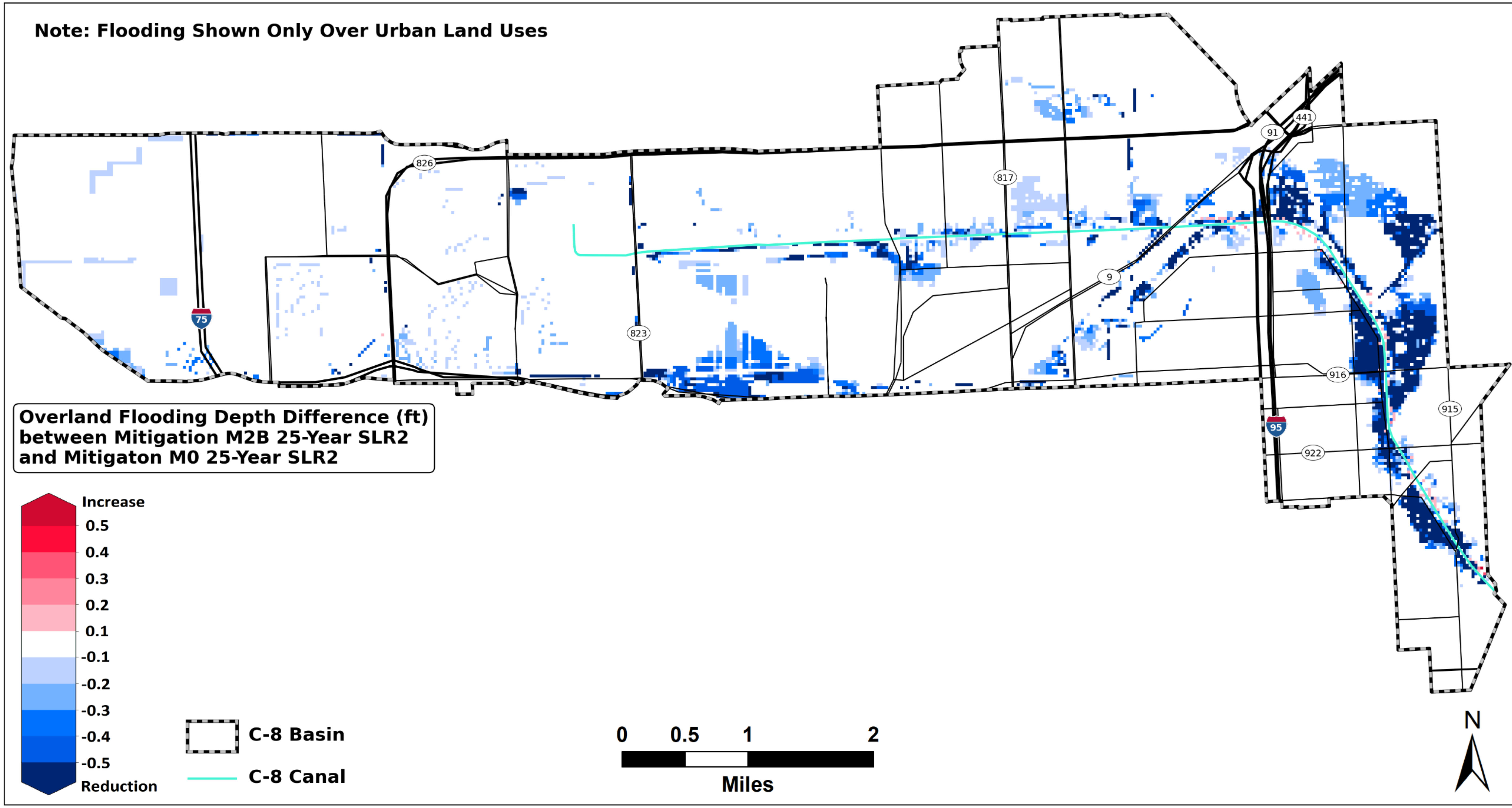


Figure 7.1-43: C-8 Watershed Flood Inundation Difference Map for Mitigation M2B 25-Year Sea Level Rise 2 versus Future Conditions without mitigation (M0) 25-Year SLR2 in Urban Land Use Areas

7.1.3.3 PM #5 – Mitigation M2C

Mitigation scenario M2C is the most aggressive form of mitigation out of the three mitigation strategies analyzed in this study. Although Mitigation M2C has a very large pumping capacity of 3,550 cfs and raised canal embankments which prevents any instance of bank exceedance, the C-8 Canal still had high enough water levels to inhibit gravity-driven drainage in the secondary/tertiary system, contributing to overland flooding of urban areas in several locations as shown in **Figure 7.1-44**. Mitigation M2C was unable to achieve a PM #1 25-year SLR3 maximum water surface profile in the C-8 Canal that was equal to or lower than existing conditions 25-year SLR0 profile, with water levels about 0.5 ft higher along the entire canal. As such, it is no surprise that there are areas of overland flooding during the 25-year SLR3 event under mitigation M2C that are greater than existing conditions, as shown in **Figure 7.1-45**. However, there is also a significant amount of area shown in **Figure 7.1-45** that has less flooding during the Mitigation M2C 25-year SLR3 event than under the 25-year SLR0 event without mitigation. Please note that some of the areas shown to have a large decrease in flood depths in **Figure 7.1-45** correspond to areas where the topography was increased to the FEMA BFE in areas of future land use change during future conditions model development. Raising the canal banks alone are not solely responsible for the reduction in flooding along most of the C-8 Canal, as this not only prevents water from spilling out of the canal into the urban areas but also prevents water from draining from urban areas into the canal. A conceptual internal gravity-driven drainage system was added along the C-8 Canal to allow one-way flow from the watershed into the C-8 Canal whenever the water level in the C-8 Canal was lower than the water level in the area draining to it. Without the conceptual drainage system and pump station in place, raising the canal embankments was actually shown to worsen flooding during the iteration testing, as all the rainfall would stack along the canal banks and would be unable to drain either due to the raised canal banks (without the internal drainage system) or due to elevated canal stages (without the pump station).

Additionally, the C-8 Canal was widened by 100 ft in this scenario, from Interstate 95 (i95) to the S-28 tidal structure. The widening of the C-8 Canal increased its conveyance capacity, causing a shift in the hydraulic grade line, decreasing the upstream water levels (western portion of C-8 Canal) / increasing the downstream water levels (eastern portion of C-8 Canal), at which point the increased pump capacity offsets the increased downstream water levels. Without widening the C-8 Canal, the 3,550 cfs pump station would have significantly lowered the immediate area upstream of the pump station but would have little to no added benefit to the water levels upstream compared to the benefits of a 2,550 cfs pump.

Unlike Mitigation M2A or M2B, the 3,550 cfs pump station in Mitigation M2C was unable to draw down the 25-year SLR3 water levels in the C-8 Canal to an elevation lower than existing conditions in any location. There are several reasons why the 25-year SLR3 water levels in the C-8 Canal are predicted to be unable to be brought down to existing conditions. These reasons include but are not limited to the increase in sea level rise reducing S-28 gravity discharge, the reduced storage caused by increased groundwater levels, reduced floodplain storage from the C-8 Canal staying within bank, and increased flow to the C-8 Canal due to the internal drainage system. Some of the increased flooding shown in **Figure 7.1-45** is related to higher groundwater elevations. As sea level rise increases, the antecedent groundwater elevations are predicted to increase. In many areas, the maximum groundwater elevation is higher than the land surface elevation, which results in an increase in flood depths that are difficult and potentially infeasible to fully mitigate. **Figure 7.1-46** presents the flooding depth differences between the 25-year SLR3 event with and without mitigation. Although the goal was to achieve flood protection equal to or better than existing conditions, it was just that, a goal. Therefore, looking at the difference between flooding under a particular mitigation strategy and the flooding that could occur if no mitigation was implemented is what really shows how effective the mitigation strategy is. **Figure 7.1-46** shows a widespread reduction in flooding ranging from 0.1 to more than 0.5 ft (with localized values as high as 3 ft). This figure highlights the areas that are most impacted or benefited by Mitigation M2C.

Although Mitigation M2C was unable to achieve a 25-year SLR3 PM #1 maximum water surface profile equal to or lower than existing conditions (25-year SLR0) and has increased PM #5 flooding when compared to existing conditions, it was actually quite effective for the 25-year SLR2 event. As the goal for Mitigation M2C was the 25-year SLR3 event, no difference maps are shown for M2C under smaller sea level rise scenarios or different rainfall events. However, looking at PM #1 provides a glimpse of the potential benefit of this Mitigation scenario under other combinations of rainfall and sea level rise. Likewise, Mitigation M2A and M2B have varying levels of performance across each rainfall and sea level rise combination, and this report is only providing a glimpse of that based on the goal of the study.

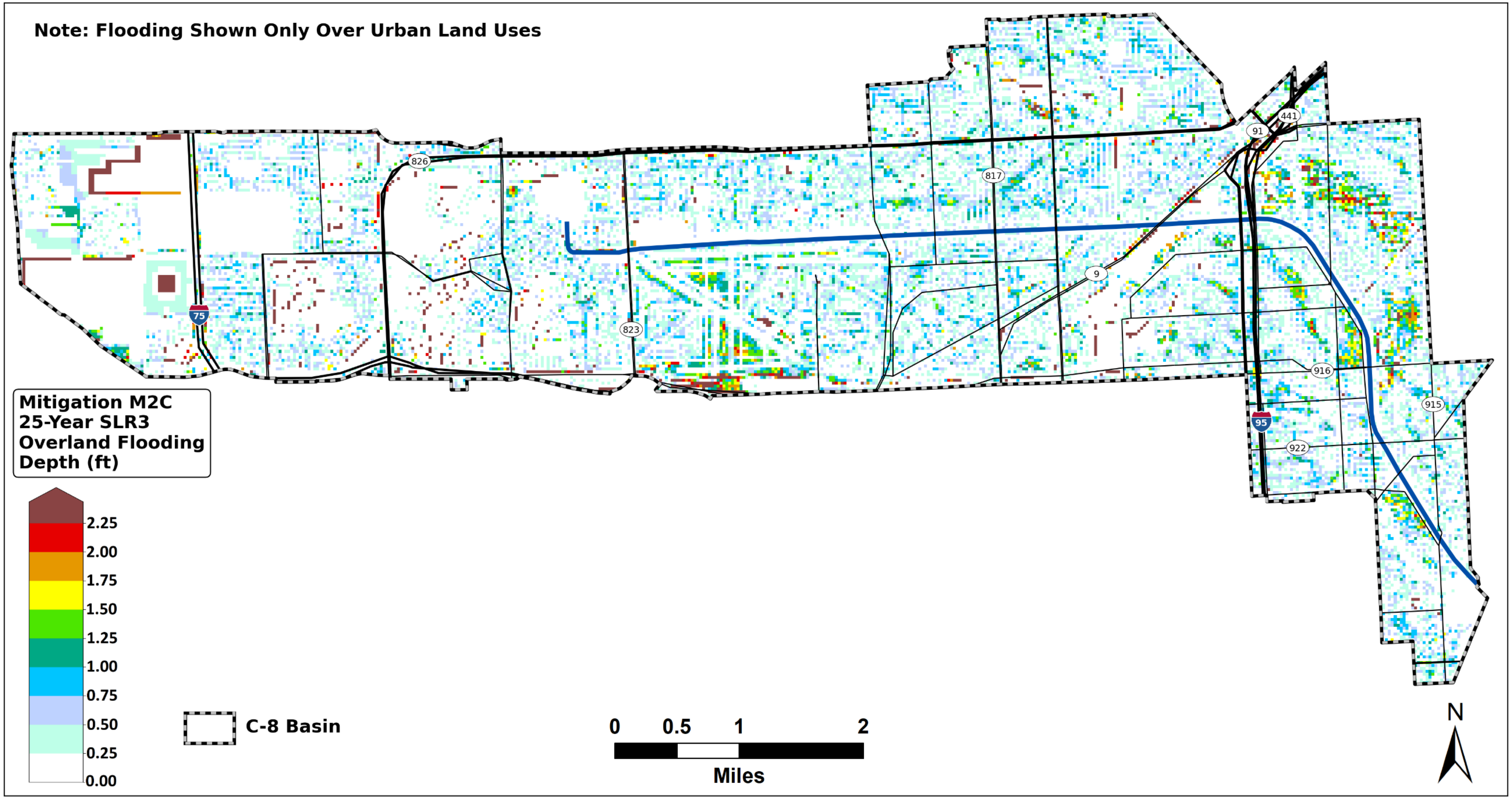


Figure 7.1-44: C-8 Watershed Flood Inundation Map for the Mitigation M2C 25-Year Sea Level Rise 3 Design Storm Event in Urban Land Use Areas

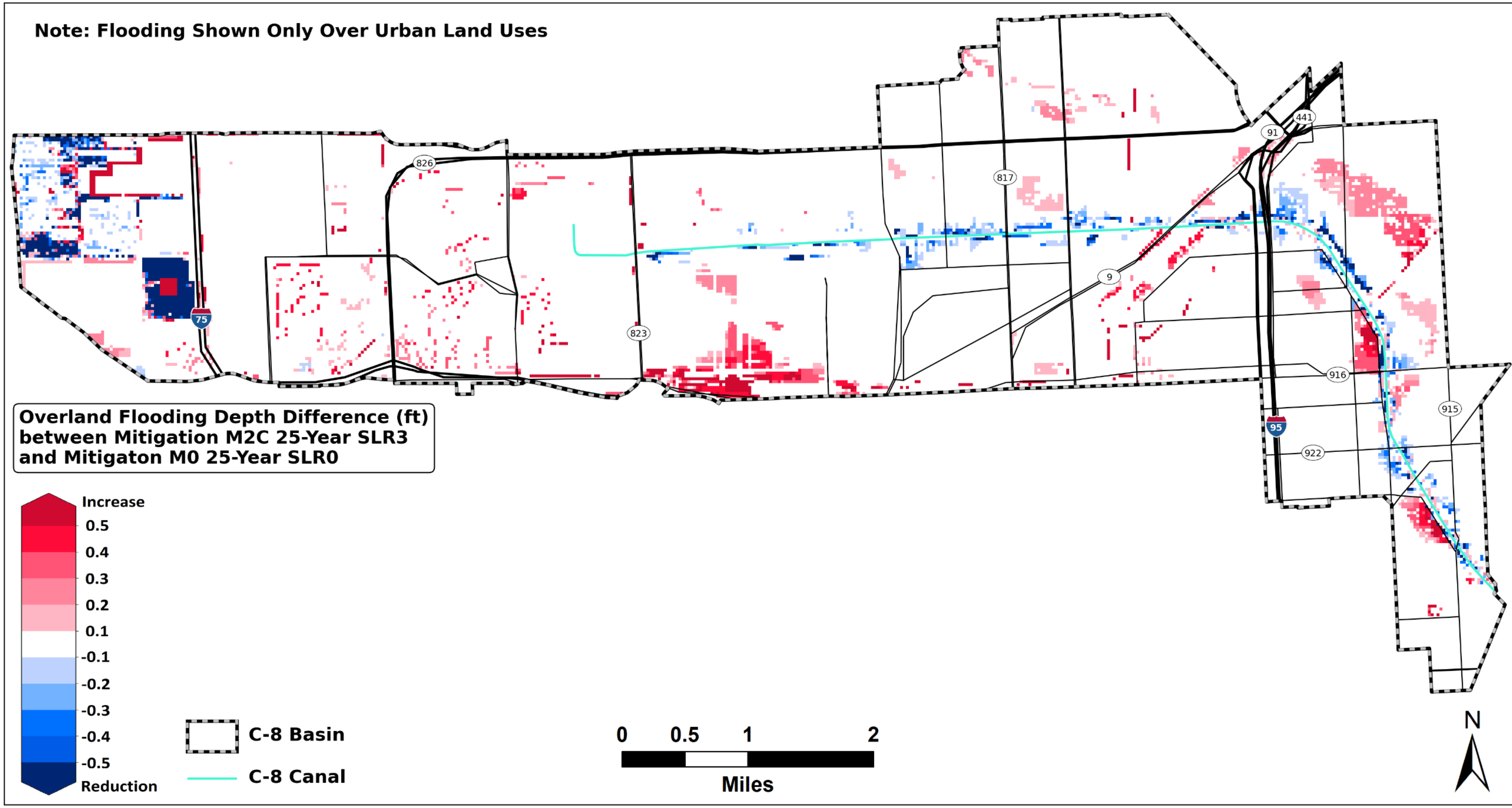


Figure 7.1-45: C-8 Watershed Flood Inundation Difference Map for Mitigation M2C 25-Year Sea Level Rise 3 versus Existing Conditions (M0) 25-Year SLR0 in Urban Land Use Areas

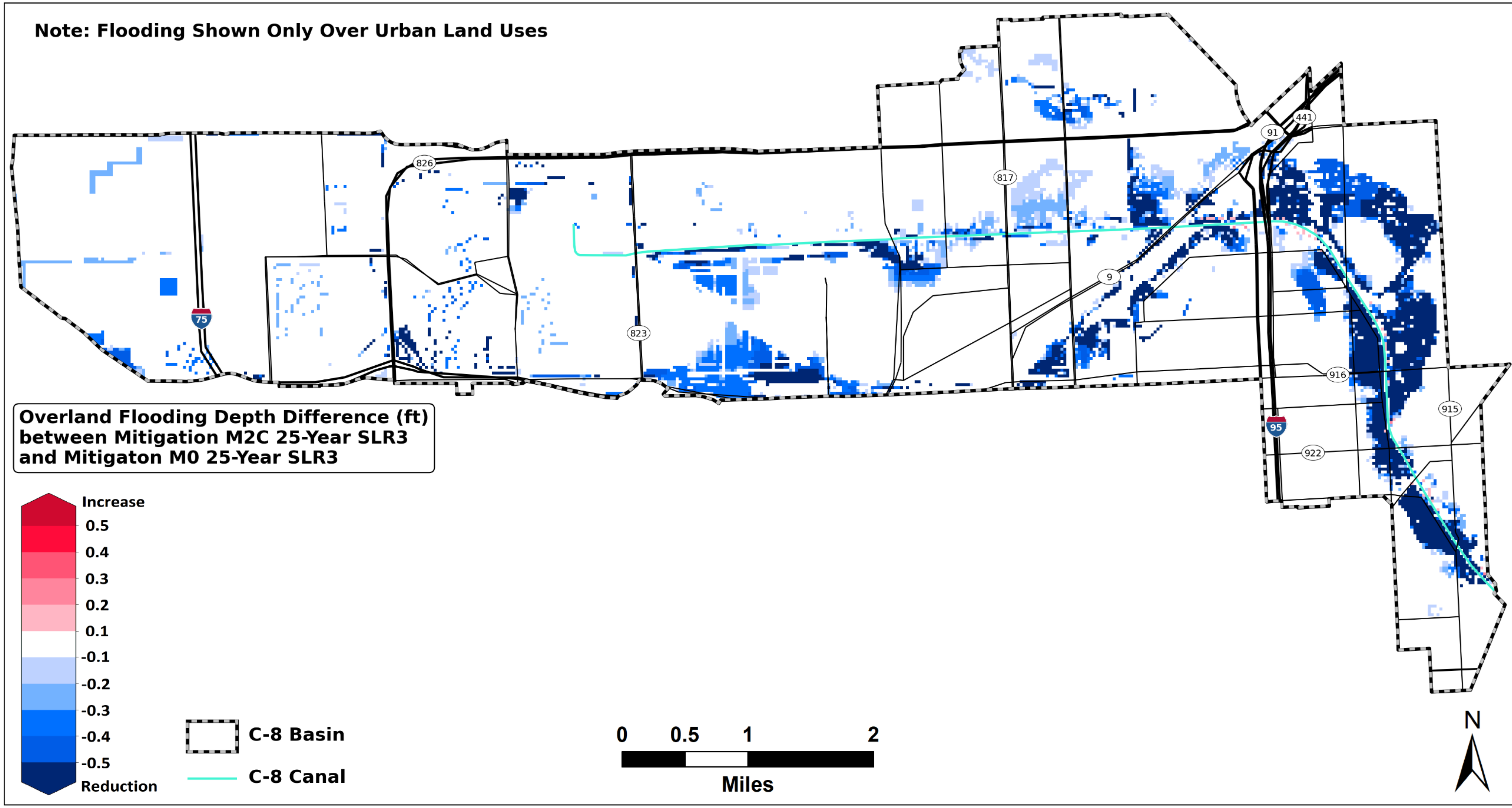


Figure 7.1-46: C-8 Watershed Flood Inundation Difference Map for Mitigation M2C 25-Year Sea Level Rise 3 versus Future Conditions without mitigation (M0) 25-Year SLR3 in Urban Land Use Areas

7.1.3.4 PM #5 – Summary for C-8 Watershed

- 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 is not predicted to be significantly better or worse than existing conditions
    - Overall, it is predicted that there will be significantly less flood inundation for the M2A 25-year SLR1 event than the 25-year SLR1 event without mitigation
- M2B
    - Overall, the M2B 25-year SLR2 flood inundation is not predicted to be significantly better or worse than existing conditions
        - There are 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, it is predicted that there will be significantly less flood inundation for the M2B 25-year SLR2 event than the 25-year SLR2 event without mitigation
- M2C
    - Overall, the M2C 25-year SLR3 flood inundation is not predicted to be significantly better or worse than existing conditions
        - There are 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, it is predicted that there will be significantly less flood inundation for the M2C 25-year SLR3 event than the 25-year SLR3 event without mitigation

7.1.4 PM #6 – Duration of Flooding

As part of this performance metric during the Phase 1 FPLOS study, a reference stage of 3.6 ft NGVD29 at S-28Z (a water level station approximately halfway up the C-8 Canal) was used to compare the time it takes the canal to return to the reference stage under current conditions and future conditions with sea level rise. However, as part of this Phase 2 FPLOS Study, a few significant assumption changes were made with respect to how the water level in the C-8 Canal is controlled under future conditions (related to salinity control). These new assumptions result in a large difference in C-8 Canal water levels between current conditions and each sea level rise scenario, making the reference stage comparison meaningless. Essentially, the water level in the C-8 Canal during SLR2 or SLR3 may never drop low enough to be compared with values from SLR, or at least not based on the modeling assumptions or within the simulated window of time. Therefore, no comparison of the duration taken for water levels in the C-8 Canal to return to a reference stage will be made.

Table 7.1-8 through **Table 7.1-11** summarizes the area with flood depths greater than 0.25 ft for various durations for the 5-year, 10-year, 25-year, and 100-year design storm events for SLR0, SLR1, SLR2, and SLR3, under existing conditions (Mitigation 0), Mitigation M2A, Mitigation M2B, and Mitigation M2C, for all land use and urban land use only. Area of flooding presented in **Table 7.1-8** through **Table 7.1-11** are cumulative in order of decreasing duration (i.e., area with duration greater than 360 hr are included in the area with duration greater than 240 hr). In these four tables under Mitigation 0 (existing conditions), a decrease in area (acres) going from SLR0 to SLR1, SLR2, or SLR3 corresponds to areas where the topography was increased in the future conditions model development to the FEMA BFE in areas of future land use change. Areas that are predicted to have decreased flood depth also have decreased flood duration. When looking at Mitigation M2A, M2B, and M2C in these tables, a decrease in area (acres) compared to Mitigation 0 correspond to a reduction in flooding due to mitigation.

Section 7.1.4.1 through **Section 7.1.4.3** presents the Phase 2 PM #6 FPLOS Assessment for Mitigation M2A, M2B, and M2C, respectively. Within each section, three figures are presented that show the 25-year flood duration map for the respective sea level rise scenario, a flood duration difference map between the 25-year SLR mitigation scenario and the 25-year SLR0 existing conditions scenario, and a flood duration difference map between the 25-year SLR mitigation scenario and the respective 25-year future sea level rise without mitigation scenario. For instance, **Section 7.1.4.1** presents the 25-year SLR1 flood duration map under Mitigation M2A, the flood duration difference map between the M2A 25-year SLR1 event and the existing conditions (M0) 25-year SLR0 event, and the flood duration difference map between the M2A 25-year SLR1 event and the future conditions without mitigation 25-year SLR1 event. **Section 7.1.4.2** and **Section 7.1.4.3** shows the same three figures but for SLR2 for Mitigation M2B and SLR3 for Mitigation M2C, respectively. Refer to **Appendix D** for the complete set of flood duration maps for the 5-year, 10-year, 25-year, and 100-year design storms for SLR1, SLR2, and SLR3, for all land use and urban land use only, for each of the three mitigation scenarios.

Areas that are predicted to have an increase in flood duration in the PM6 difference maps that do not correspond to significant increases in flood depths as shown in the PM5 difference maps are most often caused by increased groundwater elevations/durations and/or decreased overland and saturated zone drainage. Sea level rise causes an increase in groundwater elevations along the coast, which is predicted to cause inland groundwater elevations to stay elevated longer. In areas where the peak groundwater is higher than topography, this predicted increase in groundwater duration translates to increased surface water durations, even if the peak groundwater elevations do not increase. Additionally, in the MIKE SHE model, ponded drainage (simulates routing of ponded water via features that are not explicitly modeled such as curb inlets and local-scale storm drains) and saturated zone drainage (simulates surface drainage features that are not explicitly modeled such as roadside underdrains and shallow swales) turn off whenever the downstream canal water levels are higher. When the ponded drainage routine turns off, the duration of ponded water on the surface increases. When the saturated zone drainage routine turns off, the duration that localized groundwater levels are elevated increases.

Table 7.1-8: Summary of the PM#6 Area of Flooding by Flood Duration for the C-8 Watershed 5-Year Design Storm

5-Year Design Storm																
Duration of Flooding (hr)	Area with Flood Depths >0.25 ft within the C-8 Watershed (acres)															
	Mitigation 0 (Existing Conditions)				Mitigation M2A				Mitigation M2B				Mitigation M2C			
	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3
<= 0.1	363	365	358	347	371	367	367	360	386	384	382	374	388	384	384	378
>= 1	6362	6344	6525	6811	6248	6298	6374	6528	6079	6117	6192	6353	6068	6103	6171	6295
>= 4	6058	6049	6238	6532	5944	5997	6080	6237	5754	5794	5878	6041	5745	5782	5857	5984
>= 8	5807	5807	6003	6312	5697	5754	5840	6002	5506	5548	5634	5809	5495	5535	5610	5751
>= 12	5372	5364	5579	5910	5243	5307	5400	5580	5052	5103	5196	5388	5042	5089	5170	5326
>= 24	5195	5193	5412	5751	5062	5129	5228	5412	4874	4925	5022	5219	4861	4909	4996	5157
>= 48	5021	5018	5245	5594	4882	4949	5056	5250	4695	4753	4857	5058	4682	4736	4828	4994
>= 96	4861	4872	5107	5462	4727	4801	4910	5113	4548	4610	4717	4924	4536	4592	4688	4859
>= 168	4601	4613	4870	5240	4463	4542	4658	4874	4293	4357	4472	4694	4281	4335	4442	4626
>= 240	4487	4497	4761	5137	4341	4424	4537	4766	4170	4240	4353	4583	4155	4217	4322	4515
>= 360	4350	4364	4634	5025	4198	4287	4412	4644	4037	4110	4232	4467	4024	4090	4201	4396
	Area with Flood Depths >0.25 ft in Urban Land Use within the C-8 Watershed (acres)															
<= 0.1	341	343	337	326	349	346	344	339	357	355	354	347	358	356	355	350
>= 1	4859	4830	4973	5223	4753	4790	4847	4971	4621	4648	4705	4836	4614	4637	4688	4790
>= 4	4582	4563	4711	4969	4477	4518	4581	4705	4326	4355	4418	4552	4320	4345	4402	4506
>= 8	4347	4335	4488	4760	4246	4288	4353	4482	4093	4122	4188	4332	4085	4113	4170	4285
>= 12	3942	3924	4095	4385	3827	3875	3946	4090	3673	3709	3780	3939	3664	3698	3759	3890
>= 24	3773	3760	3935	4234	3655	3706	3783	3930	3505	3540	3614	3779	3494	3529	3595	3730
>= 48	3608	3592	3774	4082	3482	3534	3617	3772	3333	3376	3456	3623	3324	3363	3435	3572
>= 96	3457	3454	3643	3957	3337	3393	3479	3643	3195	3241	3324	3496	3186	3228	3302	3445
>= 168	3208	3205	3412	3740	3084	3147	3235	3412	2950	2997	3087	3273	2942	2981	3064	3219
>= 240	3097	3093	3308	3640	2968	3034	3120	3307	2832	2886	2973	3166	2823	2869	2949	3112
>= 360	2968	2966	3185	3531	2834	2903	2999	3190	2708	2761	2855	3054	2698	2745	2831	2997

Area of flooding is cumulative in order of decreasing duration (i.e., area with duration greater than or equal to 360 hr are included in the area with duration greater than or equal to 240 hr)

Table 7.1-9: Summary of the PM#6 Area of Flooding by Flood Duration for the C-8 Watershed 10-Year Design Storm

10-Year Design Storm																
Duration of Flooding (hr)	Area with Flood Depths >0.25 ft within the C-8 Watershed (acres)															
	Mitigation 0 (Existing Conditions)				Mitigation M2A				Mitigation M2B				Mitigation M2C			
	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3
<= 0.1	389	420	419	400	429	427	424	417	432	434	426	421	433	433	432	425
>= 1	7123	7111	7310	7667	6983	7035	7119	7292	6783	6823	6915	7080	6766	6804	6887	7020
>= 4	6776	6779	6987	7354	6637	6696	6787	6966	6402	6449	6544	6716	6384	6427	6515	6657
>= 8	6534	6538	6761	7146	6385	6448	6544	6738	6151	6202	6304	6489	6132	6178	6273	6426
>= 12	6078	6070	6310	6723	5904	5973	6079	6285	5670	5726	5834	6038	5652	5695	5801	5967
>= 24	5873	5871	6120	6548	5697	5769	5882	6093	5464	5524	5636	5848	5446	5493	5600	5772
>= 48	5674	5669	5921	6362	5487	5562	5676	5893	5257	5317	5435	5648	5240	5285	5395	5572
>= 96	5497	5500	5760	6206	5306	5390	5506	5734	5082	5149	5268	5495	5063	5114	5227	5414
>= 168	5200	5218	5496	5961	5008	5101	5236	5474	4791	4867	4998	5239	4770	4829	4957	5151
>= 240	5060	5087	5373	5851	4869	4965	5104	5358	4660	4741	4876	5124	4641	4704	4832	5033
>= 360	4929	4959	5253	5741	4732	4836	4977	5235	4528	4613	4752	5006	4508	4572	4706	4912
Area with Flood Depths >0.25 ft in Urban Land Use within the C-8 Watershed (acres)																
<= 0.1	364	398	397	382	406	403	402	396	409	410	405	401	411	411	409	404
>= 1	5551	5534	5698	6022	5434	5472	5536	5676	5274	5302	5373	5512	5261	5288	5352	5457
>= 4	5230	5228	5401	5734	5117	5161	5230	5377	4930	4964	5038	5183	4916	4948	5014	5129
>= 8	5003	5003	5189	5539	4884	4931	5005	5163	4697	4733	4813	4970	4681	4716	4789	4911
>= 12	4577	4565	4765	5140	4437	4487	4569	4737	4247	4288	4370	4545	4232	4264	4345	4480
>= 24	4383	4378	4587	4975	4242	4295	4383	4557	4053	4095	4184	4365	4038	4073	4155	4296
>= 48	4189	4182	4394	4795	4040	4096	4184	4363	3855	3898	3990	4172	3840	3875	3959	4101
>= 96	4021	4021	4240	4646	3867	3932	4023	4211	3685	3736	3830	4025	3670	3710	3798	3949
>= 168	3736	3750	3984	4408	3583	3656	3763	3960	3408	3465	3569	3777	3391	3437	3538	3696
>= 240	3602	3625	3866	4302	3449	3525	3635	3847	3281	3344	3451	3665	3266	3317	3417	3580
>= 360	3476	3500	3749	4195	3318	3401	3514	3727	3153	3219	3332	3550	3137	3188	3294	3465

Area of flooding is cumulative in order of decreasing duration (i.e., area with duration greater than or equal to 360 hr are included in the area with duration greater than or equal to 240 hr)

Table 7.1-10: Summary of the PM#6 Area of Flooding by Flood Duration for the C-8 Watershed 25-Year Design Storm

25-Year Design Storm																
Duration of Flooding (hr)	Area with Flood Depths >0.25 ft within the C-8 Watershed (acres)															
	Mitigation 0 (Existing Conditions)				Mitigation M2A				Mitigation M2B				Mitigation M2C			
	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3
<= 0.1	399	409	385	368	417	411	406	392	427	421	421	409	428	423	423	415
>= 1	8196	8250	8584	8940	8043	8128	8282	8517	7786	7851	7962	8200	7759	7804	7901	8080
>= 4	7801	7852	8204	8585	7628	7718	7889	8138	7334	7404	7532	7787	7304	7352	7467	7651
>= 8	7542	7573	7937	8334	7343	7435	7608	7872	7052	7121	7253	7519	7022	7069	7184	7383
>= 12	7034	7070	7456	7888	6806	6914	7107	7392	6511	6586	6734	7024	6474	6533	6658	6871
>= 24	6799	6838	7245	7687	6563	6675	6882	7179	6270	6347	6499	6807	6226	6291	6422	6648
>= 48	6613	6651	7073	7526	6365	6478	6700	7003	6074	6155	6315	6630	6031	6096	6235	6466
>= 96	6415	6452	6892	7362	6157	6278	6505	6823	5860	5950	6118	6446	5815	5890	6035	6273
>= 168	6098	6144	6617	7113	5834	5968	6216	6548	5547	5641	5829	6173	5498	5576	5736	5990
>= 240	5971	6021	6493	7007	5703	5837	6087	6424	5411	5508	5697	6047	5363	5443	5605	5862
>= 360	5820	5881	6371	6888	5550	5698	5956	6304	5265	5369	5564	5924	5216	5302	5467	5734
Area with Flood Depths >0.25 ft in Urban Land Use within the C-8 Watershed (acres)																
<= 0.1	376	375	354	338	384	377	373	360	394	389	389	376	395	389	390	381
>= 1	6519	6576	6883	7204	6403	6470	6603	6819	6197	6241	6338	6552	6175	6210	6285	6445
>= 4	6147	6199	6523	6867	6012	6082	6230	6458	5778	5828	5939	6166	5755	5792	5881	6046
>= 8	5907	5946	6280	6640	5755	5825	5975	6216	5520	5567	5684	5921	5497	5532	5621	5800
>= 12	5429	5471	5827	6219	5250	5336	5504	5765	5010	5065	5194	5454	4982	5027	5127	5317
>= 24	5208	5250	5625	6027	5021	5108	5288	5561	4780	4836	4968	5246	4746	4797	4900	5104
>= 48	5030	5073	5462	5876	4834	4924	5116	5393	4594	4655	4794	5078	4563	4612	4723	4931
>= 96	4837	4884	5290	5721	4635	4733	4931	5222	4392	4460	4608	4905	4358	4416	4535	4748
>= 168	4529	4585	5023	5476	4324	4432	4649	4954	4090	4161	4326	4638	4054	4113	4243	4473
>= 240	4407	4466	4903	5372	4197	4307	4526	4835	3958	4033	4198	4517	3922	3984	4117	4349
>= 360	4260	4330	4783	5257	4049	4171	4397	4716	3816	3896	4067	4396	3779	3847	3982	4223

Area of flooding is cumulative in order of decreasing duration (i.e., area with duration greater than or equal to 360 hr are included in the area with duration greater than or equal to 240 hr)

Table 7.1-11: Summary of the PM#6 Area of Flooding by Flood Duration for the C-8 Watershed 100-Year Design Storm

100-Year Design Storm																
Duration of Flooding (hr)	Area with Flood Depths >0.25 ft within the C-8 Watershed (acres)															
	Mitigation 0 (Existing Conditions)				Mitigation M2A				Mitigation M2B				Mitigation M2C			
	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3
<= 0.1	415	409	392	363	434	420	414	394	430	428	418	405	439	434	429	417
>= 1	9776	9942	10255	10735	9558	9755	9946	10163	9249	9403	9571	9800	9155	9253	9423	9621
>= 4	9400	9559	9897	10410	9151	9363	9566	9801	8818	8985	9171	9419	8718	8825	9013	9228
>= 8	9113	9289	9633	10172	8851	9079	9291	9530	8501	8677	8874	9135	8391	8508	8708	8932
>= 12	8594	8769	9145	9732	8297	8545	8777	9042	7914	8112	8340	8623	7795	7925	8152	8407
>= 24	8369	8543	8937	9543	8052	8310	8559	8834	7660	7870	8108	8405	7535	7673	7907	8176
>= 48	8175	8346	8749	9375	7836	8103	8359	8648	7436	7661	7901	8216	7308	7457	7699	7974
>= 96	7972	8154	8575	9213	7621	7906	8173	8475	7224	7454	7713	8033	7086	7245	7502	7786
>= 168	7651	7854	8299	8972	7280	7587	7876	8200	6876	7133	7416	7754	6727	6912	7193	7501
>= 240	7508	7717	8170	8862	7125	7441	7739	8080	6720	6980	7282	7630	6571	6749	7050	7365
>= 360	7356	7568	8043	8753	6973	7296	7607	7958	6568	6835	7141	7509	6413	6599	6906	7240
Area with Flood Depths >0.25 ft in Urban Land Use within the C-8 Watershed (acres)																
<= 0.1	397	391	374	348	414	402	395	377	412	410	401	388	421	416	411	400
>= 1	7982	8146	8424	8875	7800	7975	8148	8339	7543	7673	7822	8030	7460	7542	7686	7859
>= 4	7625	7794	8092	8574	7424	7613	7796	8003	7148	7289	7456	7680	7060	7150	7311	7499
>= 8	7349	7535	7842	8349	7139	7343	7534	7746	6854	7002	7179	7414	6758	6854	7028	7224
>= 12	6854	7042	7380	7931	6615	6839	7046	7283	6297	6468	6670	6925	6195	6303	6498	6722
>= 24	6640	6831	7186	7757	6386	6617	6843	7090	6060	6239	6454	6722	5951	6066	6270	6508
>= 48	6452	6640	7006	7597	6180	6421	6651	6912	5845	6039	6255	6541	5732	5859	6070	6315
>= 96	6260	6458	6839	7441	5978	6235	6474	6746	5643	5842	6074	6363	5521	5657	5880	6133
>= 168	5954	6171	6573	7208	5652	5928	6191	6481	5308	5534	5789	6095	5175	5337	5584	5857
>= 240	5817	6042	6452	7104	5505	5791	6061	6369	5159	5388	5661	5978	5025	5182	5447	5729
>= 360	5667	5898	6326	6998	5355	5650	5933	6249	5010	5246	5524	5859	4872	5035	5311	5606

Area of flooding is cumulative in order of decreasing duration (i.e., area with duration greater than or equal to 360 hr are included in the area with duration greater than or equal to 240 hr)

7.1.4.1 PM #6 – Mitigation M2A

Mitigation scenario M2A is the least aggressive form of mitigation out of the three mitigation strategies analyzed in this study. Although Mitigation M2A has a relatively large pumping capacity of 1,550 cfs, the C-8 Canal still had several instances of bank exceedances and had high enough water levels to inhibit gravity-driven drainage in the secondary/tertiary system, contributing to long durations of overland flooding in urban areas as shown in **Figure 7.1-47**. Mitigation M2A, although close, was unable to achieve a PM #1 25-year SLR1 maximum water surface profile in the C-8 Canal that was equal to or lower than existing conditions 25-year SLR0 profile. As such, it is no surprise that there are areas with flood durations during the 25-year SLR1 event under mitigation M2A that is greater than existing conditions, as shown in **Figure 7.1-48**. **Figure 7.1-48** shows that a significant amount of area is staying flooded longer than existing conditions, in some cases several hours or days longer, even though the corresponding flood depths may be lower or minimally different than existing conditions. Areas that are predicted to have an increase in flood duration in the PM #6 difference maps that do not correspond to significant increases in flood depths as shown in the PM #5 difference maps are most often caused by increased groundwater elevations/durations and/or decreased overland and saturated zone drainage. Sea level rise causes an increase in groundwater elevations along the coast, which is predicted to cause inland groundwater elevations to stay elevated longer. In areas where the peak groundwater is higher than topography, this predicted increase in groundwater duration translates to increased surface water durations, even if the peak groundwater elevations do not increase.

Figure 7.1-49 presents the flood duration differences between the 25-year SLR1 event with and without mitigation. Although the goal was to achieve flood protection equal to or better than existing conditions, it was just that- a goal. The reality of it is that sea level rise is going to bring about unprecedented changes in the form of higher tide levels to discharge against, higher antecedent water levels throughout the watershed which effectively removes storage that was once there, and areas with higher groundwater levels which not only removes storage that was once there but can actively rise above land surface further contributing to flooding and duration of flooding. Therefore, although achieving flood protection equal to or greater than what is currently provided under existing conditions is a great goal to aim for, this shouldn't limit the success or consideration of mitigation strategies. Therefore, looking at the difference between flooding under a particular mitigation strategy and the flooding that could occur if no mitigation was implemented really shows how effective the mitigation is. **Figure 7.1-49** shows a widespread reduction in flood duration ranging from 1 hour to more than 12 hours. This figure highlights the areas that are most impacted or benefited by Mitigation M2A in terms of flood duration.

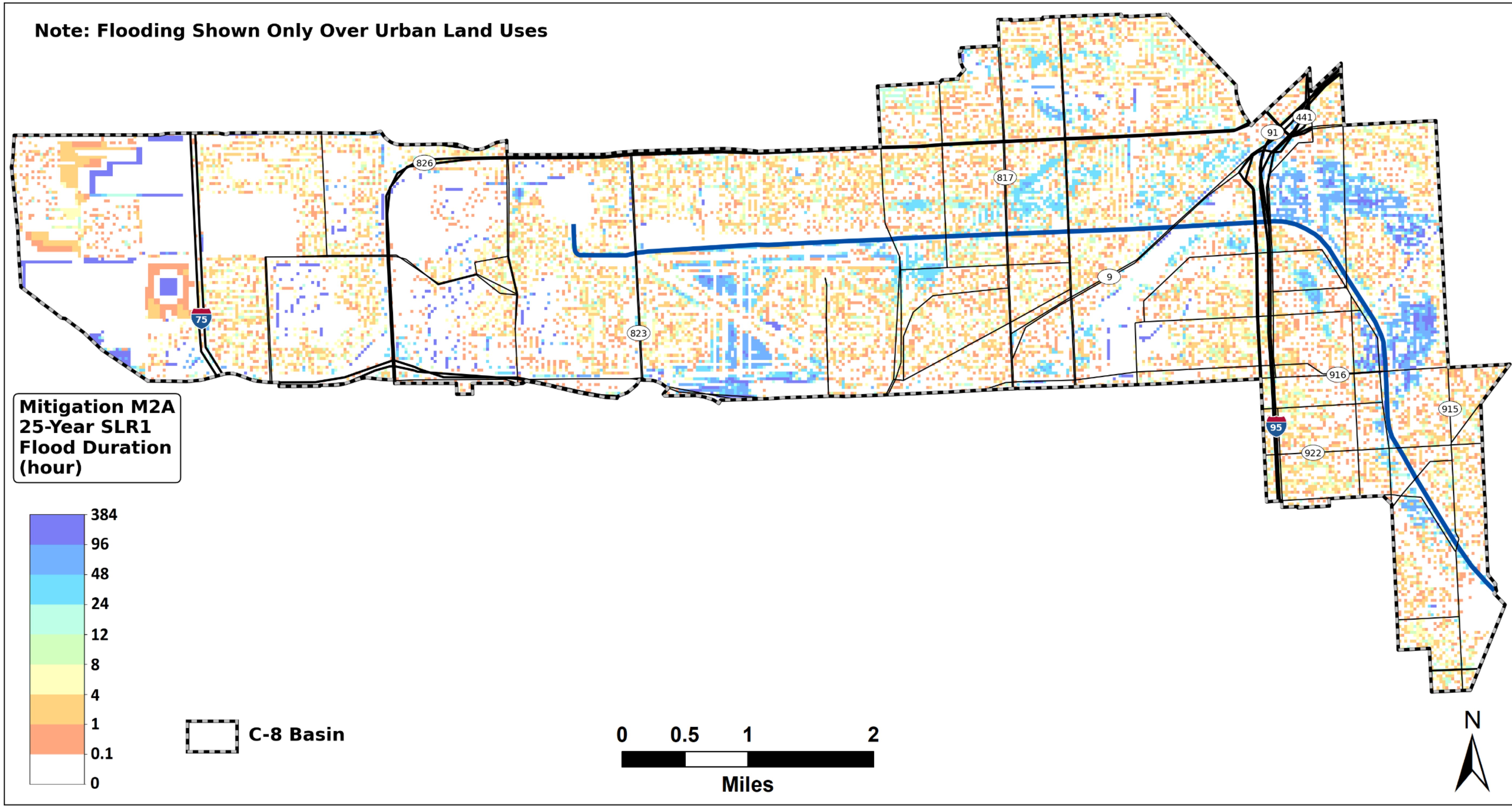


Figure 7.1-47: C-8 Watershed Flood Duration Map for the Mitigation M2A 25-Year Sea Level Rise 1 Design Storm Event in Urban Land Use Areas

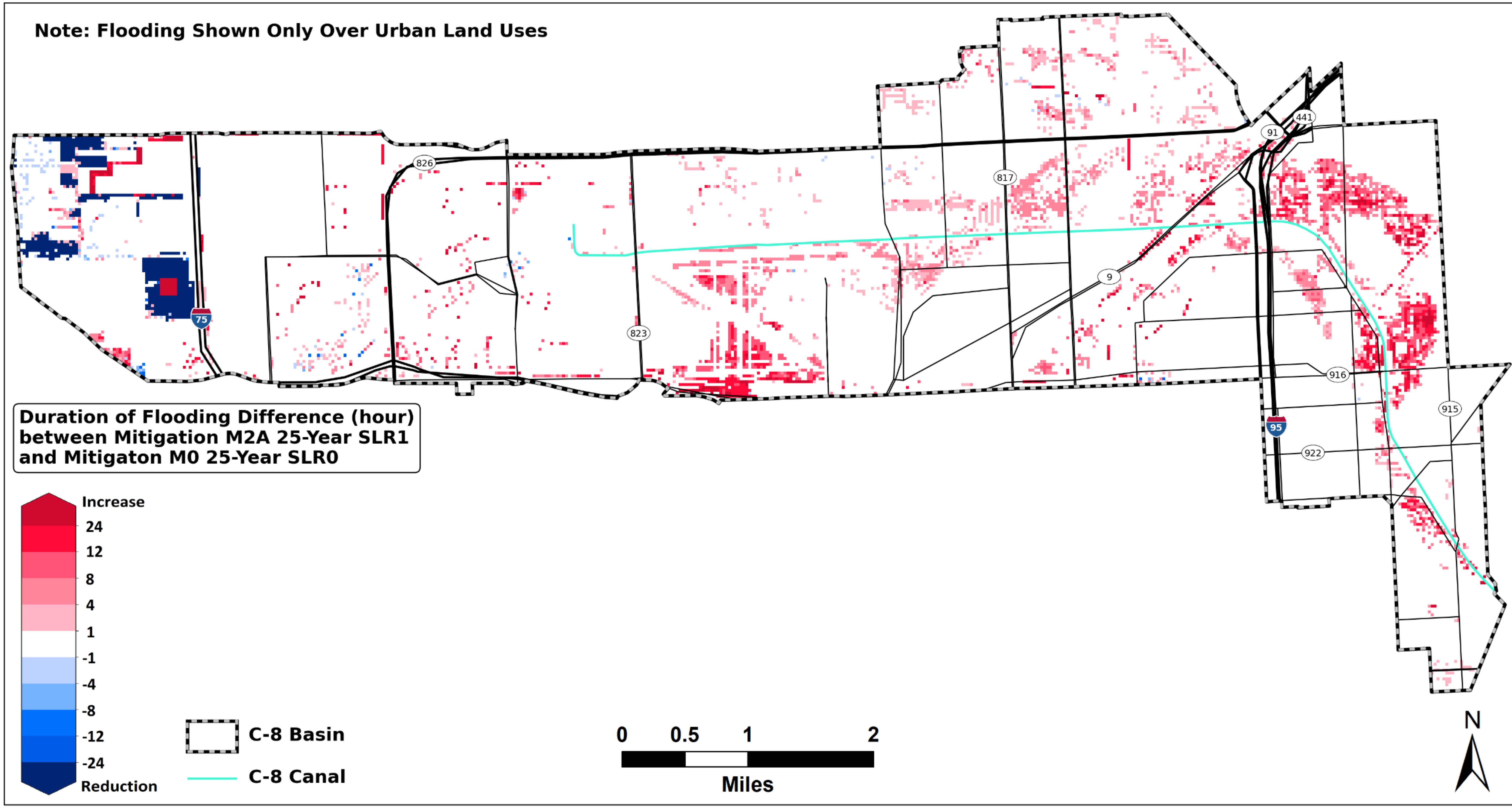


Figure 7.1-48: C-8 Watershed Flood Duration Difference Map for Mitigation M2A 25-Year Sea Level Rise 1 versus Existing Conditions (M0) 25-Year SLR0 in Urban Land Use Areas

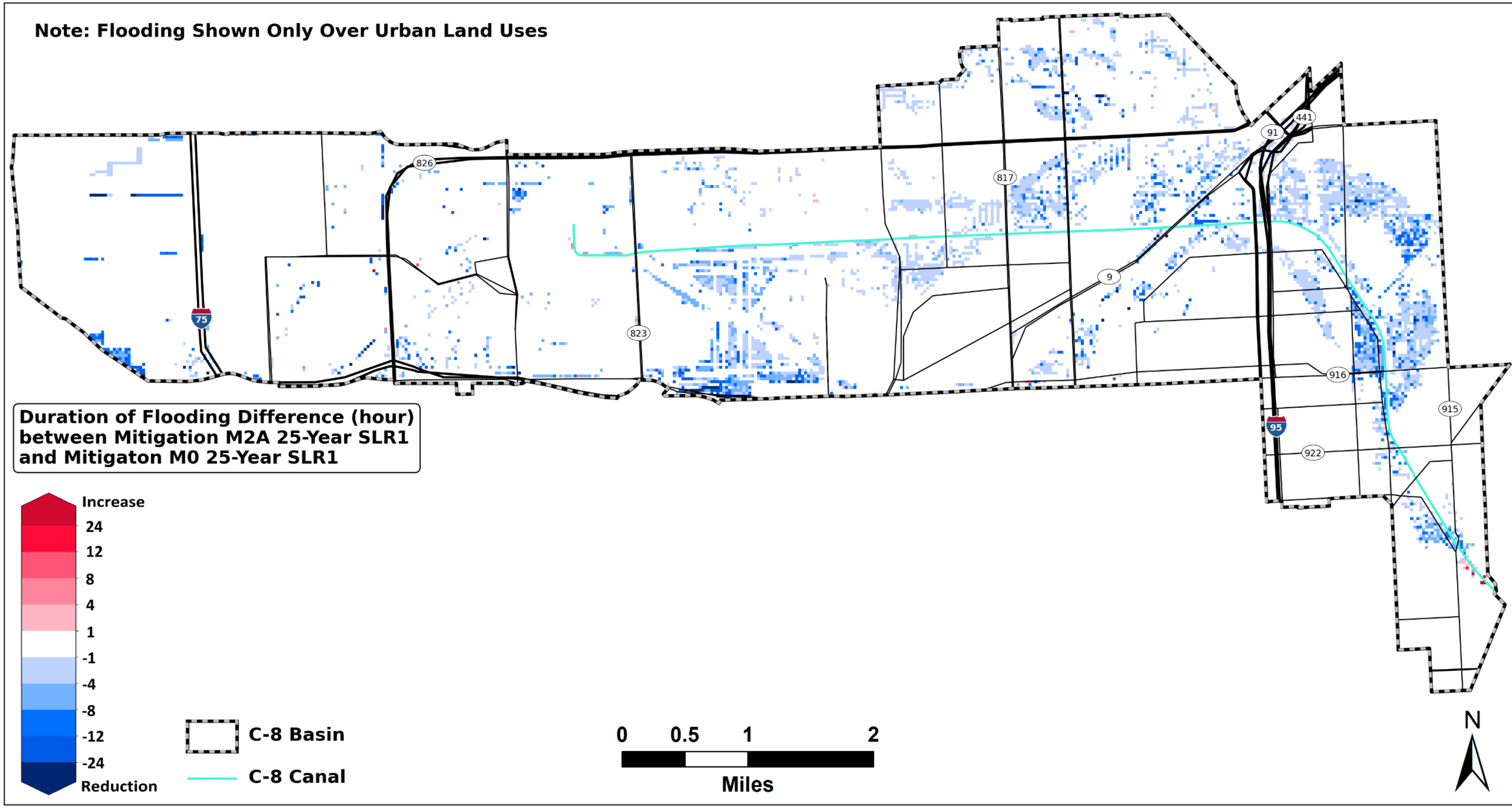


Figure 7.1-49: C-8 Watershed Flood Duration Difference Map for Mitigation M2A 25-Year Sea Level Rise 1 versus Future Conditions without mitigation (M0) 25-Year SLR1 in Urban Land Use Areas

7.1.4.2 PM #6 – Mitigation M2B

Mitigation scenario M2B is a more aggressive form of mitigation compared to M2A but less aggressive than M2C, making it the middle level of mitigation out of the three mitigation strategies analyzed in this study. Although Mitigation M2B has a large pumping capacity of 2,550 cfs and raised canal embankments which prevents any instance of bank exceedance, the C-8 Canal still had high enough water levels to inhibit gravity-driven drainage in the secondary/tertiary system, contributing to the long durations of overland flooding in urban areas as shown in **Figure 7.1-50**. Mitigation M2B, although within about 0.3 ft in any given location, was unable to achieve a PM #1 25-year SLR1 maximum water surface profile in the C-8 Canal that was equal to or lower than existing conditions 25-year SLR0 profile. As such, it is no surprise that there are areas with flood durations during the 25-year SLR2 event under mitigation M2B that is greater than existing conditions, as shown in **Figure 7.1-51**. **Figure 7.1-51** shows that a significant amount of area is staying flooded longer than existing conditions, in some cases several hours or days longer, even though the corresponding flood depths may be lower or minimally different than existing conditions. Areas that are predicted to have an increase in flood duration in the PM #6 difference maps that do not correspond to significant increases in flood depths as shown in the PM #5 difference maps are most often caused by increased groundwater elevations/durations and/or decreased overland and saturated zone drainage. Sea level rise causes an increase in groundwater elevations along the coast, which is predicted to cause inland groundwater elevations to stay elevated longer. In areas where the peak groundwater is higher than topography, this predicted increase in groundwater duration translates to increased surface water durations, even if the peak groundwater elevations do not increase. Although showing mostly an increase in flood duration, **Figure 7.1-51** does show some areas of decreased flood duration along the C-8 Canal.

Figure 7.1-52 presents the flood duration differences between the 25-year SLR2 event with and without mitigation. Although the goal was to achieve flood protection equal to or better than existing conditions, it was just that- a goal. The reality of it is that sea level rise is going to bring about unprecedented changes in the form of higher tide levels to discharge against, higher antecedent water levels throughout the watershed which effectively removes storage that was once there, and areas with higher groundwater levels which not only removes storage that was once there but can actively rise above land surface further contributing to flooding and duration of flooding. Therefore, although achieving flood protection equal to or greater than what is currently provided under existing conditions is a great goal to aim for, this shouldn’t limit the success or consideration of mitigation strategies. Therefore, looking at the difference between flooding under a particular mitigation strategy and the flooding that could occur if no mitigation was implemented really shows how effective the mitigation is. **Figure 7.1-52** shows a widespread reduction in flood duration ranging from 1 hour to more than 24 hours, with a majority of the area having more than a 12-hour reduction (localized areas with reductions of 60 hours or more). This figure highlights the areas that are most impacted or benefited by Mitigation M2B in terms of flood duration.

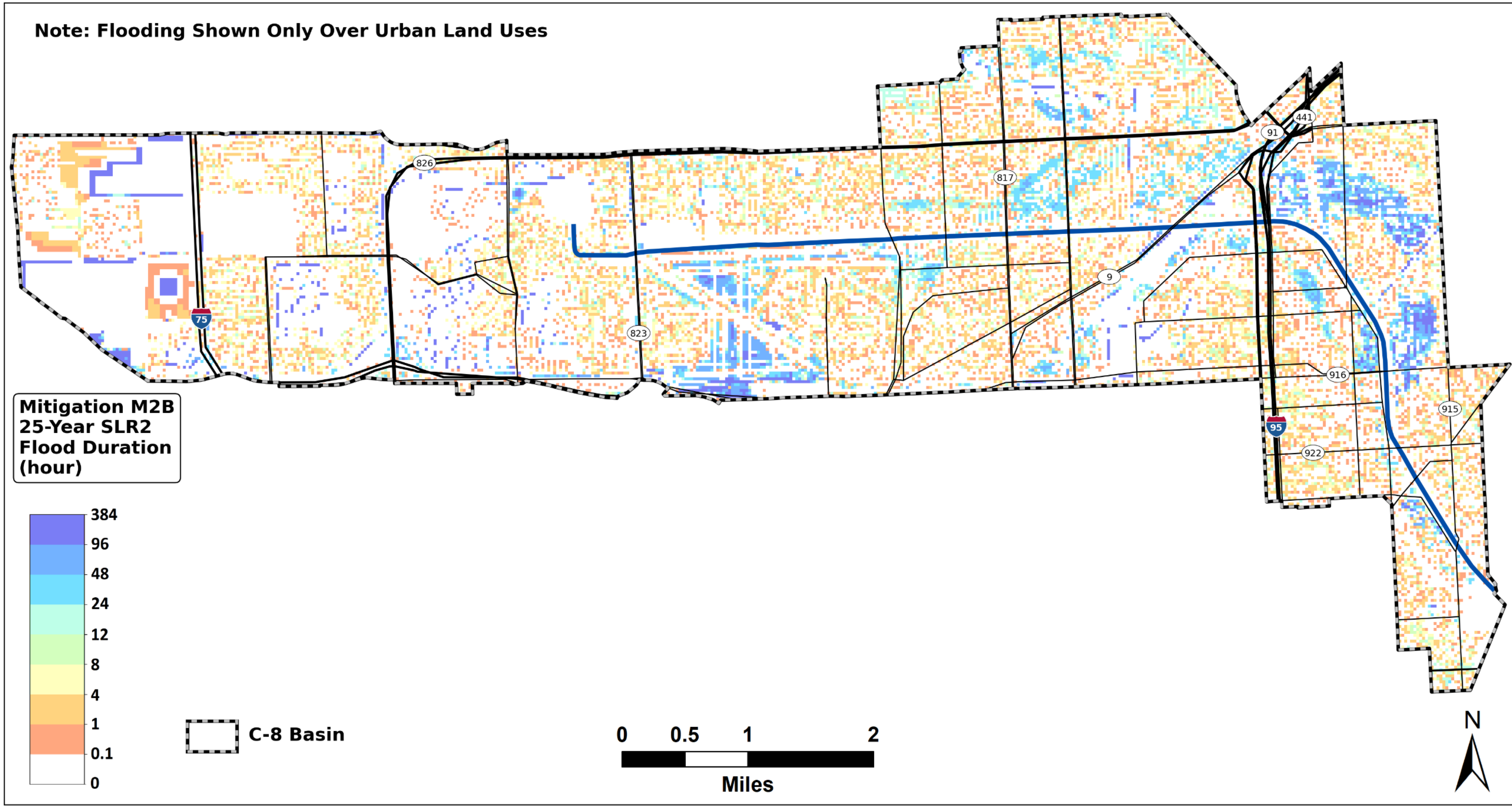


Figure 7.1-50: C-8 Watershed Flood Duration Map for the Mitigation M2B 25-Year Sea Level Rise 2 Design Storm Event in Urban Land Use Areas

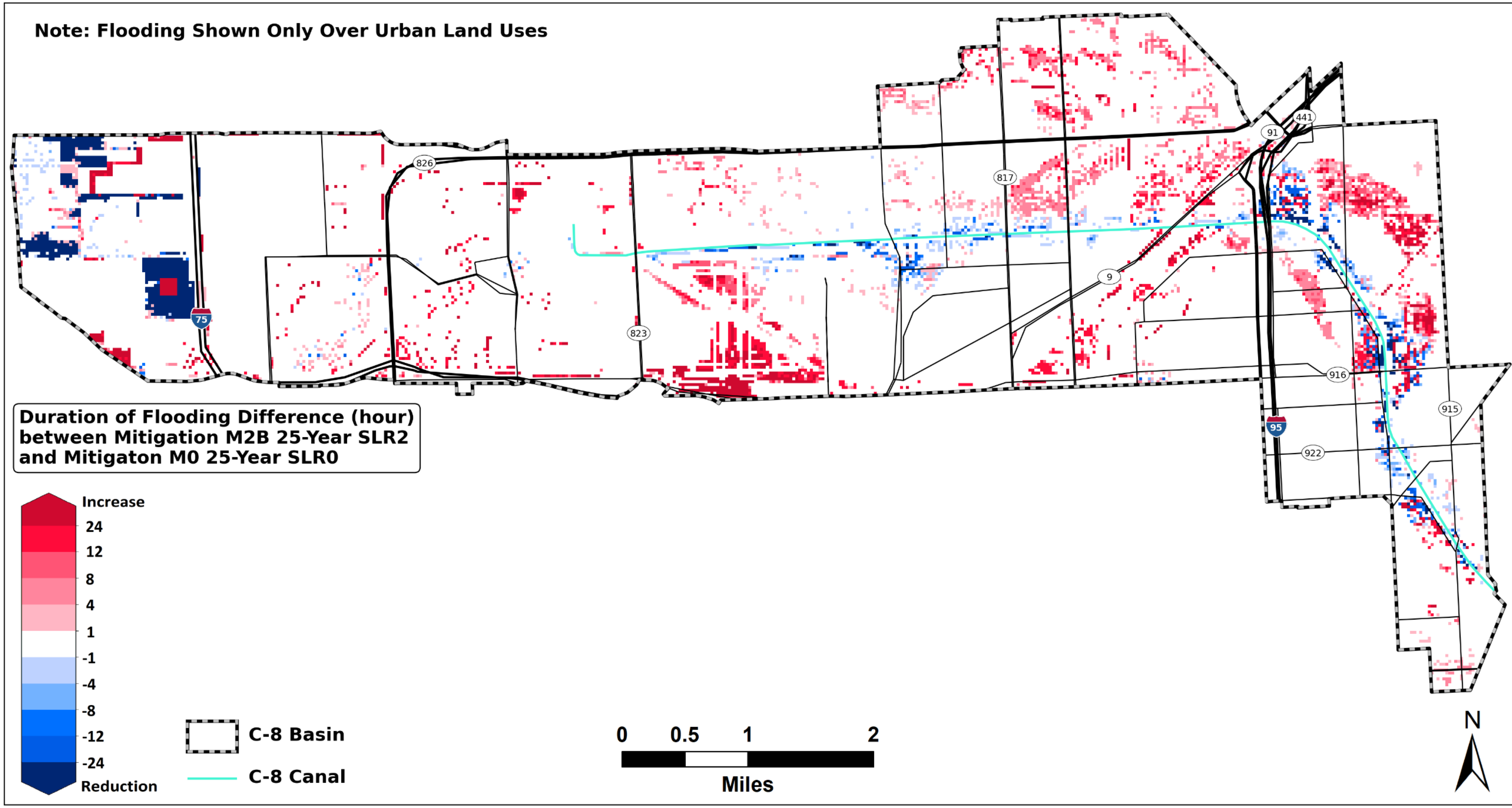


Figure 7.1-51: C-8 Watershed Flood Duration Difference Map for Mitigation M2B 25-Year Sea Level Rise 2 versus Existing Conditions (M0) 25-Year SLR0 in Urban Land Use Areas

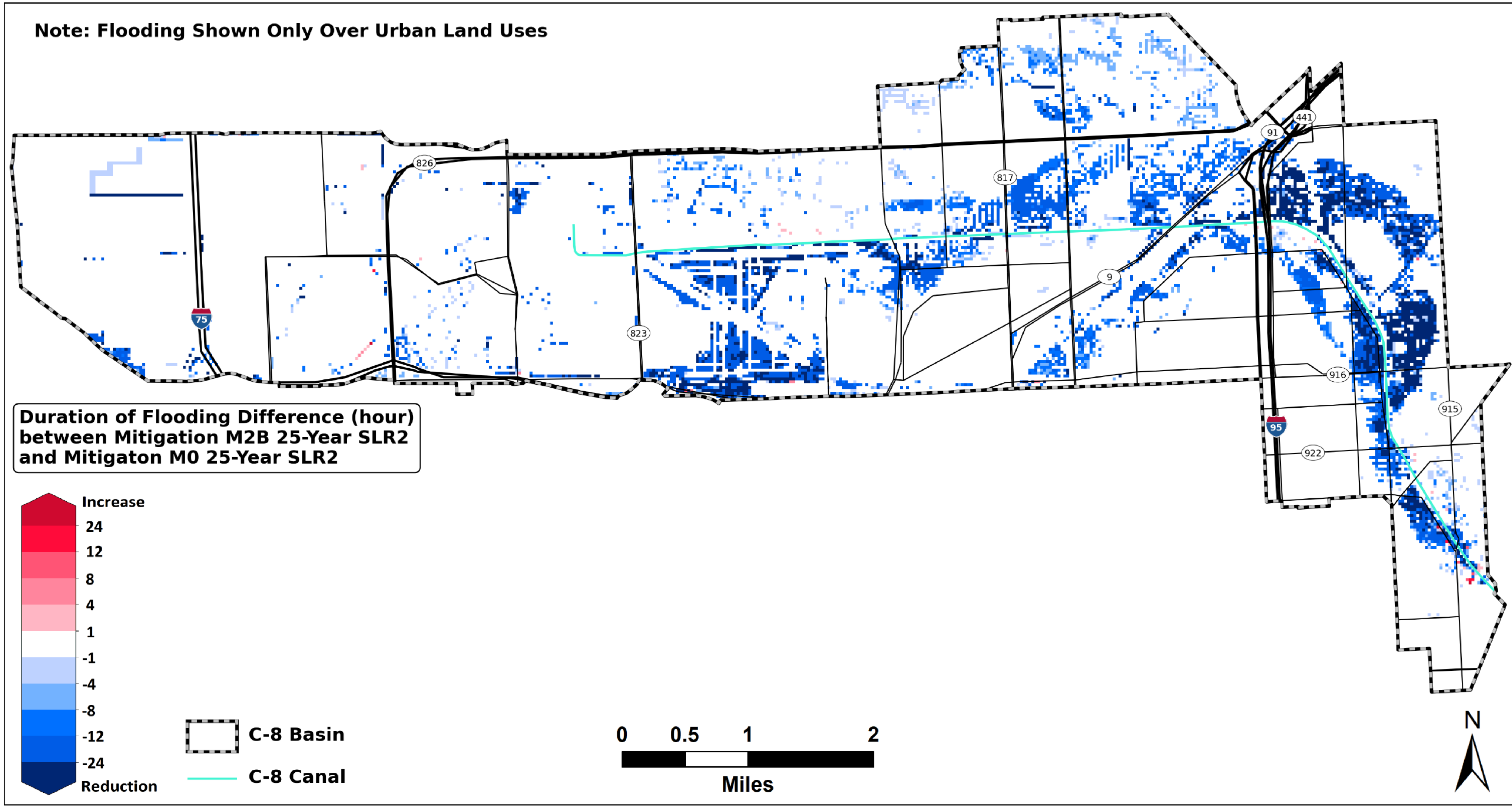


Figure 7.1-52: C-8 Watershed Flood Duration Difference Map for Mitigation M2B 25-Year Sea Level Rise 2 versus Future Conditions without mitigation (M0) 25-Year SLR2 in Urban Land Use Areas

7.1.4.3 PM #6 – Mitigation M2C

Mitigation scenario M2C is the most aggressive form of mitigation out of the three mitigation strategies analyzed in this study. Although Mitigation M2C has a very large pumping capacity of 3,550 cfs and raised canal embankments which prevents any instance of bank exceedance, the C-8 Canal still had high enough water levels to inhibit gravity-driven drainage in the secondary/tertiary system, contributing to the long durations of overland flooding in urban areas as shown **Figure 7.1-53**. Mitigation M2C was unable to achieve a PM #1 25-year SLR3 maximum water surface profile in the C-8 Canal that was equal to or lower than existing conditions 25-year SLR0 profile, with water levels about 0.5 ft higher along the entire canal. As such, it is no surprise that there are areas with flood durations during the 25-year SLR3 event under mitigation M2C that are greater than existing conditions, as shown in **Figure 7.1-54**. **Figure 7.1-54** shows that a significant amount of area is staying flooded longer than existing conditions, in some cases several hours or days longer, even though the corresponding flood depths may be lower or minimally different than existing conditions. Areas that are predicted to have an increase in flood duration in the PM #6 difference maps that do not correspond to significant increases in flood depths as shown in the PM #5 difference maps are most often caused by increased groundwater elevations/durations and/or decreased overland and saturated zone drainage. Sea level rise causes an increase in groundwater elevations along the coast, which is predicted to cause inland groundwater elevations to stay elevated longer. In areas where the peak groundwater is higher than topography, this predicted increase in groundwater duration translates to increased surface water durations, even if the peak groundwater elevations do not increase. Although showing mostly an increase in flood duration, **Figure 7.1-54** does show some areas of decreased flood duration along the C-8 Canal.

Figure 7.1-55 presents the flooding depth differences between the 25-year SLR3 event with and without mitigation. Although the goal was to achieve flood protection equal to or better than existing conditions, it was just that, a goal. The reality of it is that sea level rise is going to bring about unprecedented changes in the form of higher tide levels to discharge against, higher antecedent water levels throughout the watershed which effectively removes storage that was once there, and areas with higher groundwater levels which not only removes storage that was once there but can actively rise above land surface further contributing to flooding. Therefore, although achieving flood protection equal to or greater than what is currently provided under existing conditions is a great goal to aim for, this shouldn't limit the success or consideration of mitigation strategies. Therefore, looking at the difference between flooding under a particular mitigation strategy and the flooding that could occur if no mitigation was implemented really shows how effective the mitigation is. **Figure 7.1-55** shows a widespread reduction in flood duration ranging from 1 hour to more than 24 hours, with a majority of the area having more than a 24-hour reduction (localized areas with reductions of 120 hours or more). This figure highlights the areas that are most impacted or benefited by Mitigation M2C in terms of flood duration.

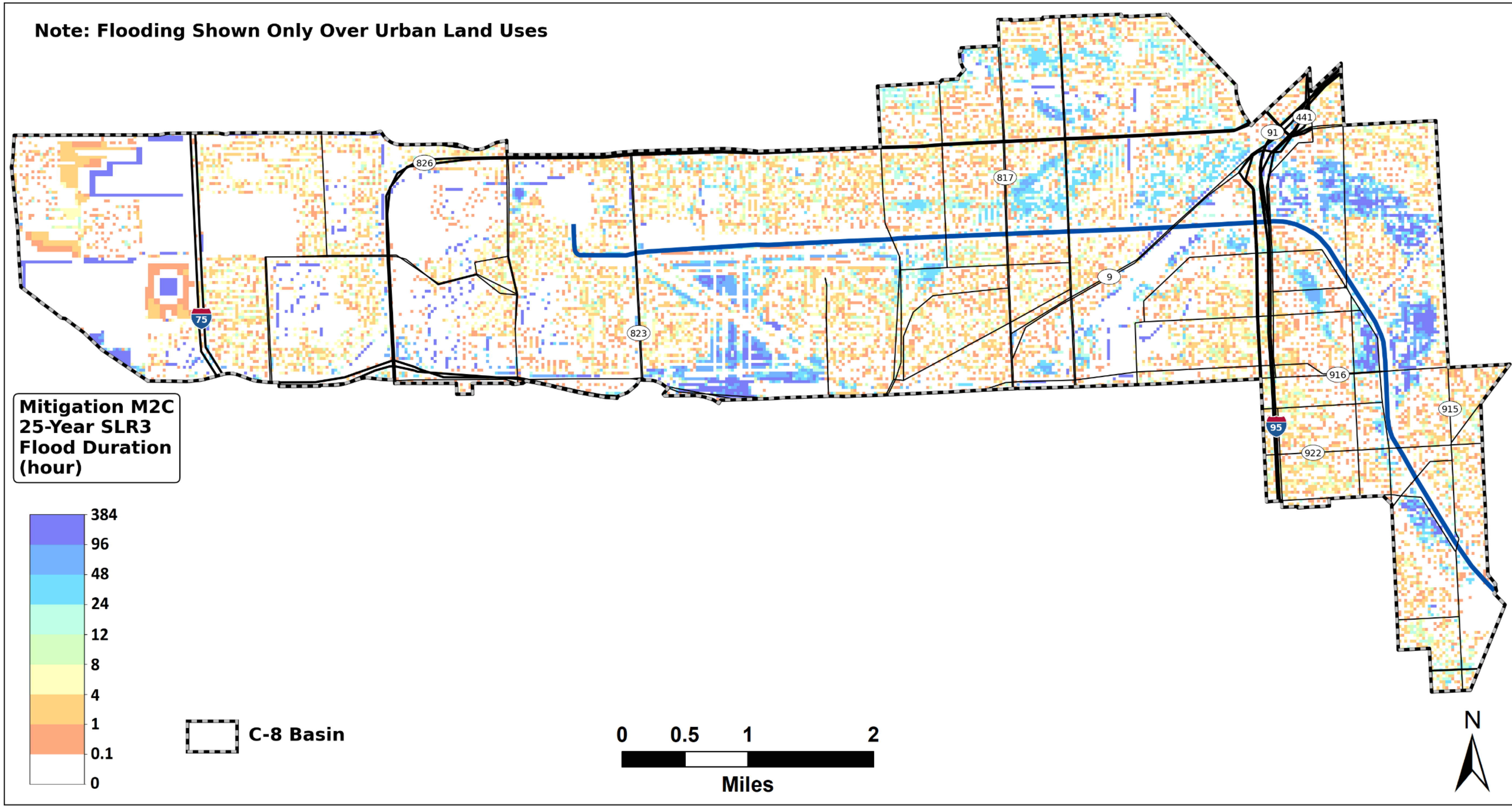


Figure 7.1-53: C-8 Watershed Flood Duration Map for the Mitigation M2C 25-Year Sea Level Rise 3 Design Storm Event in Urban Land Use Areas

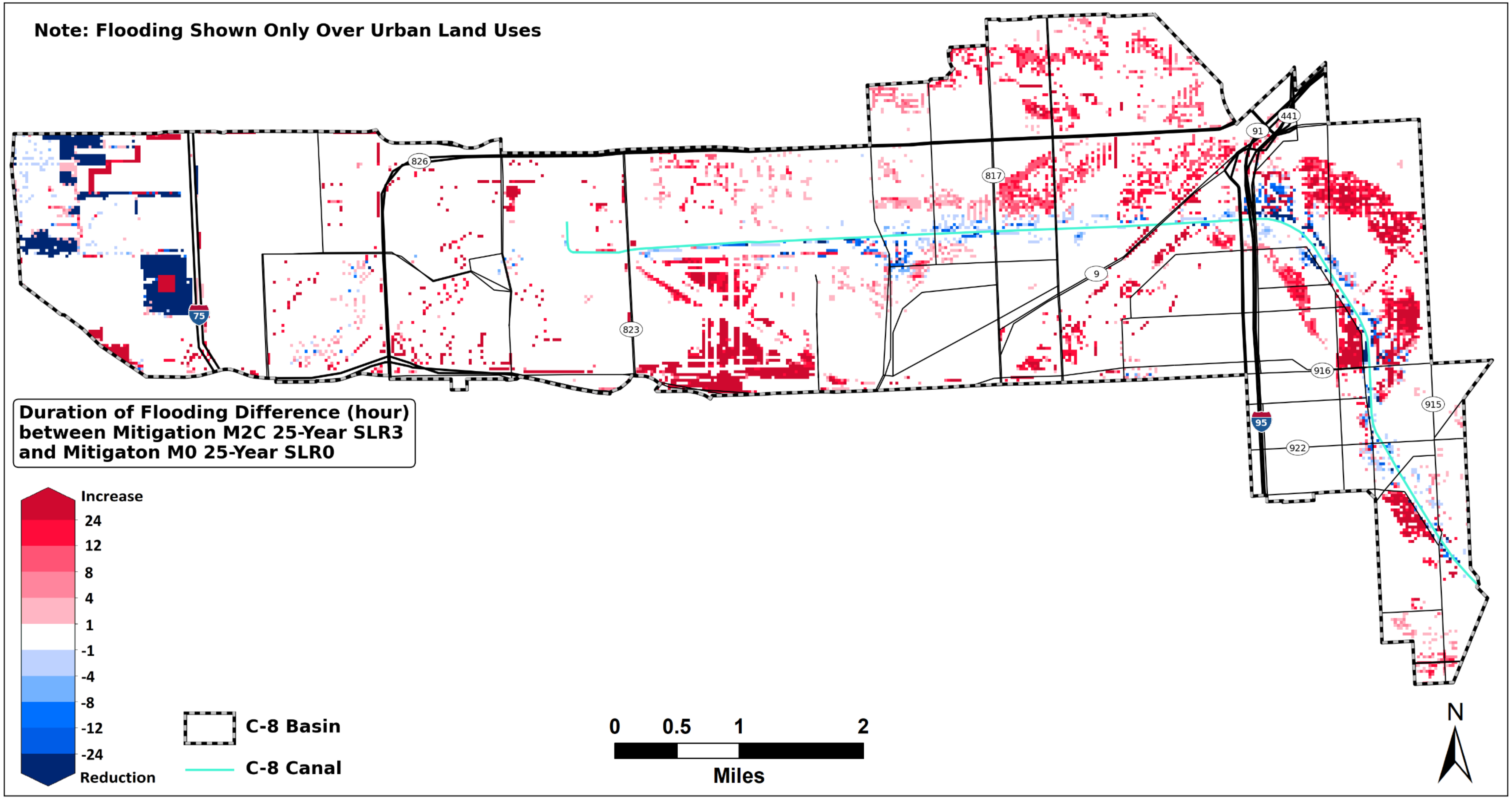


Figure 7.1-54: C-8 Watershed Flood Duration Difference Map for Mitigation M2C 25-Year Sea Level Rise 3 versus Existing Conditions (M0) 25-Year SLR0 in Urban Land Use Areas

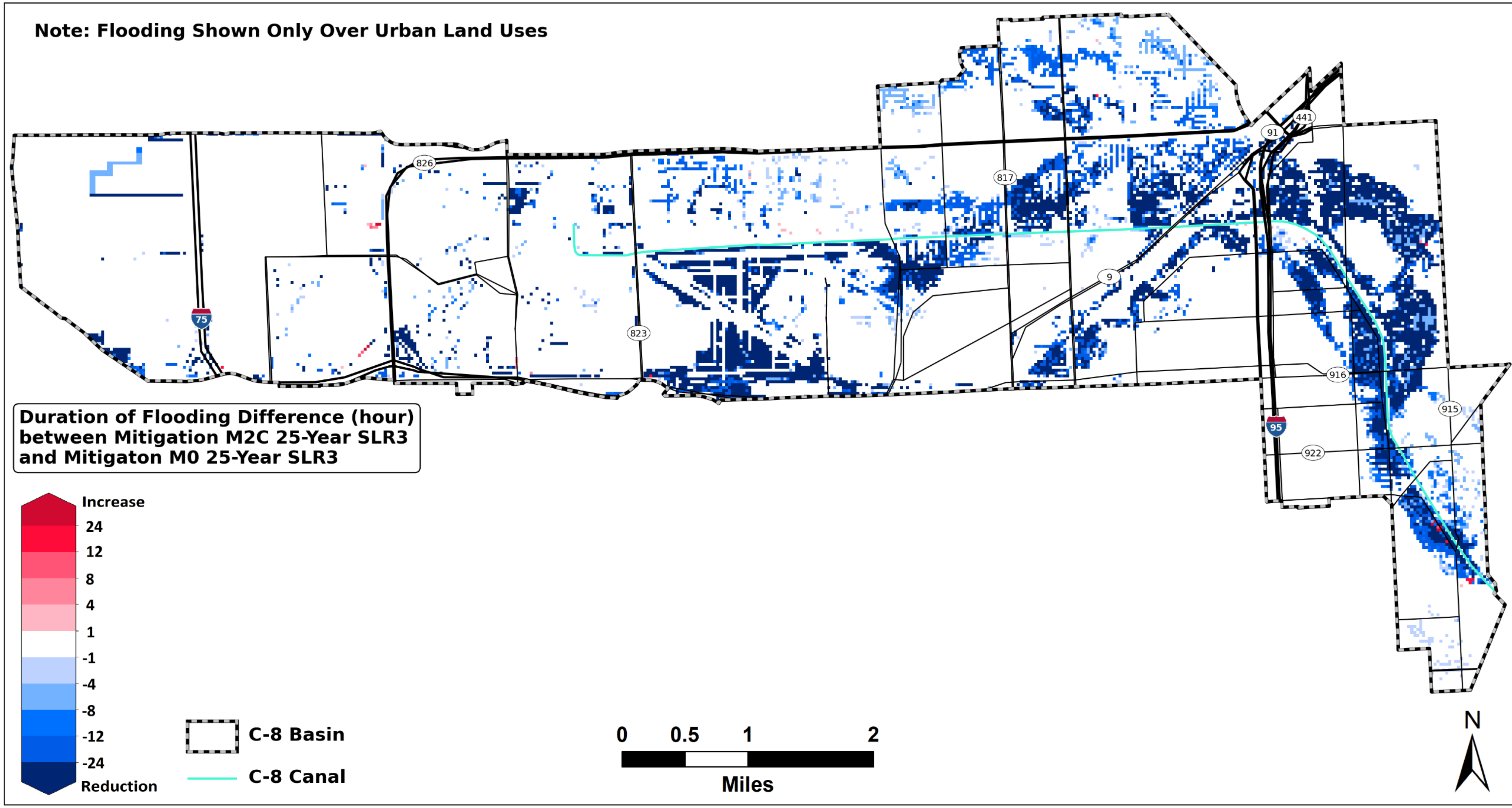


Figure 7.1-55: C-8 Watershed Flood Duration Difference Map for Mitigation M2C 25-Year Sea Level Rise 3 versus Future Conditions without mitigation (M0) 25-Year SLR3 in Urban Land Use Areas

7.1.4.4 PM #6 – Summary for C-8 Watershed

- Under all three mitigation strategies simulated, there are widespread areas that are predicted to have an increase in flood duration compared to current conditions, even if there is no corresponding increase in flood depths
    - The rise of sea level will cause an increase in groundwater elevations along the coast
    - The increase in groundwater along the coast is predicted to cause inland ground water elevations to stay elevated longer after a storm event
    - In areas where the groundwater elevation peaks higher than the land surface elevation, this increase in duration of elevated groundwater translates to increased surface water flood durations
- M2A
    - Even with Mitigation M2A, it is predicted that there will be a widespread increase in flood duration compared to existing conditions.
    - The flood duration associated with the 25-year SLR1 event under Mitigation Strategy M2A is predicted to be significantly less than the 25-year SLR1 event without mitigation
- M2B
    - Even with Mitigation M2B, it is predicted that there will be a widespread increase in flood duration compared to existing conditions.
    - The flood duration associated with the 25-year SLR2 event under Mitigation Strategy M2B is predicted to be significantly less than the 25-year SLR2 event without mitigation
- M2C
    - Even with Mitigation M2C, it is predicted that there will be a widespread increase in flood duration compared to existing conditions.
    - The flood duration associated with the 25-year SLR3 event under Mitigation Strategy M2C is predicted to be significantly less than the 25-year SLR3 event without mitigation

7.2 C-9 Watershed Flood Protection Level of Service – Future Conditions with Mitigation

The Phase 1 FPLOS Assessment analyzed the model results for the purposes of identifying deficiencies in the system and to provide a level of service rating. The level of service rating assigned to the C-9 Watershed (**Figure 7.2-1**) in the Phase 1 FPLOS Assessment describes 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 2 FPLOS Assessment, a level of service rating is not assigned, as the overall level of service watershed-wide remains largely unchanged. Therefore, instead of pointing out similar deficiencies of the system, this Phase 2 Assessment identifies improvements and compares the different mitigation strategies against each other and against both existing conditions and future conditions without mitigation.

7.2.1 PM #1 – Maximum Stage in Primary Canal (NGVD29 to NAVD88 Conversion = -1.57 ft)

Section 7.2.1.1 through **Section 7.2.1.3** discusses the PM #1 results for Mitigation Scenarios M2A, M2B, and M2C, respectively. Within each section, four figures are presented that compare the respective mitigation strategy across three sea level rise scenarios with existing conditions (M0 / SLR0) and future conditions without mitigation (M0 / SLR1 / SLR2 / SLR3) for each rainfall return frequency. These figures capture how the maximum water surface profile in the C-9 Canal changes from existing conditions with no sea level rise to future condition sea level rise without mitigation and compares that with the maximum water surface profile under future condition sea level rise with mitigation. **Section 7.2.1.4** presents an alternative assessment by comparing existing condition without sea level rise and future condition sea level rise without mitigation to each of the three mitigation strategies, for each of the twelve different combinations of rainfall return frequency and sea level rise.

7.2.1.1 <u>PM #1 – Mitigation Scenario M2A</u>

The C-9 Canal has a 10-year PM #1 LOS rating for SLR1 and SLR2 and a 5-year LOS rating for SLR3. With respect to the SLR1 scenario, Mitigation M2A is predicted to achieve a maximum water surface profile that is equal to or lower than existing conditions SLR0 for all rainfall events simulated. Although the simulated 25-year and 100-year maximum water surface profiles under Mitigation M2A is lower than existing conditions SLR0, there were still some instances of out of bank exceedance, which is a level of service deficiency that limits the PM #1 rating. However, as these predicted bank exceedances occur with a lower maximum canal elevation, the overall flood protection provided by the C-9 infrastructure is higher as there is a corresponding reduction in overland flooding that is discussed in **Section 7.2.2.4**.

Under Mitigation Scenario M2A, the improvements are predicted to lower the maximum canal profile across all sea level rise scenarios. Essentially, this mitigation scenario reduces the maximum water surface profile as if it was removing one foot of sea level rise. What that means is, the simulated maximum water surface profile for a 25-year sea level rise 3 event with Mitigation M2A is lower than the 25-year sea level rise 2 event without mitigation. Similarly, the simulated maximum water surface profile for the 5-year sea level rise 2 event with Mitigation M2A is lower than the 5-year sea level rise 1 event without mitigation. This trend is common across most combinations of rainfall and sea level rise scenarios.

Although there are still level of service deficiencies at the corresponding maximum water levels associated with the 25-year SLR0 scenario, getting back down to this condition under sea level rise 1 is an overall improvement compared to no mitigation activities. **Figure 7.2-2** through **Figure 7.2-5** present the C-9 Canal's simulated maximum water surface profile for Mitigation M2A compared to no mitigation for each rainfall and sea level rise scenario.

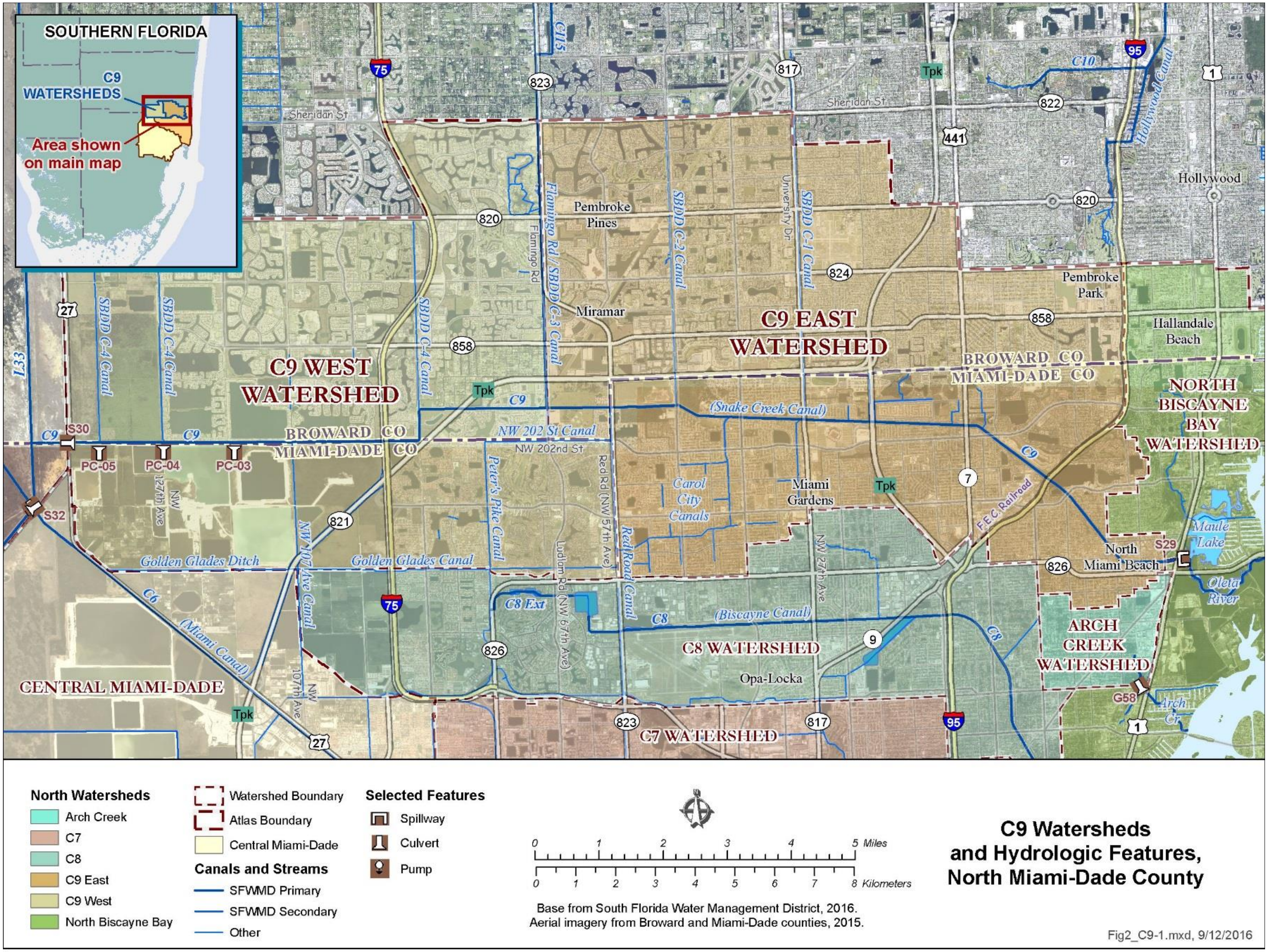


Figure 7.2-1: Map of C-9 Watershed (Figure by SFWMD)

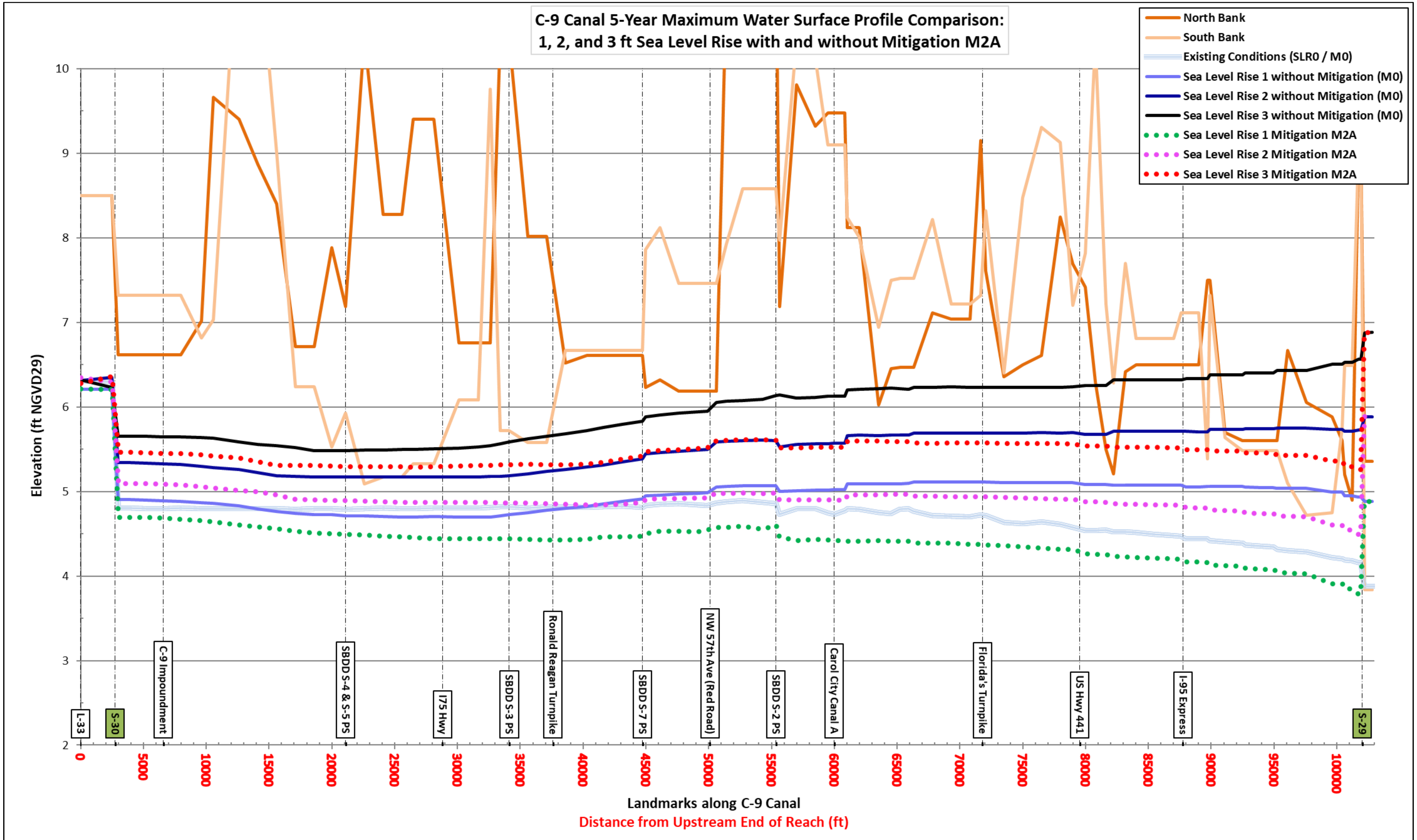


Figure 7.2-2: C-9 Canal Peak Stage Profiles for 5-Year Design Storm with and without Mitigation Scenario M2A – Current vs Future Sea Level Rise Scenarios

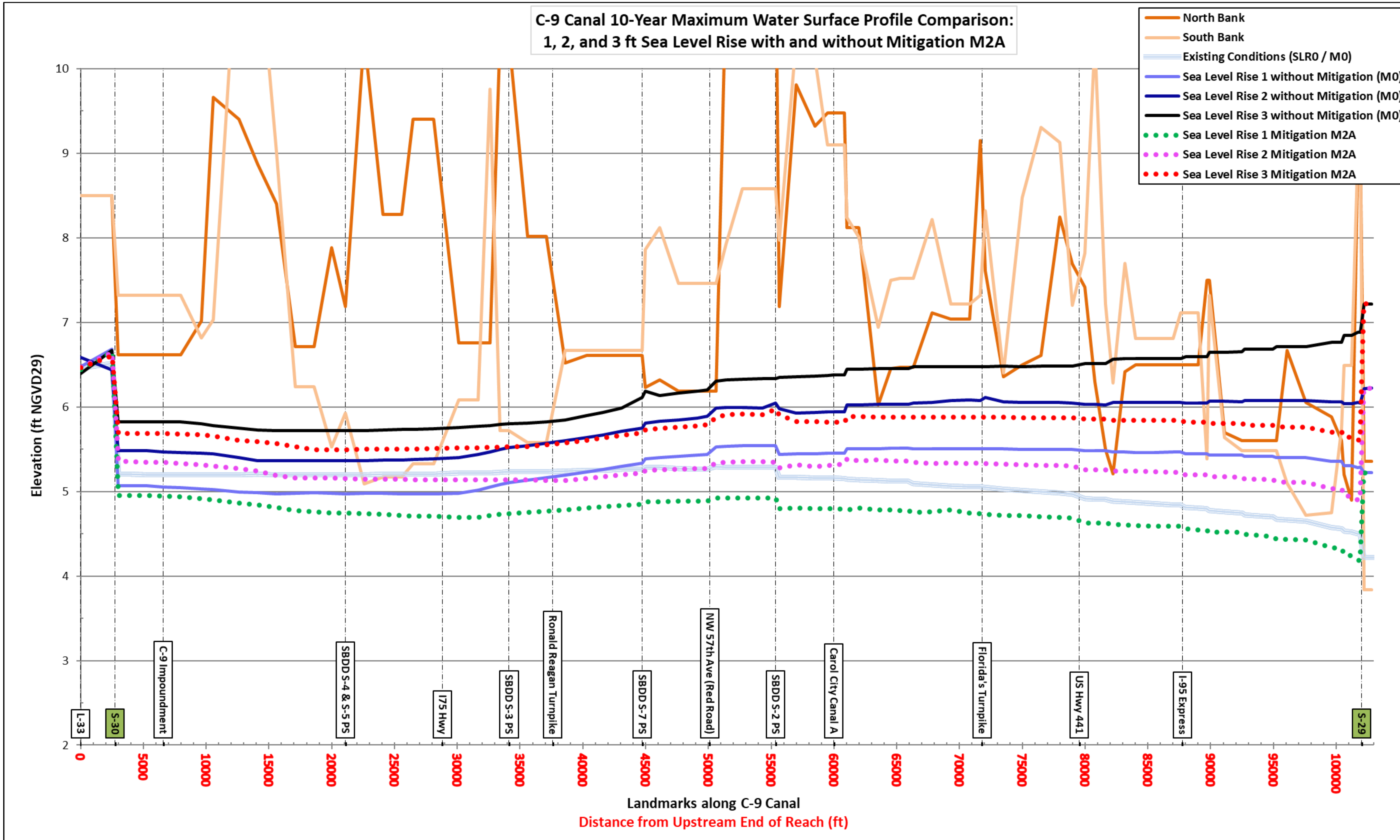


Figure 7.2-3: C-9 Canal Peak Stage Profiles for 10-Year Design Storm with and without Mitigation Scenario M2A – Current vs Future Sea Level Rise Scenarios

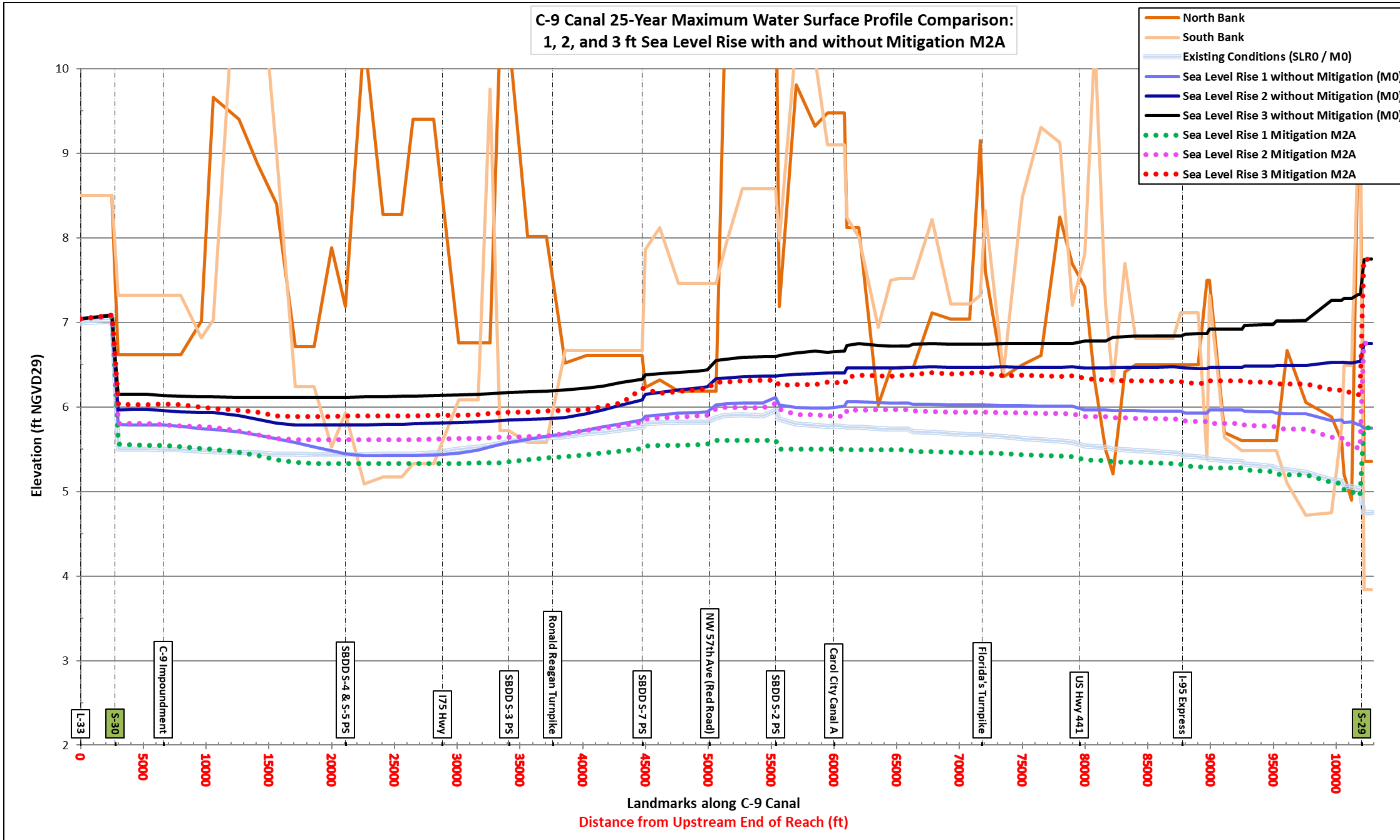


Figure 7.2-4: C-9 Canal Peak Stage Profiles for 25-Year Design Storm with and without Mitigation Scenario M2A – Current vs Future Sea Level Rise Scenarios

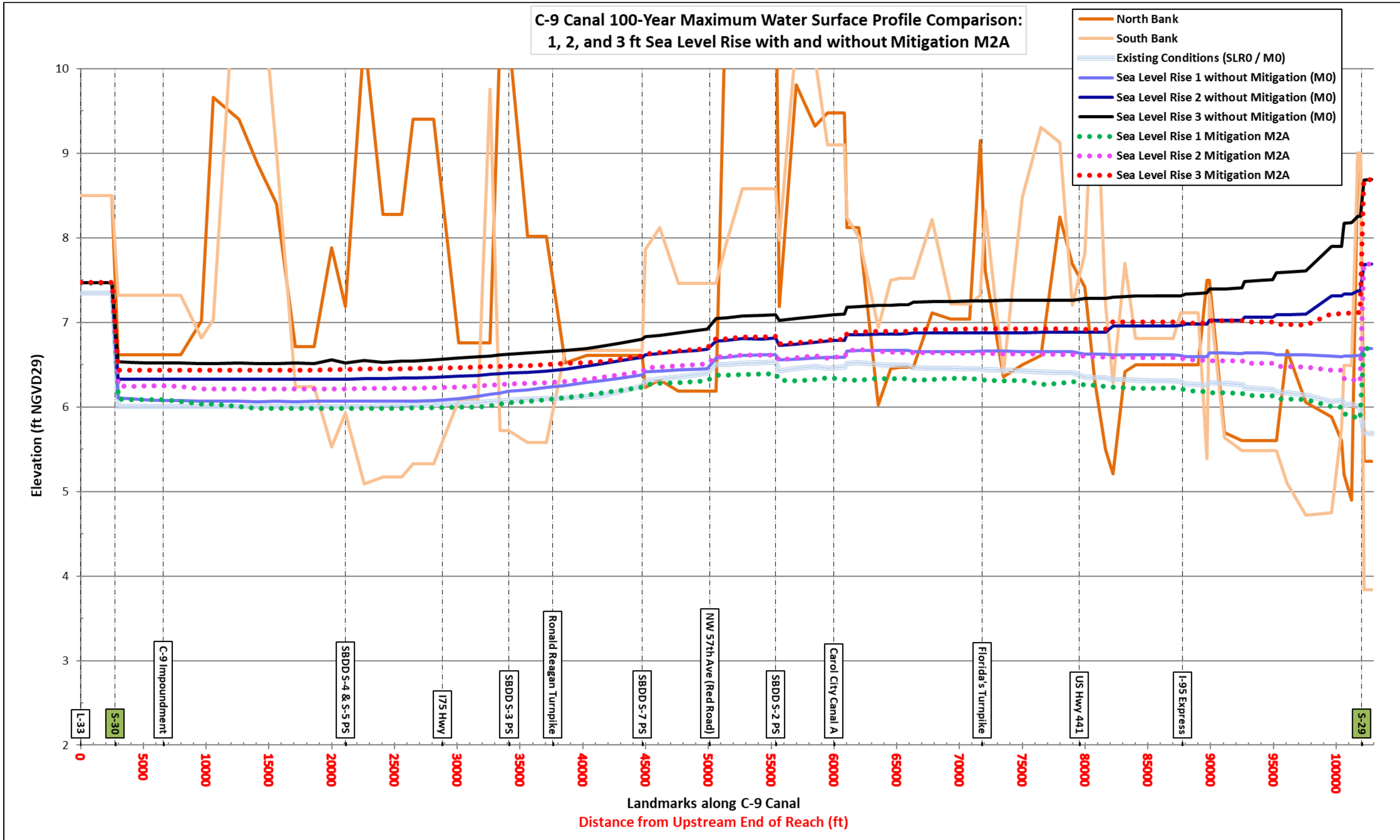


Figure 7.2-5: C-9 Canal Peak Stage Profiles for 100-Year Design Storm with and without Mitigation Scenario M2A – Current vs Future Sea Level Rise Scenarios

7.2.1.2 PM #1 – Mitigation Scenario M2B (NGVD29 to NAVD88 Conversion = -1.57 ft)

Under Mitigation Scenario M2B, the C-9 Canal has a 100-year PM #1 LOS rating for SLR1, SLR2, and SLR3 due to a critical component of the Mitigation M2B project, which includes raising the canal embankments to an elevation of 7.5 ft NGVD29. Although Mitigation Scenario M2B has an additional 1,000 cfs pumping capacity compared to Mitigation M2A, it is important to note that this improvement alone was not enough to keep the C-9 Canal in bank. With this being the case, one may ask why even add additional pumping capacity if the banks are raised under this mitigation strategy and the additional pump capacity alone doesn't keep the C-9 Canal within bank. The reason for this is that the maximum water surface profile, whether completely contained within bank or not, still plays an important role on flooding within the C-9 Watershed, especially since the C-9 Canal has relatively low topography and has several areas that rely on gravity-driven drainage from the secondary/tertiary systems. As the goal of Mitigation Scenario M2B was to achieve a 25-year SLR2 maximum stage profile equal to or lower than the existing conditions SLR0 profile, the additional 1,000 cfs pumping capacity along with some tuning adjustments to the operational controls was crucial in lowering the maximum C-9 Canal stage to the minimum desired level.

Although the C-9 Canal has a 100-year PM #1 LOS rating for SLR1, SLR2, and SLR3 under Mitigation Scenario M2B and there is a significant reduction in flooding compared to future sea level rise conditions without mitigation, the C-9 Watershed still has a low overall flood protection level of service. Elevated stages in the C-9 Canal reduce the drainage efficiency of the secondary/tertiary systems which lead to localized flooding, which is further discussed in PM #5.

Under Mitigation Scenario M2B, the improvements led to a shift in the maximum canal profile across all sea level rise scenarios. Typically, this mitigation scenario reduces the maximum water surface profile as if it was removing at least one foot of sea level rise. What that means is, the maximum surface profile for a 25-year sea level rise 3 event with Mitigation M2B is lower than the 25-year sea level rise 2 event without mitigation. Similarly, the maximum surface profile for the 5-year sea level rise 2 event with Mitigation M2B is lower than the 5-year sea level rise 1 event without mitigation. This trend is common for most segments of the C-9 Canal and occurs across most combinations of rainfall and sea level rise scenarios. The goal for Mitigation Scenario M2B was to reduce the 25-year SLR2 maximum canal stage profile to a level equal to or lower than the 25-year existing conditions SLR0 scenario. Although close, as shown in **Figure 7.2-8**, Mitigation M2B was unable to reduce the 25-year SLR2 maximum surface profile (pink dotted line) to a level equal to or below the 25-year existing conditions SLR0 profile (light blue solid line). However, when compared to the 25-year SLR2 without mitigation maximum water surface profile (dark blue solid line), the significance of this potential mitigation scenario is shown by the significant reduction in water levels, with reductions ranging from 0.2 ft to 1.4 ft, with an average reduction of 0.56 ft. Although it is predicted that there will still be level of service deficiencies at the corresponding maximum water levels associated with the 25-year SLR2 Mitigation M2B scenario, getting the system down to this condition is a significant improvement compared to no mitigation activities. Likewise, when compared with the no-mitigation scenarios, Mitigation M2B shows significant improvement across all rainfall and sea level rise scenarios, as shown in **Figure 7.2-6** through **Figure 7.2-9**.

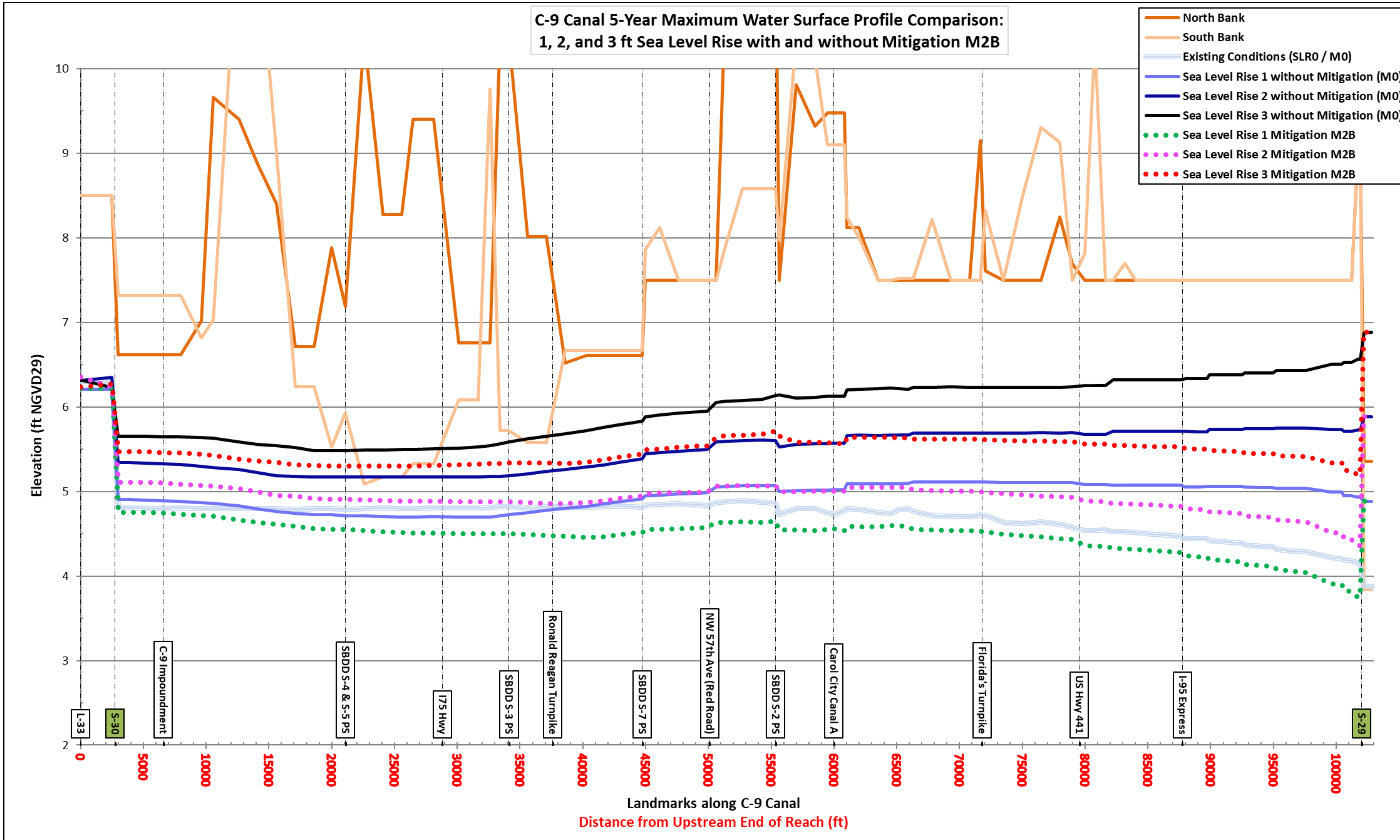


Figure 7.2-6: C-9 Canal Peak Stage Profiles for 5-Year Design Storm with and without Mitigation Scenario M2B – Current vs Future Sea Level Rise Scenarios

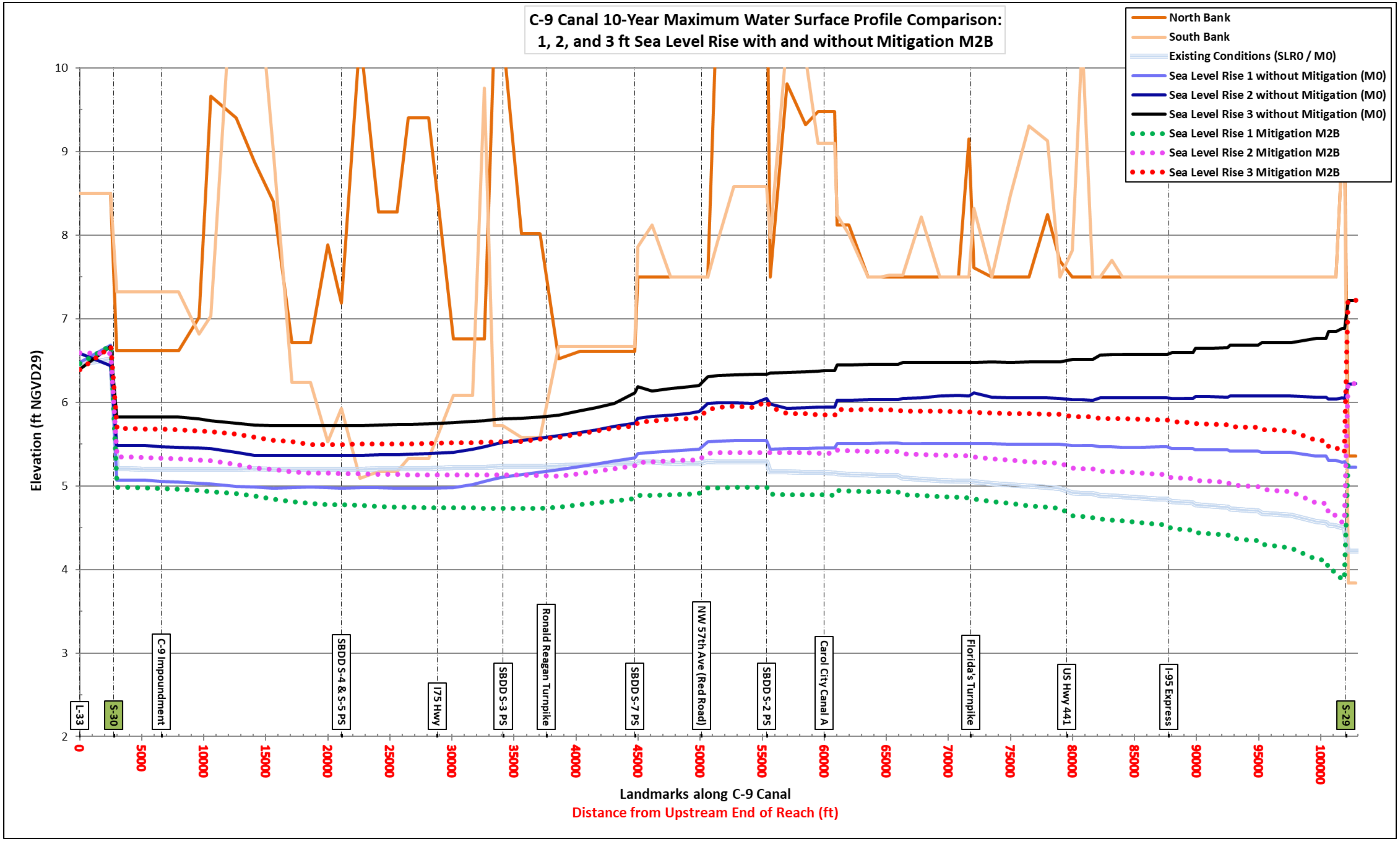


Figure 7.2-7: C-9 Canal Peak Stage Profiles for 10-Year Design Storm with and without Mitigation Scenario M2B – Current vs Future Sea Level Rise Scenarios

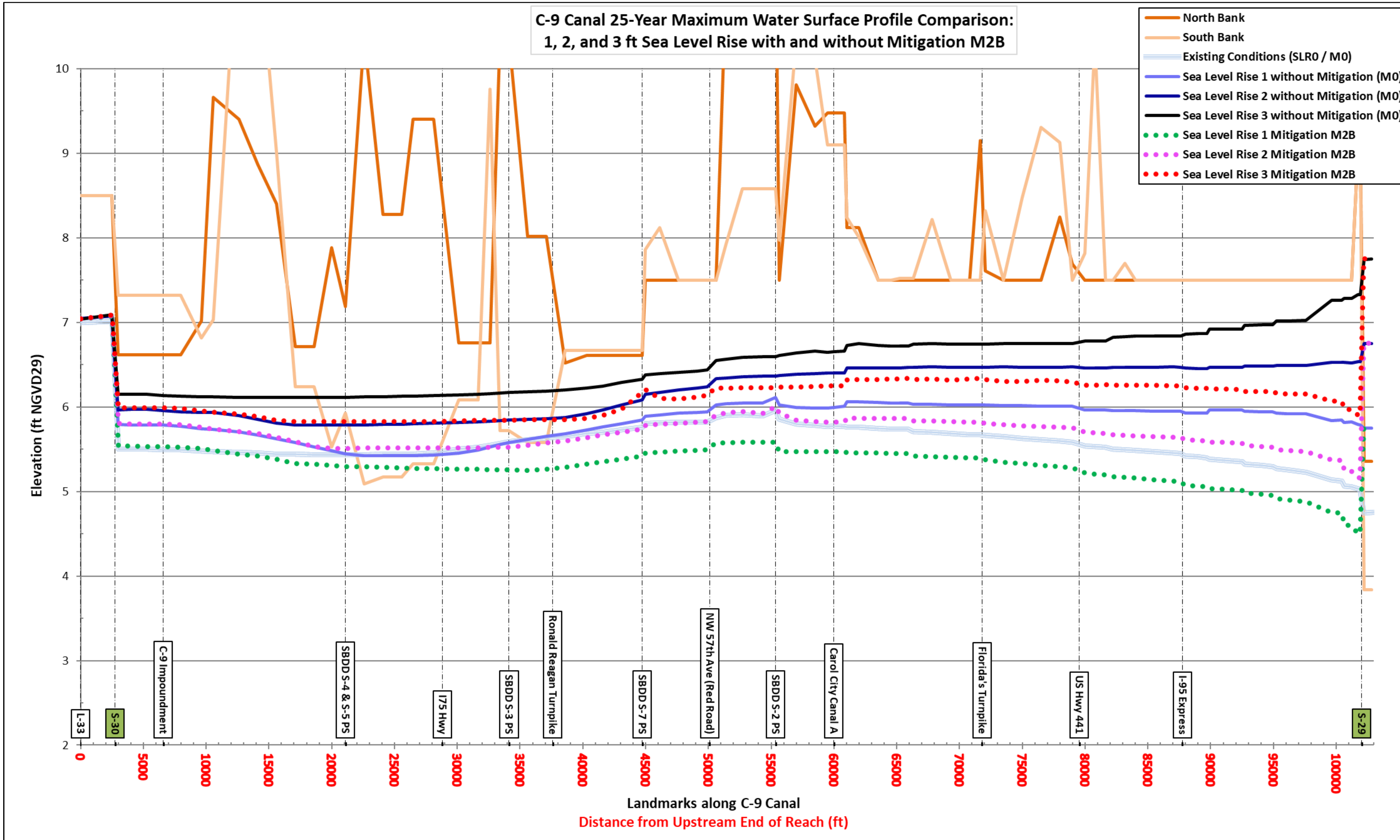


Figure 7.2-8: C-9 Canal Peak Stage Profiles for 25-Year Design Storm with and without Mitigation Scenario M2B – Current vs Future Sea Level Rise Scenarios

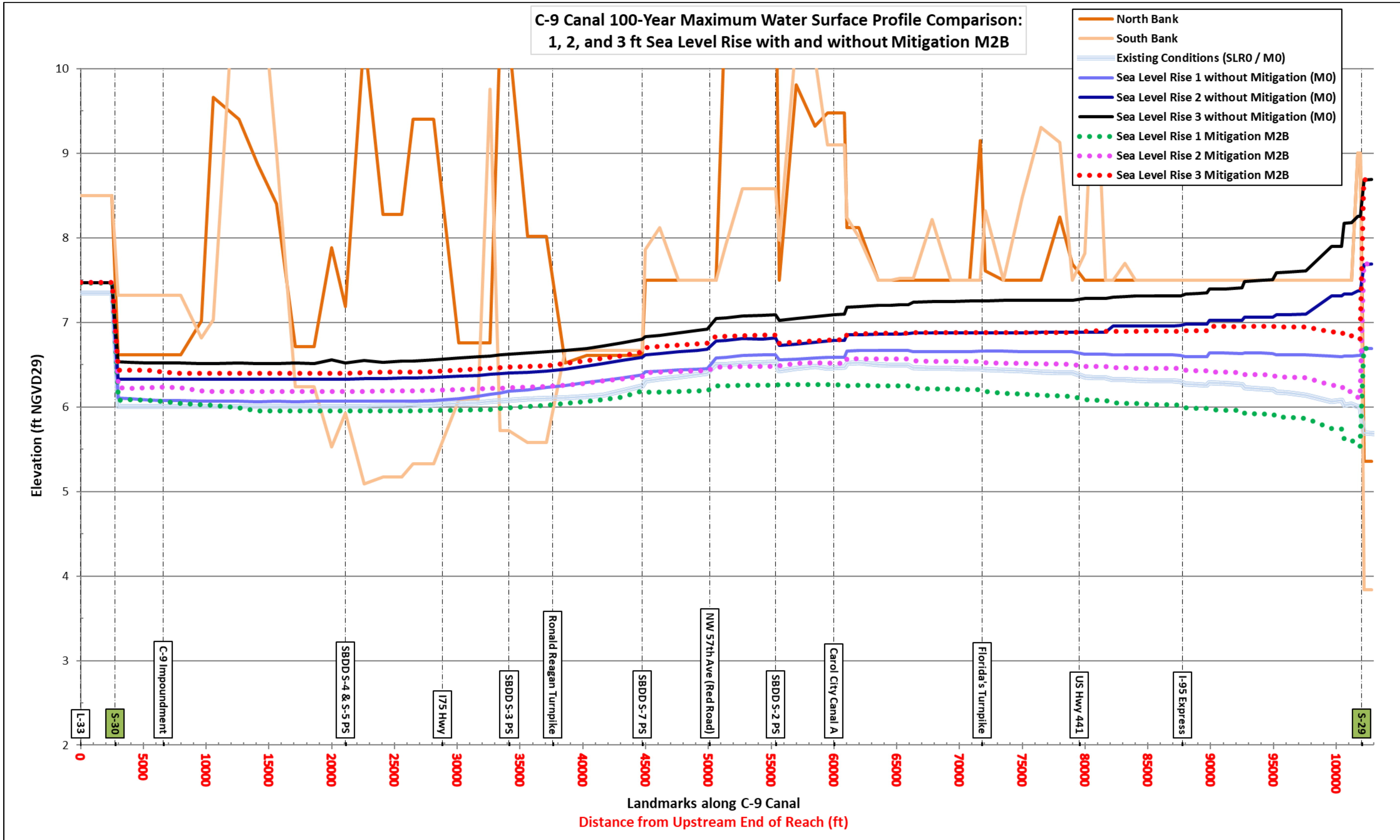


Figure 7.2-9: C-9 Canal Peak Stage Profiles for 100-Year Design Storm with and without Mitigation Scenario M2B – Current vs Future Sea Level Rise Scenarios

7.2.1.3 PM #1 – Mitigation Scenario M2C (NGVD29 to NAVD88 Conversion = -1.57 ft)

Under Mitigation Scenario M2C, the C-9 Canal has a 100-year PM #1 LOS rating for SLR1, SLR2, and SLR3 due to a critical component of both the Mitigation M2B and M2C projects, which includes raising the canal embankments to an elevation of 7.5 ft NGVD29. Mitigation Scenario M2C has an additional 2,000 cfs pumping capacity compared to Mitigation M2A and an additional 1,000 cfs pumping capacity compared to Mitigation M2B. Given that Mitigation Scenario M2B solved the bank exceedance issue in the model simulations by raising the canal banks, the thought of increasing the pump capacity by another 1,000 cfs and widening the canal may seem unnecessary. However, in order to try and achieve a 25-year SLR3 maximum water surface profile equal to or lower than the 25-year existing conditions SLR0 profile, significant changes were required.

When looking at just increasing pumping capacity, there are diminishing returns at the point where the pumping capacity becomes greater than the conveyance capacity of the canal. When that occurs, the localized water levels near the pump are drawn down, but it doesn't extend very far upstream. Therefore, the canal itself becomes the limiting element of the system and not the discharge capacity of the tidal structure. For the C-9 Canal, this point of diminishing returns was evident with the 2,550 cfs capacity under Mitigation Scenario M2B, but not necessarily due to the conveyance capacity of the canal itself. Rather, in the first 10,000 ft of C-9 Canal upstream of Structure S-29, there are five bridges, three of which are predicted to become submerged in most of the model simulations. These bridges contribute to the head loss and restrict the conveyance capacity of the C-9 Canal, especially the three that are predicted to become submerged. For comparison, the last 10,000 ft section of C-9 Canal was predicted to have as much as 1.5 ft of head loss with a pumping capacity of 2,550 cfs under Mitigation M2B, whereas the next 50,000 ft section upstream was also predicted to have about 1.5 ft or less of head loss at any given instant, but over a length 5 times greater.

As stated, since much of the head loss over the 10,000 ft section upstream of the S-29 structure is predicted to be due to bridges, this section was omitted from canal widening in the model simulations. By widening the C-9 Canal between the west side of South Broward Drainage District (approximately the east side of the C-9 Impoundment location) and the west side of Interstate 95, improvements were achieved in the form of reduced maximum water levels, both east and west of Interstate 95. To offset the increased water levels in the eastern portion of the C-9 Canal due to the increased conveyance capacity upstream and to try and achieve a 25-year SLR3 maximum water surface profile that was equal to or lower than the 25-year current conditions profile, the pumping capacity was increased by 1,000 cfs for the final total of 3,550 cfs. Again, whether completely contained within bank or not, the water level in the C-9 Canal plays an important role on flooding within the C-9 Watershed, especially since the C-9 Watershed has relatively low topography and relies on gravity-driven drainage from some of the secondary/tertiary systems. As the goal of Mitigation Scenario M2C was to achieve a 25-year existing conditions SLR0 maximum stage profile or better under Sea Level Rise 3, the additional 1,000 cfs pumping capacity over Mitigation M2B, further tuning adjustments to the operational controls, and increased canal conveyance capacity was crucial in lowering the maximum C-9 and C-8 Canal stage to the minimum desired level.

As discussed in **Section 6.3**, the C-9 Canal was not predicted to have level of service deficiencies directly related to elevated canal stages at the west side of the watershed under future sea level rise scenarios, unlike the C-8 Canal. Therefore, widening the C-9 Canal was also included in Mitigation M2C to try and provide additional relief to the C-8 Watershed by lowering upstream water levels as the C-8 and C-9 Watersheds share several basin-interconnects.

Although the C-9 Canal is predicted to have a 100-year PM #1 LOS rating for SLR1, SLR2, and SLR3 under Mitigation M2C and a significant reduction in flooding compared to future sea level rise conditions without mitigation, the C-9 Watershed would still have a low overall flood protection level of service. Elevated stages in the C-9 Canal reduce the drainage efficiency of the secondary/tertiary systems which lead to localized flooding, which is further discussed in PM #5.

Under Mitigation Scenario M2C, the improvements led to a shift in the maximum canal profile across all sea level rise scenarios. Typically, this mitigation scenario reduces the maximum water surface profile as if it was removing at least one foot of sea level rise and in some instances more than two feet (25-year rainfall events) and even three feet (100-year rainfall events) of sea level rise. What that means is, the maximum water surface profile for a 25-year sea level rise 3 event with Mitigation M2C is lower than the 25-year SLR2 and partially the SLR1 event without mitigation. Similarly, the maximum water surface profile for the 5-year sea level rise 2 event with Mitigation M2C is lower than the 5-year sea level rise 1 event without mitigation. This trend is common for most segments of the C-9 Canal and occurs across most combinations of rainfall and sea level rise scenarios. The goal for Mitigation Scenario M2C was to reduce the 25-year SLR3 maximum canal stage profile to a level equal to or lower than the 25-year existing conditions SLR0 scenario. As shown in **Figure 7.2-12**, Mitigation M2C was unable to reduce the 25-year SLR3 maximum surface profile (red dotted line) to a level equal to or below the 25-year existing conditions SLR0 profile (light blue solid line). However, when compared to the 25-year SLR3 without mitigation maximum water surface profile (black solid line), the significance of this potential mitigation scenario is shown by the significant reduction in water levels, with reductions ranging from 0.1 ft to 1.9 ft, with an average reduction of 0.67 ft. Although it is predicted that there will still be level of service deficiencies at the corresponding maximum water levels associated with the 25-year SLR3 Mitigation M2C scenario, getting the system down to this condition is a significant improvement compared to no mitigation activities. Likewise, when compared with the no-mitigation scenarios, Mitigation M2C shows significant improvement across all rainfall and sea level rise scenarios, as shown in **Figure 7.2-10** through **Figure 7.2-13**.

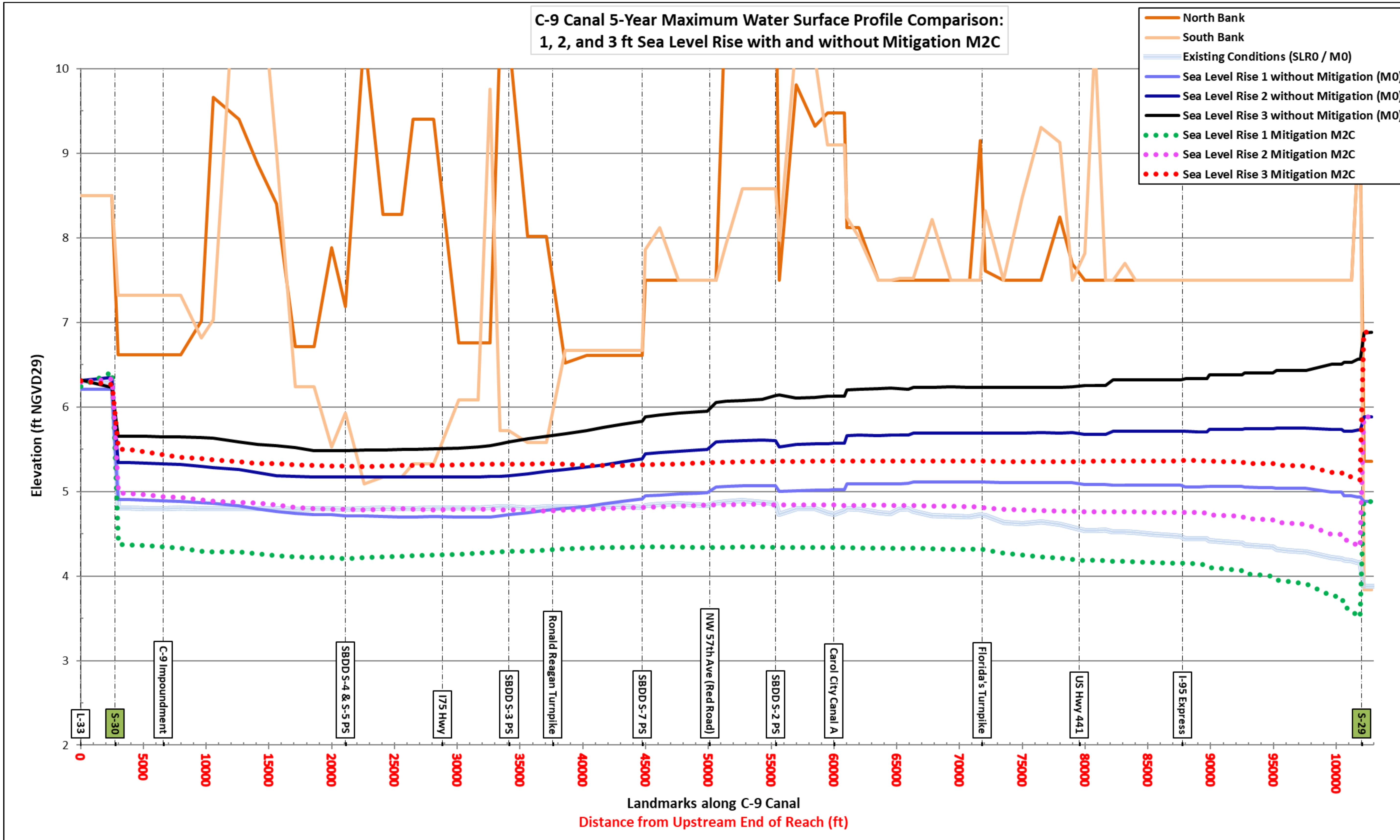


Figure 7.2-10: C-9 Canal Peak Stage Profiles for 5-Year Design Storm with and without Mitigation Scenario M2C – Current vs Future Sea Level Rise Scenarios

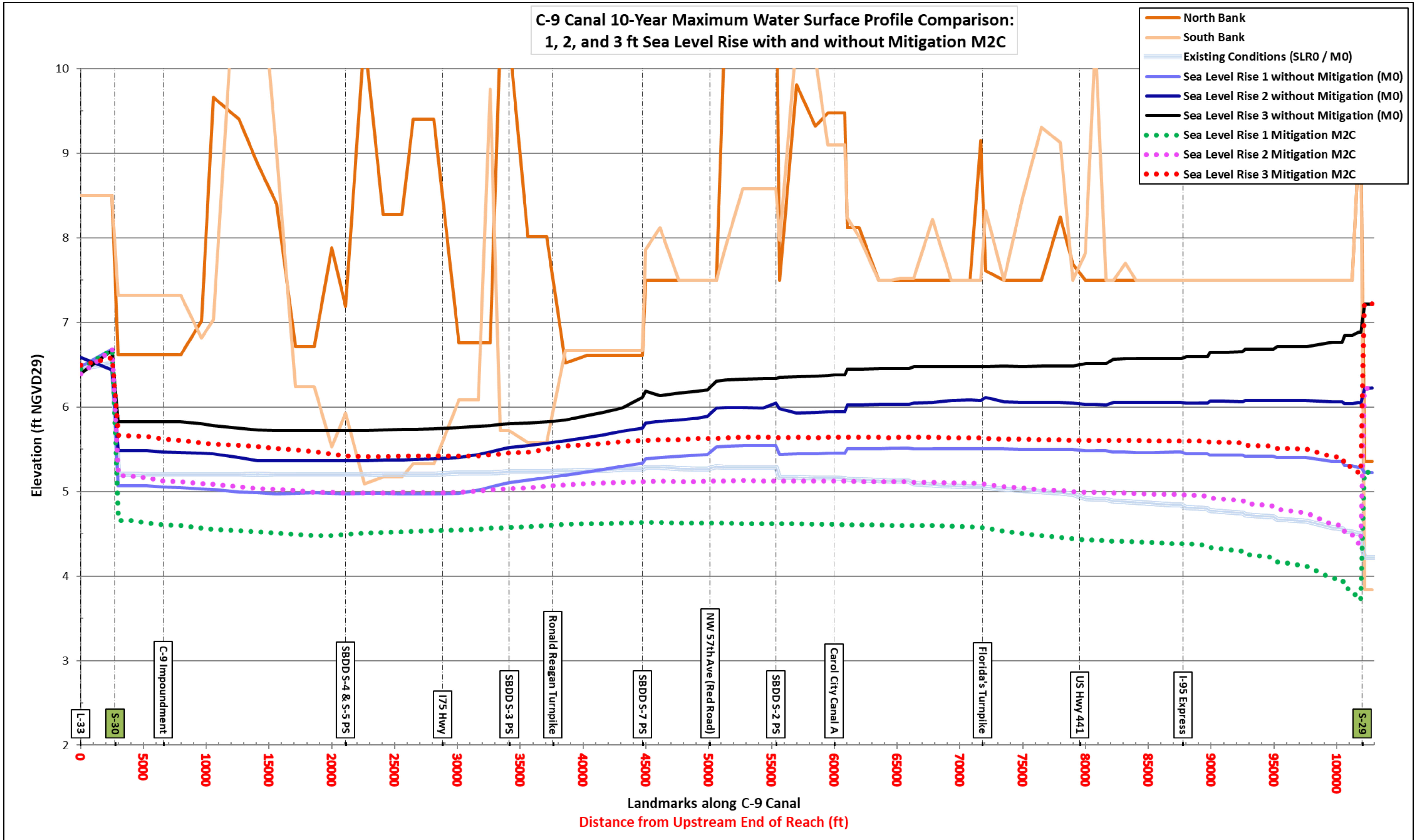


Figure 7.2-11: C-9 Canal Peak Stage Profiles for 10-Year Design Storm with and without Mitigation Scenario M2C – Current vs Future Sea Level Rise Scenarios

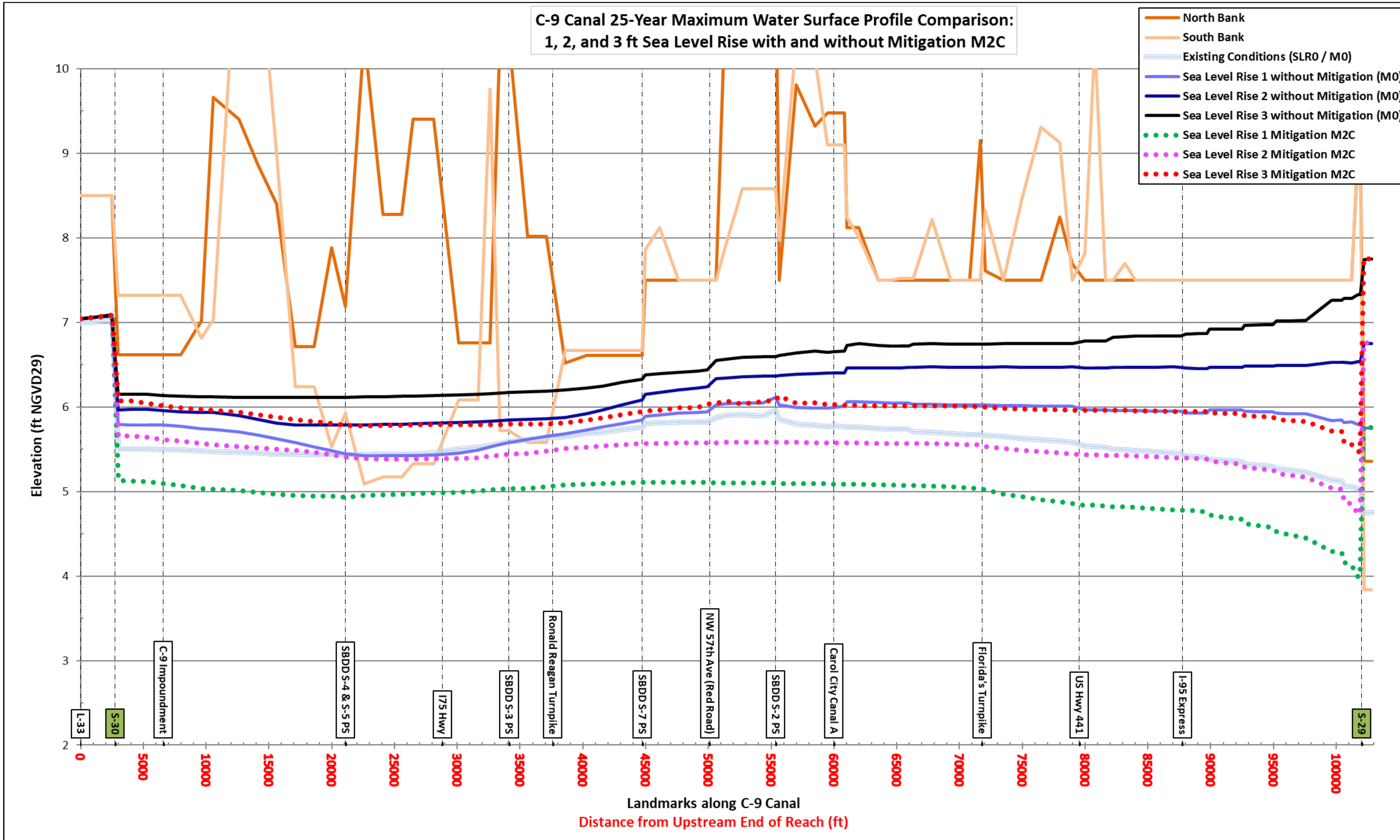


Figure 7.2-12: C-9 Canal Peak Stage Profiles for 25-Year Design Storm with and without Mitigation Scenario M2C – Current vs Future Sea Level Rise Scenarios

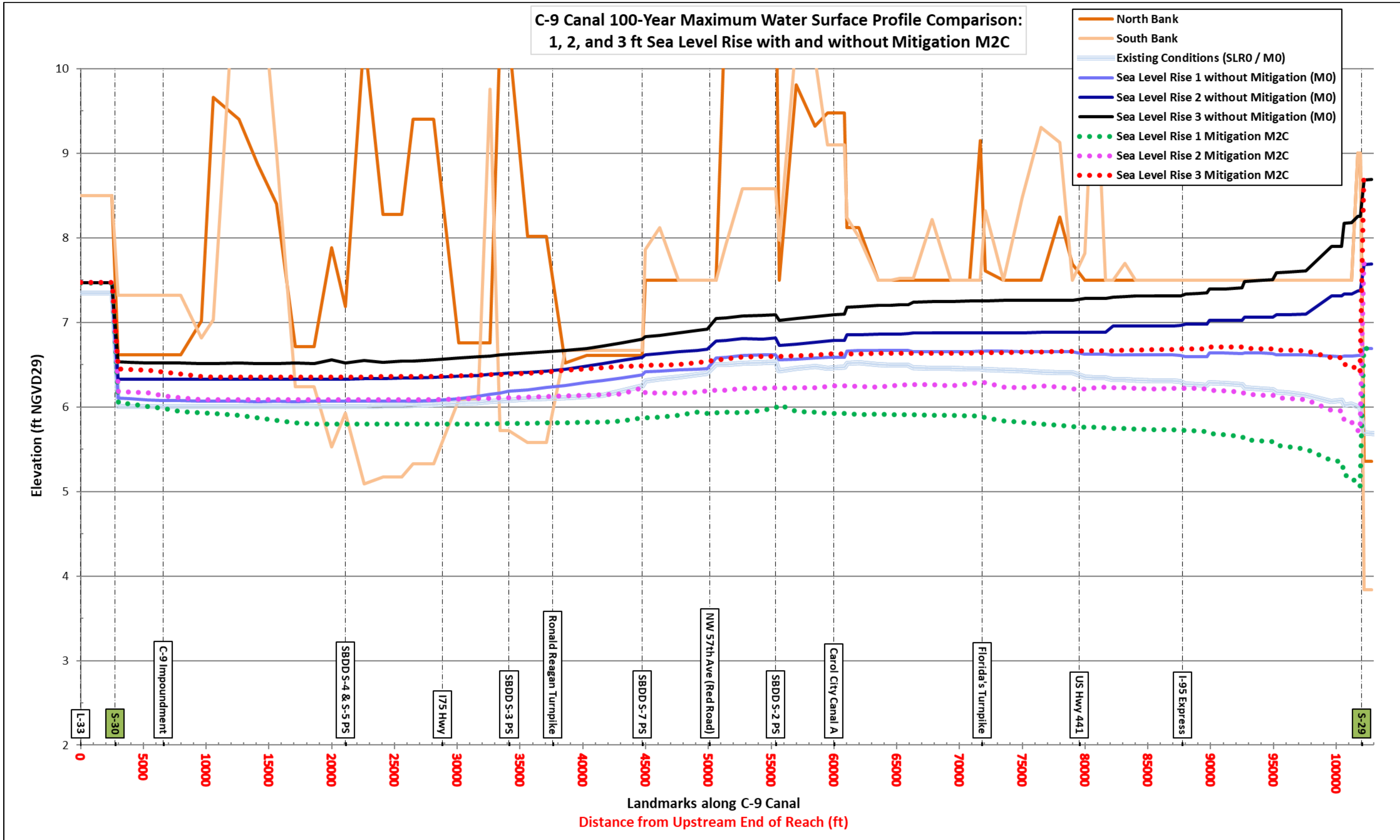


Figure 7.2-13: C-9 Canal Peak Stage Profiles for 100-Year Design Storm with and without Mitigation Scenario M2C – Current vs Future Sea Level Rise Scenarios

7.2.1.4 PM #1 – Alternative Comparison Figures

Section 7.1.2.1 through **Section 7.1.2.3** presents figures that compare the respective mitigation strategy across three sea level rise scenarios with existing conditions (M0 / SLR0) and future conditions without mitigation (M0 / SLR1 / SLR2 / SLR3) for each rainfall return frequency. This section presents the same model simulated water levels but displays them differently as an alternative source of comparison. This section presents an alternative assessment by comparing existing condition without sea level rise and future condition sea level rise without mitigation to each of the three mitigation strategies, for each of the twelve different combinations of rainfall return frequency and sea level rise. These figures provide an alternative way of looking at the model results and provide a direct comparison of what the existing PM #1 level of service is under existing conditions, what the PM #1 level of service may be in the future if no mitigation is implemented, and what PM #1 level of service could be under the three different mitigation scenarios, for each combination of rainfall and sea level rise.

It is important to note that the canal embankments were raised in the model setup under Mitigation Scenario M2B and M2C, however, only one set of canal embankments are displayed in **Figure 7.2-14** through **Figure 7.2-25**. Therefore, when comparing Mitigation Scenario M2A, M2B, and M2C in these figures, it will appear that there are out of bank exceedances under Mitigation M2B and M2C, but that is an artifact of showing the original embankments for Mitigation M2A. Please ignore any bank exceedances associated with M2B and M2C in **Figure 7.2-14** through **Figure 7.2-25**.

Although each figure on its own provides valuable information, comparing different figures with each other reveals findings that may otherwise go unnoticed. For instance, **Figure 7.1-21** shows that for the 25-year SLR2 scenario, Mitigation Scenario M2C is able to achieve a maximum water surface profile that is equal to or lower than current conditions. Looking at **Figure 7.1-21** by itself, one would assume that if the 25-year SLR2 profile is equal to or lower than current conditions, than so will the 5-year and 10-year SLR2 profiles. However, when looking at **Figure 7.1-15** and **Figure 7.1-18**, Mitigation Scenario M2C was unable to bring the maximum water surface profile back down to current conditions for the 5-year and 10-year SLR2 scenarios, respectively. In fact, for the 5-year and 10-year rainfall events, only under sea level rise 1 were any of the simulated mitigation strategies able to achieve a PM #1 maximum water surface profile that was equal to or lower than current conditions. This is brought up because this is likely the harsh reality of sea level rise. Even during the model iteration testing, where pump capacities upwards of 5,550 cfs were examined, the 5-year and 10-year rainfall scenarios under future sea level rise scenarios were unable to be consistently brought back to current condition levels. The reason for this is simply the fact that sea level rise will cause water levels on the tailwater side of the tidal structure that are high enough to cause the antecedent upstream water levels to be at an elevation that drastically hinders the ability of the system to not peak higher than it did in the past. In some cases, the new antecedent headwater levels may be nearly equal to or even higher than where the 5-year or 10-year design storm peaked under existing conditions. Therefore, if the future condition starting upstream water levels before rainfall are nearly equal to or greater than the existing conditions peak water levels with rainfall, no amount of mitigation will achieve a maximum water surface profile equal to or lower than current conditions. This is less of an issue with the larger 25-year and 100-year rainfall events as the C-8 Canal peaks a lot higher, providing a wider-range of water levels to work with under the mitigation scenarios before exceeding the maximum current condition elevations.

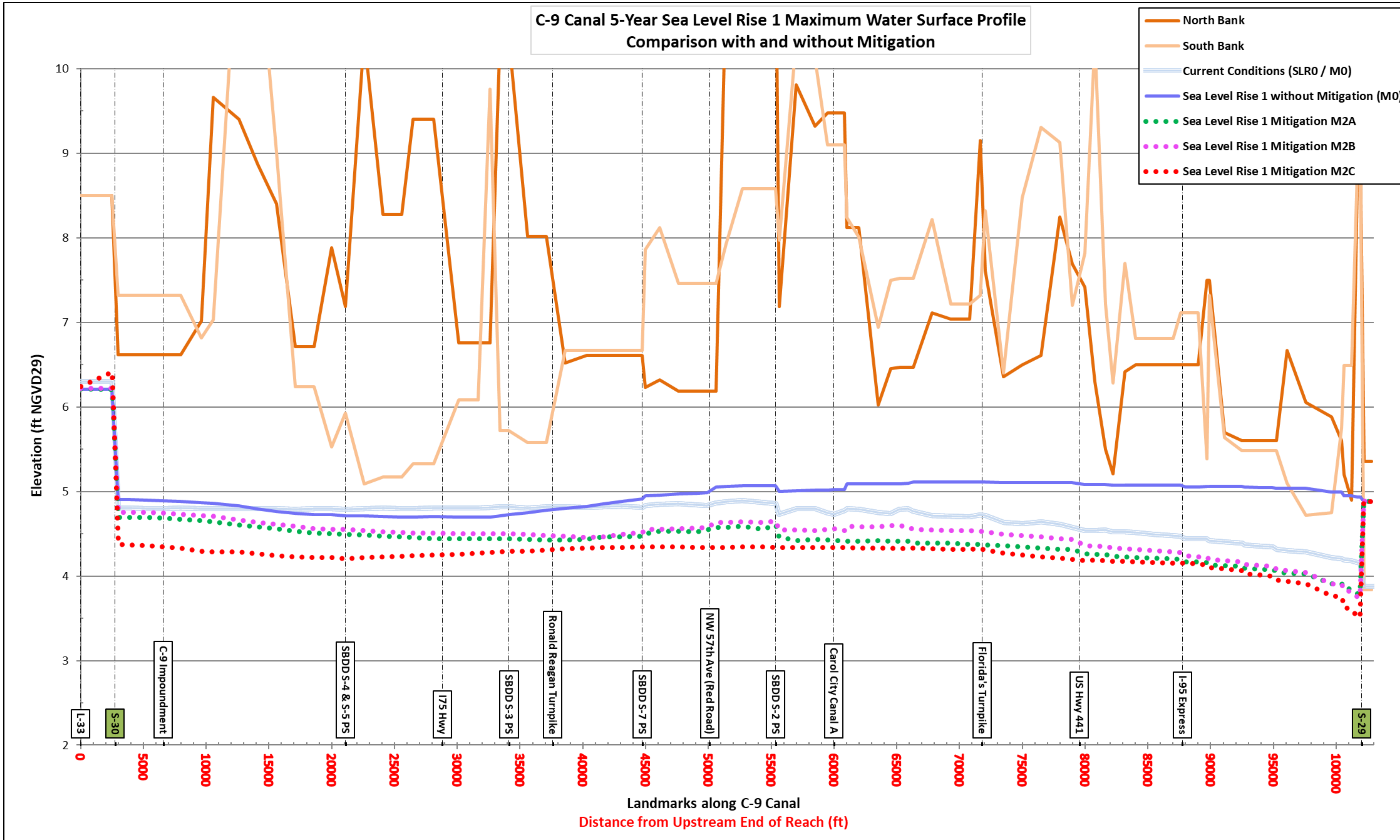


Figure 7.2-14: C-9 Canal Peak Stage Profiles for 5-Year Sea Level Rise 1 Design Storm with and without Mitigation

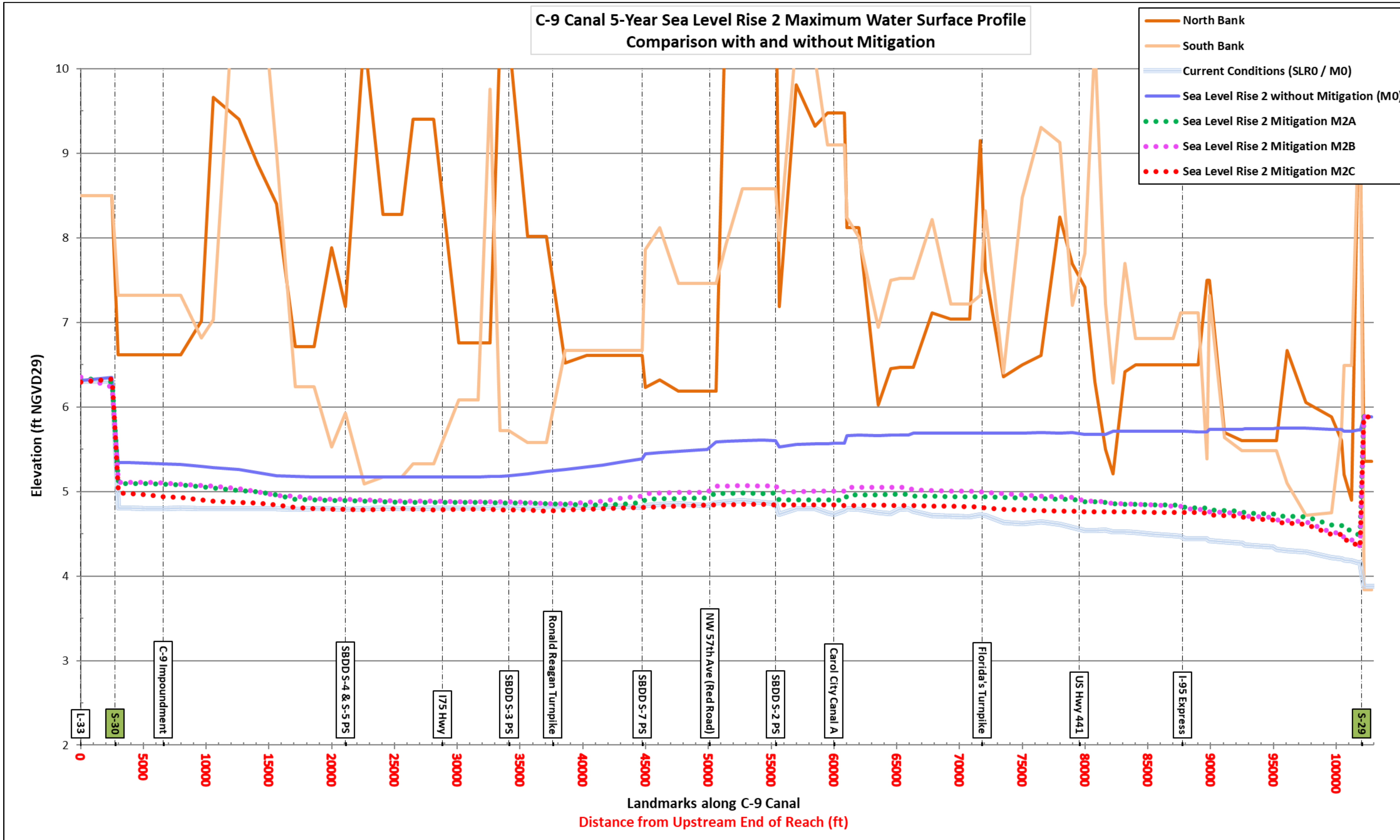


Figure 7.2-15: C-9 Canal Peak Stage Profiles for 5-Year Sea Level Rise 2 Design Storm with and without Mitigation

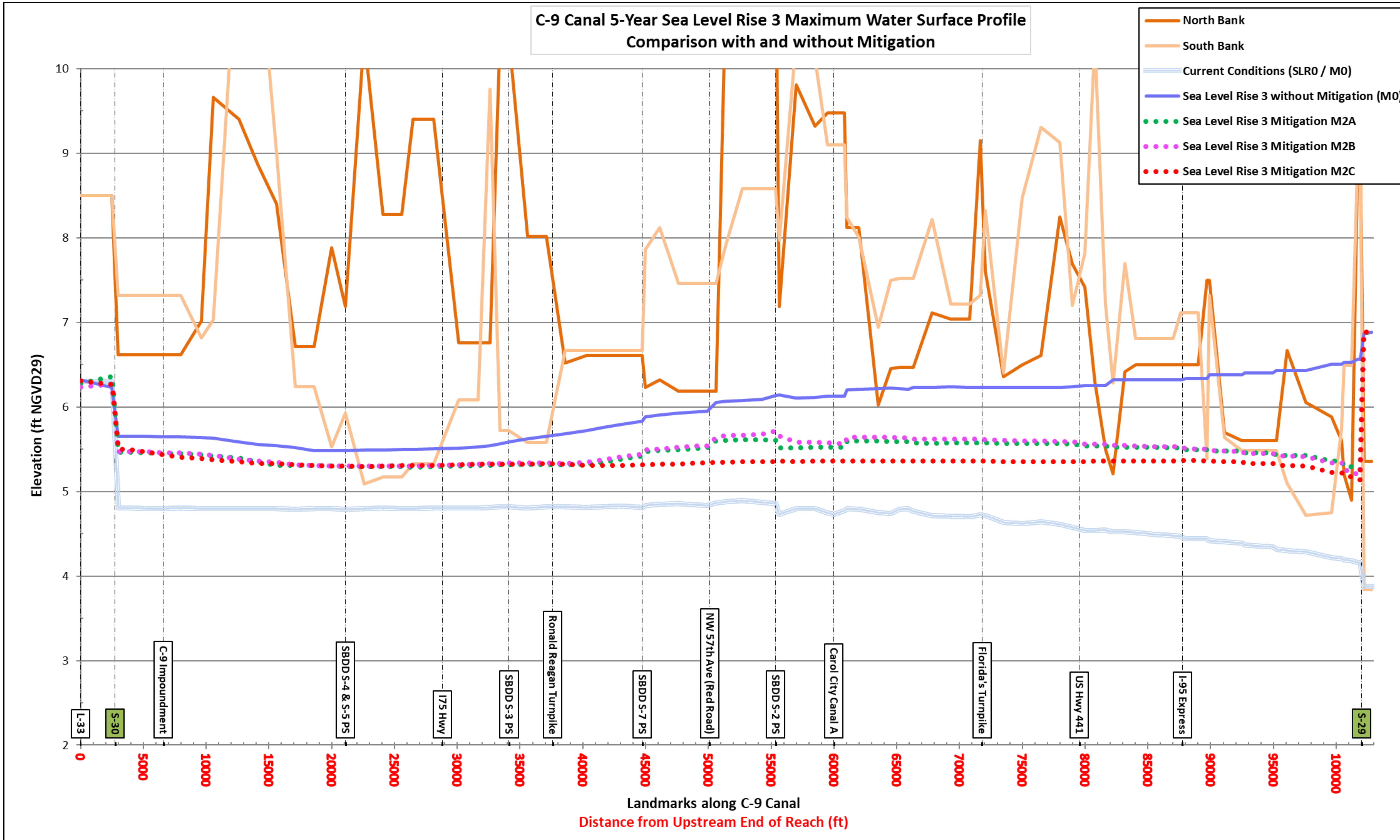


Figure 7.2-16: C-9 Canal Peak Stage Profiles for 5-Year Sea Level Rise 3 Design Storm with and without Mitigation

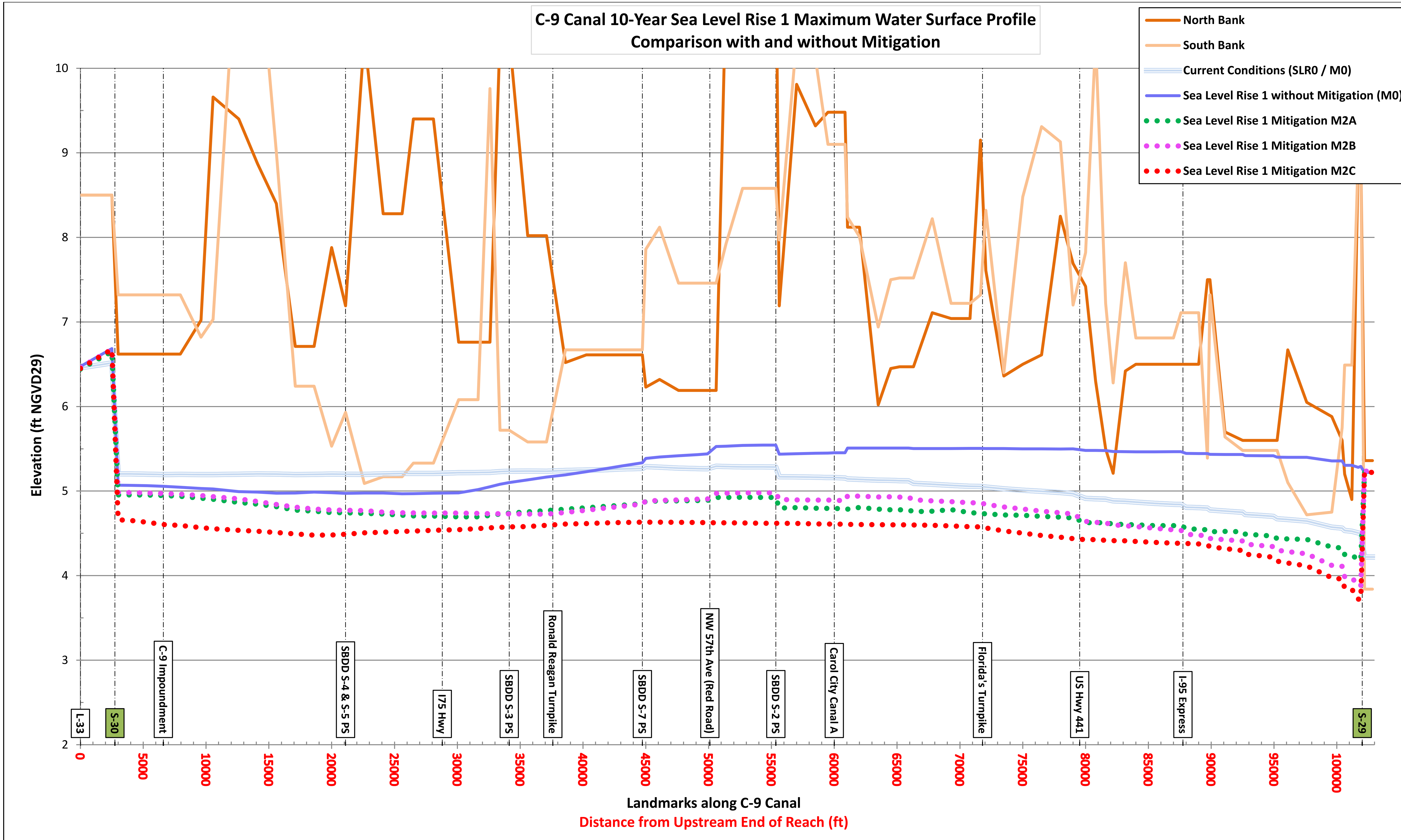


Figure 7.2-17: C-9 Canal Peak Stage Profiles for 10-Year Sea Level Rise 1 Design Storm with and without Mitigation

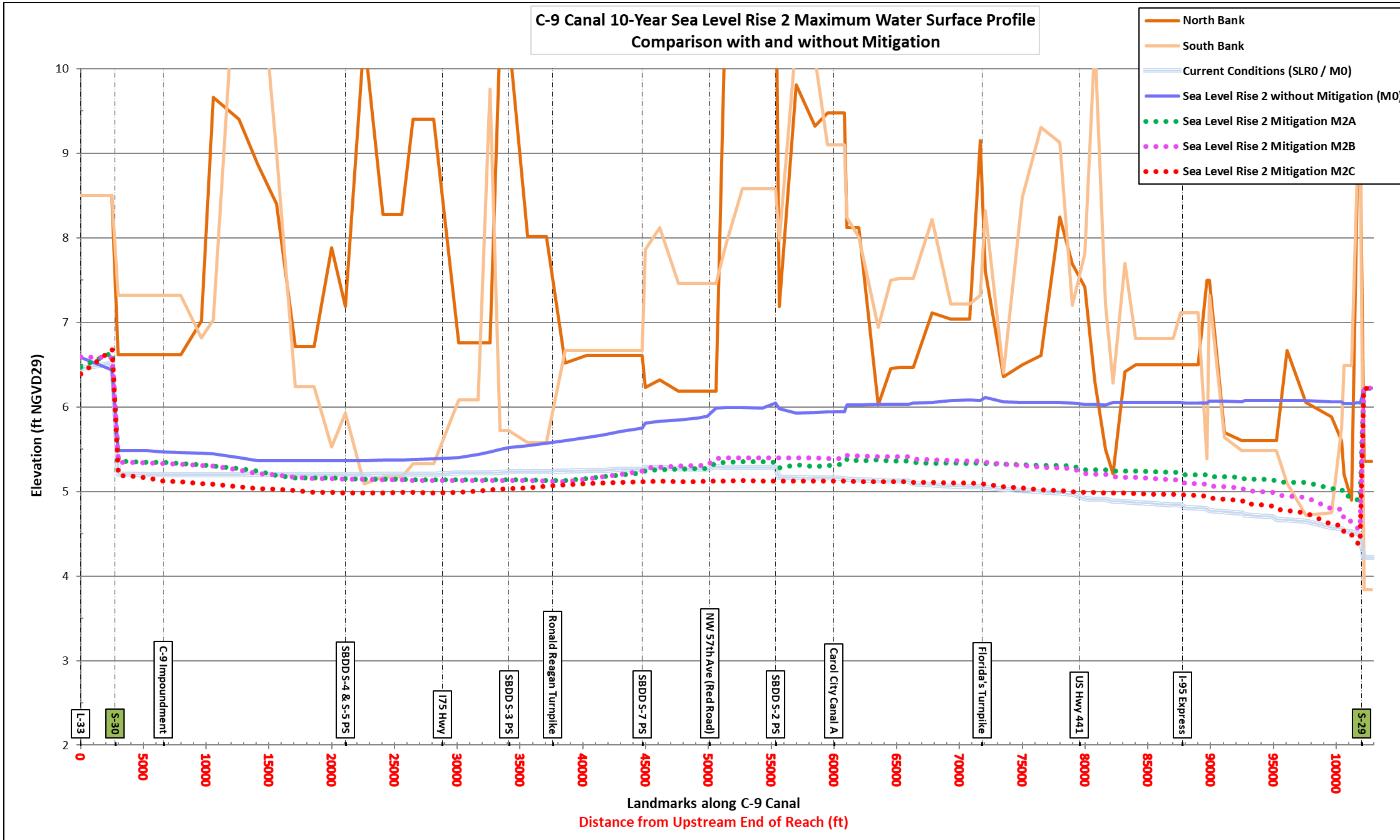


Figure 7.2-18: C-9 Canal Peak Stage Profiles for 10-Year Sea Level Rise 2 Design Storm with and without Mitigation

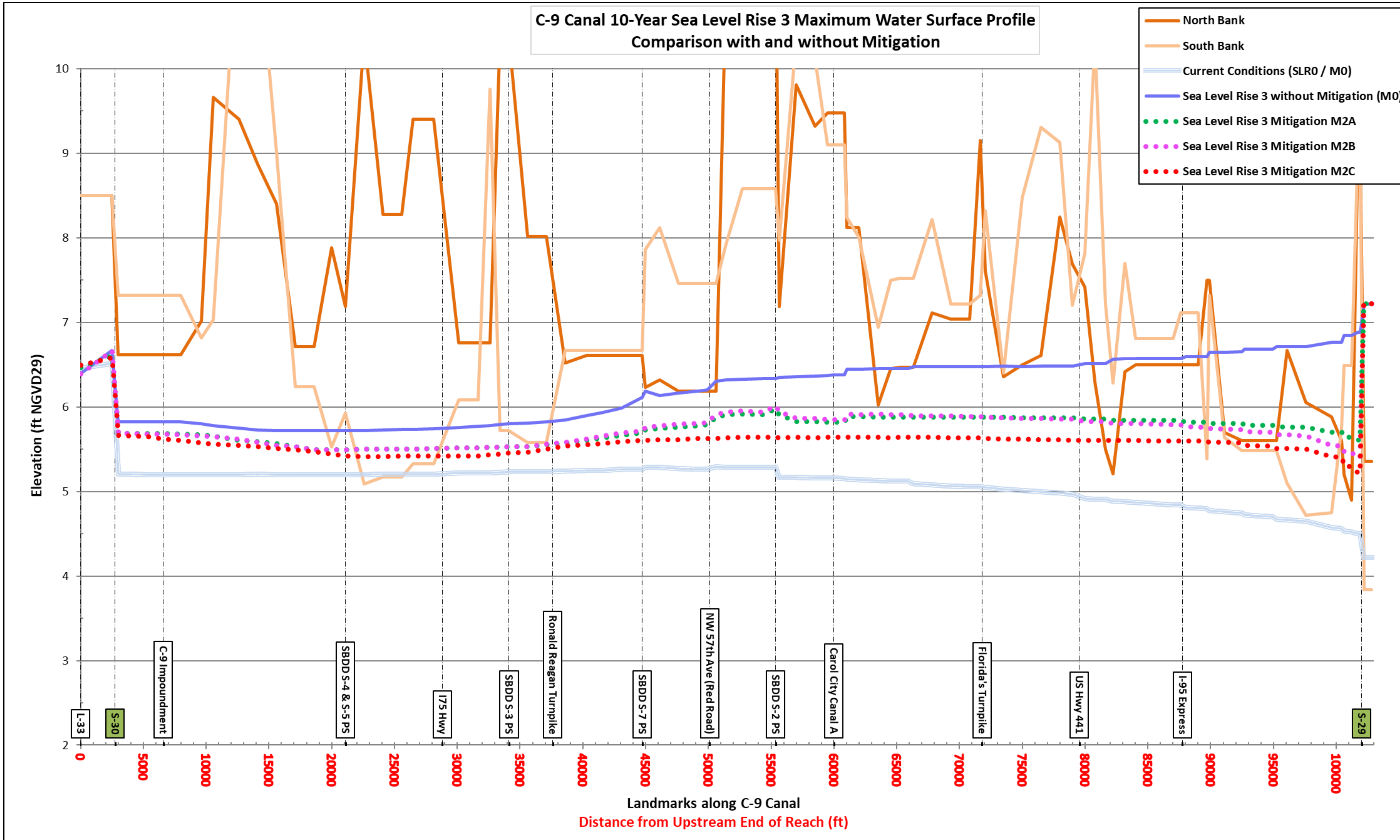


Figure 7.2-19: C-9 Canal Peak Stage Profiles for 10-Year Sea Level Rise 3 Design Storm with and without Mitigation

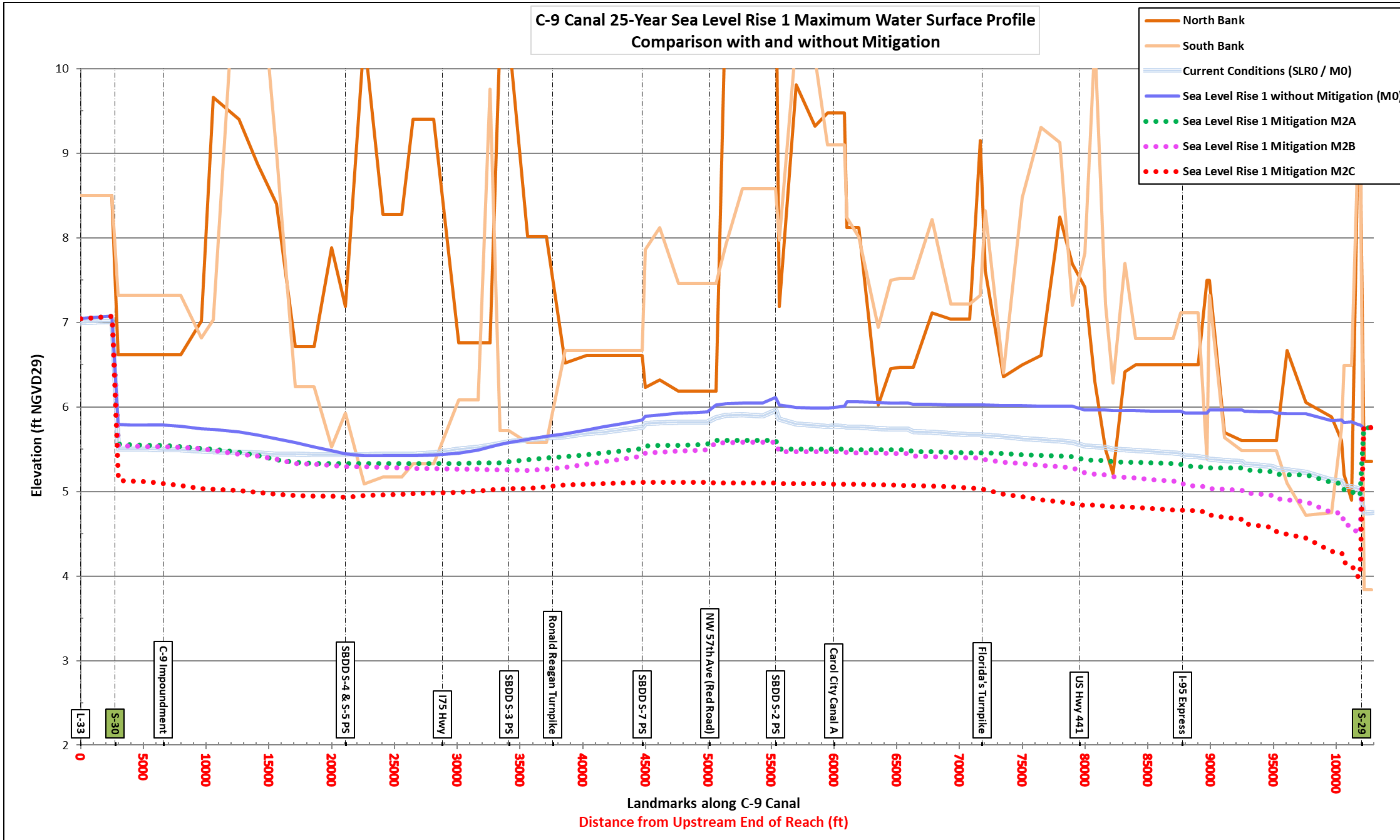


Figure 7.2-20: C-9 Canal Peak Stage Profiles for 25-Year Sea Level Rise 1 Design Storm with and without Mitigation

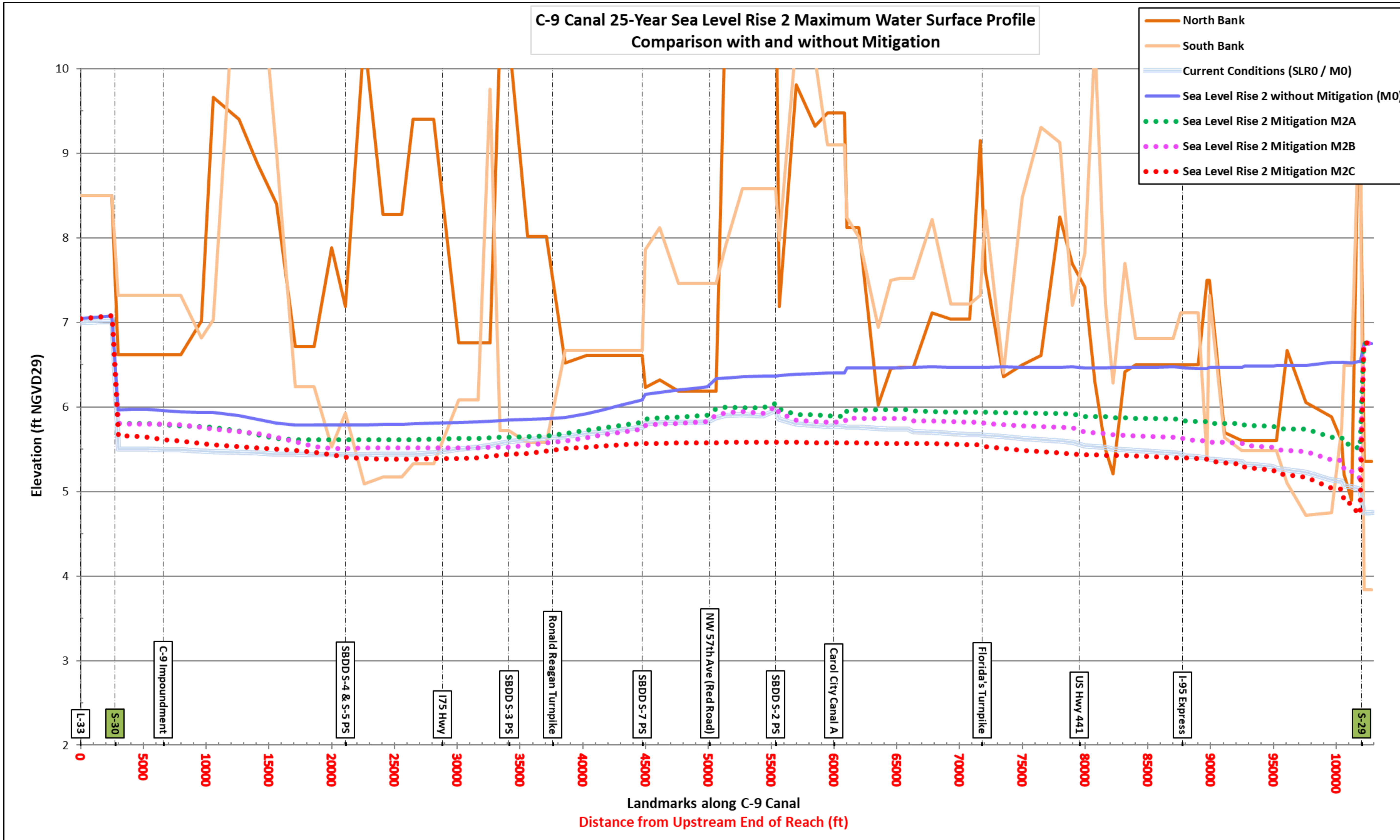


Figure 7.2-21: C-9 Canal Peak Stage Profiles for 25-Year Sea Level Rise 2 Design Storm with and without Mitigation

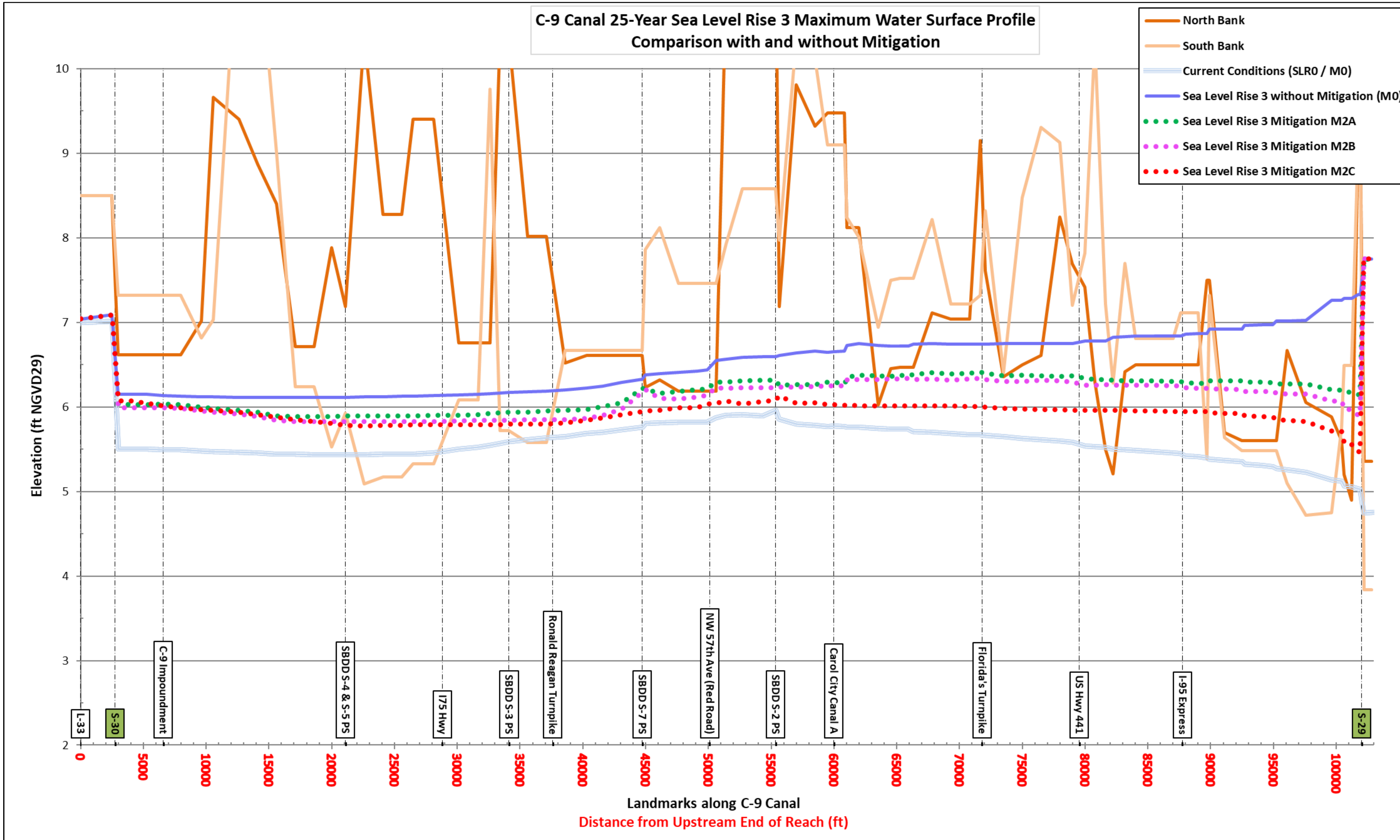


Figure 7.2-22: C-9 Canal Peak Stage Profiles for 25-Year Sea Level Rise 3 Design Storm with and without Mitigation

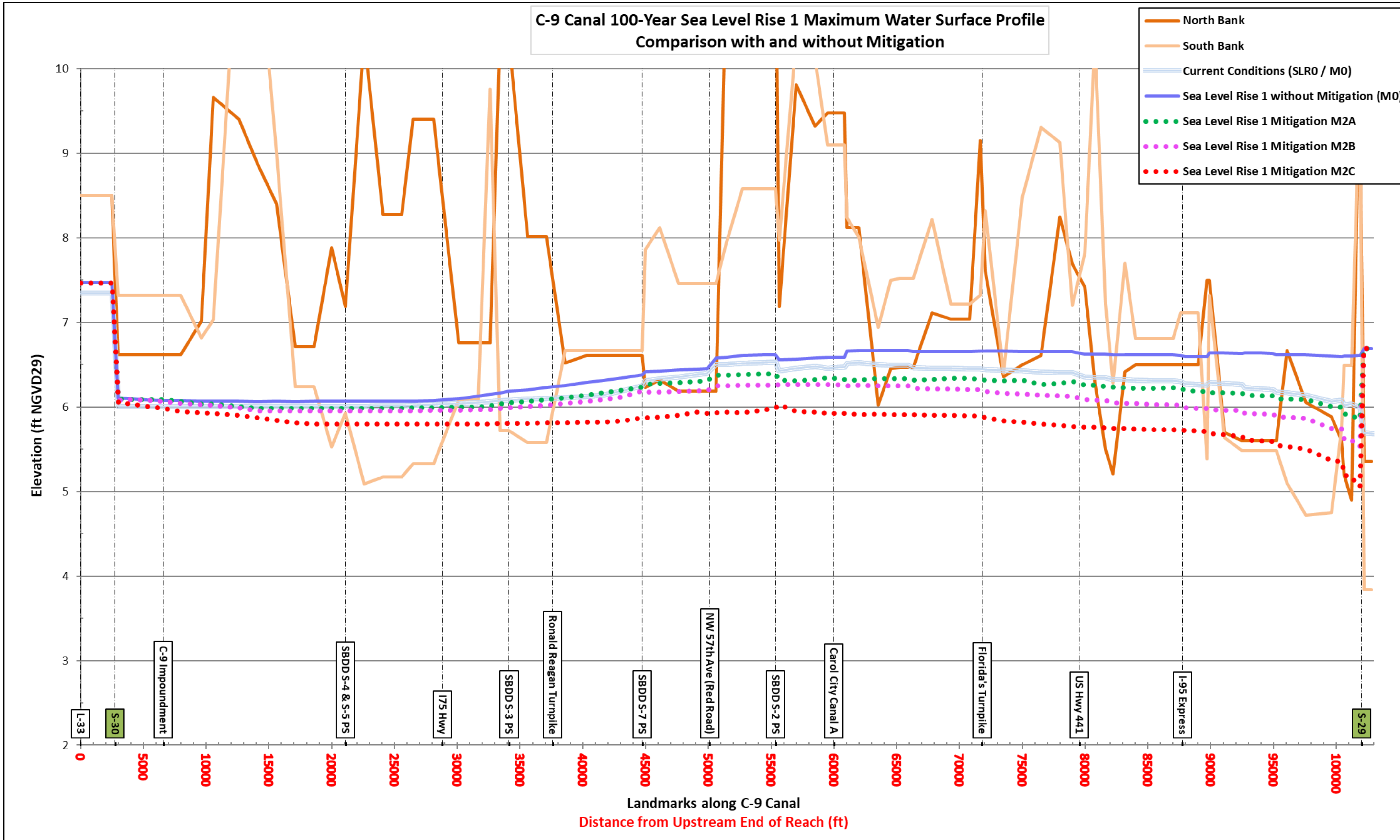


Figure 7.2-23: C-9 Canal Peak Stage Profiles for 100-Year Sea Level Rise 1 Design Storm with and without Mitigation

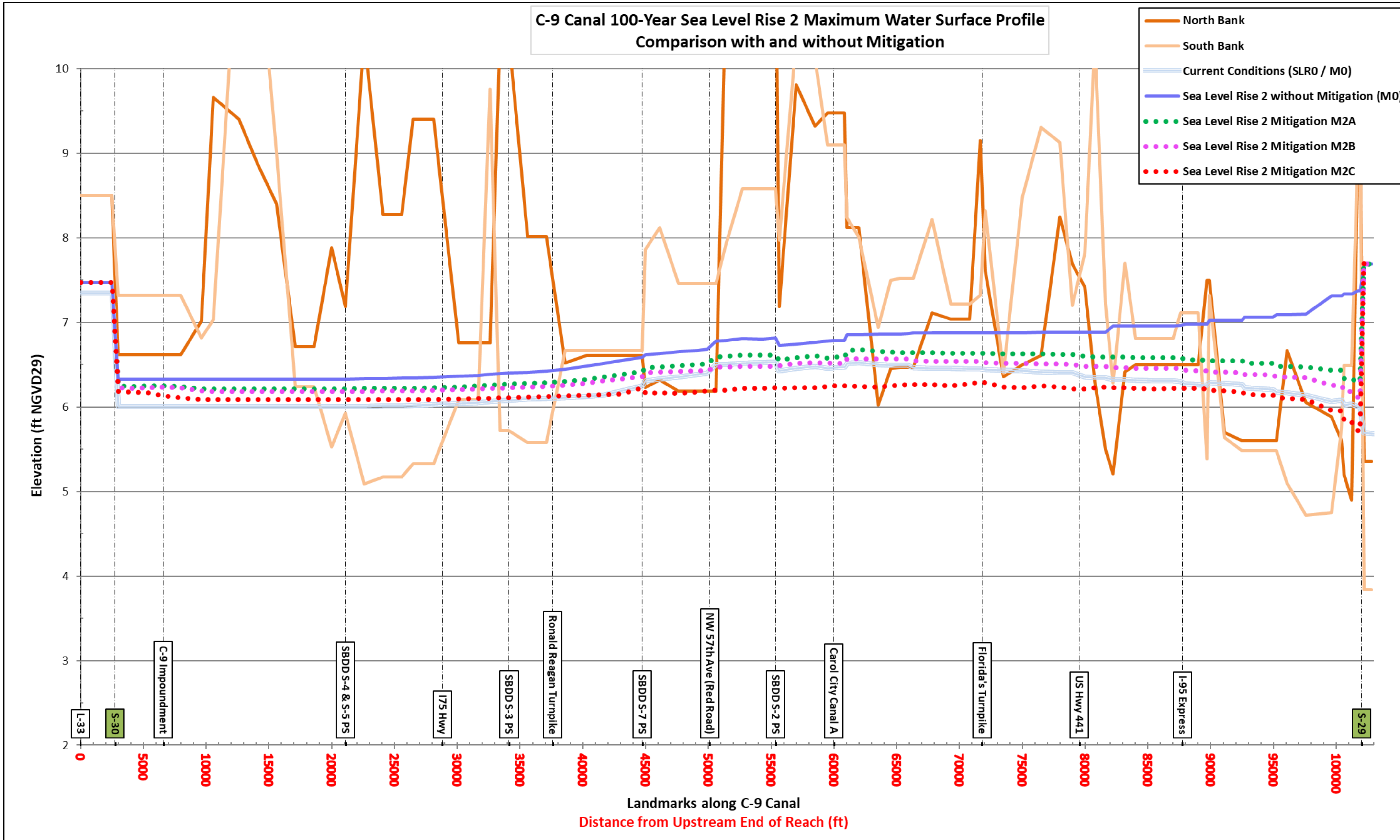


Figure 7.2-24: C-9 Canal Peak Stage Profiles for 100-Year Sea Level Rise 2 Design Storm with and without Mitigation

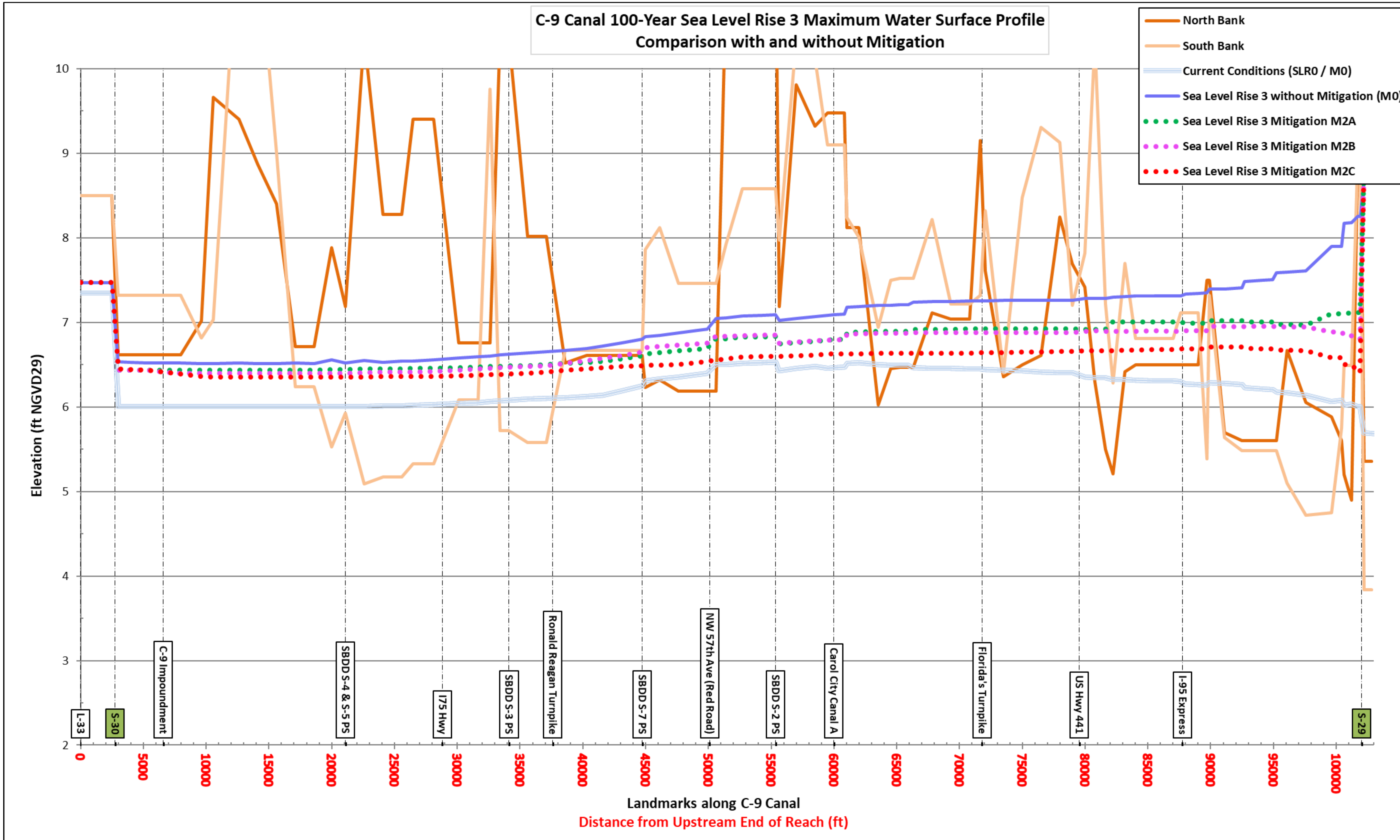


Figure 7.2-25: C-9 Canal Peak Stage Profiles for 100-Year Sea Level Rise 3 Design Storm with and without Mitigation

7.2.1.5 <u>PM #1 – Summary for C-9 Watershed</u>

- Mitigation M2A
  - Mitigation M2A is predicted to achieve a maximum water surface profile that is lower than existing conditions for the eliminate bank exceedance for the 5, 10, 25, and 100-year SLR1 event
  - Although Mitigation M2A is not predicted to eliminate bank exceedances under the 25-year SLR1 storm event, it is predicted to reduce the level of exceedance
  - Mitigation M2A is predicted to lower the maximum canal profile across all sea level rise scenarios as if it was 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 predicted to significantly improve the C-9 Watershed's provided LOS compared to existing conditions
  - Mitigation M2A is predicted to significantly improve the C-9 Watershed's LOS provided compared to future conditions without mitigation
  - Mitigation M2A is predicted to significantly reduce the impact of sea level rise
- Mitigation M2B
  - Although M2B has an additional 1,000 cfs pumping capacity compared to M2A, it is predicted to not contain the canal within bank by itself, therefore the bank elevations were increased for the eastern canal segment (western bank exceedances are in 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 "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 predicted 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 predicted to reduce the 25-year SLR2 maximum elevations in the C-8 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 predicted to lower the maximum canal profile across all sea level rise scenarios as if it was 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 predicted to significantly improve the C-9 Watershed's provided LOS compared to existing conditions
    - Mitigation M2B is predicted to significantly improve the C-9 Watershed's LOS provided compared to future conditions without mitigation
    - Mitigation M2B is predicted to significantly reduce the impact of sea level rise
- Mitigation 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 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 predicted to reduce the 25-year SLR3 maximum elevations in the C-8 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 predicted to lower the maximum canal profile across all sea level rise scenarios as if it was 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 predicted to significantly improve the C-9 Watershed's provided LOS compared to existing conditions
    - Mitigation M2C is predicted to significantly improve the C-9 Watershed's LOS provided compared to future conditions without mitigation
    - Mitigation M2C is predicted to significantly reduce the impact of sea level rise

Table 7.2-1: PM #1 Summary for the C-8 Canal

Rainfall Return Period	Sea Level Rise Scenario	Mitigation M2A		Mitigation M2B		Mitigation M2C	
		Canal Elevation with Mitigation lower than Existing Conditions	Eliminates Bank Exceedance	Canal Elevation with Mitigation lower than Existing Conditions	Eliminates Bank Exceedance	Canal Elevation 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

7.2.2 PM #2 – Maximum Daily Discharge Capacity through the Primary Canal

The maximum daily discharge capacity through the C-9 Canal is a function of the drainage from the entire C-9 Watershed. Per the District's ERP Handbook, the C-9 Watershed is allowed "20 CSM pumped and essentially unlimited inflow by gravity connections west of Red Road or Flamingo BLVD", making a direct comparison with the simulated data presented in this section rather meaningless. Rather, the simulated peak 12-hour moving average discharge from the contributing drainage area in terms of cfs/sq.mi (CSM) are compared across rainfall events, sea level rise scenarios, and mitigation strategies. **Table** 7.2-2 summarizes the C-9 Watershed's peak 12-hour moving average discharge per square mile calculated for each design storm event. The peak 12-hour moving average discharge per square mile was calculated by dividing the peak discharge through structure S-29 by the C-9 Canal's contributing drainage area.

Under existing conditions (Mitigation 0), there are two trends that apply to every storm event, with one being an increase in peak discharge as rainfall increases and the other being a decrease in peak discharge as sea level rise increases, which are to be expected. Using the 25-year rainfall event as an example, **Table** 7.2-2 shows structure S-29 had a 25-year simulated peak 12-hour average discharge of 36.5 CSM under existing conditions SLR0, 28.4 CSM for SLR1 under Mitigation M2A, 29.6 CSM for SLR2 under Mitigation M2B, and 28.3 CSM for SLR3 under Mitigation M2C. As simulated, the S-29 pump station is meant to supplement the discharge from the tidal structure whenever the gravity structure is unable to discharge due to operational constraints and has a pumping capacity that is less than the gravity structure's design capacity. Therefore, as sea level rise increases, regardless of the level of mitigation, it is expected that the average peak discharge will decrease, which is what the model results show.

Comparing peak 12-hour average discharges for the same rainfall and sea level rise scenario across the three mitigation strategies shows that, typically, the discharge increases as the pumping capacity increases. An example of this is the 10-year SLR1 scenario, with model simulations showing a peak 12-hour average discharge of 22.8 CSM, 26.4 CSM, and 28.0 CSM for Mitigation M2A, M2B, and M2C, respectively. However, there are also instances where the model simulations show a reduction in peak 12-hour average discharge as the pumping capacity increases, such as the 5-year SLR3 scenario and the 10-year SLR3 scenario. In these two instances, M2B has a larger discharge than both M2A and M2C, even though M2C has the largest pumping capacity. There are several potential reasons for this phenomenon, but the most likely one in this case is that the larger pumping capacity under Mitigation M2C suppresses the headwater, resulting in a lower head differential across the tidal structure which ultimately means a lower peak discharge by the gravity structure when the pump turns off. In this case, the reduction in peak 12-hour average-discharge does not indicate less performance, as there is actually a significantly higher total discharge volume under Mitigation M2C, even with the lower peak discharge. For the 10-year SLR3 scenario, Mitigation M2B has a pumping capacity of 2,550 cfs, a peak 12-hour average discharge of 21.1 CSM, and a total discharge volume of approximately 19,384 ac-ft, whereas Mitigation M2C has a pumping capacity of 3,550 cfs, a peak 12-hour average discharge of 19.8 CSM, and a total discharge volume of approximately 23,101 ac-ft. In the example above, Mitigation M2C has a peak 12-hour average discharge that is 1.3 CSM less than Mitigation M2B, but a total discharge volume that is more than 3,700 ac-ft, or nearly 162 million cubic feet more than Mitigation M2B.

Table 7.2-2: C-9 Watershed Peak 12-Hour Average Area-Weighted Discharge Summary

C-9 Watershed Structure S-28				
Rainfall Return Frequency	Peak 12-Hour Moving Average Discharge from the Contributing Drainage Area (cfs/sq.mi)			
	M0	M2A	M2B	M2C
	SLR0			
5-year	28.2	23.7	26.0	27.6
10-year	31.4	27.1	29.7	31.6
25-year	36.5	33.0	35.9	37.4
100-year	44.7	41.8	45.7	46.4
	SLR1			
5-year	22.6	20.2	22.5	23.9
10-year	26.1	22.8	26.4	28.0
25-year	32.4	28.4	32.1	34.0
100-year	41.2	38.3	40.8	42.9
	SLR2			
5-year	18.4	17.3	19.3	19.9
10-year	23.2	20.3	23.5	23.3
25-year	29.1	25.5	29.6	33.0
100-year	35.6	32.9	36.9	40.0
	SLR3			
5-year	15.3	13.6	14.7	13.8
10-year	18.8	18.3	21.1	19.8
25-year	22.8	22.3	27.5	28.3
100-year	27.6	27.8	31.8	36.9

Please note the following important points about **Table 7.2-2**:

- The peak discharges presented in this table are highly sensitive to timing of operations, headwater/tailwater differential, and flow rating.
- A decrease in peak discharge does not necessarily indicate a decrease in performance. There are instances where the peak discharge decreased (see previous point) but the total discharge volume increased (see **Figure 7.2-26** through **Figure 7.2-37**).
- An increase in peak discharge does not necessarily indicate an increase in performance. There are instances where the peak discharge increased (see first point) but the total discharge volume decreased (see **Figure 7.2-26** through **Figure 7.2-37**).
- In most instances, the peak discharge is coming from the gravity structure, as the discharge capacity (regardless of rated design discharge) of the sluice gates far exceed that of the simulated pump stations.
- The impact of the pump station is not apparent in this dataset. The pump station discharges when the gravity structure is unable to, which suppresses the headwater (reduces flooding) and shifts the timing and characteristics of discharge. This often leads to a smaller (or larger)

headwater/tailwater differential and timing change in discharge, which may be reflected as smaller (or larger) peak discharges in this table.

Table 7.2-3 provides a summary of the instantaneous and 12-hour moving average peak discharge, peak headwater, and peak tailwater, for the 25-year rainfall event for all sea level rise combinations for each mitigation strategy. Refer to **Appendix A** for the complete set of summary tables for all rainfall events.

Section 7.2.2.1 through **Section 7.2.2.3** present PM #2 figures for each of the three mitigation strategies. **Figure 7.2-26** through **Figure 7.2-37** presents the 12-hour moving average discharge hydrographs for the C-9 Canal for each rainfall frequency and sea level rise scenario while comparing existing conditions (no mitigation) versus Mitigation M2A, M2B, and M2C. These hydrographs also show that for each mitigation strategy, there is an overall decrease in discharge volume as sea level rises, although this difference typically becomes smaller as the level of mitigation increases.

Table 7.2-3: Summary of Structure S-29 25-Year Simulated Peak Discharge, Peak Headwater, and Peak Tailwater (NGVD29 to NAVD88 Conversion = -1.57 ft)

25-Year Design Storm												
Sea Level Rise Scenario	Summary of the Instantaneous Peak Discharge, Peak Headwater, and Peak Tailwater at Structure S-29 in the C-9 Watershed											
	Existing Conditions (Mitigation 0)			Mitigation M2A			Mitigation M2B			Mitigation M2C		
	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)
SLR0	4603	5.03	4.75	4403	4.53	4.75	4706	4.2	4.75	4804	3.75	4.75
SLR1	4475	5.79	5.75	4052	4.95	5.75	4475	4.5	5.75	4323	3.99	5.75
SLR2	4557	6.54	6.75	3975	5.51	6.75	4074	5.16	6.75	3841	4.73	6.75
SLR3	4580	7.33	7.75	3732	6.14	7.75	3540	5.9	7.75	3550	5.46	7.75
Summary of the 12-Hour Moving Average Peak Discharge, Peak Headwater, and Peak Tailwater at Structure S-29 in the C-9 Watershed												
SLR0	3631	4.46	4.37	3282	4.2	4.37	3568	3.92	4.37	3712	3.7	4.37
SLR1	3232	5.37	5.37	2820	4.76	5.37	3189	4.29	5.37	3376	3.76	5.37
SLR2	2895	6.21	6.37	2535	5.42	6.37	2946	4.95	6.37	3279	4.44	6.37
SLR3	2264	7.04	7.37	2220	6.07	7.37	2731	5.66	7.37	2808	5.35	7.37

7.2.2.1 PM #2 Figures – Mitigation M2A

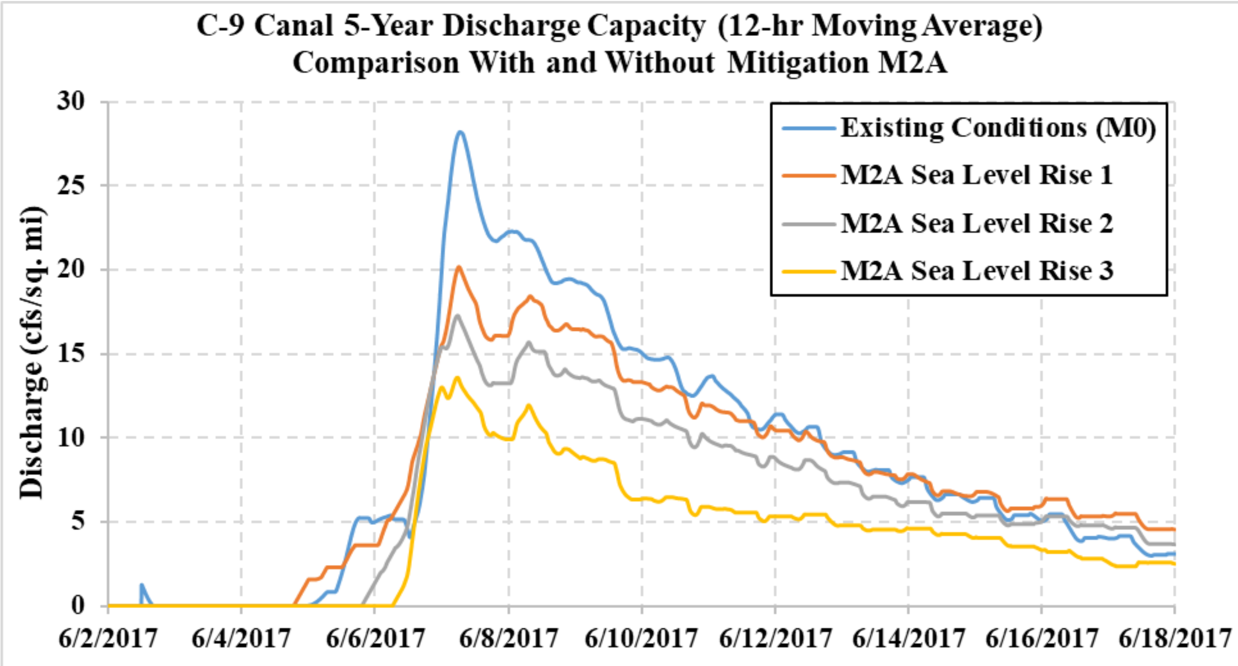


Figure 7.2-26: Mitigation M2A 12-Hour Moving Average Discharge Hydrographs (cfs/sq-mi) for C-9 Canal Structure S-29 for 5-Year Design Storms

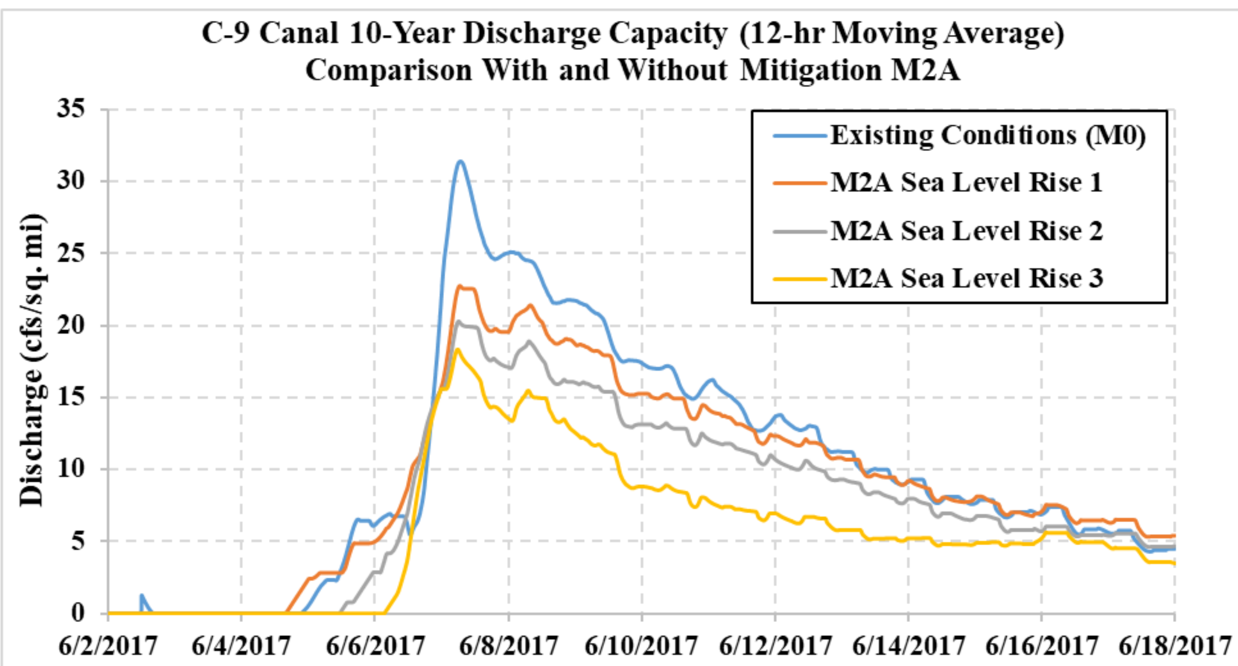


Figure 7.2-27: Mitigation M2A 12-Hour Moving Average Discharge Hydrographs (cfs/sq-mi) for C-9 Canal Structure S-29 for 10-Year Design Storms

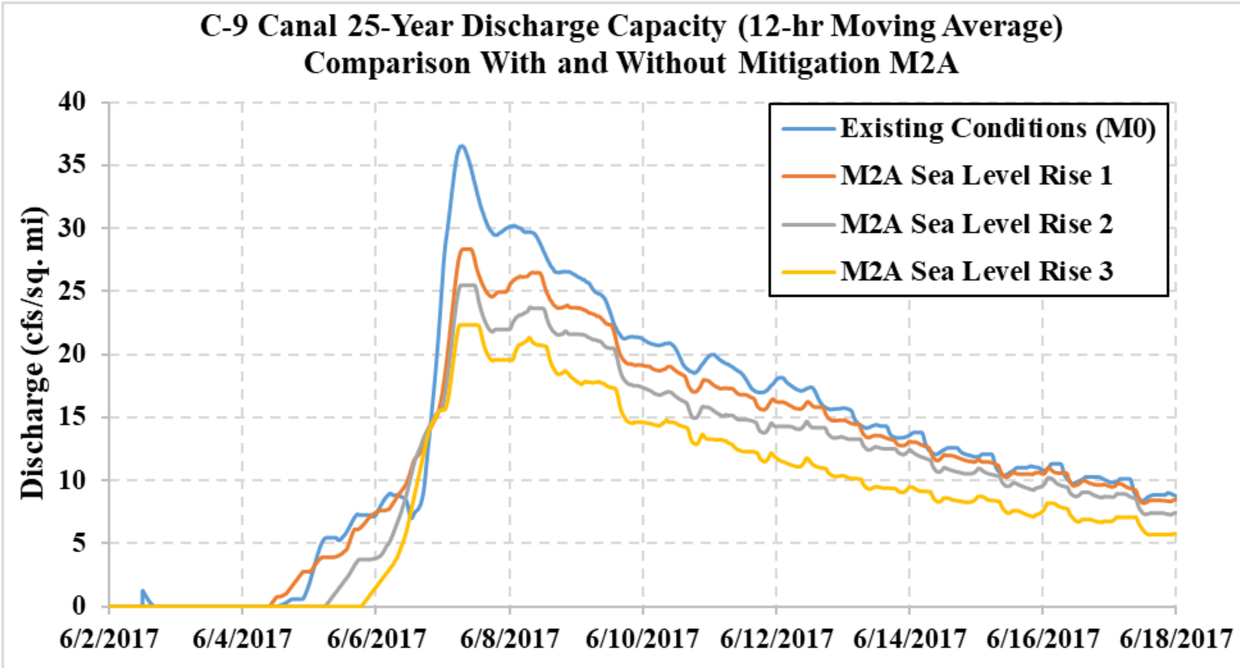


Figure 7.2-28: Mitigation M2A 12-Hour Moving Average Discharge Hydrographs (cfs/sq-mi) for C-9 Canal Structure S-29 for 25-Year Design Storms

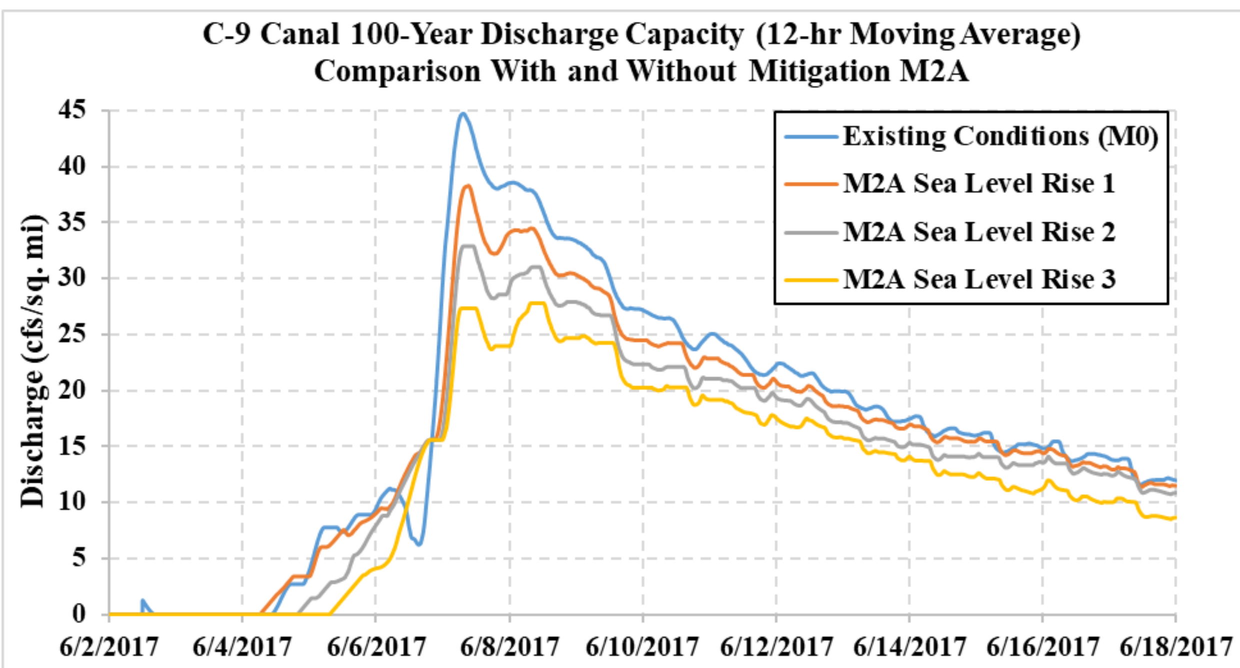


Figure 7.2-29: Mitigation M2A 12-Hour Moving Average Discharge Hydrographs (cfs/sq-mi) for C-9 Canal Structure S-29 for 100-Year Design Storms

7.2.2.2 PM #2 Figures – Mitigation M2B

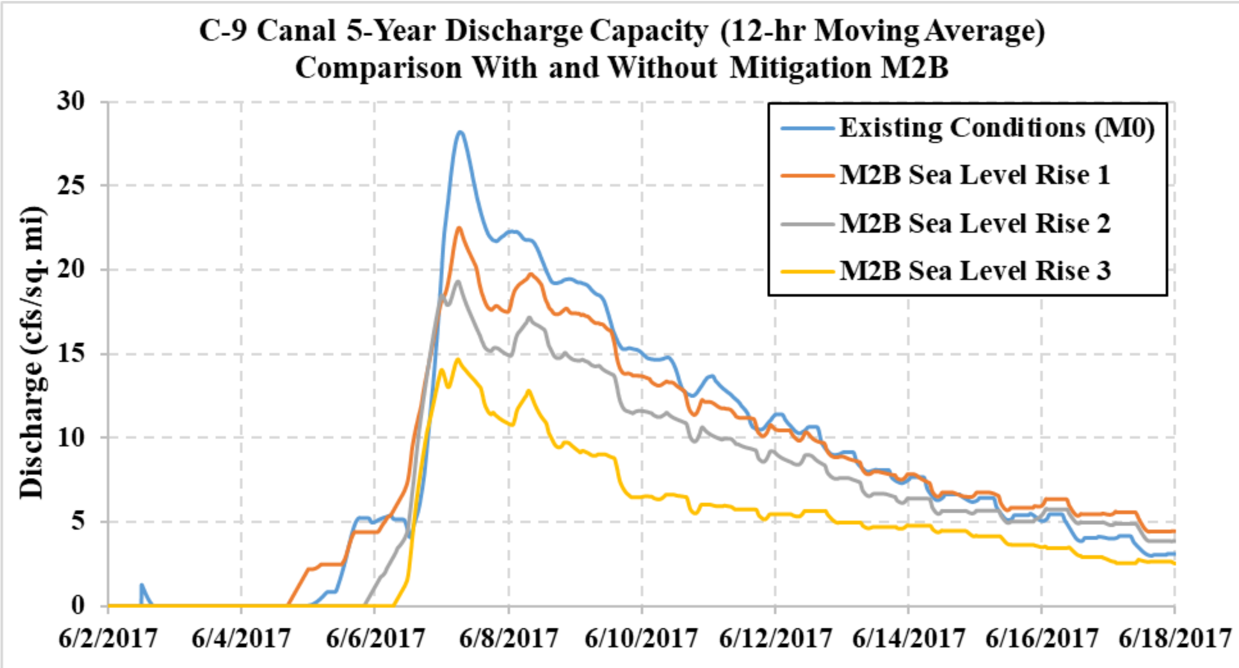


Figure 7.2-30: Mitigation M2B 12-Hour Moving Average Discharge Hydrographs (cfs/sq-mi) for C-9 Canal Structure S-29 for 5-Year Design Storms

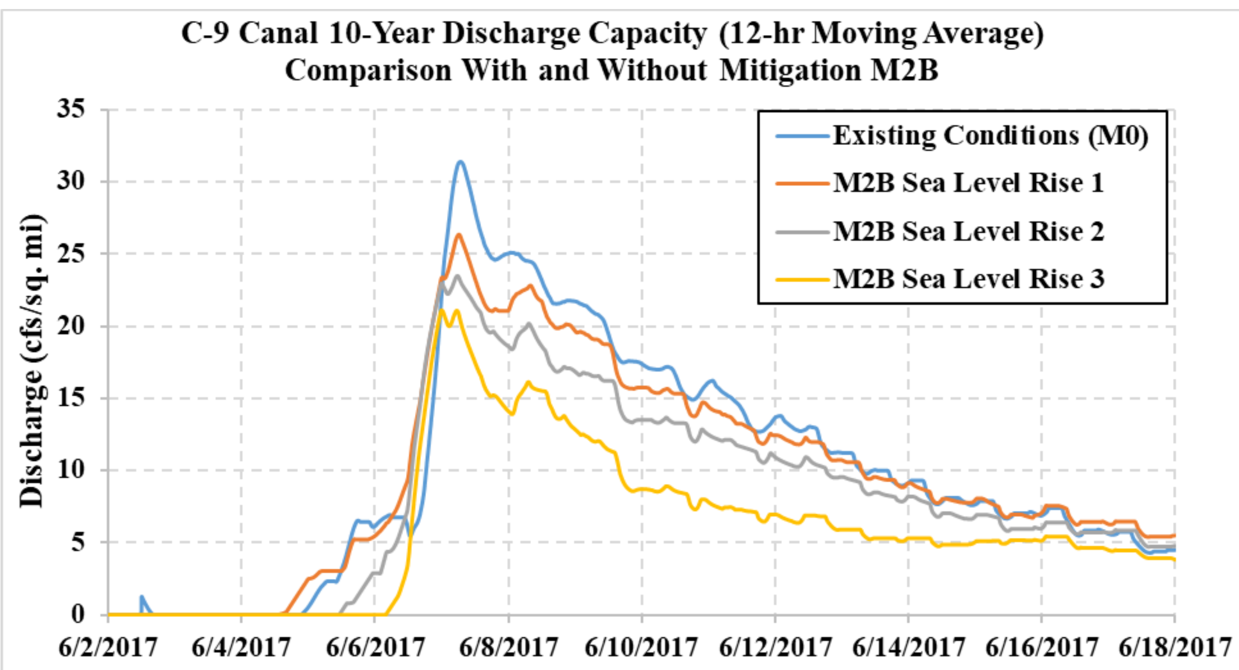


Figure 7.2-31: Mitigation M2B 12-Hour Moving Average Discharge Hydrographs (cfs/sq-mi) for C-9 Canal Structure S-29 for 10-Year Design Storms

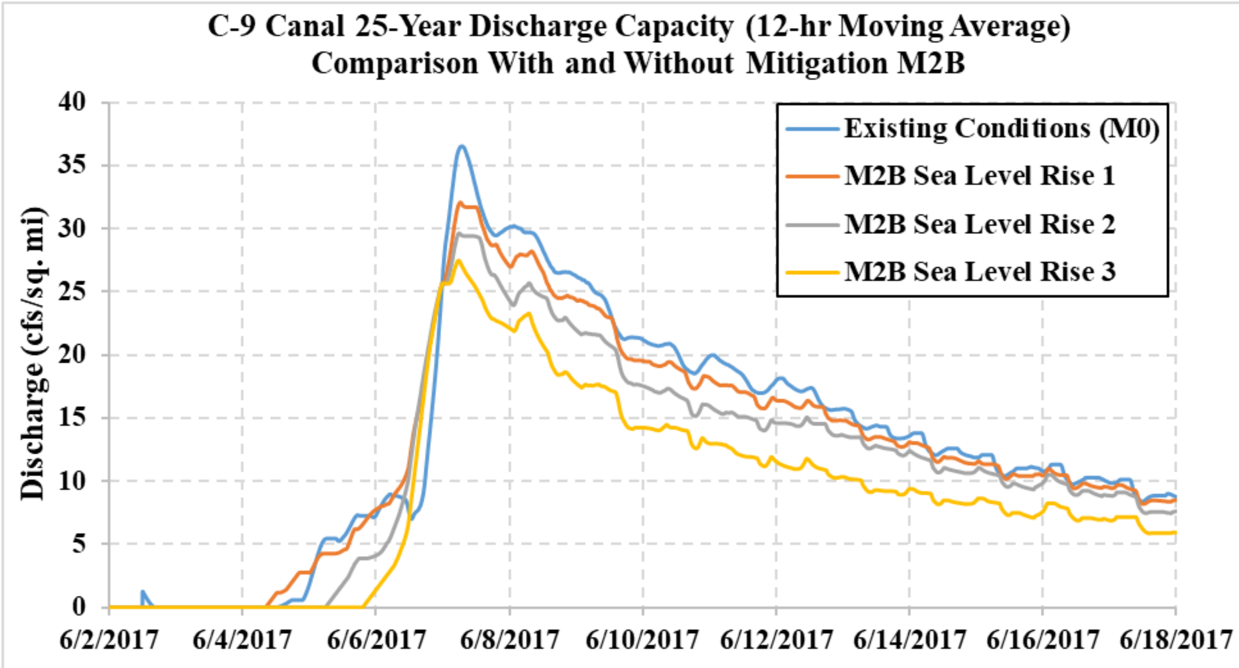


Figure 7.2-32: Mitigation M2B 12-Hour Moving Average Discharge Hydrographs (cfs/sq-mi) for C-9 Canal Structure S-29 for 25-Year Design Storms

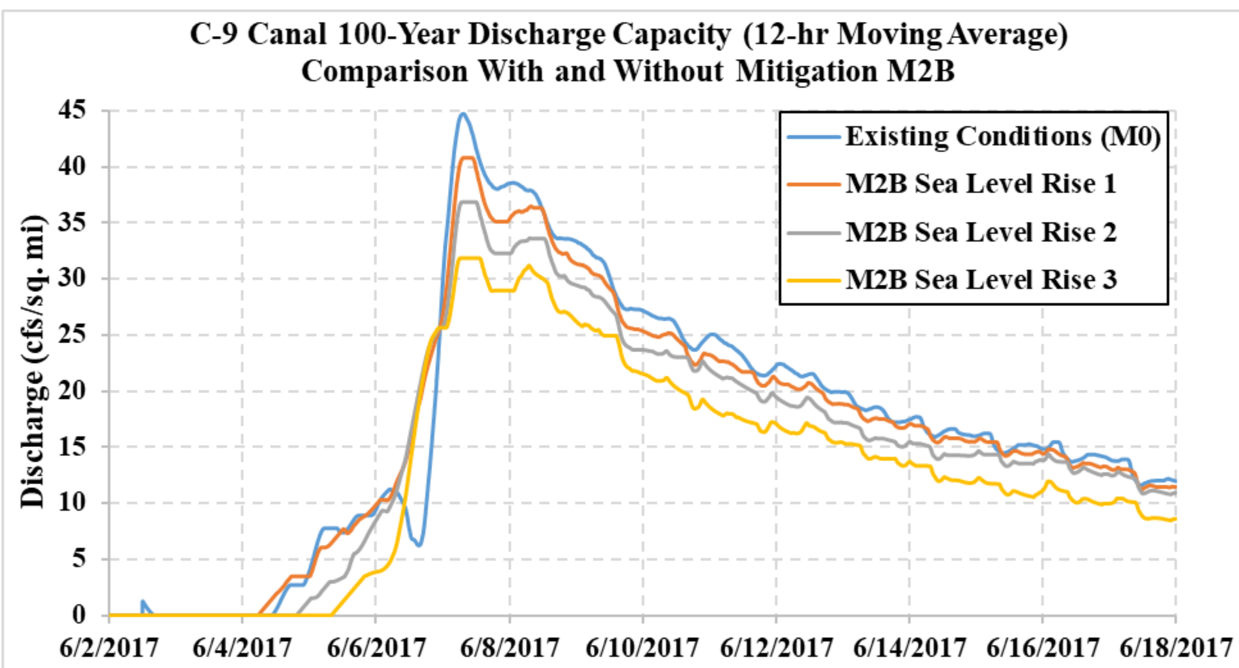


Figure 7.2-33: Mitigation M2B 12-Hour Moving Average Discharge Hydrographs (cfs/sq-mi) for C-9 Canal Structure S-29 for 100-Year Design Storms

7.2.2.3 PM #2 Figures – Mitigation M2C

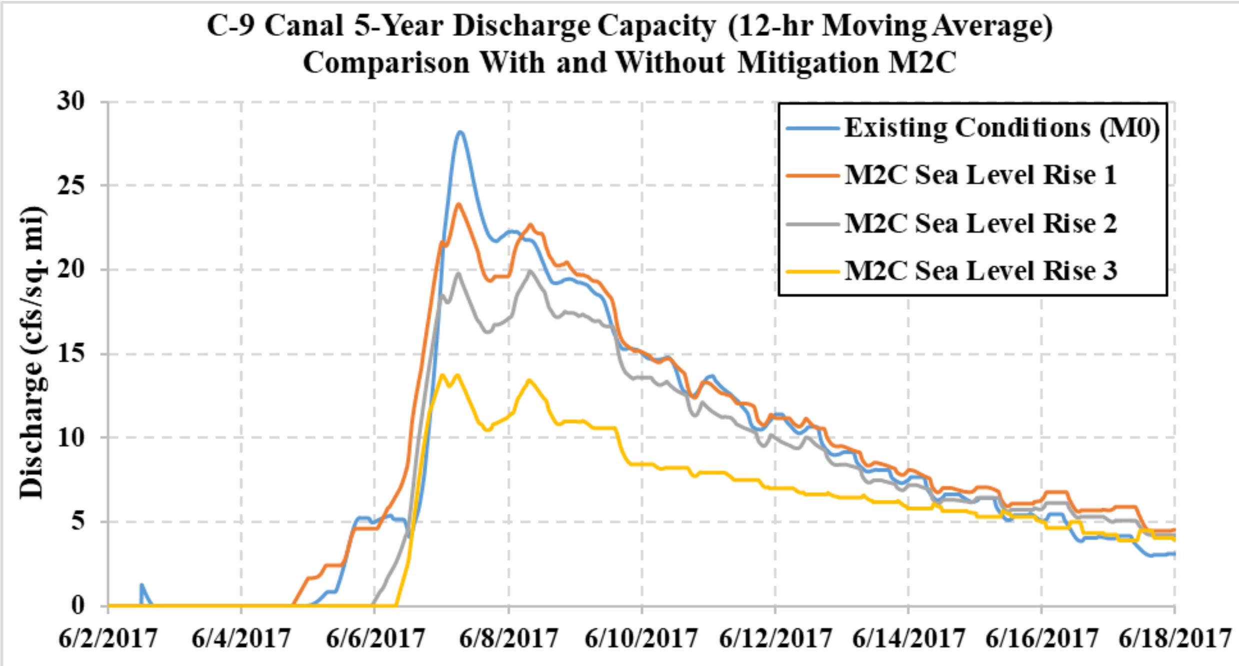


Figure 7.2-34: Mitigation M2C 12-Hour Moving Average Discharge Hydrographs (cfs/sq-mi) for C-9 Canal Structure S-29 for 5-Year Design Storms

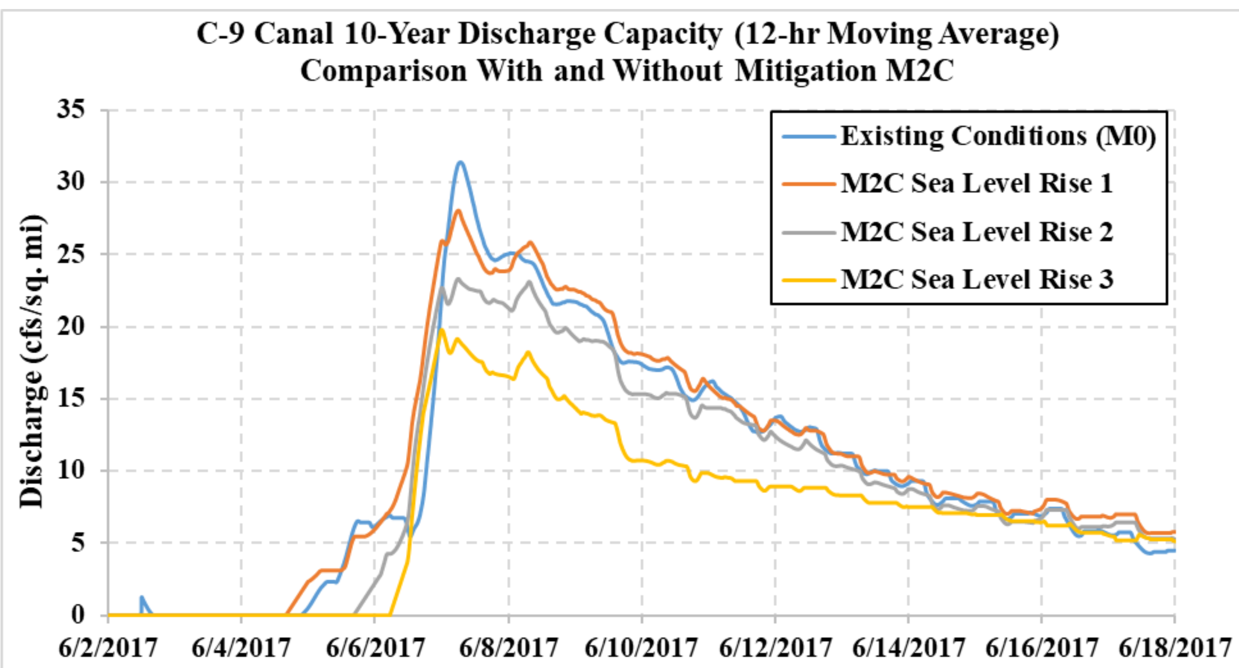


Figure 7.2-35: Mitigation M2C 12-Hour Moving Average Discharge Hydrographs (cfs/sq-mi) for C-9 Canal Structure S-29 for 10-Year Design Storms

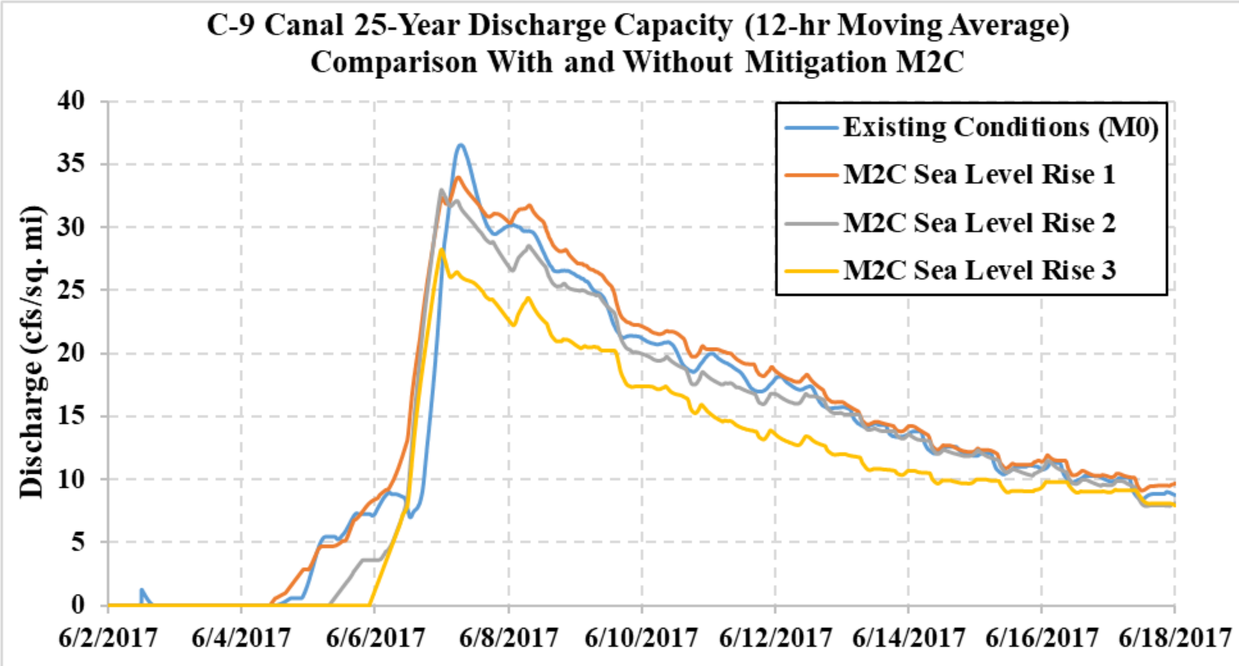


Figure 7.2-36: Mitigation M2C 12-Hour Moving Average Discharge Hydrographs (cfs/sq-mi) for C-9 Canal Structure S-29 for 25-Year Design Storms

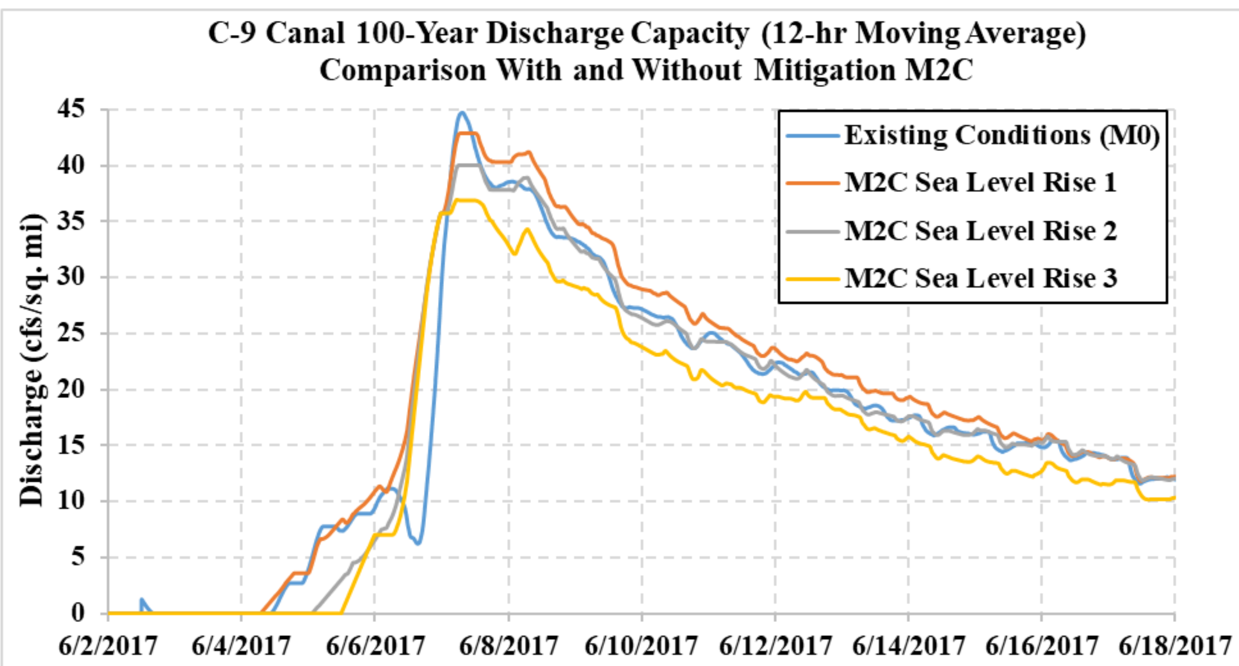


Figure 7.2-37: Mitigation M2C 12-Hour Moving Average Discharge Hydrographs (cfs/sq-mi) for C-9 Canal Structure S-29 for 100-Year Design Storms

7.2.2.4 PM #2 Summary – C-9 Watershed

- M2A
    - Even with 1,550 cfs pump station, there is a decrease in peak discharge as sea level rises
        - This is because the peak discharge is still from the sluice gate and is highly dependent on the headwater and tailwater differential
        - The pump station is actively working to reduce or maintain headwater when tailwater inhibits gravity discharge, which ultimately decreases the headwater and tailwater differential when the gravity structure is able to discharge, resulting in smaller peak discharge
    - Even with 1,550 cfs pump station, there is an overall decrease in discharge volume as sea level rises
        - Total discharge volume should not be used as an indicator of structure performance
            - The raised gate overtopping elevation blocks storm surge, which directly reduces the total discharge volume as there is no reverse flow or structure bypass for the tidal structure to discharge like there is under the without mitigation scenarios.
        - Simulated pump station has a discharge capacity that is about 33% of the sluice gate design discharge
- M2B
    - Even with 2,550 cfs pump station, there is a decrease in peak discharge as sea level rises
        - This is because the peak discharge is still from the sluice gate and is highly dependent on the headwater and tailwater differential
        - The pump station is actively working to reduce or maintain headwater when tailwater inhibits gravity discharge, which ultimately decreases the headwater and tailwater differential when the gravity structure is able to discharge, resulting in smaller peak discharge
    - Even with 2,550 cfs pump station, there is an overall decrease in discharge volume as sea level rises
        - Total discharge volume should not be used as an indicator of structure performance
            - The raised gate overtopping elevation blocks storm surge, which directly reduces the total discharge volume as there is no reverse flow or structure bypass for the tidal structure to discharge like there is under the without mitigation scenarios.
        - Simulated pump station has a discharge capacity that is about 53% of the sluice gate design discharge

- M2C
    - Even with 3,550 cfs pump station, there is a decrease in peak discharge as sea level rises
        - This is because the peak discharge is still from the sluice gate and is highly dependent on the headwater and tailwater differential
        - The pump station is actively working to reduce or maintain headwater when tailwater inhibits gravity discharge, which ultimately decreases the headwater and tailwater differential when the gravity structure is able to discharge, resulting in smaller peak discharge
    - Even with 3,550 cfs pump station, there is an overall decrease in discharge volume as sea level rises
        - Total discharge volume should not be used as an indicator of structure performance
            - The raised gate overtopping elevation blocks storm surge, which directly reduces the total discharge volume as there is no reverse flow or structure bypass for the tidal structure to discharge like there is under the without mitigation scenarios.
        - Simulated pump station has a discharge capacity that is about 74% of the sluice gate design discharge

7.2.3 PM #5 – Frequency of Flooding

The Phase 1 FPLOS PM #5 Assessment analyzed overland flooding for the purposes of identifying deficiencies in the system, both those related to or unrelated to PM #1 deficiencies, and to assign an overall level of service rating in conjunction with the results from PM #1. The PM #5 level of service analysis of the C-9 Watershed in the Phase 1 FPLOS Assessment was also used as a way to identify areas of flooding due to water levels in the C-9 Canal that may not show up as bank exceedances in PM #1. As a reminder, bank exceedances are just one component of flood protection and just because there are bank exceedances doesn't necessarily mean there will be inundation of urban areas, and likewise, just because there are areas where there are not bank exceedances doesn't necessarily mean there isn't flooding of urban areas. As these bank exceedances and areas of overland flooding were identified in the Phase 1 FPLOS Assessment, the focus of this Phase 2 FPLOS PM #5 assessment is to show how of the flooding compares to both existing conditions and future condition sea level rise with no mitigation. For the purposes of the Phase 2 FPLOS Assessment, the goal was to provide a flood protection level of service equal to or better than the 25-year SLR0 event during a 25-year SLR1 event for Mitigation M2A, 25-year SLR2 event for Mitigation M2B, and 25-year SLR3 event for Mitigation M2C.

Table 7.2-4 through **Table 7.2-7** summarizes the area of flooding for the 5-year, 10-year, 25-year, and 100-year design storm events for SLR0, SLR1, SLR2, and SLR3, under existing conditions (Mitigation 0), Mitigation M2A, Mitigation M2B, and Mitigation M2C, for all land use and urban land use only. Please note that the area with water depth less than 0.25 ft presented in these tables do not include area with water depth equal to zero. Area of flooding presented in **Table 7.2-4** through **Table 7.2-7** are cumulative in order of decreasing depths (i.e., area greater than 2.5 ft are included in the area greater than 2.25 ft). Depths less than 0.25 ft are not included in the cumulative area calculations.

Section 7.2.3.1 through **Section 7.2.3.3** presents the Phase 2 PM #5 FPLOS Assessment for Mitigation M2A, M2B, and M2C, respectively. Within each section, three figures are presented that show the 25-year flood inundation map for the respective sea level rise scenario, a flood inundation difference map between the 25-year SLR mitigation scenario and the 25-year SLR0 existing conditions scenario, and a flood inundation difference map between the 25-year SLR mitigation scenario and the respective 25-year future sea level rise without mitigation scenario. For instance, **Section 7.2.3.1** presents the 25-year SLR1 flood inundation map under Mitigation M2A, the flood inundation difference map between the M2A 25-year SLR1 event and the existing conditions (M0) 25-year SLR0 event, and the flood inundation difference map between the M2A 25-year SLR1 event and the future conditions without mitigation 25-year SLR1 event. **Section 7.2.3.2** and **Section 7.2.3.3** show the same three figures but for SLR2 for Mitigation M2B and SLR3 for Mitigation M2C, respectively. Refer to **Appendix C** for the complete set of flood inundation maps for the 5-year, 10-year, 25-year, and 100-year design storms for SLR1, SLR2, and SLR3, for all land use and urban land use only, for each of the three mitigation scenarios.

Table 7.2-4: Summary of the PM #5 Flood Inundation Area for the C-9 Watershed 5-Year Design Storm

5-Year Design Storm																
Water Depth (ft)	Area of Flooding within the C-9 Watershed (acres) (C-9 Watershed is approximately 63,600 acres)															
	Mitigation 0 (Existing Conditions)				Mitigation M2A				Mitigation M2B				Mitigation M2C			
	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3
< 0.25	9686	9570	9405	9267	9751	9643	9444	9378	9852	9753	9554	9483	9881	9833	9596	9492
>= 0.25	25584	25978	26362	26846	25581	25835	26203	26507	25440	25696	26060	26359	25366	25537	25989	26303
>= 0.50	17773	18497	19143	19753	18054	18319	18856	19369	17931	18199	18759	19249	17853	18040	18618	19177
>= 0.75	13594	14771	15398	16164	14237	14593	15083	15742	14143	14505	15013	15674	14048	14292	14885	15566
>= 1.00	11190	12708	13363	14156	12156	12495	13073	13722	12074	12427	13025	13691	12013	12203	12869	13553
>= 1.25	9730	11394	12040	12819	10954	11209	11736	12411	10879	11143	11698	12384	10825	10967	11530	12261
>= 1.50	8609	10252	10782	11650	9866	10120	10540	11197	9771	10049	10508	11176	9698	9907	10374	11031
>= 1.75	7644	9365	9811	10665	8611	9154	9575	10250	8569	9104	9527	10226	8424	8790	9458	10068
>= 2.00	6081	7970	8863	9474	7171	7511	8465	9163	7094	7479	8534	9145	6922	7261	8196	9066
>= 2.25	4348	6267	7072	7908	5538	5921	6639	7410	5436	5850	6609	7392	5368	5631	6451	7254
>= 2.50	2848	5023	5617	6455	4421	4668	5277	6102	4314	4555	5265	6076	4263	4508	5092	5953
Area of Flooding in Urban Land Use within the C-9 Watershed (acres) (C-9 Watershed Urban Area by Land Use is approximately 43,700 acres)																
< 0.25	8081	8126	8075	8004	8180	8152	8086	8062	8259	8231	8166	8134	8272	8247	8174	8142
>= 0.25	11580	11582	11741	12013	11453	11530	11664	11807	11361	11438	11568	11705	11335	11407	11553	11674
>= 0.50	5527	5581	5802	6103	5428	5515	5693	5891	5344	5427	5614	5799	5314	5383	5576	5765
>= 0.75	2845	2907	3119	3425	2755	2848	2998	3222	2691	2787	2944	3166	2675	2740	2902	3129
>= 1.00	1738	1813	2005	2273	1684	1754	1909	2108	1646	1716	1875	2083	1636	1678	1831	2033
>= 1.25	1248	1323	1475	1704	1212	1277	1387	1570	1180	1248	1364	1556	1167	1207	1334	1522
>= 1.50	992	1036	1162	1362	963	1001	1101	1235	929	967	1081	1223	923	957	1051	1188
>= 1.75	819	868	962	1124	791	835	908	1034	765	806	882	1024	754	796	871	996
>= 2.00	665	717	793	911	637	674	752	836	611	652	728	828	604	637	717	801
>= 2.25	523	570	657	741	500	532	610	692	477	511	592	681	475	503	580	670
>= 2.50	393	456	525	635	379	420	480	576	357	397	465	567	355	392	460	548

Area of flooding is cumulative in order of decreasing depths (i.e., area greater than or equal to 2.5 ft are included in the area greater than or equal to 2.25 ft)

Table 7.2-5: Summary of the PM #5 Flood Inundation Area for the C-9 Watershed 10-Year Design Storm

10-Year Design Storm																
Water Depth (ft)	Area of Flooding within the C-9 Watershed (acres) (C-9 Watershed is approximately 63,600 acres)															
	Mitigation 0 (Existing Conditions)				Mitigation M2A				Mitigation M2B				Mitigation M2C			
	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3
< 0.25	8916	8852	8719	8648	9010	8896	8804	8720	9137	9023	8932	8859	9200	9111	8949	8872
>= 0.25	27760	28094	28510	29035	27731	27968	28241	28647	27553	27780	28046	28431	27441	27639	27987	28351
>= 0.50	19971	20608	21151	21844	20057	20396	20849	21316	19894	20232	20677	21131	19773	19994	20573	21033
>= 0.75	15357	16354	17026	17741	15819	16153	16668	17263	15704	16040	16559	17127	15576	15818	16406	17047
>= 1.00	12614	14020	14650	15459	13395	13810	14296	15006	13307	13718	14219	14932	13171	13434	14083	14815
>= 1.25	10767	12455	13108	13913	11877	12217	12775	13464	11797	12142	12716	13429	11672	11921	12543	13270
>= 1.50	9571	11146	11943	12750	10672	10947	11422	12325	10593	10876	11366	12306	10509	10697	11212	12163
>= 1.75	8526	10170	10743	11615	9793	10023	10406	11144	9711	9943	10345	11128	9509	9829	10231	10981
>= 2.00	7618	9242	9701	10697	8474	9015	9494	10233	8418	8939	9432	10202	8207	8629	9336	10010
>= 2.25	5481	7328	8562	9433	6613	7095	8234	9094	6533	6915	8159	9058	6247	6672	7832	8940
>= 2.50	4087	6066	6718	7777	5309	5681	6442	7329	5205	5606	6379	7292	5170	5433	6199	7061
Area of Flooding in Urban Land Use within the C-9 Watershed (acres) (C-9 Watershed Urban Area by Land Use is approximately 43,700 acres)																
< 0.25	7587	7642	7585	7555	7681	7653	7625	7579	7769	7741	7710	7662	7785	7762	7712	7673
>= 0.25	13166	13185	13409	13735	13049	13130	13255	13482	12932	13006	13123	13338	12907	12973	13102	13288
>= 0.50	6920	6996	7229	7635	6802	6914	7077	7308	6685	6794	6950	7169	6640	6724	6917	7107
>= 0.75	3717	3809	4067	4415	3616	3727	3917	4145	3537	3649	3843	4048	3500	3586	3796	4012
>= 1.00	2281	2377	2587	2913	2199	2305	2457	2693	2149	2249	2411	2638	2121	2184	2368	2594
>= 1.25	1573	1679	1855	2132	1537	1613	1759	1965	1499	1578	1730	1936	1479	1530	1676	1892
>= 1.50	1219	1298	1445	1668	1175	1248	1353	1550	1143	1218	1329	1537	1133	1174	1295	1489
>= 1.75	1027	1065	1184	1368	1004	1032	1111	1253	967	999	1088	1245	953	987	1059	1202
>= 2.00	880	907	988	1140	853	883	932	1057	828	850	911	1046	811	842	895	1015
>= 2.25	746	774	852	951	712	751	810	890	684	722	786	878	673	703	776	853
>= 2.50	613	661	730	805	571	625	693	754	547	603	673	743	539	582	662	727

Area of flooding is cumulative in order of decreasing depths (i.e., area greater than or equal to 2.5 ft are included in the area greater than or equal to 2.25 ft)

Table 7.2-6: Summary of the PM #5 Flood Inundation Area for the C-9 Watershed 25-Year Design Storm

25-Year Design Storm																
Water Depth (ft)	Area of Flooding within the C-9 Watershed (acres) (C-9 Watershed is approximately 63,600 acres)															
	Mitigation 0 (Existing Conditions)				Mitigation M2A				Mitigation M2B				Mitigation M2C			
	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3
< 0.25	8013	7940	7841	7699	8016	7990	7903	7819	8154	8128	8073	7988	8171	8150	8085	7990
>= 0.25	30792	31161	31619	32305	30779	30979	31315	31750	30543	30719	31007	31453	30462	30619	30902	31311
>= 0.50	23246	23759	24331	25117	23303	23562	23951	24502	23062	23290	23639	24181	22876	23140	23501	23965
>= 0.75	18312	19067	19631	20454	18496	18876	19262	19809	18338	18683	19018	19540	18096	18400	18884	19349
>= 1.00	15173	16305	16860	17607	15661	16079	16540	17036	15566	15937	16401	16839	15342	15626	16209	16711
>= 1.25	13031	14513	15144	15854	13895	14290	14842	15347	13812	14174	14722	15222	13537	13864	14432	15098
>= 1.50	11390	13128	13760	14465	12449	12909	13432	14049	12385	12802	13324	13952	12138	12414	13064	13798
>= 1.75	9941	11794	12447	13130	11227	11565	12126	12702	11169	11458	12015	12623	10945	11189	11731	12470
>= 2.00	8962	10805	11499	12181	10290	10656	11166	11802	10221	10542	11024	11717	10024	10255	10790	11528
>= 2.25	8044	9713	10377	11146	9277	9582	10021	10689	9216	9484	9908	10588	8704	9232	9689	10409
>= 2.50	6552	8673	9396	10245	7437	8452	9130	9604	7355	8359	9010	9533	6953	7757	8742	9427
Area of Flooding in Urban Land Use within the C-9 Watershed (acres) (C-9 Watershed Urban Area by Land Use is approximately 43,700 acres)																
< 0.25	6976	7012	6949	6866	7037	7036	6995	6934	7125	7122	7093	7042	7127	7127	7102	7052
>= 0.25	15447	15531	15835	16314	15316	15423	15616	15912	15157	15247	15411	15700	15132	15209	15357	15594
>= 0.50	9120	9219	9555	10091	8976	9100	9319	9639	8795	8902	9094	9424	8755	8852	9022	9281
>= 0.75	5328	5422	5730	6216	5207	5328	5506	5803	5084	5186	5331	5619	5024	5124	5279	5490
>= 1.00	3327	3428	3672	4081	3207	3340	3508	3744	3137	3262	3412	3611	3076	3172	3370	3543
>= 1.25	2305	2399	2602	2932	2212	2315	2483	2667	2163	2258	2432	2593	2106	2182	2358	2539
>= 1.50	1718	1825	1990	2259	1653	1754	1897	2072	1620	1719	1866	2032	1563	1634	1805	1981
>= 1.75	1343	1461	1611	1795	1323	1403	1528	1662	1296	1372	1496	1640	1251	1302	1437	1600
>= 2.00	1143	1228	1336	1500	1111	1189	1267	1389	1077	1158	1243	1367	1060	1084	1212	1322
>= 2.25	1005	1032	1134	1254	963	993	1080	1166	934	965	1054	1145	922	940	1013	1126
>= 2.50	857	903	966	1081	825	869	934	992	800	843	915	981	780	823	890	960

Area of flooding is cumulative in order of decreasing depths (i.e., area greater than or equal to 2.5 ft are included in the area greater than or equal to 2.25 ft)

Table 7.2-7: Summary of the PM #5 Flood Inundation Area for the C-9 Watershed 100-Year Design Storm

100-Year Design Storm																
Water Depth (ft)	Area of Flooding within the C-9 Watershed (acres) (C-9 Watershed is approximately 63,600 acres)															
	Mitigation 0 (Existing Conditions)				Mitigation M2A				Mitigation M2B				Mitigation M2C			
	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3
< 0.25	6944	6889	6764	6600	6977	6947	6851	6739	7152	7137	7046	6929	7192	7147	7072	6990
>= 0.25	35247	35616	36175	36856	35058	35328	35784	36341	34737	34971	35416	35984	34598	34800	35211	35724
>= 0.50	28009	28475	29120	29931	27790	28153	28659	29305	27473	27762	28241	28920	27279	27532	27987	28599
>= 0.75	22733	23382	24035	24952	22671	23028	23558	24254	22385	22693	23185	23858	22194	22448	22929	23539
>= 1.00	18849	19703	20357	21201	19029	19369	19878	20558	18843	19120	19574	20202	18670	18916	19339	19915
>= 1.25	16152	17269	17866	18673	16695	17012	17441	18039	16603	16852	17214	17758	16318	16663	17027	17518
>= 1.50	14215	15629	16177	16885	15056	15406	15817	16359	15005	15313	15658	16128	14666	15052	15508	15934
>= 1.75	12612	14294	14793	15499	13695	14079	14512	15019	13679	14018	14417	14844	13332	13714	14234	14676
>= 2.00	11312	13001	13537	14167	12425	12847	13265	13776	12413	12771	13179	13664	12009	12453	12979	13511
>= 2.25	10175	12068	12565	13165	11398	11875	12312	12800	11402	11821	12238	12687	11036	11434	12031	12504
>= 2.50	9175	10964	11533	12108	10215	10665	11252	11753	10192	10563	11176	11675	10007	10232	10908	11500
Area of Flooding in Urban Land Use within the C-9 Watershed (acres) (C-9 Watershed Urban Area by Land Use is approximately 43,700 acres)																
< 0.25	6161	6161	6060	5925	6226	6212	6132	6040	6343	6329	6260	6156	6351	6339	6283	6217
>= 0.25	19037	19216	19648	20186	18811	18991	19332	19768	18572	18736	19074	19532	18508	18628	18908	19312
>= 0.50	12727	12914	13376	14024	12445	12672	13020	13510	12206	12391	12727	13256	12100	12246	12542	12982
>= 0.75	8309	8507	8961	9642	8066	8276	8607	9104	7848	8036	8362	8855	7758	7893	8179	8600
>= 1.00	5400	5565	5971	6580	5189	5365	5655	6093	5043	5186	5464	5876	4988	5096	5307	5666
>= 1.25	3705	3833	4157	4675	3568	3692	3909	4245	3489	3585	3769	4091	3422	3524	3661	3924
>= 1.50	2711	2809	3081	3490	2599	2707	2888	3162	2555	2648	2793	3046	2482	2578	2726	2919
>= 1.75	2100	2181	2380	2736	2022	2107	2248	2471	2000	2077	2198	2384	1935	2012	2141	2298
>= 2.00	1688	1769	1918	2205	1614	1715	1829	1993	1603	1691	1795	1944	1539	1611	1743	1877
>= 2.25	1396	1479	1606	1815	1362	1432	1525	1666	1351	1413	1499	1634	1310	1364	1457	1579
>= 2.50	1197	1266	1346	1515	1147	1218	1285	1398	1134	1199	1271	1375	1110	1142	1240	1325

Area of flooding is cumulative in order of decreasing depths (i.e., area greater than or equal to 2.5 ft are included in the area greater than or equal to 2.25 ft)

7.2.3.1 PM #5 – Mitigation M2A

Mitigation scenario M2A is the least aggressive form of mitigation out of the three mitigation strategies analyzed in this study. Although Mitigation M2A has a relatively large pumping capacity of 1,550 cfs, the C-9 Canal still had several instances of bank exceedances and had high enough water levels to inhibit gravity-driven drainage in the secondary/tertiary system, contributing to overland flooding of urban areas in several locations as shown in **Figure 7.2-38**. Mitigation M2A is predicted to achieve a PM #1 25-year SLR1 maximum water surface profile in the C-9 Canal that was equal to or lower than the existing conditions 25-year SLR0 profile. As such, there are some areas in the secondary/tertiary system that have overland flood depths during the 25-year SLR1 event under mitigation M2A that are lower than existing conditions, as shown in **Figure 7.2-39**. **Figure 7.2-39** shows an area of flood reduction just north of where the highway FL-91 (Florida Turnpike) crosses the C-9 Canal and a handful of areas where just a small strip along a secondary/tertiary canal are lower. However, there are also several small areas with increased flooding, although minimally larger. These areas of increase occur in low-lying areas and are a result of increased groundwater elevations due to sea level rise. Although **Figure 7.2-39** shows some increased flooding compared to existing conditions, **Figure 7.2-40** shows how much flooding this mitigation strategy is mitigating by presenting the flooding depth differences between the 25-year SLR1 event with and without mitigation. In **Figure 7.2-40**, there are three main areas of flood reduction just north of where the highway FL-91 (Florida Turnpike) crosses the C-9 Canal, a small area on the east side of the C-9 Canal where County Road 854 crosses, and a long strip on the south side of the canal just upstream of Structure S-29. These three areas of flood reduction are directly related to lower stages in the C-9 Canal, which is a function of both blocking storm surge and pumping to tide.

Although the goal was to achieve flood protection equal to or better than existing conditions, it was just that- a goal. The reality of it is that sea level rise is going to bring about unprecedented changes in the form of higher tide levels to discharge against, higher antecedent water levels throughout the watershed which effectively removes storage that was once there, and areas with higher groundwater levels which not only removes storage that was once there but can actively rise above land surface, further contributing to flooding. Therefore, although achieving flood protection equal to or greater than what is currently provided under existing conditions is an appropriate goal to aim for, this shouldn't limit the success or consideration of mitigation strategies. Therefore, looking at the difference between flooding under a particular mitigation strategy and the flooding that could occur if no mitigation was implemented really shows how effective the mitigation is.

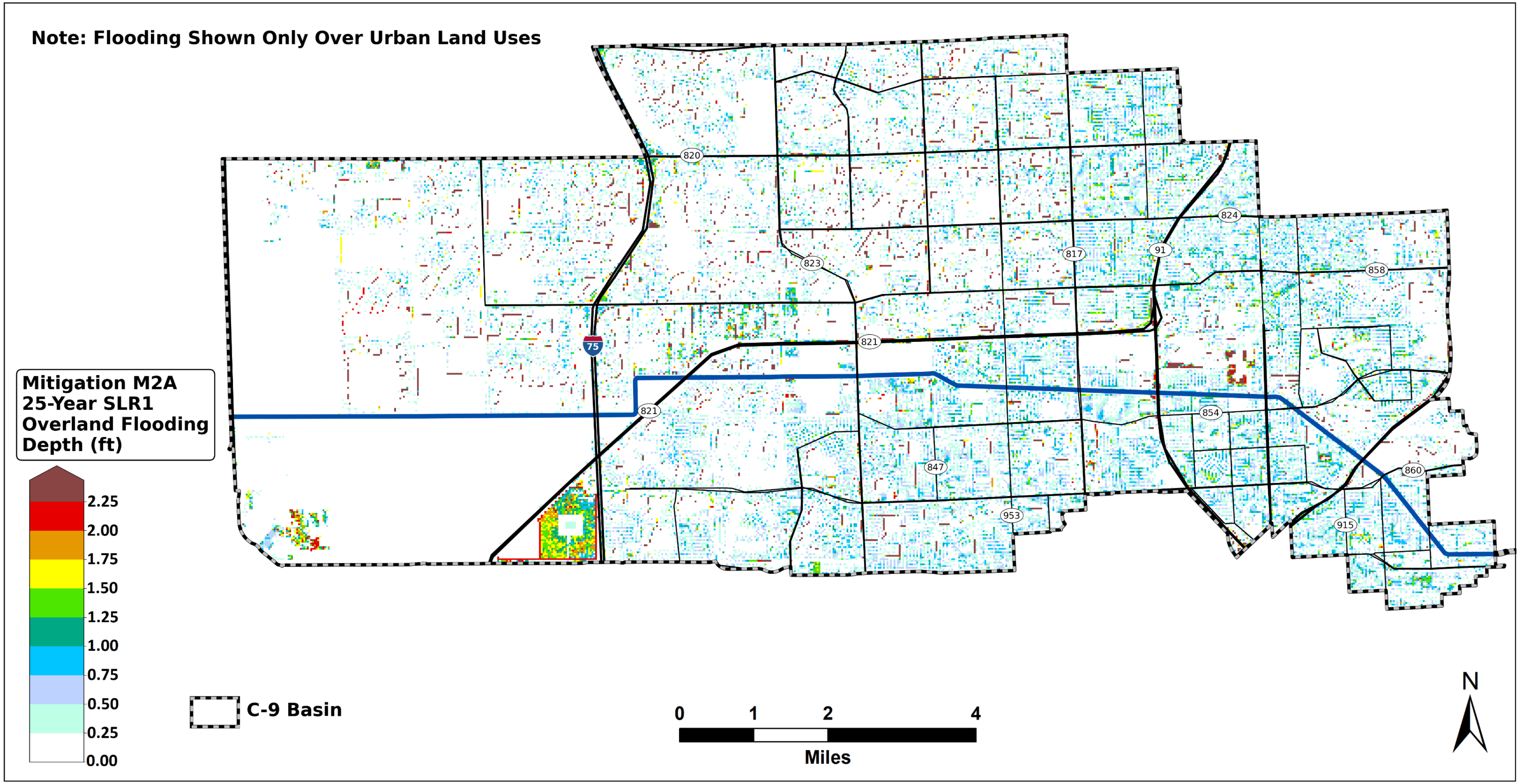


Figure 7.2-38: C-9 Watershed Flood Inundation Map for the Mitigation M2A 25-Year Sea Level Rise 1 Design Storm Event in Urban Land Use Areas

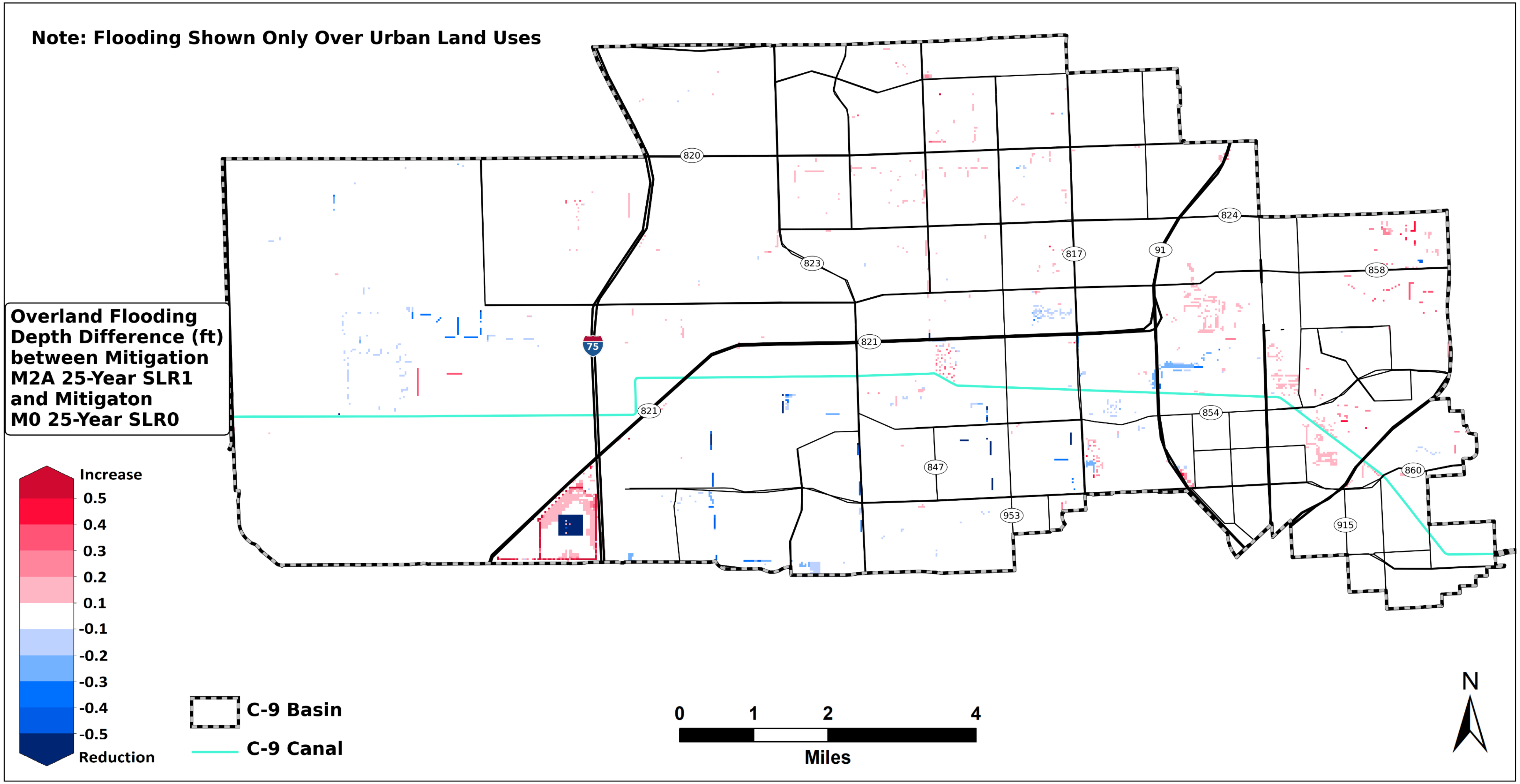


Figure 7.2-39: C-9 Watershed Flood Inundation Difference Map for Mitigation M2A 25-Year Sea Level Rise 1 versus Existing Conditions (M0) 25-Year SLR0 in Urban Land Use Areas

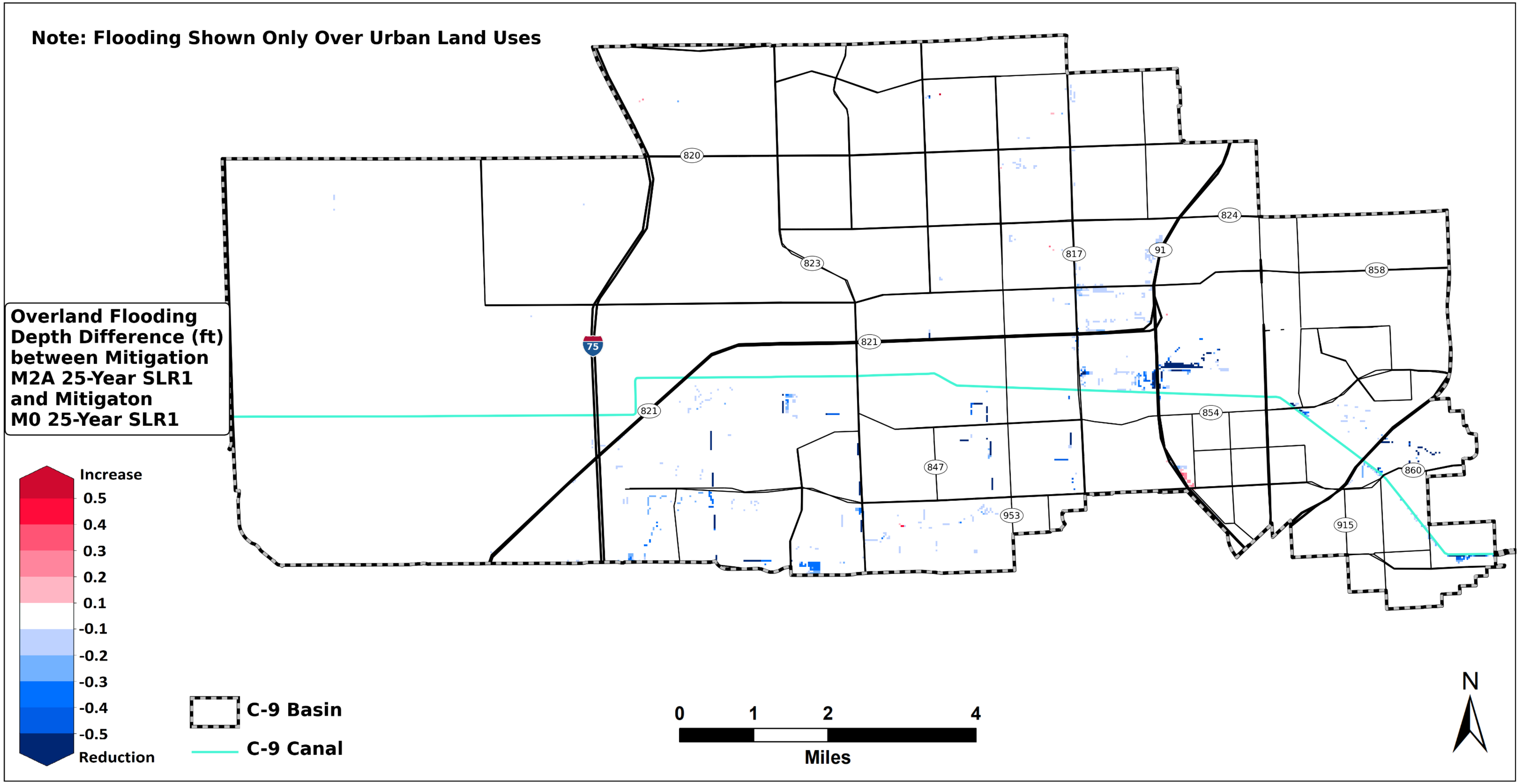


Figure 7.2-40: C-9 Watershed Flood Inundation Difference Map for Mitigation M2A 25-Year Sea Level Rise 1 versus Future Conditions without mitigation (M0) 25-Year SLR1 in Urban Land Use Areas

7.2.3.2 PM #5 – Mitigation M2B

Mitigation scenario M2B is a more aggressive form of mitigation compared to M2A but less aggressive than M2C, making it the middle level of mitigation out of the three mitigation strategies analyzed in this study. Although Mitigation M2B has a large pumping capacity of 2,550 cfs and raised canal embankments which prevents any instance of bank exceedance, the C-9 Canal still had high enough water levels to inhibit gravity-driven drainage in parts of the secondary/tertiary system, contributing to overland flooding of urban areas in several locations as shown in **Figure 7.2-41**. Mitigation M2B, although within about 0.3 ft or less in any given location, was unable to achieve a PM #1 25-year SLR1 maximum water surface profile in the C-9 Canal that was equal to or lower than the existing conditions 25-year SLR0 profile. As such, it is no surprise that there are areas of overland flooding during the 25-year SLR2 event under mitigation M2B that is greater than existing conditions, as shown in **Figure 7.2-42**. However, there is also a significant amount of area shown in **Figure 7.2-42** that has less flooding during the Mitigation M2B 25-year SLR2 event than under the 25-year SLR0 event without mitigation, mostly limited to areas along the C-9 Canal. Raising the canal banks alone are not solely responsible for the reduction in flooding along most of the C-9 Canal, as this not only prevents water from spilling out of the canal into the urban areas but also prevents water from draining from urban areas into the canal. A conceptual internal gravity-driven drainage system was added along the C-9 Canal to allow one-way flow from the watershed into the C-9 Canal whenever the water level in the C-9 Canal was lower than the water level in the area draining to it. Without the conceptual drainage system and pump station in place, raising the canal embankments was actually shown to worsen flooding in some areas during the iteration testing, as all the rainfall would stack along the canal banks and would be unable to drain either due to the raised canal banks (without the internal drainage system) or due to elevated canal stages (without the pump station).

Unlike Mitigation M2A, Mitigation M2B is predicted to not be able to draw down the C-9 Canal to an elevation lower than existing conditions. Although 1,000 cfs larger than the pump capacity under Mitigation M2A, the C-9 Canal water levels aren't pulled down further under Mitigation M2B as result of the increase in sea level rise reducing S-29 gravity discharge, reduced floodplain storage from the C-9 Canal staying within the raised banks, and increased flow to the C-9 Canal due to the internal drainage system. However, as shown in **Figure 7.2-42**, just because the maximum water levels in the C-9 Canal are predicted to be higher than existing conditions doesn't mean flooding will be worse, as evident by the reduction in flooding along nearly the entire eastern half of the C-9 Canal.

The increased flooding shown in **Figure 7.2-42** is related to higher groundwater elevations. As sea level rise increases, the antecedent groundwater elevations are predicted to increase. In some areas, the maximum groundwater elevation is higher than the land surface elevation, which results in an increase in flood depths that are difficult and potentially infeasible to fully mitigate. **Figure 7.2-43** presents the flooding depth differences between the 25-year SLR2 event with and without mitigation. Although the goal was to achieve flood protection equal to or better than existing conditions, it was just that, a goal. The reality of it is that sea level rise is going to bring about unprecedented changes in the form of higher tide levels to discharge against, higher antecedent water levels throughout the watershed which effectively removes storage that was once there, and areas with higher groundwater levels which not only removes storage that was once there but can actively rise above land surface further contributing to flooding. Therefore, although achieving flood protection equal to or greater than what is currently provided under existing conditions is a great goal to aim for, this shouldn't limit the success or consideration of mitigation strategies. Therefore, looking at the difference between flooding under a particular mitigation strategy and the flooding that could occur if no mitigation was implemented is what really shows how effective the mitigation strategy is. **Figure 7.2-43** shows a widespread reduction in flooding ranging from 0.1 to more than 0.5 ft (with localized values of more than as 2 ft). This figure highlights the areas that are most impacted or benefited by Mitigation M2B.

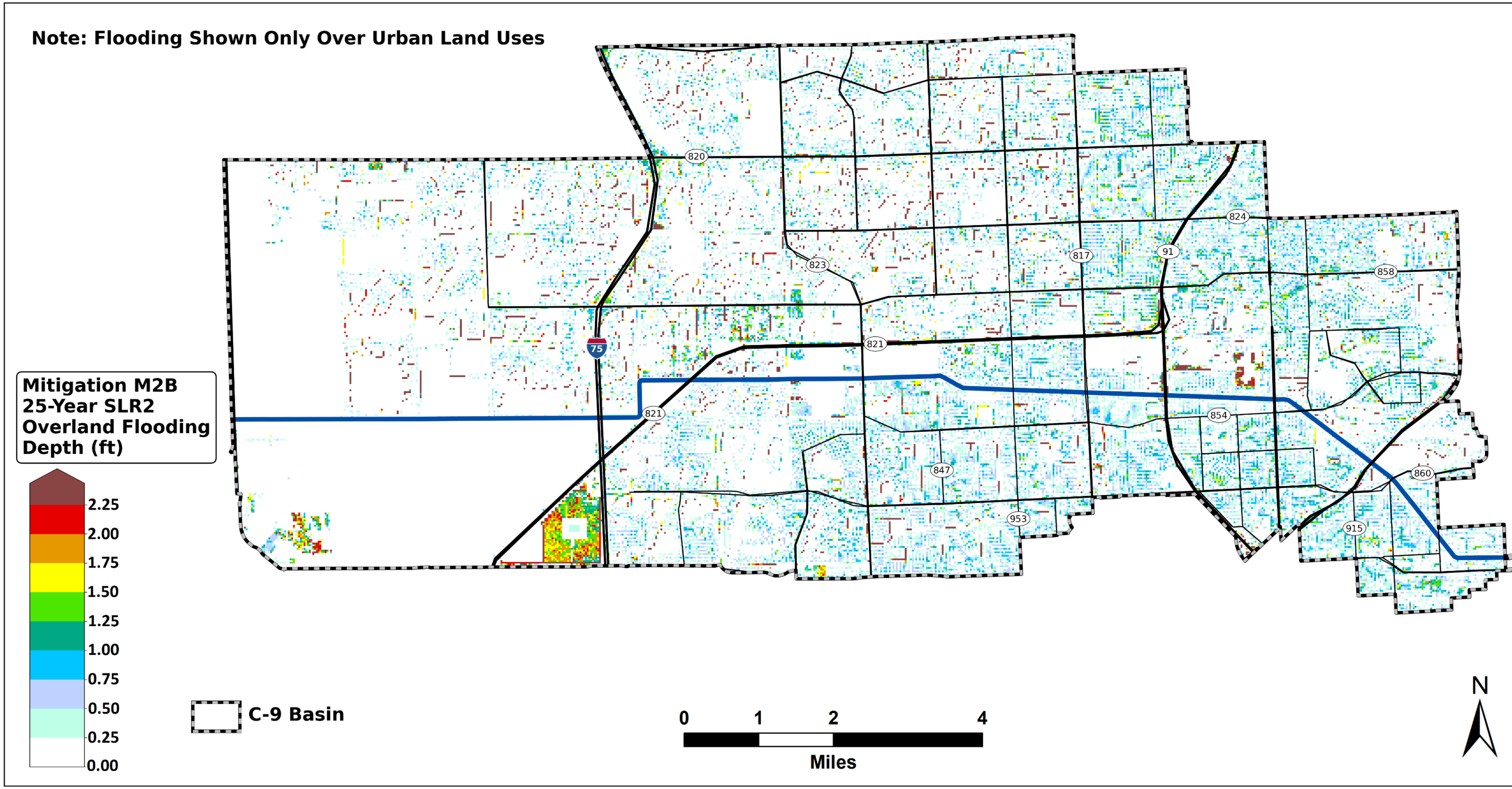


Figure 7.2-41: C-9 Watershed Flood Inundation Map for the Mitigation M2B 25-Year Sea Level Rise Design Storm Event in Urban Land Use Areas

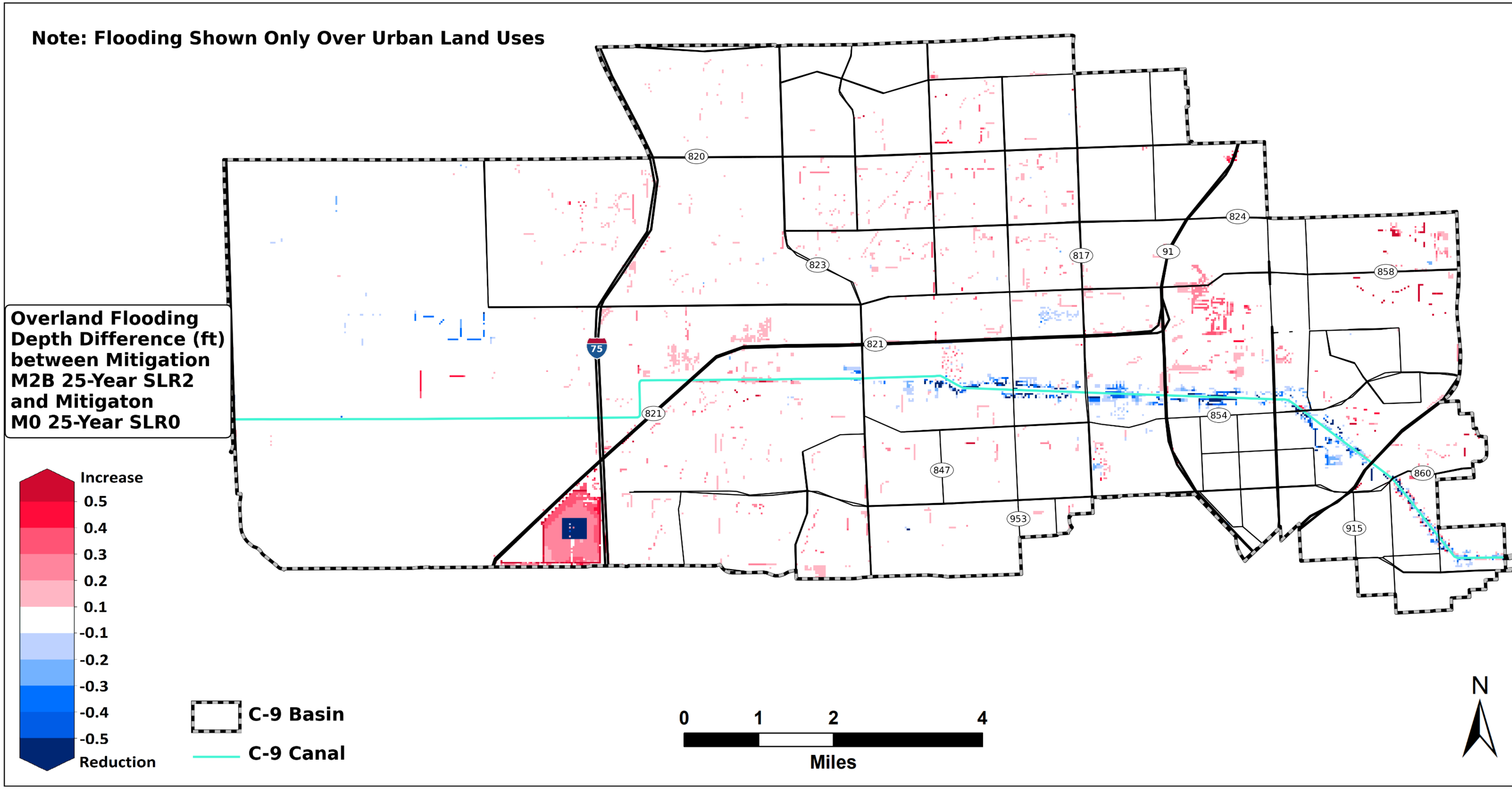


Figure 7.2-42: C-9 Watershed Flood Inundation Difference Map for Mitigation M2B 25-Year Sea Level Rise 2 versus Existing Conditions (M0) 25-Year SLR0 in Urban Land Use Areas

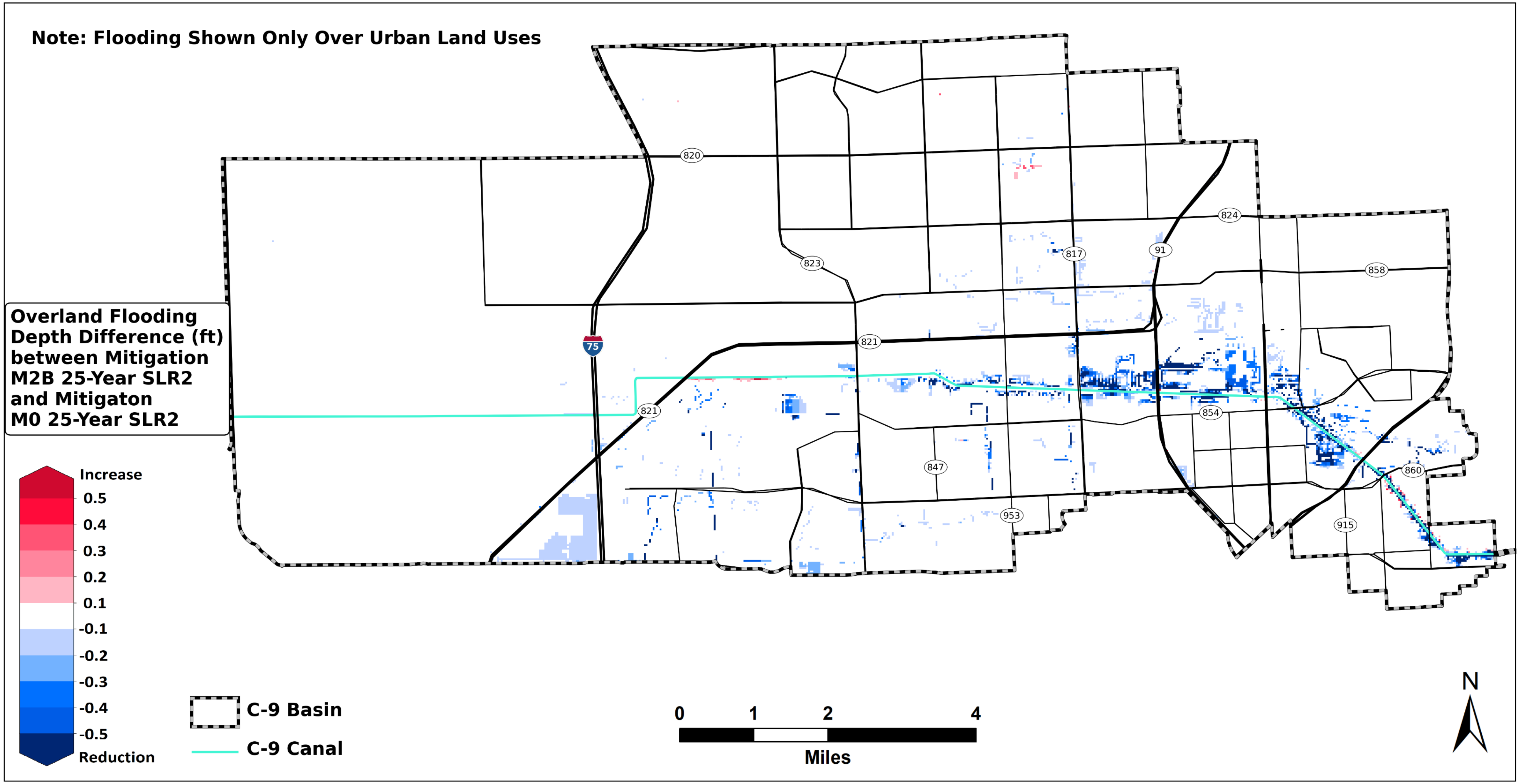


Figure 7.2-43: C-9 Watershed Flood Inundation Difference Map for Mitigation M2B 25-Year Sea Level Rise 2 versus Future Conditions without mitigation (M0) 25-Year SLR2 in Urban Land Use Areas

7.2.3.3 PM #5 – Mitigation M2C

Mitigation scenario M2C is the most aggressive form of mitigation out of the three mitigation strategies analyzed in this study. Although Mitigation M2C has a very large pumping capacity of 3,550 cfs and raised canal embankments which prevents any instance of bank exceedance, the C-9 Canal still had high enough water levels to inhibit gravity-driven drainage in parts the secondary/tertiary system, contributing to overland flooding of urban areas in several locations as shown in **Figure 7.2-44**. Mitigation M2C was unable to achieve a PM #1 25-year SLR3 maximum water surface profile in the C-9 Canal that was equal to or lower than existing conditions 25-year SLR0 profile, with water levels on average about 0.36 ft higher along the entire canal. As such, it is no surprise that there are areas of overland flooding during the 25-year SLR3 event under mitigation M2C that are greater than existing conditions, as shown in **Figure 7.2-45**. However, there is also a significant amount of area shown in **Figure 7.2-45** that has less flooding during the Mitigation M2C 25-year SLR3 event than under the 25-year SLR0 event without mitigation. Raising the canal banks alone are not solely responsible for the reduction in flooding along most of the C-9 Canal, as this not only prevents water from spilling out of the canal into the urban areas but also prevents water from draining from urban areas into the canal. A conceptual internal gravity-driven drainage system was added along the C-9 Canal to allow one-way flow from the watershed into the C-9 Canal whenever the water level in the C-9 Canal was lower than the water level in the area draining to it. Without the conceptual drainage system and pump station in place, raising the canal embankments was actually shown to worsen flooding during the iteration testing, as all the rainfall would stack along the canal banks and would be unable to drain either due to the raised canal banks (without the internal drainage system) or due to elevated canal stages (without the pump station).

Additionally, the C-9 Canal was widened by an average of approximately 75 ft along about 79,000 of canal in this scenario, from the west side of South Broward Drainage District (approximately the east side of the C-9 Impoundment location) to the west side of Interstate 95. The widening of the C-9 Canal increased its conveyance capacity, causing a shift in the hydraulic grade line, decreasing the water levels throughout the middle segment, and increasing the water levels in the eastern segment of the C-9 Canal, at which point the increased pump capacity offsets the increased downstream water levels. Without widening the C-9 Canal, the 3,550 cfs pump station would have further lowered the immediate area upstream of the pump station but would have little to no added benefit to the water levels upstream compared to the benefits of a 2,550 cfs pump.

Like Mitigation M2B, Mitigation M2C is predicted to be unable to achieve 25-year SLR3 water levels in the C-9 Canal that are equal to or lower than existing conditions in any location. There are several reasons why the 25-year SLR3 water levels in the C-9 Canal are predicted to be unable to be brought down to existing conditions. These reasons include but are not limited to the increase in sea level rise reducing S-29 gravity discharge, the reduced storage caused by increased groundwater levels, reduced floodplain storage from the C-9 Canal staying within the raised banks, and increased flow to the C-9 Canal due to the internal drainage system. Some of the increased flooding shown in **Figure 7.2-45** is related to higher groundwater elevations, while other areas of increased flooding are due to higher surface water elevations caused by sea level rise. As sea level rise increases, the antecedent groundwater elevations are predicted to increase. In many areas, the maximum groundwater elevation is higher than the land surface elevation, which results in an increase in flood depths that are difficult and potentially infeasible to fully mitigate. **Figure 7.2-46** presents the flooding depth differences between the 25-year SLR3 event with and without mitigation. Although the goal was to achieve flood protection equal to or better than existing conditions, it was just that, a goal. The reality of it is that sea level rise is going to bring about unprecedented changes in the form of higher tide levels to discharge against, higher antecedent water levels throughout the watershed which effectively removes storage that was once there, and areas with higher groundwater levels which not only removes storage that was once there but can actively rise above land surface further contributing to flooding. Therefore, although achieving flood protection equal to or greater than what is currently provided under existing conditions is a great goal to aim for, this shouldn't limit the success or consideration of mitigation strategies. Therefore, looking at the difference between flooding under a particular mitigation strategy and the flooding that could occur if no mitigation was implemented really shows how effective the mitigation is. **Figure 7.2-46** shows a widespread reduction in flooding ranging from 0.1 to more than 0.5 ft (with localized values of more than as 2 ft). This figure highlights the areas that are most impacted or benefited by Mitigation M2C.

Although Mitigation M2C was unable to achieve a 25-year SLR3 PM #1 maximum water surface profile equal to or lower than existing conditions (25-year SLR0) and has increased PM #5 flooding when compared to existing conditions, it was actually quite effective for the 25-year SLR2 event. As the goal for Mitigation M2C was the 25-year SLR3 event, no difference maps are shown for M2C under smaller sea level rise scenarios or different rainfall events. However, looking at PM #1 provides a glimpse of the potential benefit of this Mitigation scenario under other combinations of rainfall and sea level rise. Likewise, Mitigation M2A and M2B have varying levels of performance across each rainfall and sea level rise combination, and this report is only providing a glimpse of that based on the goal of the study.

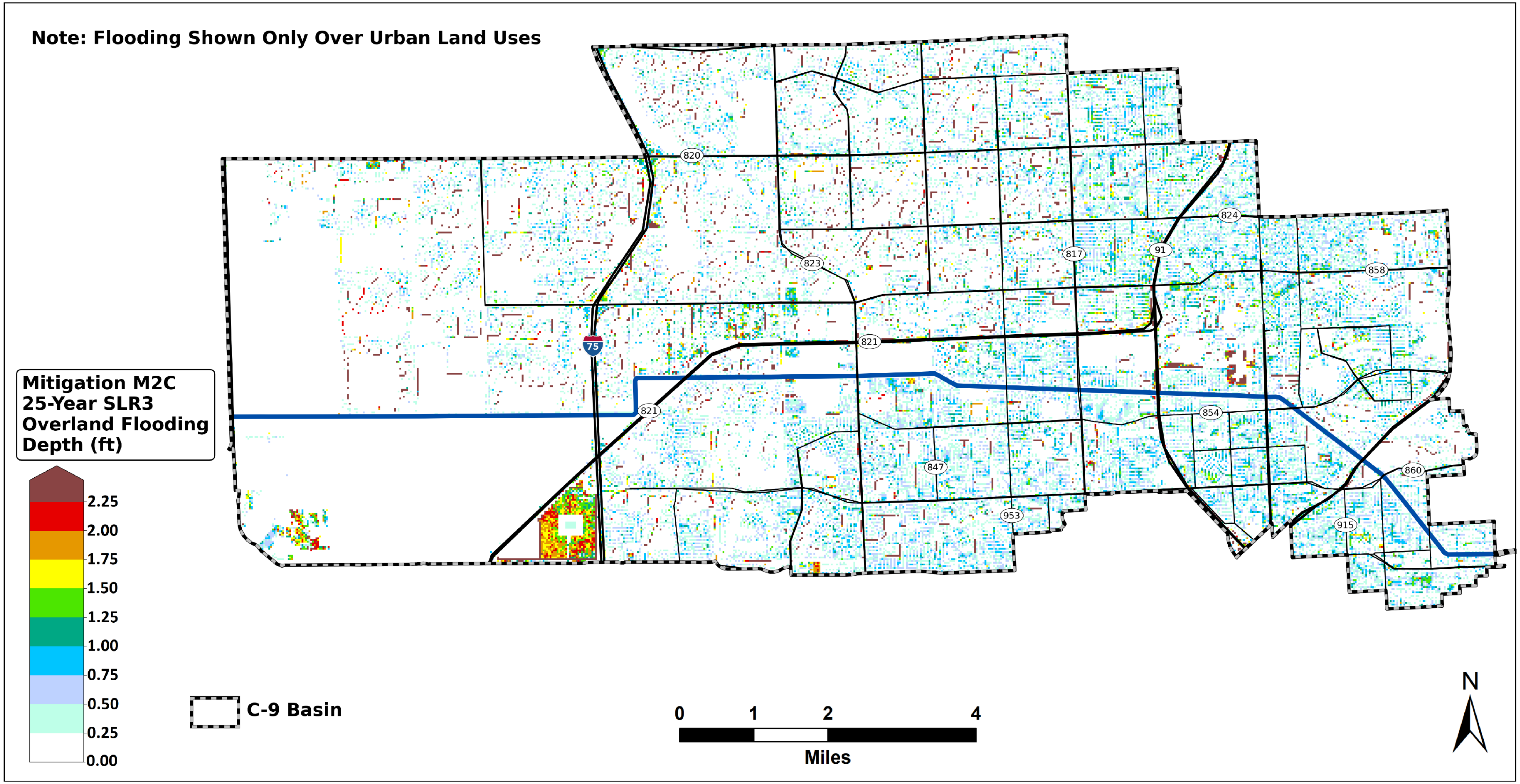


Figure 7.2-44: C-9 Watershed Flood Inundation Map for the Mitigation M2C 25-Year Sea Level Rise 3 Design Storm Event in Urban Land Use Areas

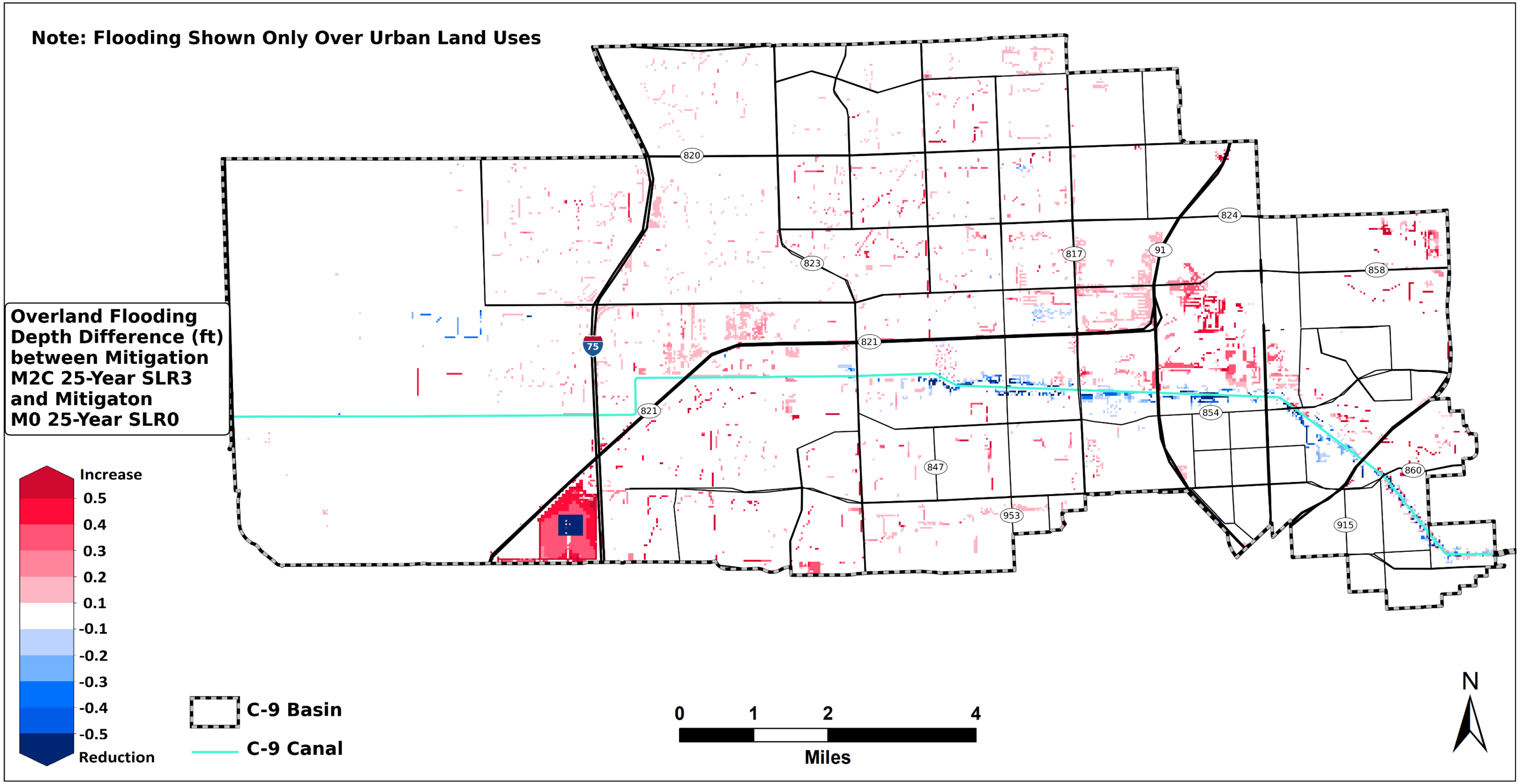


Figure 7.2-45: C-9 Watershed Flood Inundation Difference Map for Mitigation M2A 25-Year Sea Level Rise 3 versus Existing Conditions (M0) 25-Year SLR0 in Urban Land Use Areas

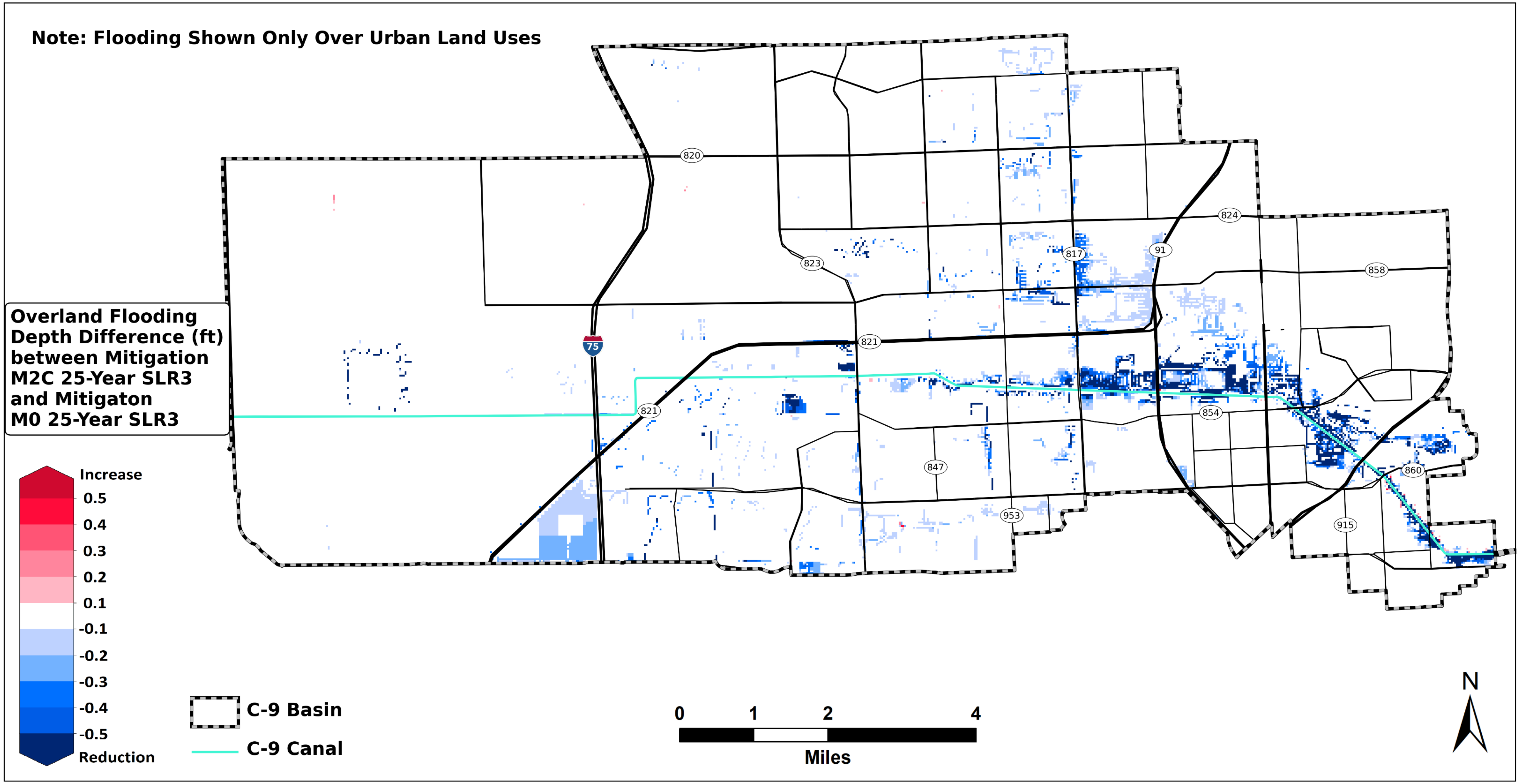


Figure 7.2-46: C-9 Watershed Flood Inundation Difference Map for Mitigation M2C 25-Year Sea Level Rise 3 versus Future Conditions without mitigation (M0) 25-Year SLR3 in Urban Land Use Areas

7.2.3.4 PM #5 – Summary for C-9 Watershed

- M2A
    - Even with Mitigation M2A, it is predicted that there will be areas with higher levels of overland flooding compared to existing conditions. However, there are also areas predicted to have lower levels of overland flooding.
    - Overall, the M2A 25-year SLR1 flood inundation is not predicted to be significantly better or worse than existing conditions
    - Overall, it is predicted that there will be less flood inundation for the M2A 25-year SLR1 event than the 25-year SLR1 event without mitigation
- M2B
    - Overall, the M2B 25-year SLR2 flood inundation is not predicted to be significantly better or worse than existing conditions
        - It is predicted 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, it is predicted that there will be significantly less flood inundation for the M2B 25-year SLR2 event than the 25-year SLR2 event without mitigation
- M2C
    - Overall, the M2C 25-year SLR3 flood inundation is not predicted to be significantly better or worse than existing conditions
        - It is predicted 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, it is predicted that there will be significantly less flood inundation for the M2C 25-year SLR3 event than the 25-year SLR3 event without mitigation

7.2.4 PM #6 – Duration of Flooding

As part of this performance metric during the Phase 1 FPLOS study, a reference stage of 3.5 ft NGVD29 at S-29Z (a water level station approximately halfway up the C-9 Canal) was used to compare the time it takes the canal to return to the reference stage under current conditions and future conditions with sea level rise. However, as part of this Phase 2 FPLOS Study, a few significant assumptions were changed with respect to how the water level in the C-9 Canal is controlled under future conditions (related to salinity control). These new assumptions result in a large difference in C-9 Canal water levels between current conditions and each sea level rise scenario, making the reference stage comparison meaningless. Essentially, the water level in the C-9 Canal during SLR2 or SLR3 is predicted to never drop low enough to be compared with values from SLR0, or at least not based on the modeling assumptions used in this Phase 2 study. Therefore, no comparison of the duration taken for water levels in the C-9 Canal to return to a reference stage will be made.

Table 7.1-8 through **Table 7.1-11** summarizes the area with flood depths greater than 0.25 ft for various durations for the 5-year, 10-year, 25-year, and 100-year design storm events for SLR0, SLR1, SLR2, and SLR3, under existing conditions (Mitigation 0), Mitigation M2A, Mitigation M2B, and Mitigation M2C, for all land use and urban land use only. Area of flooding presented in **Table 7.1-8** through **Table 7.1-11** are cumulative in order of decreasing duration (i.e., area with duration greater than 360 hr are included in the area with duration greater than 240 hr). In these four tables under Mitigation 0 (existing conditions), a decrease in area (acres) going from SLR0 to SLR1, SLR2, or SLR3 corresponds to areas where the topography was increased in the future conditions model development to the FEMA BFE in areas of future land use change. Areas that are predicted to have decreased flood depth also have decreased flood duration. When looking at Mitigation M2A, M2B, and M2C in these tables, a decrease in area (acres) compared to Mitigation 0 correspond to a reduction in flooding due to mitigation.

Section 7.1.4.1 through **Section 7.1.4.3** presents the Phase 2 PM #6 FPLOS Assessment for Mitigation M2A, M2B, and M2C, respectively. Within each section, three figures are presented that show the 25-year flood duration map for the respective sea level rise scenario, a flood duration difference map between the 25-year SLR mitigation scenario and the 25-year SLR0 existing conditions scenario, and a flood duration difference map between the 25-year SLR mitigation scenario and the respective 25-year future sea level rise without mitigation scenario. For instance, **Section 7.1.4.1** presents the 25-year SLR1 flood duration map under Mitigation M2A, the flood duration difference map between the M2A 25-year SLR1 event and the existing conditions (M0) 25-year SLR0 event, and the flood duration difference map between the M2A 25-year SLR1 event and the future conditions without mitigation 25-year SLR1 event. **Section 7.1.4.2** and **Section 7.1.4.3** shows the same three figures but for SLR2 for Mitigation M2B and SLR3 for Mitigation M2C, respectively. Refer to **Appendix E** for the complete set of flood duration maps for the 5-year, 10-year, 25-year, and 100-year design storms for SLR1, SLR2, and SLR3, for all land use and urban land use only, for each of the three mitigation scenarios.

Areas that are predicted to have an increase in flood duration in the PM6 difference maps that do not correspond to significant increases in flood depths as shown in the PM5 difference maps are most often caused by increased groundwater elevations/durations and/or decreased overland and saturated zone drainage. Sea level rise causes an increase in groundwater elevations along the coast, which is predicted to cause inland groundwater elevations to stay elevated longer. In areas where the peak groundwater is higher than topography, this predicted increase in groundwater duration translates to increased surface water durations, even if the peak groundwater elevations do not increase. Additionally, in the MIKE SHE model, ponded drainage (simulates routing of ponded water via features that are not explicitly modeled such as curb inlets and local-scale storm drains) and saturated zone drainage (simulates surface drainage features that are not explicitly modeled such as roadside underdrains and shallow swales) turn off whenever the downstream canal water levels are higher. When the ponded drainage routine turns off, the duration of ponded water on the surface increases. When the saturated zone drainage routine turns off, the duration that localized groundwater levels are elevated increases.

Table 7.2-8: Summary of the PM#6 Area of Flooding by Flood Duration for the C-9 Watershed 5-Year Design Storm

5-Year Design Storm																
Duration of Flooding (hr)	Area with Flood Depths >0.25 ft within the C-9 Watershed (acres)															
	Mitigation 0 (Existing Conditions)				Mitigation M2A				Mitigation M2B				Mitigation M2C			
	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3
<= 0.1	1126	1115	1098	1068	1130	1117	1101	1089	1134	1124	1107	1098	1140	1128	1114	1101
>= 1	24861	25254	25652	26162	24849	25115	25484	25807	24705	24975	25337	25652	24625	24814	25270	25594
>= 4	23765	24165	24583	25118	23750	24019	24395	24739	23590	23869	24235	24571	23502	23698	24161	24503
>= 8	23050	23457	23900	24459	23033	23309	23699	24072	22871	23157	23539	23906	22782	22983	23464	23832
>= 12	21966	22401	22871	23474	21959	22240	22649	23061	21795	22088	22487	22885	21703	21909	22409	22811
>= 24	21495	21947	22430	23052	21497	21786	22199	22619	21341	21638	22045	22452	21244	21456	21968	22374
>= 48	21087	21551	22048	22678	21089	21383	21814	22241	20934	21243	21663	22073	20841	21061	21582	21997
>= 96	20684	21160	21673	22320	20686	20990	21428	21867	20531	20844	21274	21699	20433	20660	21192	21625
>= 168	20094	20587	21130	21804	20103	20410	20868	21333	19954	20271	20718	21167	19856	20078	20632	21087
>= 240	19836	20334	20877	21554	19849	20156	20615	21077	19697	20012	20464	20910	19596	19817	20375	20830
>= 360	19559	20063	20608	21304	19565	19882	20342	20819	19420	19743	20188	20649	19317	19546	20106	20562
Area with Flood Depths >0.25 ft in Urban Land Use within the C-9 Watershed (acres)																
<= 0.1	988	974	967	947	980	975	969	961	990	985	977	971	992	987	982	975
>= 1	10931	10940	11108	11398	10808	10890	11025	11182	10710	10794	10925	11073	10683	10760	10907	11037
>= 4	9986	10004	10178	10488	9864	9949	10085	10255	9759	9849	9978	10139	9727	9809	9957	10096
>= 8	9364	9384	9580	9905	9239	9329	9475	9664	9131	9225	9366	9546	9098	9185	9345	9499
>= 12	8428	8466	8676	9032	8308	8400	8562	8774	8195	8293	8446	8647	8163	8248	8422	8599
>= 24	8032	8076	8290	8660	7915	8009	8170	8385	7807	7904	8060	8263	7771	7859	8040	8214
>= 48	7680	7732	7955	8331	7565	7661	7833	8054	7461	7563	7727	7932	7428	7519	7705	7884
>= 96	7330	7391	7624	8014	7217	7319	7496	7725	7115	7220	7388	7606	7078	7175	7366	7560
>= 168	6826	6892	7144	7551	6715	6816	7008	7251	6616	6721	6903	7130	6579	6671	6876	7083
>= 240	6591	6664	6917	7323	6486	6589	6780	7023	6386	6492	6675	6903	6349	6440	6644	6853
>= 360	6344	6417	6673	7093	6230	6340	6531	6785	6137	6246	6425	6664	6100	6194	6398	6609

Area of flooding is cumulative in order of decreasing duration (i.e., area with duration greater than or equal to 360 hr are included in the area with duration greater than or equal to 240 hr)

Table 7.2-9: Summary of the PM#6 Area of Flooding by Flood Duration for the C-9 Watershed 10-Year Design Storm

10-Year Design Storm																
Duration of Flooding (hr)	Area with Flood Depths >0.25 ft within the C-9 Watershed (acres)															
	Mitigation 0 (Existing Conditions)				Mitigation M2A				Mitigation M2B				Mitigation M2C			
	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3
<= 0.1	1145	1136	1125	1087	1143	1139	1133	1122	1141	1134	1133	1127	1147	1137	1137	1130
>= 1	27003	27354	27766	28332	26981	27225	27502	27909	26803	27044	27302	27689	26689	26900	27236	27603
>= 4	25746	26116	26554	27160	25724	25975	26274	26709	25515	25761	26040	26458	25391	25610	25970	26359
>= 8	25004	25380	25840	26469	24967	25231	25549	25995	24766	25023	25317	25748	24638	24868	25247	25642
>= 12	23790	24189	24713	25366	23748	24037	24392	24863	23530	23812	24139	24598	23399	23645	24063	24485
>= 24	23299	23710	24242	24911	23247	23548	23924	24401	23029	23320	23663	24130	22896	23147	23584	24014
>= 48	22853	23287	23828	24523	22800	23107	23494	24001	22595	22890	23242	23730	22459	22714	23156	23608
>= 96	22414	22874	23418	24141	22374	22691	23083	23599	22176	22478	22833	23332	22040	22299	22747	23206
>= 168	21769	22252	22816	23550	21737	22057	22468	22995	21545	21851	22218	22732	21409	21671	22129	22610
>= 240	21487	21975	22562	23319	21457	21783	22206	22751	21276	21590	21967	22489	21132	21407	21871	22365
>= 360	21188	21679	22272	23041	21155	21482	21903	22476	20981	21292	21664	22219	20837	21113	21570	22092
Area with Flood Depths >0.25 ft in Urban Land Use within the C-9 Watershed (acres)																
<= 0.1	1021	1016	1013	982	1021	1017	1015	1011	1017	1012	1013	1014	1018	1013	1015	1015
>= 1	12471	12500	12726	13084	12357	12443	12575	12804	12242	12326	12441	12655	12217	12291	12414	12604
>= 4	11374	11421	11664	12056	11268	11358	11501	11750	11128	11212	11341	11576	11096	11173	11310	11514
>= 8	10753	10799	11059	11466	10635	10731	10888	11144	10500	10591	10729	10973	10465	10547	10698	10905
>= 12	9691	9754	10060	10488	9577	9685	9866	10142	9427	9532	9688	9949	9389	9483	9651	9876
>= 24	9259	9331	9643	10081	9138	9257	9450	9729	8988	9099	9266	9532	8950	9050	9227	9454
>= 48	8867	8949	9266	9727	8748	8866	9064	9365	8608	8715	8887	9167	8566	8663	8844	9086
>= 96	8483	8583	8899	9380	8374	8494	8698	9004	8239	8351	8524	8811	8199	8299	8480	8727
>= 168	7910	8027	8353	8838	7807	7933	8144	8455	7675	7793	7971	8268	7638	7743	7927	8187
>= 240	7661	7782	8125	8625	7561	7690	7909	8233	7442	7563	7745	8047	7399	7508	7696	7965
>= 360	7394	7513	7857	8370	7290	7419	7634	7982	7177	7293	7472	7798	7134	7239	7428	7713

Area of flooding is cumulative in order of decreasing duration (i.e., area with duration greater than or equal to 360 hr are included in the area with duration greater than or equal to 240 hr)

Table 7.2-10: Summary of the PM#6 Area of Flooding by Flood Duration for the C-9 Watershed 25-Year Design Storm

25-Year Design Storm																
Duration of Flooding (hr)	Area with Flood Depths >0.25 ft within the C-9 Watershed (acres)															
	Mitigation 0 (Existing Conditions)				Mitigation M2A				Mitigation M2B				Mitigation M2C			
	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3
<= 0.1	1168	1161	1123	1083	1199	1182	1158	1119	1201	1187	1168	1128	1206	1195	1173	1135
>= 1	29989	30355	30842	31563	29945	30150	30512	30981	29709	29892	30204	30681	29625	29784	30089	30531
>= 4	28607	28998	29519	30288	28556	28784	29169	29672	28283	28485	28825	29341	28190	28364	28694	29169
>= 8	27911	28311	28841	29642	27853	28089	28482	29003	27573	27781	28129	28660	27478	27653	27992	28482
>= 12	26502	26943	27510	28368	26437	26703	27132	27676	26146	26382	26762	27329	26033	26239	26618	27133
>= 24	25925	26372	26971	27856	25855	26121	26573	27146	25564	25803	26197	26793	25450	25655	26051	26595
>= 48	25437	25904	26506	27421	25374	25652	26109	26688	25085	25322	25727	26338	24968	25174	25578	26130
>= 96	24956	25449	26069	27005	24902	25189	25662	26259	24604	24855	25271	25892	24485	24702	25119	25677
>= 168	24289	24804	25440	26407	24230	24527	25026	25638	23927	24190	24632	25272	23810	24027	24467	25046
>= 240	24013	24539	25180	26164	23948	24266	24765	25391	23652	23921	24371	25020	23530	23760	24206	24795
>= 360	23707	24253	24904	25908	23649	23966	24482	25131	23346	23625	24092	24758	23224	23460	23916	24527
Area with Flood Depths >0.25 ft in Urban Land Use within the C-9 Watershed (acres)																
<= 0.1	1012	1003	972	947	1035	1022	1003	970	1037	1026	1013	976	1040	1032	1018	984
>= 1	14745	14836	15163	15663	14591	14705	14922	15245	14434	14529	14715	15030	14407	14489	14654	14919
>= 4	13509	13615	13972	14507	13352	13480	13714	14061	13164	13271	13478	13819	13132	13224	13404	13689
>= 8	12894	13006	13372	13936	12732	12866	13106	13470	12538	12651	12862	13218	12505	12599	12782	13084
>= 12	11666	11804	12204	12815	11499	11653	11916	12303	11297	11427	11660	12048	11248	11366	11577	11900
>= 24	11156	11301	11724	12357	10986	11142	11422	11829	10781	10918	11160	11567	10734	10853	11075	11417
>= 48	10711	10873	11297	11955	10552	10711	10995	11408	10349	10478	10726	11149	10301	10415	10641	10992
>= 96	10279	10458	10897	11577	10126	10292	10588	11016	9913	10052	10312	10740	9863	9985	10224	10579
>= 168	9670	9868	10315	11023	9517	9690	10004	10442	9299	9448	9724	10168	9251	9376	9629	9998
>= 240	9416	9625	10074	10794	9259	9451	9767	10214	9047	9202	9485	9936	8995	9130	9389	9767
>= 360	9130	9361	9820	10553	8983	9173	9504	9970	8764	8930	9227	9690	8714	8856	9122	9517

Area of flooding is cumulative in order of decreasing duration (i.e., area with duration greater than or equal to 360 hr are included in the area with duration greater than or equal to 240 hr)

Table 7.2-11: Summary of the PM#6 Area of Flooding by Flood Duration for the C-9 Watershed 100-Year Design Storm

100-Year Design Storm																
Duration of Flooding (hr)	Area with Flood Depths >0.25 ft within the C-9 Watershed (acres)															
	Mitigation 0 (Existing Conditions)				Mitigation M2A				Mitigation M2B				Mitigation M2C			
	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3	SLR0	SLR1	SLR2	SLR3
<= 0.1	1123	1117	1097	1068	1159	1137	1122	1090	1165	1146	1133	1103	1172	1164	1154	1116
>= 1	34438	34826	35392	36104	34220	34512	34979	35578	33894	34152	34605	35213	33748	33966	34383	34940
>= 4	33247	33643	34247	35000	32991	33306	33813	34435	32644	32924	33423	34059	32483	32724	33188	33769
>= 8	32327	32739	33375	34166	32053	32386	32918	33579	31687	31987	32505	33178	31514	31777	32257	32870
>= 12	30907	31367	32040	32895	30620	30990	31560	32271	30233	30560	31123	31847	30036	30325	30847	31502
>= 24	30291	30763	31461	32333	29995	30378	30964	31686	29608	29953	30532	31265	29398	29700	30244	30922
>= 48	29792	30287	31000	31900	29481	29884	30492	31242	29089	29460	30053	30822	28880	29192	29758	30469
>= 96	29284	29798	30538	31445	28964	29387	30008	30766	28575	28955	29570	30344	28346	28679	29263	29981
>= 168	28569	29115	29901	30852	28241	28681	29355	30145	27846	28252	28912	29719	27609	27951	28583	29337
>= 240	28244	28826	29616	30599	27938	28381	29063	29889	27534	27949	28616	29461	27291	27645	28275	29071
>= 360	27929	28516	29329	30344	27618	28077	28763	29607	27216	27644	28314	29176	26969	27333	27971	28775
Area with Flood Depths >0.25 ft in Urban Land Use within the C-9 Watershed (acres)																
<= 0.1	1032	1029	1008	979	1059	1045	1033	1000	1071	1052	1041	1011	1078	1068	1058	1022
>= 1	18283	18479	18918	19494	18033	18233	18584	19060	17786	17973	18322	18814	17714	17852	18141	18585
>= 4	17198	17402	17871	18480	16919	17139	17521	18016	16654	16858	17244	17761	16570	16728	17053	17516
>= 8	16389	16603	17100	17743	16096	16329	16729	17259	15818	16034	16432	16986	15721	15895	16232	16723
>= 12	15126	15379	15910	16610	14818	15083	15521	16094	14523	14764	15205	15801	14409	14607	14983	15506
>= 24	14560	14824	15376	16093	14245	14521	14975	15558	13949	14207	14662	15267	13826	14035	14429	14973
>= 48	14102	14387	14953	15696	13773	14069	14539	15151	13472	13750	14219	14859	13347	13567	13980	14555
>= 96	13647	13951	14542	15290	13313	13626	14109	14724	13014	13300	13787	14432	12873	13109	13542	14122
>= 168	13000	13329	13962	14749	12657	12982	13514	14157	12354	12660	13188	13859	12205	12449	12924	13533
>= 240	12695	13058	13696	14511	12375	12700	13239	13918	12066	12376	12910	13619	11911	12162	12635	13284
>= 360	12402	12769	13423	14271	12078	12418	12957	13650	11769	12091	12624	13350	11611	11876	12348	13005

Area of flooding is cumulative in order of decreasing duration (i.e., area with duration greater than or equal to 360 hr are included in the area with duration greater than or equal to 240 hr)

7.2.4.1 PM #6 – Mitigation M2A

Mitigation scenario M2A is the least aggressive form of mitigation out of the three mitigation strategies analyzed in this study. Although Mitigation M2A has a relatively large pumping capacity of 1,550 cfs, the C-9 Canal still had several instances of bank exceedances and had high enough water levels to inhibit gravity-driven drainage in parts of the secondary/tertiary system, contributing to long durations of overland flooding in urban areas as shown in **Figure 7.2-47**. Although Mitigation M2A is predicted to achieve a PM #1 25-year SLR1 maximum water surface profile in the C-9 Canal that was equal to or lower than existing conditions, model results indicate there will not much if any decrease in duration of flooding, as shown in **Figure 7.2-48. Figure 7.2-48** shows that a significant amount of area is staying flooded longer than existing conditions, in some cases several hours or days longer, even though the corresponding flood depths may be lower or minimally different than existing conditions. Areas that are predicted to have an increase in flood duration in the PM #6 difference maps that do not correspond to significant increases in flood depths as shown in the PM #5 difference maps are most often caused by increased groundwater elevations/durations and/or decreased overland and saturated zone drainage (when canal water elevations are higher than existing conditions). Sea level rise causes an increase in groundwater elevations along the coast, which is predicted to cause inland groundwater elevations to stay elevated longer. In areas where the peak groundwater is higher than topography, this predicted increase in groundwater duration translates to increased surface water durations, even if the peak groundwater elevations do not increase.

Figure 7.2-49 presents the flood duration differences between the 25-year SLR1 event with and without mitigation. Although the goal was to achieve flood protection equal to or better than existing conditions, it was just that- a goal. The reality of it is that sea level rise is going to bring about unprecedented changes in the form of higher tide levels to discharge against, higher antecedent water levels throughout the watershed which effectively removes storage that was once there, and areas with higher groundwater levels which not only removes storage that was once there but can actively rise above land surface further contributing to flooding and duration of flooding. Therefore, although achieving flood protection equal to or greater than what is currently provided under existing conditions is an appropriate goal to aim for, this shouldn't limit the success or consideration of mitigation strategies. Therefore, looking at the difference between flooding under a particular mitigation strategy and the flooding that could occur if no mitigation was implemented really shows how effective the mitigation is. **Figure 7.2-49** shows a widespread reduction in flood duration ranging from 1 hour to more than 24 hours. This figure highlights the areas that are most impacted or benefited by Mitigation M2A in terms of flood duration.

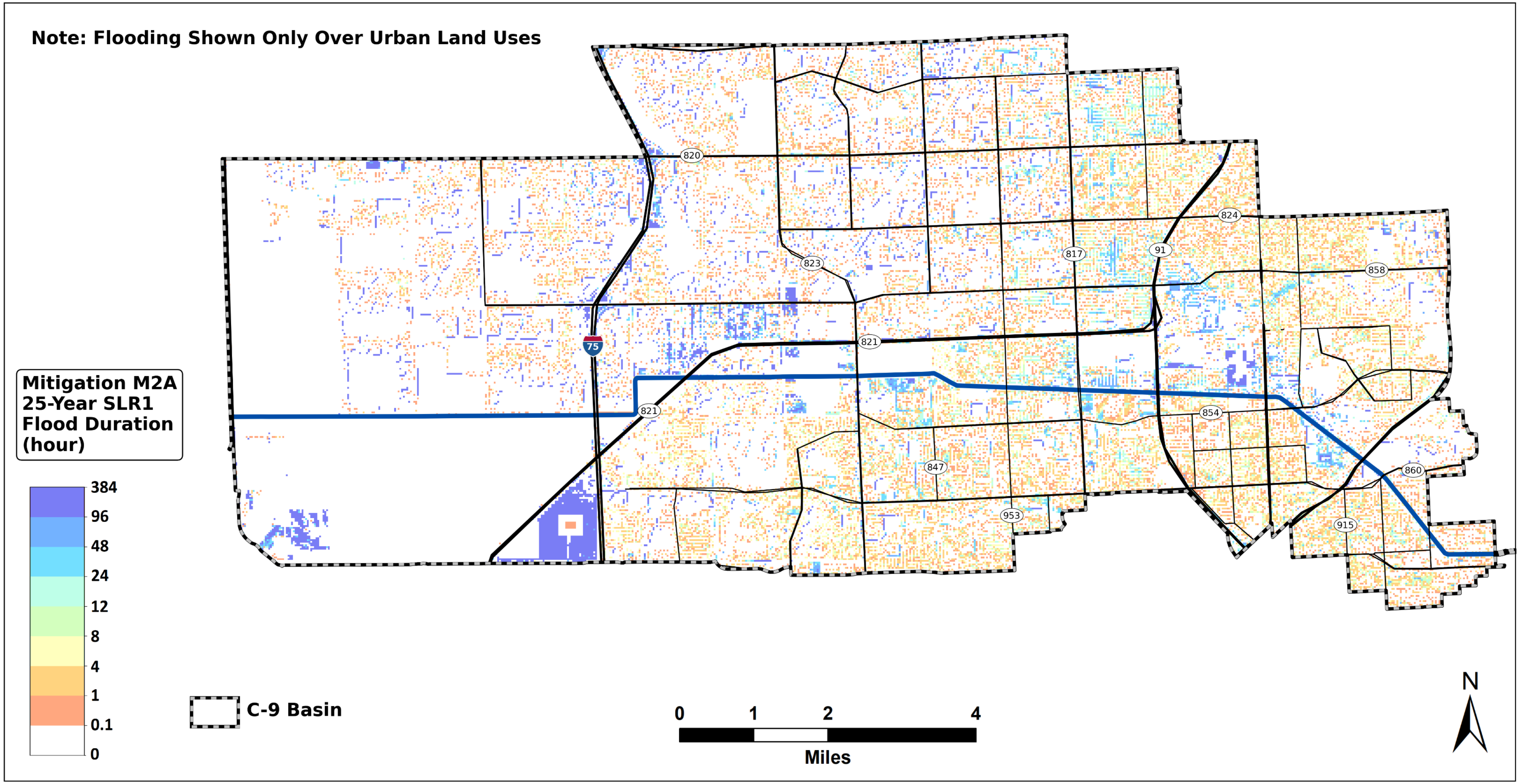


Figure 7.2-47: C-9 Watershed Flood Duration Map for the Mitigation M2A 25-Year Sea Level Rise 1 Design Storm Event in Urban Land Use Areas

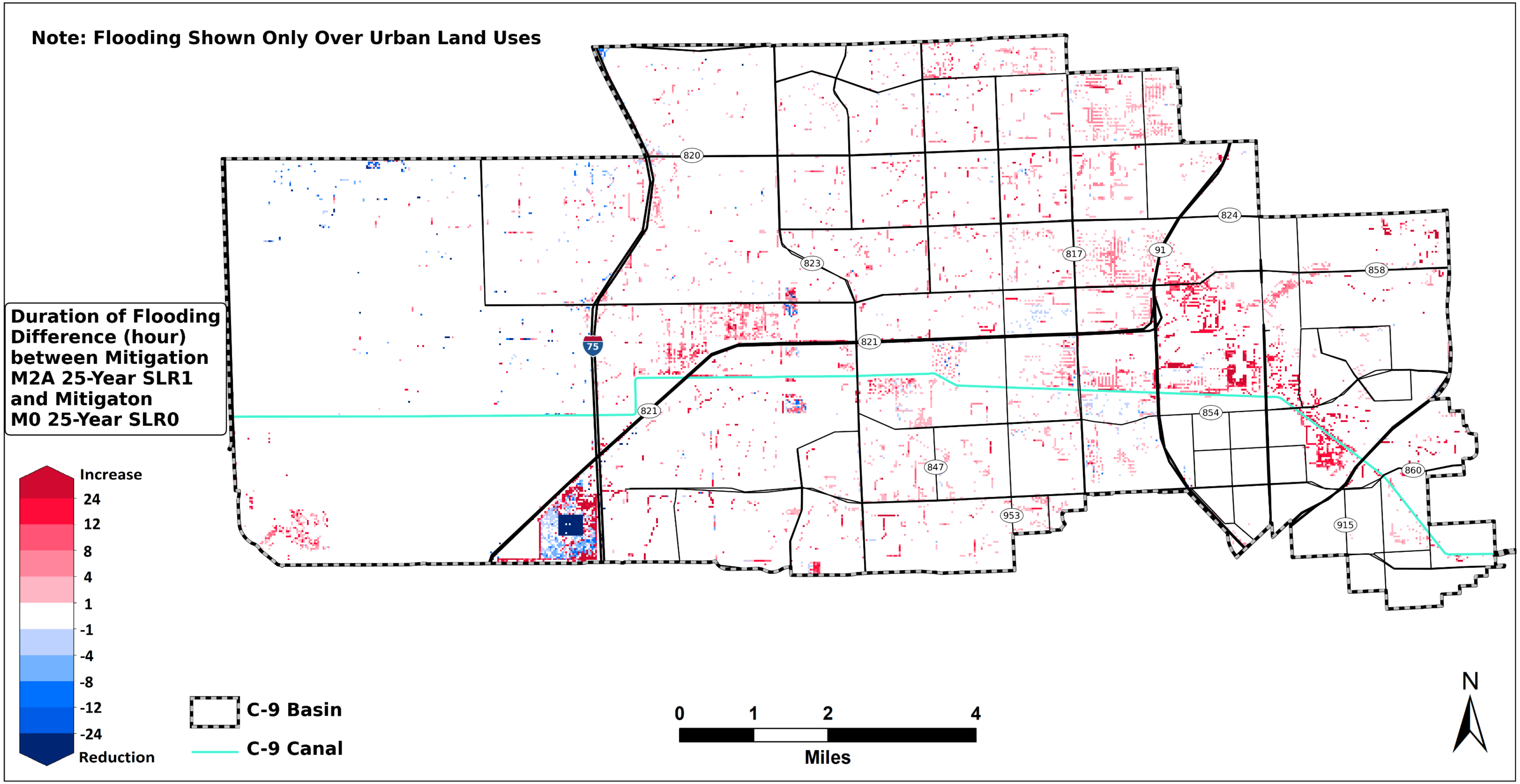


Figure 7.2-48: C-9 Watershed Flood Duration Difference Map for Mitigation M2A 25-Year Sea Level Rise 1 versus Existing Conditions (M0) 25-Year SLR0 in Urban Land Use Areas

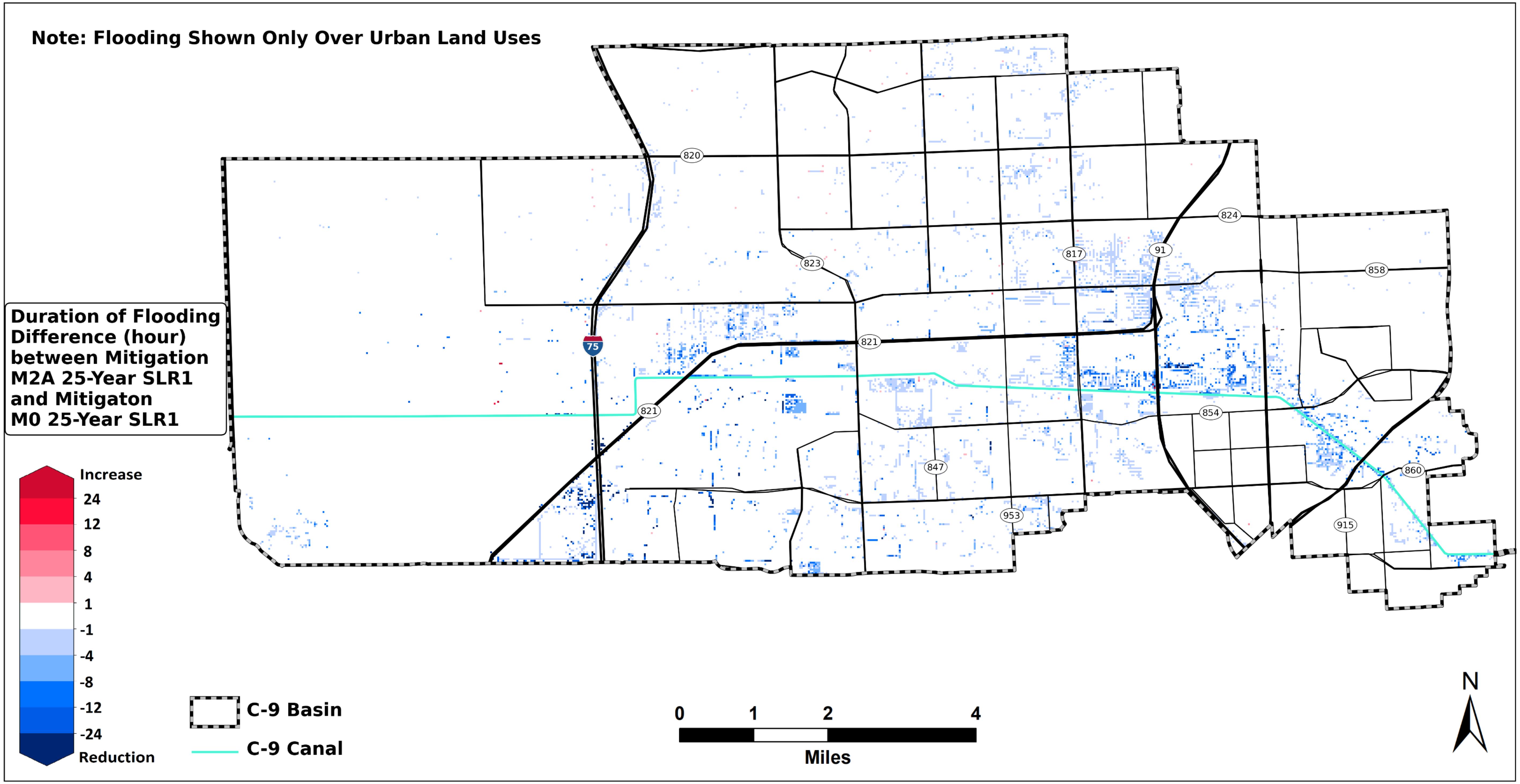


Figure 7.2-49: C-9 Watershed Flood Duration Difference Map for Mitigation M2A 25-Year Sea Level Rise 1 versus Future Conditions without mitigation (M0) 25-Year SLR1 in Urban Land Use Areas

7.2.4.2 PM #6 – Mitigation M2B

Mitigation scenario M2B is a more aggressive form of mitigation compared to M2A but less aggressive than M2C, making it the middle level of mitigation out of the three mitigation strategies analyzed in this study. Although Mitigation M2B has a large pumping capacity of 2,550 cfs and raised canal embankments which prevents any instance of bank exceedance, the C-9 Canal still had high enough water levels to inhibit gravity-driven drainage in parts of the secondary/tertiary system, contributing to the long durations of overland flooding in urban areas as shown in **Figure 7.2-50**. Mitigation M2B, although within about 0.3 ft or less in any given location, was unable to achieve a PM #1 25-year SLR1 maximum water surface profile in the C-9 Canal that was equal to or lower than the existing conditions 25-year SLR0 profile. As such, it is no surprise that there are areas with flood durations during the 25-year SLR2 event under mitigation M2B that are greater than existing conditions, as shown in **Figure 7.2-51**. **Figure 7.2-51** shows that a significant amount of area is staying flooded longer than existing conditions, in some cases several hours or days longer, even though the corresponding flood depths may be lower or minimally different than existing conditions. Areas that are predicted to have an increase in flood duration in the PM #6 difference maps that do not correspond to significant increases in flood depths as shown in the PM #5 difference maps are most often caused by increased groundwater elevations/durations and/or decreased overland and saturated zone drainage. Sea level rise causes an increase in groundwater elevations along the coast, which is predicted to cause inland groundwater elevations to stay elevated longer. In areas where the peak groundwater is higher than topography, this predicted increase in groundwater duration translates to increased surface water durations, even if the peak groundwater elevations do not increase. Although showing mostly an increase in flood duration, **Figure 7.2-51** does show areas with decreased flood duration along the C-9 Canal. These three areas with flood duration reduction are directly related to lower stages in the C-9 Canal, which is a function of blocking storm surge, pumping to tide, and improved drainage along the C-9 Canal.

Figure 7.2-52 presents the flood duration differences between the 25-year SLR2 event with and without mitigation. Although the goal was to achieve flood protection equal to or better than existing conditions, it was just that- a goal. The reality of it is that sea level rise is going to bring about unprecedented changes in the form of higher tide levels to discharge against, higher antecedent water levels throughout the watershed which effectively removes storage that was once there, and areas with higher groundwater levels which not only removes storage that was once there but can actively rise above land surface further contributing to flooding and duration of flooding. Therefore, although achieving flood protection equal to or greater than what is currently provided under existing conditions is an appropriate goal to aim for, this shouldn’t limit the success or consideration of mitigation strategies. Therefore, looking at the difference between flooding under a particular mitigation strategy and the flooding that could occur if no mitigation was implemented really shows how effective the mitigation is. **Figure 7.2-52** shows a widespread reduction in flood duration ranging from 1 hour to more than 24 hours, with a majority of the area having more than a 12-hour reduction (localized areas with reductions of 60 hours or more). This figure highlights the areas that are most impacted or benefited by Mitigation M2B in terms of flood duration.

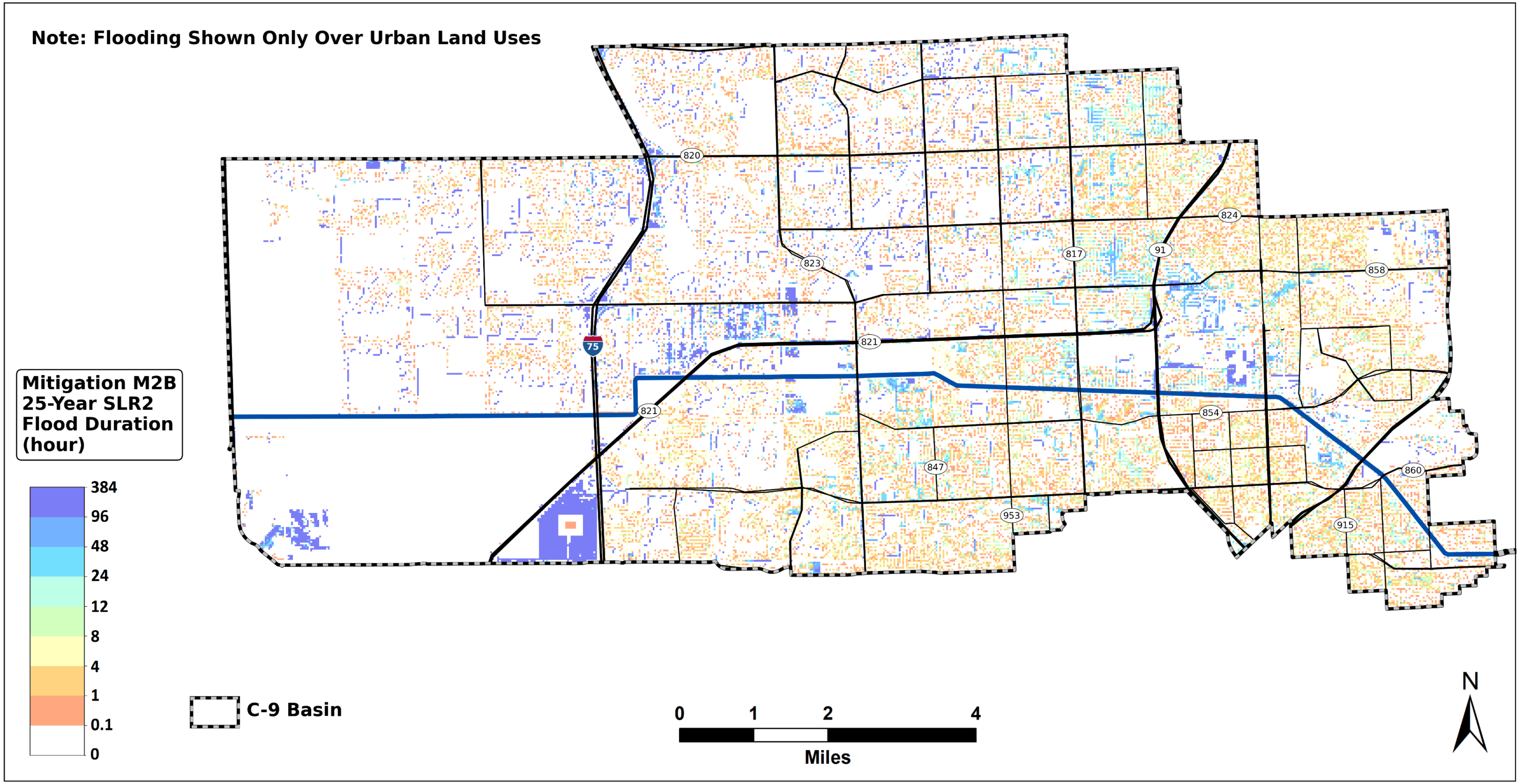


Figure 7.2-50: C-9 Watershed Flood Duration Map for the Mitigation M2B 25-Year Sea Level Rise 2 Design Storm Event in Urban Land Use Areas

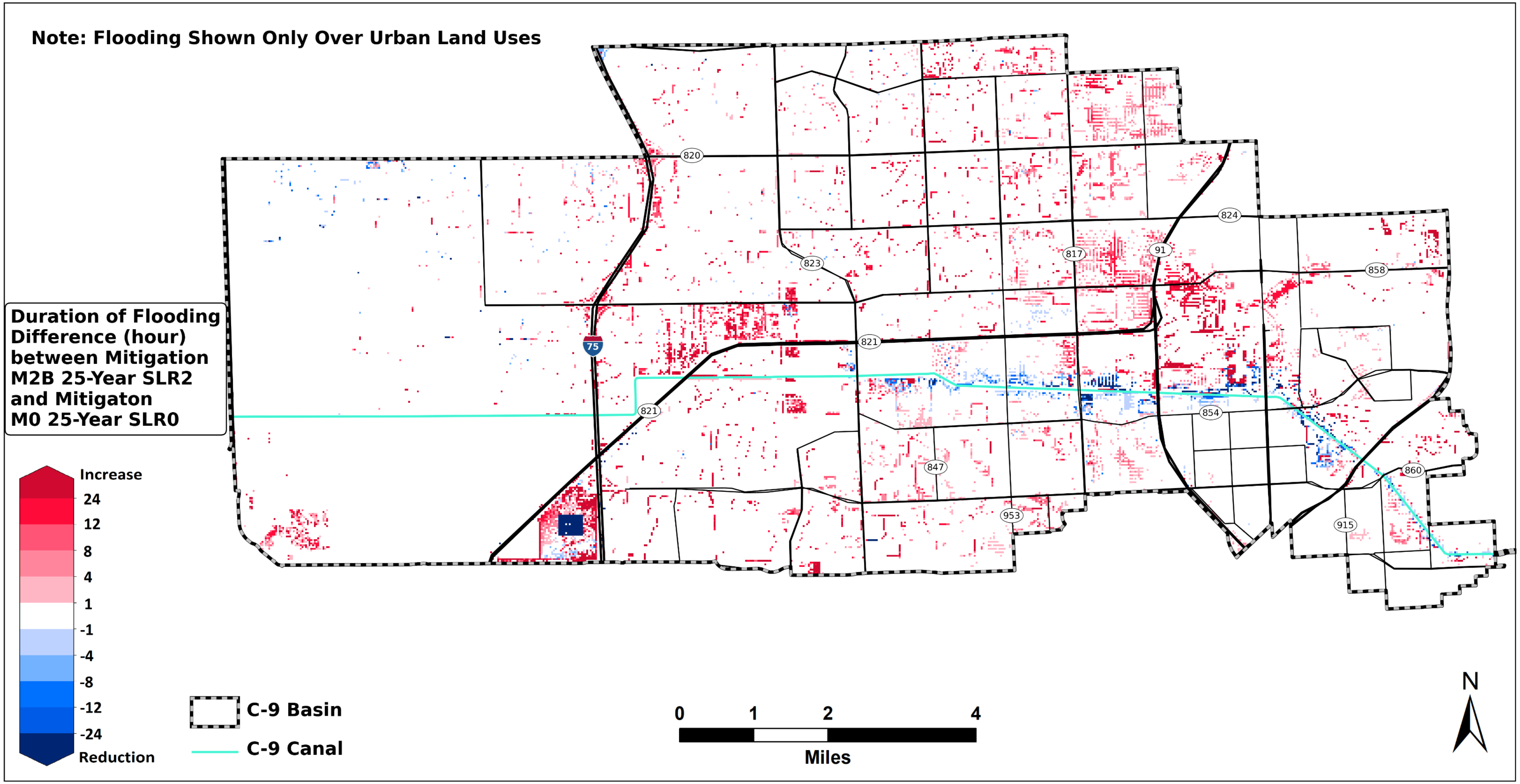


Figure 7.2-51: C-9 Watershed Flood Duration Difference Map for Mitigation M2B 25-Year Sea Level Rise 2 versus Existing Conditions (M0) 25-Year SLR0 in Urban Land Use Areas

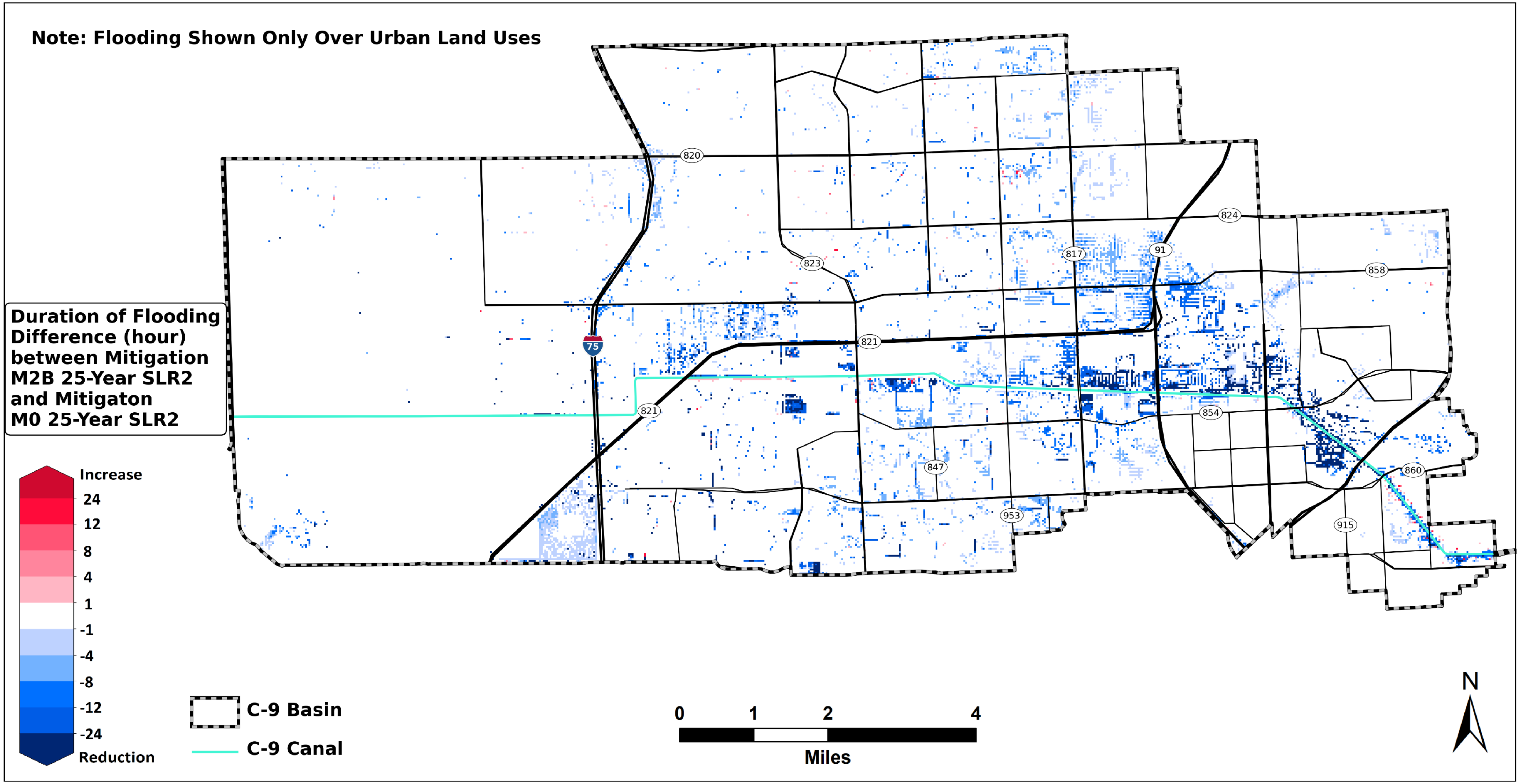


Figure 7.2-52: C-9 Watershed Flood Duration Difference Map for Mitigation M2B 25-Year Sea Level Rise 2 versus Future Conditions without mitigation (M0) 25-Year SLR2 in Urban Land Use Areas

7.2.4.3 PM #6 – Mitigation M2C

Mitigation scenario M2C is the most aggressive form of mitigation out of the three mitigation strategies analyzed in this study. Although Mitigation M2C has a very large pumping capacity of 3,550 cfs and raised canal embankments which prevents any instance of bank exceedance, the C-9 Canal still had high enough water levels to inhibit gravity-driven drainage in parts of the secondary/tertiary system, contributing to the long durations of overland flooding in urban areas as shown in **Figure 7.2-53**. Mitigation M2C was unable to achieve a PM #1 25-year SLR3 maximum water surface profile in the C-9 Canal that was equal to or lower than existing conditions 25-year SLR0 profile, with water levels on average about 0.36 ft higher along the entire canal. As such, it is no surprise that there are areas with flood durations during the 25-year SLR3 event under mitigation M2C that are greater than existing conditions, as shown in **Figure 7.2-54**. **Figure 7.2-54** shows that a significant amount of area is staying flooded longer than existing conditions, in some cases several hours or days longer, even though the corresponding flood depths may be lower or minimally different than existing conditions. Areas that are predicted to have an increase in flood duration in the PM #6 difference maps that do not correspond to significant increases in flood depths as shown in the PM #5 difference maps are most often caused by increased groundwater elevations/durations and/or decreased overland and saturated zone drainage. Sea level rise causes an increase in groundwater elevations along the coast, which is predicted to cause inland groundwater elevations to stay elevated longer. In areas where the peak groundwater is higher than topography, this predicted increase in groundwater duration translates to increased surface water durations, even if the peak groundwater elevations do not increase. Although showing mostly an increase in flood duration, **Figure 7.2-54** does show some areas of decreased flood duration along the C-9 Canal. These three areas with flood duration reduction are directly related to lower stages in the C-9 Canal, which is a function of blocking storm surge, pumping to tide, and improved drainage along the C-9 Canal.

Figure 7.2-55 presents the flooding depth differences between the 25-year SLR3 event with and without mitigation. Although the goal was to achieve flood protection equal to or better than existing conditions, it was just that, a goal. The reality of it is that sea level rise is going to bring about unprecedented changes in the form of higher tide levels to discharge against, higher antecedent water levels throughout the watershed which effectively removes storage that was once there, and areas with higher groundwater levels which not only removes storage that was once there but can actively rise above land surface further contributing to flooding. Therefore, although achieving flood protection equal to or greater than what is currently provided under existing conditions is an appropriate goal to aim for, this shouldn't limit the success or consideration of mitigation strategies. Therefore, looking at the difference between flooding under a particular mitigation strategy and the flooding that could occur if no mitigation was implemented really shows how effective the mitigation is. **Figure 7.2-55** shows a widespread reduction in flood duration ranging from 1 hour to more than 24 hours, with a large percentage of the area having more than a 24-hour reduction (localized areas with reductions of 80 hours or more). This figure highlights the areas that are most impacted or benefited by Mitigation M2C in terms of flood duration.

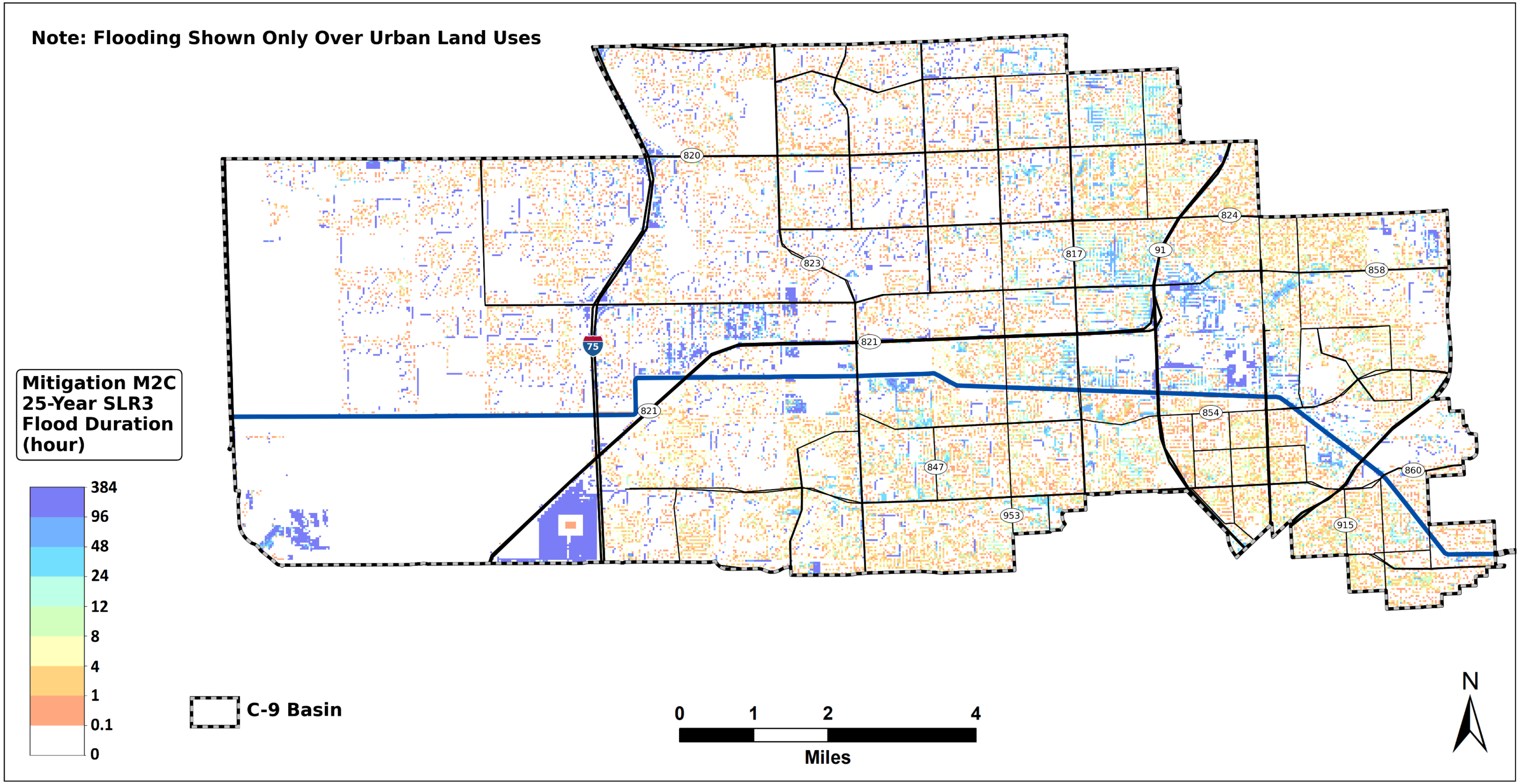


Figure 7.2-53: C-9 Watershed Flood Duration Map for the Mitigation M2C 25-Year Sea Level Rise 3 Design Storm Event in Urban Land Use Areas

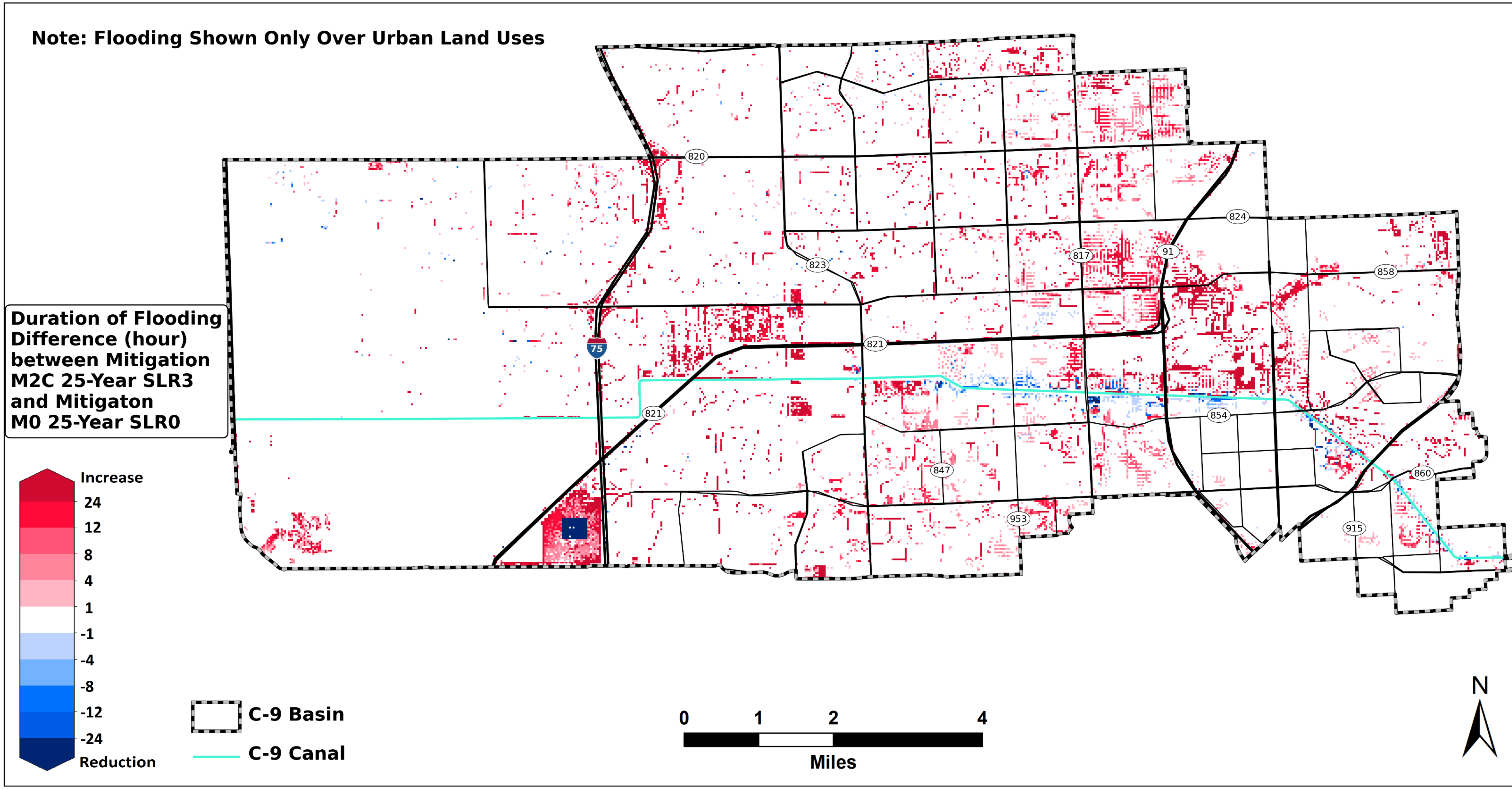


Figure 7.2-54: C-9 Watershed Flood Duration Difference Map for Mitigation M2C 25-Year Sea Level Rise 3 versus Existing Conditions (M0) 25-Year SLR0 in Urban Land Use Areas

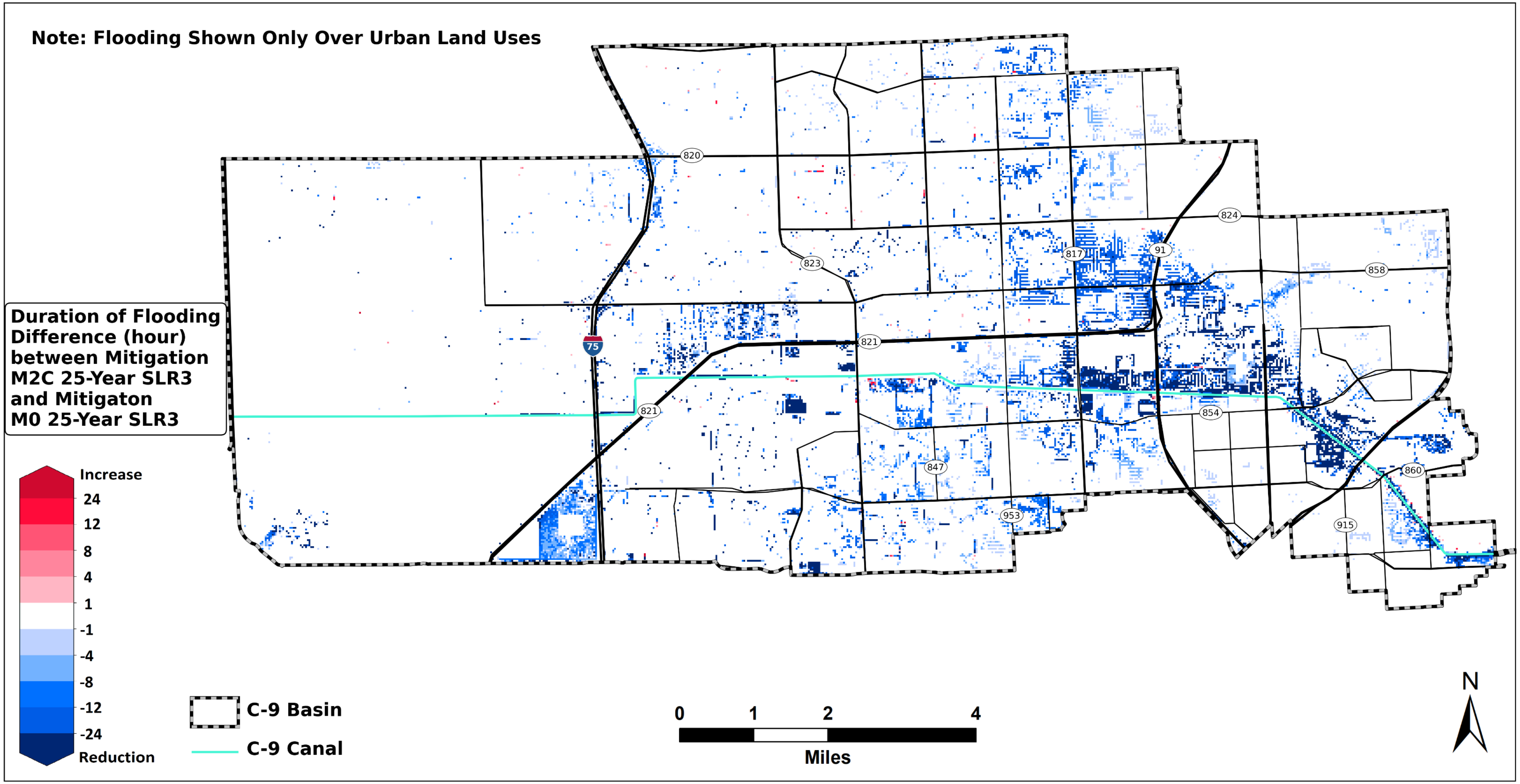


Figure 7.2-55: C-9 Watershed Flood Duration Difference Map for Mitigation M2C 25-Year Sea Level Rise 3 versus Future Conditions without mitigation (M0) 25-Year SLR3 in Urban Land Use Areas

7.2.4.4 PM #6 – Summary for C-9 Watershed

- Under all three mitigation strategies simulated, there are widespread areas that are predicted to have an increase in flood duration compared to current conditions, even if there is no corresponding increase in flood depths
    - The rise of sea level will cause an increase in groundwater elevations along the coast
    - The increase in groundwater along the coast is predicted to cause inland ground water elevations to stay elevated longer after a storm event
    - In areas where the groundwater elevation peaks higher than the land surface elevation, this increase in duration of elevated groundwater translates to increased surface water flood durations
- M2A
    - Even with Mitigation M2A, it is predicted that there will be a widespread increase in flood duration compared to existing conditions.
    - The flood duration associated with the 25-year SLR1 event under Mitigation Strategy M2A is predicted to be significantly less than the 25-year SLR1 event without mitigation
- M2B
    - Even with Mitigation M2B, it is predicted that there will be a widespread increase in flood duration compared to existing conditions.
    - The flood duration associated with the 25-year SLR2 event under Mitigation Strategy M2B is predicted to be significantly less than the 25-year SLR2 event without mitigation
- M2C
    - Even with Mitigation M2C, it is predicted that there will be a widespread increase in flood duration compared to existing conditions.
    - The flood duration associated with the 25-year SLR3 event under Mitigation Strategy M2C is predicted to be significantly less than the 25-year SLR3 event without mitigation

8 MITIGATION ACTIVITIES COST ESTIMATES

To understand the relative benefit of a mitigation activity with respect to its cost, this study developed planning level cost estimates. As discussed earlier, the mitigation activities identified through the study are conceptual and will undergo further refinement and development. At this stage of development, it is only possible to estimate rough order of magnitude costs for each of the mitigation projects. The team used the best available data and engineering judgment to quantify the costs. Unless specifically mentioned, all cost estimates provided in this study exclude the costs of real estate acquisition and operation/maintenance.

8.1 M1 Projects

As previously discussed, the M1 projects would benefit local drainage areas and are small scale efforts. Many of the M1 projects simply identified an area of concern and stated, “stormwater improvements”, or “pump station” and so forth. Given the lack of details for most of these projects, the team extrapolated data from similar projects in other locations for which specific data was available.

8.1.1 Cost Estimation Methodology

The M1 projects, presented in **Section 3.1**, provided the limited project information used in the cost estimates. Approximately 15% of the projects within the project list included cost estimates, but all included a project name or description. Approximately 10% of the projects had construction plan sets. These plan sets allowed development of a general understanding of the type of projects being considered in the C-8 and C-9 Watersheds. The team applied this understanding and the project name/description to categorize most of the projects into one of the following categories:

- Drainage Improvements (typically exfiltration systems)
- Sluice Gate Construction (operational canal controls)
- Pump Station Construction (Level 1 through 3)

Many of the M1 projects identified by partner communities address maintenance of systems. This study assumes systems are fully operational and maintained. Maintenance is critical to good flood control but is not “new” to the system and, therefore, was not included.

With the cost estimates provided in the project list, the team calculated an average project cost for the drainage improvements and sluice gate construction projects. However, the project list did not provide sufficient information to develop an average cost for the pump station projects. Furthermore, pump station projects vary in cost wildly based on the size of the facility, which necessitated developing more granular categories for pump station projects (Level 1 through 3). Based on the locations of the pump station projects and typical pump station sizes, this study defined the pump station levels and assigned each a cost proportional to the detailed S-28 pump station cost (see **Section 8.2**). The three levels are defined as follows:

- Level 1 - Neighborhood Pump Station - 1% of S-28 Costs ($1.25M)
- Level 2 – Tributary Canal Pump Station - 25% of S-28 Costs ($30M)
- Level 3 – Main Canal (C-8 or C-9) – 75% of S-28 costs ($100M)

These planning level costs apply appropriate assumptions and are in line with typical engineering projects of similar size and type. **Table 8.1-1** presents the project types, counts, average costs, and total costs. Individual project costs are also provided in **Table 8.1-2** and **Table 8.1-3**.

Table 8.1-1: M1 Projects Cost Estimate

Project Type	Project Count	Average Cost	Total Cost
Drainage Improvements	19	$ 542,000	$ 10,298,000
Sluice Gate	10	$ 108,000	$ 1,080,000
Pump Station - Level 1	1	$ 1,250,000	$ 1,250,000
Pump Station - Level 2	5	$ 30,000,000	$ 150,000,000
Pump Station - Level 3	3	$ 100,000,000	$ 300,000,000
Total Projects Cost			**$ 462,628,000**

8.1.2 Project Influence

Estimating the limits of project influence on the water surfaces elevations of various storm events required a series of assumptions. Lacking modelling results and construction plans for most projects, the team assumed a conservative estimate of 0.25 ft of water surface level improvement for all projects and storm events. Given the information provided, the general scope of the projects, and prior history with projects like these, the team believes this estimate is in line with typical drainage infrastructure projects. None of the M1 projects were large stormwater impoundment projects that would result in a significant reduction in water surface elevations. Instead, the identified projects, especially the projects with available plans, depicted somewhat modest improvements. Projects such as exfiltration systems with no positive outfall other than infiltration into the groundwater table would be expected to only provide minor improvements to the peak water surface elevations. Larger projects such as the pump station and sluice gate projects would affect larger areas but also may only produce local improvements.

In addition to water surface level improvement, this approach assumed an influence area for each project. Aerial interpretation of hydraulic flow paths and typical municipal storm sewer layout lead the development of the areas depicted in **Figure 3.1-1** and **Figure 3.1-2**. 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. This approach also limited the influence areas at logical termination points such as major culvert crossings, edges of developments, or crowns of roads. For additional clarity, the tables from **Figure 3.1-1** and **Figure 3.1-2** are provided in **Table 8.1-2** and **Table 8.1-3**.

Project types are defined as:

- DI – Drainage Improvements
- SG – sluice gate
- PS-LVL1 – pump station, level 1, estimated by projected area it serves and, therefore, pump size
- PS-LVL2 – pump station, level 2, estimated by projected area it serves and, therefore, pump size
- PS-LVL3 – pump station, level 3, estimated by projected area it serves and, therefore, pump size

Table 8.1-2: M1 Projects within C-8 Watershed

Project ID	Project Name	Project Location	Project Type	Cost	Influence Area (AC)
0	105 Street Drainage Pump Station	10050 NE 2nd Avenue	PS-LVL1	$1,250,000	8.35
2	NW 146 St and NW 7 Ave (east end of street)	NW 146 Street and NW 7 Avenue (east end of street)	DI	$542,000	4.50
5	NE 154 Street and NE 5 Court	NE 154 Street and NE 5 Court	DI	$182,000	17.31
6	NW 159 Street Stormwater Drainage Project	5400 NW 159 ST	DI	$542,000	13.95
7	NW 163 Street Drainage Improvement Project	5501 NW 163 ST	DI	$542,000	16.58
9	Drainage Improvements NW 170 St west of 22 Ave	NW 170 Street and NW 22 Avenue	DI	$542,000	18.09
33	Potential Future Pump	Lat: 25.905942, Long: -80.197007	PS-LVL3	$100,000,000	770.19
34	Potential Future Pump	Lat: 25.915311, Long: -80.221486	PS-LVL3	$100,000,000	1371.88
35	Potential Future Pump	Lat: 25.916061, Long: -80.227938	PS-LVL2	$30,000,000	227.21

Table 8.1-3: M1 Projects within C-9 Watershed

Project ID	Project Name	Project Location	Project Type	Cost	Influence Area (AC)
8	NW 42 Avenue and NW 167 Terrace	16760 NW 42 AVE	DI	$542,000	6.40
10	NE 167 Street and NE 14 Avenue	NE 167 Street and NE 14 Avenue	DI	$542,000	7.56
14	NW 191 Street-196 Terrace	18605 NW 27 Avenue	DI	$350,000	7.90
16	NW 195 Street West of NW 12 Avenue	18605 NW 27 Avenue	DI	$542,000	7.69
17	Leslie Estates #4 Road and Drainage Improvements	Leslie Estates #4	DI	$1,500,000	3.69
18	40 NE 197 Street NE 17 Avenue Drainage Improvements	NE 197 Terrace and NE 17 Avenue	DI	$620,000	12.08
19	20021 to 20081 NW 13 Ave	20021-20081 NW 13 Avenue	DI	$542,000	3.28
20	20601 NW 44 Court	20601 NW 44 Court	DI	$542,000	5.06
22	Emergency Sluice Gate into the C-9 Canal	Lat: 25.964469, Long: -80.334142	SG	$120,000	53.67
24	Emergency Discharge Sluice Gate	Lat: 25.957094, Long: -80.407552	SG	$120,000	1,606.00
26	NW 178 ST AND NW 82 AVE	Lat: 25.935552, Long: -80.335089	DI	$542,000	6.99
27	Drainage Improvements Multiple Sites	Lat: 25.948436, Long: -80.278625	DI	$542,000	3.66
28	NW 57 PL FROM NW 194 ST TO NW 198 TR	Lat: 25.949321, Long: -80.295854	DI	$542,000	4.31
29	Sluice Gate at the S-1 Pump Station	Lat: 25.973091, Long: -80.246634	SG	$100,000	51.77
30	Interconnect at County Club Ranches	Lat: 25.971419, Long: -80.311584	SG	$75,000	337.09
36	Potential Future Pump	Lat: 25.960342 Long: -80.2293	PS-LVL3	$100,000,000	540.35
37	Potential Future Pump	Lat: 25.960937, Long: -80.228514	PS-LVL2	$30,000,000	444.27
38	Potential Future Pump	Lat: 25.961627, Long: -80.24617	PS-LVL2	$30,000,000	218.78
39	Potential Future Pump	Lat: 25.961127, Long: -80.247645	PS-LVL2	$30,000,000	301.61
40	Potential Future Pump	Lat: 25.961793, Long: -80.265468	PS-LVL2	$30,000,000	233.07
41	Potential Future Control Structure	Lat: 25.963727, Long: -80.324448	SG	$108,000	306.18

Project ID	Project Name	Project Location	Project Type	Cost	Influence Area (AC)
42	Potential Future Control Structure	Lat: 25.963875, Long: -80.311213	SG	$108,000	74.14
43	Potential Future Control Structure	Lat: 25.964084, Long: -80.294765	SG	$108,000	103.66
54	Encantada Sluice Gate	Lat: 25.996313, Long: -80.39266	SG	$108,000	289.71
55	Harbour Lake Estates Sluice Gate	Lat: 25.989761, Long: -80.39191	SG	$108,000	309.30
57	Lakeside Key Storm Drainage System	Lat: 25.996111, Long: -80.273469	DI	$100,000	6.97
58	Pembroke Pines Three Basin Interconnect	Lat: 25.99511, Long: -80.312098	SG	$125,000	54.95
61	Pembroke Park SW 52nd Avenue Drainage	Lat: 25.981743, Long: -80.195122	DI	$500,000	17.22
69	NE 10th Avenue/NE 159th Street and NMB Boulevard	NE 10th Avenue/NE 159th Street and NMB Boulevard	DI	$542,000	5.91

8.2 **M2 Projects** (NGVD29 to NAVD88 Conversion = -1.57 ft)

8.2.1 Cost Estimation Methodology

Cost estimates for the M2 projects (M2A, M2B, and M2C) are based largely on prior cost estimates from SFWMD. SFWMD provided cost estimates from the Coastal Resiliency Program which were updated to represent the improvement strategies identified by the modeling team. This mainly involved modifying the pump and generator size, spillway elevation, tie-back levy elevation, and associated costs. Specifically, SFWMD provided the structure replacement costs with a 5 ft increase in spillway elevation as shown in **Figure F- 2**. Taylor developed all other pump station costs based on the cost estimates provided by SFWMD (Vjiay Mishra), as part of the Coastal Resiliency Program (SFWMD, 2022). Furthermore, Taylor proportionally modified (scaled up or down) the pump system items (pumps, generators, and associated control systems/structures) to develop the costs for the range of pump sizes used in the M2 projects. Based on the Coastal Resiliency Program cost estimates, Taylor used 15% of the construction costs for design and construction management. Please see **Table F- 1** through **Table F- 3** for the M2 projects cost estimates with references depicting the source of the item costs. In addition, Taylor developed the costs for expanding surface storage of floodwaters assuming a total of 500 acres of land is available across both watersheds combined, or 250 acres in each of the C—8 and C-9 Watersheds. Taylor also assumed each storage area would provide 1 ft of storage depth with the ultimate goal of providing 500 ac-ft of storage within the watersheds. This estimate excluded the real estate costs of these storage areas. While some of the areas identified are SFWMD or FDEP-owned, most would require purchasing the land or other intergovernmental agreements. These cost estimates are very general in nature and cannot increase in specificity until a project location and size is determined. Each site will have its unique challenges that will greatly influence the construction costs.

To develop these general costs, the team used the FDOT Historical Costs Database and considered the following factors:

- Clearing
- Erosion Control
- Excavation
- Final Grade and Sod
- Bonds and Insurance 1.5%
- Profit 10%
- Overhead 6%
- Contingency 30%

Taylor also prepared costs for canal improvements including raising the canal banks to elevation 7.5 ft for M2B and M2C and widening the C-8 and C-9 Canals for M2C. **Table 8.2-1** through **Table 8.2-6** depict the overall cost estimates for the M2A, M2B, and M2C projects.

Table 8.2-1: Mitigation Project M2A Cost Estimate For C-8 Watershed

Pump Station		
Structure Replacement	$	19,056,898
Forward Pump (1550 cfs)	$	79,639,466
Forward Pump Backup Generator Facility	$	9,085,601
Structure Tie Back (Flood Barrier)	$	2,987,463
Design & Construction Management	$	16,615,414
Real Estate	$	7,000,000
Total Pump Station Cost	**$**	**134,384,842**
Storage		
Distributed Storage (~250 Ac-Ft)	$	38,859,600
Design & Construction Management	$	5,828,940
Total Storage Cost	**$**	**44,688,540**
Total Cost of Mitigation M2A for C-8 Watershed	**$**	**179,073,382**

Table 8.2-2: Mitigation Project M2A Cost Estimate For C-9 Watershed

Pump Station		
Structure Replacement	$	19,056,898
Forward Pump (1550 cfs)	$	84,291,017
Forward Pump Backup Generator Facility	$	9,618,145
Structure Tie Back (Flood Barrier)	$	2,769,122
Design & Construction Management	$	17,360,277
Real Estate	$	16,000,000
Total Pump Station Cost	**$**	**149,095,459**
Storage		
Distributed Storage (~250 Ac-Ft)	$	38,859,600
Design & Construction Management	$	5,828,940
Total Storage Cost	**$**	**44,688,540**
Total Cost of Mitigation M2A for C-9 Watershed	**$**	**193,783,999**

Table 8.2-3: Mitigation Project M2B Cost Estimate For C-8 Watershed

Pump Station		
Structure Replacement	$	19,056,898
Forward Pump (2550 cfs)	$	107,001,675
Forward Pump Backup Generator Facility	$	11,440,141
Structure Tie Back (Flood Barrier)	$	2,987,463
Design & Construction Management	$	21,072,927
Real Estate	$	7,000,000
Total Pump Station Cost	**$**	**168,559,105**
Storage		
Distributed Storage (~250 Ac-Ft)	$	38,859,600
Design & Construction Management	$	5,828,940
Total Storage Cost	**$**	**44,688,540**
Canal Improvements		
Raise Canal Banks (to 7.5 ft NGVD29)	$	12,412,542
Design & Construction Management	$	1,861,881
Total Canal Improvements Cost	**$**	**14,274,423**
Total Cost of Mitigation M2B for C-8 Watershed	**$**	**227,522,068**

Table 8.2-4: Mitigation Project M2B Cost Estimate For C-9 Watershed

Pump Station		
Structure Replacement	$	19,056,898
Forward Pump (2550 cfs)	$	111,668,639
Forward Pump Backup Generator Facility	$	11,918,924
Structure Tie Back (Flood Barrier)	$	2,769,122
Design & Construction Management	$	21,812,037
Real Estate	$	16,000,000
Total Pump Station Cost	**$**	**183,225,620**
Storage		
Distributed Storage (~250 Ac-Ft)	$	38,859,600
Design & Construction Management	$	5,828,940
Total Storage Cost	**$**	**44,688,540**
Canal Improvements		
Raise Canal Banks (to 7.5 ft)	$	7,118,542
Design & Construction Management	$	1,067,781
Total Canal Improvements Cost	**$**	**8,186,323**
Total Cost of Mitigation M2B for C-9 Watershed	**$**	**236,100,483**

Table 8.2-5: Mitigation Project M2C Cost Estimate For C-8 Watershed

Pump Station		
Structure Replacement	$	19,056,898
Forward Pump (3550 cfs)	$	134,481,716
Forward Pump Backup Generator Facility	$	13,791,922
Structure Tie Back (Flood Barrier)	$	2,987,463
Design & Construction Management	$	25,547,700
Real Estate	$	7,000,000
Total Pump Station Cost	**$**	**202,865,699**
Storage		
Distributed Storage (~250 Ac-Ft)	$	38,859,600
Design & Construction Management	$	5,828,940
Total Storage Cost	**$**	**44,688,540**
Canal Improvements		
Raise Canal Banks (to 7.5 ft NGVD29)	$	12,412,542
Widen Canal (approx. 20,000 linear ft by 100 ft)	$	31,618,782
Design & Construction Management	$	6,604,699
Total Canal Improvements Cost	**$**	**50,636,022**
Total Cost of Mitigation M2C for C-8 Watershed	**$**	**298,190,261**

Table 8.2-6: Mitigation Project M2C Cost Estimate For C-9 Watershed

Pump Station		
Structure Replacement	$	19,056,898
Forward Pump (3550 cfs)	$	139,005,527
Forward Pump Backup Generator Facility	$	14,217,365
Structure Tie Back (Flood Barrier)	$	2,769,122
Design & Construction Management	$	26,257,337
Real Estate	$	16,000,000
Total Pump Station Cost	**$**	**217,306,249**
Storage		
Distributed Storage (~250 Ac-Ft)	$	38,859,600
Design & Construction Management	$	5,828,940
Total Storage Cost	**$**	**44,688,540**
Canal Improvements		
Raise Canal Banks (to 7.5 ft NGVD29)	$	7,118,542
Widen Canal (approx. 79,000 linear ft by ~75 ft)	$	107,725,296
Design & Construction Management	$	17,226,576
Total Canal Improvements Cost	**$**	**132,070,414**
Total C-9 Cost	**$**	**394,065,203**

8.3 M3 Projects

8.3.1 Cost Estimation Methodology

This study followed the approach applied by Deltares (2018) to estimate the cost of raising buildings and roads. For buildings, Deltares used estimates by FEMA (2019) and Aerts et al (2013) to estimate a unit cost of raising a residential building by 2 to 6 ft. This unit cost is very general and only provides a gross estimate of what the possible costs could be. To identify the number of buildings that need to be elevated, the team used MIKE SHE model results for existing conditions and added 1, 2, and 3 ft, and added the number of buildings in each flood layer.

Estimates to elevate roads follow a similar approach and use a unit cost per ft of road based on road costs values provided by Miami-Dade. The values provided by Miami-Dade included an average for elevating a 2-lane road in 50 ft of right-of-way. This study applies the average of elevating roads 1, 2, and 3 ft for a unit cost of $673, $892, and $1,111 per linear foot, respectively. **Figure F- 1** depicts the source email for the costs and the conversion from 2017 dollars to 2021. The M3 Cost Estimates are presented in **Table 8.3-1** through **Table 8.3-6**. Please note that the units EA and LF stand for “each” and “linear feet”, respectively.

Table 8.3-1: C-8 Watershed Cost Estimate of Mitigation M3 (1 ft)

Type	Unit Costs	Units	Value	Total Costs
Buildings	$ 55,386	EA	1,648	$ 91,300,000
Roads	$ 673	LF	130,416	$ 87,800,000
			Total	$ 179,100,000

Table 8.3-2: C-8 Watershed Cost Estimate of Mitigation M3 (2 ft)

Type	Unit Costs	Units	Value	Total Costs
Buildings	$ 55,386	EA	2,255	$ 124,900,000
Roads	$ 892	LF	175,296	$ 156,300,000
			Total	$ 281,200,000

Table 8.3-3: C-8 Watershed Cost Estimate of Mitigation M3 (3 ft)

Type	Unit Costs	Units	Value	Total Costs
Buildings	$ 55,386	EA	3,193	$ 176,800,000
Roads	$ 1,111	LF	232,848	$ 258,700,000
			Total	$ 435,500,000

Table 8.3-4: C-9 Watershed Cost Estimate of Mitigation M3 (1 ft)

Type	Unit Costs	Units	Value	Total Costs
Buildings	$ 55,386	EA	1,064	$ 58,900,000
Roads	$ 673	LF	304,656	$ 205,200,000
			Total	$ 264,100,000

Table 8.3-5: C-9 Watershed Cost Estimate of Mitigation M3 (2 ft)

Type	Unit Costs	Units	Value	Total Costs
Buildings	$ 55,386	EA	1,225	$ 67,800,000
Roads	$ 892	LF	340,560	$ 303,700,000
			Total	$ 371,500,000

Table 8.3-6: C-9 Watershed Cost Estimate of Mitigation M3 (3 ft)

Type	Unit Costs	Units	Value	Total Costs
Buildings	$ 55,386	EA	1,616	$ 89,500,000
Roads	$ 1,111	LF	413,952	$ 459,900,000
			Total	$ 549,400,000

9 CONCLUSIONS

The Phase 1 Assessment assigned FPLOS ratings to the C-8 and C-9 Watershed, which describes 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 2 FPLOS Assessment, a level of service rating is not assigned, as the overall level of service watershed-wide remains largely unchanged. Therefore, instead of pointing out similar deficiencies of the system, this Phase 2 Assessment identifies improvements and compares the different mitigation strategies against each other and against both existing conditions and future conditions without mitigation.

M1 Mitigation Strategies

The M1 mitigation strategies identified many local scale projects that had limited detailed information. This project developed an approach to assign flood reduction benefits and assign an area of influence for each of the M1 projects. These analytic solutions have been developed for future tasks, including expected annual damage calculations. Since the M1 projects are not at a scale that can be incorporated into the existing hydrologic and hydraulic model, there are no modeling results that can be compared to PM metrics. The value of the analytic solutions will be shown in the EAD calculations.

M2 Mitigation Strategies

The M2 mitigation strategies were modeled and compared to FPLOS PM metrics. For the C-8 and C-9 Watersheds, three M2 mitigation strategies were configured and evaluated to try and achieve a simulated level of service equal to or greater than the existing conditions 25-year SLR0 scenario for the 25-year SLR1, SLR2, and SLR3.

- Mitigation M2A had a goal of achieving a level of service equal to or greater than the existing conditions 25-year SLR0 event for the 25-year SLR1 scenario and was configured with tidal structure improvements and tieback levees/floodwalls to block storm surge, 1,550 cfs forward pump station, and 500 ac-ft of distributed water storage combined across both watersheds.
- Mitigation M2B had a goal of achieving a level of service equal to or greater than the existing conditions 25-year SLR0 event for the 25-year SLR2 scenario and was configured with tidal structure improvements and tieback levees/floodwalls to block storm surge, 2,550 cfs forward pump station, canal improvements including raised bank elevations and improved canal conveyance capacity through geometry changes (such as dredging and re-grading), and 500 ac-ft of distributed water storage combined across both watersheds.
- Mitigation M2C had a goal of achieving a level of service equal to or greater than the existing conditions 25-year SLR0 event for the 25-year SLR3 scenario and was configured with tidal structure improvements and tieback levees/floodwalls to block storm surge, 3,550 cfs forward pump station, canal improvements including raised bank elevations, improved geometry, and canal widening, and 500 ac-ft of distributed water storage combined across both watersheds.
- Both Mitigation M2B and M2C include an internal drainage system that was needed to allow watershed drainage to the C-8 and C-9 Canals due to the raised banks, so it can be considered a sub-project to the proposed canal improvements.

M3 Mitigation Strategies

The M3 mitigation strategies (raising all the roads and buildings within a watershed) are only planning in nature and no analytic or modeling solutions are required. The M3 strategy will be applied in the EAD calculations to show the planning benefit of raising houses and roads.

The following subsections summarize the findings from each of the three M2 mitigation strategies evaluated in this FPLOS study for the C-8 and C-9 Watersheds.

9.1 C-8 Watershed

The C-8 Watershed was predicted to have mostly less than a 5-year LOS rating in the Phase 1 Study, due to high canal stages, several instances of bank exceedance, and flooding of urban areas. To address these level of service deficiencies, the team developed three mitigation strategies, each progressively more aggressive to overcome the increase in sea level rise. To address the SLR1 deficiencies, Mitigation M2A was developed with the primary intention of blocking storm surge and pumping flood water to tide, while also storing a limited quantity of flood water. Together, the components of Mitigation M2A are predicted to reduce peak stages in the C-8 Canal across all sea level rise scenarios, essentially acting to remove the effects of at least 1 ft of sea level rise from each storm event simulated. The goal of Mitigation M2A was to achieve a LOS during the 25-year SLR1 event that is equal to or greater than the LOS provided by existing infrastructure during the 25-year SLR0 event. Although close, typically within less than 0.1 ft with an average difference of just 0.03 ft, Mitigation M2A was unable to achieve simulated peak canal stages during the 25-year SLR1 event that were equal to or lower than the 25-year existing conditions peak stages along the entire canal length. In some areas, the simulated peak stages were reduced below existing conditions and contribute to the decreased flooding of urban areas that were predicted in the PM #5 analysis. However, there are also several small areas with increased flooding, although minimally larger. These areas of increase are predicted to occur in low-lying areas and as simulated are a result of increased groundwater elevations due to sea level rise. When compared to the 25-year SLR1 event without mitigation, the significance of this potential mitigation scenario is shown by the predicted reduction in peak C-8 Canal stages, with reductions ranging from 0.25 ft to 0.9 ft, with an average reduction of 0.47 ft. This predicted reduction in peak C-8 Canal stages largely contributed to the widespread reduction in flooding shown in the PM #5 analysis ranging from 0.1 ft to more than 0.5 ft, with localized values as high as 1 ft.

To address the SLR2 deficiencies, Mitigation M2B was developed with the primary intention of blocking storm surge, pumping flood water to tide, and preventing bank exceedances in the C-8 Canal, while also storing a limited quantity of flood water. Together, the components of Mitigation M2B are predicted to reduce peak stages in the C-8 Canal across all sea level rise scenarios, essentially acting to remove the effects of at least 1 ft of sea level rise from each storm event simulated. The goal of Mitigation M2B was to achieve a LOS during the 25-year SLR2 event that is equal to or greater than the existing conditions 25-year SLR0 event LOS. Although close, within less than 0.30 ft with an average difference of just 0.11 ft, Mitigation M2B was unable to achieve simulated peak canal stages during the 25-year SLR2 event that were equal to or lower than the 25-year existing conditions peak stages along the entire canal length. As such, it is not a surprise that there are areas during the simulated 25-year SLR2 event that are predicted to have a higher level of flooding compared to existing conditions. However, many of these areas are located in low-lying parts of the watershed and are a result of increased groundwater elevations due to sea level rise. There is also a significant amount of area that has less flooding during the Mitigation M2B

25-year SLR2 event than under the 25-year SLR0 event without mitigation, which is a direct contribution of raising the canal banks and the improvements to the tidal structure. When compared to the 25-year SLR2 event without mitigation, the significance of this potential mitigation scenario is shown by the predicted reduction in peak C-8 Canal stages, with reductions ranging from 0.50 ft to 1.9 ft, with an average reduction of 0.92 ft. This predicted reduction in peak C-8 Canal stages largely contributed to the widespread reduction in flooding shown in the PM #5 analysis ranging from 0.1 ft to more than 0.5 ft, with localized values as high as 2 ft.

To address the SLR3 deficiencies, Mitigation M2C was developed with the primary intention of blocking storm surge, pumping flood water to tide, preventing bank exceedances in the C-8 Canal, and improving canal conveyance capacity, while also storing a limited quantity of flood water. Together, the components of Mitigation M2C are predicted to reduce peak stages in the C-8 Canal across all sea level rise scenarios, essentially acting to remove the effects of at least 1 ft of sea level rise from each storm event simulated, and in some instances as much as 2 ft. The goal of Mitigation M2C was to achieve a LOS during the 25-year SLR3 event that is equal to or greater than the existing conditions 25-year SLR0 event LOS. Mitigation M2C was unable to achieve simulated peak canal stages during the 25-year SLR3 event that were equal to or lower than the 25-year existing conditions peak stages at any point along the entire canal length. However, even with elevated C-8 Canal stages, it is predicted that there would be areas area along the C-8 Canal that have less flooding during the Mitigation M2C 25-year SLR3 event than under the 25-year SLR0 event without mitigation. Mitigation M2C is predicted to reduce the 25-year SLR3 maximum stages in the C-8 Canal to a level between the simulated maximum elevations of the 25-year existing conditions SLR0 and SLR1 scenarios. When compared to the 25-year SLR3 event without mitigation, the significance of this potential mitigation scenario is shown by the predicted reduction in peak C-8 Canal stages, with reductions ranging from 0.70 ft to 1.9 ft, with an average reduction of 1.2 ft. This predicted reduction in peak C-8 Canal stages largely contributes to the widespread reduction in flooding predicted in the PM #5 analysis, ranging from 0.1 ft to more than 0.5 ft, with localized values as high as 3 ft.

For all three mitigation strategies evaluated, some of the increased flooding is related to higher groundwater elevations. As sea level rise increases, the antecedent groundwater elevations are predicted to increase. In some areas, the maximum groundwater elevation is higher than the land surface elevation, which results in an increase in flood depths that are difficult and potentially infeasible to fully mitigate. Although the goal was to achieve flood protection equal to or better than existing conditions, it was just that, a goal. The reality of it is that sea level rise is going to bring about unprecedented changes in the form of higher tide levels to discharge against, higher antecedent water levels throughout the watershed which effectively removes storage that was once there, and areas with higher groundwater levels which not only removes storage that was once there but can actively rise above land surface further contributing to flooding. Therefore, although achieving flood protection equal to or greater than what is currently provided under existing conditions is a great goal to aim for, this shouldn't limit the success or consideration of mitigation strategies.

For all three mitigation strategies evaluated, there are widespread areas that are predicted to have an increase in flood duration that do not correspond to increases in flood depths. This is most often caused by increased groundwater elevations or an increased duration of elevated groundwater. Sea level rise causes an increase in groundwater elevations along the coast, which is predicted to cause inland groundwater elevations to stay elevated longer. In areas where the peak groundwater is higher than the topography, this predicted increase in groundwater duration translates to increased surface water durations, even if the peak groundwater elevations do not increase. Compared to existing conditions, there is an overall increase in flood duration throughout the C-9 Watershed, which is heavily dependent on groundwater. However, compared to future sea level rise without mitigation, Mitigation M2A, M2B, and M2C is predicted to have widespread reduction in flood duration. Mitigation M2A is predicted to have a widespread reduction in flood duration in the C-9 Watershed ranging from 1 hour to more than 24 hours. Mitigation M2B is predicted to have a widespread reduction in flood duration in the C-9 Watershed ranging from 1 hour to more than 24 hours, with a majority of the area having more than a 12-hour reduction and localized areas with reductions of more than 60 hours. Mitigation M2C is predicted to have a widespread reduction in flood duration in the C-8 Watershed with the majority of the area having more than a 24-hour reduction and localized areas with reductions of more than 80 hours.

9.2 C-9 Watershed

The C-9 Watershed was predicted to have a 10-year LOS rating in the Phase 1 Study for SLR1 and 5-year LOS rating for SLR2 and SLR3, due to a combination of high canal stages, instances of bank exceedance, and flooding of urban areas. To address these level of service deficiencies, the team developed three mitigation strategies, each progressively more aggressive to overcome the increase in sea level rise. To address the SLR1 deficiencies, Mitigation M2A was developed with the primary intention of blocking storm surge and pumping flood water to tide, while also storing a limited quantity of flood water. Together, the components of Mitigation M2A are predicted to reduce peak stages in the C-9 Canal across all sea level rise scenarios, essentially acting to remove the effects of at least 1 ft of sea level rise from each storm event simulated. The goal of Mitigation M2A was to achieve a LOS during the 25-year SLR1 event that is equal to or greater than the existing conditions 25-year SLR0 event LOS. Mitigation M2A is predicted to achieve a maximum water surface profile that is equal to or lower than existing conditions SLR0 for all rainfall events simulated. Although the simulated 25-year and 100-year maximum water levels in the C-9 Canal under Mitigation M2A are lower than the existing conditions SLR0 maximum water levels, there were still some instances of out of bank exceedance. However, as these predicted bank exceedances occur with a lower maximum canal elevation, the overall flood protection provided by the C-9 infrastructure under Mitigation M2A is higher. There are also several small areas with increased flooding, although minimally larger. These areas of increase are predicted to occur in low-lying areas and are a result of increased groundwater elevations due to sea level rise. Although Mitigation M2A helped the C-9 Watershed achieve peak water levels in the C-9 Canal that were lower than existing conditions for all sea level rise 1 storm events, it is also important to understand the significance of this potential mitigation scenario compared to what is predicted to occur with future sea level rise without mitigation. Mitigation M2A is predicted to achieve peak stages in the C-9 Canal that are as much as 0.84 ft lower than what is predicted without mitigation, with an average reduction along the entire canal by 0.45 ft. For SLR1, this reduction in peak canal stages is predicted to have less effect on watershed-wide flooding than it does for the C-8 Watershed, largely due to the higher topography in the C-9 Watershed and less bank exceedances. Under SLR2 and SLR3, the predicted reduction in peak canal stages has a more pronounced effect on flooding.

To address the SLR2 deficiencies, Mitigation M2B was developed with the primary intention of blocking storm surge, pumping flood water to tide, and preventing bank exceedances in the C-9 Canal, while also storing a limited quantity of flood water. Together, the components of Mitigation M2B are predicted to reduce peak stages in the C-9 Canal across all sea level rise scenarios, essentially acting to remove the effects of at least 1 ft of sea level rise from each storm event simulated. The goal of Mitigation M2B was to achieve a LOS during the 25-year SLR2 event that is equal to or greater than the existing conditions 25-year SLR0 event LOS. Although close, within less than 0.30 ft with an average difference of just 0.12 ft, Mitigation M2B was unable to achieve simulated peak canal stages during the 25-year SLR2 event that were equal to or lower than the 25-year existing conditions peak stages along the entire canal length. Although there are no bank exceedances under Mitigation M2B due raising the C-9 Canal embankments in the model simulation, it is still important to aim for peak stages in the C-9 Canal that are equal to or lower than current conditions to ensure gravity-drainage isn’t inhibited. Although predicted peak C-9 Canal stages are higher in some locations than existing conditions, it is predicted that there would be a significant amount of area along the C-9 Canal that has less flooding during the 25-year SLR2 event than under the 25-year existing conditions SLR0 event, which is a direct contribution of raising the canal banks. However, without the other mitigation projects that keep the C-9 Canal from getting too high, these areas would likely not see this reduction in flooding as they would not be able to actively drain by gravity. There are several areas with increased flooding, although minimally larger. There are areas during the simulated 25-year SLR2 event that are predicted to have a higher level of flooding compared to existing conditions. However, many of these areas are located in low-lying parts of the watershed and are a result of increased groundwater elevations due to sea level rise. When compared to the 25-year SLR2 event without mitigation, the significance of this potential mitigation scenario is shown by the predicted reduction in peak C-9 Canal stages, with reductions ranging from 0.20 ft to 1.4 ft, with an average reduction of 0.56 ft. This predicted reduction in peak C-9 Canal stages largely contributed to the widespread reduction in flooding shown in the PM #5 analysis ranging from 0.1 ft to more than 0.5 ft, with localized values as high as 2 ft.

To address the SLR3 deficiencies, Mitigation M2C was developed with the primary intention of blocking storm surge, pumping flood water to tide, preventing bank exceedances in the C-9 Canal, and improving canal conveyance capacity, while also storing a limited quantity of flood water. Together, the components of Mitigation M2C are predicted to reduce peak stages in the C-9 Canal across all sea level rise scenarios, essentially acting to remove the effects of at least 1 ft of sea level rise from each storm event simulated, and in some instances as much as 2 ft. The goal of Mitigation M2C was to achieve a LOS during the 25-year SLR3 event that is equal to or greater than the existing conditions 25-year SLR0 event LOS. Mitigation M2C was unable to achieve simulated peak canal stages during the 25-year SLR3 event that were equal to or lower than the 25-year existing conditions peak stages at any point along the entire canal length. However, even with C-9 Canal stages higher than predicted under existing conditions, it is predicted that there would be areas along the C-9 Canal that have less flooding during a 25-year SLR3 event due to components of Mitigation M2C such as preventing bank exceedances. Mitigation M2C is predicted to reduce the 25-year SLR3 maximum stages in the C-9 Canal to a level around the simulated maximum elevations of the 25-year SLR1 without mitigation scenario, which is a significant improvement. When compared to the 25-year SLR3 event without mitigation, the significance of this potential mitigation scenario is shown by the predicted reduction in peak C-9 Canal stages, with reductions ranging from 0.10 ft to 1.9 ft, with an average reduction of 0.67 ft. This predicted reduction in peak C-9 Canal stages largely contributes to the widespread reduction in flooding predicted in the PM #5 analysis, ranging from 0.1 ft to more than 0.5 ft, with localized values as high as 2 ft.

For all three mitigation strategies evaluated, some of the increased flooding is related to higher groundwater elevations. As sea level rise increases, the antecedent groundwater elevations are predicted to increase. In some areas, the maximum groundwater elevation is higher than the land surface elevation, which results in an increase in flood depths that are difficult and potentially infeasible to fully mitigate.

Although the goal was to achieve flood protection equal to or better than existing conditions, it was just that, a goal. The reality of it is that sea level rise is going to bring about unprecedented changes in the form of higher tide levels to discharge against, higher antecedent water levels throughout the watershed which effectively removes storage that was once there, and areas with higher groundwater levels which not only removes storage that was once there but can actively rise above land surface further contributing to flooding. Therefore, although achieving flood protection equal to or greater than what is currently provided under existing conditions is a great goal to aim for, this shouldn't limit the success or consideration of mitigation strategies.

For all three mitigation strategies evaluated, there are widespread areas that are predicted to have an increase in flood duration that do not correspond to increases in flood depths. This is most often caused by increased groundwater elevations or an increased duration of elevated groundwater. Sea level rise causes an increase in groundwater elevations along the coast, which is predicted to cause inland groundwater elevations to stay elevated longer. In areas where the peak groundwater is higher than the topography, this predicted increase in groundwater duration translates to increased surface water durations, even if the peak groundwater elevations do not increase. Compared to existing conditions, there is an overall increase in flood duration throughout the C-9 Watershed, which is heavily dependent on groundwater. However, compared to future sea level rise without mitigation, Mitigation M2A, M2B, and M2C is predicted to have widespread reduction in flood duration. Mitigation M2A is predicted to have a widespread reduction in flood duration in the C-9 Watershed ranging from 1 hour to more than 24 hours. Mitigation M2B is predicted to have a widespread reduction in flood duration in the C-9 Watershed ranging from 1 hour to more than 24 hours, with a majority of the area having more than a 12-hour reduction and localized areas with reductions of more than 60 hours. Mitigation M2C is predicted to have a widespread reduction in flood duration in the C-9 Watershed with the majority of the area having more than a 24-hour reduction and localized areas with reductions of more than 80 hours.

9.3 Summary of Conclusions

The following points summarize the conclusions of the Phase II study as presented in **Section 9.1** and **Section 9.2** and present additional key points as summarized in the various summary sections within the report.

9.3.1 General Conclusions

- The results of the individual performance metrics cannot be used to assess the overall performance of the watersheds
- Three mitigation strategies were simulated with the goal of achieving a level of service equal to or greater than existing conditions for the 25-year event under sea level rise 1, 2, and 3
- Mitigation M2A was the least aggressive form of "regional mitigation" evaluated and was configured with tidal structure improvements (raised overtopping elevation of 9.0 ft NGVD29) and tieback levees/floodwalls (conceptually represented at 9.0 ft NGVD29) to block storm surge, a 1,550 cfs forward pump station, and 500 ac-ft of distributed water storage combined across both watersheds
- Mitigation M2B was a more-aggressive form of "regional mitigation" compared to M2A and was configured with tidal structure improvements (raised overtopping elevation of 9.0 ft NGVD29) and tieback levees/floodwalls (conceptually represented at 9.0 ft NGVD29) to block storm surge,

a 2,550 cfs forward pump station, canal improvements including raised bank elevations and improved canal conveyance capacity through geometry changes (such as dredging and re-grading), and 500 ac-ft of distributed water storage combined across both watersheds

- Mitigation M2C was the most aggressive form of "regional mitigation" evaluated and was configured with tidal structure improvements (raised overtopping elevation of 9.0 ft NGVD29) and tieback levees/floodwalls (conceptually represented at 9.0 ft NGVD29) to block storm surge, a 3,550 cfs forward pump station, improved canal conveyance capacity through geometry changes within the existing banks (such as dredging and re-grading) and widening, and 500 ac-ft of distributed water storage combined across both watersheds

9.3.2 PM #1 Conclusions

- C-8 Watershed
  - For M2A, strictly based on PM #1 without consideration for PM #5, the C-8 Canal is predicted to have a 5-year LOS for SLR1 and a less than 5-year LOS for SLR2 and SLR3
    - Under SLR1, only the 5-year event has maximum canal stages that do not exceed the canal bank elevations
    - Under SLR2 and SLR3, all rainfall events simulated are predicted to have maximum canal stages that exceed canal bank elevations in certain locations and are higher than existing conditions
  - For M2B, strictly based on PM #1 without consideration for PM #5, the C-8 Canal is predicted to have a 100-year LOS for SLR1, SLR2, and SLR3
    - This is simply based on not having any bank exceedances due to the mitigation activity of raising the bank elevations
    - Under SLR1, the 5, 10, 25, and 100-year rainfall events were predicted to have maximum canal stages lower than existing conditions
    - Under SLR2, none of the rainfall events simulated were predicted to have maximum canal stages lower than existing conditions
    - Under SLR3, none of the rainfall events simulated were predicted to have maximum canal stages lower than existing conditions
  - For M2C, strictly based on PM #1 without consideration for PM #5, the C-8 Canal is predicted to have a 100-year LOS for SLR1, SLR2, and SLR3
    - This is simply based on not having any bank exceedances due to the mitigation activity of raising the bank elevations
    - Under SLR1, the 5, 10, 25, and 100-year rainfall events were predicted to have maximum canal stages lower than existing conditions
    - Under SLR2, the 25-year and 100-year rainfall events were predicted to have maximum canal stages lower than existing conditions (the 5-year and 10-year SLR2 maximum canal stages were close to getting back to existing conditions)

        - Under SLR3, none of the rainfall events simulated were predicted to have maximum canal stages lower than existing conditions

- C-9 Watershed
    - For M2A, strictly based on PM #1 without consideration for PM #5, the C-9 Canal is predicted to have a 10-year LOS for SLR1 and a less than 5-year LOS for SLR2 and SLR3
        - Under SLR1, only the 5-year and 10-year rainfall events are predicted to have maximum canal stages that do not exceed the canal bank elevations
        - Under SLR2 and SLR3, all rainfall events simulated are predicted to have maximum canal stages that exceed canal bank elevations in certain locations and are higher than existing conditions
    - For M2B, strictly based on PM #1 without consideration for PM #5, the C-9 Canal is predicted to have a 100-year LOS for SLR1, SLR2, and SLR3
        - This is simply based on not having any bank exceedances due to the mitigation activity of raising the bank elevations
        - Under SLR1, the 5, 10, 25, and 100-year rainfall events were predicted to have maximum canal stages lower than existing conditions
        - Under SLR2, none of the rainfall events simulated were predicted to have maximum canal stages lower than existing conditions (the 25-year and 100-year SLR2 maximum canal stages were close to getting back to existing conditions)
        - Under SLR3, none of the rainfall events simulated were predicted to have maximum canal stages lower than existing conditions
    - For M2C, strictly based on PM #1 without consideration for PM #5, the C-8 Canal is predicted to have a 100-year LOS for SLR1, SLR2, and SLR3
        - This is simply based on not having any bank exceedances due to the mitigation activity of raising the bank elevations
        - Under SLR1, the 5, 10, 25, and 100-year rainfall events were predicted to have maximum canal stages lower than existing conditions
        - Under SLR2, the 10, 25, and 100-year rainfall events were predicted to have maximum canal stages lower than existing conditions (the 5-year SLR2 maximum canal stages were close to getting back to existing conditions along most of the canal)
        - Under SLR3, none of the rainfall events simulated were predicted to have maximum canal stages lower than existing conditions

9.3.3 PM #2 Conclusions

- C-8 Watershed
    - Under all three mitigation scenarios, there is a decrease in peak discharge as sea level rises (peak discharge SLR1 > SLR2 > SLR3)
        - Peak discharge for M2A and M2B is less than existing conditions and M2C is greater than existing conditions (increased canal conveyance capacity)
        - Peak discharge is most often from the sluice gate and is highly dependent on the headwater and tailwater differential
        - The pump station is actively working to reduce or maintain headwater when tailwater inhibits gravity discharge, which ultimately decreases the headwater and tailwater differential when the gravity structure is able to discharge, resulting in smaller peak discharge
    - Under all three mitigation scenarios, there is a decrease in total discharge volume as sea level rises (discharge volume SLR1 > SLR2 > SLR3)
        - Total discharge volume should not be used as an indicator of structure performance
        - Partially due to the raised gate overtopping elevation, which directly reduces the total discharge volume as there is no reverse flow or structure bypass for the tidal structure to discharge like there is under the without mitigation scenarios
        - The total discharge volume under M2A and M2B is less than existing conditions, whereas in some instances under M2C, the total discharge volume is greater than existing conditions (partially due to increased canal conveyance capacity and larger pump capacity)
    - Pump capacity under mitigation M2A, M2B, and M2C is approximately 50%, 80%, and 110% of the design discharge of the S-28 gravity structure, respectively
        - The gravity structure design discharge of 3,220 cfs is based on very specific headwater and tailwater conditions. Under future conditions without mitigation, the S-28 sluice gate is predicted to have peak discharge rates of more than 5,000 cfs
        - Does not indicate that the pump station will cause downstream impacts just based on capacity
        - The pump station allows longer periods of “smaller” discharge rates whereas gravity structure tends to operate in short bursts of “larger” discharge rates
- C-9 Watershed
    - Under all three mitigation scenarios, there is a decrease in peak discharge as sea level rises (peak discharge SLR1 > SLR2 > SLR3)
        - Peak discharge for M2A, M2B, and M2C is less than existing conditions

    - Peak discharge is most often from the sluice gate and is highly dependent on the headwater and tailwater differential
    - The pump station is actively working to reduce or maintain headwater when tailwater inhibits gravity discharge, which ultimately decreases the headwater and tailwater differential when the gravity structure is able to discharge, resulting in smaller peak discharge
  - Under all three mitigation scenarios, there is a decrease in total discharge volume as sea level rises (discharge volume SLR1 > SLR2 > SLR3)
    - The total discharge volume under M2A, M2B, and M2C is less than existing conditions
    - Total discharge volume should not be used as an indicator of structure performance
    - Partially due to the raised gate overtopping elevation, which directly reduces the total discharge volume as there is no reverse flow or structure bypass for the tidal structure to discharge like there is under the without mitigation scenarios
  - Pump capacity under mitigation M2A, M2B, and M2C is approximately 33%, 53%, and 74% of the design discharge of the S-28 gravity structure, respectively
    - The pump station allows longer periods of "smaller" discharge rates whereas gravity structure tends to operate in short bursts of "larger" discharge rates

9.3.4 PM #5 Conclusions

- M2A
  - For both C-8 and C-9 Watersheds, it is predicted that there will be areas with higher levels of overland flooding compared to existing conditions. However, there are also areas predicted to have lower levels of overland flooding.
  - For both C-8 and C-9 Watersheds, the 25-year SLR1 flood inundation is not predicted to be significantly better or worse than existing conditions
  - For both C-8 and C-9 Watersheds, it is predicted that there will be less flood inundation for the 25-year SLR1 event than the 25-year SLR1 event without mitigation
- M2B
  - For both C-8 and C-9 Watersheds, it is predicted that there will be areas with higher levels of overland flooding compared to existing conditions. However, there are also areas predicted to have lower levels of overland flooding.
  - For both C-8 and C-9 Watersheds, the 25-year SLR2 flood inundation is not predicted to be significantly better or worse than existing conditions
  - For both C-8 and C-9 Watersheds, it is predicted that there will be less flood inundation for the 25-year SLR2 event than the 25-year SLR2 event without mitigation
- M2C

- For both C-8 and C-9 Watersheds, it is predicted that there will be areas with higher levels of overland flooding compared to existing conditions. However, there are also areas predicted to have lower levels of overland flooding.
- For both C-8 and C-9 Watersheds, the 25-year SLR3 flood inundation is not predicted to be significantly better or worse than existing conditions
- For both C-8 and C-9 Watersheds, it is predicted that there will be less flood inundation for the 25-year SLR3 event than the 25-year SLR3 event without mitigation

9.3.5 PM #6 Conclusions

- Under all three mitigation strategies simulated, there are widespread areas that are predicted to have an increase in flood duration compared to current conditions, even if there is no corresponding increase in flood depths. For both the C-8 and C-9 Watersheds:
  - The rise of sea level will cause an increase in groundwater elevations along the coast
  - The increase in groundwater along the coast is predicted to cause inland ground water elevations to stay elevated longer after a storm event
  - In areas where the groundwater elevation peaks higher than the land surface elevation, this increase in duration of elevated groundwater translates to increased surface water flood durations
- M2A
  - For both C-8 and C-9 Watersheds, it is predicted that there will be a widespread increase in flood duration compared to existing conditions.
  - For both C-8 and C-9 Watersheds, the flood duration associated with the 25-year SLR1 event is predicted to be significantly less than the flood duration associated with the 25-year SLR1 event without mitigation
- M2B
  - For both C-8 and C-9 Watersheds, it is predicted that there will be a widespread increase in flood duration compared to existing conditions.
  - For both C-8 and C-9 Watersheds, the flood duration associated with the 25-year SLR2 event is predicted to be significantly less than the flood duration associated with the 25-year SLR2 event without mitigation
- M2C
  - For both C-8 and C-9 Watersheds, it is predicted that there will be a widespread increase in flood duration compared to existing conditions.
  - For both C-8 and C-9 Watersheds, the flood duration associated with the 25-year SLR3 event is predicted to be significantly less than the flood duration associated with the 25-year SLR3 event without mitigation

9.3.6 Key Takeaways

- The goal of Mitigation M2A, M2B, and M2C was to achieve a PM #1 maximum water surface profile and PM #5 flood depths that were equal to or lower than existing conditions for the 25-year SLR1, SLR2, and SLR3 storm events, respectively
- Although Mitigation M2A was unable to completely achieve the goals set for the 25-year SLR1 event, it is still predicted to be very effective in reducing negative effects of 1 foot of sea level rise in both the C-8 and C-9 Watersheds.
    - Under SLR2 and SLR3, Mitigation M2A is not predicted to be able to achieve canal stages or flood levels equal to or lower than predicted under existing conditions, however, it is predicted to have significant improvements compared to no mitigation
- Although Mitigation M2B was unable to completely achieve the goals set for the 25-year SLR2 event, it is still predicted to be very effective in reducing negative effects of 2 feet of sea level rise in both the C-8 and C-9 Watersheds.
    - Under SLR1, Mitigation M2B is predicted to be able to achieve canal stages and flood levels equal to or lower than predicted under existing conditions for all four rainfall events simulated
    - Overall, Mitigation M2B is predicted to achieve the goals set for Mitigation M2A
    - Mitigation M2B is not predicted to be effective at achieving the goals set for SLR3, however, it is predicted to have significant improvements compared to no mitigation
- Although Mitigation M2C was unable to completely achieve the goals set for the 25-year SLR3 event, it is still predicted to be very effective in reducing negative effects of 3 feet of sea level rise in both the C-8 and C-9 Watersheds.
    - Under SLR1, Mitigation M2C is predicted to be able to achieve canal stages and flood levels equal to or lower than predicted under existing conditions for all four rainfall events simulated
    - Under SLR2, Mitigation M2C is predicted to be able to mostly achieve canal stages and flood levels equal to or lower than predicted under existing conditions for all four rainfall events simulated
    - Mitigation M2C is not predicted to be fully effective at achieving the goals set for SLR3, however, it is predicted to have significant improvements compared to no mitigation

9.4 Summary of Cost Estimates

The following table summarizes cost estimates discussed under **Section 8** and present all mitigation project costs within one table. M1 and M3 projects are rough order of magnitude estimates based on limited data. M2 project costs are based on projects with more data/definition and allowed SFWMD to create reasonable cost estimates. The SFWMD cost estimates were leveraged in this study to scale them according to the M2 projects. These costs are developed to help assess the net present value (NPV) or cost benefits in future tasks.

Table 9.4-1: Summary of Cost Estimates

Project	Costs (2021 M$)	
	C-8 Watershed	C-9 Watershed
M1	234	229
M2A	179	194
M2B	228	236
M2C	298	394
M3(1ft)	179	264
M3(2ft)	281	372
M3(3ft)	436	549

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Appendix A Summary of Simulated Peak Discharge, Peak Headwater, and Peak Tailwater

Table A- 1: Summary of Structure S-28 5-Year Simulated Peak Discharge, Peak Headwater, and Peak Tailwater

5-Year Design Storm												
Sea Level Rise Scenario	Summary of the Instantaneous Peak Discharge, Peak Headwater, and Peak Tailwater at Structure S-28 in the C-8 Watershed											
	Existing Conditions (Mitigation 0)			Mitigation M2A			Mitigation M2B			Mitigation M2C		
	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)
SLR0	1895	4.26	3.98	1767	3.28	3.98	1918	3.39	3.98	2697	3.46	3.98
SLR1	1958	5.05	4.98	1660	3.55	4.98	1831	3.71	4.98	2550	3.59	4.98
SLR2	2158	5.84	5.98	1629	4.3	5.98	2050	4.22	5.98	2687	4.37	5.98
SLR3	2416	6.73	6.98	1590	5.2	6.98	1780	5.21	6.98	2653	5.18	6.98
Summary of the 12-Hour Moving Average Peak Discharge, Peak Headwater, and Peak Tailwater at Structure S-28 in the C-8 Watershed												
SLR0	1642	3.68	3.58	1466	3.18	3.58	1598	3.2	3.58	2058	3.27	3.58
SLR1	1620	4.63	4.58	1437	3.48	4.58	1582	3.52	4.58	2005	3.47	4.58
SLR2	1618	5.56	5.58	1453	4.24	5.58	1607	4.18	5.58	2046	4.24	5.58
SLR3	1487	6.41	6.58	1234	5.16	6.58	1346	5.16	6.58	1834	5.15	6.58

Table A- 2: Summary of Structure S-28 10-Year Simulated Peak Discharge, Peak Headwater, and Peak Tailwater

10-Year Design Storm												
	Summary of the Instantaneous Peak Discharge, Peak Headwater, and Peak Tailwater at Structure S-28 in the C-8 Watershed											
	Existing Conditions (Mitigation 0)			Mitigation M2A			Mitigation M2B			Mitigation M2C		
	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)
SLR0	2213	4.6	4.33	2068	3.35	4.33	2281	3.57	4.33	3306	3.54	4.33
SLR1	2343	5.38	5.33	2023	4.05	5.33	2457	3.76	5.33	3339	3.74	5.33
SLR2	2554	6.15	6.33	2051	4.69	6.33	2430	4.39	6.33	3550	4.44	6.33
SLR3	2883	7.02	7.33	1844	5.27	7.33	1989	5.23	7.33	2930	5.27	7.33
Summary of the 12-Hour Moving Average Peak Discharge, Peak Headwater, and Peak Tailwater at Structure S-28 in the C-8 Watershed												
SLR0	1943	3.96	3.89	1766	3.24	3.89	1917	3.4	3.89	2466	3.44	3.89
SLR1	1952	4.94	4.89	1729	3.78	4.89	1930	3.71	4.89	2454	3.54	4.89
SLR2	1953	5.84	5.89	1695	4.59	5.89	2033	4.23	5.89	2547	4.37	5.89
SLR3	1754	6.72	6.89	1594	5.22	6.89	1752	5.18	6.89	2328	5.19	6.89

Table A- 3: Summary of Structure S-28 25-Year Simulated Peak Discharge, Peak Headwater, and Peak Tailwater

25-Year Design Storm												
	Summary of the Instantaneous Peak Discharge, Peak Headwater, and Peak Tailwater at Structure S-28 in the C-8 Watershed											
	Existing Conditions (Mitigation 0)			Mitigation M2A			Mitigation M2B			Mitigation M2C		
	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)
SLR0	2833	5.22	4.87	2697	4.32	4.87	2994	4.01	4.87	4031	3.89	4.87
SLR1	2990	5.92	5.87	2726	5.01	5.87	2818	4.34	5.87	3813	4.22	5.87
SLR2	3354	6.68	6.87	2795	5.49	6.87	2813	4.83	6.87	3717	4.93	6.87
SLR3	3442	7.39	7.87	2644	5.87	7.87	2708	5.41	7.87	3990	5.5	7.87
Summary of the 12-Hour Moving Average Peak Discharge, Peak Headwater, and Peak Tailwater at Structure S-28 in the C-8 Watershed												
SLR0	2506	4.45	4.36	2340	4.04	4.36	2546	3.71	4.36	3227	3.70	4.36
SLR1	2535	5.41	5.36	2224	4.68	5.36	2577	3.84	5.36	3227	3.81	5.36
SLR2	2585	6.32	6.36	2135	5.29	6.36	2566	4.49	6.36	3473	4.53	6.36
SLR3	2176	7.14	7.36	1877	5.72	7.36	2269	5.36	7.36	3195	5.39	7.36

Table A- 4: Summary of Structure S-28 100-Year Simulated Peak Discharge, Peak Headwater, and Peak Tailwater

100-Year Design Storm												
	Summary of the Instantaneous Peak Discharge, Peak Headwater, and Peak Tailwater at Structure S-28 in the C-8 Watershed											
	Existing Conditions (Mitigation 0)			Mitigation M2A			Mitigation M2B			Mitigation M2C		
	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)
SLR0	3845	6.03	5.81	3751	5.39	5.81	4159	5	5.81	5276	5.01	5.81
SLR1	4088	6.74	6.81	3862	5.85	6.81	4309	5.29	6.81	5571	5.32	6.81
SLR2	4268	7.41	7.81	3963	6.16	7.81	4141	5.66	7.81	5822	5.8	7.81
SLR3	4290	8.81	8.81	3320	6.45	8.81	3475	6.05	8.81	5544	6.12	8.81
Summary of the 12-Hour Moving Average Peak Discharge, Peak Headwater, and Peak Tailwater at Structure S-28 in the C-8 Watershed												
SLR0	3353	5.26	5.19	3169	4.91	5.19	3438	4.68	5.19	4411	4.68	5.19
SLR1	3399	6.18	6.19	3072	5.56	6.19	3305	5.13	6.19	4411	5.18	6.19
SLR2	3155	7.05	7.19	2697	5.97	7.19	3070	5.51	7.19	4370	5.66	7.19
SLR3	2542	8.19	8.19	2166	6.21	8.19	2742	5.9	8.19	4035	6.05	8.19

Table A- 5: Summary of Structure S-29 5-Year Simulated Peak Discharge, Peak Headwater, and Peak Tailwater

5-Year Design Storm												
Sea Level Rise Scenario	Summary of the Instantaneous Peak Discharge, Peak Headwater, and Peak Tailwater at Structure S-29 in the C-9 Watershed											
	Existing Conditions (Mitigation 0)			Mitigation M2A			Mitigation M2B			Mitigation M2C		
	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)
SLR0	3526	4.16	3.88	3166	3.54	3.88	3480	3.53	3.88	3681	3.51	3.88
SLR1	3198	4.93	4.88	2855	3.79	4.88	3165	3.75	4.88	3207	3.52	4.88
SLR2	3005	5.73	5.88	2479	4.49	5.88	2687	4.36	5.88	2981	4.35	5.88
SLR3	3056	6.56	6.88	2043	5.26	6.88	2259	5.2	6.88	2130	5.14	6.88
Summary of the 12-Hour Moving Average Peak Discharge, Peak Headwater, and Peak Tailwater at Structure S-29 in the C-9 Watershed												
SLR0	2803	3.7	3.59	2353	3.36	3.59	2580	3.4	3.59	2743	3.39	3.59
SLR1	2243	4.6	4.59	2005	3.7	4.59	2237	3.71	4.59	2377	3.48	4.59
SLR2	1832	5.49	5.59	1717	4.31	5.59	1920	4.22	5.59	1981	4.21	5.59
SLR3	1519	6.31	6.59	1352	5.18	6.59	1460	5.17	6.59	1366	5.01	6.59

Table A- 6: Summary of Structure S-29 10-Year Simulated Peak Discharge, Peak Headwater, and Peak Tailwater

10-Year Design Storm												
Sea Level Rise Scenario	Summary of the Instantaneous Peak Discharge, Peak Headwater, and Peak Tailwater at Structure S-29 in the C-9 Watershed											
	Existing Conditions (Mitigation 0)			Mitigation M2A			Mitigation M2B			Mitigation M2C		
	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)
SLR0	3983	4.50	4.22	3584	3.91	4.22	3879	3.74	4.22	4232	3.68	4.22
SLR1	3720	5.29	5.22	3365	4.19	5.22	3620	3.88	5.22	3608	3.72	5.22
SLR2	3693	6.05	6.22	2976	4.90	6.22	3096	4.56	6.22	3222	4.38	6.22
SLR3	3770	6.88	7.22	2735	5.61	7.22	2778	5.4	7.22	2657	5.22	7.22
Summary of the 12-Hour Moving Average Peak Discharge, Peak Headwater, and Peak Tailwater at Structure S-29 in the C-9 Watershed												
SLR0	3119	3.99	3.89	2696	3.71	3.89	2953	3.58	3.89	3140	3.48	3.89
SLR1	2590	4.90	4.89	2261	4.10	4.89	2619	3.76	4.89	2787	3.57	4.89
SLR2	2309	5.79	5.89	2016	4.76	5.89	2334	4.40	5.89	2317	4.35	5.89
SLR3	1865	6.61	6.89	1823	5.50	6.89	2098	5.26	6.89	1967	5.17	6.89

Table A- 7: Summary of Structure S-29 25-Year Simulated Peak Discharge, Peak Headwater, and Peak Tailwater

25-Year Design Storm												
Sea Level Rise Scenario	Summary of the Instantaneous Peak Discharge, Peak Headwater, and Peak Tailwater at Structure S-29 in the C-9 Watershed											
	Existing Conditions (Mitigation 0)			Mitigation M2A			Mitigation M2B			Mitigation M2C		
	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)
SLR0	4603	5.03	4.75	4403	4.53	4.75	4706	4.2	4.75	4804	3.75	4.75
SLR1	4475	5.79	5.75	4052	4.95	5.75	4475	4.5	5.75	4323	3.99	5.75
SLR2	4557	6.54	6.75	3975	5.51	6.75	4074	5.16	6.75	3841	4.73	6.75
SLR3	4580	7.33	7.75	3732	6.14	7.75	3540	5.9	7.75	3550	5.46	7.75
Summary of the 12-Hour Moving Average Peak Discharge, Peak Headwater, and Peak Tailwater at Structure S-29 in the C-9 Watershed												
SLR0	3631	4.46	4.37	3282	4.2	4.37	3568	3.92	4.37	3712	3.7	4.37
SLR1	3232	5.37	5.37	2820	4.76	5.37	3189	4.29	5.37	3376	3.76	5.37
SLR2	2895	6.21	6.37	2535	5.42	6.37	2946	4.95	6.37	3279	4.44	6.37
SLR3	2264	7.04	7.37	2220	6.07	7.37	2731	5.66	7.37	2808	5.35	7.37

Table A- 8: Summary of Structure S-29 100-Year Simulated Peak Discharge, Peak Headwater, and Peak Tailwater

100-Year Design Storm												
Sea Level Rise Scenario	Summary of the Instantaneous Peak Discharge, Peak Headwater, and Peak Tailwater at Structure S-29 in the C-9 Watershed											
	Existing Conditions (Mitigation 0)			Mitigation M2A			Mitigation M2B			Mitigation M2C		
	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)	Peak Discharge (cfs)	Peak Headwater (ft)	Peak Tailwater (ft)
SLR0	5566	6.00	5.69	5364	5.49	5.69	5819	5.19	5.69	5879	4.73	5.69
SLR1	5626	6.61	6.69	5429	5.86	6.69	5757	5.53	6.69	5681	5.06	6.69
SLR2	5829	7.37	7.69	5498	6.30	7.69	5739	6.10	7.69	5274	5.71	7.69
SLR3	5413	8.26	8.69	4929	7.12	8.69	4855	6.8	8.69	4431	6.41	8.69
Summary of the 12-Hour Moving Average Peak Discharge, Peak Headwater, and Peak Tailwater at Structure S-29 in the C-9 Watershed												
SLR0	4443	5.27	5.22	4156	4.98	5.22	4538	4.88	5.22	4612	4.39	5.22
SLR1	4106	6.11	6.22	3803	5.64	6.22	4055	5.36	6.22	4260	4.75	6.22
SLR2	3542	6.94	7.22	3268	6.21	7.22	3662	5.89	7.22	3977	5.34	7.22
SLR3	2742	7.83	8.22	2764	6.94	8.22	3165	6.56	8.22	3671	5.98	8.22

Appendix B Complete Set of PM #5 Flood Inundation Maps for the C-8 Watershed

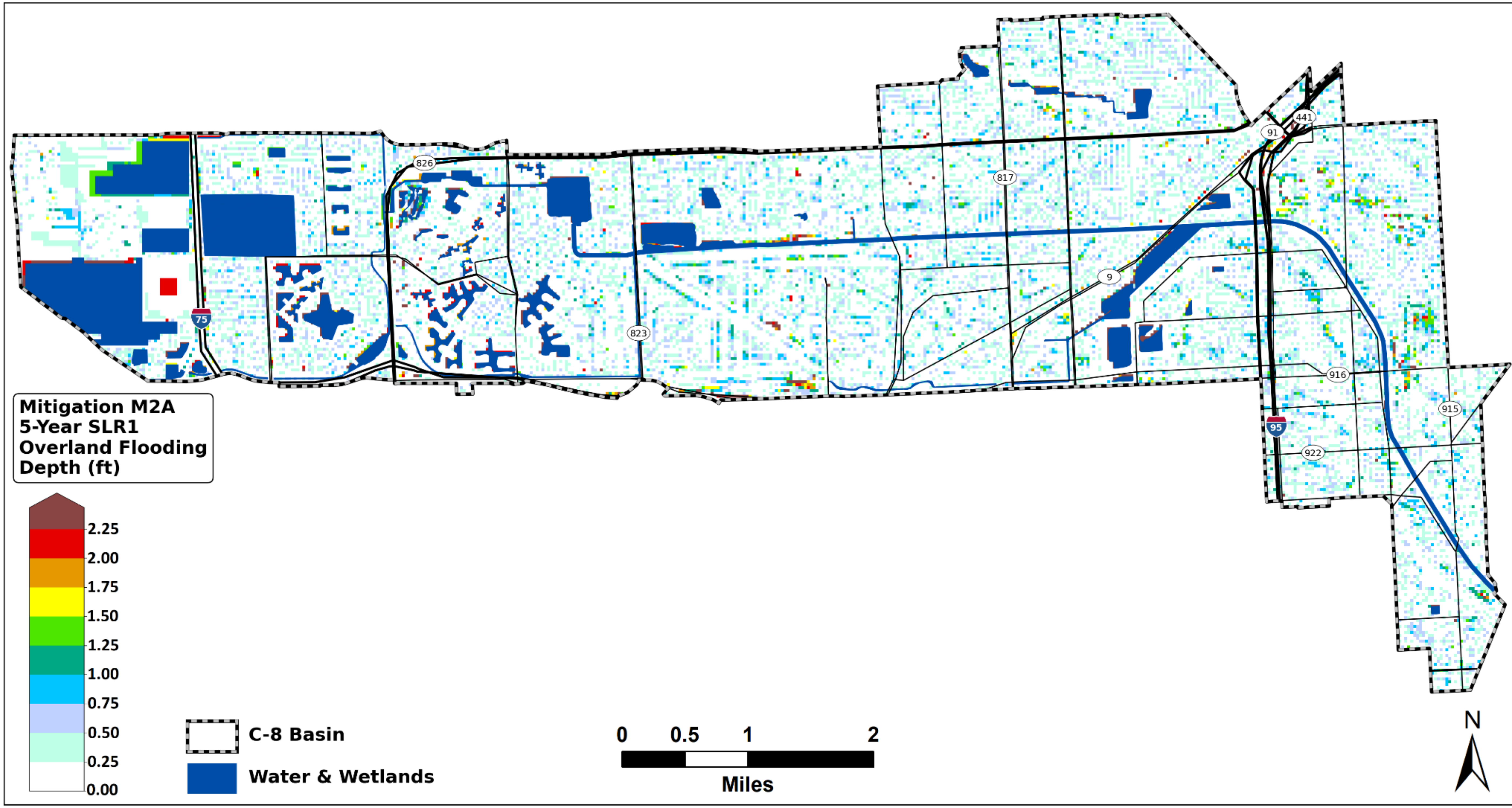


Figure B- 1: C-8 Watershed Flood Inundation Map for the Mitigation M2A 5-Year Sea Level Rise 1 Design Storm Event

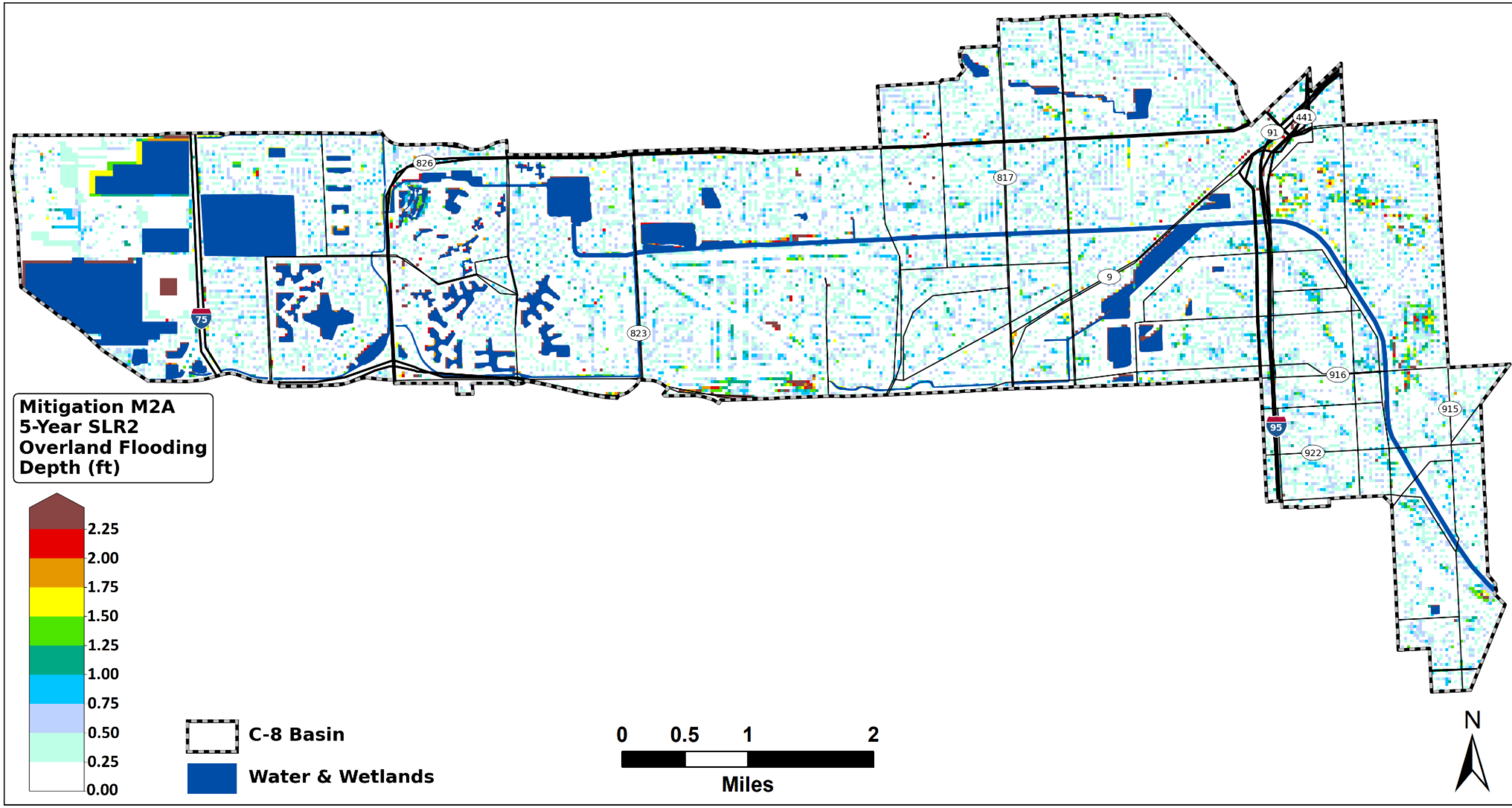


Figure B- 2: C-8 Watershed Flood Inundation Map for the Mitigation M2A 5-Year Sea Level Rise 2 Design Storm Event

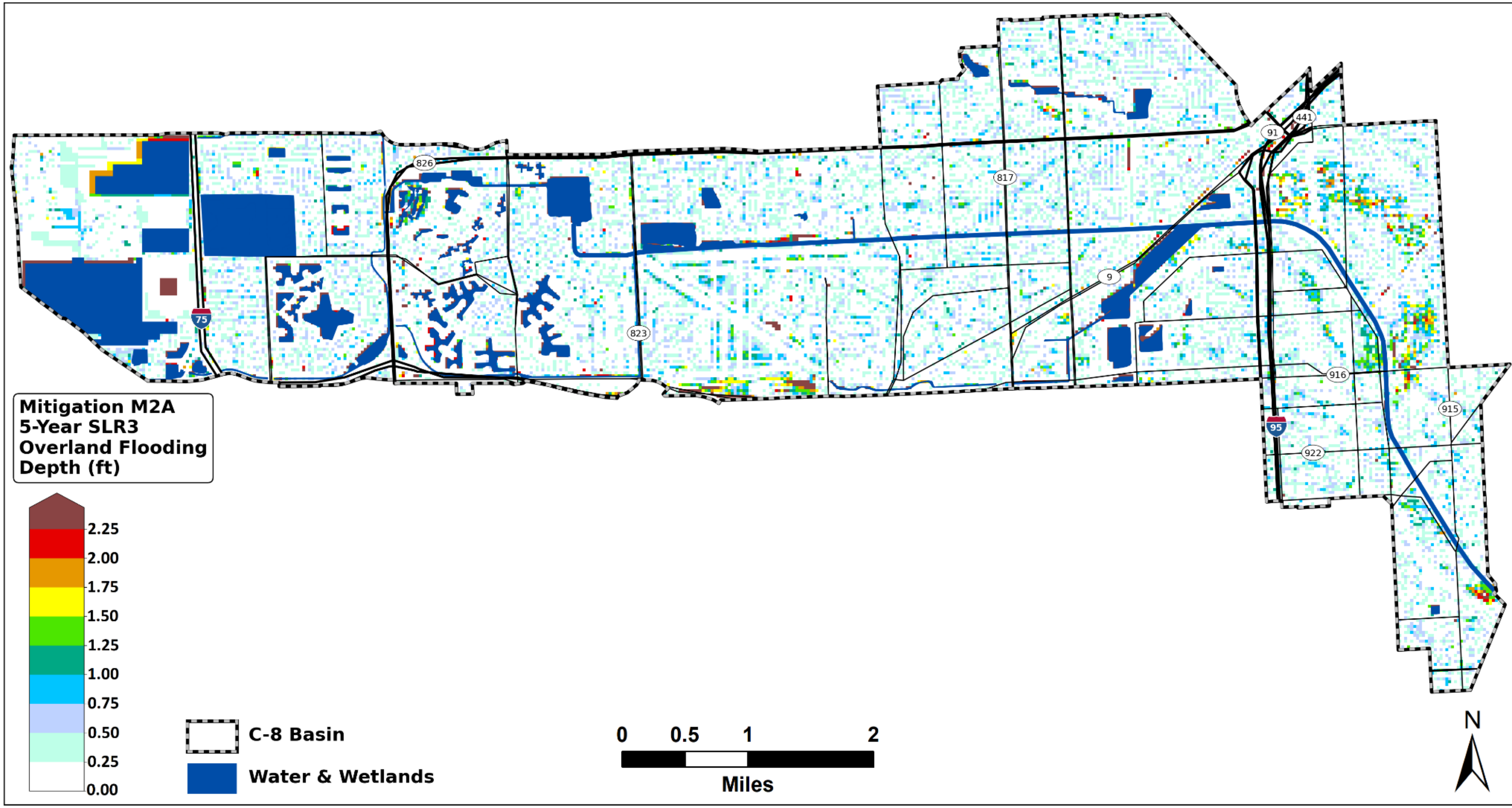


Figure B- 3: C-8 Watershed Flood Inundation Map for the Mitigation M2A 5-Year Sea Level Rise 3 Design Storm Event

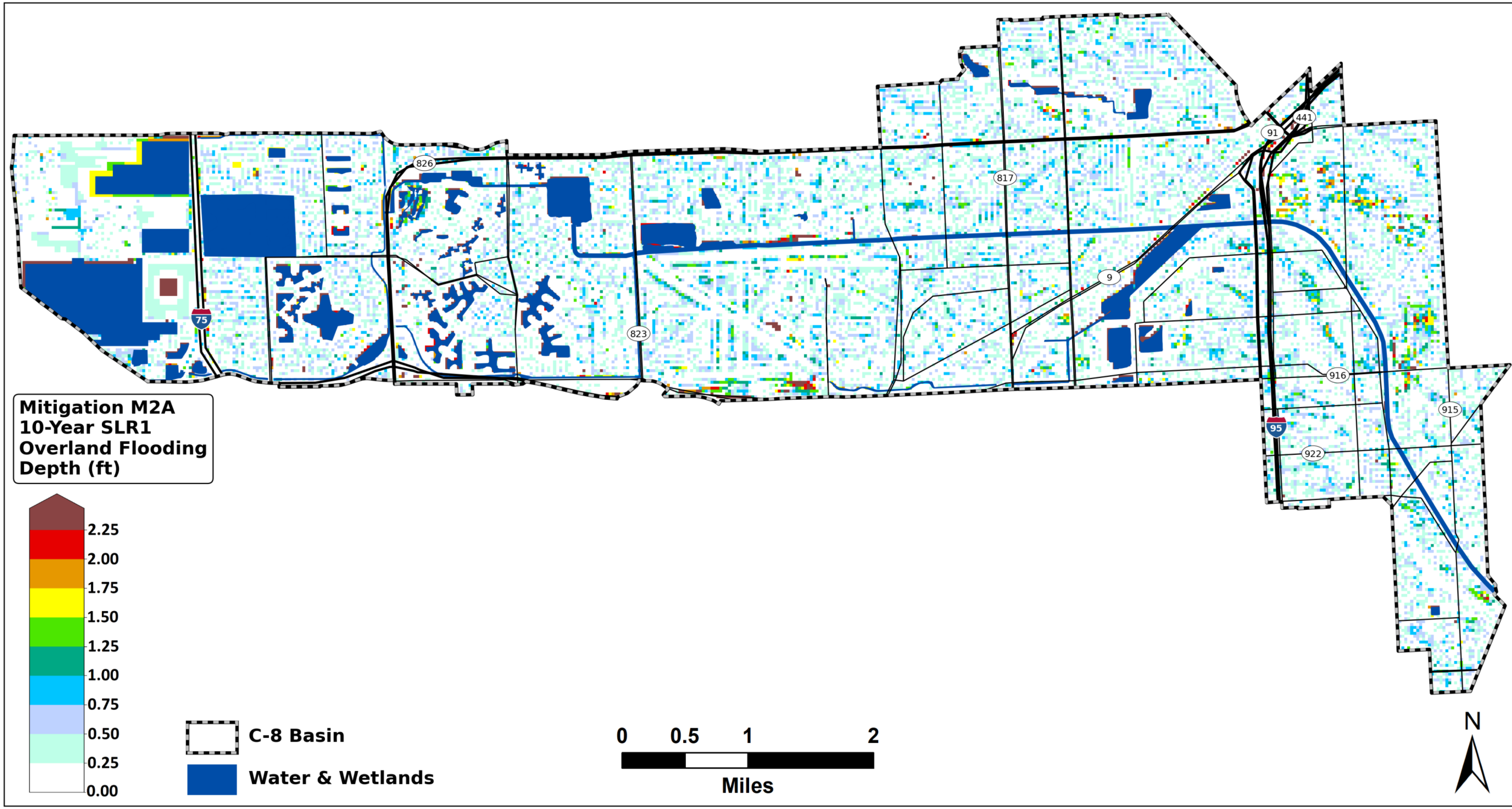


Figure B- 4: C-8 Watershed Flood Inundation Map for the Mitigation M2A 10-Year Sea Level Rise 1 Design Storm Event

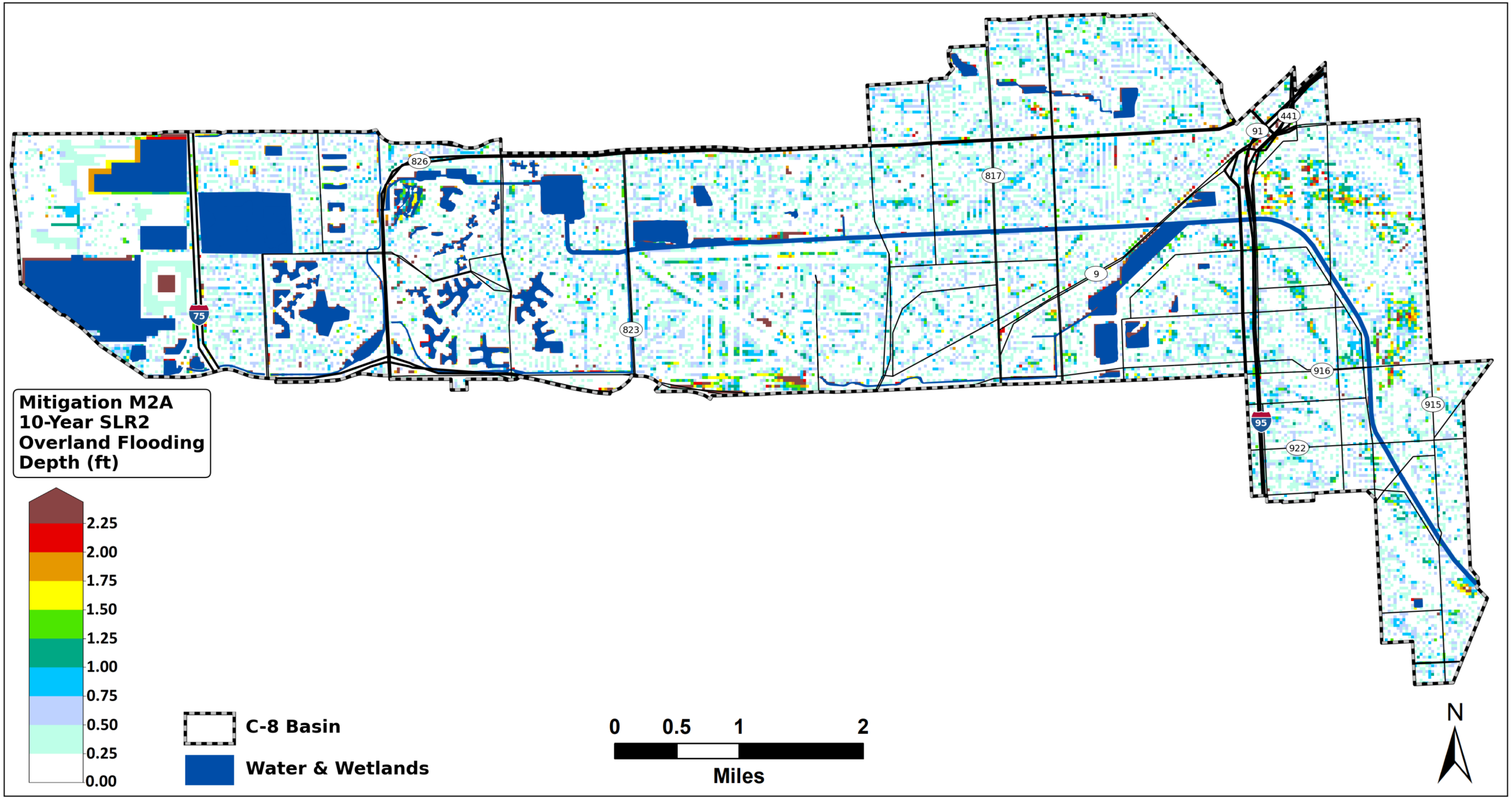


Figure B- 5: C-8 Watershed Flood Inundation Map for the Mitigation M2A 10-Year Sea Level Rise 2 Design Storm Event

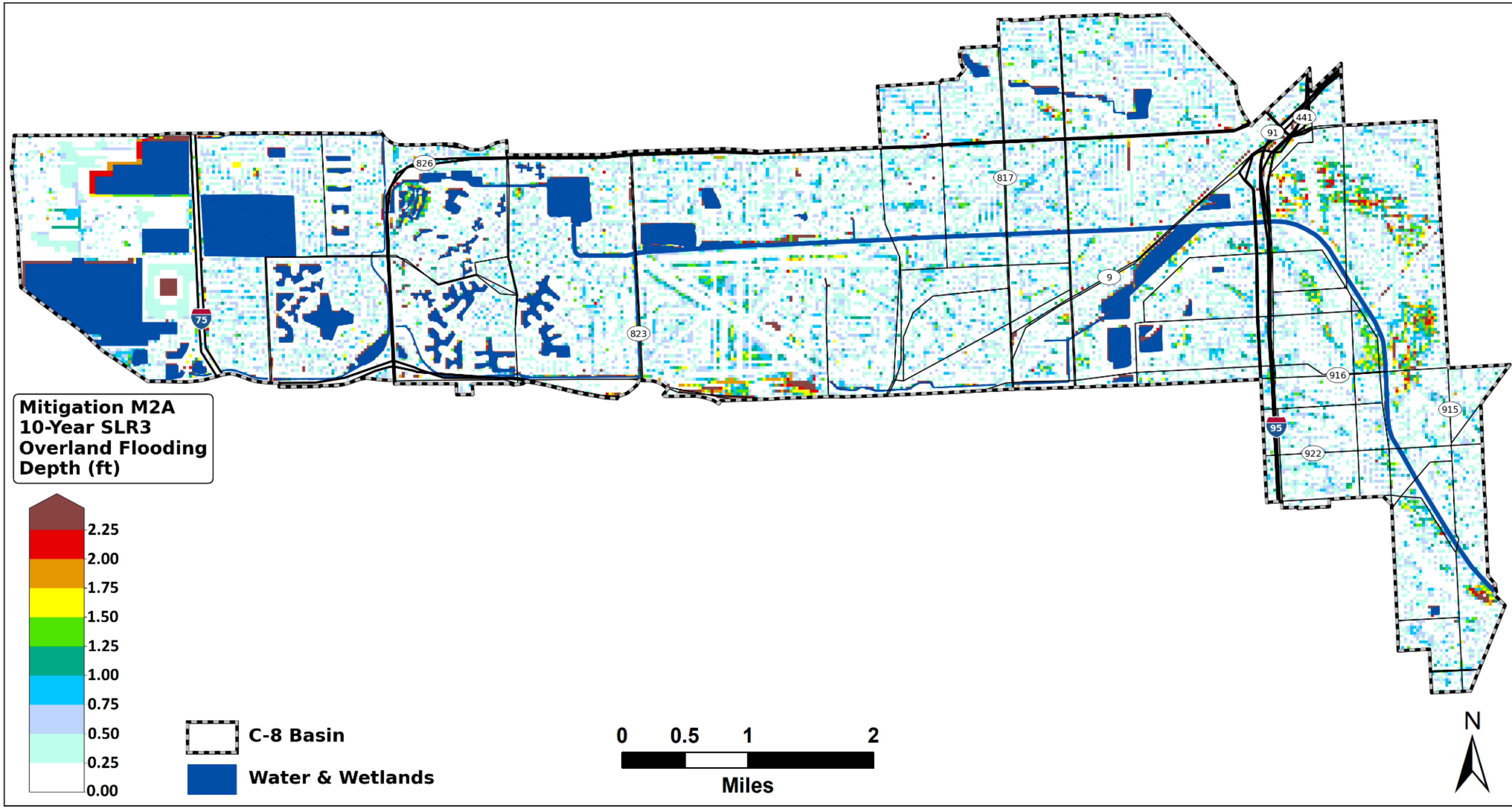


Figure B- 6: C-8 Watershed Flood Inundation Map for the Mitigation M2A 10-Year Sea Level Rise 3 Design Storm Event

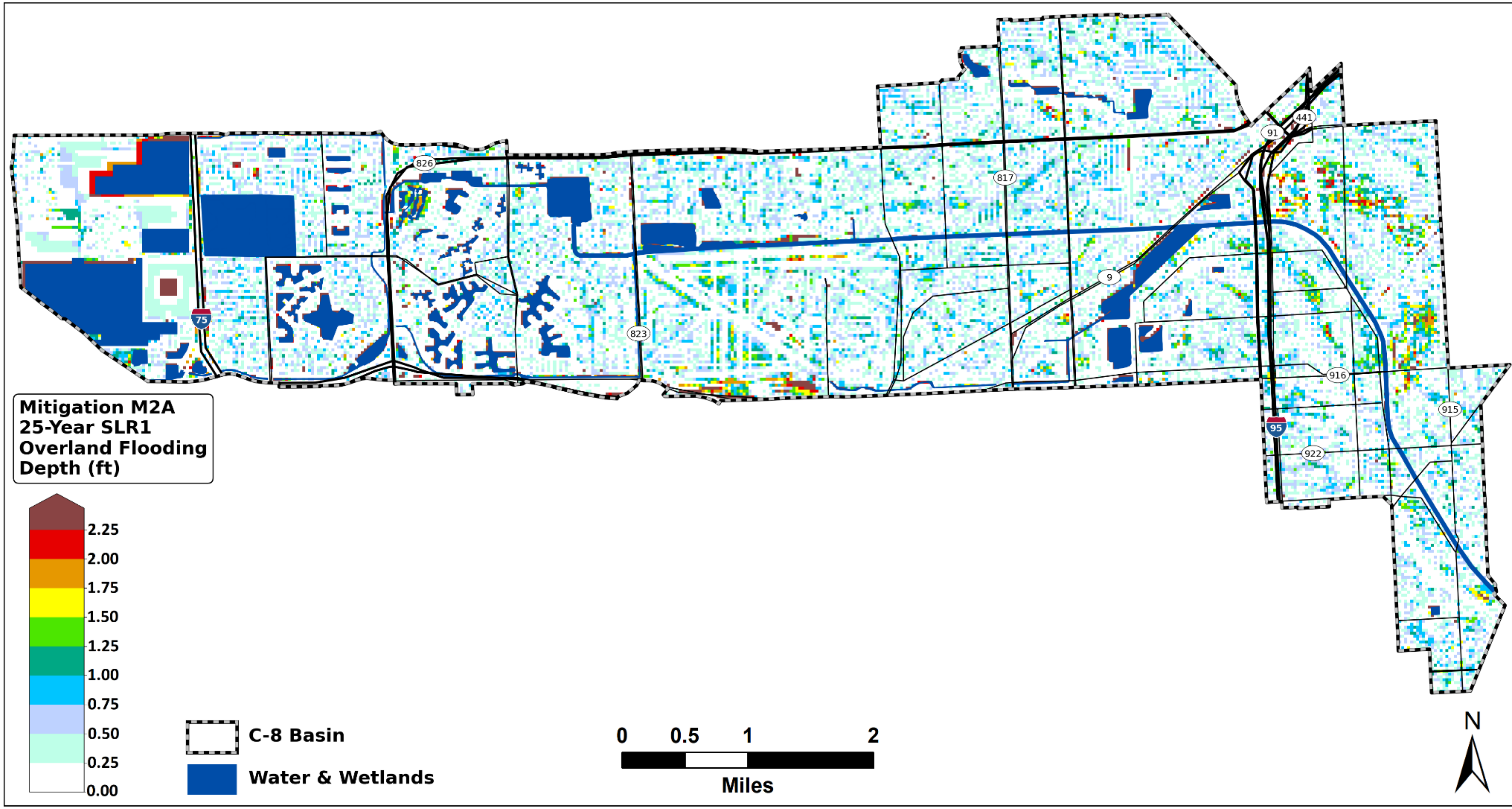


Figure B- 7: C-8 Watershed Flood Inundation Map for the Mitigation M2A 25-Year Sea Level Rise 1 Design Storm Event

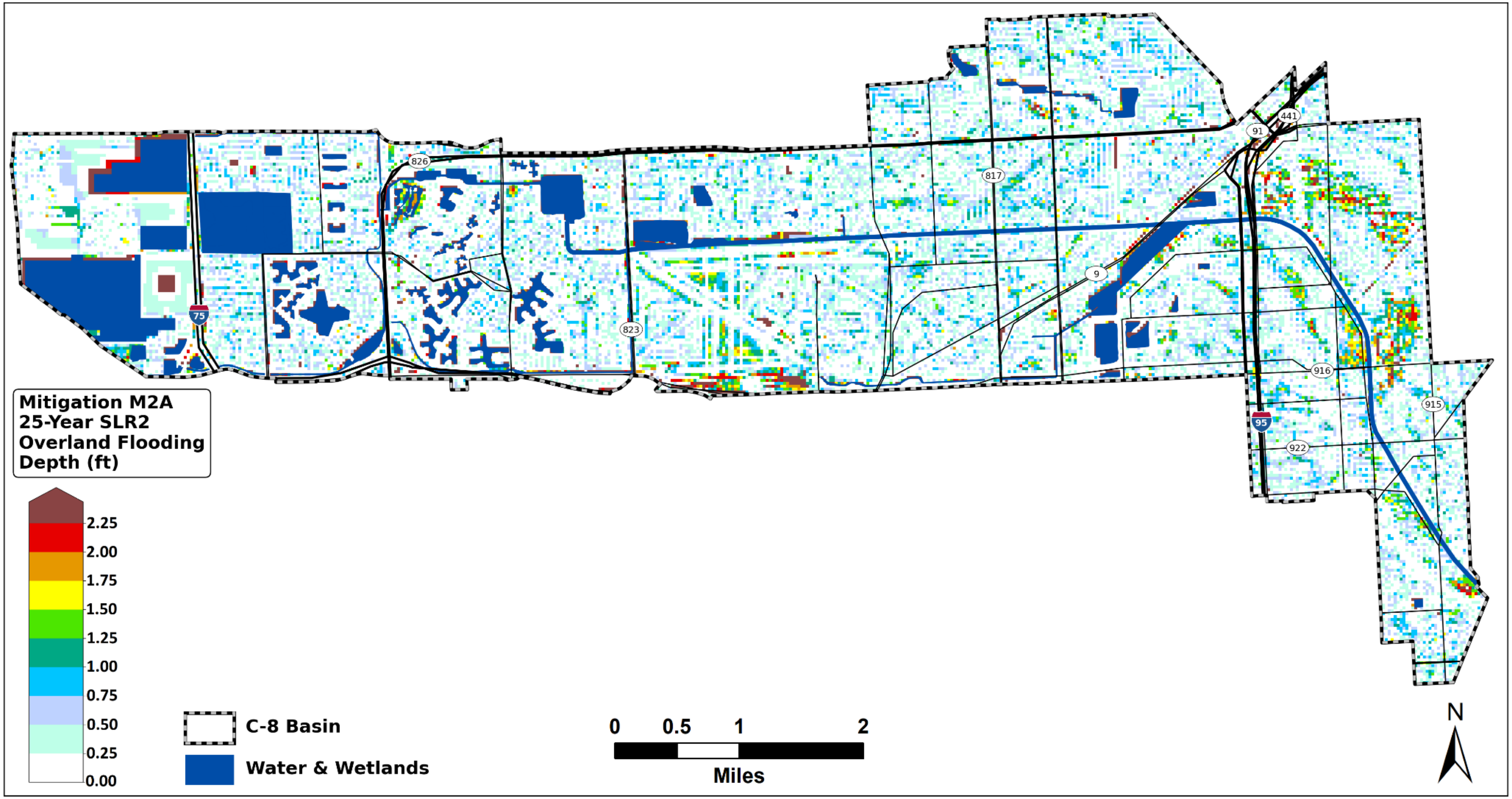


Figure B- 8: C-8 Watershed Flood Inundation Map for the Mitigation M2A 25-Year Sea Level Rise 2 Design Storm Event

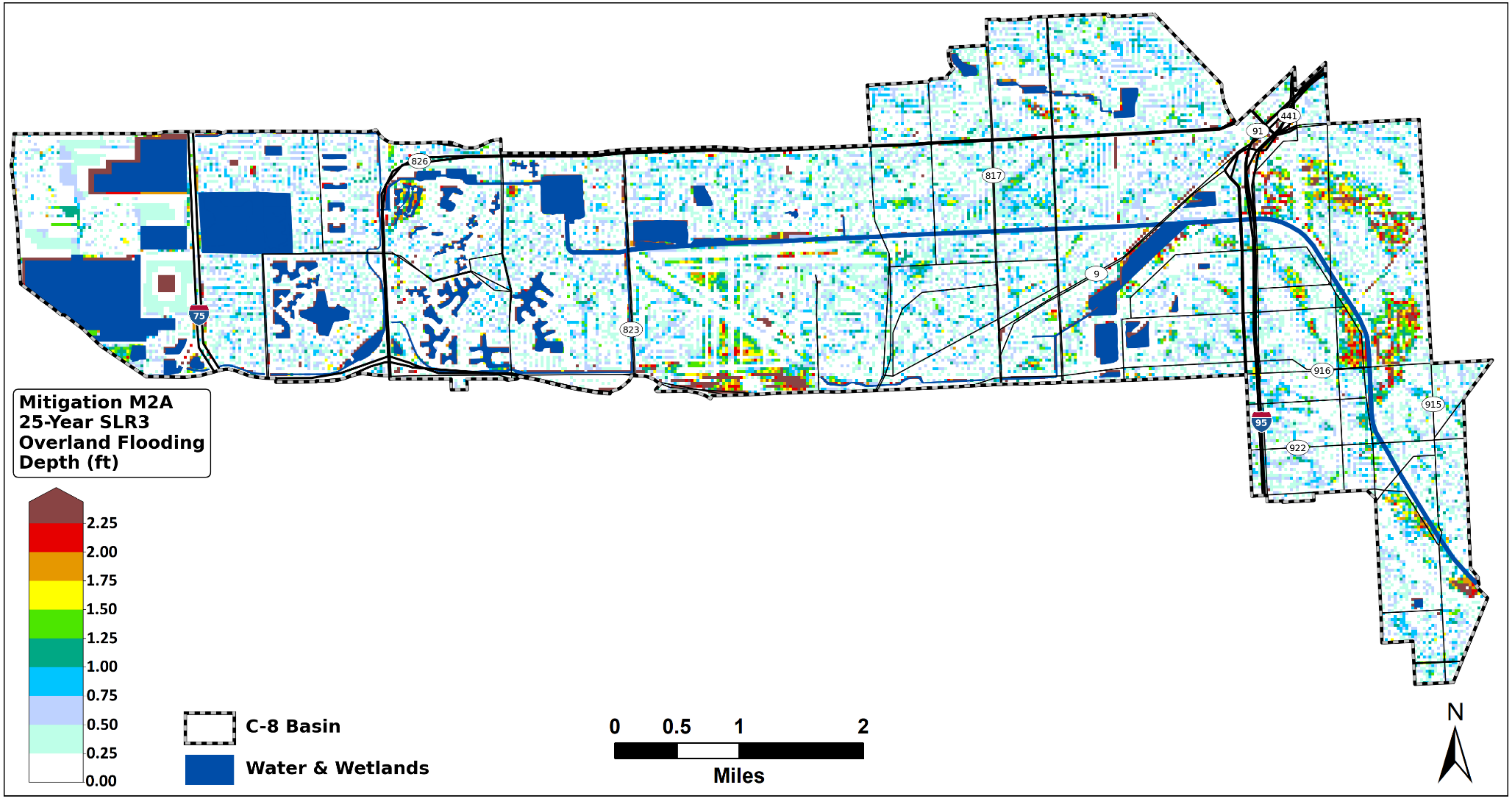


Figure B- 9: C-8 Watershed Flood Inundation Map for the Mitigation M2A 25-Year Sea Level Rise 3 Design Storm Event

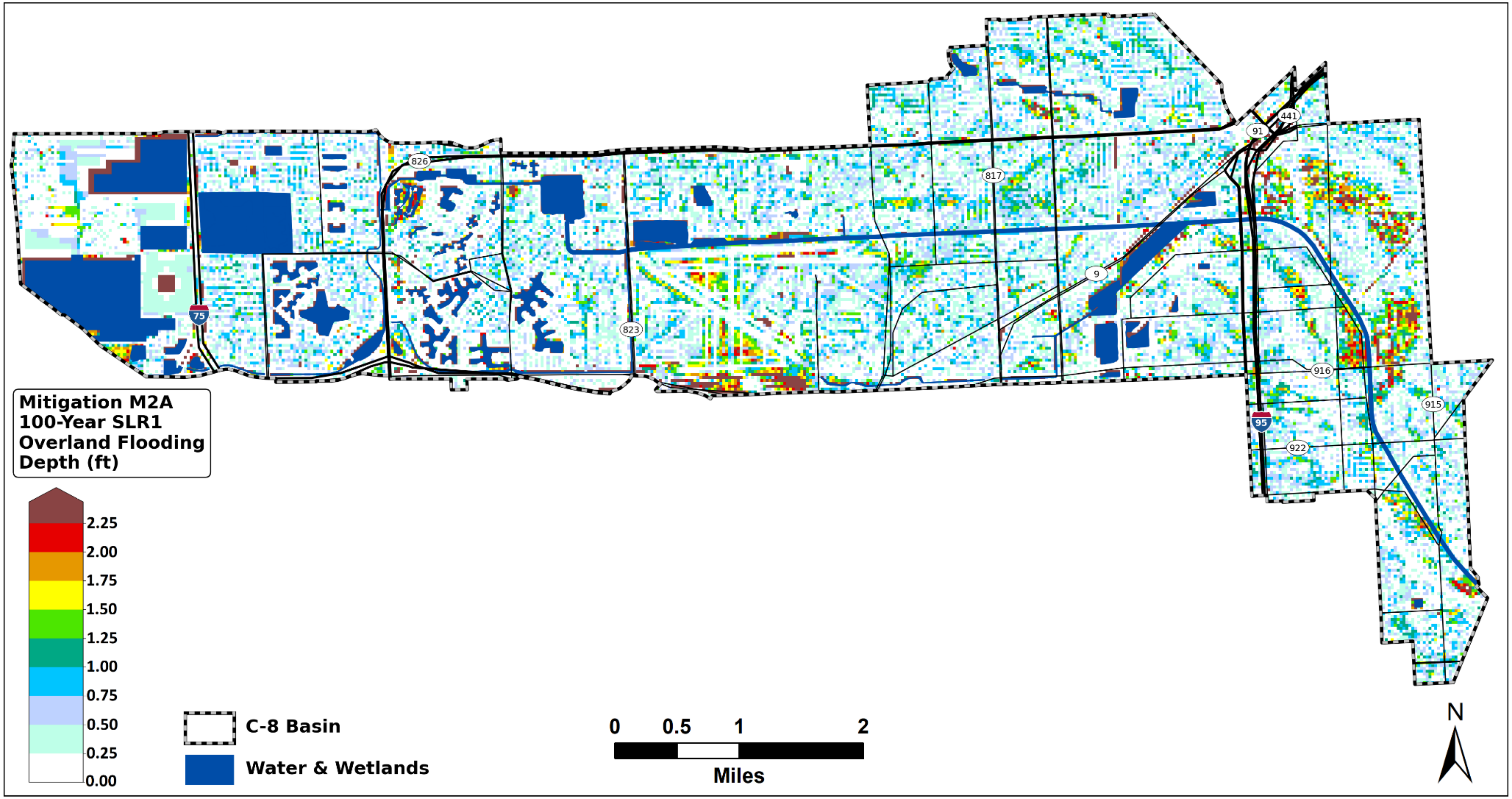


Figure B- 10: C-8 Watershed Flood Inundation Map for the Mitigation M2A 100-Year Sea Level Rise 1 Design Storm Event

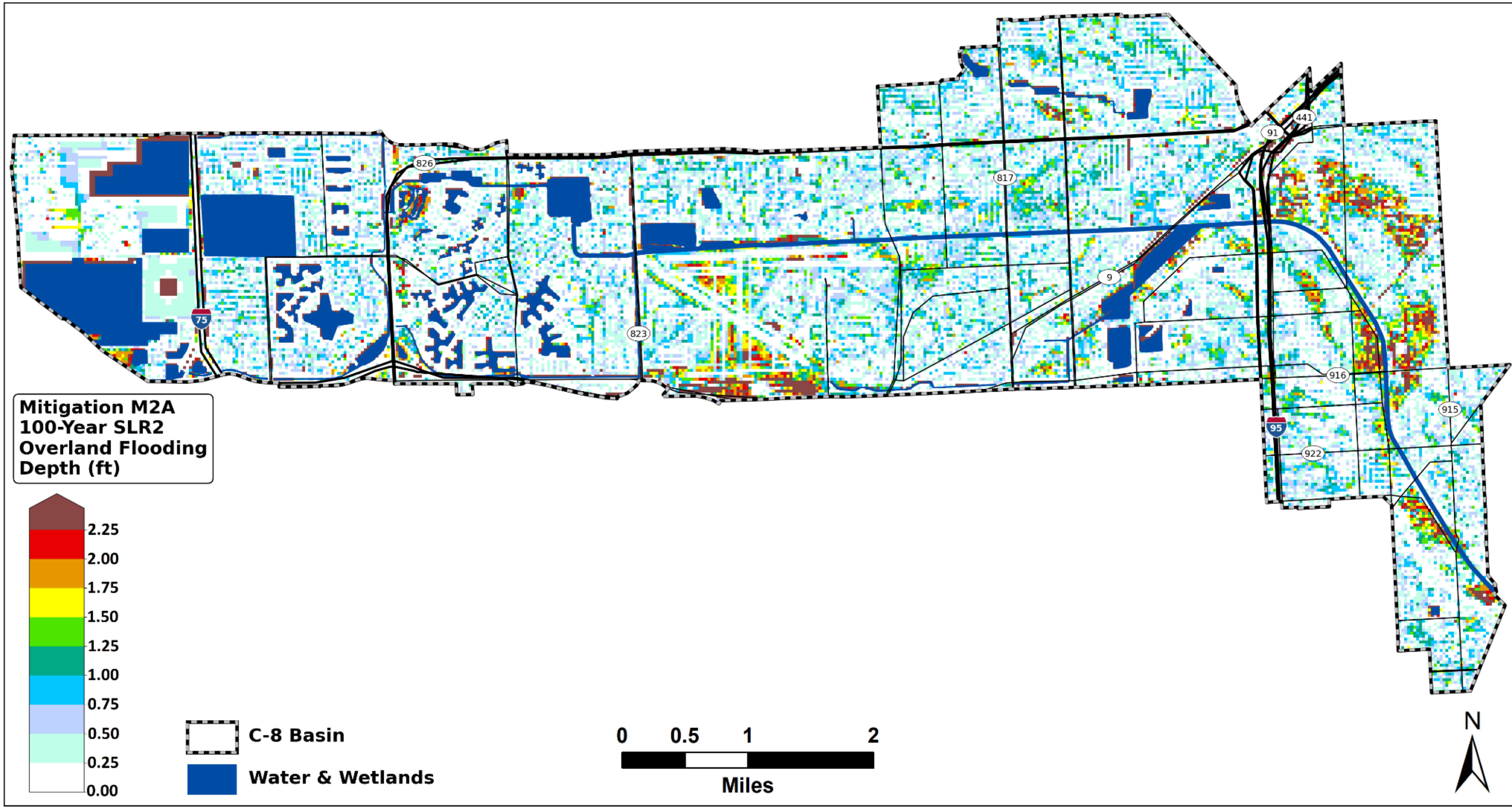


Figure B- 11: C-8 Watershed Flood Inundation Map for the Mitigation M2A 100-Year Sea Level Rise 2 Design Storm Event

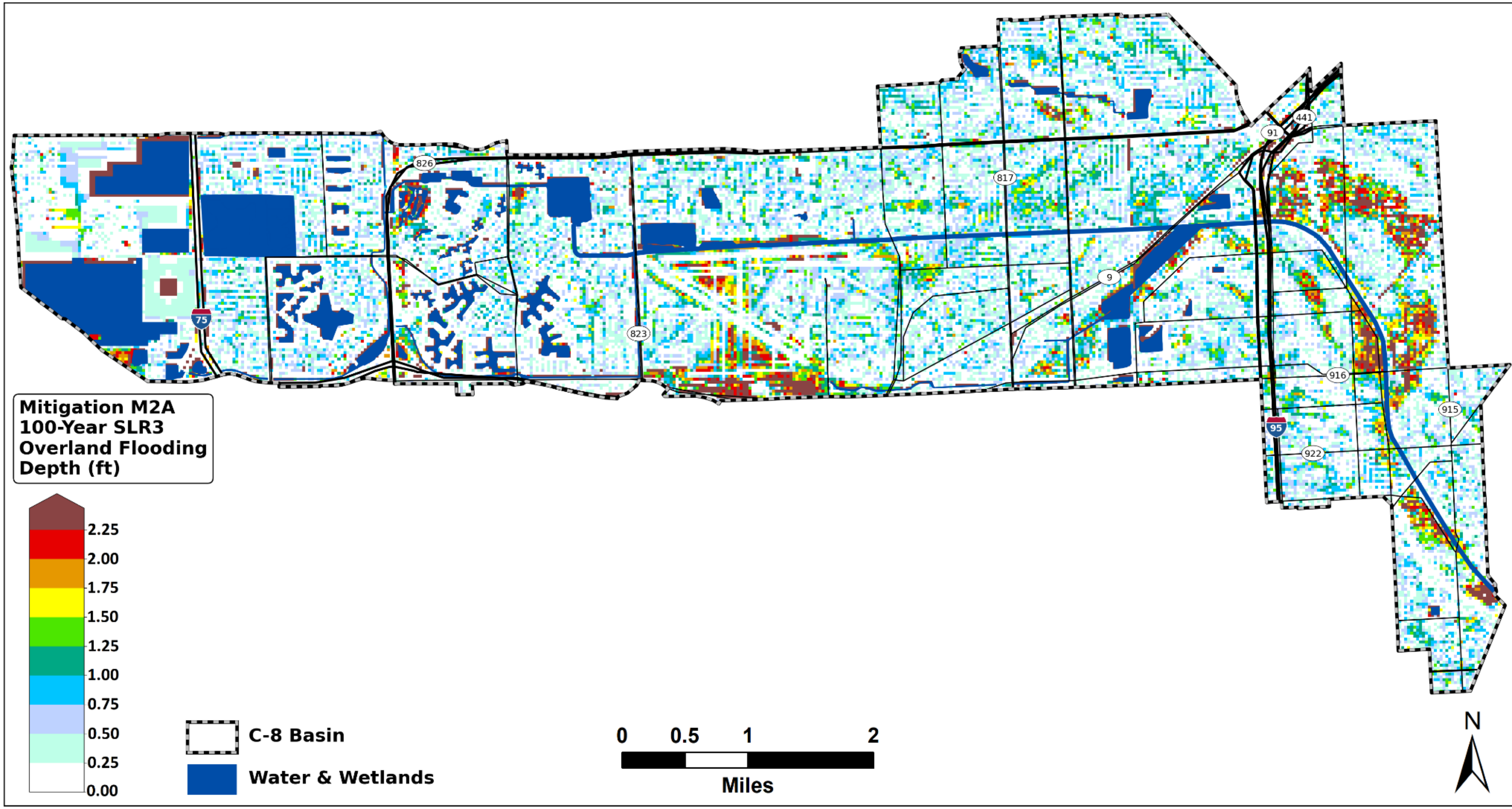


Figure B- 12: C-8 Watershed Flood Inundation Map for the Mitigation M2A 100-Year Sea Level Rise 3 Design Storm Event

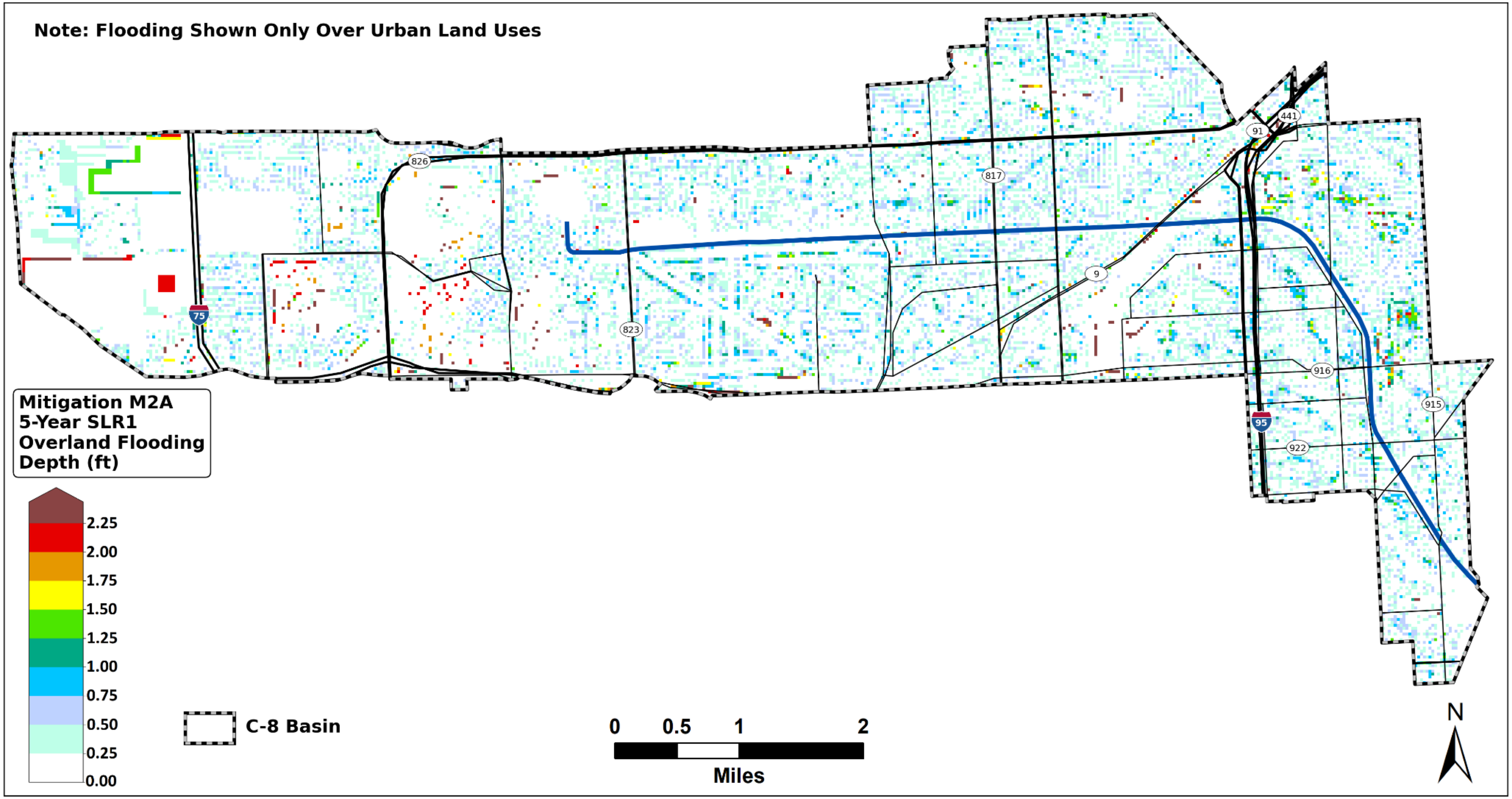


Figure B- 13: C-8 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2A 5-Year Sea Level Rise 1 Design Storm Event

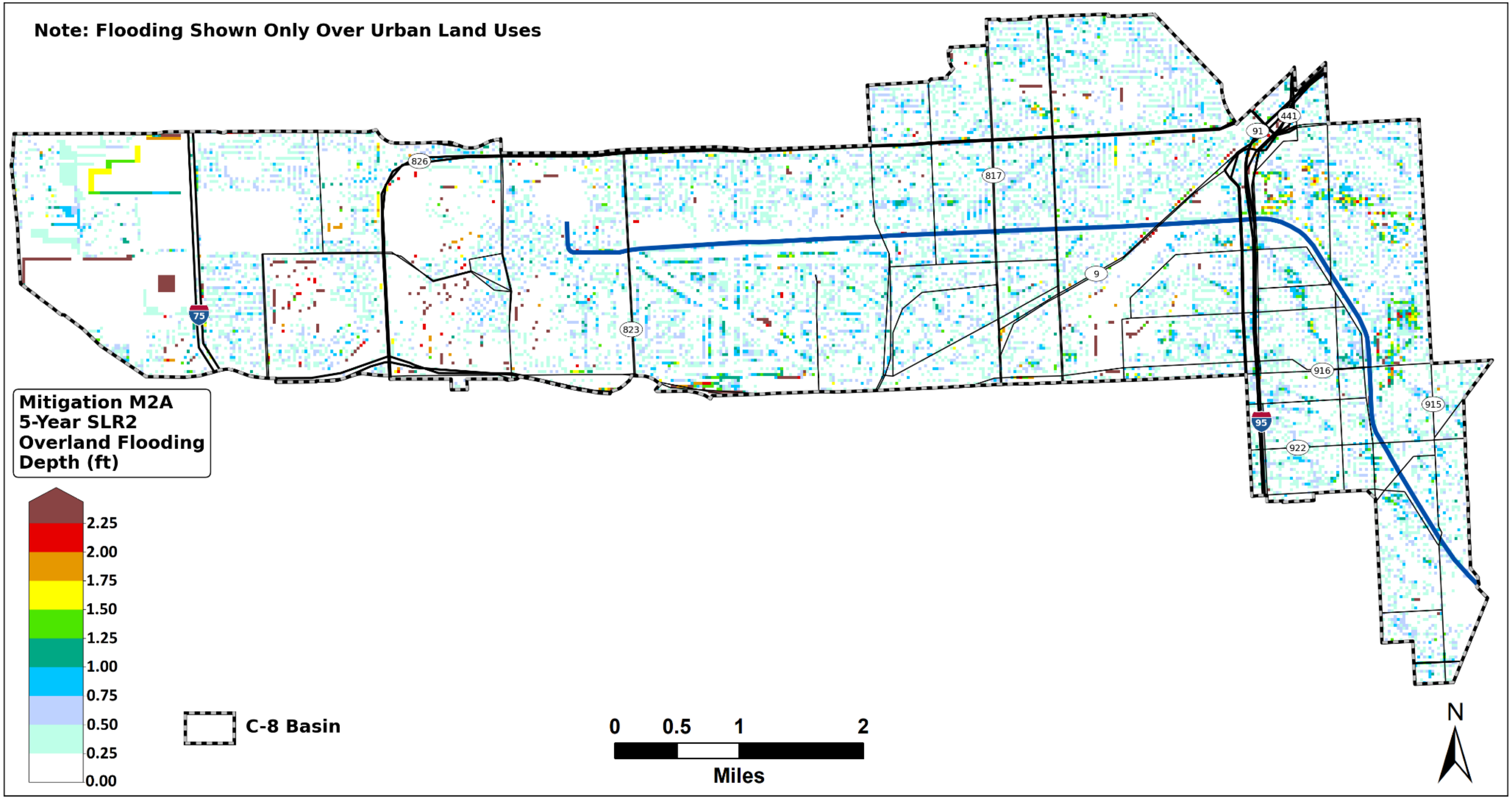


Figure B- 14: C-8 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2A 5-Year Sea Level Rise 2 Design Storm Event

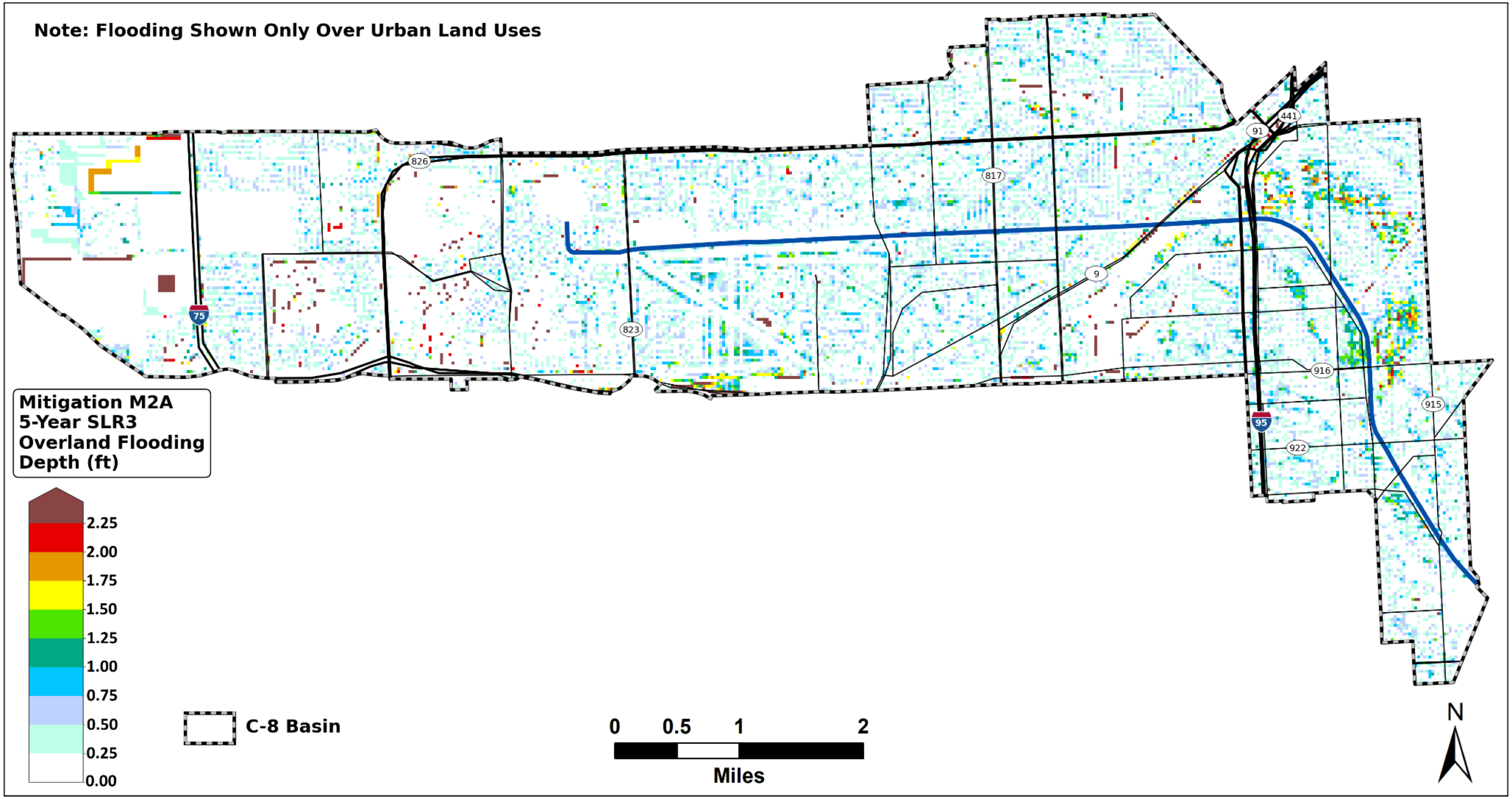


Figure B- 15: C-8 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2A 5-Year Sea Level Rise 3 Design Storm Event

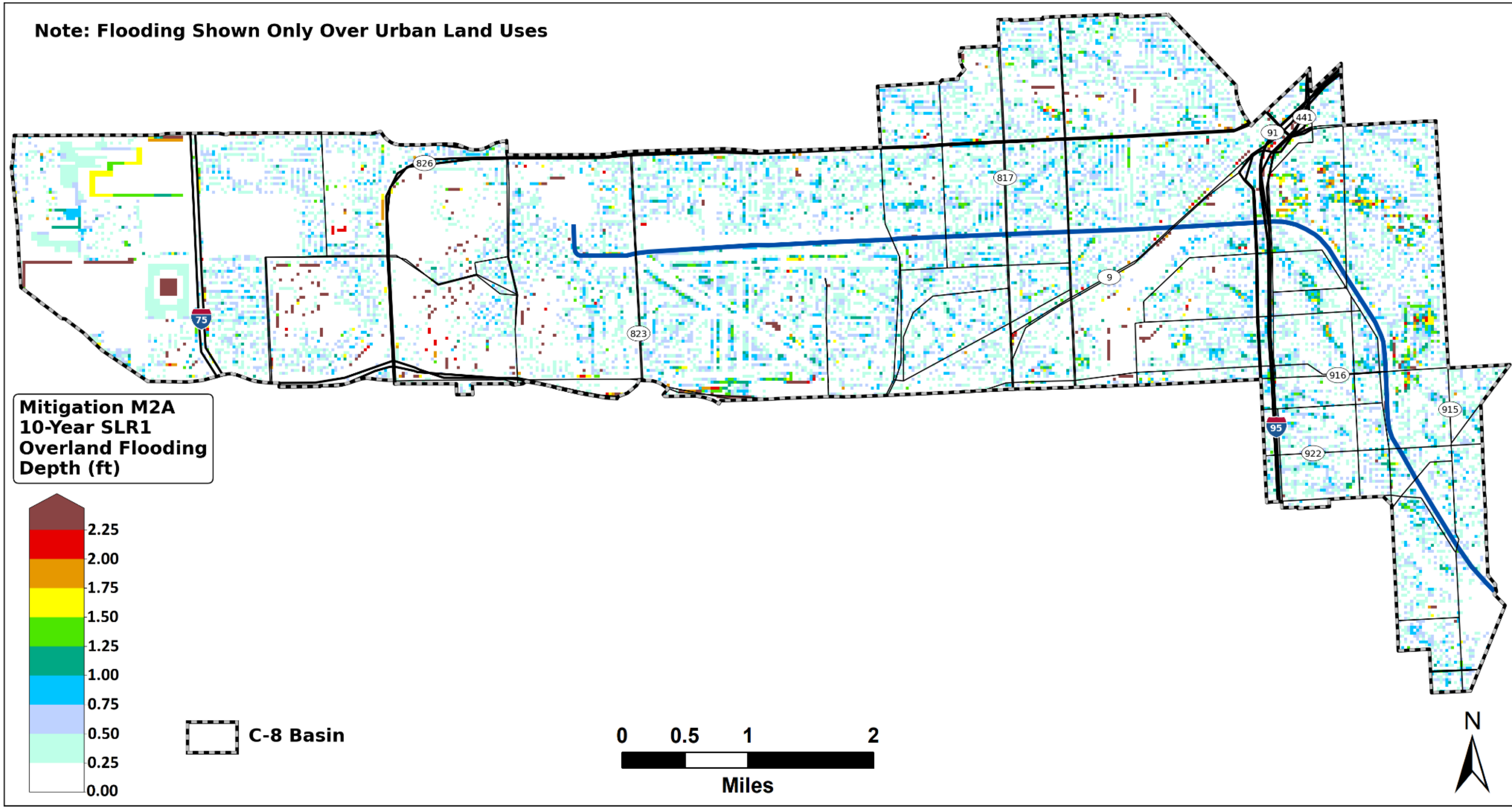


Figure B- 16: C-8 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2A 10-Year Sea Level Rise 1 Design Storm Event

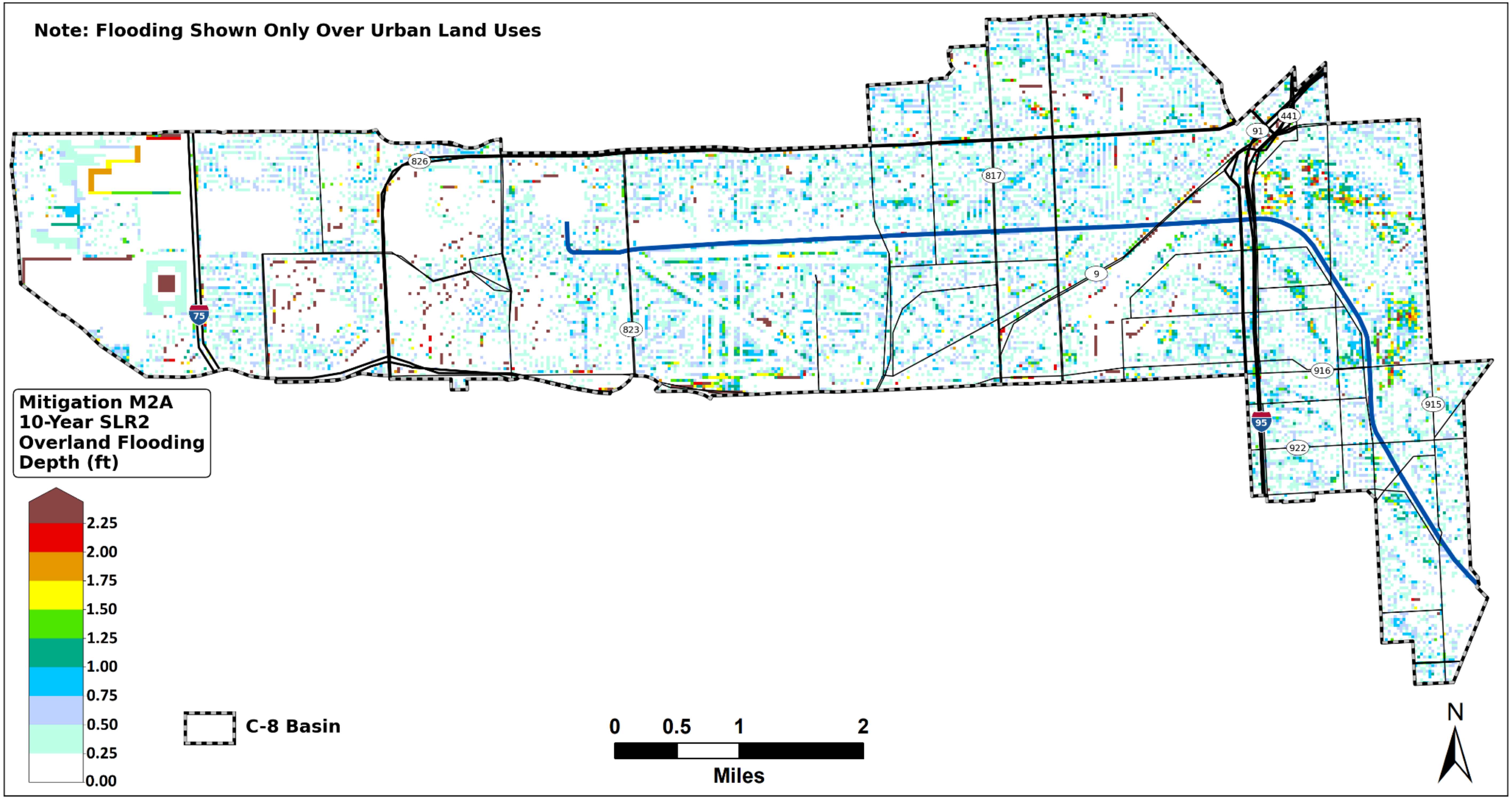


Figure B- 17: C-8 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2A 10-Year Sea Level Rise 2 Design Storm Event

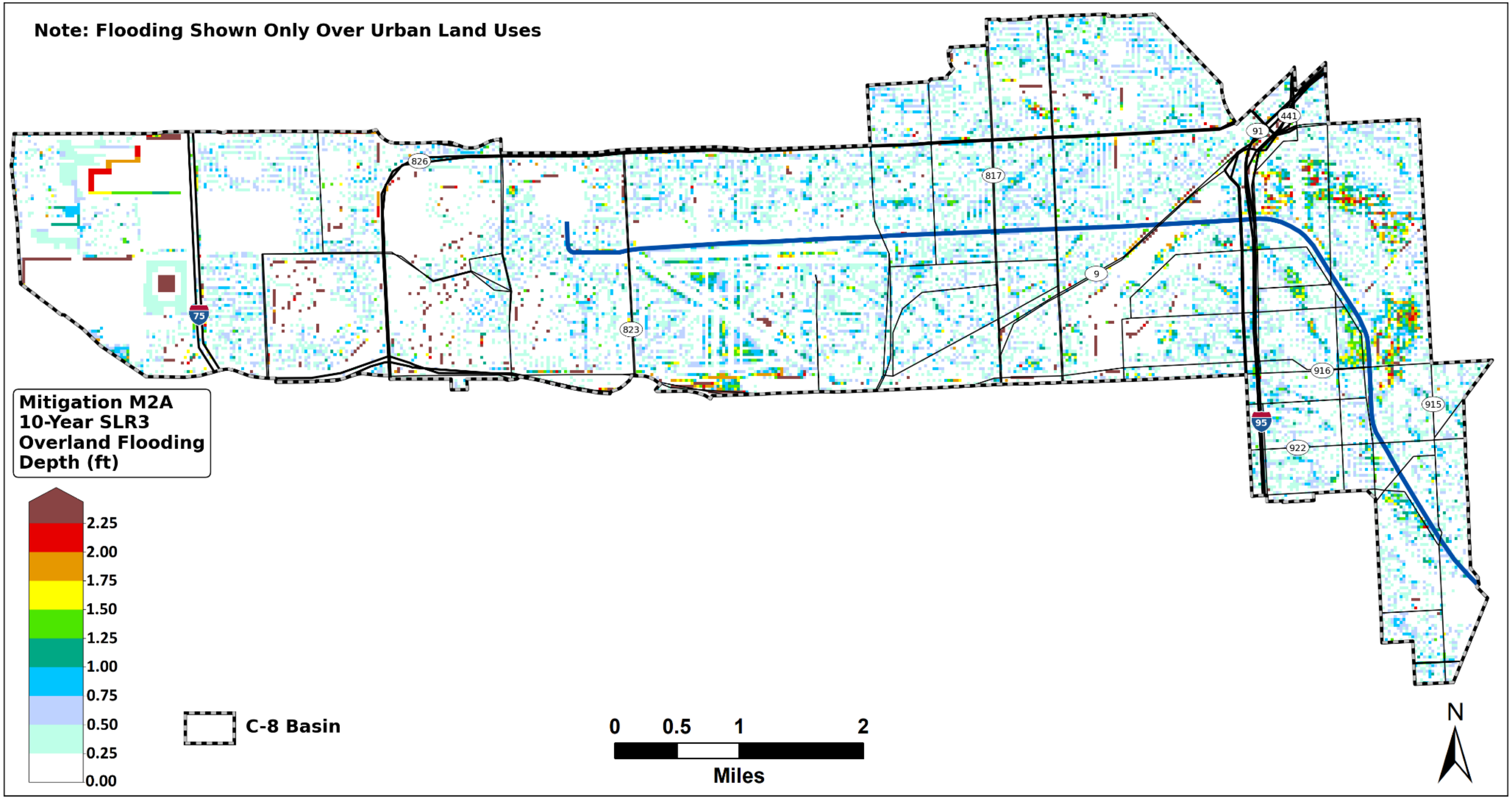


Figure B- 18: C-8 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2A 10-Year Sea Level Rise 3 Design Storm Event

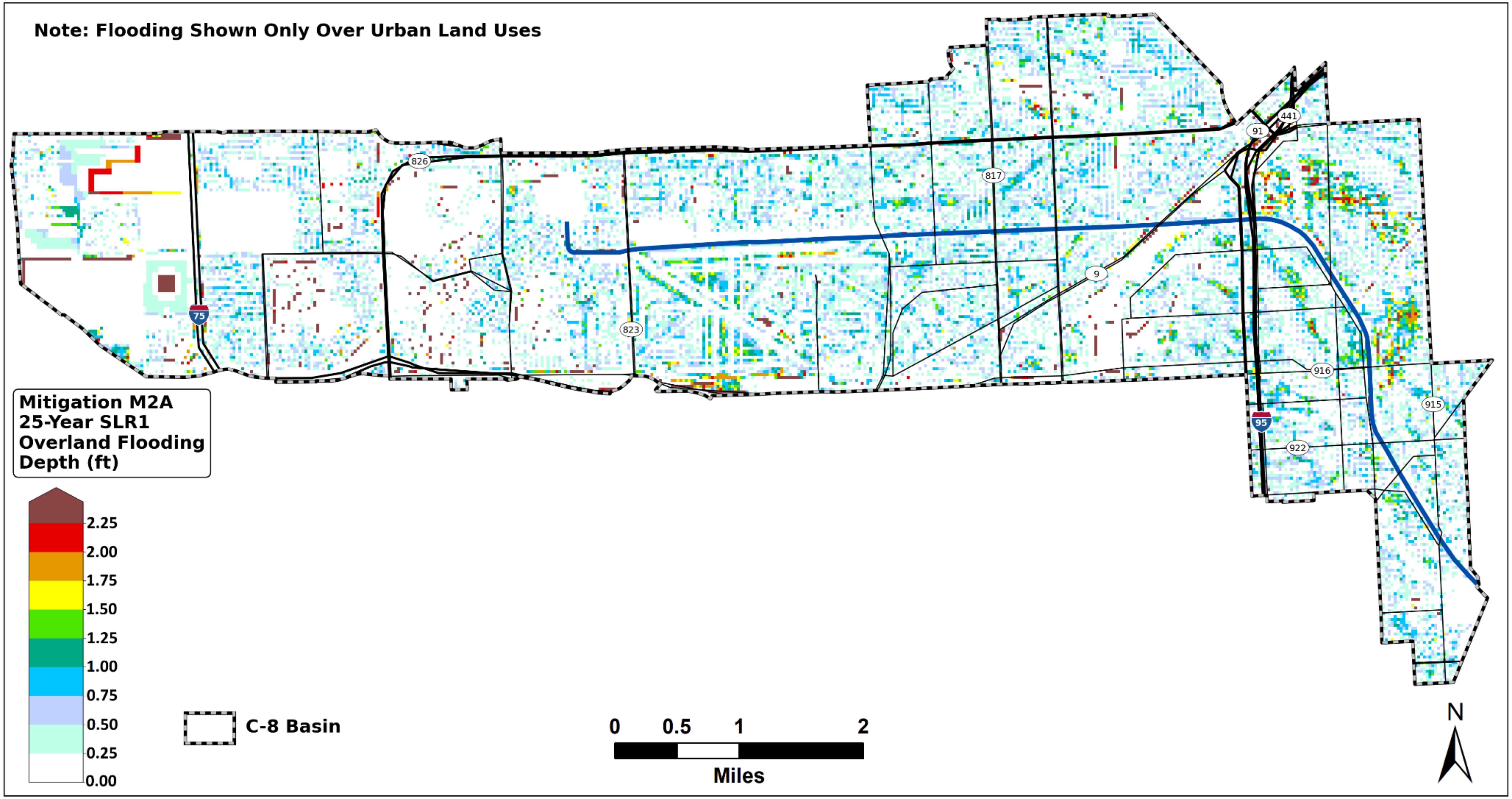


Figure B- 19: C-8 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2A 25-Year Sea Level Rise 1 Design Storm Event

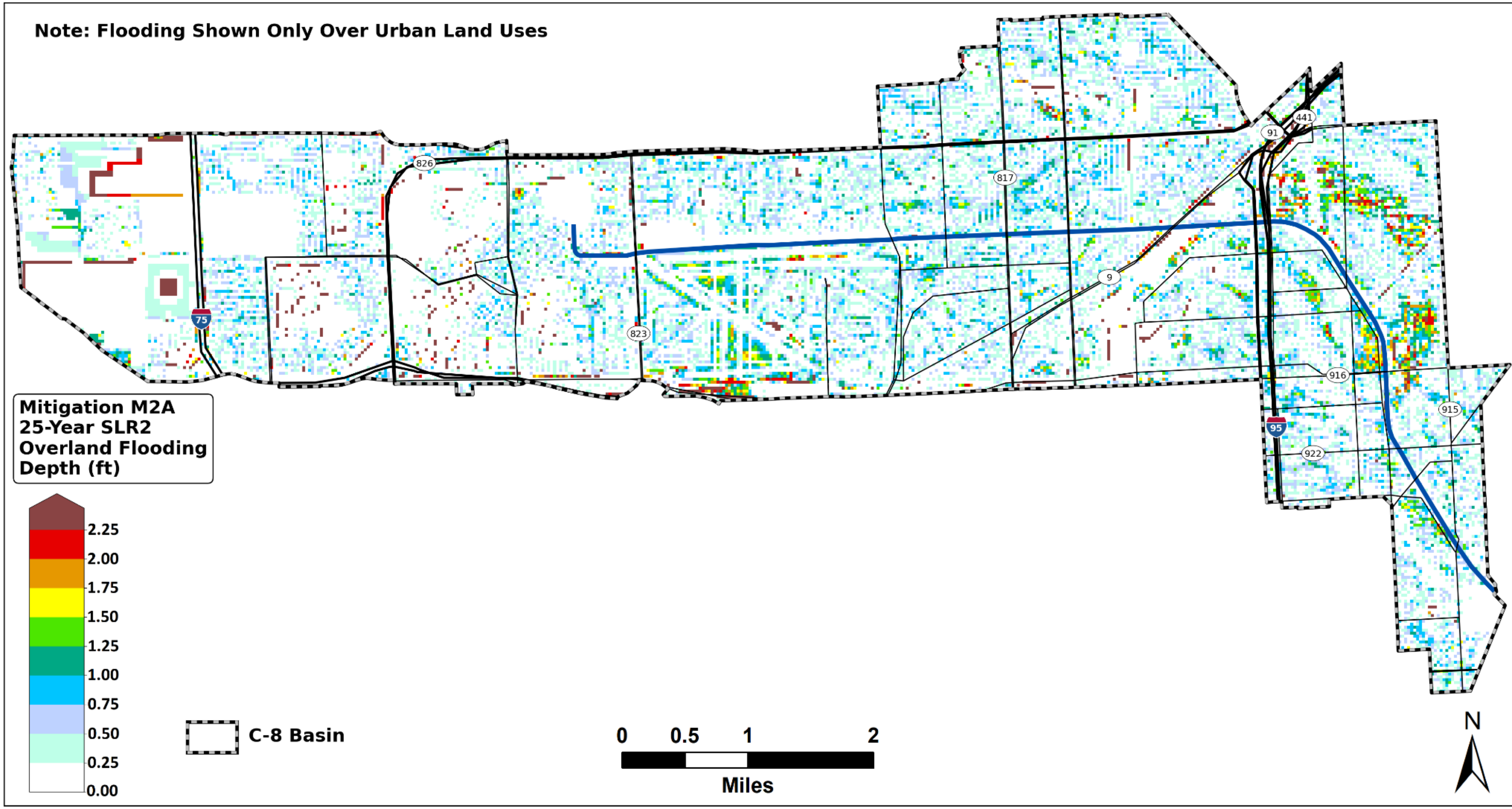


Figure B- 20: C-8 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2A 25-Year Sea Level Rise 2 Design Storm Event

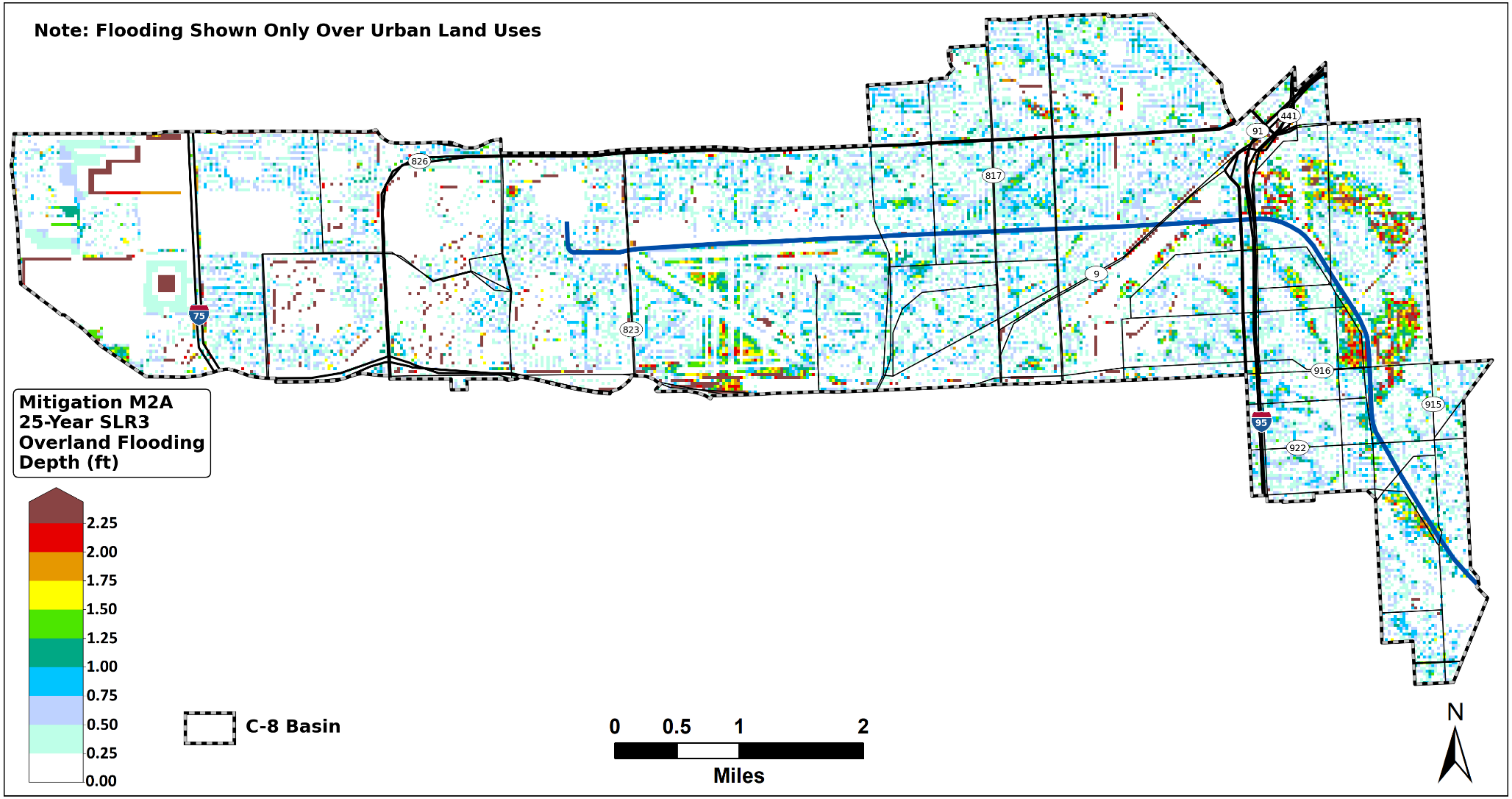


Figure B- 21: C-8 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2A 25-Year Sea Level Rise 3 Design Storm Event

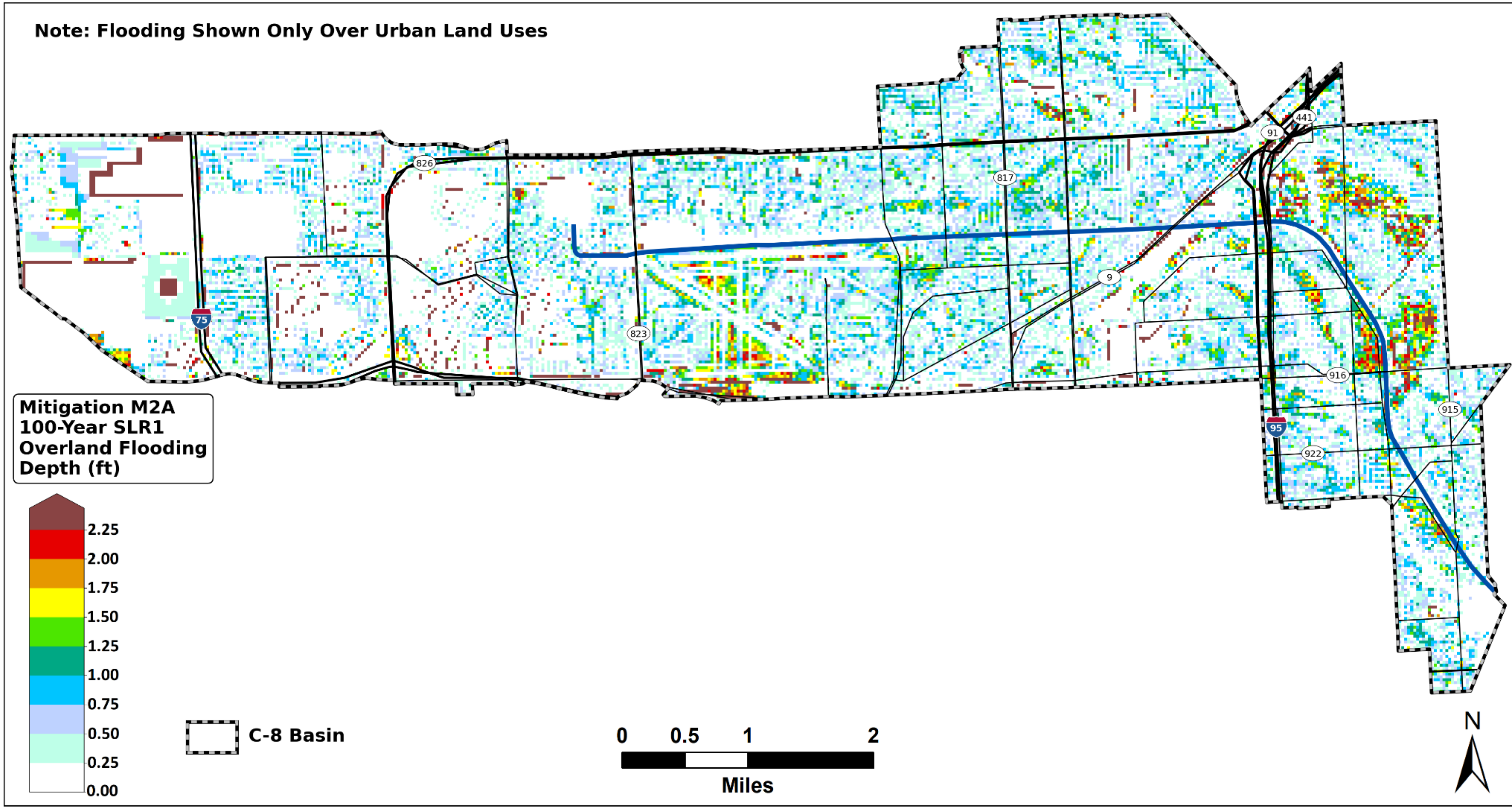


Figure B- 22: C-8 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2A 100-Year Sea Level Rise 1 Design Storm Event

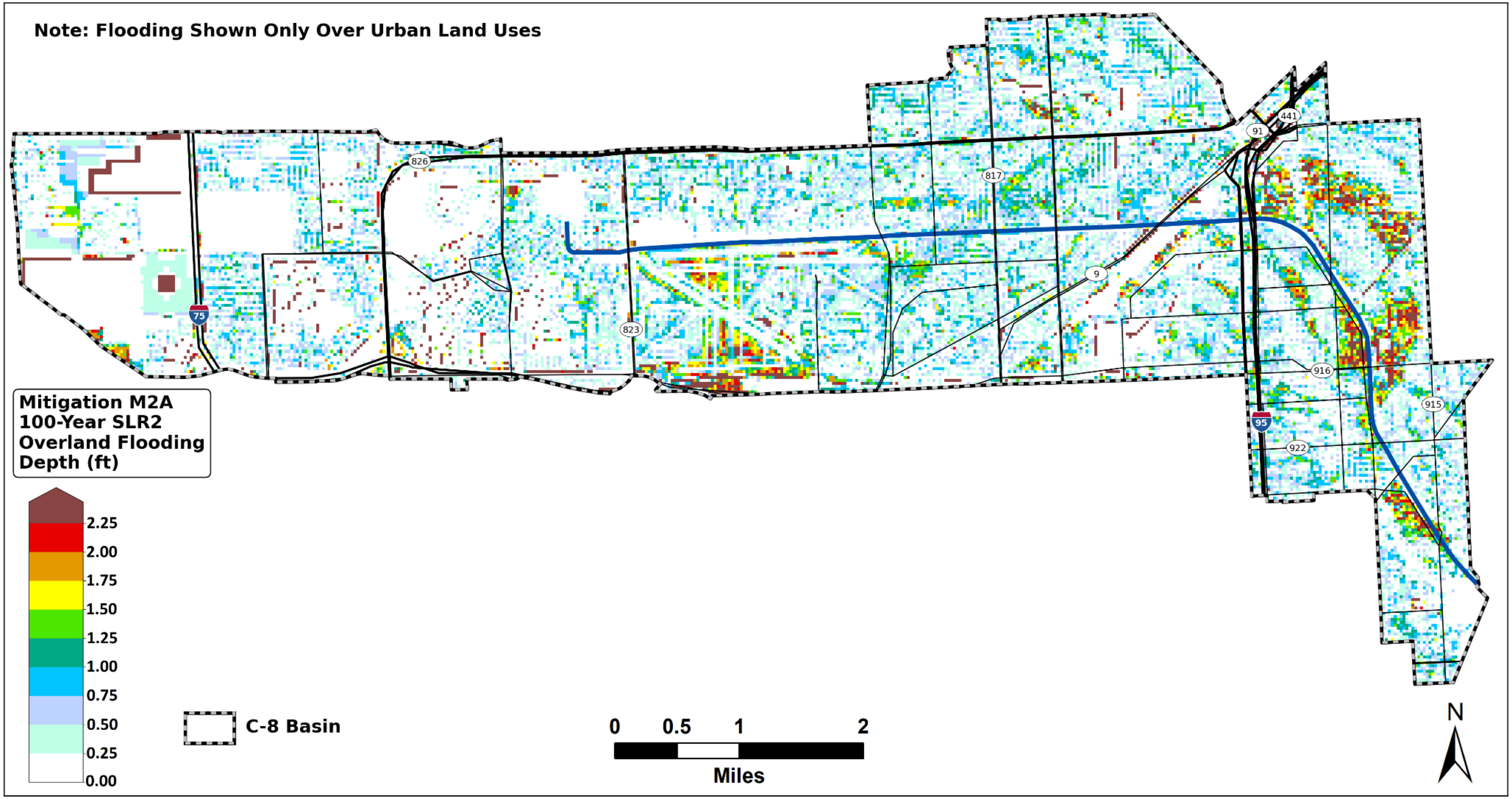


Figure B- 23: C-8 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2A 100-Year Sea Level Rise 2 Design Storm Event

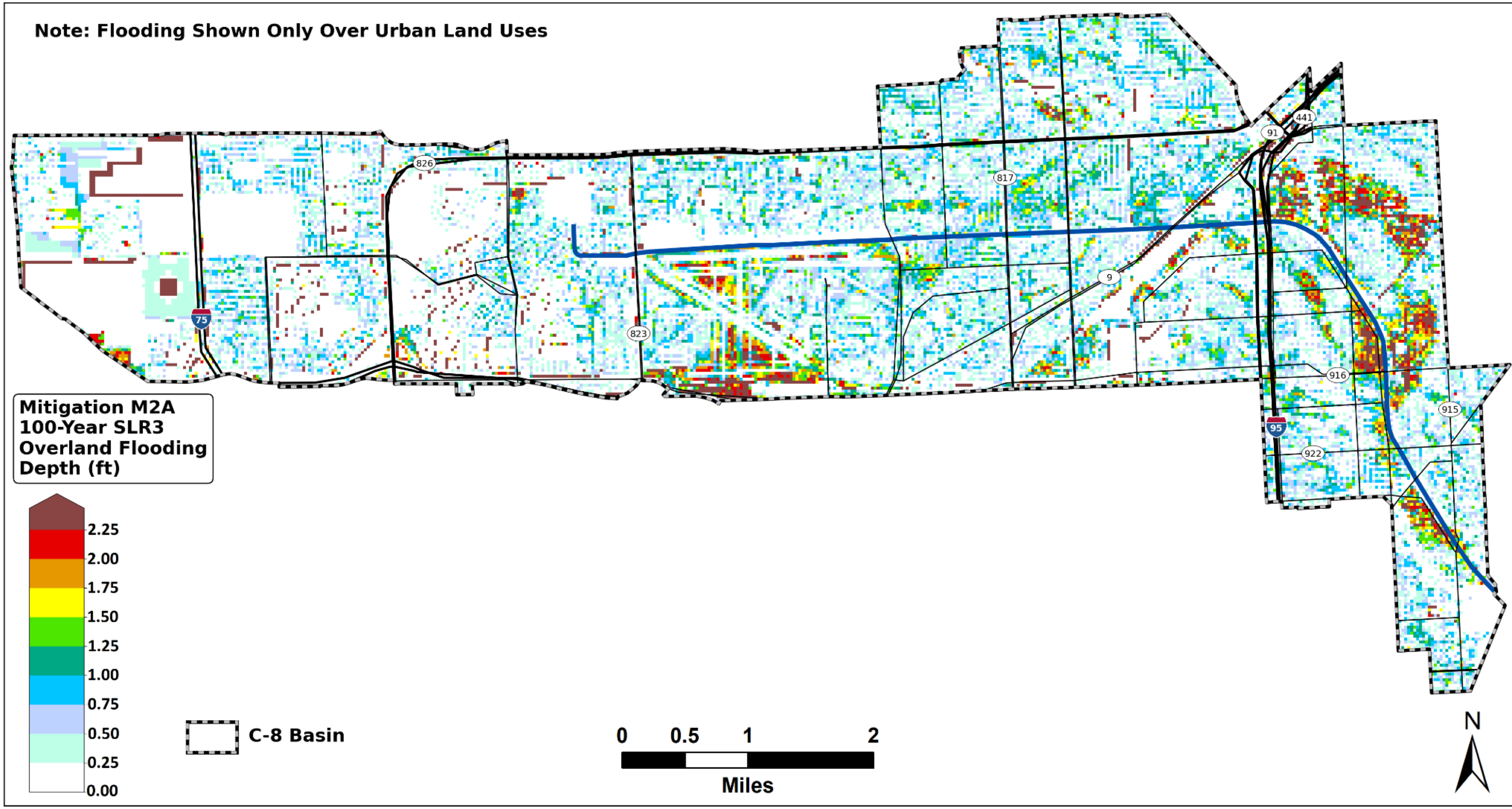


Figure B- 24: C-8 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2A 100-Year Sea Level Rise 3 Design Storm Event

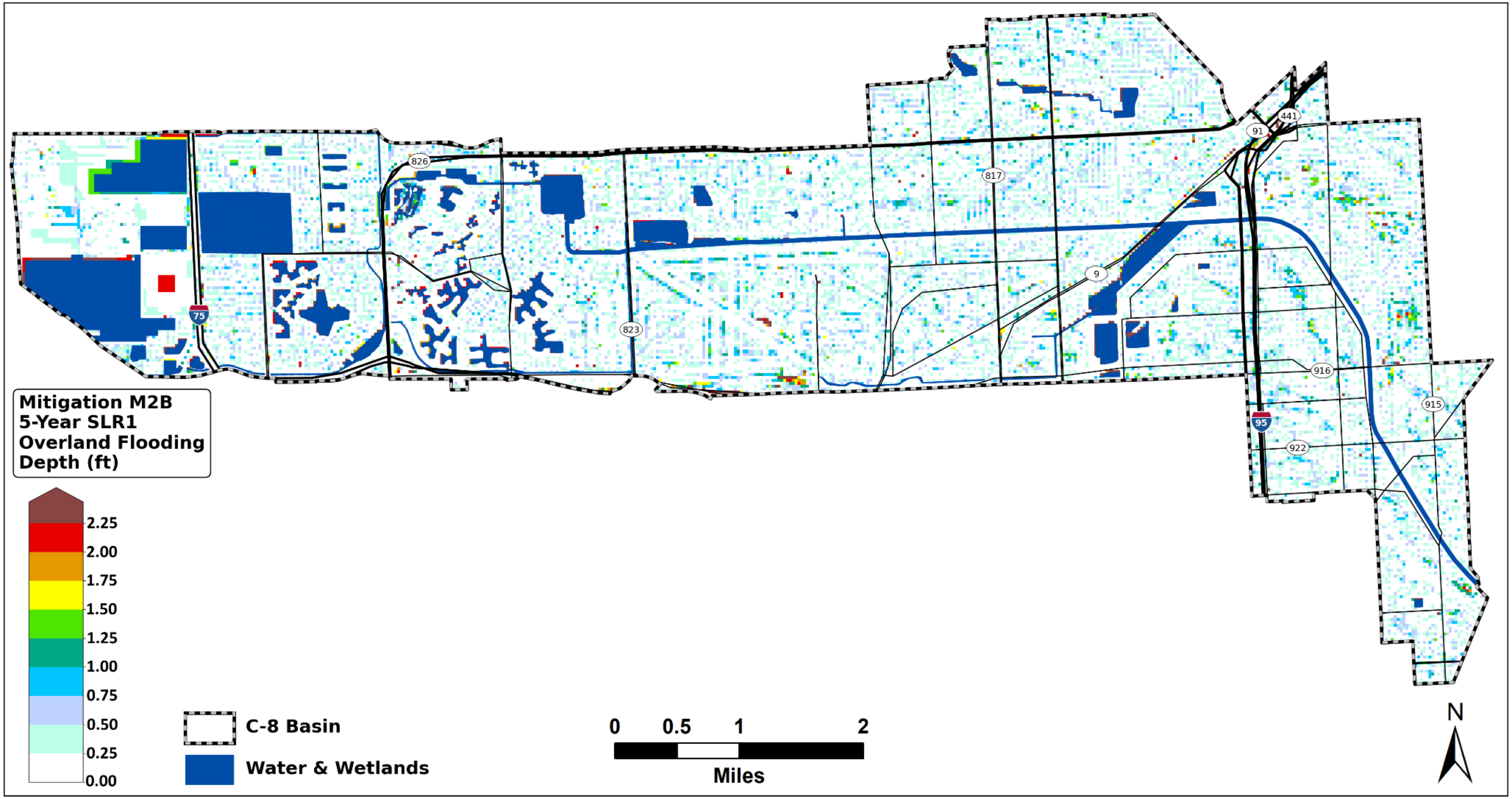


Figure B- 25: C-8 Watershed Flood Inundation Map for the Mitigation M2B 5-Year Sea Level Rise 1 Design Storm Event

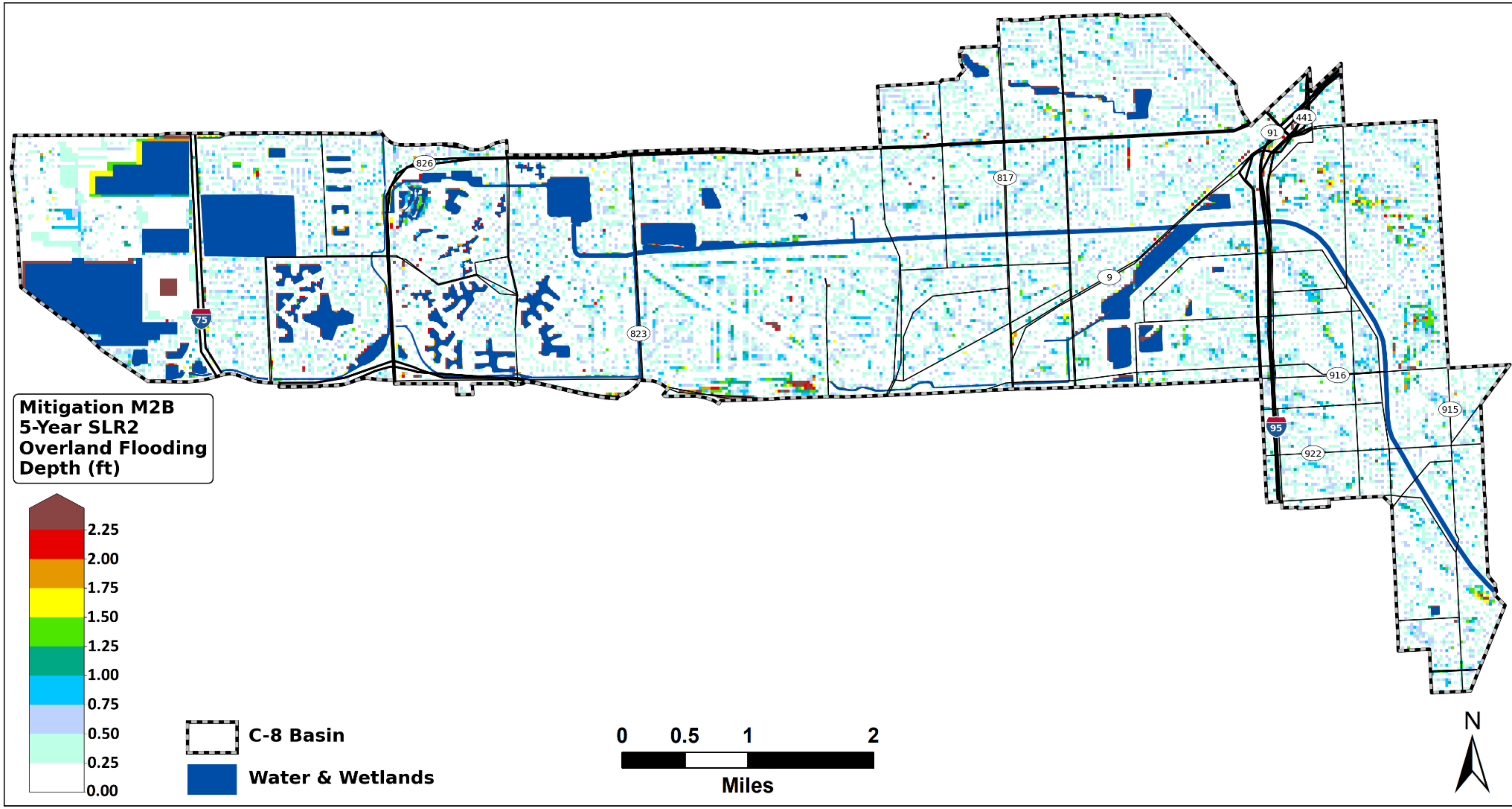


Figure B- 26: C-8 Watershed Flood Inundation Map for the Mitigation M2B 5-Year Sea Level Rise 2 Design Storm Event

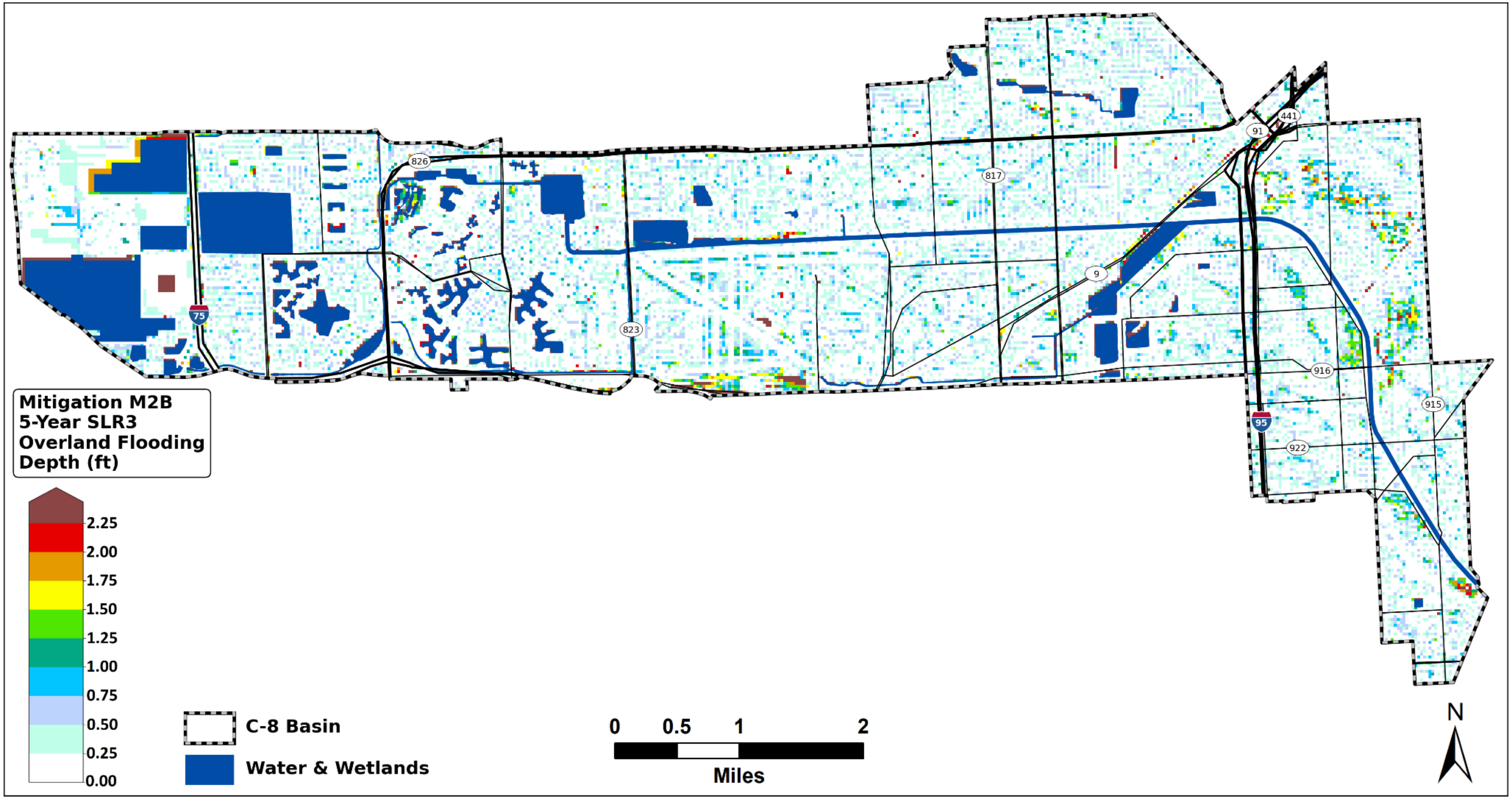


Figure B- 27: C-8 Watershed Flood Inundation Map for the Mitigation M2B 5-Year Sea Level Rise 3 Design Storm Event

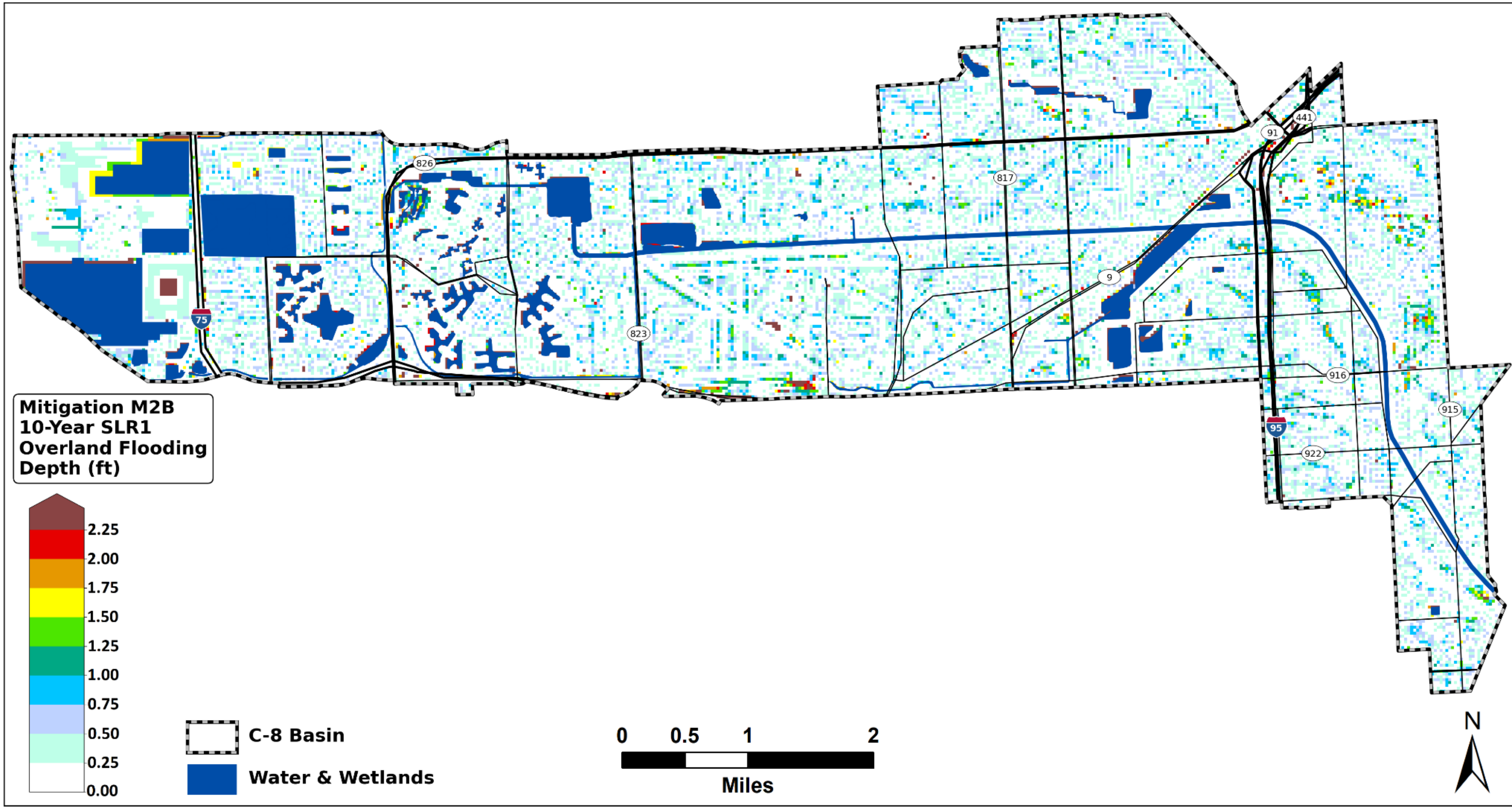


Figure B- 28: C-8 Watershed Flood Inundation Map for the Mitigation M2B 10-Year Sea Level Rise 1 Design Storm Event

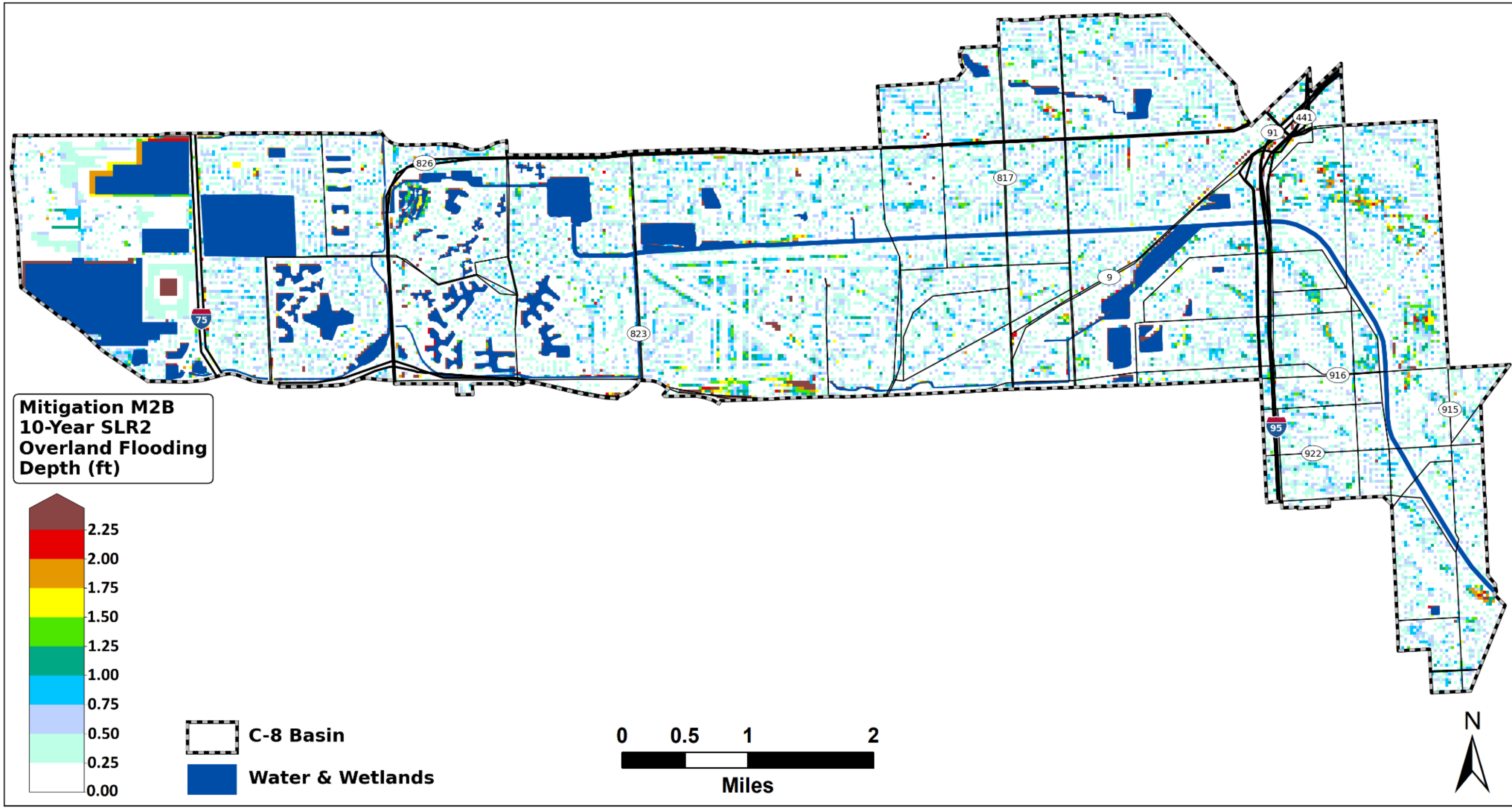


Figure B- 29: C-8 Watershed Flood Inundation Map for the Mitigation M2B 10-Year Sea Level Rise 2 Design Storm Event

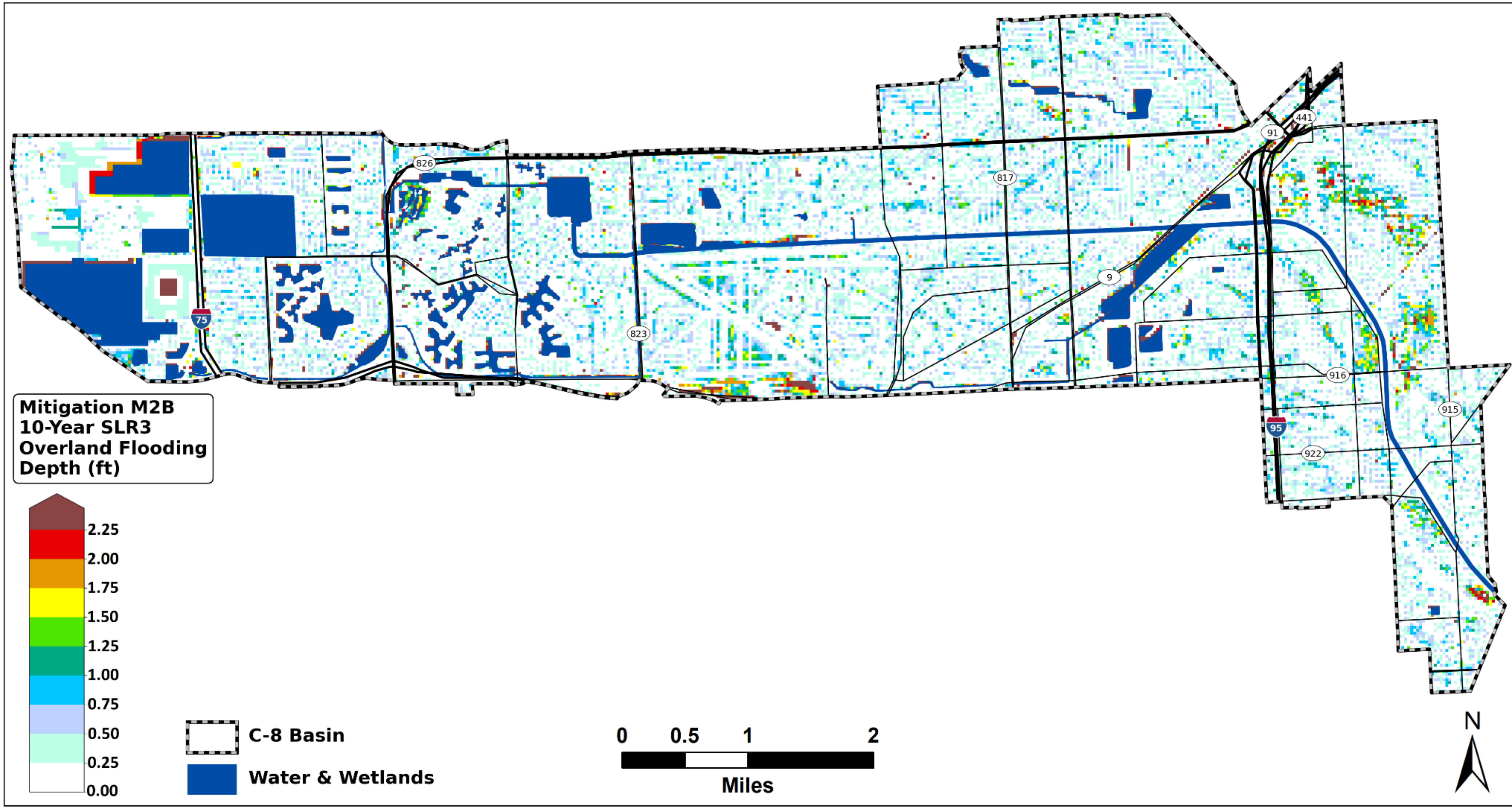


Figure B- 30: C-8 Watershed Flood Inundation Map for the Mitigation M2B 10-Year Sea Level Rise 3 Design Storm Event

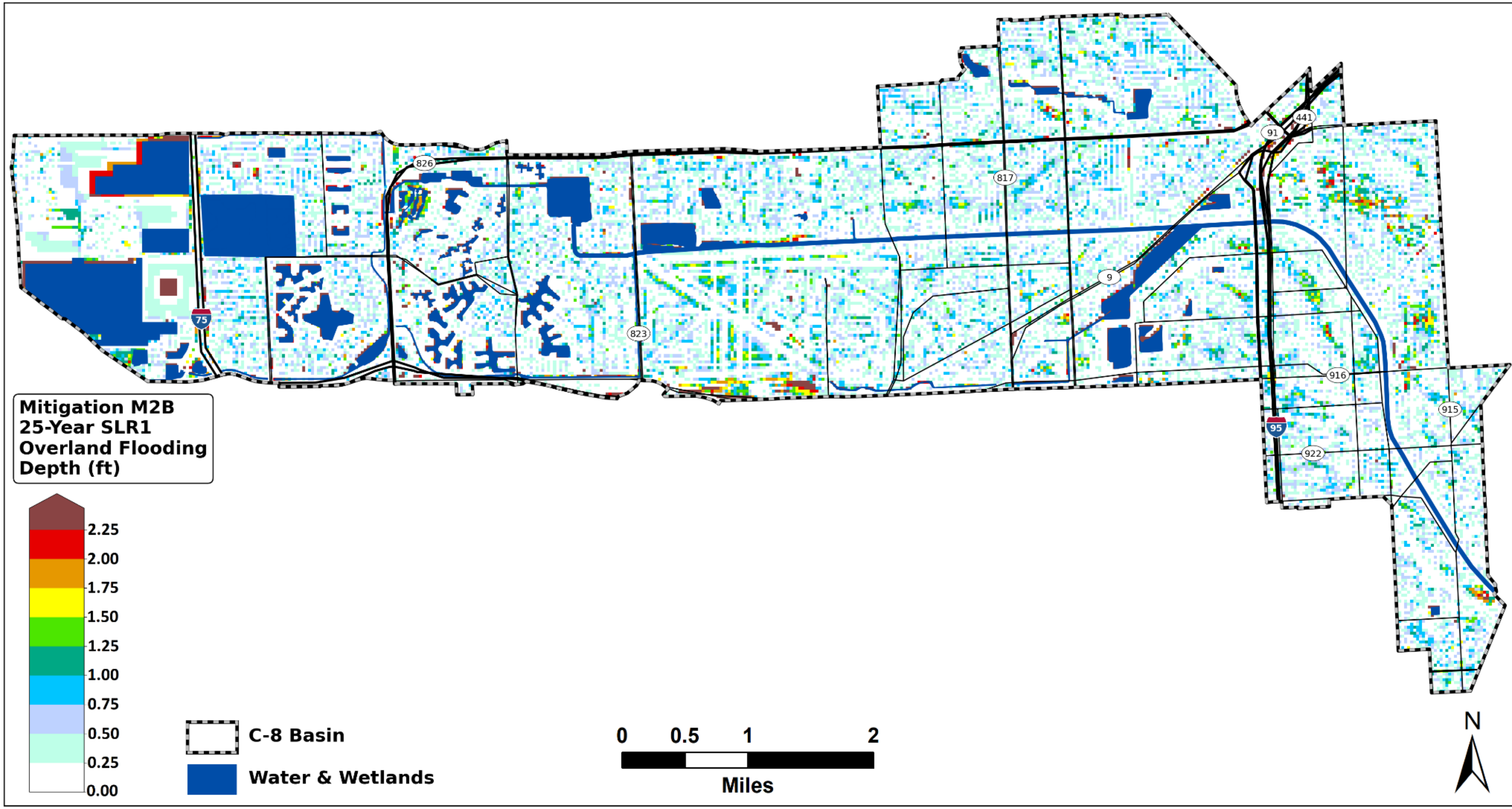


Figure B- 31: C-8 Watershed Flood Inundation Map for the Mitigation M2B 25-Year Sea Level Rise 1 Design Storm Event

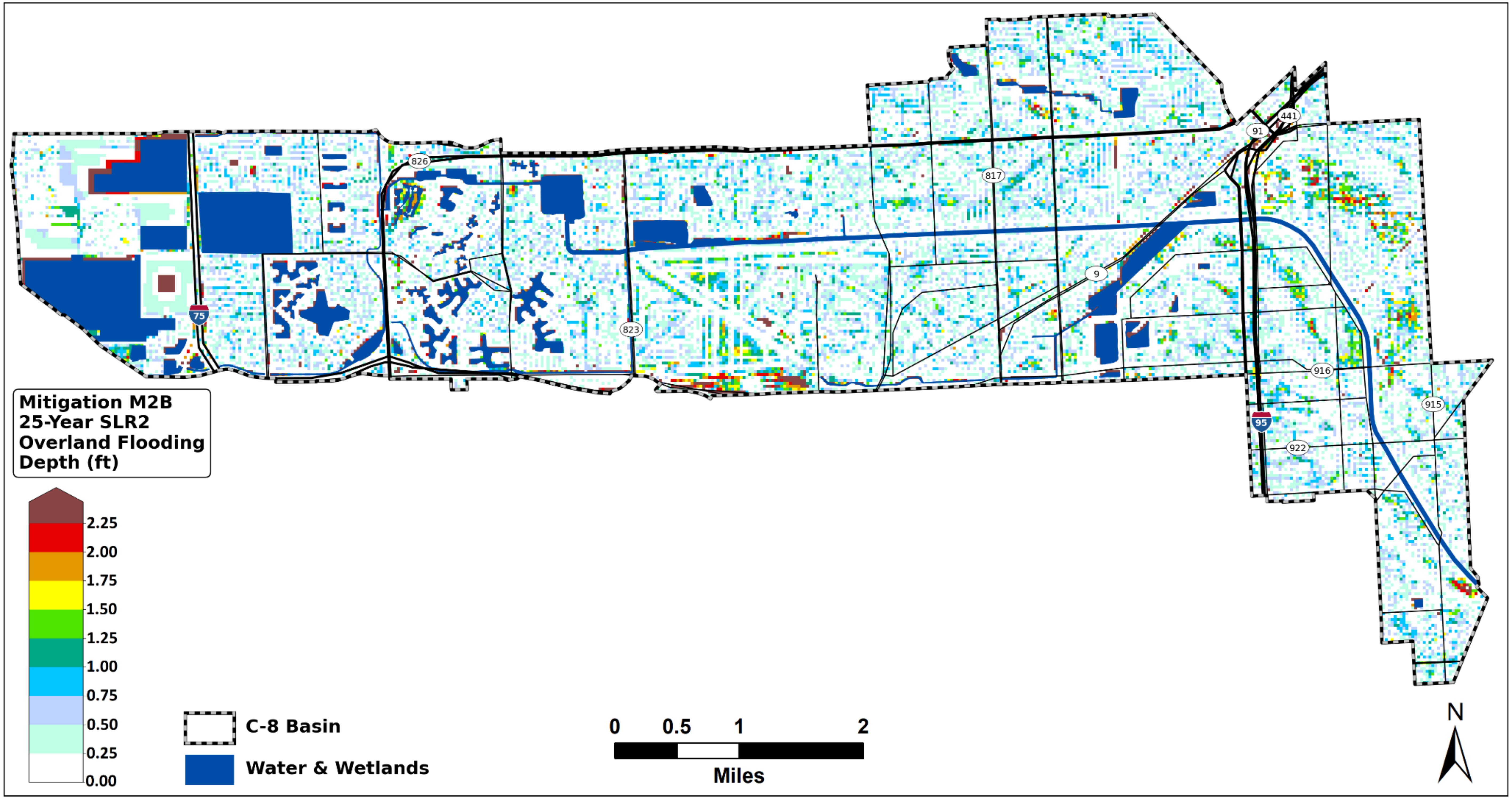


Figure B- 32: C-8 Watershed Flood Inundation Map for the Mitigation M2B 25-Year Sea Level Rise 2 Design Storm Event

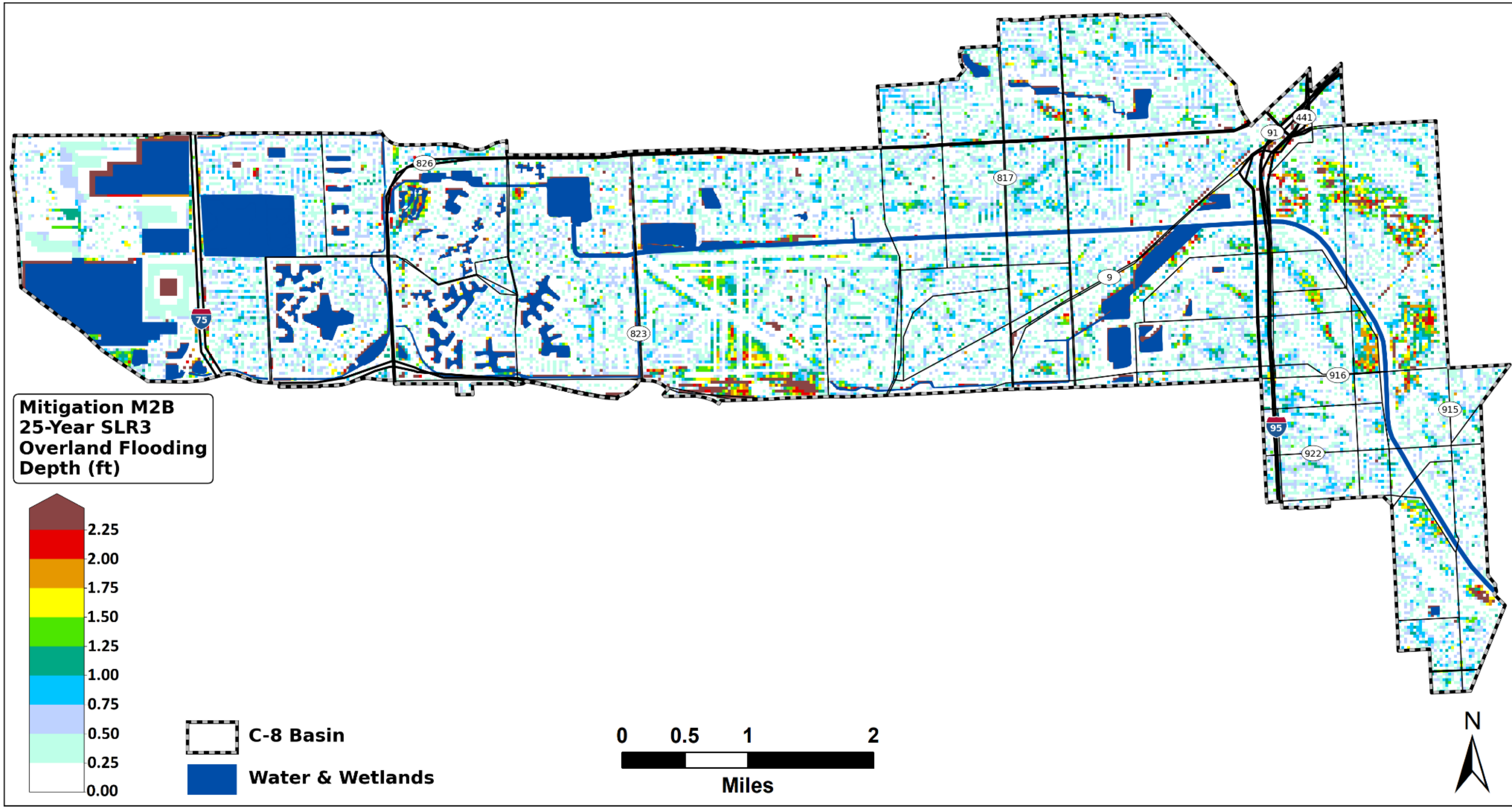


Figure B- 33: C-8 Watershed Flood Inundation Map for the Mitigation M2B 25-Year Sea Level Rise 3 Design Storm Event

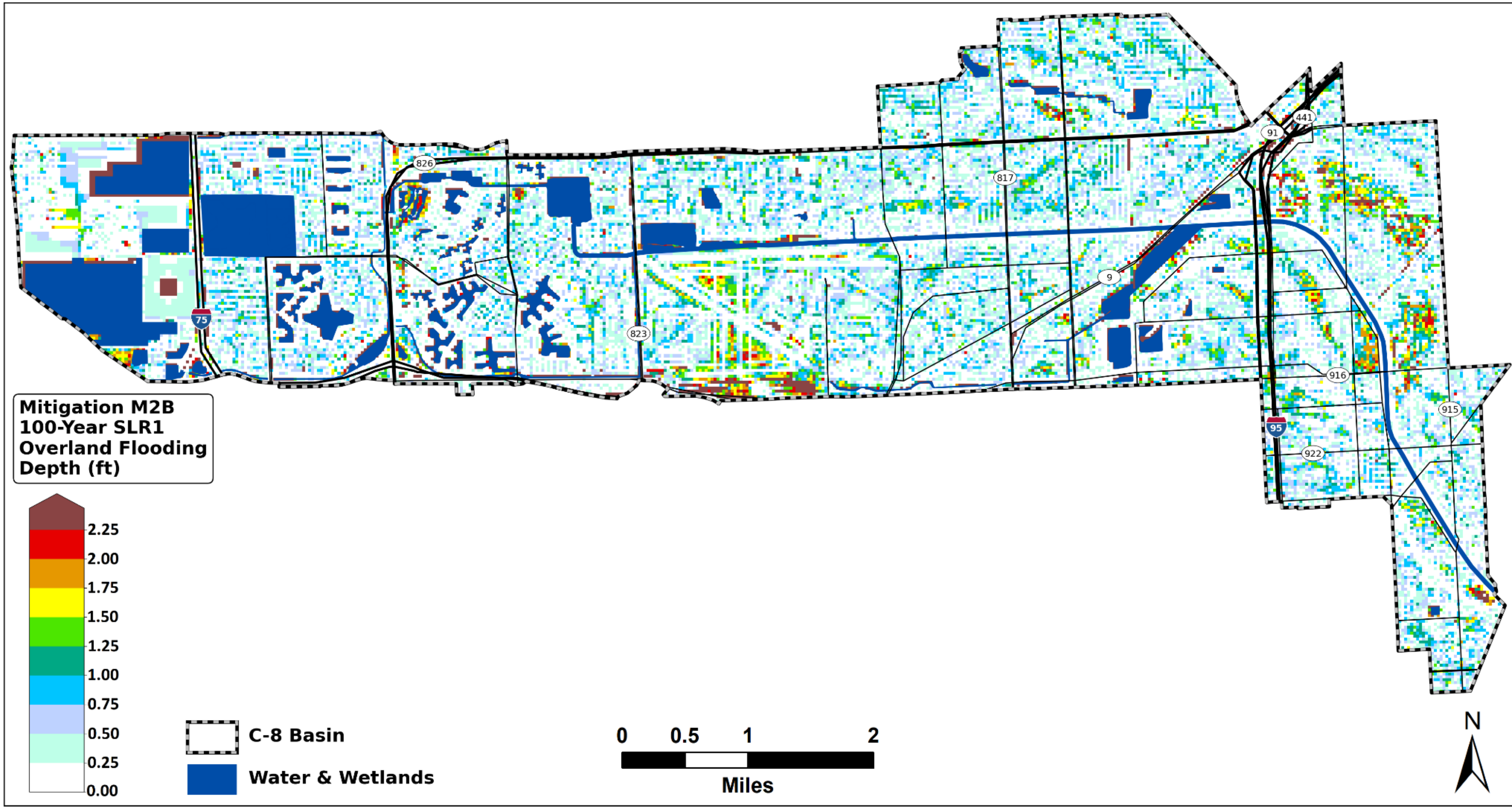


Figure B- 34: C-8 Watershed Flood Inundation Map for the Mitigation M2B 100-Year Sea Level Rise 1 Design Storm Event

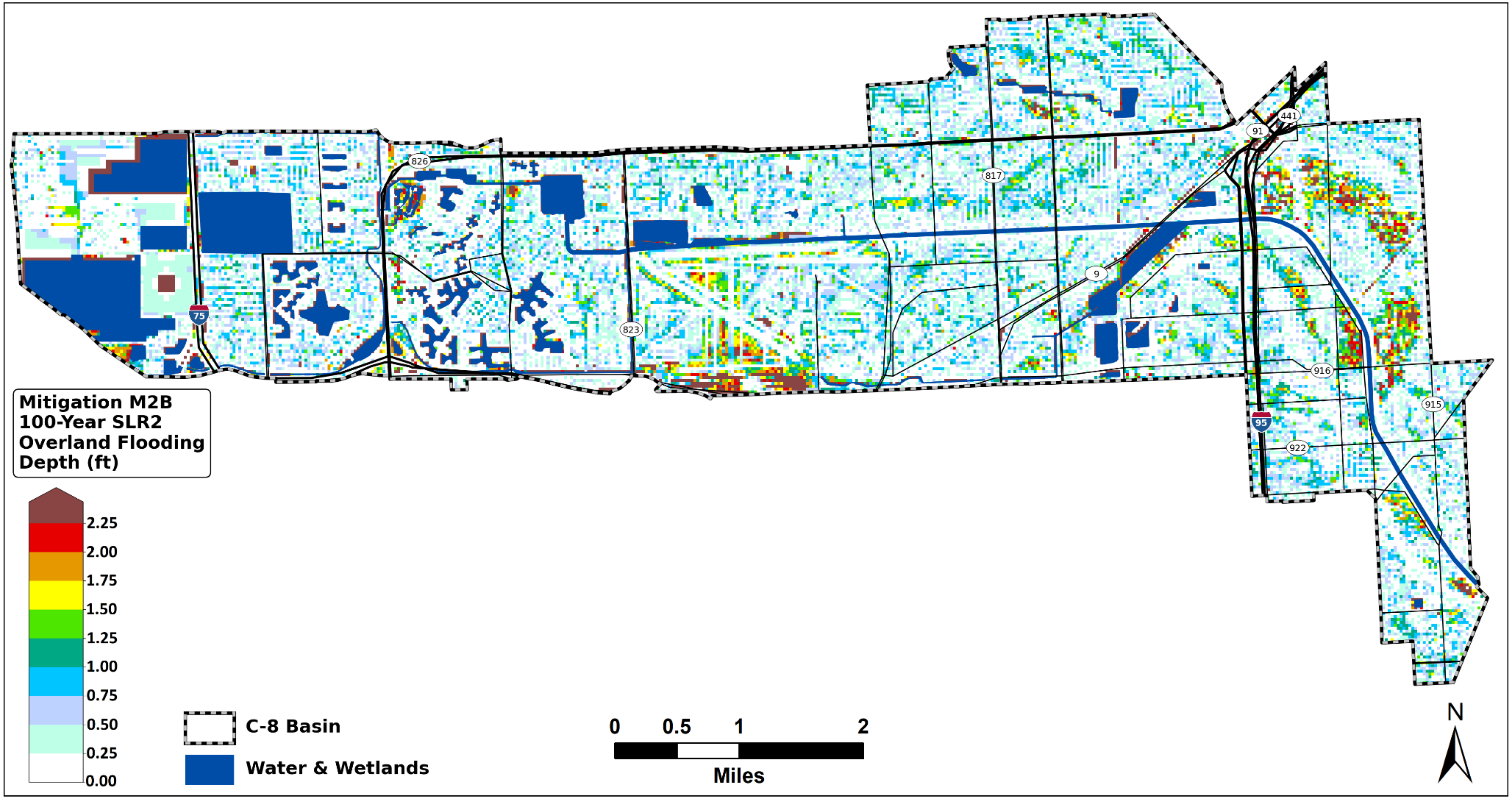


Figure B- 35: C-8 Watershed Flood Inundation Map for the Mitigation M2B 100-Year Sea Level Rise 2 Design Storm Event

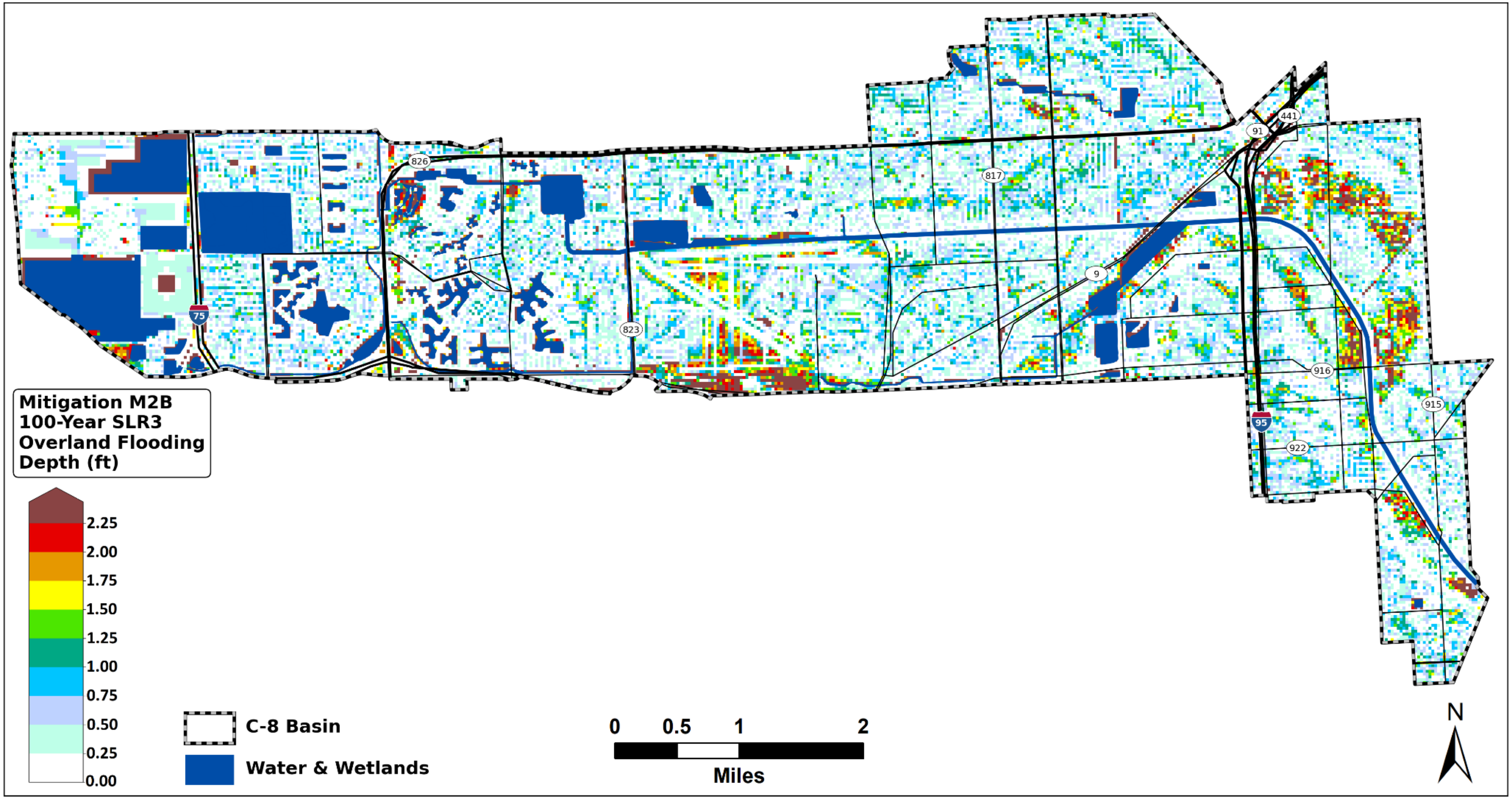


Figure B- 36: C-8 Watershed Flood Inundation Map for the Mitigation M2B 100-Year Sea Level Rise 3 Design Storm Event

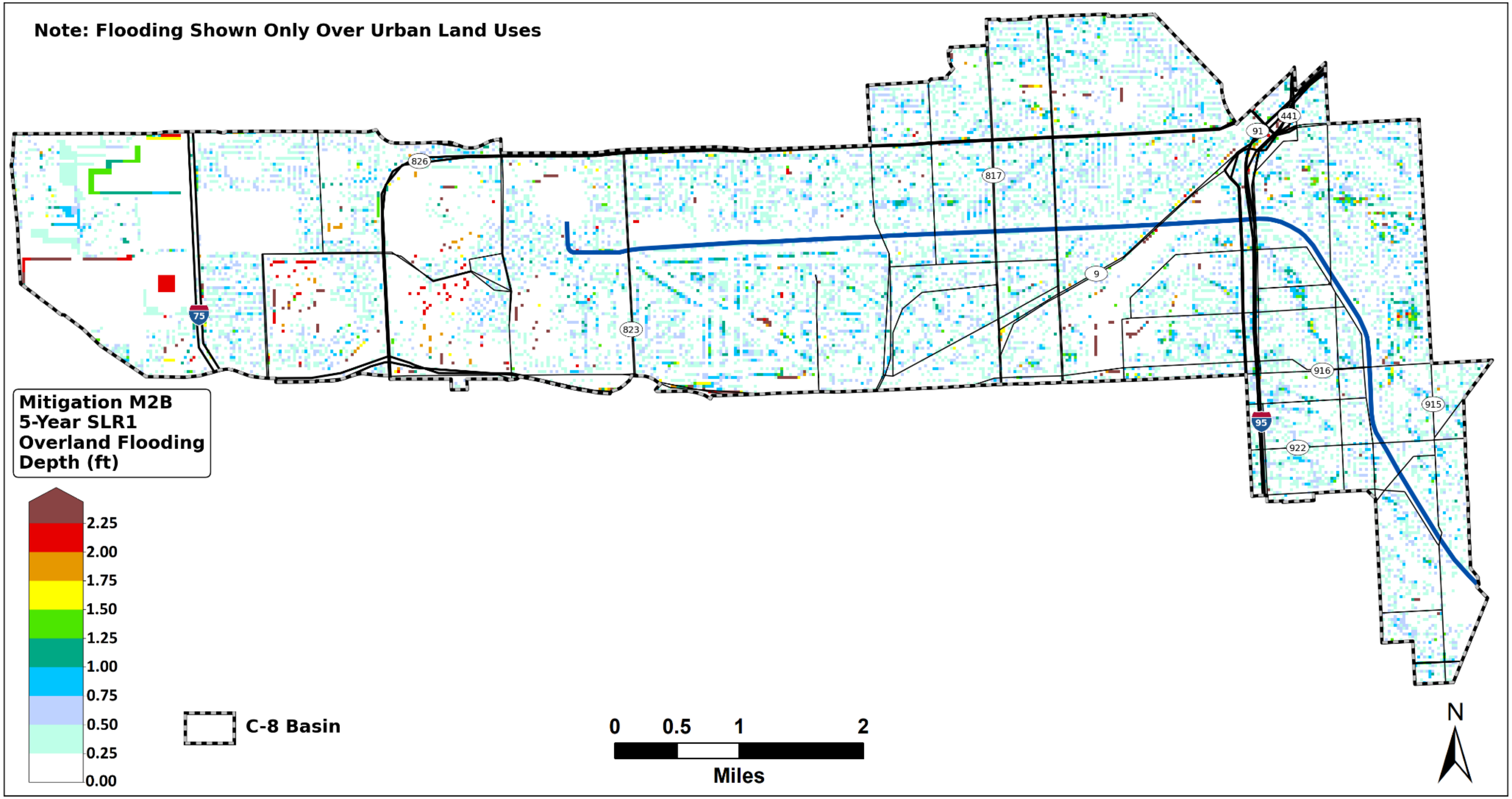


Figure B- 37: C-8 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2B 5-Year Sea Level Rise 1 Design Storm Event

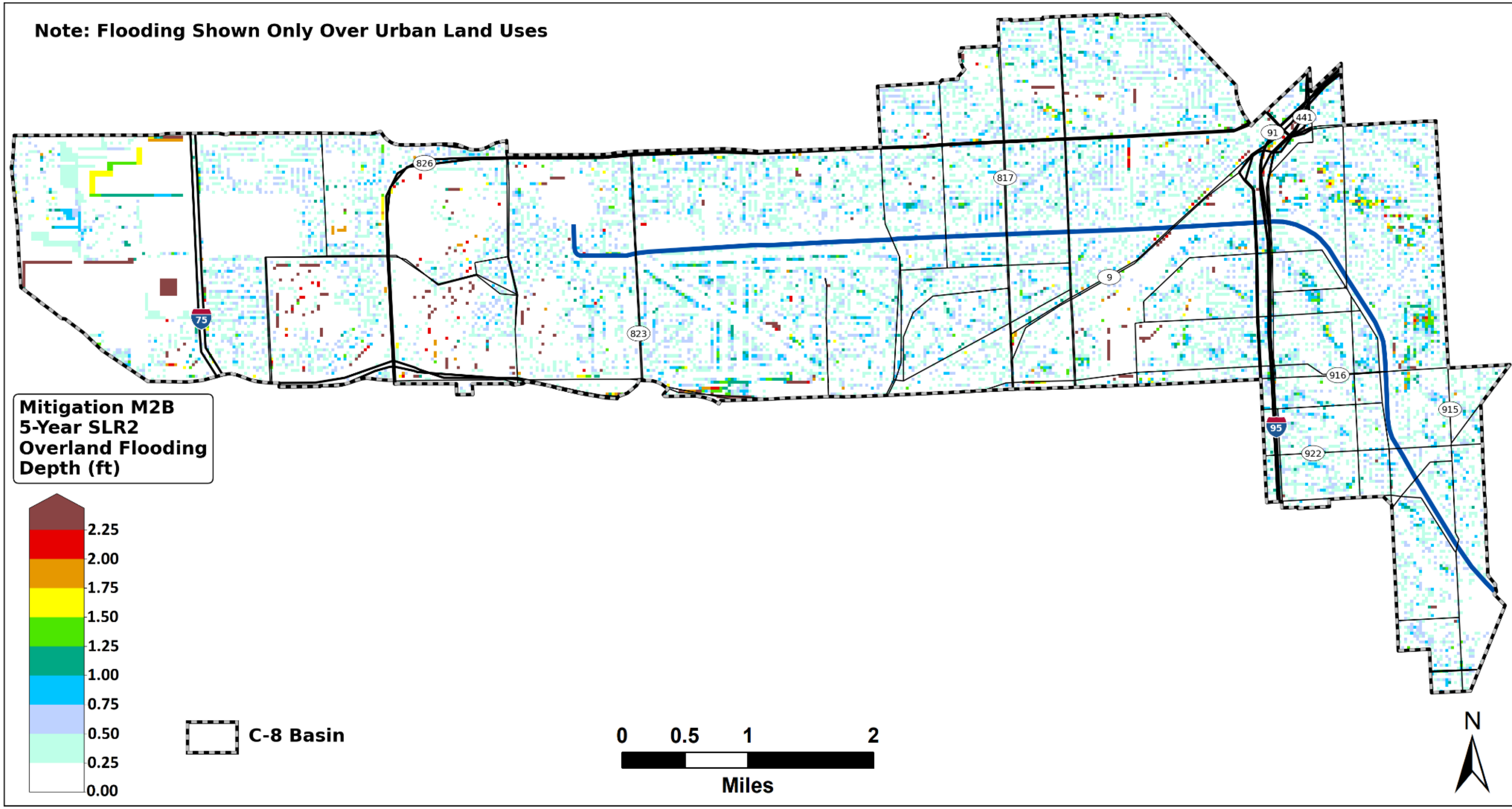


Figure B- 38: C-8 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2B 5-Year Sea Level Rise 2 Design Storm Event

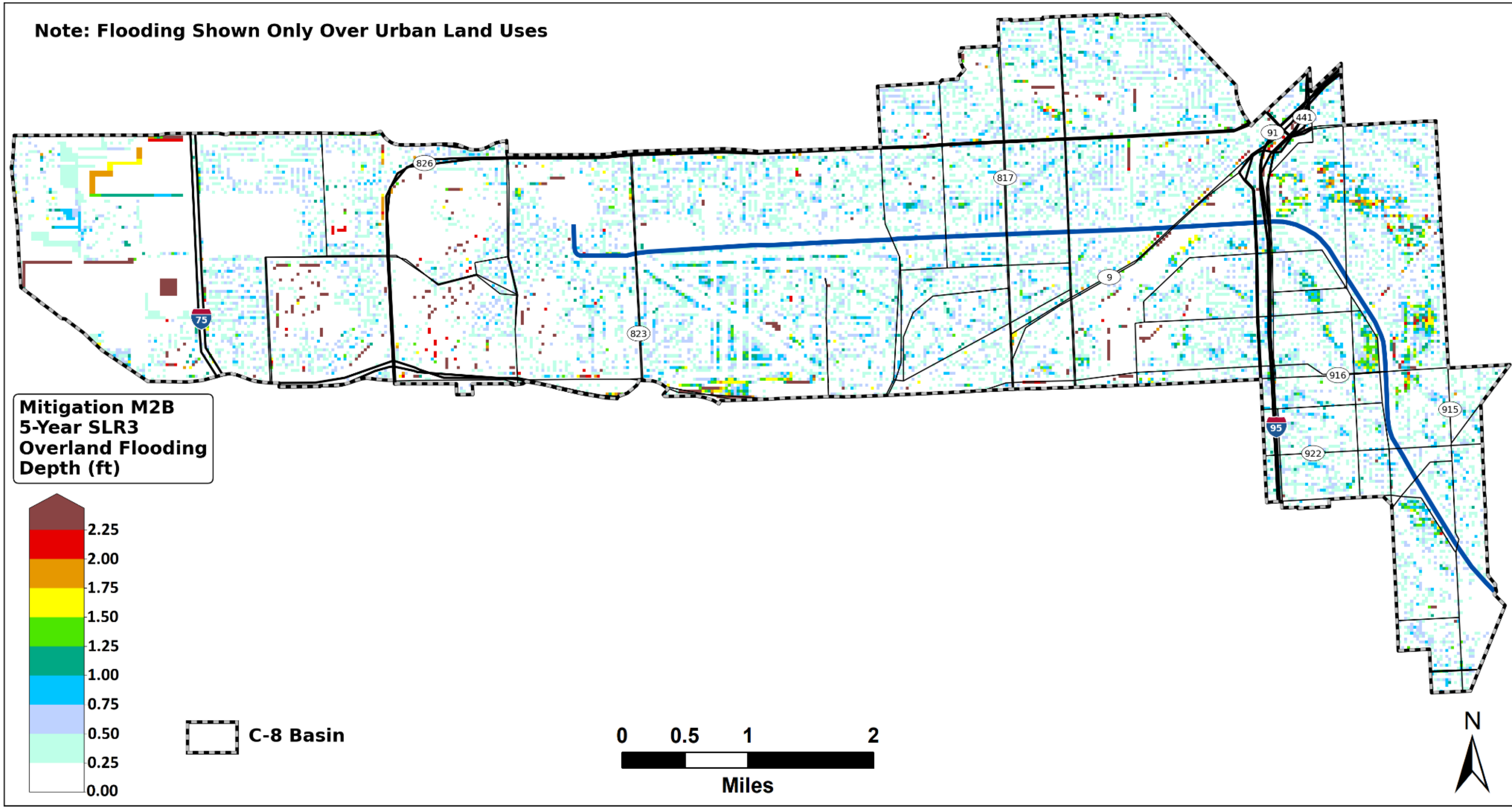


Figure B- 39: C-8 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2B 5-Year Sea Level Rise 3 Design Storm Event

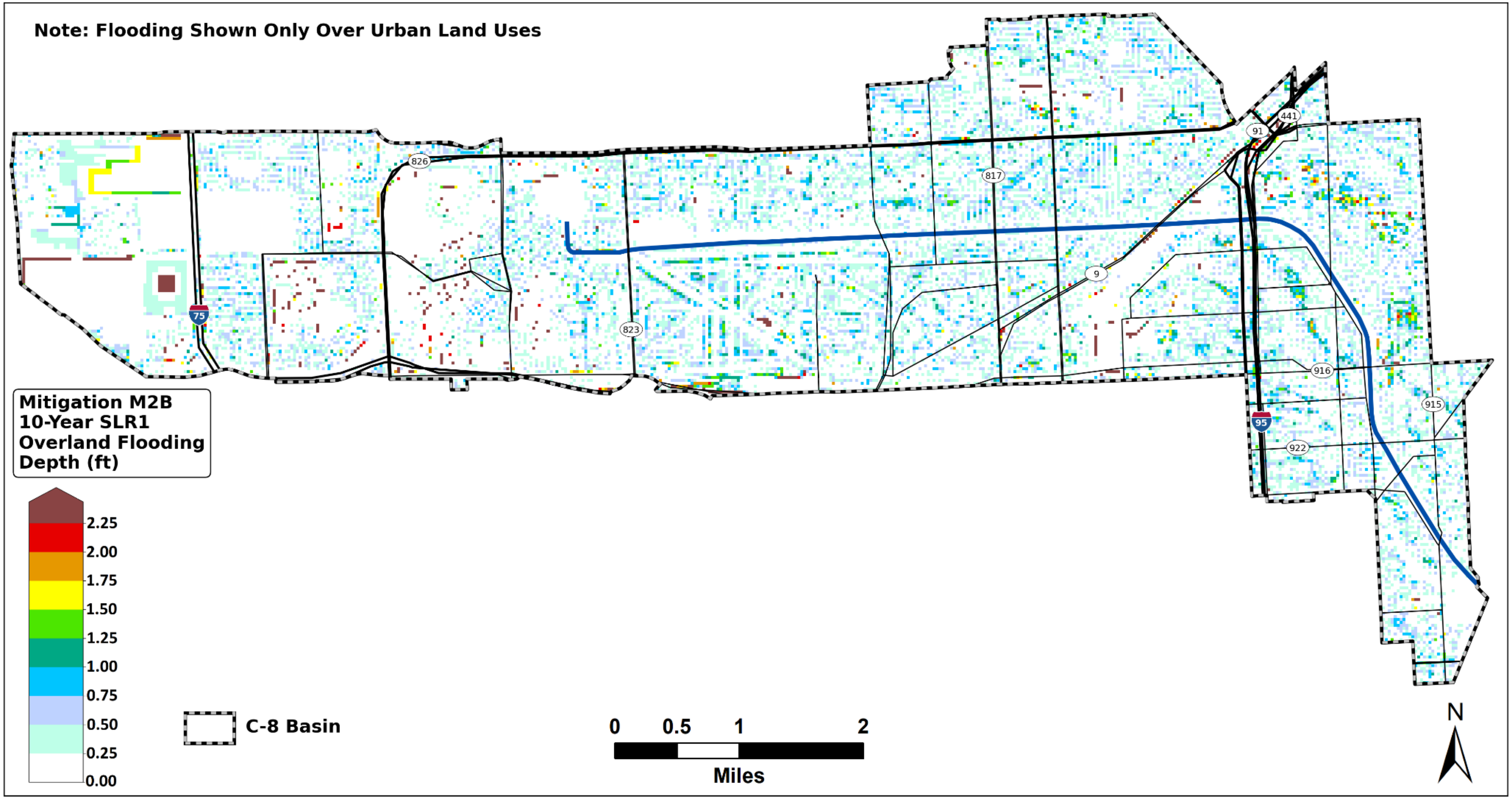


Figure B- 40: C-8 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2B 10-Year Sea Level Rise 1 Design Storm Event

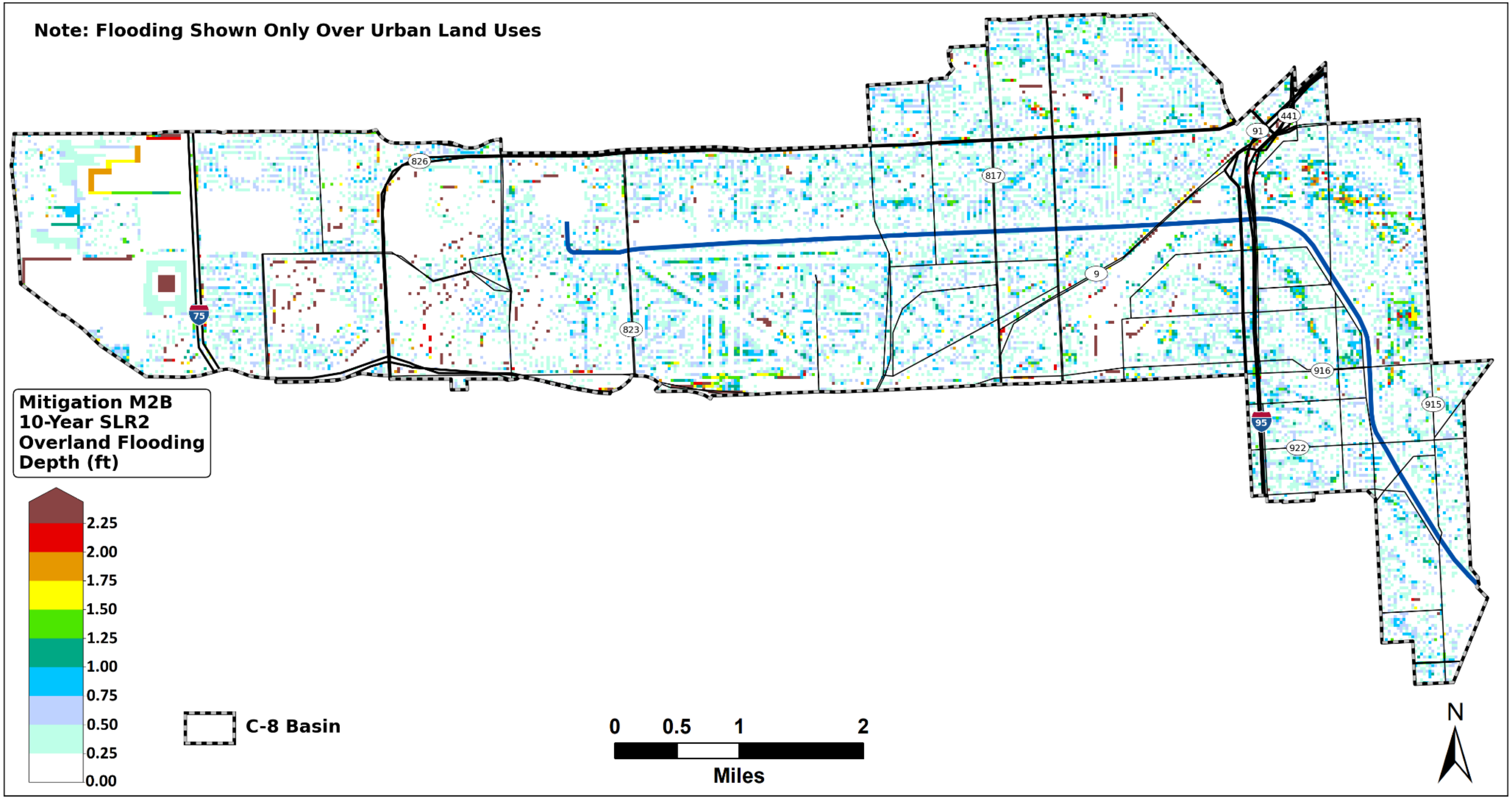


Figure B- 41: C-8 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2B 10-Year Sea Level Rise 2 Design Storm Event

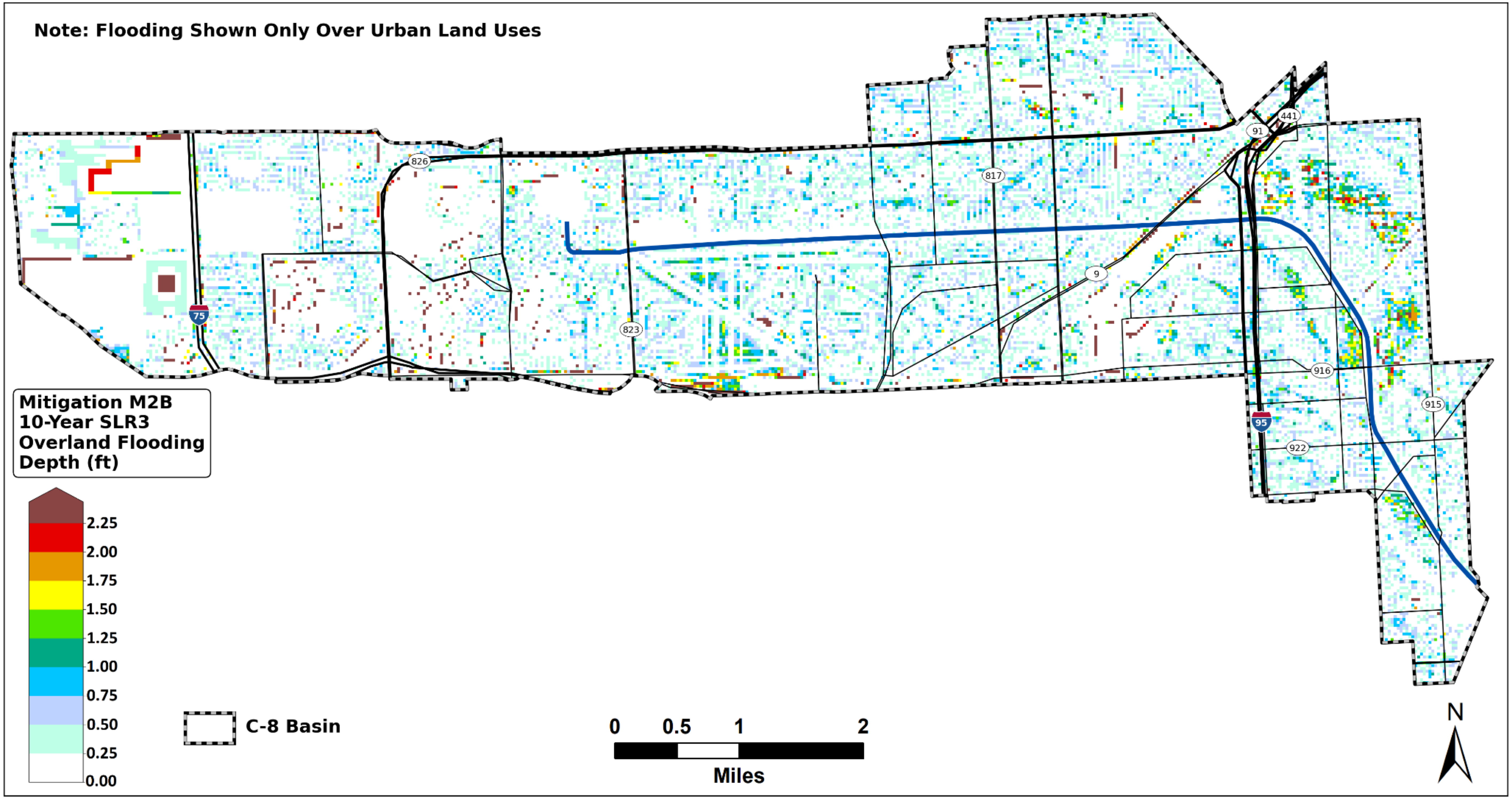


Figure B- 42: C-8 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2B 10-Year Sea Level Rise 3 Design Storm Event

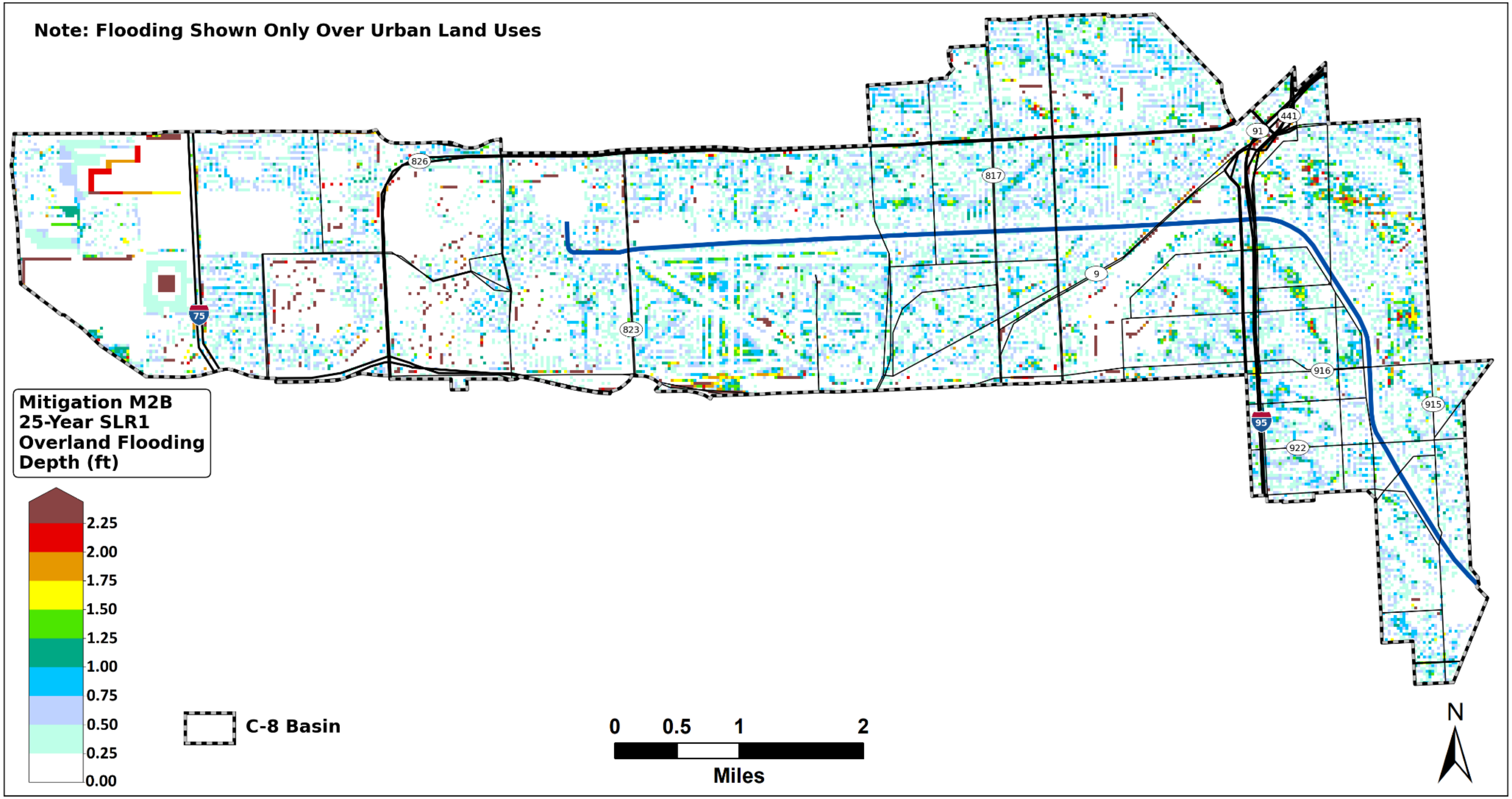


Figure B- 43: C-8 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2B 25-Year Sea Level Rise 1 Design Storm Event

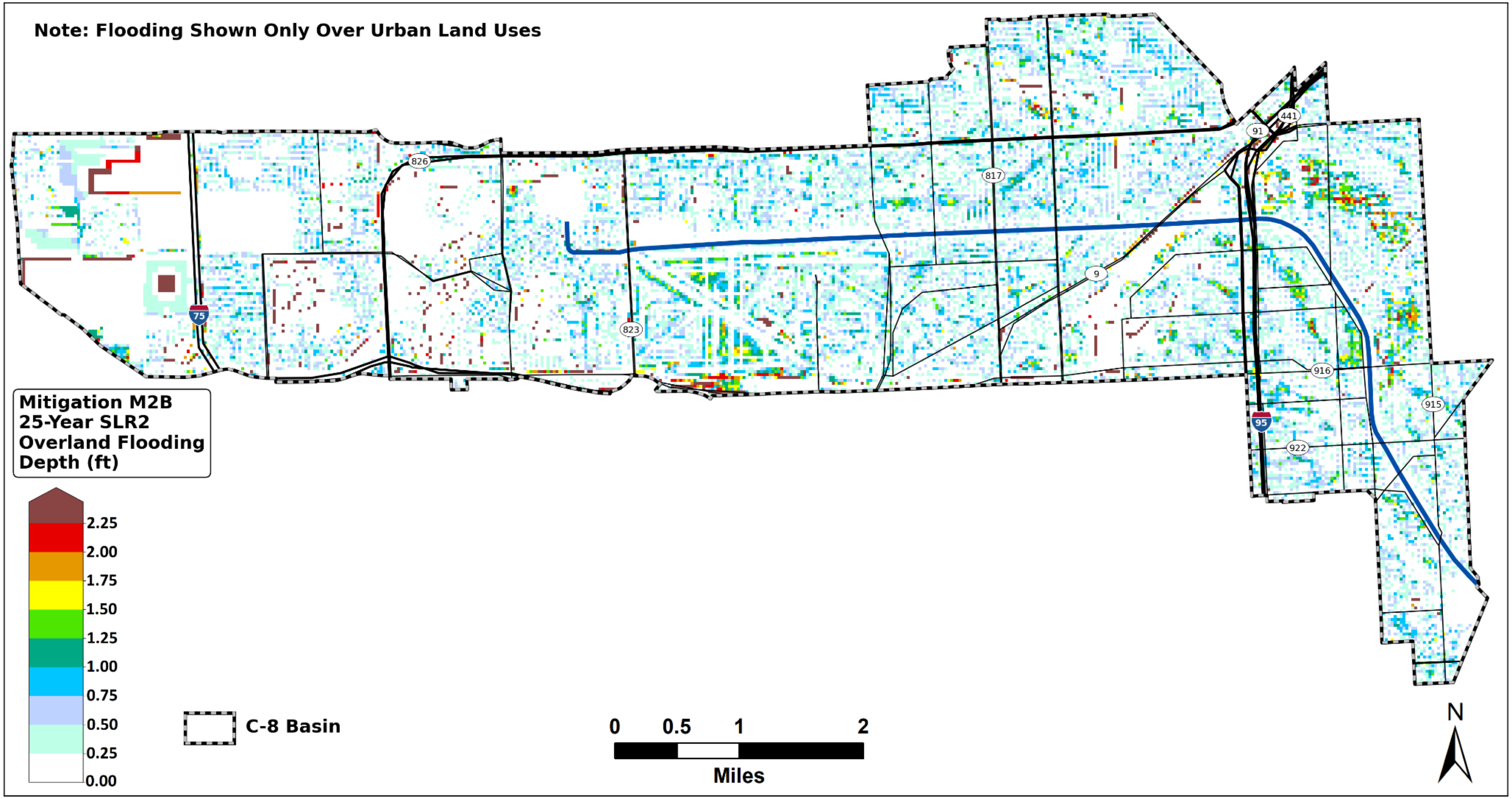


Figure B- 44: C-8 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2B 25-Year Sea Level Rise 2 Design Storm Event

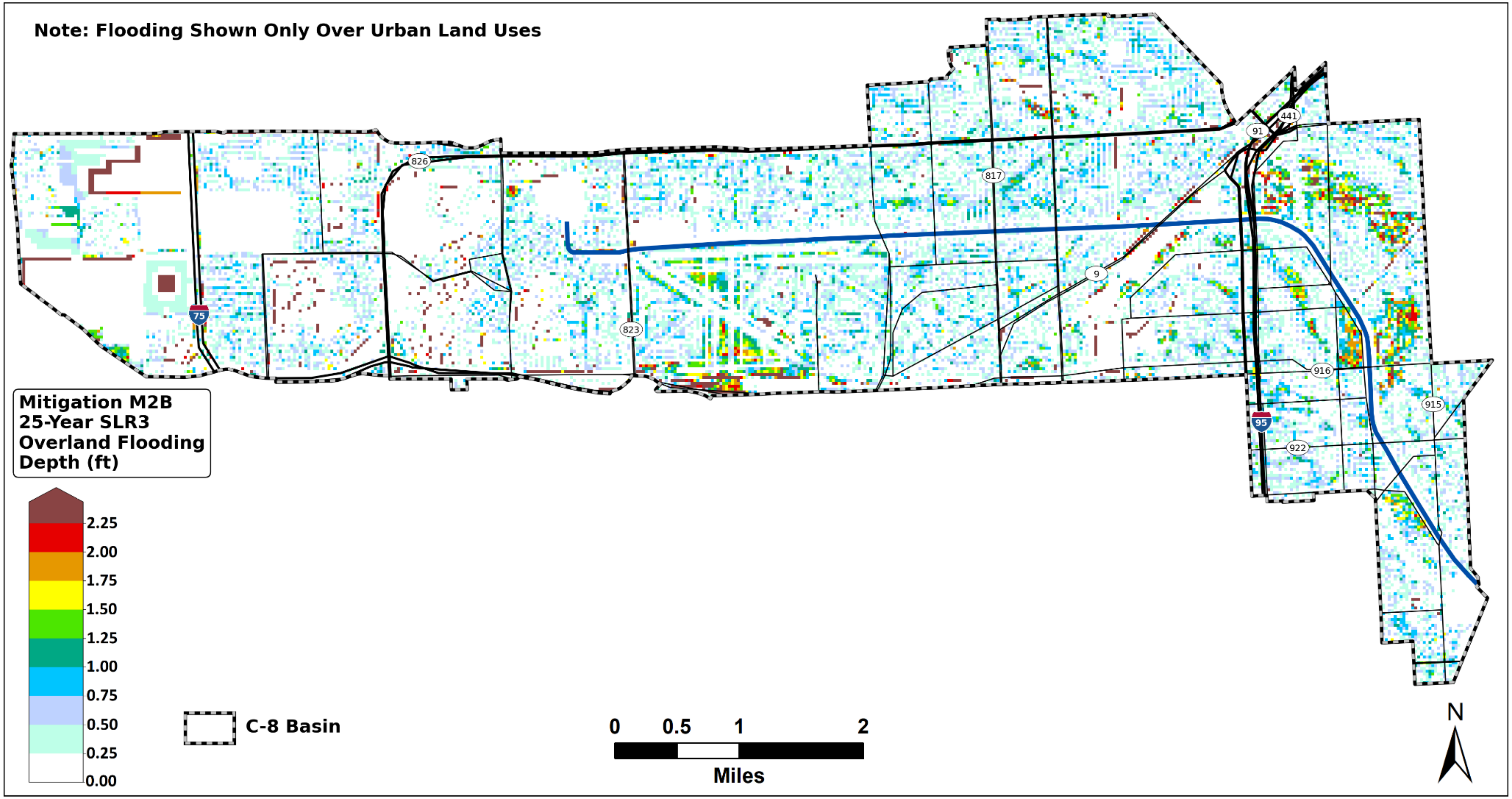


Figure B- 45: C-8 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2B 25-Year Sea Level Rise 3 Design Storm Event

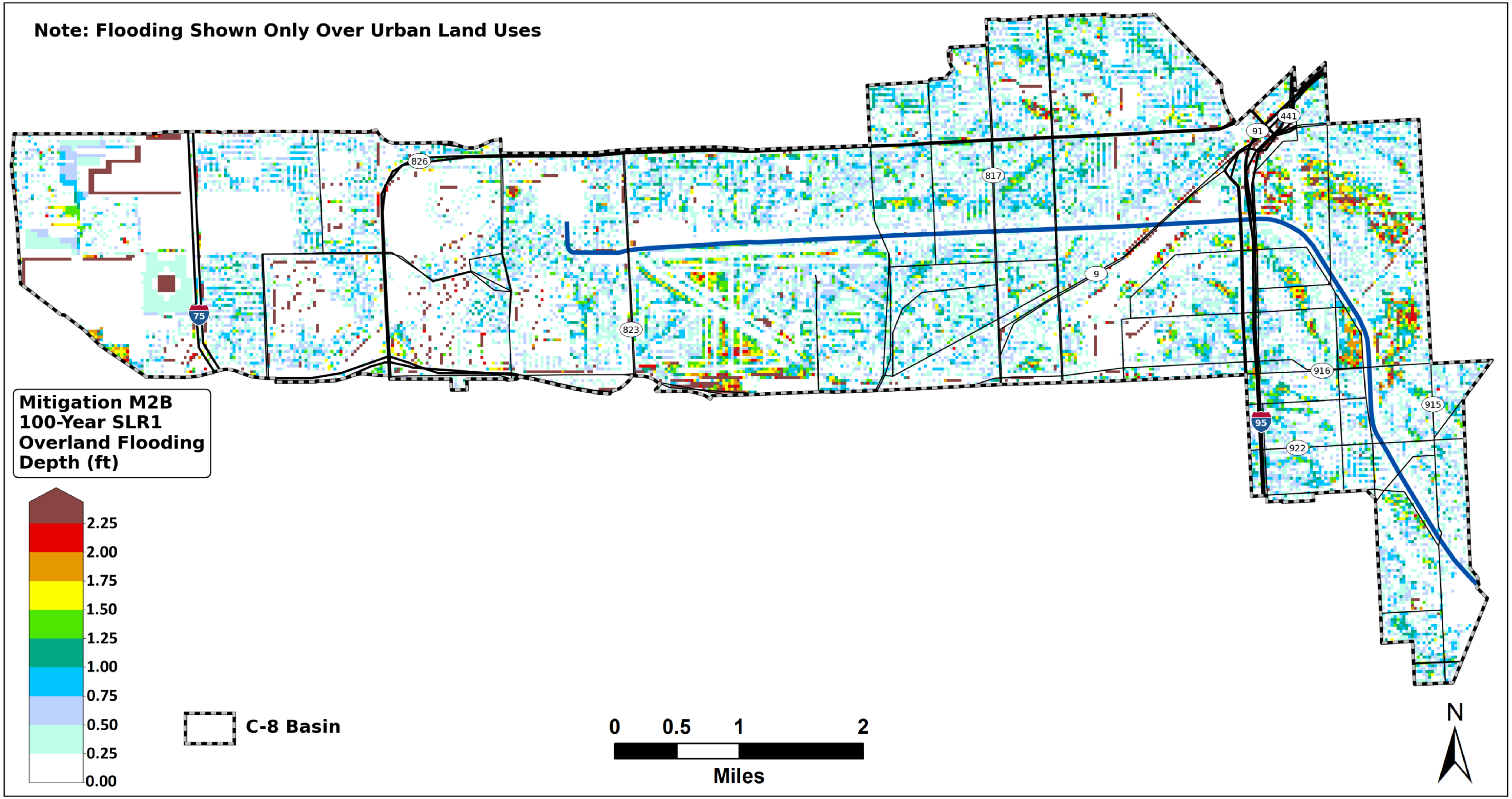


Figure B- 46: C-8 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2B 100-Year Sea Level Rise 1 Design Storm Event

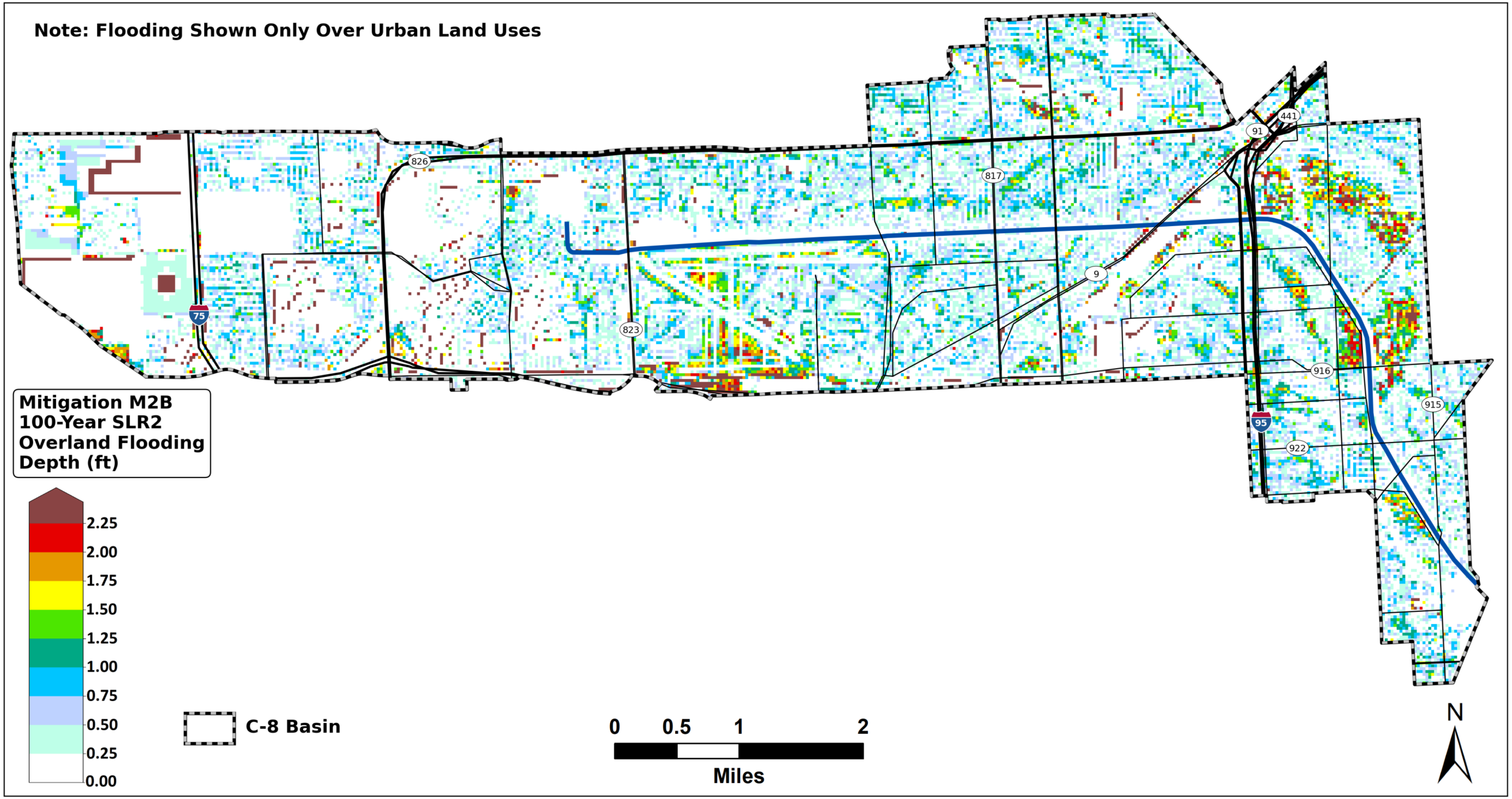


Figure B- 47: C-8 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2B 100-Year Sea Level Rise 2 Design Storm Event

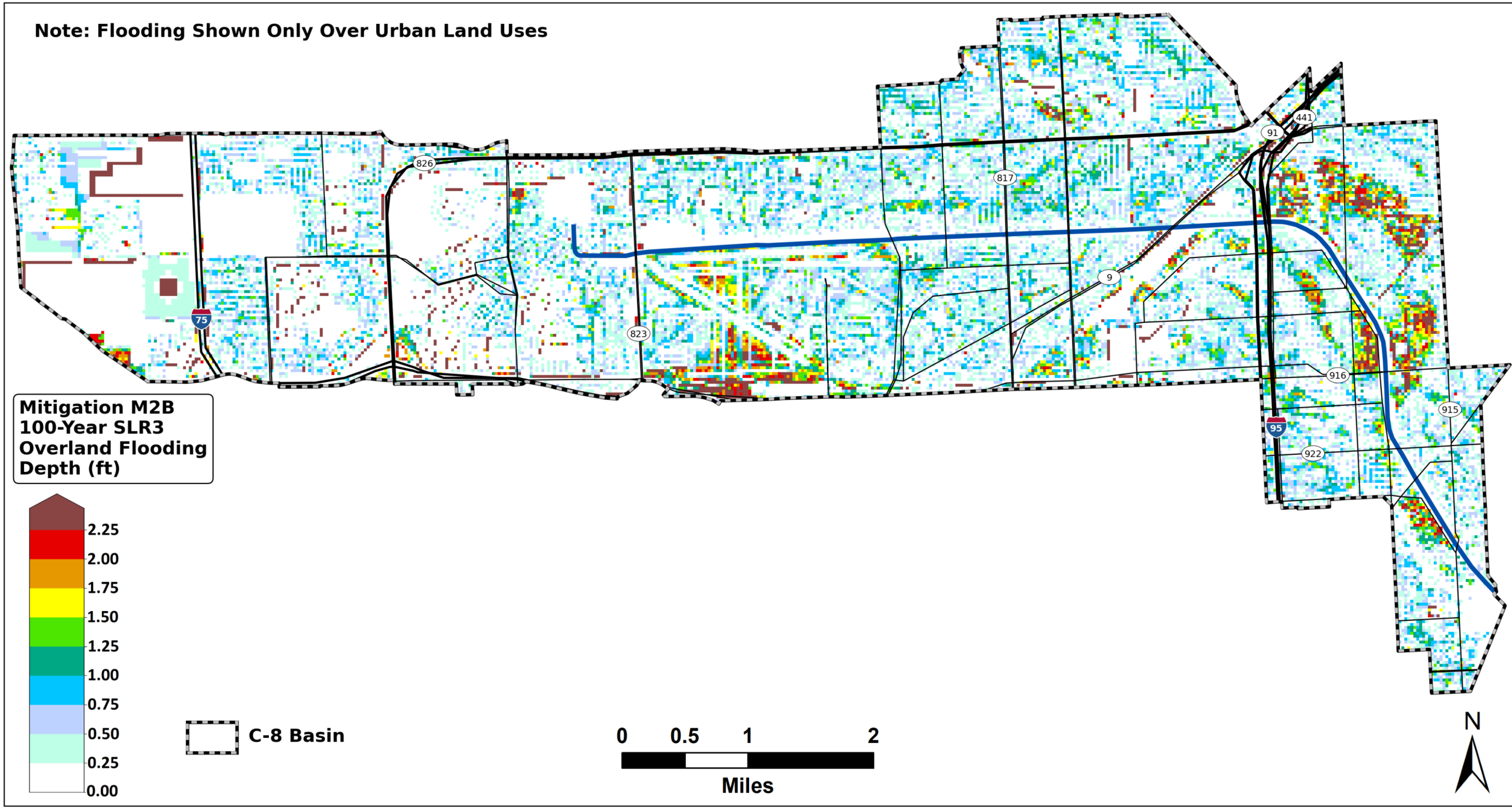


Figure B- 48: C-8 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2B 100-Year Sea Level Rise 3 Design Storm Event

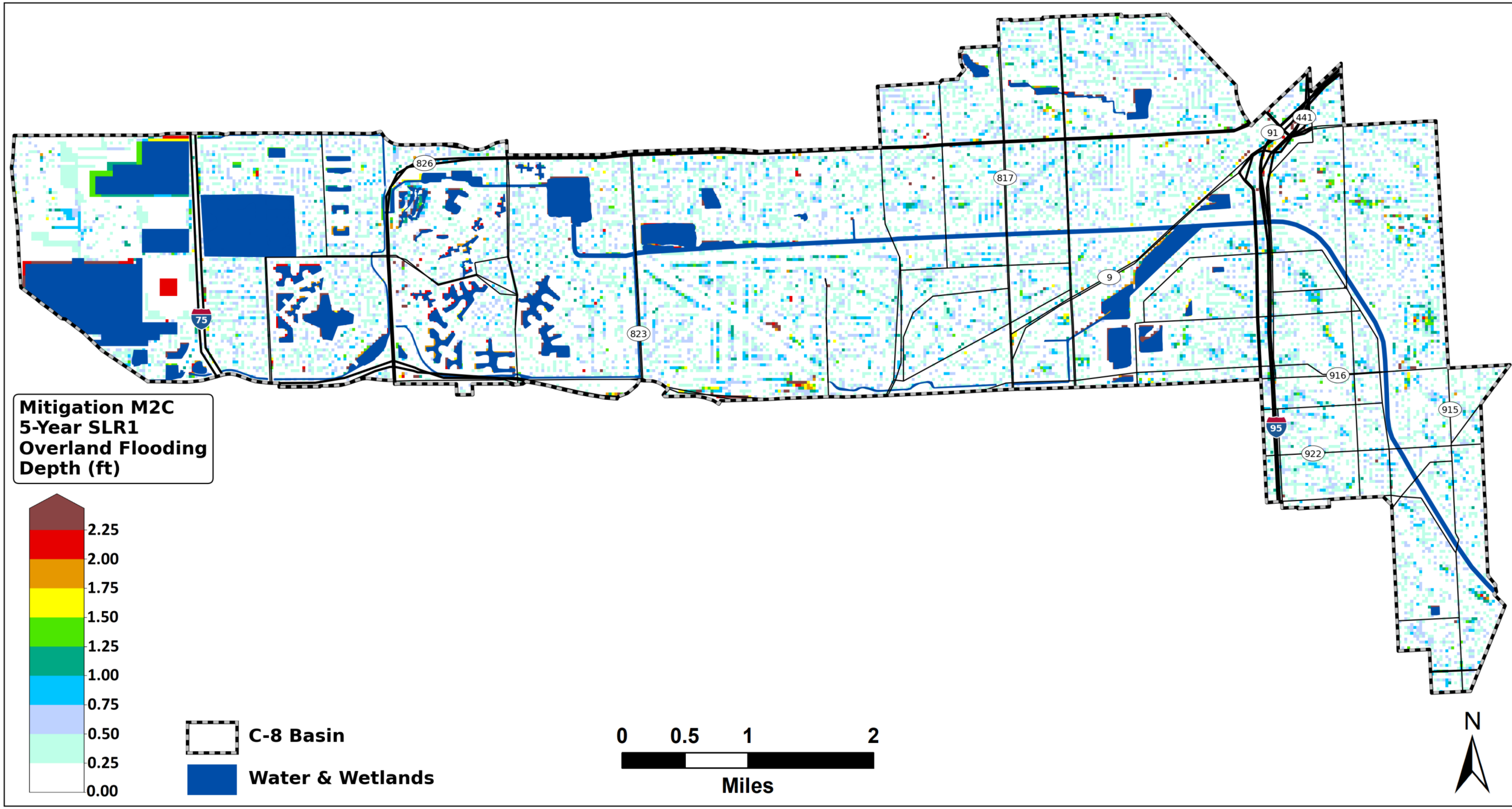


Figure B- 49: C-8 Watershed Flood Inundation Map for the Mitigation M2C 5-Year Sea Level Rise 1 Design Storm Event

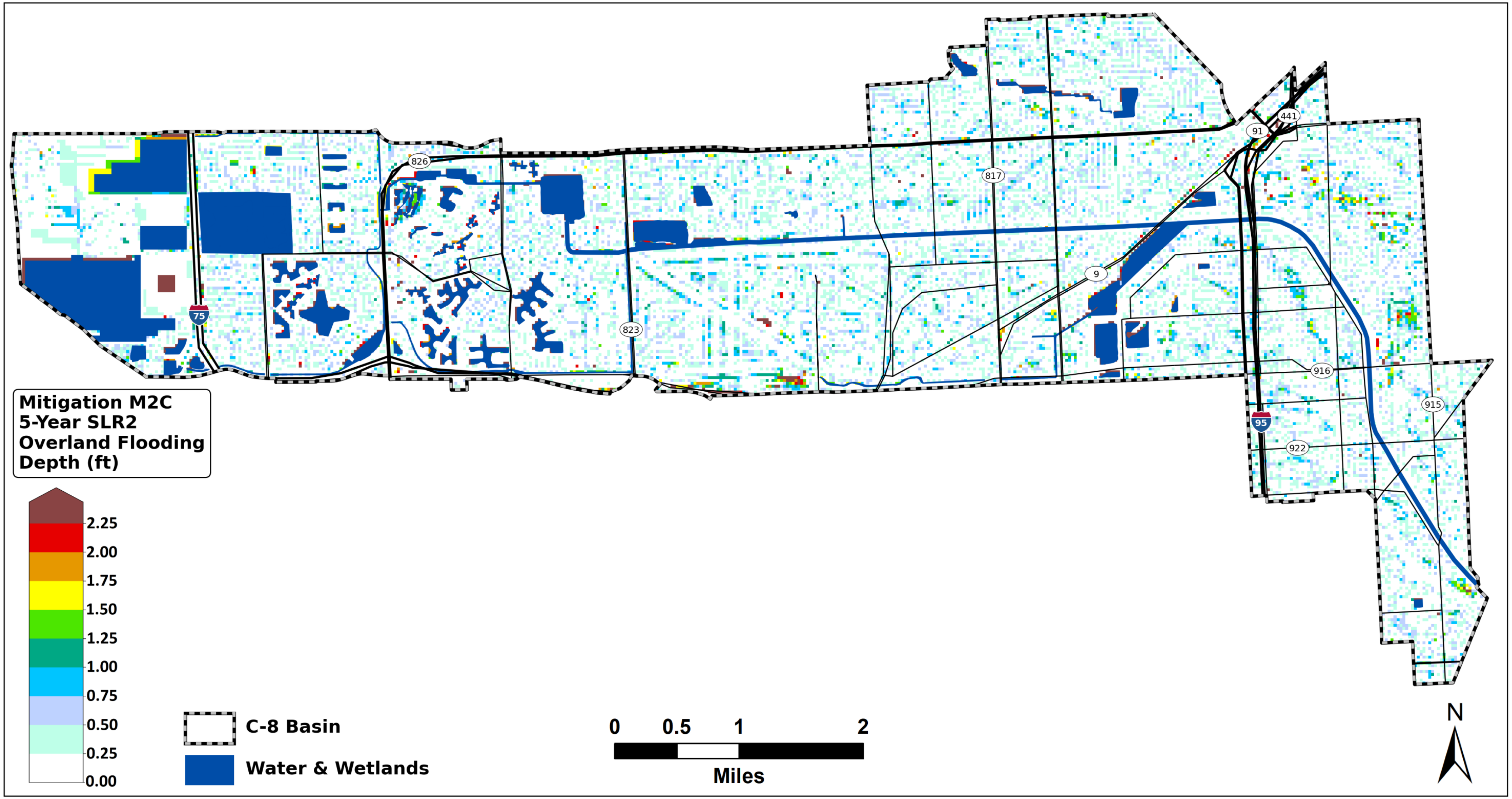


Figure B- 50: C-8 Watershed Flood Inundation Map for the Mitigation M2C 5-Year Sea Level Rise 2 Design Storm Event

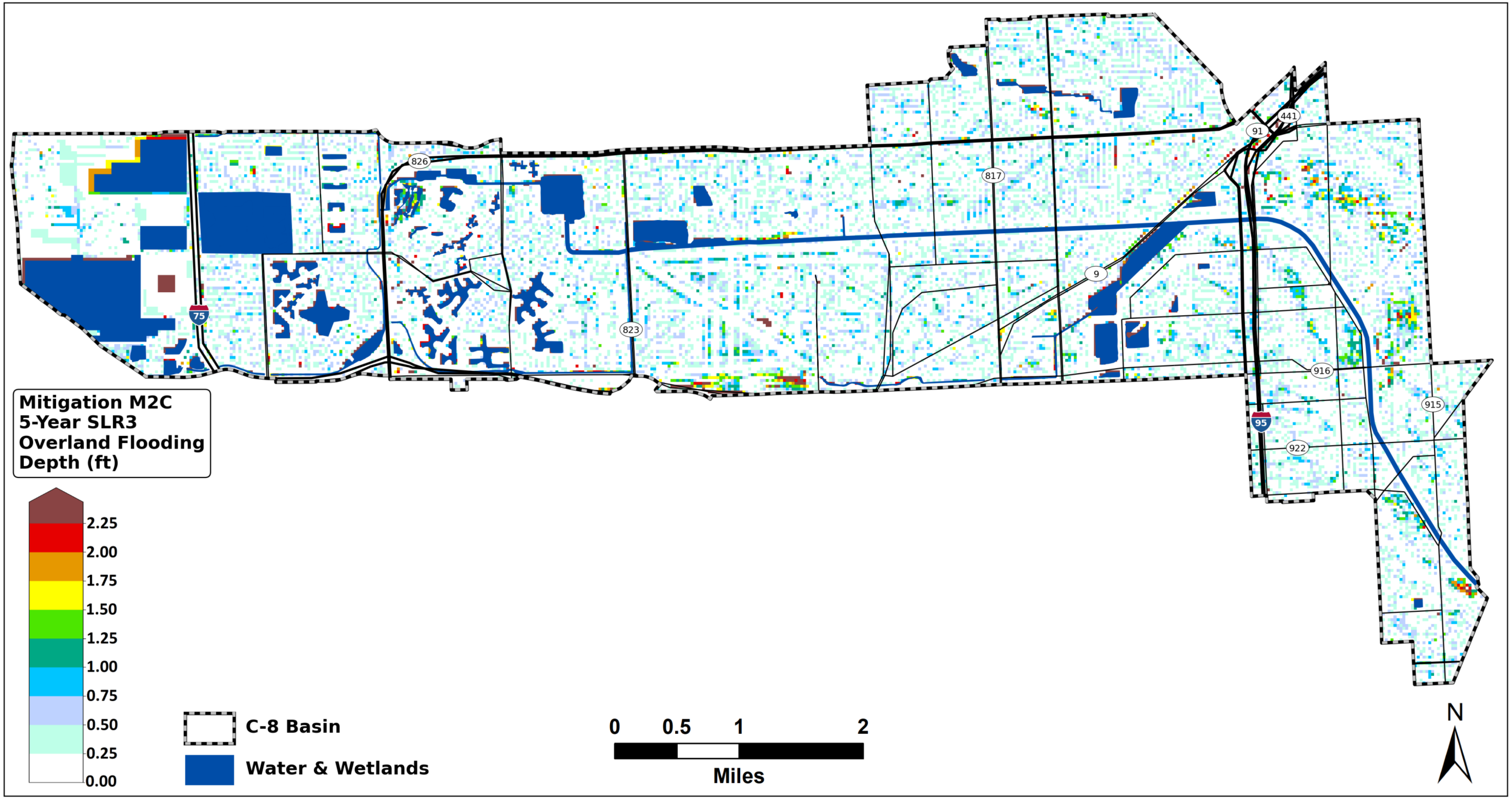


Figure B- 51: C-8 Watershed Flood Inundation Map for the Mitigation M2C 5-Year Sea Level Rise 3 Design Storm Event

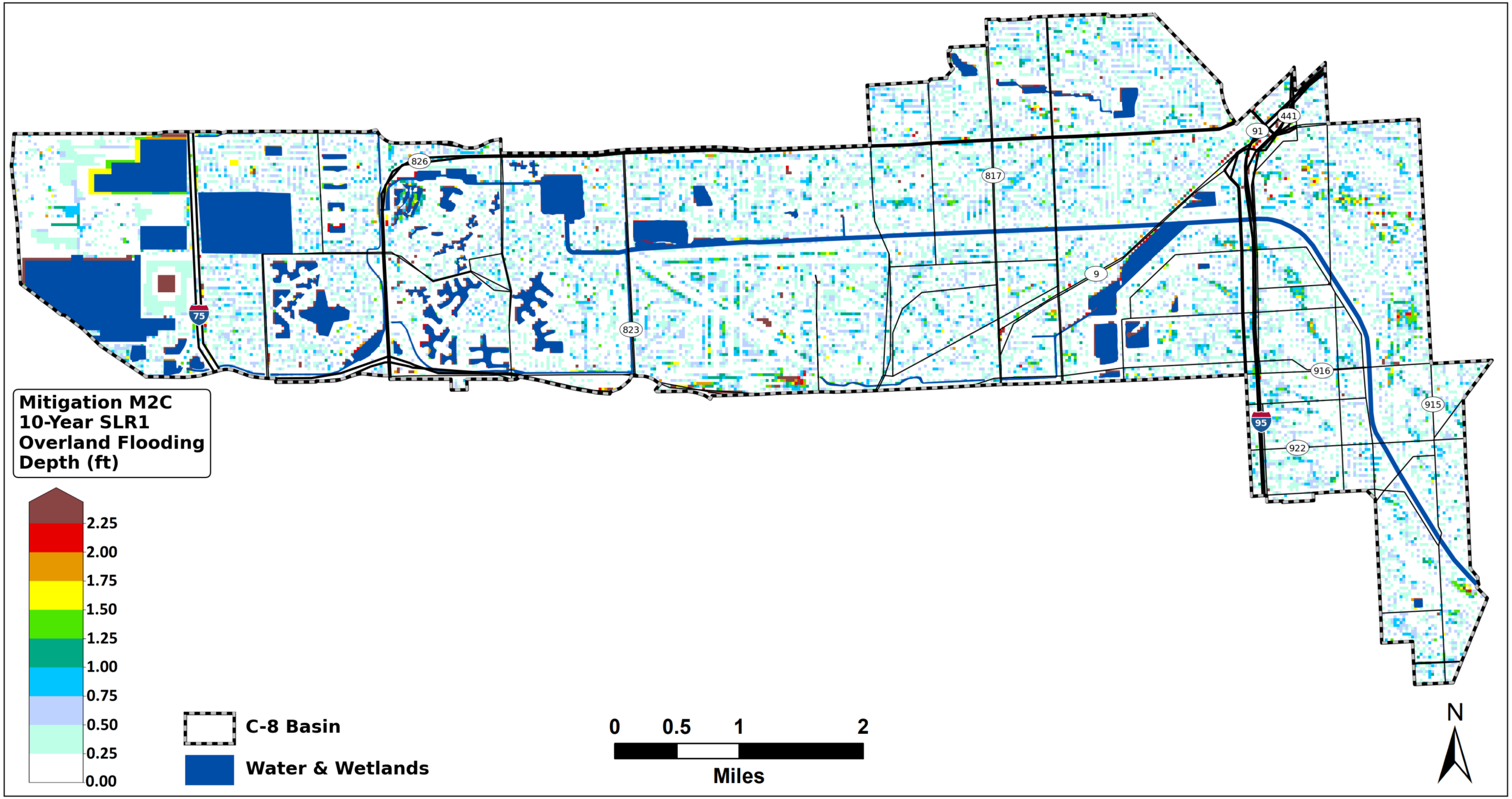


Figure B- 52: C-8 Watershed Flood Inundation Map for the Mitigation M2C 10-Year Sea Level Rise 1 Design Storm Event

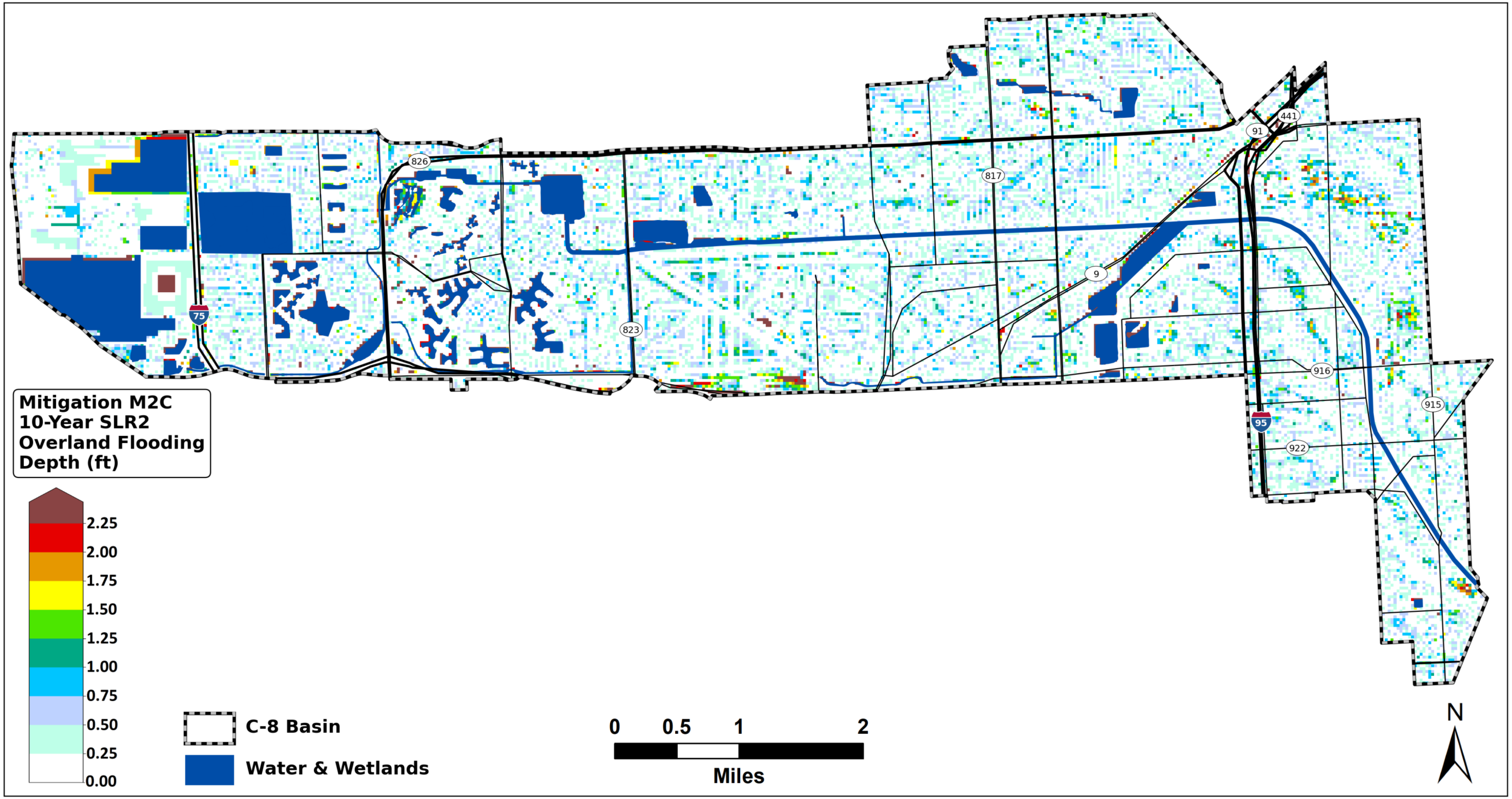


Figure B- 53: C-8 Watershed Flood Inundation Map for the Mitigation M2C 10-Year Sea Level Rise 2 Design Storm Event

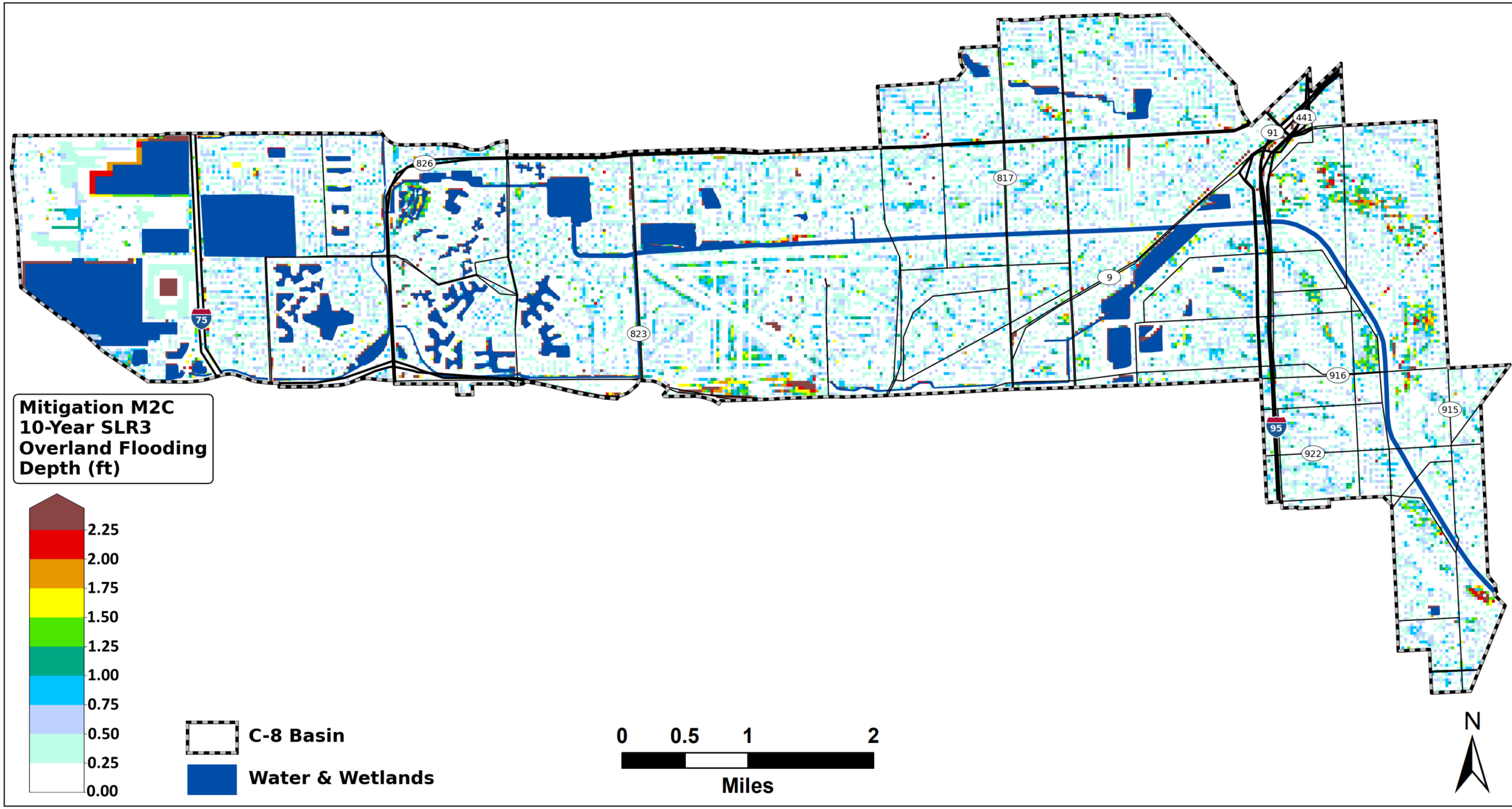


Figure B- 54: C-8 Watershed Flood Inundation Map for the Mitigation M2C 10-Year Sea Level Rise 3 Design Storm Event

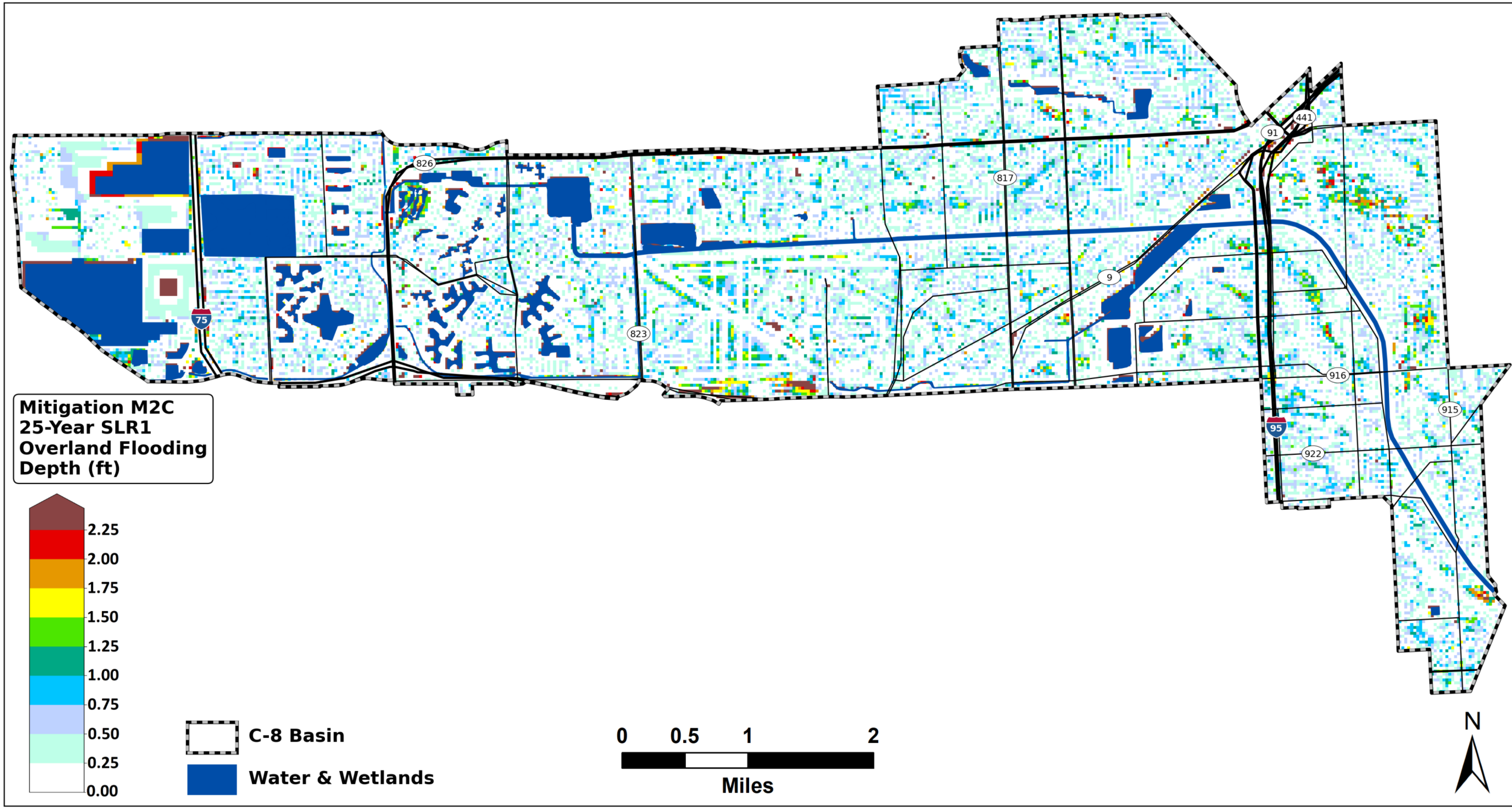


Figure B- 55: C-8 Watershed Flood Inundation Map for the Mitigation M2C 25-Year Sea Level Rise 1 Design Storm Event

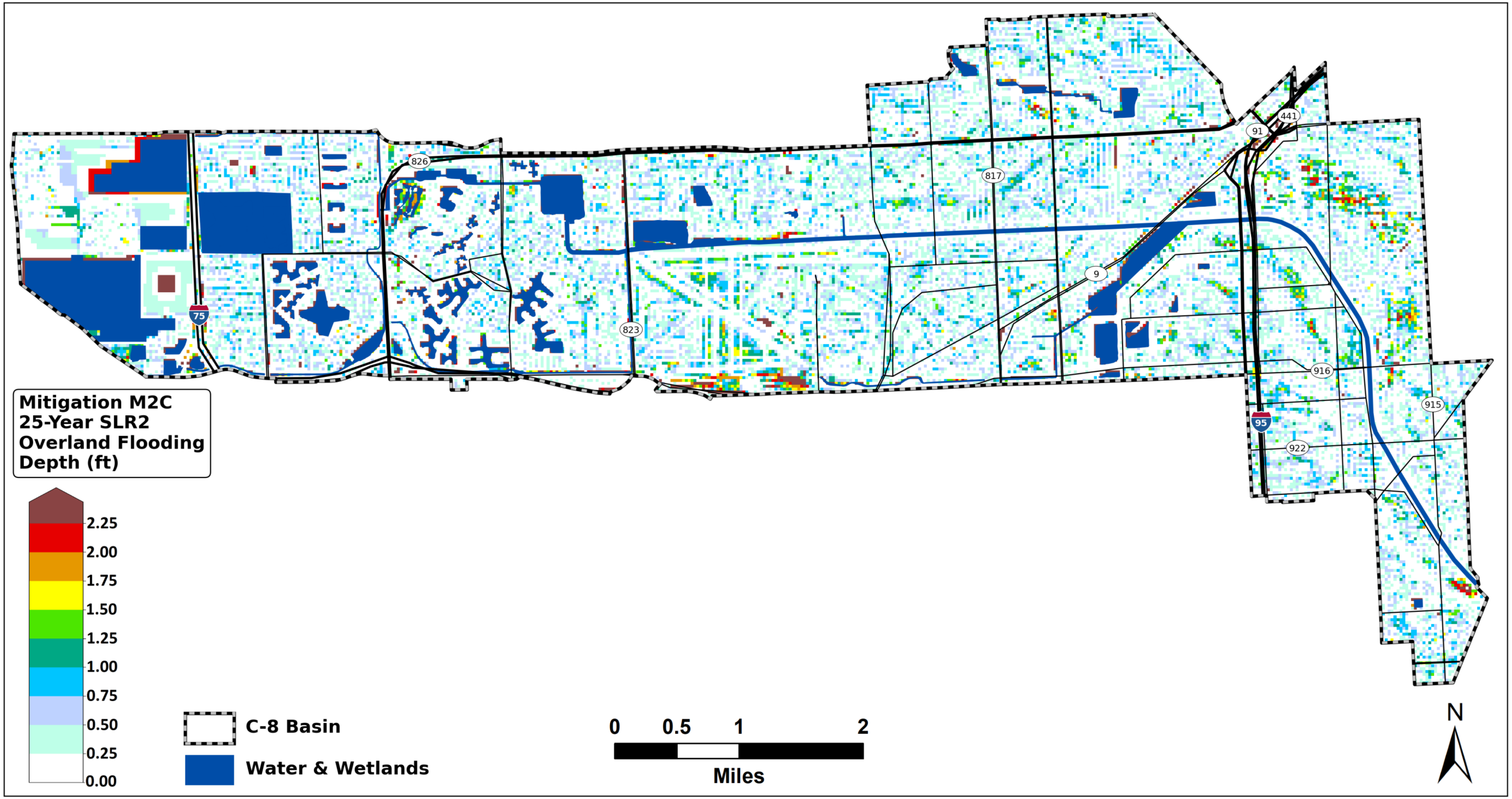


Figure B- 56: C-8 Watershed Flood Inundation Map for the Mitigation M2C 25-Year Sea Level Rise 2 Design Storm Event

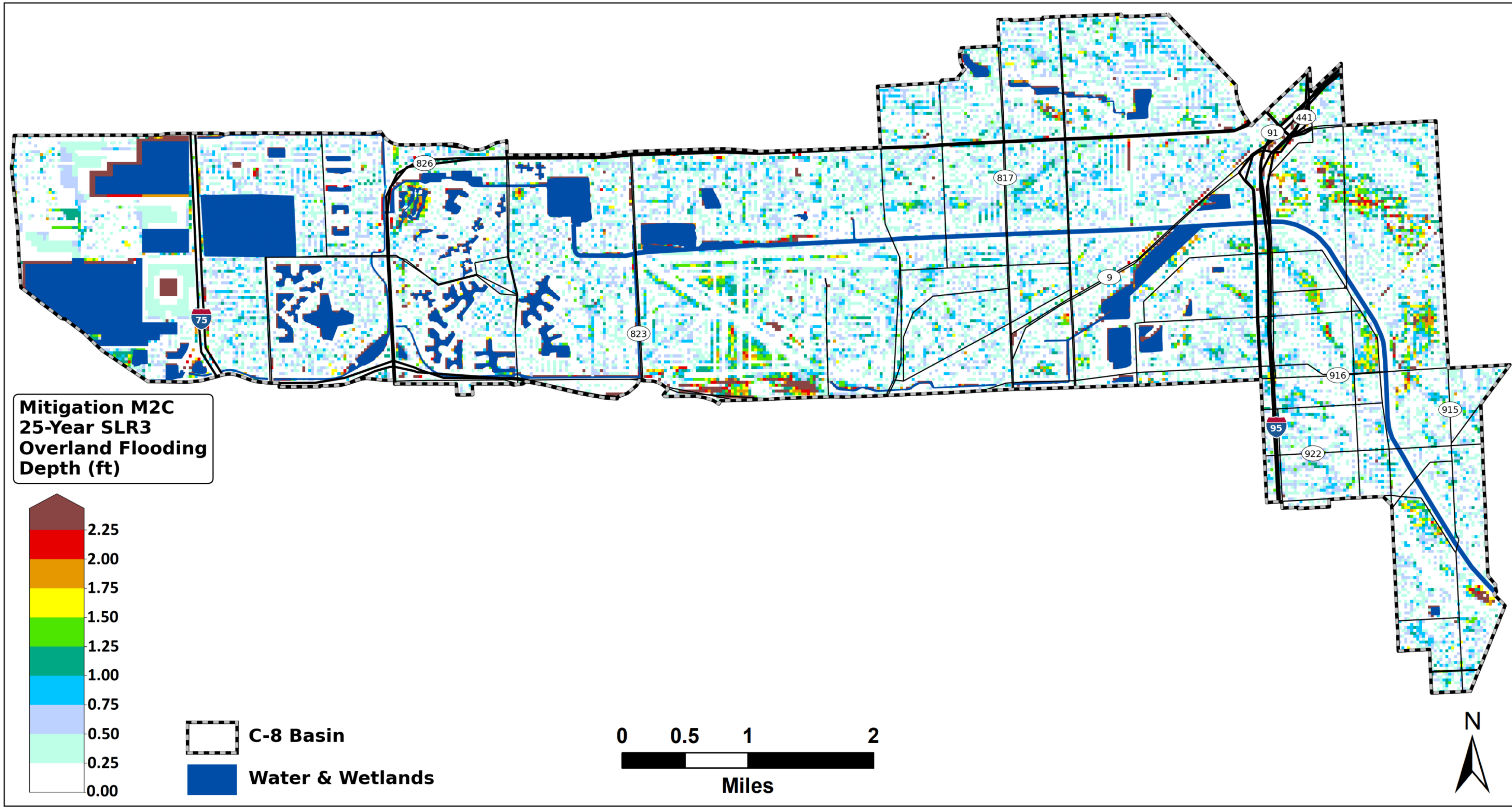


Figure B- 57: C-8 Watershed Flood Inundation Map for the Mitigation M2C 25-Year Sea Level Rise 3 Design Storm Event

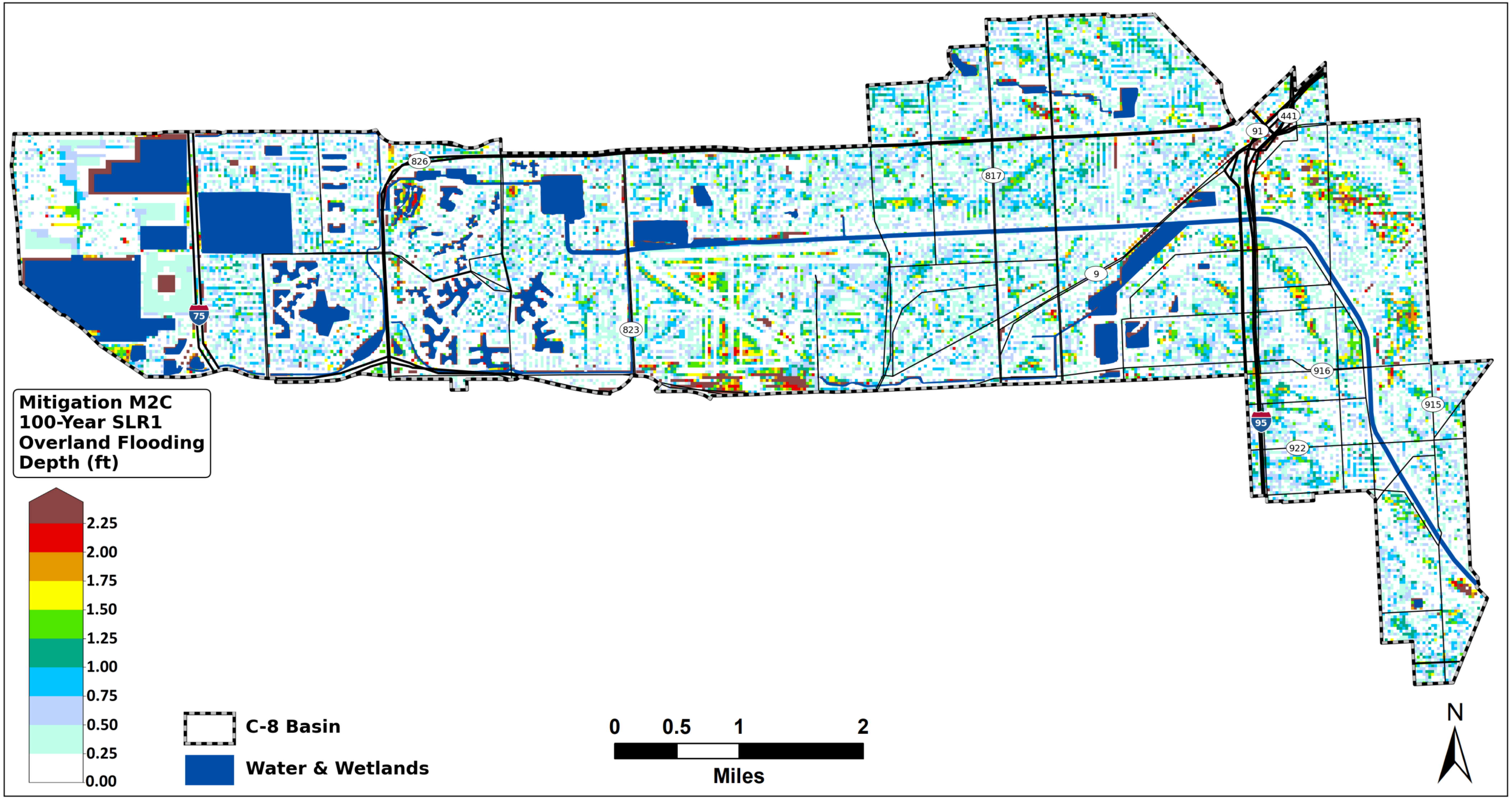


Figure B- 58: C-8 Watershed Flood Inundation Map for the Mitigation M2C 100-Year Sea Level Rise 1 Design Storm Event

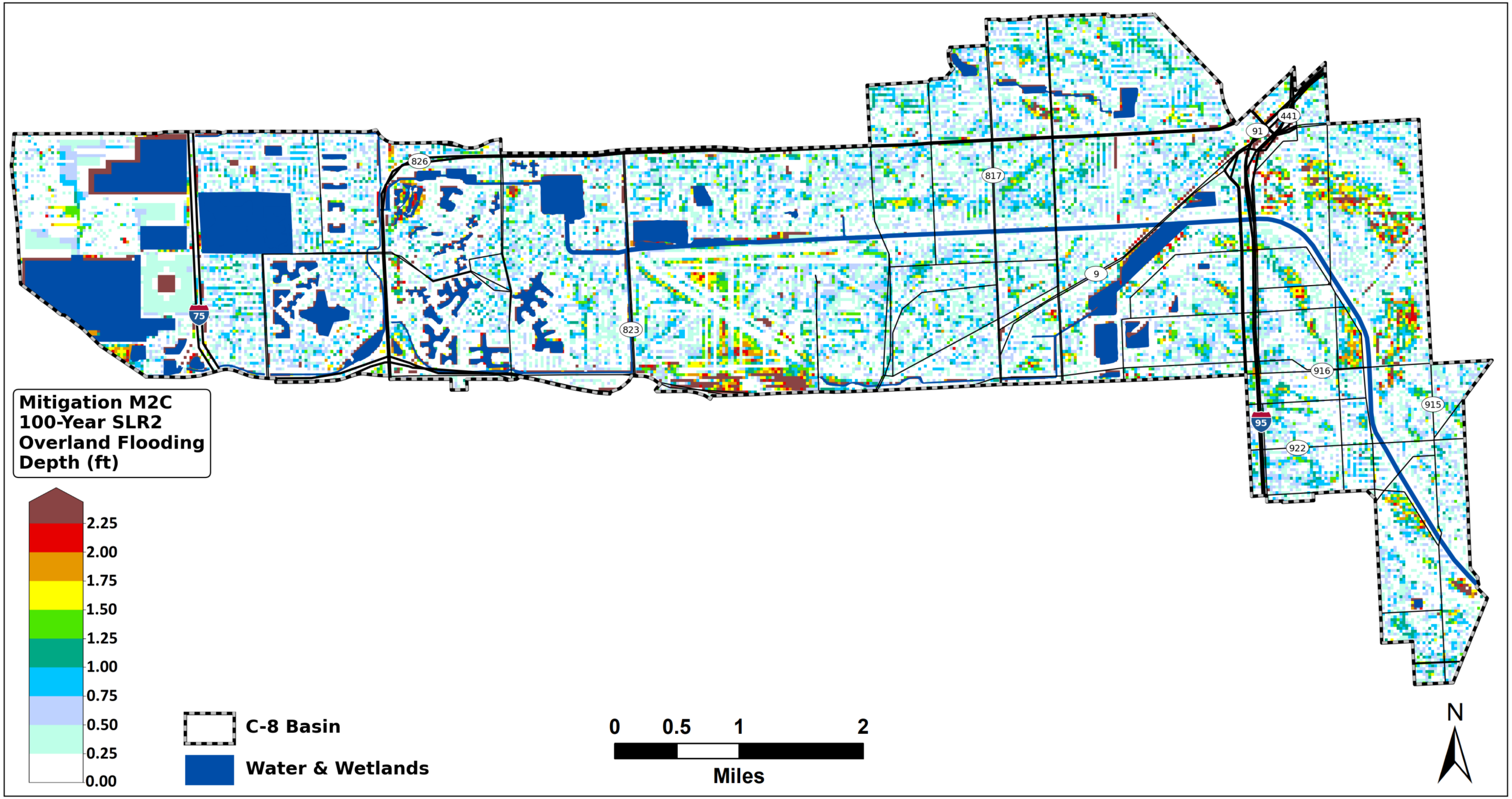


Figure B- 59: C-8 Watershed Flood Inundation Map for the Mitigation M2C 100-Year Sea Level Rise 2 Design Storm Event

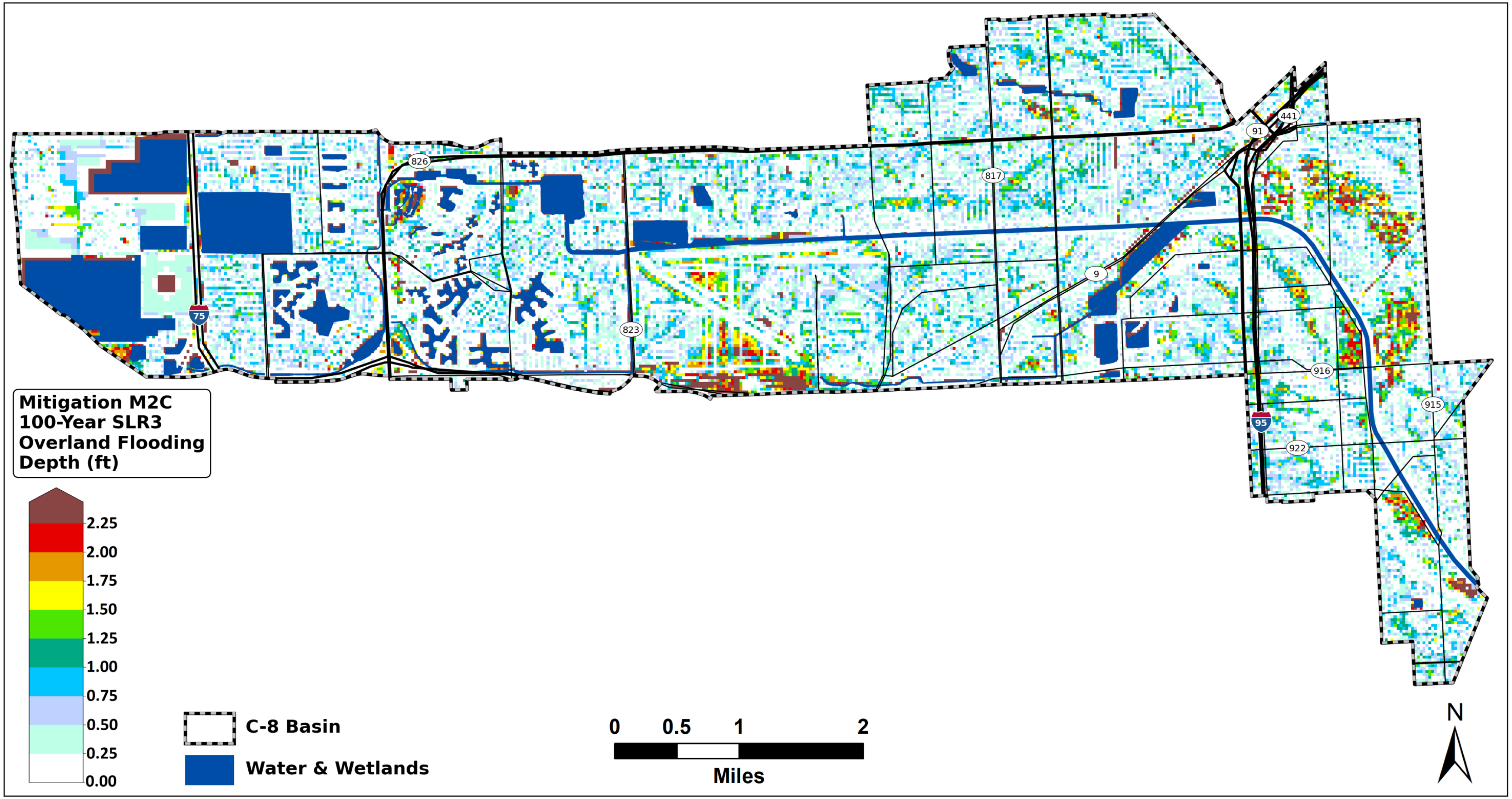


Figure B- 60: C-8 Watershed Flood Inundation Map for the Mitigation M2C 100-Year Sea Level Rise 3 Design Storm Event

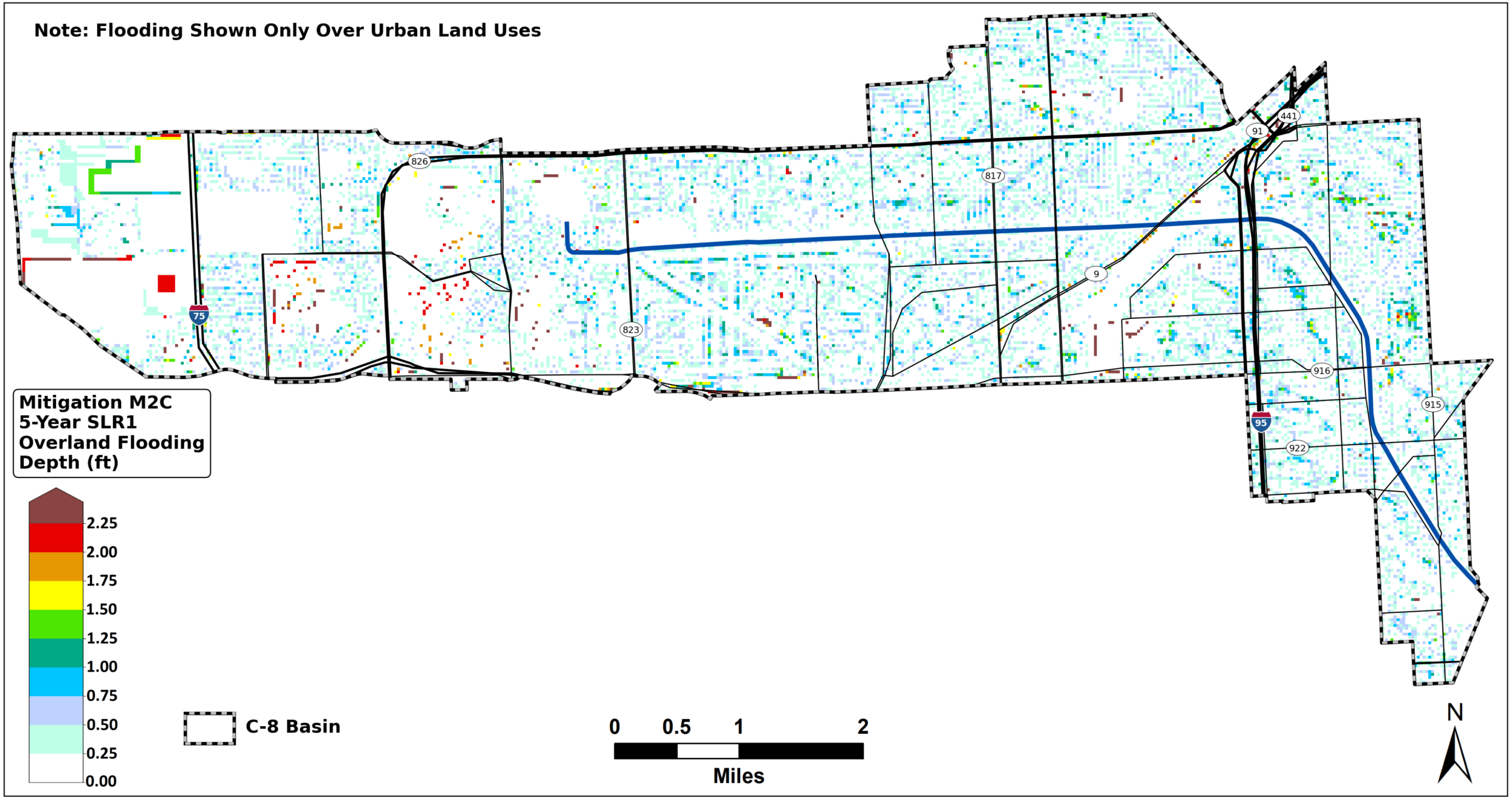


Figure B- 61: C-8 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2C 5-Year Sea Level Rise 1 Design Storm Event

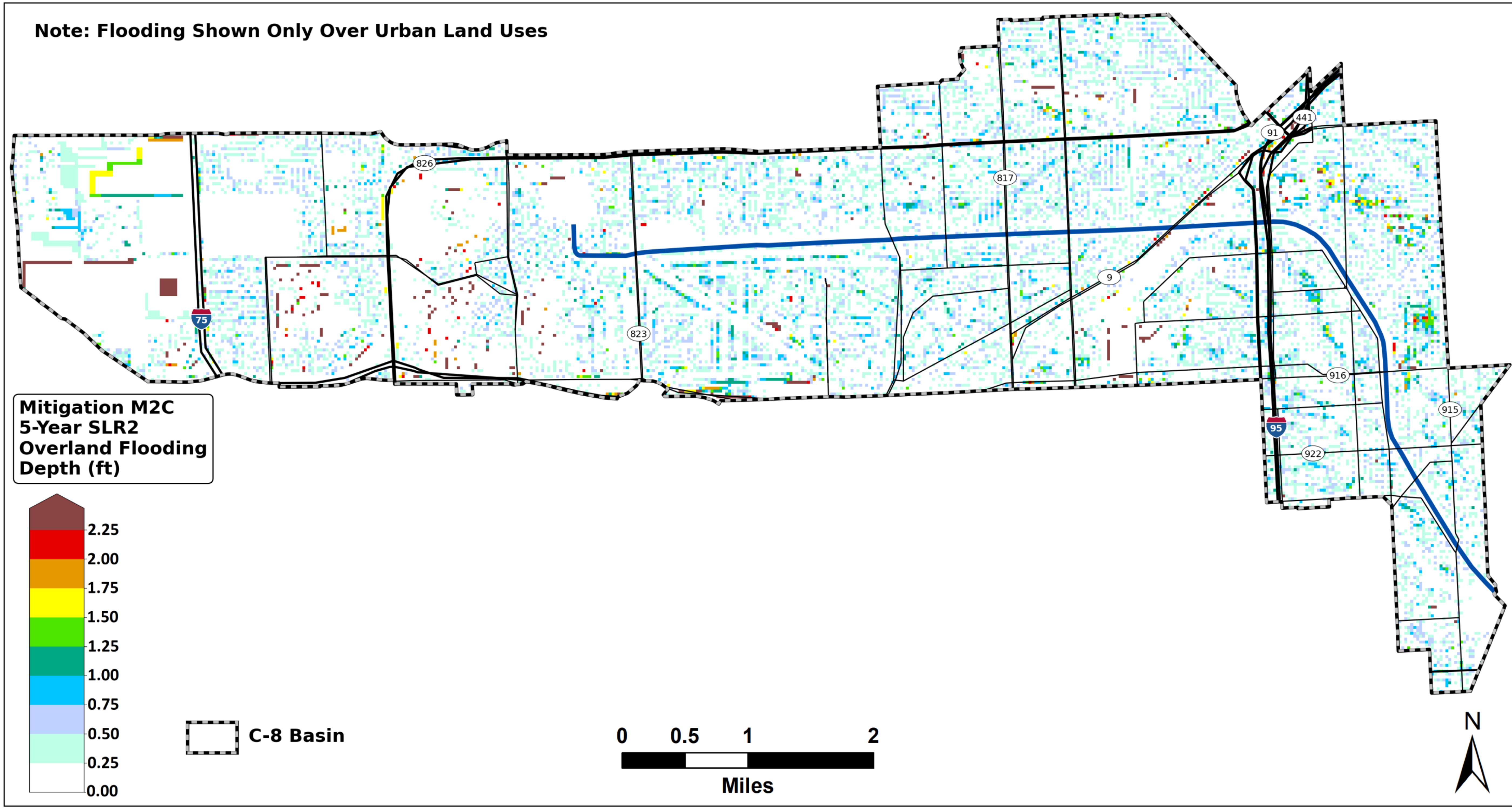


Figure B- 62: C-8 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2C 5-Year Sea Level Rise 2 Design Storm Event

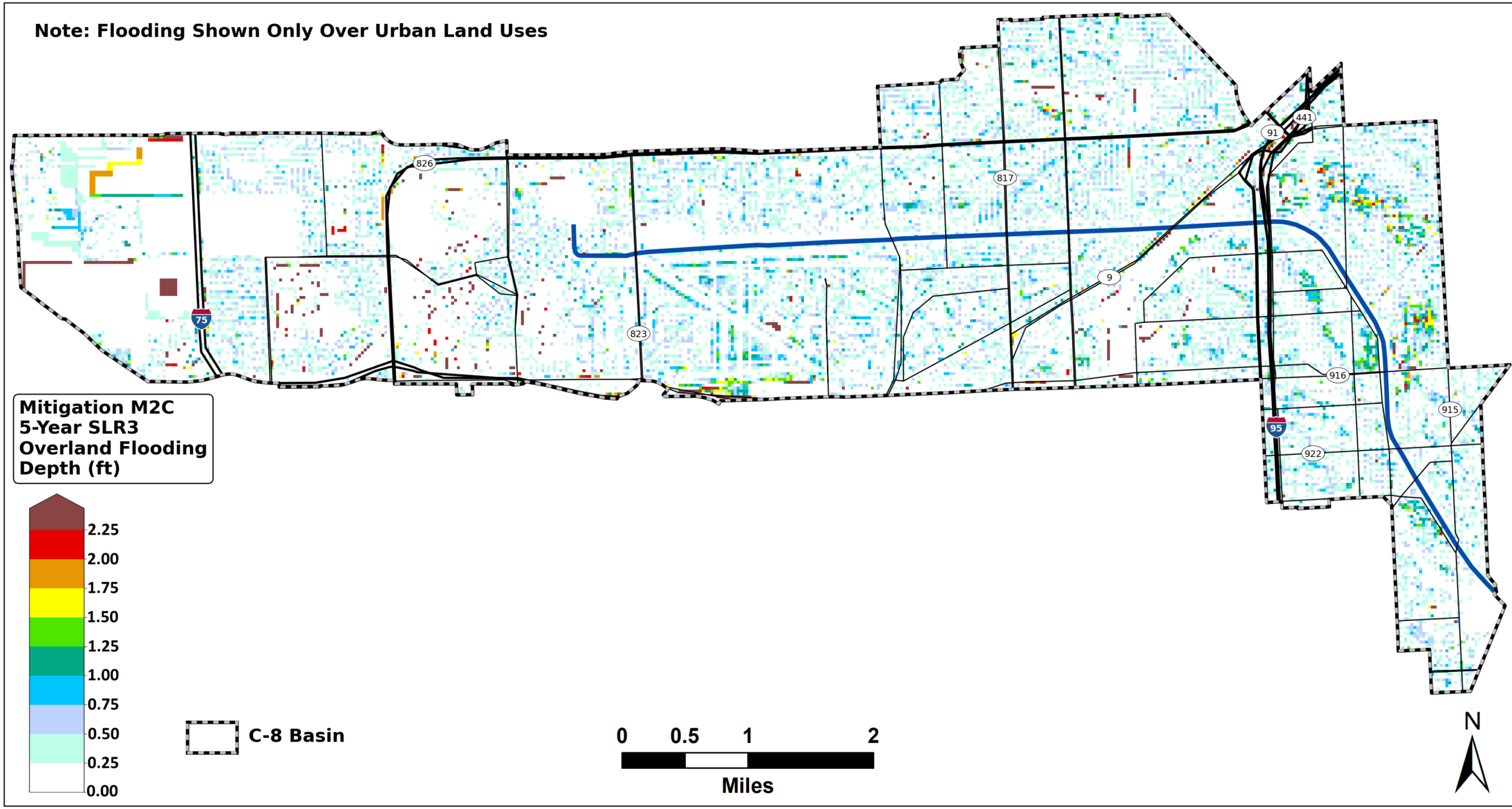


Figure B- 63: C-8 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2C 5-Year Sea Level Rise 3 Design Storm Event

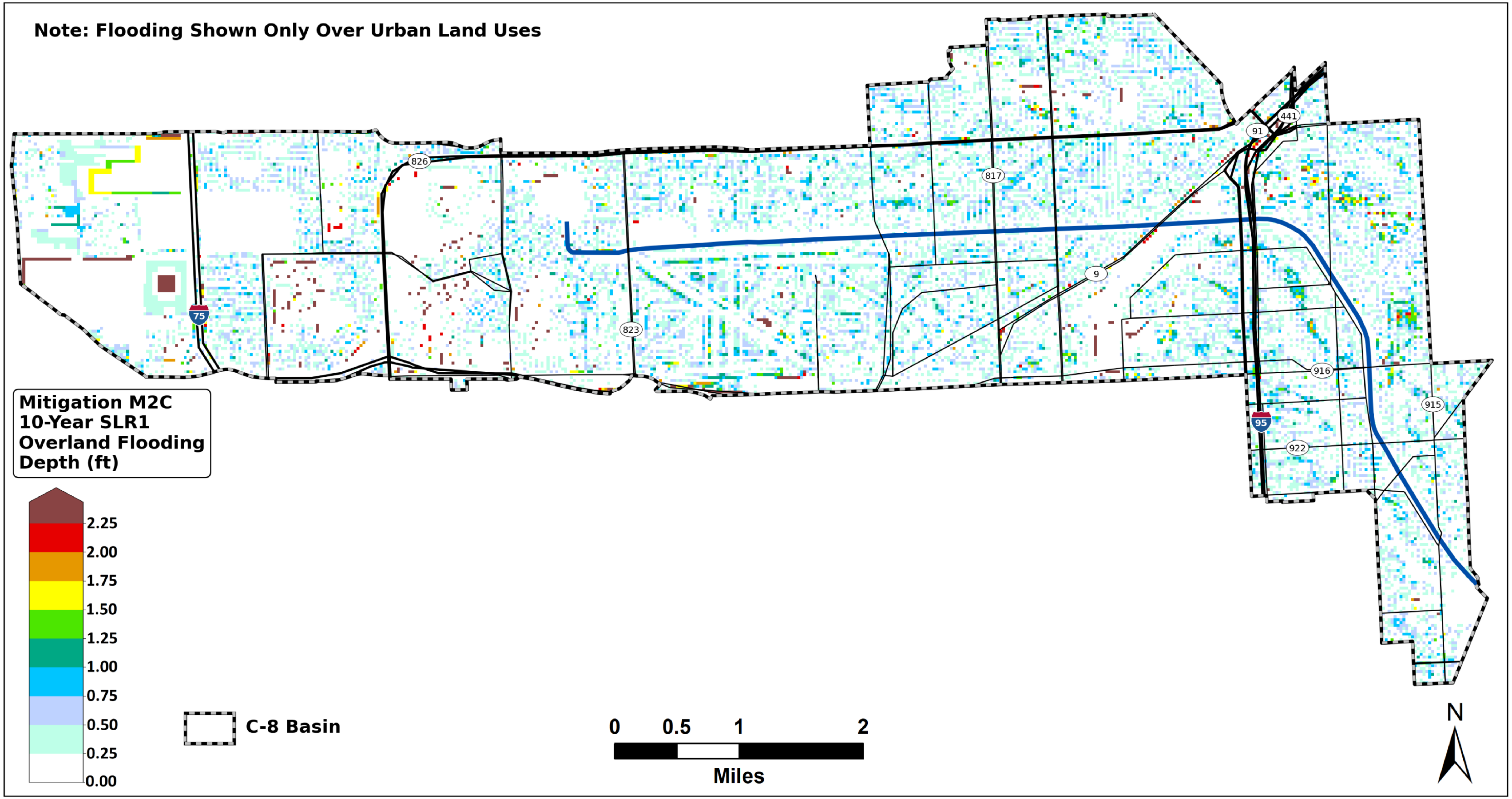


Figure B- 64: C-8 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2C 10-Year Sea Level Rise 1 Design Storm Event

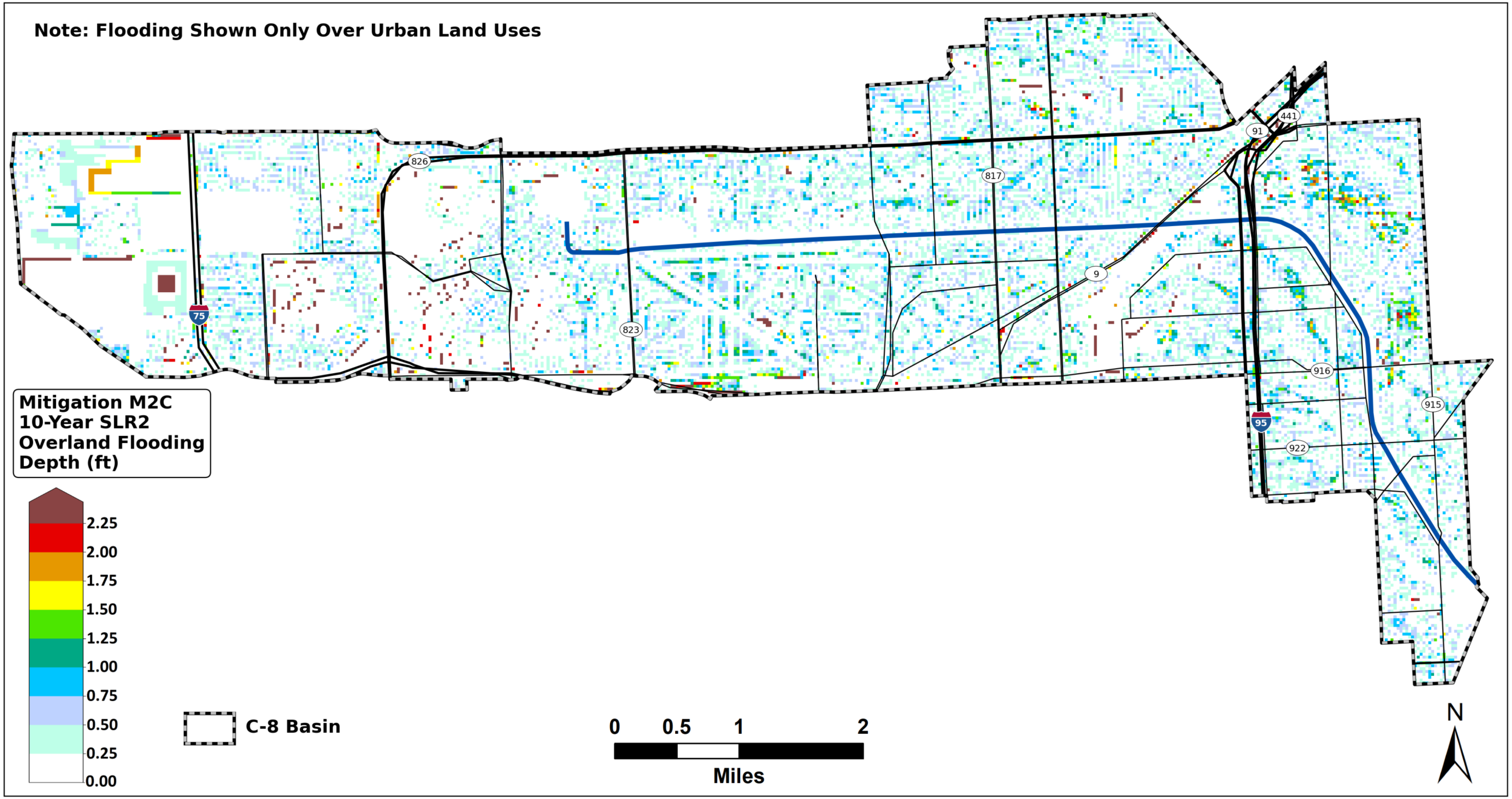


Figure B- 65: C-8 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2C 10-Year Sea Level Rise 2 Design Storm Event

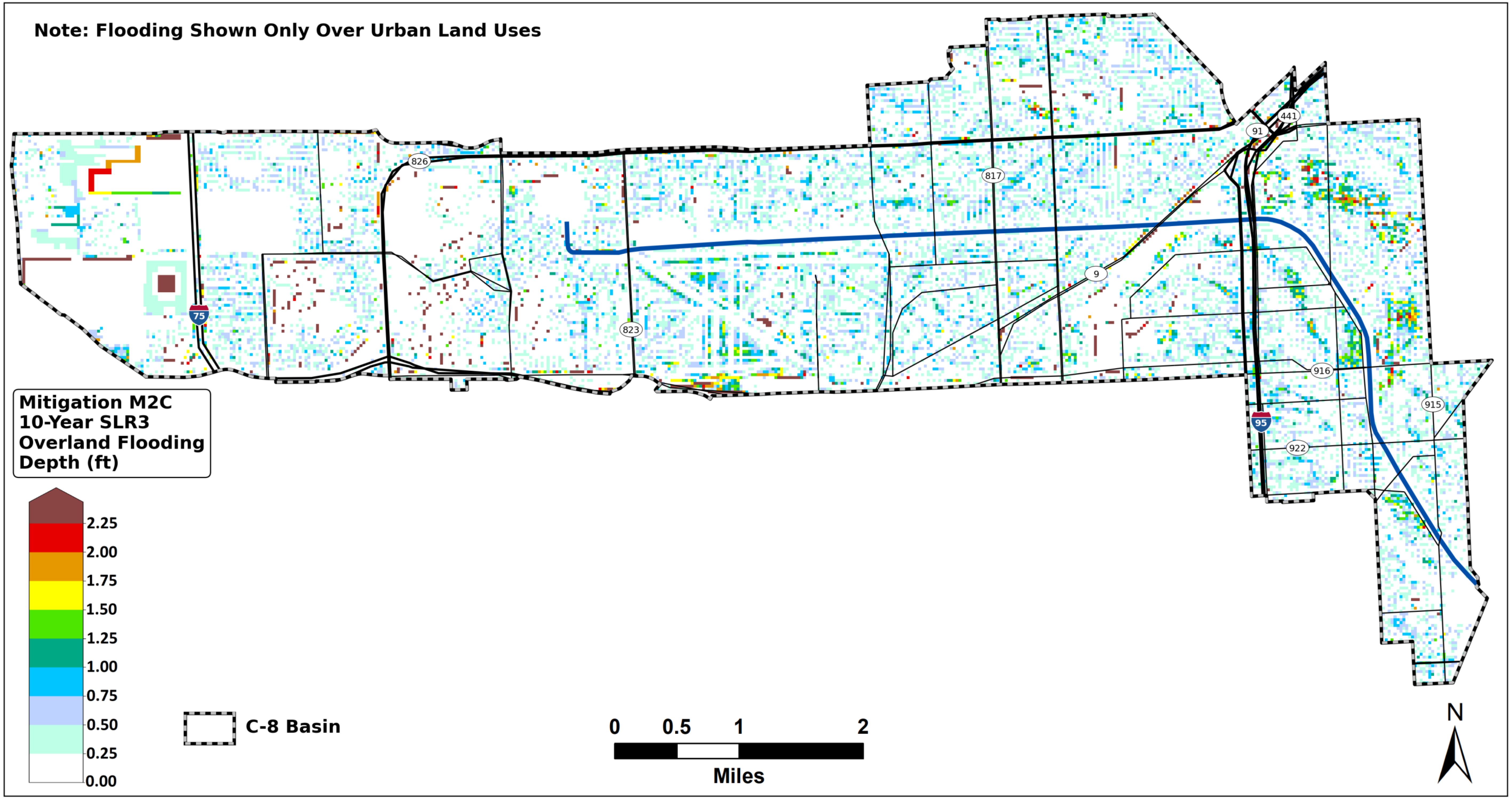


Figure B- 66: C-8 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2C 10-Year Sea Level Rise 3 Design Storm Event

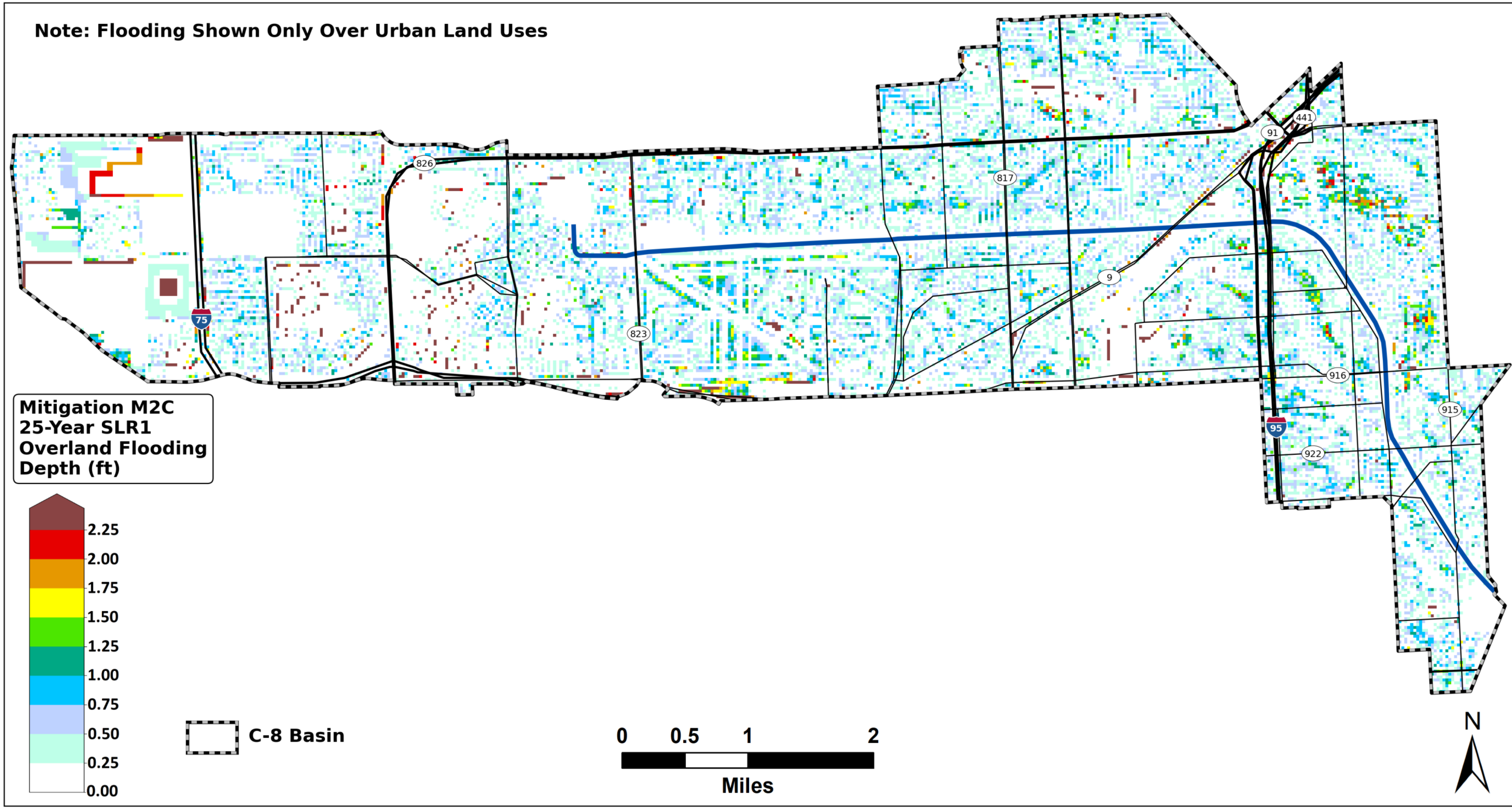


Figure B- 67: C-8 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2C 25-Year Sea Level Rise 1 Design Storm Event

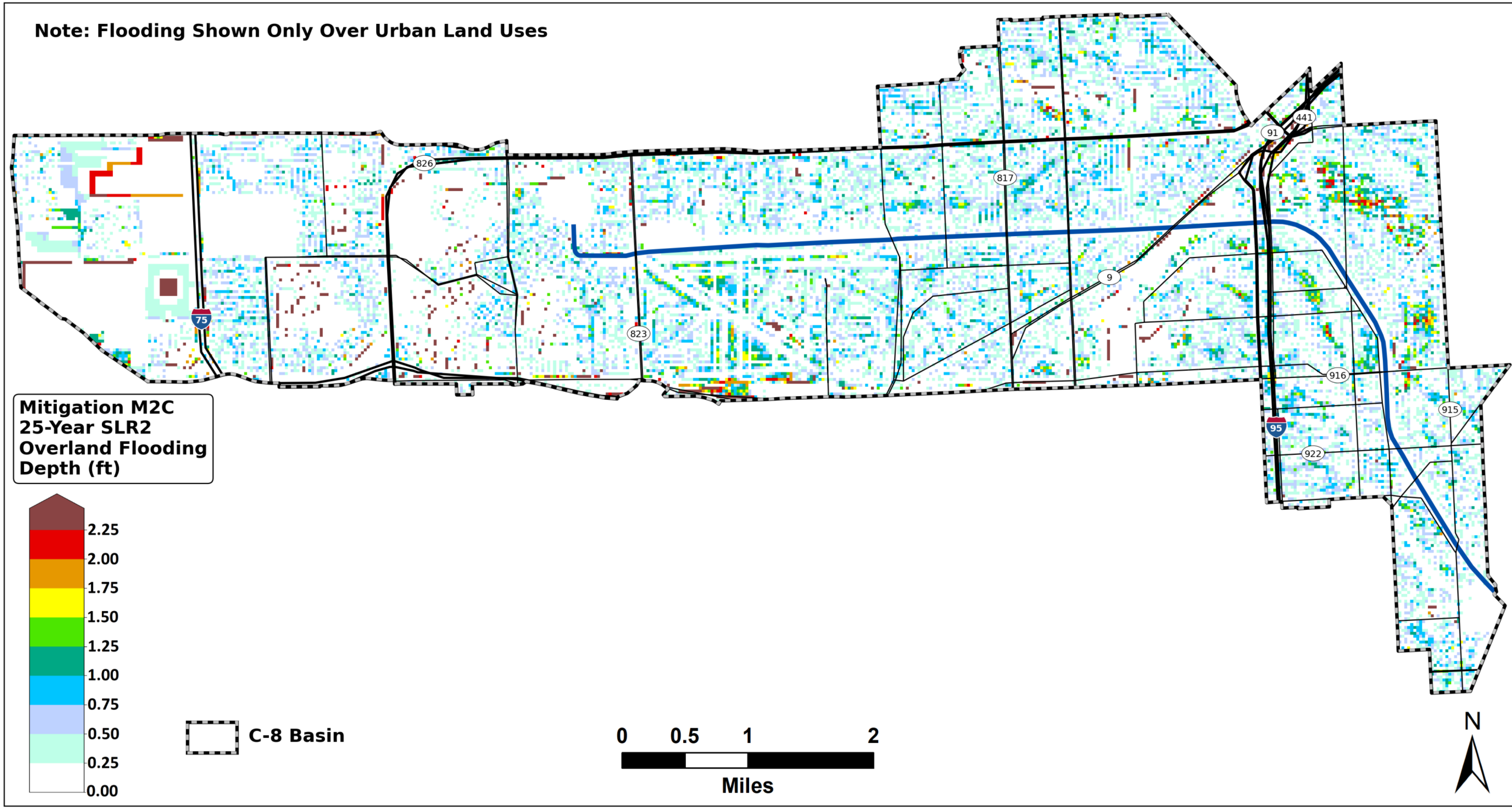


Figure B- 68: C-8 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2C 25-Year Sea Level Rise 2 Design Storm Event

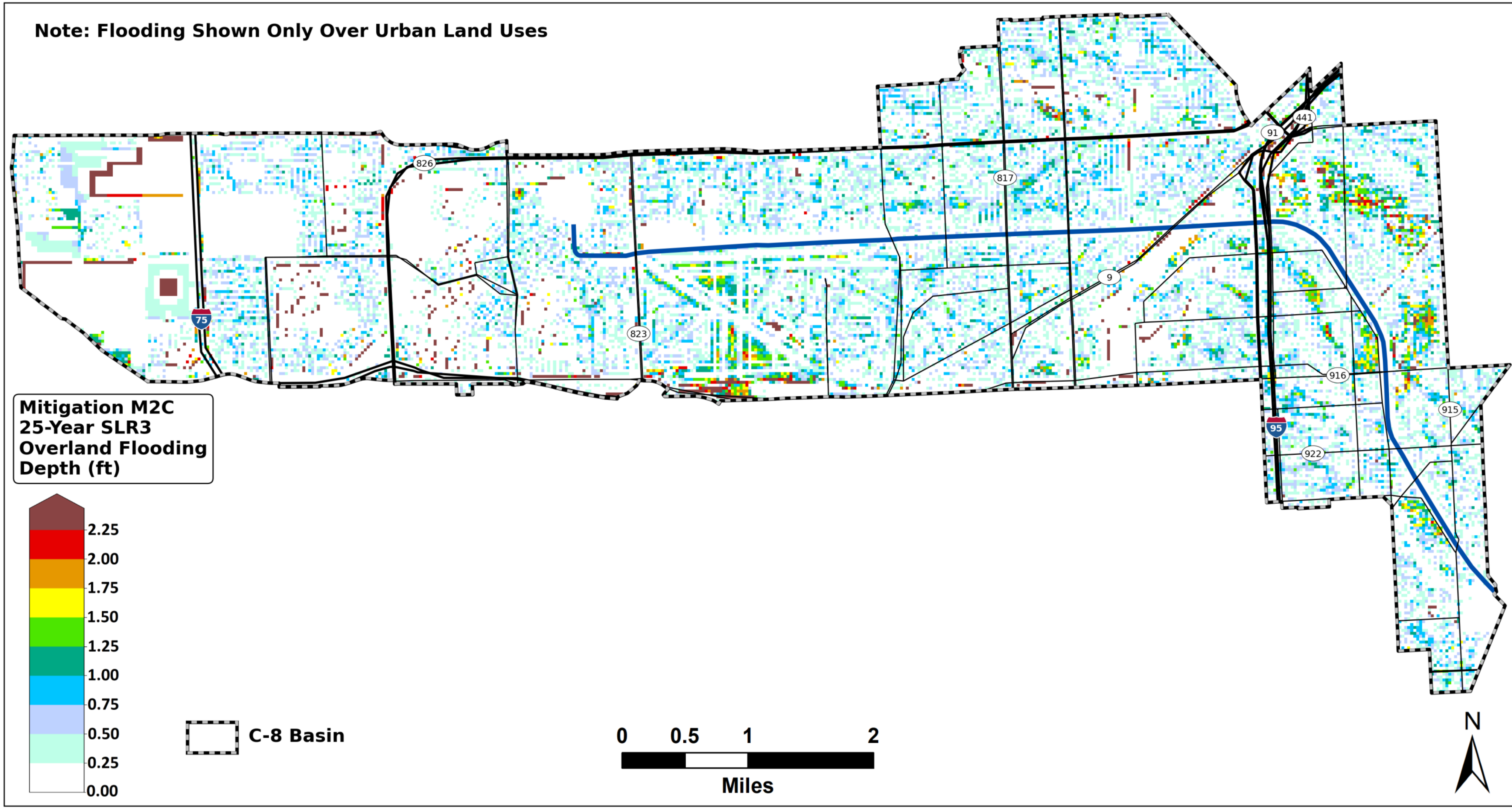


Figure B- 69: C-8 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2C 25-Year Sea Level Rise 3 Design Storm Event

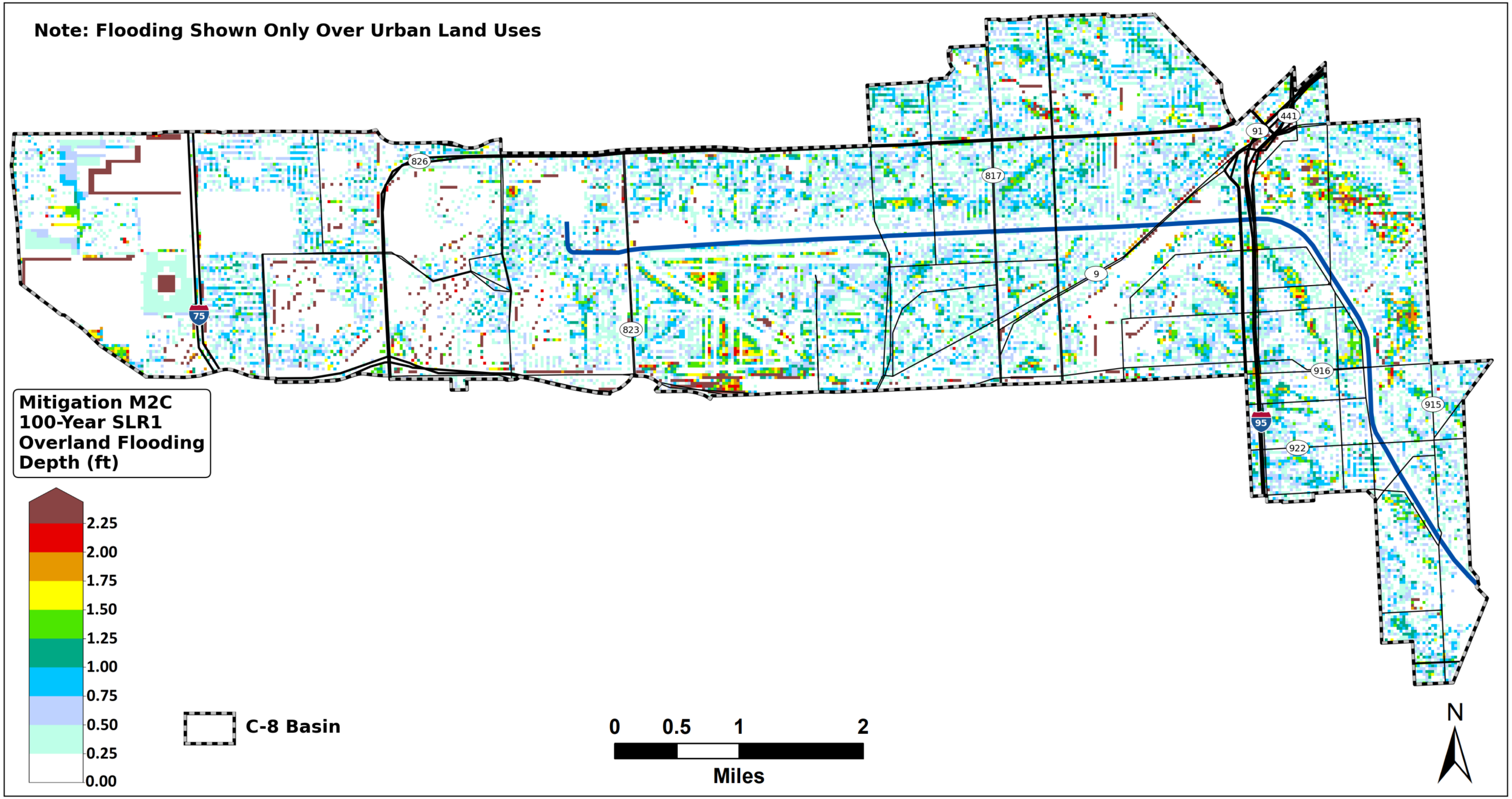


Figure B- 70: C-8 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2C 100-Year Sea Level Rise 1 Design Storm Event

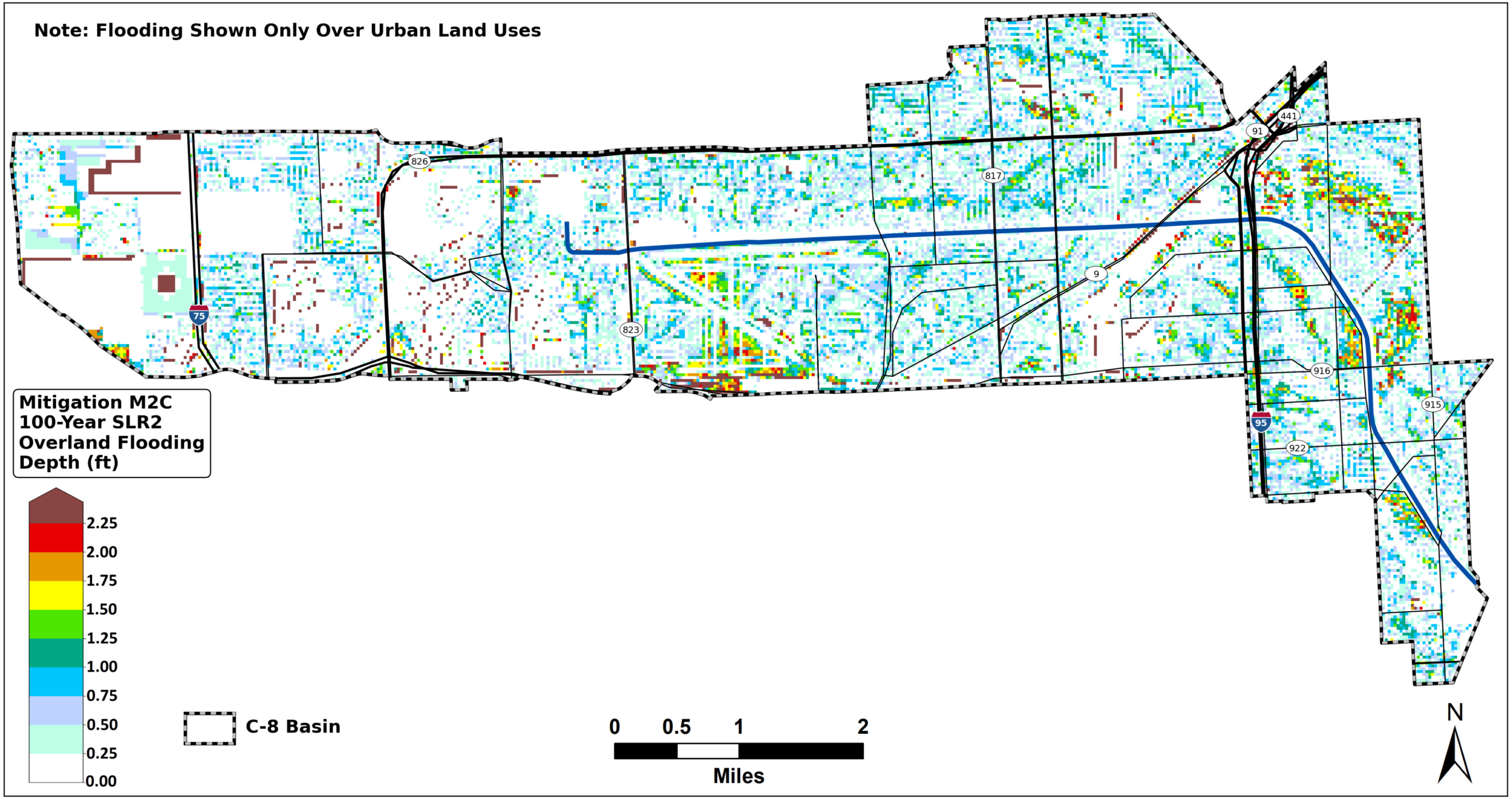


Figure B- 71: C-8 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2C 100-Year Sea Level Rise 2 Design Storm Event

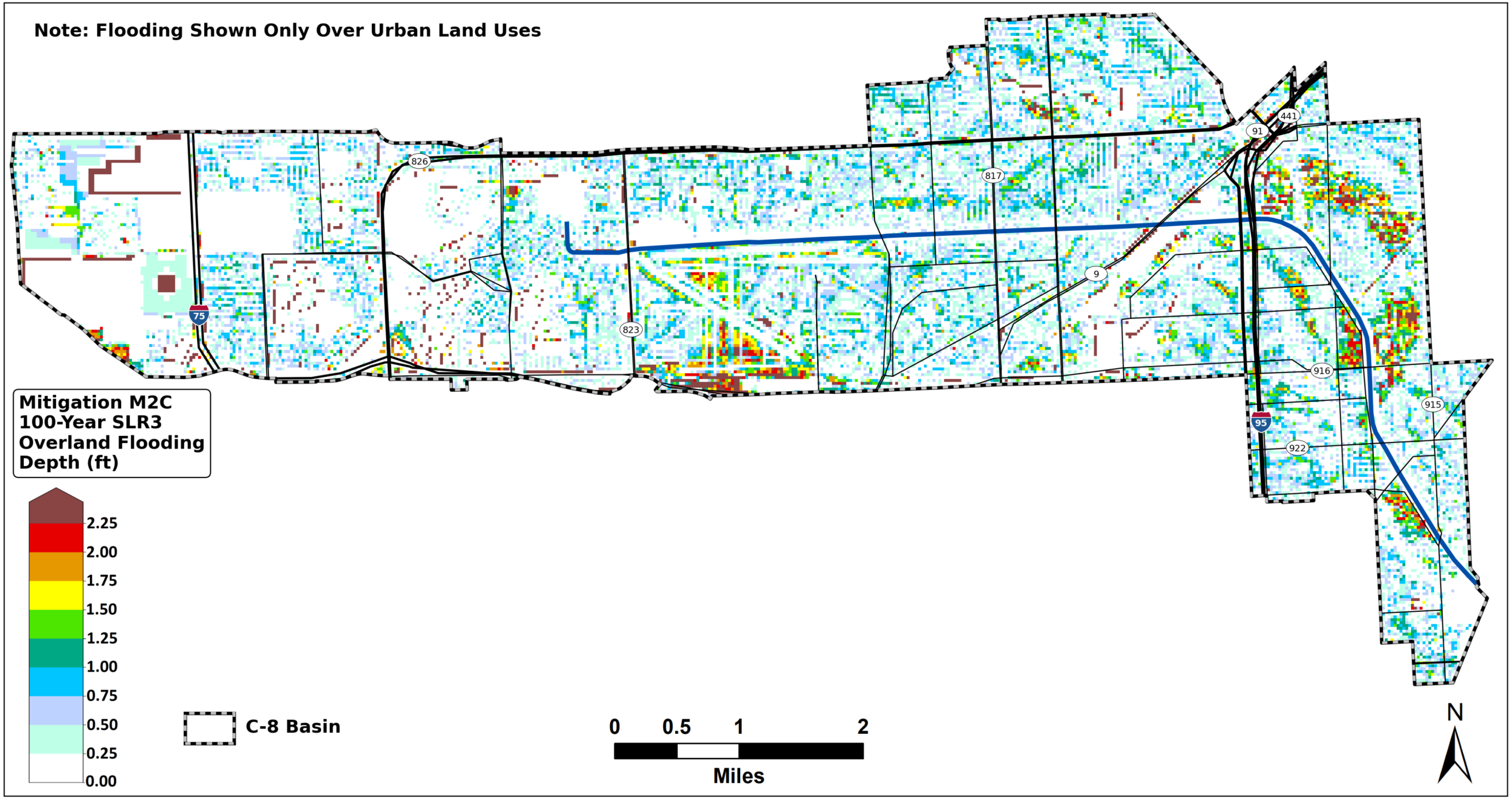


Figure B- 72: C-8 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2C 100-Year Sea Level Rise 3 Design Storm Event

Appendix C Complete Set of PM #5 Flood Inundation Maps for the C-9 Watershed

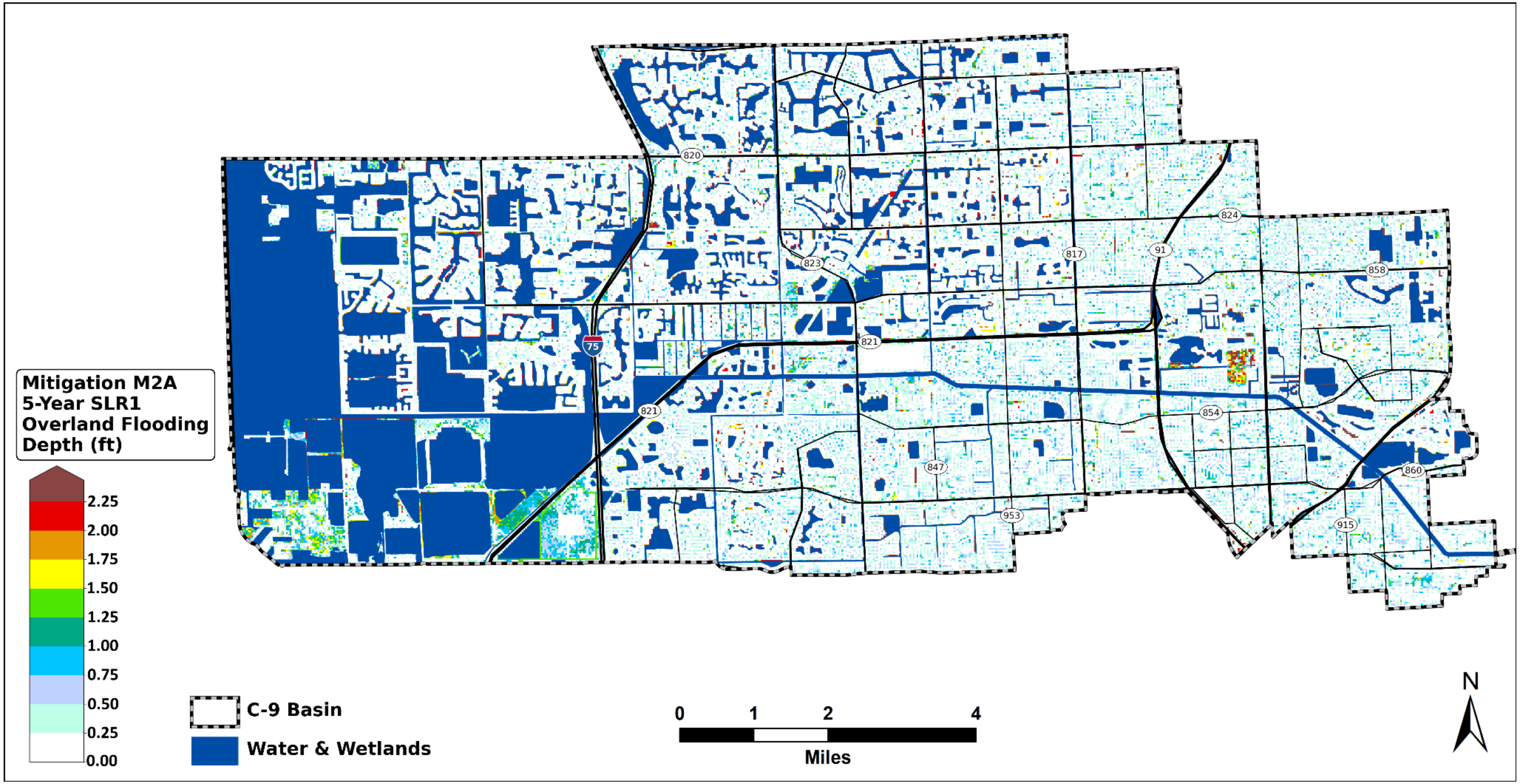


Figure C- 1: C-9 Watershed Flood Inundation Map for the Mitigation M2A 5-Year Sea Level Rise 1 Design Storm Event

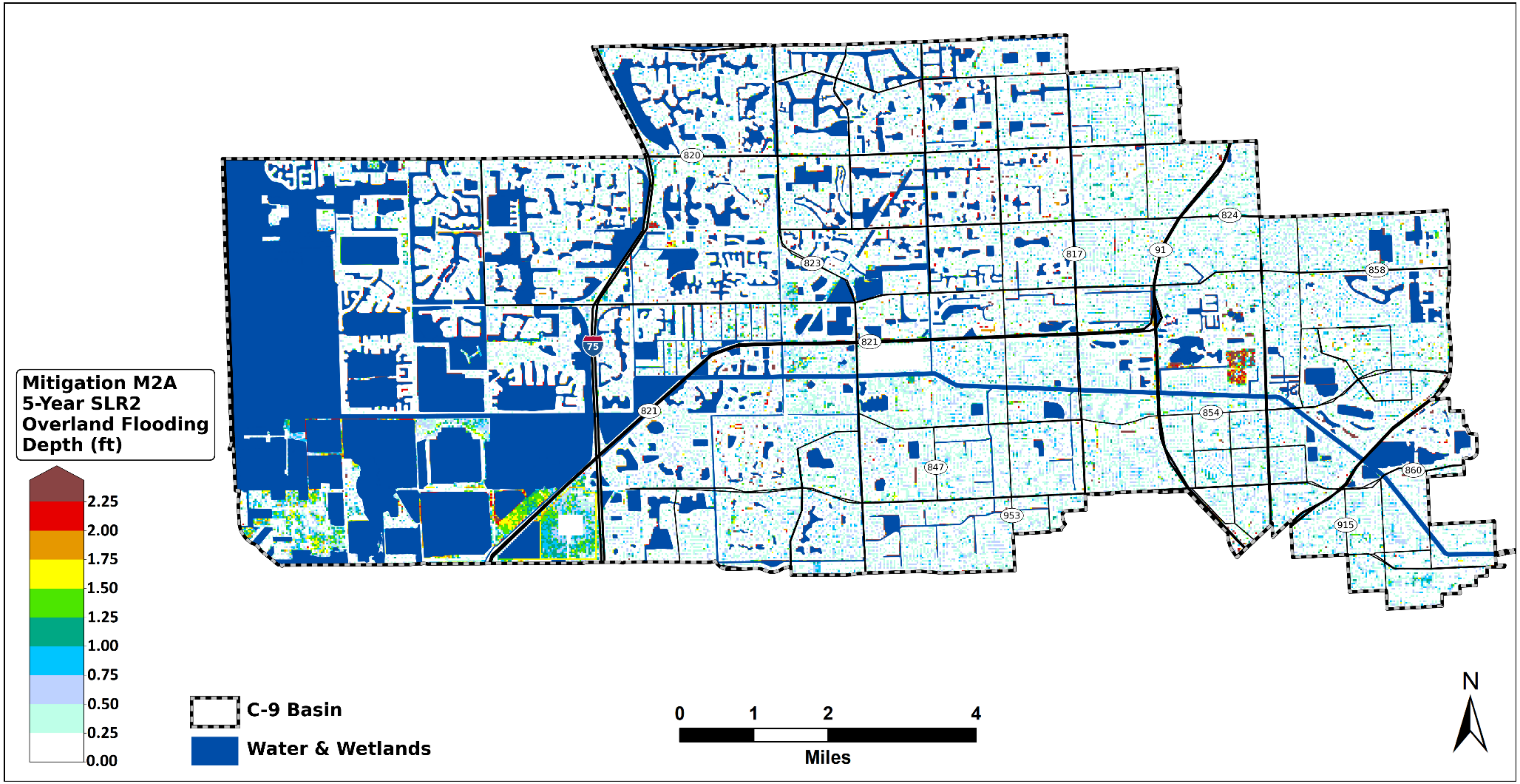


Figure C- 2: C-9 Watershed Flood Inundation Map for the Mitigation M2A 5-Year Sea Level Rise 2 Design Storm Event

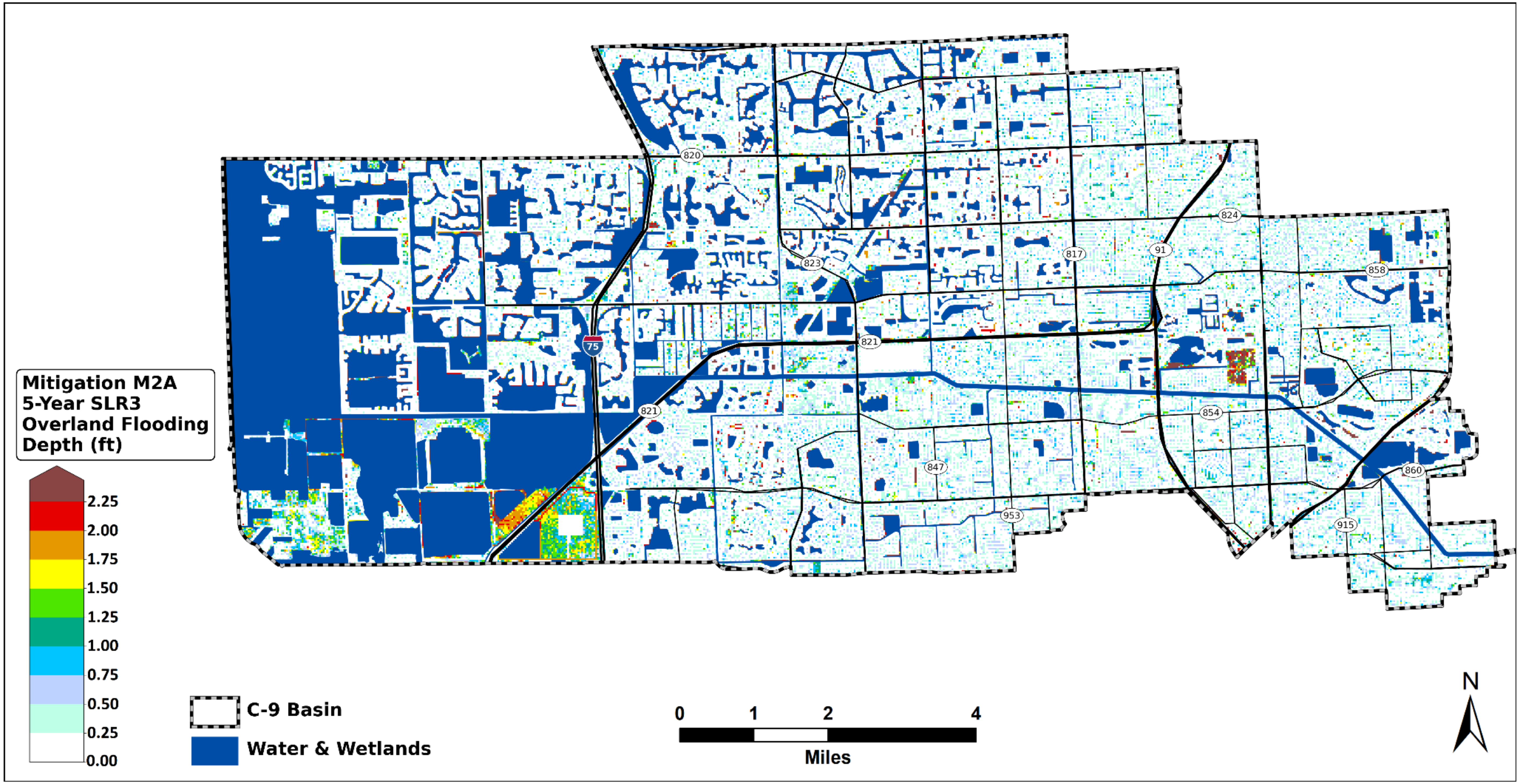


Figure C- 3: C-9 Watershed Flood Inundation Map for the Mitigation M2A 5-Year Sea Level Rise 3 Design Storm Event

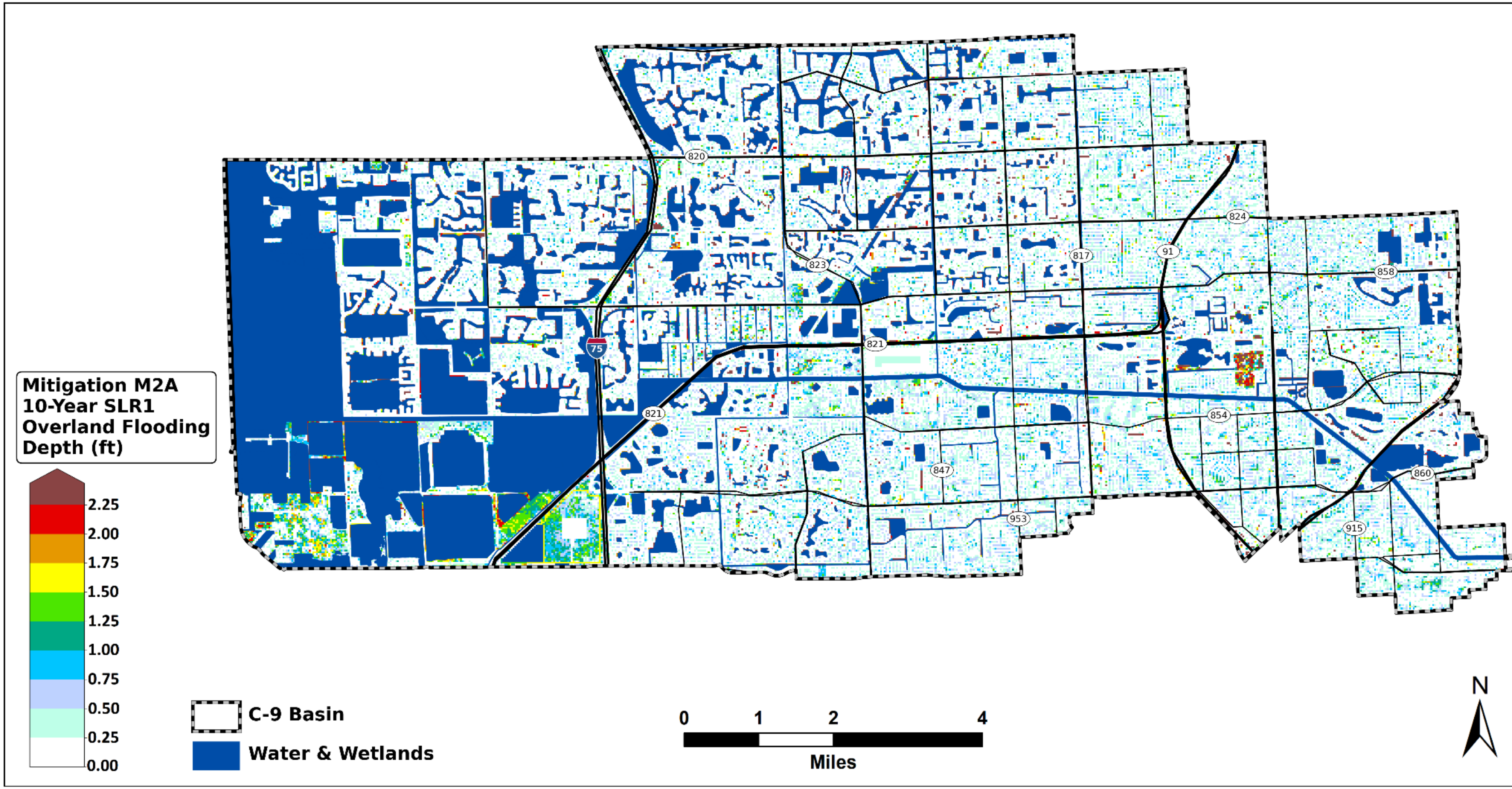


Figure C- 4: C-9 Watershed Flood Inundation Map for the Mitigation M2A 10-Year Sea Level Rise 1 Design Storm Event

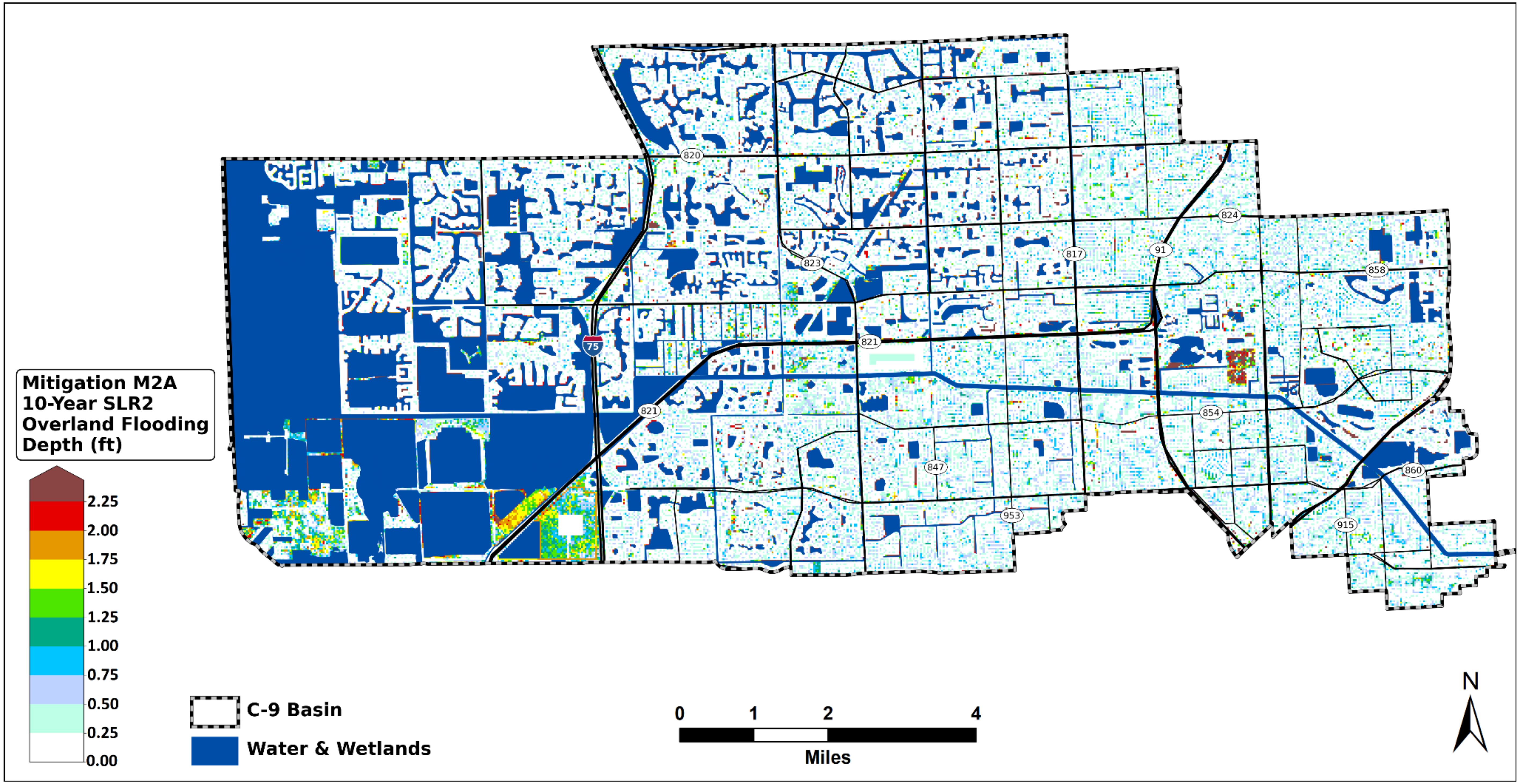


Figure C- 5: C-9 Watershed Flood Inundation Map for the Mitigation M2A 10-Year Sea Level Rise 2 Design Storm Event

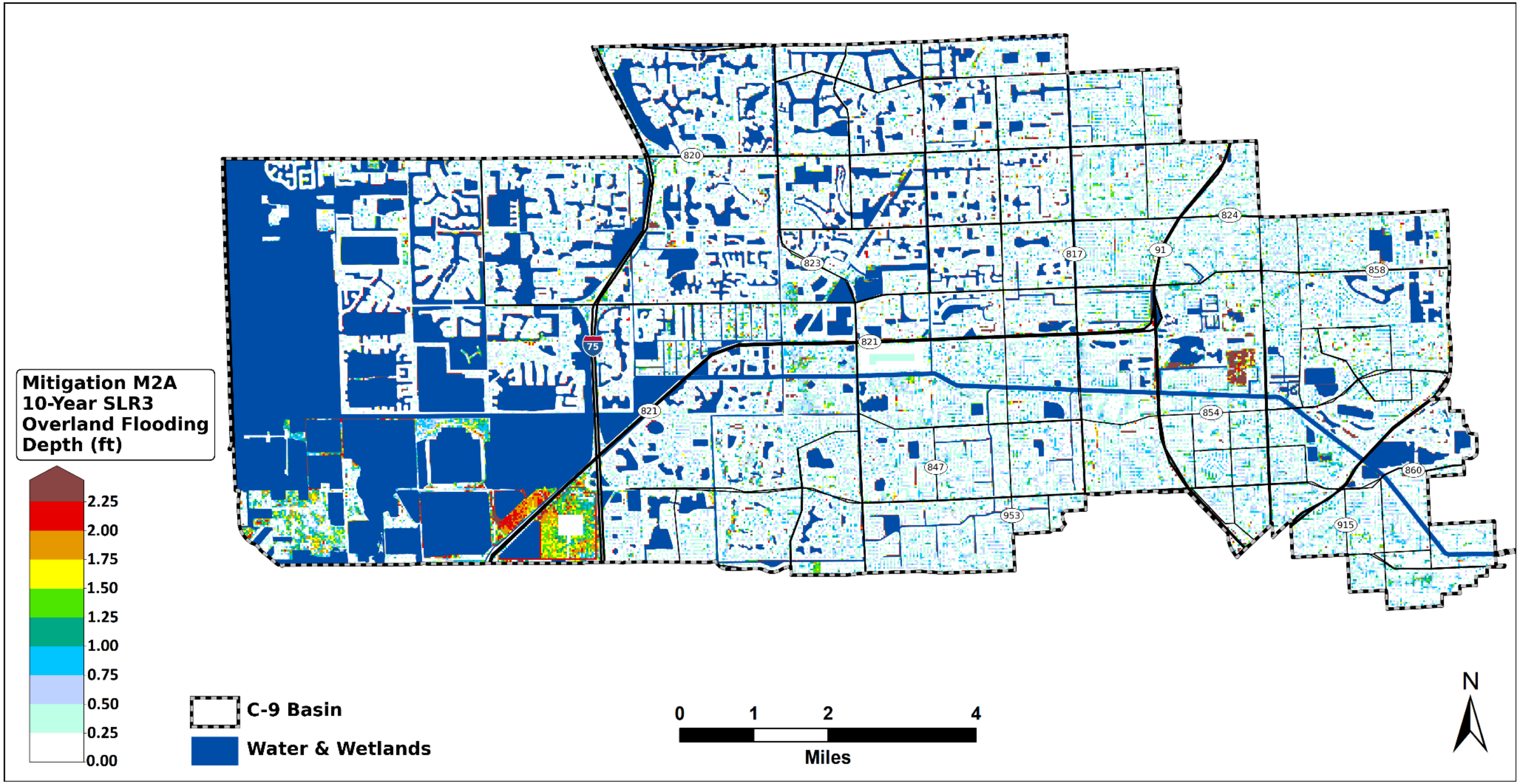


Figure C- 6: C-9 Watershed Flood Inundation Map for the Mitigation M2A 10-Year Sea Level Rise 3 Design Storm Event

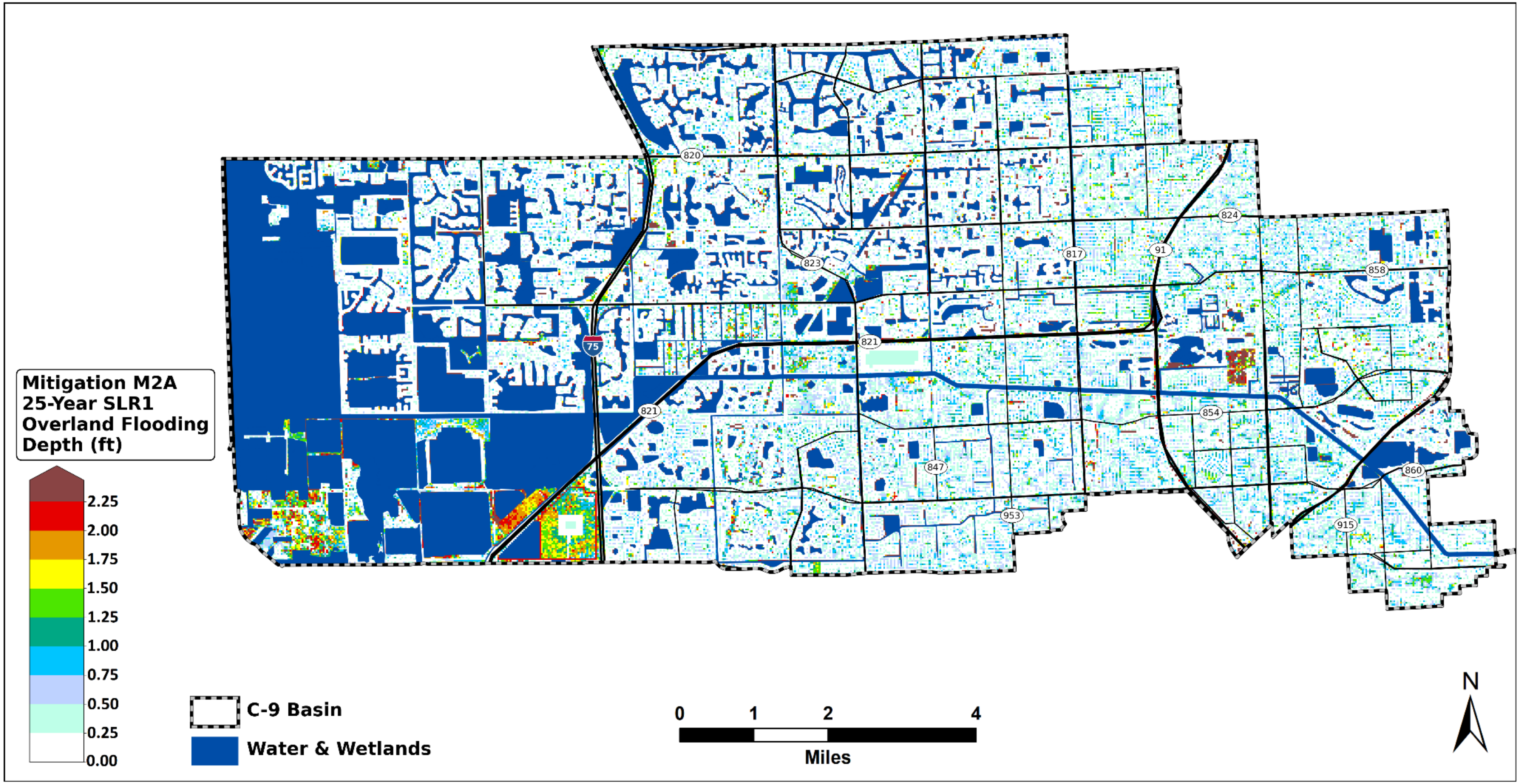


Figure C- 7: C-9 Watershed Flood Inundation Map for the Mitigation M2A 25-Year Sea Level Rise 1 Design Storm Event

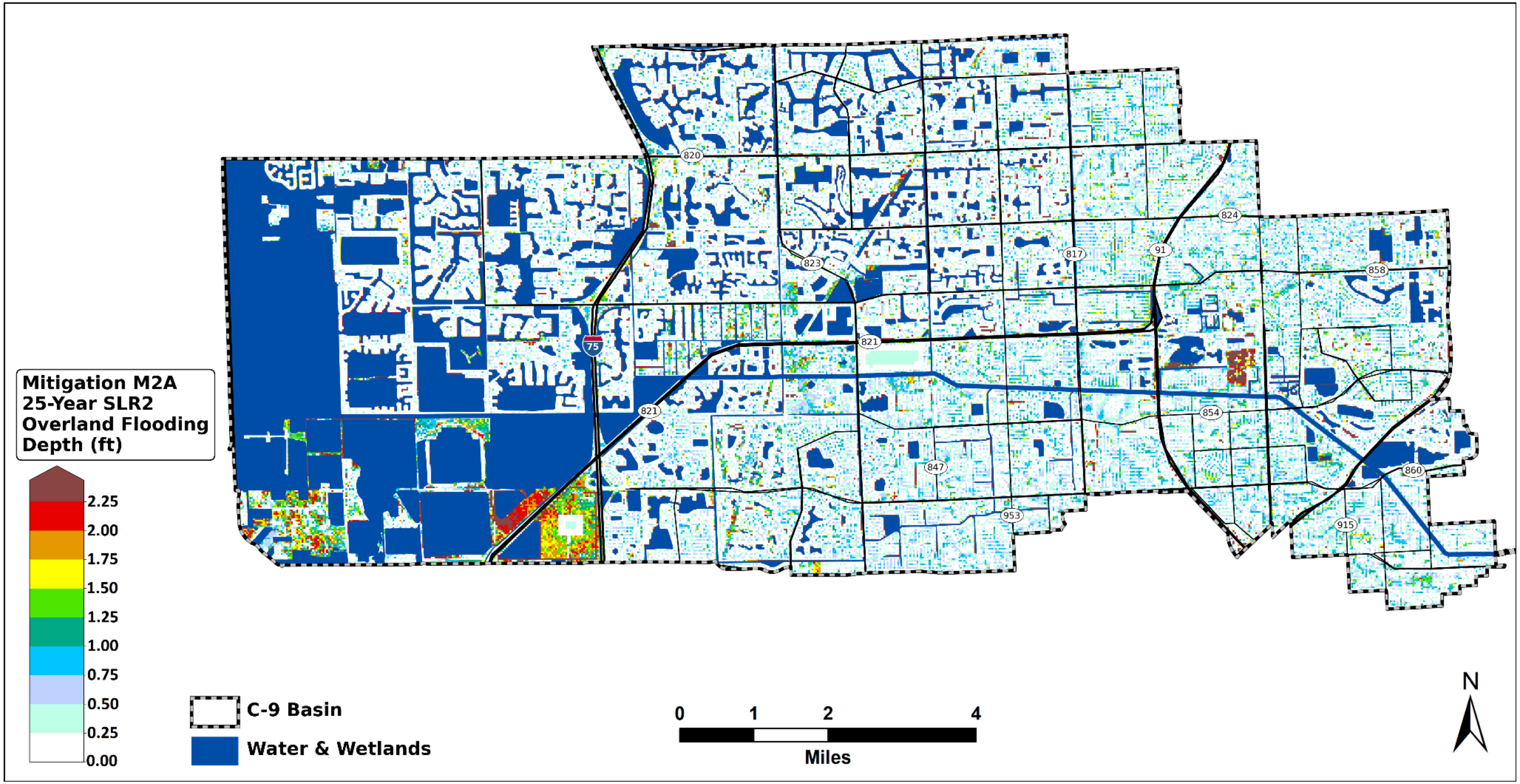


Figure C- 8: C-9 Watershed Flood Inundation Map for the Mitigation M2A 25-Year Sea Level Rise 2 Design Storm Event

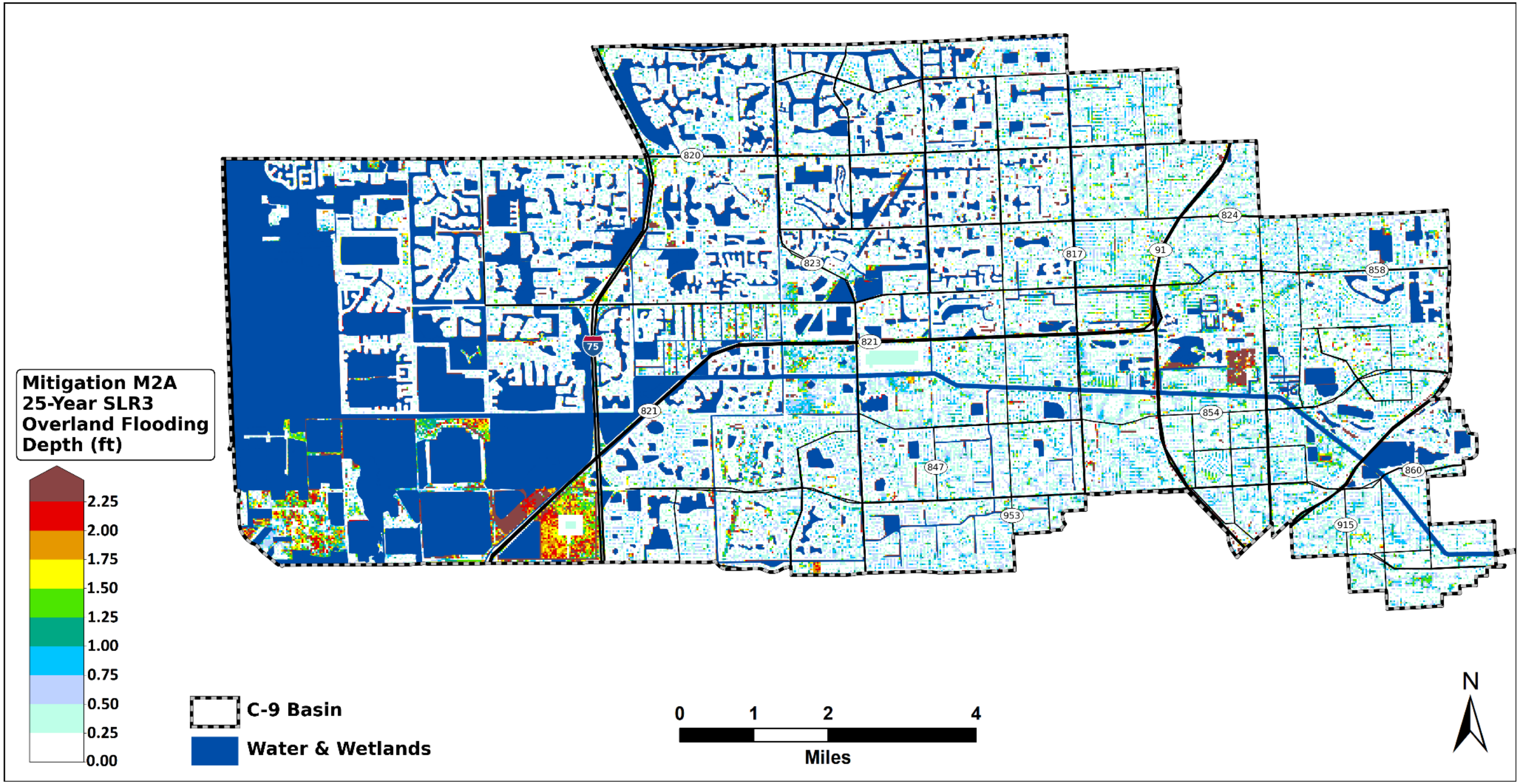


Figure C- 9: C-9 Watershed Flood Inundation Map for the Mitigation M2A 25-Year Sea Level Rise 3 Design Storm Event

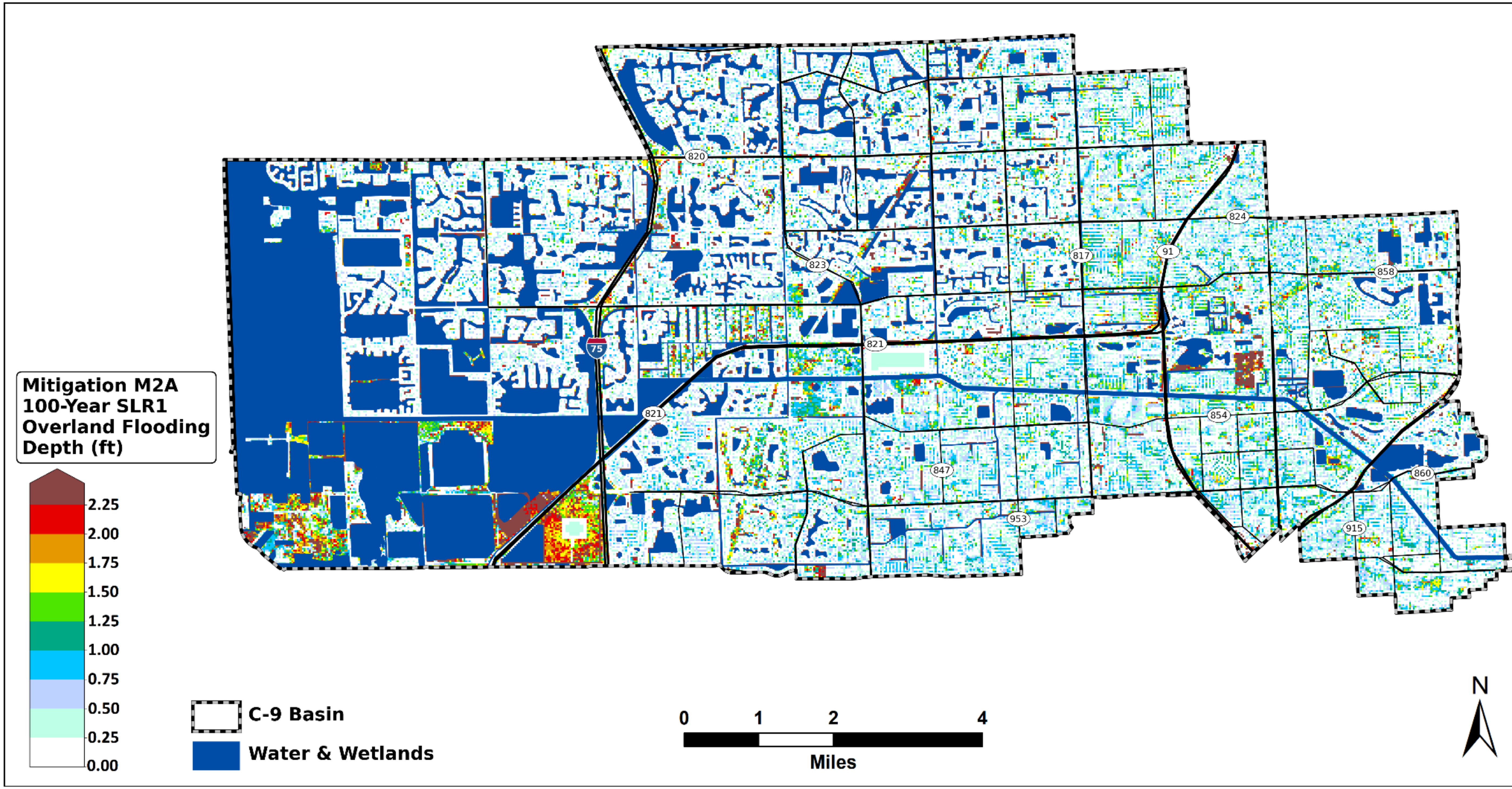


Figure C- 10: C-9 Watershed Flood Inundation Map for the Mitigation M2A 100-Year Sea Level Rise 1 Design Storm Event

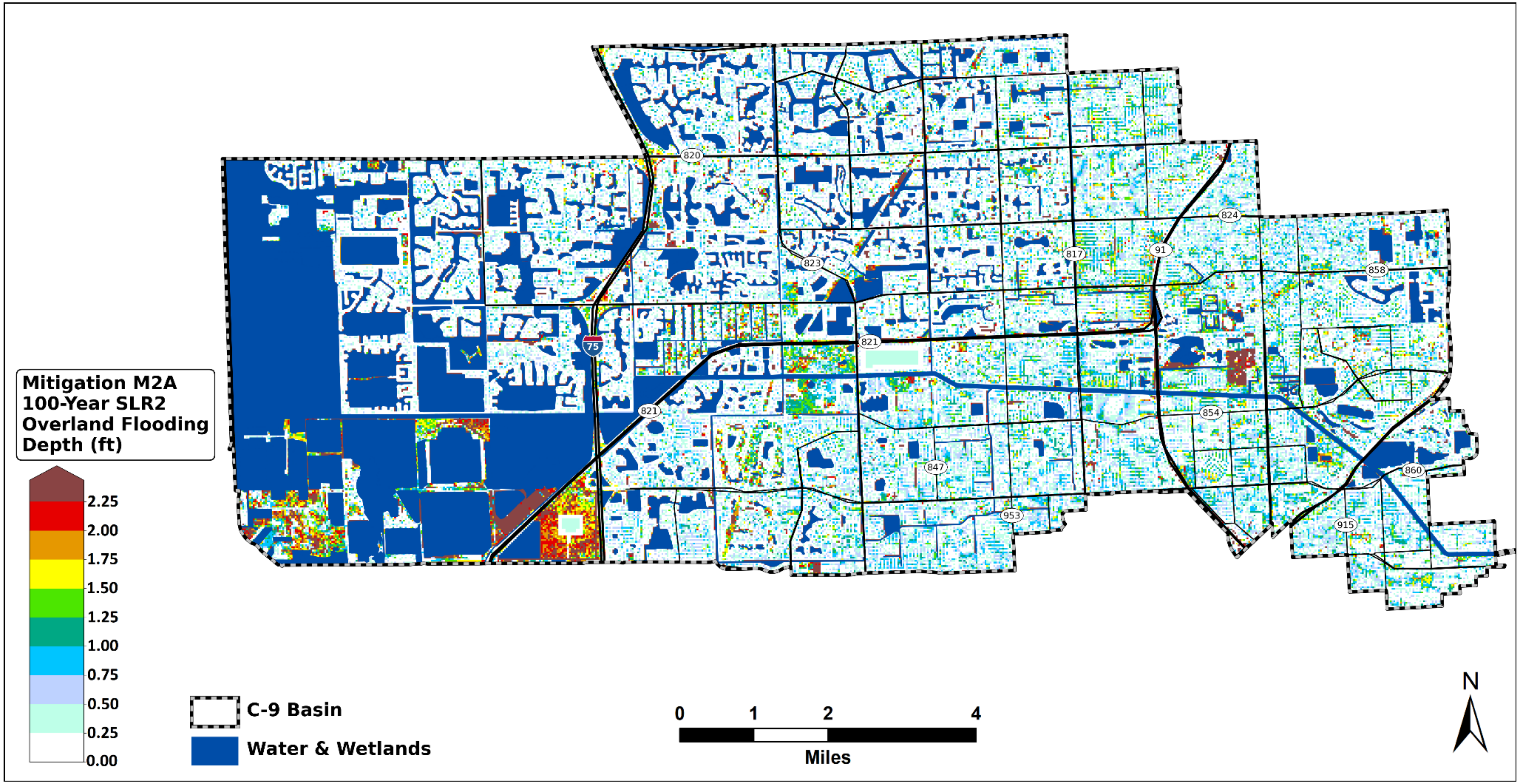


Figure C- 11: C-9 Watershed Flood Inundation Map for the Mitigation M2A 100-Year Sea Level Rise 2 Design Storm Event

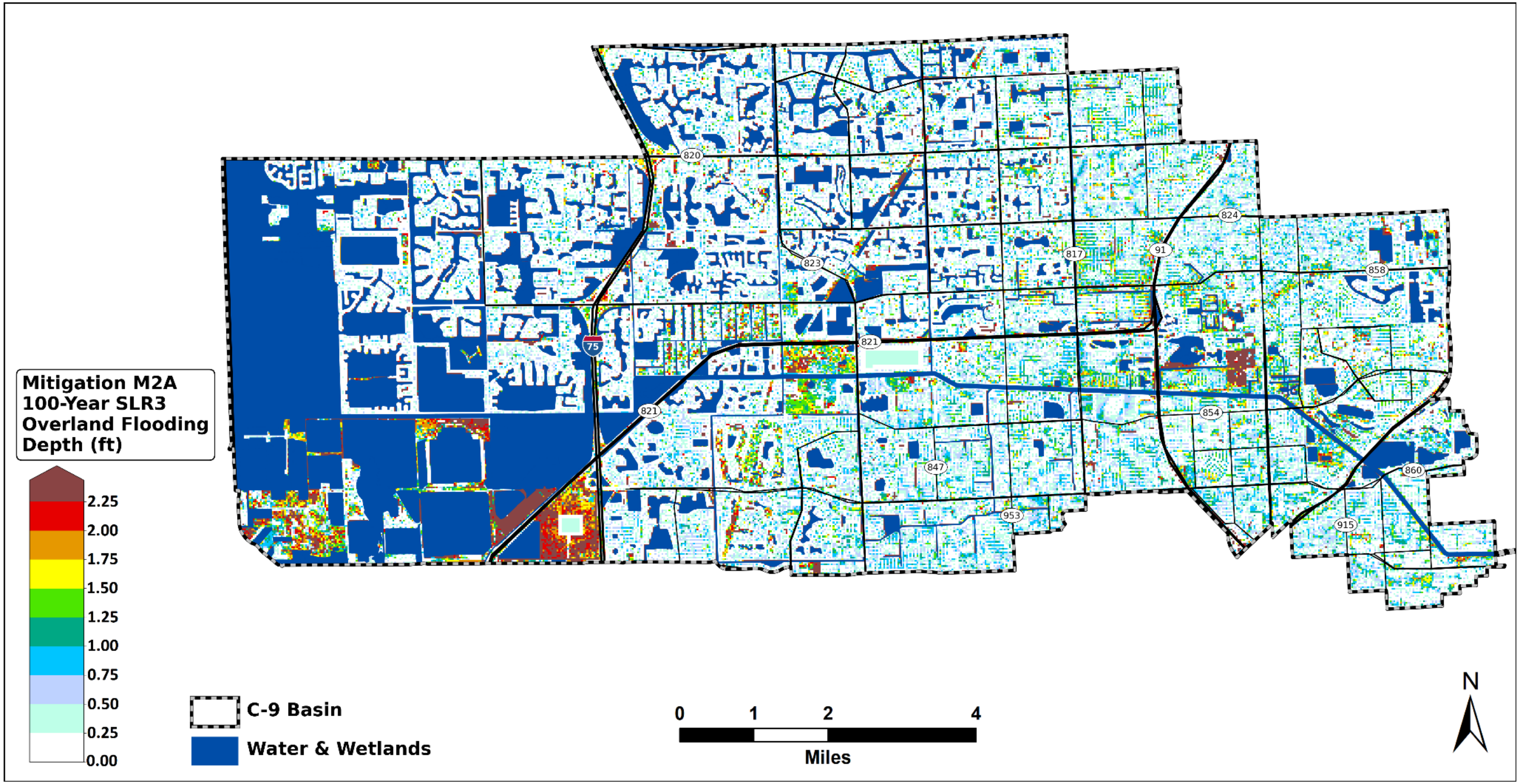


Figure C- 12: C-9 Watershed Flood Inundation Map for the Mitigation M2A 100-Year Sea Level Rise 3 Design Storm Event

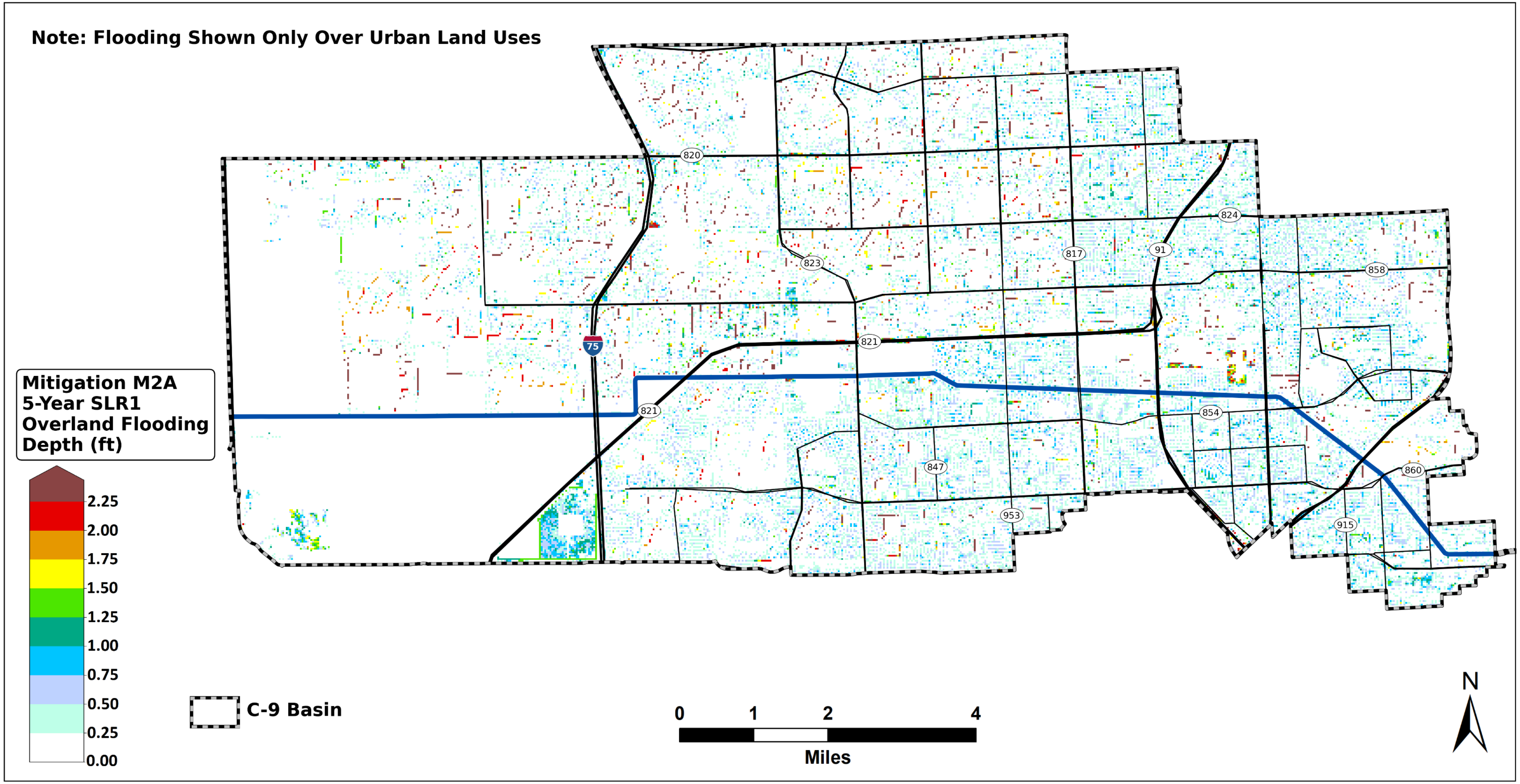


Figure C- 13: C-9 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2A 5-Year Sea Level Rise 1 Design Storm Event

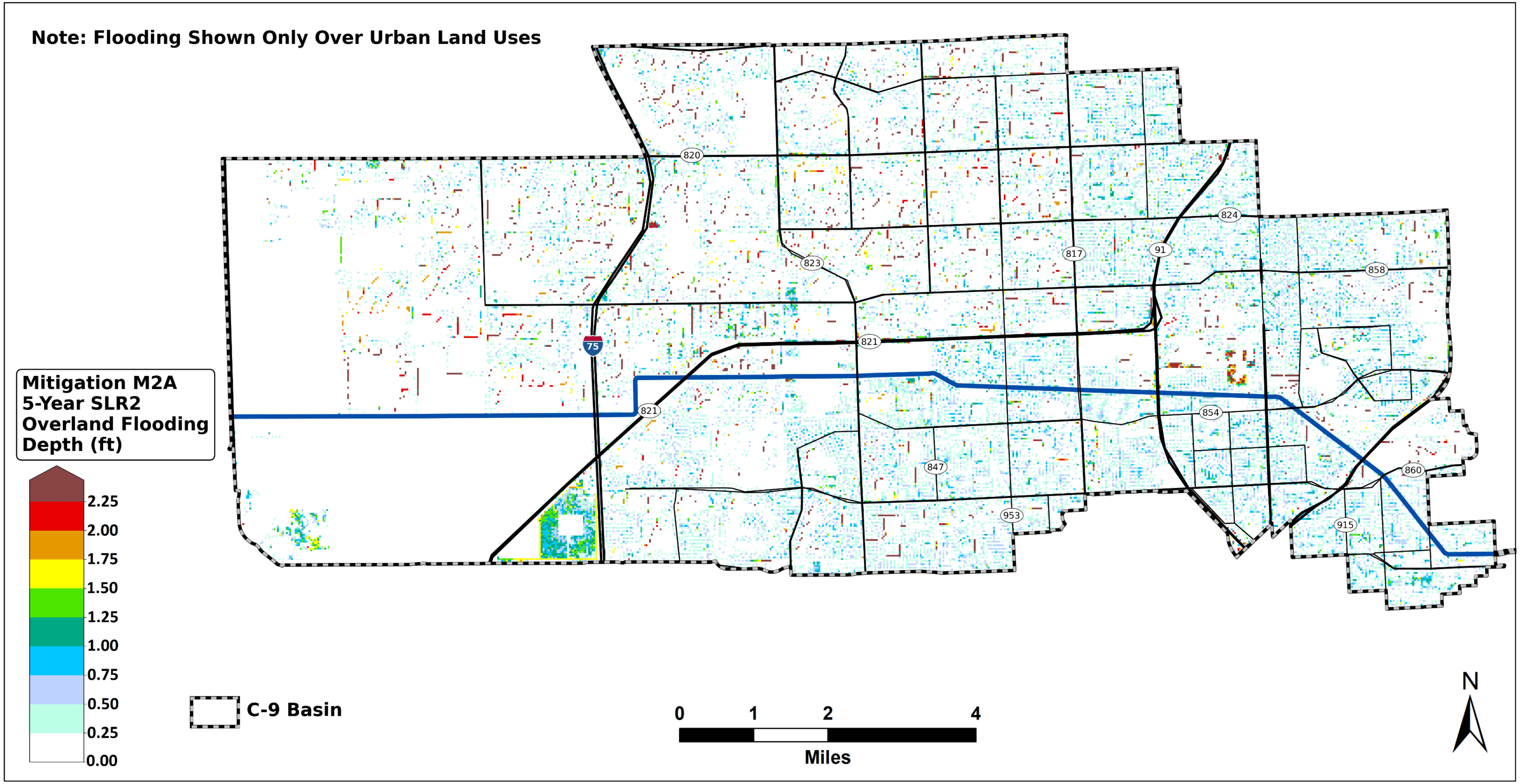


Figure C- 14: C-9 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2A 5-Year Sea Level Rise 2 Design Storm Event

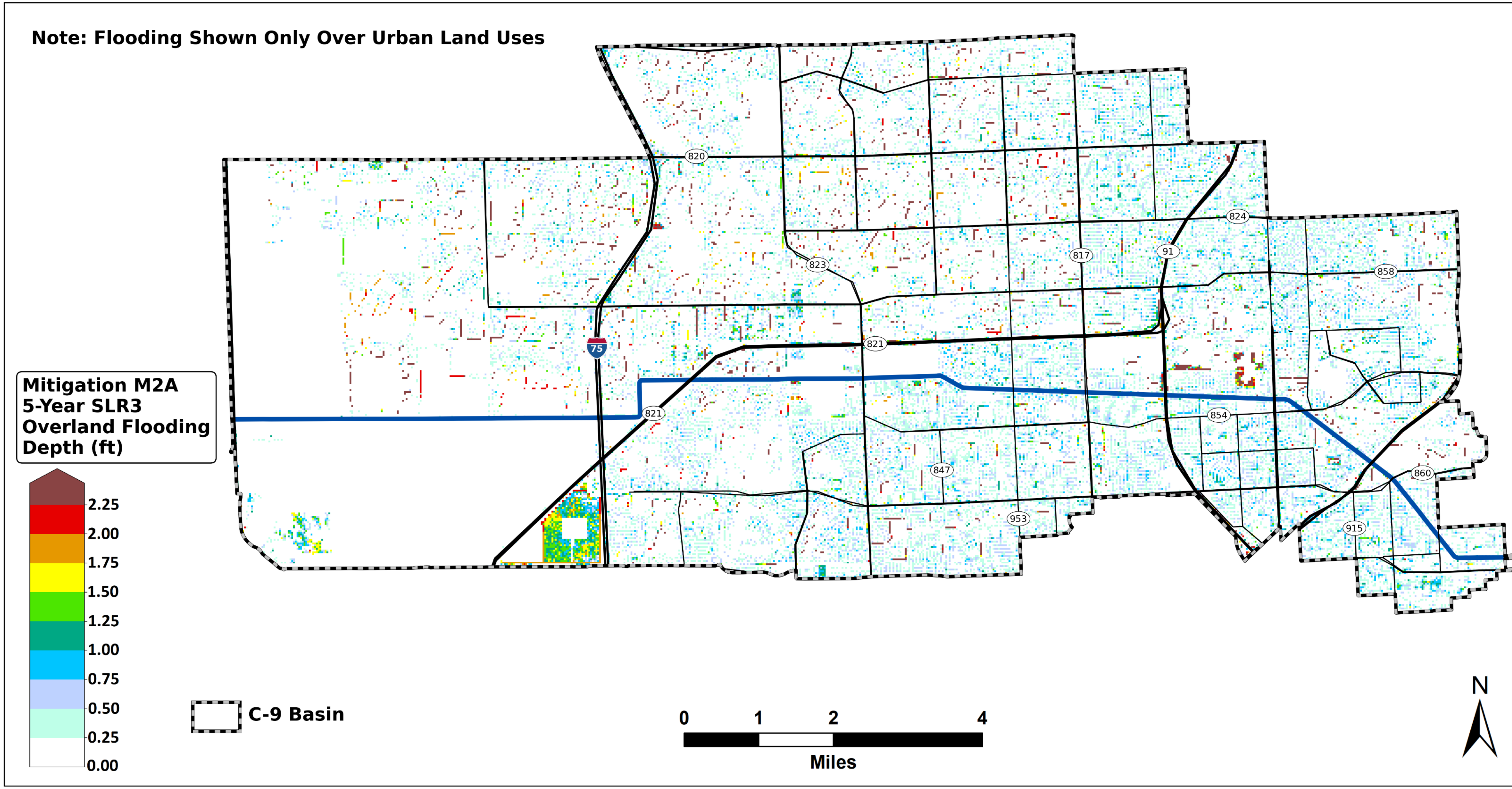


Figure C- 15: C-9 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2A 5-Year Sea Level Rise 3 Design Storm Event

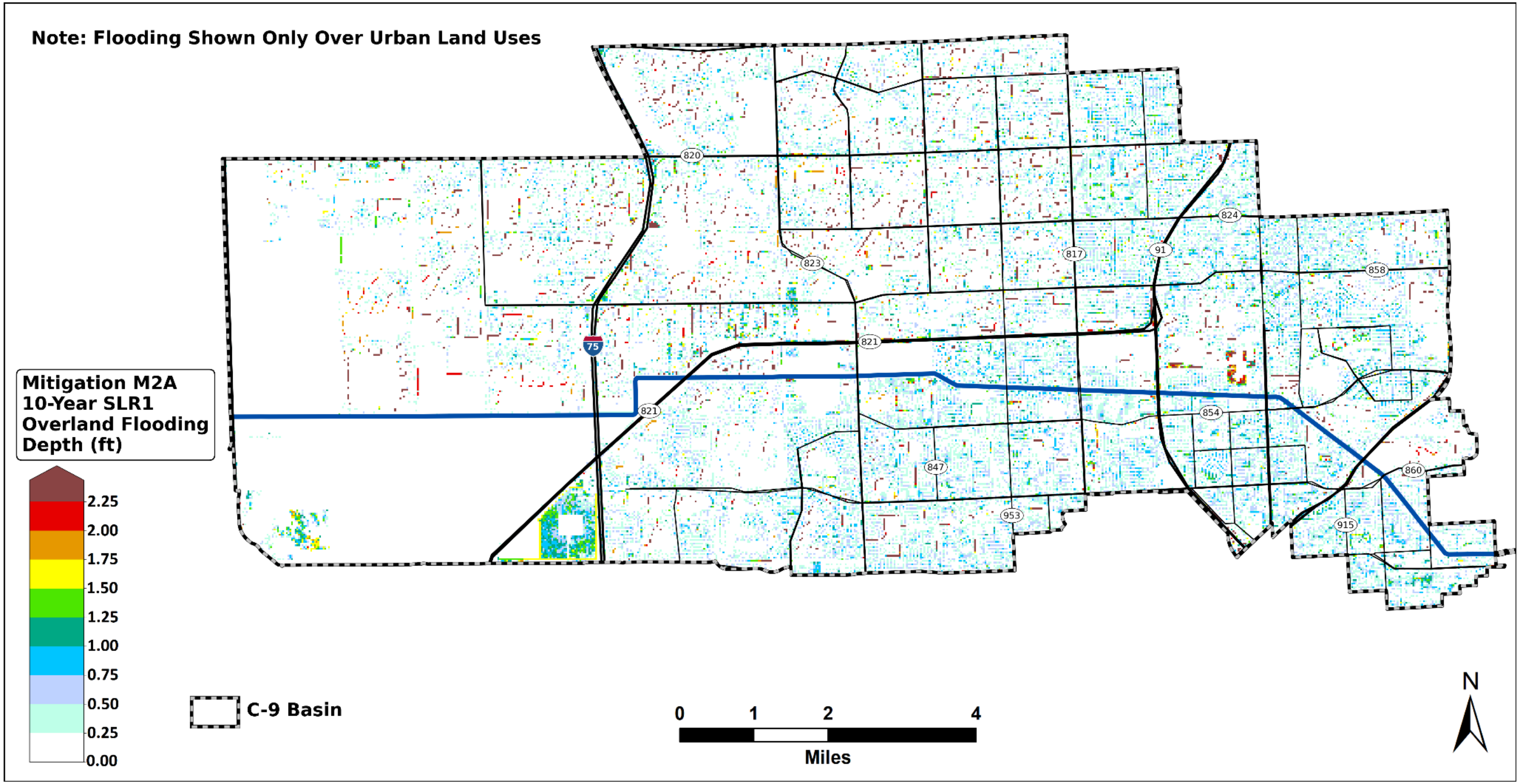


Figure C- 16: C-9 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2A 10-Year Sea Level Rise 1 Design Storm Event

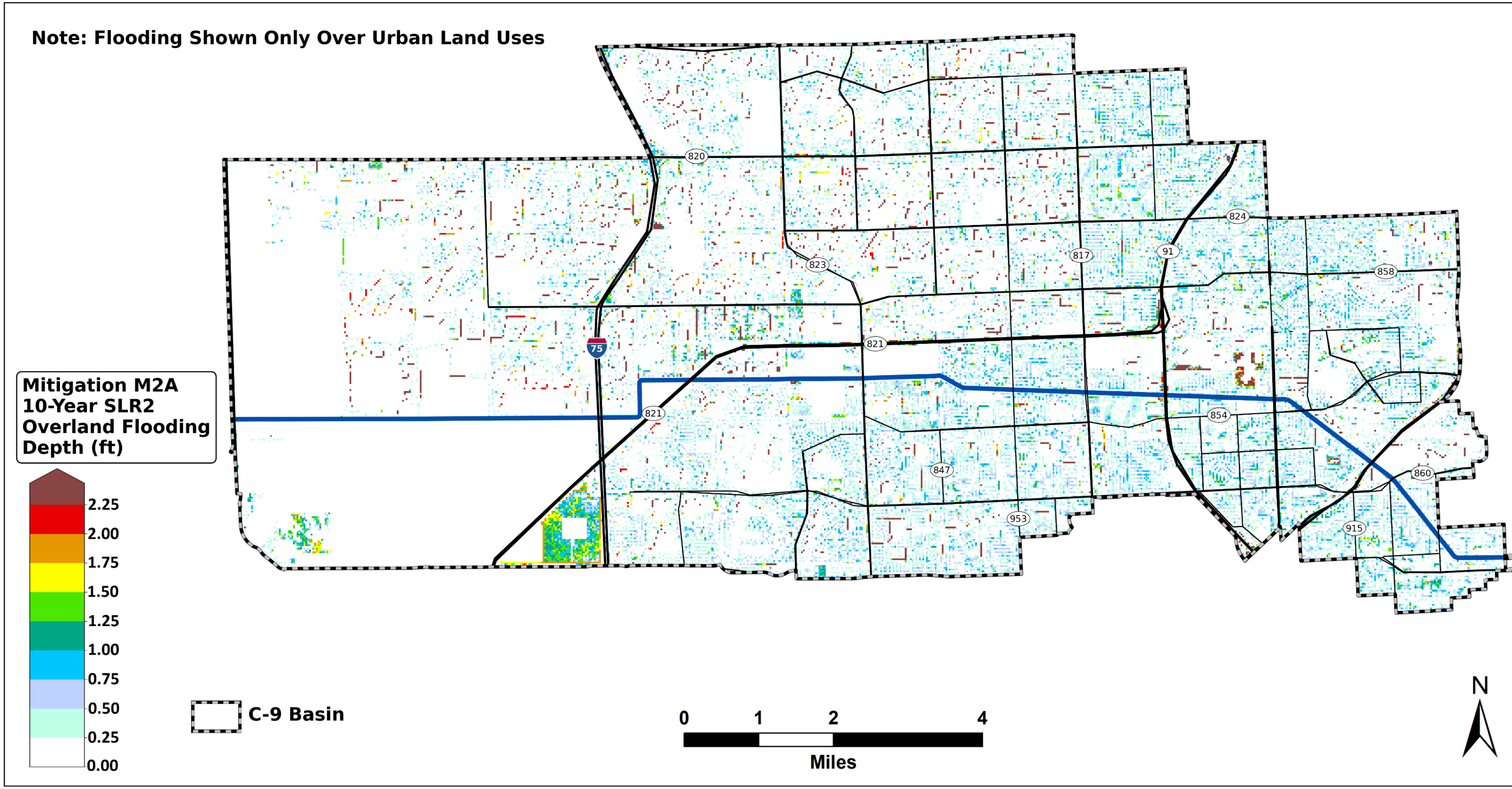


Figure C- 17: C-9 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2A 10-Year Sea Level Rise 2 Design Storm Event

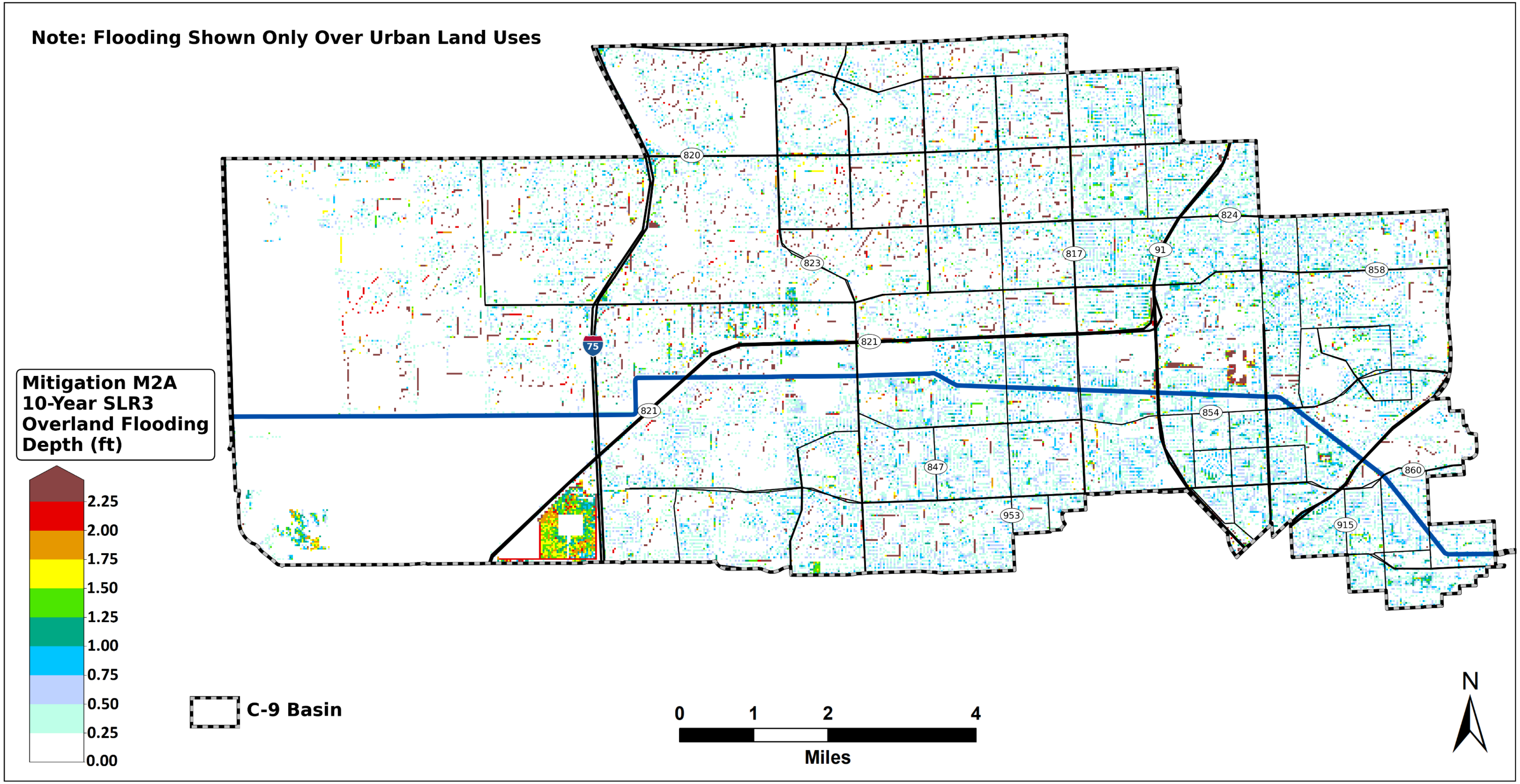


Figure C- 18: C-9 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2A 10-Year Sea Level Rise 3 Design Storm Event

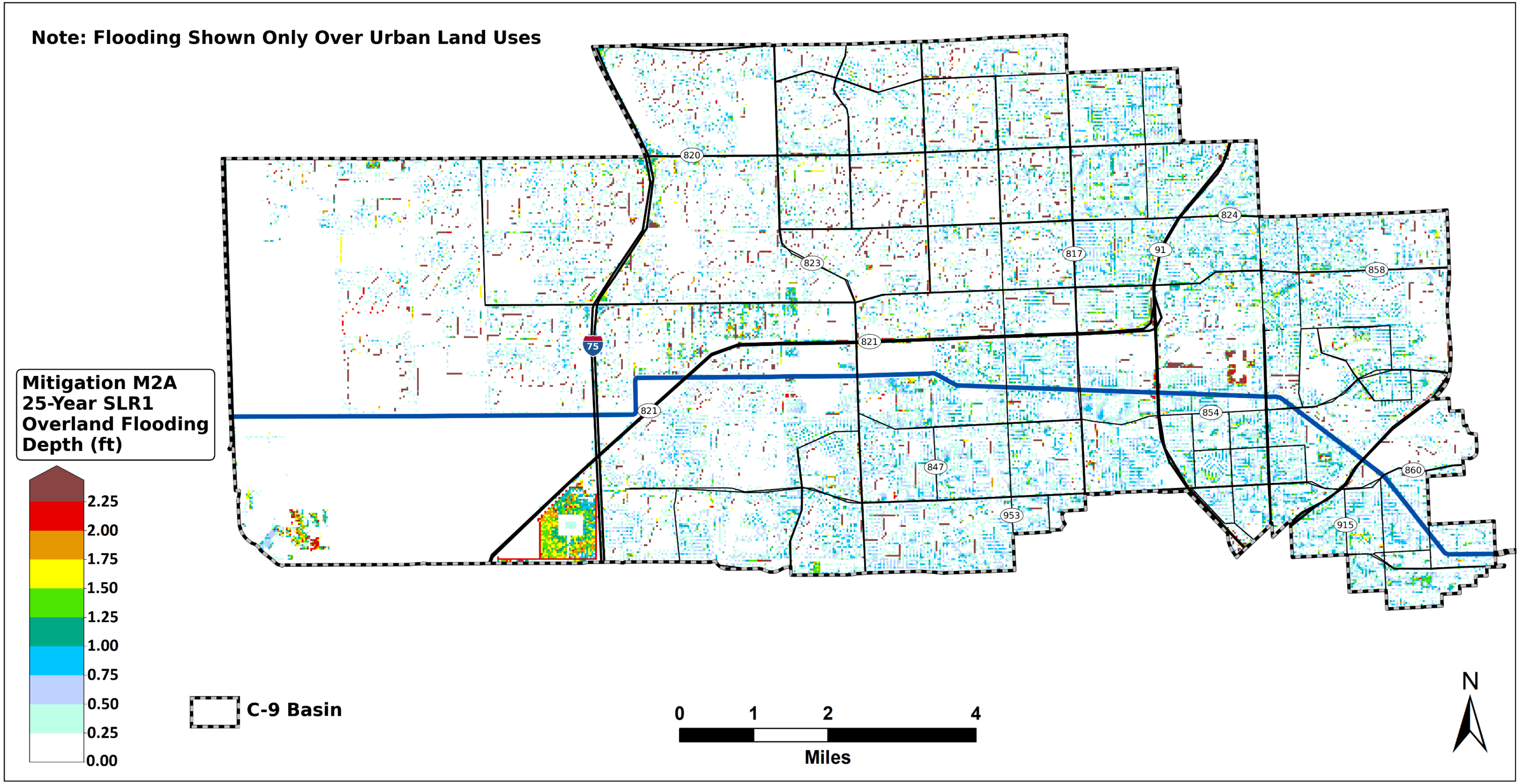


Figure C- 19: C-9 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2A 25-Year Sea Level Rise 1 Design Storm Event

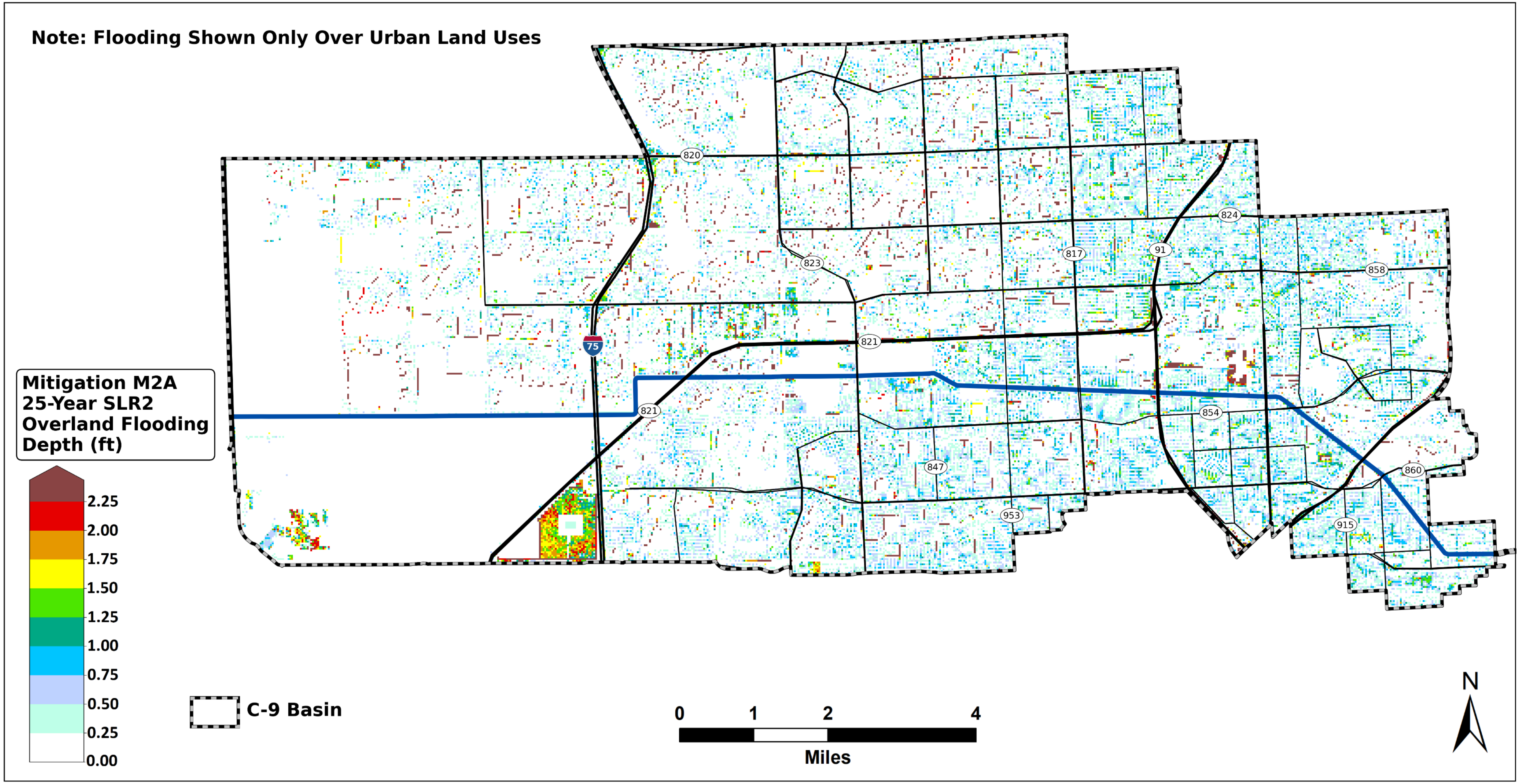


Figure C- 20: C-9 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2A 25-Year Sea Level Rise 2 Design Storm Event

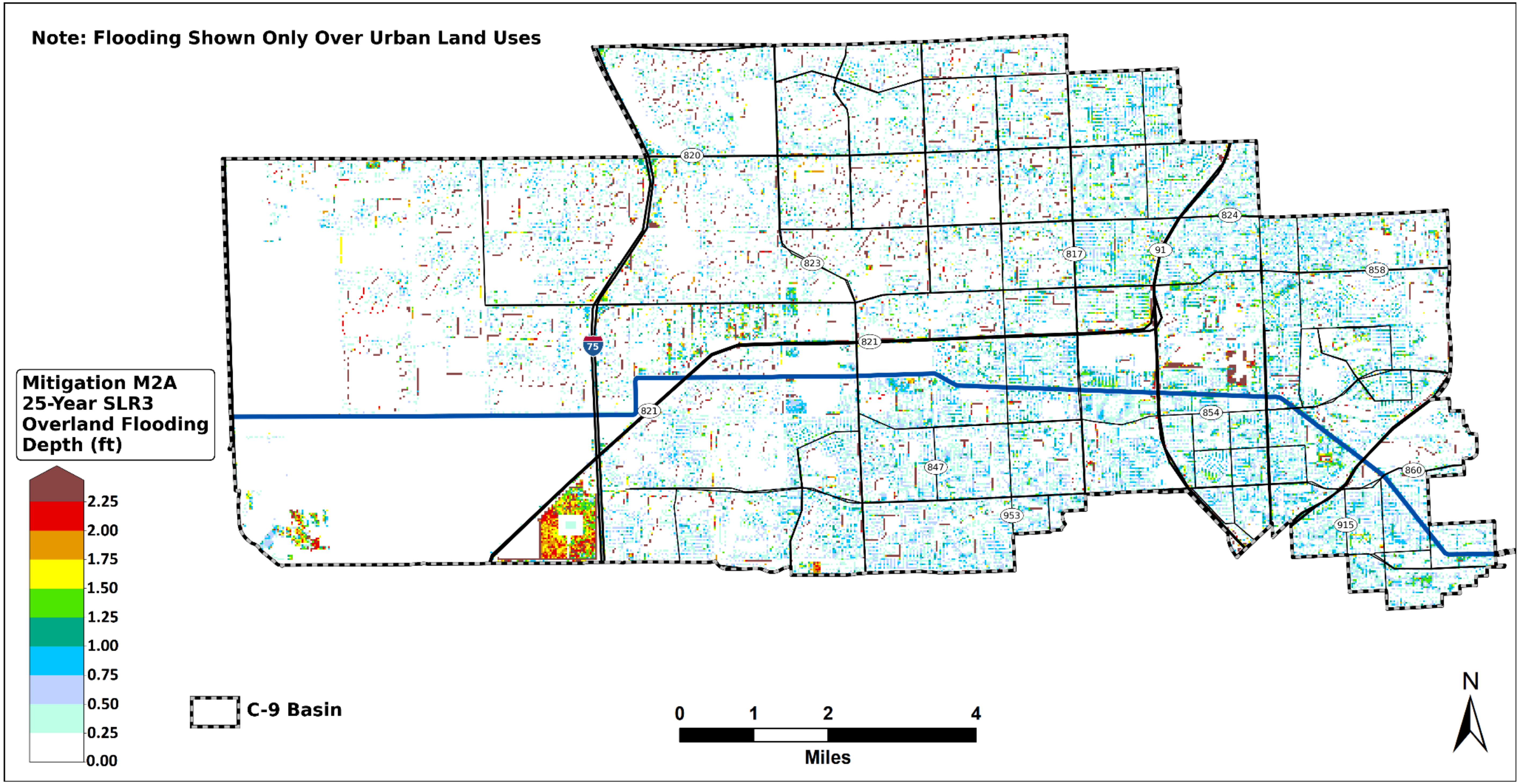


Figure C- 21: C-9 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2A 25-Year Sea Level Rise 3 Design Storm Event

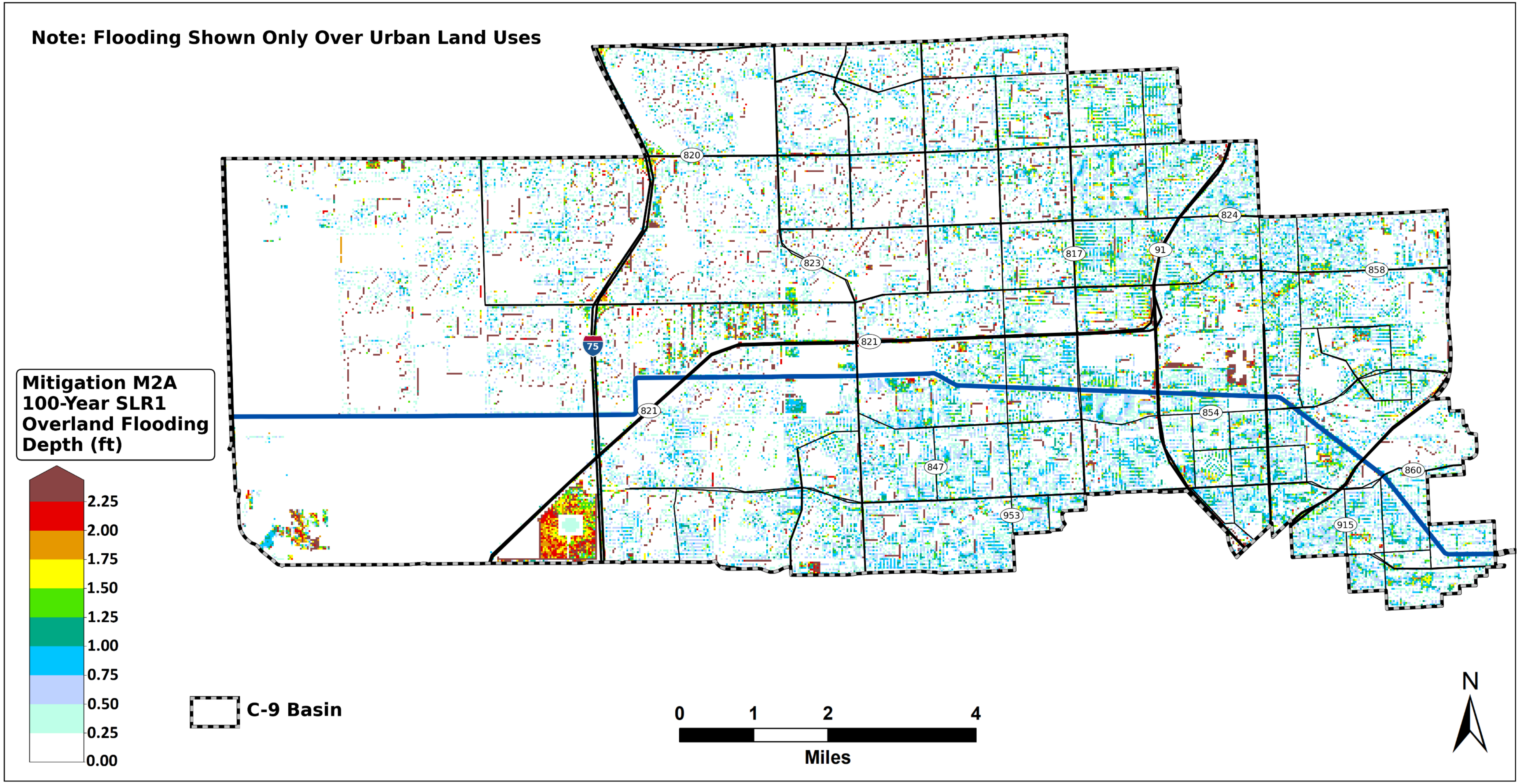


Figure C- 22: C-9 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2A 100-Year Sea Level Rise 1 Design Storm Event

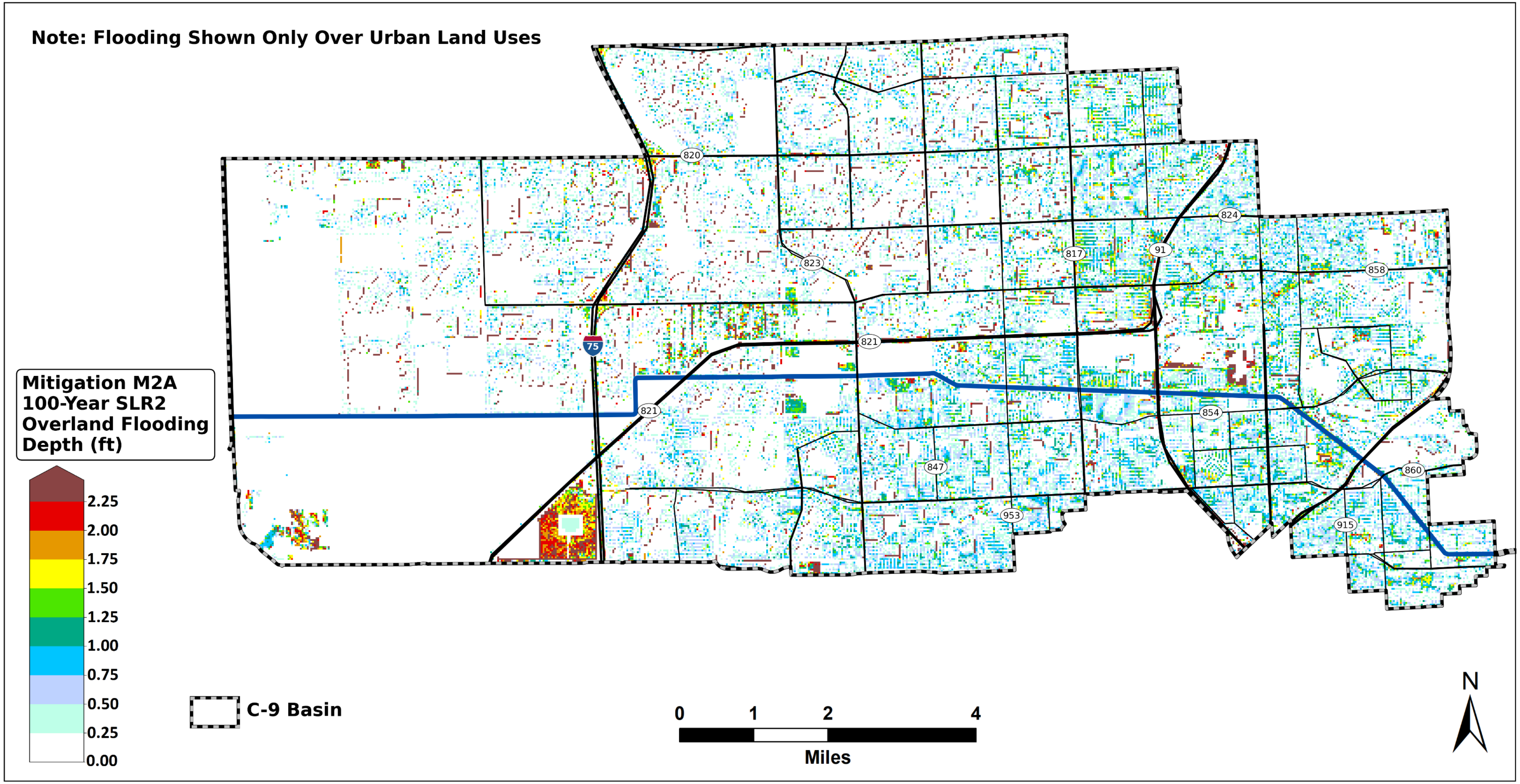


Figure C- 23: C-9 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2A 100-Year Sea Level Rise 2 Design Storm Event

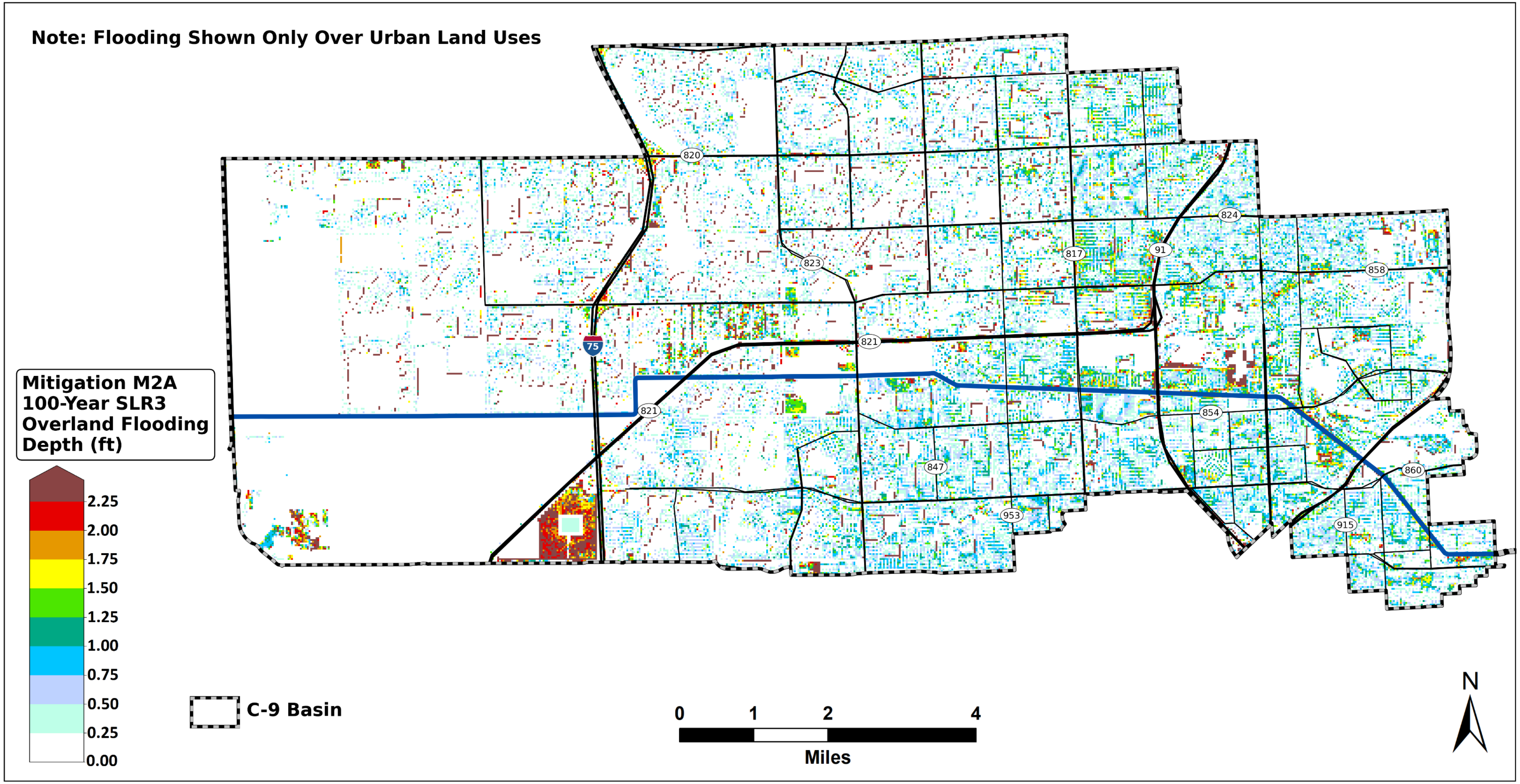


Figure C- 24: C-9 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2A 100-Year Sea Level Rise 3 Design Storm Event

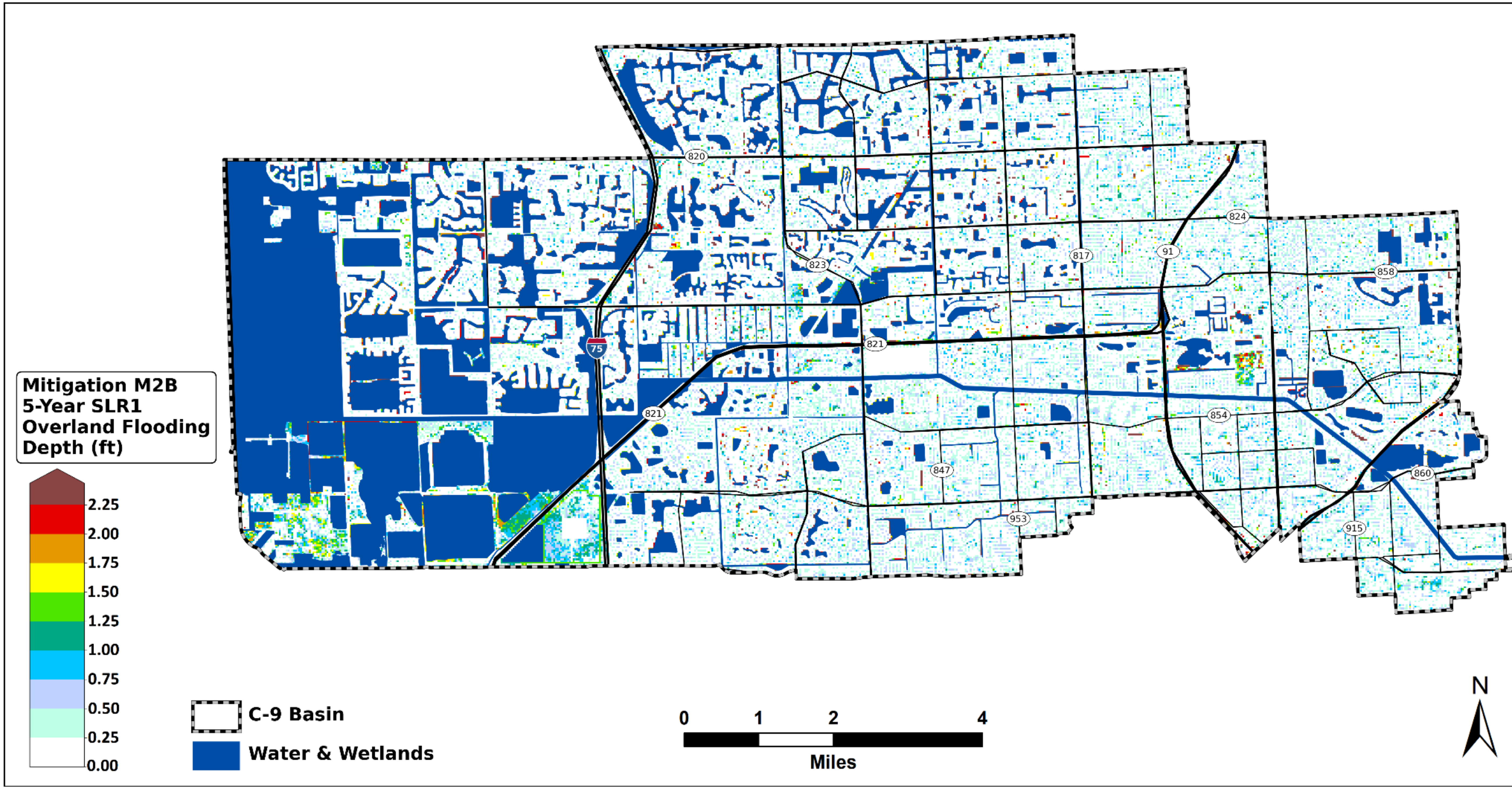


Figure C- 25: C-9 Watershed Flood Inundation Map for the Mitigation M2B 5-Year Sea Level Rise 1 Design Storm Event

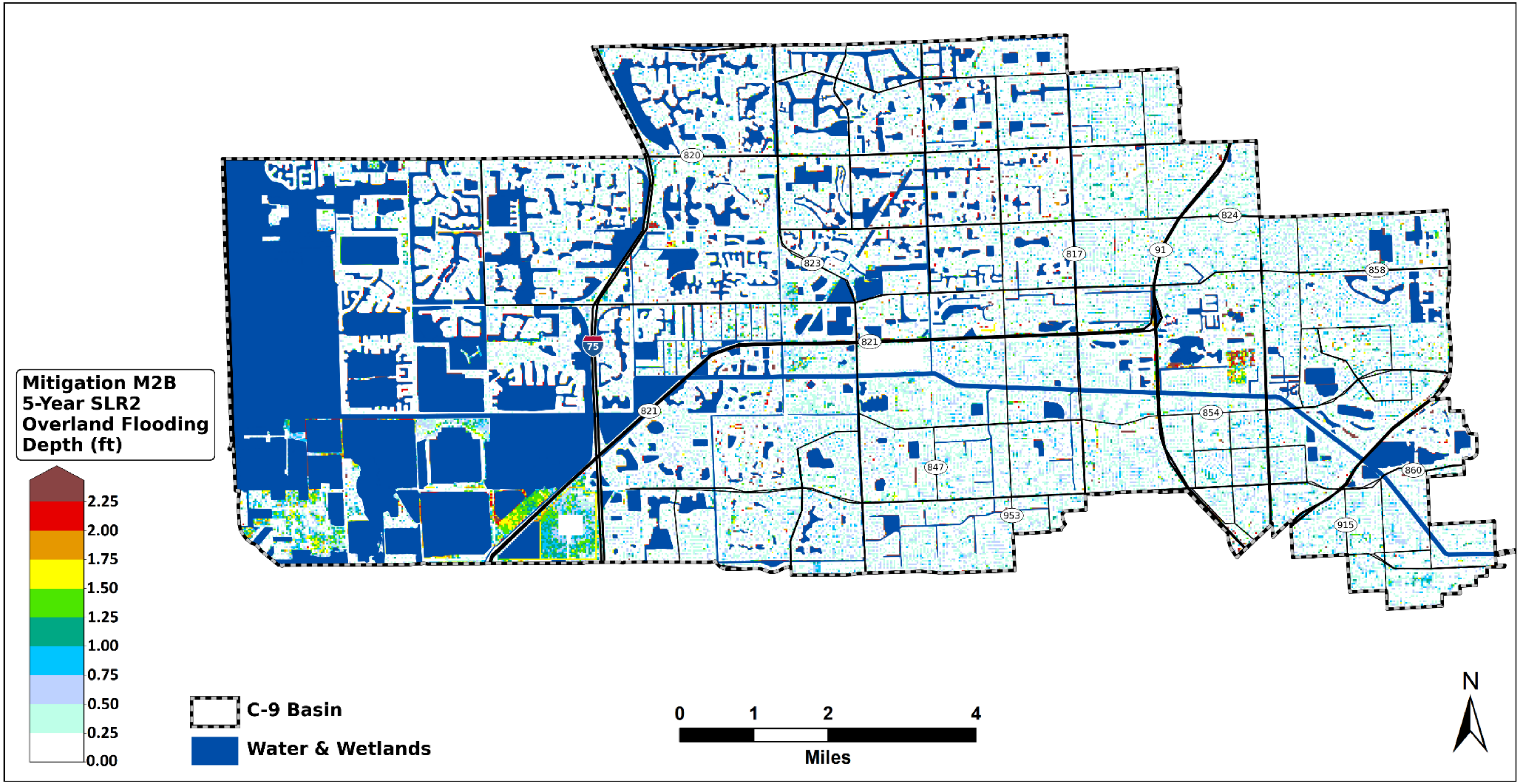


Figure C- 26: C-9 Watershed Flood Inundation Map for the Mitigation M2B 5-Year Sea Level Rise 2 Design Storm Event

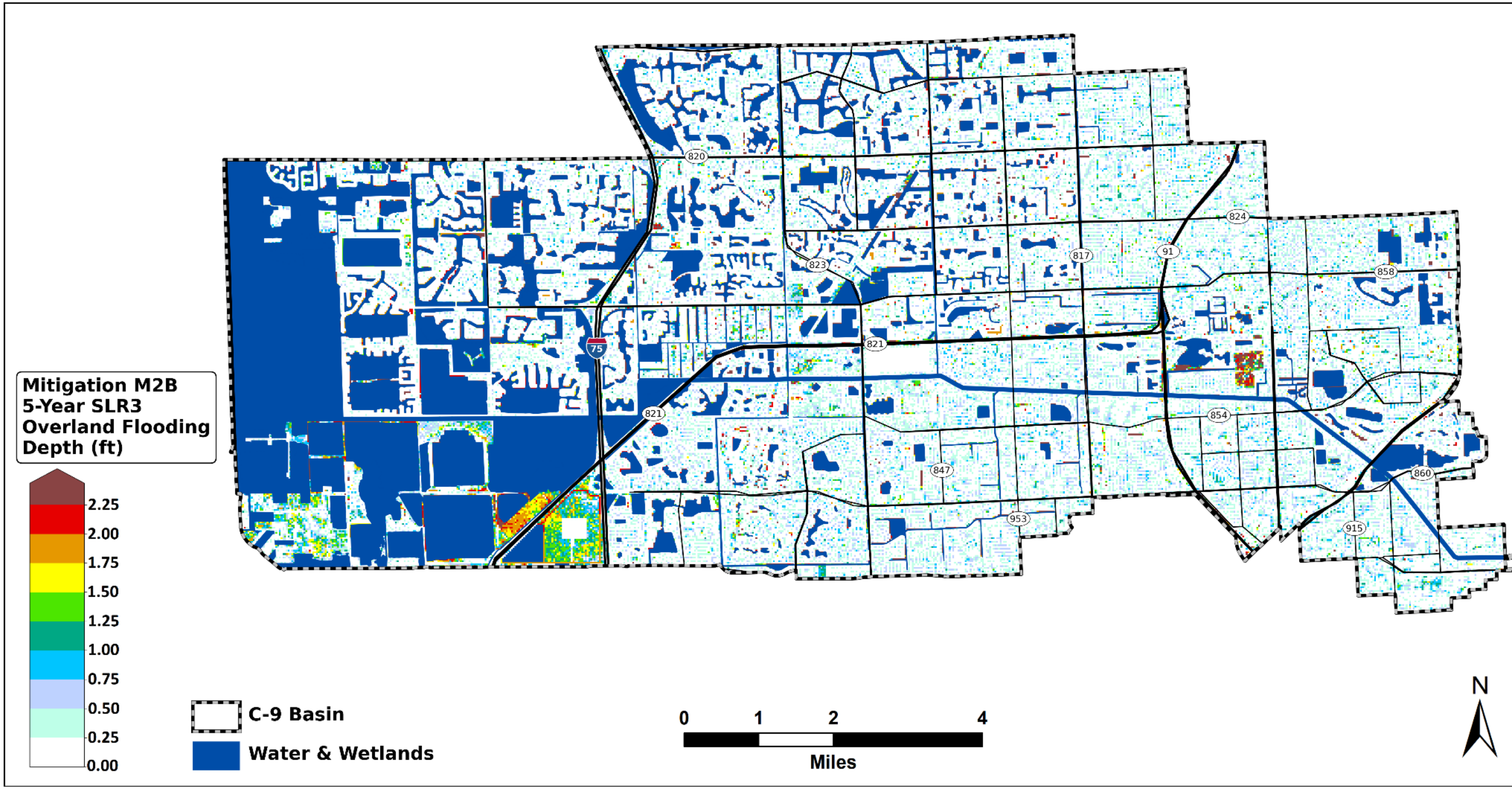


Figure C- 27: C-9 Watershed Flood Inundation Map for the Mitigation M2B 5-Year Sea Level Rise 3 Design Storm Event

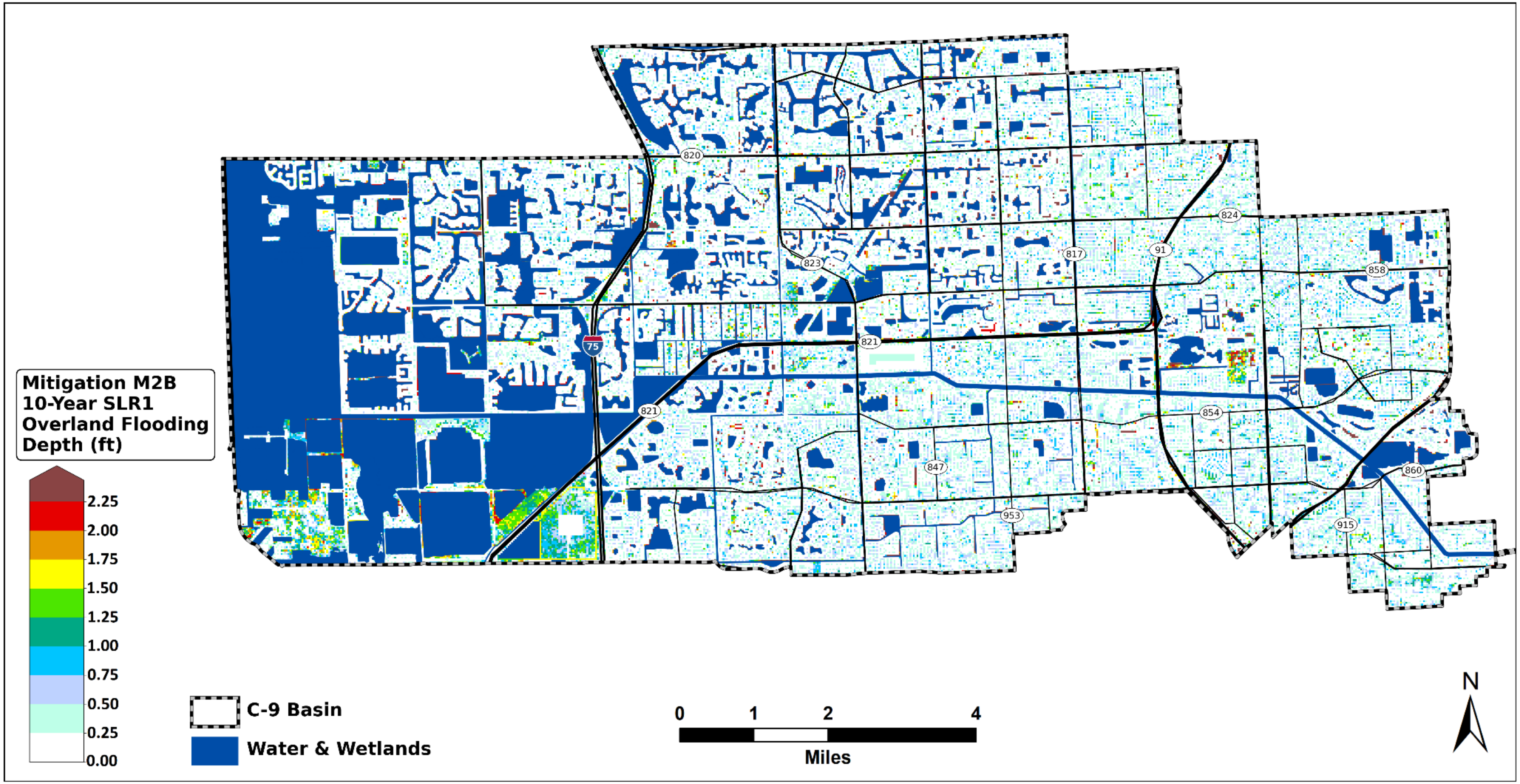


Figure C- 28: C-9 Watershed Flood Inundation Map for the Mitigation M2B 10-Year Sea Level Rise 1 Design Storm Event

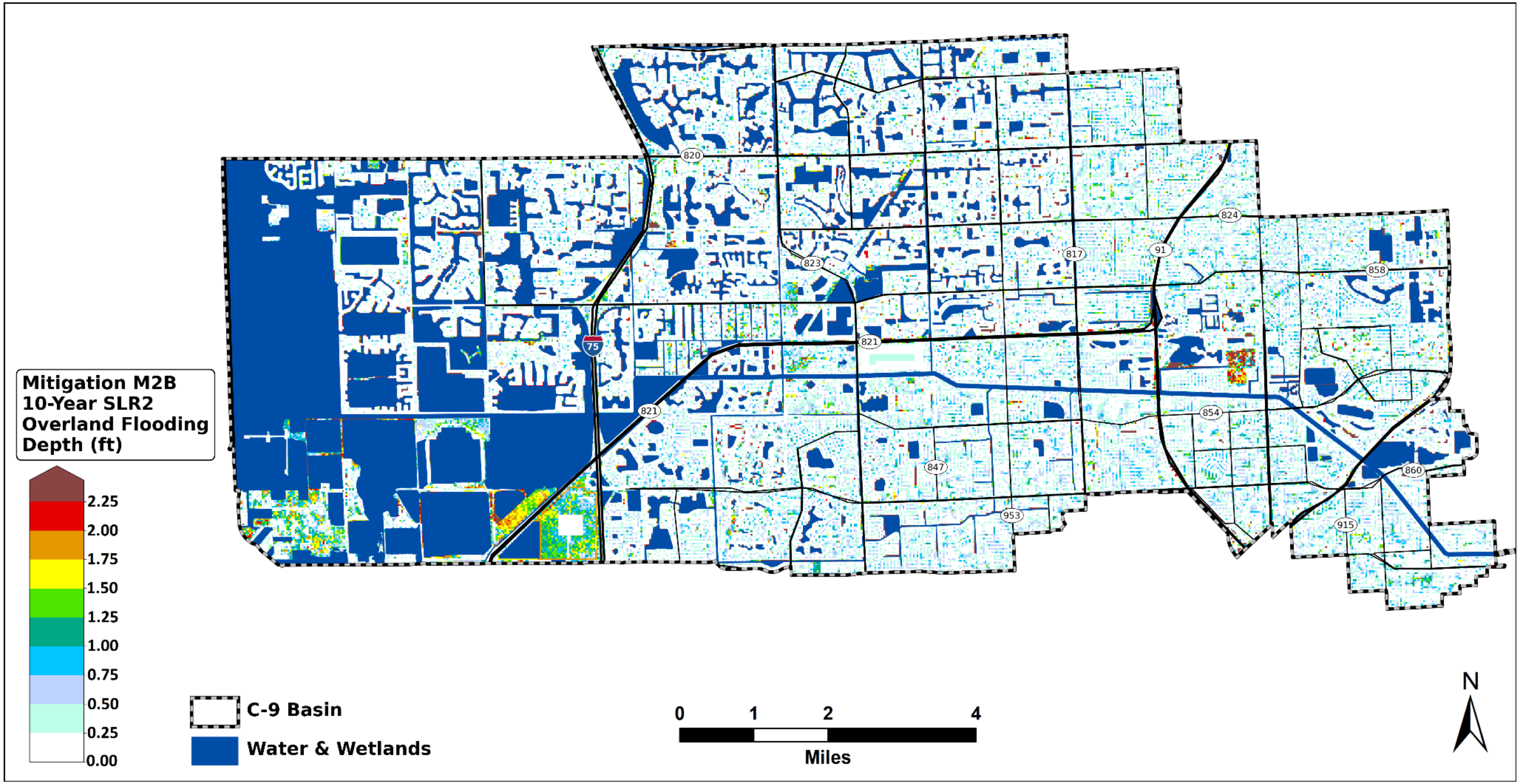


Figure C- 29: C-9 Watershed Flood Inundation Map for the Mitigation M2B 10-Year Sea Level Rise 2 Design Storm Event

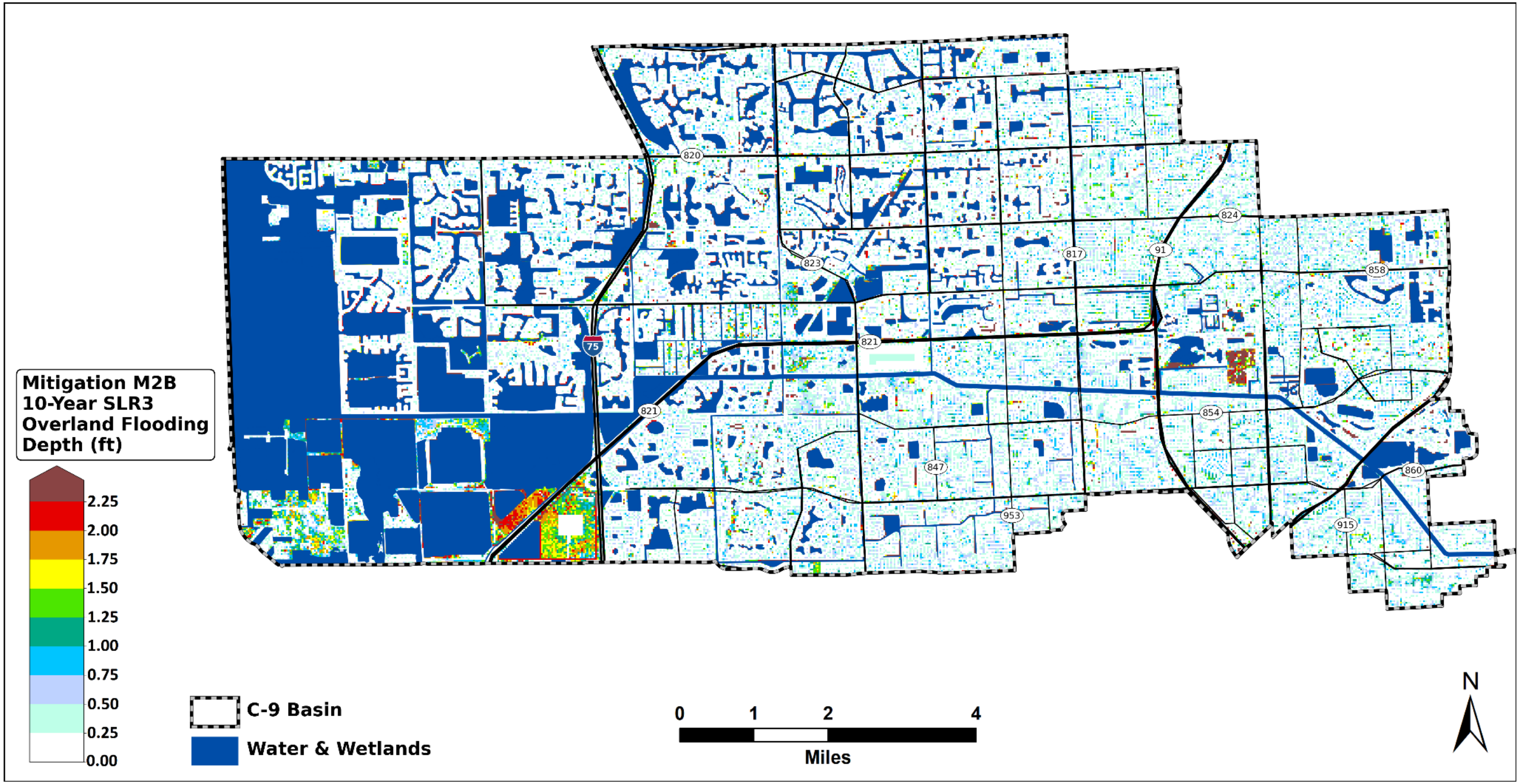


Figure C- 30: C-9 Watershed Flood Inundation Map for the Mitigation M2B 10-Year Sea Level Rise 3 Design Storm Event

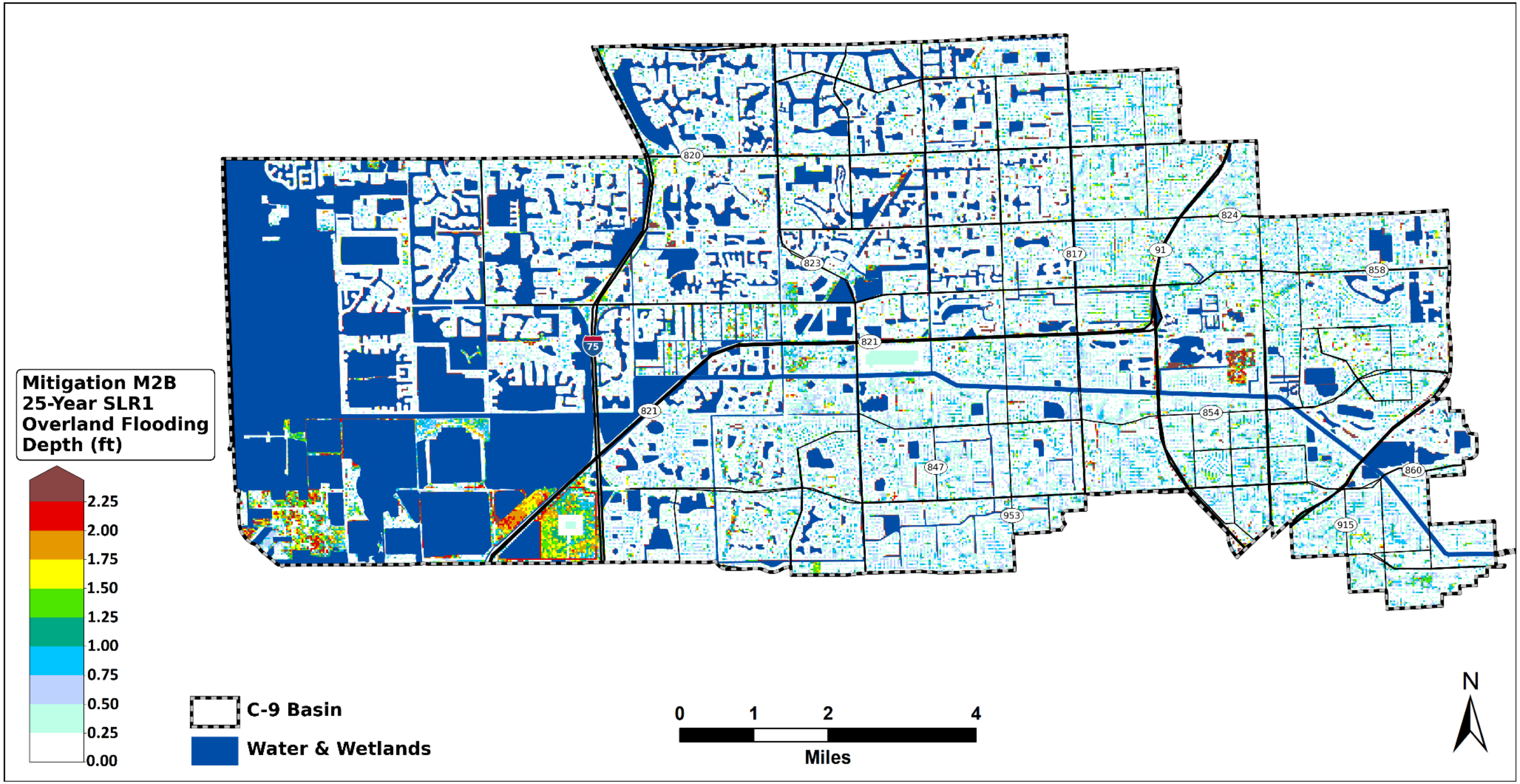


Figure C- 31: C-9 Watershed Flood Inundation Map for the Mitigation M2B 25-Year Sea Level Rise 1 Design Storm Event

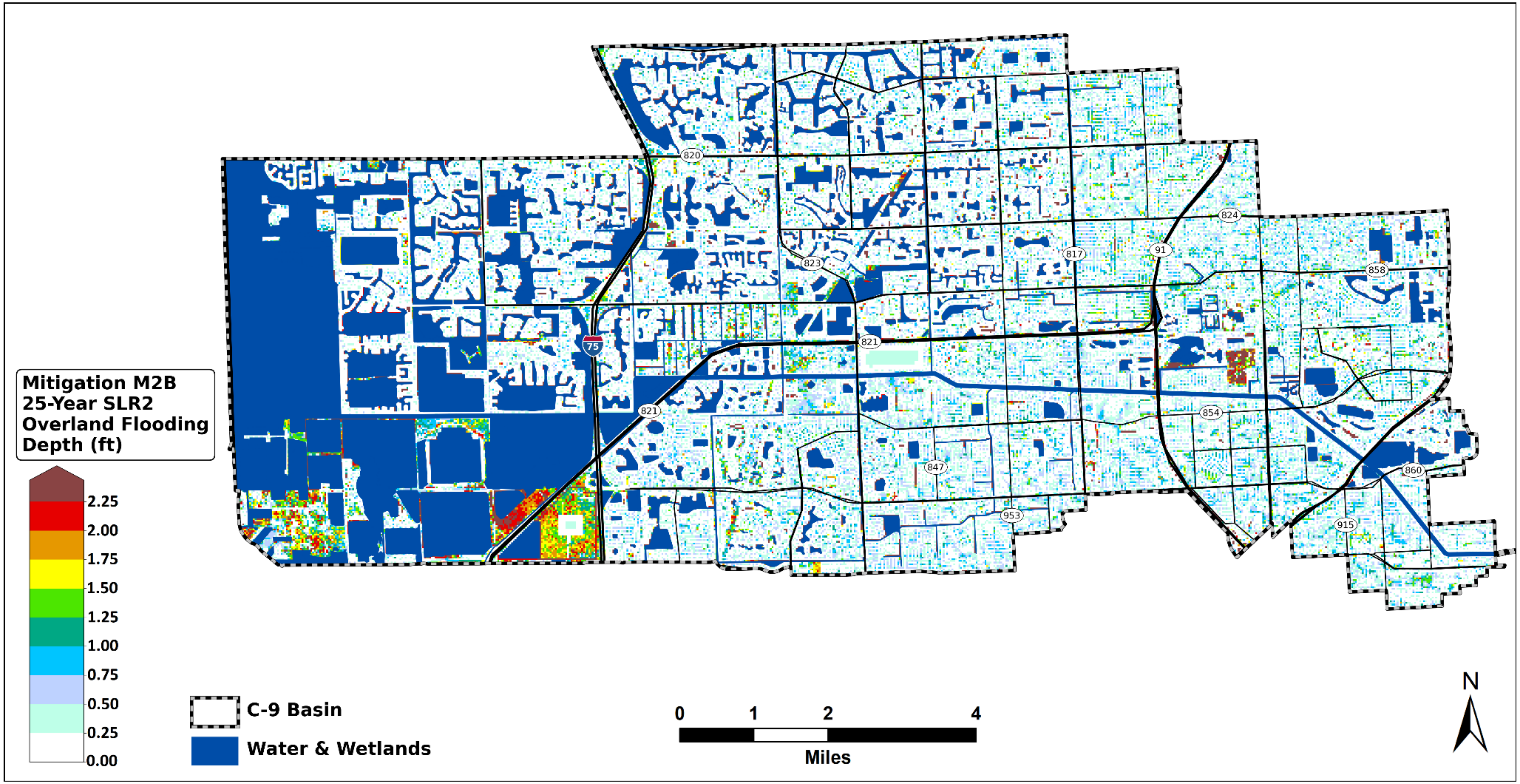


Figure C- 32: C-9 Watershed Flood Inundation Map for the Mitigation M2B 25-Year Sea Level Rise 2 Design Storm Event

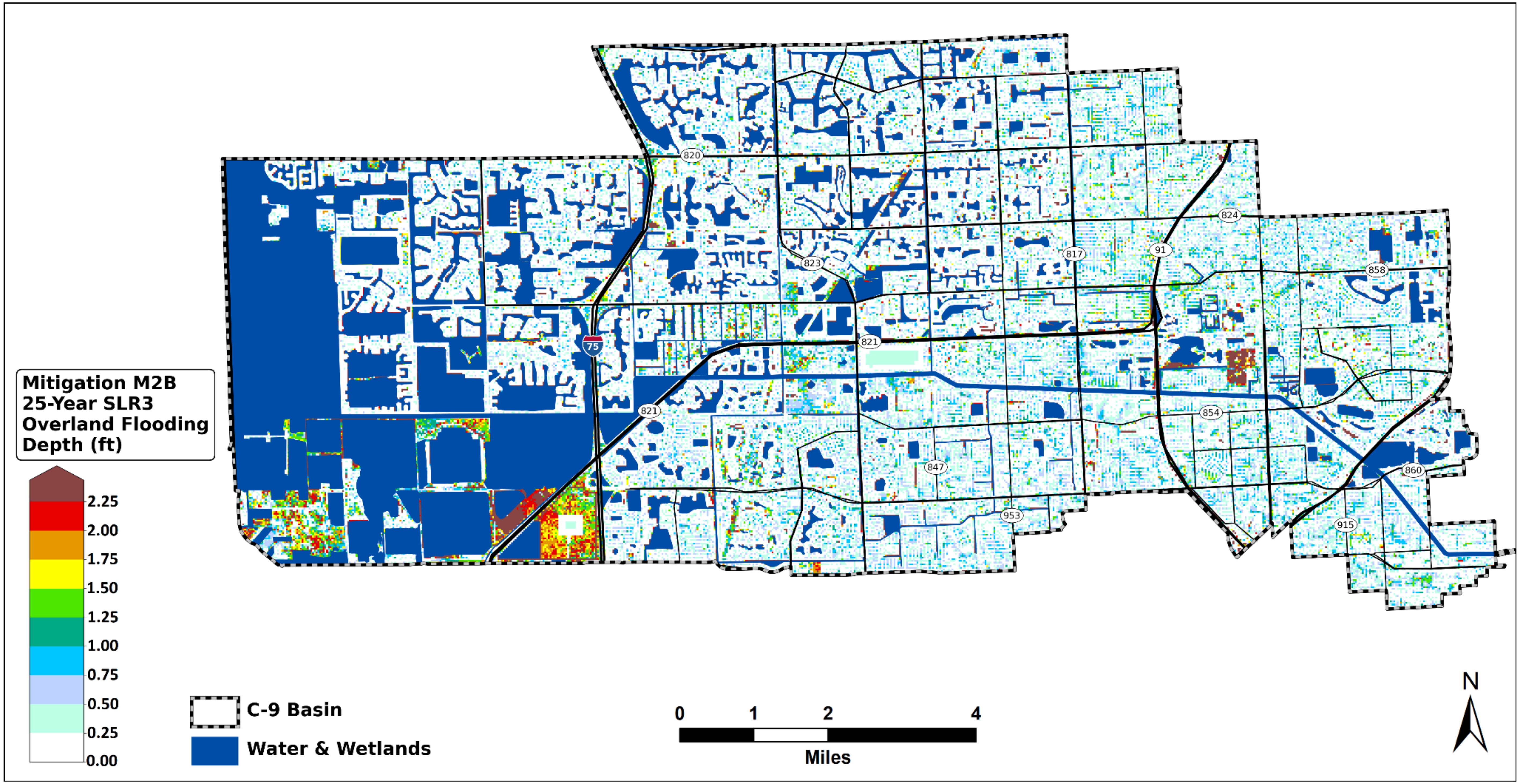


Figure C- 33: C-9 Watershed Flood Inundation Map for the Mitigation M2B 25-Year Sea Level Rise 3 Design Storm Event

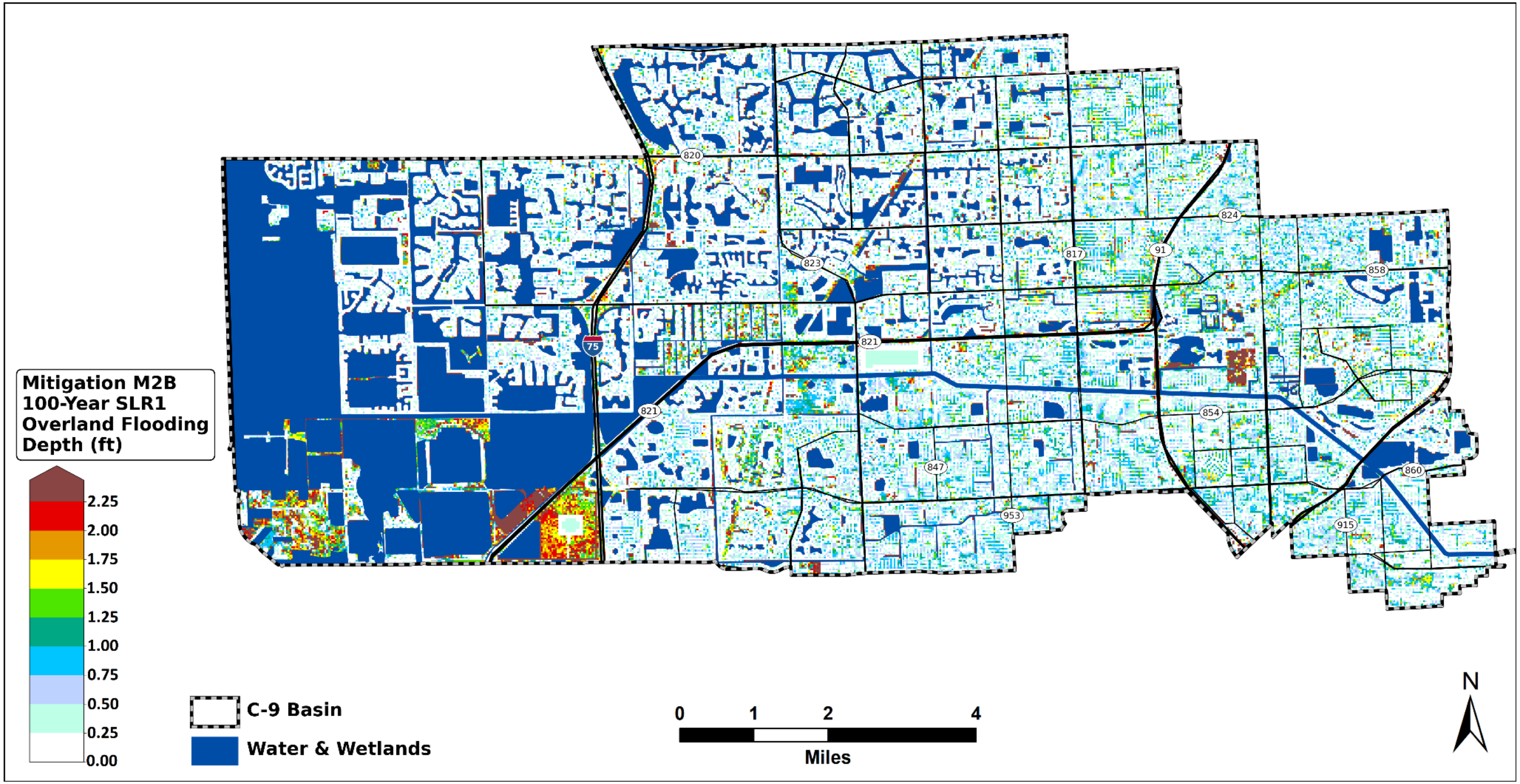


Figure C- 34: C-9 Watershed Flood Inundation Map for the Mitigation M2B 100-Year Sea Level Rise 1 Design Storm Event

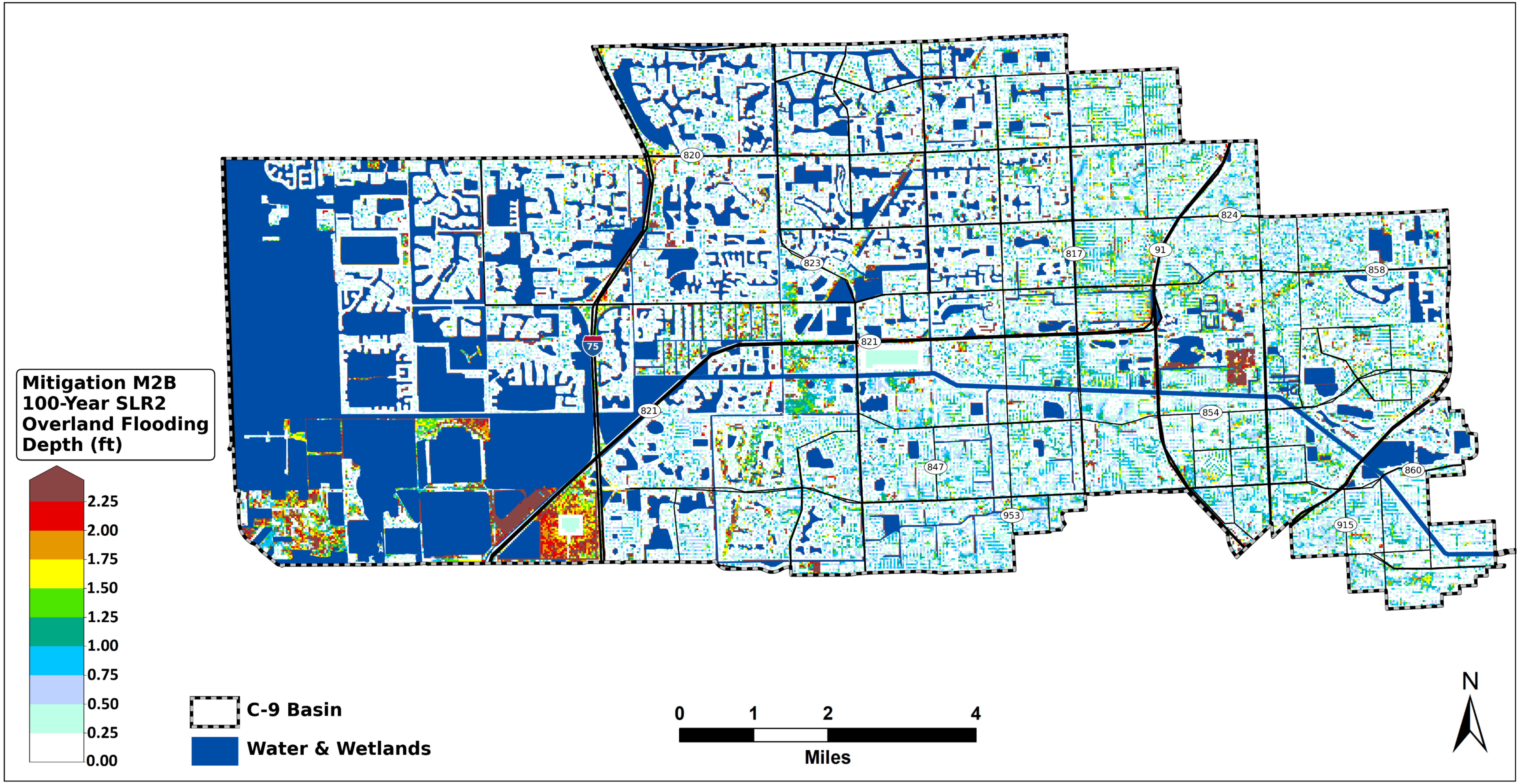


Figure C- 35: C-9 Watershed Flood Inundation Map for the Mitigation M2B 100-Year Sea Level Rise 2 Design Storm Event

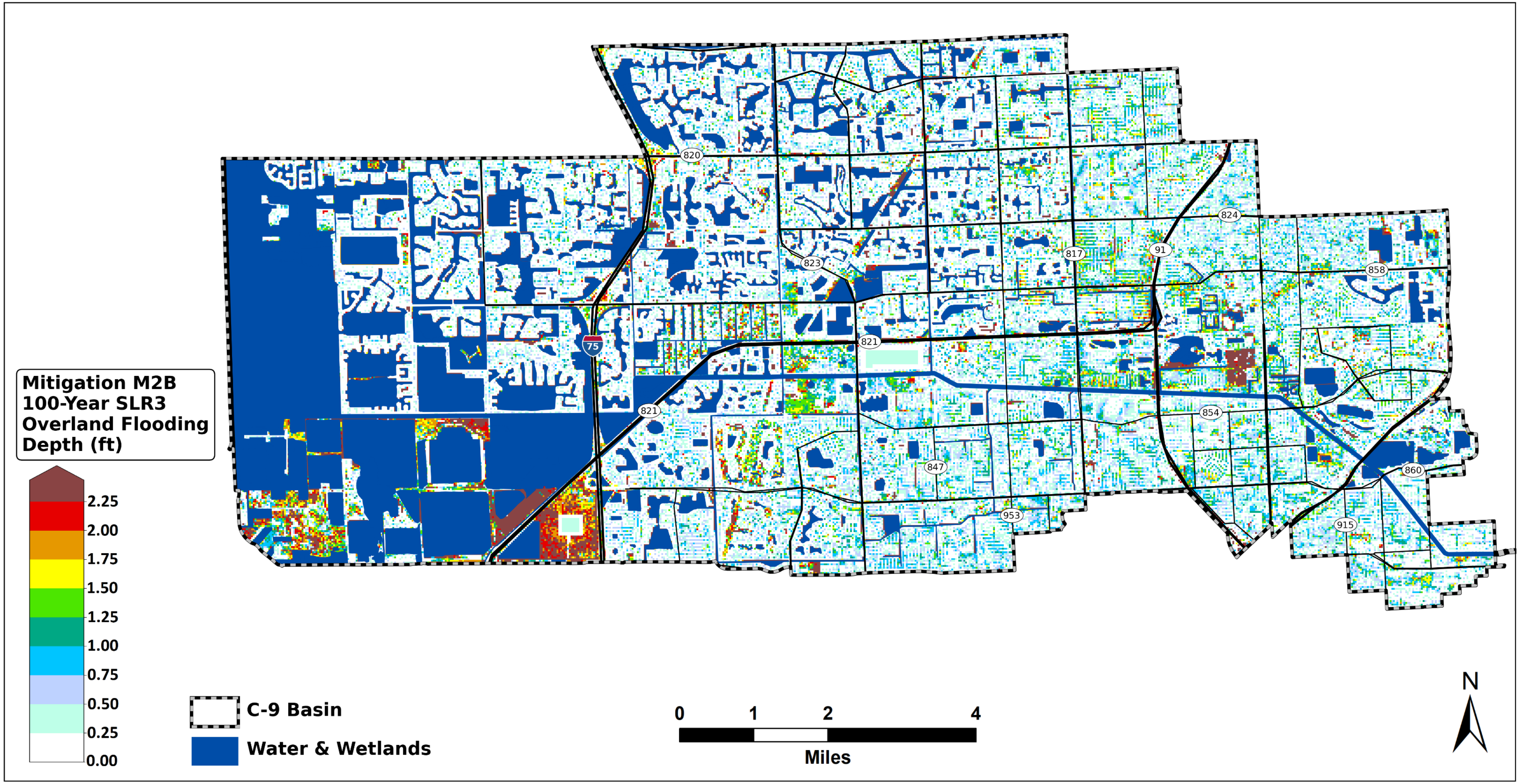


Figure C- 36: C-9 Watershed Flood Inundation Map for the Mitigation M2B 100-Year Sea Level Rise 3 Design Storm Event

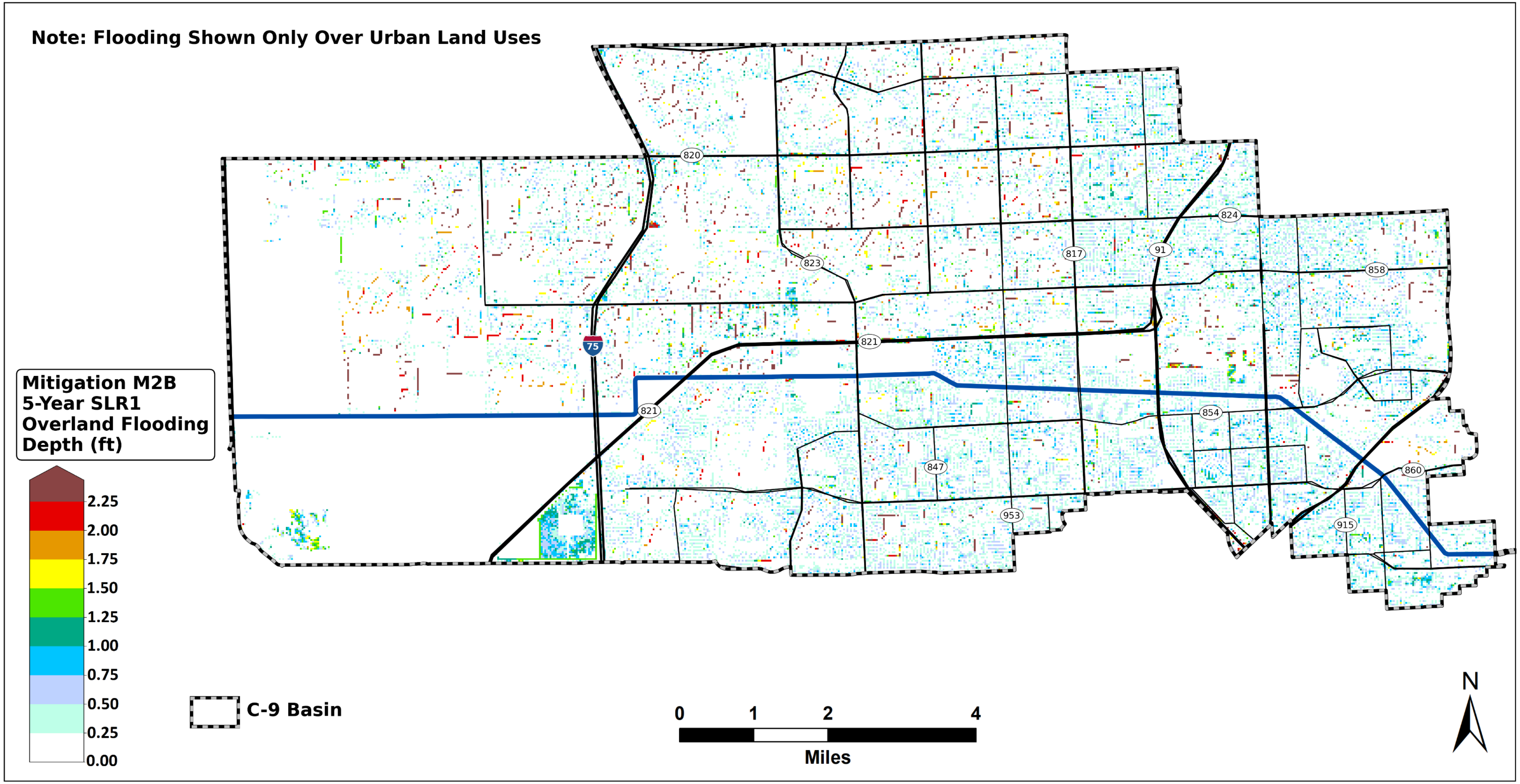


Figure C- 37: C-9 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2B 5-Year Sea Level Rise 1 Design Storm Event

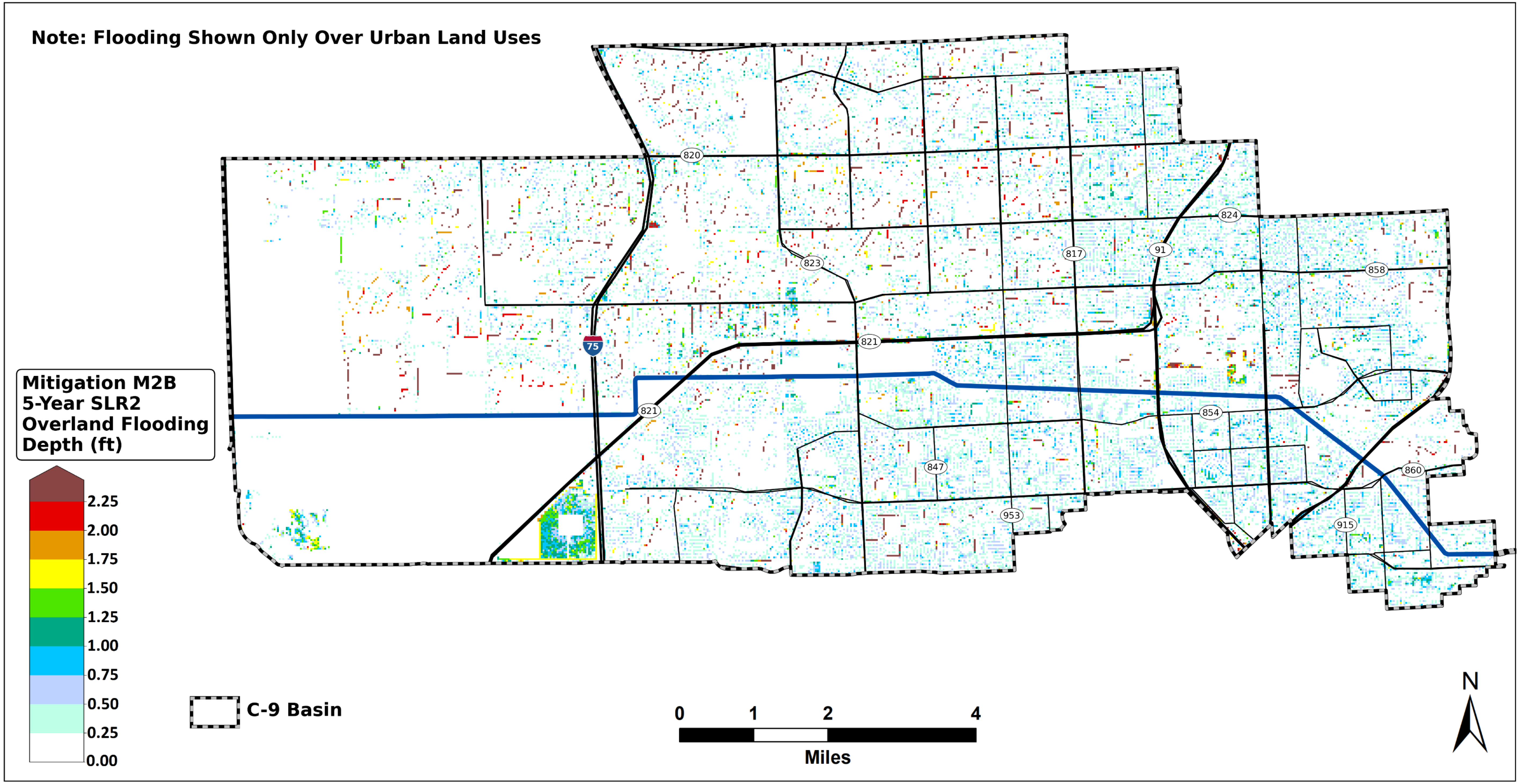


Figure C- 38: C-9 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2B 5-Year Sea Level Rise 2 Design Storm Event

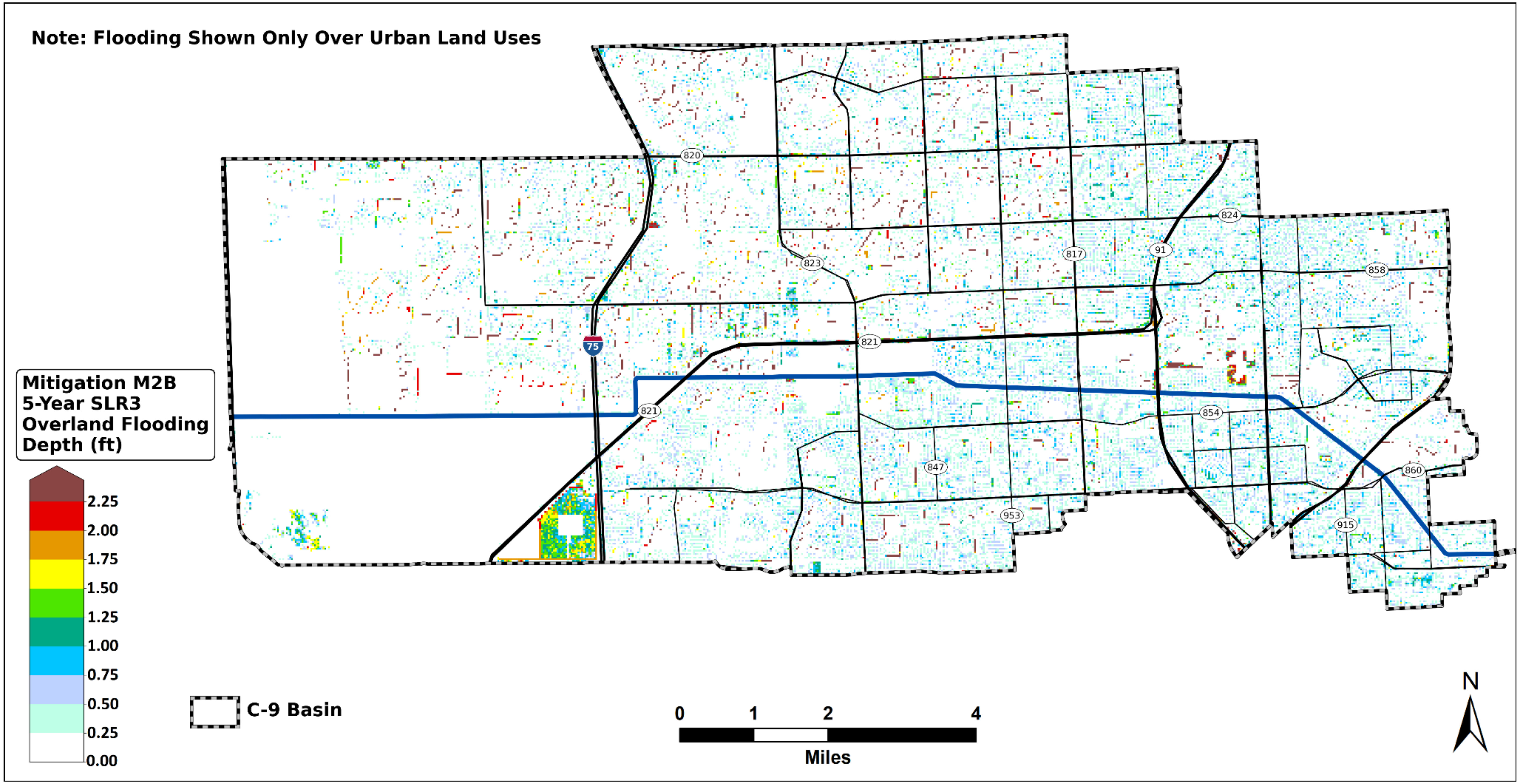


Figure C- 39: C-9 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2B 5-Year Sea Level Rise 3 Design Storm Event

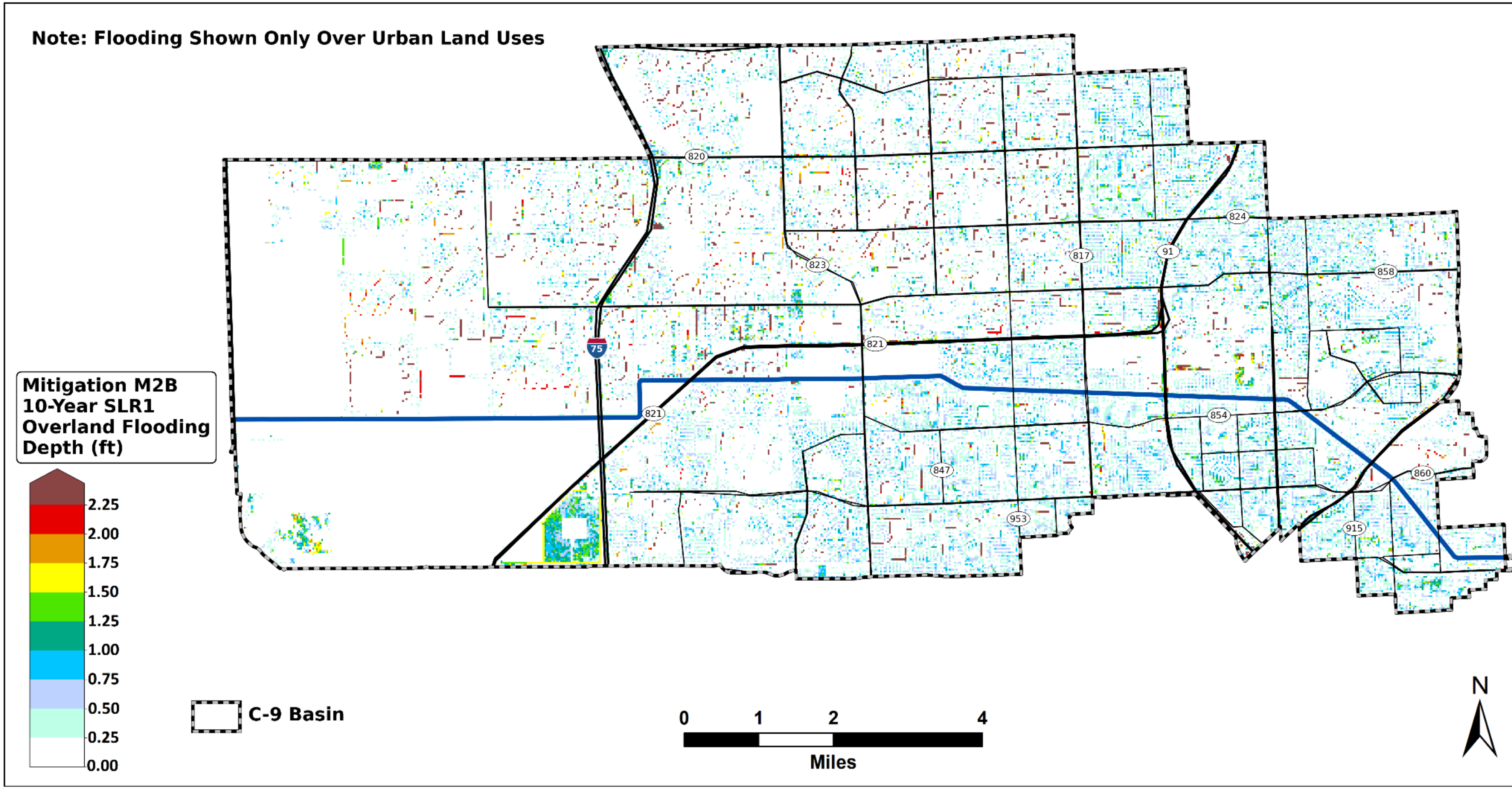


Figure C- 40: C-9 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2B 10-Year Sea Level Rise 1 Design Storm Event

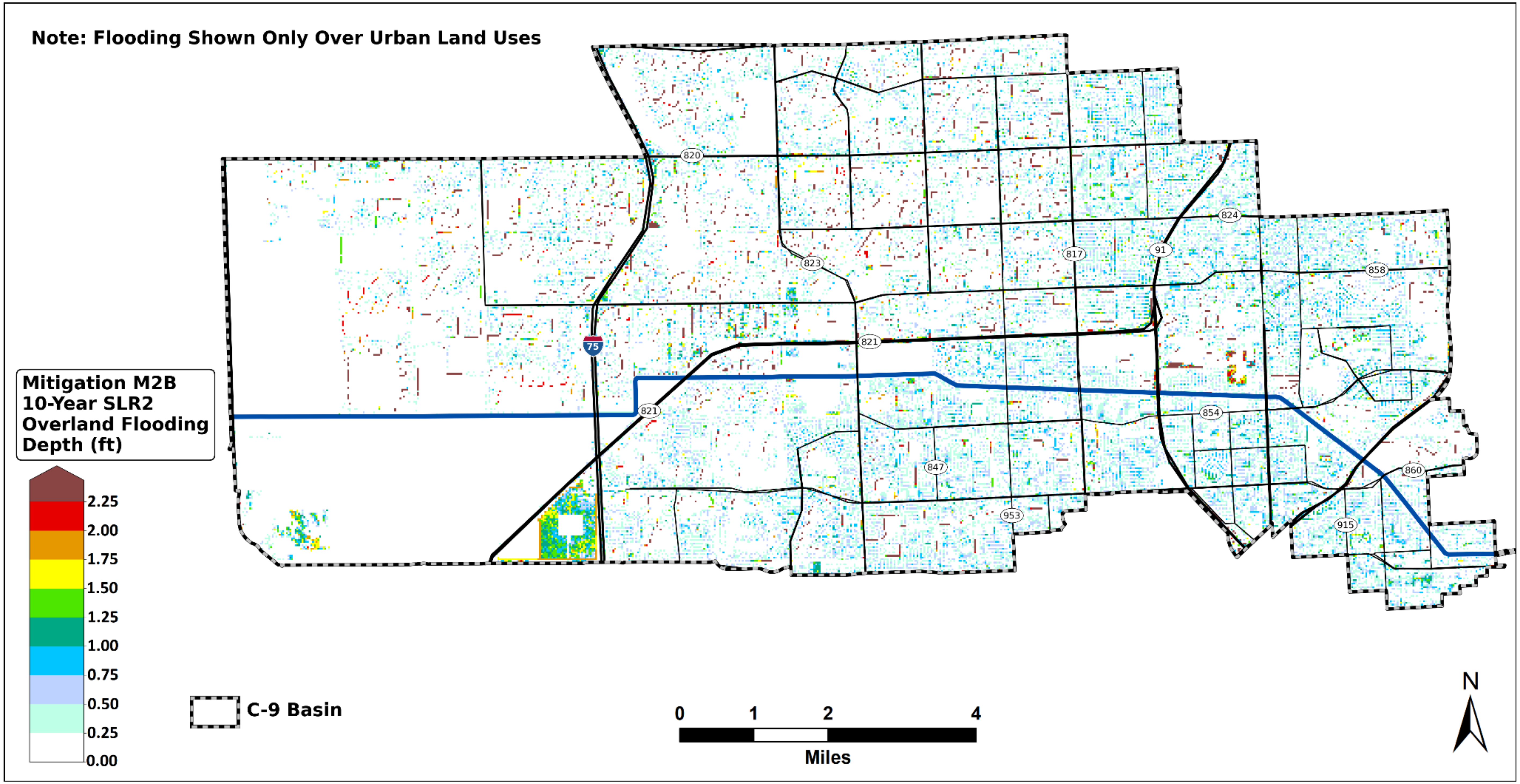


Figure C- 41: C-9 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2B 10-Year Sea Level Rise 2 Design Storm Event

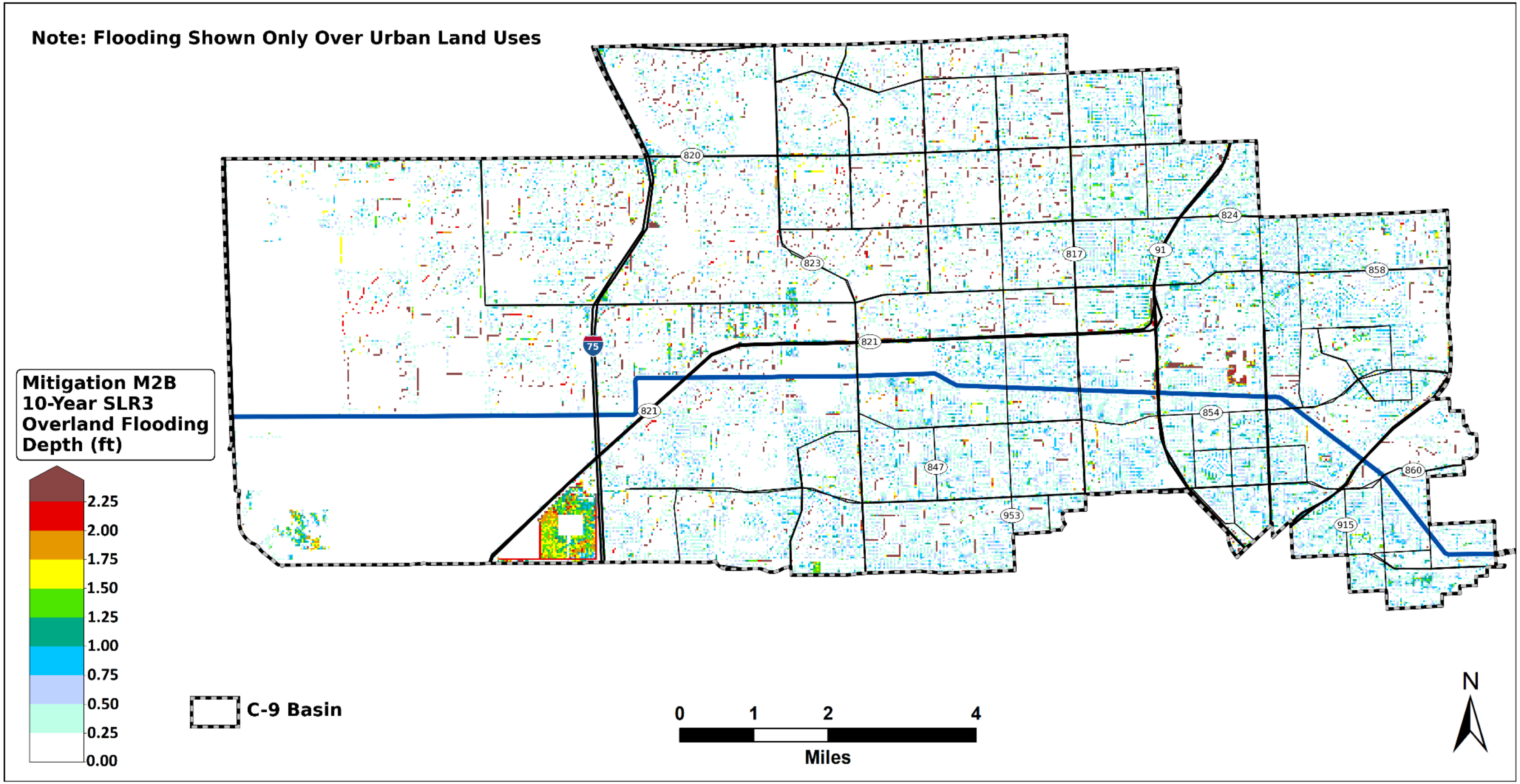


Figure C- 42: C-9 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2B 10-Year Sea Level Rise 3 Design Storm Event

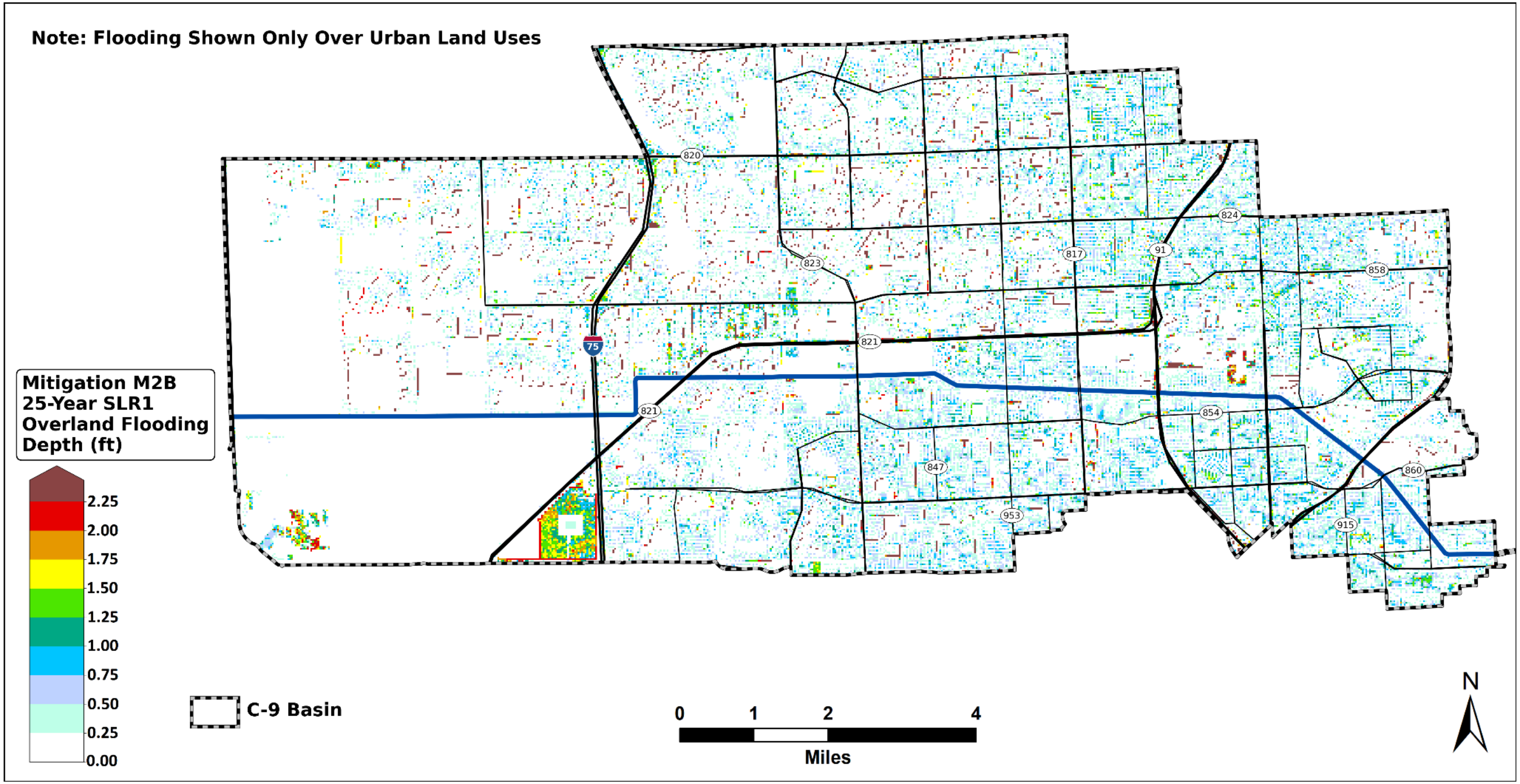


Figure C- 43: C-9 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2B 25-Year Sea Level Rise 1 Design Storm Event

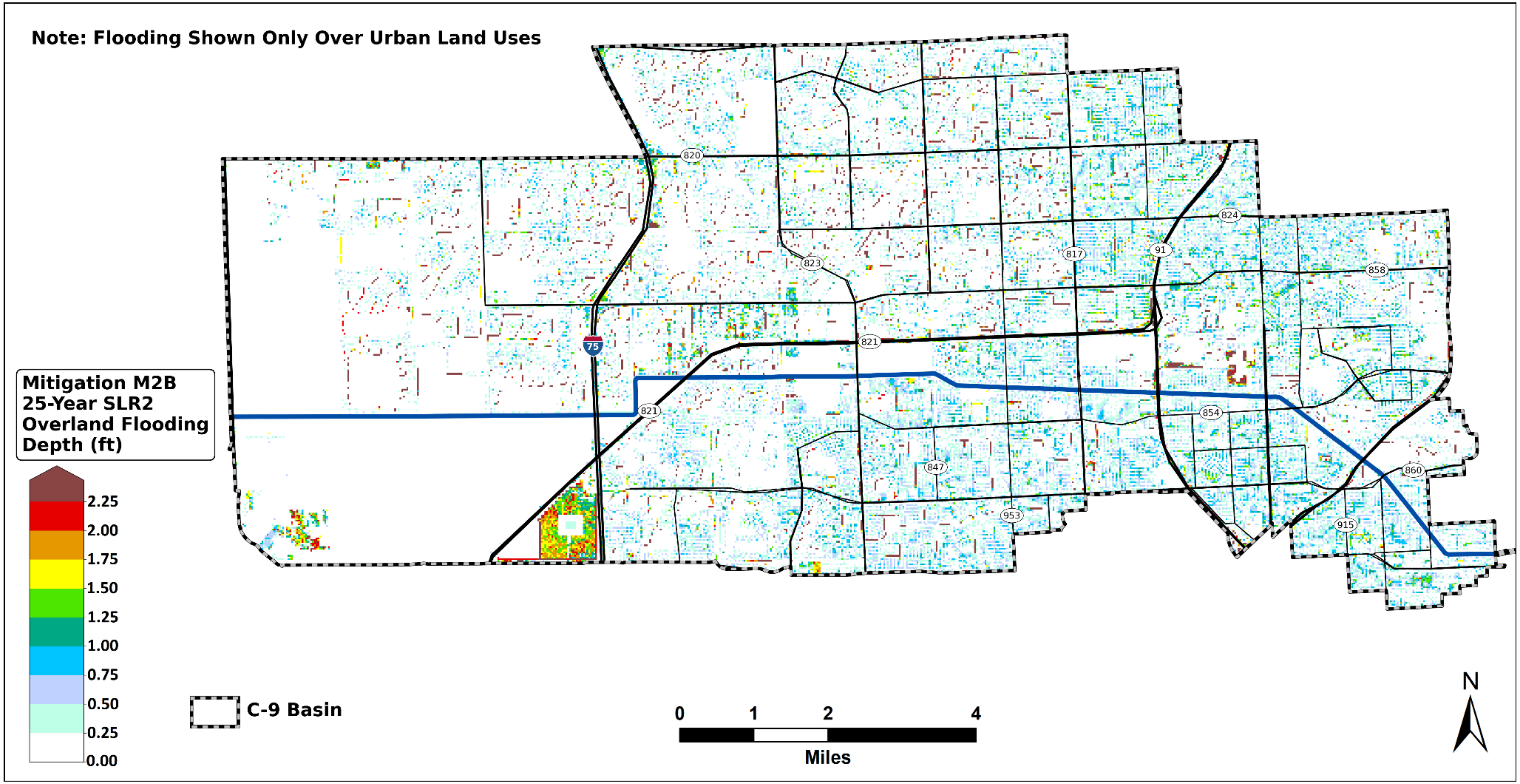


Figure C- 44: C-9 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2B 25-Year Sea Level Rise 2 Design Storm Event

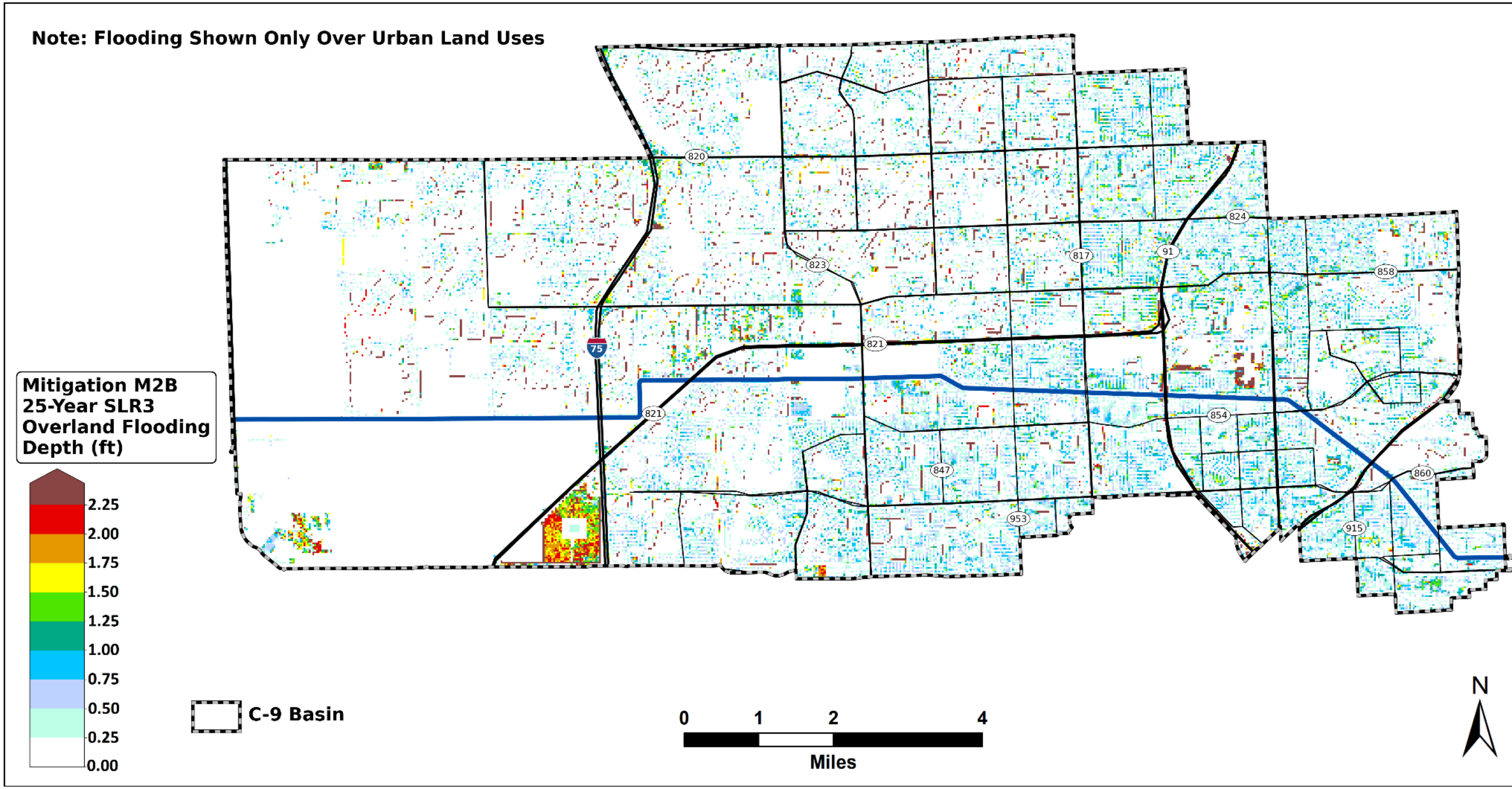


Figure C- 45: C-9 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2B 25-Year Sea Level Rise 3 Design Storm Event

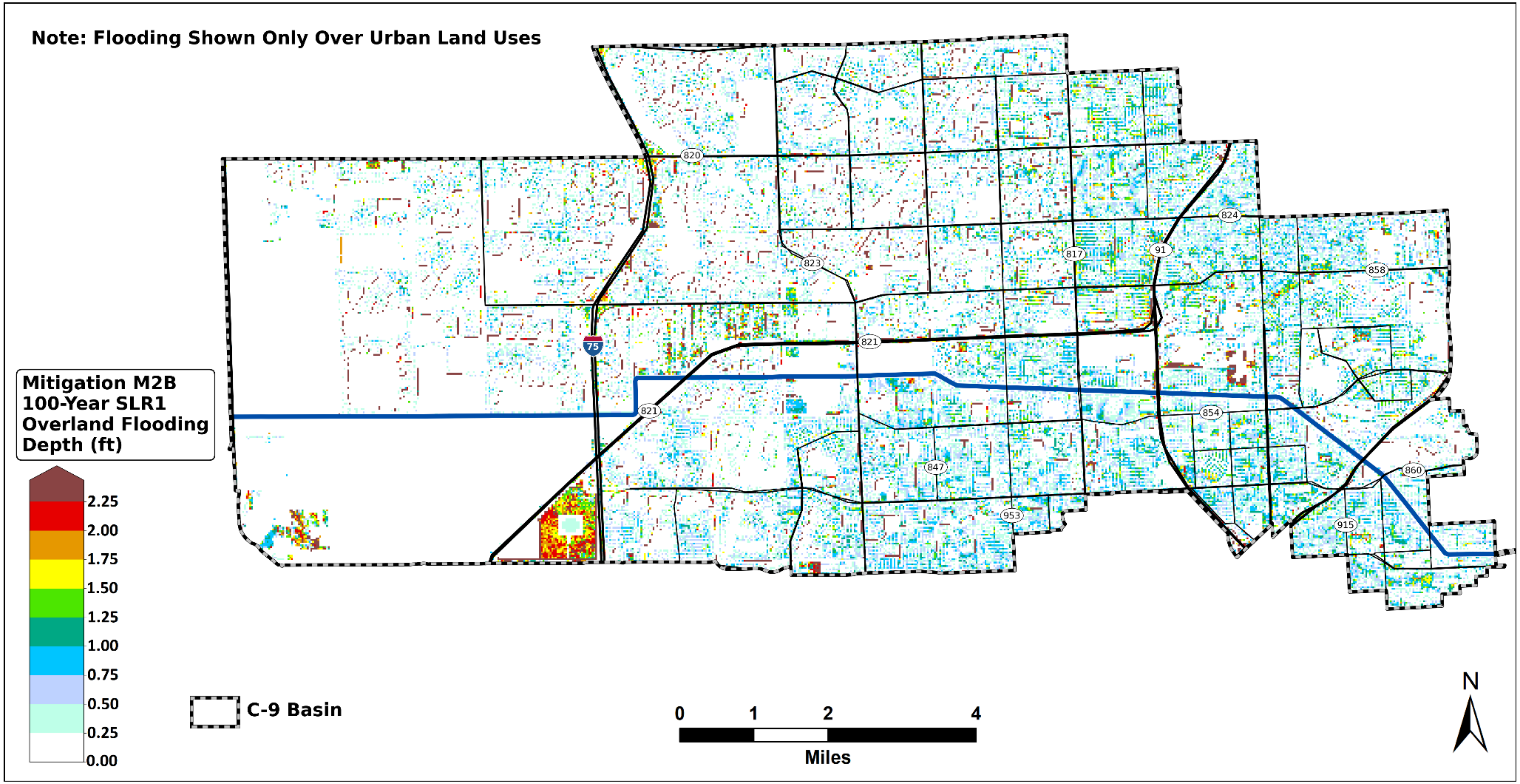


Figure C- 46: C-9 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2B 100-Year Sea Level Rise 1 Design Storm Event

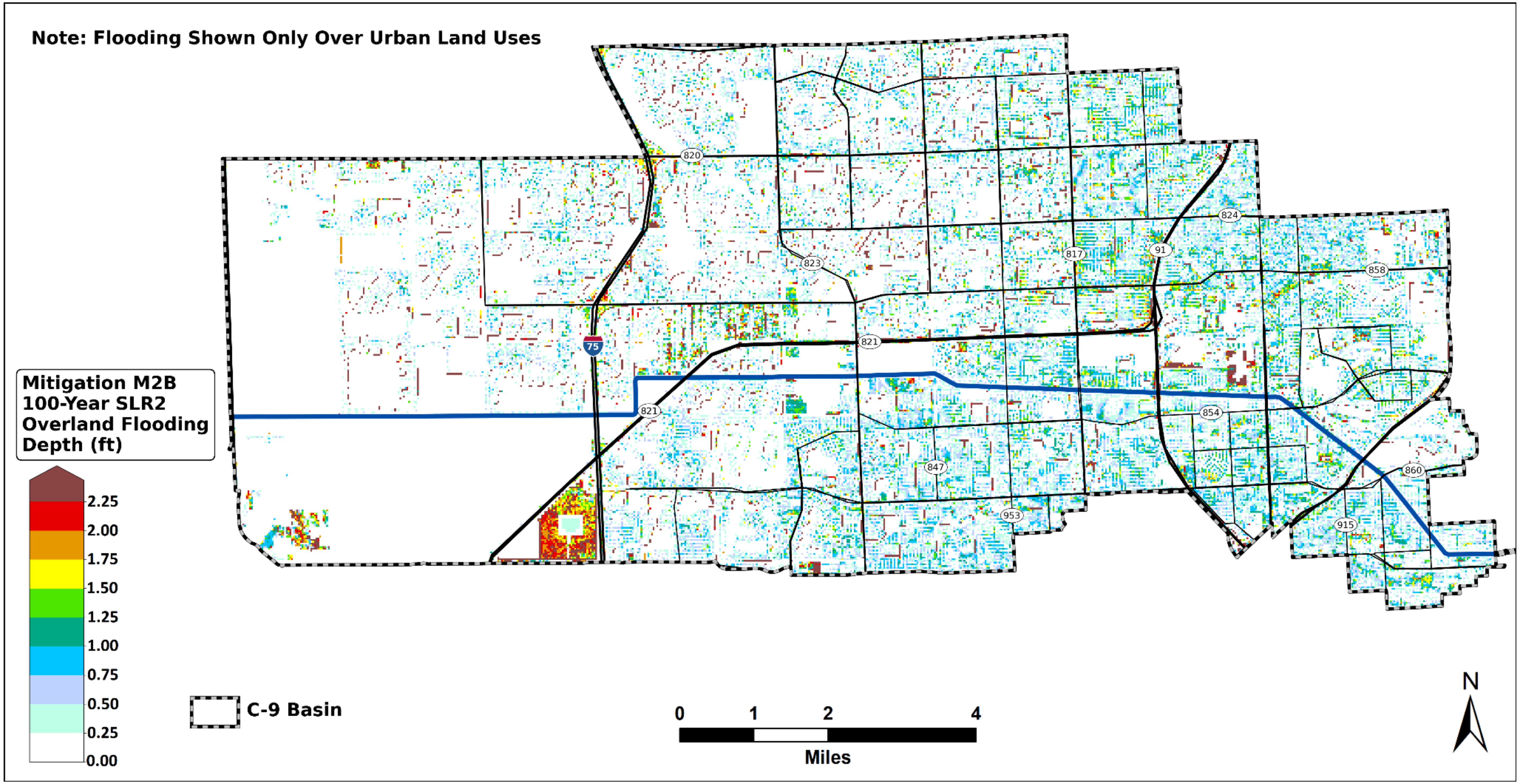


Figure C- 47: C-9 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2B 100-Year Sea Level Rise 2 Design Storm Event

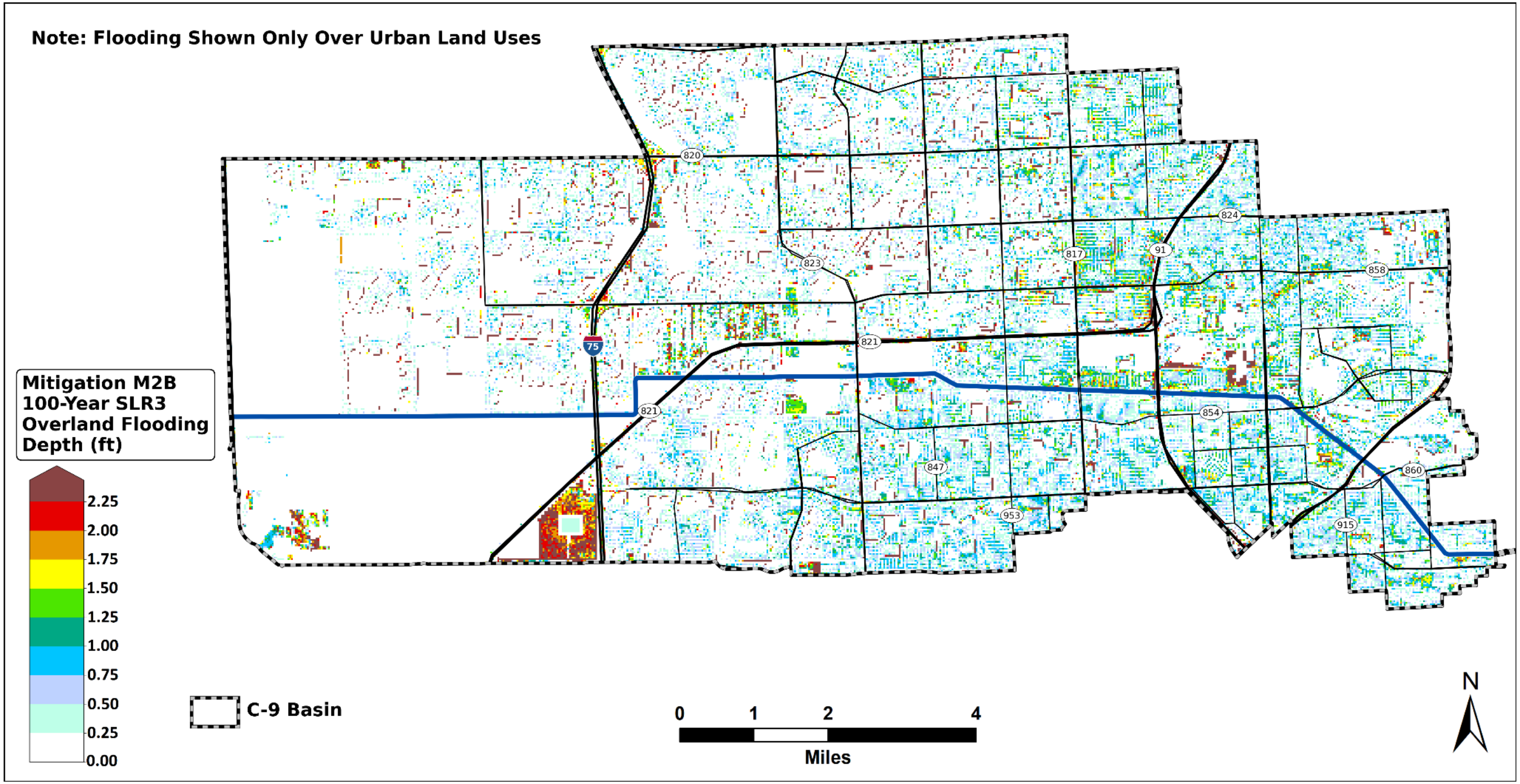


Figure C- 48: C-9 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2B 100-Year Sea Level Rise 3 Design Storm Event

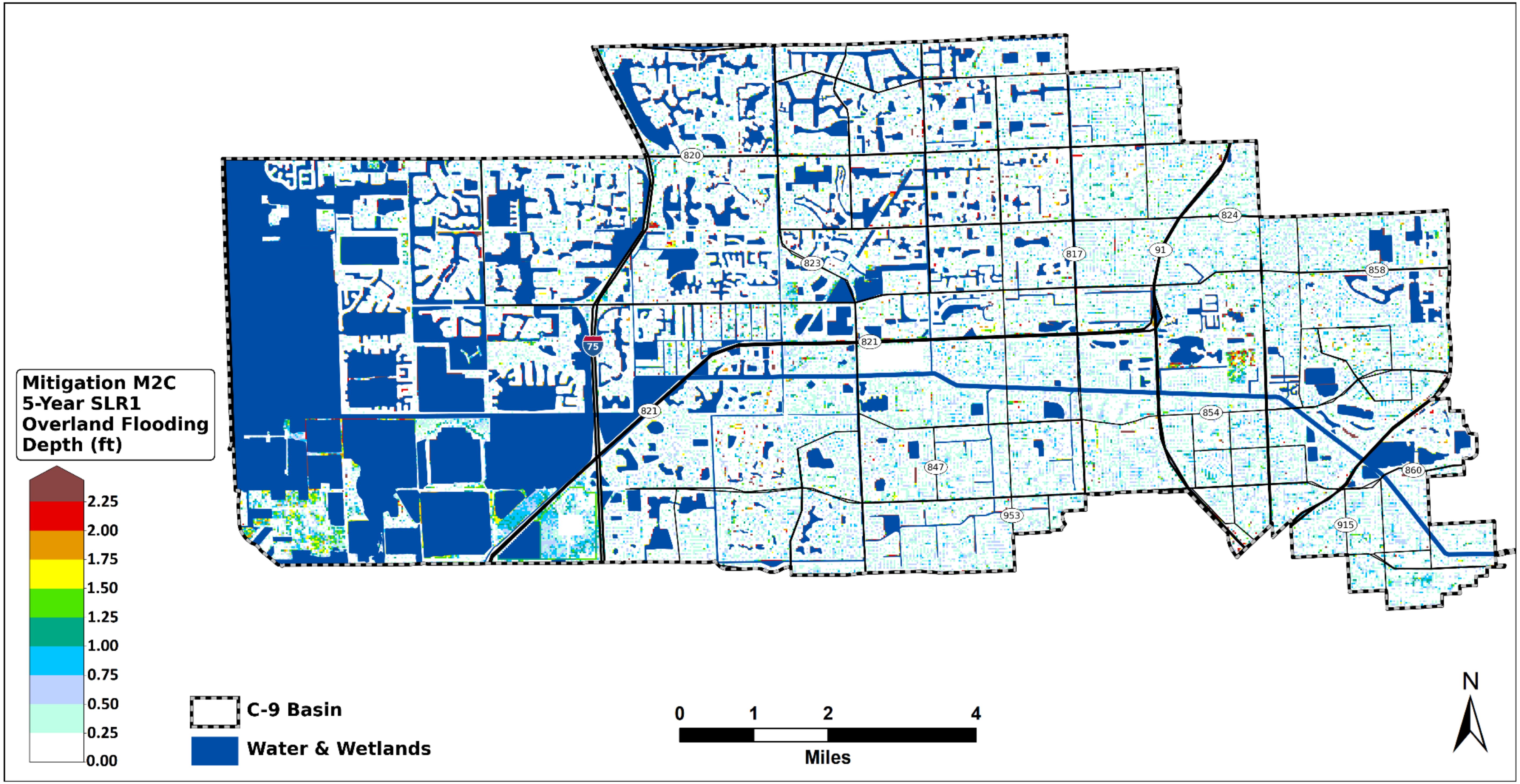


Figure C- 49: C-9 Watershed Flood Inundation Map for the Mitigation M2C 5-Year Sea Level Rise 1 Design Storm Event

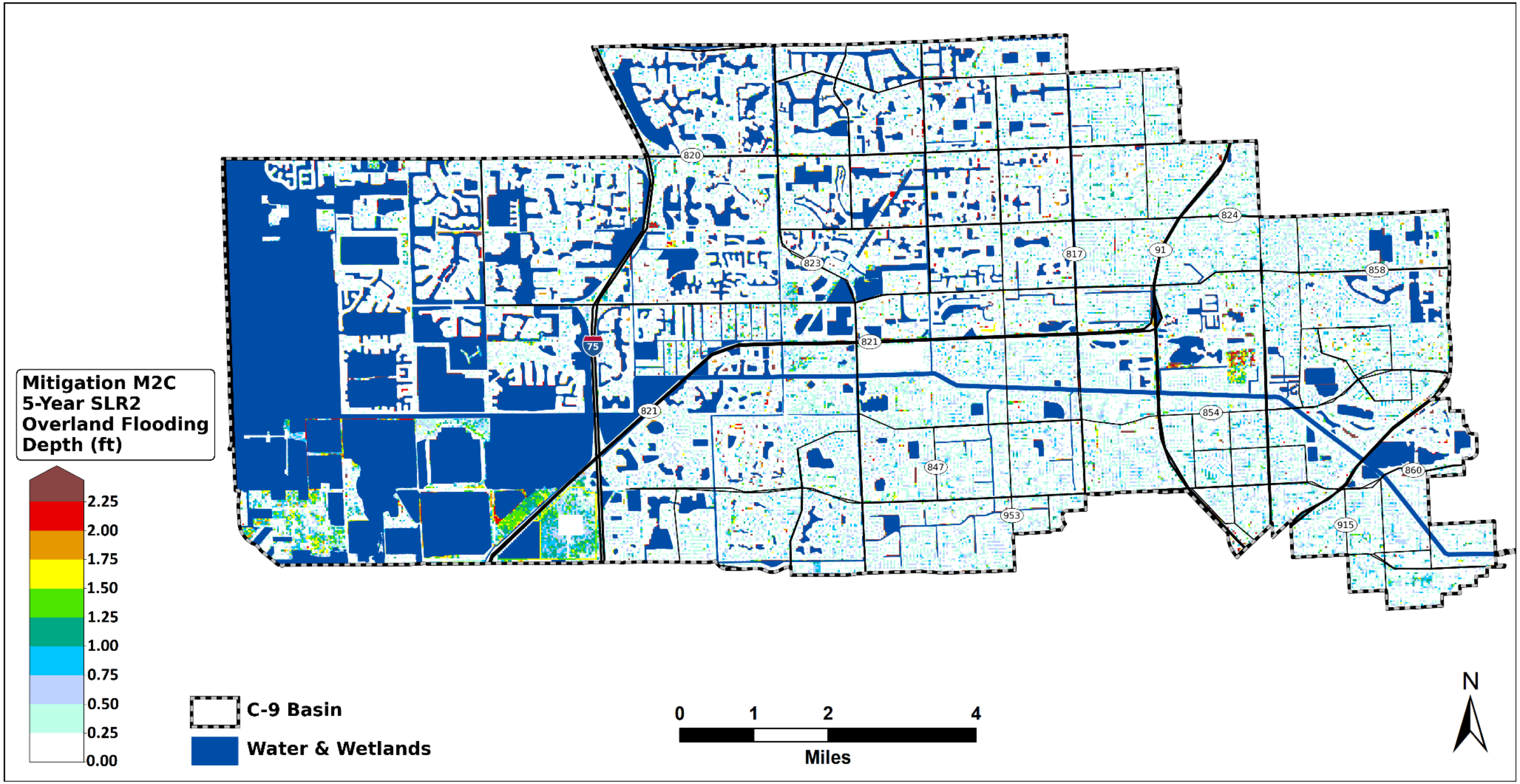


Figure C- 50: C-9 Watershed Flood Inundation Map for the Mitigation M2C 5-Year Sea Level Rise 2 Design Storm Event

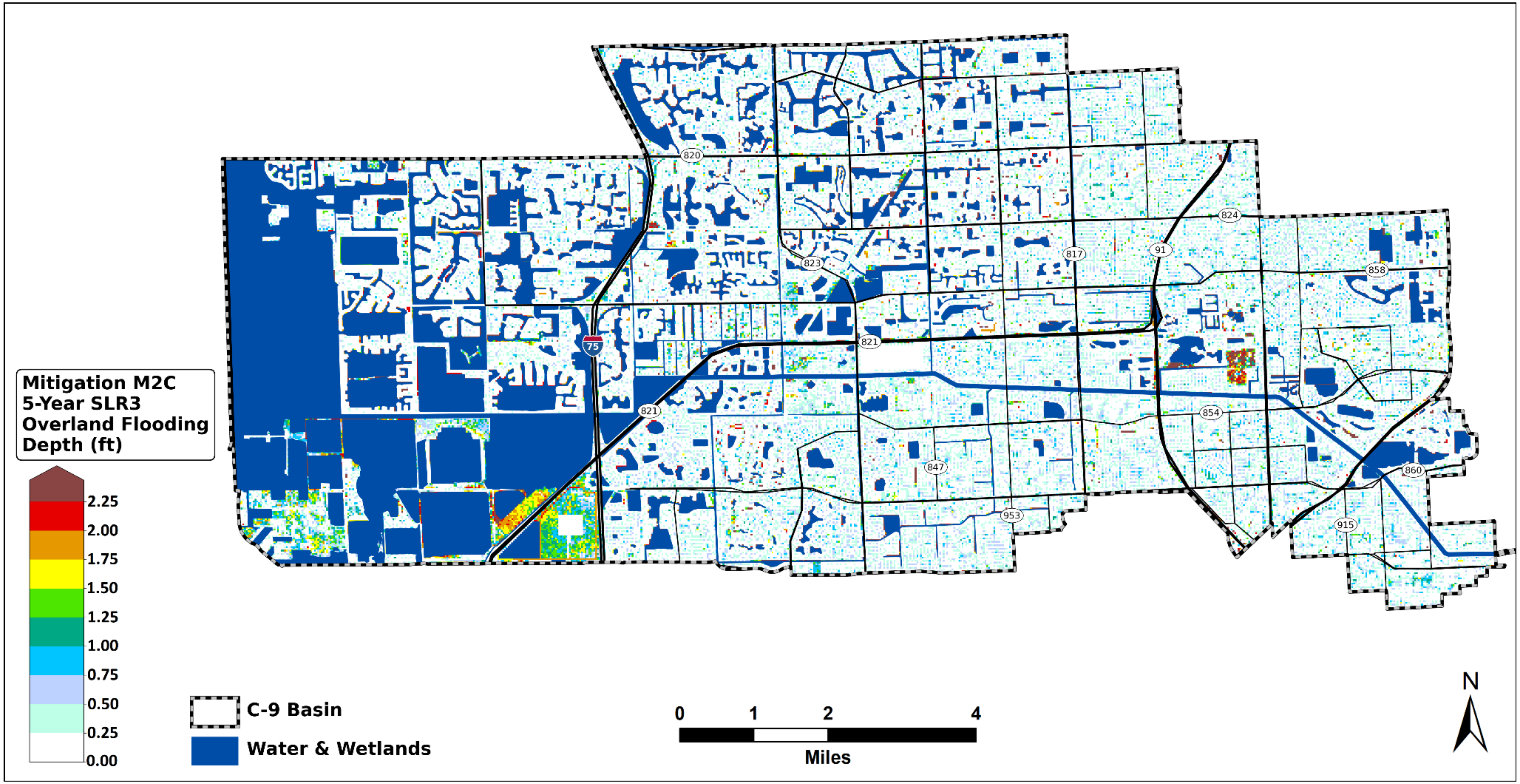


Figure C- 51: C-9 Watershed Flood Inundation Map for the Mitigation M2C 5-Year Sea Level Rise 3 Design Storm Event

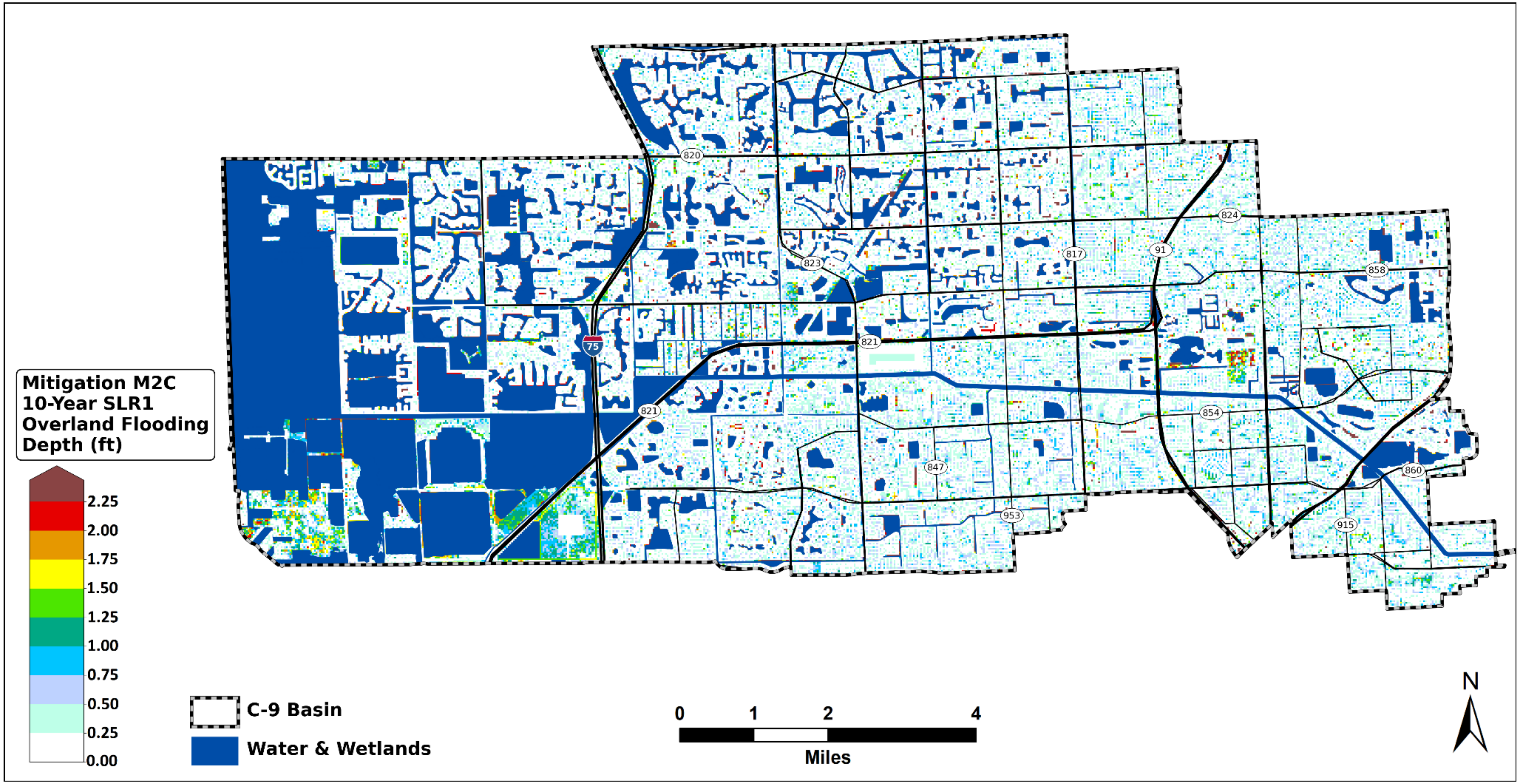


Figure C- 52: C-9 Watershed Flood Inundation Map for the Mitigation M2C 10-Year Sea Level Rise 1 Design Storm Event

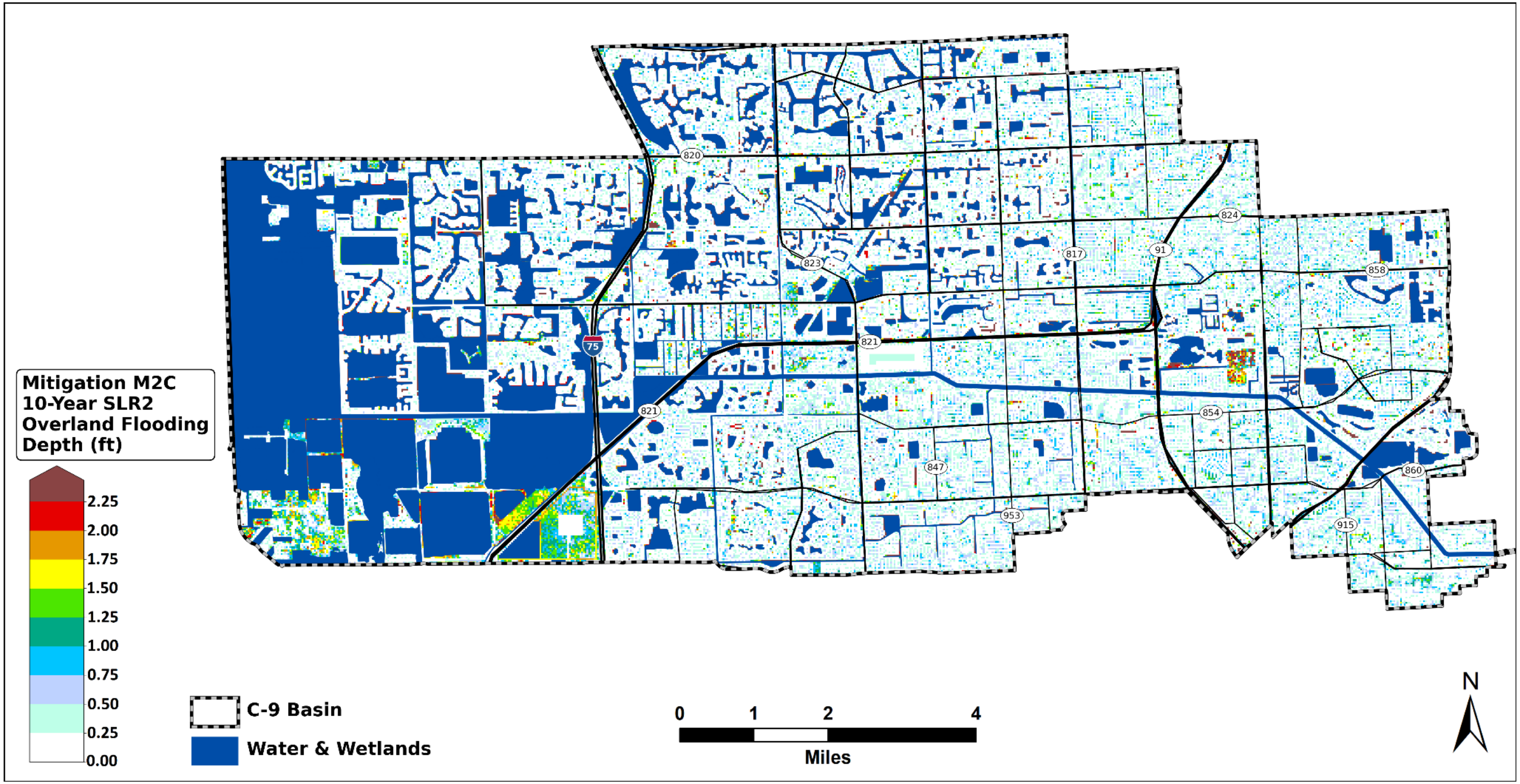


Figure C- 53: C-9 Watershed Flood Inundation Map for the Mitigation M2C 10-Year Sea Level Rise 2 Design Storm Event

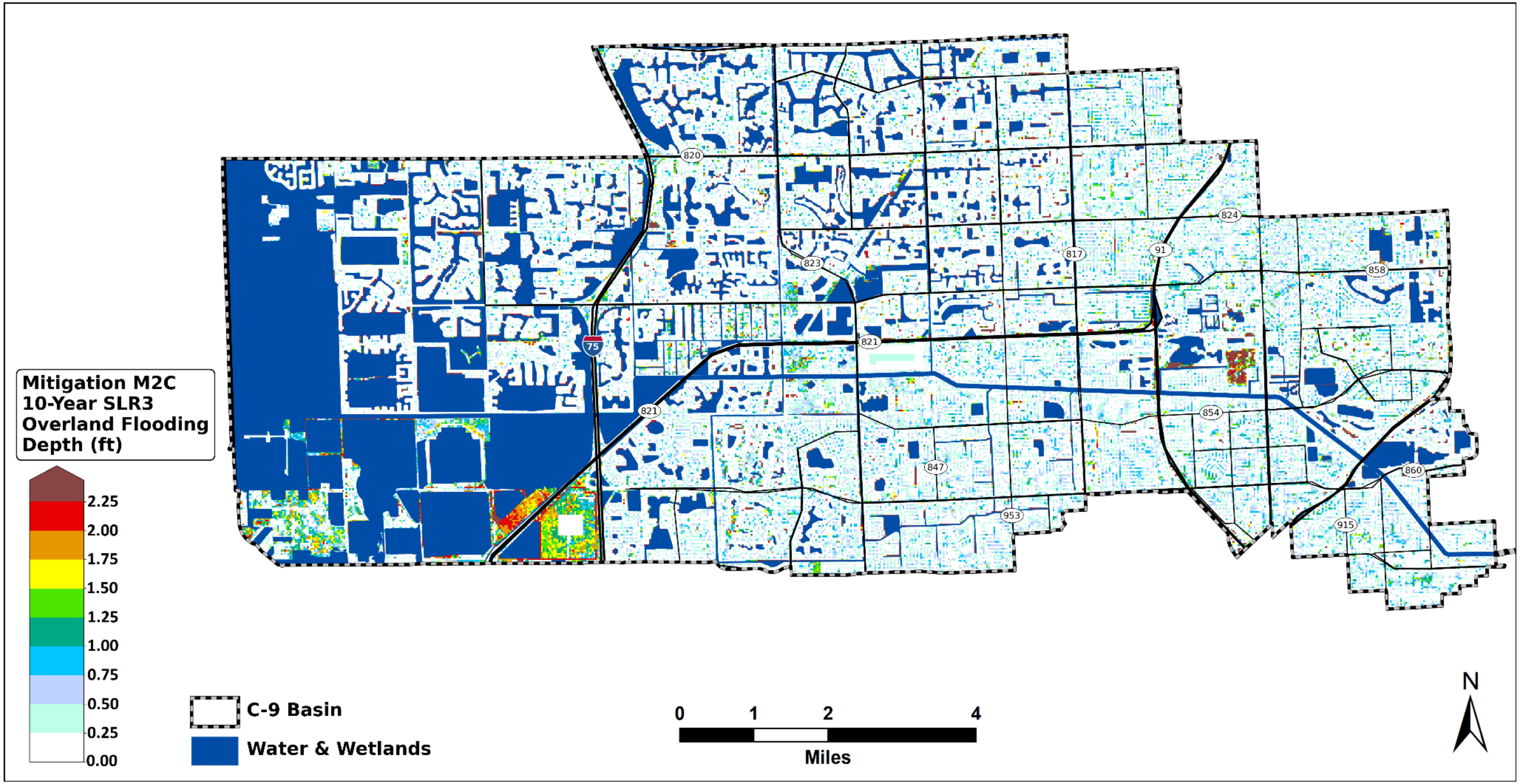


Figure C- 54: C-9 Watershed Flood Inundation Map for the Mitigation M2C 10-Year Sea Level Rise 3 Design Storm Event

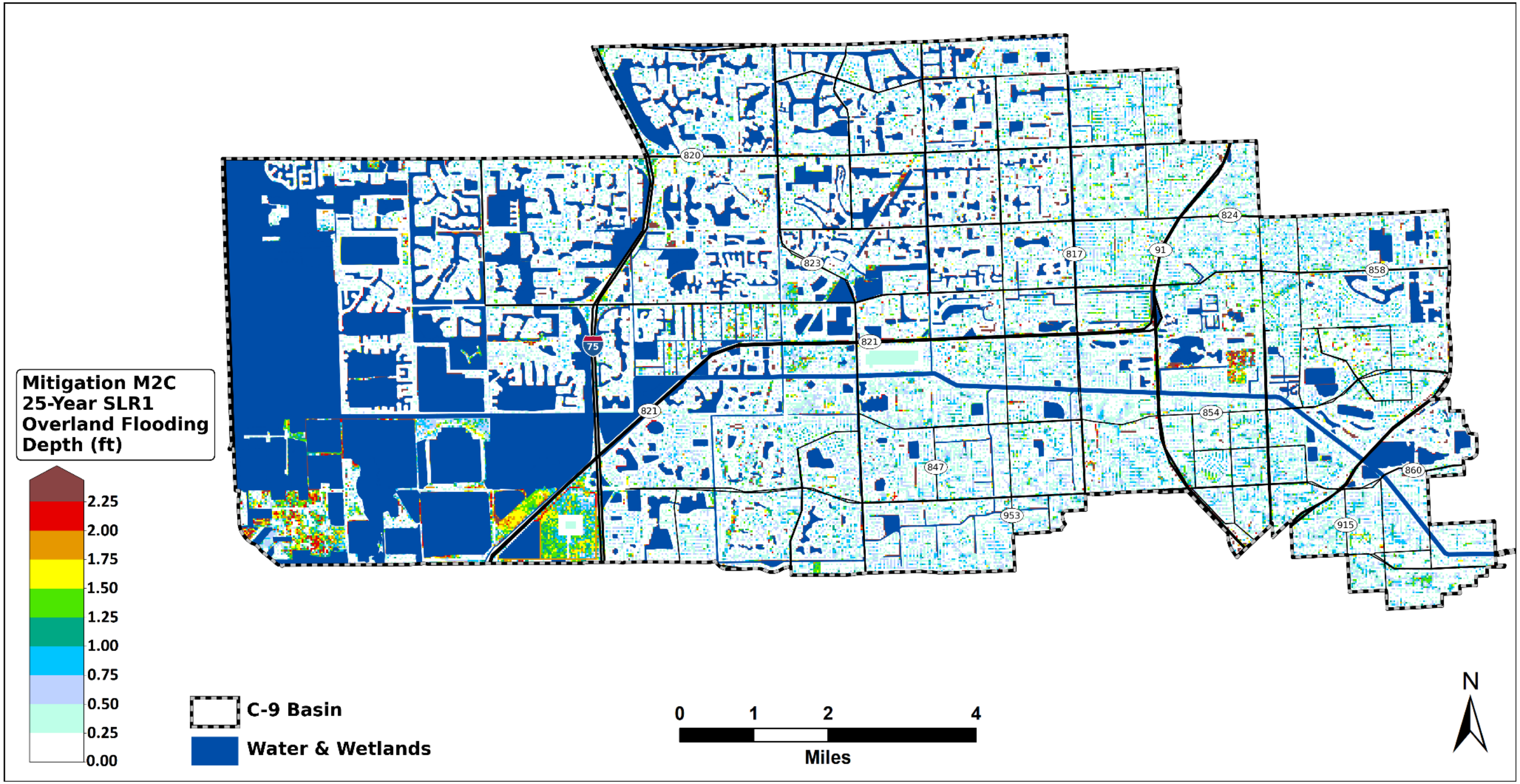


Figure C- 55: C-9 Watershed Flood Inundation Map for the Mitigation M2C 25-Year Sea Level Rise 1 Design Storm Event

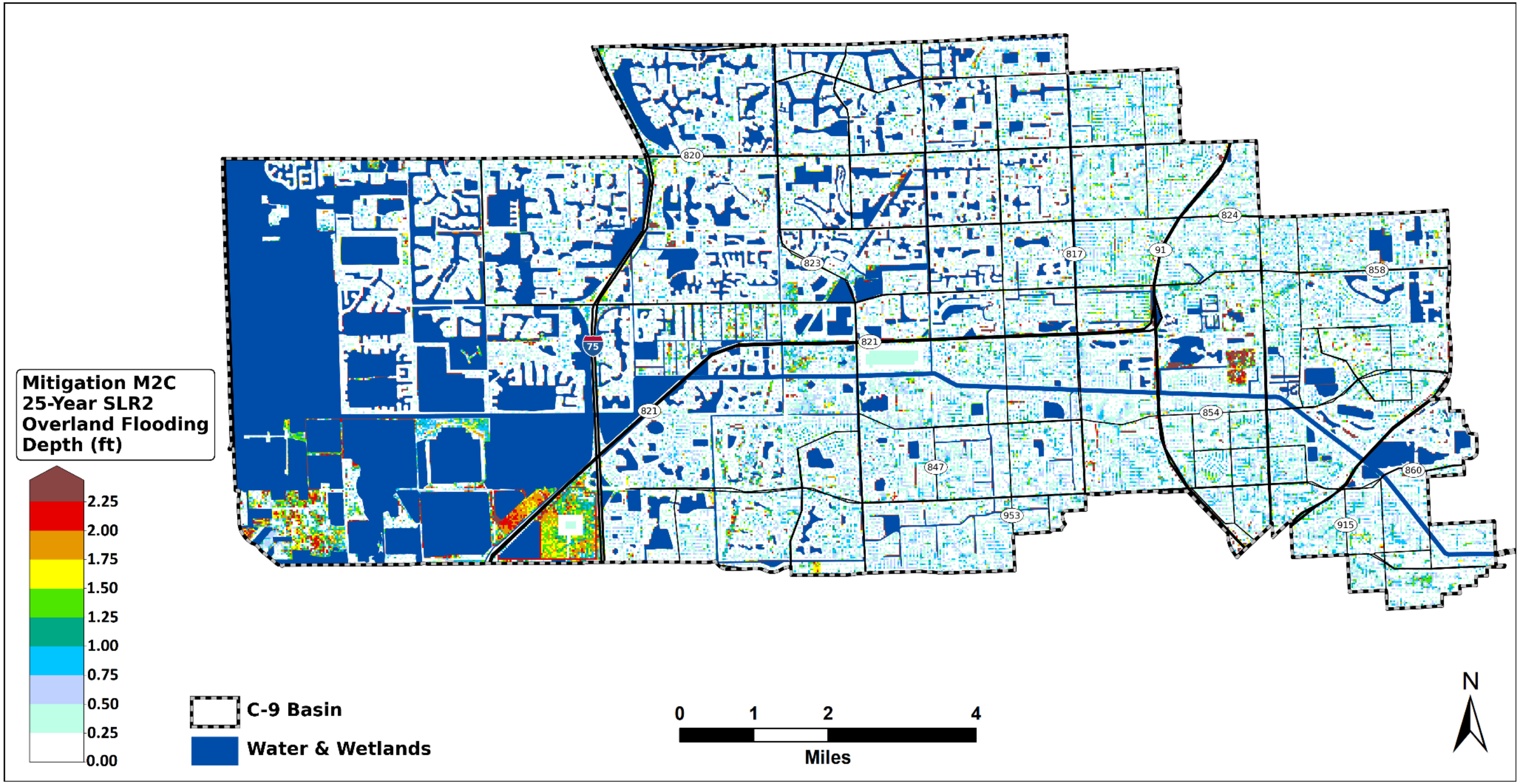


Figure C- 56: C-9 Watershed Flood Inundation Map for the Mitigation M2C 25-Year Sea Level Rise 2 Design Storm Event

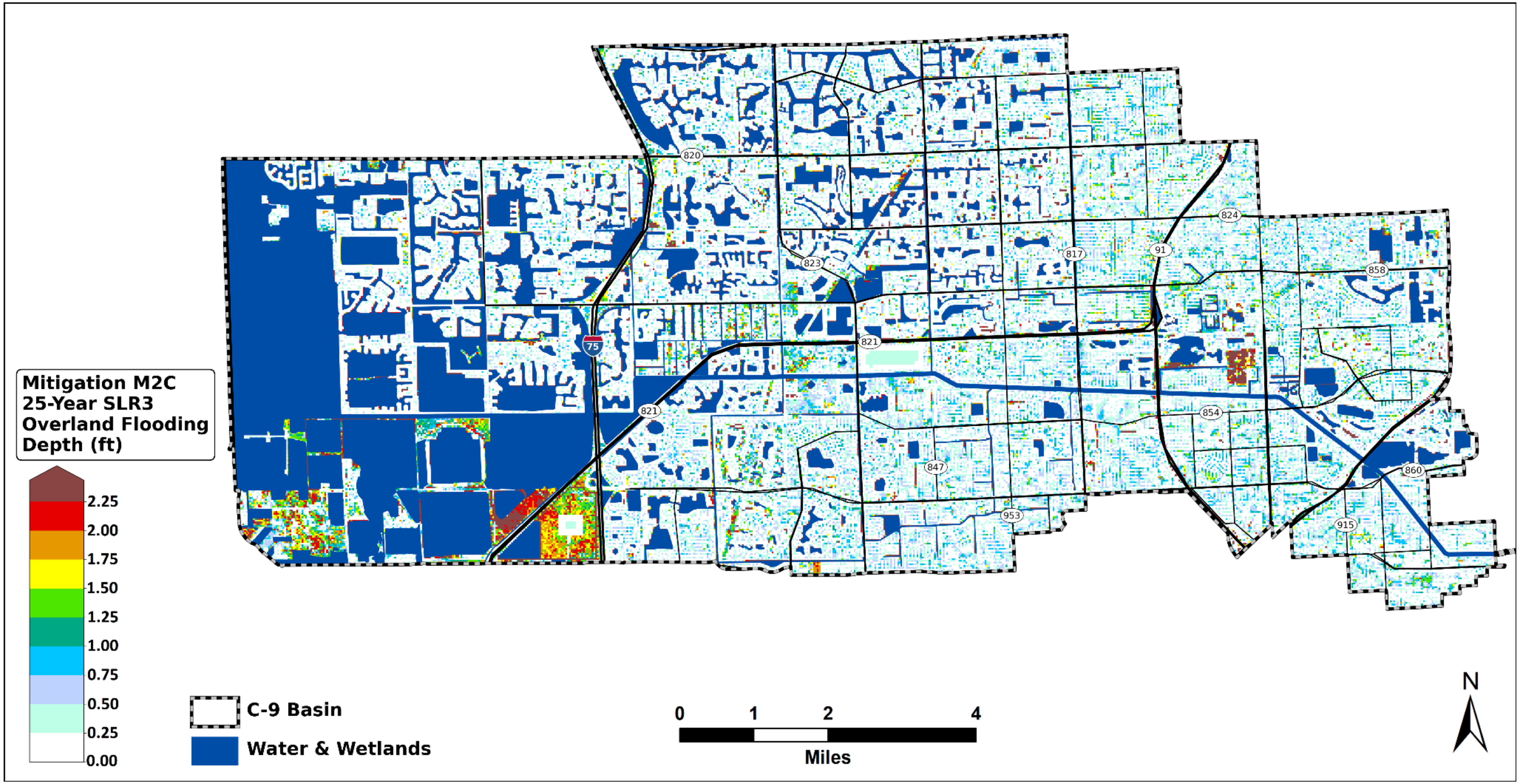


Figure C- 57: C-9 Watershed Flood Inundation Map for the Mitigation M2C 25-Year Sea Level Rise 3 Design Storm Event

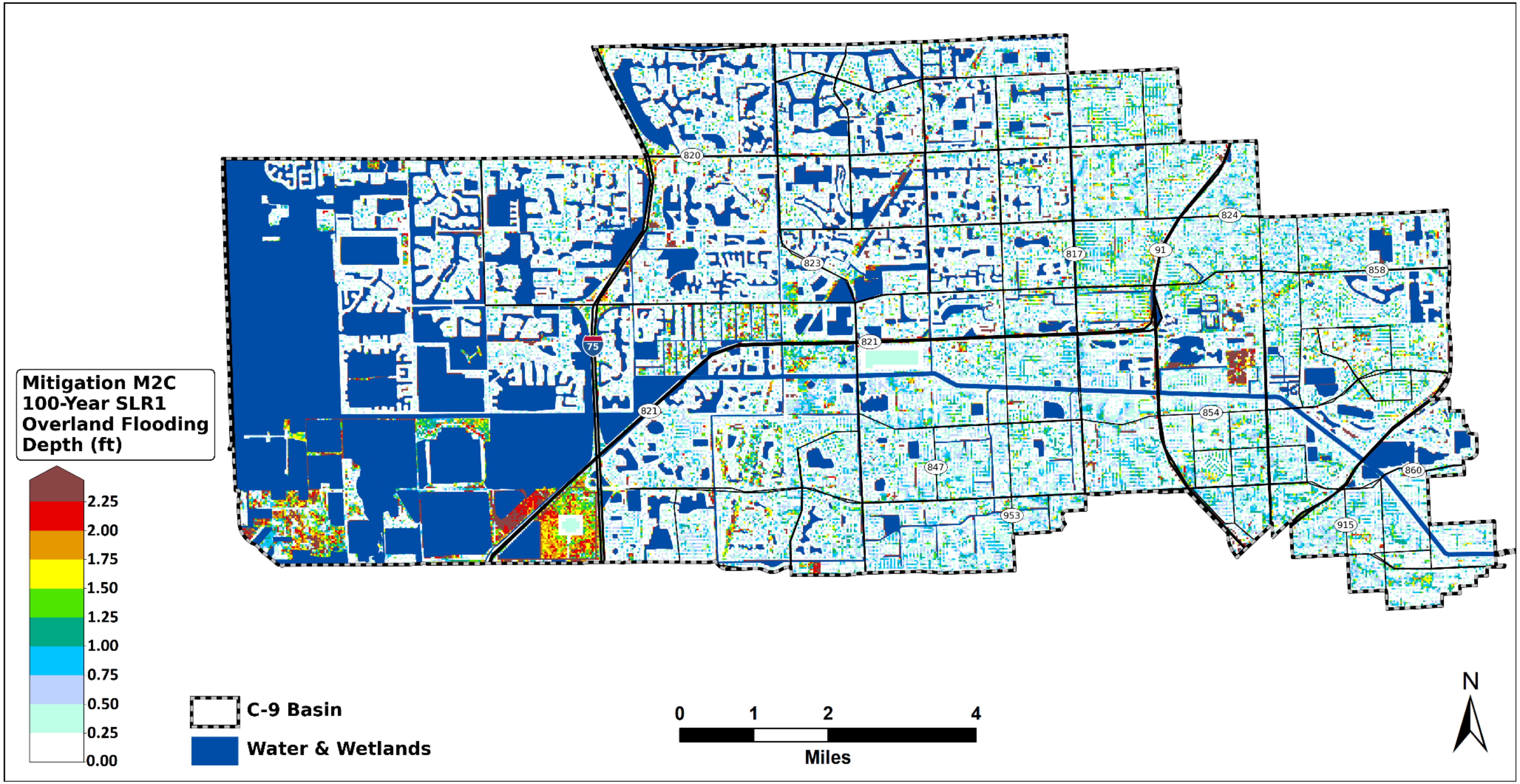


Figure C- 58: C-9 Watershed Flood Inundation Map for the Mitigation M2C 100-Year Sea Level Rise 1 Design Storm Event

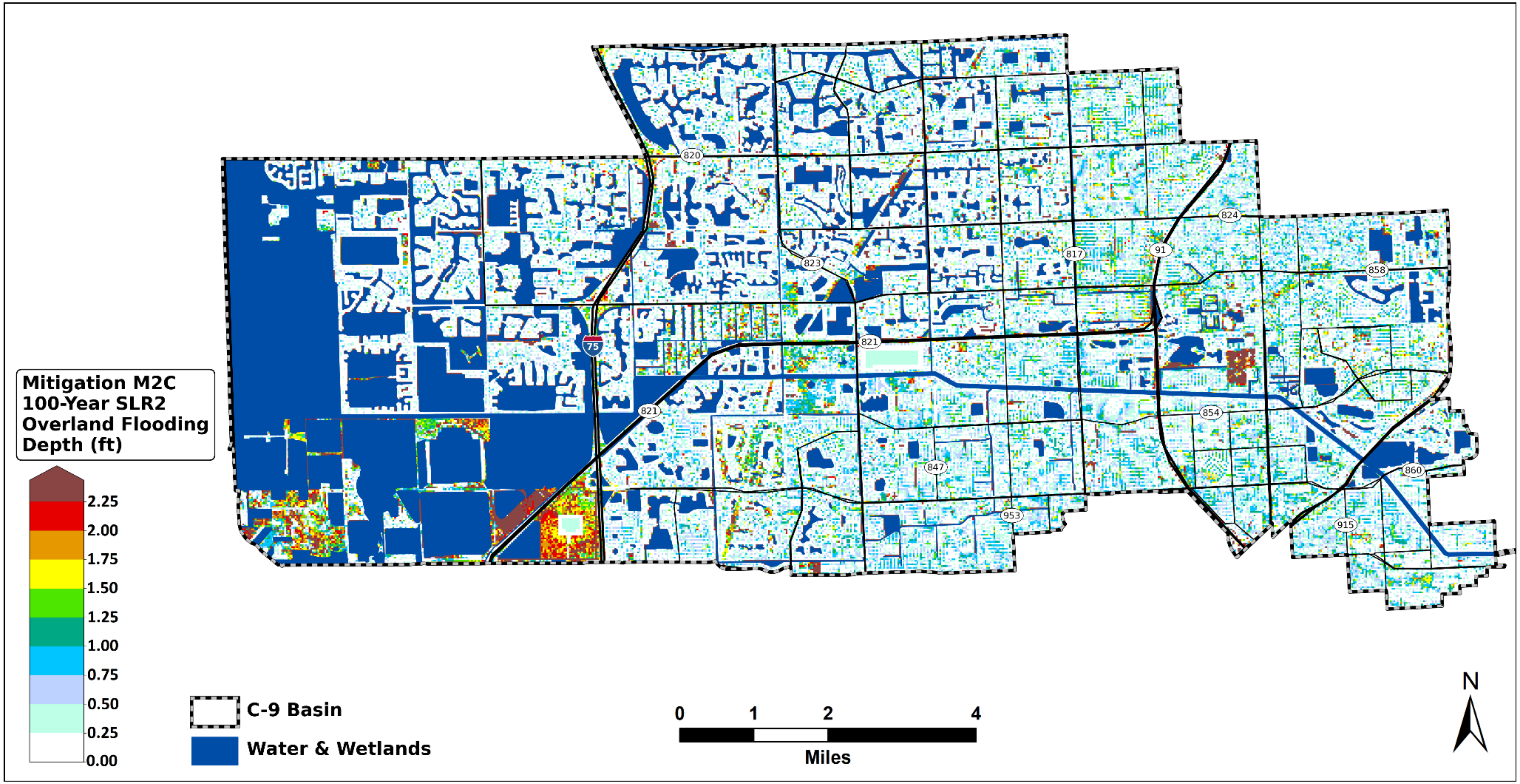


Figure C- 59: C-9 Watershed Flood Inundation Map for the Mitigation M2C 100-Year Sea Level Rise 2 Design Storm Event

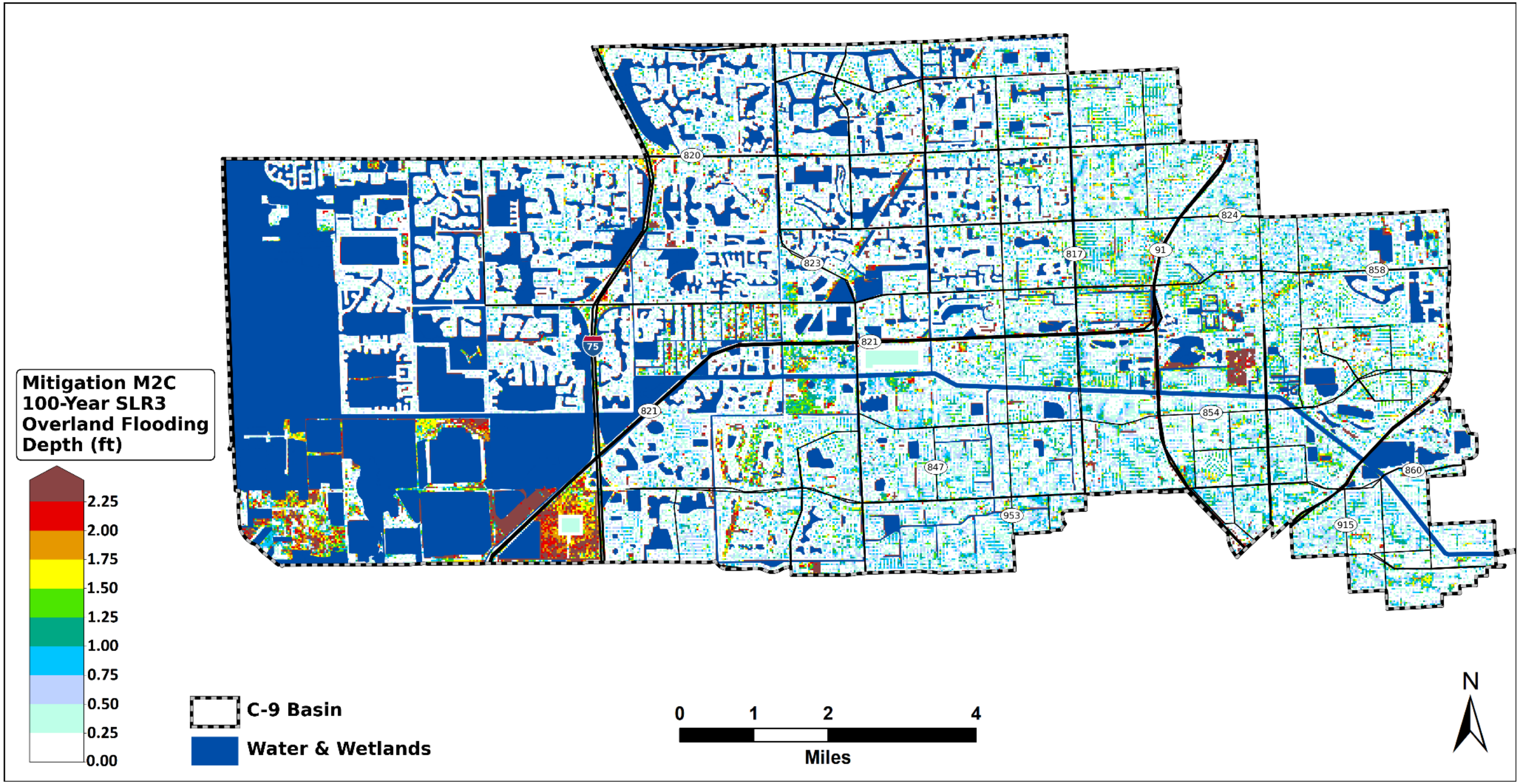


Figure C- 60: C-9 Watershed Flood Inundation Map for the Mitigation M2C 100-Year Sea Level Rise 3 Design Storm Event

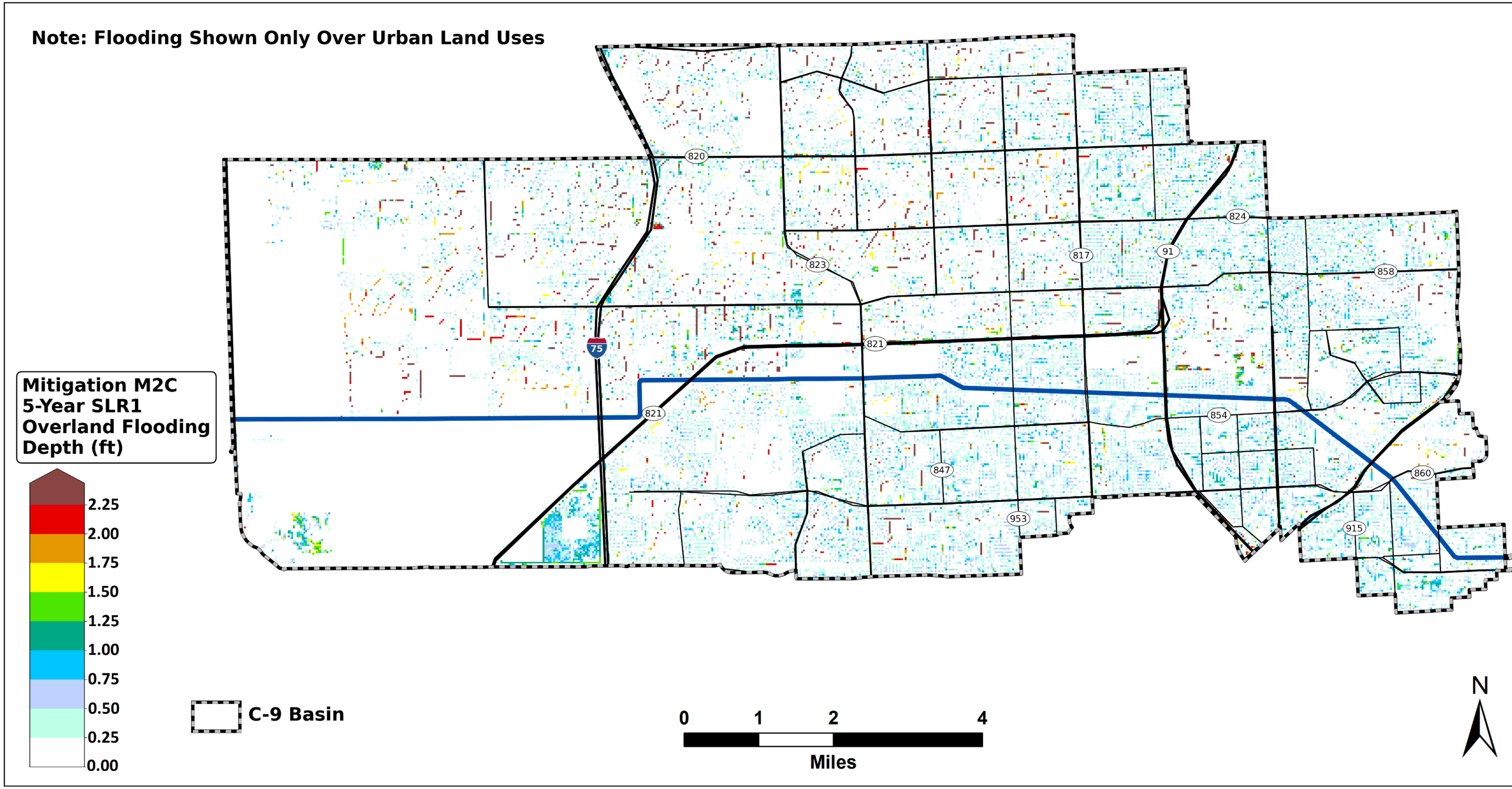


Figure C- 61: C-9 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2C 5-Year Sea Level Rise 1 Design Storm Event

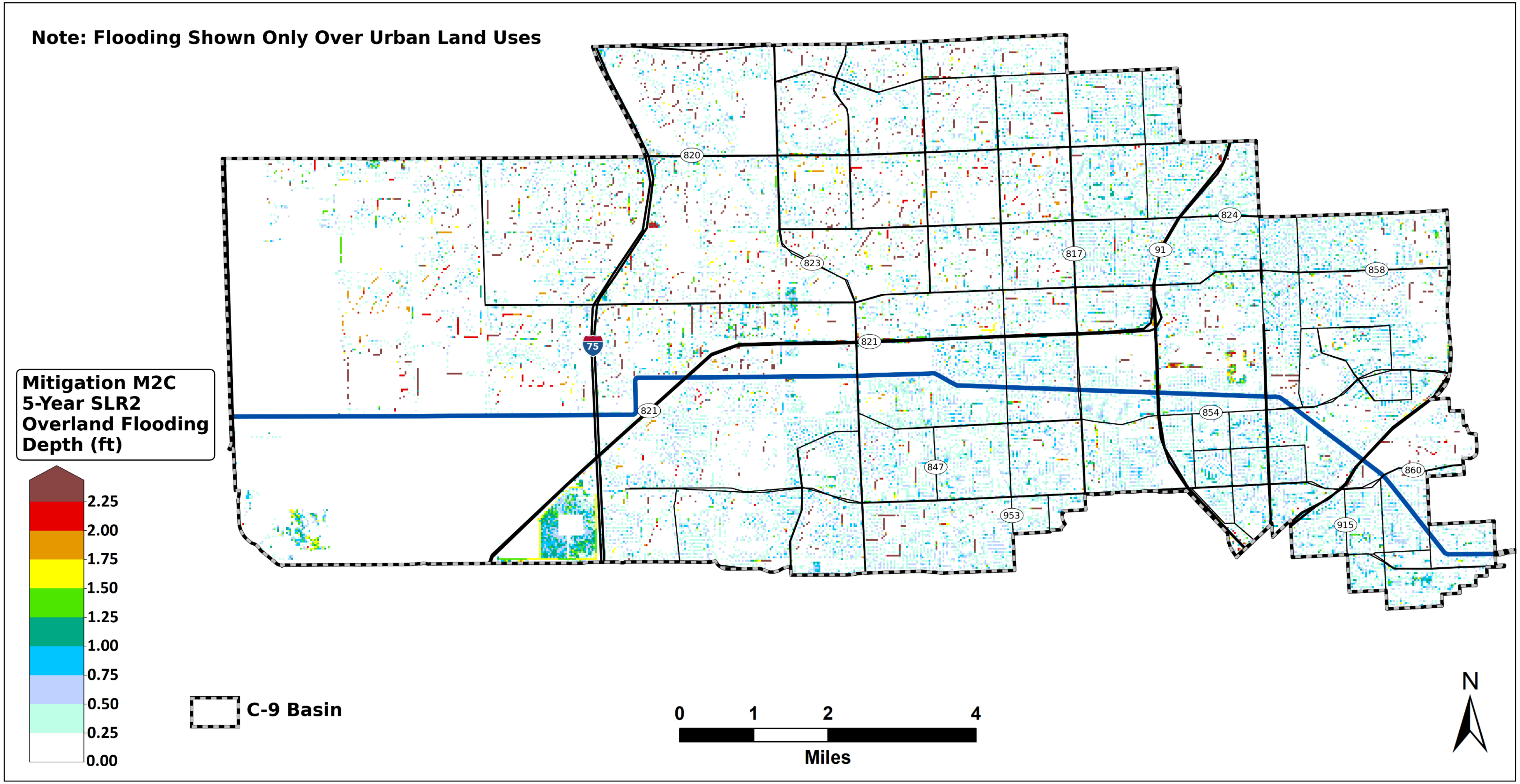


Figure C- 62: C-9 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2C 5-Year Sea Level Rise 2 Design Storm Event

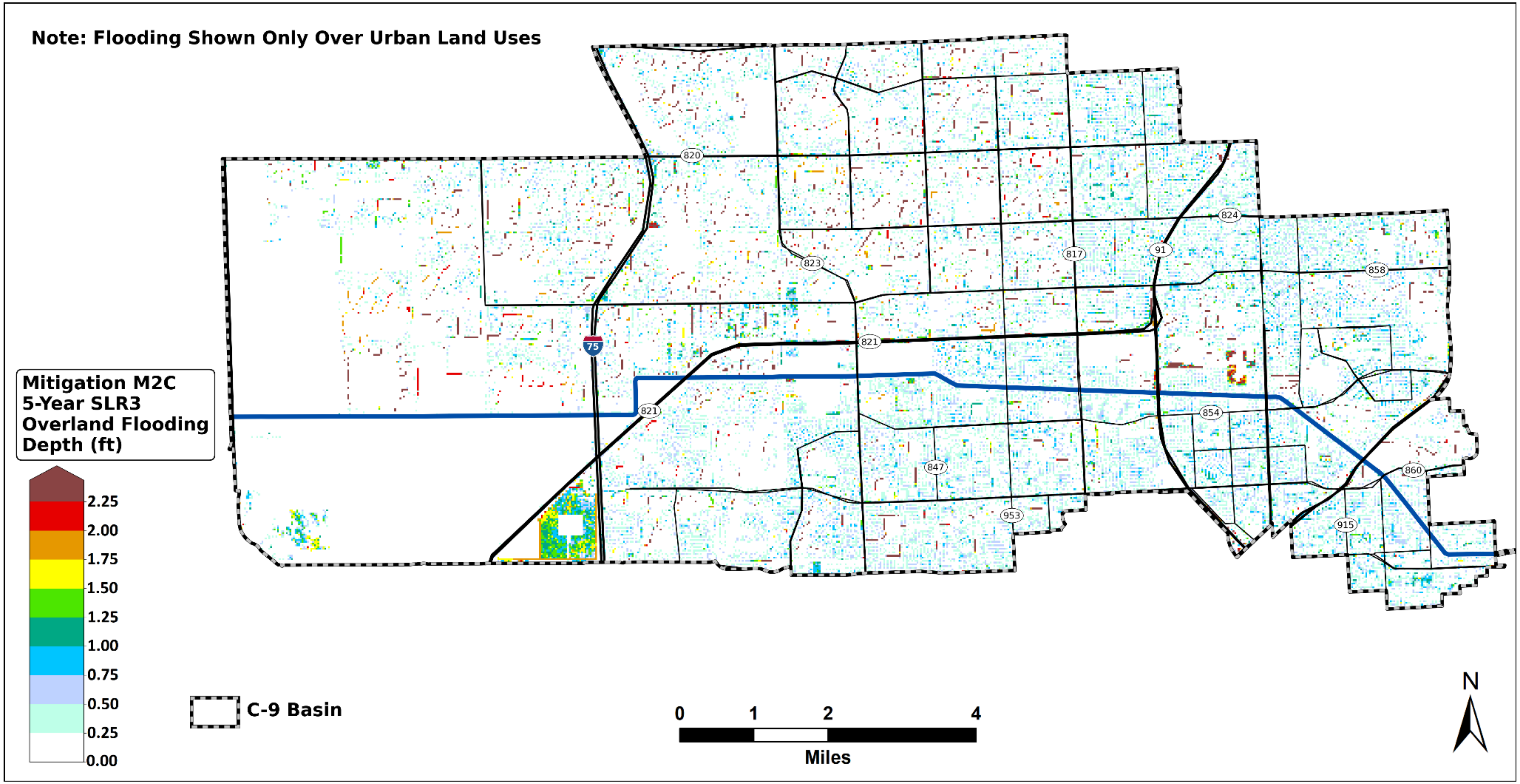


Figure C- 63: C-9 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2C 5-Year Sea Level Rise 3 Design Storm Event

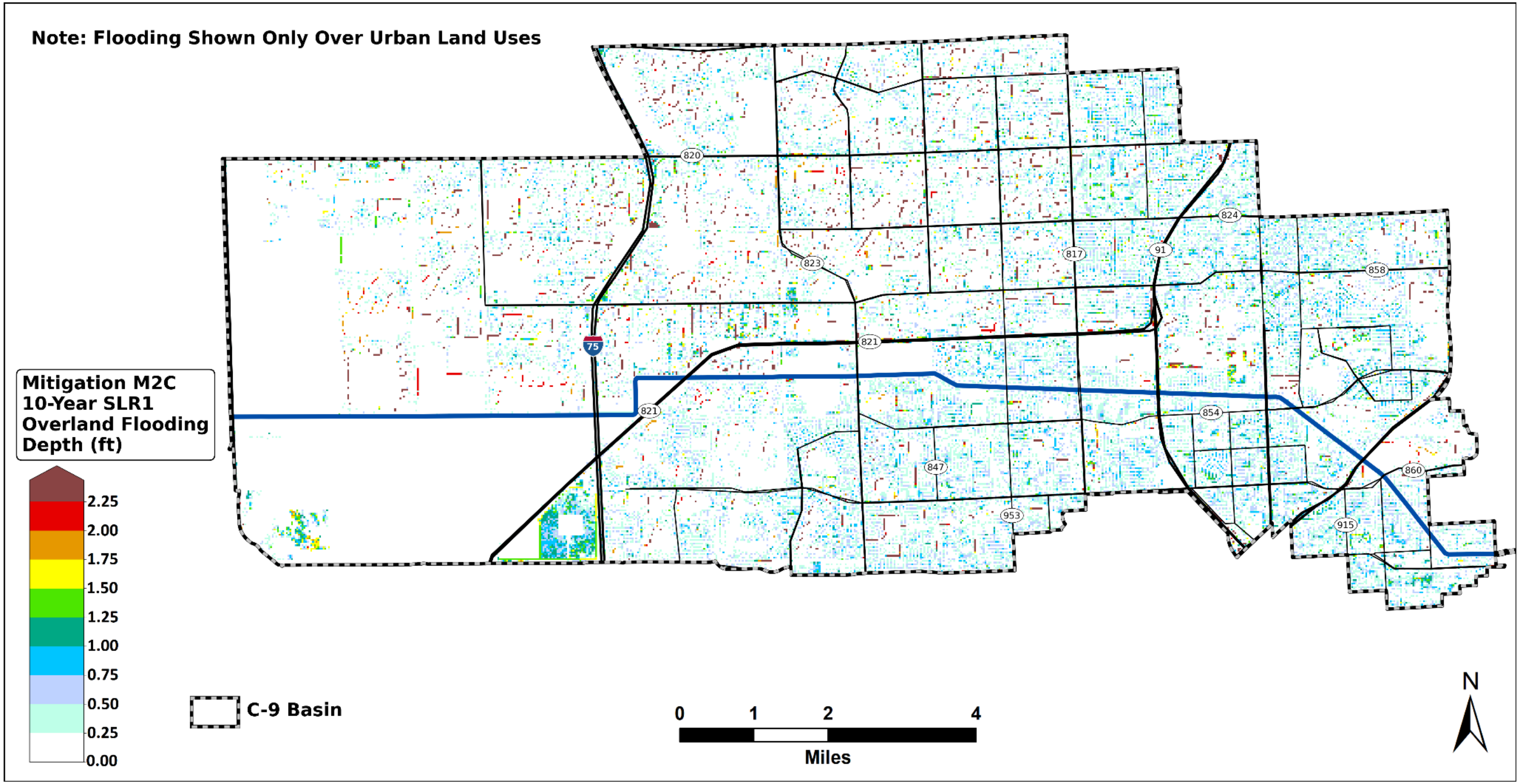


Figure C- 64: C-9 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2C 10-Year Sea Level Rise 1 Design Storm Event

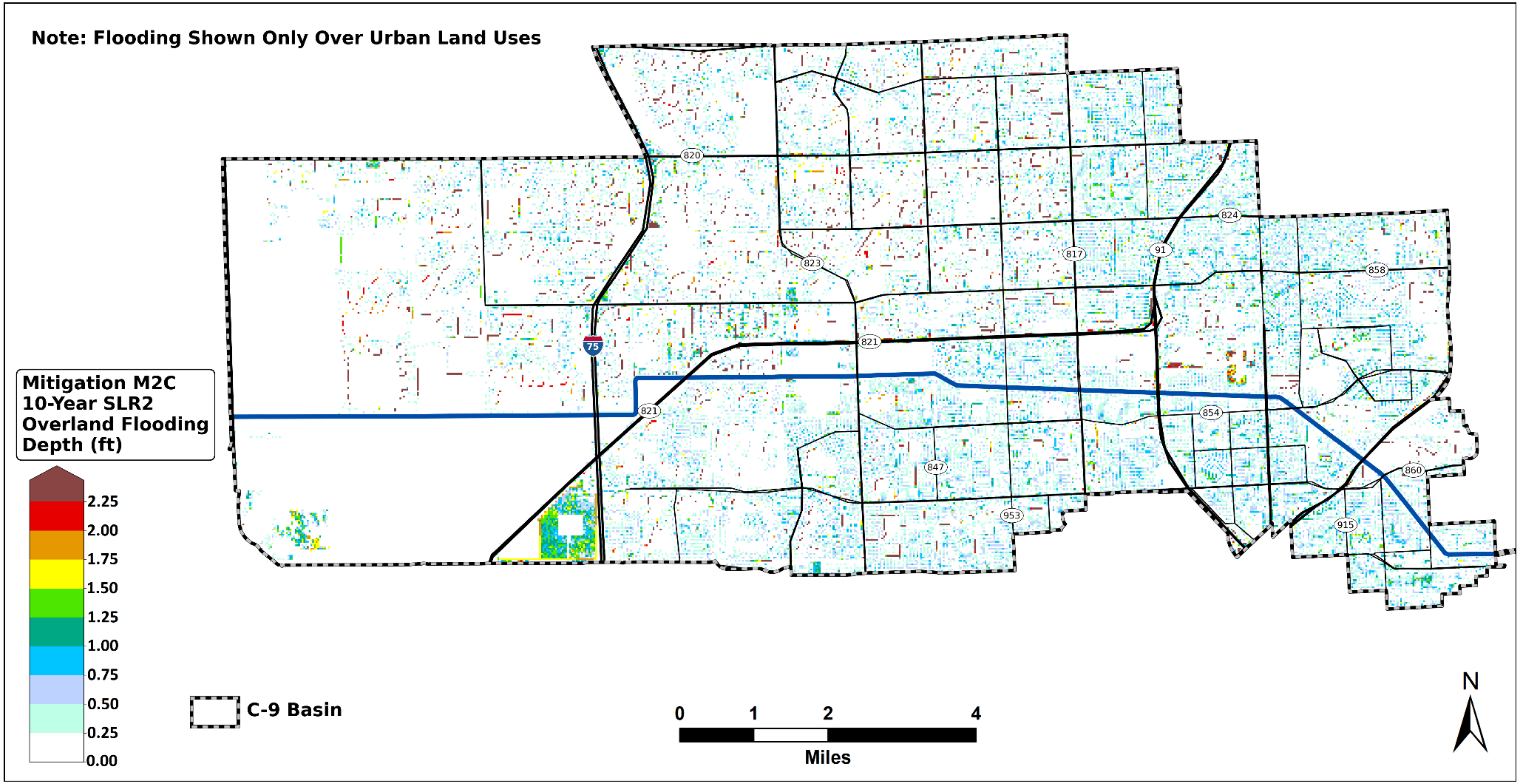


Figure C- 65: C-9 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2C 10-Year Sea Level Rise 2 Design Storm Event

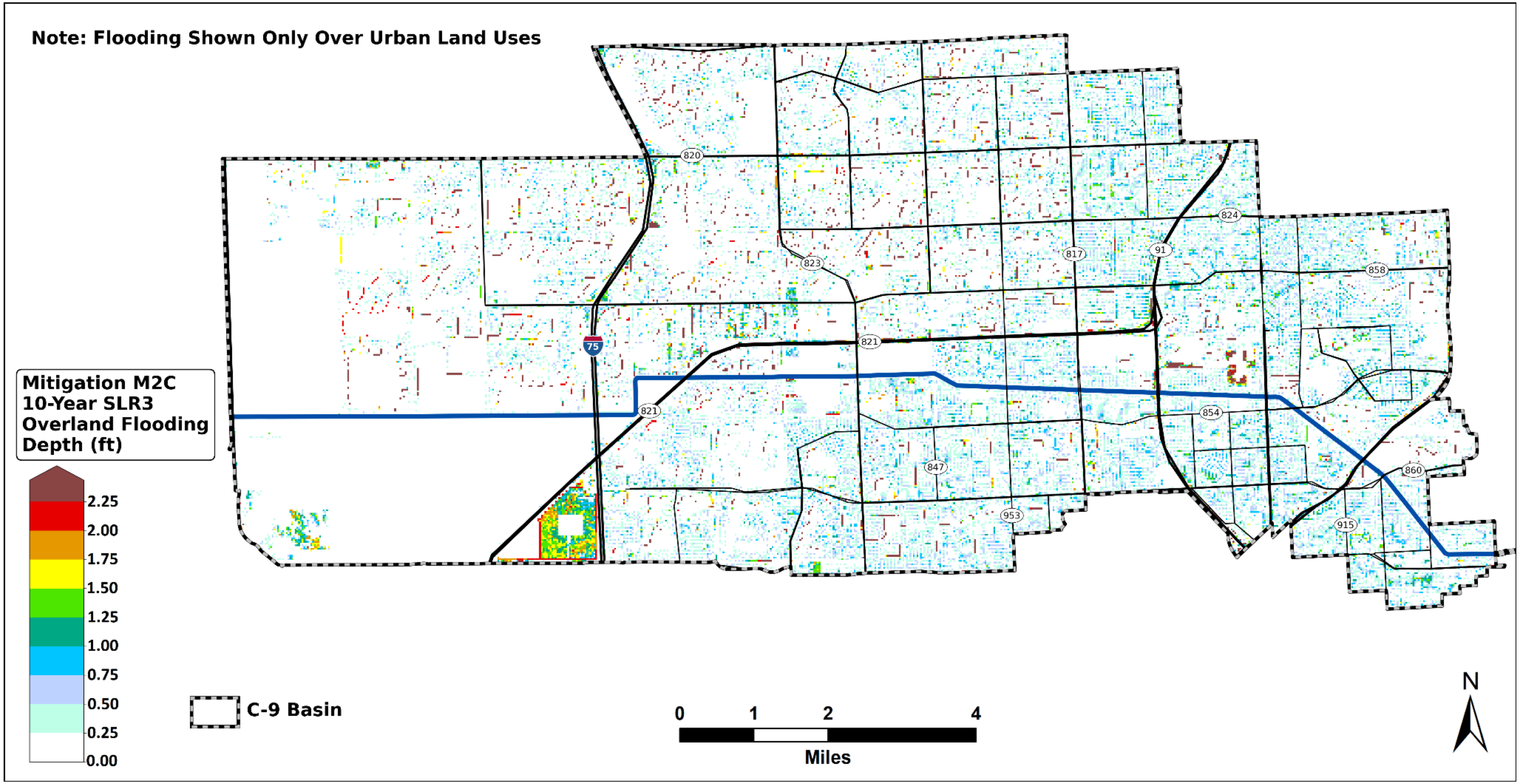


Figure C- 66: C-9 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2C 10-Year Sea Level Rise 3 Design Storm Event

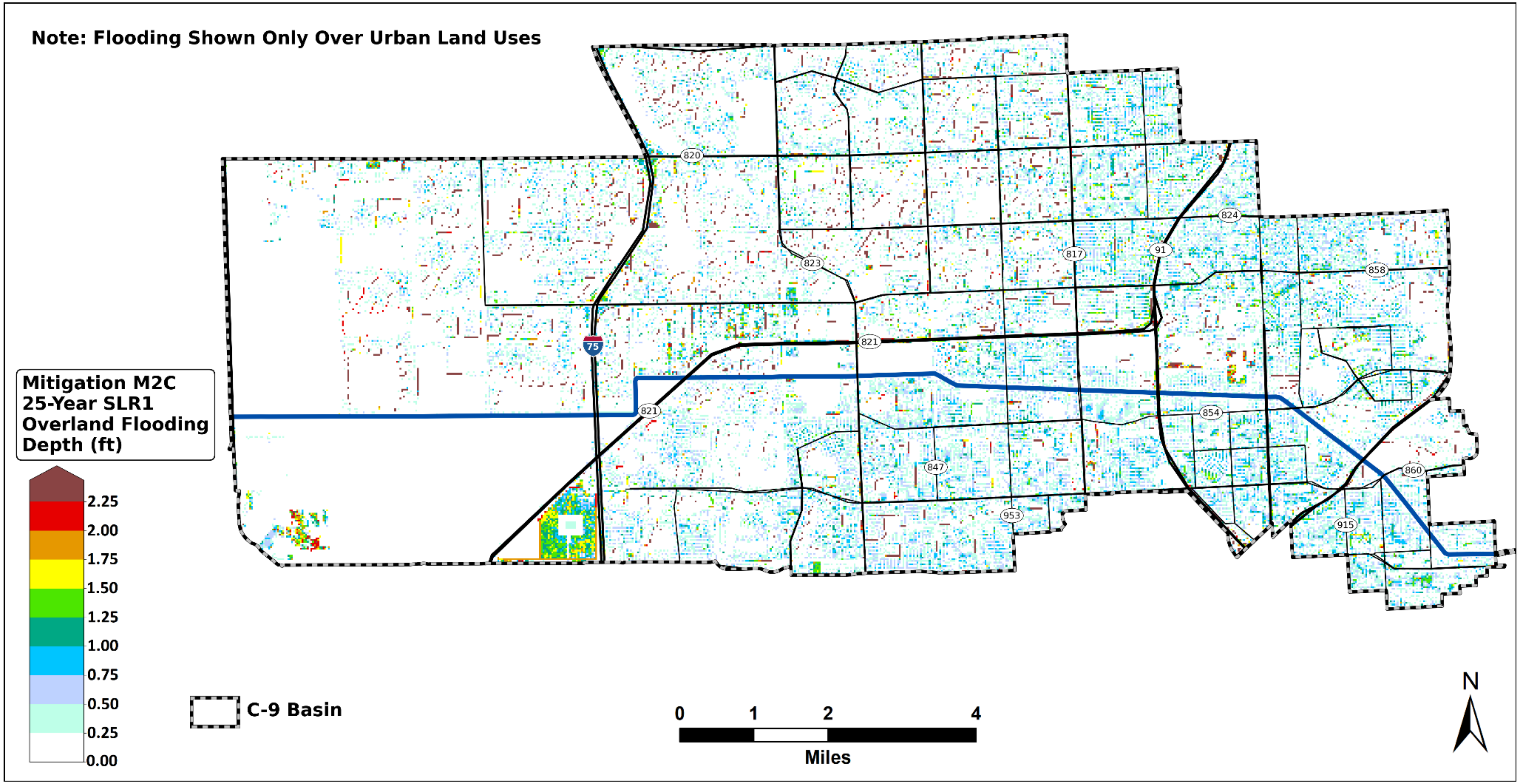


Figure C- 67: C-9 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2C 25-Year Sea Level Rise 1 Design Storm Event

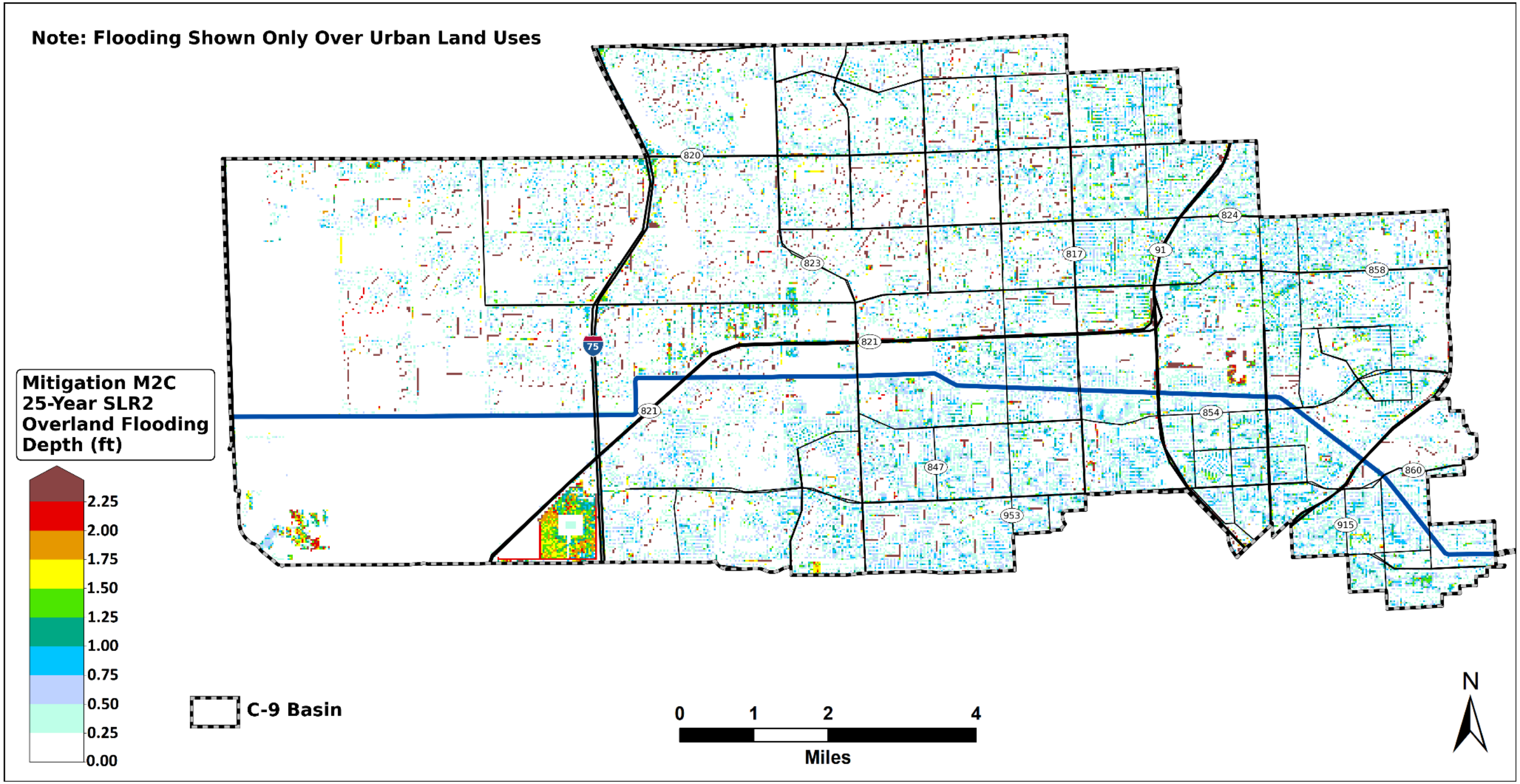


Figure C- 68: C-9 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2C 25-Year Sea Level Rise 2 Design Storm Event

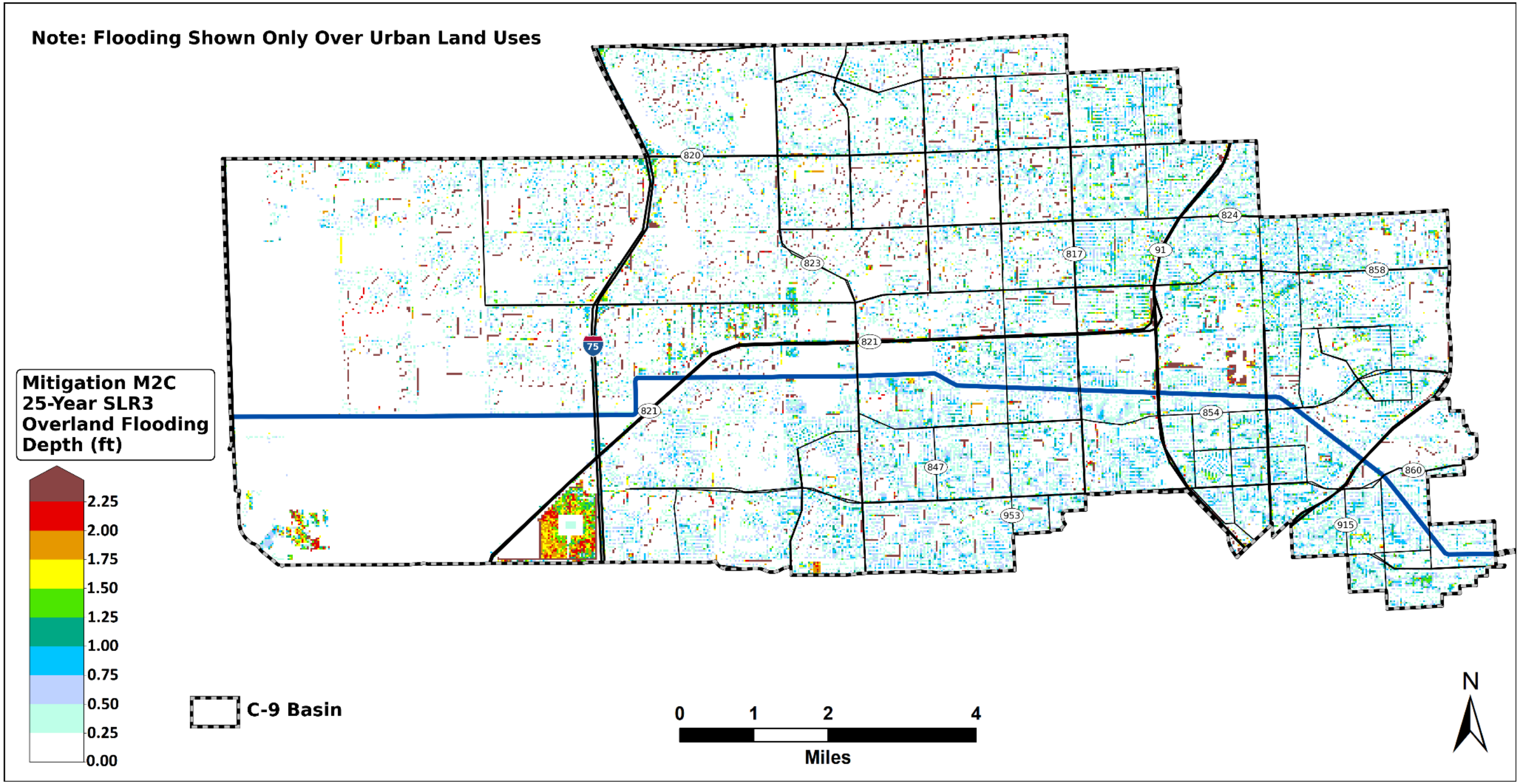


Figure C- 69: C-9 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2C 25-Year Sea Level Rise 3 Design Storm Event

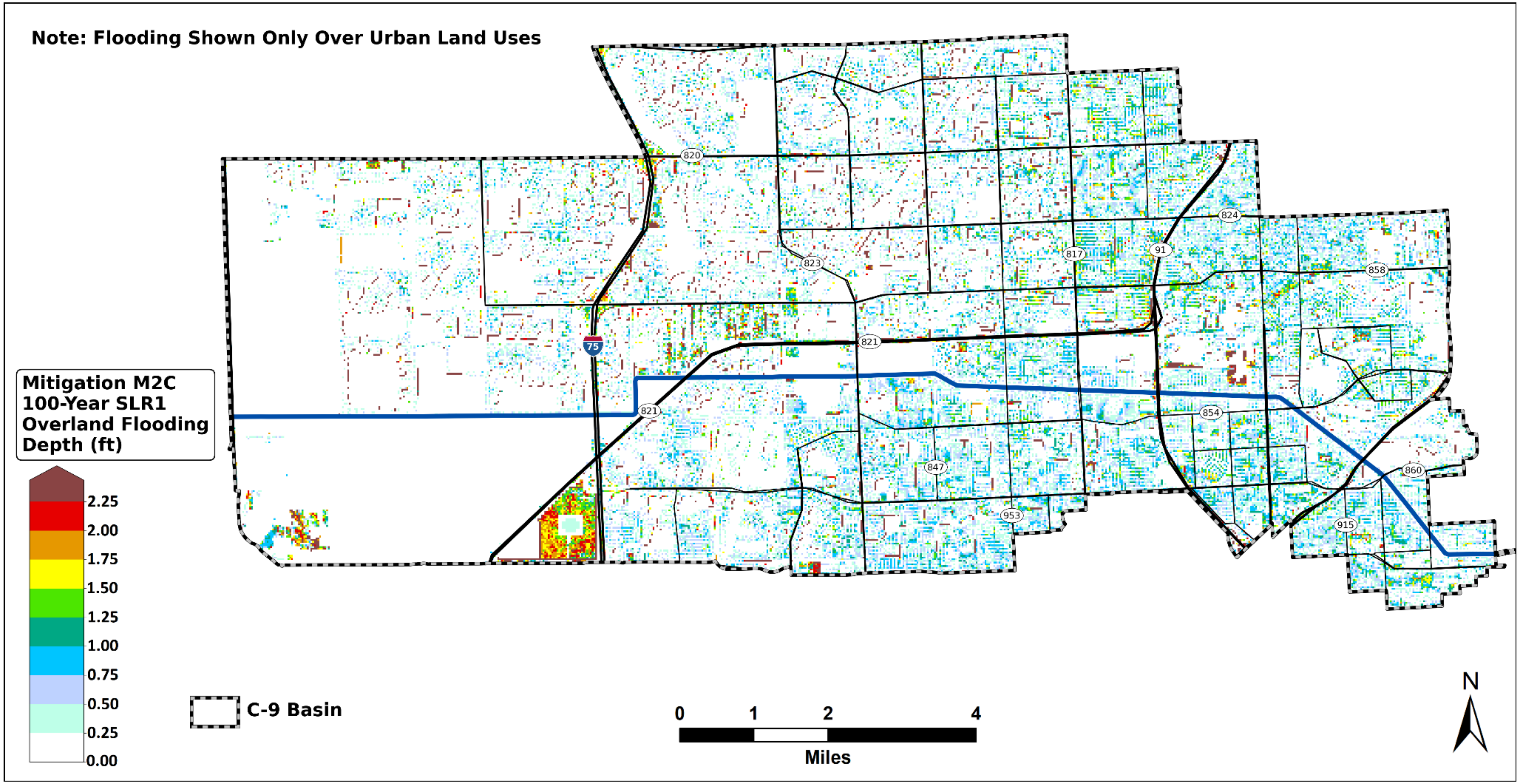


Figure C- 70: C-9 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2C 100-Year Sea Level Rise 1 Design Storm Event

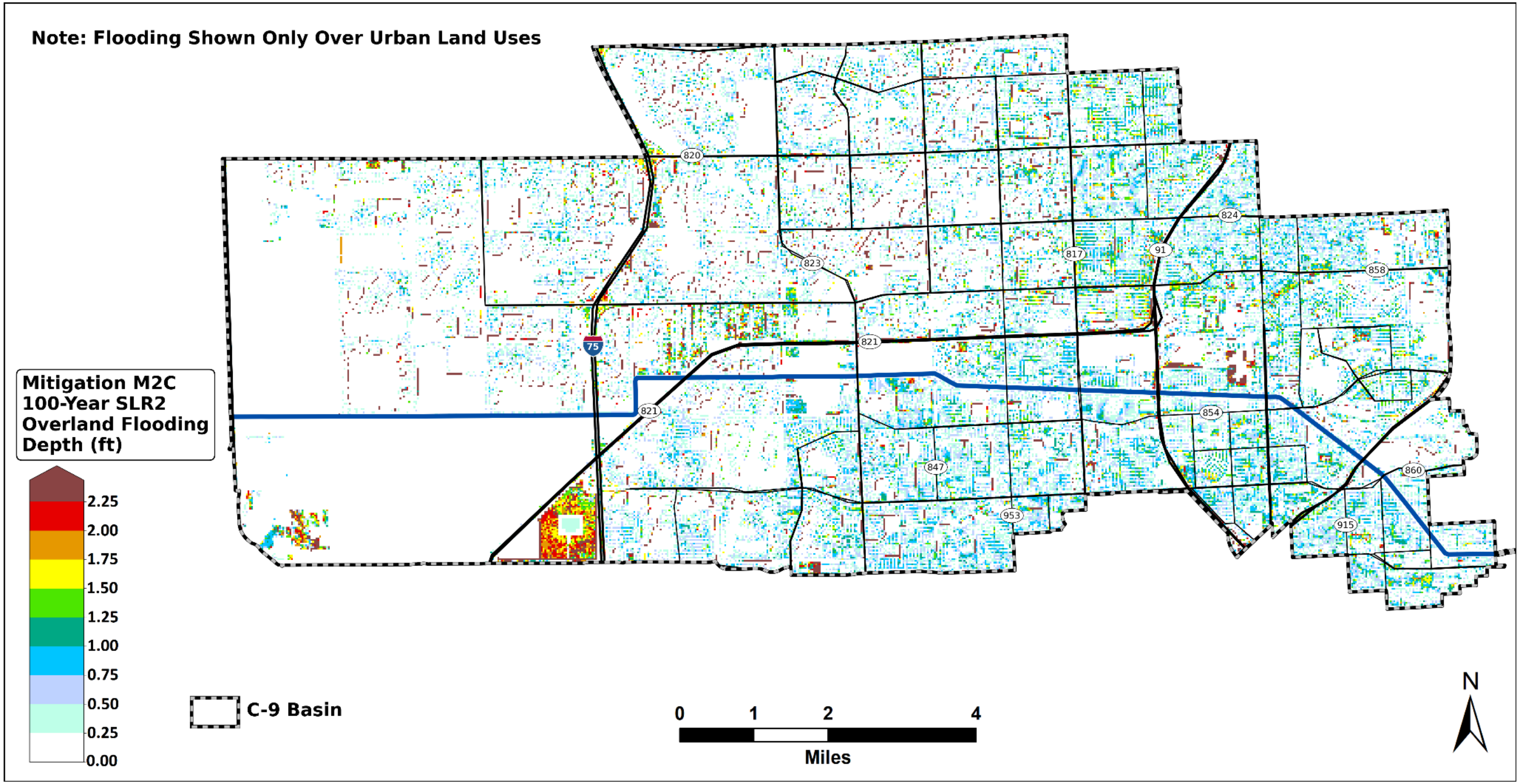


Figure C- 71: C-9 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2C 100-Year Sea Level Rise 2 Design Storm Event

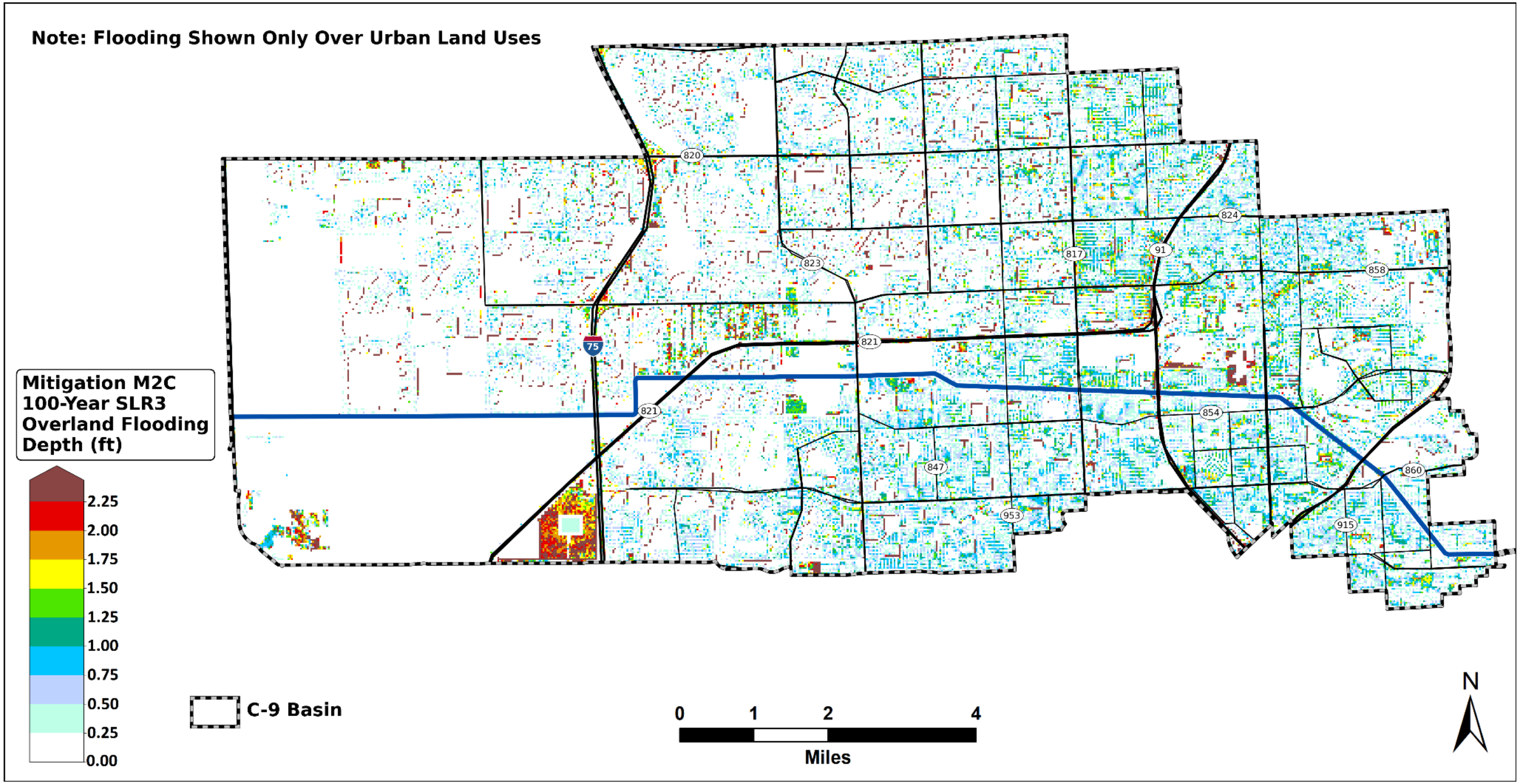


Figure C- 72: C-9 Watershed Flood Inundation Map of Urban Land Use Areas for the Mitigation M2C 100-Year Sea Level Rise 3 Design Storm Event

Appendix D Complete Set of PM #6 Flood Duration Maps for the C-8 Watershed

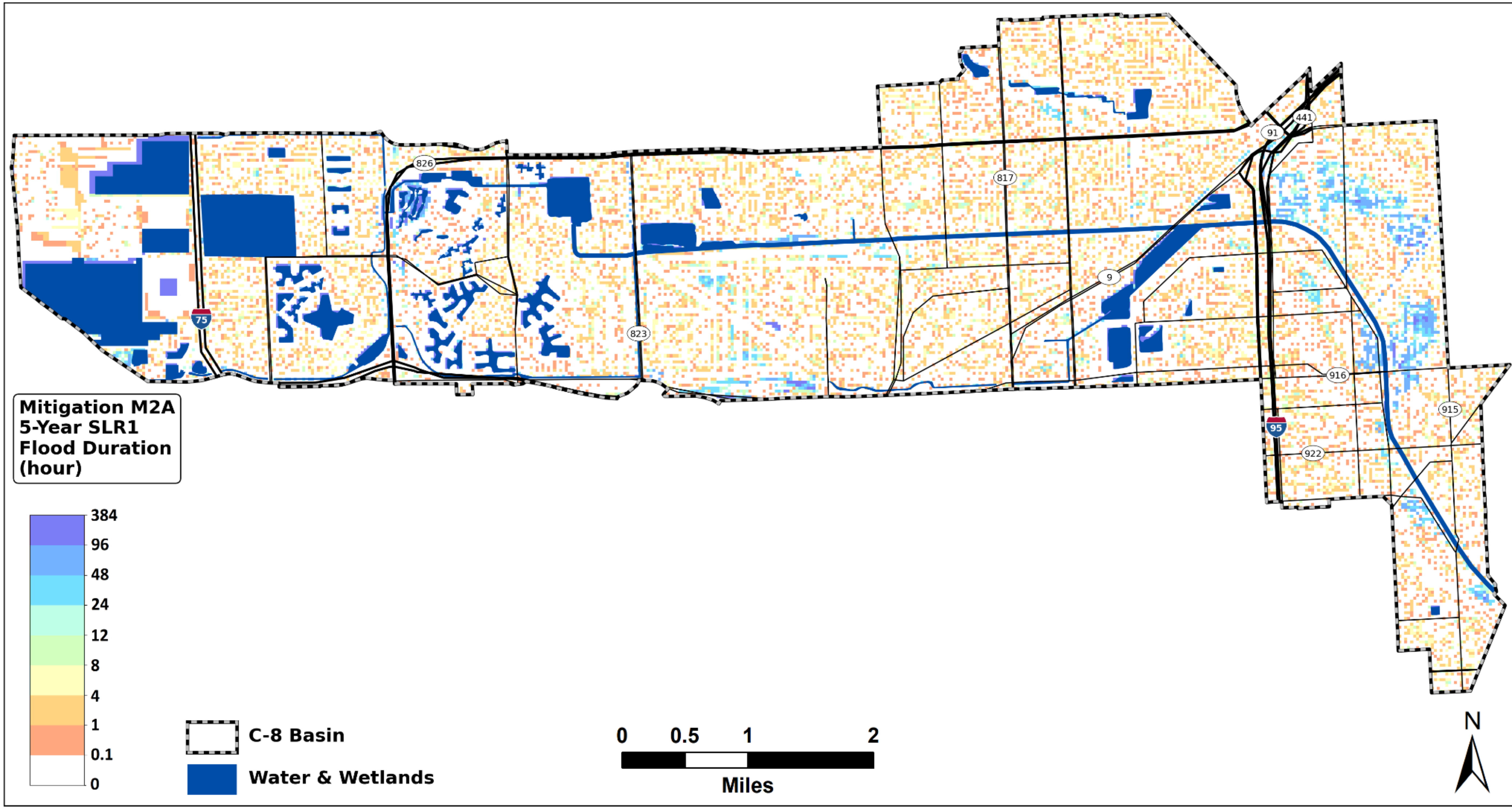


Figure D- 1: C-8 Watershed Flood Duration Map for the Mitigation M2A 5-Year Sea Level Rise 1 Design Storm Event

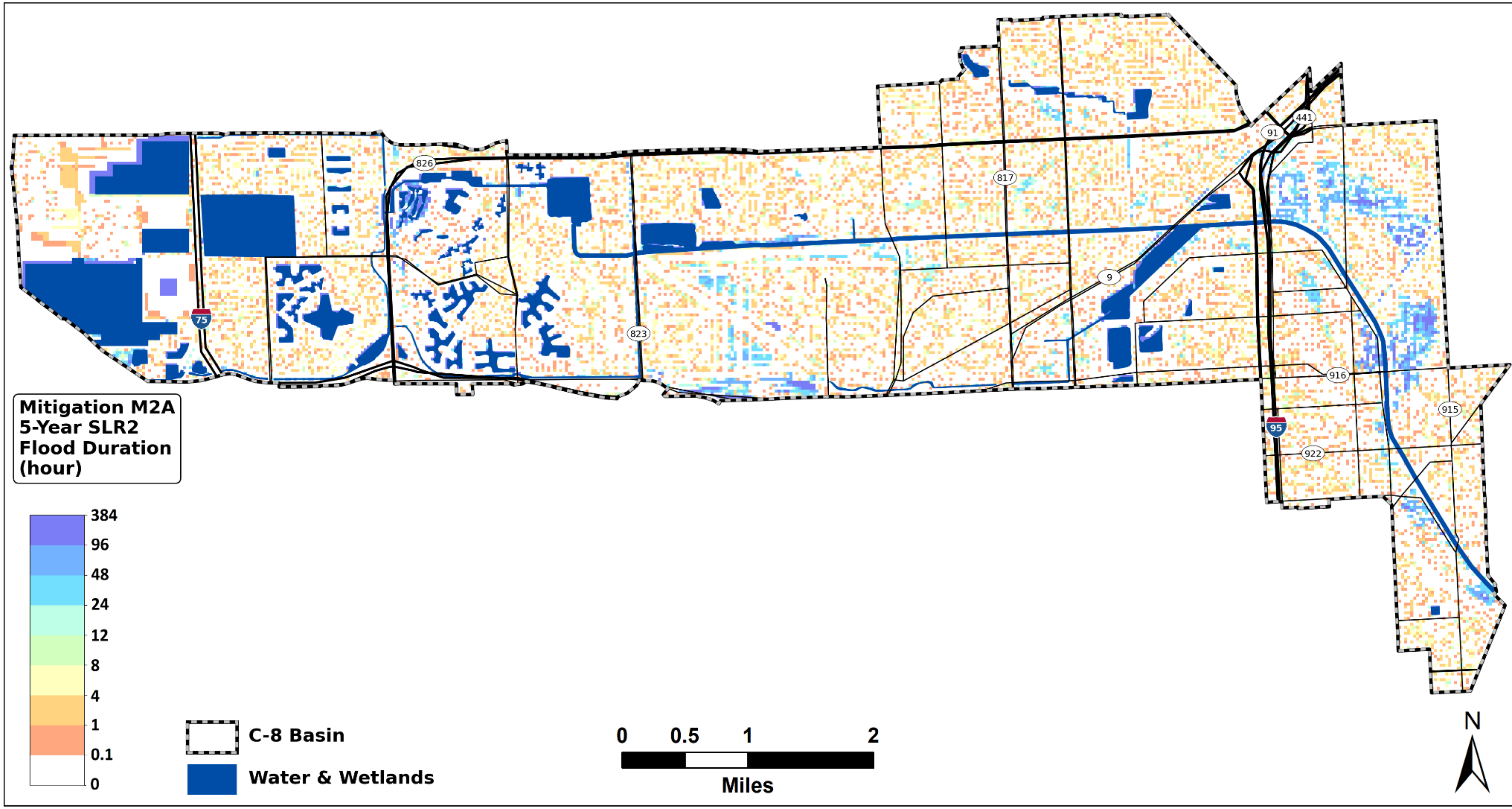


Figure D- 2: C-8 Watershed Flood Duration Map for the Mitigation M2A 5-Year Sea Level Rise 2 Design Storm Event

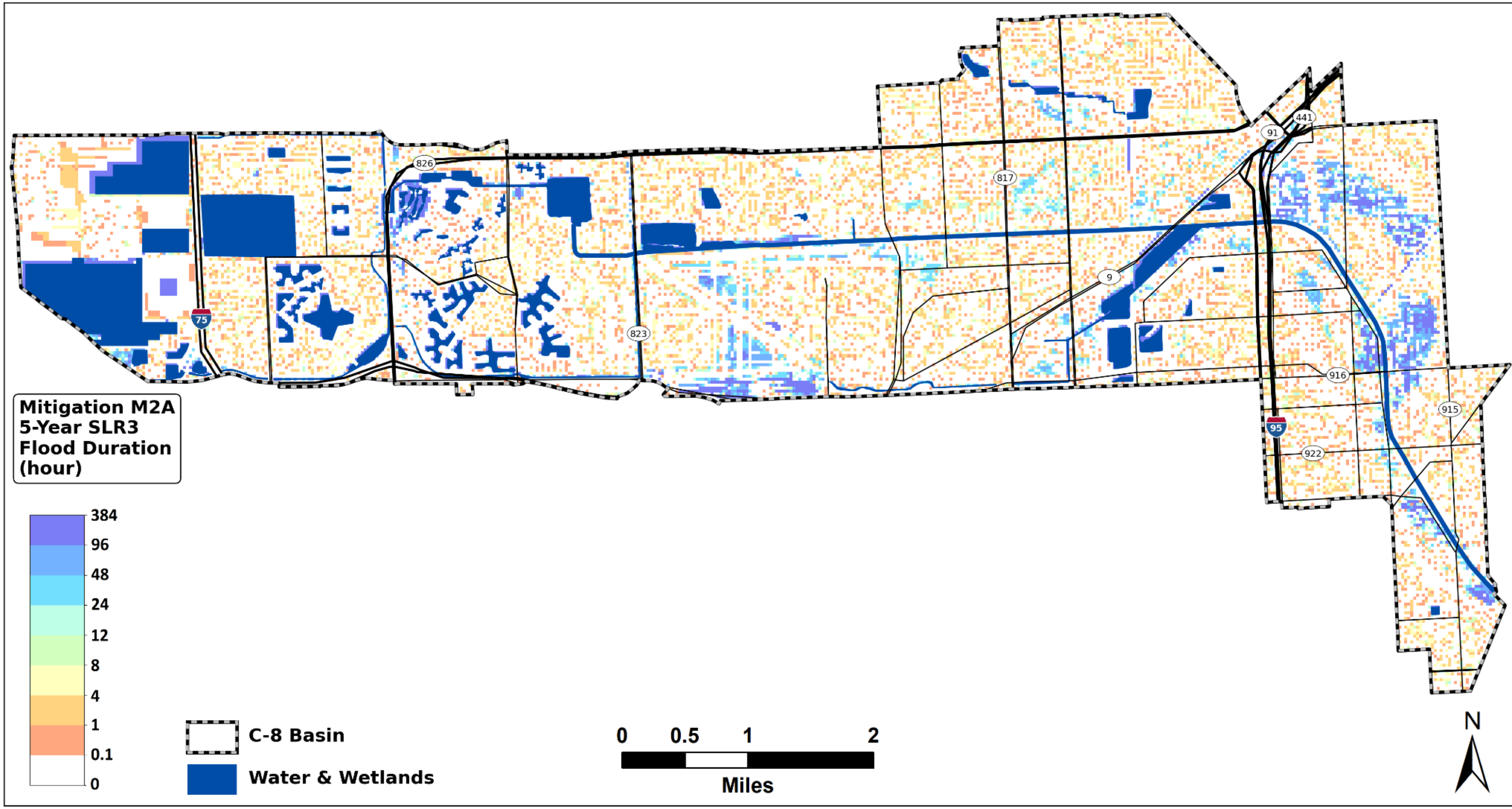


Figure D- 3: C-8 Watershed Flood Duration Map for the Mitigation M2A 5-Year Sea Level Rise 3 Design Storm Event

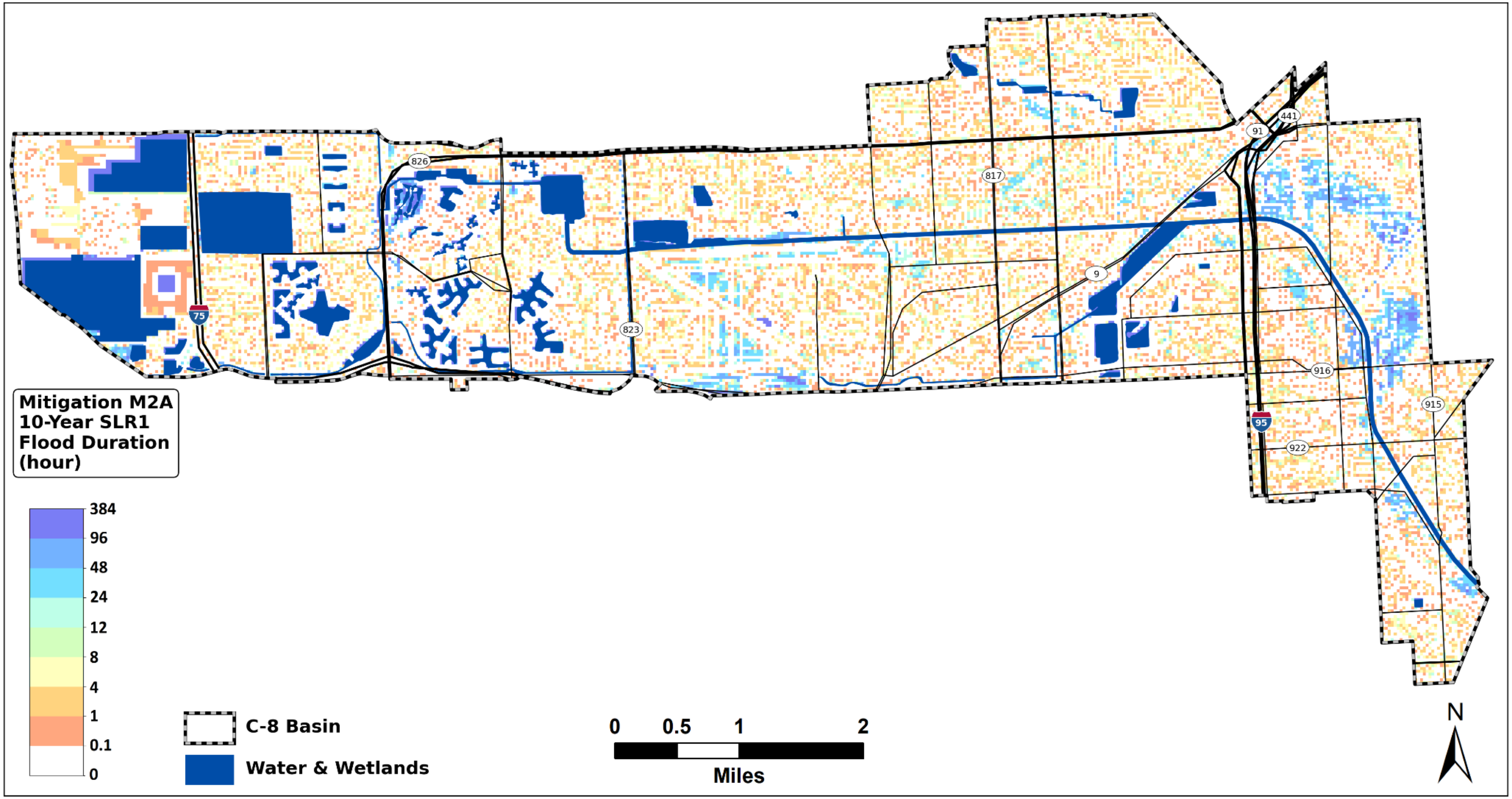


Figure D- 4: C-8 Watershed Flood Duration Map for the Mitigation M2A 10-Year Sea Level Rise 1 Design Storm Event

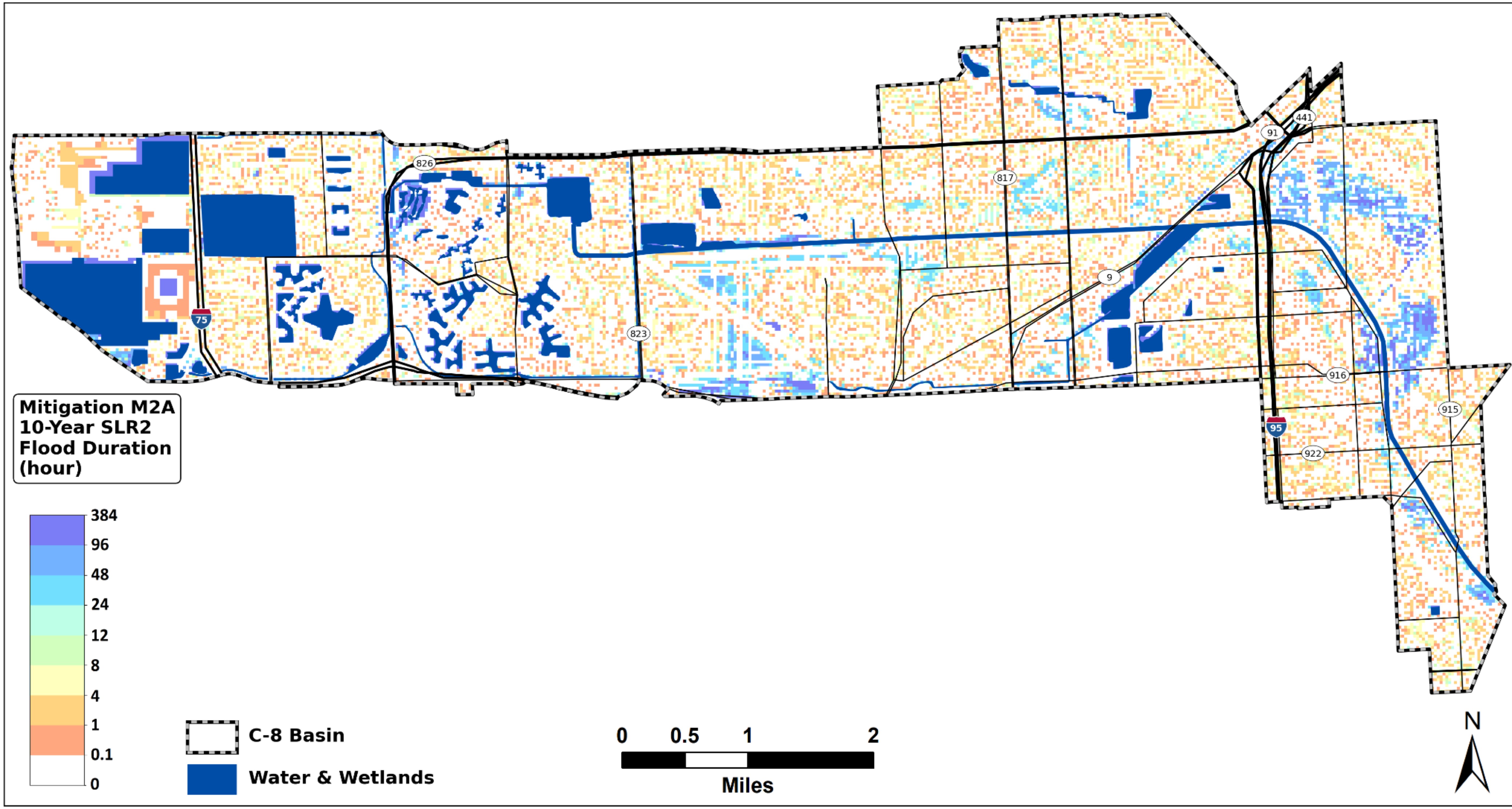


Figure D- 5: C-8 Watershed Flood Duration Map for the Mitigation M2A 10-Year Sea Level Rise 2 Design Storm Event

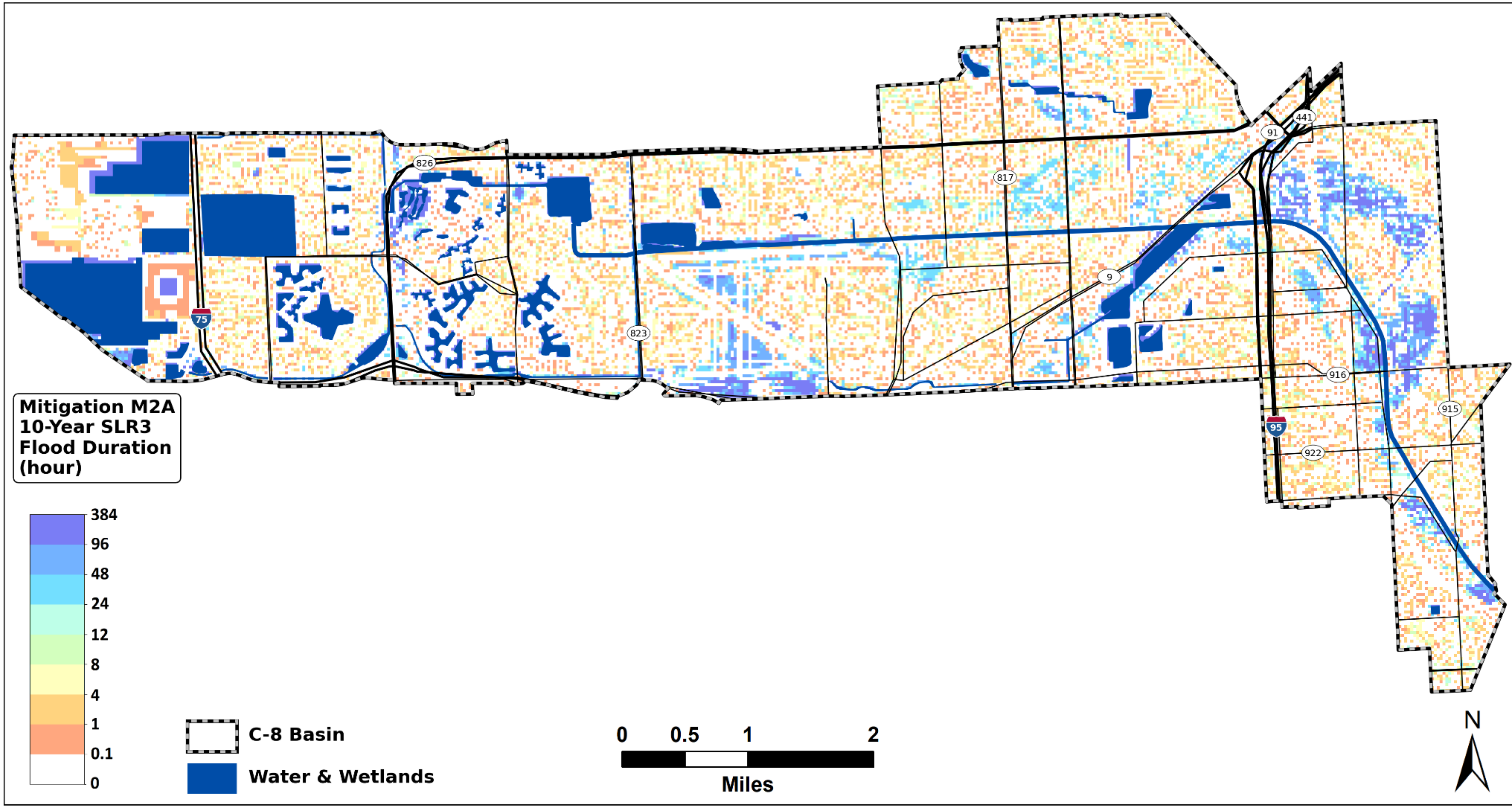


Figure D- 6: C-8 Watershed Flood Duration Map for the Mitigation M2A 10-Year Sea Level Rise 3 Design Storm Event

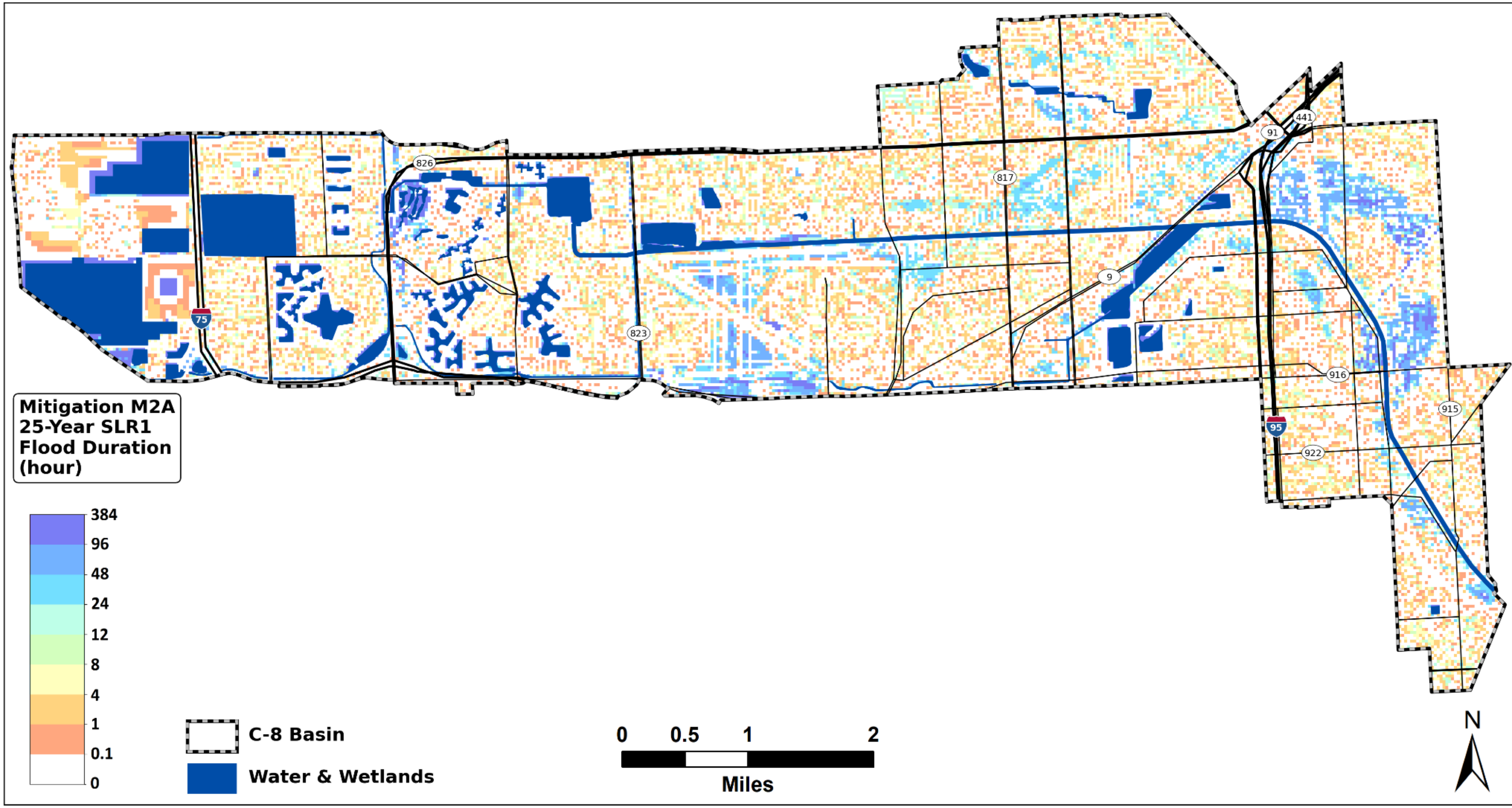


Figure D- 7: C-8 Watershed Flood Duration Map for the Mitigation M2A 25-Year Sea Level Rise 1 Design Storm Event

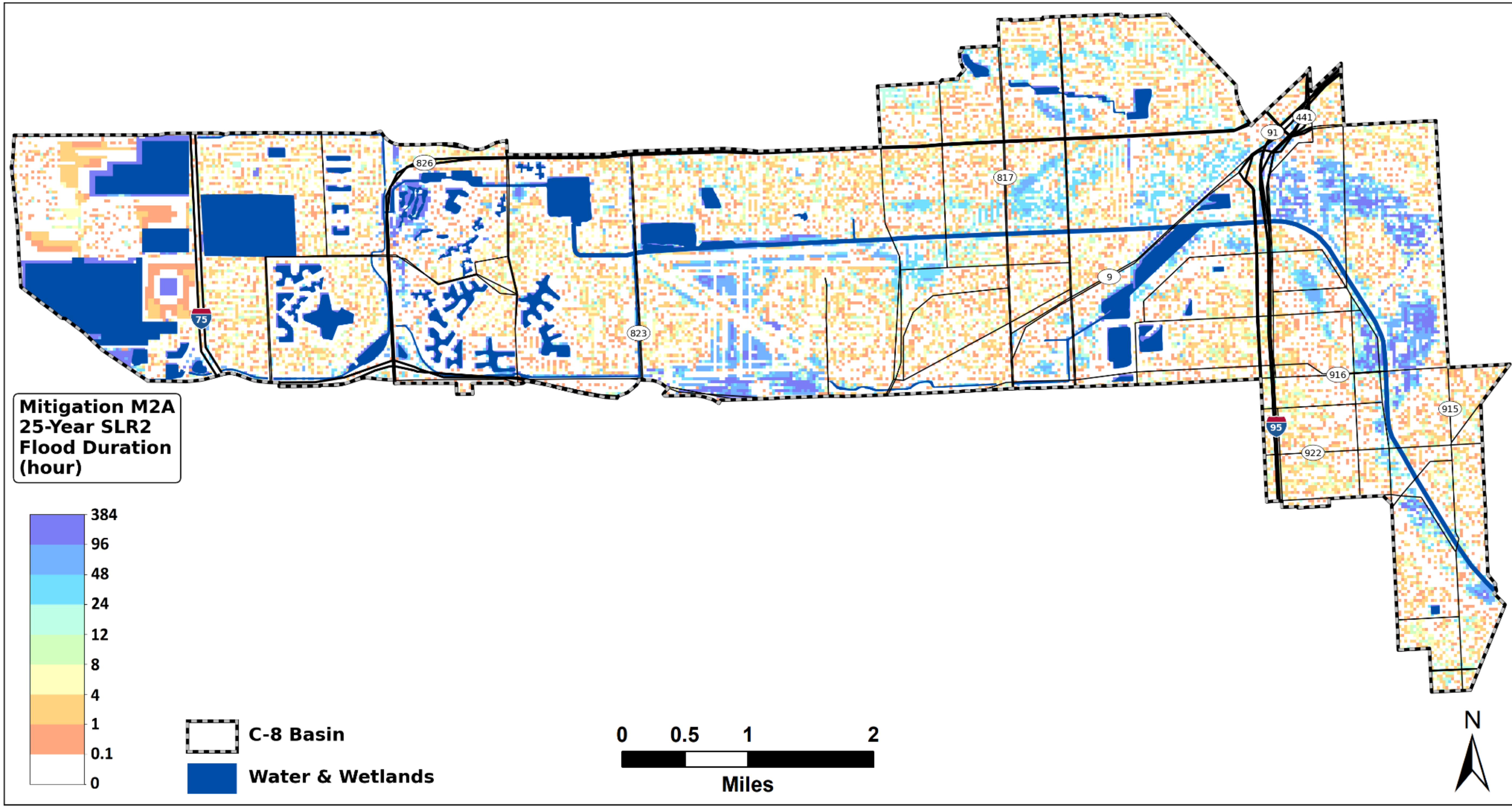


Figure D- 8: C-8 Watershed Flood Duration Map for the Mitigation M2A 25-Year Sea Level Rise 2 Design Storm Event

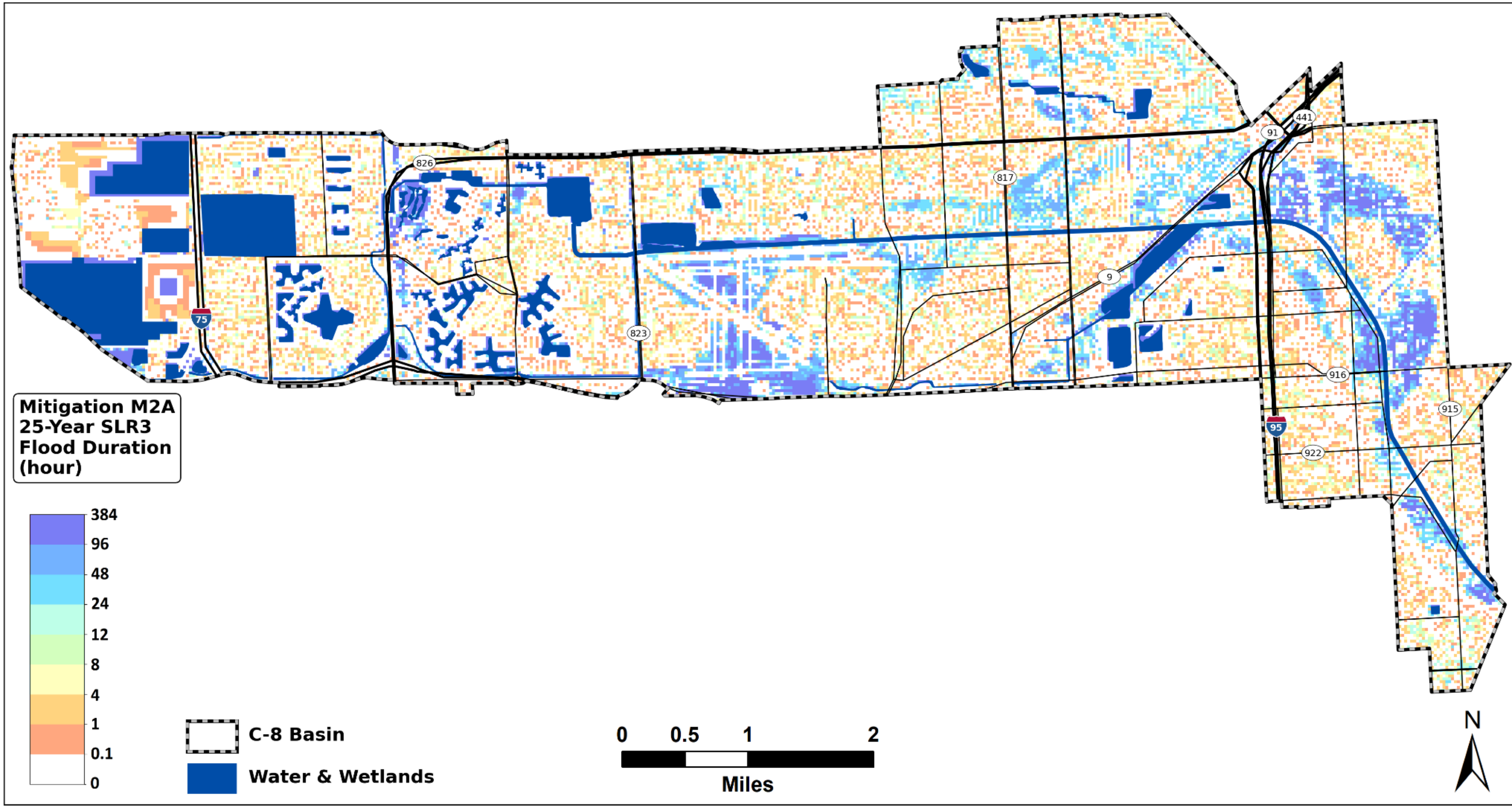


Figure D- 9: C-8 Watershed Flood Duration Map for the Mitigation M2A 25-Year Sea Level Rise 3 Design Storm Event

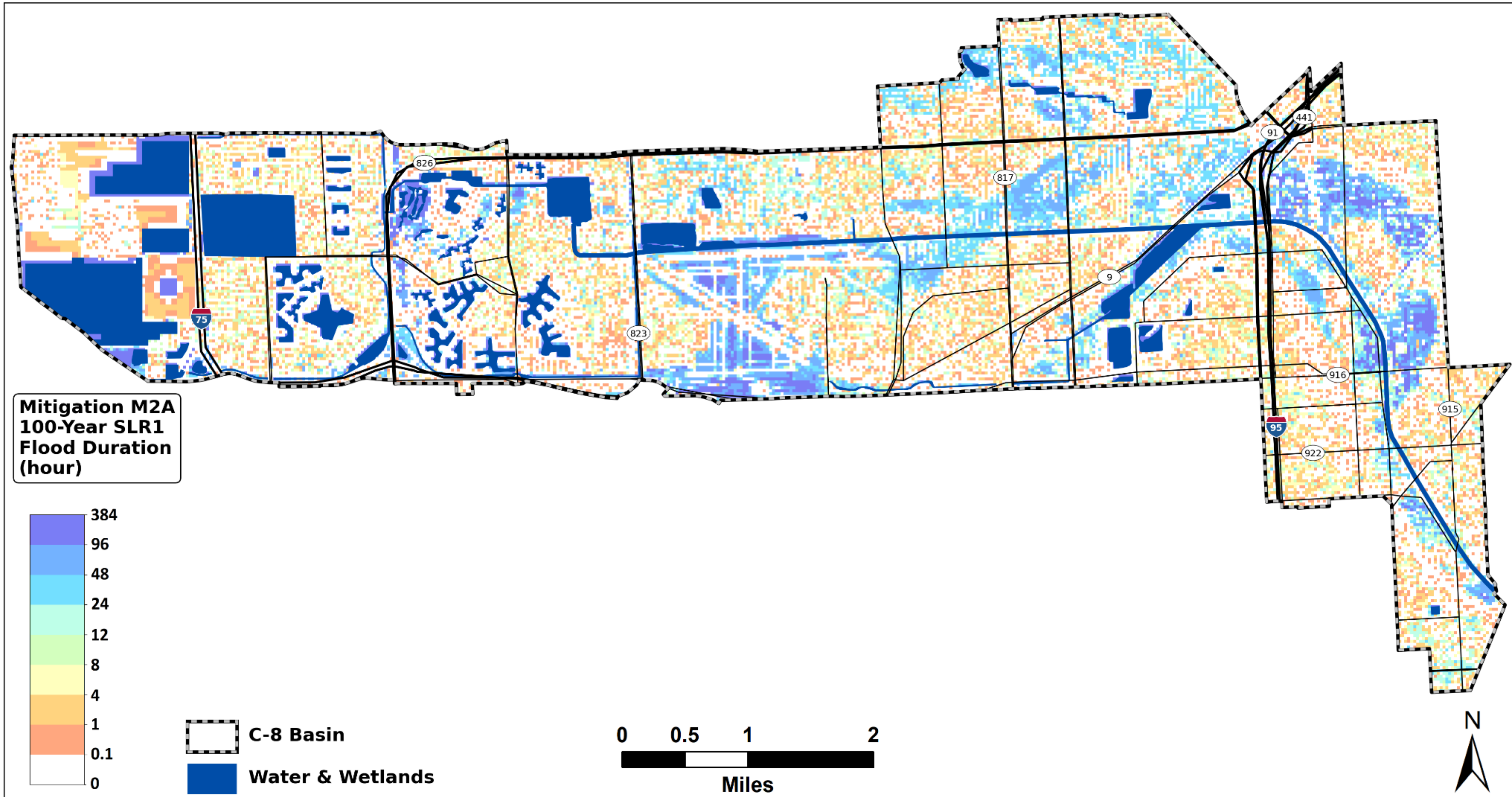


Figure D- 10: C-8 Watershed Flood Duration Map for the Mitigation M2A 100-Year Sea Level Rise 1 Design Storm Event

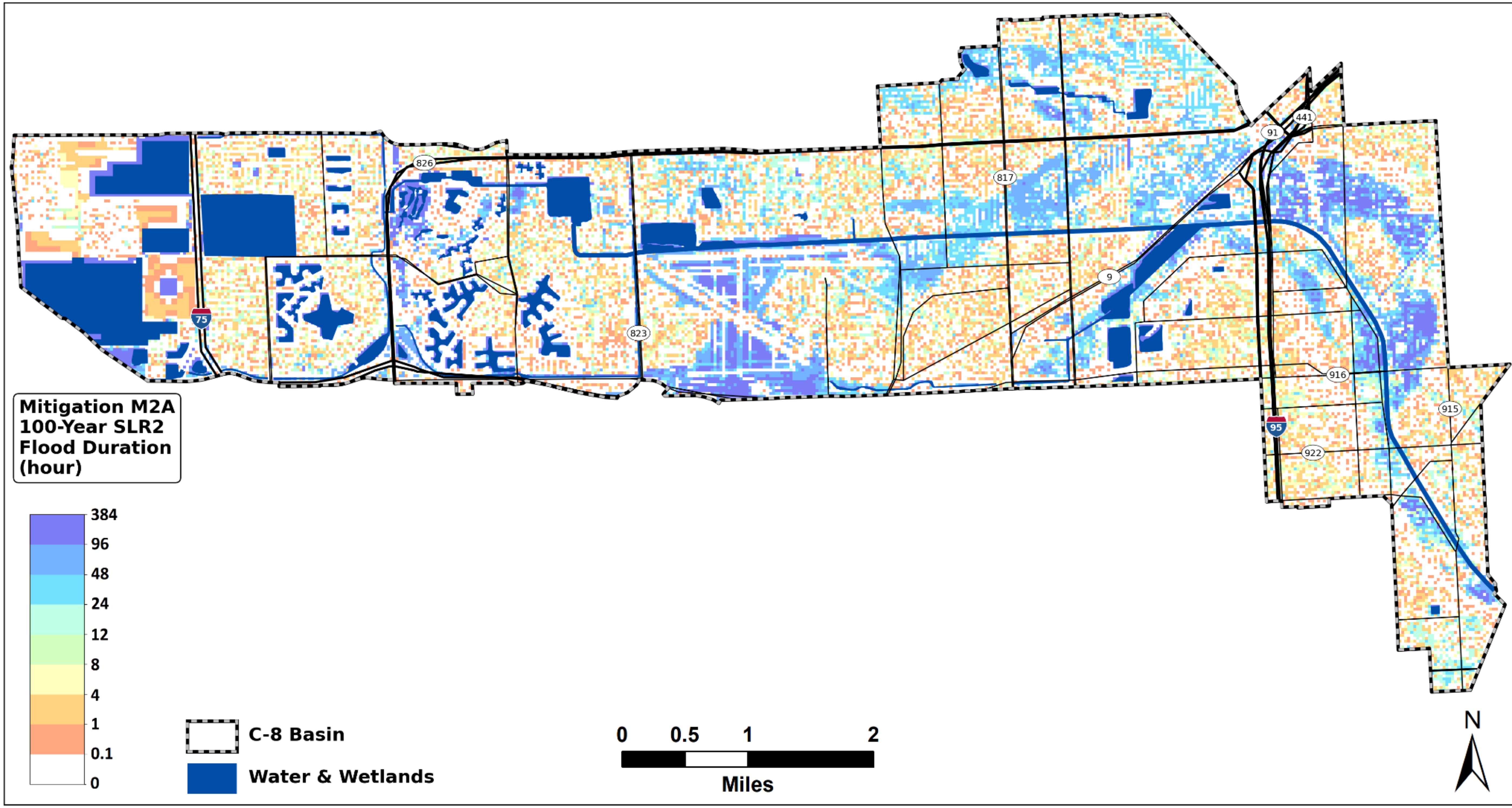


Figure D- 11: C-8 Watershed Flood Duration Map for the Mitigation M2A 100-Year Sea Level Rise 2 Design Storm Event

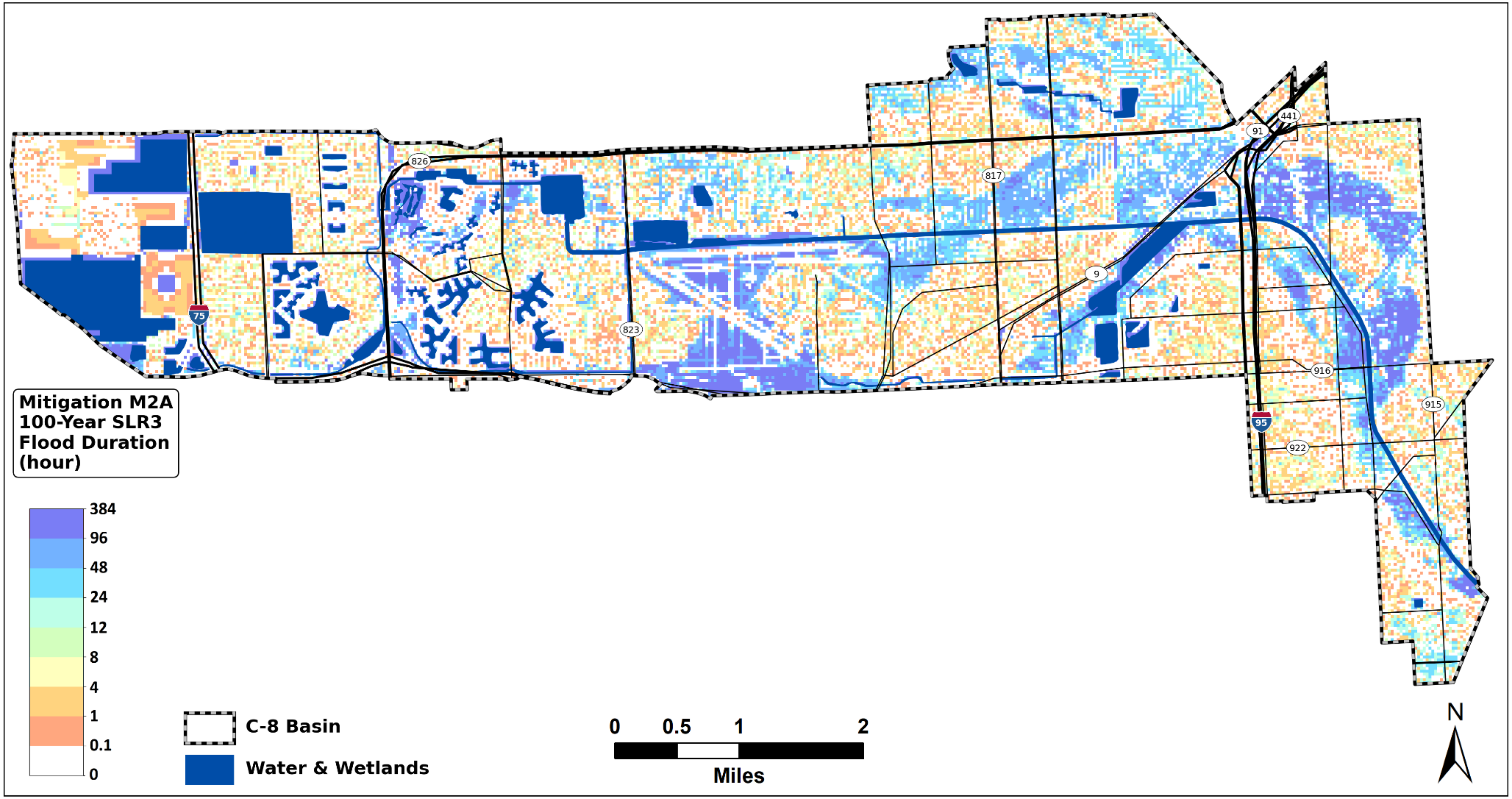


Figure D- 12: C-8 Watershed Flood Duration Map for the Mitigation M2A 100-Year Sea Level Rise 3 Design Storm Event

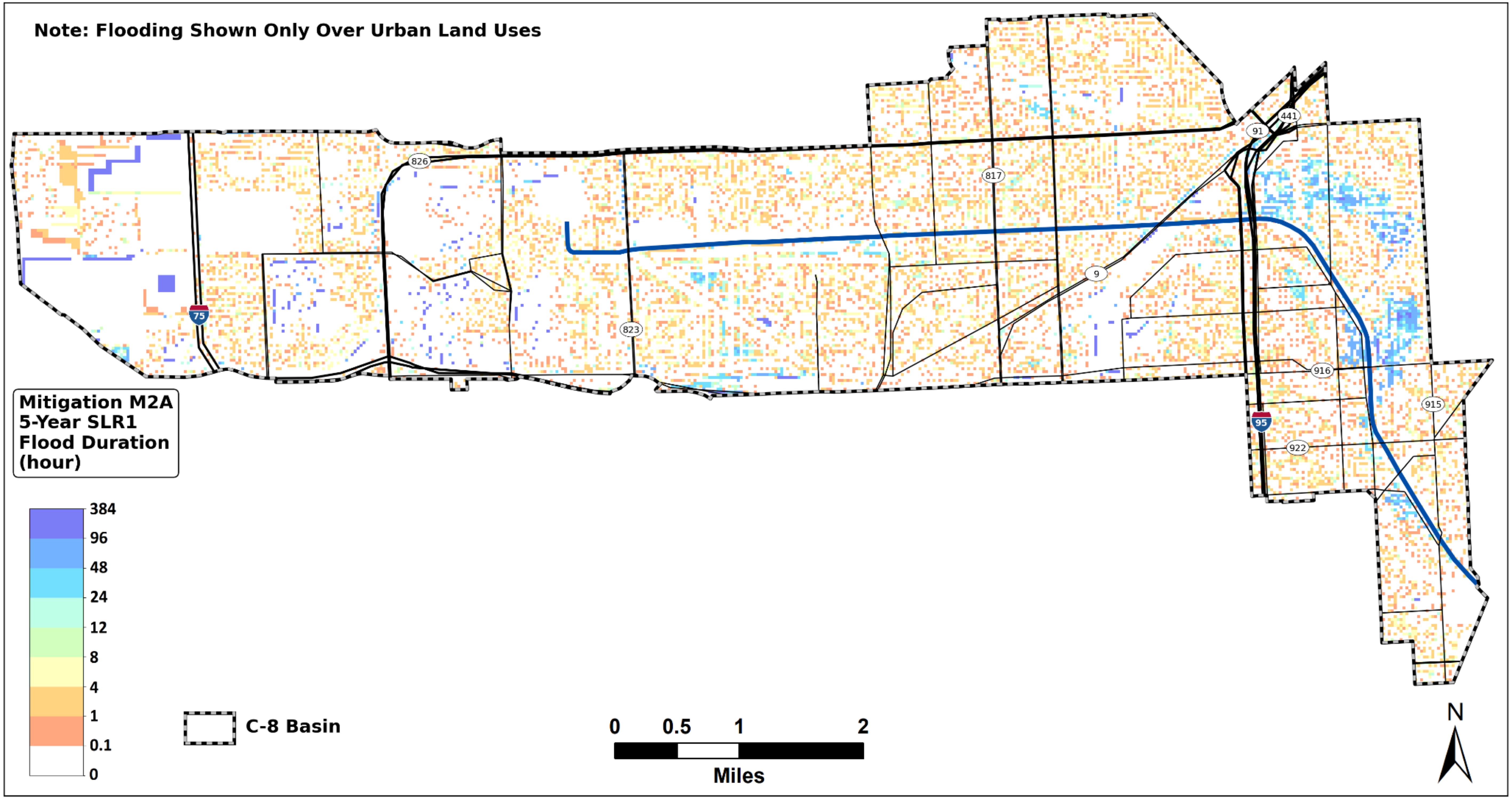


Figure D- 13: C-8 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2A 5-Year Sea Level Rise 1 Design Storm Event

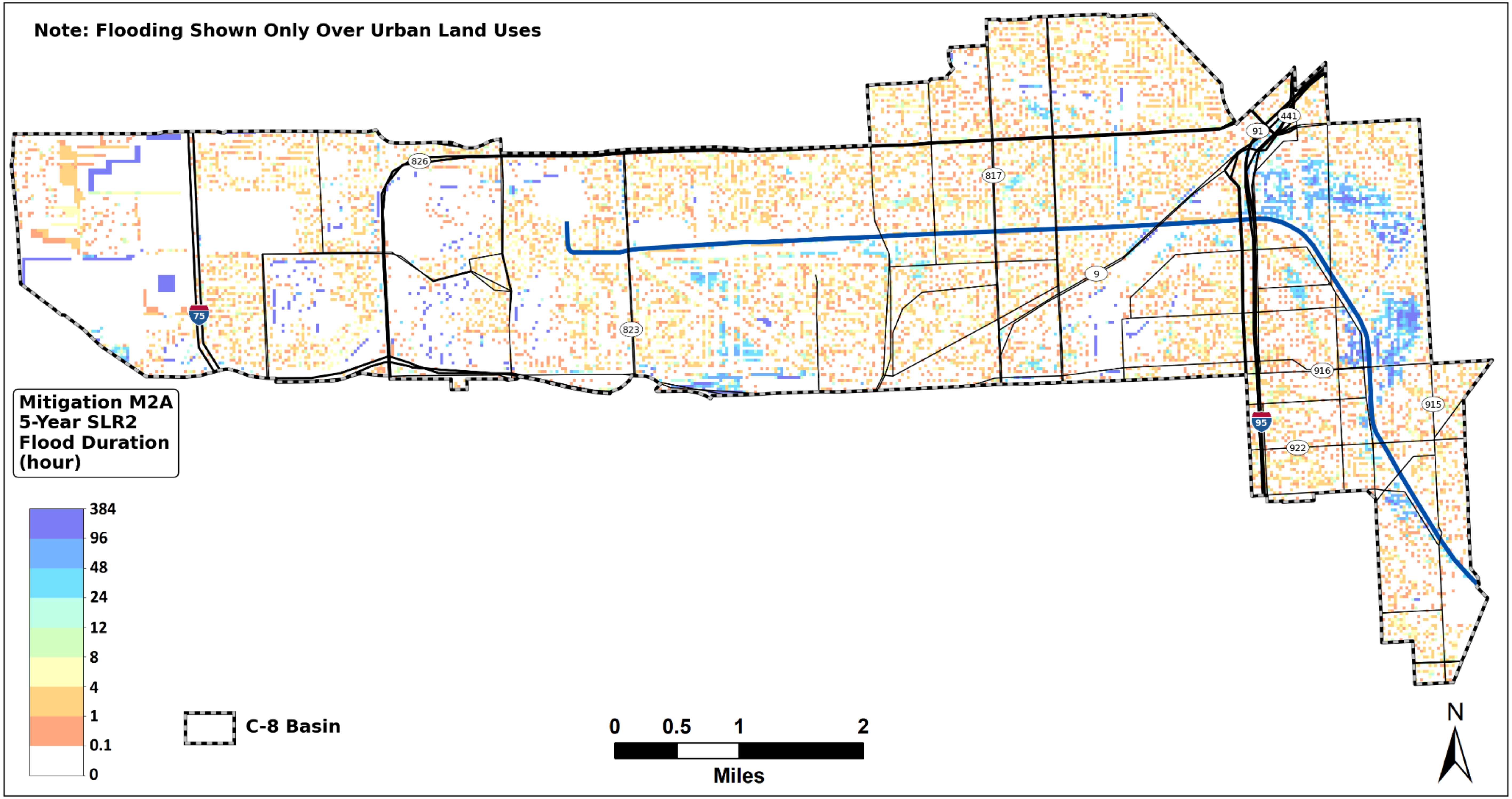


Figure D- 14: C-8 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2A 5-Year Sea Level Rise 2 Design Storm Event

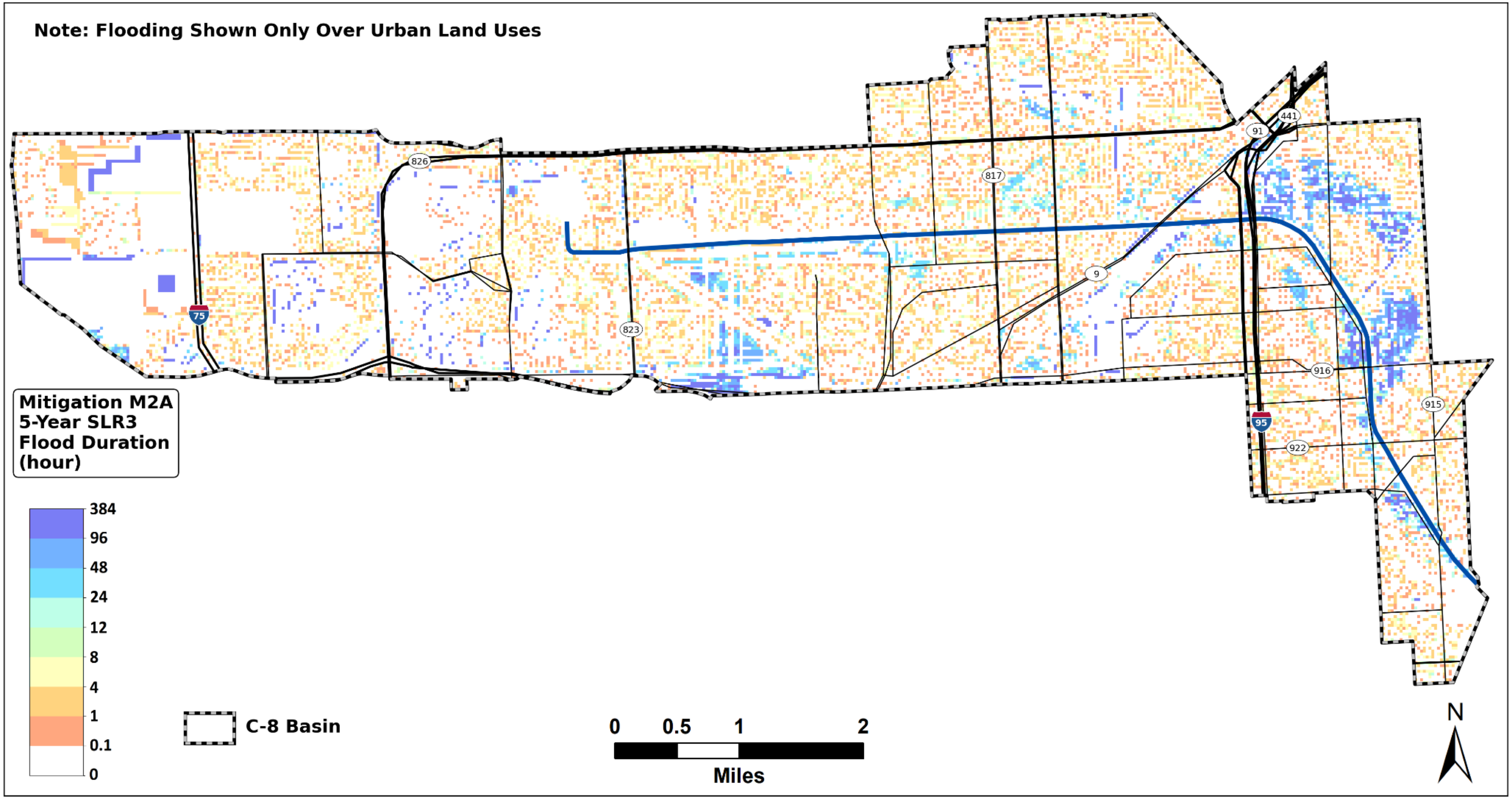


Figure D- 15: C-8 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2A 5-Year Sea Level Rise 3 Design Storm Event

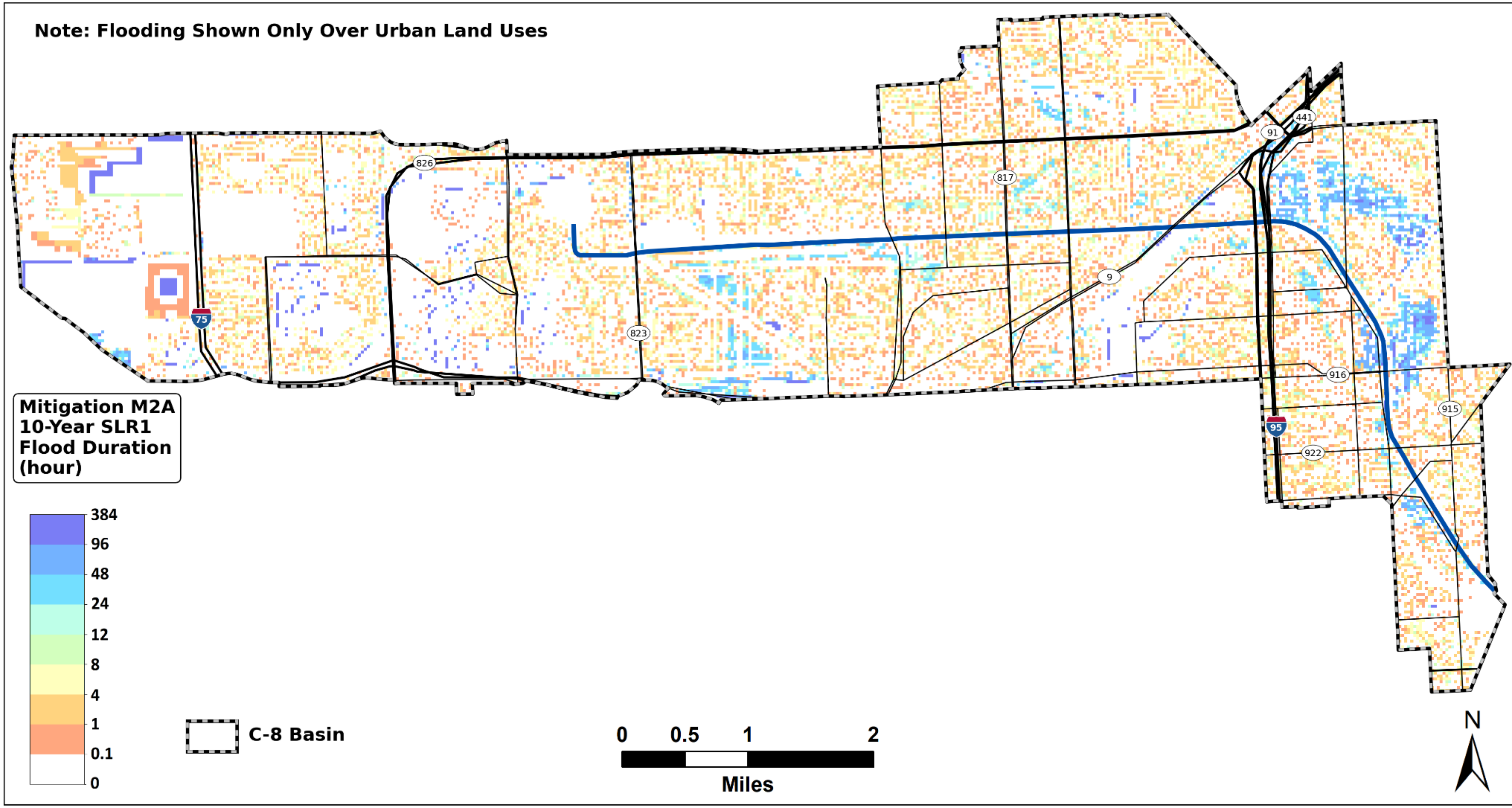


Figure D- 16: C-8 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2A 10-Year Sea Level Rise 1 Design Storm Event

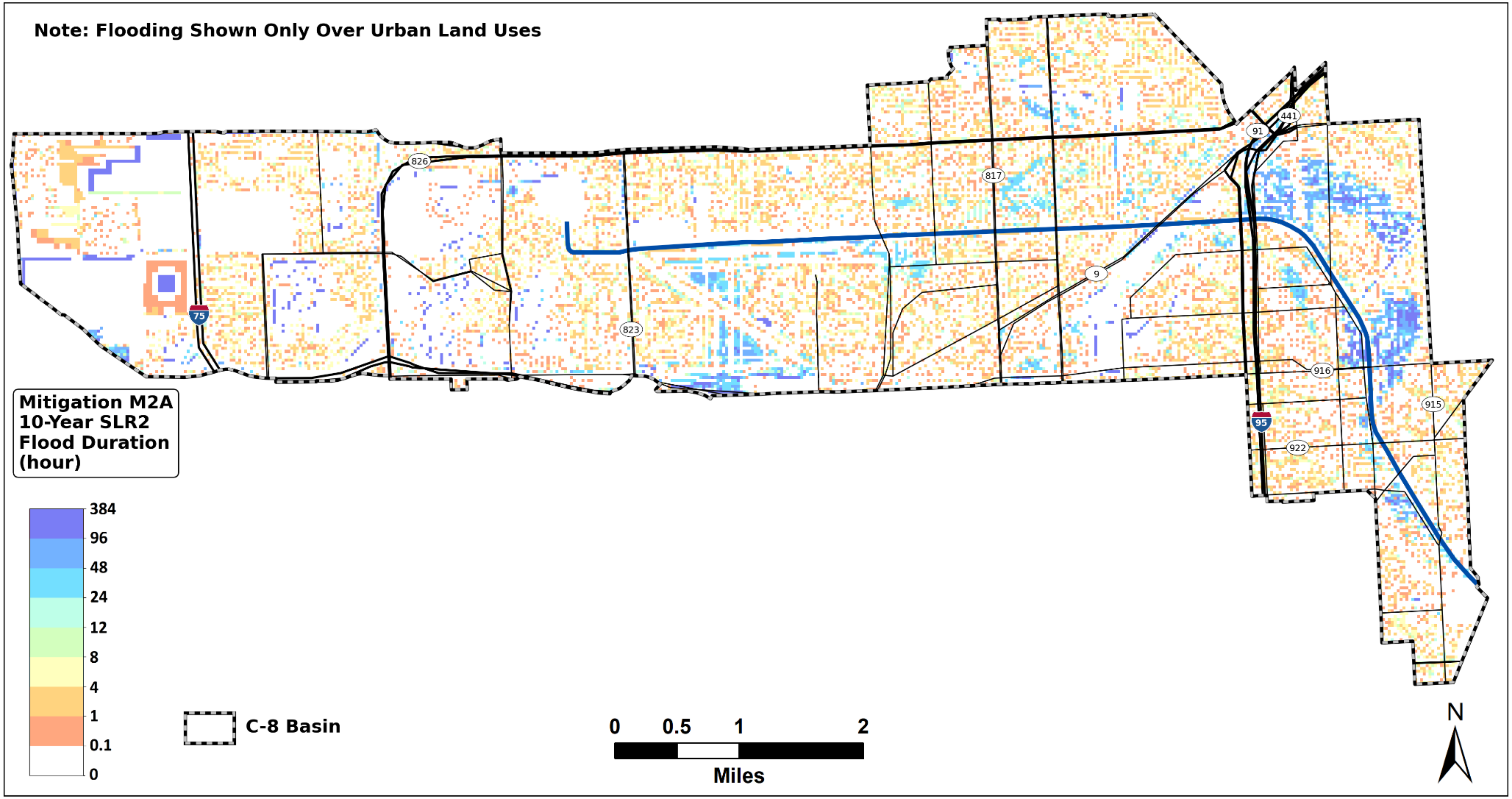


Figure D- 17: C-8 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2A 10-Year Sea Level Rise 2 Design Storm Event

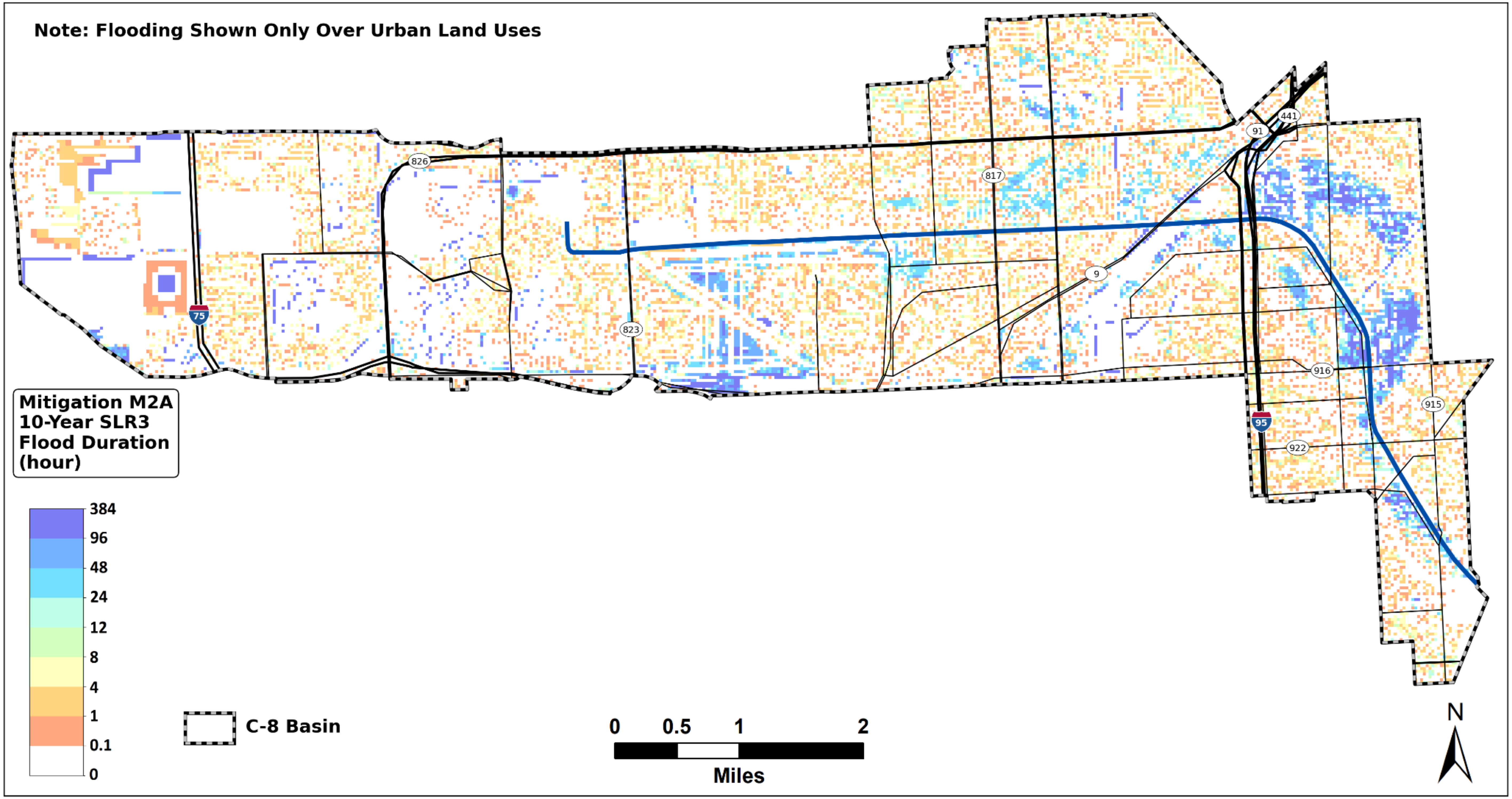


Figure D- 18: C-8 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2A 10-Year Sea Level Rise 3 Design Storm Event

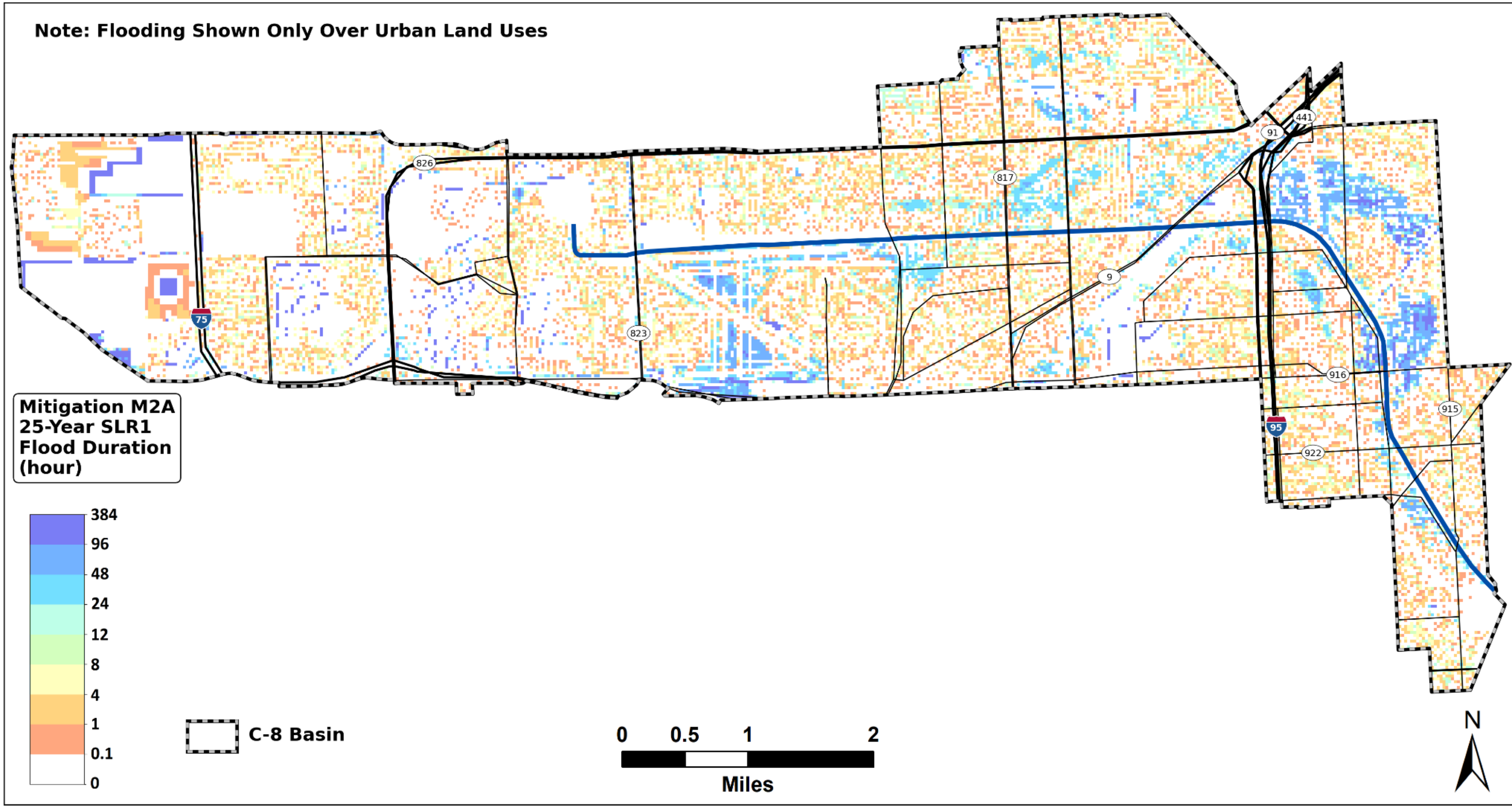


Figure D- 19: C-8 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2A 25-Year Sea Level Rise 1 Design Storm Event

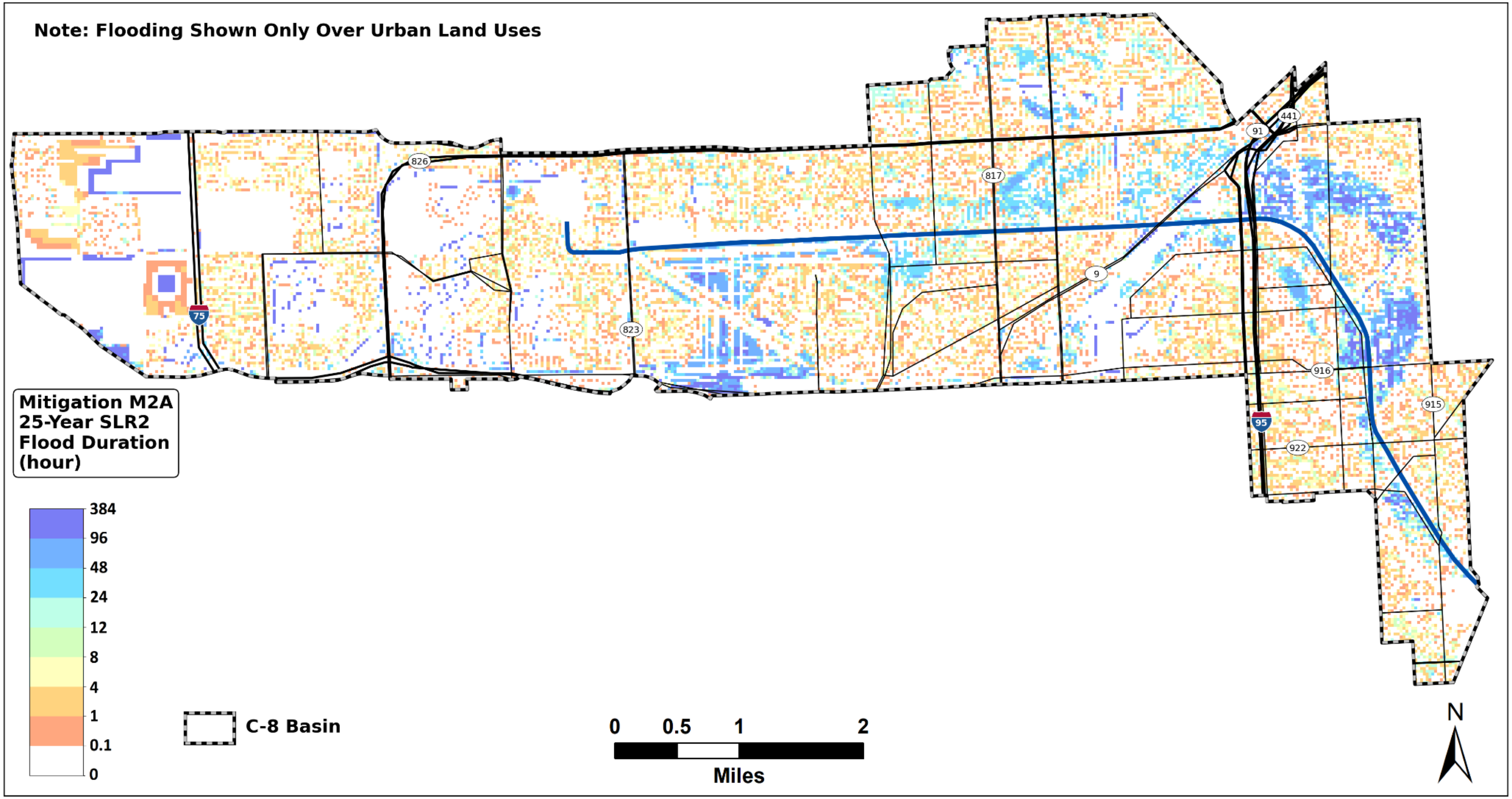


Figure D- 20: C-8 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2A 25-Year Sea Level Rise 2 Design Storm Event

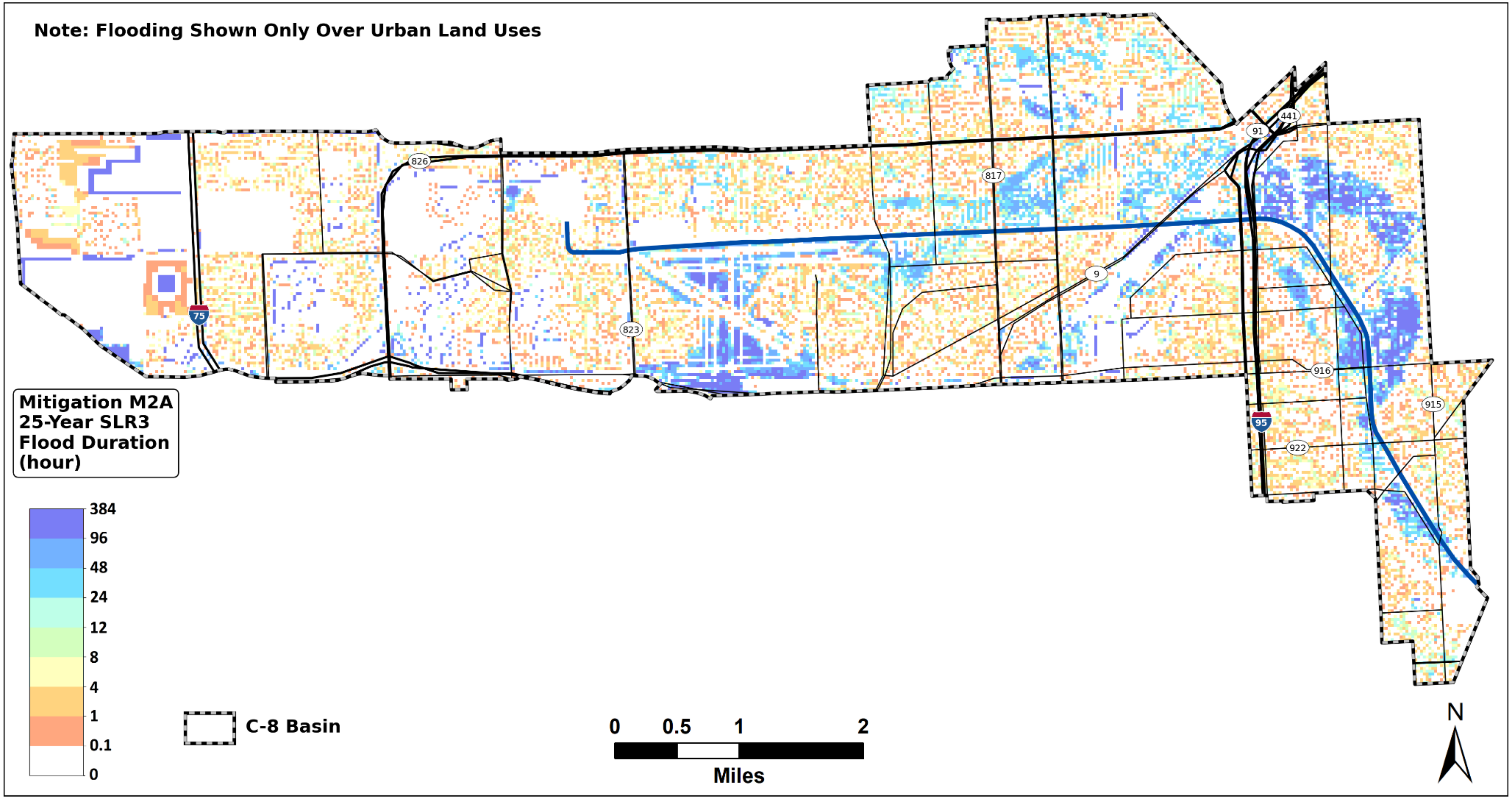


Figure D- 21: C-8 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2A 25-Year Sea Level Rise 3 Design Storm Event

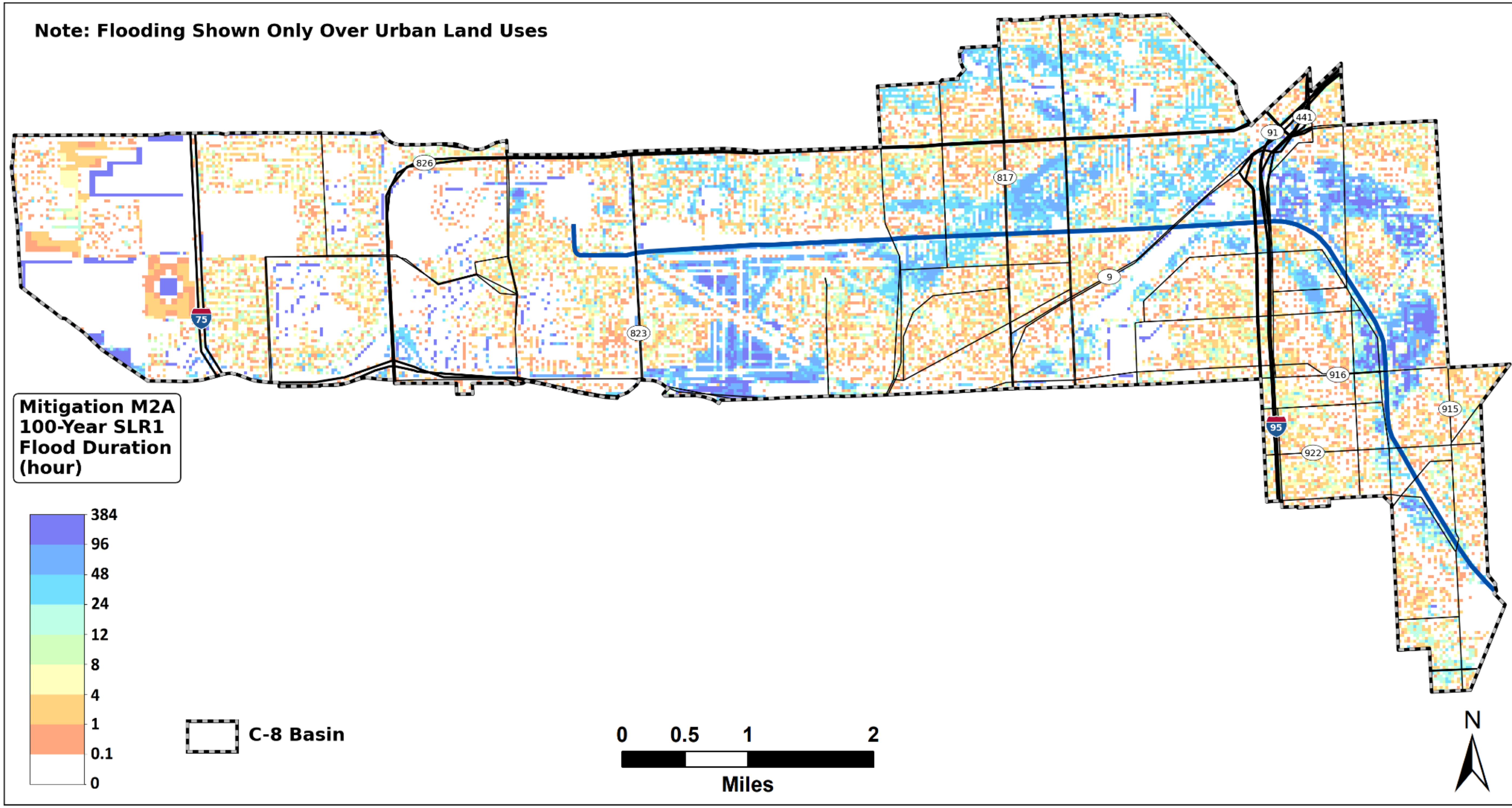


Figure D- 22: C-8 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2A 100-Year Sea Level Rise 1 Design Storm Event

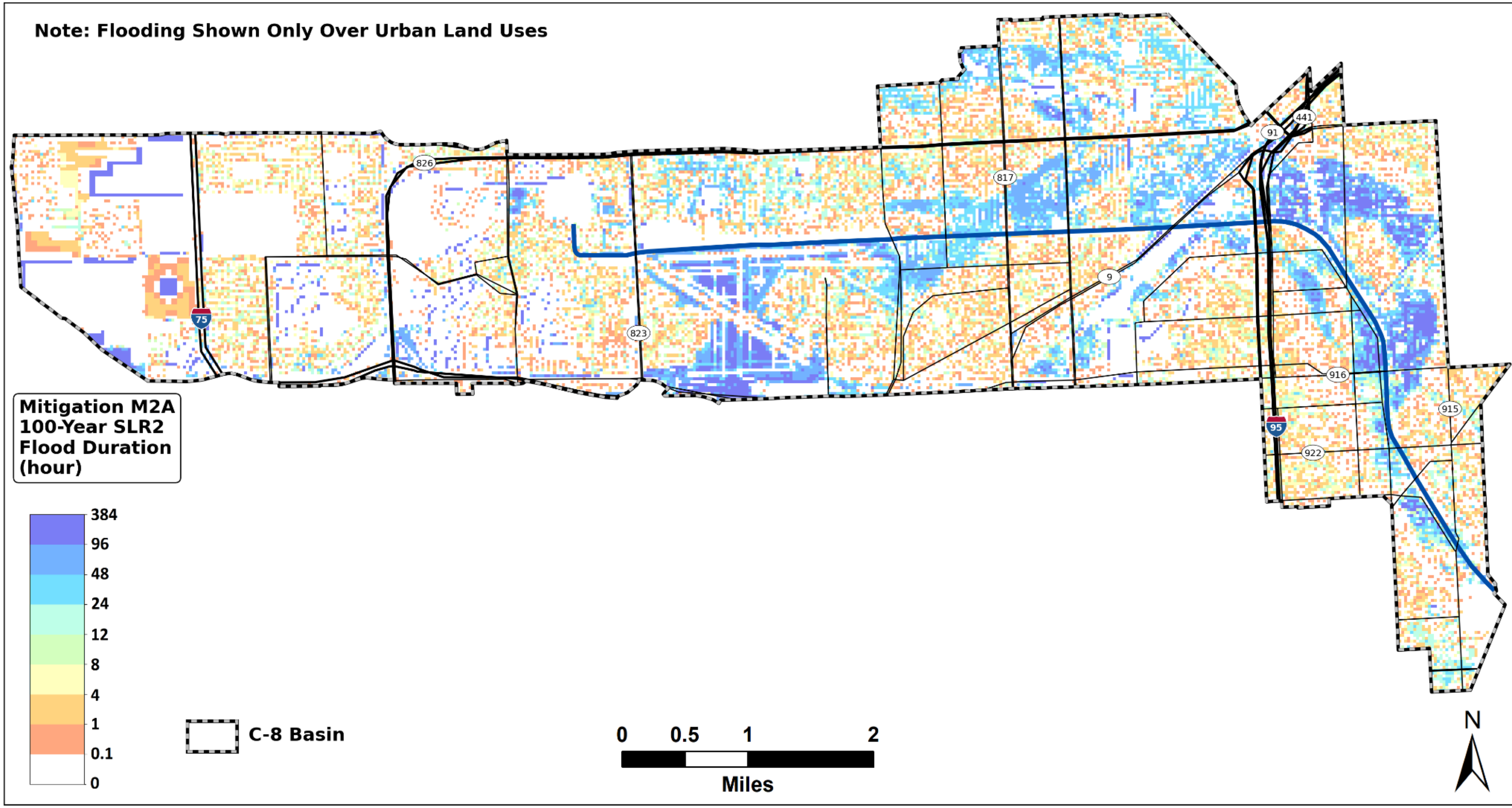


Figure D- 23: C-8 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2A 100-Year Sea Level Rise 2 Design Storm Event

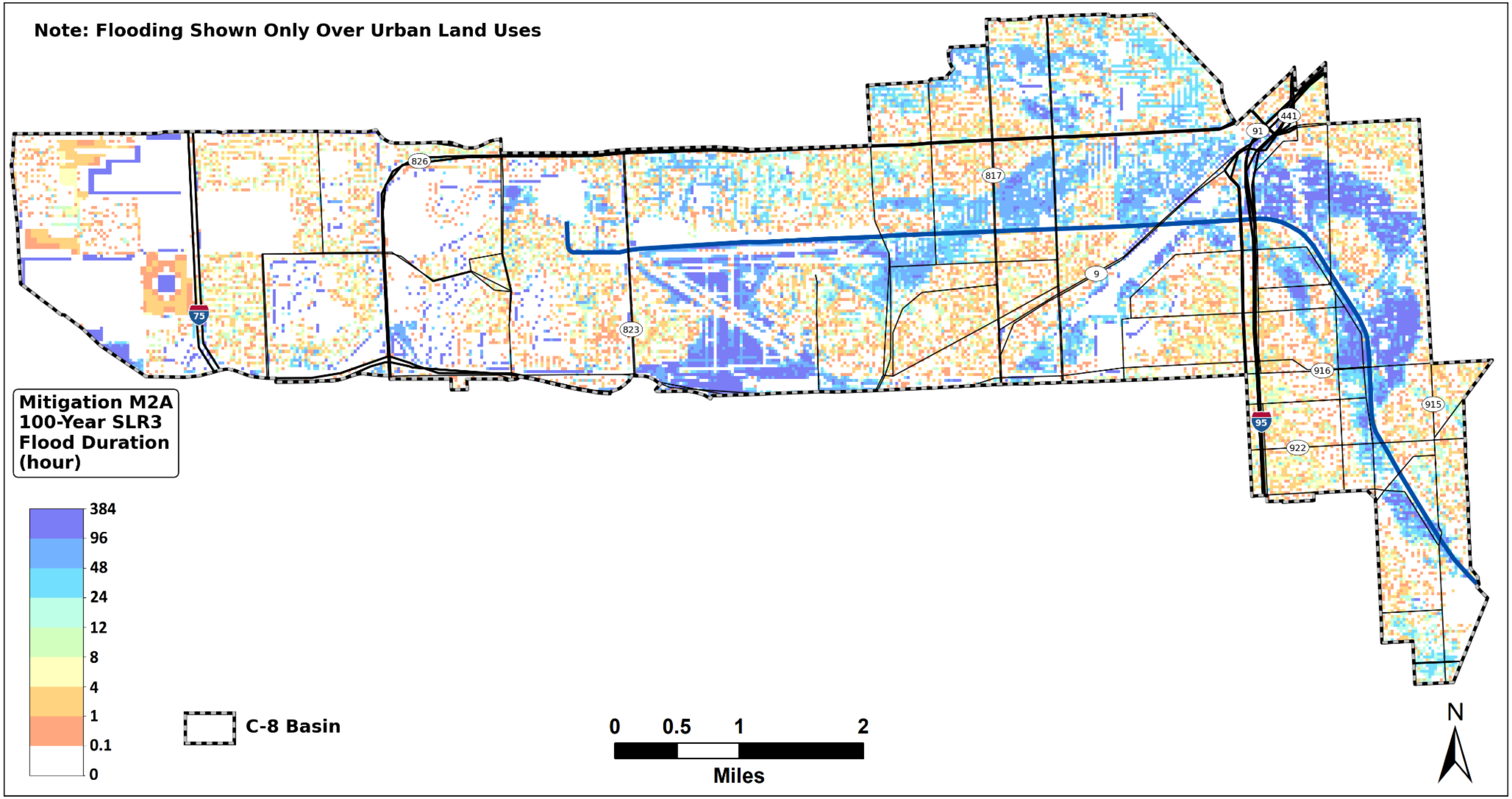


Figure D- 24: C-8 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2A 100-Year Sea Level Rise 3 Design Storm Event

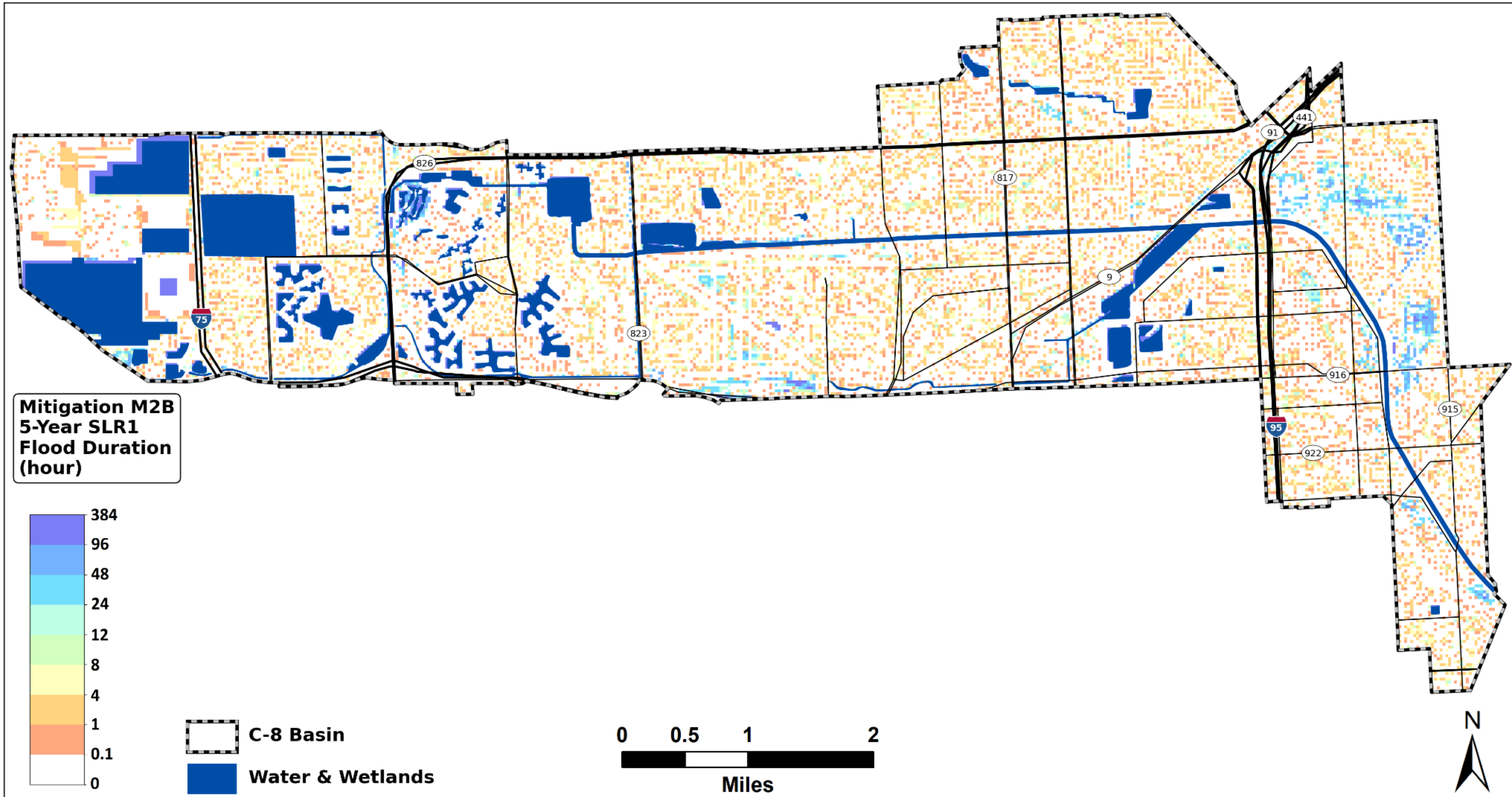


Figure D- 25: C-8 Watershed Flood Duration Map for the Mitigation M2B 5-Year Sea Level Rise 1 Design Storm Event

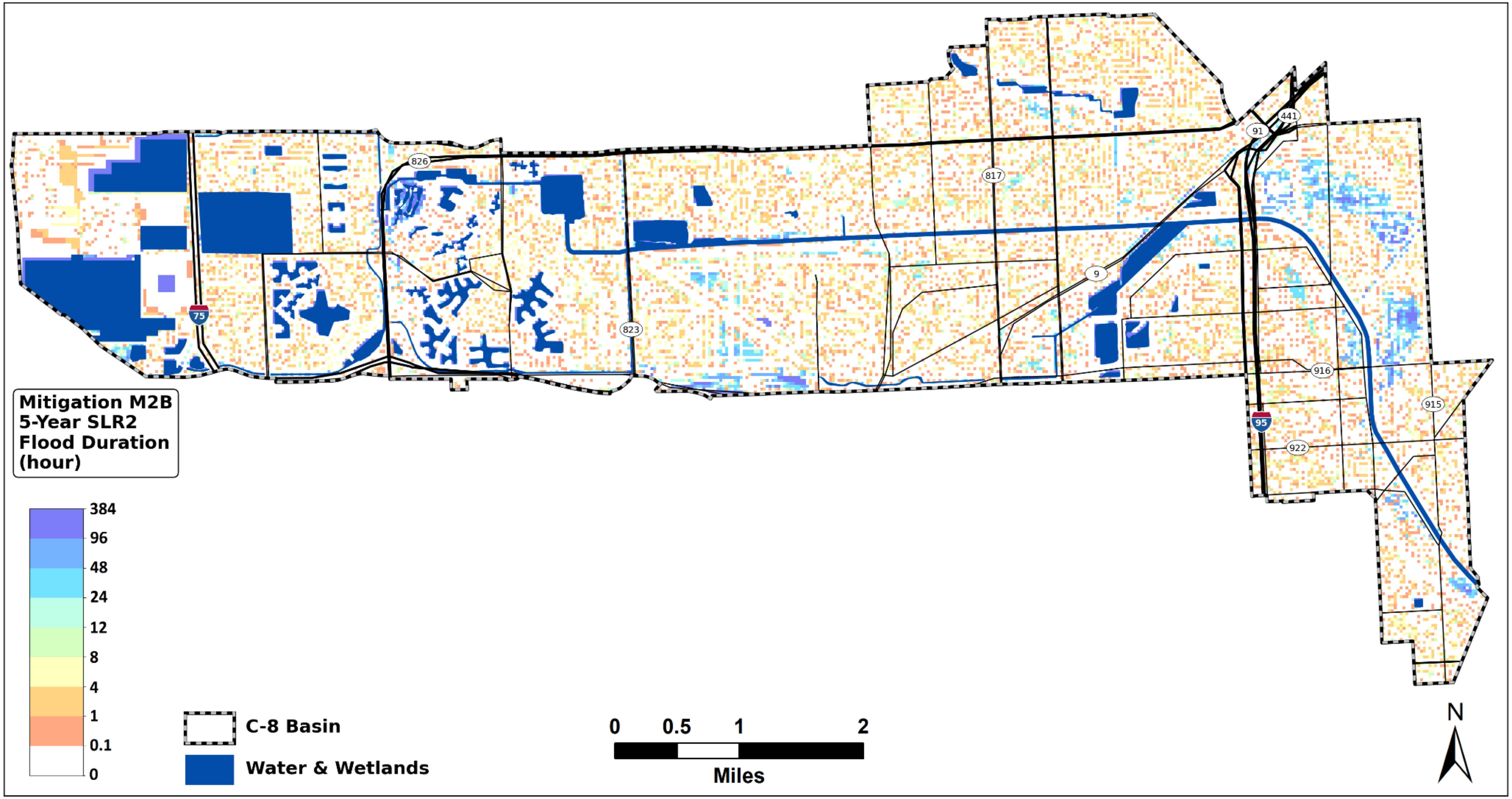


Figure D- 26: C-8 Watershed Flood Duration Map for the Mitigation M2B 5-Year Sea Level Rise 2 Design Storm Event

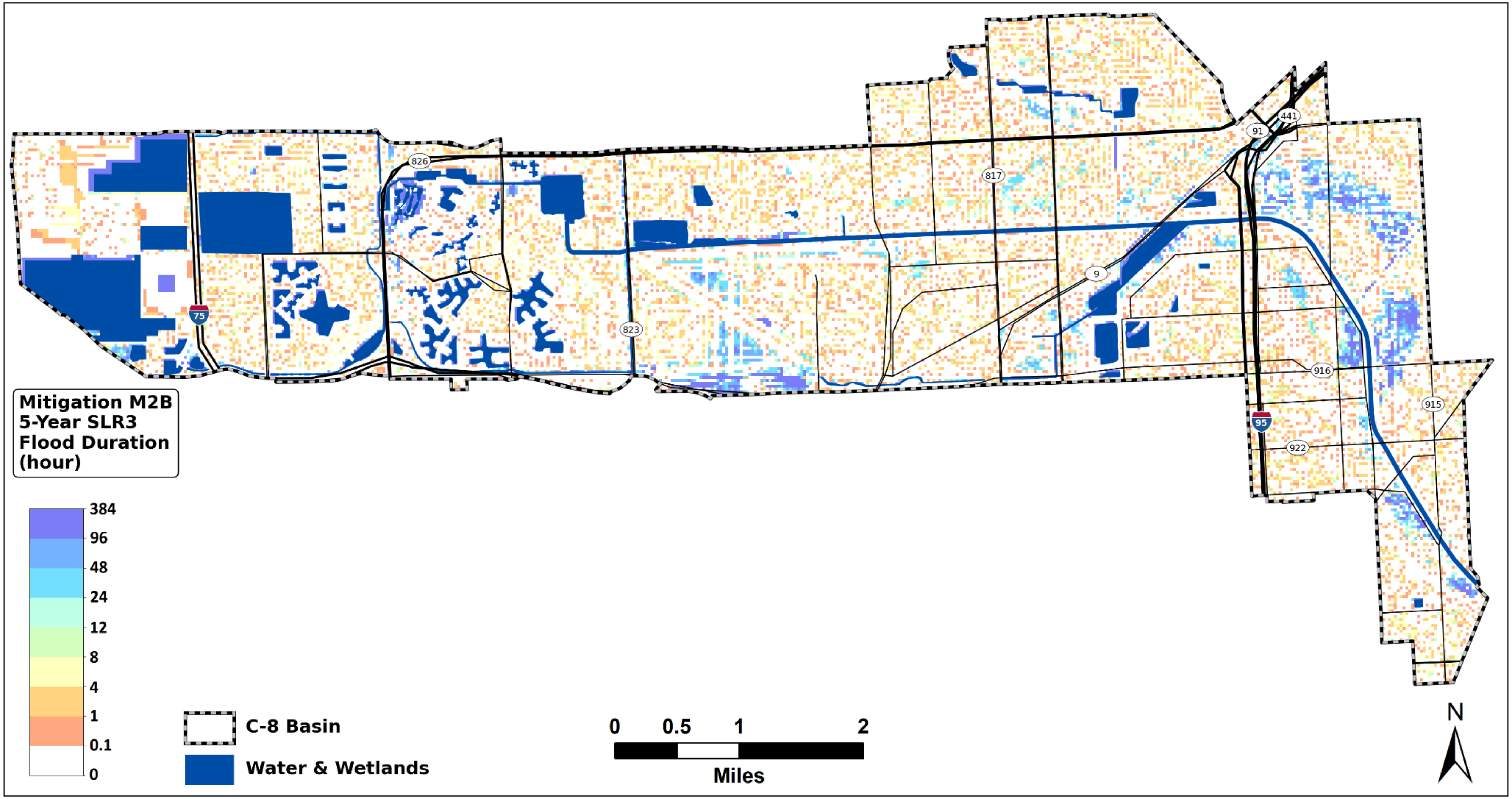


Figure D- 27: C-8 Watershed Flood Duration Map for the Mitigation M2B 5-Year Sea Level Rise 3 Design Storm Event

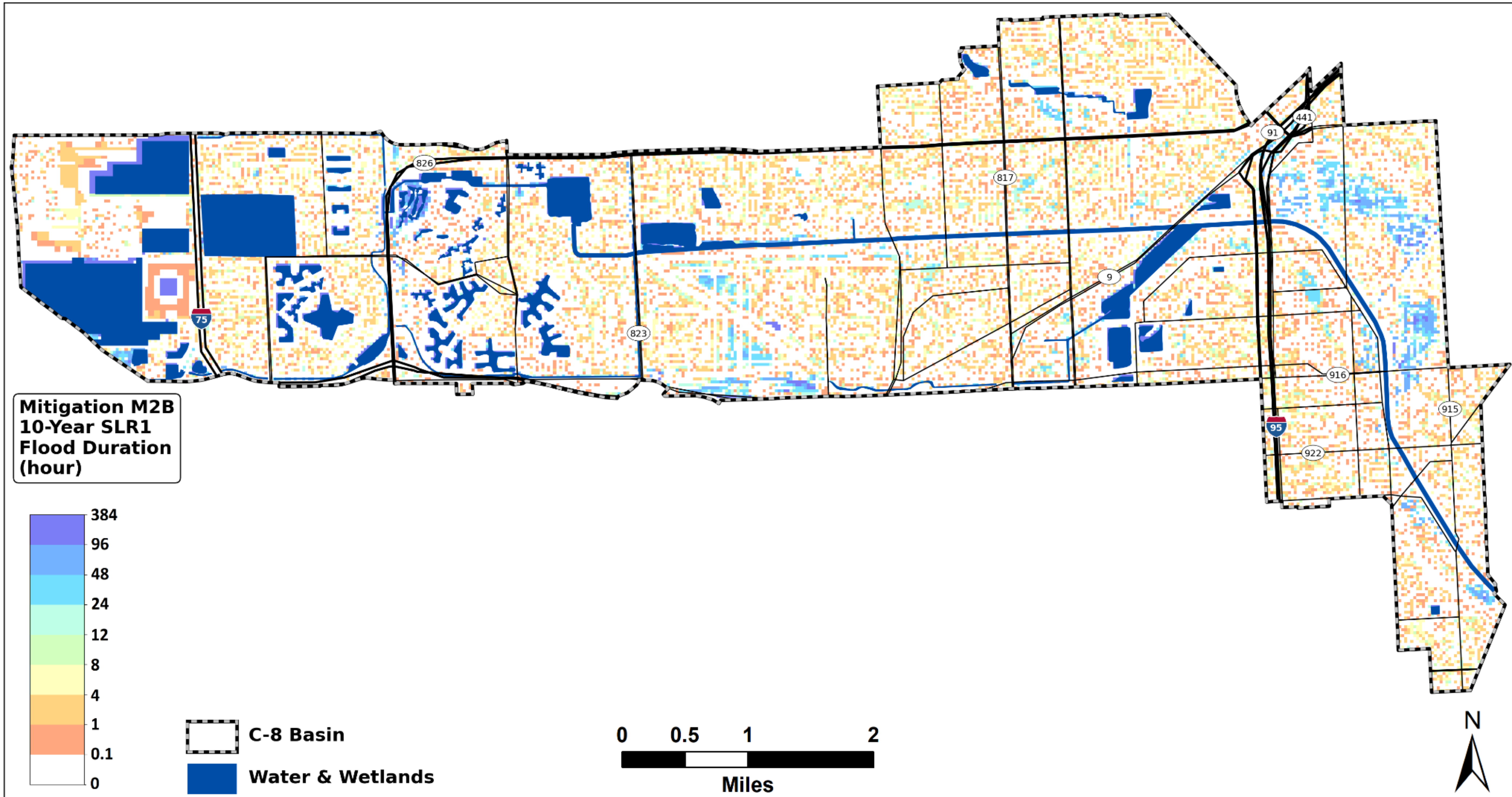


Figure D- 28: C-8 Watershed Flood Duration Map for the Mitigation M2B 10-Year Sea Level Rise 1 Design Storm Event

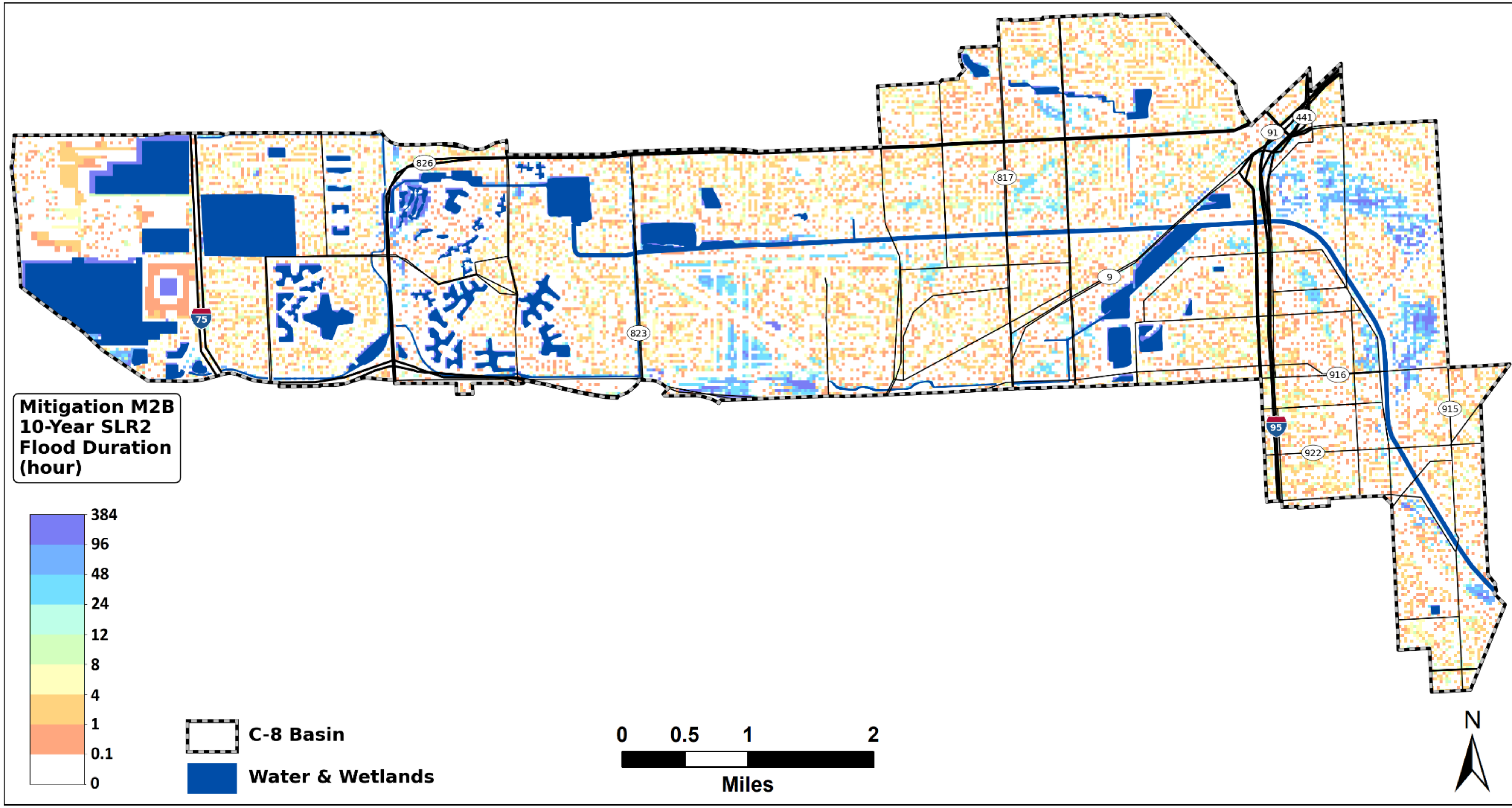


Figure D- 29: C-8 Watershed Flood Duration Map for the Mitigation M2B 10-Year Sea Level Rise 2 Design Storm Event

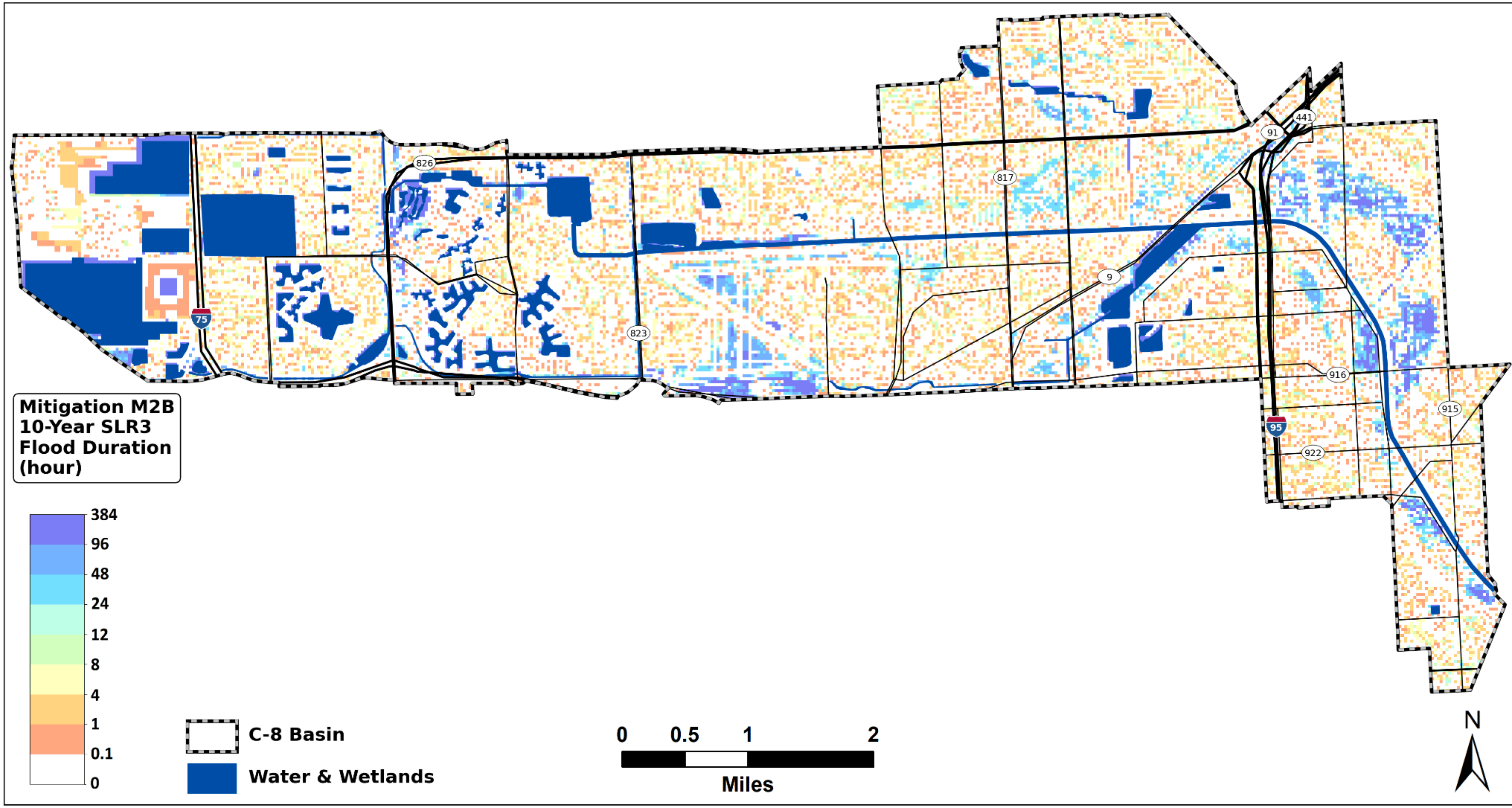


Figure D- 30: C-8 Watershed Flood Duration Map for the Mitigation M2B 10-Year Sea Level Rise 3 Design Storm Event

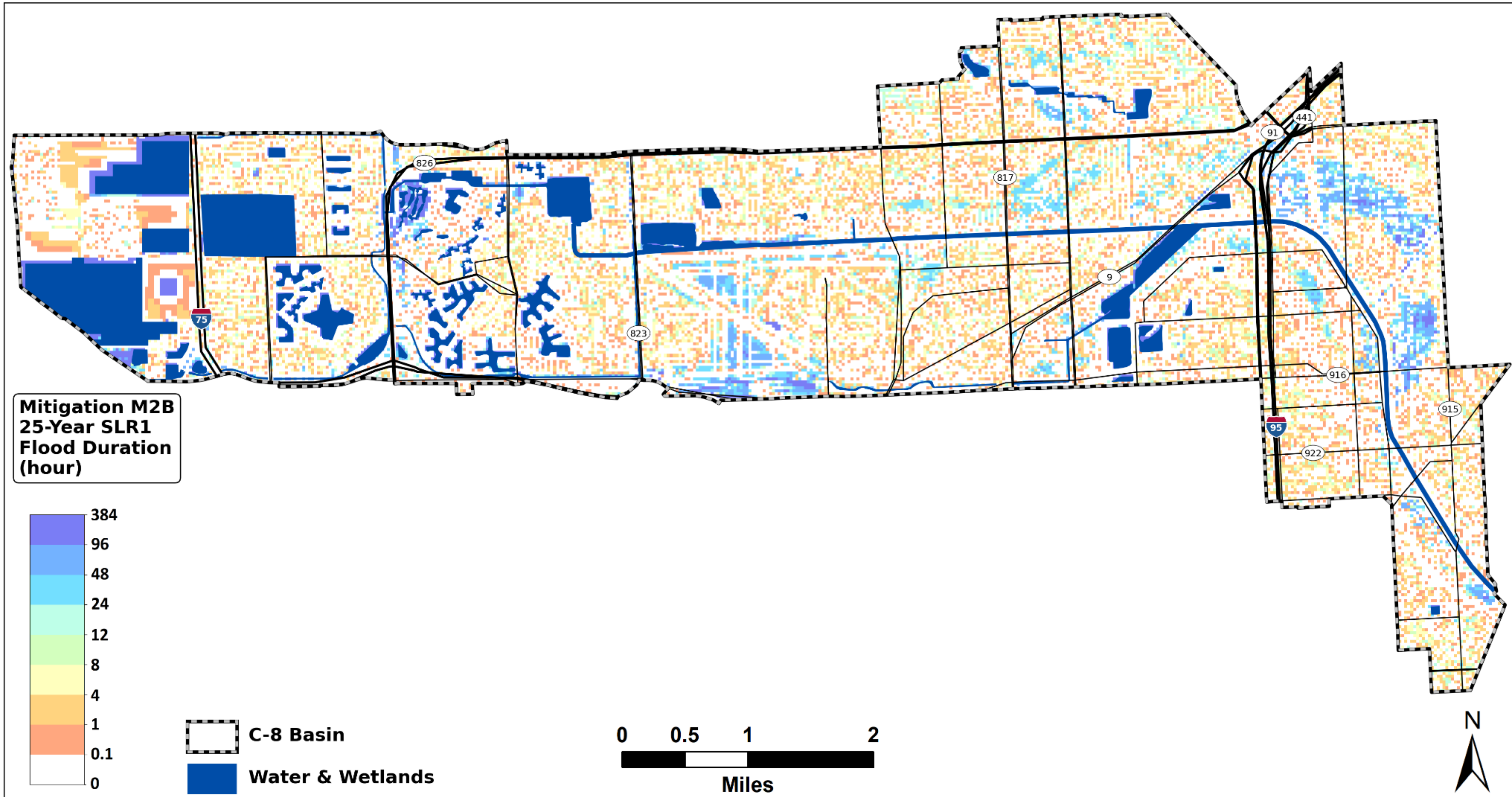


Figure D- 31: C-8 Watershed Flood Duration Map for the Mitigation M2B 25-Year Sea Level Rise 1 Design Storm Event

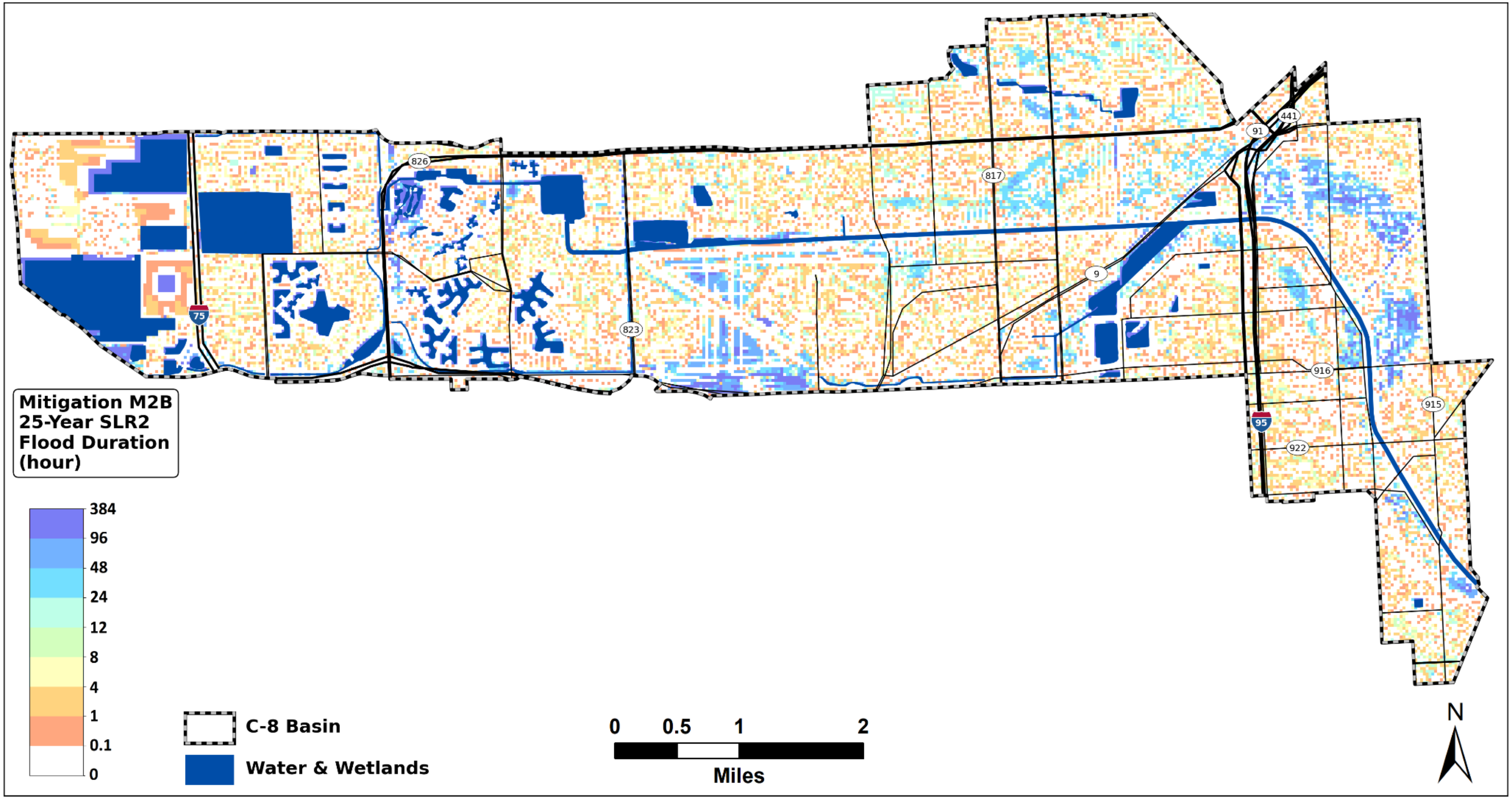


Figure D- 32: C-8 Watershed Flood Duration Map for the Mitigation M2B 25-Year Sea Level Rise 2 Design Storm Event

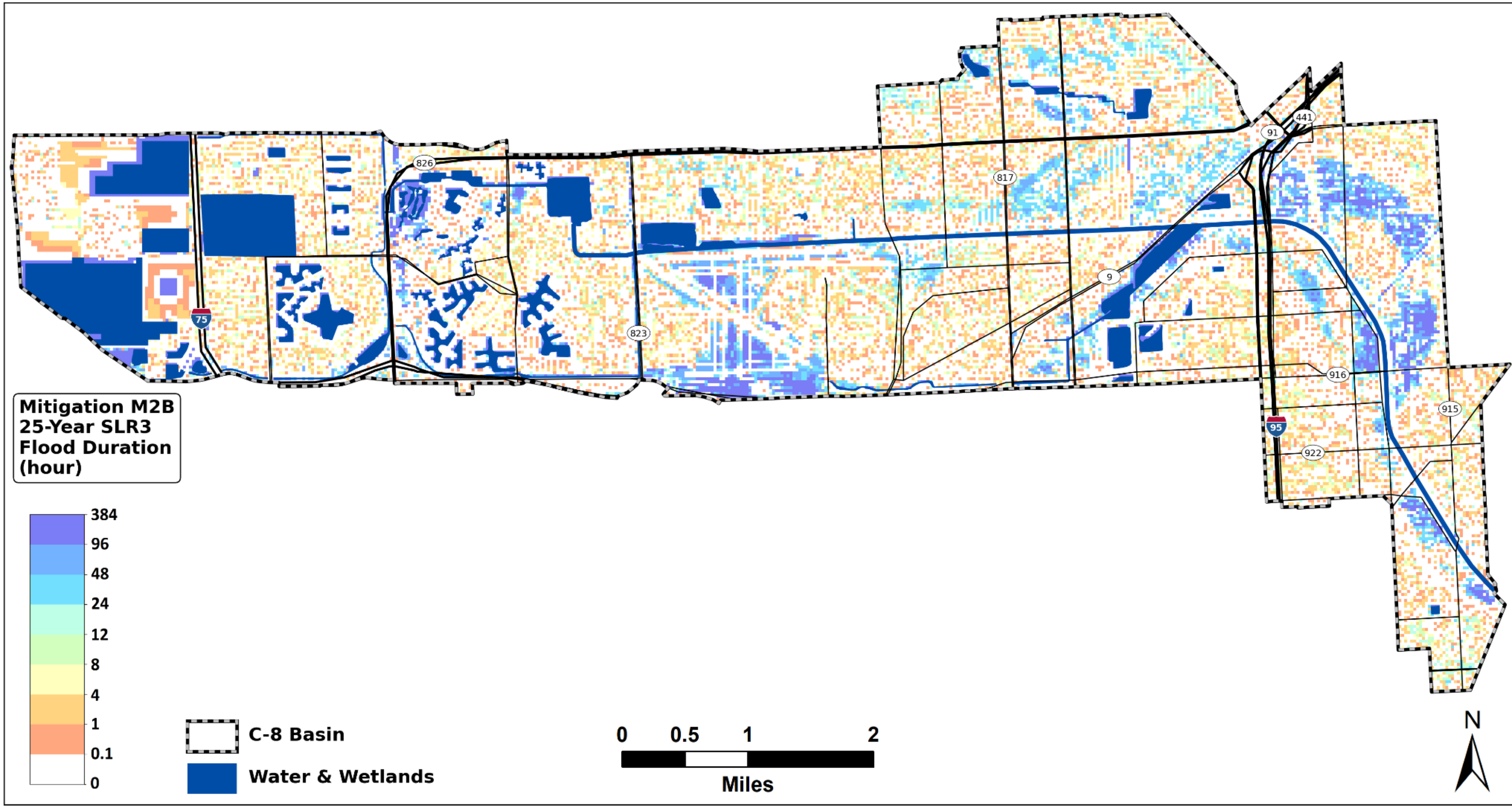


Figure D- 33: C-8 Watershed Flood Duration Map for the Mitigation M2B 25-Year Sea Level Rise 3 Design Storm Event

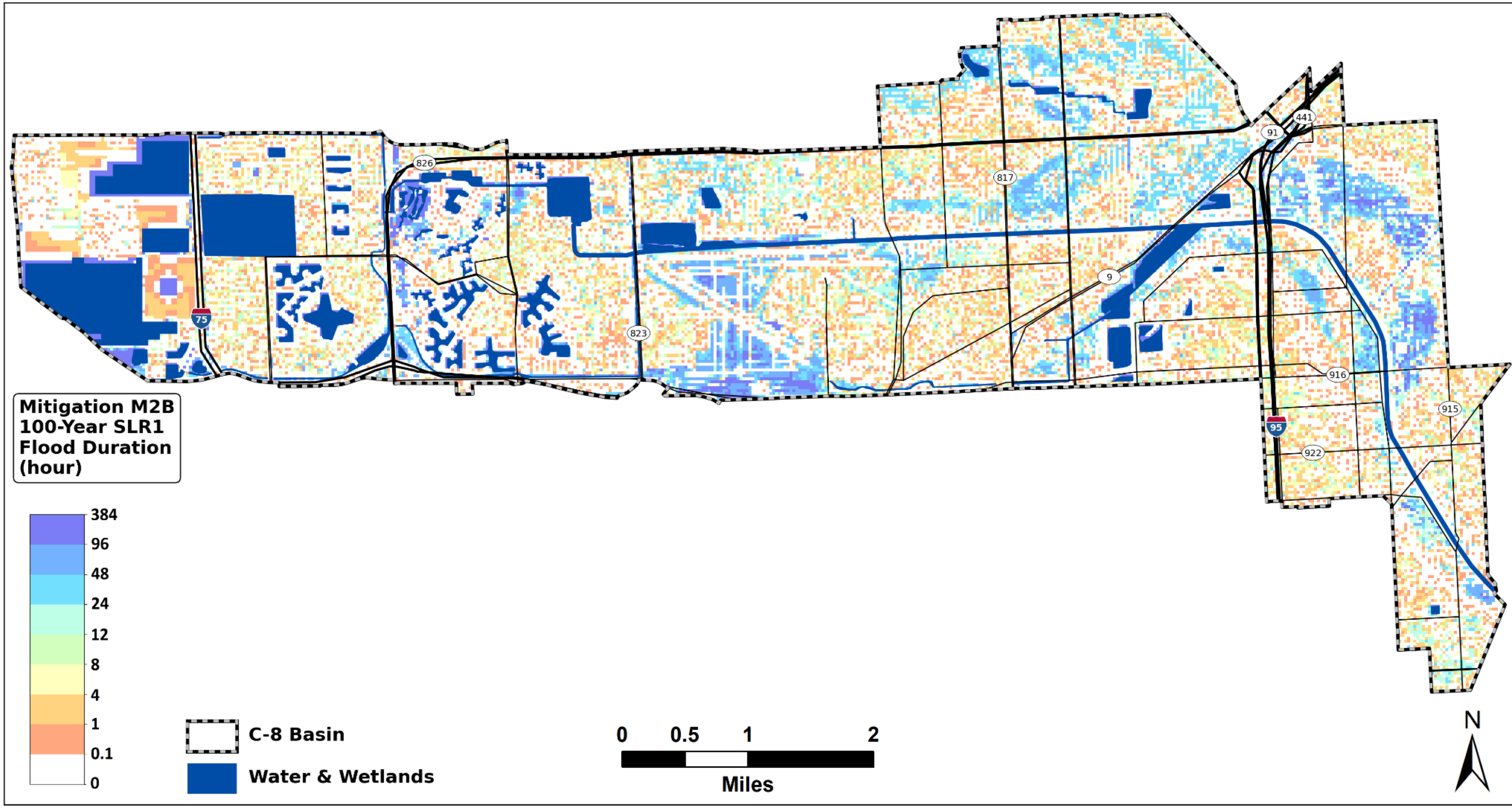


Figure D- 34: C-8 Watershed Flood Duration Map for the Mitigation M2B 100-Year Sea Level Rise 1 Design Storm Event

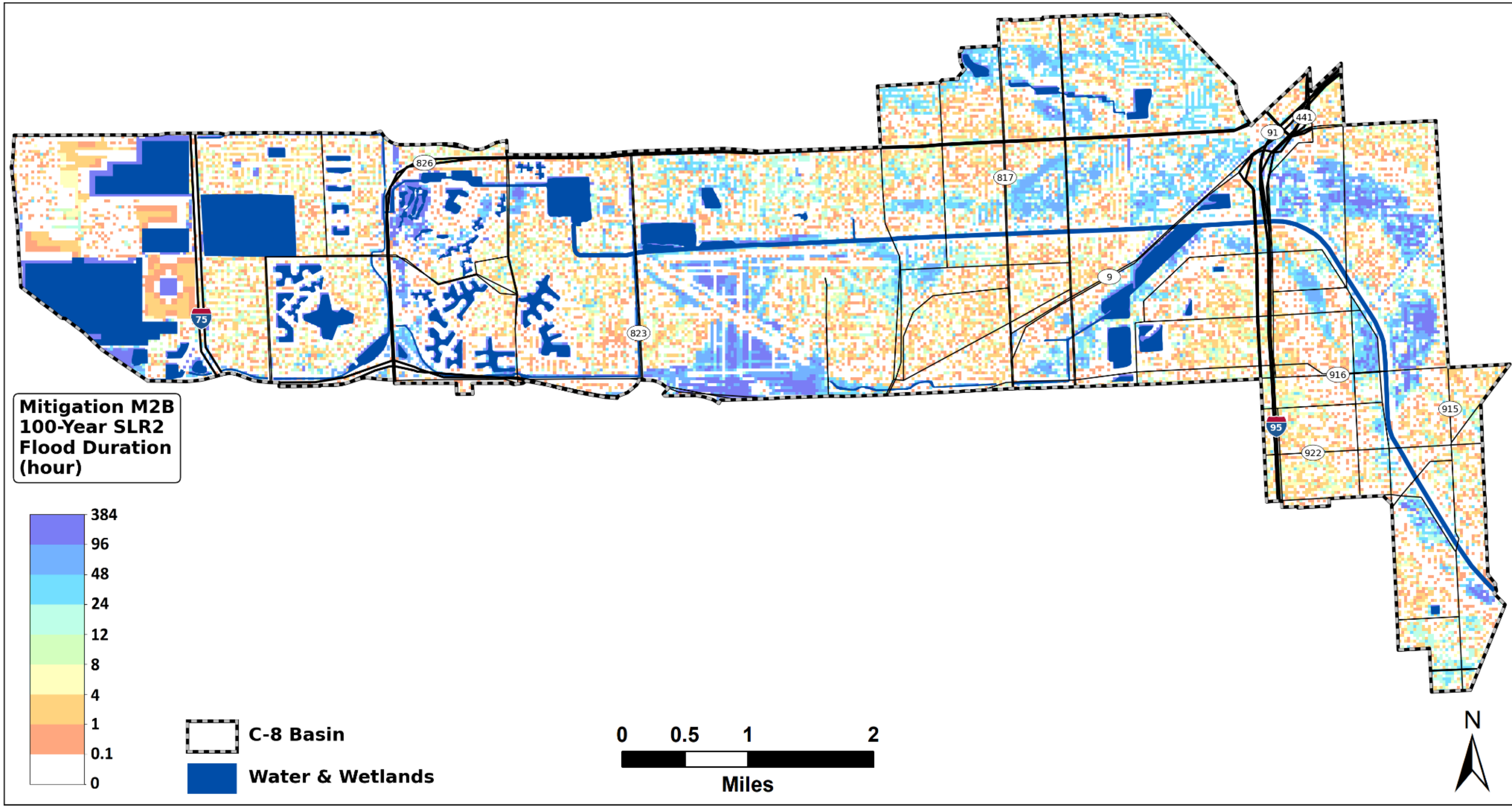


Figure D- 35: C-8 Watershed Flood Duration Map for the Mitigation M2B 100-Year Sea Level Rise 2 Design Storm Event

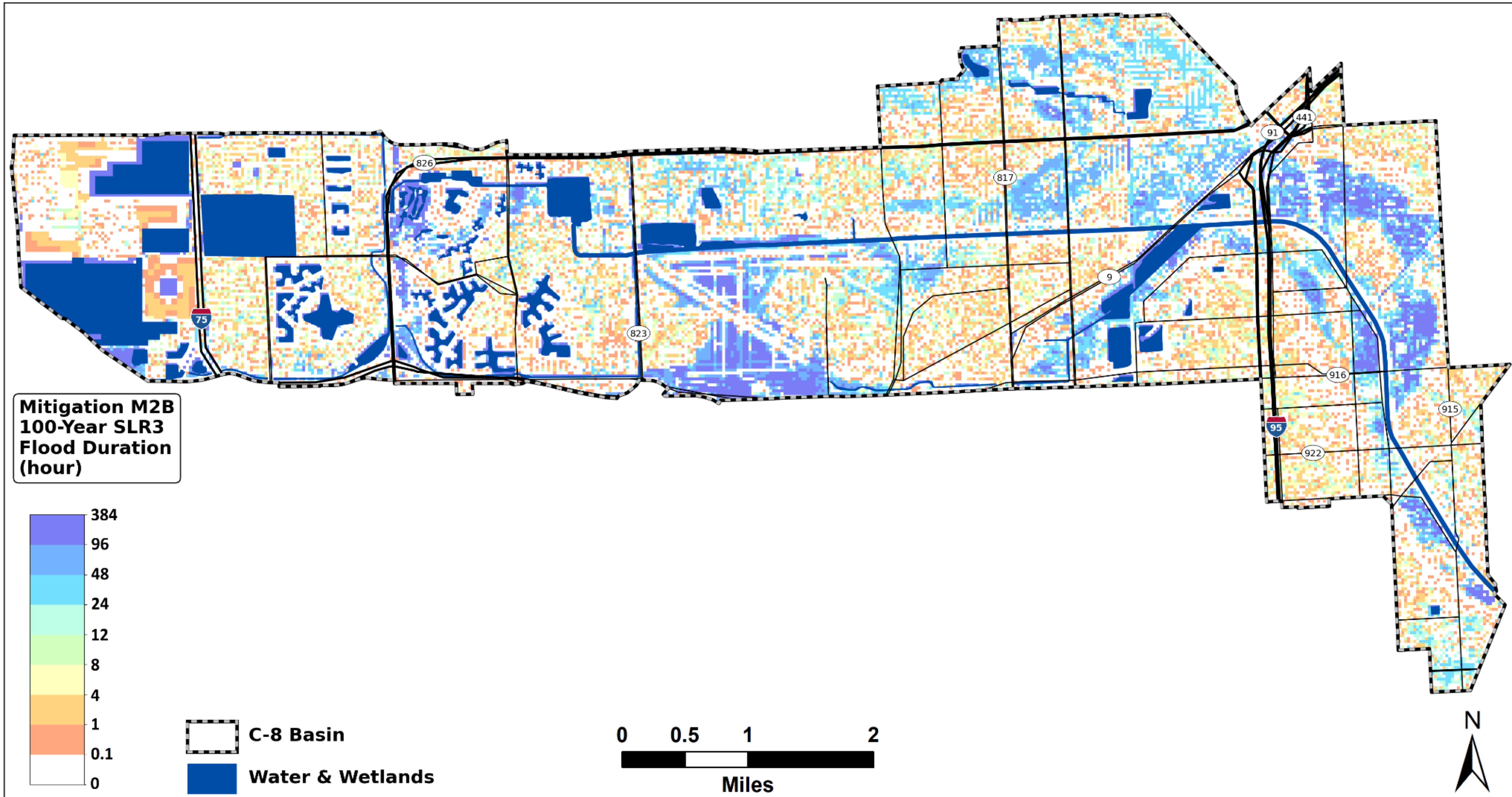


Figure D- 36: C-8 Watershed Flood Duration Map for the Mitigation M2B 100-Year Sea Level Rise 3 Design Storm Event

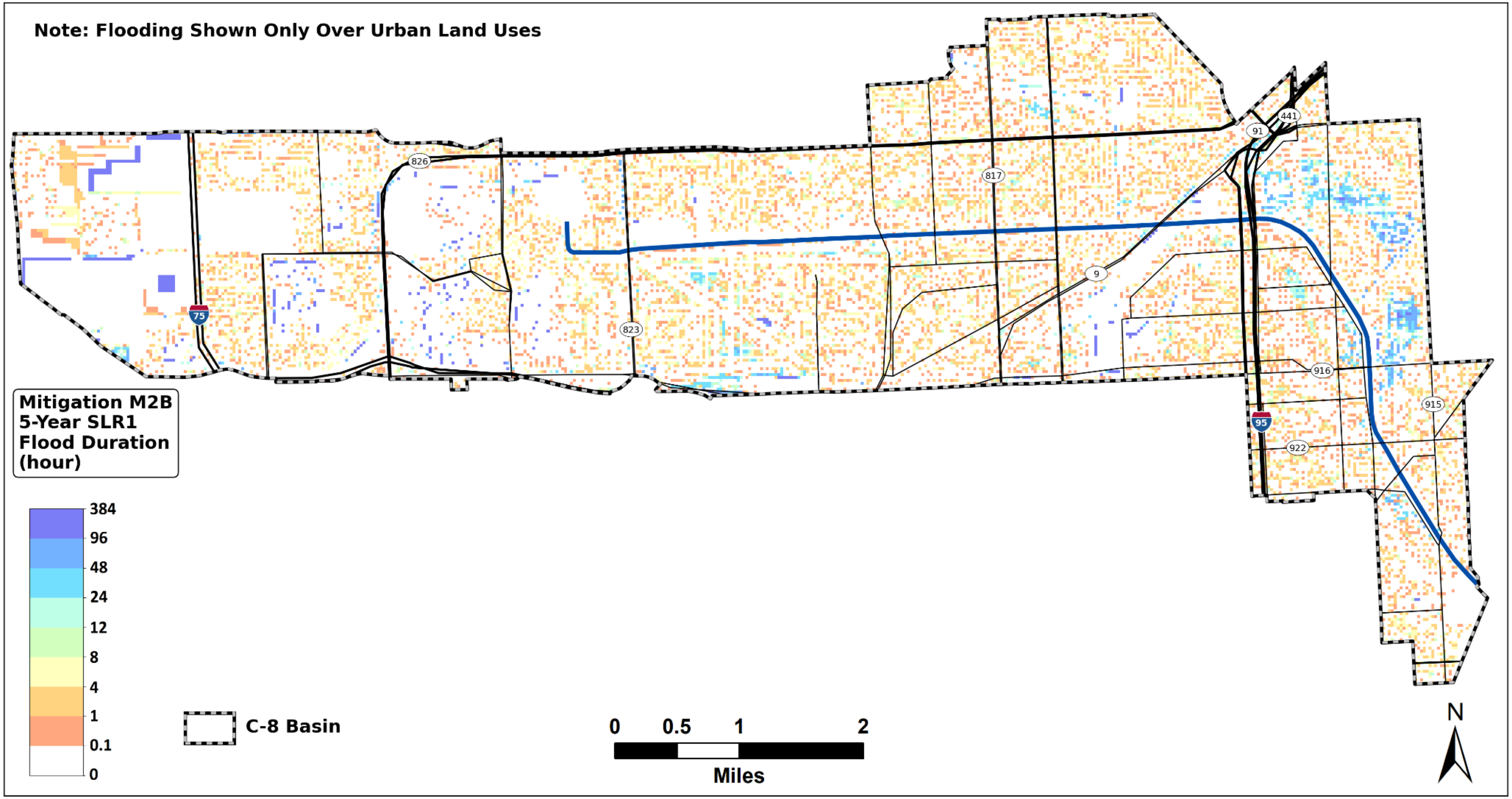


Figure D- 37: C-8 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2B 5-Year Sea Level Rise 1 Design Storm Event

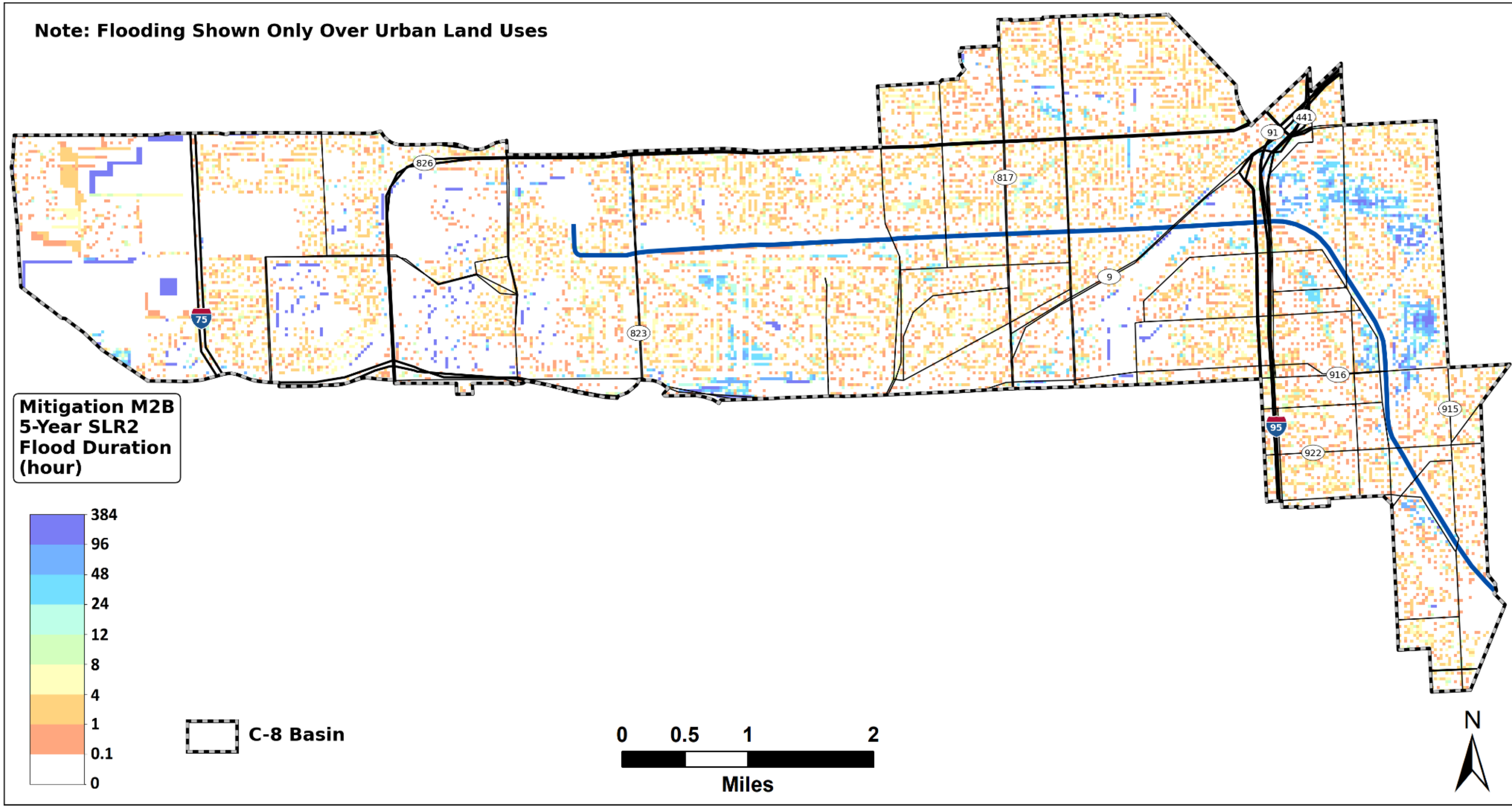


Figure D- 38: C-8 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2B 5-Year Sea Level Rise 2 Design Storm Event

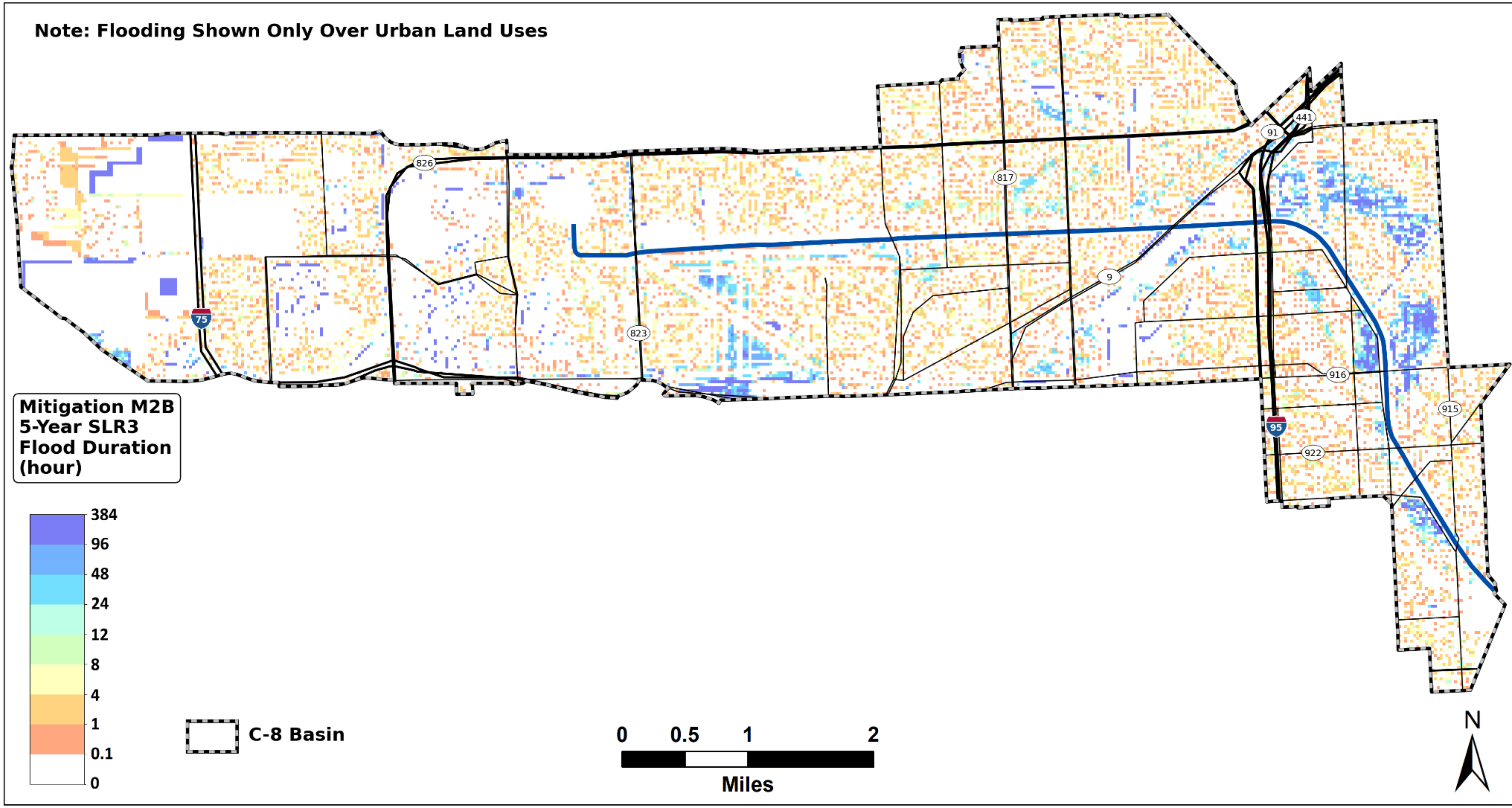


Figure D- 39: C-8 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2B 5-Year Sea Level Rise 3 Design Storm Event

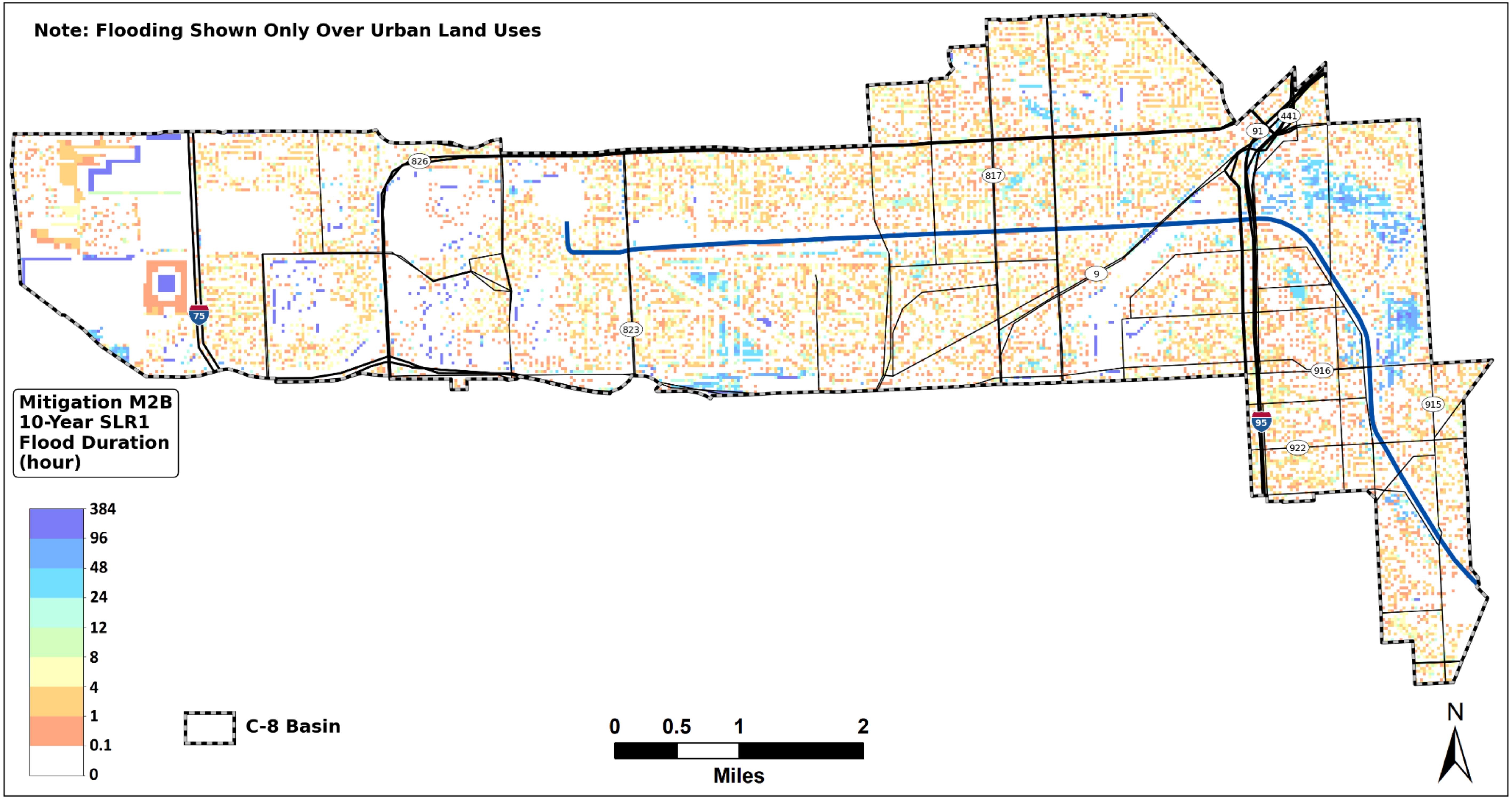


Figure D- 40: C-8 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2B 10-Year Sea Level Rise 1 Design Storm Event

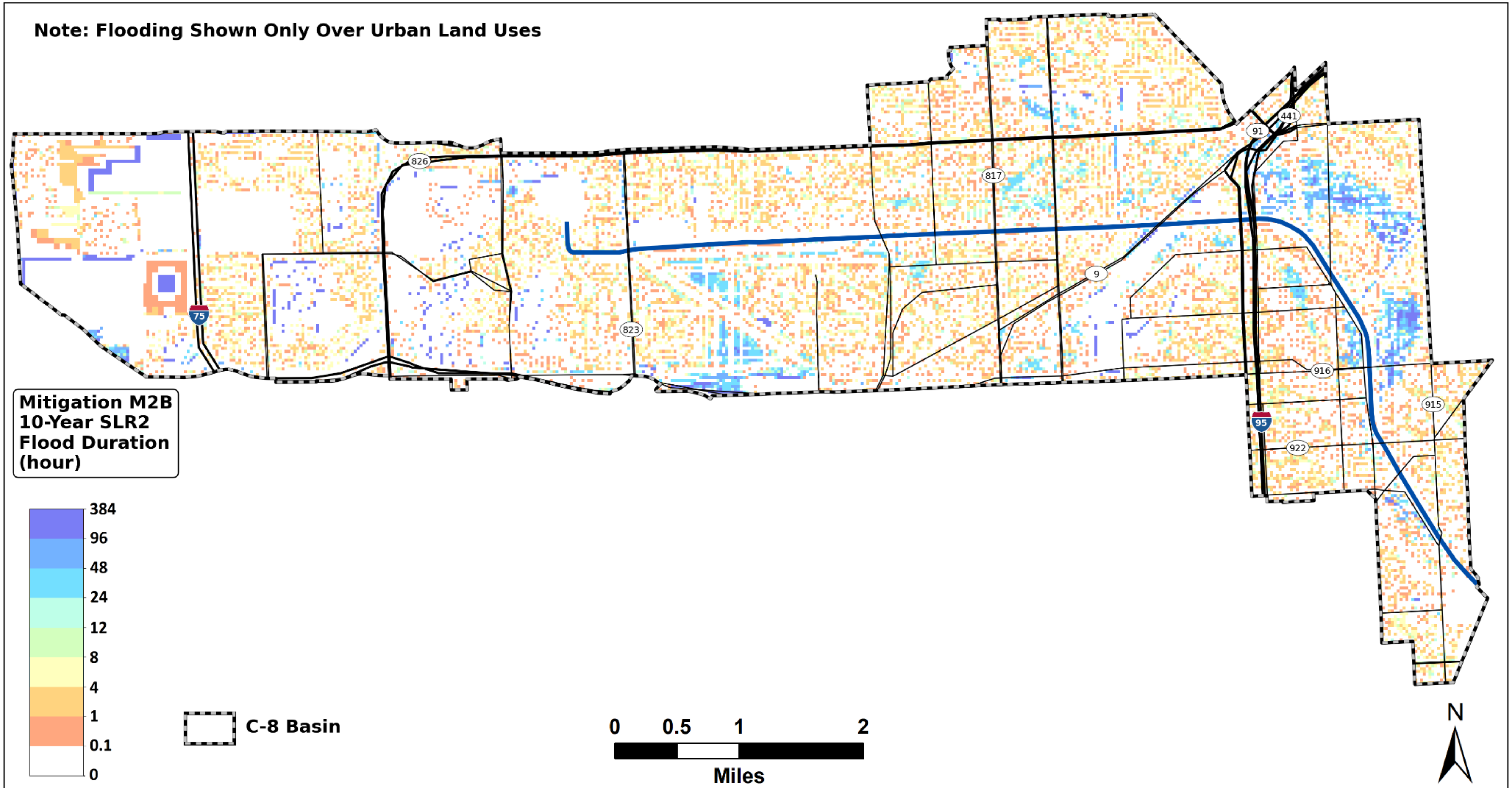


Figure D- 41: C-8 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2B 10-Year Sea Level Rise 2 Design Storm Event

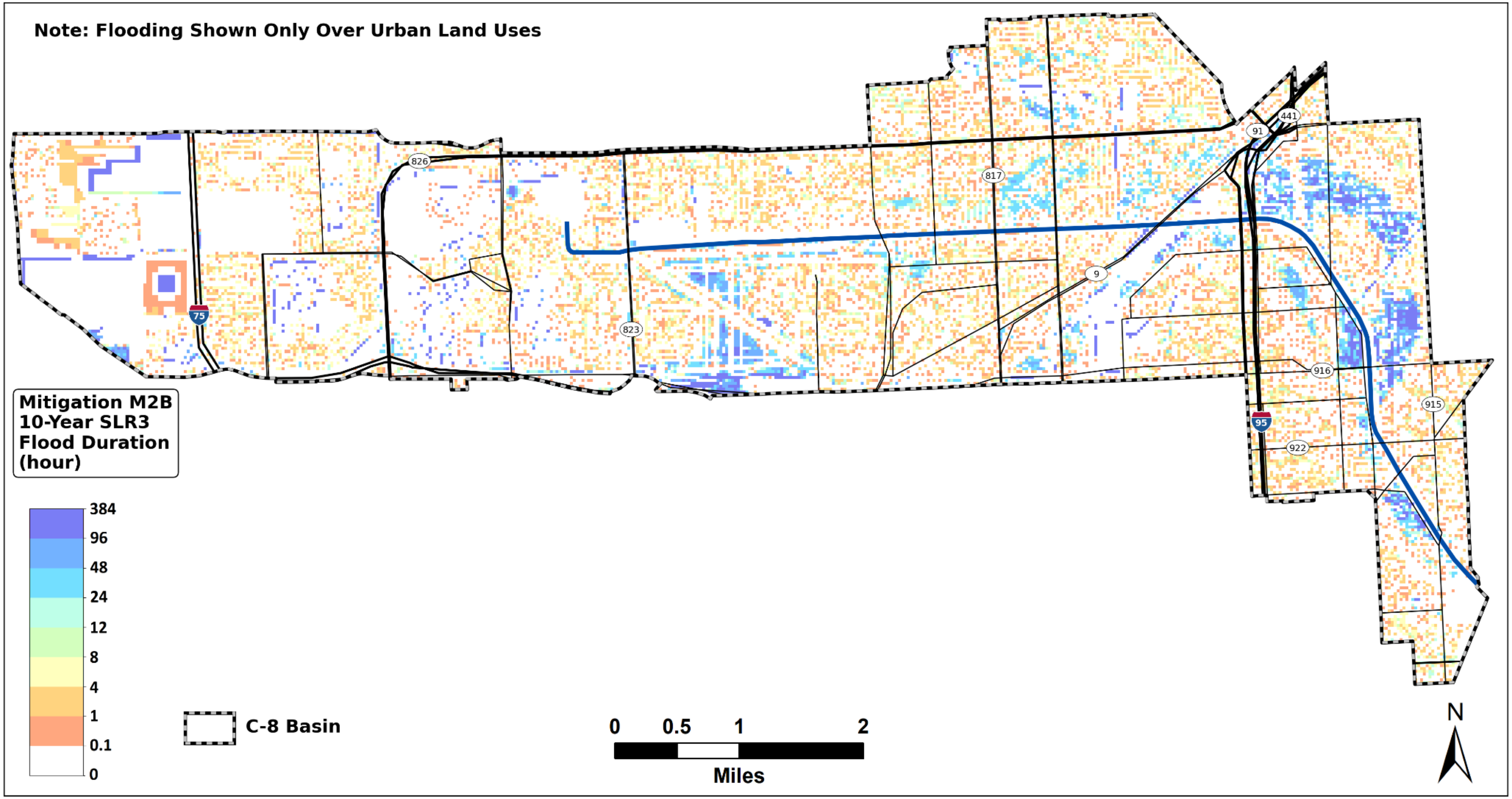


Figure D- 42: C-8 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2B 10-Year Sea Level Rise 3 Design Storm Event

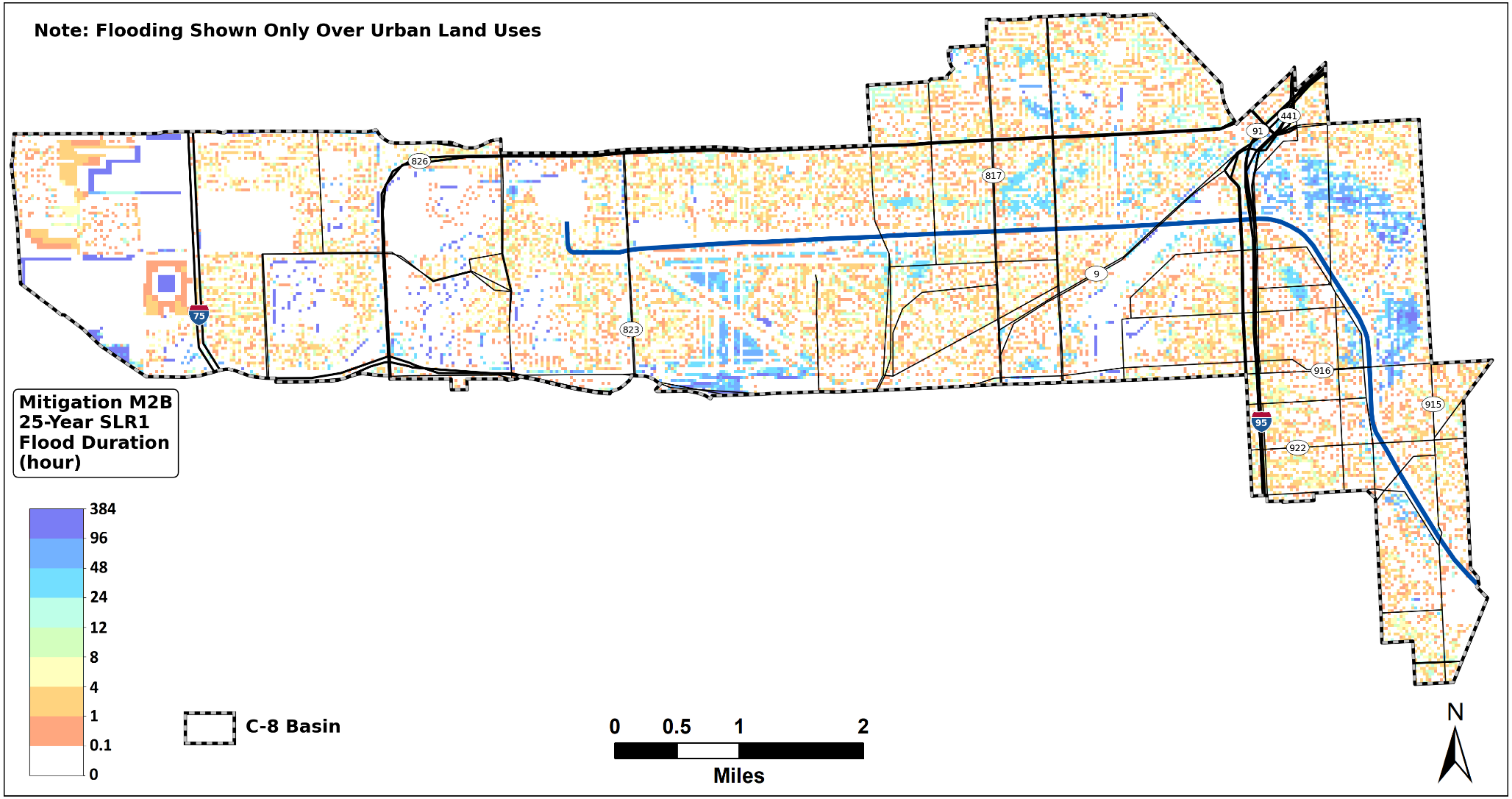


Figure D- 43: C-8 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2B 25-Year Sea Level Rise 1 Design Storm Event

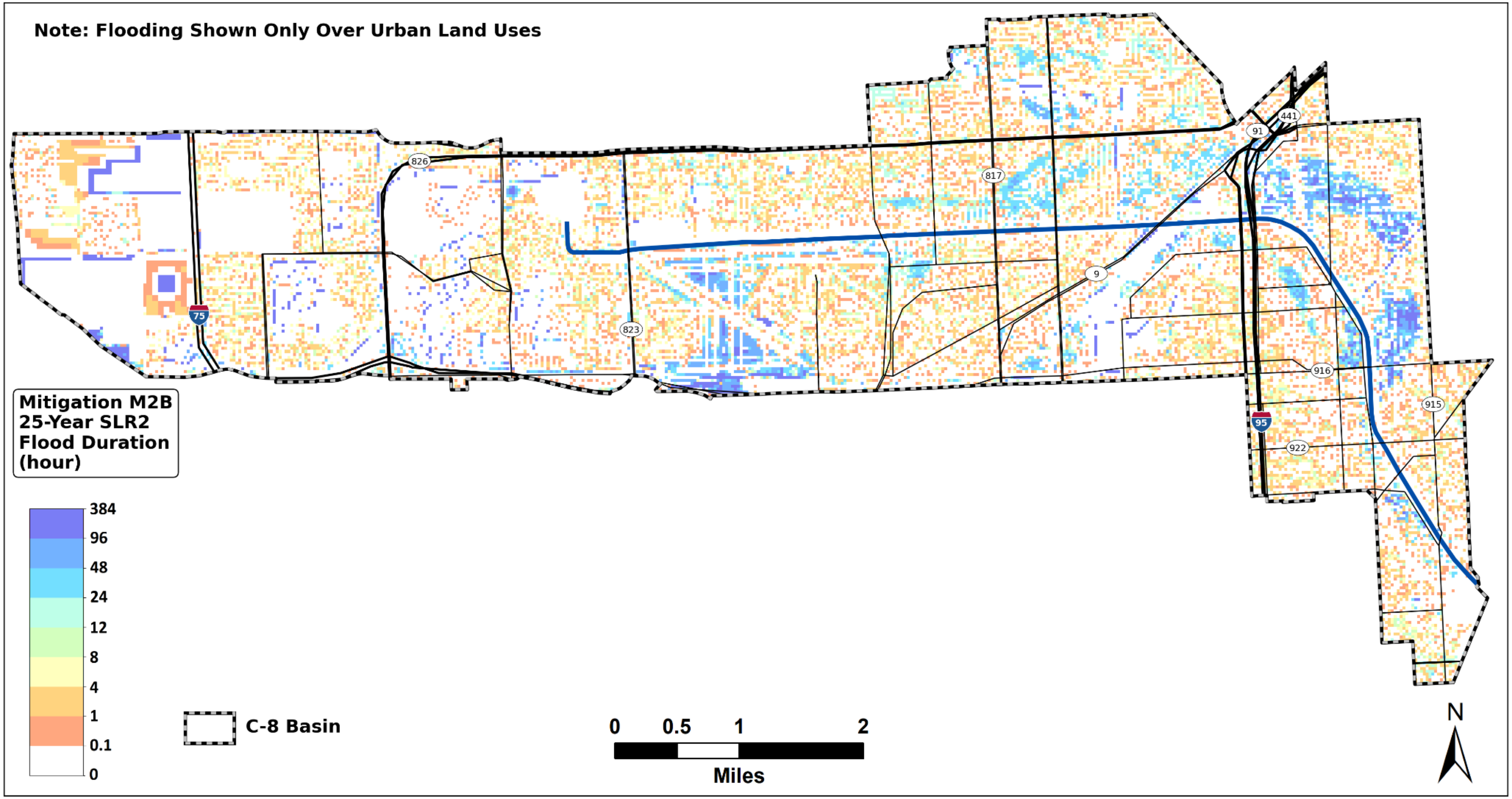


Figure D- 44: C-8 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2B 25-Year Sea Level Rise 2 Design Storm Event

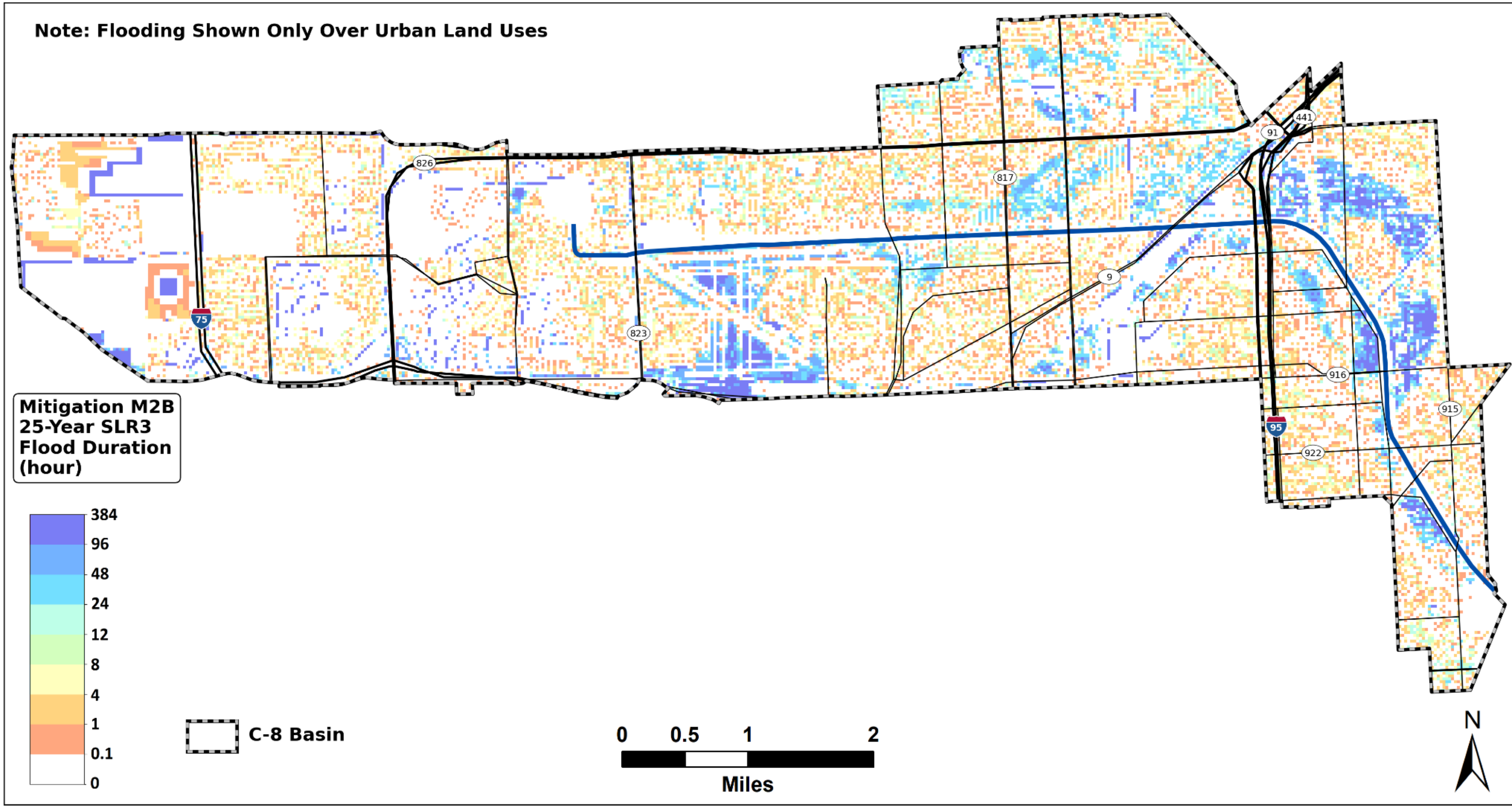


Figure D- 45: C-8 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2B 25-Year Sea Level Rise 3 Design Storm Event

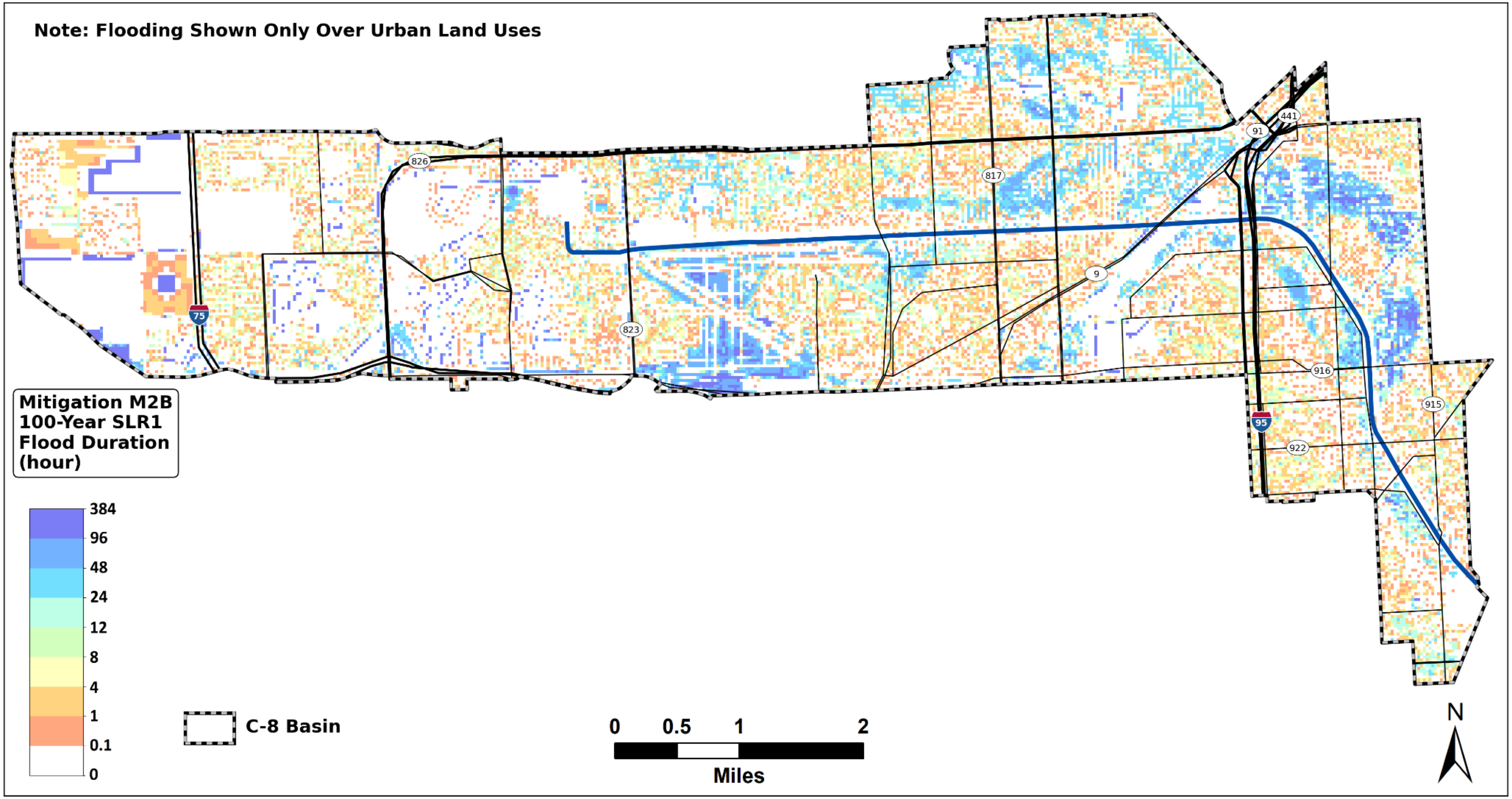


Figure D- 46: C-8 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2B 100-Year Sea Level Rise 1 Design Storm Event

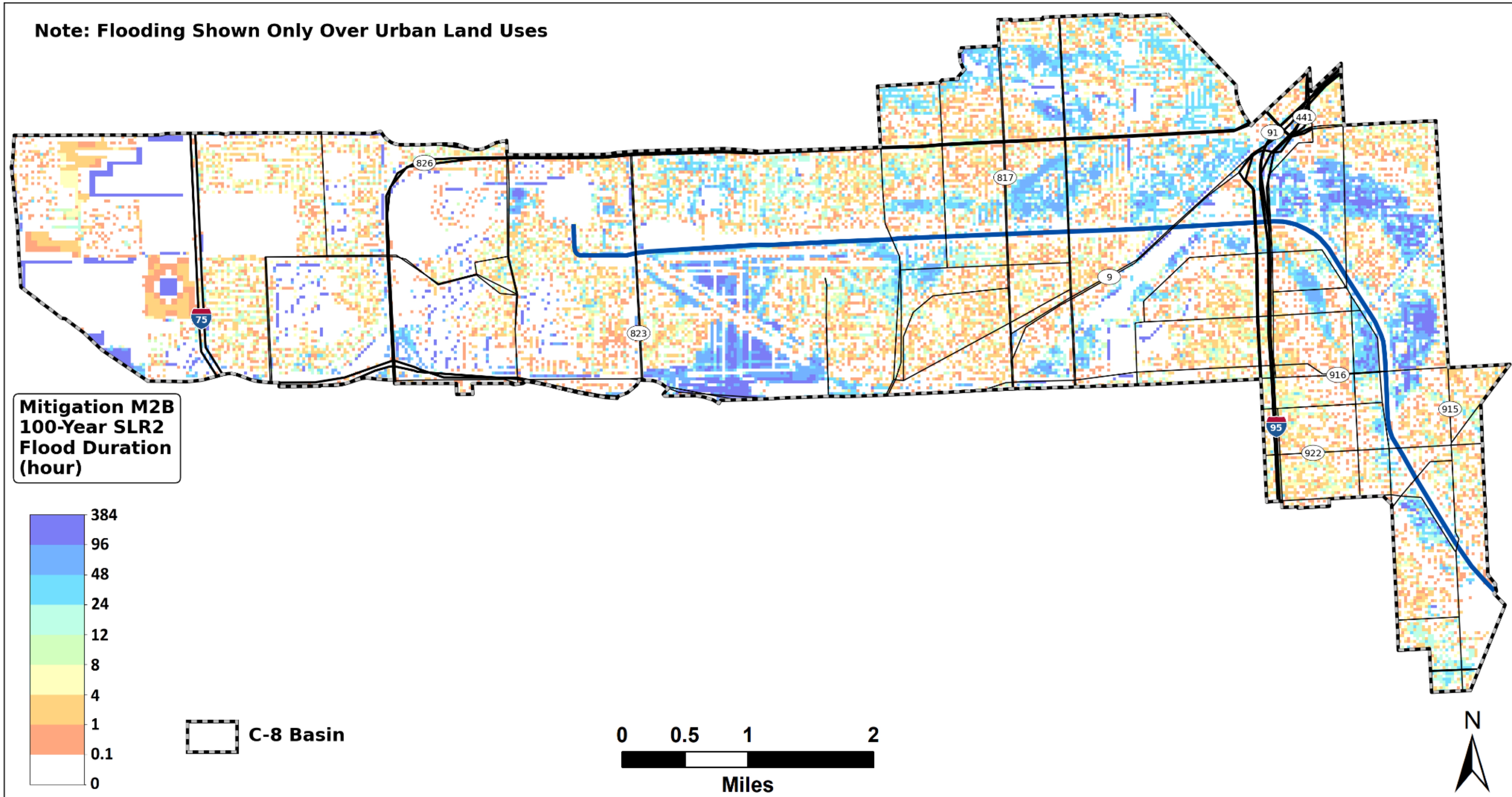


Figure D- 47: C-8 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2B 100-Year Sea Level Rise 2 Design Storm Event

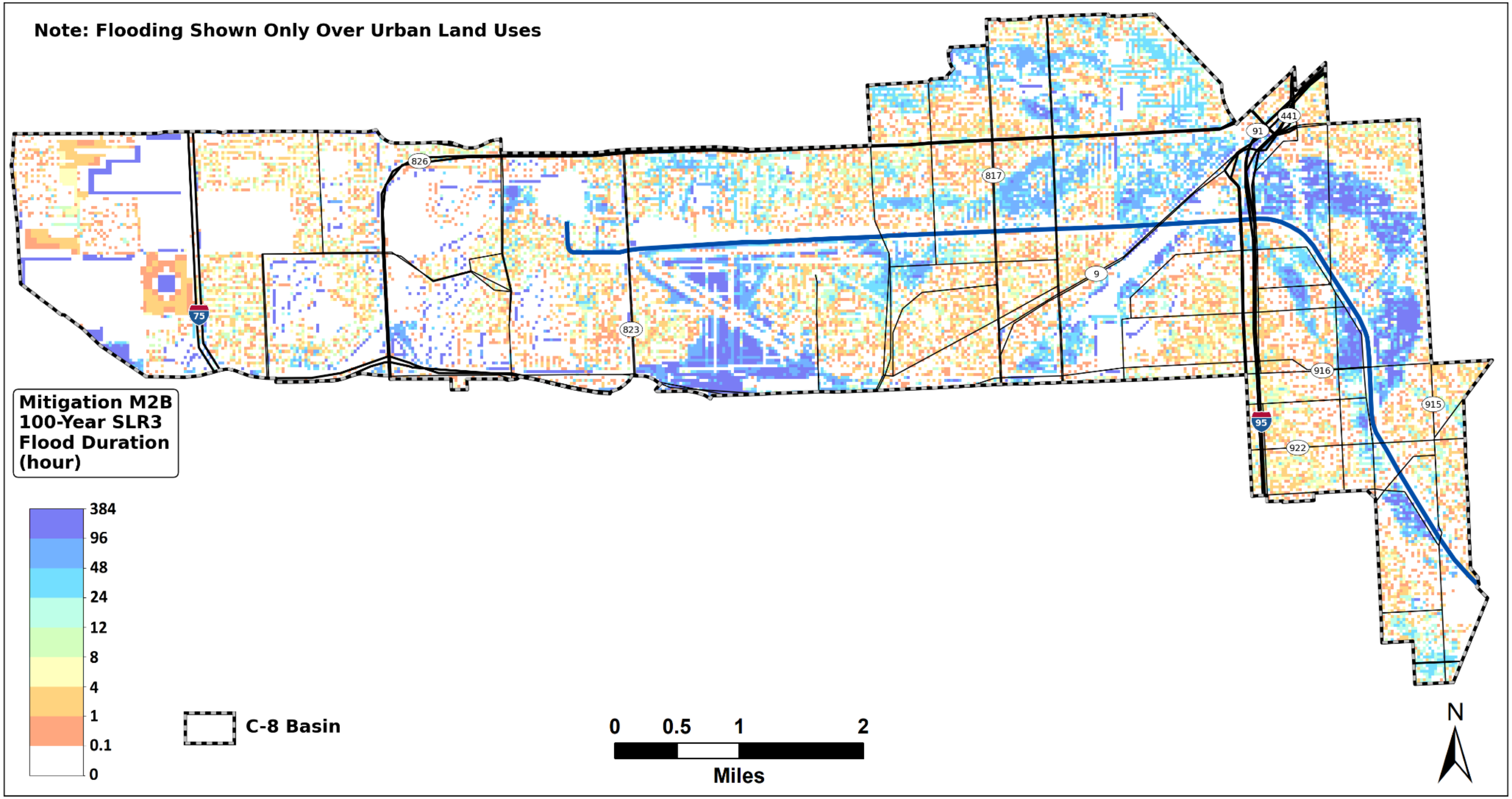


Figure D- 48: C-8 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2B 100-Year Sea Level Rise 3 Design Storm Event

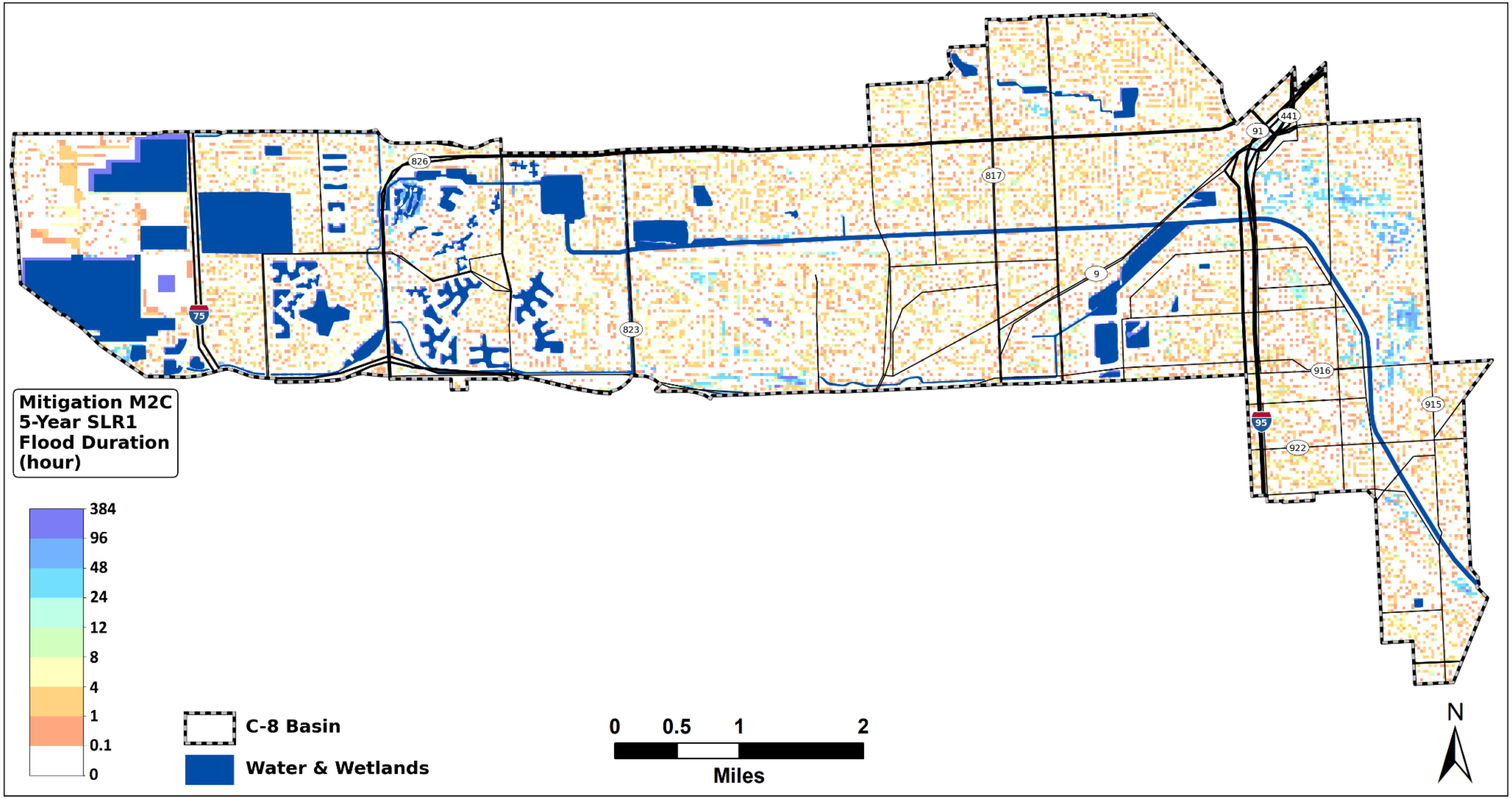


Figure D- 49: C-8 Watershed Flood Duration Map for the Mitigation M2C 5-Year Sea Level Rise 1 Design Storm Event

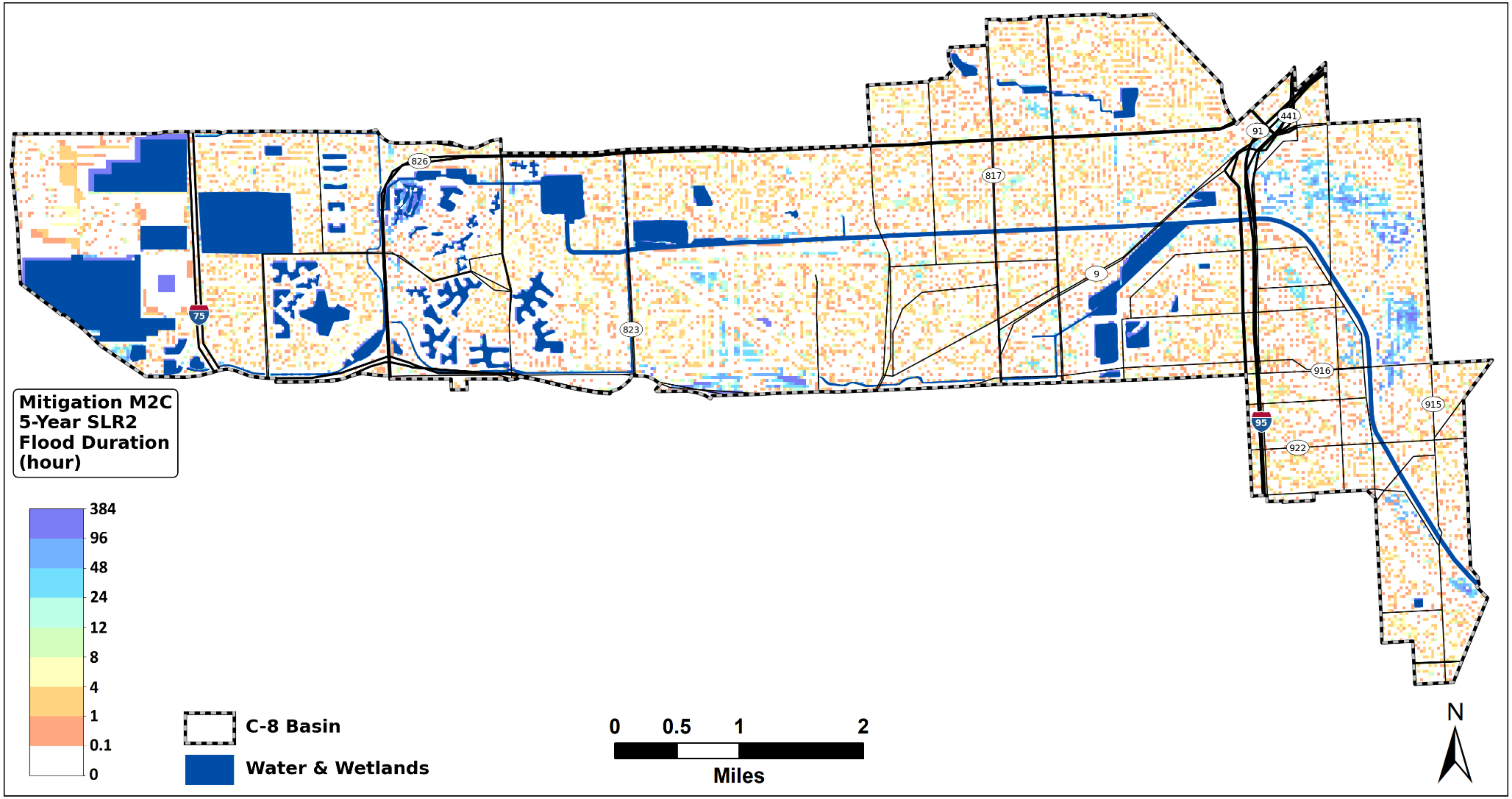


Figure D- 50: C-8 Watershed Flood Duration Map for the Mitigation M2C 5-Year Sea Level Rise 2 Design Storm Event

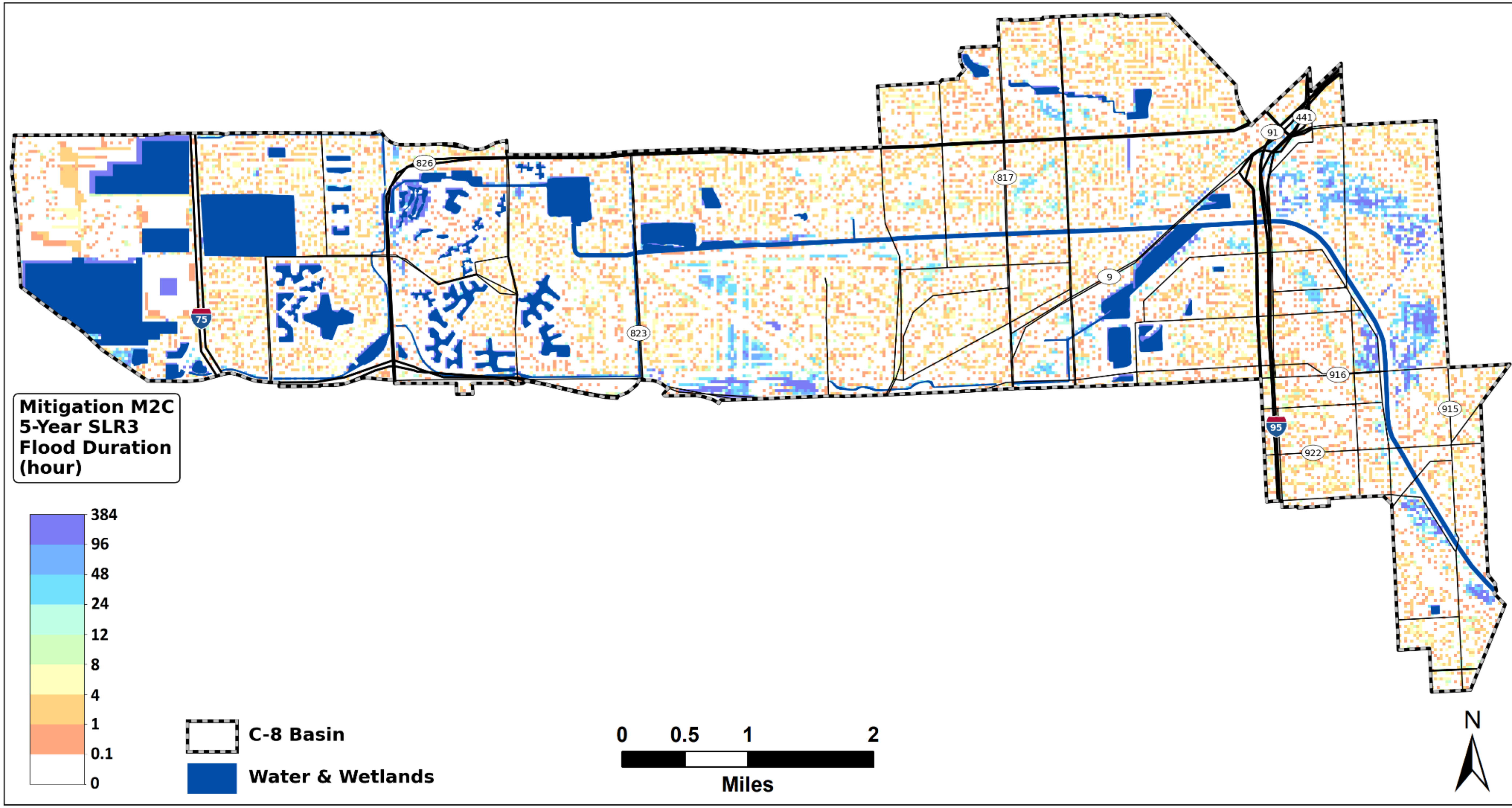


Figure D- 51: C-8 Watershed Flood Duration Map for the Mitigation M2C 5-Year Sea Level Rise 3 Design Storm Event

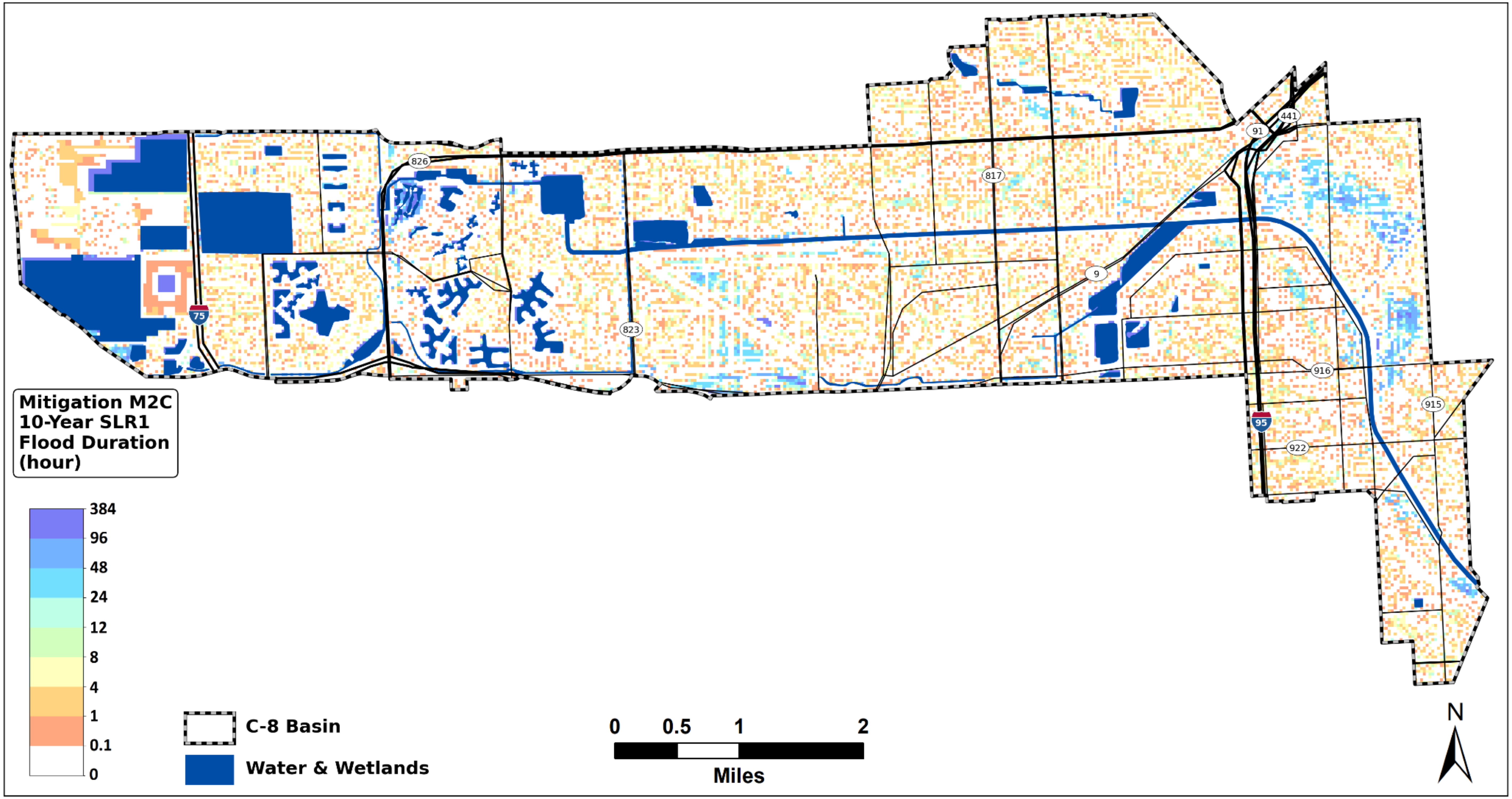


Figure D- 52: C-8 Watershed Flood Duration Map for the Mitigation M2C 10-Year Sea Level Rise 1 Design Storm Event

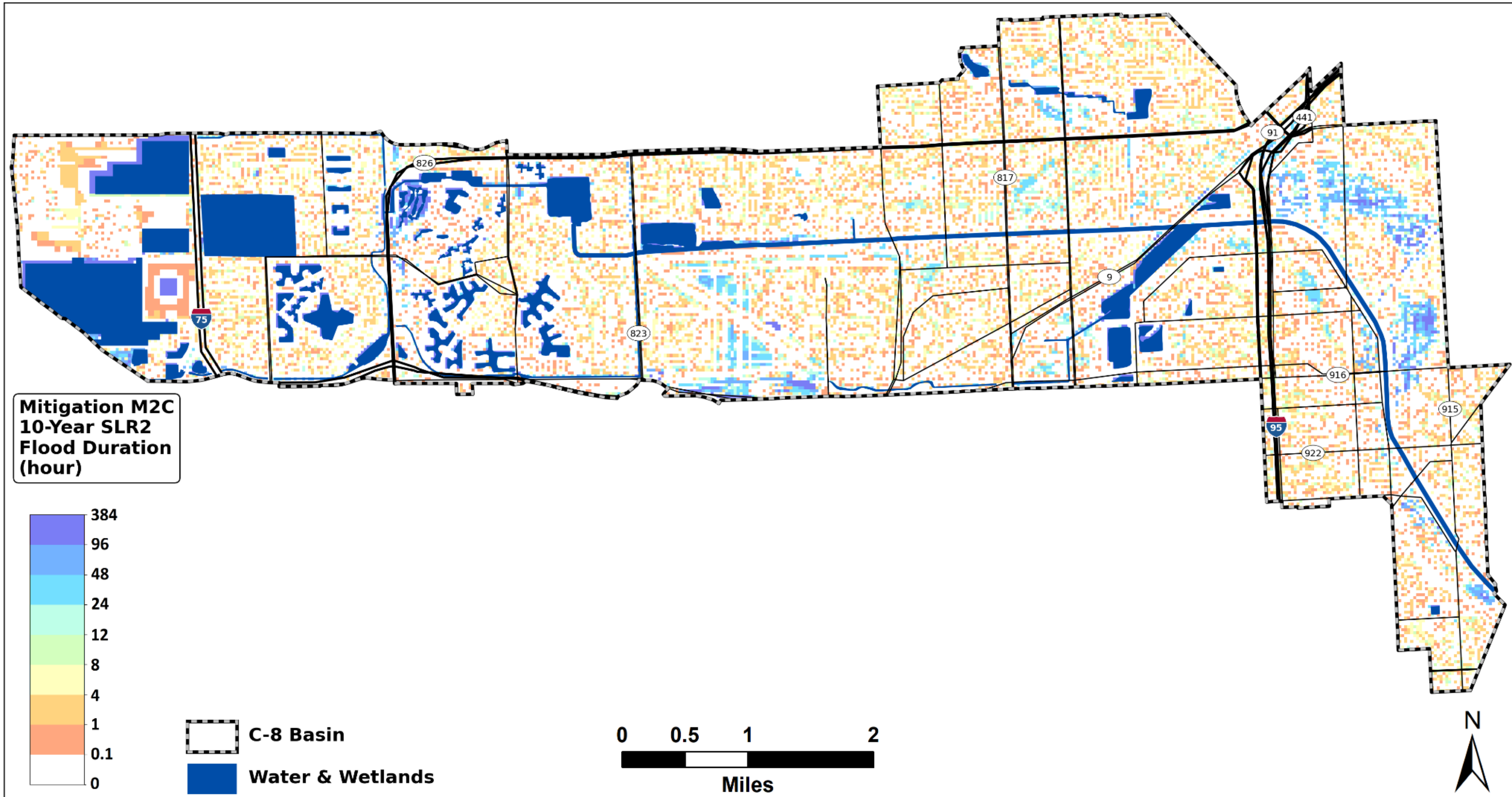


Figure D- 53: C-8 Watershed Flood Duration Map for the Mitigation M2C 10-Year Sea Level Rise 2 Design Storm Event

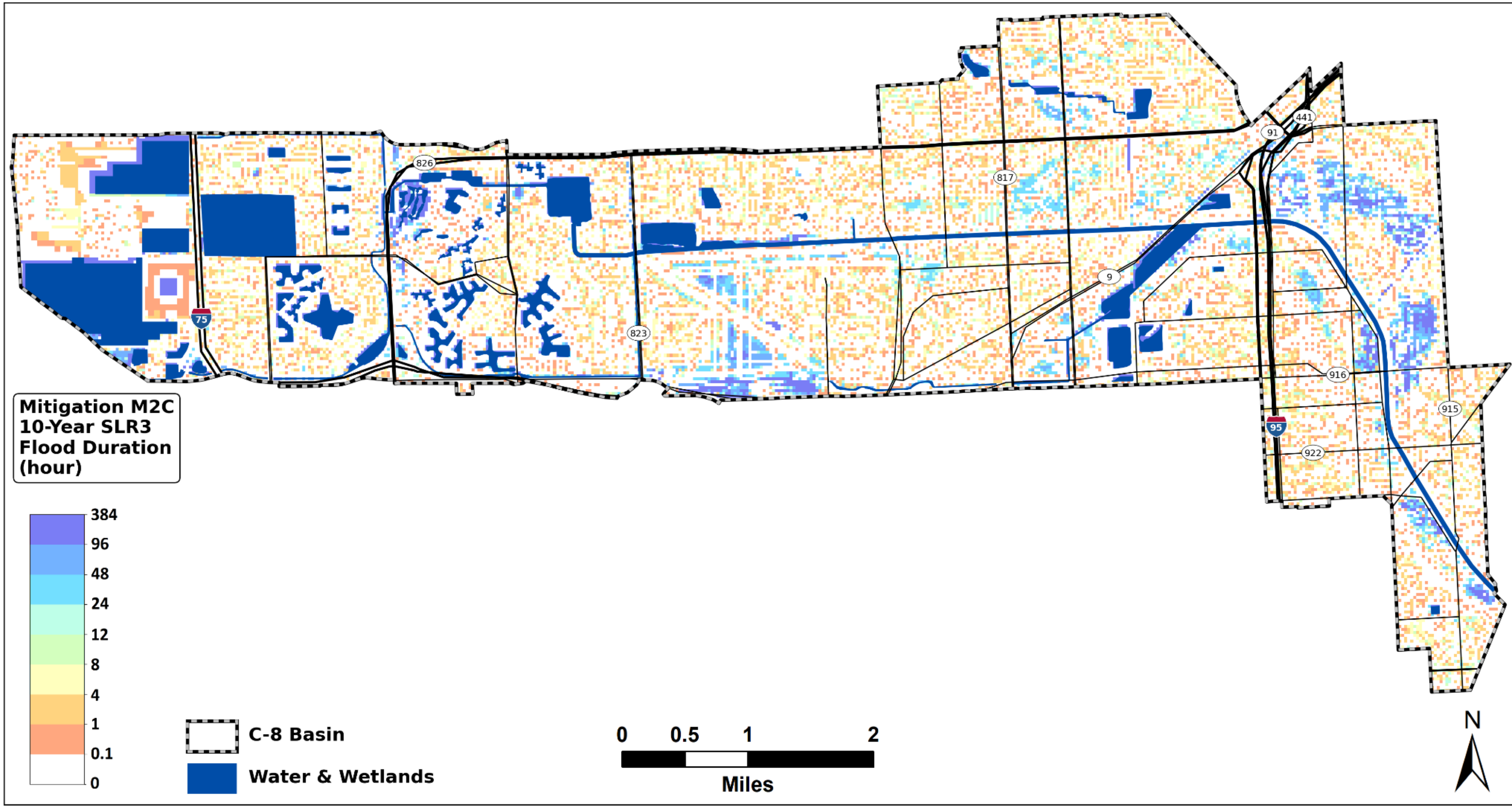


Figure D- 54: C-8 Watershed Flood Duration Map for the Mitigation M2C 10-Year Sea Level Rise 3 Design Storm Event

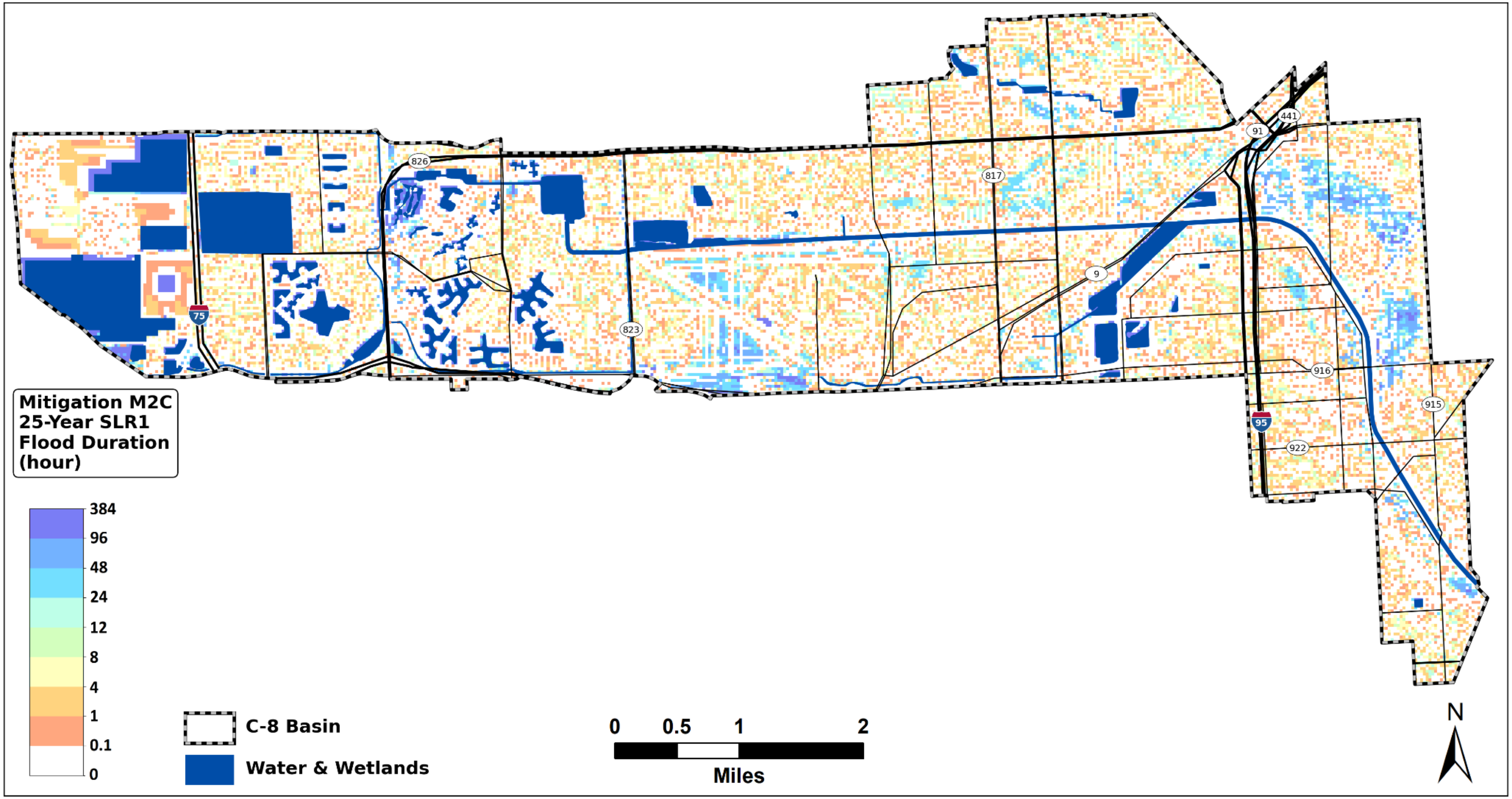


Figure D- 55: C-8 Watershed Flood Duration Map for the Mitigation M2C 25-Year Sea Level Rise 1 Design Storm Event

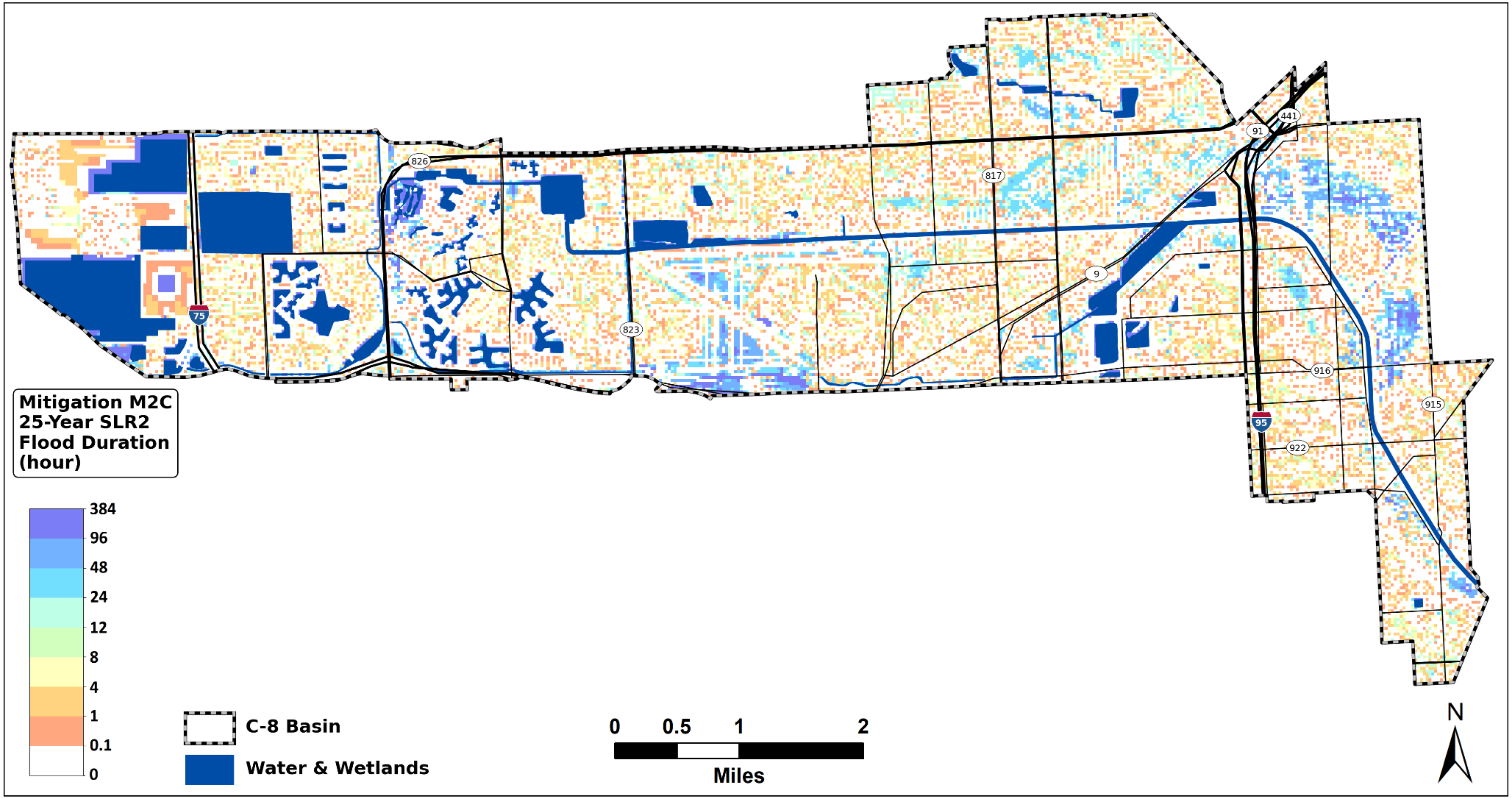


Figure D- 56: C-8 Watershed Flood Duration Map for the Mitigation M2C 25-Year Sea Level Rise 2 Design Storm Event

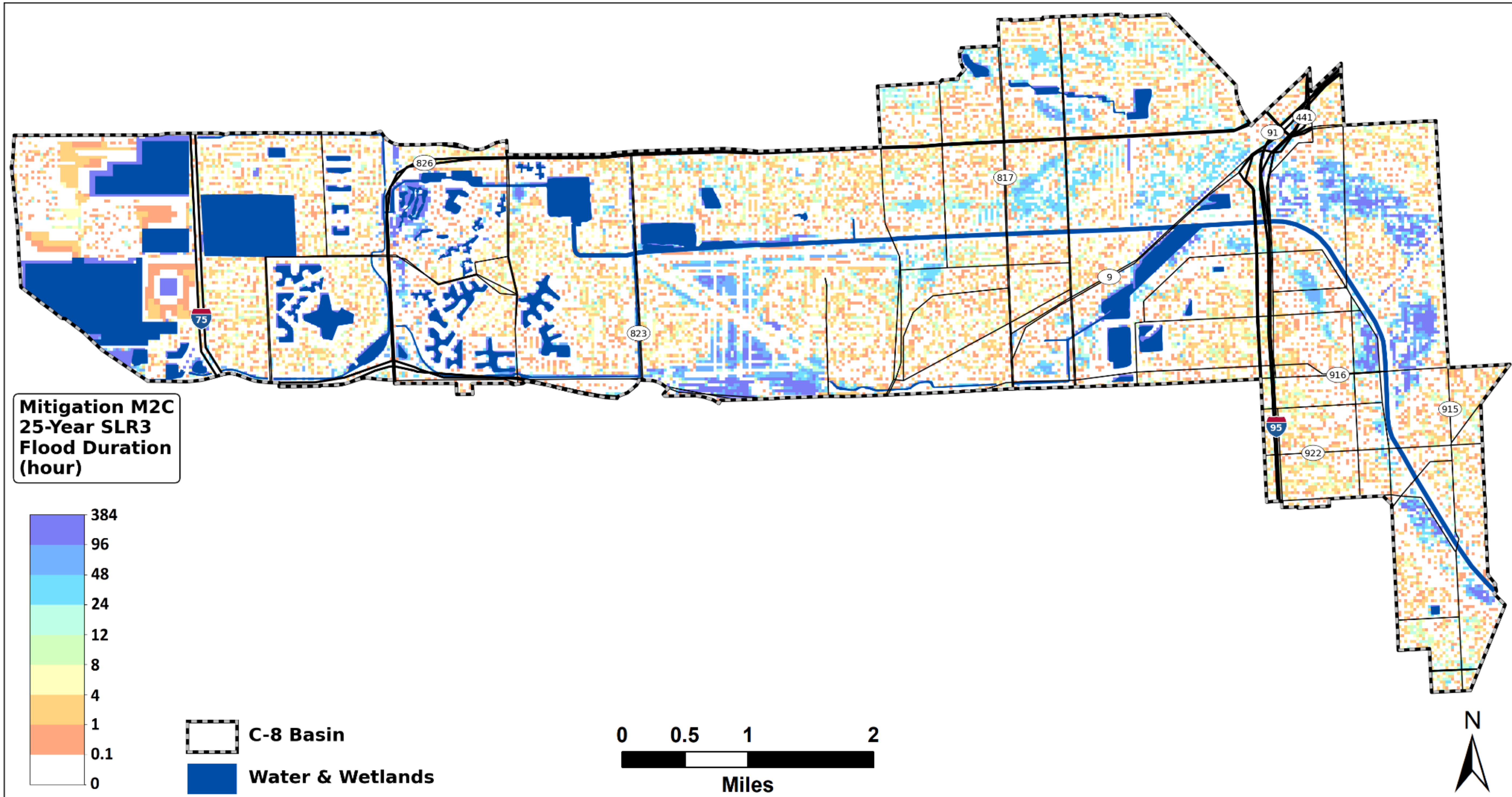


Figure D- 57: C-8 Watershed Flood Duration Map for the Mitigation M2C 25-Year Sea Level Rise 3 Design Storm Event

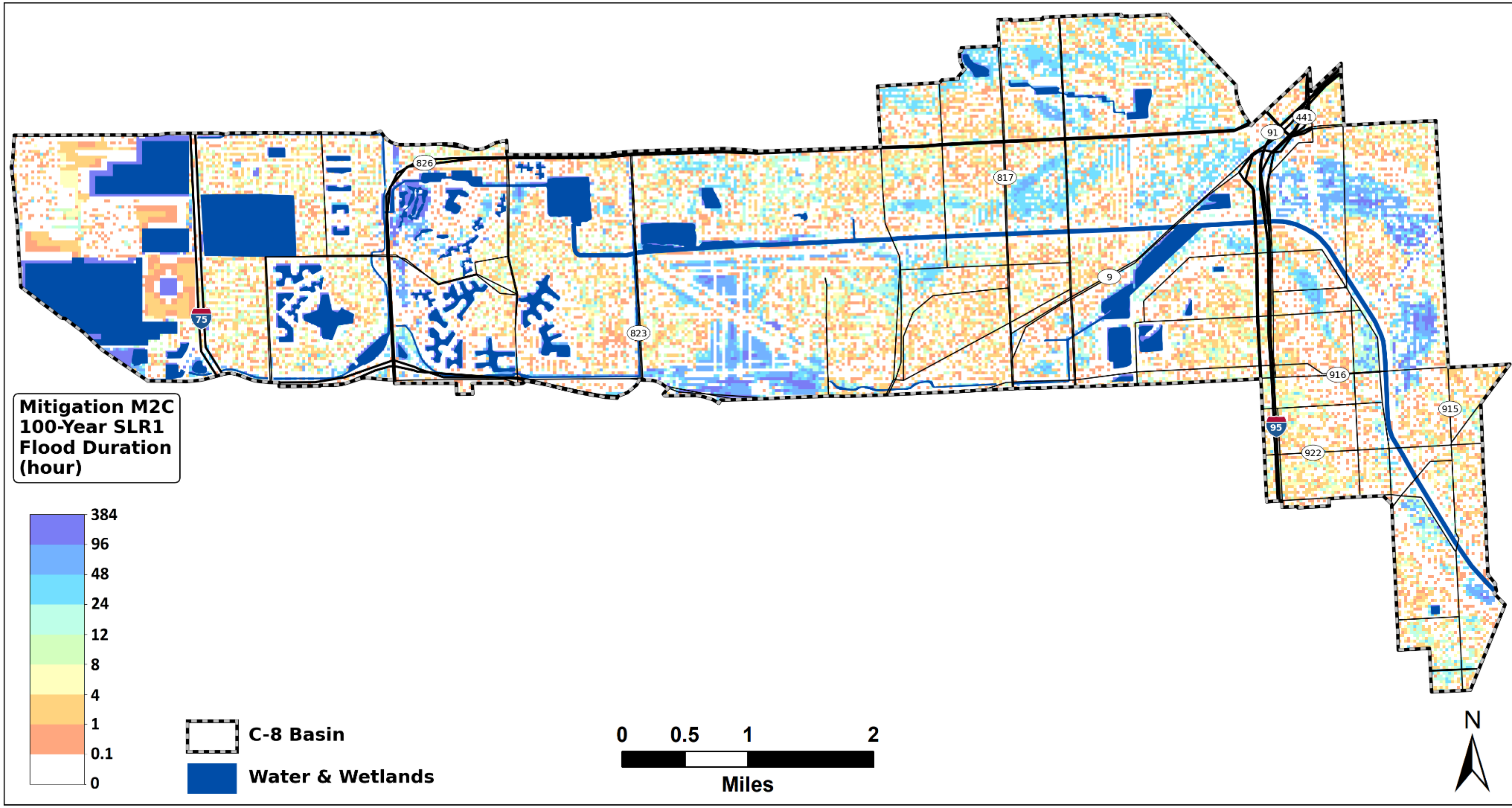


Figure D- 58: C-8 Watershed Flood Duration Map for the Mitigation M2C 100-Year Sea Level Rise 1 Design Storm Event

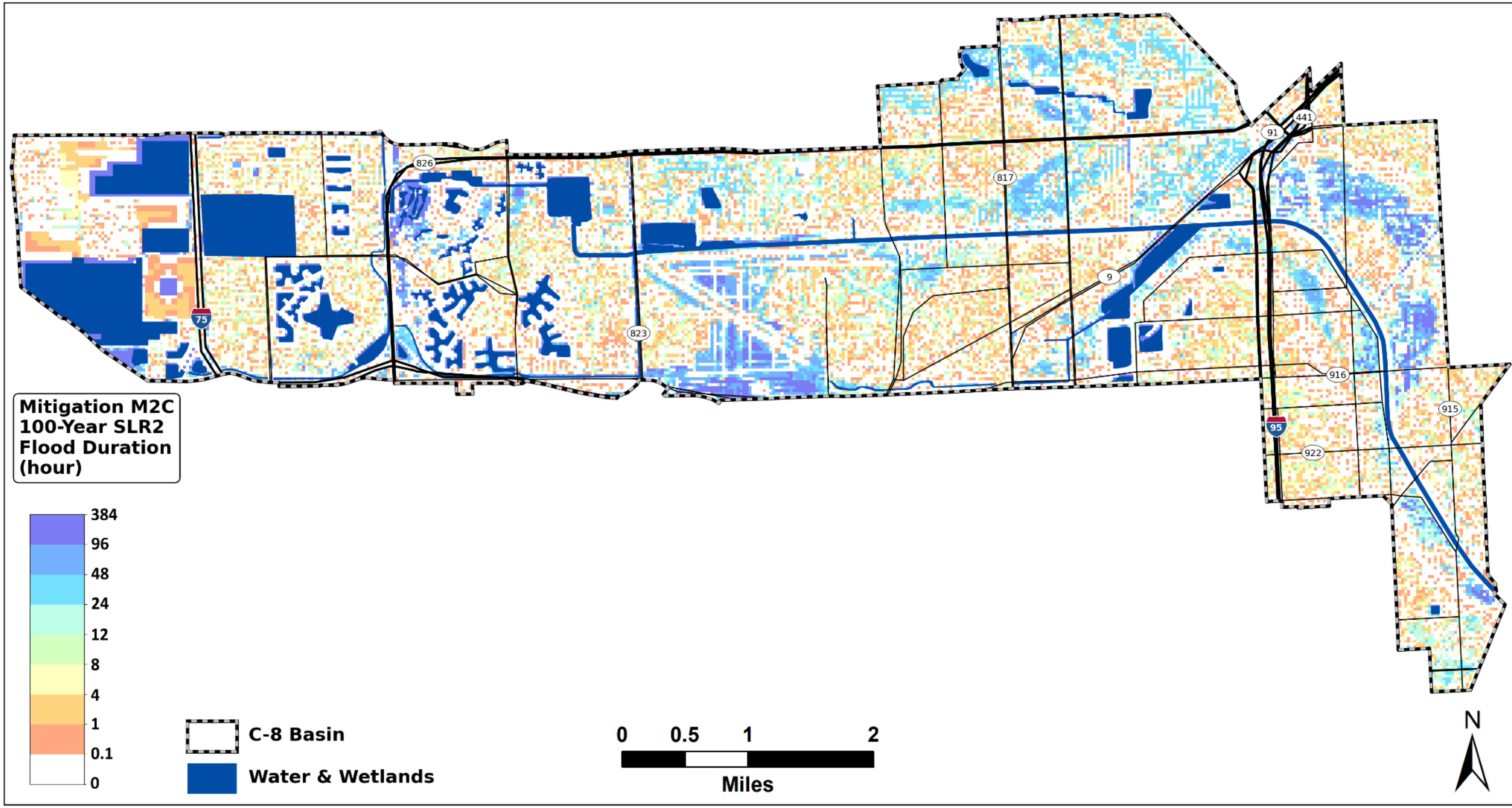


Figure D- 59: C-8 Watershed Flood Duration Map for the Mitigation M2C 100-Year Sea Level Rise 2 Design Storm Event

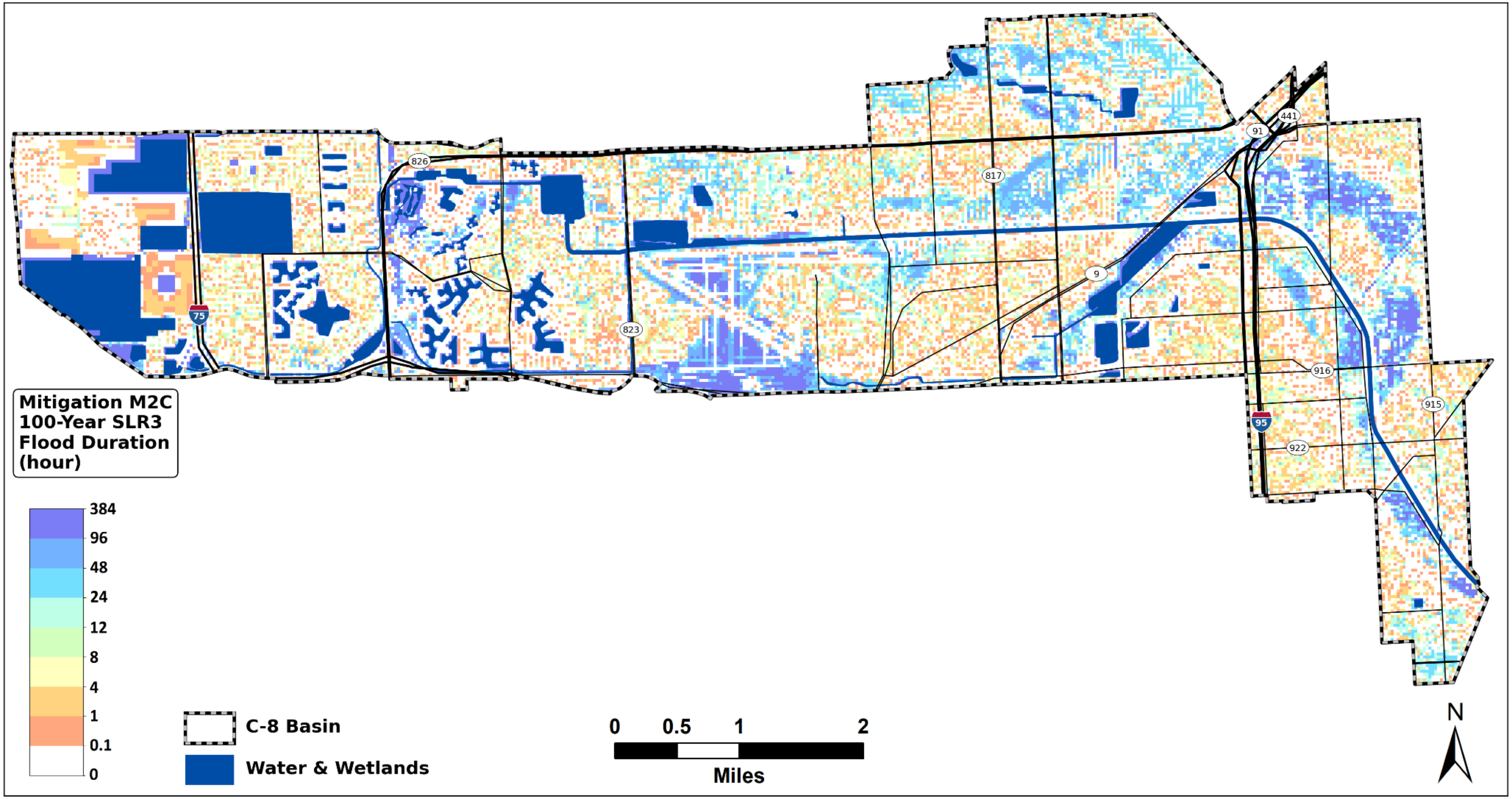


Figure D- 60: C-8 Watershed Flood Duration Map for the Mitigation M2C 100-Year Sea Level Rise 3 Design Storm Event

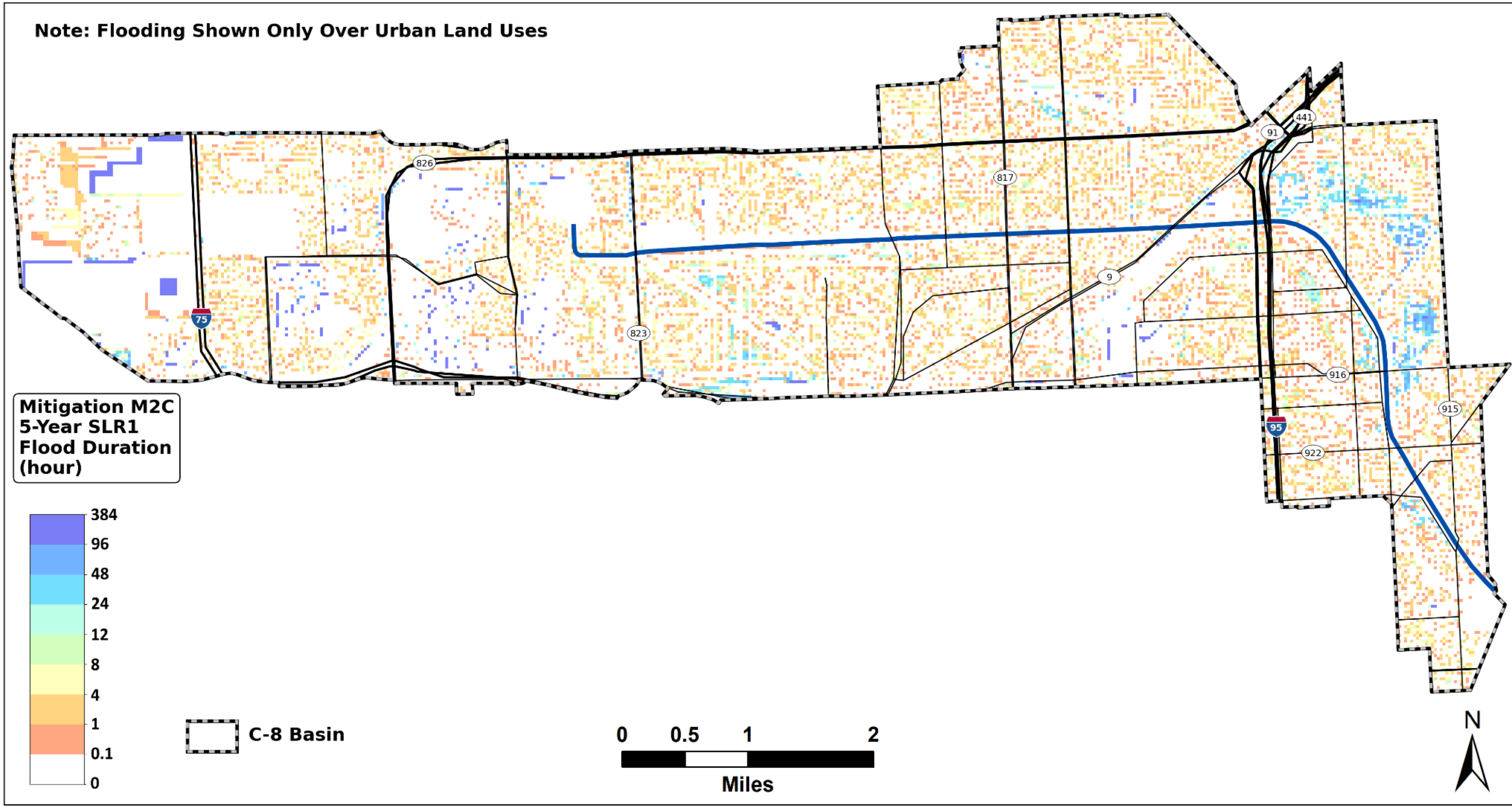


Figure D- 61: C-8 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2C 5-Year Sea Level Rise 1 Design Storm Event

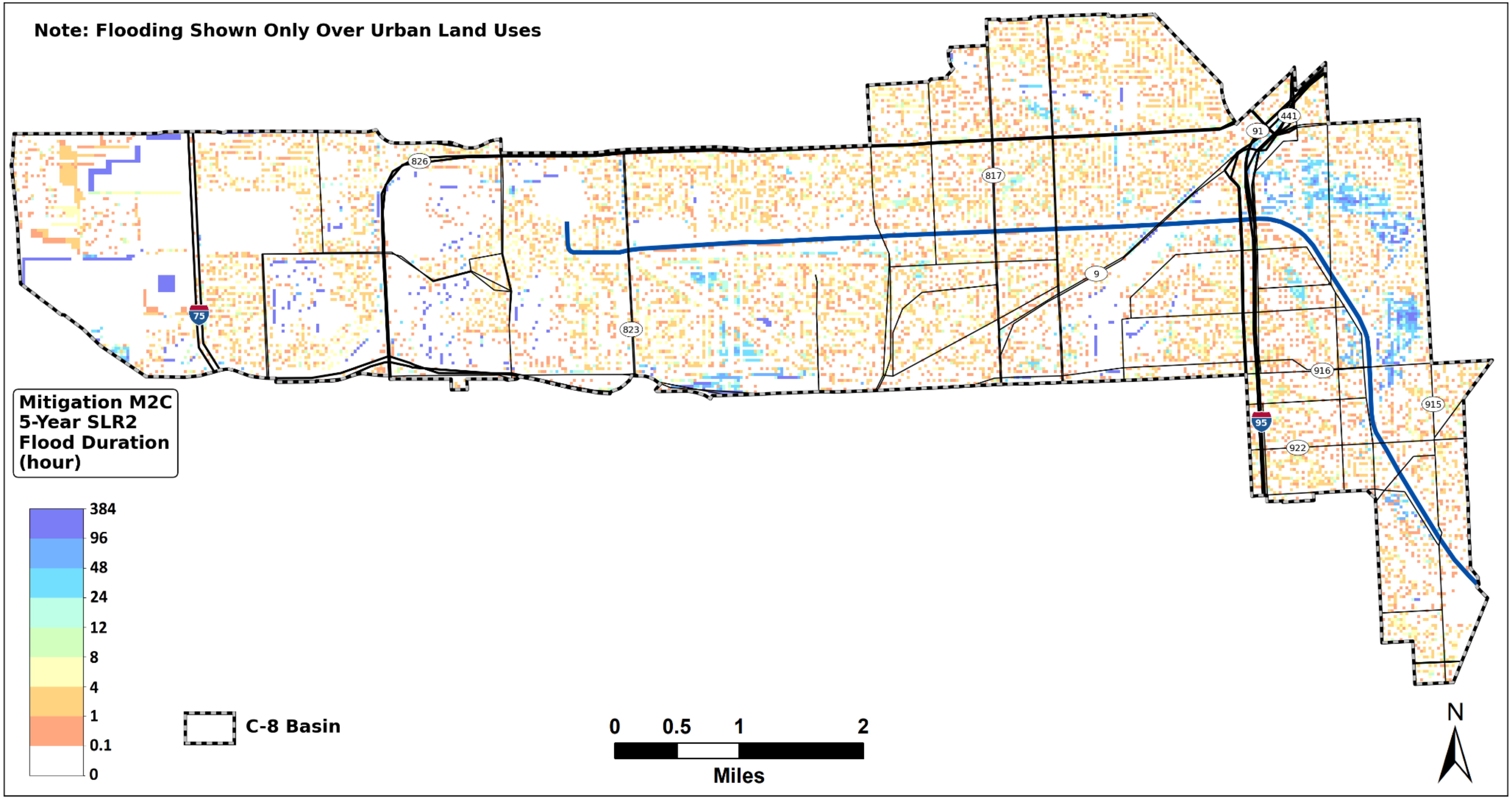


Figure D- 62: C-8 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2C 5-Year Sea Level Rise 2 Design Storm Event

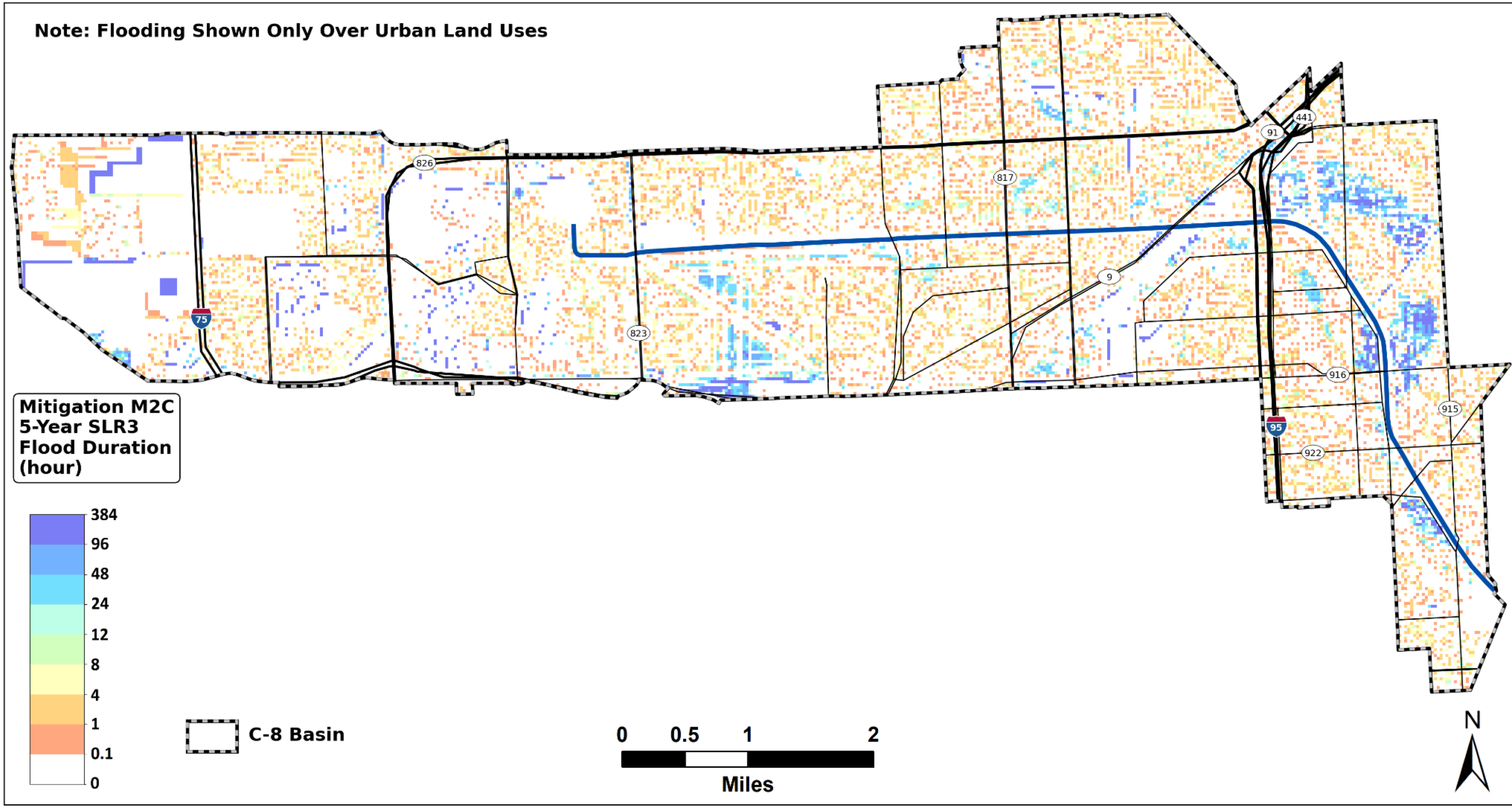


Figure D- 63: C-8 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2C 5-Year Sea Level Rise 3 Design Storm Event

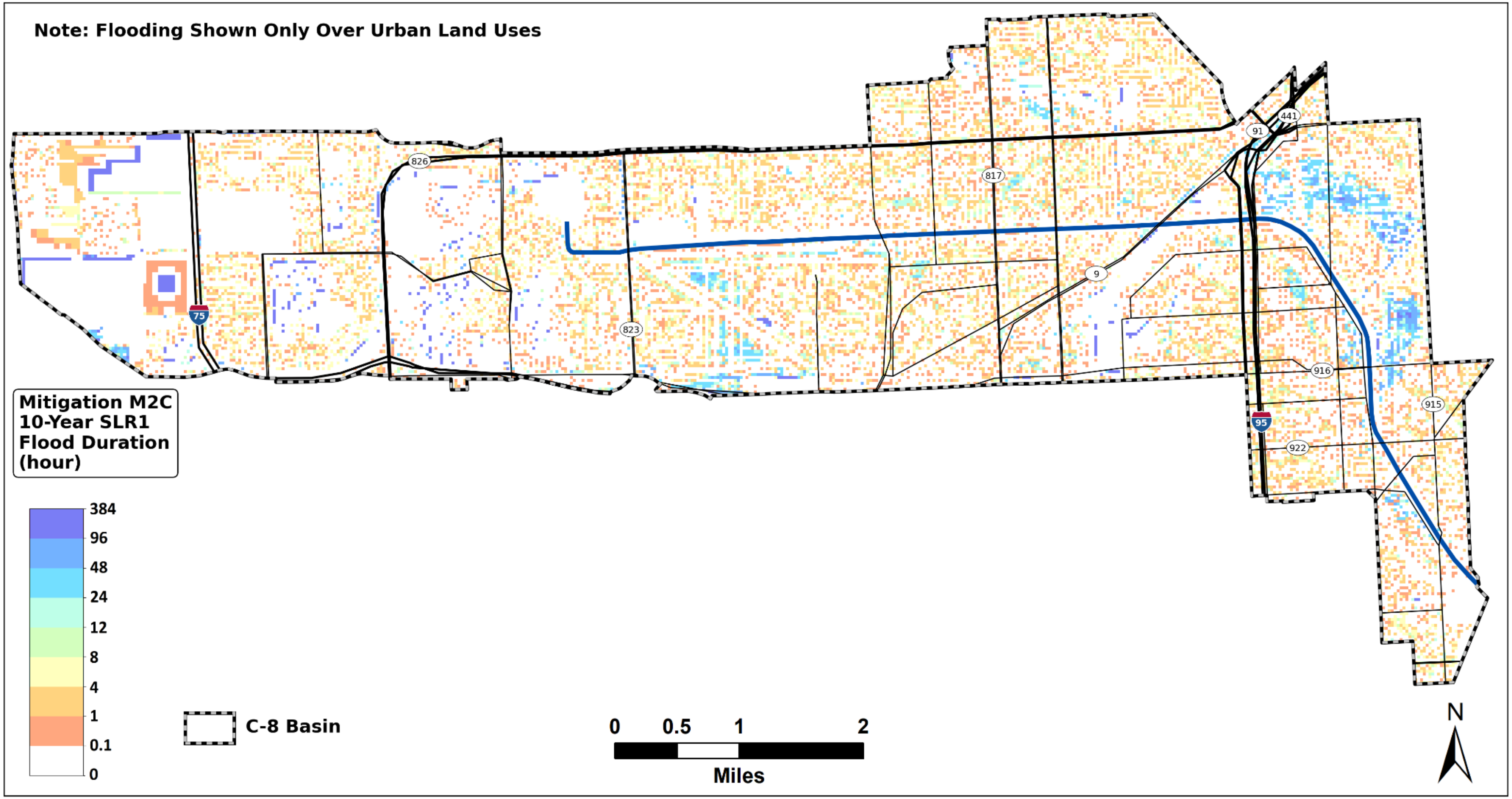


Figure D- 64: C-8 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2C 10-Year Sea Level Rise 1 Design Storm Event

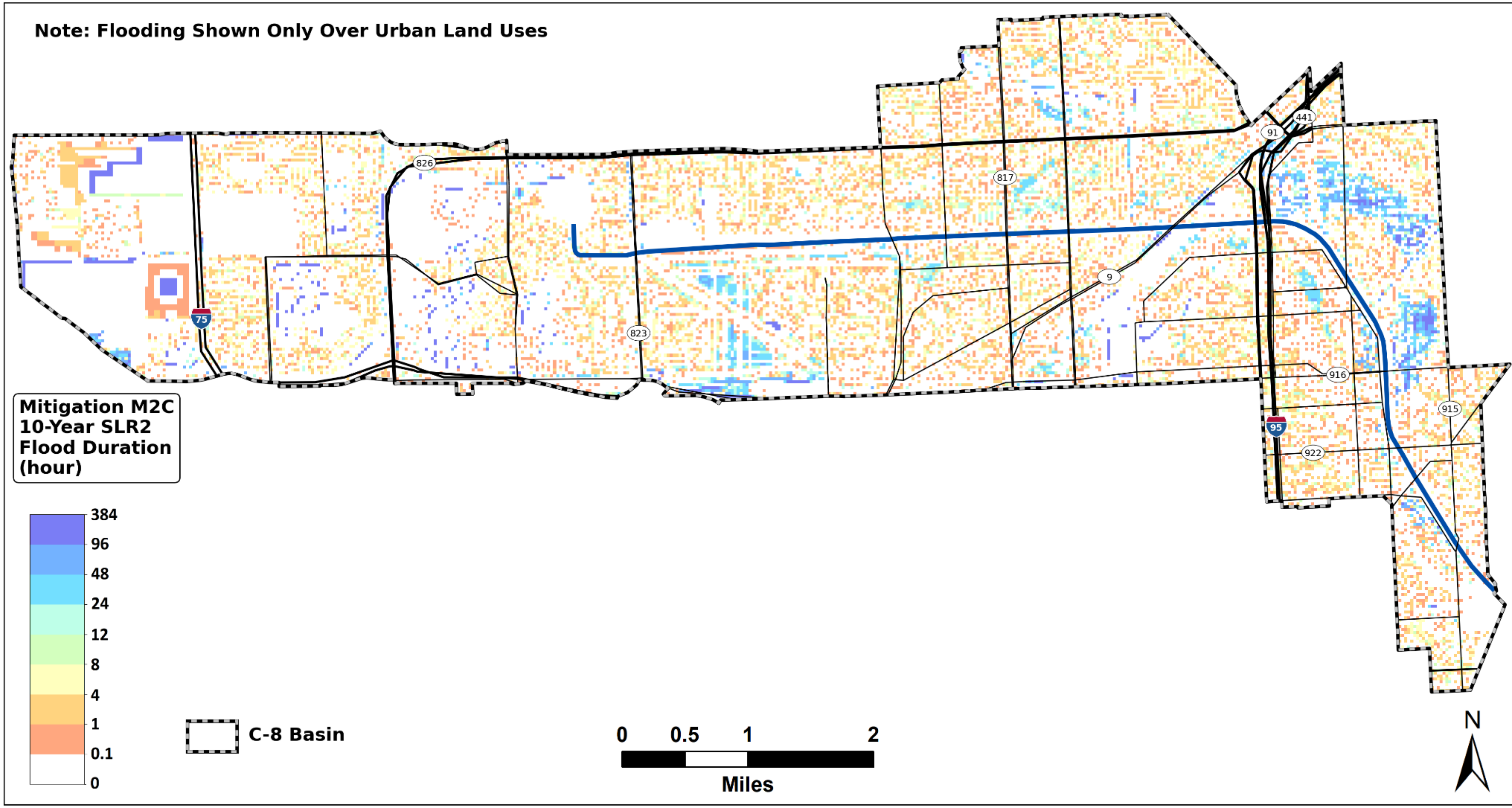


Figure D- 65: C-8 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2C 10-Year Sea Level Rise 2 Design Storm Event

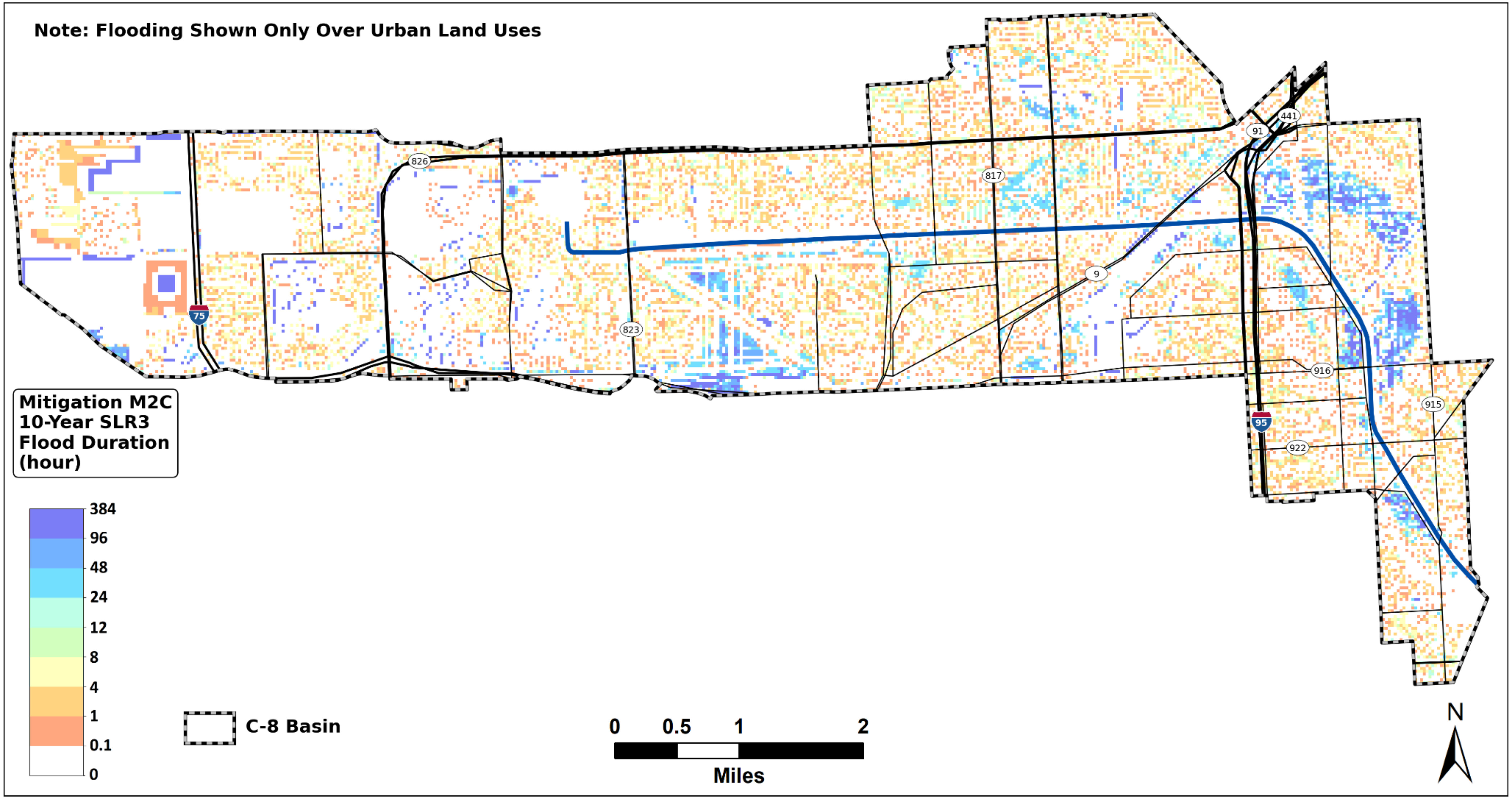


Figure D- 66: C-8 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2C 10-Year Sea Level Rise 3 Design Storm Event

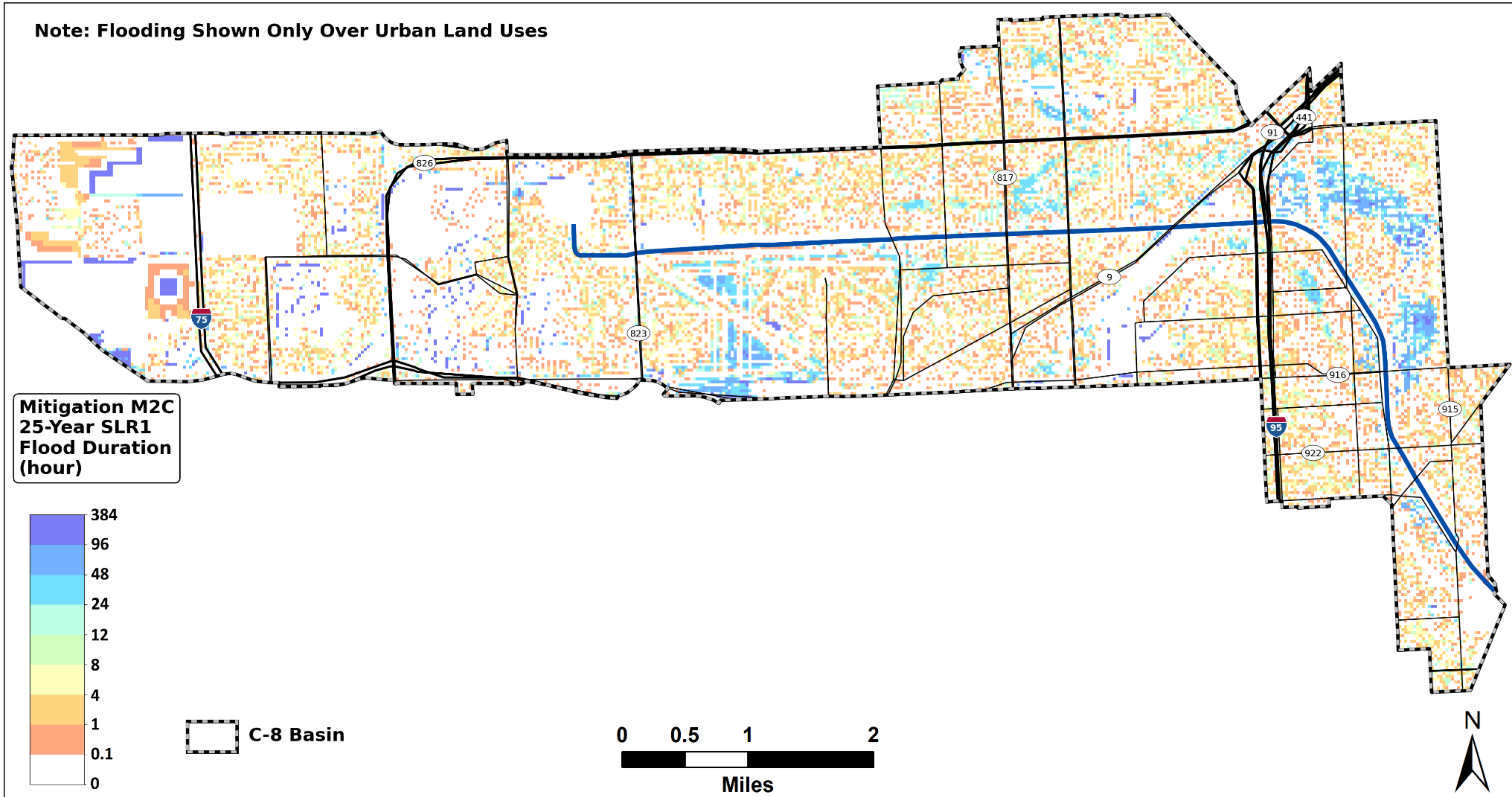


Figure D- 67: C-8 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2C 25-Year Sea Level Rise 1 Design Storm Event

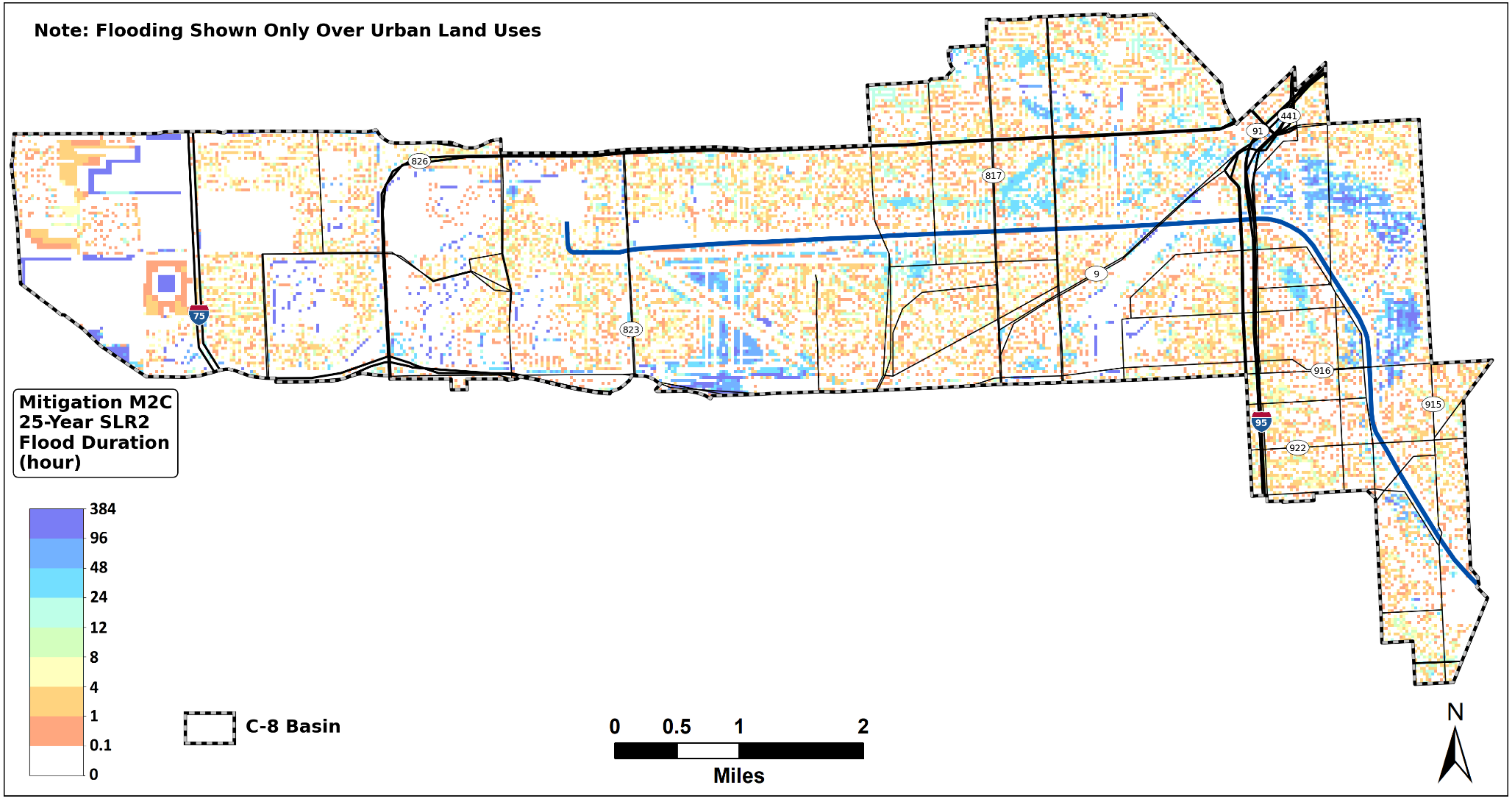


Figure D- 68: C-8 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2C 25-Year Sea Level Rise 2 Design Storm Event

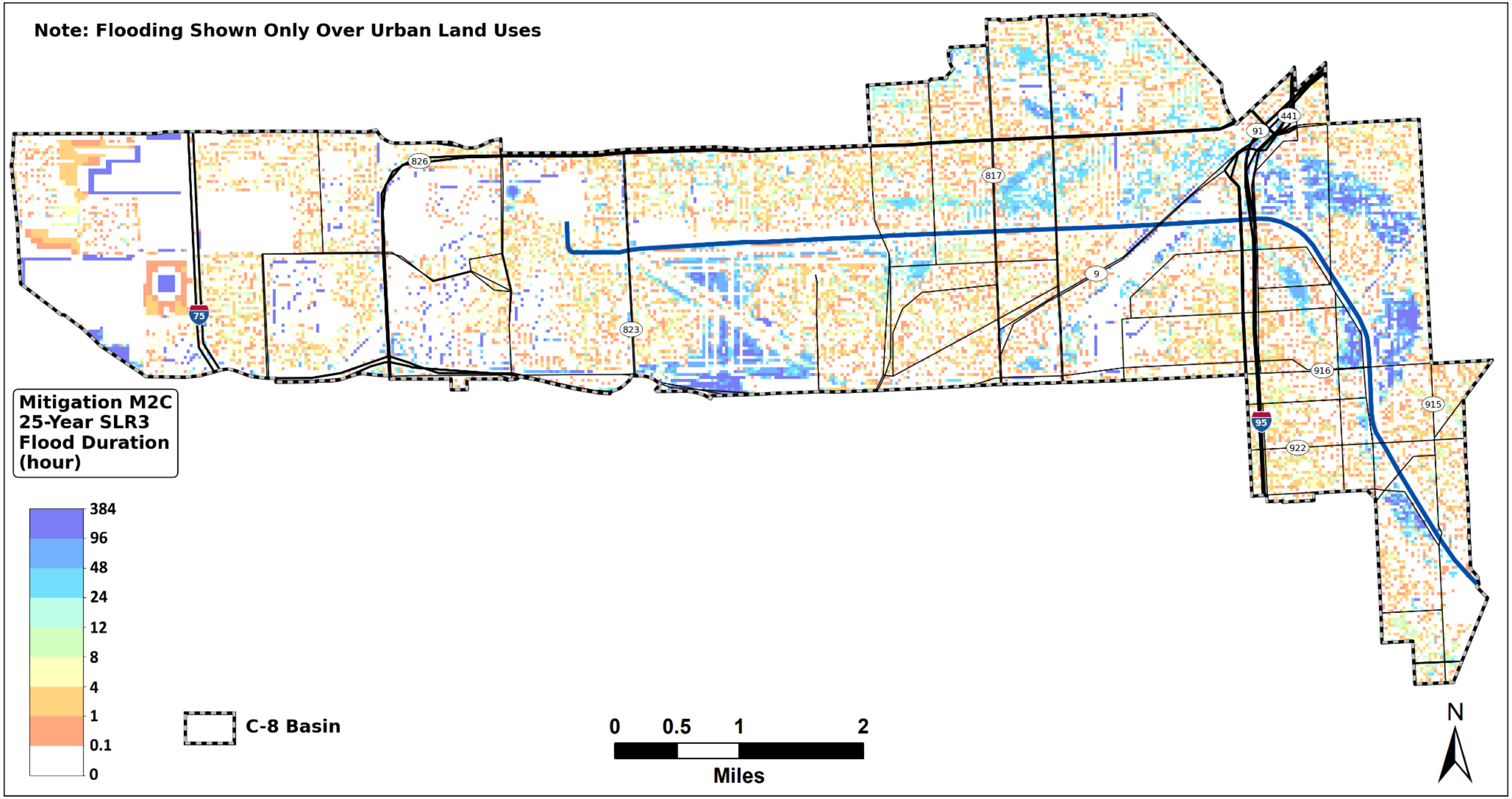


Figure D- 69: C-8 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2C 25-Year Sea Level Rise 3 Design Storm Event

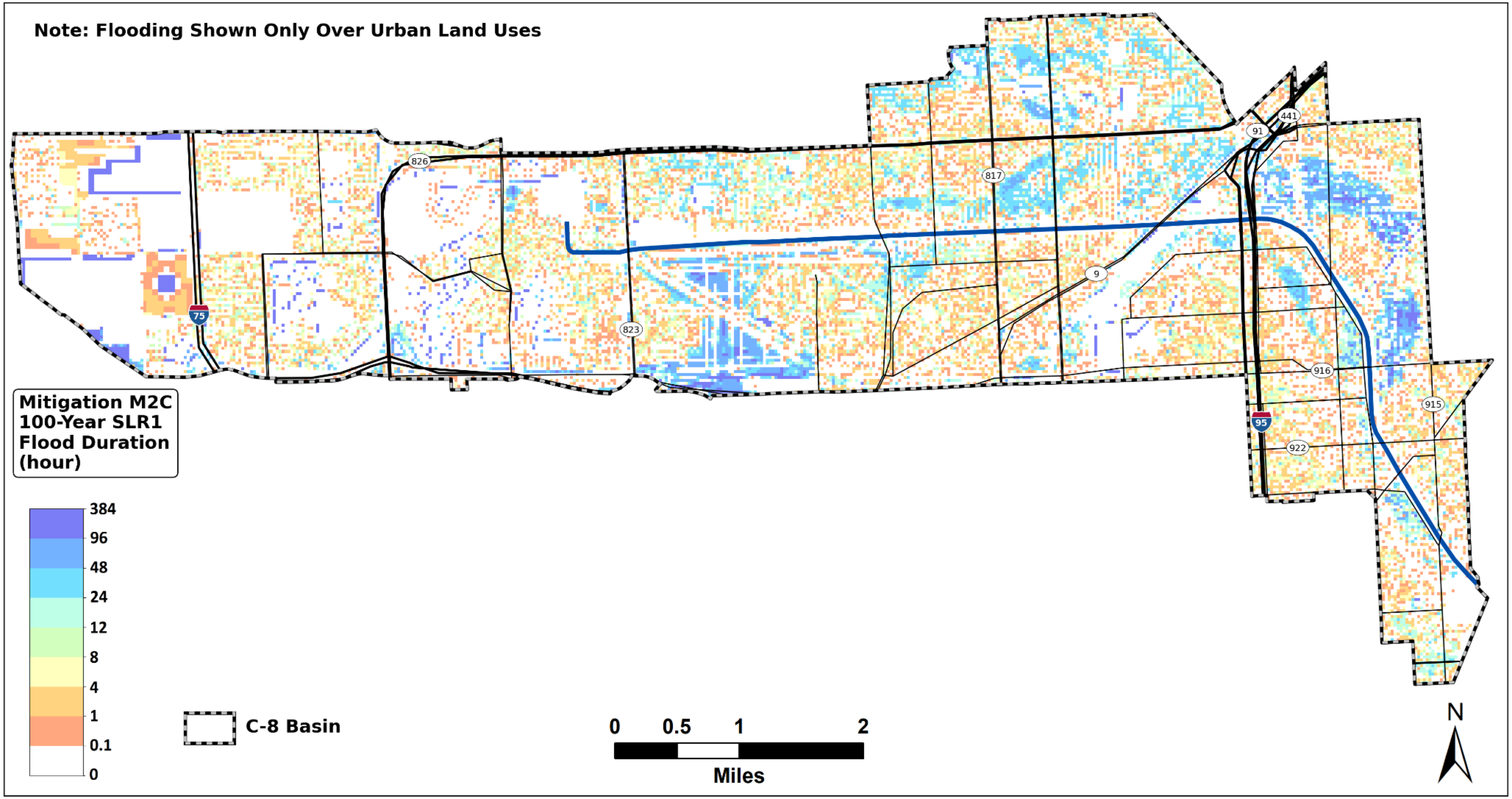


Figure D- 70: C-8 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2C 100-Year Sea Level Rise 1 Design Storm Event

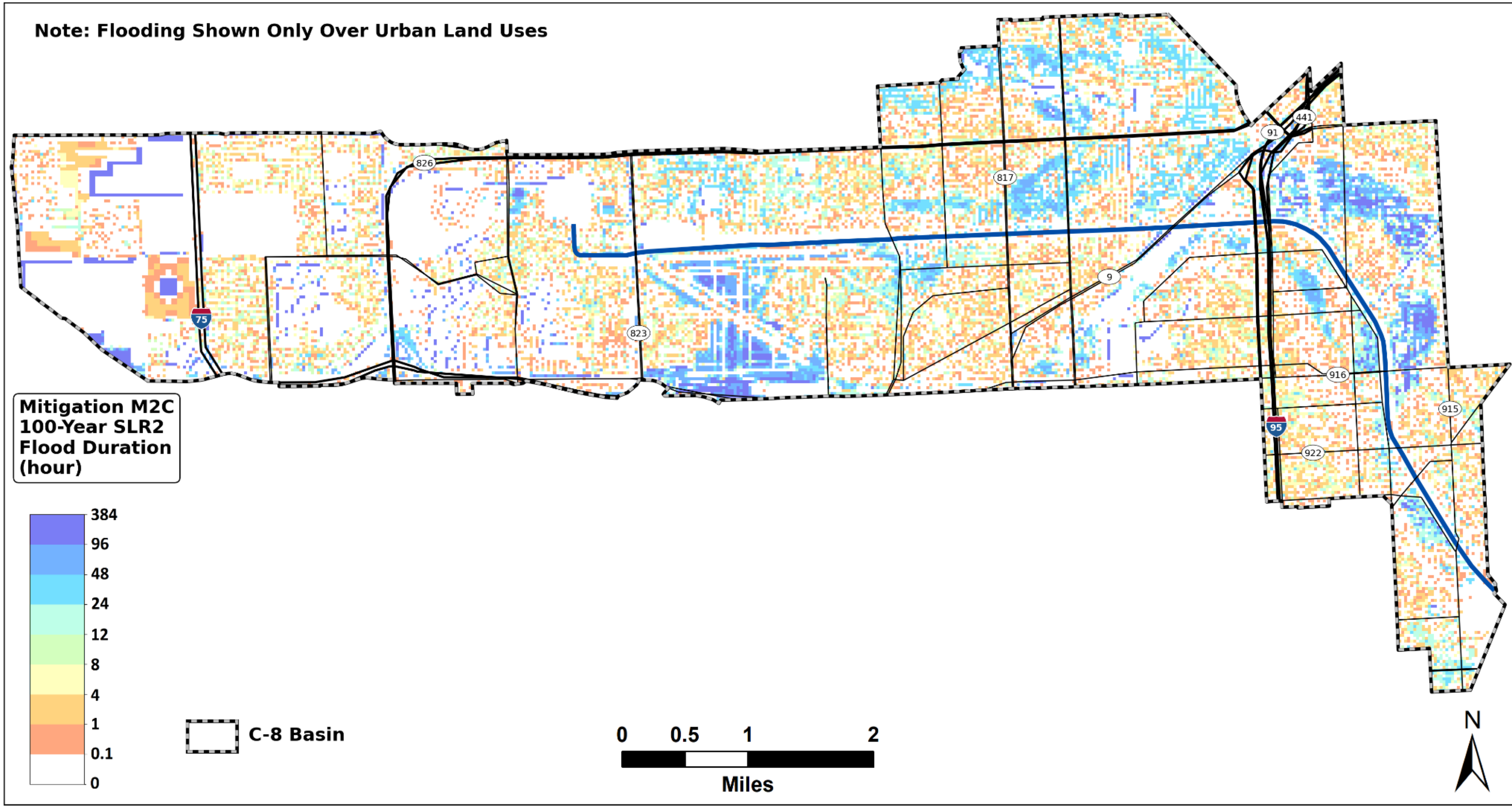


Figure D- 71: C-8 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2C 100-Year Sea Level Rise 2 Design Storm Event

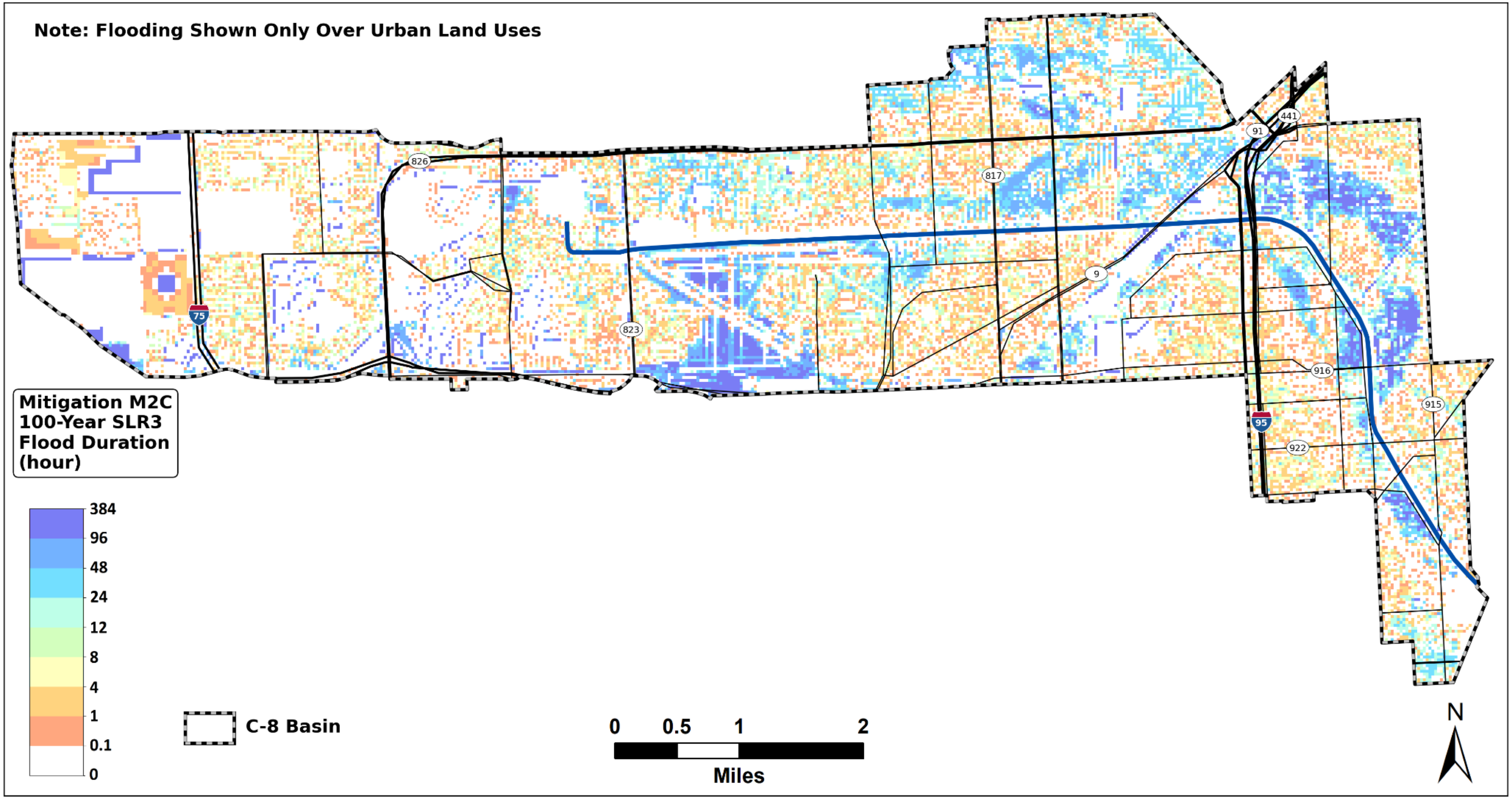


Figure D- 72: C-8 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2C 100-Year Sea Level Rise 3 Design Storm Event

Appendix E Complete Set of PM #6 Flood Duration Maps for the C-9 Watershed

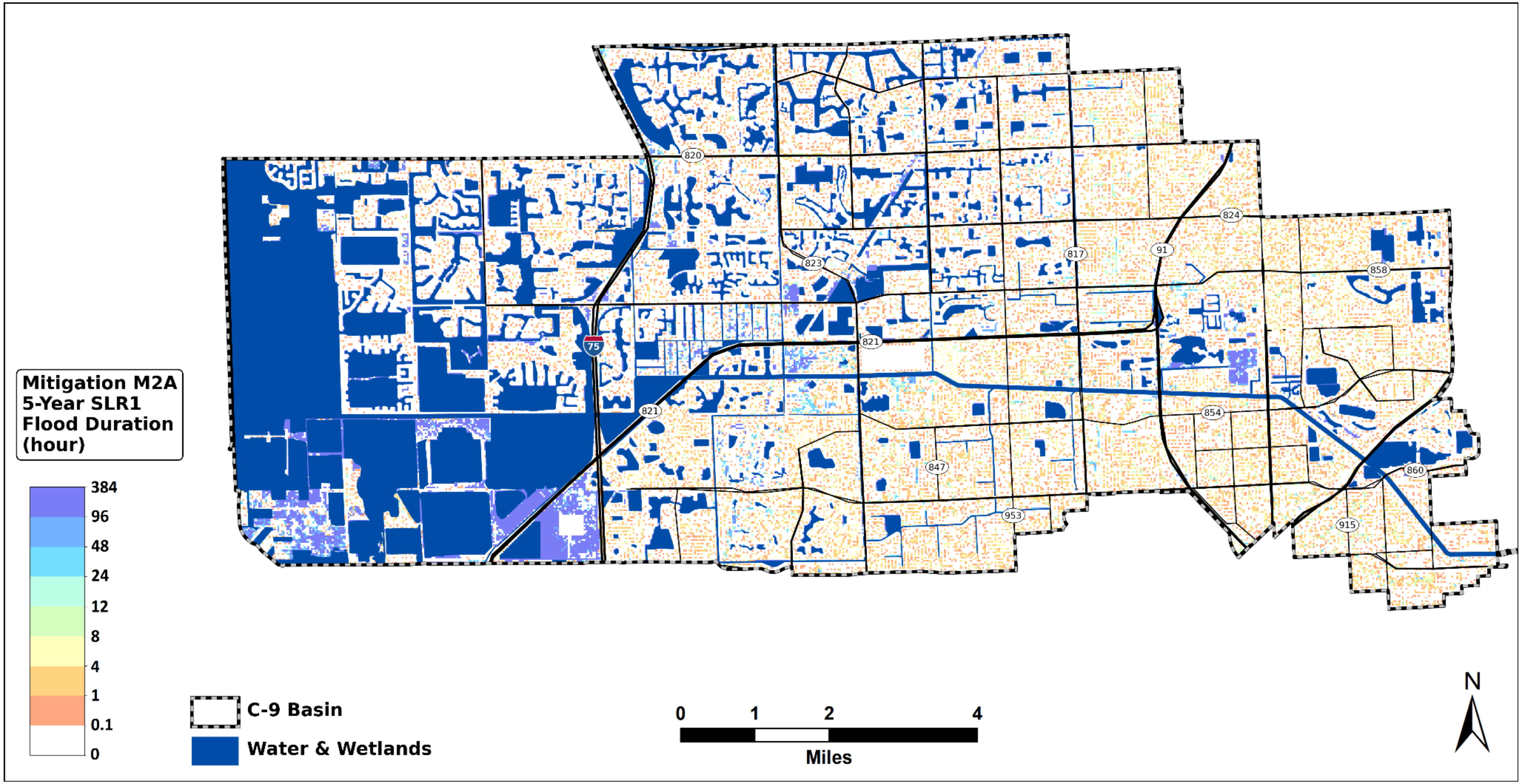


Figure E- 1: C-9 Watershed Flood Duration Map for the Mitigation M2A 5-Year Sea Level Rise 1 Design Storm Event

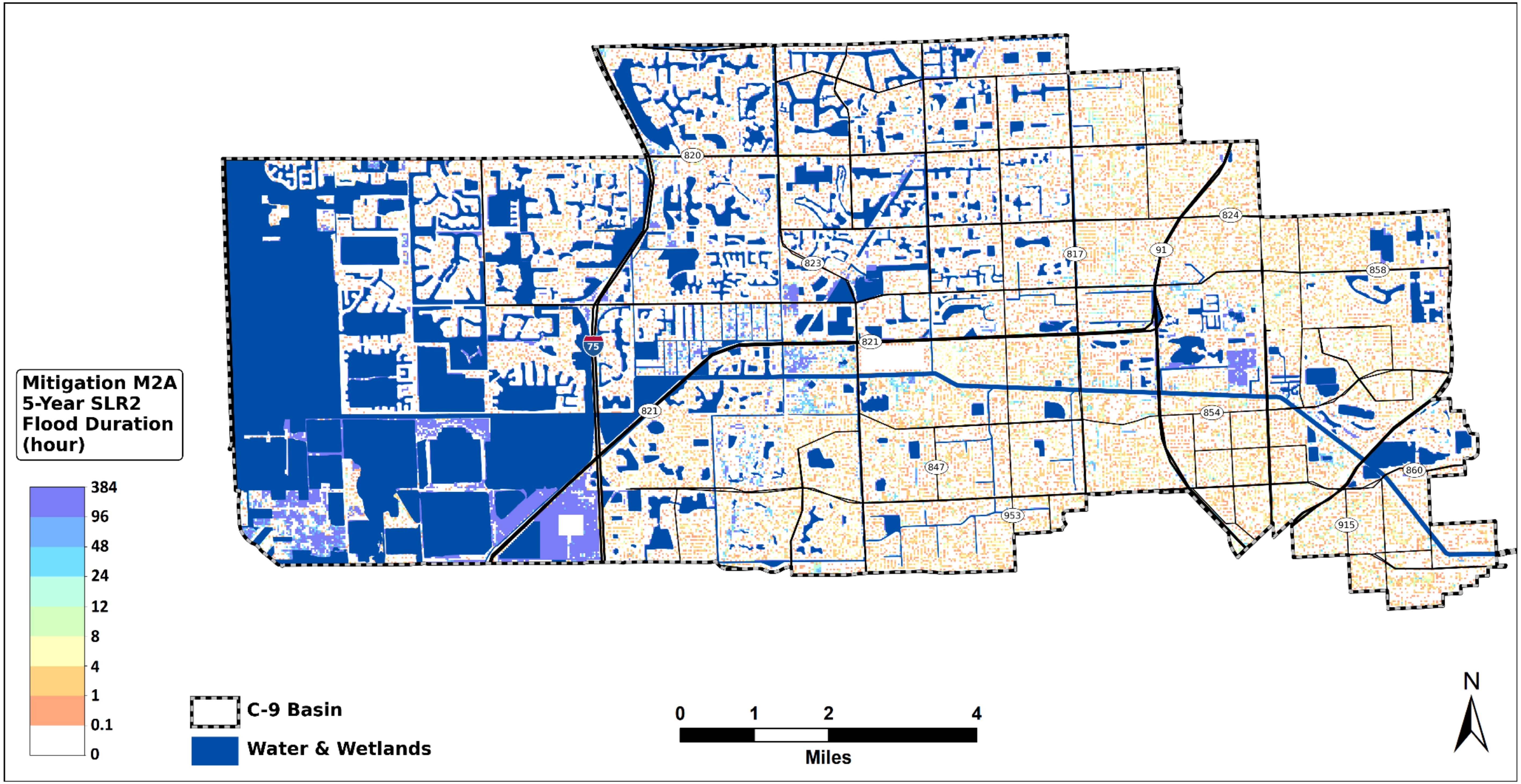


Figure E- 2: C-9 Watershed Flood Duration Map for the Mitigation M2A 5-Year Sea Level Rise 2 Design Storm Event

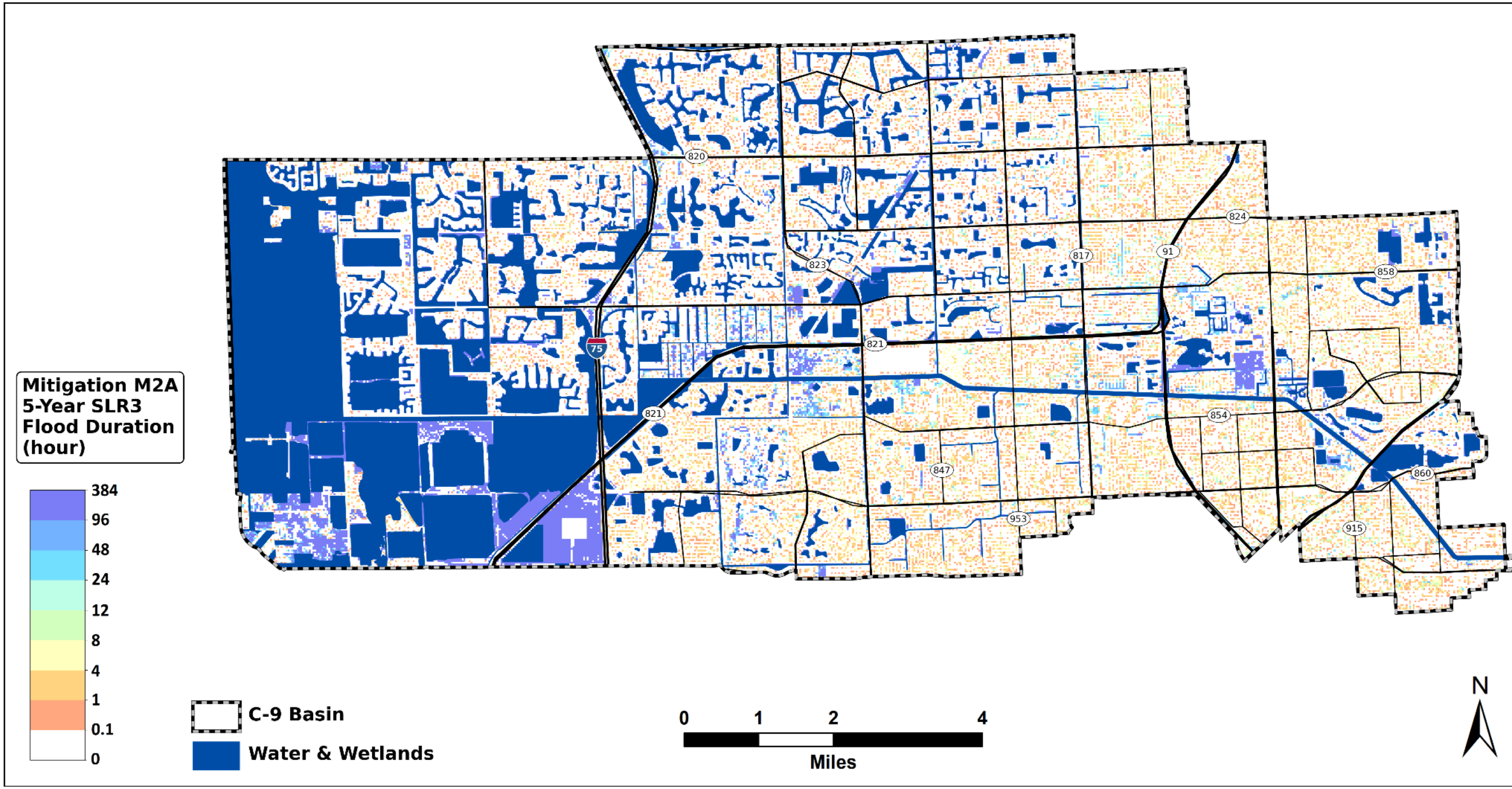


Figure E- 3: C-9 Watershed Flood Duration Map for the Mitigation M2A 5-Year Sea Level Rise 3 Design Storm Event

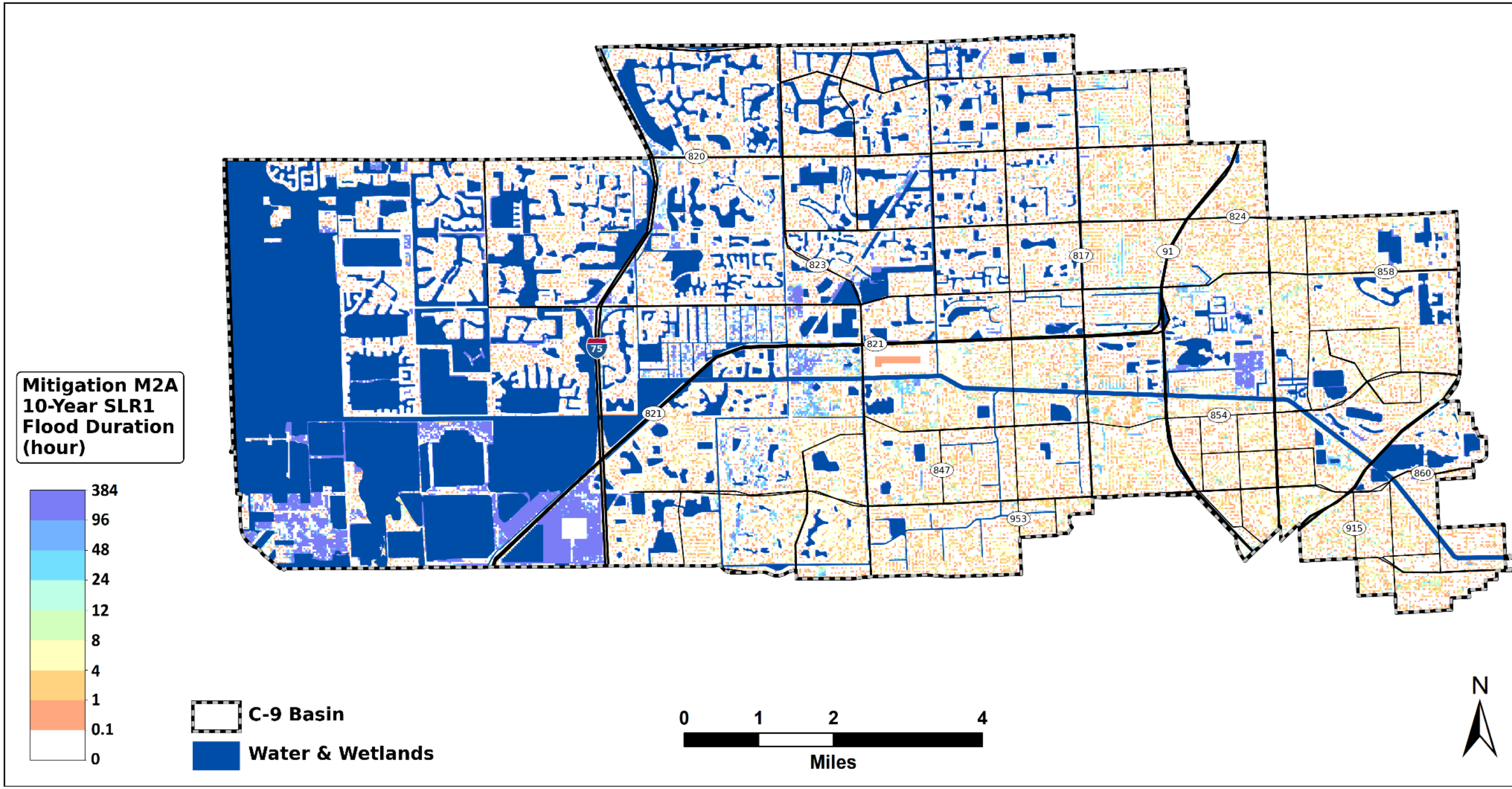


Figure E- 4: C-9 Watershed Flood Duration Map for the Mitigation M2A 10-Year Sea Level Rise 1 Design Storm Event

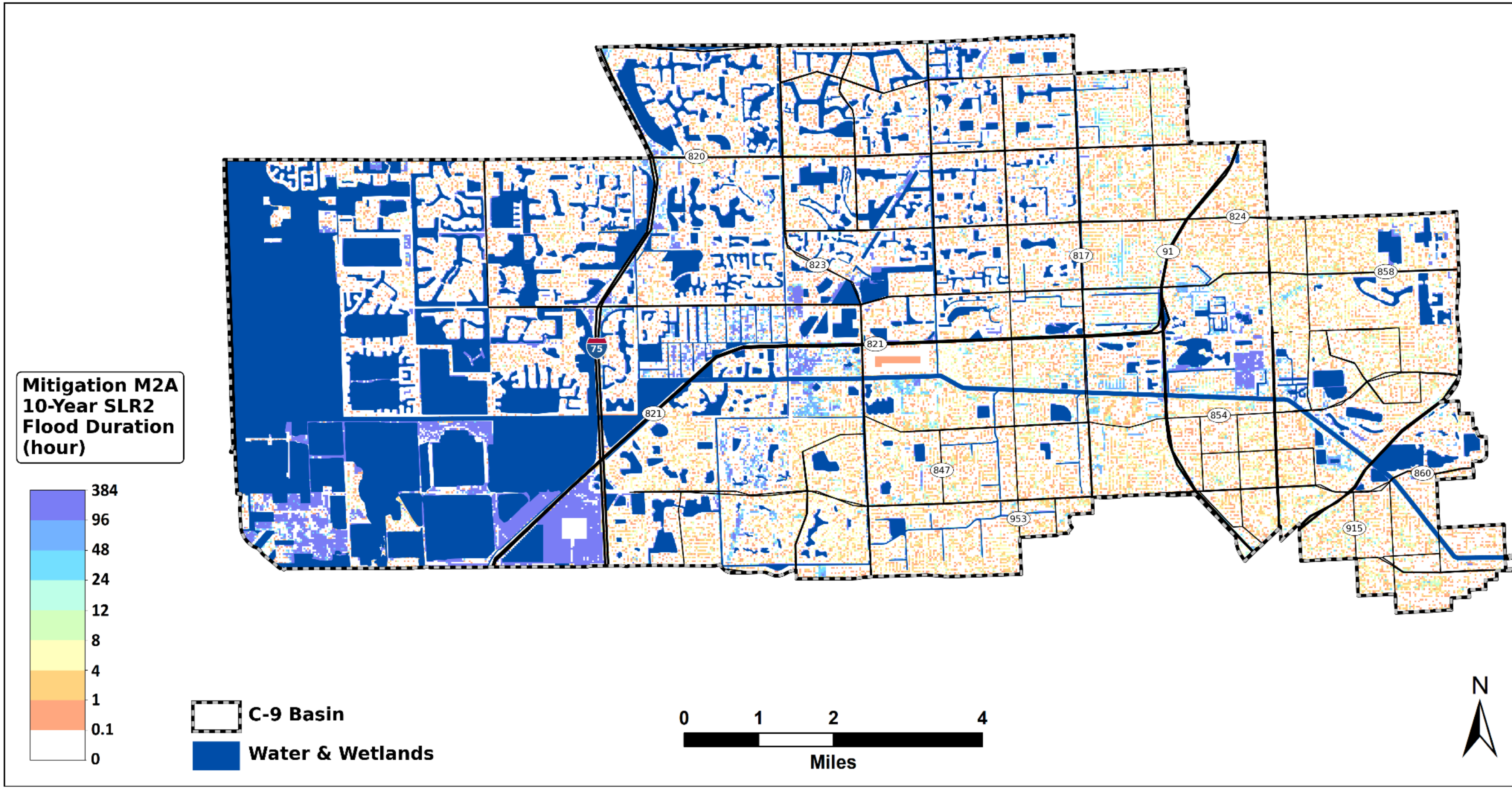


Figure E- 5: C-9 Watershed Flood Duration Map for the Mitigation M2A 10-Year Sea Level Rise 2 Design Storm Event

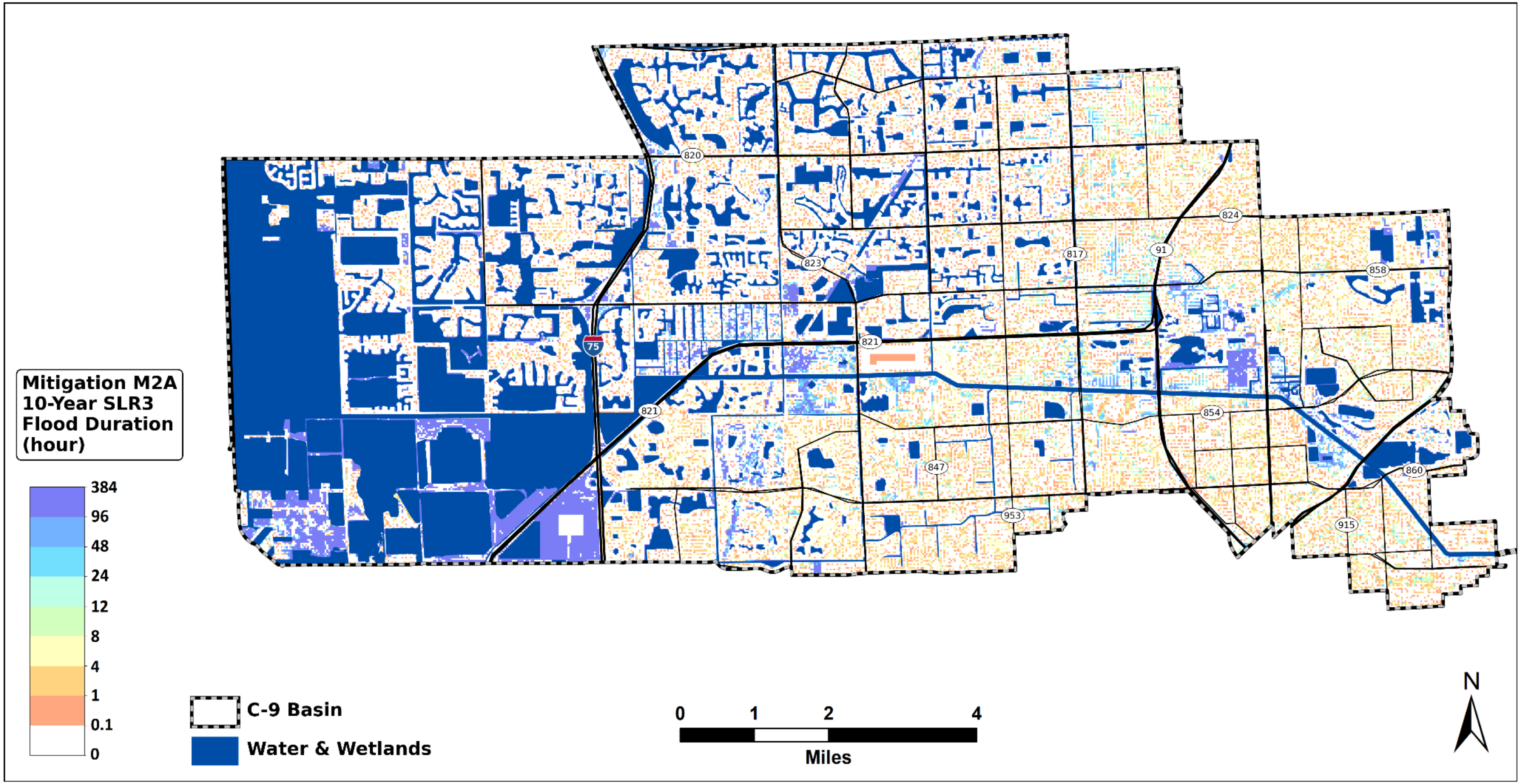


Figure E- 6: C-9 Watershed Flood Duration Map for the Mitigation M2A 10-Year Sea Level Rise 3 Design Storm Event

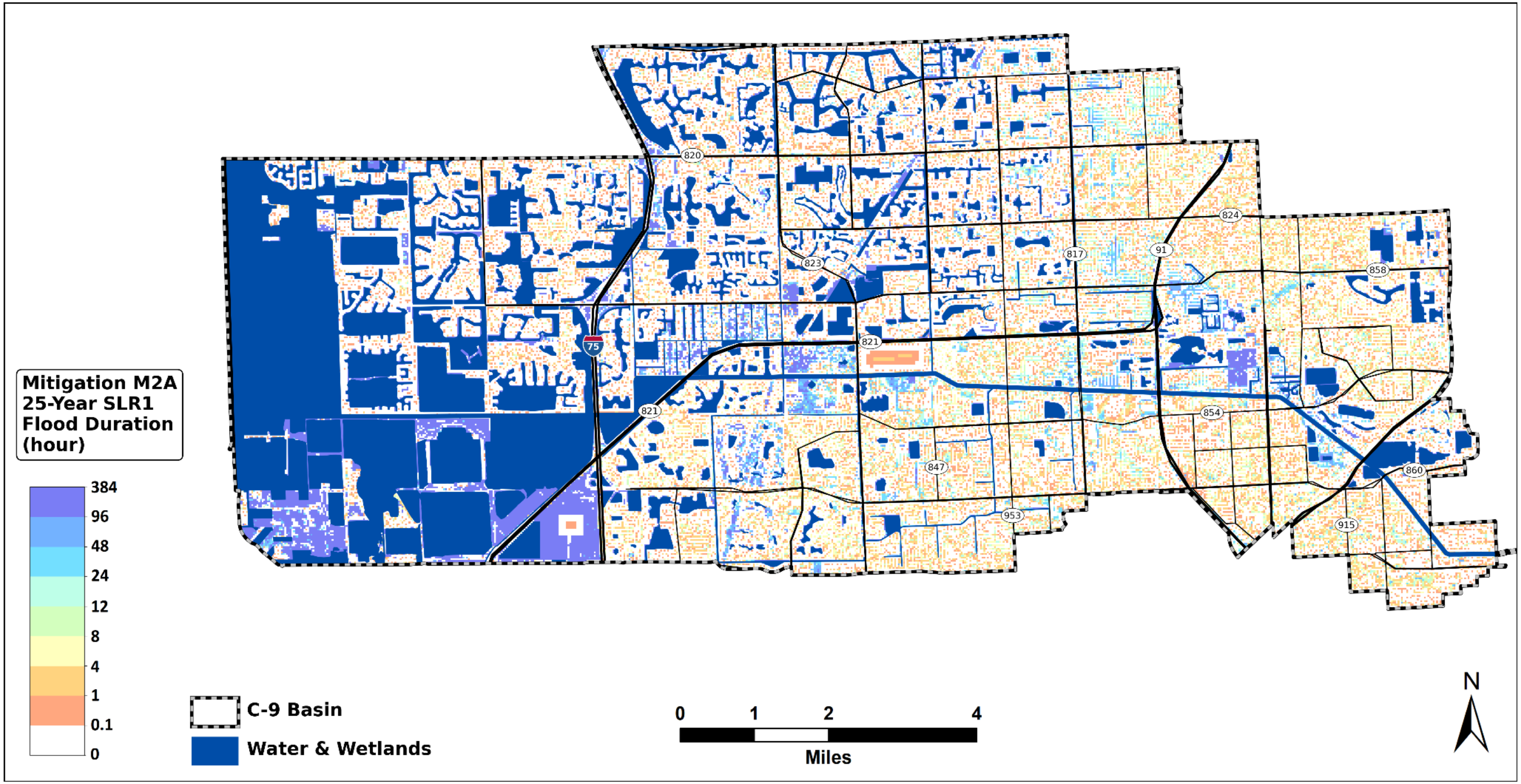


Figure E- 7: C-9 Watershed Flood Duration Map for the Mitigation M2A 25-Year Sea Level Rise 1 Design Storm Event

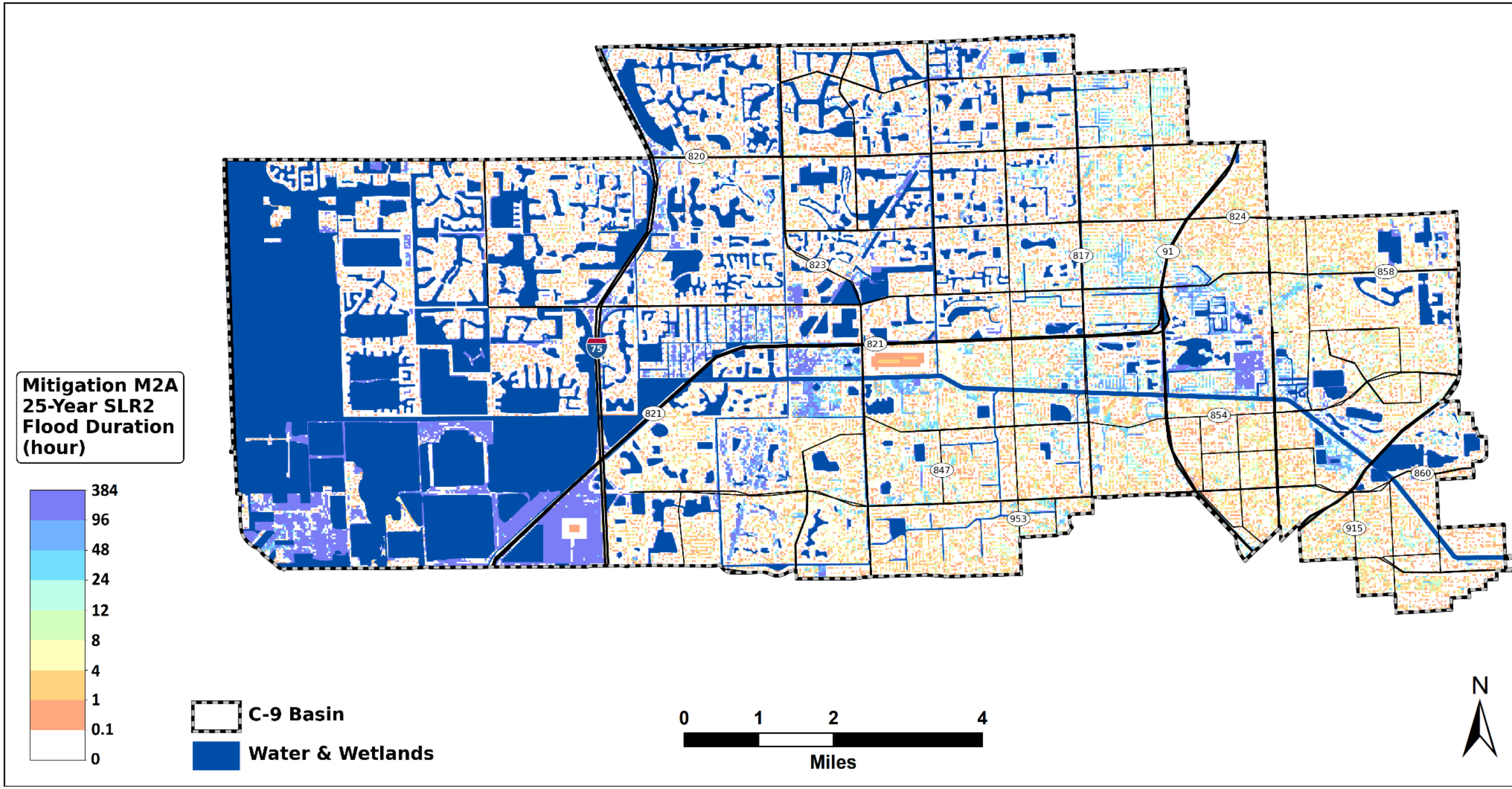


Figure E- 8: C-9 Watershed Flood Duration Map for the Mitigation M2A 25-Year Sea Level Rise 2 Design Storm Event

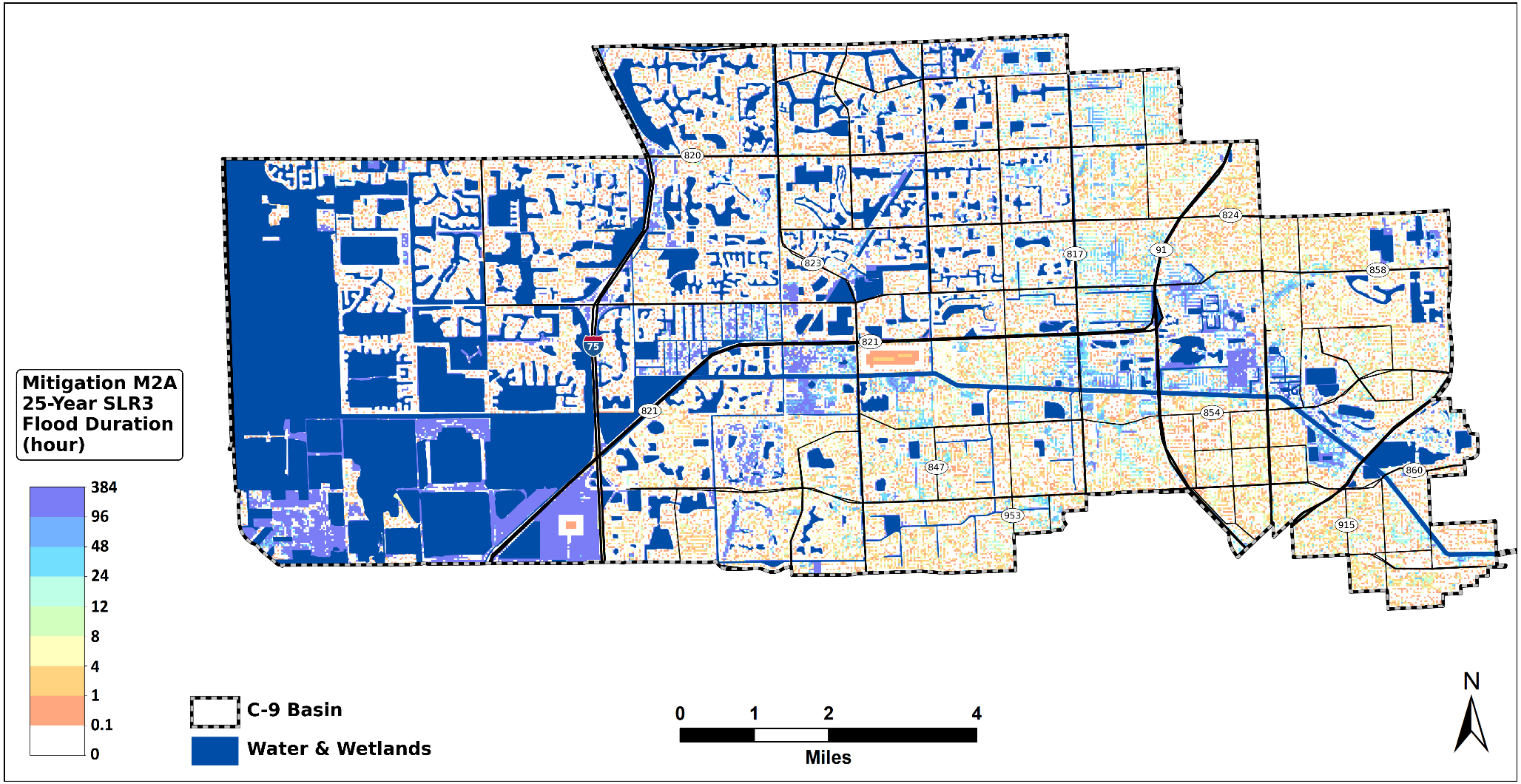


Figure E- 9: C-9 Watershed Flood Duration Map for the Mitigation M2A 25-Year Sea Level Rise 3 Design Storm Event

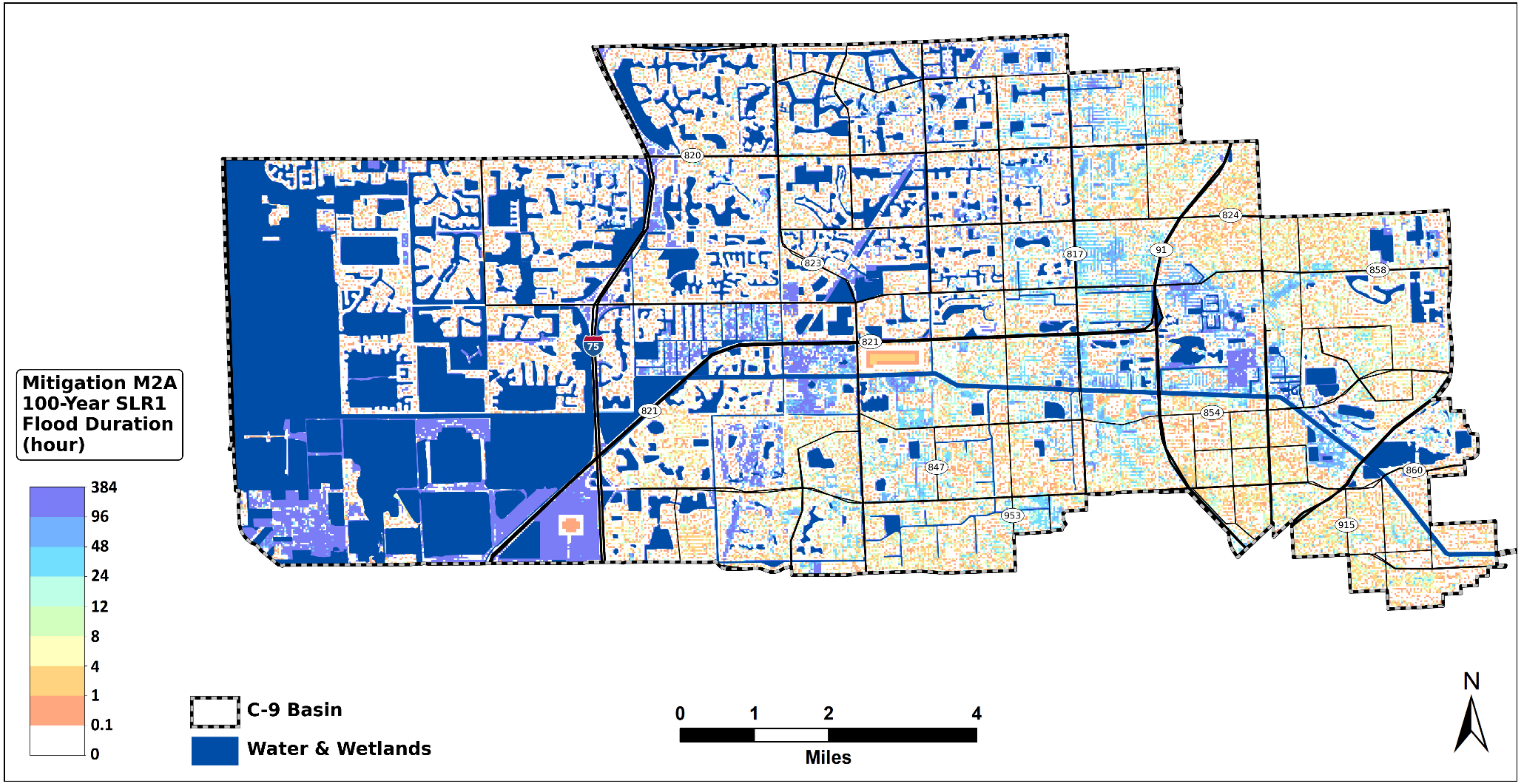


Figure E- 10: C-9 Watershed Flood Duration Map for the Mitigation M2A 100-Year Sea Level Rise 1 Design Storm Event

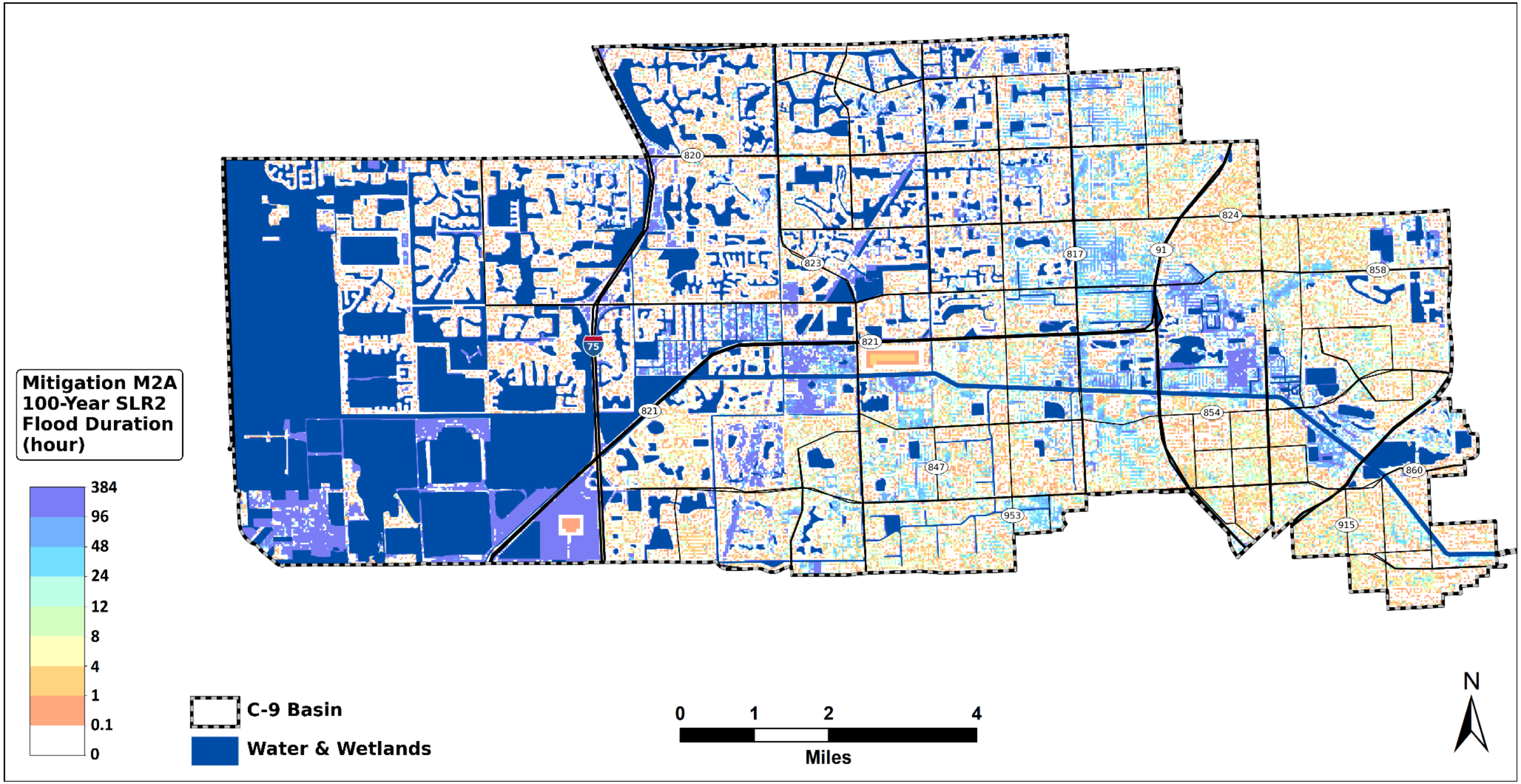


Figure E- 11: C-9 Watershed Flood Duration Map for the Mitigation M2A 100-Year Sea Level Rise 2 Design Storm Event

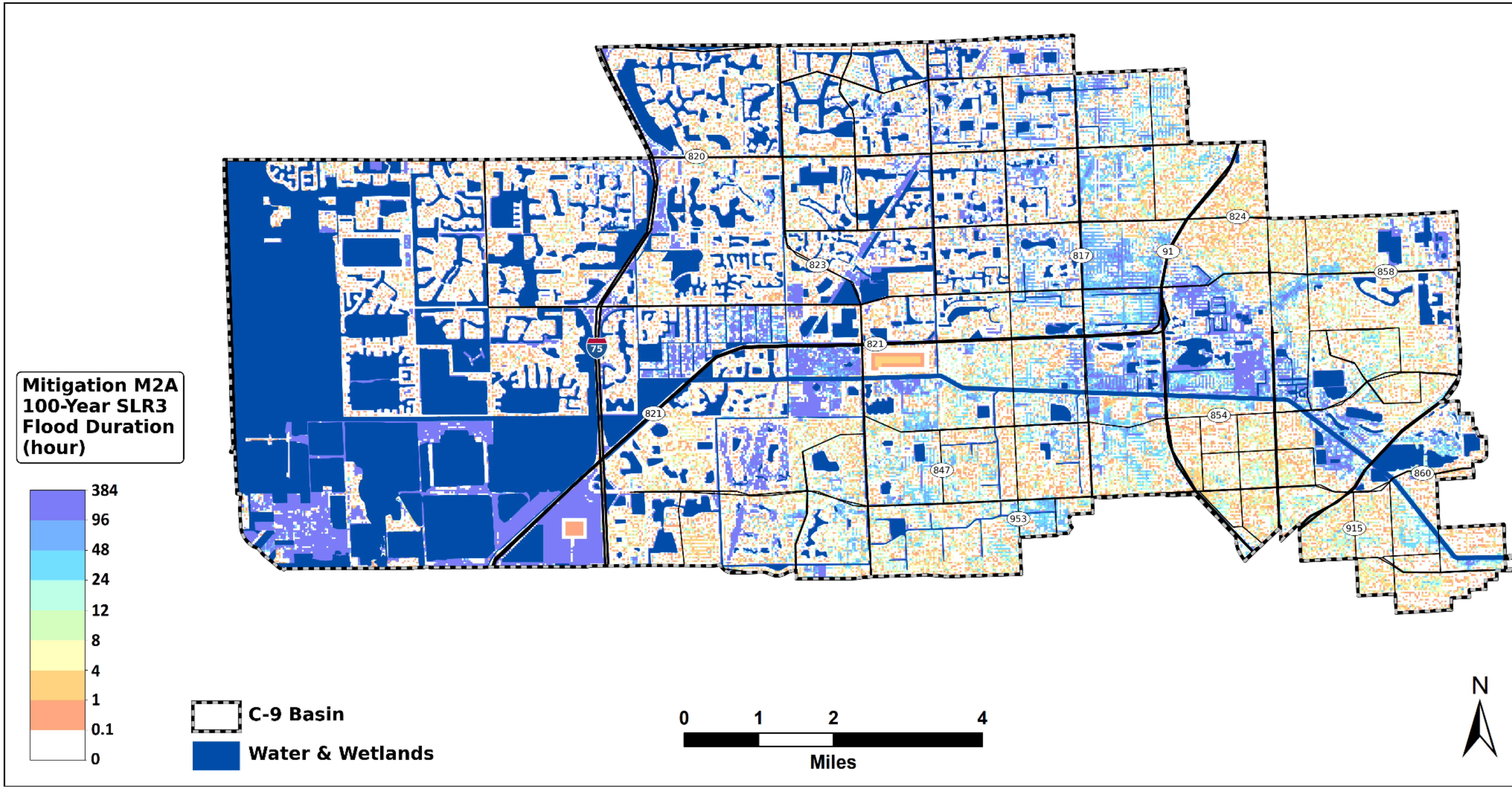


Figure E- 12: C-9 Watershed Flood Duration Map for the Mitigation M2A 100-Year Sea Level Rise 3 Design Storm Event

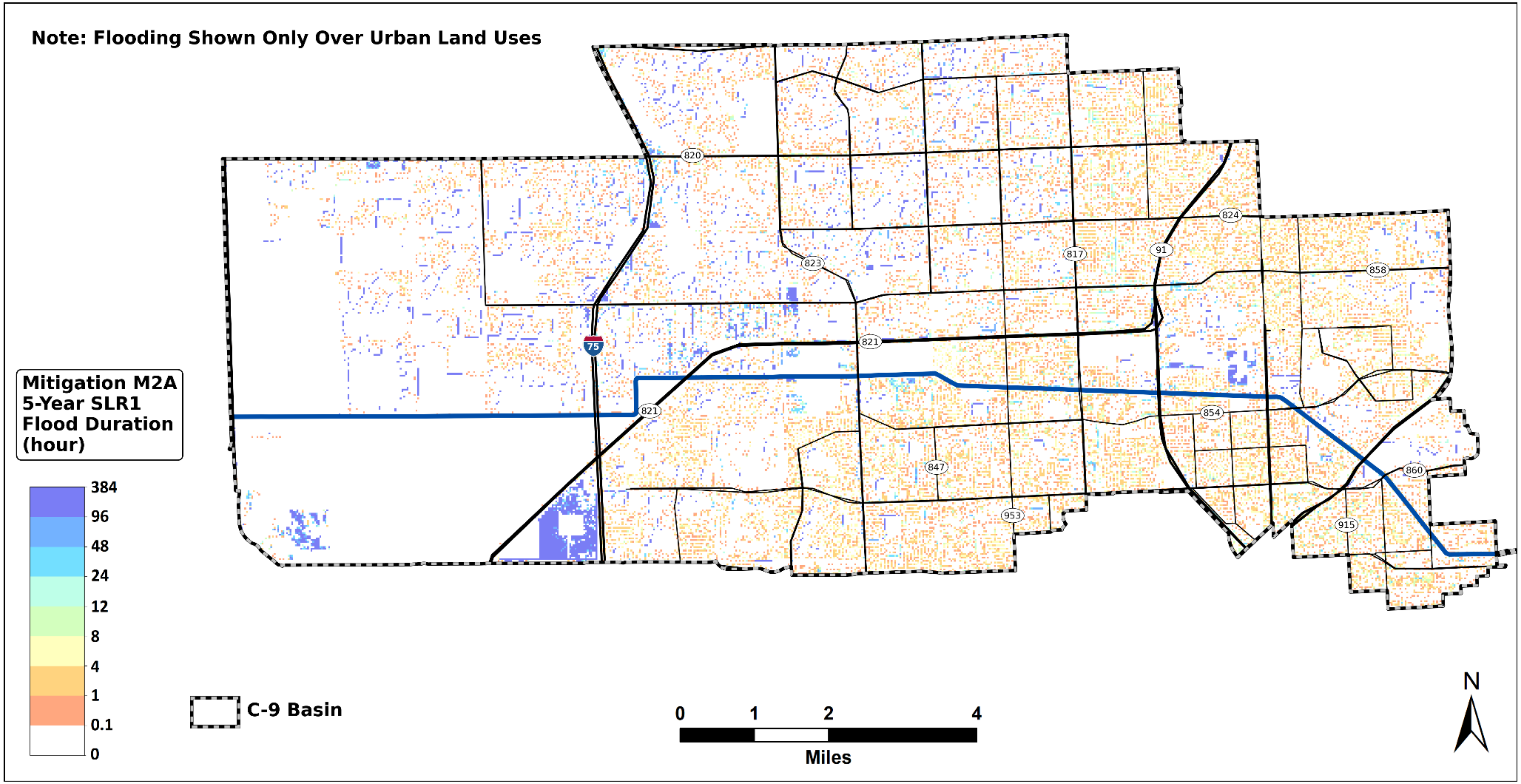


Figure E- 13: C-9 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2A 5-Year Sea Level Rise 1 Design Storm Event

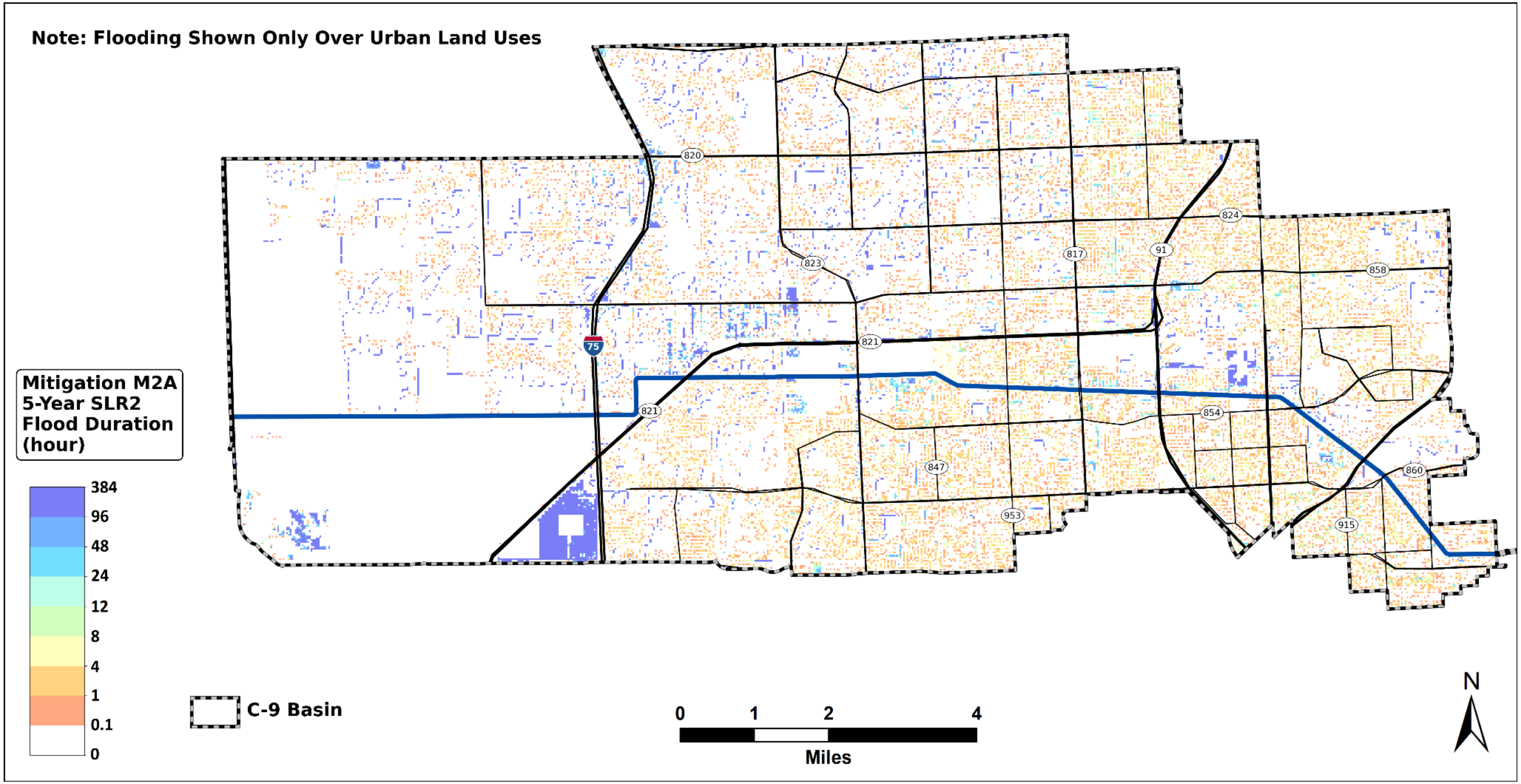


Figure E- 14: C-9 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2A 5-Year Sea Level Rise 2 Design Storm Event

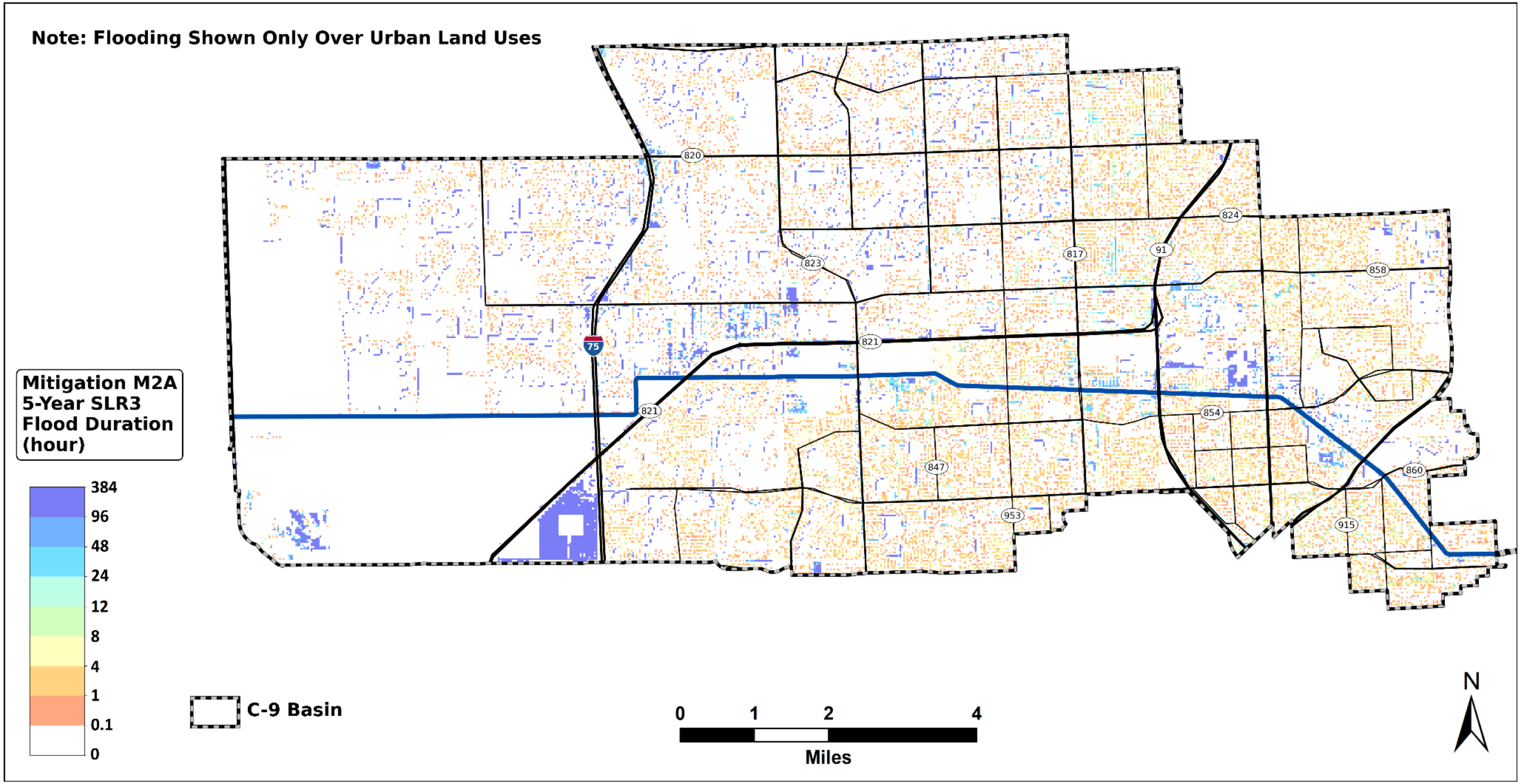


Figure E- 15: C-9 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2A 5-Year Sea Level Rise 3 Design Storm Event

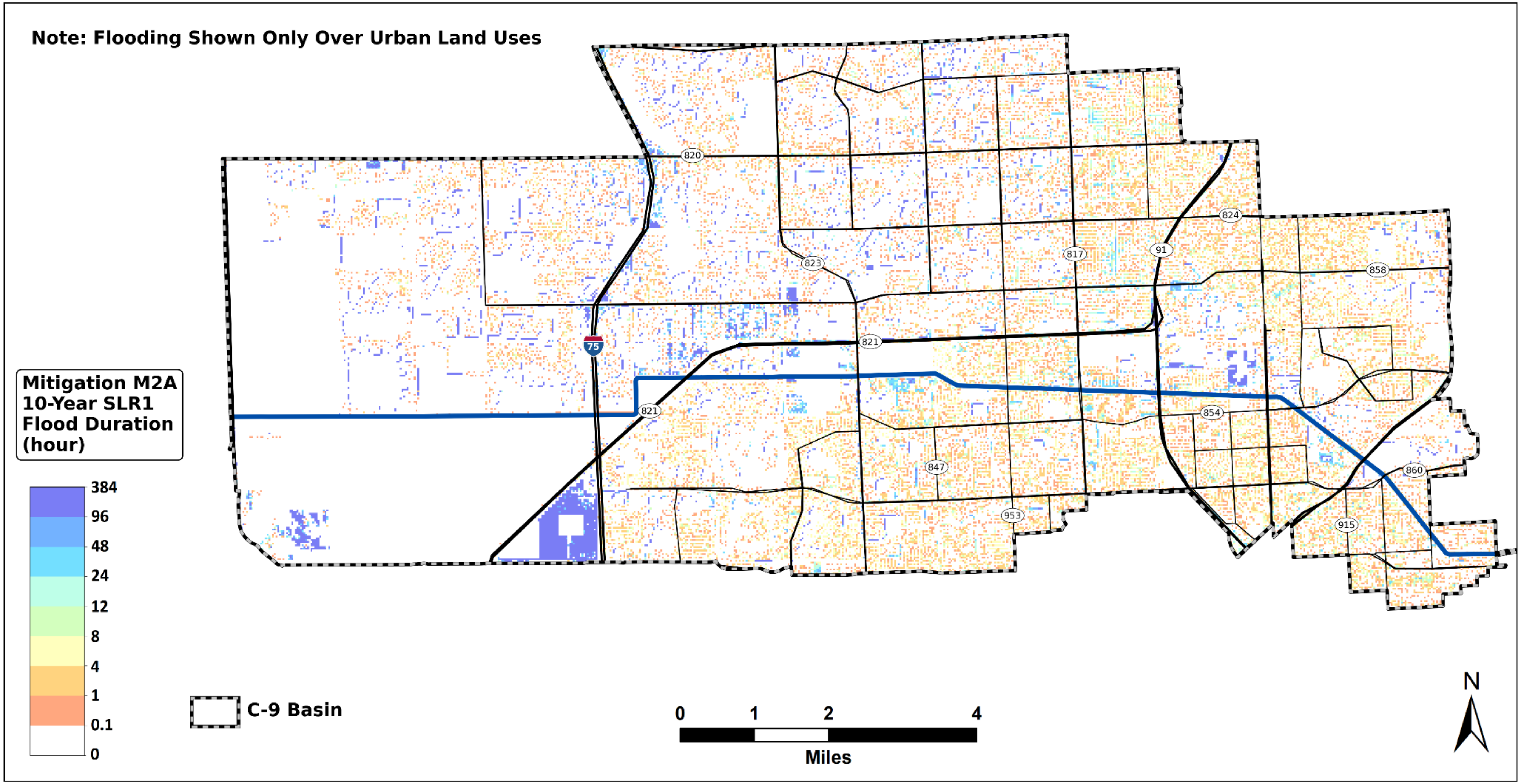


Figure E- 16: C-9 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2A 10-Year Sea Level Rise 1 Design Storm Event

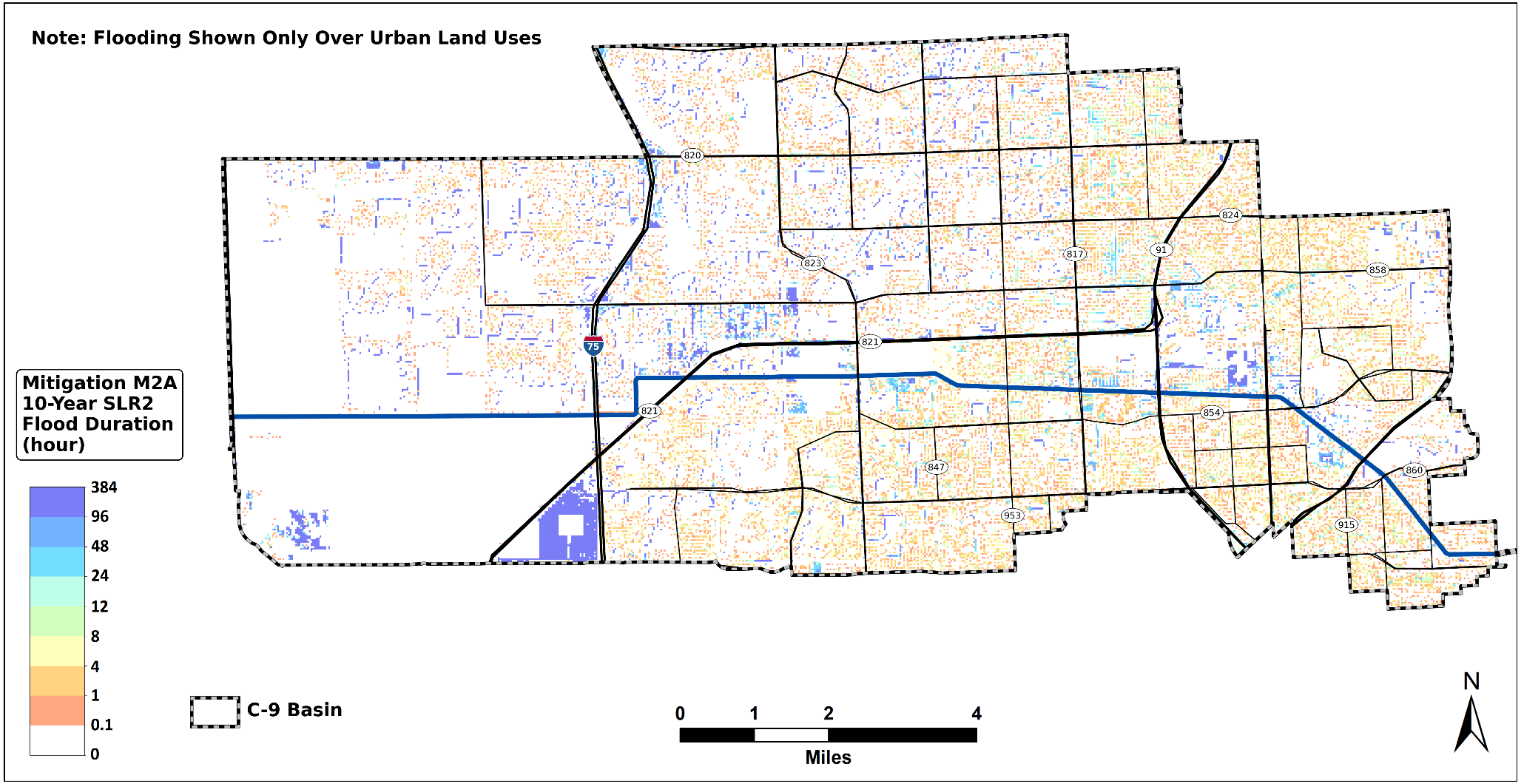


Figure E- 17: C-9 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2A 10-Year Sea Level Rise 2 Design Storm Event

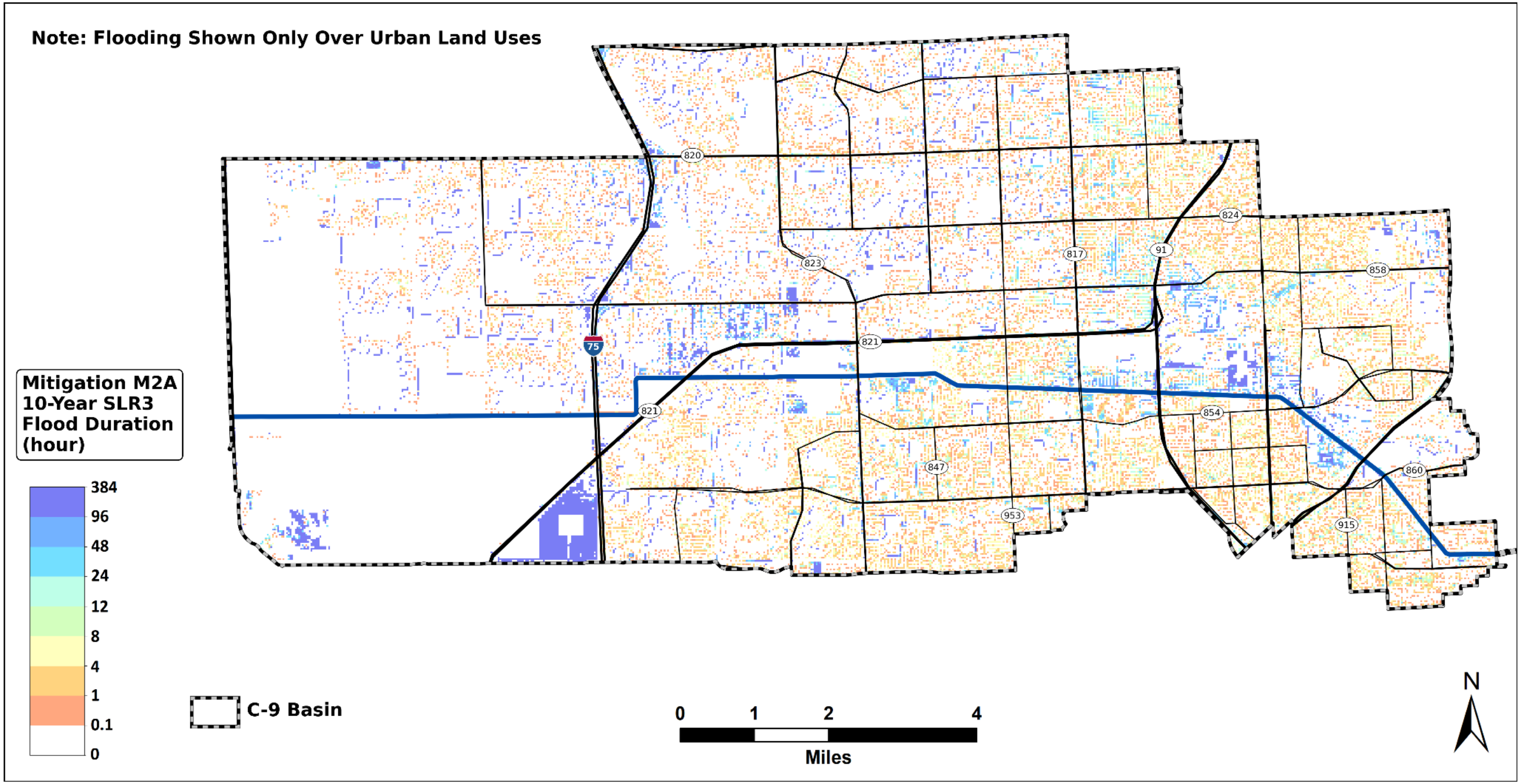


Figure E- 18: C-9 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2A 10-Year Sea Level Rise 3 Design Storm Event

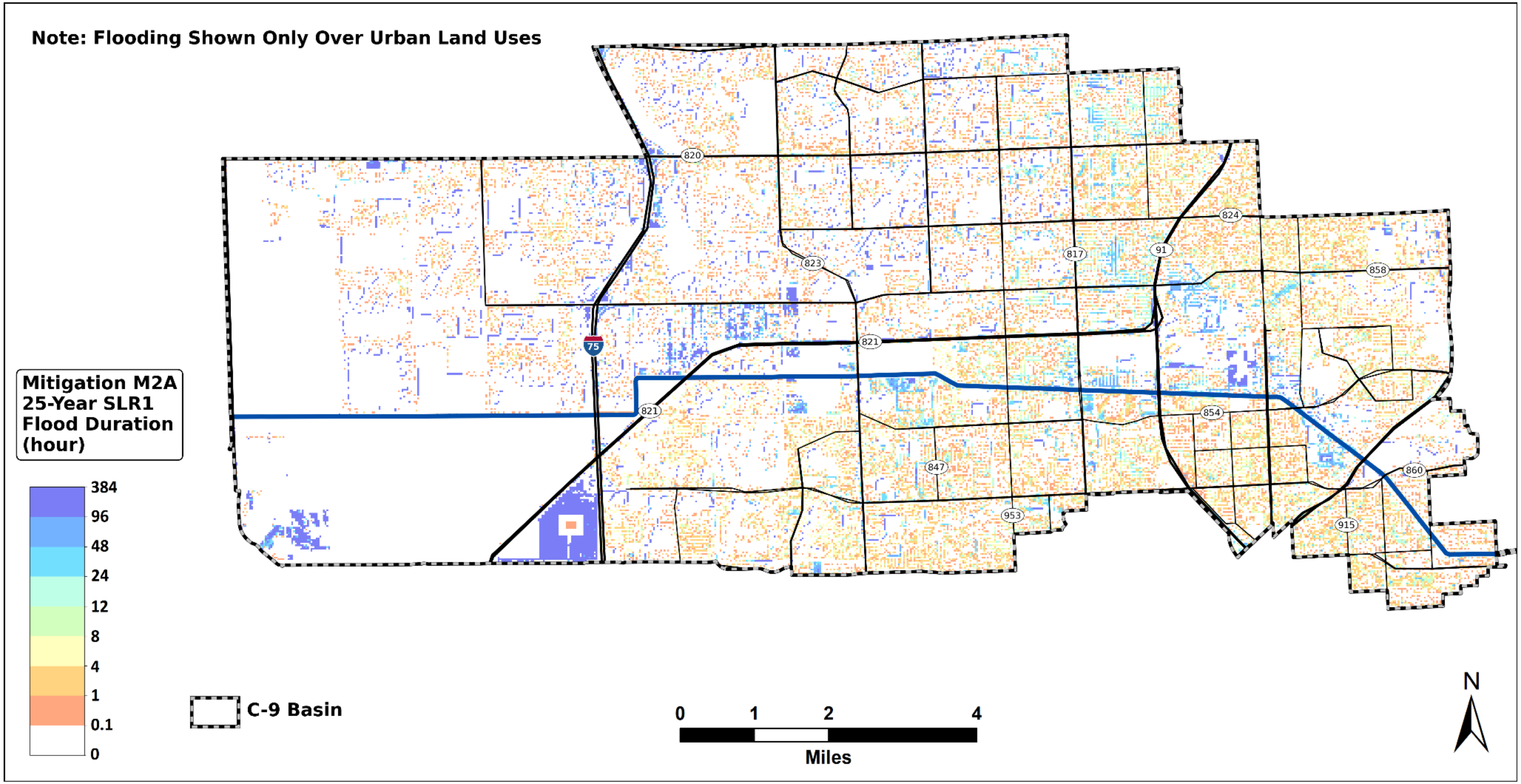


Figure E- 19: C-9 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2A 25-Year Sea Level Rise 1 Design Storm Event

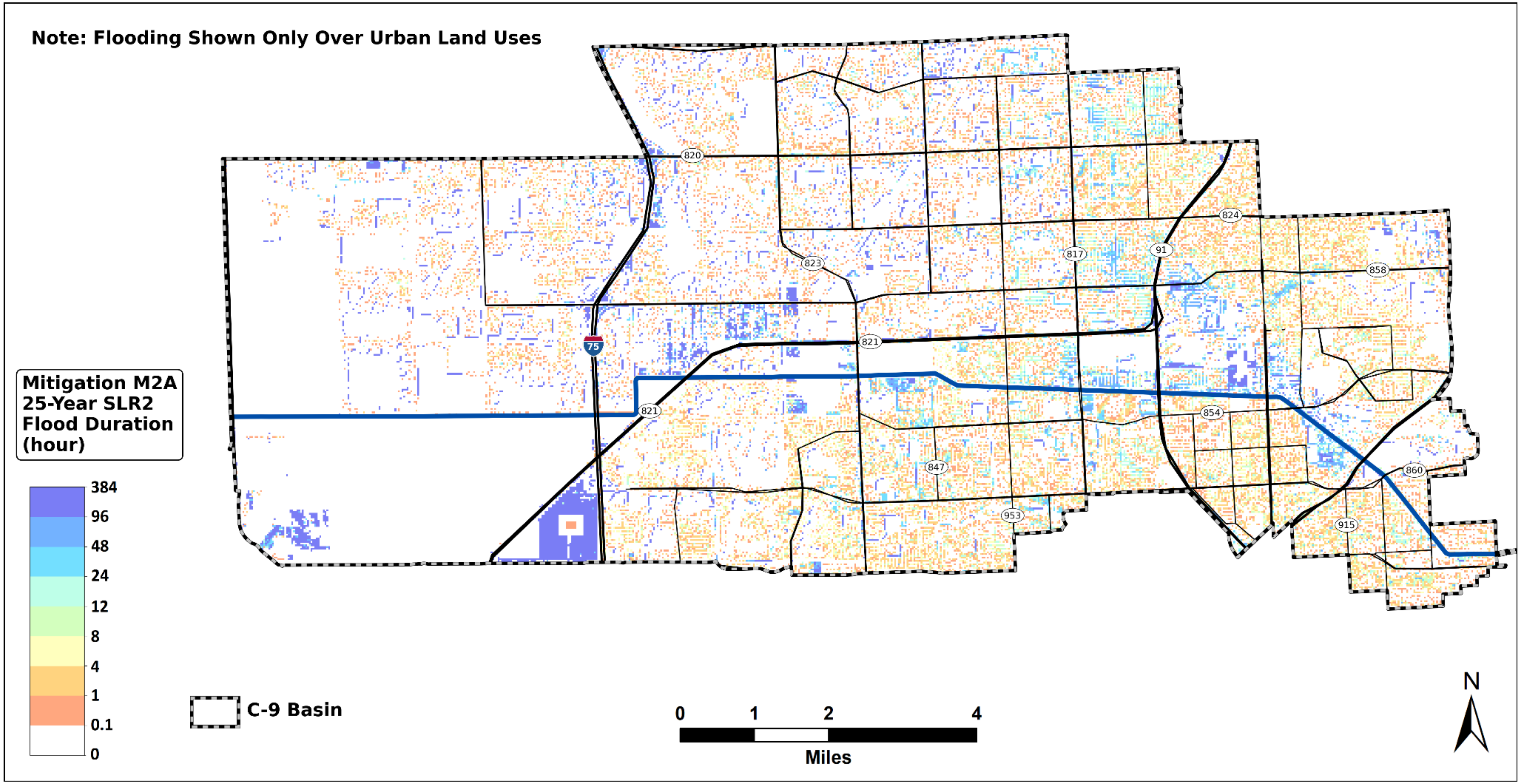


Figure E- 20: C-9 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2A 25-Year Sea Level Rise 2 Design Storm Event

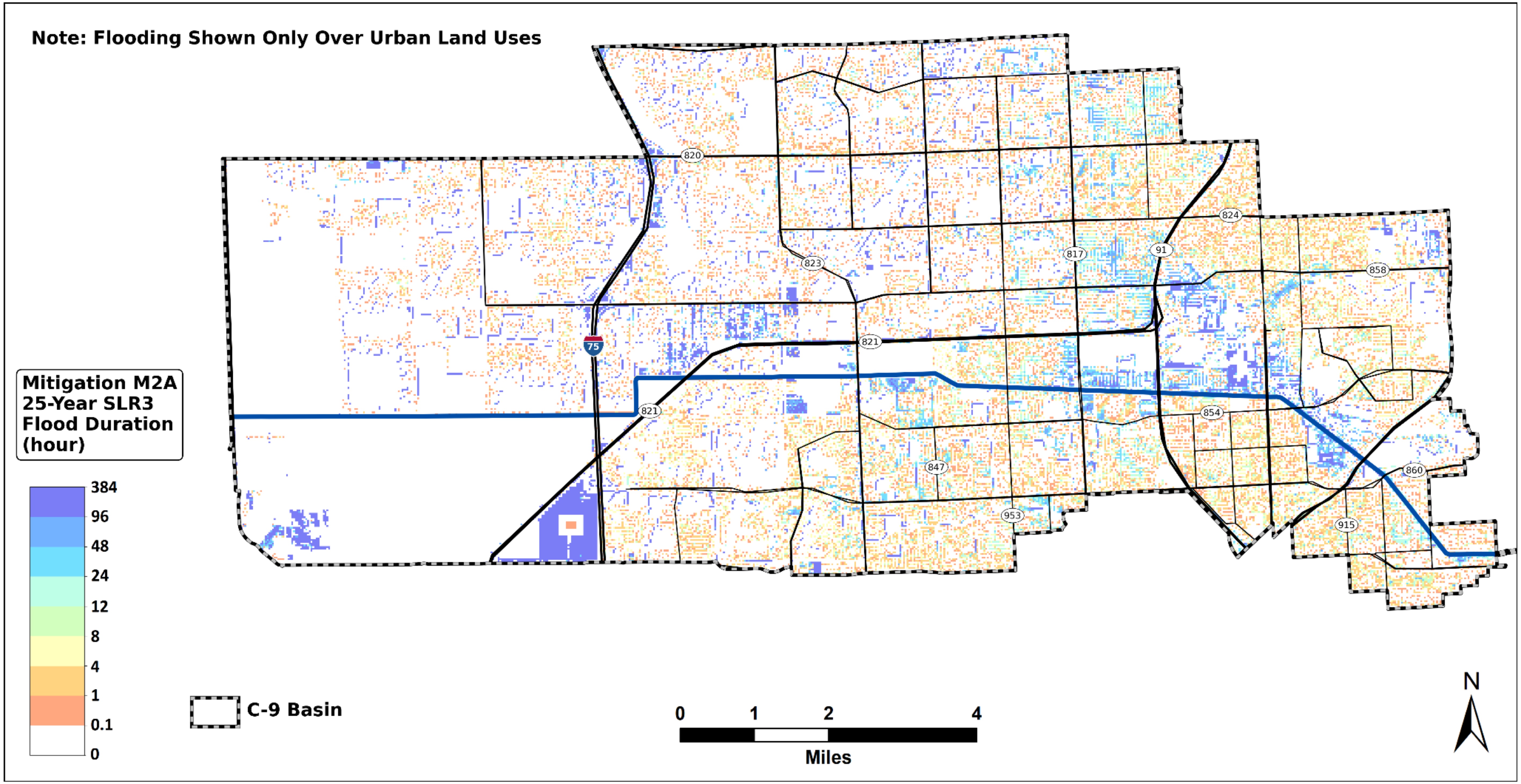


Figure E- 21: C-9 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2A 25-Year Sea Level Rise 3 Design Storm Event

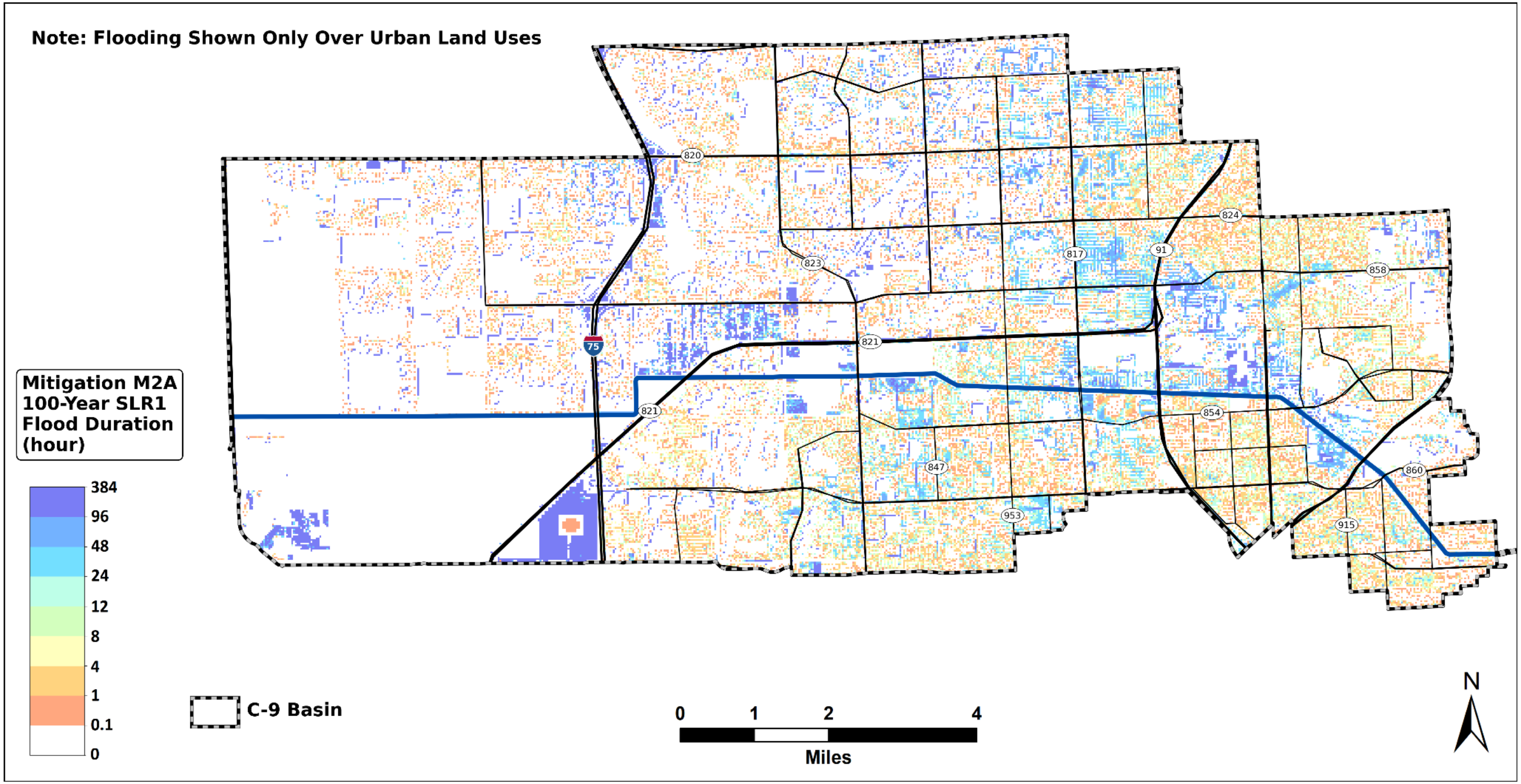


Figure E- 22: C-9 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2A 100-Year Sea Level Rise 1 Design Storm Event

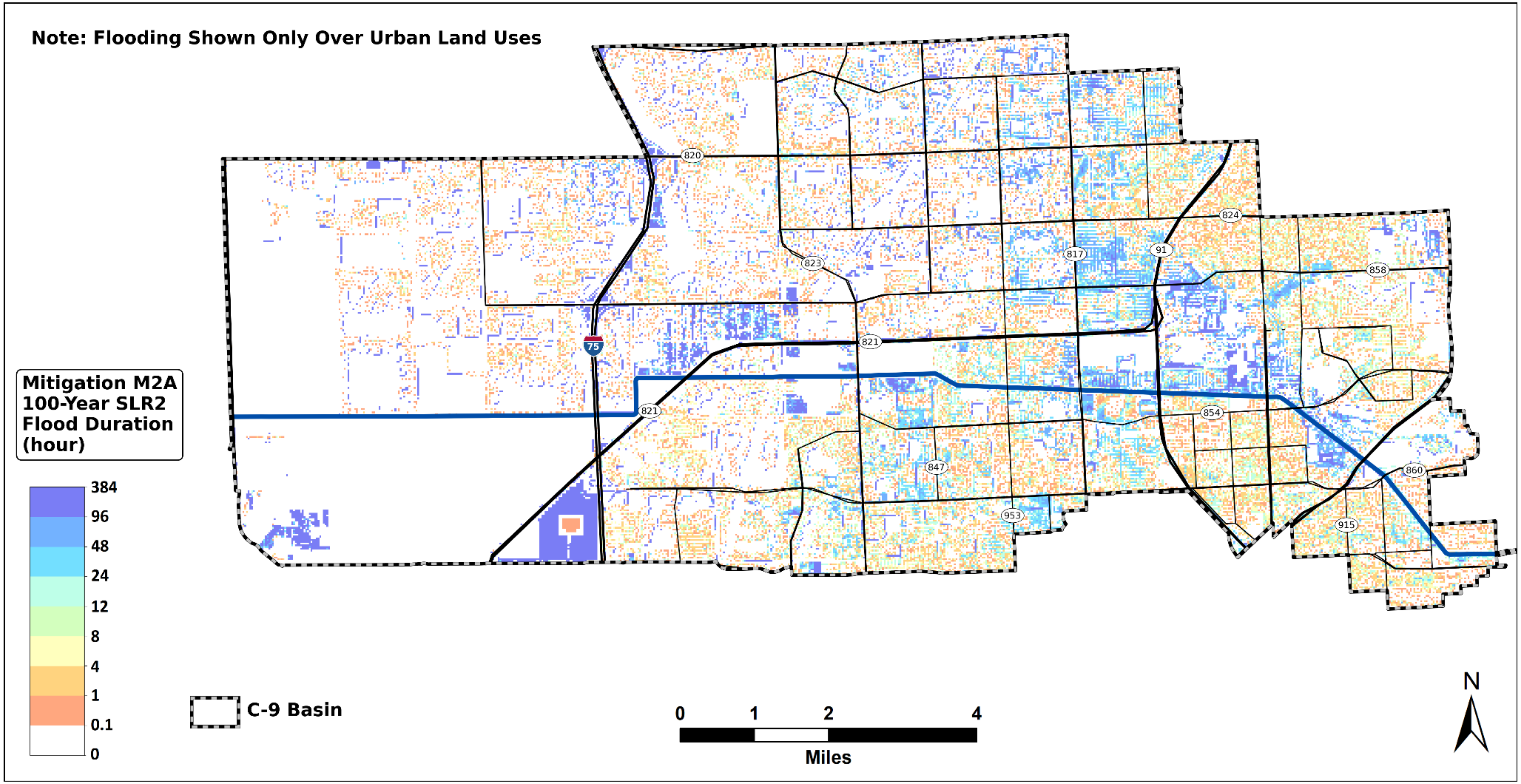


Figure E- 23: C-9 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2A 100-Year Sea Level Rise 2 Design Storm Event

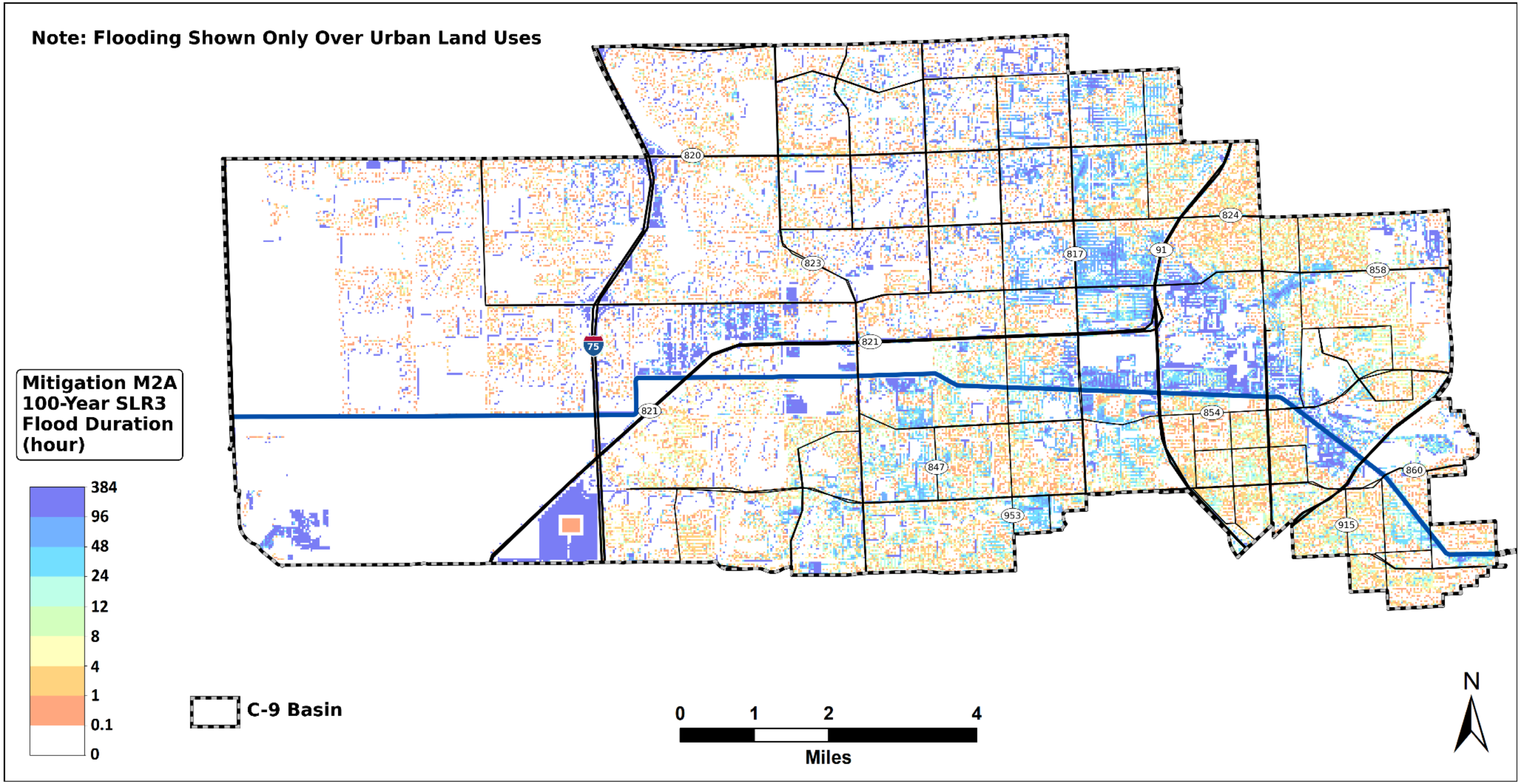


Figure E- 24: C-9 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2A 100-Year Sea Level Rise 3 Design Storm Event

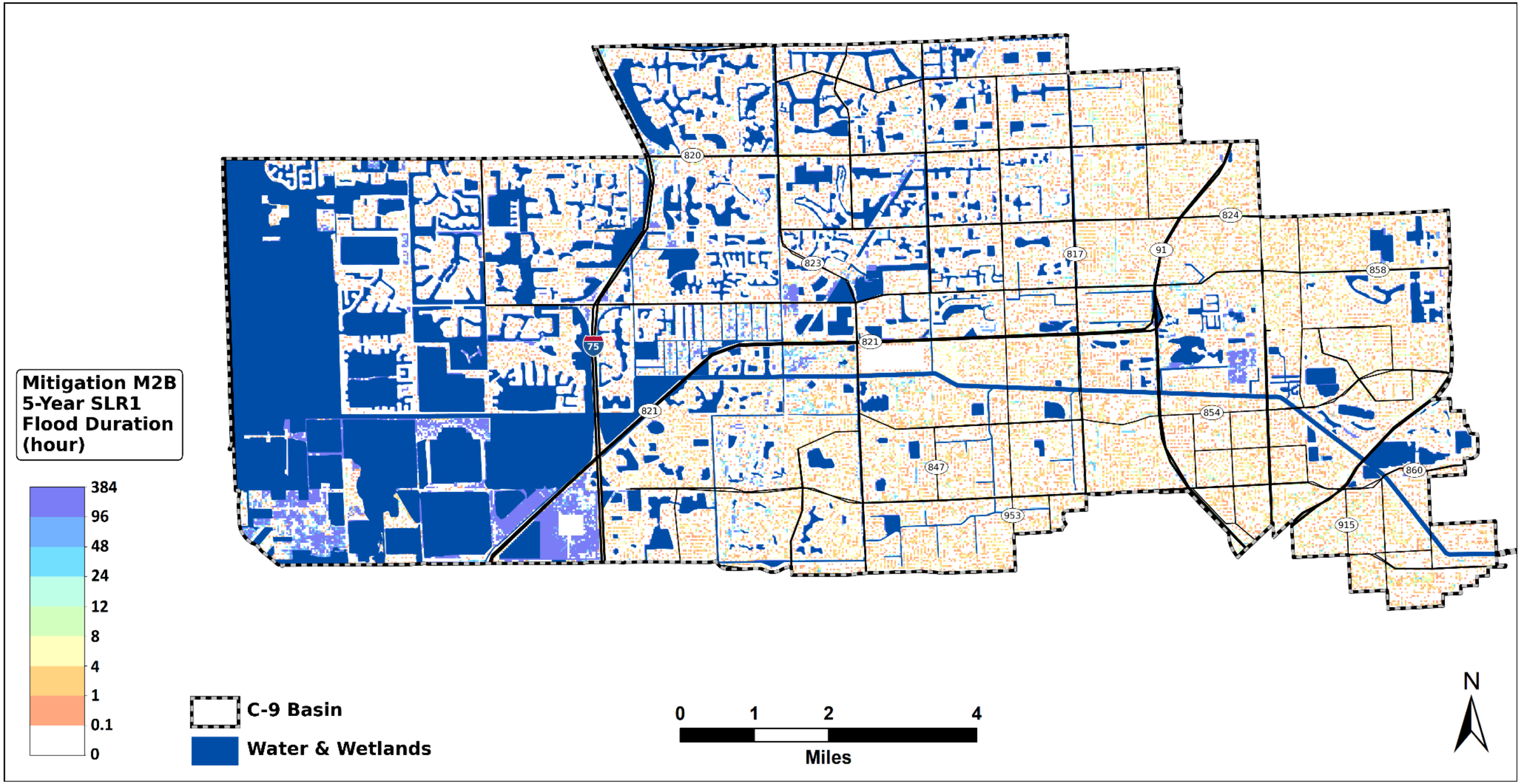


Figure E- 25: C-9 Watershed Flood Duration Map for the Mitigation M2B 5-Year Sea Level Rise 1 Design Storm Event

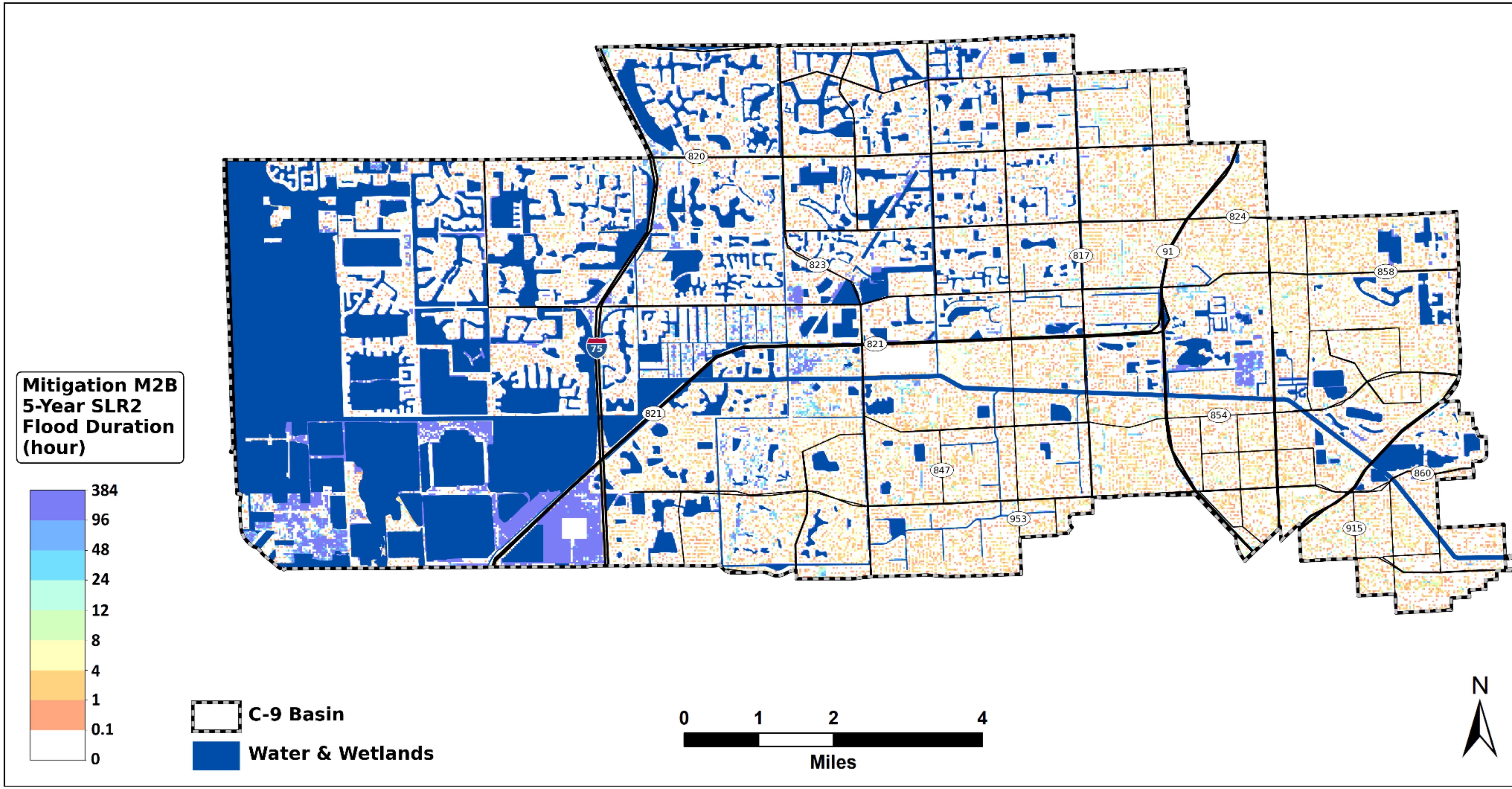


Figure E- 26: C-9 Watershed Flood Duration Map for the Mitigation M2B 5-Year Sea Level Rise 2 Design Storm Event

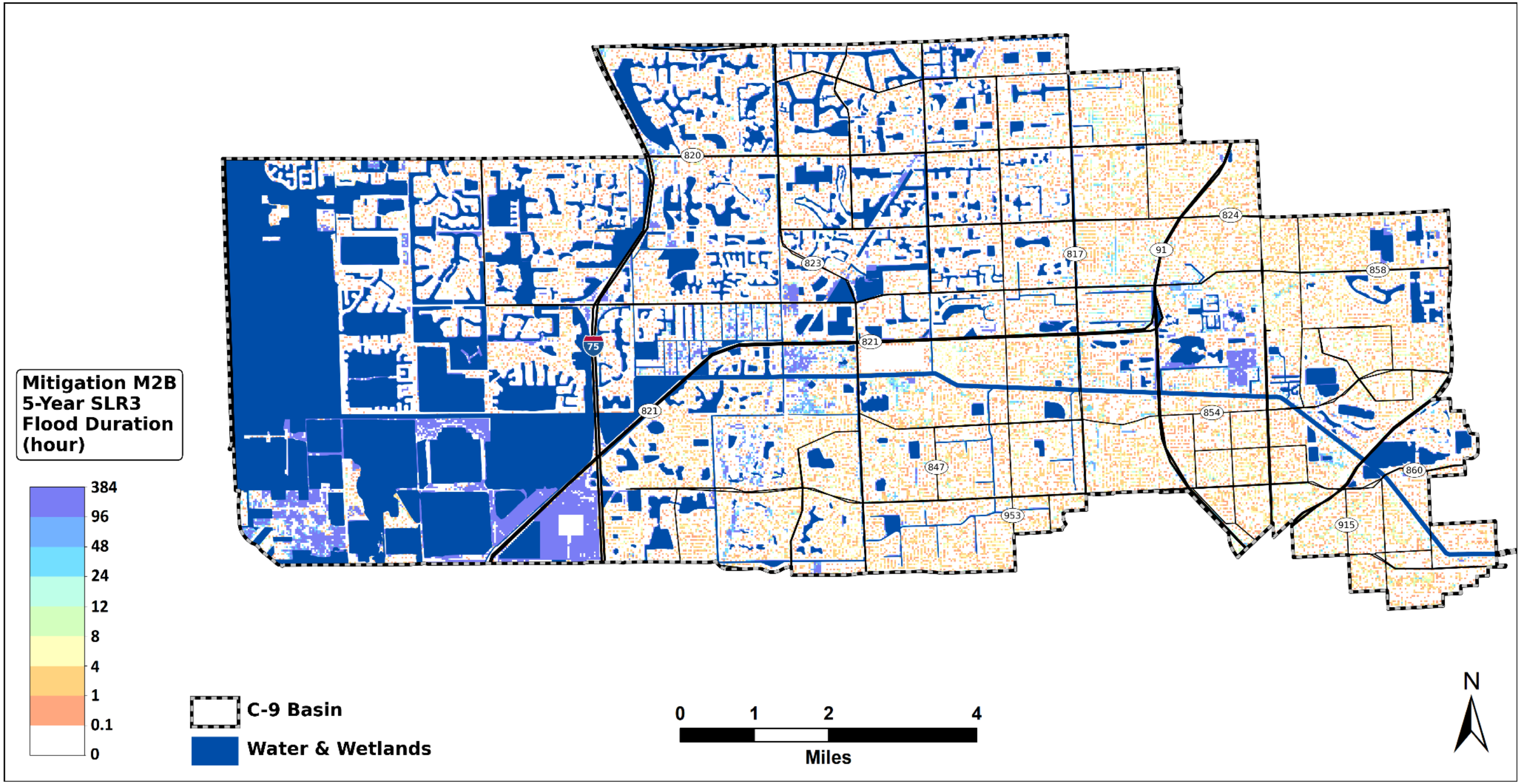


Figure E- 27: C-9 Watershed Flood Duration Map for the Mitigation M2B 5-Year Sea Level Rise 3 Design Storm Event

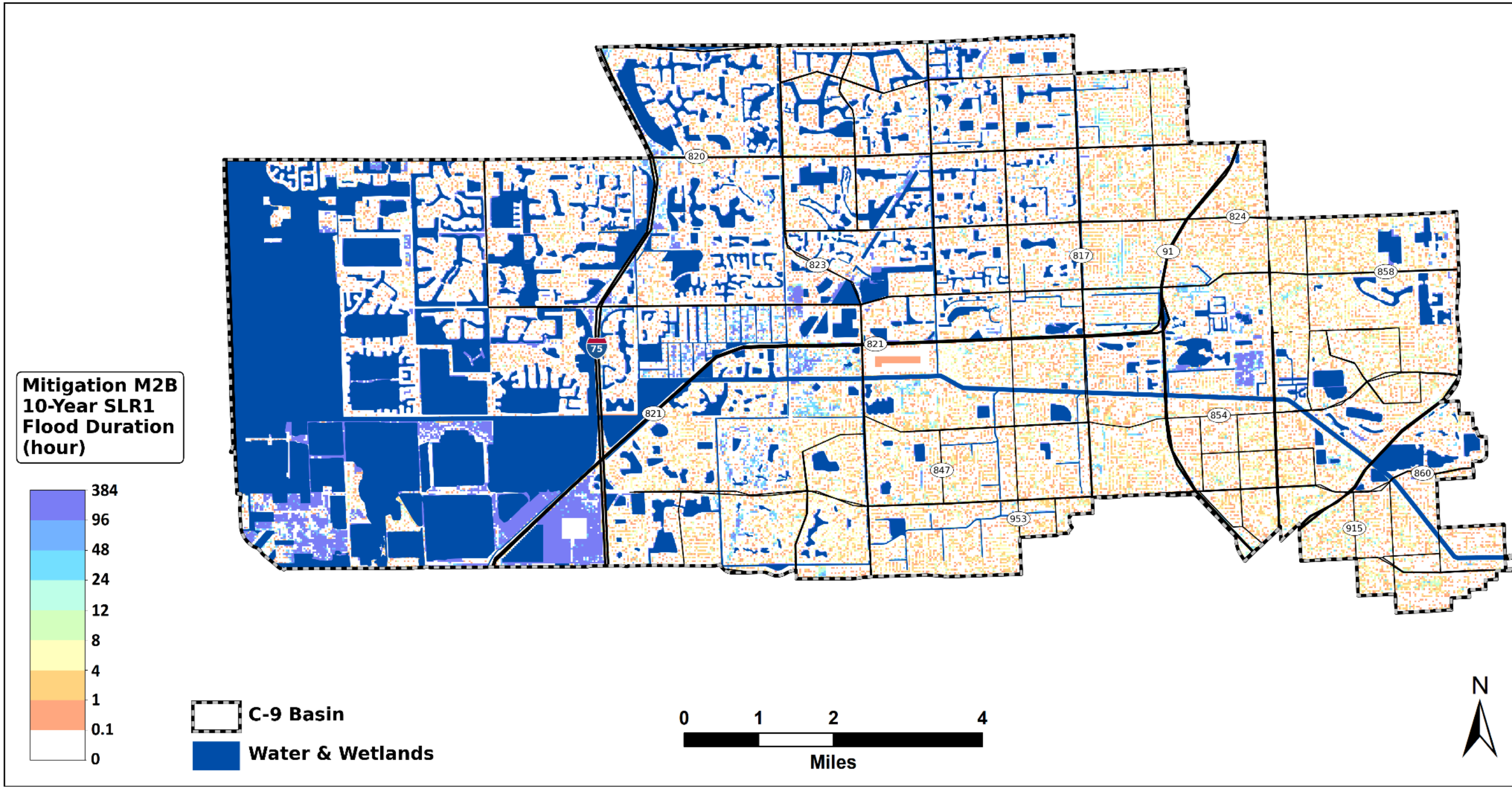


Figure E- 28: C-9 Watershed Flood Duration Map for the Mitigation M2B 10-Year Sea Level Rise 1 Design Storm Event

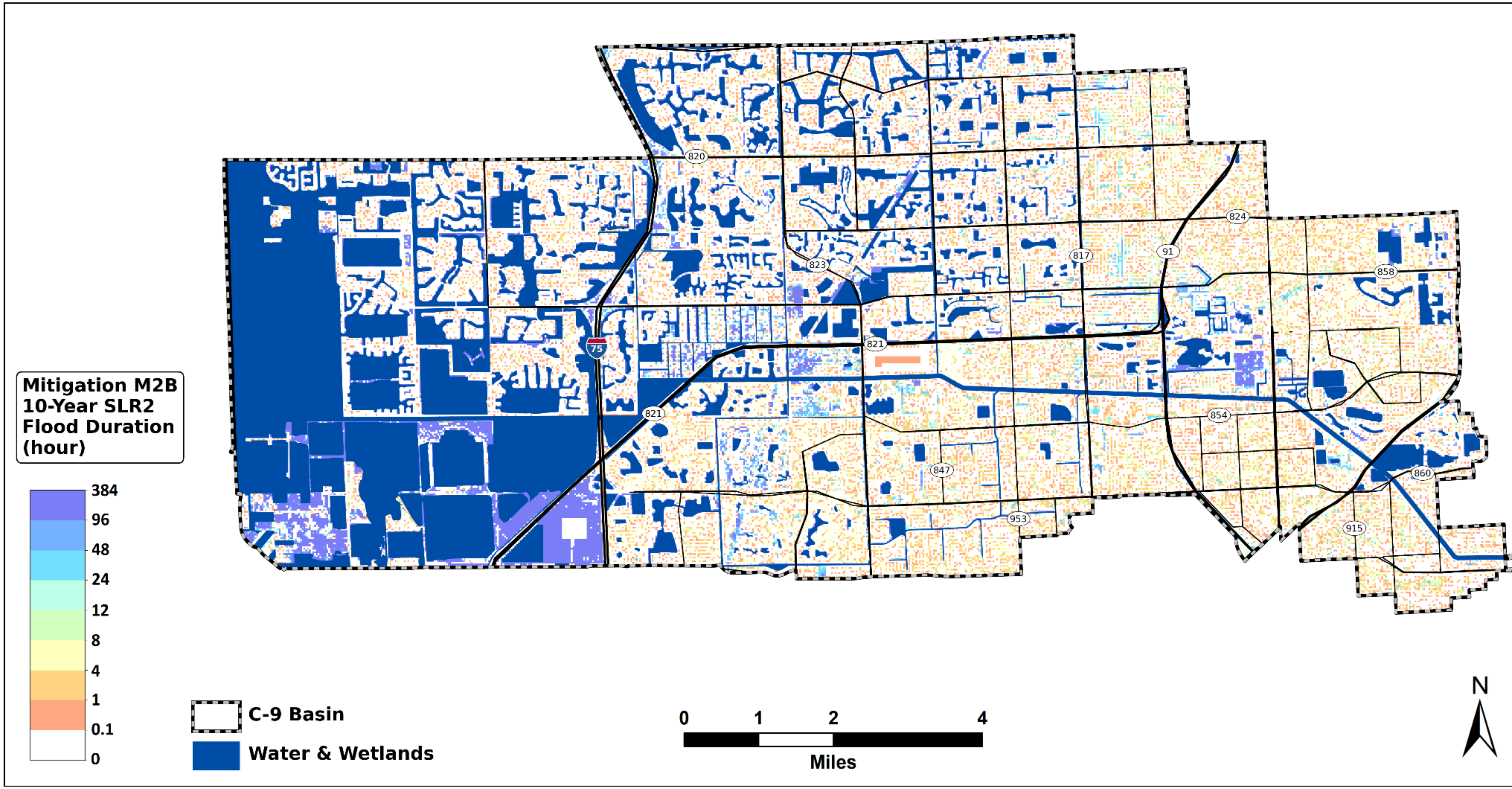


Figure E- 29: C-9 Watershed Flood Duration Map for the Mitigation M2B 10-Year Sea Level Rise 2 Design Storm Event

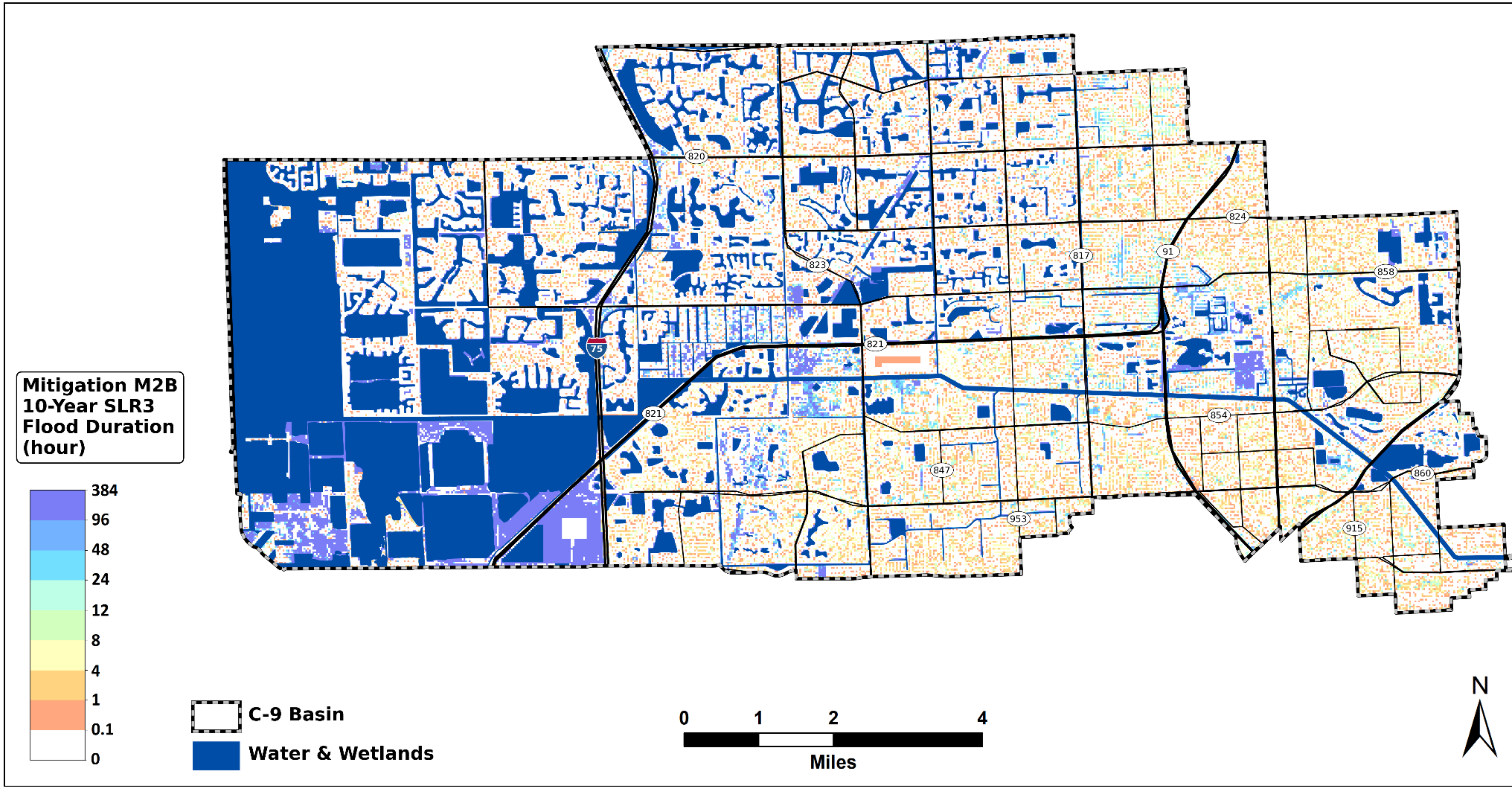


Figure E- 30: C-9 Watershed Flood Duration Map for the Mitigation M2B 10-Year Sea Level Rise 3 Design Storm Event

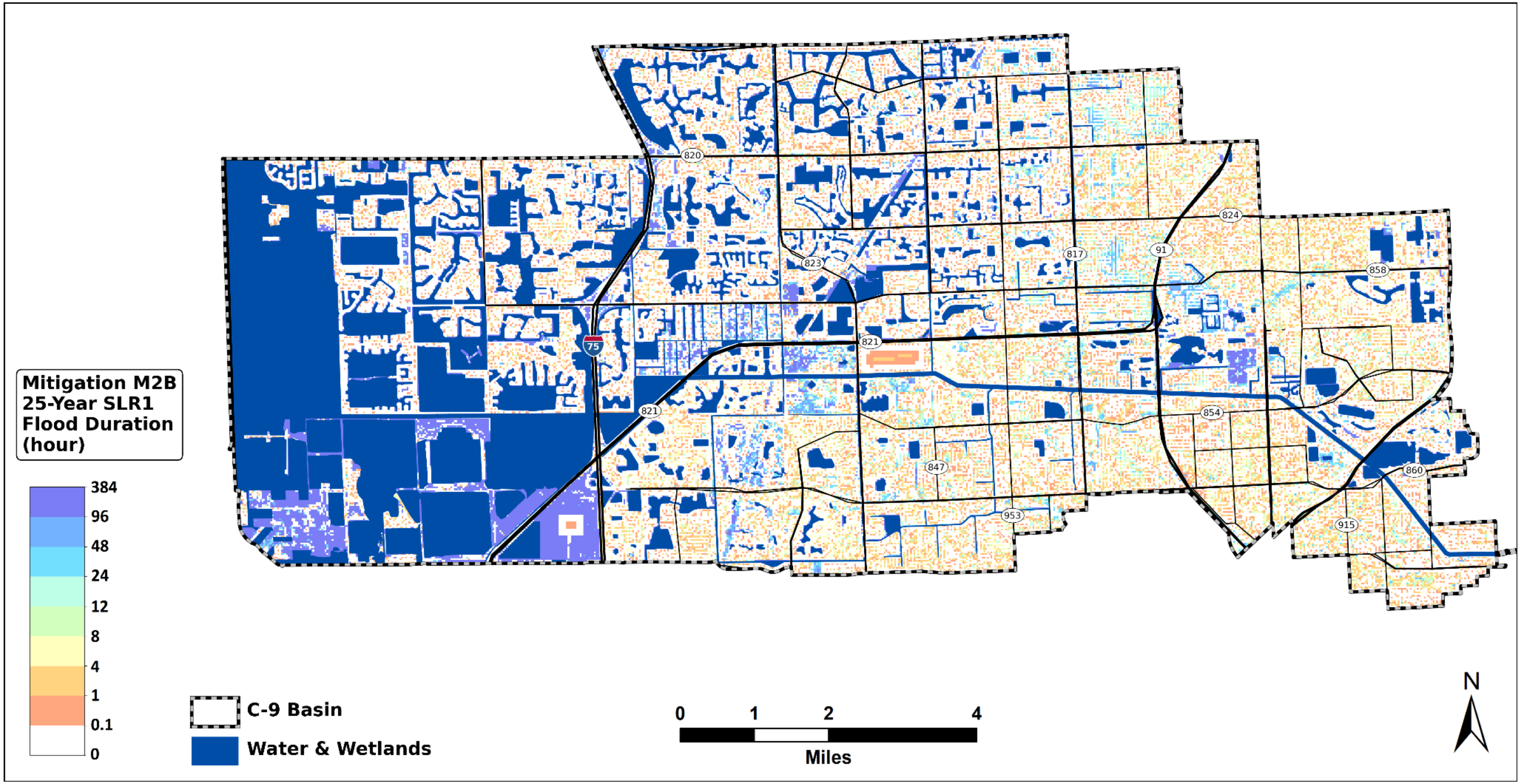


Figure E- 31: C-9 Watershed Flood Duration Map for the Mitigation M2B 25-Year Sea Level Rise 1 Design Storm Event

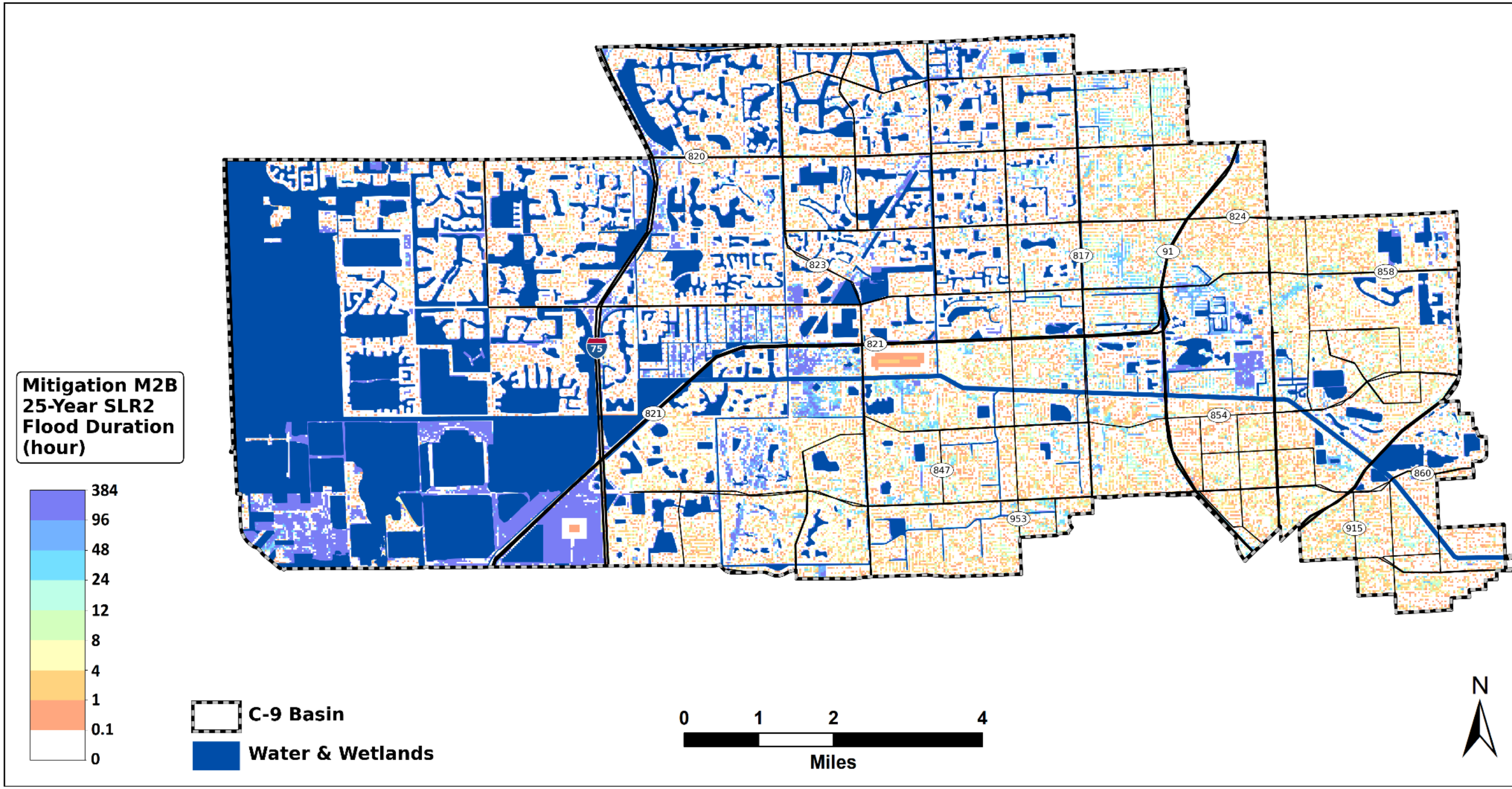


Figure E- 32: C-9 Watershed Flood Duration Map for the Mitigation M2B 25-Year Sea Level Rise 2 Design Storm Event

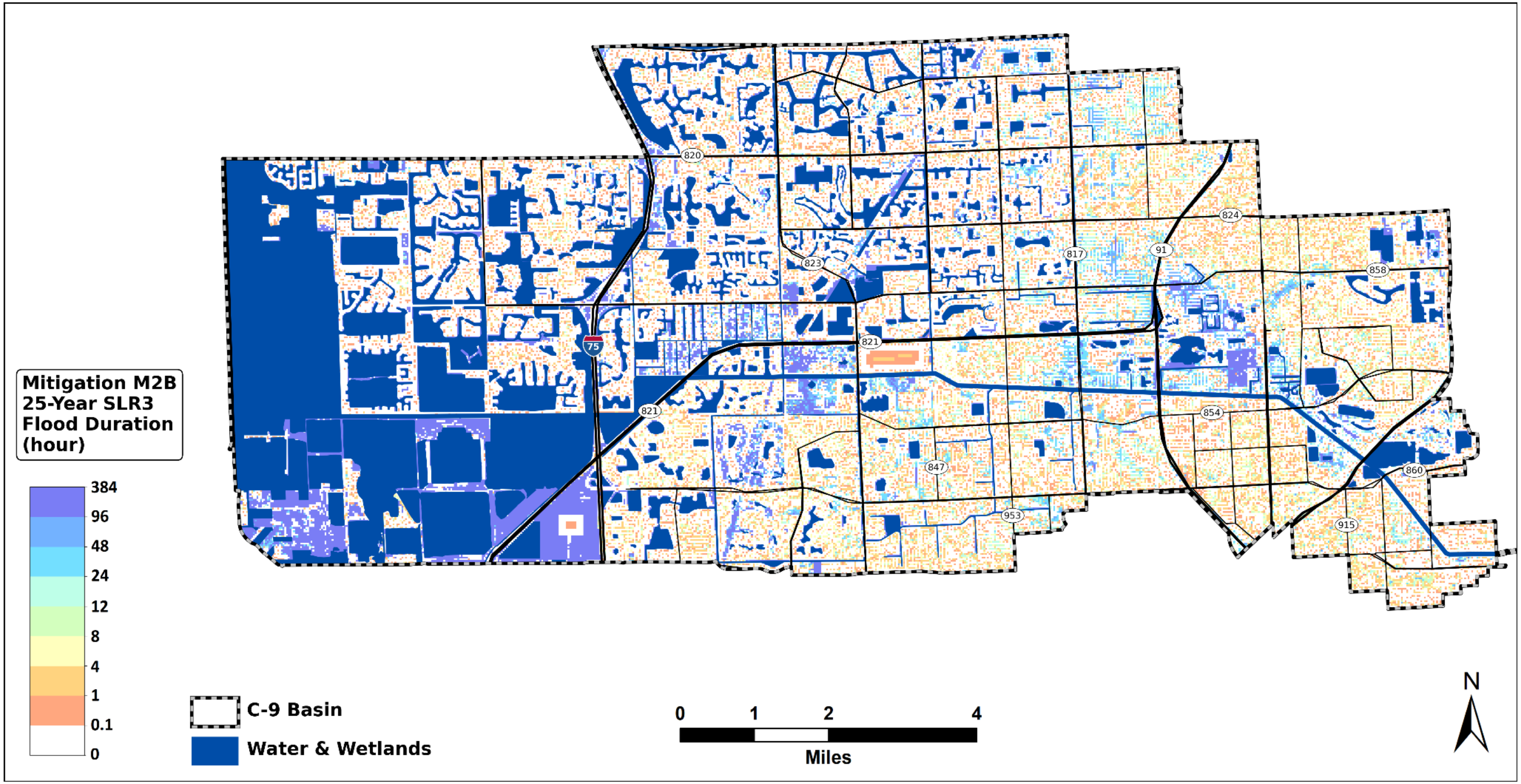


Figure E- 33: C-9 Watershed Flood Duration Map for the Mitigation M2B 25-Year Sea Level Rise 3 Design Storm Event

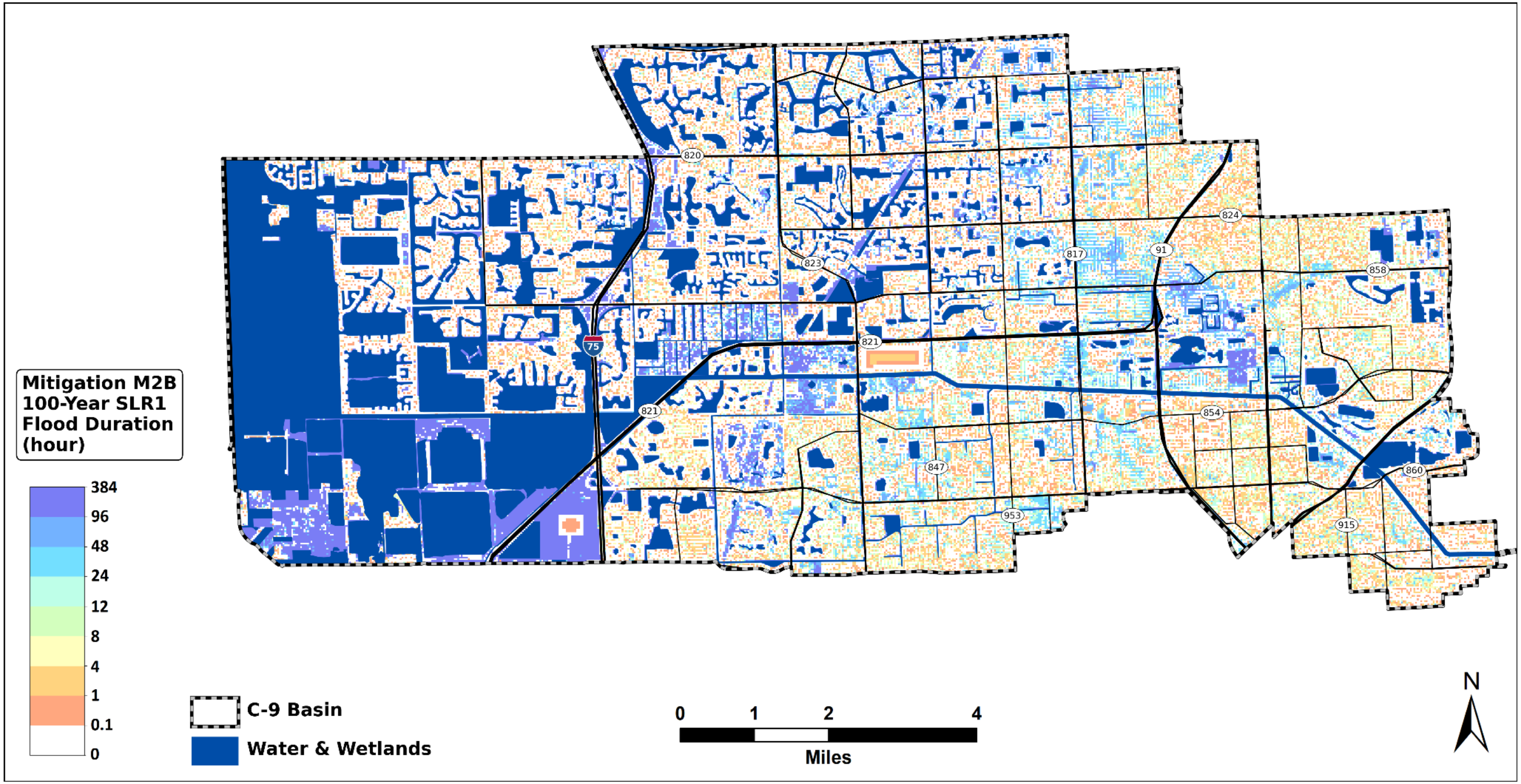


Figure E- 34: C-9 Watershed Flood Duration Map for the Mitigation M2B 100-Year Sea Level Rise 1 Design Storm Event

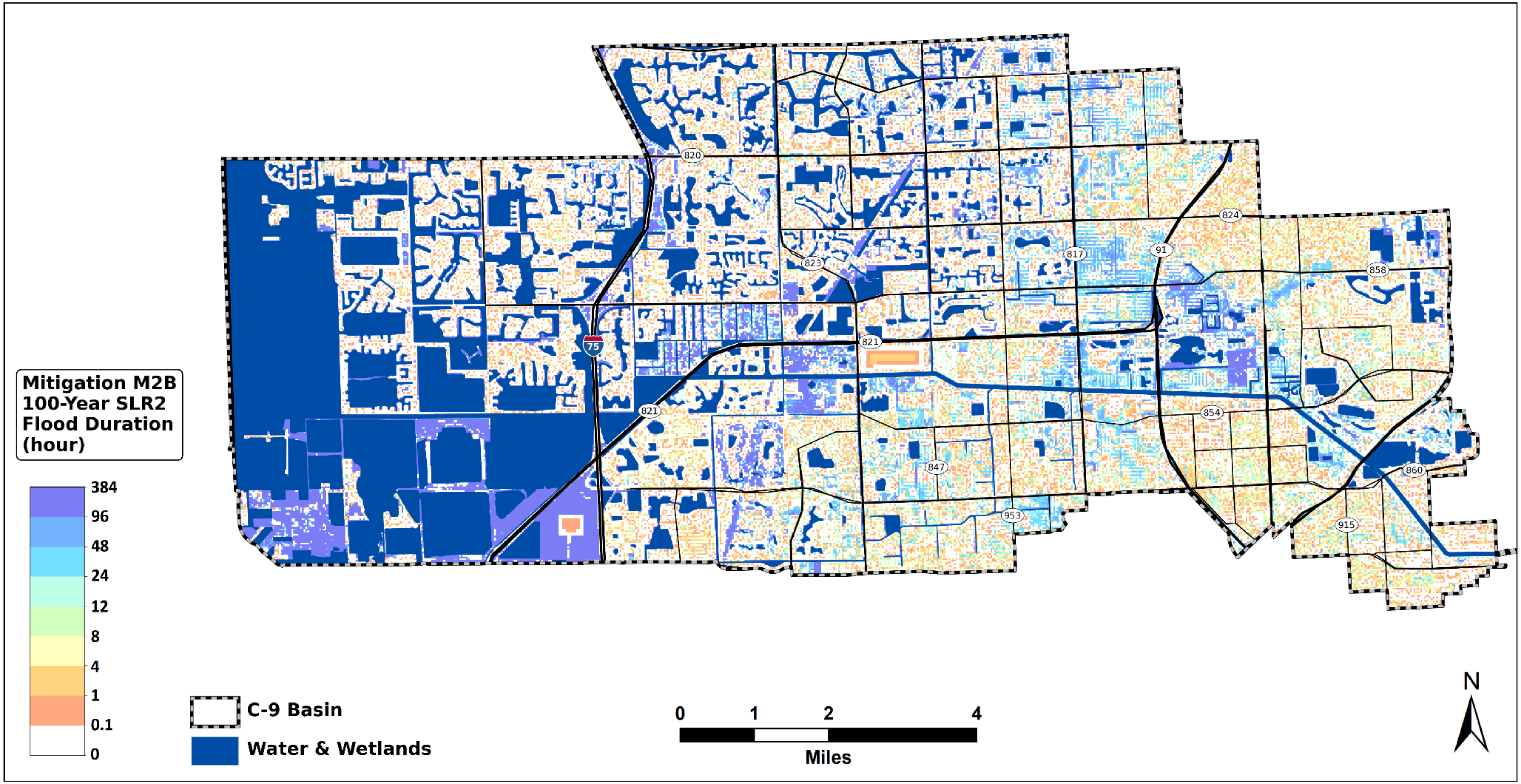


Figure E- 35: C-9 Watershed Flood Duration Map for the Mitigation M2B 100-Year Sea Level Rise 2 Design Storm Event

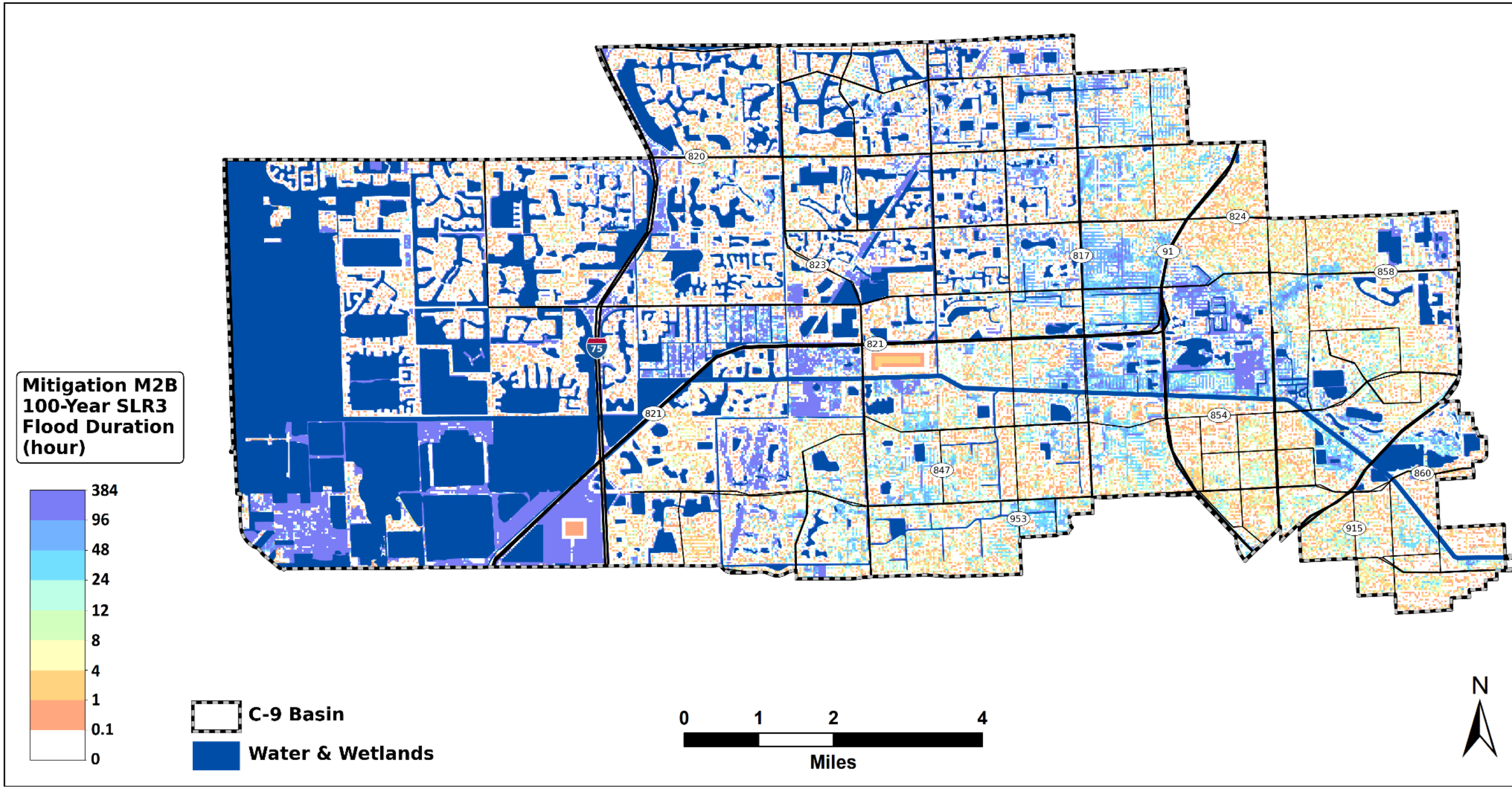


Figure E- 36: C-9 Watershed Flood Duration Map for the Mitigation M2B 100-Year Sea Level Rise 3 Design Storm Event

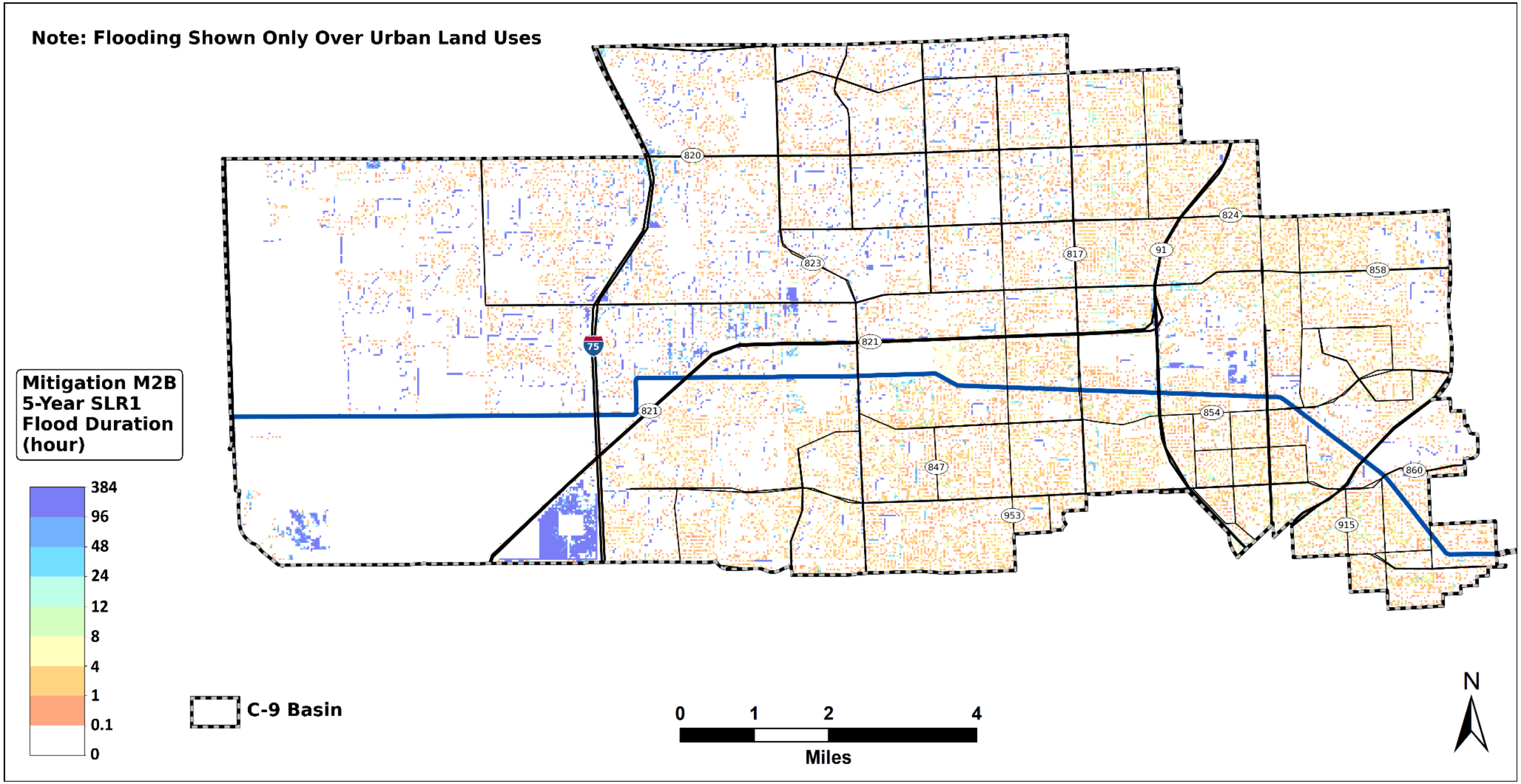


Figure E- 37: C-9 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2B 5-Year Sea Level Rise 1 Design Storm Event

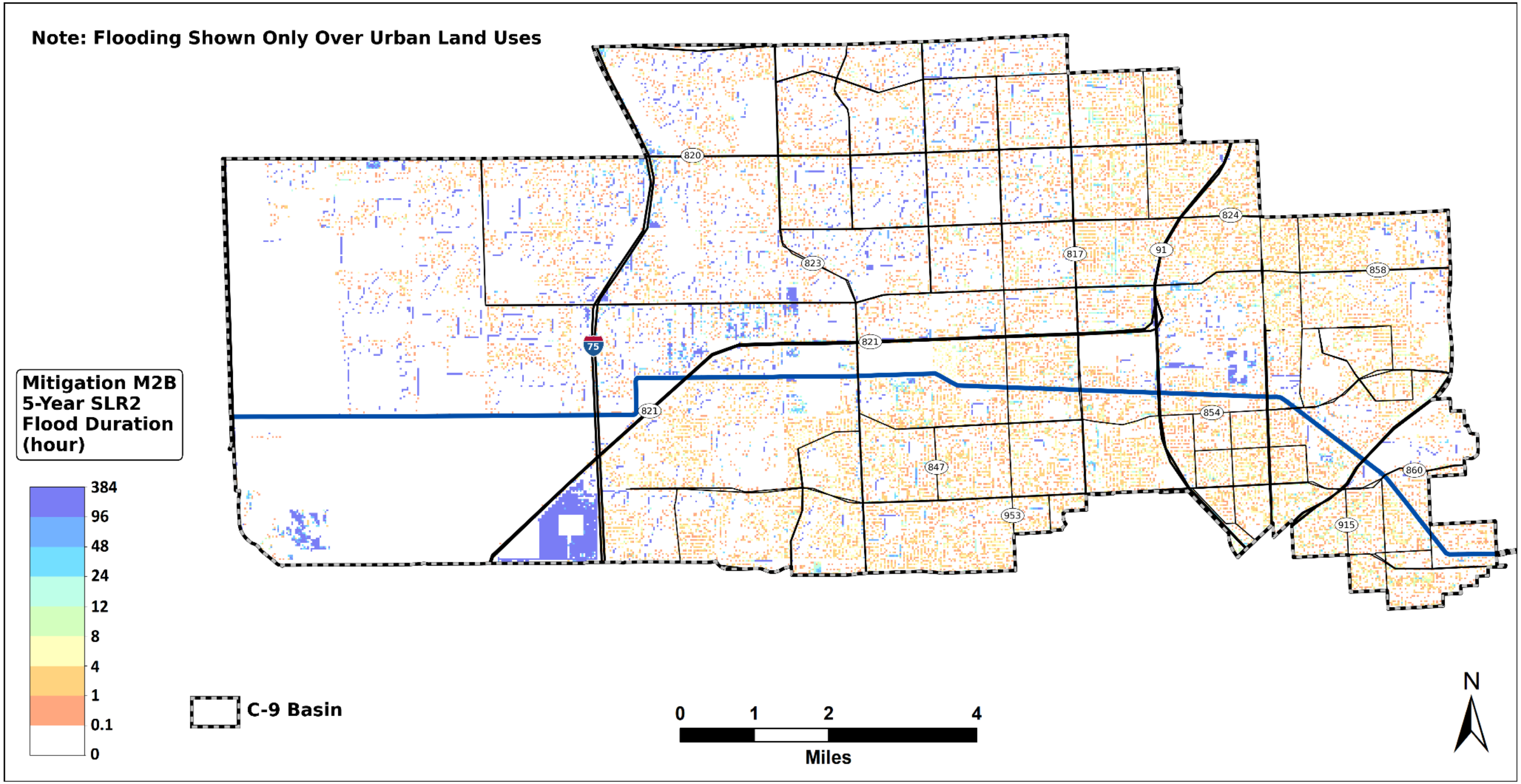


Figure E- 38: C-9 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2B 5-Year Sea Level Rise 2 Design Storm Event

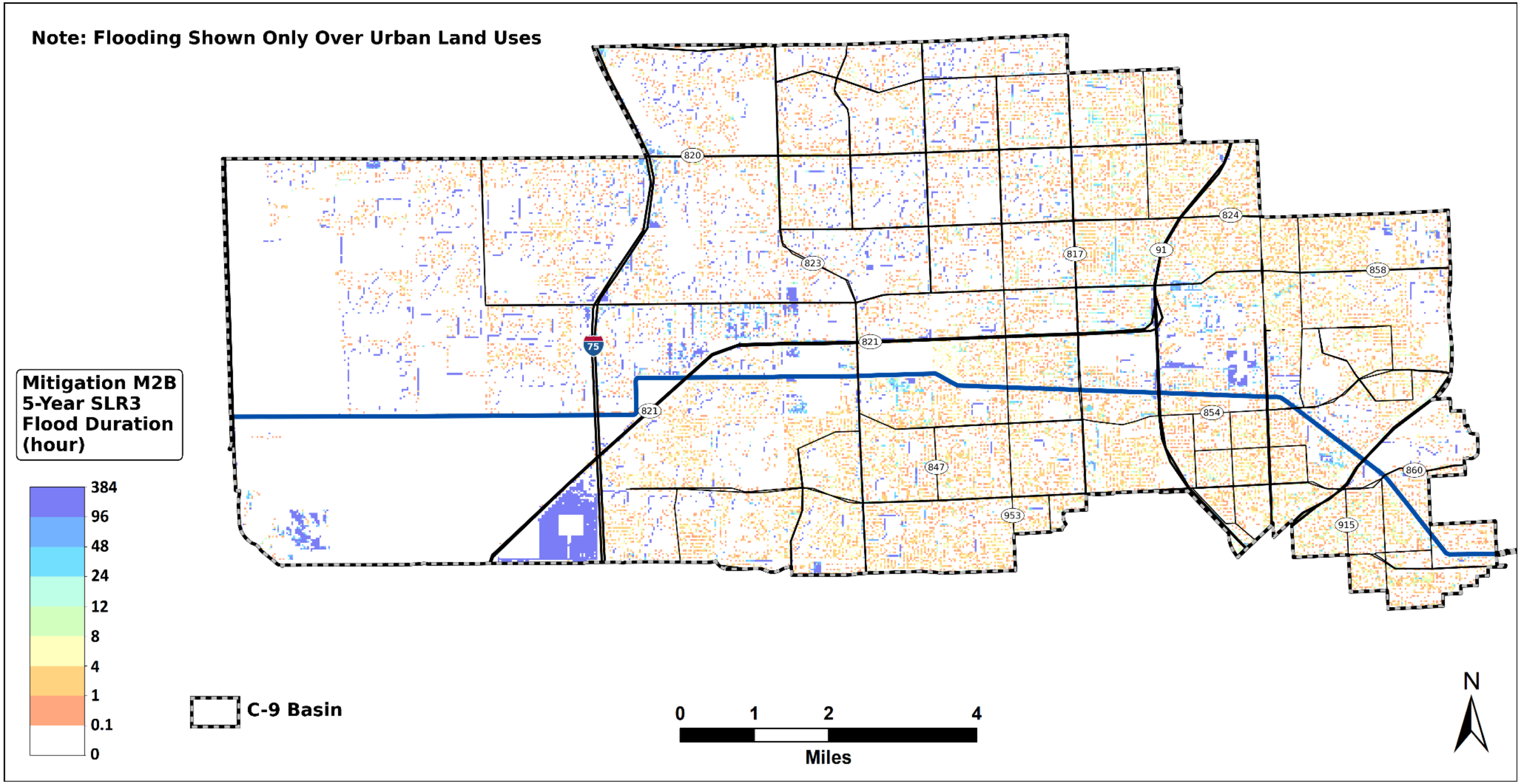


Figure E- 39: C-9 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2B 5-Year Sea Level Rise 3 Design Storm Event

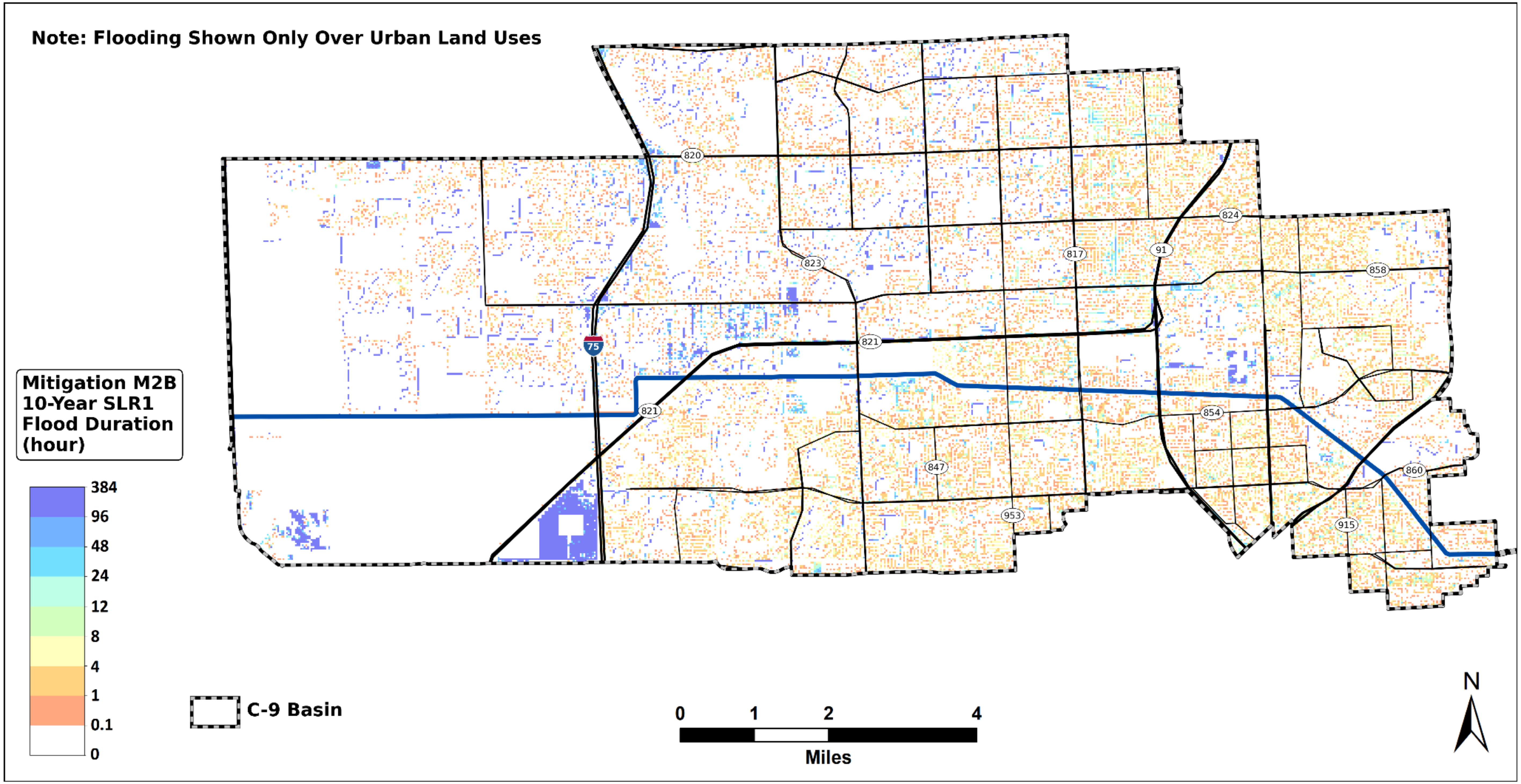


Figure E- 40: C-9 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2B 10-Year Sea Level Rise 1 Design Storm Event

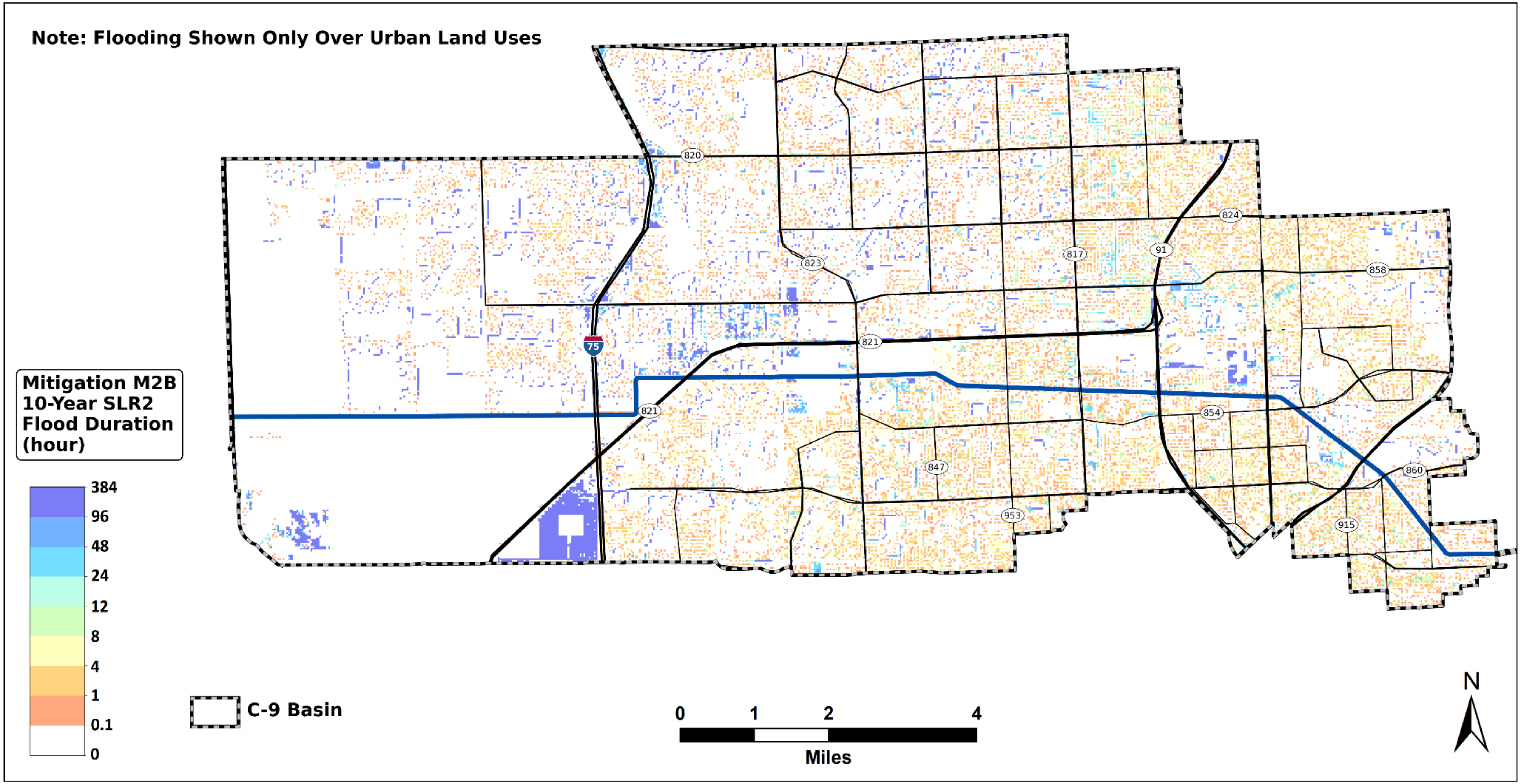


Figure E- 41: C-9 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2B 10-Year Sea Level Rise 2 Design Storm Event

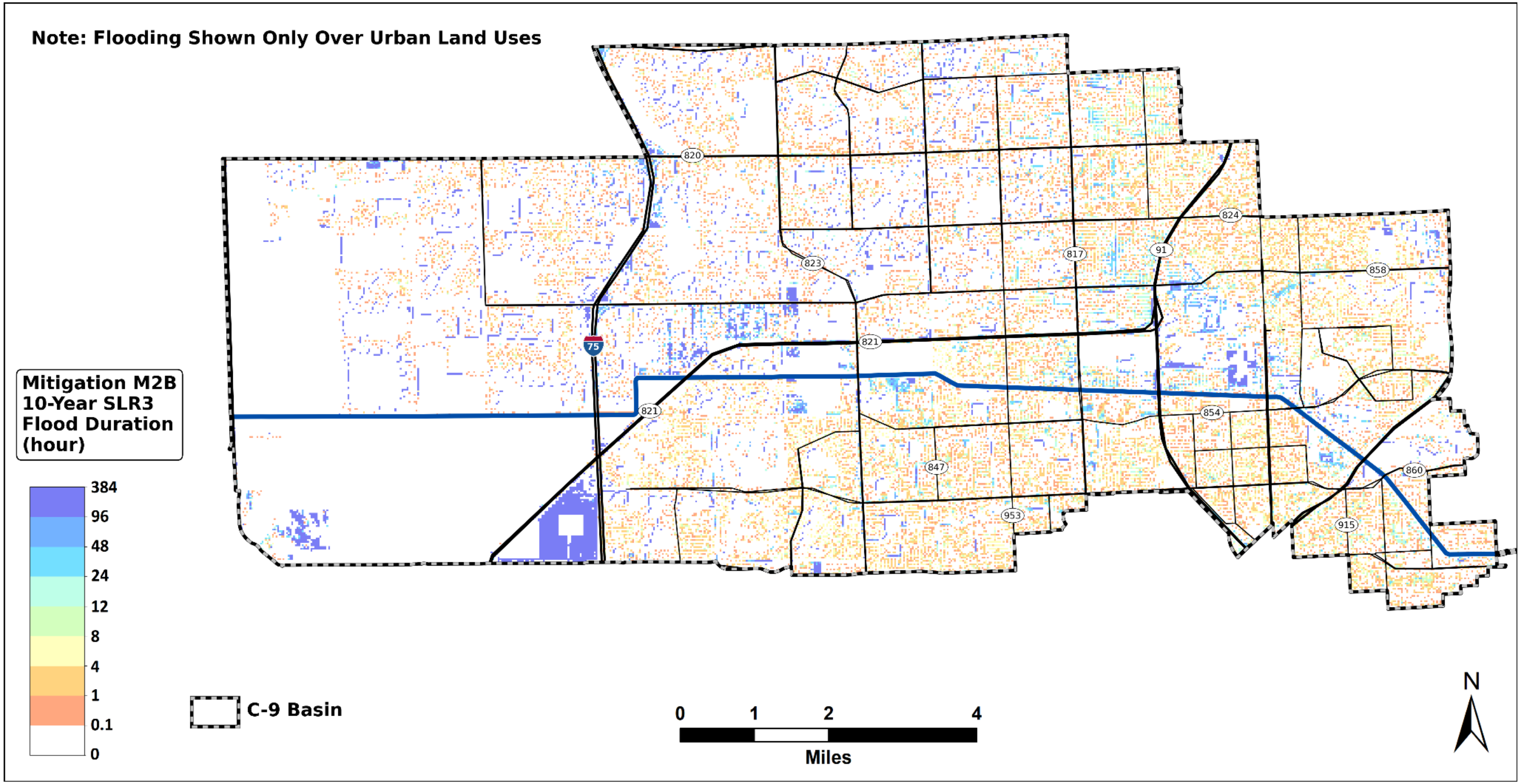


Figure E- 42: C-9 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2B 10-Year Sea Level Rise 3 Design Storm Event

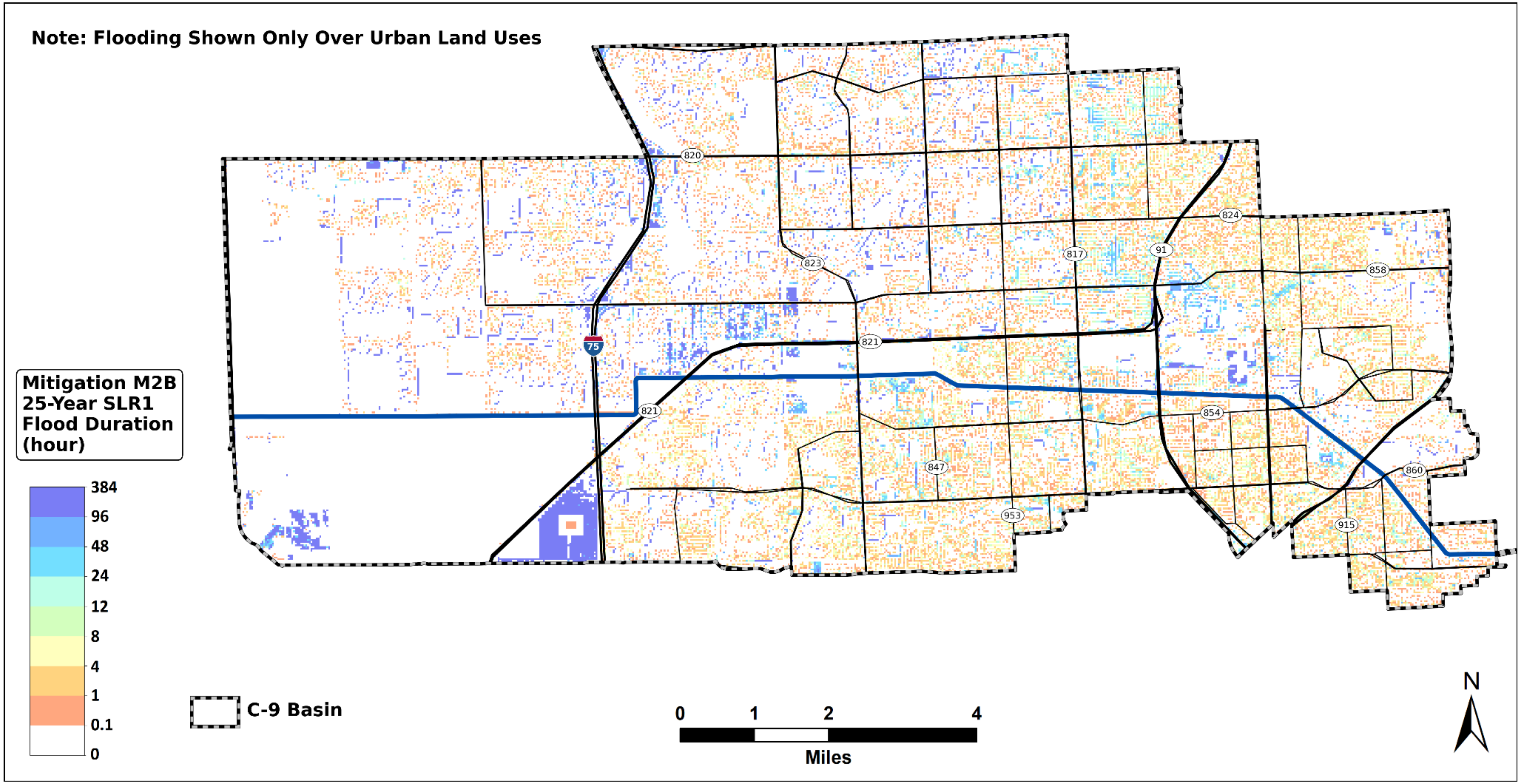


Figure E- 43: C-9 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2B 25-Year Sea Level Rise 1 Design Storm Event

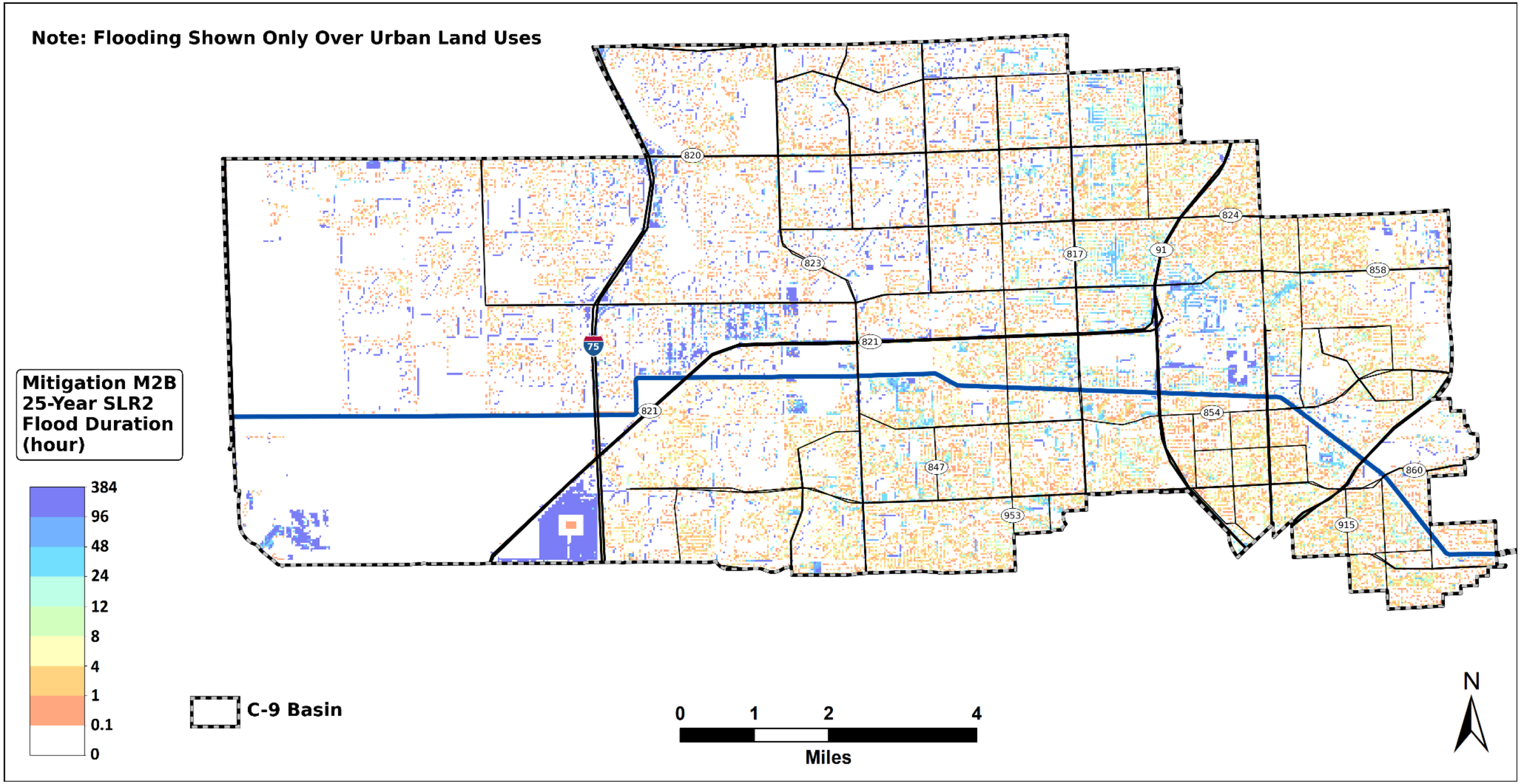


Figure E- 44: C-9 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2B 25-Year Sea Level Rise 2 Design Storm Event

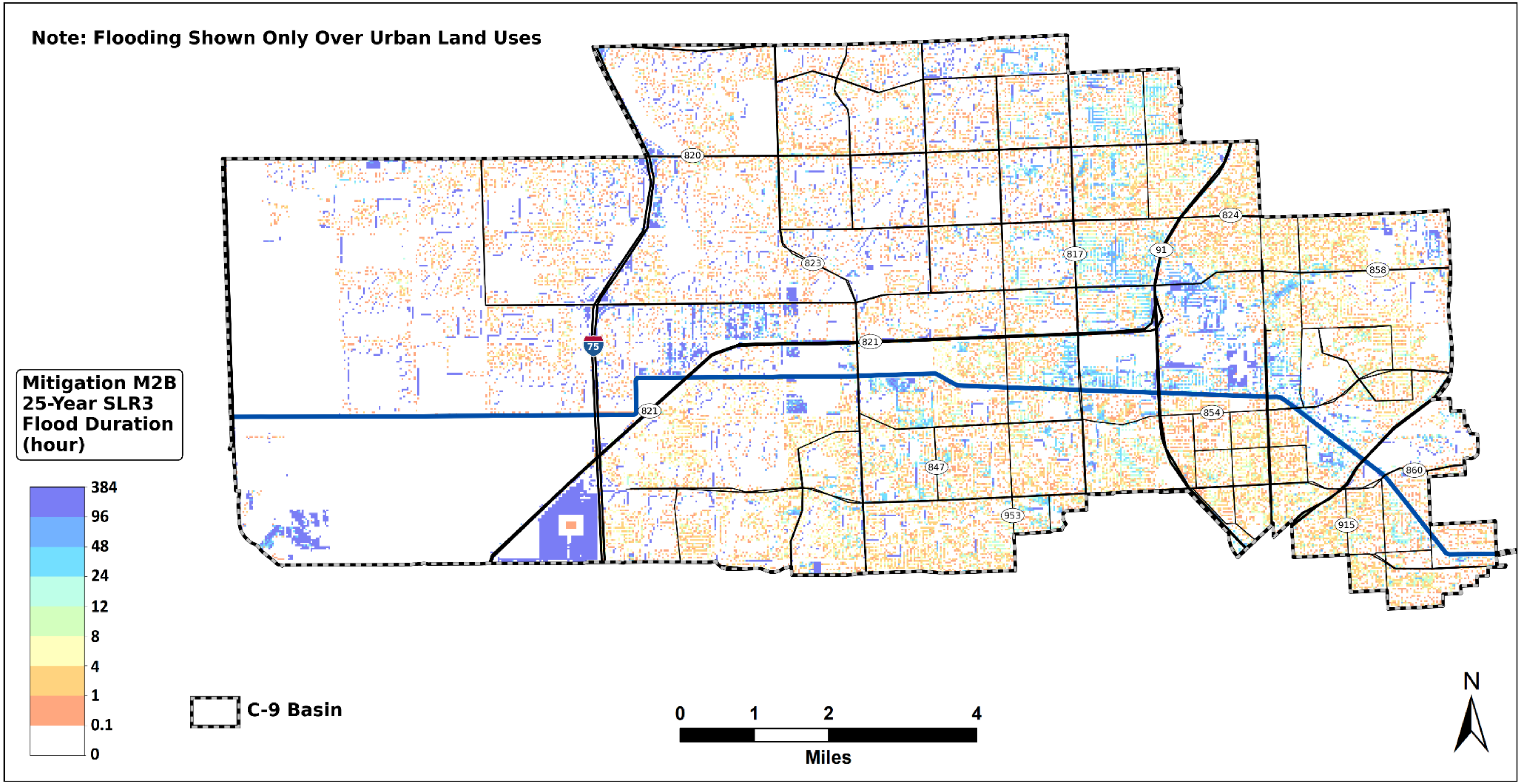


Figure E- 45: C-9 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2B 25-Year Sea Level Rise 3 Design Storm Event

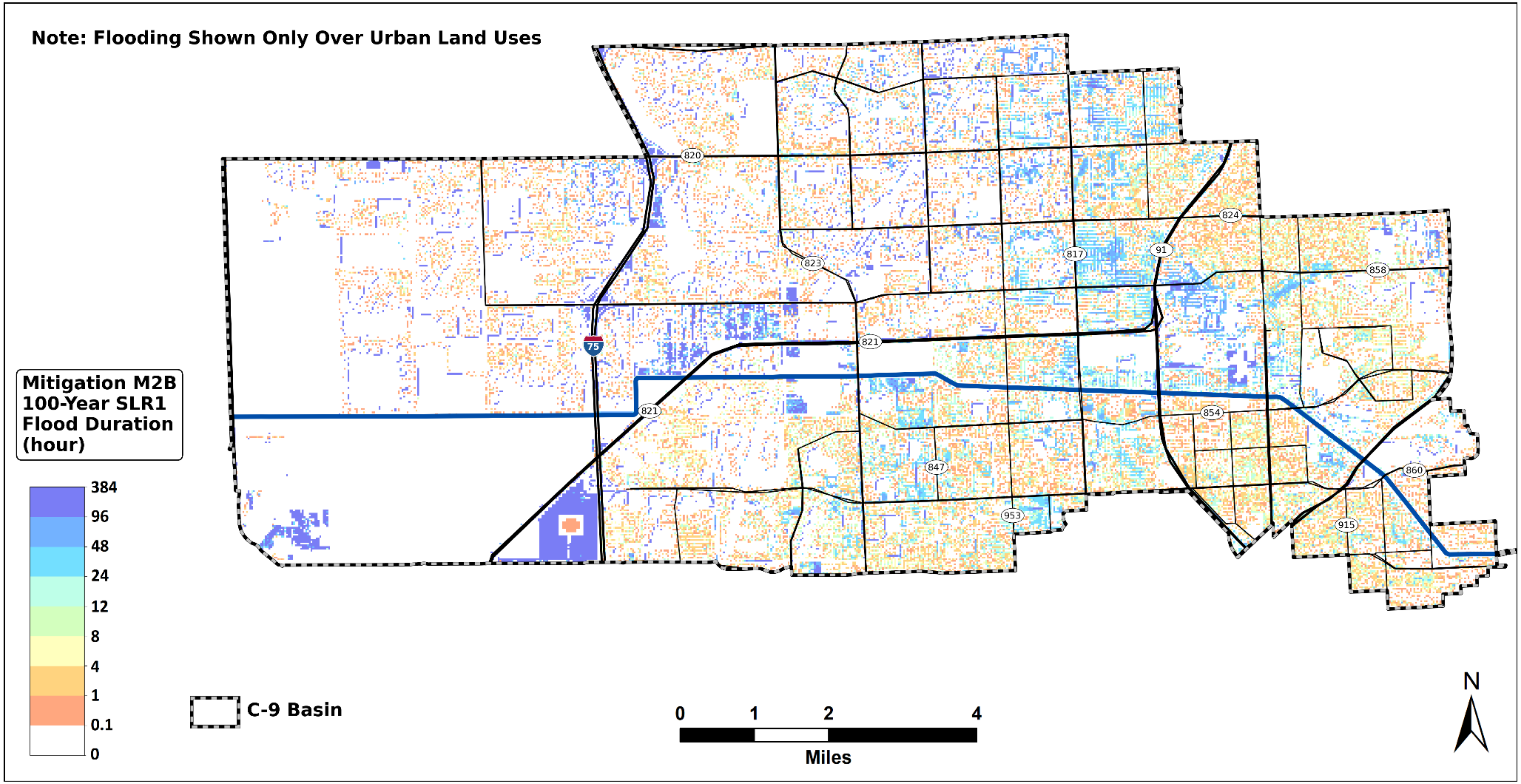


Figure E- 46: C-9 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2B 100-Year Sea Level Rise 1 Design Storm Event

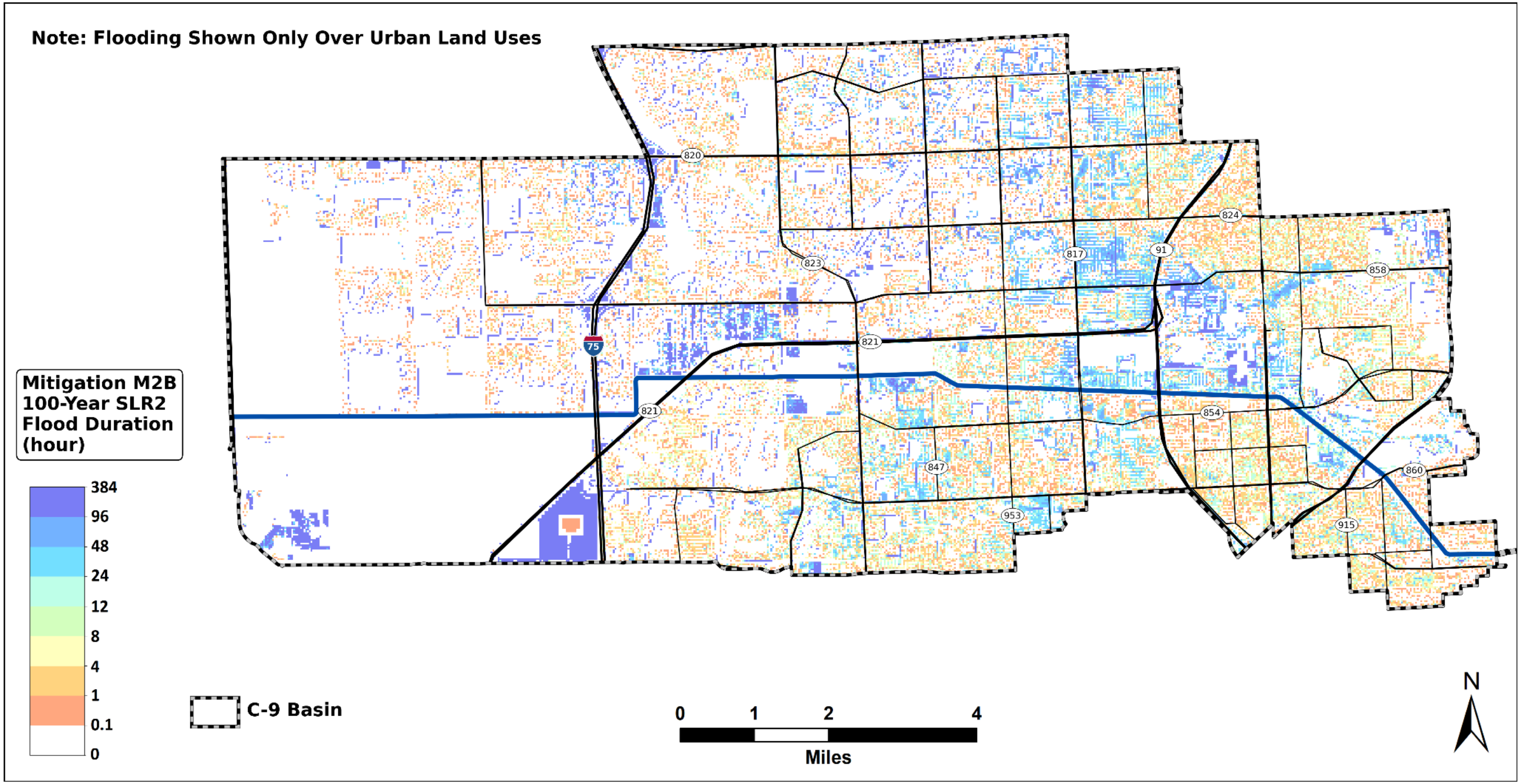


Figure E- 47: C-9 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2B 100-Year Sea Level Rise 2 Design Storm Event

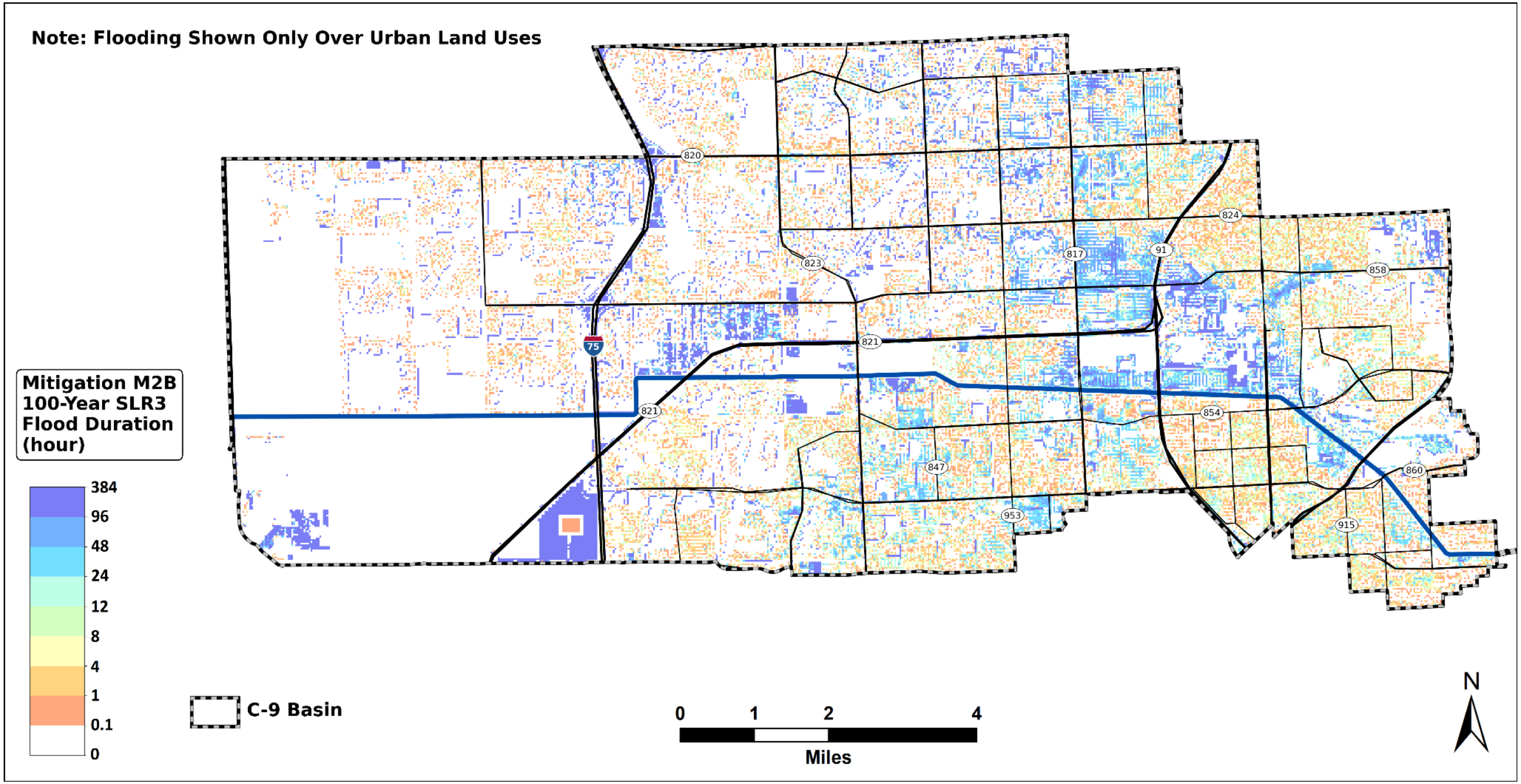


Figure E- 48: C-9 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2B 100-Year Sea Level Rise 3 Design Storm Event

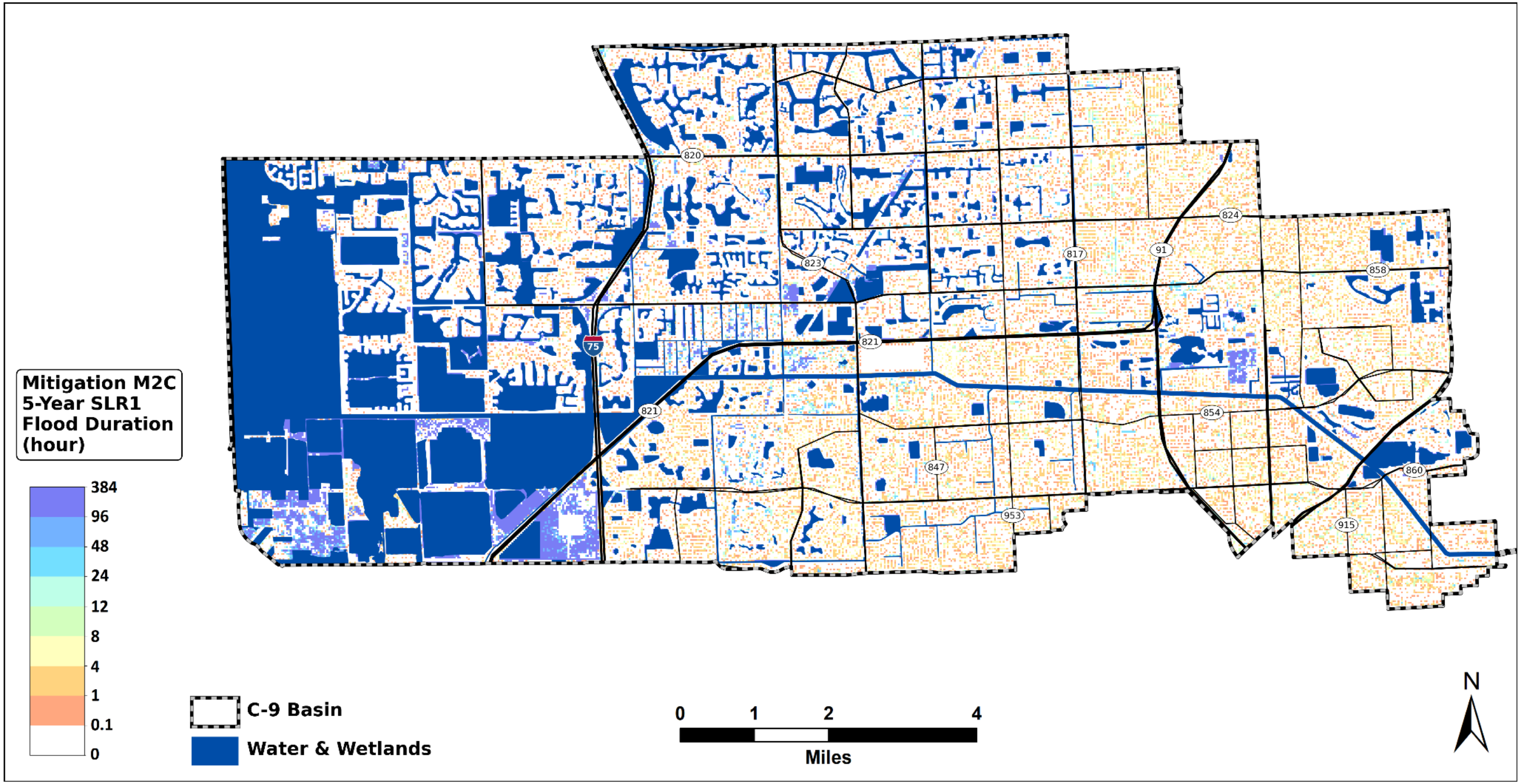


Figure E- 49: C-9 Watershed Flood Duration Map for the Mitigation M2C 5-Year Sea Level Rise 1 Design Storm Event

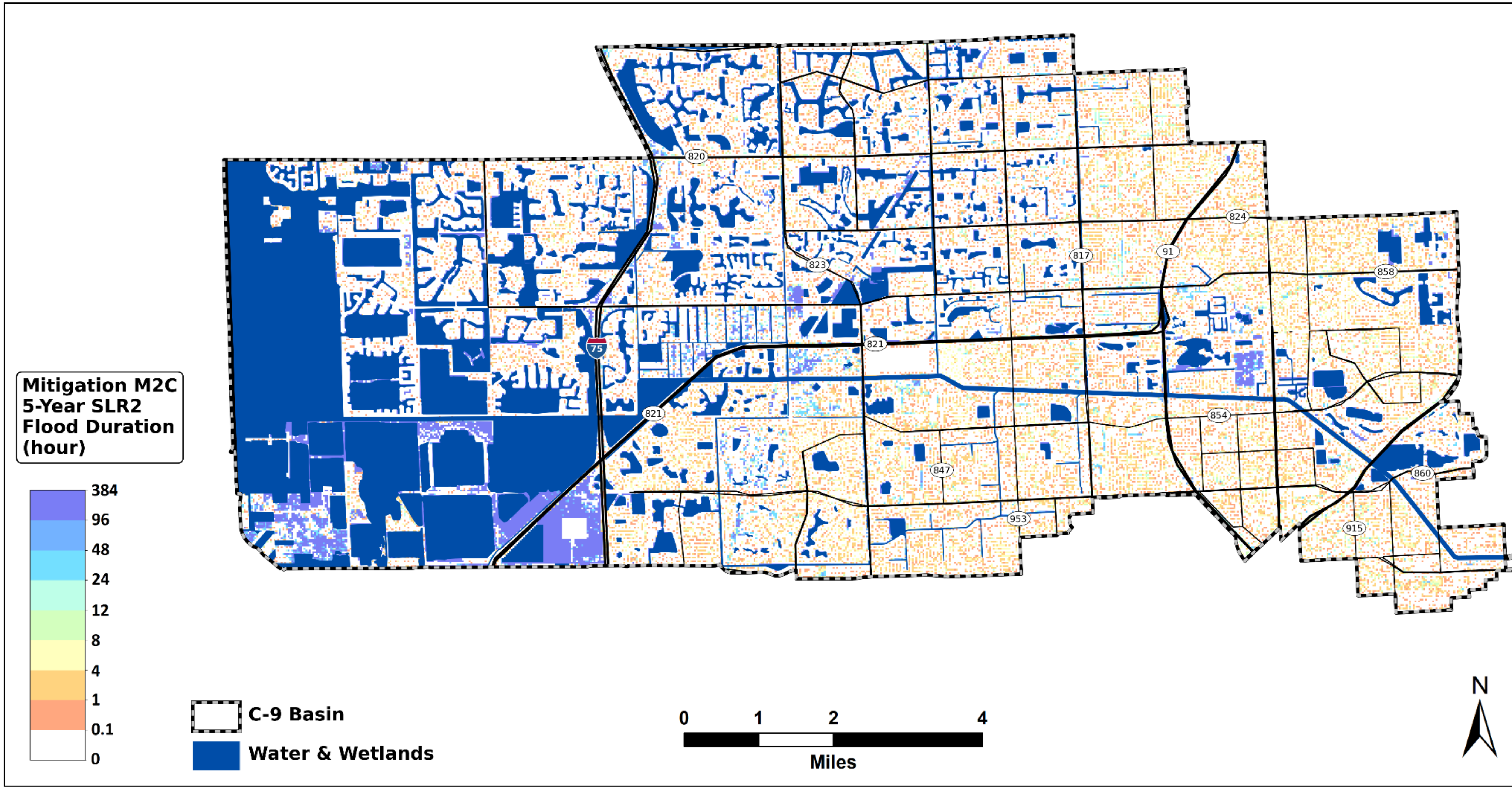


Figure E- 50: C-9 Watershed Flood Duration Map for the Mitigation M2C 5-Year Sea Level Rise 2 Design Storm Event

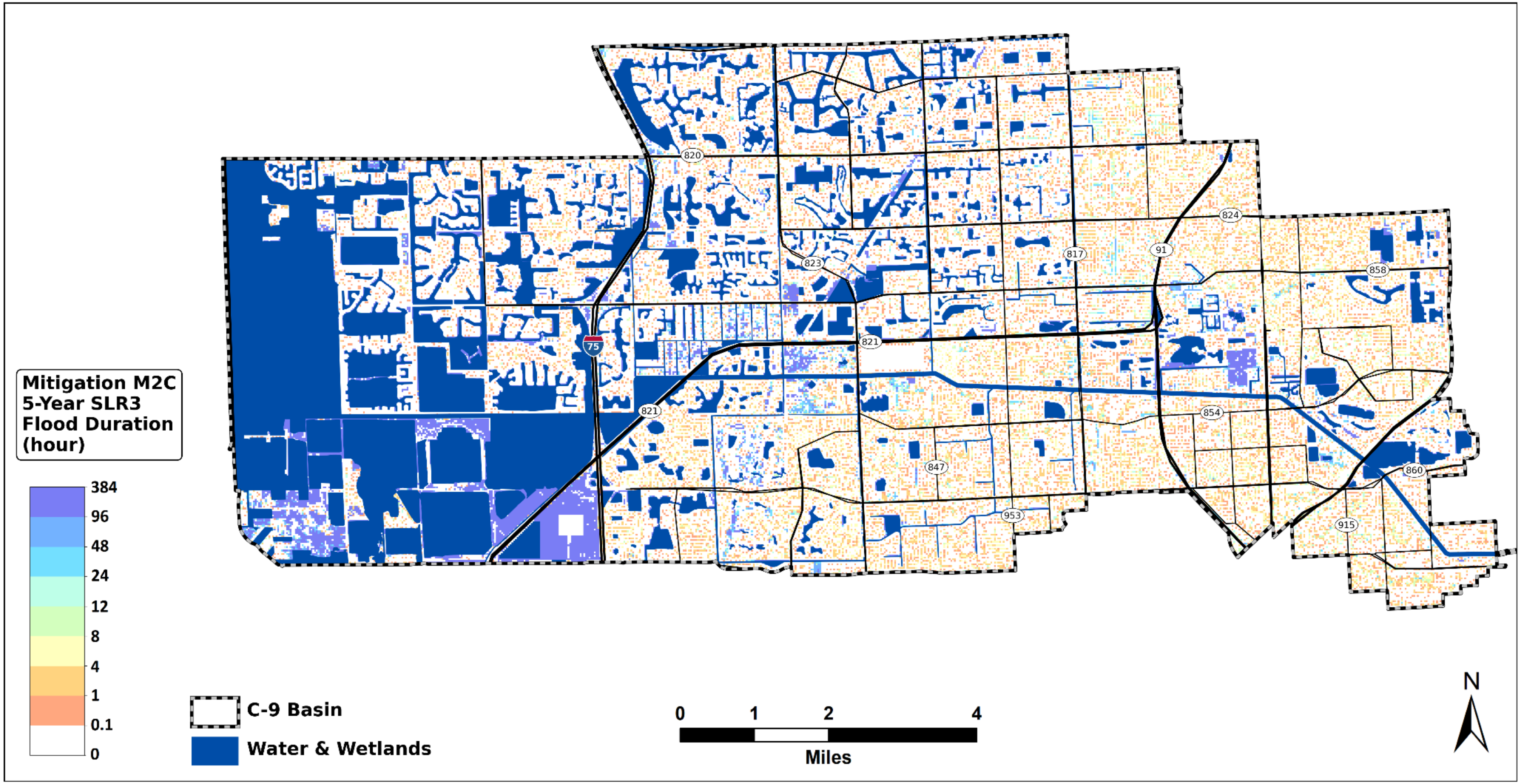


Figure E- 51: C-9 Watershed Flood Duration Map for the Mitigation M2C 5-Year Sea Level Rise 3 Design Storm Event

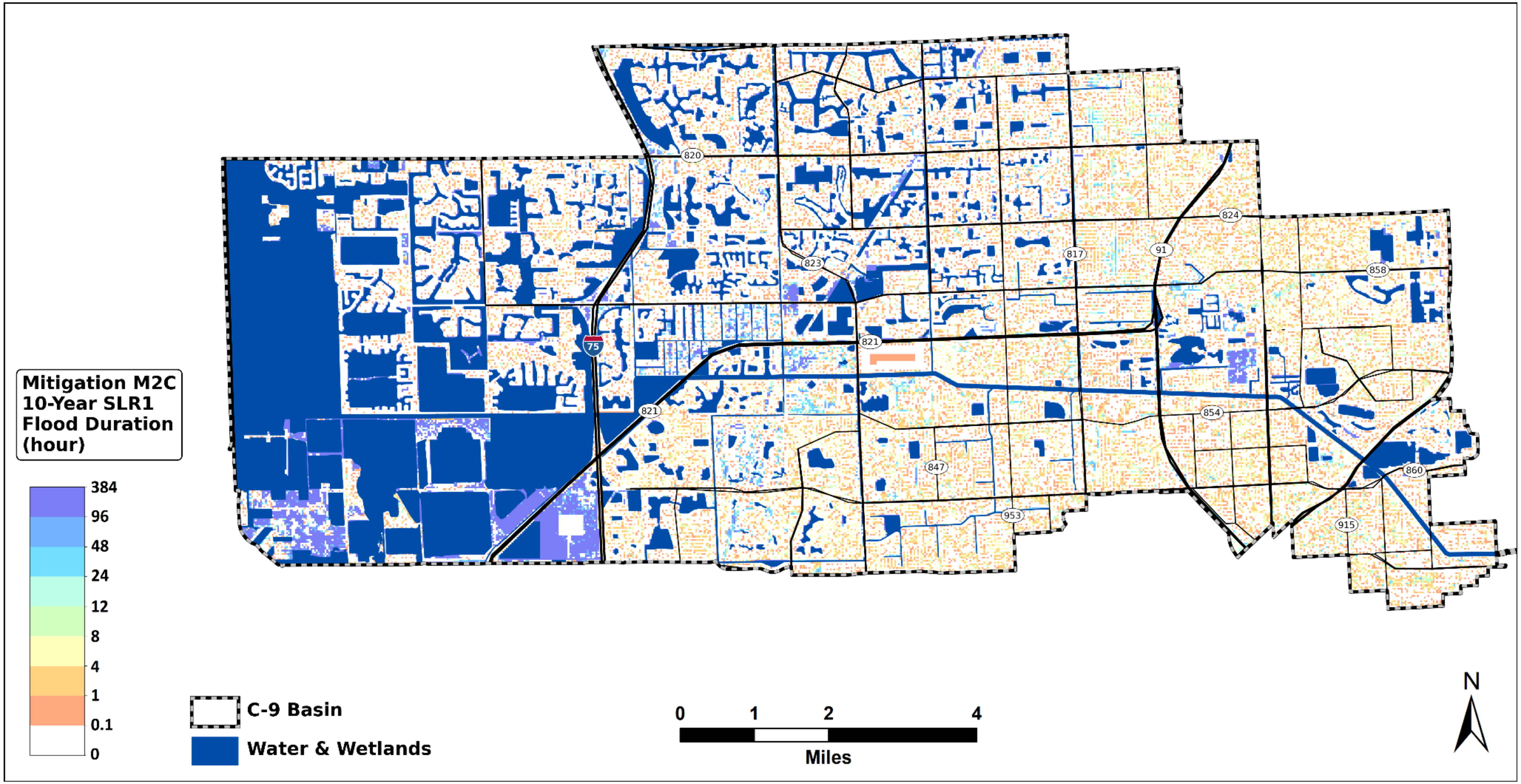


Figure E- 52: C-9 Watershed Flood Duration Map for the Mitigation M2C 10-Year Sea Level Rise 1 Design Storm Event

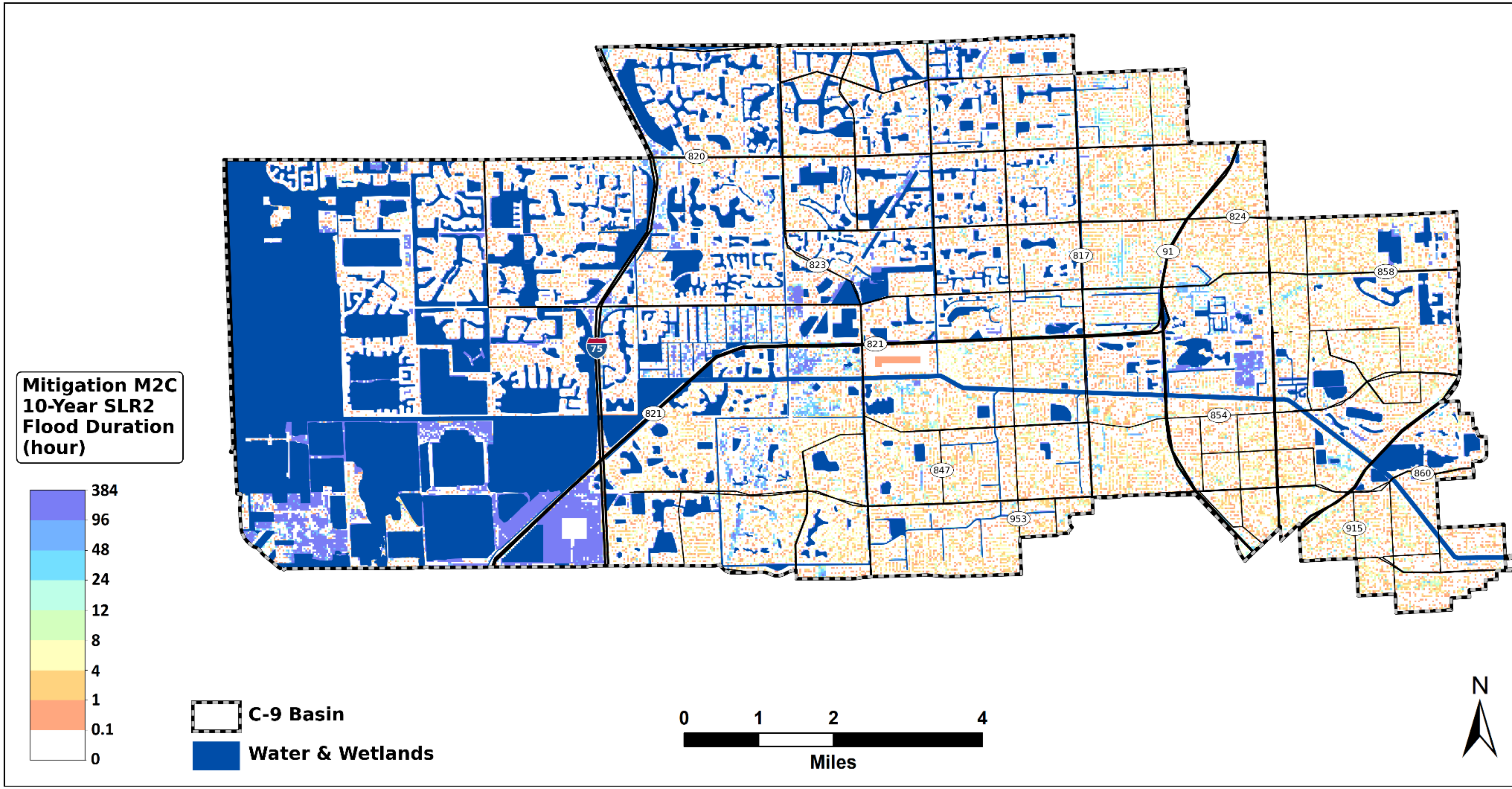


Figure E- 53: C-9 Watershed Flood Duration Map for the Mitigation M2C 10-Year Sea Level Rise 2 Design Storm Event

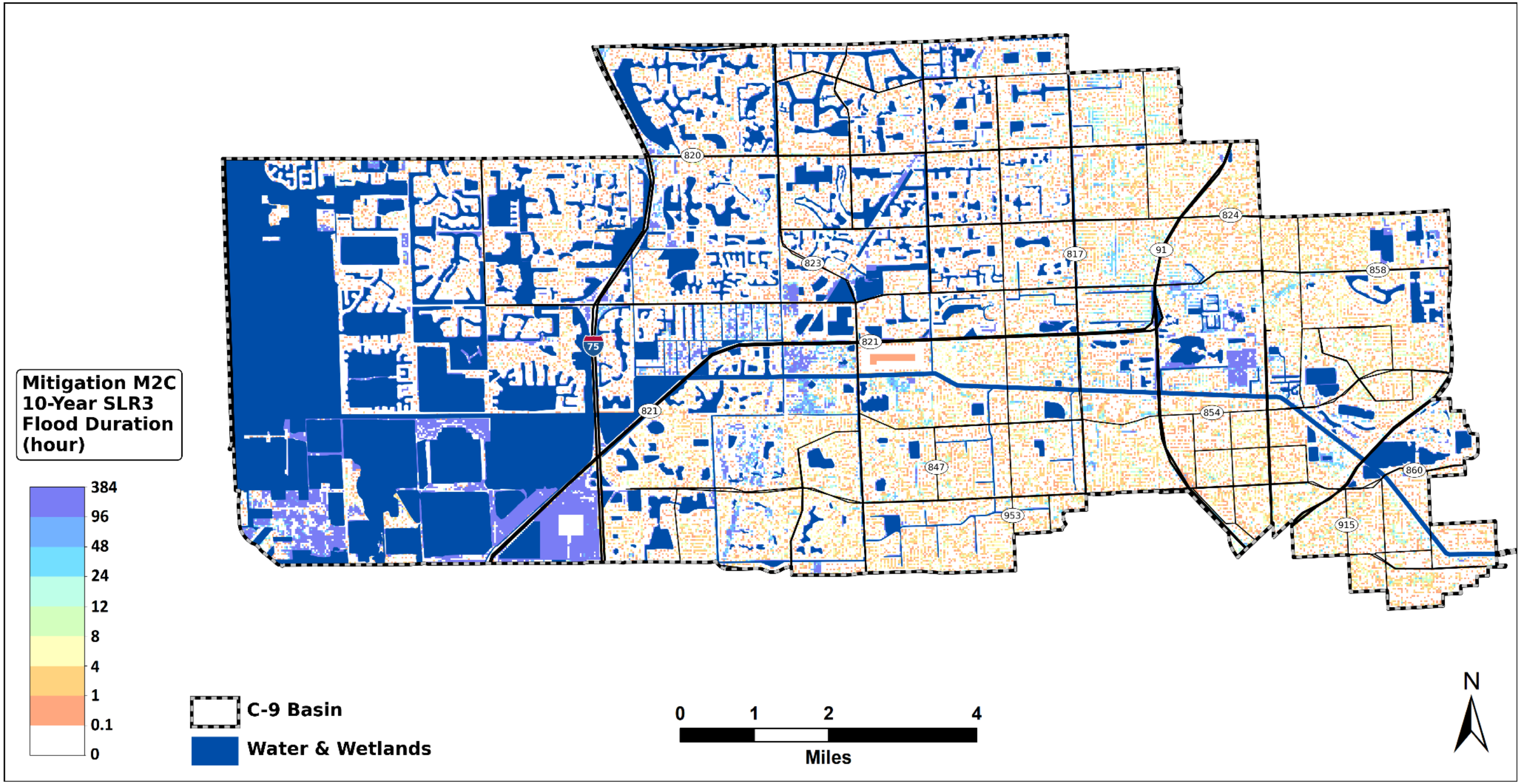


Figure E- 54: C-9 Watershed Flood Duration Map for the Mitigation M2C 10-Year Sea Level Rise 3 Design Storm Event

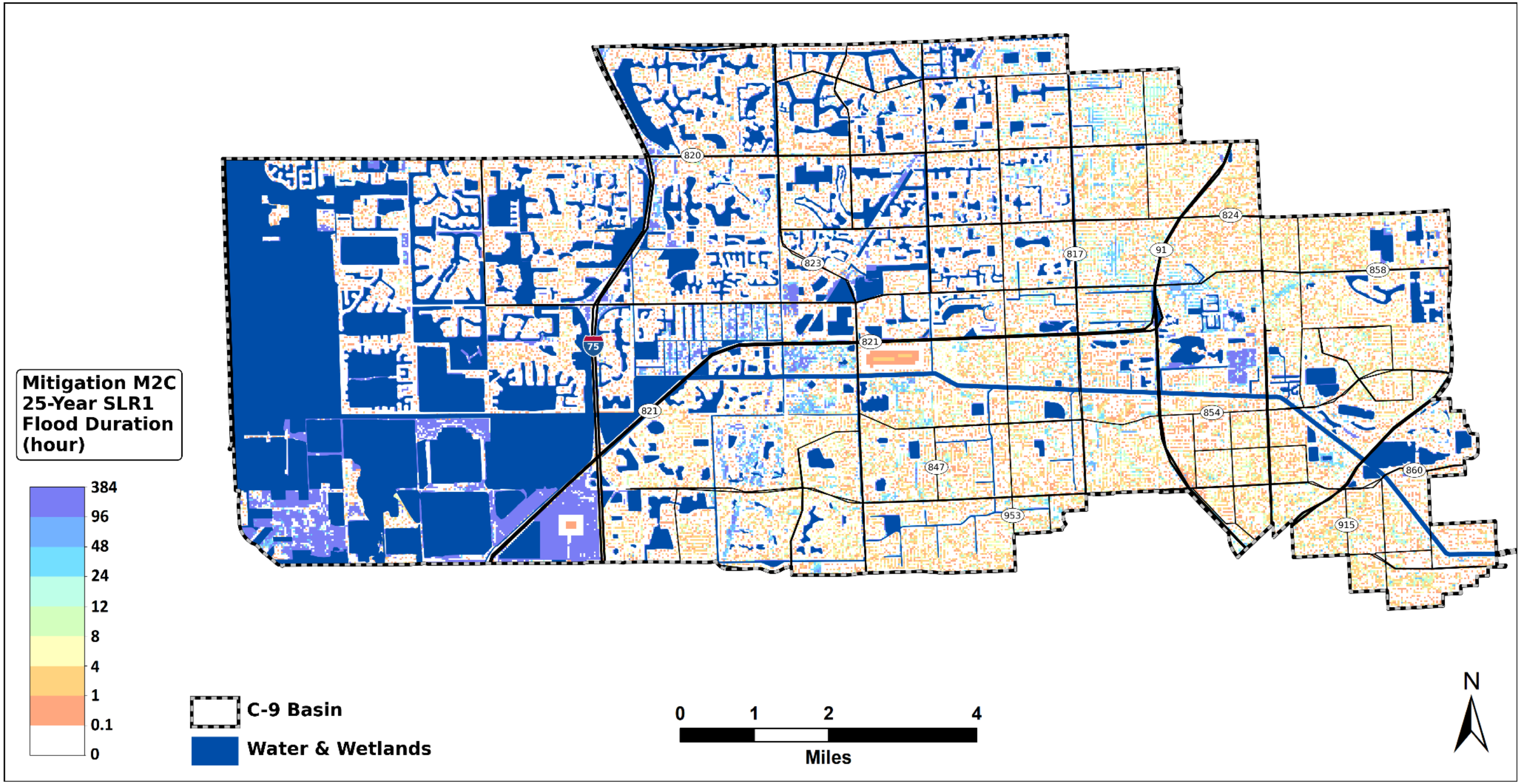


Figure E- 55: C-9 Watershed Flood Duration Map for the Mitigation M2C 25-Year Sea Level Rise 1 Design Storm Event

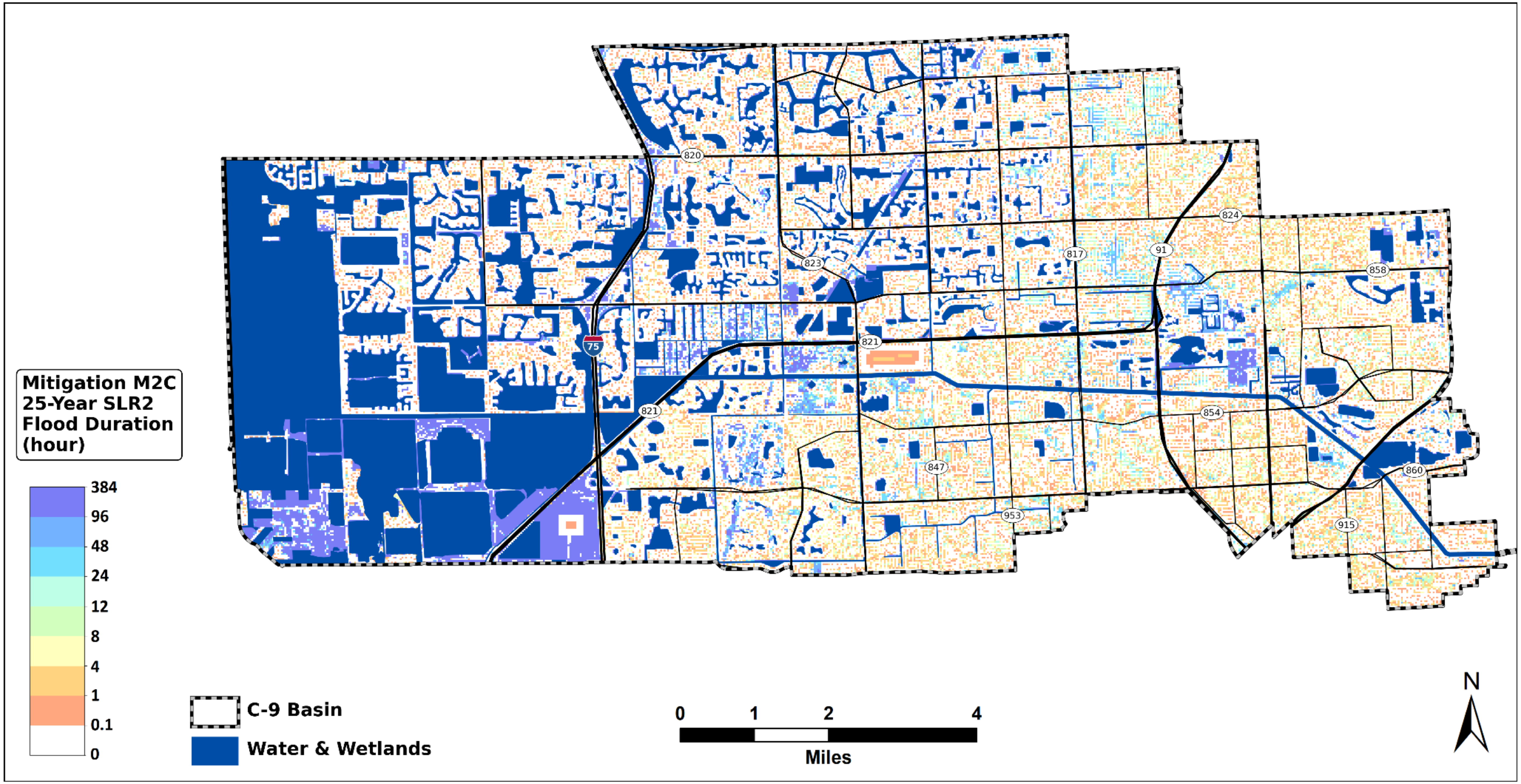


Figure E- 56: C-9 Watershed Flood Duration Map for the Mitigation M2C 25-Year Sea Level Rise 2 Design Storm Event

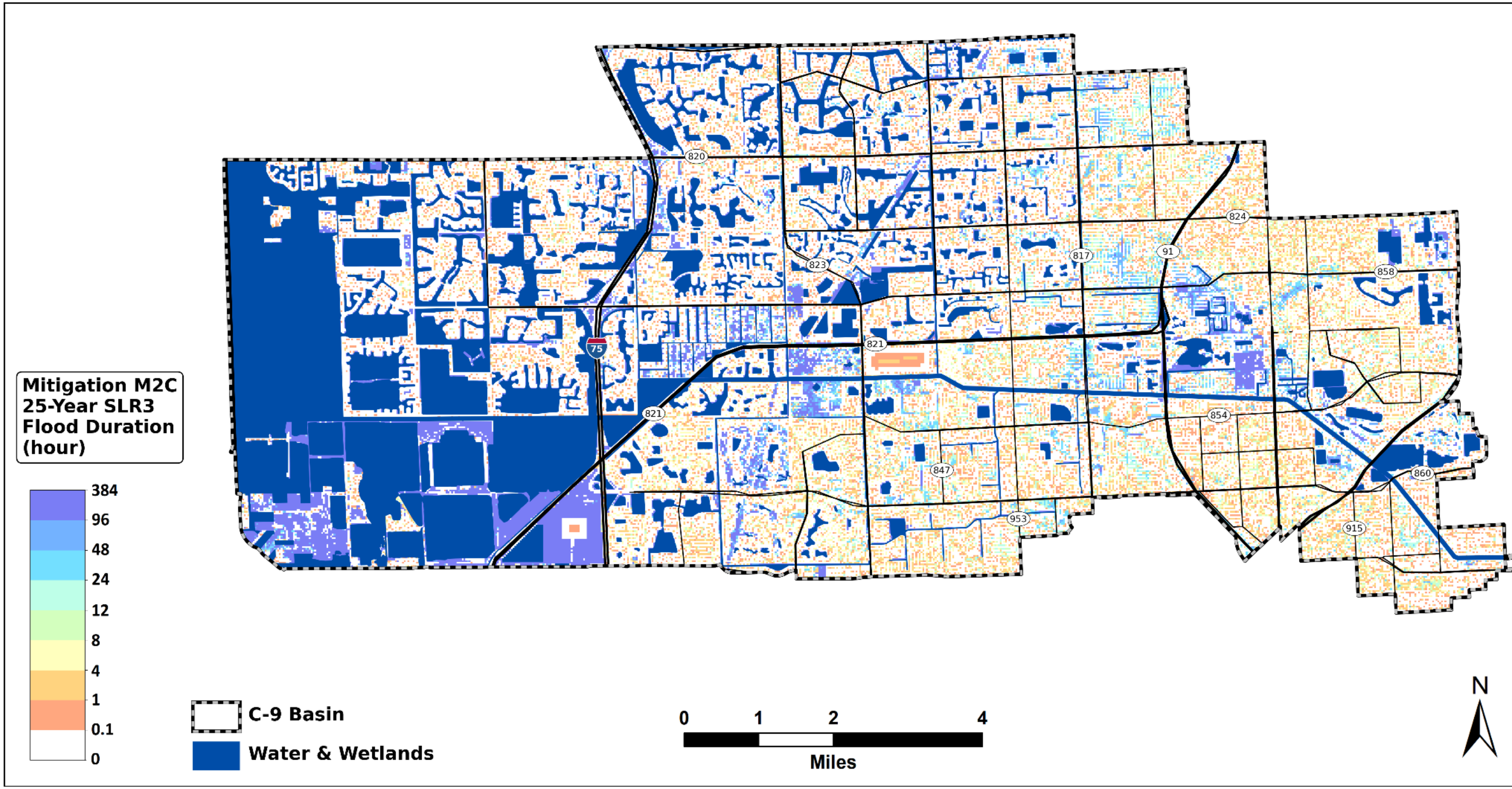


Figure E- 57: C-9 Watershed Flood Duration Map for the Mitigation M2C 25-Year Sea Level Rise 3 Design Storm Event

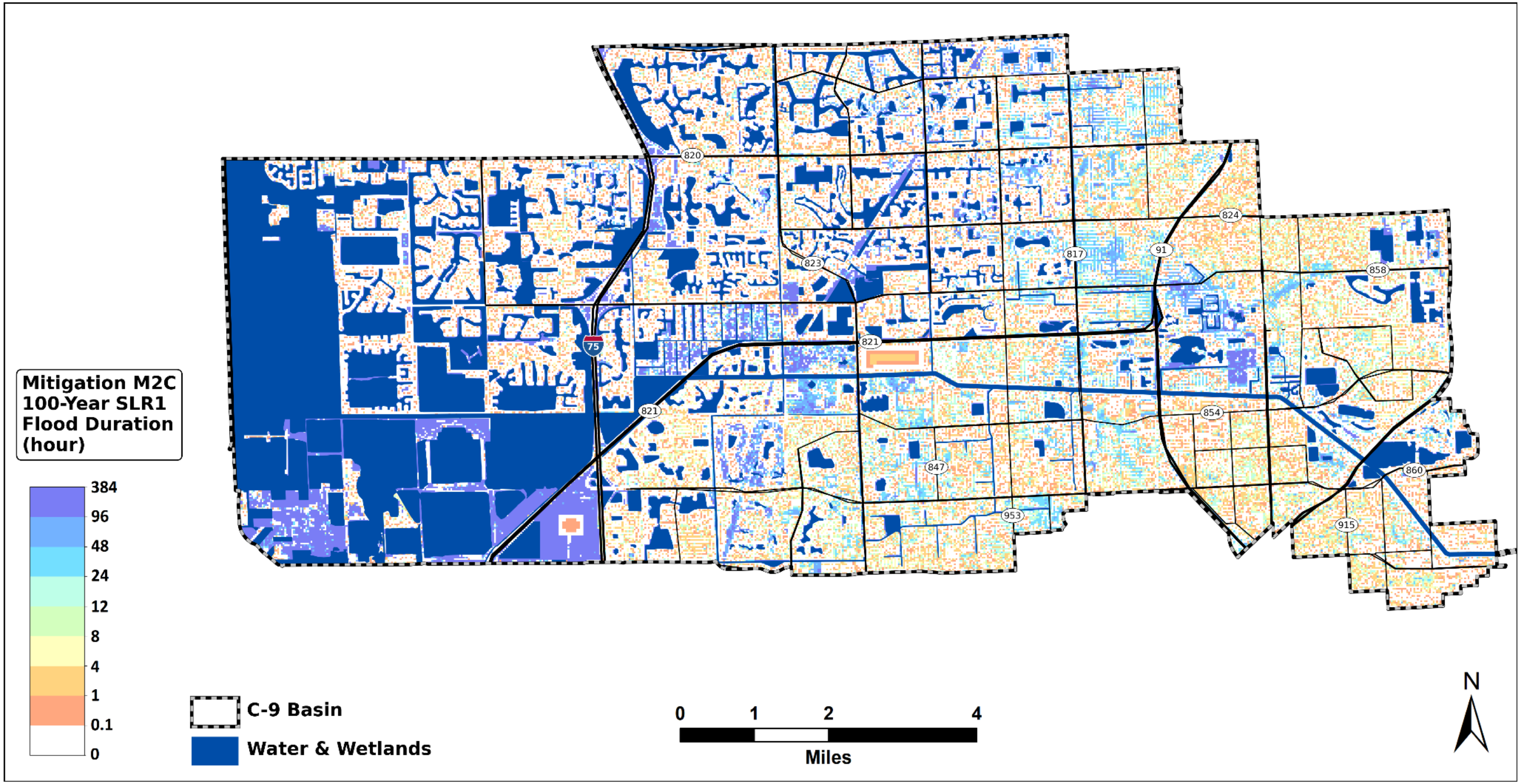


Figure E- 58: C-9 Watershed Flood Duration Map for the Mitigation M2C 100-Year Sea Level Rise 1 Design Storm Event

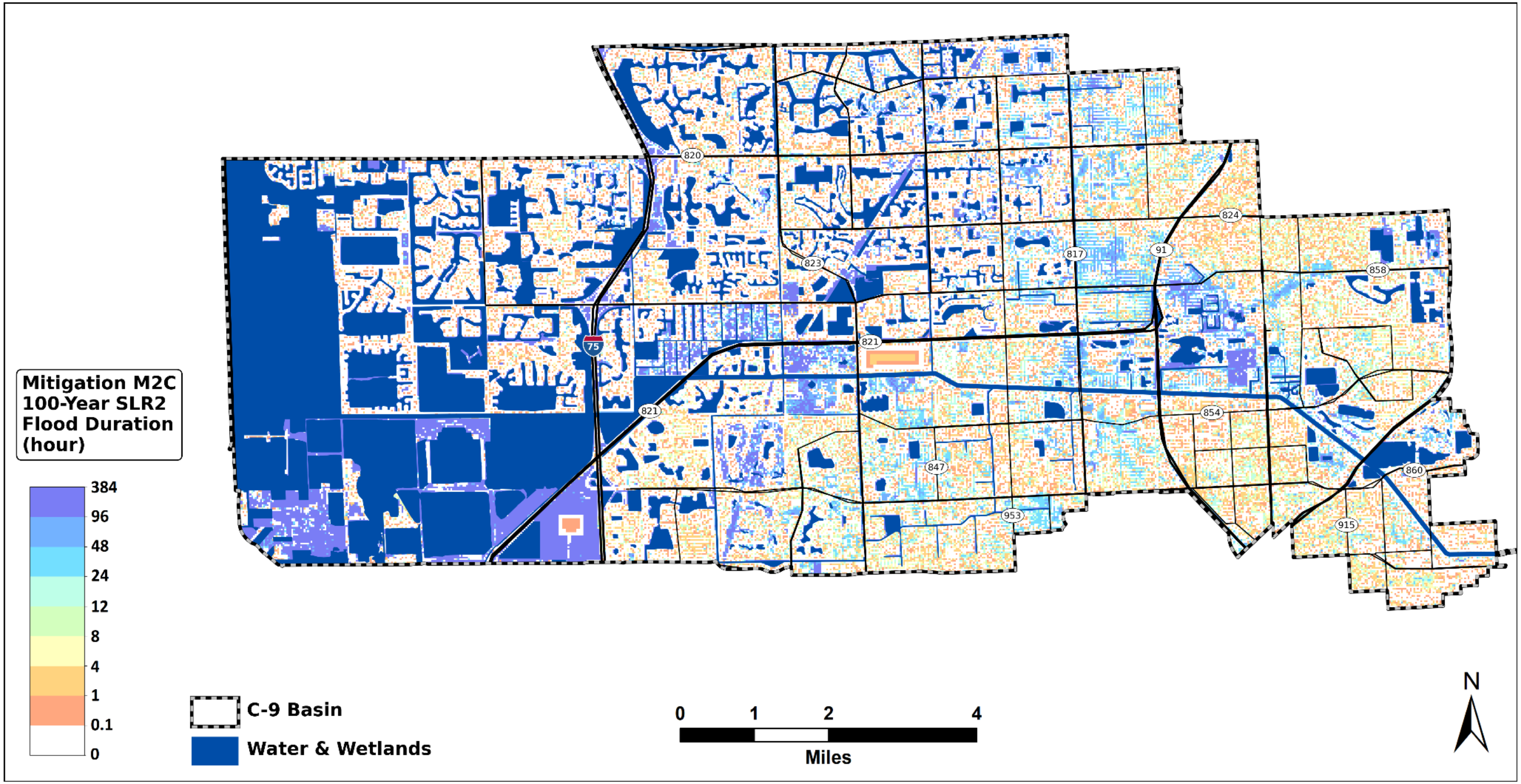


Figure E- 59: C-9 Watershed Flood Duration Map for the Mitigation M2C 100-Year Sea Level Rise 2 Design Storm Event

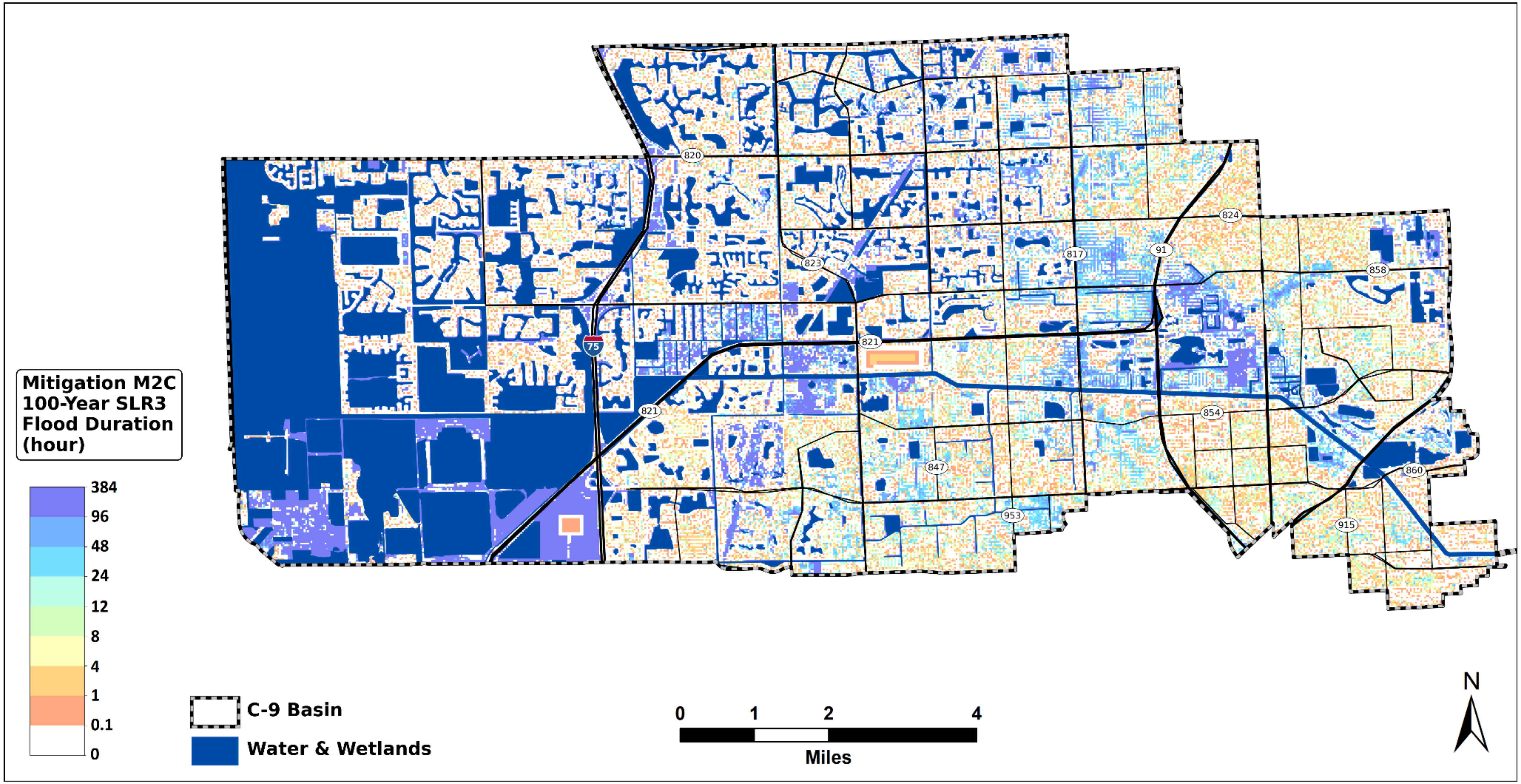


Figure E- 60: C-9 Watershed Flood Duration Map for the Mitigation M2C 100-Year Sea Level Rise 3 Design Storm Event

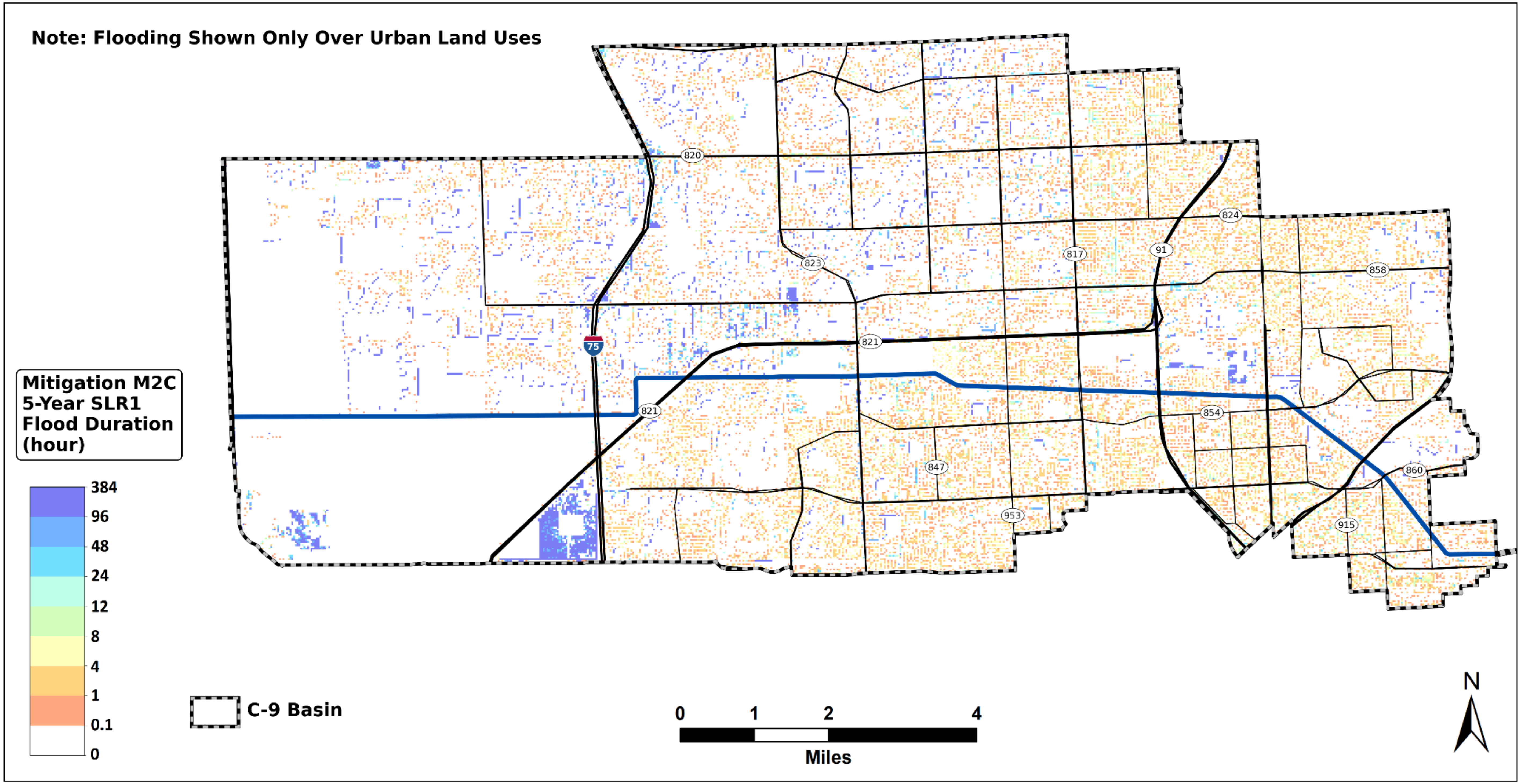


Figure E- 61: C-9 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2C 5-Year Sea Level Rise 1 Design Storm Event

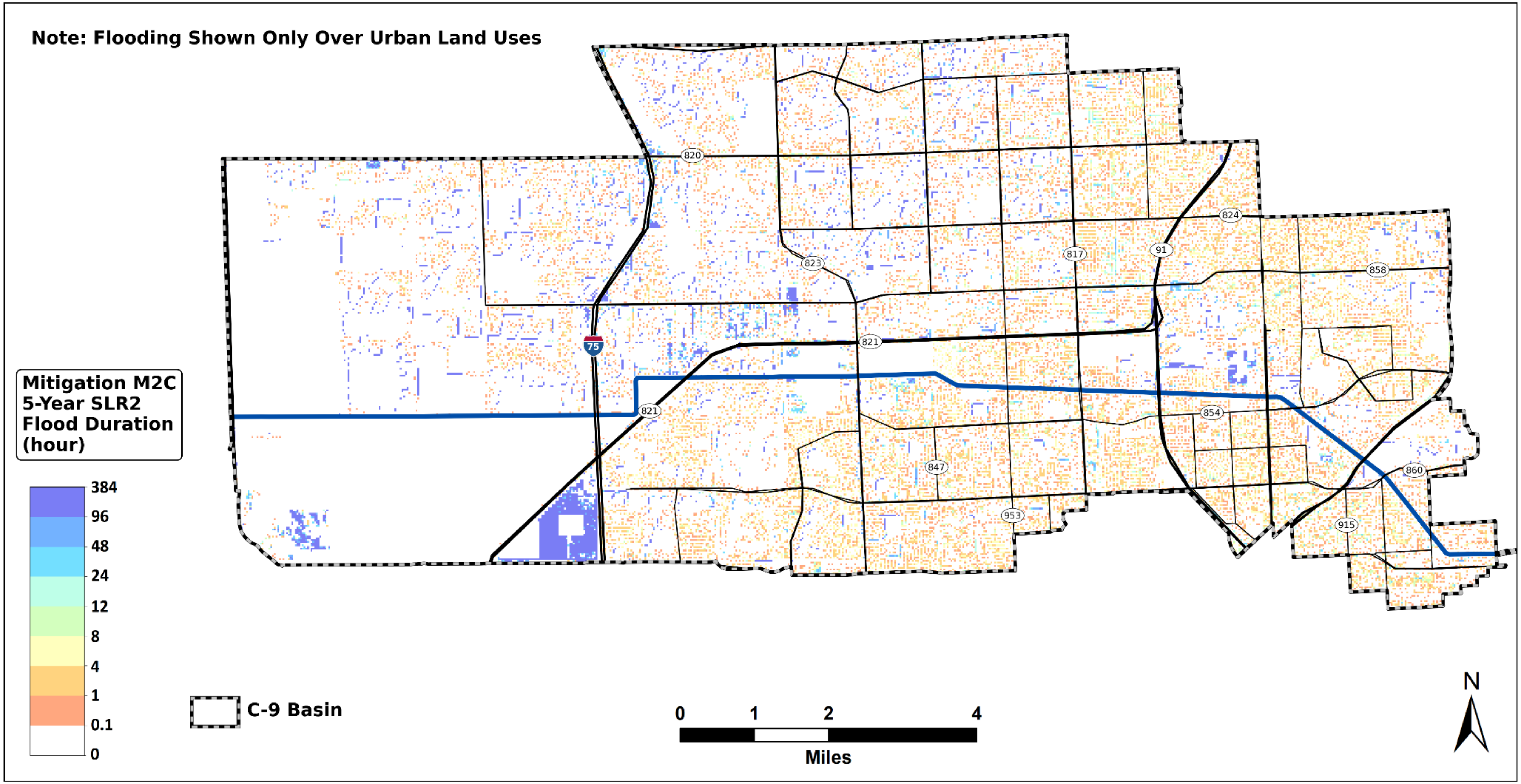


Figure E- 62: C-9 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2C 5-Year Sea Level Rise 2 Design Storm Event

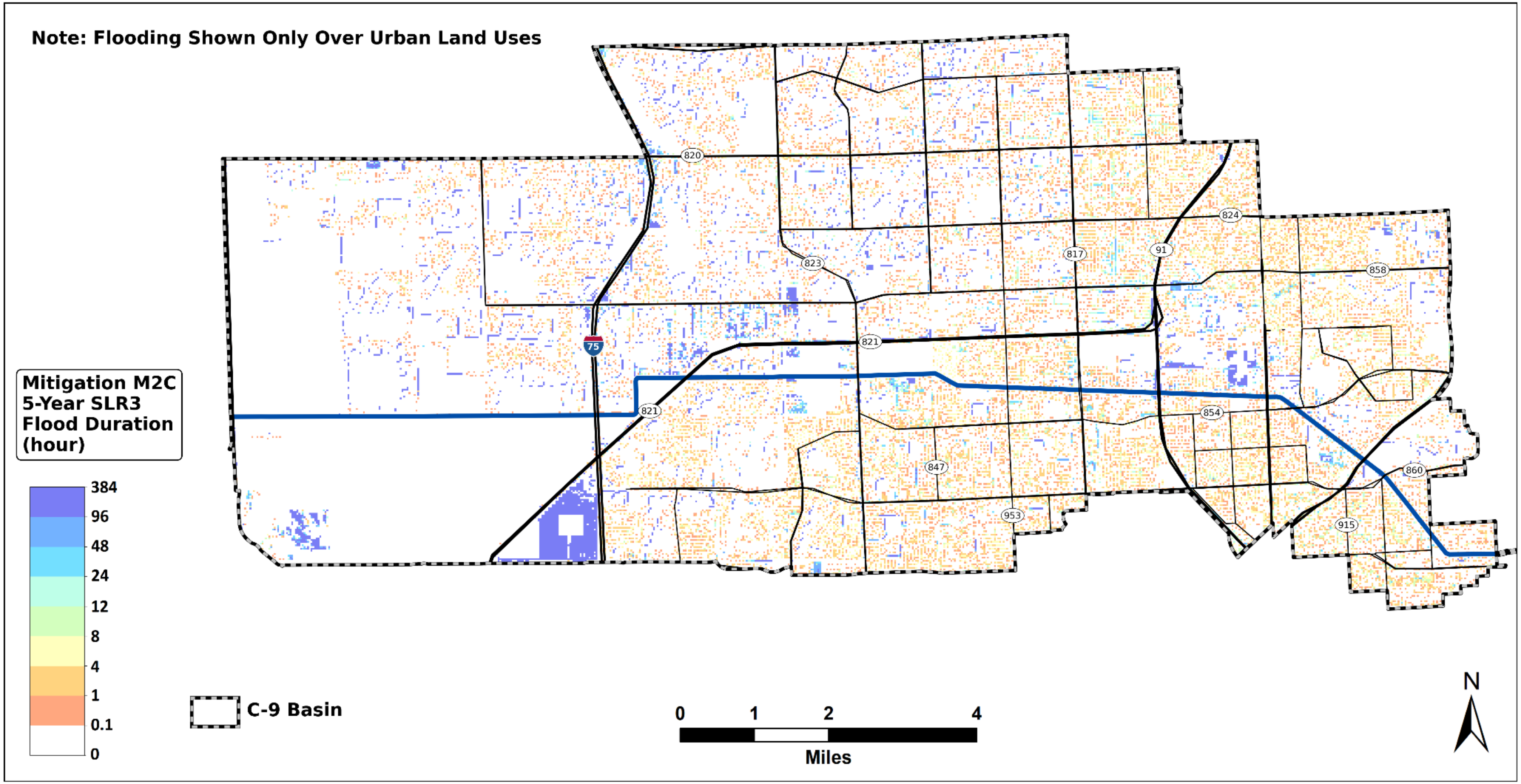


Figure E- 63: C-9 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2C 5-Year Sea Level Rise 3 Design Storm Event

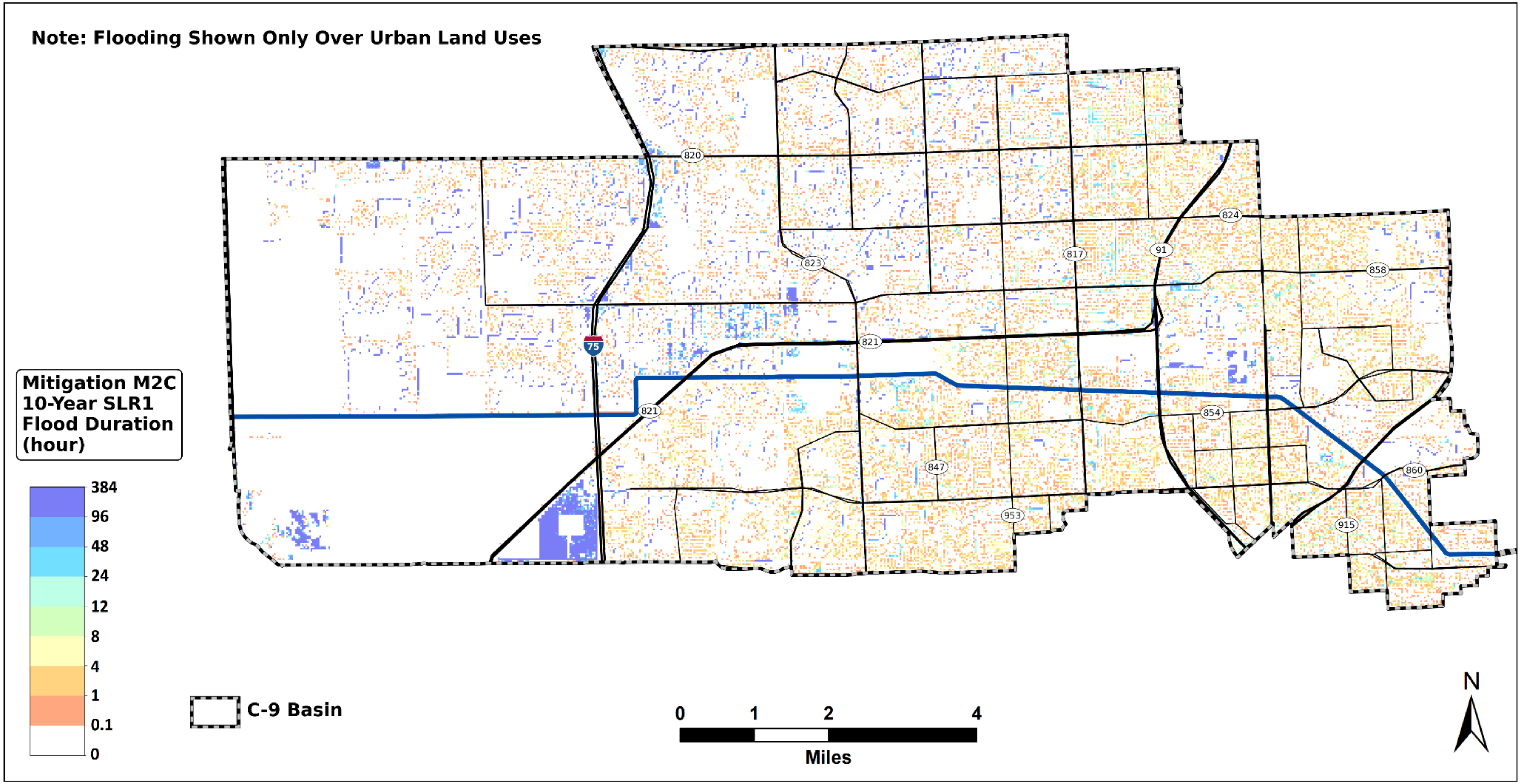


Figure E- 64: C-9 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2C 10-Year Sea Level Rise 1 Design Storm Event

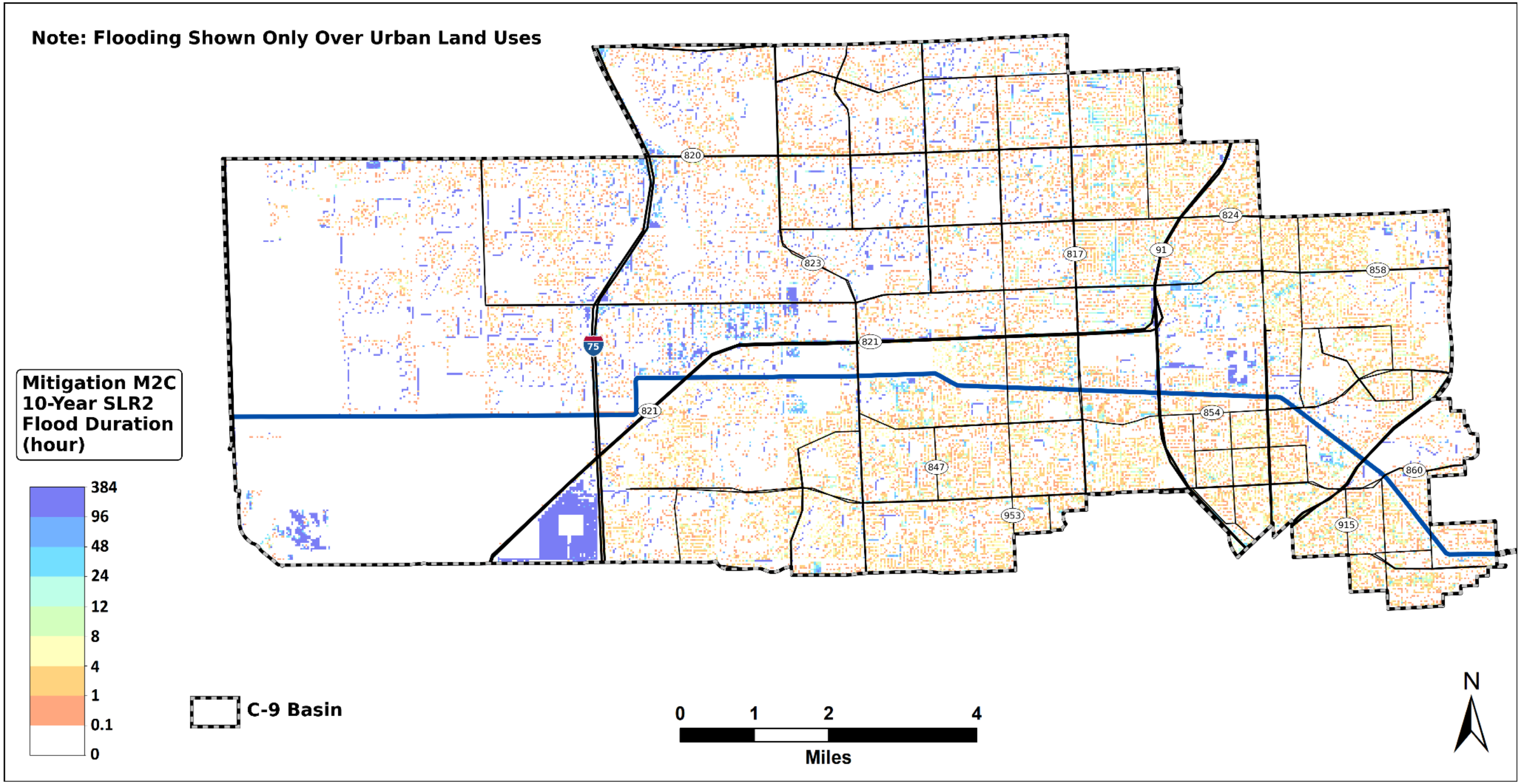


Figure E- 65: C-9 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2C 10-Year Sea Level Rise 2 Design Storm Event

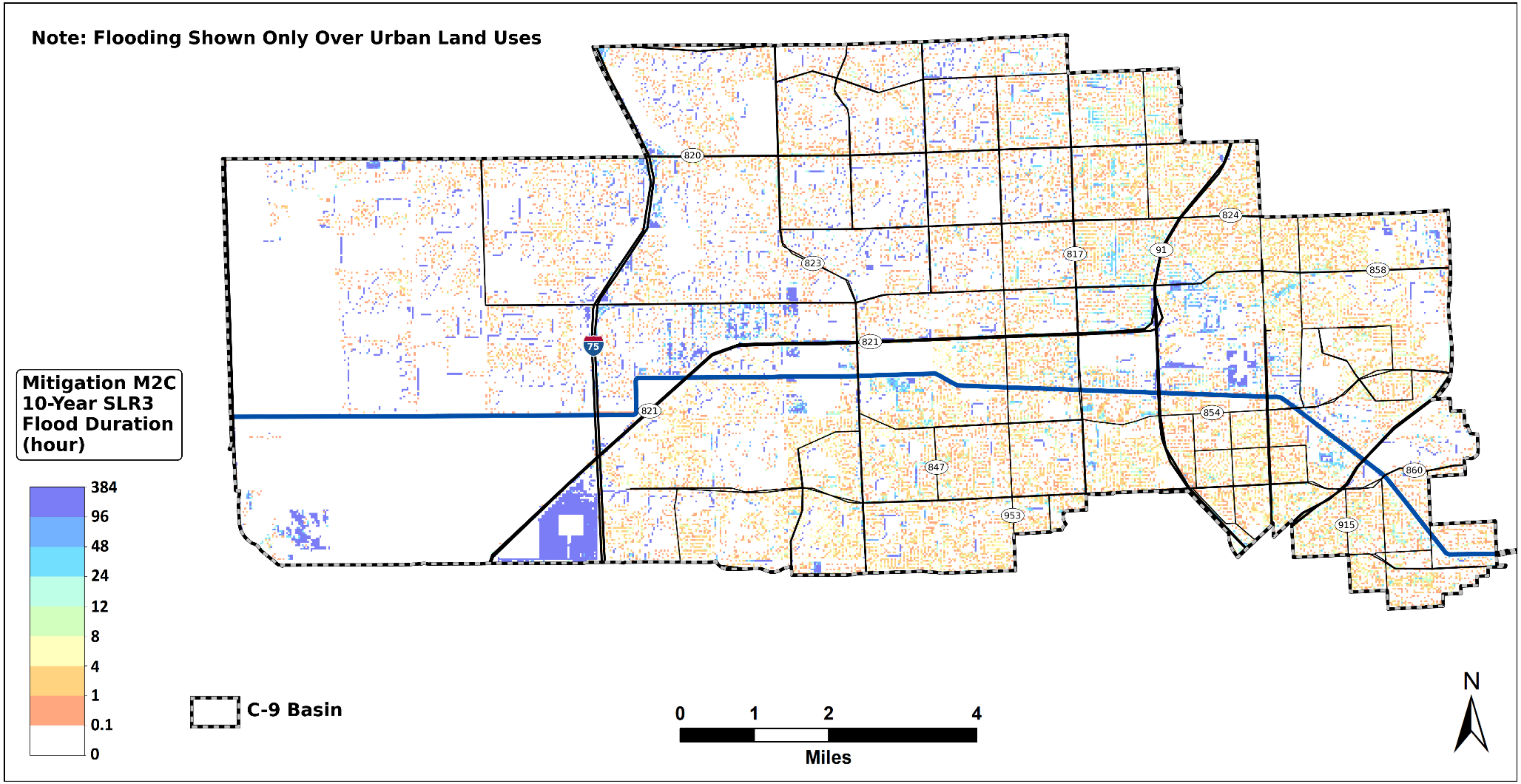


Figure E- 66: C-9 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2C 10-Year Sea Level Rise 3 Design Storm Event

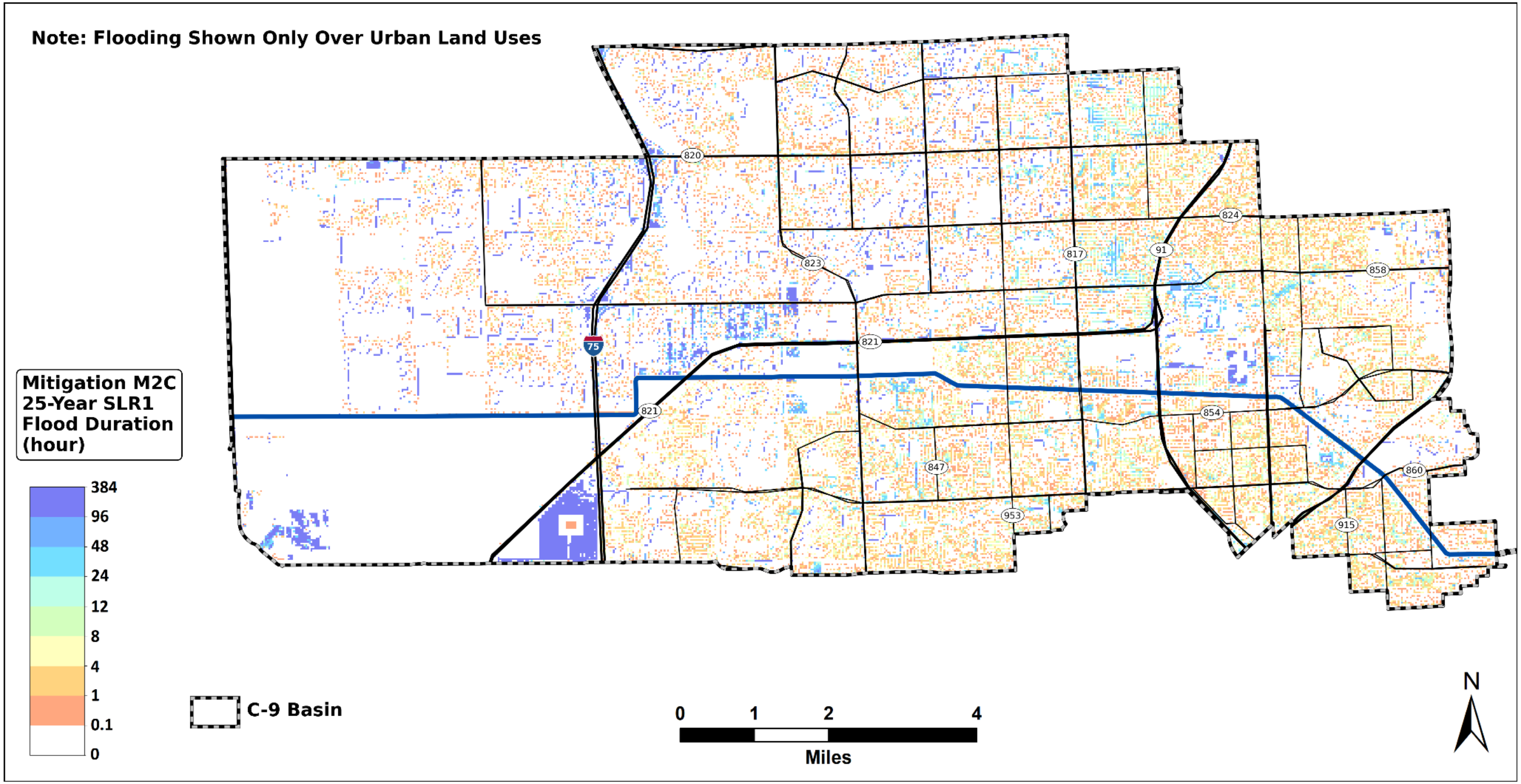


Figure E- 67: C-9 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2C 25-Year Sea Level Rise 1 Design Storm Event

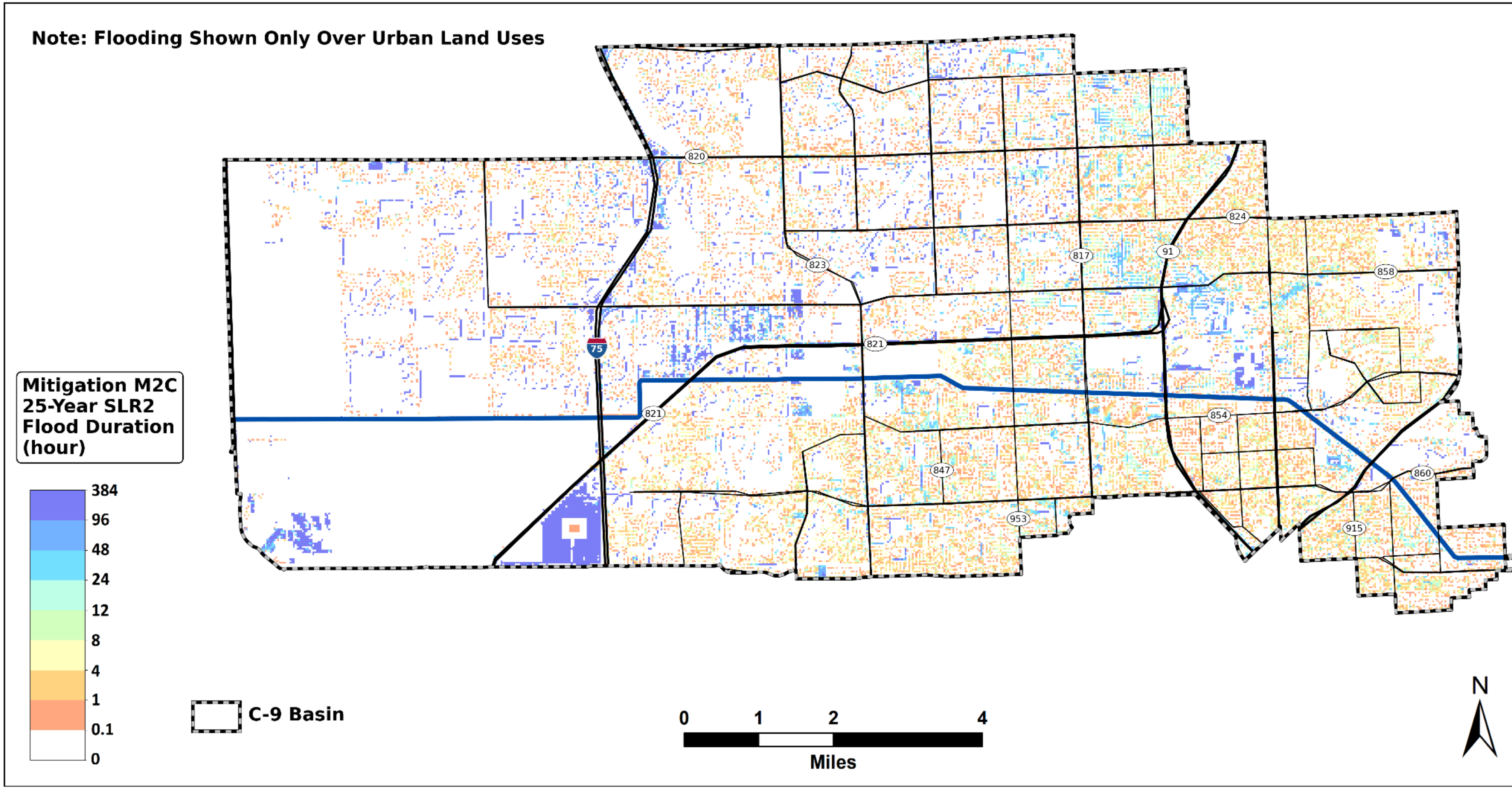


Figure E- 68: C-9 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2C 25-Year Sea Level Rise 2 Design Storm Event

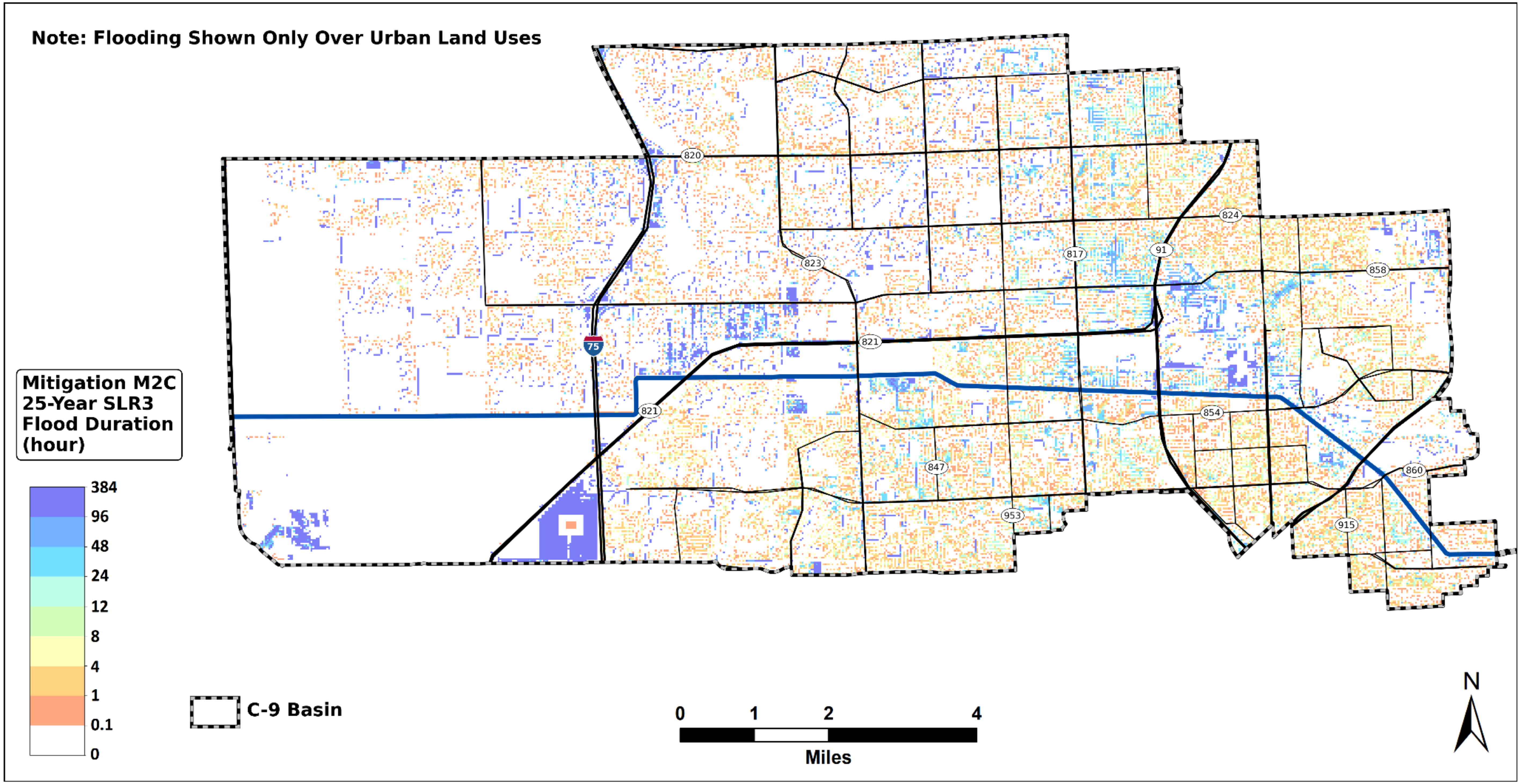


Figure E- 69: C-9 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2C 25-Year Sea Level Rise 3 Design Storm Event

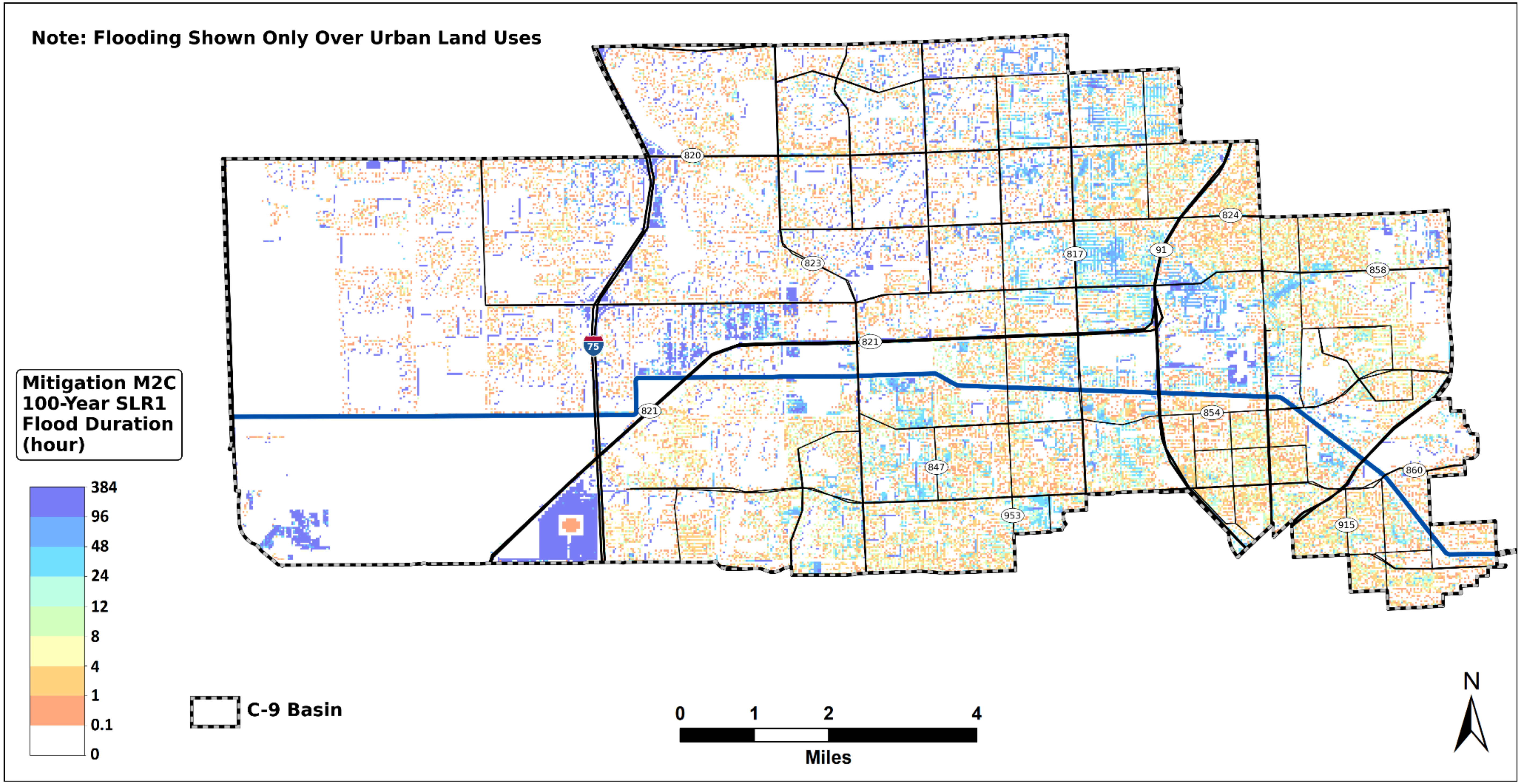


Figure E- 70: C-9 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2C 100-Year Sea Level Rise 1 Design Storm Event

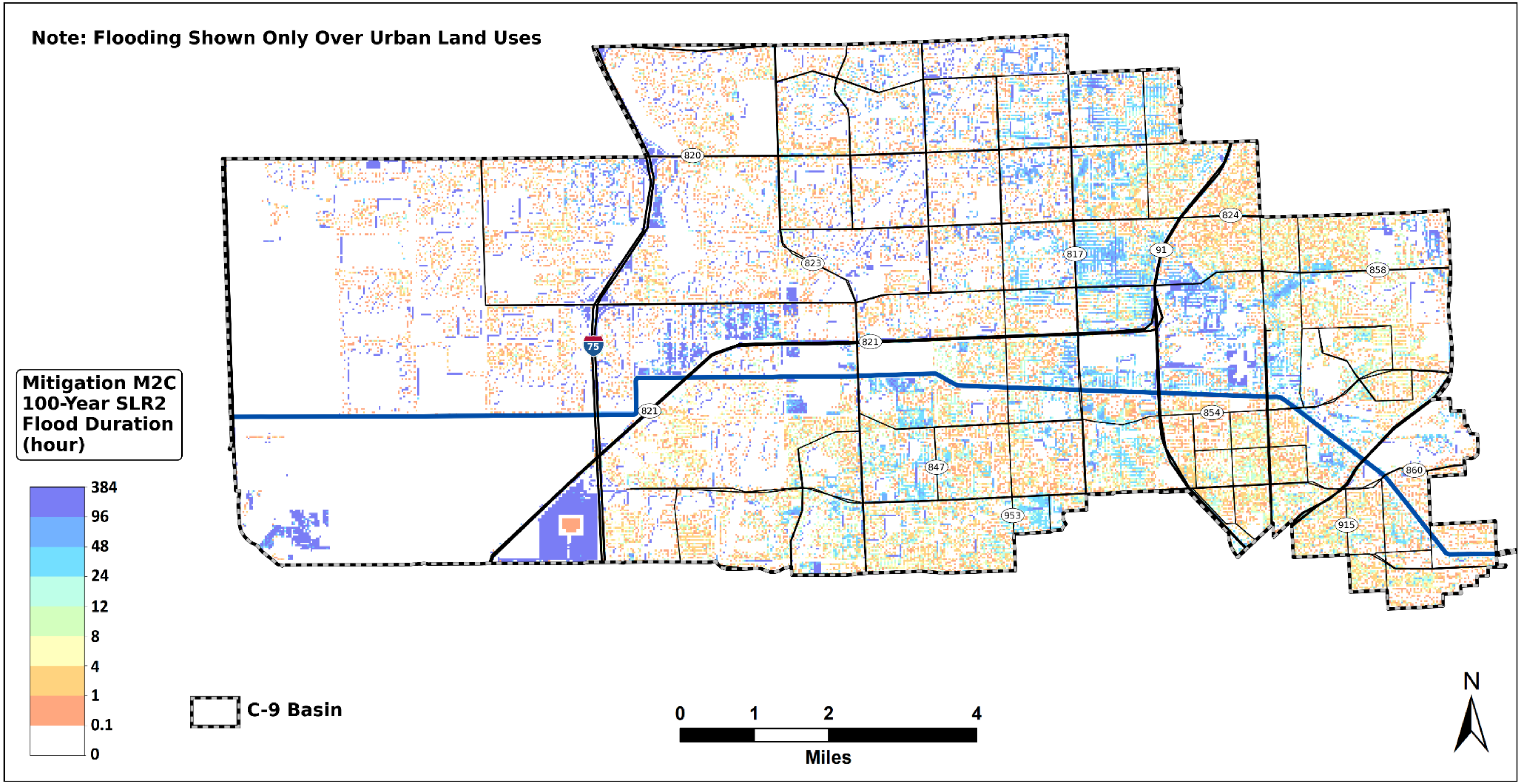


Figure E- 71: C-9 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2C 100-Year Sea Level Rise 2 Design Storm Event

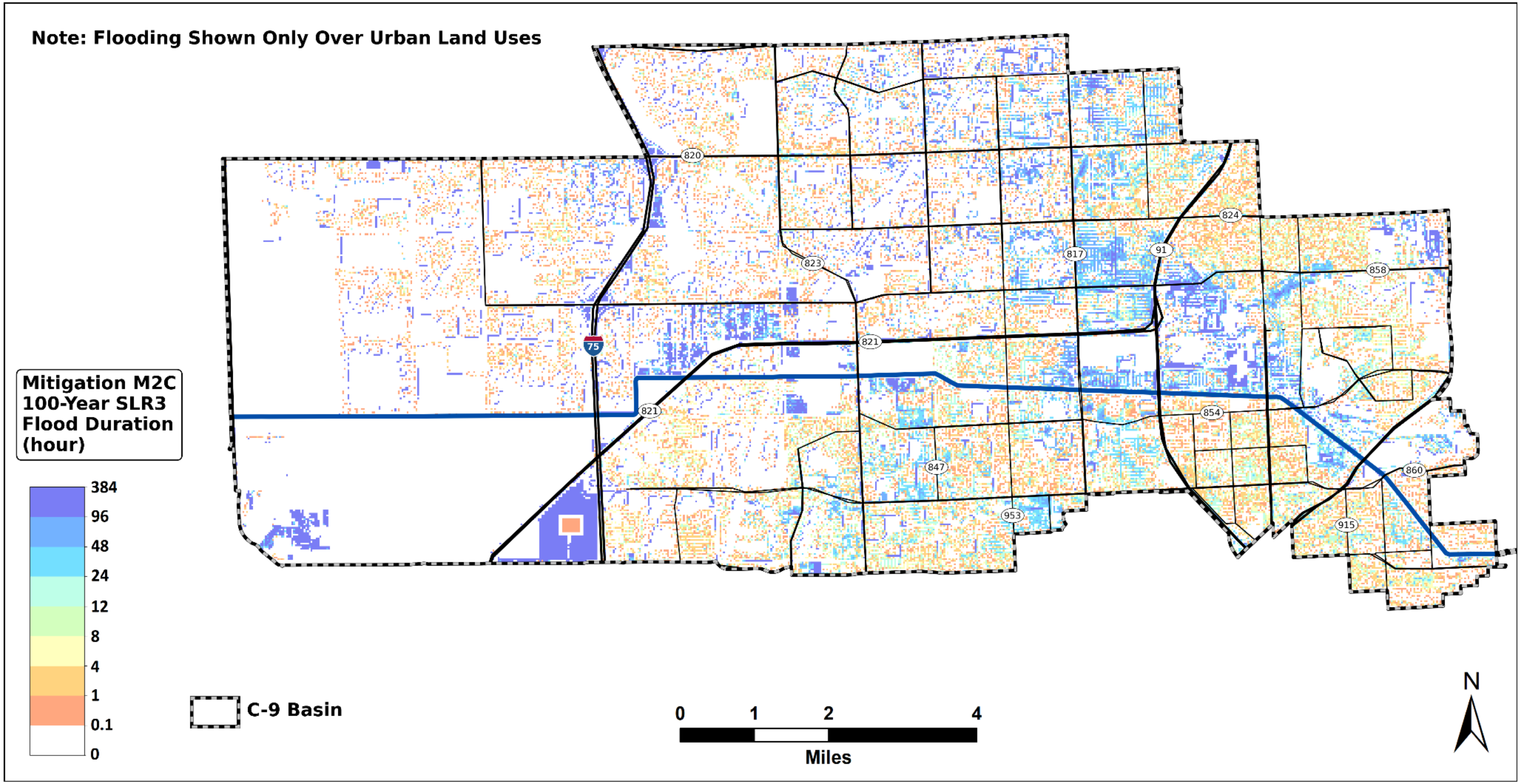


Figure E- 72: C-9 Watershed Flood Duration Map of Urban Land Use Areas for the Mitigation M2C 100-Year Sea Level Rise 3 Design Storm Event

Appendix F Supporting Documentation for Cost Estimation

Table F- 1: M2A Cost Estimation with References

M2A for 25-year SLR1		
C-8/S-28 Cost Estimate		
Pump Station	**Costs**	**References/Notes**
Structure Replacement	$19,056,898	S28 Costs from SFWMD PDF Costs (Assumed 250' DS; raise spillway by 5')
Forward Pump (1550 cfs)	$79,639,466	S28 Costs from SFWMD's XLS Costs (S28:AN271)
Forward Pump Backup Generator Facility	$9,085,601	S28 Costs from SFWMD's XLS Costs (S28:BH118)
Structure Tie Back (Flood Barrier)	$2,987,463	S28 Costs from SFWMD's XLS Costs (raise berm by 3'x250') (S28:AX47)
Design & Construction Management	$16,615,414	S28 Costs from SFWMD's XLS Costs (15% of costs excluding real estate)
Real Estate	$7,000,000	S28 Costs from SFWMD's XLS Costs (S28:BR10)
Total Pump Station Cost	**$134,384,842**	
Storage		
Distributed Storage (500 Ac-Ft)	$38,859,600	Real estate costs excluded
Design & Construction Management	$5,828,940	15% of costs excluding real estate
Total Storage Cost	**$44,688,540**	
Total C-8 Cost	**$179,073,382**	
C-9/S-29 Cost Estimate		
Pump Station		
Structure Replacement	$19,056,898	S28 Costs from SFWMD's PDF Costs (raise spillway by 5') at minimum
Forward Pump (1550 cfs)	$84,291,017	S29 Costs from SFWMD's XLS Costs Modified to 1500 CFS Pump (S29:J9)
Forward Pump Backup Generator Facility	$9,618,145	S29 Costs from SFWMD's XLS Costs (S29:J10)
Structure Tie Back (Flood Barrier)	$2,769,122	S29 Costs from SFWMD's XLS Costs (raise berm by 3') (S29:J11)
Design & Construction Management	$17,360,277	S29 Costs from SFWMD's XLS Costs (15% of costs excluding real estate)
Real Estate	$16,000,000	S29 Costs from SFWMD's XLS Costs (S29:J13)
Total Pump Station Cost	**$149,095,459**	
Storage		
Distributed Storage (500 Ac-Ft)	$38,859,600	Real estate costs excluded
Design & Construction Management	$5,828,940	15% of costs excluding real estate
Total Storage Cost	**$44,688,540**	
Total C-9 Cost	**$193,783,999**	

Table F- 2: M2B Cost Estimation with References

M2B for 25-year SLR1		
C-8/S-28 Cost Estimate		
Pump Station	**Costs**	**References/Notes**
Structure Replacement	$19,056,898	S28 Costs from SFWMD's PDF Costs (Assumed 250' DS; raise spillway by 5')
Forward Pump (2550 cfs)	$107,001,675	S28 Costs from SFWMD's XLS Costs scaled to 2500 CFS Pump (S28-M2B:AN271)
Forward Pump Backup Generator Facility	$11,440,141	S28 Costs from SFWMD's XLS Costs, Scaled generator to match pump (S28:BH118)
Structure Tie Back (Flood Barrier)	$2,987,463	S28 Costs from SFWMD's XLS Costs (raise berm by 3'x250') (S28:AX47)
Design & Construction Management	$21,072,927	S28 Costs from SFWMD's XLS Costs (15% of costs excluding real estate)
Real Estate	$7,000,000	S28 Costs from SFWMD's XLS Costs (S28:BR10)
Total Pump Station Cost	**$168,559,105**	
Storage		
Distributed Storage (500 Ac-Ft)	$38,859,600.00	Real estate costs excluded
Design & Construction Management	$5,828,940.00	15% of costs excluding real estate
Total Storage Cost	**$44,688,540.00**	
Canal Improvements		
Raise Canal Banks (to 7.5 ft)	$12,412,542	Costs from SFWMD's email estimate (real estate costs excluded)
Design & Construction Management	$1,861,881	15% of costs excluding real estate
Total Canal Improvements Cost	**$14,274,423**	
Total C-8 Cost	**$227,522,068**	
C-9/S-29 Cost Estimate		
Pump Station		
Structure Replacement	$19,056,898	S28 Costs from SFWMD's PDF Costs (raise spillway by 5') at minimum
Forward Pump (2550 cfs)	$111,668,639	S29 Costs from SFWMD's XLS Costs Scaled to 2500 CFS Pump (S29-M2B:J9)
Forward Pump Backup Generator Facility	$11,918,924	S29 Costs from SFWMD's XLS Costs, Scaled generator to match pump (S29:J10)
Structure Tie Back (Flood Barrier)	$2,769,122	S29 Costs from SFWMD's XLS Costs (raise berm by 3') (S29:J11)
Design & Construction Management	$21,812,037	S29 Costs from SFWMD's XLS Costs (15% of costs excluding real estate)
Real Estate	$16,000,000	S29 Costs from SFWMD's XLS Costs (S29:J13)
Total Pump Station Cost	**$183,225,620**	
Storage		
Distributed Storage (500 Ac-Ft)	$38,859,600	Real estate costs excluded
Design & Construction Management	$5,828,940	15% of costs excluding real estate
Total Storage Cost	**$44,688,540**	
Canal Improvements		
Raise Canal Banks (to 7.5 ft)	$7,118,542	Costs from SFWMD's email estimate (real estate costs excluded)
Design & Construction Management	$1,067,781	15% of costs excluding real estate
Total Canal Improvements Cost	**$8,186,323**	
Total C-9 Cost	**$236,100,483**	

Table F- 3: M2C Cost Estimation with References

M2C for 25-year SLR3		
C-8/S-28 Cost Estimate		
Pump Station	**Costs**	**References/Notes**
Structure Replacement	$19,056,898	S28 Costs from SFWMD's PDF Costs (Assumed 250' DS; raise spillway by 5')
Forward Pump (3550 cfs)	$134,481,716	S28 Costs from SFWMD's XLS Costs scaled to 3500 CFS Pump (S28-M2C:AN271)
Forward Pump Backup Generator Facility	$13,791,922	S28 Costs from SFWMD's XLS Costs, Scaled generator to match pump (S28:BH118)
Structure Tie Back (Flood Barrier)	$2,987,463	S28 Costs from SFWMD's XLS Costs (raise berm by 3'x250') (S28:AX47)
Design & Construction Management	$25,547,700	S28 Costs from SFWMD's XLS Costs (15% of costs excluding real estate)
Real Estate	$7,000,000	S28 Costs from SFWMD's XLS Costs (S28:BR10)
Total Pump Station Cost	**$202,865,699**	
Storage		
Distributed Storage (500 Ac-Ft)	$38,859,600	Real estate costs excluded
Design & Construction Management	$5,828,940	15% of costs excluding real estate
Total Storage Cost	**$44,688,540**	
Canal Improvements		
Raise Canal Banks (to 7.5 ft)	$12,412,542	Raise Tab using SFWMD's email estimate (real estate costs excluded)
Widen Canal (by 100 ft)	$31,618,782	Widen Tab using (real estate costs excluded)
Design & Construction Management	$6,604,699	15% of costs excluding real estate
Total Canal Improvements Cost	**$50,636,022**	
Total C-8 Cost	**$298,190,261**	
C-9/S-29 Cost Estimate		
Pump Station		
Structure Replacement	$19,056,898	S28 Costs from SFWMD's PDF Costs (raise spillway by 5') at minimum
Forward Pump (3550 cfs)	$139,005,527	S29 Costs from SFWMD's XLS Costs Modified to 3500 CFS Pump (S29-M2C:J9)
Forward Pump Backup Generator Facility	$14,217,365	S29 Costs from SFWMD's XLS Costs, Scaled generator to match pump (S29:J10)
Structure Tie Back (Flood Barrier)	$2,769,122	S29 Costs from SFWMD's XLS Costs (raise berm by 3') (S29:J11)
Design & Construction Management	$26,257,337	S29 Costs from SFWMD's XLS Costs (15% of costs excluding real estate)
Real Estate	$16,000,000	S29 Costs from SFWMD's XLS Costs (S29:J13)
Total Pump Station Cost	**$217,306,249**	
Storage		
Distributed Storage (500 Ac-Ft)	$38,859,600	Real estate costs excluded
Design & Construction Management	$5,828,940	15% of costs excluding real estate
Total Storage Cost	**$44,688,540**	
Canal Improvements		
Raise Canal Banks (to 7.5 ft)	$7,118,542	Costs from SFWMD's email estimate (real estate costs excluded)
Widen Canal (by ~75 ft)	$107,725,296	Widen Tab using (real estate costs excluded)
Design & Construction Management	$17,226,576	15% of costs excluding real estate
Total Canal Improvements Cost	**$132,070,414**	
Total C-9 Cost	**$394,065,203**	

From: Herrera, Liza (DTPW)
To: Michael DelCharco
Cc: Gonzalez, Francisco L (DTPW); Barrios, Alex (DTPW)
Subject: RE: Road raising costs - order of magnitude estimate
Date: Tuesday, September 6, 2022 10:45:35 AM

Good Morning Michael,

The updated costs to elevate roads for sea level rise are as follows:

	2015 $/LF	2021 $/LF
Raise 2-lane roadway in 50' right-of-way 1 foot =	**$608.00** ~~LF~~	681
Raise 2-lane roadway in 50' right-of-way 2 foot =	**$805.00** ~~LF~~	901
Raise 2-lane roadway in 50' right-of-way 3 foot =	**$1,003.00** ~~LF~~	1,123

Regards,

Liza Herrera, P.E.,ENV SP
Manager, Stormwater Drainage Design Section
Roadway Engineering and Right-of-Way Division
Miami-Dade County Department of Transportation and Public Works
305-375-4526 Phone
305-375-4969 Fax
herrel@miamidade.gov
"Delivering Excellence Every Day"

From: Michael DelCharco <mdelcharco@taylorengineering.com>
Sent: Friday, September 2, 2022 1:32 PM
To: Barrios, Alex (DTPW) <Alex.Barrios@miamidade.gov>
Cc: Foley, Jessica (RER) <Jessica.Foley@miamidade.gov>; Herrera, Liza (DTPW) <Liza.Herrera@miamidade.gov>; Molina, Maria (DTPW) <Maria.Molina@miamidade.gov>
Subject: RE: Road raising costs - order of magnitude estimate

EMAIL RECEIVED FROM EXTERNAL SOURCE

Thank you for letting me know.
Liza, Let me know if you have any ideas on updated costs for road, as was outlined below in 2017.
Thank you,
Michael

Michael DelCharco, P.E., CFM | **Senior Vice President/Water Resources**
Main: 904-731-7040 | Direct: 904-256-1346 | Cell: 904-472-0082

From: Barrios, Alex (DTPW) <Alex.Barrios@miamidade.gov>
Sent: Thursday, September 1, 2022 3:29 PM
To: Michael DelCharco <mdelcharco@taylorengineering.com>
Cc: Foley, Jessica (RER) <Jessica.Foley@miamidade.gov>; Herrera, Liza (DTPW) <Liza.Herrera@miamidade.gov>; Molina, Maria (DTPW) <Maria.Molina@miamidade.gov>
Subject: RE: Road raising costs - order of magnitude estimate

Figure F- 1: Updated M3 Project Road Raising Cost Estimate

Summary Conceptual Cost Estimate for S28 Structure Replacement and new Forward Pumping Station	
S28 Structure Replacement	
Replace the 60 year old spillway with a (3) bay spillway with a 50% increase in capacity capacity, 81 ft. net weir length (4830 cfs design discharge rate). Increase surge protection elevation of spillway 5 ft. Structure Replacement Cost used due to the same 5' increase in spillway elevation.	$ 19,056,898
S28 New Forward Pumping (500CFS)	
Construction of a 500 cfs forward pump station immediately downstream of proposed replacement S28 spillway (upstream of old spillway) Control room for spillway to house electrical, I&C, and communications for station.	$ 30,712,294
S28 Tie Back	
Construct precast sheet bulkhead from new S28 Spillway to FEC railroad embankment approx. 250 ft. upstream.Bulkhead to provide 3 ft. increase protection elevation above current protection level. Bulkhead to run along existing canal banks. Assume railroad embankment elevation provides necessary tie-back protection elevation,	$ 2,412,951
Project Construction Cost	**$ 52,182,143**
Other Cost	
Engineering Design	$ 3,000,000
Construction Management Services (CMS)	$ 4,000,000
Engineering During Construction (EDC)	$ 1,500,000
Real-estate Purchase	$ -
Total for Project	**$ 60,682,143**

Reviewed and Approved By
Vijay Mishra, P.E.
Lead Project Manager
South Florida Water Management District
Engineering & Construction Bureau
PE # 81967

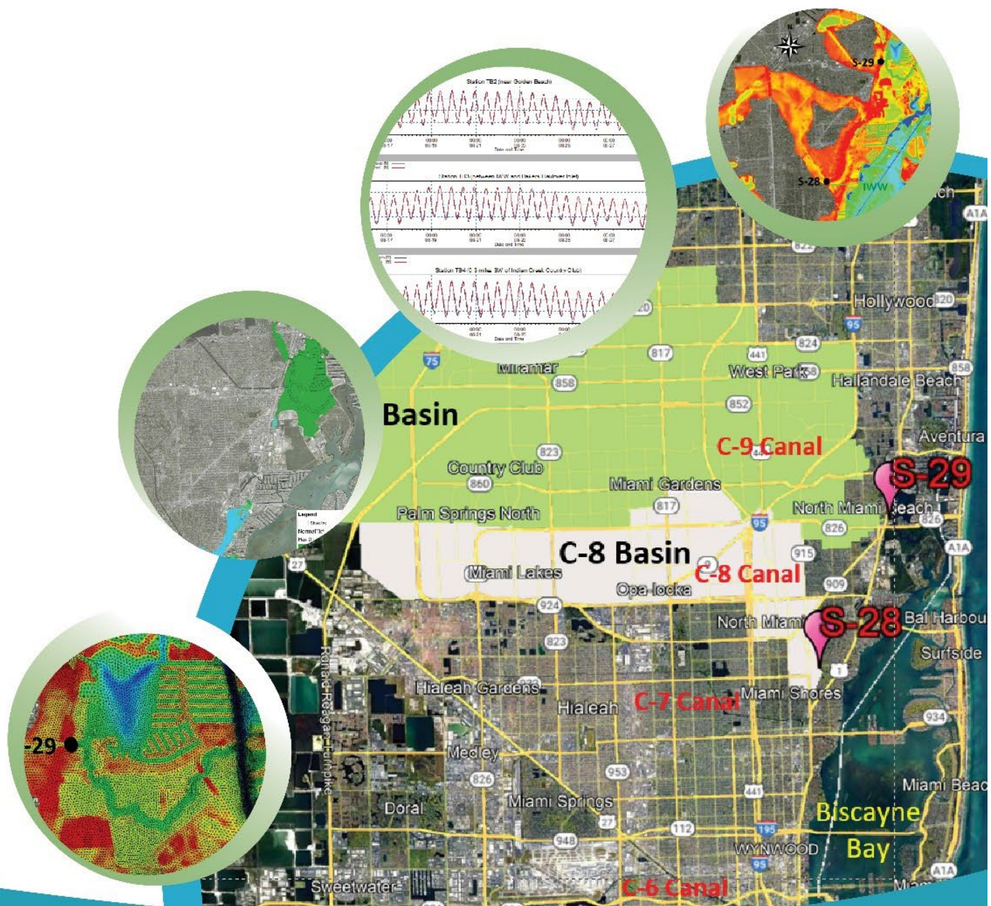
VIJAY KUMAR MISHRA
LICENSE
10/11/2021
No. 81967
STATE OF
FLORIDA
PROFESSIONAL ENGINEER

Assumption: The cost estimate uses updated material quotes and unit prices as currently available. This estimate is based on generally accepted cost estimating practices and standards. Costs are provided in Fiscal Year 2021 dollars. Contractor for the project must hold a valid, current Florida Contractor's license applicable to this type of project. This estimate is based on fair market value and is an estimated cost of time and materials and not a prediction of contractor's low bid. Labor cost is based on a 40-hour work week. It assumes that stable market conditions will prevail during the project.

Figure F- 2: SFWMD Structure Replacement Costs with 5' Increase in Spillway Elevation

TAYLOR ENGINEERING, INC.

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



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Jacksonville, Florida 32256
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Task 2B Hydrodynamic Modeling to Evaluate Downstream Coastal Area Water Levels Prepared for SFWMD C-8 C-9 Phase II, Deliverable 2.B

Miami-Dade County, FL

Final Report

Prepared for

South Florida Water Management District

by

Taylor Engineering, Inc.
10199 Southside Blvd., Suite 310
Jacksonville, FL 32256
(904) 731-7040
Certificate of Authorization 4815

February 2023

C2021-033 Task 2b.1

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1.0 INTRODUCTION

Biscayne Bay, an estuary system that connects to the Atlantic Ocean through a multi-inlet system, has hydraulic conditions mostly influenced from south to north by the Government Cut, Bakers Haulover Inlet, and Port Everglades Inlet. In addition, the bay receives upstream water outflows from numerous canals (e.g., C-6, C-7, C-8, and C-9 canals in Figure 1.1) that connect along the bay's western shore. The South Florida Water Management District (SFWMD) commissioned a C-8 and C-9 basins Floodplain Level of Service (FPLOS) modeling study that evaluated improvements for the S-28 and S-29 structures. The FPLOS modeling evaluated three C-8 and C-9 basins flood mitigation alternatives—M2A, M2B, and M2C alternatives.

For the FPLOS modeling, the SFWMD-provided storm surge time series along Biscayne Bay that was applied as a two-dimensional (2D) overland downstream flow boundary in the FPLOS model. FPLOS model simulations of the 20-, 10-, 4-, 1-percent annual exceedance probability rainfall events with 1-ft, 2-ft, and 3-ft sea level rise scenarios provided estimates of the gate flows and pump flows across the S-28 and S-29 structures. Table 1.1 provides a summary of the features and components of M2A, M2B, and M2C flood mitigation alternatives.

However, the FPLOS modeling is 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, 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 Biscayne Bay during normal tides and 10-yr surge event conditions. Appendix A provides the S-28 and S-29 structures gate and pump flow hydrographs.

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.

Following this introduction, Chapter 2 of this report presents details of the data collection and data analyses. Chapter 3 describes the development of the BBM hydrodynamic model, including model mesh, model boundary conditions setup, and model validation. Chapter 4 describes the evaluation of the effects of S-28 and S-29 structures outflows on downstream water levels for normal tides and 10-yr flood event conditions. Finally, Chapter 5 concludes the report with a summary of the findings and recommendations.

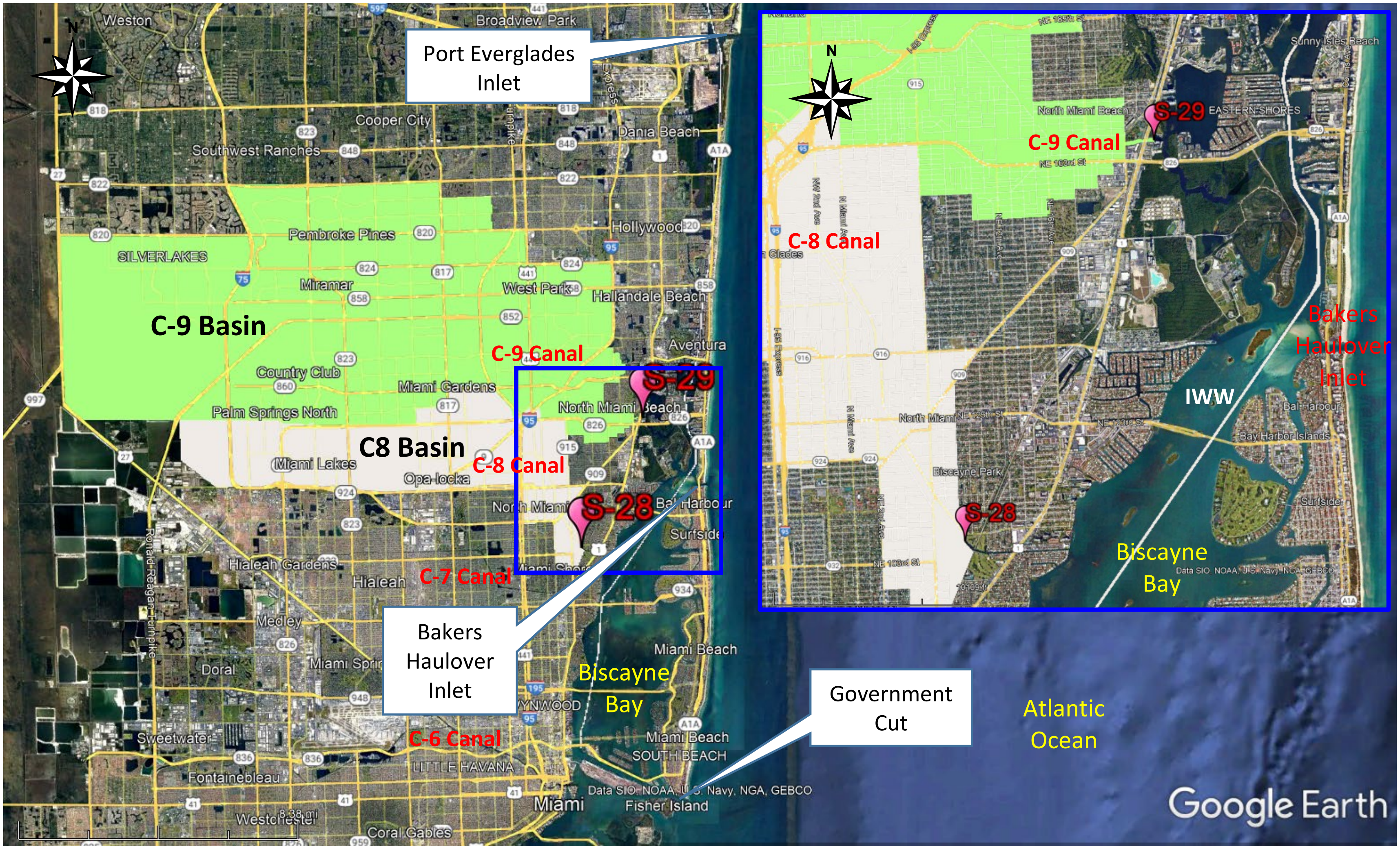

Figure 1.1 Locations of C-8 and C-9 Basins and S-28 and S-29 Structures West of Biscayne Bay

Table 1.1 Features of C-8 and C-9 Basins Flood Mitigation Alternatives M2A, M2B, and M2C

Features	Alternatives		
	M2A	M2B	M2C
S-28 and S-29 forward pumps capacity	1550 cfs	2550 cfs	3550 cfs
S-28 and S-29 gate improvement overtopping elevation	9.0 ft-NGVD29	9.0 ft-NGVD29	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	○ 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	○ 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 acre-ft distributed storage across both C-8 and C-9 combined	○ conceptually represented – gravity-driven drainage areas only	○ conceptually represented – gravity-driven drainage areas only	○ conceptually represented – gravity-driven drainage areas only
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 canals ○ raised bank elevations to elevation 7.5 ft-NGVD29 anywhere lower than 7.5 ft-NGVD29 (this does not include freeboard)	○ 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 canals <u>were not widened</u> ○ widened cross sections ▪ C-8 canal widened along approximately 20,000 ft by a width of 100 ft from Interstate 95 to S-28 ▪ C-9 Canal widened along approximately 79,000 ft by an average of approximately 75 ft, from the west side of the South Broward Drainage District to Interstate 95. ○ raised bank elevations to elevation 7.5 ft-NGVD29 anywhere 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 canals elevations are lower than water elevation in the surrounding floodplain (the same way as if the raised banks weren't there)	○ 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 canals 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	Yes	Yes	Yes

2.0 DATA COLLECTION AND ANALYSIS

The study area spans portions of the Atlantic Ocean, Bakers Haulover Inlet, Stranahan River, West Lake, North Lake, South Lake, Golden Isles Lake, Dumfoundling Bay, Maule Lake, Little Arch Creek, Biscayne Bay, Indian Creek Lake, Indian Creek, Tatum Waterway, Flamingo Waterway, Surprise Lake, Surprise Waterway, Biscayne Waterway, Normandy Waterway, Sabal Lake, Little River/C7 Canal, Biscayne Canal/C-8 Canal, and C-9 Canal. Tides, waves, and winds influence these areas daily and occasionally storm winds produce elevated water levels (surge) and increase wave heights. The paragraphs below describe the data collection to support BBM development, validation, and application.

2.1 Water Level Data

Semi-diurnal tides—two high and two low per day—and mixed tides during neap period characterize the astronomical tides in the study area. Collection and review of published tide records as well as field measurements of tides contributed to a comprehensive set of tide data for this study. The following sections describe published tidal data and measured tide data.

2.1.1 NOAA Tide Data

Figure 2.1 and Table 2.1 show the locations of the National Oceanic and Atmospheric Administration (NOAA) tidal datum stations near the area of interest. Inshore tidal data from these stations indicate inshore mean tidal range equals 2.21 ft at Whiskey Creek South Entrance, FL (NOAA 8722971), 2.03 ft at Golden Beach, IWW, FL (NOAA 8723026), 2.02 ft at Dumfoundling Bay, FL (NOAA 8723044), 2.01 ft at Haulover Inside, FL (NOAA 8723073), 2.15 ft at Biscayne Creek, IWW, FL (NOAA 8723089), 2.20 ft at San Marino Island, FL (NOAA 8723156), and 2.18 ft at Miami, Biscayne Bay, FL (NOAA 8723165). Tidal data indicate ocean mean tidal range equals 2.49 ft at North Miami Beach, FL (NOAA 8723050), 2.48 ft at Haulover Pier, N. Miami Beach, FL (NOAA 8723080), and 2.46 ft at Miami Beach City Pier, FL (NOAA 8723170). Table 2.1 presents tidal datums for these stations based on the 1983 – 2001 tidal epoch referenced to North American Vertical Datum of 1988 (NAVD).

2.1.2 Field Measured Inshore Tide Level

A FIND sedimentation study deployed tide gages from August 12, 2020 to September 24, 2020 that recorded water level at six locations (Stations TB1 – TB6) and provided hydrodynamic model water level validation data for the inshore area. Figure 2.2 shows the locations of the tide measurement stations and Table 2.2 provides the locations, periods of record, and interval of the tide measurements. Inspection of the measured tides show measurements reflect mean tide ranges consistent with tidal ranges from NOAA stations. Notably, the measured water level data reflects wind setup that caused non-tidal fluctuations in the measured tides.

2.1.3 FEMA Flood Insurance Study Data for 10-yr High Water Level

The FEMA recently completed a preliminary Flood Insurance Study (FIS) for Miami Dade County and Figure 2.3 shows the east-end portions of the C-8 and C-9 basins (where S-28 and S-29 structures are located) with respect to FEMA transects in Biscayne Bay (FEMA, 2021). The FEMA transect information includes still water elevation (SWEL) values near the project sites, including the 10-yr SWELs.

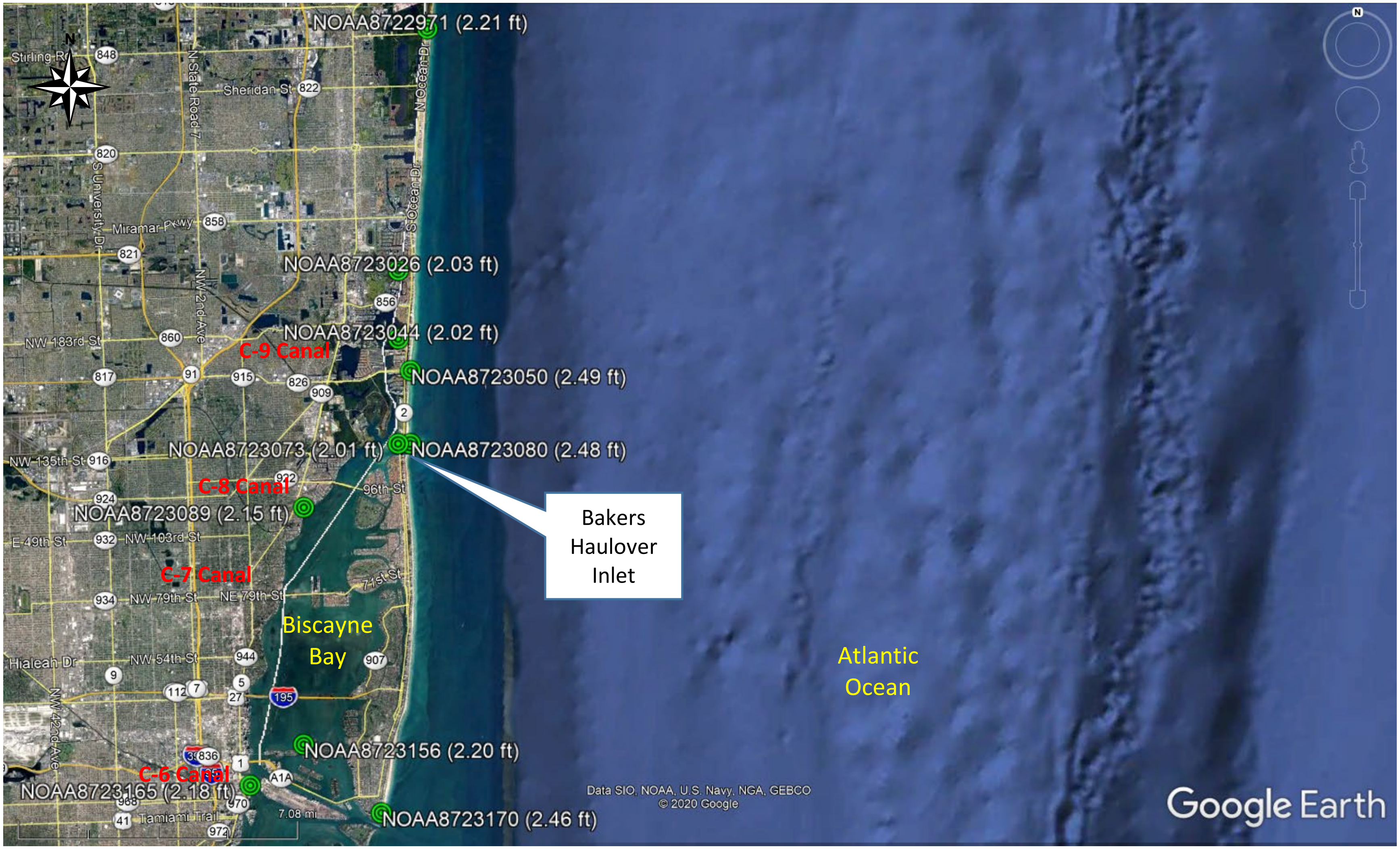

Figure 2.1 Locations of Select NOAA Tide Stations and Wind Stations (Inset) with Mean Tidal Ranges (in parentheses)

Table 2.1 NOAA Tide Datums and Locations of Select Stations near the Area of Interest (1983 – 2001 Tidal Epoch)

Tide Datums, Mean Tide Range, and Coordinates	NOAA 8722971 Whiskey Creek South Entrance, FL (ft-NAVD)	NOAA 8723044 Dumfoundling Bay, FL (ft-NAVD)	NOAA 8723073 Haulover Inside, FL (ft-NAVD)	NOAA 8723080 Haulover Pier, N. Miami Beach, FL (ft-NAVD)	NOAA 8723026 Golden Beach, IWW, FL* (ft-NAVD)
Mean Higher High Water (MHHW)	0.42	0.34	0.27	0.43	0.23
Mean High Water (MHW)	0.33	0.27	0.20	0.36	0.16
Mean Sea Level (MSL)	-0.79	-0.74	-0.85	-0.87	-0.86
Mean Low Water (MLW)	-1.88	-1.75	-1.81	-2.12	-1.87
Mean Lower Low Water (MLLW)	-2.04	-1.89	-1.94	-2.25	-2.01
Mean Tide Range (ft)	2.21	2.02	2.01	2.48	2.03
Latitude	26°03.3'N	25°56.5'N	25°54.2'N	25°54.2'N	25°58.0'N
Longitude	80°06.8'W	80°07.5'W	80°07.5'W	80°07.2'W	80°07.5'W

Tide Datums, Mean Tide Range, and Coordinates	NOAA 8723050 North Miami Beach, FL (ft-NAVD)	NOAA 8723089 Biscayne Creek, IWW, FL (ft-NAVD)	NOAA 8723165 Miami, Biscayne Bay, FL (ft-NAVD)	NOAA 8723170 Miami Beach City Pier, FL (ft-NAVD)	NOAA 8723156 San Marino Island, FL* (ft-NAVD)
Mean Higher High Water (MHHW)	0.37	0.24	0.26	0.33	0.29
Mean High Water (MHW)	0.27	0.17	0.20	0.25	0.22
Mean Sea Level (MSL)	-0.96	-0.91	-0.89	-0.96	-0.90
Mean Low Water (MLW)	-2.22	-1.98	-1.98	-2.20	-1.98
Mean Lower Low Water (MLLW)	-2.39	-2.11	-2.11	-2.37	-2.11
Mean Tide Range (ft)	2.49	2.15	2.18	2.46	2.20
Latitude	25°55.8'N	25°52.8'N	25°46.7'N	25°46.1'N	25°47.6'N
Longitude	80°07.2'W	80°09.8'W	80°11.1'W	80°07.9'W	80°09.8'W

Note: * From Vdatum conversion

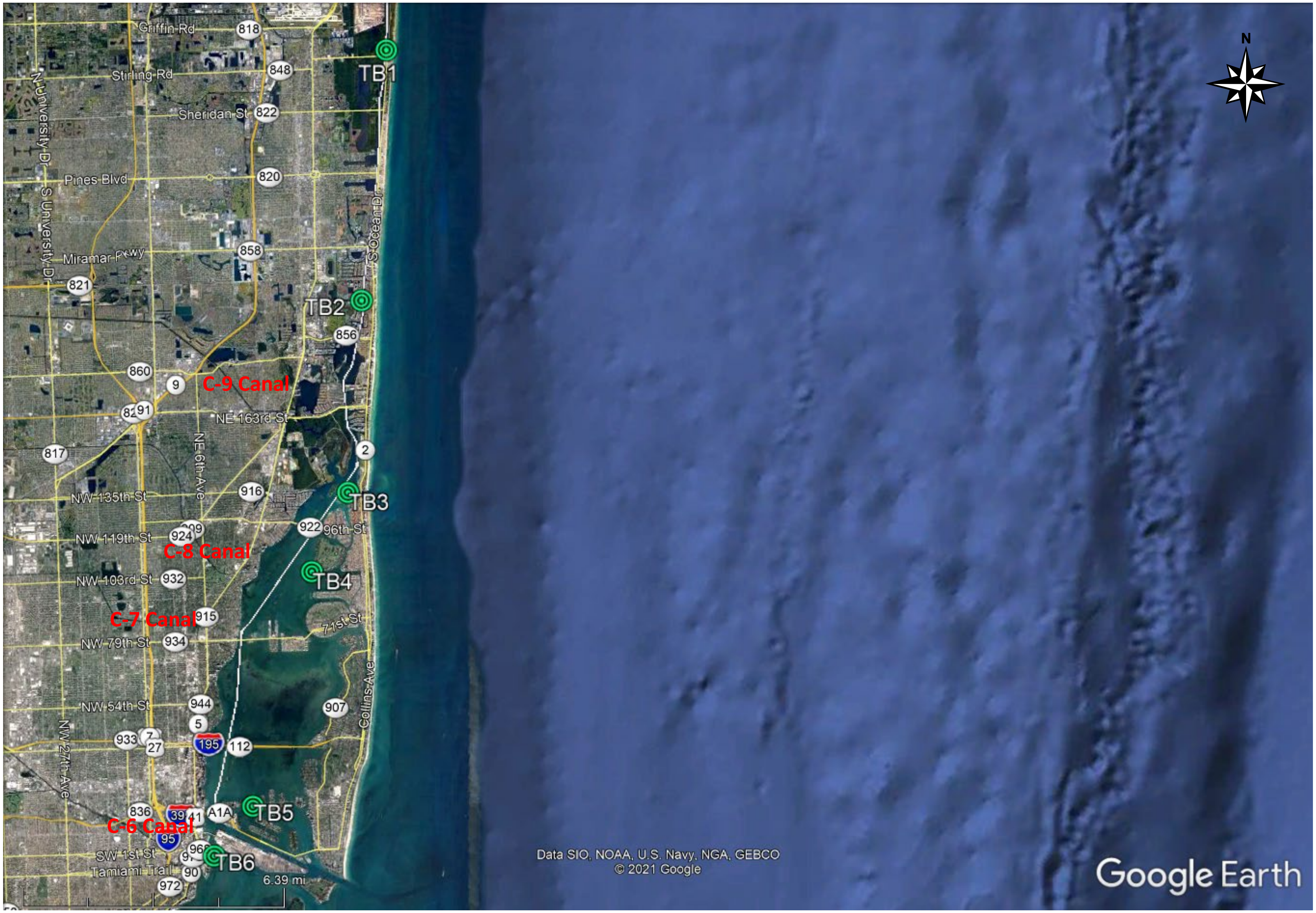

Figure 2.2 Locations of the Tide Level Measurement Stations

Table 2.2 Coordinates, Period of Record, and Time Interval of Measured Tide Level (TB) Stations

Station	Coordinates		Period of Record	Time Interval	Location/ Remarks
	Latitude	Longitude			
TB1	26°03'19.06"N	80°06'52.61"W	8/12/2020 – 9/24/2020	15 minutes	Near IWW Cut-BW52
TB2	25°58'2.02"N	80°07'26.99"W	8/12/2020 – 9/24/2020	15 minutes	Near IWW Cut-DA1
TB3	25°53'59.19"N	80°07'45.71"W	8/12/2020 – 9/24/2020	15 minutes	Between Bakers Haulover Inlet and IWW Cut-DA9
TB4	25°52'18.92"N	80° 8'36.57"W	8/12/2020 – 9/24/2020	15 minutes	0.7 mi east of IWW Cut-DA9
TB5	25°47'22.00"N	80°09'59.17"W	8/12/2020 – 9/24/2020	15 minutes	0.9 mi east of IWW Cut-DA9
TB6	25°46'18.96"N	80°10'53.72"W	8/12/2020 – 9/24/2020	15 minutes	0.4 mi east of Miami River Entrance

In addition to the FIS transects, Taylor Engineering obtained FEMA Geographic Information Systems (GIS) data for the S-28 and S-29 structures locations based on the same modeling as the FIS data. Table 2.3 provides the 10-yr SWELs for both the FIS and GIS data. The 10-yr FIS and GIS data fall within 0.1 ft at both structures. NOAA's extreme water level analysis of the recorded water level at Miami Beach City Pier (NOAA 8723170) (https://tidesandcurrents.noaa.gov/est/est_station.shtml?stnid=8723170) shows a 10-yr high water level of approximately 2.7 ft-NAVD.

2.1.4 ADCIRC+SWAN Model Provided Water Levels for 10-yr Flood Modeling

The recently completed FEMA Coastal South Florida Flood Insurance Study (SFLFIS) provides modeled offshore hydrographs that were produced from a high-resolution 2D ADCIRC+SWAN model (FEMA, 2021). The ADCIRC model was validated to astronomical tides and to five historical tropical cyclones—Hurricanes Andrew, Wilma, Georges, David, and Betsy. The SFLFIS included ADCIRC+SWAN modeling of 392 storms to produce FEMA's 1% SWELs at various locations in the ADCIRC+SWAN model domain. The 392 storm suites included several synthetic storms with different tracks, forward speeds, pressures, wind speeds, and Holland B parameters. Evaluation of the maximum water levels from each of the 392 production suite storm simulations at the downstream side of the S-28 and S-29 structures resulted in selection of candidate storms that provided highwater levels nearest to the values listed in Table 2.3. Appendix B describes the evaluation and selection of the ADCIRC+SWAN storm that provides good estimates of the water level hydrographs with highwater levels near those listed in Table 2.3.

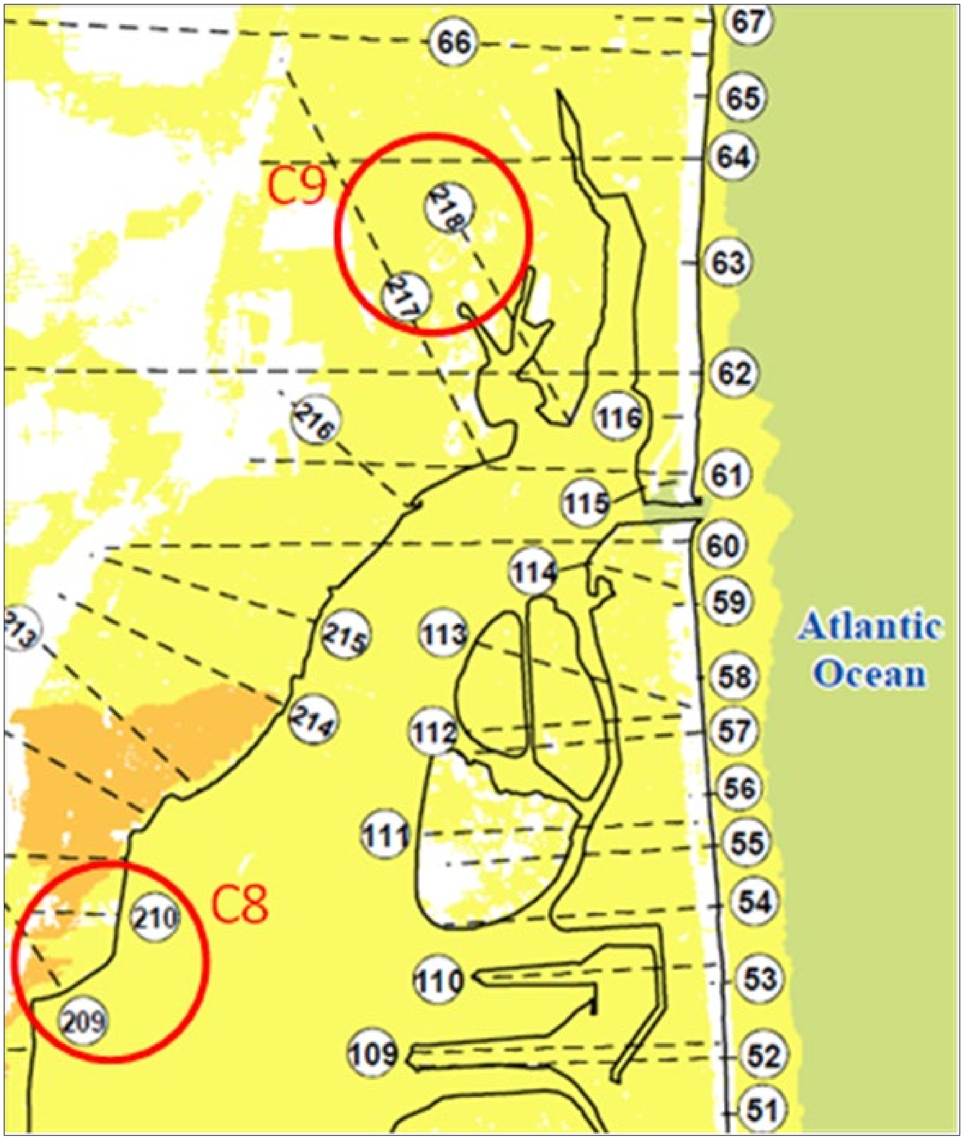

Figure 2.3 Locations of C-8 and C-9 Canals Outlets and FIS Transects (Source: FEMA, 2021)

Table 2.3 10-yr Still Water Elevations at S-28 and S-29 Structures

Station	10-yr SWEL (ft-NAVD)	
	FIS Transects	GIS Data
S-28	2.5	2.4
S-29	2.4	2.3

2.2 Bathymetric and Topographic Data

This study sourced its bathymetric and topographic data from three sources—(a) the FEMA 2016 South Florida ADCIRC+SWAN model Version 11 mesh; (b) USACE 2019 Cut-DA9, Bakers Haulover Inlet, and Biscayne Bay bathymetric survey data; and (c) 2018 FDEP survey of Broward and Miami-Dade Counties beaches. The ADCIRC+SWAN model Version 11 mesh provided the base topographic and bathymetric data in the upland areas, Atlantic Ocean, Bakers Haulover Inlet, Stranahan River, Dumfoundling Bay, Biscayne Bay, and other inshore waterways. The other survey data provided updated bed elevation data in IWW Cut-DA9 north of Broad Causeway, Bakers Haulover Inlet, Stranahan River, Dumfoundling Bay, Biscayne Bay, other inshore waterways, and Martin and Palm Beach Counties beaches and nearshore areas. Using either Surface Modeling System (SMS) Version 13.0.13, Vdatum Version 4.0.1, or USACE's Corpscon 6.0.1, this study converted the applied bed elevation data sets to horizontal control reference Universal Transverse Mercator North American Datum of 1983 (NAD83) Zone 17 and vertical control reference NAVD.

2.2.1 FEMA 2016 South Florida ADCIRC+SWAN Model Mesh Data

Figure 2.4 shows the FEMA 2016 South Florida ADCIRC+SWAN model Version 11 mesh and domain. It includes the Gulf of Mexico, Caribbean Sea, and a portion of the Atlantic Ocean. As shown in Figure 2.5, the mesh provided bed elevation data in the Atlantic Ocean, inshore areas, and upland areas. The horizontal coordinates of the FEMA 2016 South Florida ADCIRC+SWAN model Version 11 mesh are in latitude and longitude and the bed elevation is referenced to m-NAVD.

2.2.2 USACE 2019 Cut-DA9, Bakers Haulover Inlet, and IWW Rerouting Area Bathymetric Survey Data

Figure 2.6 shows the coverage area of the USACE June 11 – 13, 2019 IWW Cut-DA9, Bakers Haulover Inlet, and portions of Biscayne Bay bathymetric survey. The data is provided in feet horizontally projected in State Plane Florida East Zone 0901 referenced to the North American Datum of 1983 (NAD83) and vertically referenced to ft-MLLW. The data replaced the bathymetry data in Cut-DA9 north of Broad Causeway, Bakers Haulover Inlet, and portions of Biscayne Bay.

2.2.3 FDEP Bathymetric and Topographic Beaches Survey Data

This study compiled FDEP Broward County April 10, 2018 and Miami-Dade County May 23, 2016, August 16, 2016, and November 25, 2018 beach monitoring bathymetric and topographic surveys to update the bed elevations along these counties' beaches and nearshore areas. Figure 2.7 shows the Broward County 2018 (red), Miami-Dade County 2016 (teal), and Miami-Dade County 2018 (red) coverage areas of the compiled bathymetric surveys which are referenced to ft-NAVD. For the model mesh development, this study replaced the ADCIRC+SWAN model mesh bathymetry data in their common coverage area to apply recent updates on the bathymetry and topography data.

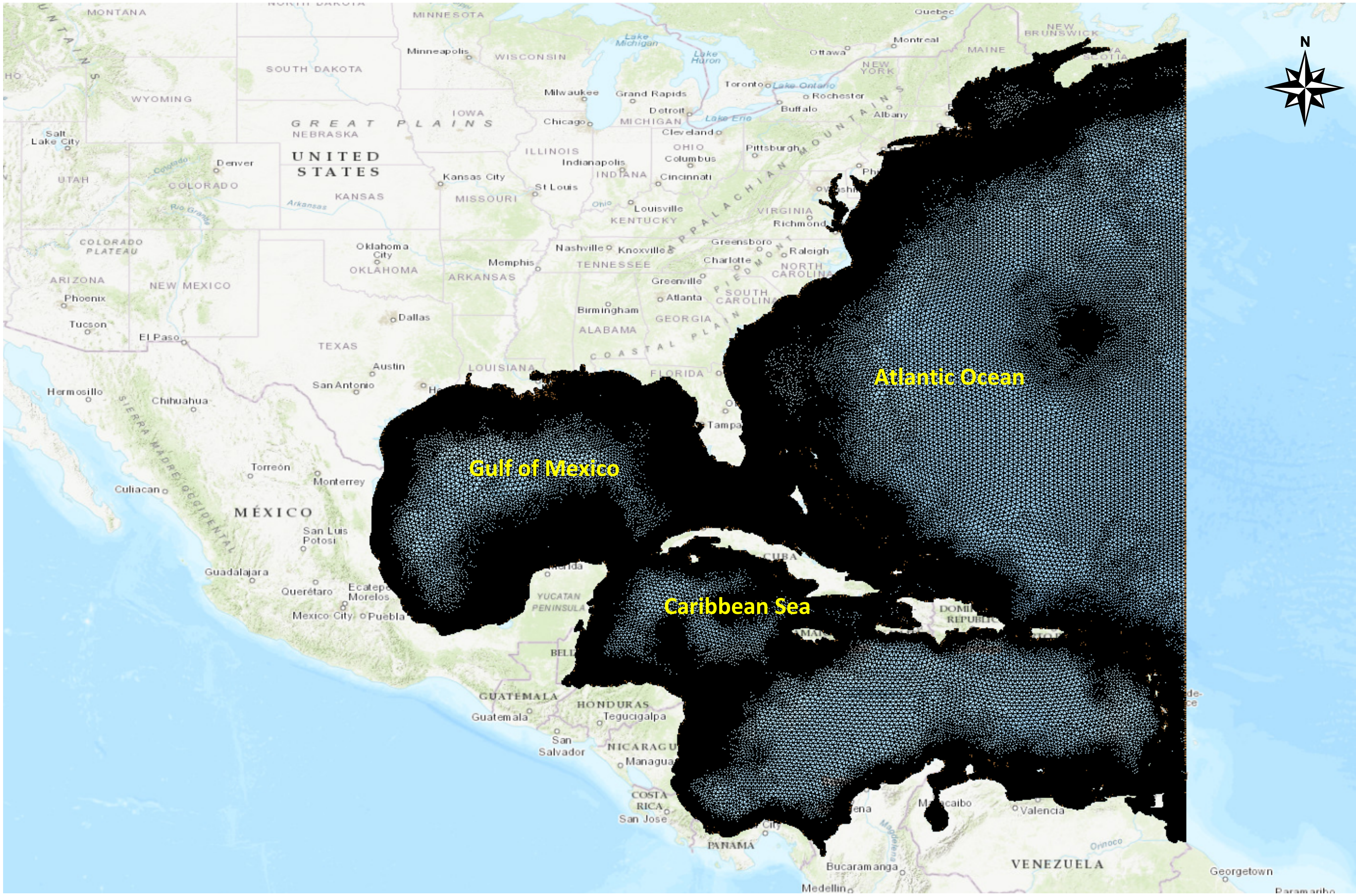

Figure 2.4 FEMA 2016 South Florida Version 11 ADCIRC+SWAN Model Mesh and Domain

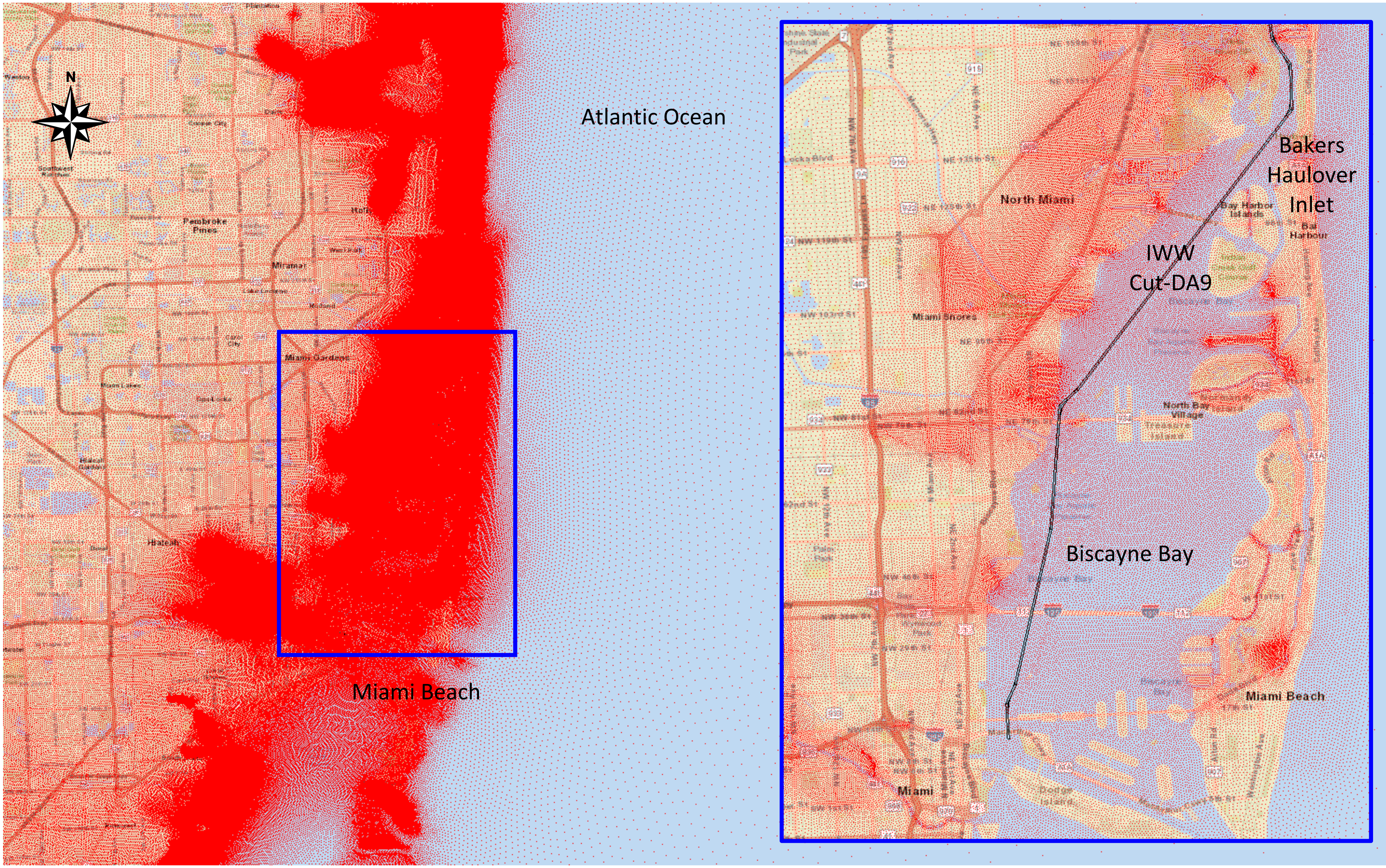

Figure 2.5 FEMA 2016 South Florida Version 11 ADCIRC+SWAN Model Bed Elevation Points

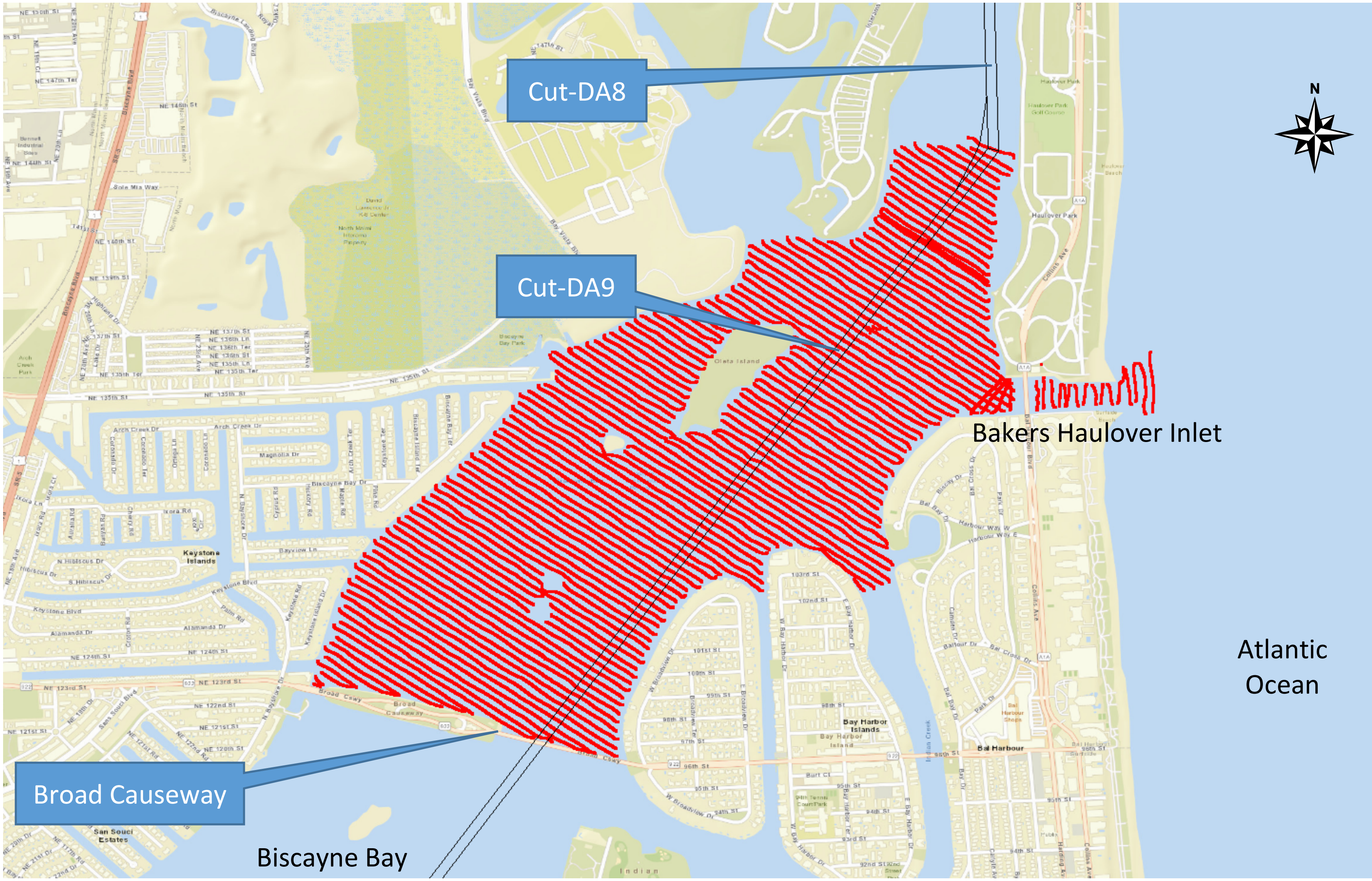

Figure 2.6 Area of 2019 Cut-DA9, Bakers Haulover Inlet, and IWW Rerouting Area Bathymetric Survey Data Update

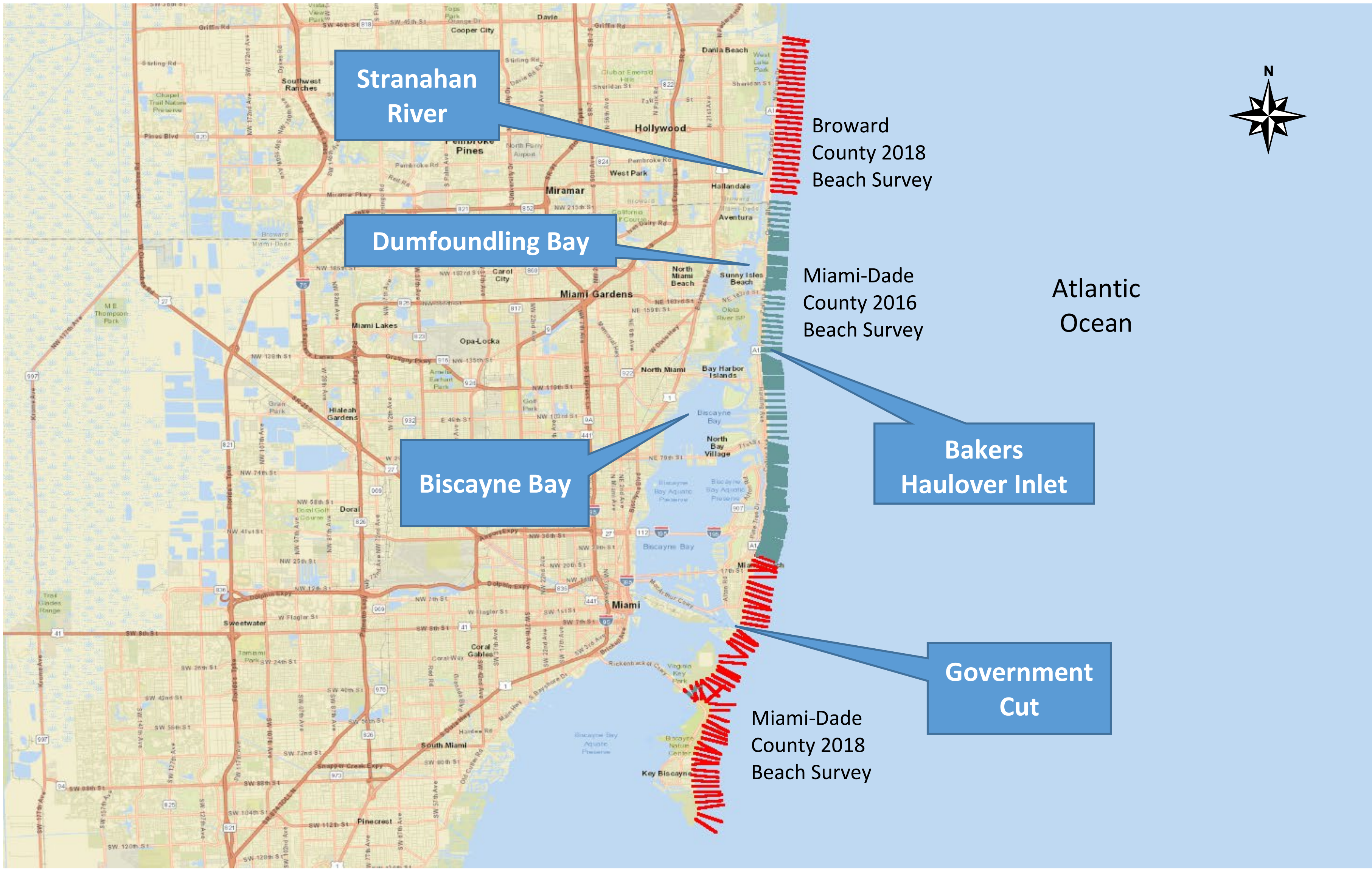

Figure 2.7 Broward and Miami-Dade Counties Bathymetry and Topography Data Update along Beaches and Nearshore Areas

3.0 BISCAYNE BAY MODEL DEVELOPMENT AND MODEL VALIDATION

The BBM applied the MIKE21 Flexible (FM) Mesh Hydrodynamic (HD) Model Version 2022. The BBM calculates water surface elevation, water depth, and flow velocity in Biscayne Bay, connected waterways, and at the area downstream of the S-28 and S-29 structures. The BBM represents portions of the Atlantic Ocean, Bakers Haulover Inlet, Stranahan River, West Lake, North Lake, South Lake, Golden Isles Lake, Dumfoundling Bay, Maule Lake, Little Arch Creek, Biscayne Bay, Indian Creek Lake, Indian Creek, Tatum Waterway, Flamingo Waterway, Surprise Lake, Surprise Waterway, Biscayne Waterway, Normandy Waterway, Sabal Lake, Little River/C-7 Canal, Biscayne Canal/C-8 Canal, C-9 Canal, and other inshore waterways as 2D waterways.

The MIKE21 FM HD modeling system applies the time-dependent mass and momentum conservation equations to compute transient flows and water surface elevations. The HD model requires flows, velocities, or stage hydrographs at its boundaries. Given the hydraulic conditions at the boundaries, MIKE21 FM HD—a two-dimensional, transient, and depth-averaged model—employs finite volume methods to compute flows and water surface elevations inside the model domain. The governing equations treat conservation of mass, conservation of momentum in the x- and y-directions, and turbulence closure. Model capabilities include wetting and drying, Coriolis acceleration, wind stress, bed friction assignment, eddy viscosity or Smagorinsky definition of turbulent exchange coefficients, choices for boundary conditions (including flow, velocity, or elevation), and inclusion of flow sources (inflows or outflows).

The engineering community applies the MIKE21 FM HD modeling system for riverine, estuarine, and coastal hydrodynamics purposes worldwide. The sections below focus on the BBM description, model setup including mesh generation, development of boundary conditions, and validation of the model to water levels in Biscayne Bay.

3.1 Biscayne Bay Model Setup

The application of the MIKE21 FM HD modeling system to an area requires development of a finite volume mesh to map the bathymetry and topography into the model's input format. The mesh divides the model domain into triangular and/or quadrilateral elements. The size of the elements usually varies from large sizes (e.g., model mesh element side length approximately at 400 ft) in regions far from the area of interest to very small sizes (e.g., model mesh element side length approximately at 30 ft) at the area of interest. The next step of model setup after mesh development consists of defining the model boundary conditions. The following paragraphs describe the development of the model mesh and application of the model boundary data.

3.1.1 Model Schematization

The BBM mesh development takes advantage of the existing BHIM and existing FEMA South Florida ADCIRC+SWAN model Version 11 meshes. The BHIM, developed by Taylor Engineering for a FIND sedimentation study, used available shoreline and IWW delineation data to generate the BHIM mesh in the IWW and in areas between the IWW and the Stranahan River, Dumfoundling Bay and Biscayne Bay shorelines. Multiple sources provided the topographic and bathymetric data for the BHIM—(a) the Federal Emergency Management Agency (FEMA) 2016 South Florida ADCIRC model Version 11 mesh; (b) USACE 2019 Cut-DA9, Bakers Haulover Inlet, and potential IWW rerouting area bathymetric survey data; and (c) 2018 FDEP survey of Broward and Miami-Dade Counties beaches. Section 2.2 describes the application of these data sets to the existing model mesh. Taylor Engineering added portions of the

ADCIRC+SWAN model mesh to the BHIM mesh to extend the BHIM mesh to upland and barrier island areas that would be inundated during the 10-yr flood surge event. Thus, the BBM mesh and elevation data comes from the existing BHIM for the Biscayne Bay and connected waterways areas and from the existing ADCIRC+SWAN model for upland and barrier island areas.

Requirements for computational efficiency limited the BBM mesh from the mouth of Bakers Haulover Inlet to approximately 7.7 miles (mi) west, 10.7 mi north to the south entrance of Whiskey Creek (NOAA 8722971), and 7.2 mi to San Marino Island (NOAA 8723156) in Biscayne Bay. The BBM mesh also includes smaller waterways near Stranahan River including West Lake, North Lake, South Lake, and Golden Isles Lake; and smaller waterways near Biscayne Bay including Little Arch Creek (located 0.8 mi southwest of Sandspur Island), 0.7 mi of Indian Creek Lake, 7.6 mi of Indian Creek, 0.6 mi of Tatum Waterway, 0.4 mi of Flamingo Waterway, Surprise Lake, 0.3 mi of Surprise Waterway, 1.1 mi of Biscayne Waterway, 1.1 mi of Normandy Waterway, Sabal Lake, Sunset Lake, 1.2 mi of Little River/C-7 Canal, 1.0 mi of Biscayne Canal/C-8 Canal, and 0.1 mi of C-9 Canal. Small elements provided the means to delineate and evaluate in more detail the water levels and water depths in areas downstream of the S-28 and S-29 structures.

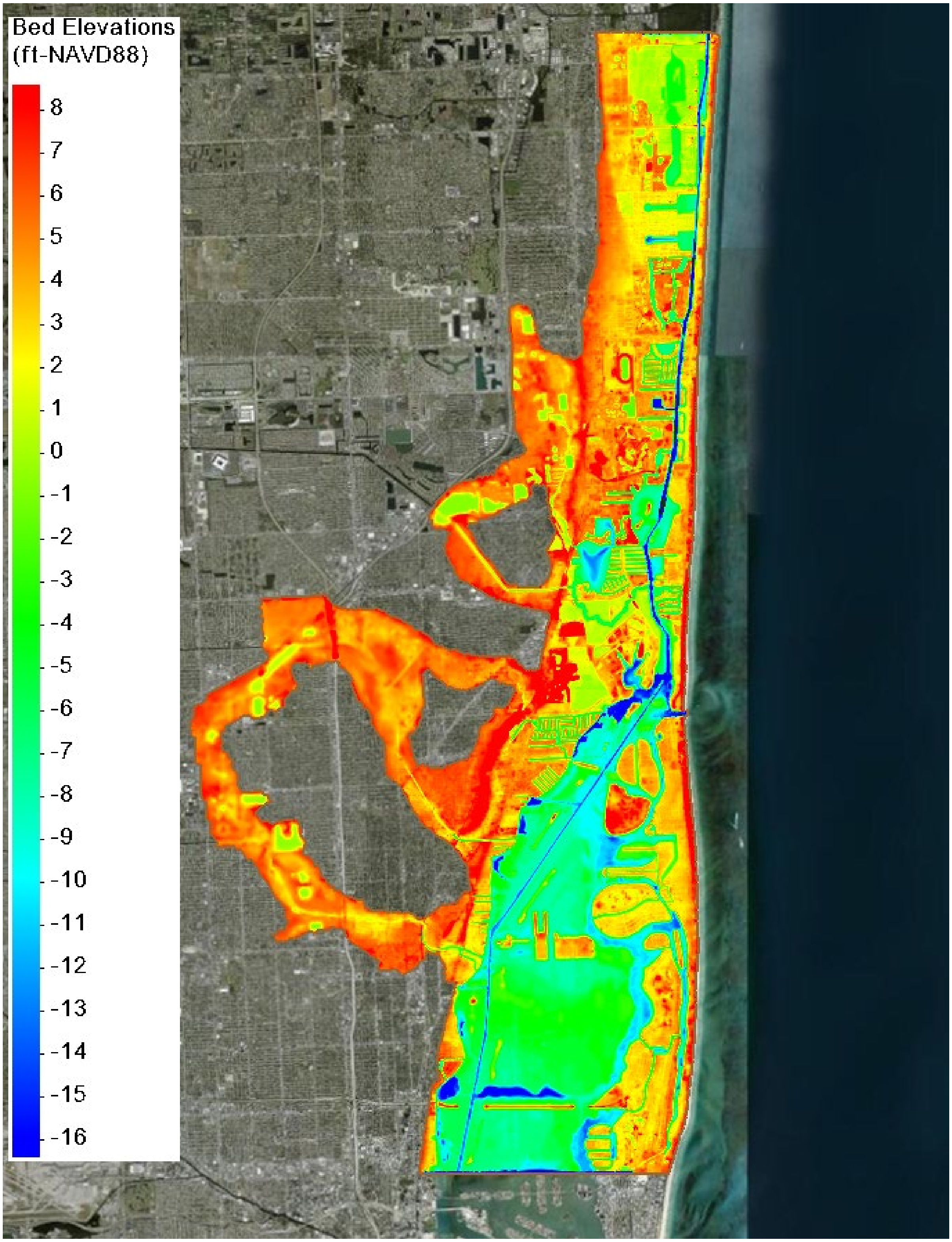

Figure 3.1 shows the BBM domain bed elevations referenced to NAVD and indicates the area of interest in the red inset. Figure 3.2 shows the bed elevations and model mesh at the area of interest that includes portions of C-8 canal, C-9 canal, areas downstream of S-28 and S-29 structures, Maule Lake, Oleta

River State Park, and Biscayne Bay. The mesh horizontal control references the Universal Transverse Mercator North American Datum of 1983 (NAD83) Zone 17.

The programs SMS Version 13.0.13 and MIKEZero Version 2022 (DHI, 2022) provided the user interface for BBM setup. The user constructs a mesh from several of the tools provided and then adds the appropriate resolution in the areas of interest. The program allows the user to input ASCII data files of digitized bathymetry and interpolate the bathymetry onto a mesh.

3.1.2 Model Boundary Conditions

The final step in the BBM setup involved specification of known boundary conditions at the external boundaries of the model mesh. The MIKE21 FM HD modeling system provides several options for external boundaries. For an unspecified mesh boundary, the program automatically assumes a land barrier with a "slip" boundary condition. In short, the flow at nodes on a slip boundary does not have velocity components perpendicular to the boundary. Specified boundary conditions include time-varying free surface elevation, flow, flux, and velocity. 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 as time-varying flow sources at locations downstream of these structures. A constant flow based on the average monthly outflow from C-7 canal is also included for future model expansion to include outflows from the C-7 canal.

For model validation runs and normal tides production runs, recorded water levels at tide gages at Stranahan River (Station TB1) and Biscayne Bay (Station TB5), and BHIM-calculated water level at the mouth of Bakers Haulover Inlet provided water level forcing data. Table 2.2 provides the coordinates and period of records and Figure 2.2 shows the locations of the water level measurement stations. For 10-yr surge event production runs, ADCIRC+SWAN model calculated water levels at the three model boundaries provided the bases for the development of the BBM boundary forcing data.

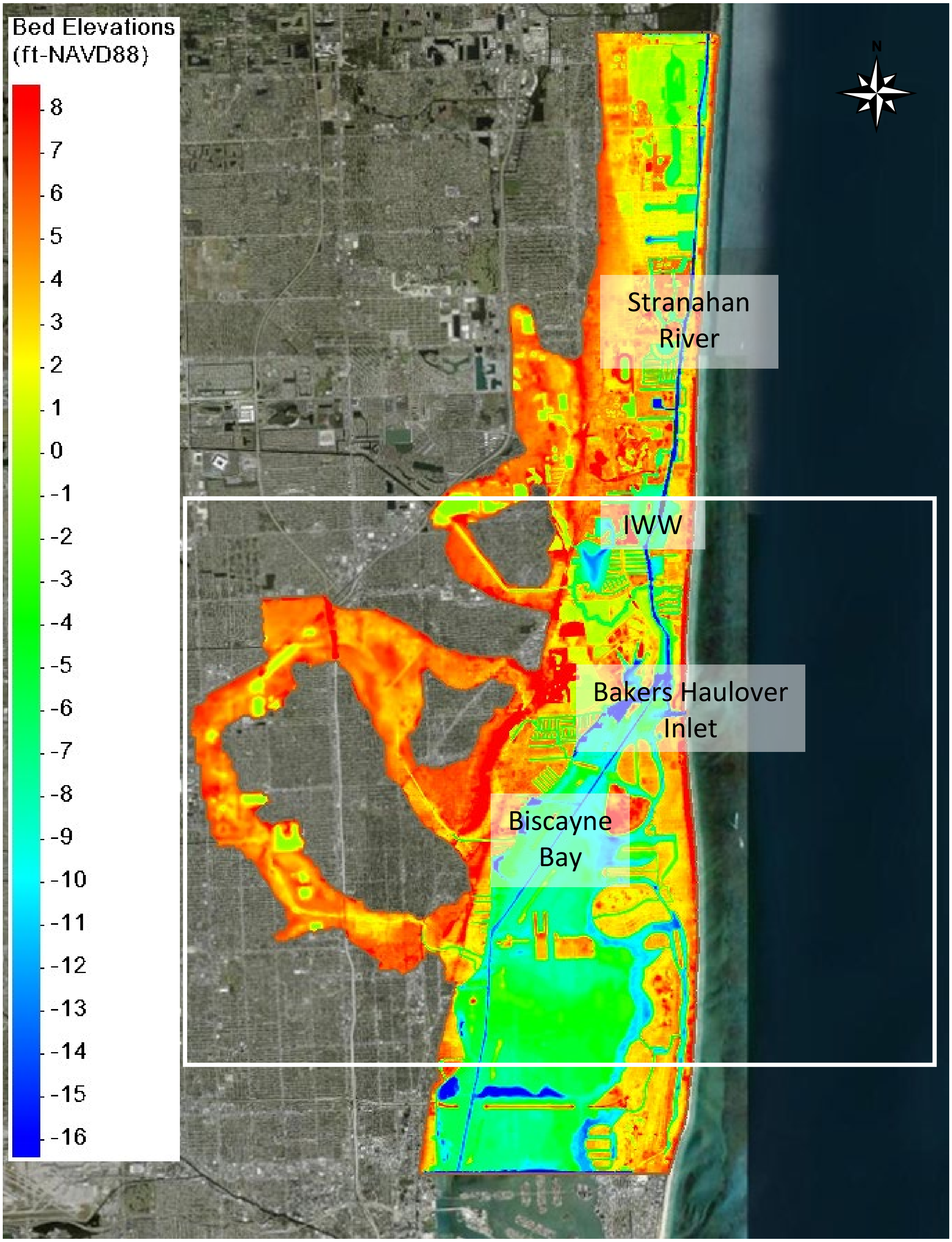

Figure 3.1 BBM Domain, Bed Elevations, and Model Mesh (Inset, shown in Figure 3.2) at the Area of Interest

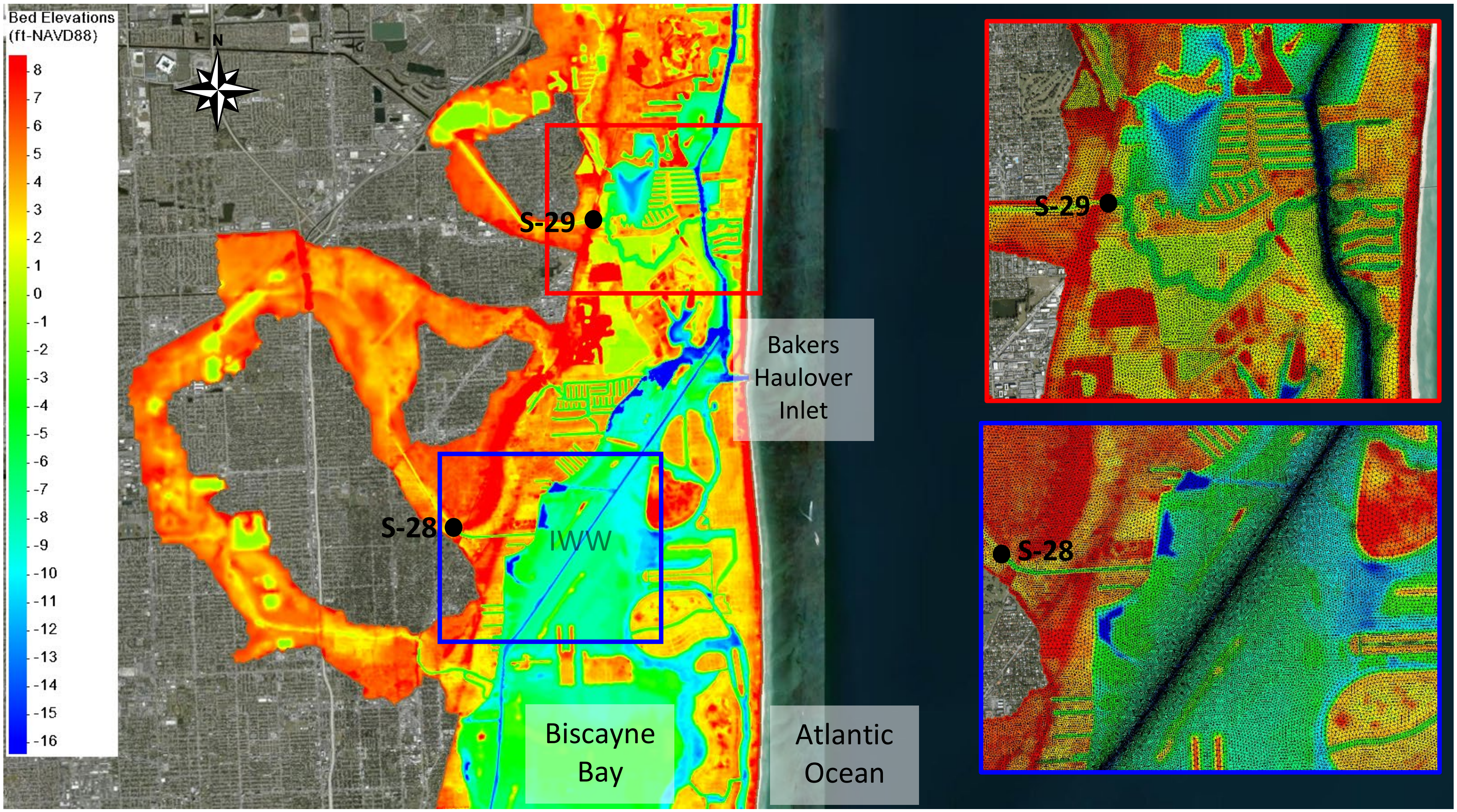

Figure 3.2 BBM Bed Elevations and Mesh at the Area of Interest

3.2 Biscayne Bay Model Validation

Model validation demonstrates a model's capability to reproduce observed hydrodynamic conditions in the study area. BBM validation for this study consisted of application of model parameters sourced from the BHIM and ADCIRC+SWAN, BBM simulation of water levels for a BHIM validation period, and comparison of modeled and measured water levels at Stations TB2, TB3, and TB4 to check if the BBM model provides good estimation of measured water levels. Thus, this study performed the BBM validation using measured water level data in August 2020.

This study used several statistical tools like the mean error (ME), root mean square error (RMSE), and correlation coefficient (CORREL) to quantify the goodness-of-fit of model results with measured data. The ME (Equation 3.1) measures the average difference between the modeled and measured values, the RMSE (Equation 3.2) measures the absolute differences between the modeled and measured values with large RMSE values indicating data outliers, and CORREL (Equation 3.3) quantifies the quality of fit of the model values to measured values (or the degree to which the variation of model values reflects the variation of the measured values):

$$\boldsymbol{ME(X_m, X_c) = \frac{1}{n}\sum_{i=1}^{n}(X_{m,i} - X_{c,i})}$$

Equation 3.1

$$RMSE(X_m, X_c) = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(X_{m,i} - X_{c,i})^2} \qquad \text{Equation 3.2}$$

$$CORREL(X_m, X_c) = \frac{\sum_{i=1}^{n}\left(X_{m,i} - \frac{1}{n}\sum_{i=1}^{n}X_{m,i}\right)\left(X_{c,i} - \frac{1}{n}\sum_{i=1}^{n}X_{c,i}\right)}{\sqrt{\sum_{i=1}^{n}\left(X_{m,i} - \frac{1}{n}\sum_{i=1}^{n}X_{m,i}\right)^2 \sum_{i=1}^{n}\left(X_{c,i} - \frac{1}{n}\sum_{i=1}^{n}X_{c,i}\right)^2}} \qquad \text{Equation 3.3}$$

where X_m are the measured values and X_c are the model calculated values. Correlation coefficients of -1 and 1 indicate a perfect negative and positive relationship between two data sets.

3.2.1 Validation of BBM Calibration and Verification

The BHIM used initial Manning's n values based on land use and land cover classifications as defined by the SFWMD 2014 – 2016 Land Cover and Land Use dataset. Then, BHIM calibration evaluated bed resistance Manning's n at 0.025, 0.030, 0.035, and 0.040 for Bakers Haulover Inlet, Stranahan River, Biscayne Bay, and smaller inshore waterways and found a Manning's n value of 0.035 at inshore waterways provided the best agreement with measurements. Thus, the BBM applied Manning's n values based on BHIM's Manning's n spatial distribution in Biscayne Bay and the ADCIRC+SWAN model's Manning's n spatial distribution in upland areas.

The BBM validation period was August 15 – 29, 2020. Measured water level at Stations TB2 (near NOAA 8723026 at Golden Beach), TB3 (near NOAA 8723073 at Bakers Haulover Inlet), and TB4 (near NOAA 8723089 at Biscayne Creek) provided the BBM validation data. Figure 2.2 shows the locations of these water level measurements stations. This study applied 1-hr moving averaging to the measured tide data to remove short-term water level oscillations caused by local boat traffic and winds. The measured 1-hr moving averaged water levels at Stranahan River in Station TB1 and Biscayne Bay (Station TB5) provided the BBM boundary conditions. The BBM model's correlation with water level measurements taken at Stations TB2, TB3, and TB4 are important because these locations are near the S-28 and S-29 structures downstream areas. The BBM ability to accurately estimate water levels in this portion of Biscayne Bay is essential.

Table 3.1 provides the ME, RMSE, and CORREL that relate BBM modeled and measured water levels at Stations TB2, TB3, and TB4. The comparison of the modeled and measured water levels in Table 3.1 shows mean error ME of -0.090 to 0.056 ft. Local wind effects and boat wakes contributed to this ME between measured and modeled water level. Given a mean tidal range of approximately 2.03 ft (Station TB2 derived from NOAA 8723026), 2.01 ft (Station TB3 derived from NOAA 8723073), and 2.15 ft (Station TB4 derived from NOAA 8723089), the small ME values comprise less than 2.6% to 4.5% of the mean tidal ranges at these stations. The model-calculated water level compares very well with recorded measurements—with a small RMSE range of 0.087 – 0.153 ft for the 15-day long validation data set. The calibrated water level parameters—when compared to the measured water levels—resulted in correlation coefficients greater than 0.991. A positive correlation coefficient means modeled water levels increase with increasing measured water levels and vice-versa.

Table 3.1 ME, RMSE, and CORREL for Water Levels Comparisons at Select Stations for BBM Validation

Location	Mean Error, ME (ft)	Root Mean Square Error, RMSE (ft)	Correlation Coefficient, CORREL
Station TB2	0.056	0.087	0.998
Station TB3	-0.080	0.104	0.998
Station TB4	-0.090	0.153	0.991

Figure 3.3 shows comparison of the calibration model-calculated (red line) and measured (blue line) water level time series (hydrographs) at Stations TB2, TB3, and TB4 over the BBM validation period. In general, except for slight underestimation of low tides at Stations TB3 and TB4 (likely due to unknown changes in bathymetry and deviations due to local wind setups), Figure 3.3 shows very good agreement between data and model-calculated water levels.

Based on favorable comparison statistics and very good visual comparisons of the model and measured water level, this study deemed the BBM well validated to estimate water levels and water depths in Biscayne Bay and nearby waterways.

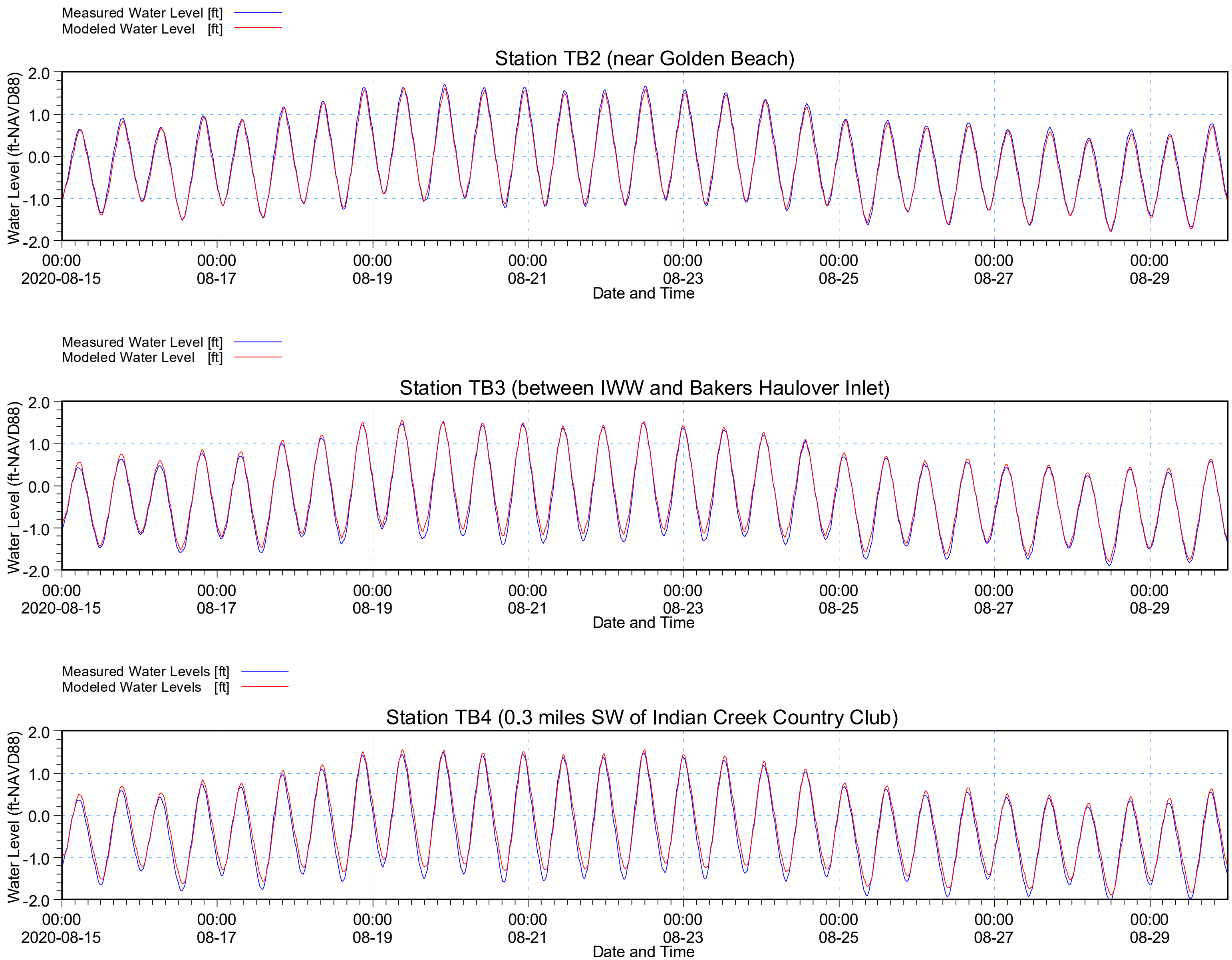

Figure 3.3 Comparison of Modeled and Measured Water Levels at Stations TB2, TB3, and TB4 for BBM Validation

4.0 EVALUATION OF EFFECTS OF S-28 AND S-29 STRUCTURES OUTFLOWS

The evaluation of the effects of outflows from the S-28 and S-29 structures requires (a) an understanding of the various alternatives modeled in FPLOS, (b) an understanding of the flow distribution in the area immediately downstream of the structures, through the canals that connects to Biscayne Bay, and to waterways connected to the bay; and (c) accurate estimation of the water levels in Biscayne Bay. Table 1.1 summarizes alternatives M2A, M3B, and M2C modeled in FPLOS. The BBM presents the flow distribution in areas downstream of the S-28 and S-29 structures, Biscayne Bay, and waterways connected to the bay. The BBM validation in Section 3.2.1 showed the BBM accurately estimates water level in Biscayne Bay and connected waterways. The BBM includes FPLOS source inflows at locations immediately downstream of the structures to evaluate the effects of the structure outflows on Biscayne Bay water level.

This chapter details the magnitude of changes in the peak water levels and the specific areas where such changes would likely occur. The paragraphs below describe the evaluation of the effect of structure outflows on maximum water depths under (1) normal tides, (2) 10-yr surge, and (3) sea level rise conditions.

4.1 Normal Tides Conditions

Recorded water levels at tide gages at Stranahan River (Station TB1) and Biscayne Bay (Station TB5), and BHIM-calculated water level at the mouth of Bakers Haulover Inlet provided BBM water level forcing data. Appendix A provides the FPLOS gate flow and pump flow hydrographs at S-28 and S-29 structures. Temporal translation of these hydrographs allowed consistent tide phasing of the flow hydrographs with the observed tide phase applied in the BBM. Table 4.1 lists the structure outflows and sea level rise conditions applied in the 16-day BBM normal tides conditions simulation period. Baseline (M0) runs characterize conditions without the C-8 and C-9 basins flood mitigation projects (thus no pump flows at the structures). With concurrence of the SFWMD, this study evaluated the effects of Alternative M2C outflows on Biscayne Bay water levels because this alternative provides the largest structure outflows (and therefore the largest potential effect on water levels) when compared to Alternatives M2A and M2B (see Table 1.1).

Table 4.1 Normal Tides Conditions BBM Runs (see Appendix A Figures)

Run	Condition	S-28 Structure Flow		S-29 Structure Flow		Sea Level Rise (ft)
		Gate Flow	Pump Flow	Gate Flow	Pump Flow	
M0-SLR0	Baseline	Figure A.1	none	Figure A.1	none	0
M0-SLR1	Baseline	Figure A.3	none	Figure A.3	none	1
M0-SLR2	Baseline	Figure A.5	none	Figure A.5	none	2
M0-SLR3	Baseline	Figure A.7	none	Figure A.7	none	3
M2C-SLR0	M2C	Figure A.2	Figure A.2	Figure A.2	Figure A.2	0
M2C-SLR1	M2C	Figure A.4	Figure A.4	Figure A.4	Figure A.4	1
M2C-SLR2	M2C	Figure A.6	Figure A.6	Figure A.6	Figure A.6	2
M2C-SLR3	M2C	Figure A.8	Figure A.8	Figure A.8	Figure A.8	3

4.1.1 Effects on Normal Tides with No Sea Level Rise

This study calculated the maximum water depths for each BBM cell in model runs M0-SLR0 and M2C-SLR0 for the normal tides model simulation period. Subtraction of M0-SLR0 element maximum water depth from the corresponding M2C-SLR0 element maximum water depth provided estimates of the effect of Alternative M2C structure outflows on downstream water levels. Figure 4.1 shows the difference in the modeled maximum water depths between M2C-SLR0 and M0-SLR0. The figure shows S-28 structure outflows can increase maximum depths by 0.25 – 1.0 ft in a limited area downstream of S-28 structure. The figure also shows S-29 structure outflows can increase maximum depths by up to 0.25 ft in a small area downstream of S-29 structure (around Maule Lake and Oleta River State Park). Notably, model results do not show substantial change in water levels in Biscayne Bay with M2C-SLR0 structure outflows because the tidal prism flows from the ocean are very much larger than the structure outflows.

4.1.2 Effects on Normal Tides with 1-, 2-, and 3-ft Sea Level Rises

BBM simulations with sea level rises added a constant 1 ft, 2 ft, and 3 ft respectively to each of the three BBM external water level boundaries for the SLR1, SLR2, and SLR3 sea level rise conditions. The evaluation of the effect of S-28 and S-29 structure outflows on downstream water levels followed the same procedure as described in the above section. The calculated differences between the maximum water depths of M2C-SLR1 and M0-SLR1, M2C-SLR2 and M0-SLR2, M2C-SLR3 and M0-SLR3 show (see Figure 4.2 to Figure 4.4 respectively):

a) M2C-SLR1 S-28 outflows can increase maximum water depths by 0.5 – 1.0 ft over a limited area downstream of S-28 structure.

b) M2C-SLR1 S-29 outflows can increase maximum depths by up to 0.25 ft in a small area downstream of S-29 structure (around Maule Lake and Oleta River State Park).

c) M2C-SLR2 and M2C-SLR3 S-28 outflows can increase maximum water depths by 0.1 – 1.0 ft over a slightly larger area (compared to M2C-SLR1) downstream of S-28 structure.

d) M2C-SLR2 and M2C-SLR3 S-29 outflows can increase maximum depths by up 0.1 to 0.25 ft in a slightly larger small area (compared to M2C-SLR1) downstream of S-29 structure. Additionally, water depths are increased in Oleta River north to and including Enchanted Lake of up to 1 ft. (west of US1).

e) The increase in the sea level rise did not substantially increase the difference between baseline and M2C modeled maximum water depths but only slightly enlarges the area affected by M2C structures outflows. This is not surprising as rising sea levels will dampen the effect of any structure outflows on downstream water levels. Thus, normal tides conditions model results generally indicate rising sea levels decrease the effect of S-28 and S-29 outflows on water levels.

f) Normal tides conditions model results indicate the effect of S-28 and S-29 outflows is limited to downstream areas near the structures and do not reach the main Biscayne Bay area.

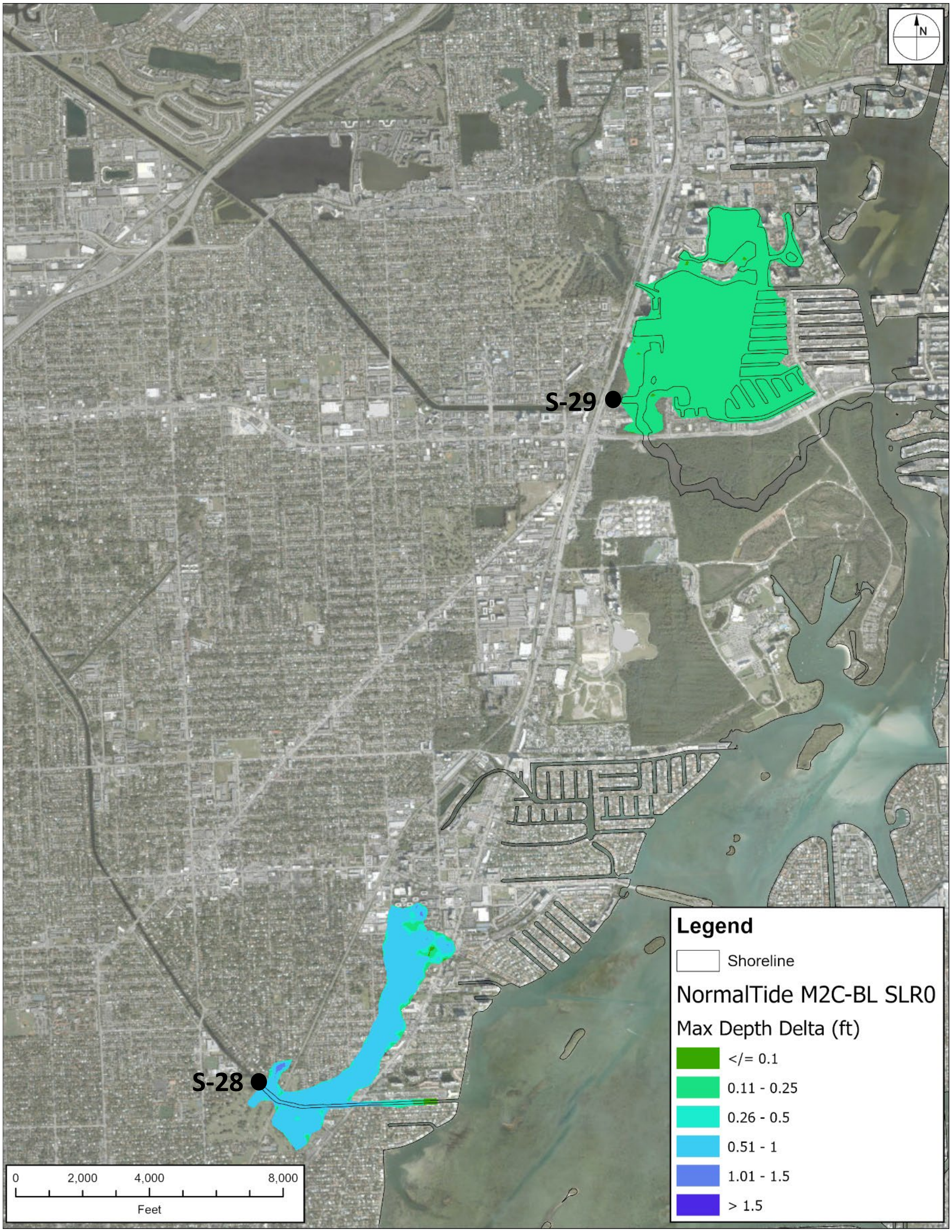

Figure 4.1 S-28 and S-29 Structures Downstream Difference in Normal Tides Maximum Depths Between With and Without M2C Alternative Conditions (Sea level Rise = 0 ft)

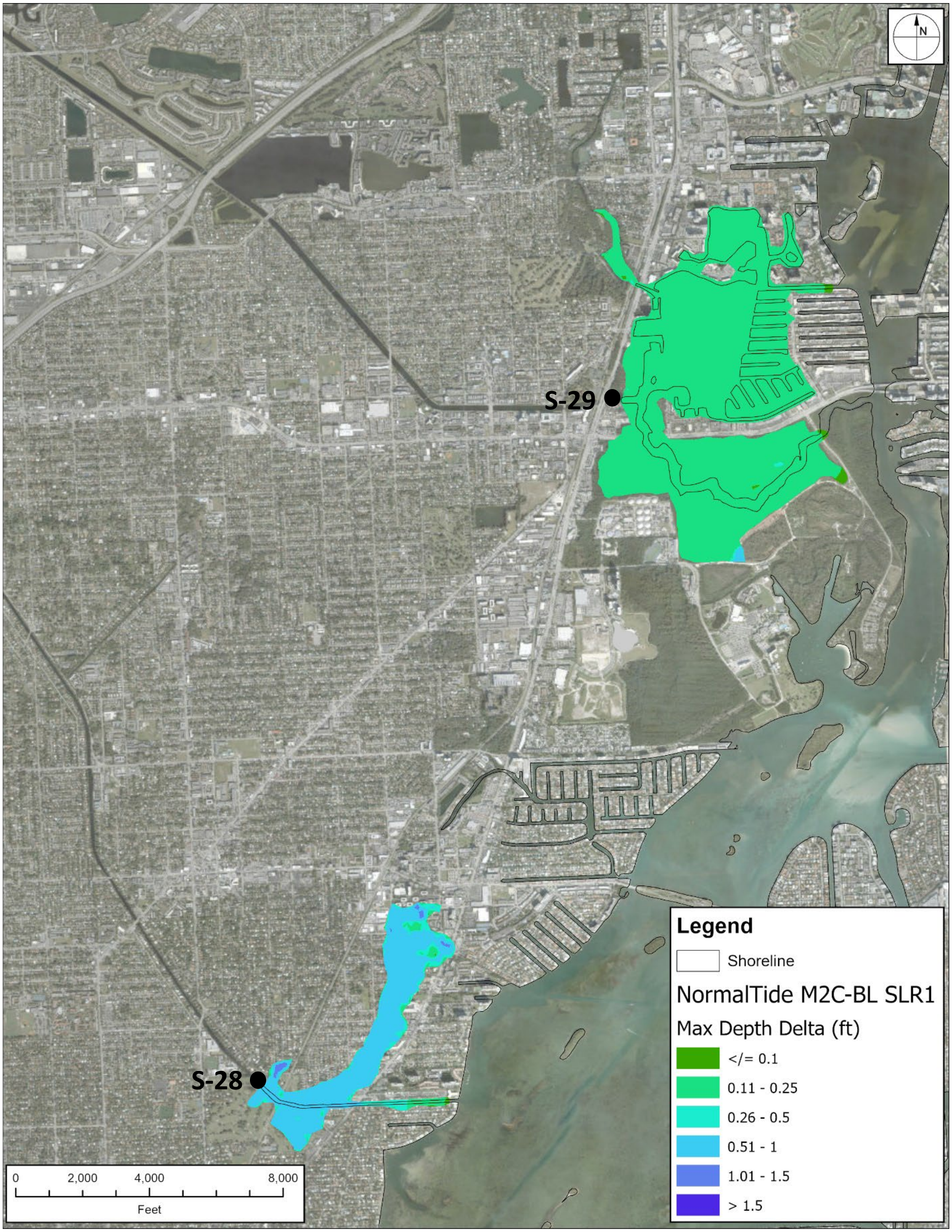

Figure 4.2 S-28 and S-29 Structures Downstream Difference in Normal Tides Maximum Depths Between With and Without M2C Alternative Conditions (Sea level Rise = 1 ft)

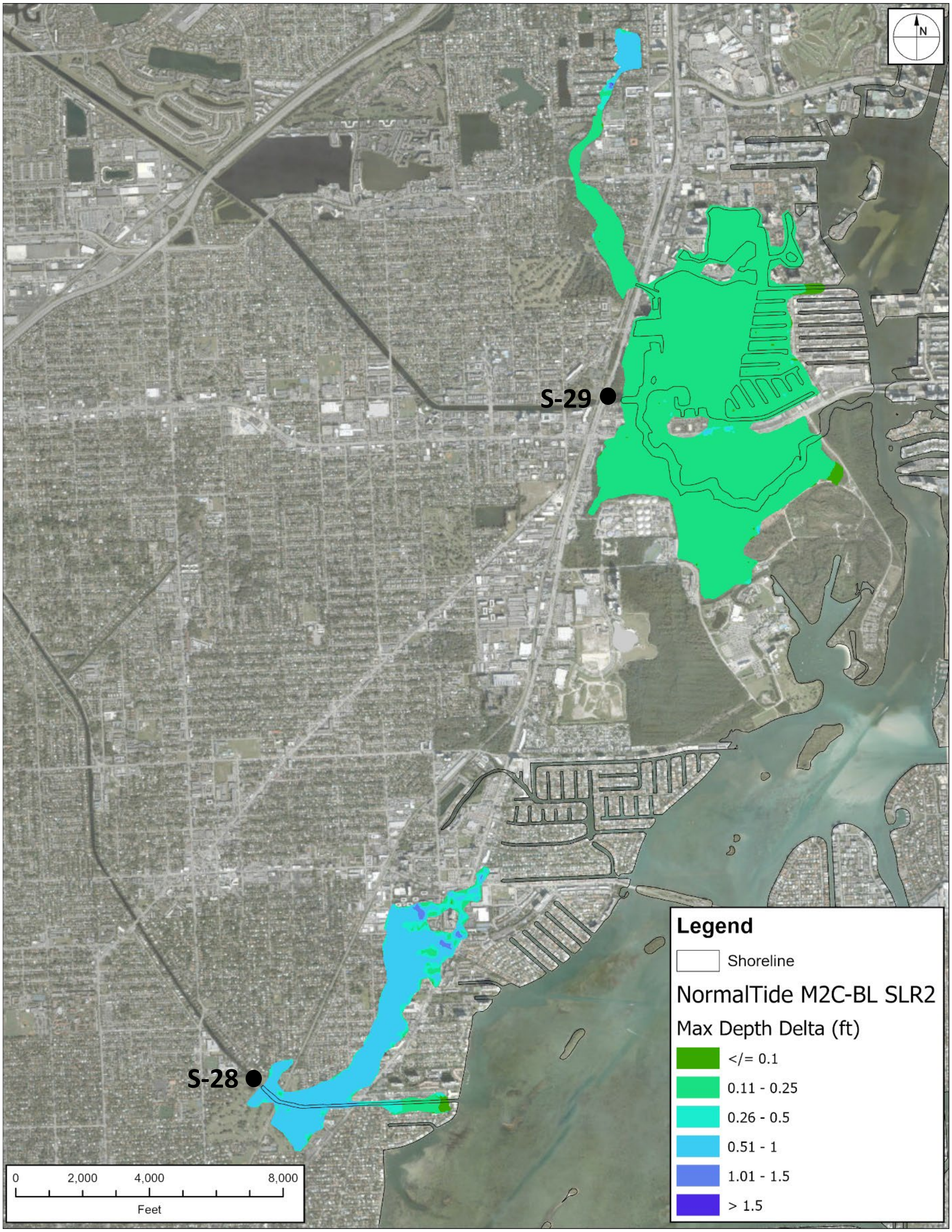

Figure 4.3 S-28 and S-29 Structures Downstream Difference in Normal Tides Maximum Depths Between With and Without M2C Alternative Conditions (Sea level Rise = 2 ft)

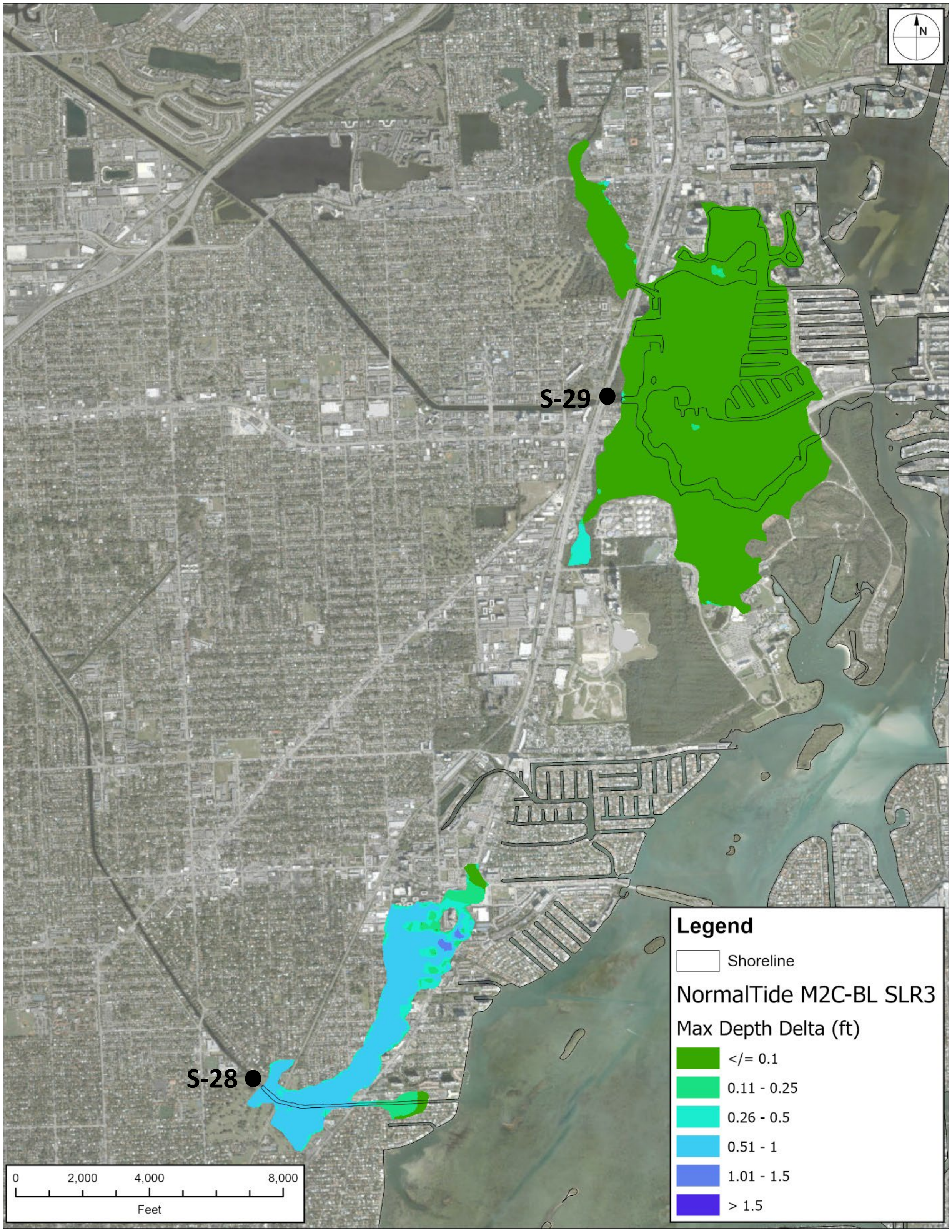

Figure 4.4 S-28 and S-29 Structures Downstream Difference in Normal Tides Maximum Depths Between With and Without M2C Alternative Conditions (Sea level Rise = 3 ft)

4.2 10-yr Surge Event Conditions

Appendix B describes the development of BBM water level boundary conditions at the mouth of Bakers Haulover, IWW North, and IWW South boundaries. Table 4.2 lists the structure outflows and sea level rise conditions applied in the 6.4-day BBM 10-yr surge conditions simulation period. Baseline (M0) runs characterize conditions without the C-8 and C-9 basins flood mitigation projects (thus no pump flows at the structures). With concurrence of the SFWMD, this study evaluated the effects of Alternative M2C outflows on Biscayne Bay water levels because this alternative provides the largest structure outflows (and therefore the largest effect on water levels) when compared to Alternatives M2A and M2B (see Table 1.1). The SFWMD also added Alternatives M2A with 1-ft sea level rise and M2B with 2-ft sea level rise to specifically evaluate S-28 and S-29 structure outflows for alternatives that are likely to be constructed in the near the future. Appendix A provides the FPLOS gate flow and pump flow hydrographs at S-28 and S-29 structures.

Table 4.2 10-yr Surge Conditions BBM Runs (see Appendix A Figures)

Run	Condition	S-28 Structure Flow		S-29 Structure Flow		Sea Level Rise (ft)
		Gate Flow	Pump Flow	Gate Flow	Pump Flow	
10-yr M0-SLR0	Baseline	Figure A.9	none	Figure A.9	none	0
10-yr M0-SLR1	Baseline	Figure A.11	none	Figure A.11	none	1
10-yr M0-SLR2	Baseline	Figure A.13	none	Figure A.13	none	2
10-yr M0-SLR3	Baseline	Figure A.15	none	Figure A.15	none	3
10-yr M2C-SLR0	M2C	Figure A.10	Figure A.10	Figure A.10	Figure A.10	0
10-yr M2C-SLR1	M2C	Figure A.12	Figure A.12	Figure A.12	Figure A.12	1
10-yr M2C-SLR2	M2C	Figure A.14	Figure A.14	Figure A.14	Figure A.14	2
10-yr M2C-SLR3	M2C	Figure A.16	Figure A.16	Figure A.16	Figure A.16	3
10-yr M2A-SLR1	M2C	Figure A.17	Figure A.17	Figure A.17	Figure A.17	1
10-yr M2B-SLR1	M2C	Figure A.18	Figure A.18	Figure A.18	Figure A.18	2

4.2.1 Effect of M2C S-28 and S-29 Structures Outflows with No SLR on 10-yr Surge Highwater Levels

This study calculated the maximum water depths for each BBM element in model runs 10-yr M0-SLR0 and 10-yr M2C-SLR0. Subtraction of 10-yr M0-SLR0 element maximum water depth from the corresponding 10-yr M2C-SLR0 element maximum water depth provided estimates of the effect of Alternative M2C S-28 and S-29 structure outflows on 10-yr surge downstream water levels. Figure 4.5 shows the difference in the modeled maximum water depths between 10-yr M2C-SLR0 and 10-yr M0-SLR0. The figure shows S-28 structure outflows can increase maximum depths by mostly 0.25 – 1.5 ft in a limited area downstream of S-28 structure. The figure also shows S-29 structure outflows can increase maximum depths by mostly up to 0.10 ft in a small area downstream of S-29 structure (around Maule Lake and Oleta River State Park). Notably, model results do not show substantial change in water levels in Biscayne Bay with M2C-SLR0 structure outflows because the surge prism flows from the ocean are very much larger than the structure outflows.

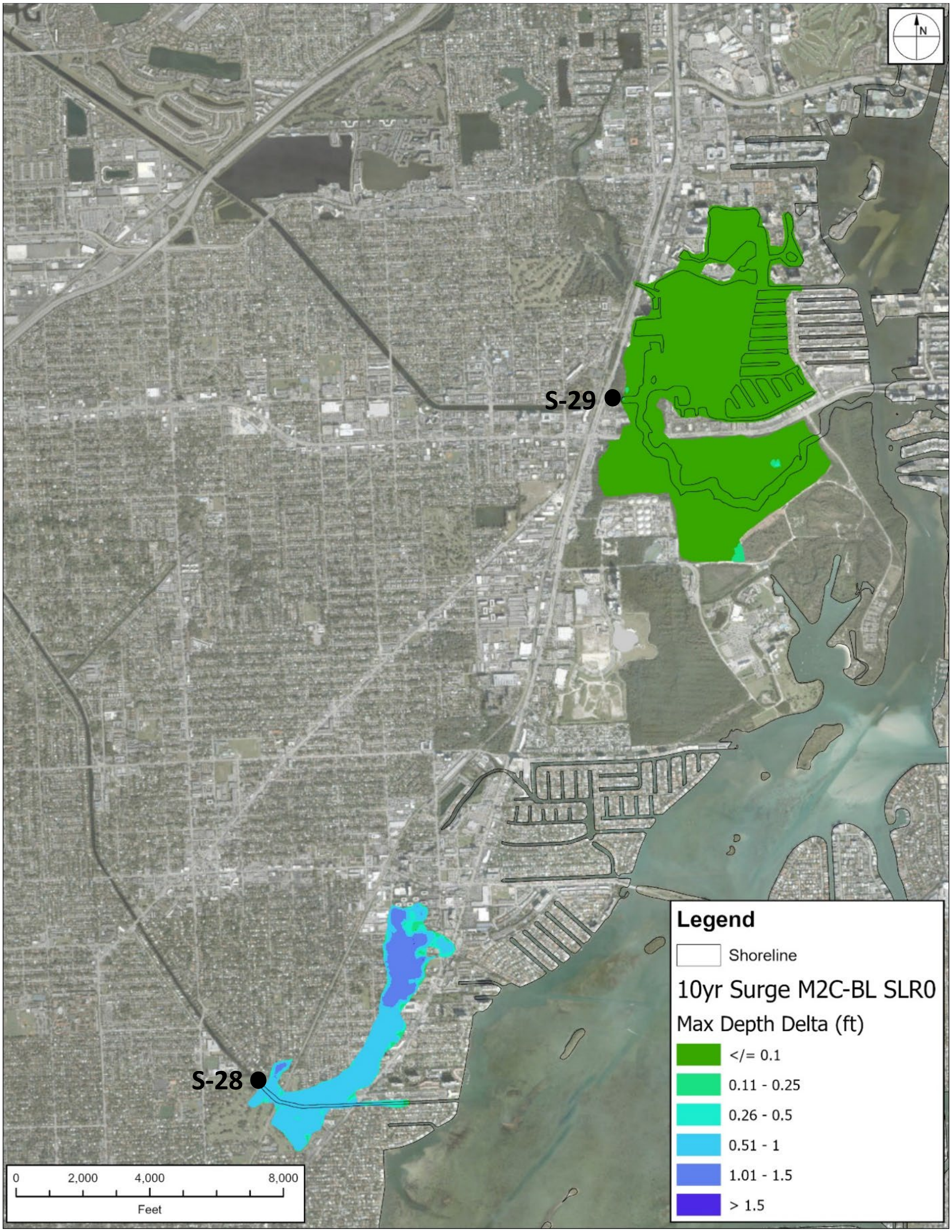

Figure 4.5 S-28 and S-29 Structures Downstream Difference in 10-yr Maximum Depths Between With and Without M2C Alternative Conditions (Sea level Rise = 0 ft)

4.2.2 Effect of M2C S-28 and S-29 Structures Outflows with SLR on 10-yr Surge Highwater Levels

BBM M2C 10-yr surge simulations with sea level rises added a constant 1 ft, 2 ft, and 3 ft respectively to each of the three BBM external water level boundaries for the SLR1, SLR2, and SLR3 sea level rise conditions. The evaluation of the effect of S-28 and S-29 structure outflows on downstream water levels followed the same procedure as described in the above section. The calculated differences between the maximum water depths of 10-yr M2C-SLR1 and 10-yr M0-SLR1, 10-yr M2C-SLR2 and 10-yr M0-SLR2, 10-yr M2C-SLR3 and 10-yr M0-SLR3 show (see Figure 4.6 to Figure 4.8 respectively):

a) 10-yr M2C-SLR1 S-28 outflows can increase maximum water depths by mostly 0.5 – 1.5 ft over a limited area downstream of S-28 structure.

b) 10-yr M2C-SLR1 S-29 outflows can increase maximum depths by mostly up to 0.1 – 0.25 ft in a small area downstream of S-29 structure (around Maule Lake and Oleta River State Park) and increased in Oleta River north and west of US1 of up to 1 ft.

c) 10-yr M2C-SLR2 S-28 outflows can increase maximum water depths by mostly 0.25 – 1.0 ft over the same area (compared to 10-yr M2C-SLR1) downstream of S-28 structure.

d) 10-yr M2C-SLR2 and 10-yr M2C-SLR3 S-29 outflows will likely not substantially change maximum depths downstream of S-28 and S-29 structures.

e) 10-yr M2C-SLR3 S-28 outflows can increase maximum water depths by mostly 0.1 – 0.5 ft over a slightly larger area (compared to 10-yr M2C-SLR1 and 10-yr M2C-SLR2) downstream of S-28 structure.

f) As with normal tides conditions wherein rising sea levels dampen the effect of any structure outflows on downstream water levels, the increase in the sea level rise did not substantially increase the difference between 10-yr surge baseline and M2C modeled maximum water depths but only slightly enlarges the area affected by M2C structure outflows. Thus, 10-yr surge conditions model results generally indicate rising sea levels decrease the effect of S-28 and S-29 outflows on water levels.

g) 10-yr surge conditions model results indicate the effect of S-28 and S-29 outflows is limited to downstream areas near the structures and do not reach the main Biscayne Bay area.

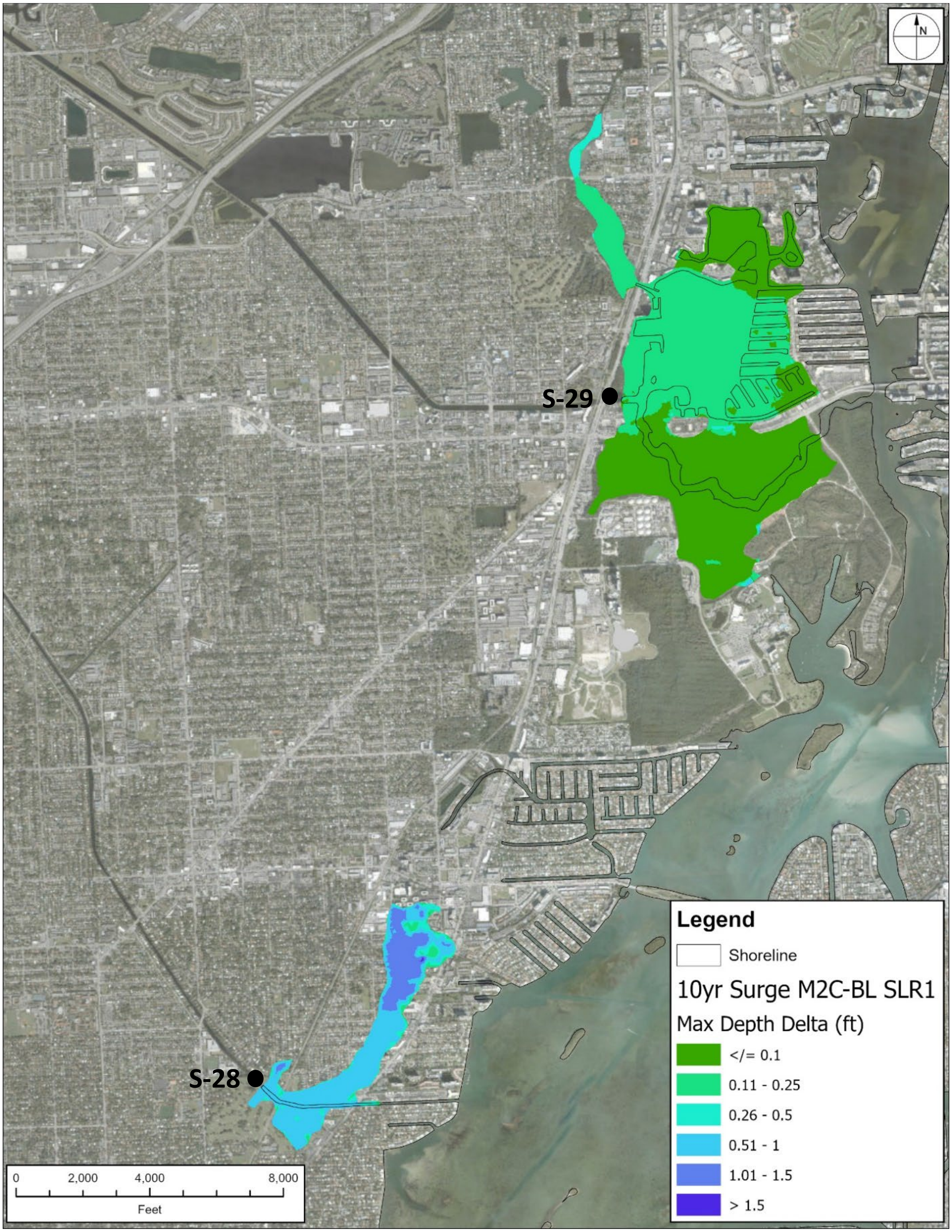

Figure 4.6 S-28 and S-29 Structures Downstream Difference in 10-yr Maximum Depths Between With and Without M2C Alternative Conditions (Sea level Rise = 1 ft)

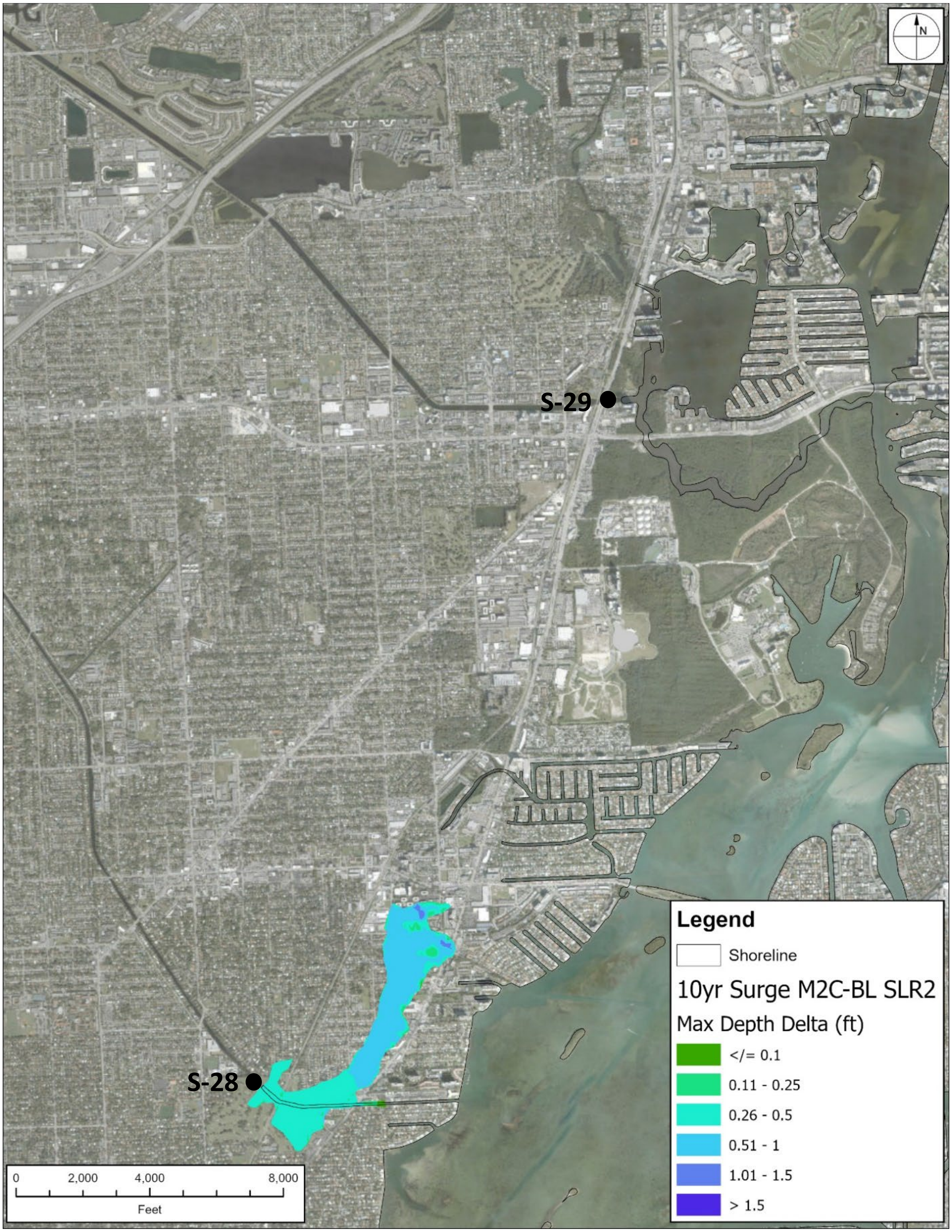

Figure 4.7 S-28 and S-29 Structures Downstream Difference in 10-yr Maximum Depths Between With and Without M2C Alternative Conditions (Sea level Rise = 2 ft)

Figure 4.8 S-28 and S-29 Structures Downstream Difference in 10-yr Maximum Depths Between With and Without M2C Alternative Conditions (Sea level Rise = 3 ft)

4.2.3 Effect of M2A S-28 and S-29 Structures Outflows with 1-ft SLR on 10-yr Surge Highwater Levels

Figure 4.9 shows the difference in the modeled maximum water depths between 10-yr M2A-SLR1 and 10-yr M0-SLR1. The figure shows S-28 structure outflows can <u>decrease</u> maximum depths by mostly 0.0 – 1.5 ft in a limited area downstream of S-28 structure. The figure also shows S-29 structure outflows can increase maximum depths mostly up to 0 – 0.25 ft in a small area (around Maule Lake and Oleta River State Park) downstream of S-29 structure. Notably, model results do not show substantial change in water levels in Biscayne Bay with M2A S-28 and S-29 structure outflows because the surge prism flows from the ocean are very much larger than the structure outflows.

4.2.4 Effect of M2B S-28 and S-29 Structures Outflows with 2-ft SLR on 10-yr Surge Highwater Levels

Figure 4.10 shows the difference in the modeled maximum water depths between 10-yr M2B-SLR2 and 10-yr M0-SLR2. The figure shows S-28 structure outflows can increase maximum depths by mostly 0.1 – 0.25 ft in a smaller area (compared to 10-yr M2C SLR1, SLR2, and SLR3) downstream of S-28 structure. The figure also shows S-29 structure outflows will likely not substantially change maximum depths downstream of S-29 structure. Notably, model results do not show substantial change in water levels in Biscayne Bay with M2B S-28 and S-29 structure outflows because the surge prism flows from the ocean are very much larger than the structure outflows.

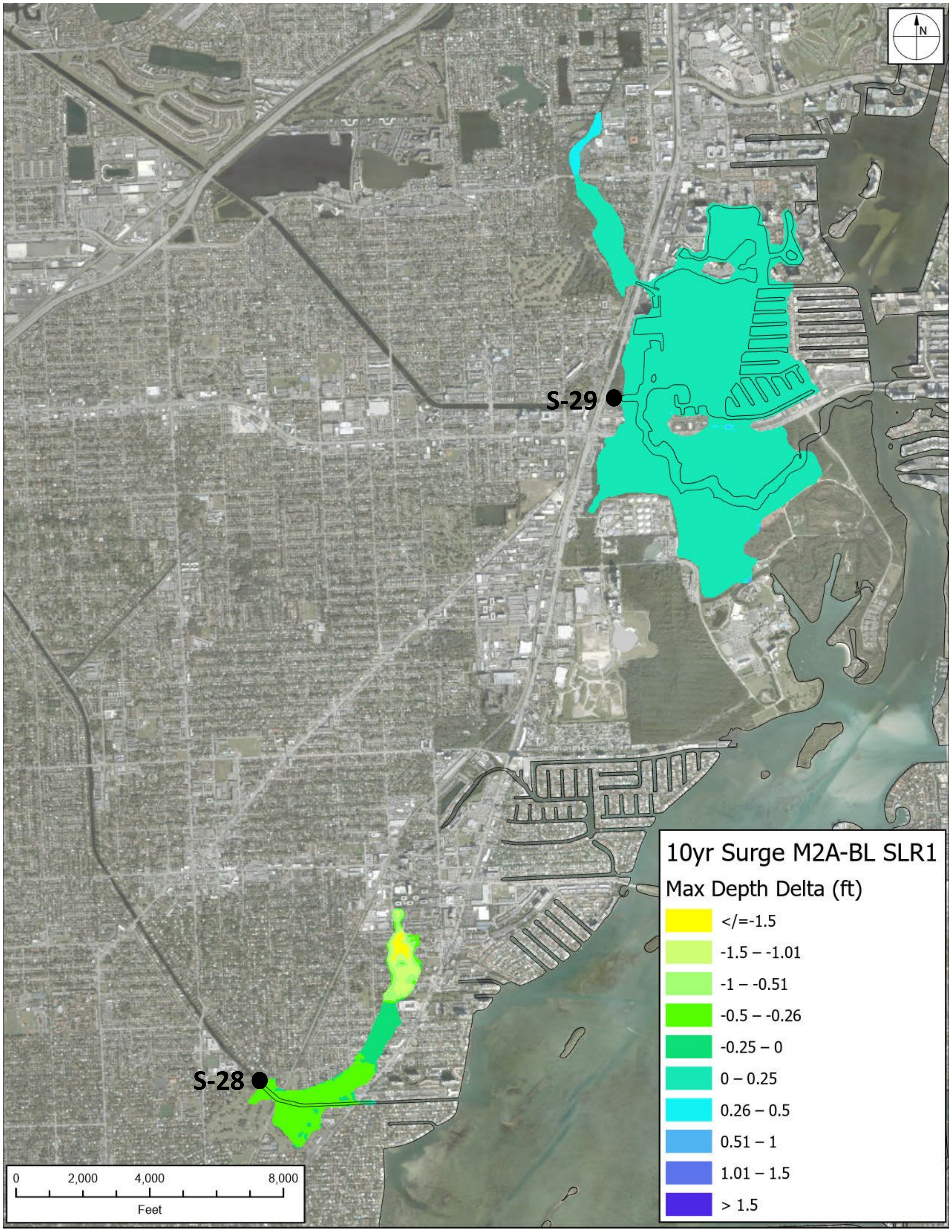

Figure 4.9 S-28 and S-29 Structures Downstream Difference in 10-yr Maximum Depths Between With and Without M2A Alternative Conditions (Sea level Rise = 1 ft)

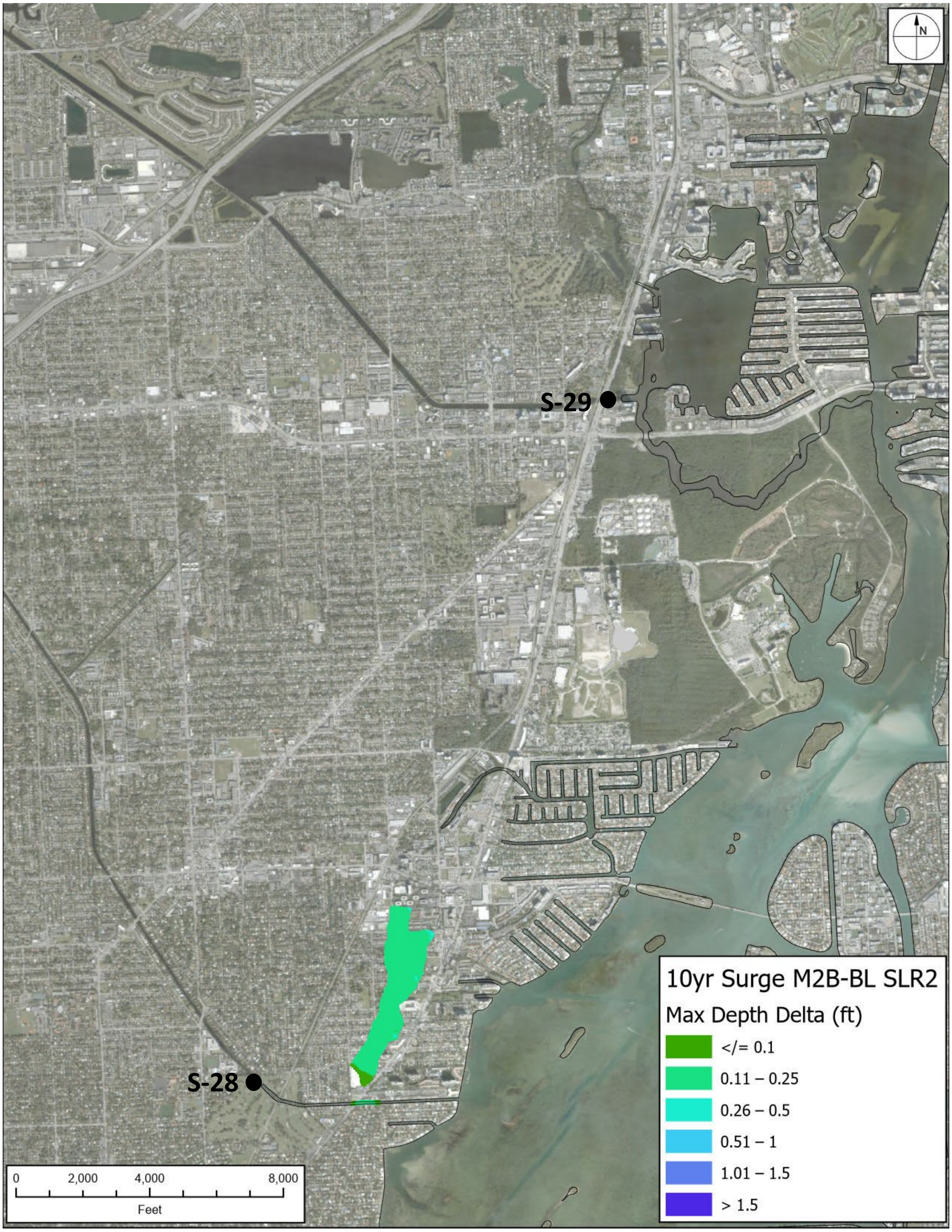

Figure 4.10 S-28 and S-29 Structures Downstream Difference in 10-yr Maximum Depths Between With and Without M2B Alternative Conditions (Sea level Rise = 2 ft)

5.0 CONCLUSIONS AND RECOMMENDATIONS

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 statistics 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 Biscayne Bay 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 5.1 summarizes the effects of the S-28 and S-29 structures outflows on downstream maximum water depths.

5.1 Conclusions on Effects of S-28 and S-29 Structures Outflows

Alternative M2C can cause larger peak depth increases downstream of S-28 structure than at 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 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 FPLOS S-28 and S-29 structure outflows. Model results also indicate rising sea levels generally decrease 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.

5.2 Recommendations

Based on the model simulations performed and analyses of model results, this study makes the below recommendation.The current model setup relies on the outflow from the decoupled FPLOS model as an inflow to the BBM. This setup does have its limitations. To better capture the interaction of the headwater and tailwater at the structures, we suggest the District develop a compound rainfall and surge hydrodynamic model simulating the overland flooding from simultaneous or overlapped rainfall and surge events for upstream basins and Biscayne Bay. Couple the FPLOS model (i.e., MIKE-SHE and MIKE overland model) with the compound rainfall and surge hydrodynamic model to evaluate flooding in C-6, C-7, C-8, C-9 basins and Biscayne Bay flooding under different flood mitigation alternatives and storm conditions.

Table 5.1 Summary of Effects of FPLOS Outflows at S-28 and S-29 Structures on Normal Tides and 10-yr 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)

6.0 REFERENCES

Danish Hydraulic Institute (DHI). 2022. *MIKE 21 Flow Model FM Hydrodynamic Module User Guide*. Horsholm, Denmark.

FEMA. 2021. *Flood Insurance Study for Miami-Dade County, Florida and Incorporated Areas*. Flood Insurance Study Number 12086CV001B, Preliminary 2/25/2021.

T A Y L O R   E N G I N E E R I N G ,   I N C .

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

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

Deliverable 3.2
CONTRACT 4600004085
Work Order 05

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

Revised Submitted 4/14/2023
Draft

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Task 3.2 Technical Memorandum
Expected Annual Damage and Benefit Cost Calculations

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Draft

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April 14, 2023

Taylor Project Number: C2021-033

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1.0 INTRODUCTION

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

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

2.0 GENERAL ECONOMIC DAMAGES APPROACH AND THE SFWMD-FIAT

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

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

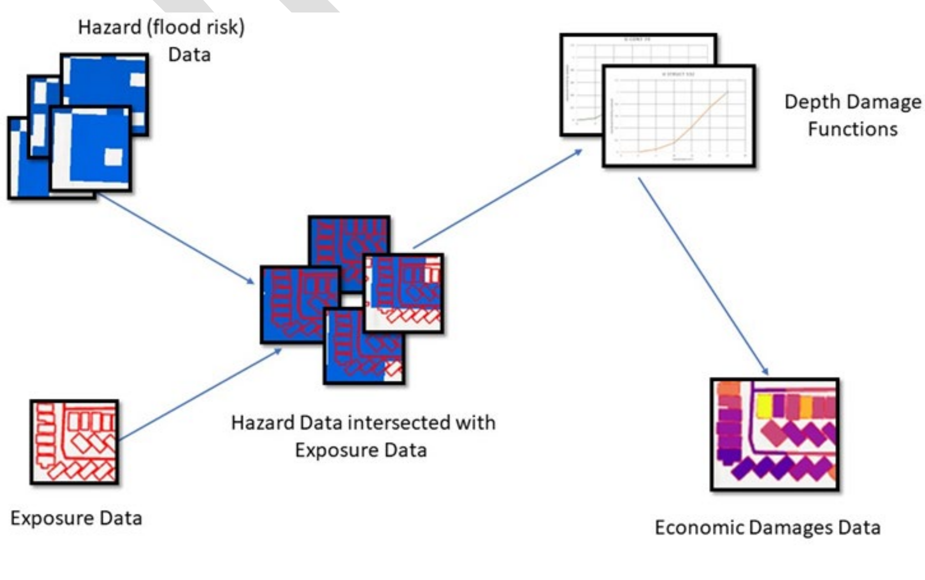

Figure 2.1: Calculation of Expected Annual Damages

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

2.1.1 Depth Damage Functions (DDFs)

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

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

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

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

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

2.1.2 Exposure Data

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

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

Table 2.1 Layers Compiled for SFWMD-FIAT

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

2.1.3 Hazard (flood risk) Data

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

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

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

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

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

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

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

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

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

3.0 TOOL IMPLEMENTATION

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

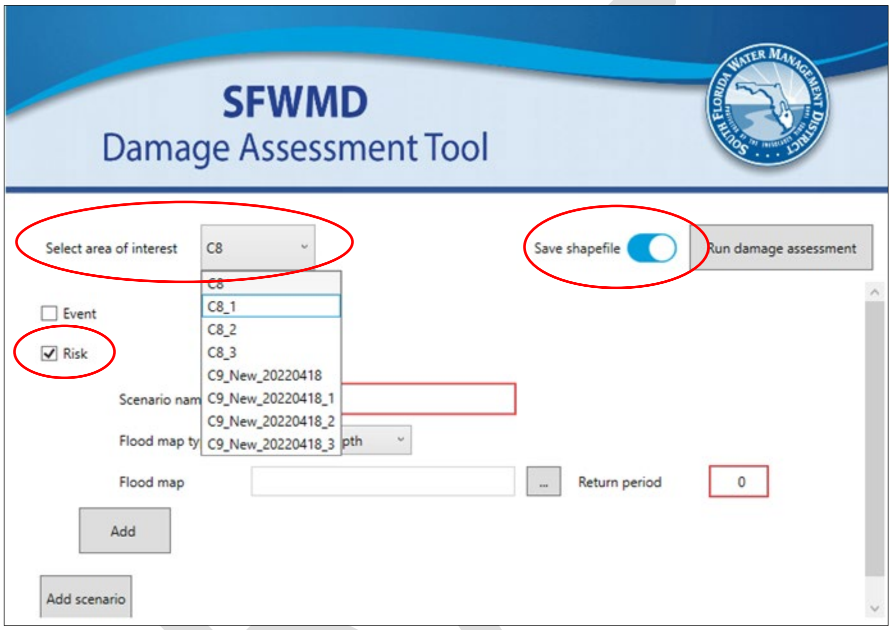

Figure 3.1 SFWMD-FIAT Setup
(The three red circles highlight the initial parameters for the tool.)

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

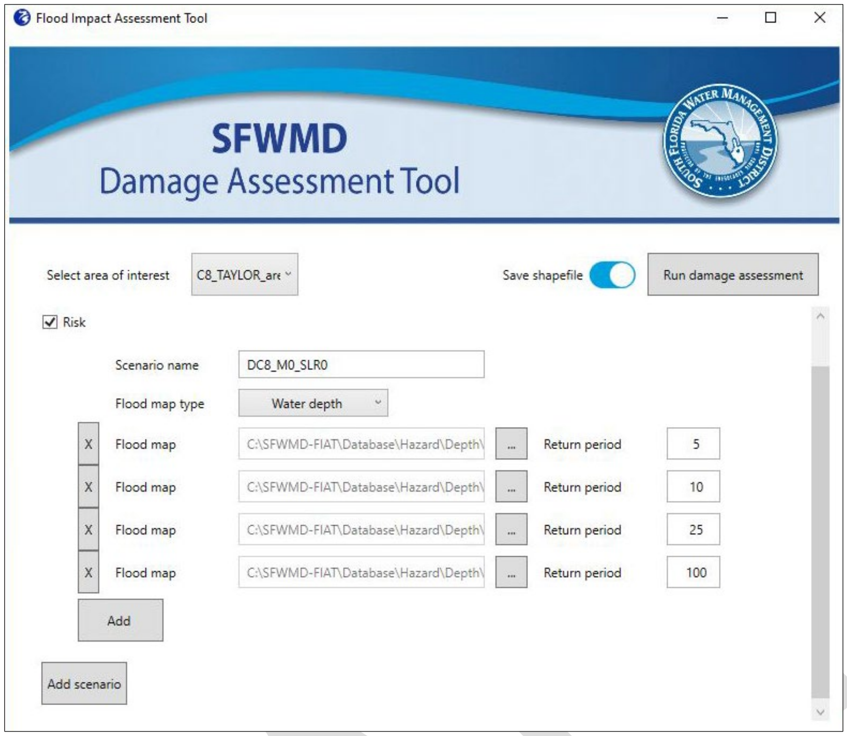

Figure 3.2 An Example Scenario Configuration

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

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

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

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

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

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

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

Table 3.1 Data Structure Explained

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

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

4.0 SFWMD-FIAT RESULTS (C-8)

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

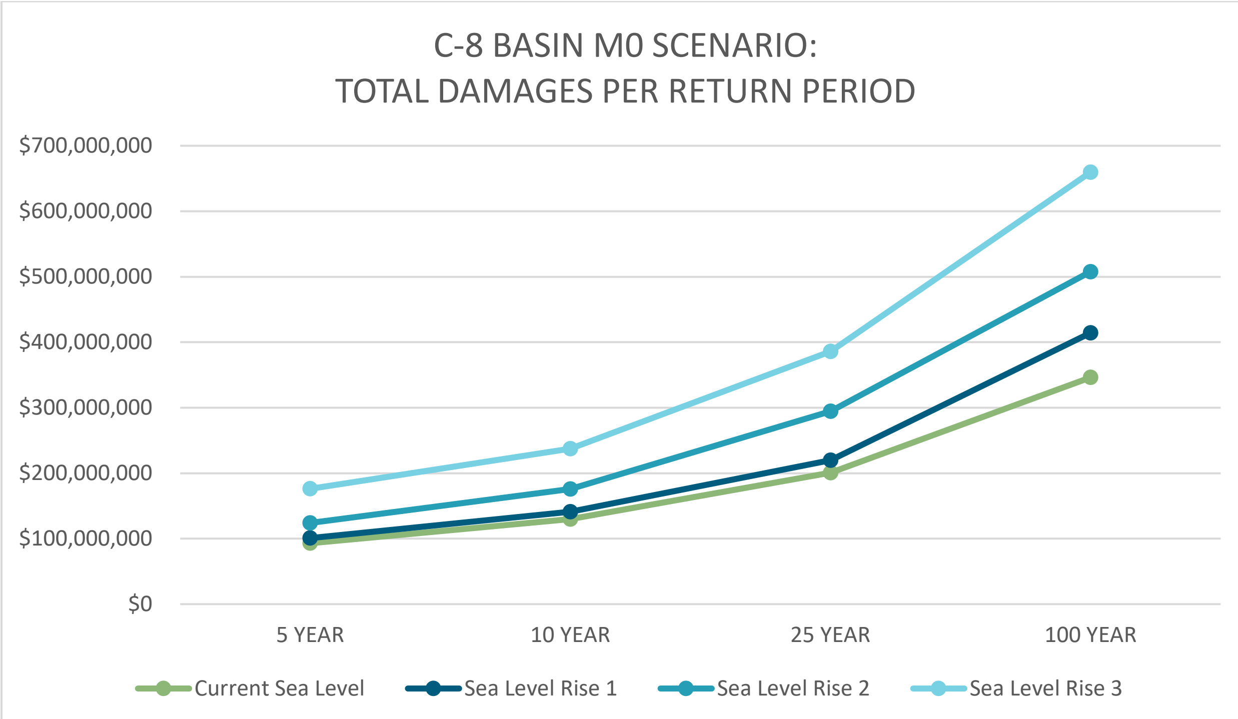

Figure 4.1 Economic Impacts for M0 (no mitigation) in the C-8 Basin

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

5.0 SFWMD-FIAT RESULTS (C-9)

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

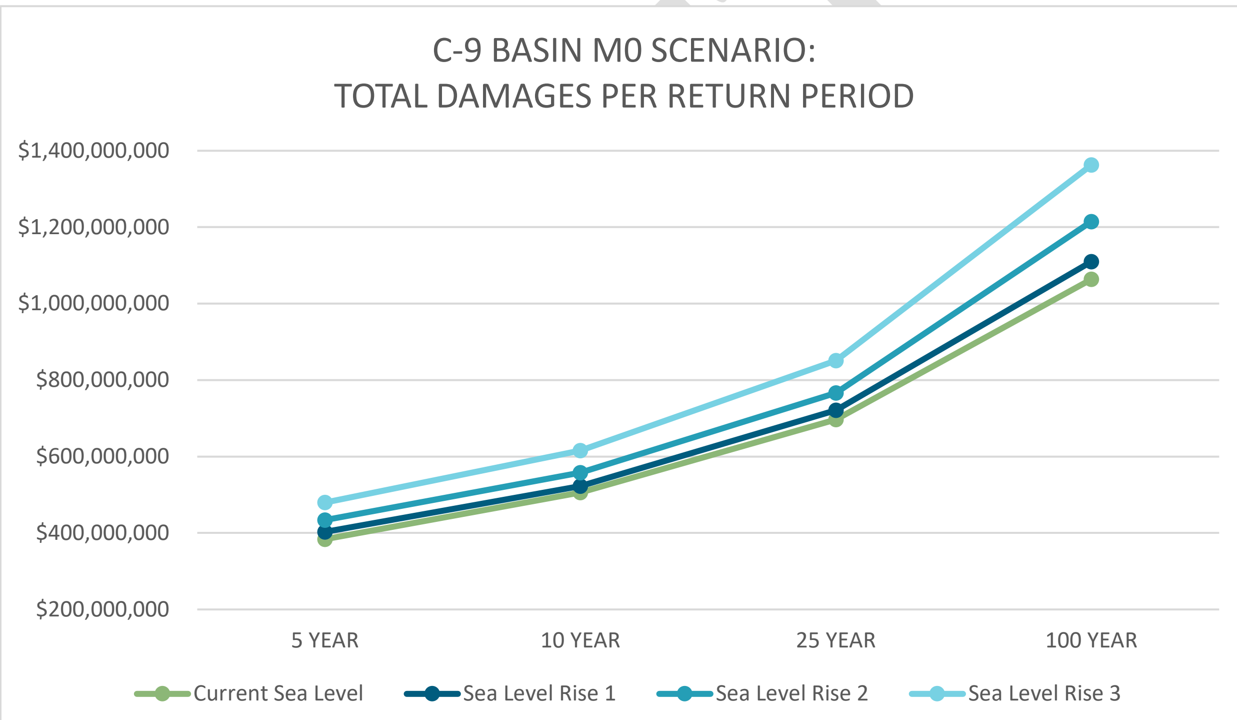

Figure 5.1 Economic Impacts for M0 (no mitigation) in the C-9 Basin

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

Table 5.1 C-9 Percent Change Comparing M0 Damages

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

6.0 EAD SUMMARY

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

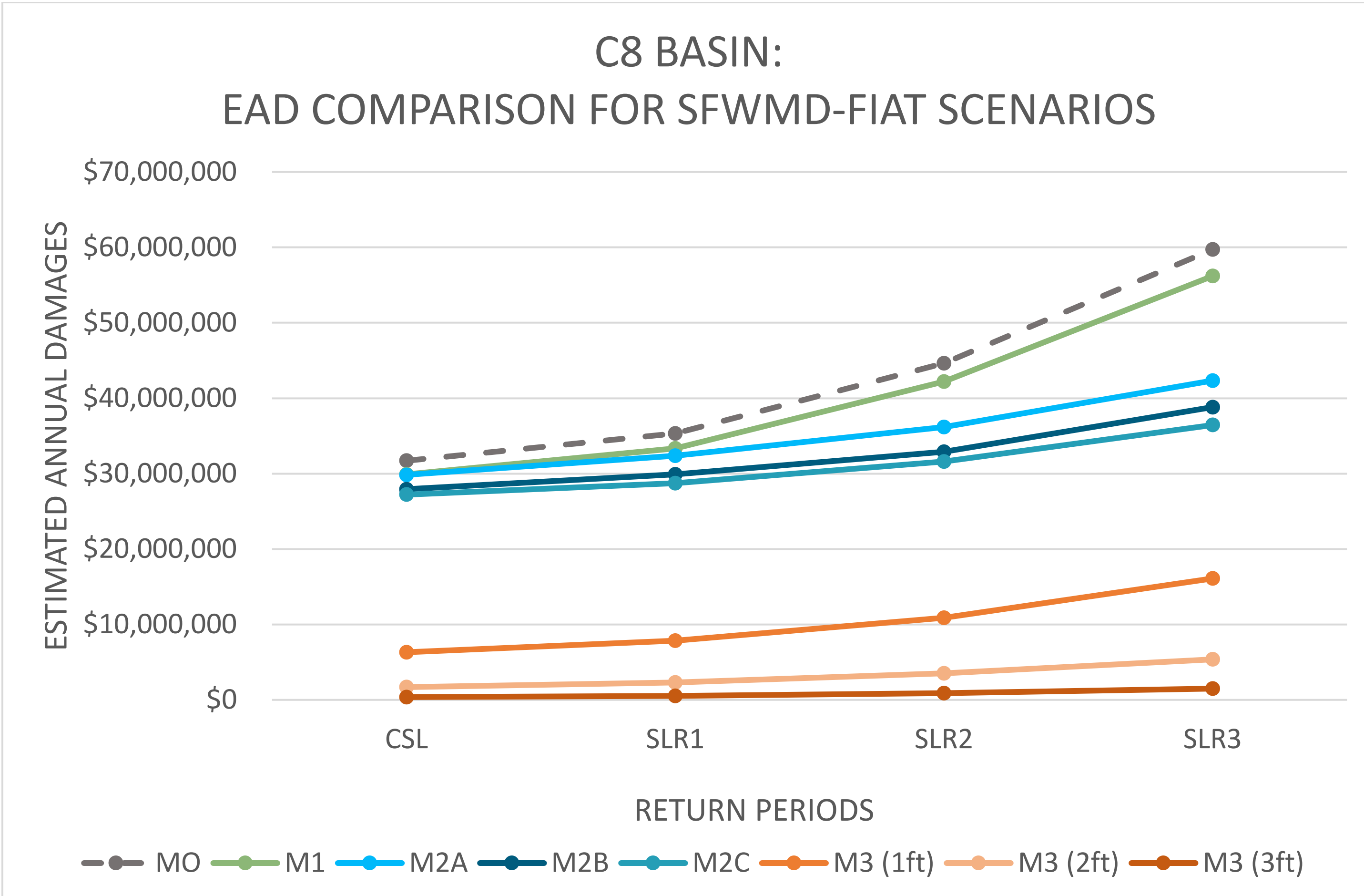

Figure 6.1 C-8 Basin - EAD Comparison for SFWMD-FIAT Scenarios

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

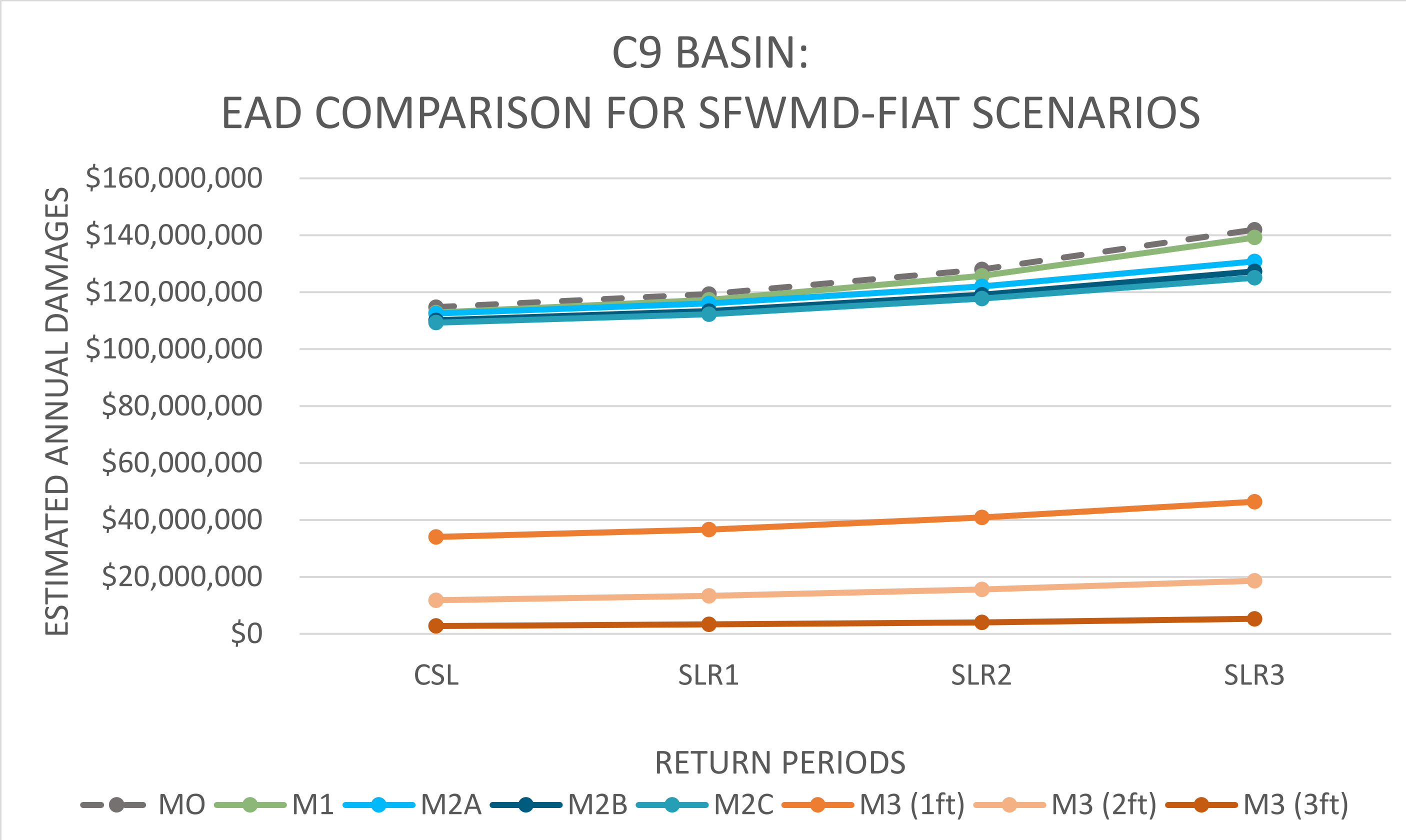

Figure 6.2 C-9 Basin - EAD Comparison for SFWMD-FIAT Scenarios

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

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

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

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

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

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

7.0 CALCULATION OF BENEFIT-COST RATIO

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

7.1 Benefit-Cost Approach and Procedure

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

Project Configuration

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

Cost Estimation

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

Damage Analysis Parameters - Damage Frequency Assessment

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

Professional Expected Damages Before Mitigation

Damages Before Mitigation:

Add Row Delete Row(s)

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

View Annualized Results

Professional Expected Damages After Mitigation

Damages After Mitigation:

Add Row Delete Row(s)

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

View Annualized Results

Standard Benefits - Ecosystem Services

Additional Benefits - Social

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

Benefit-Cost Summary

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

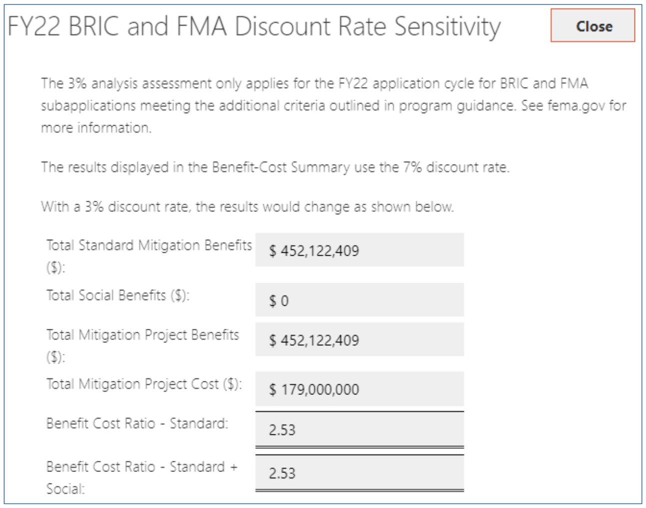

Figure 7.1 FEMA BCA Toolkit Example

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

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

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

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

Where,

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

7.1.1 Assumptions and limitations

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

7.2 Results

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

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

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

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

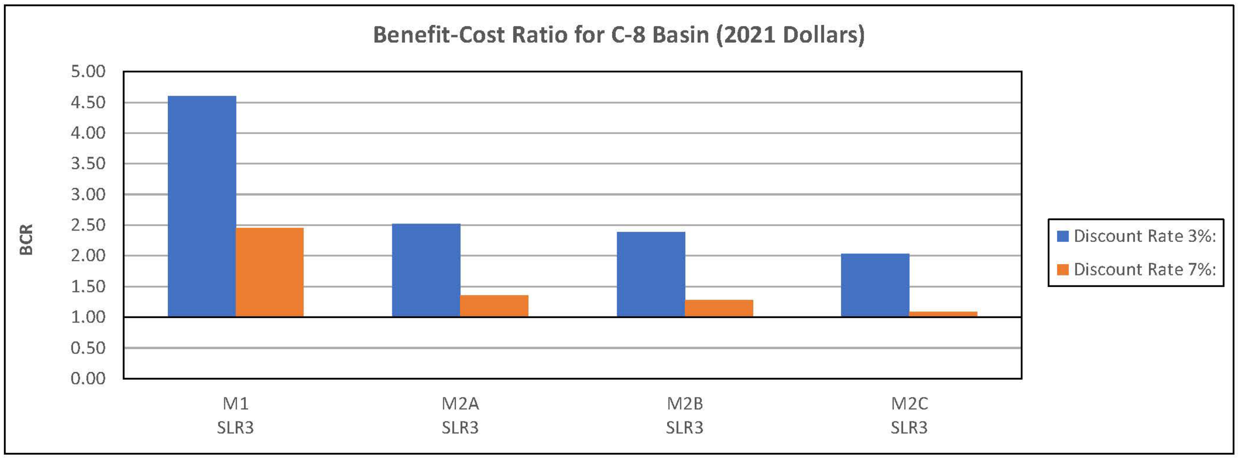

Figure 7.2 Benefit-Cost Ratio Graph for the C-8 Basin

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

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

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

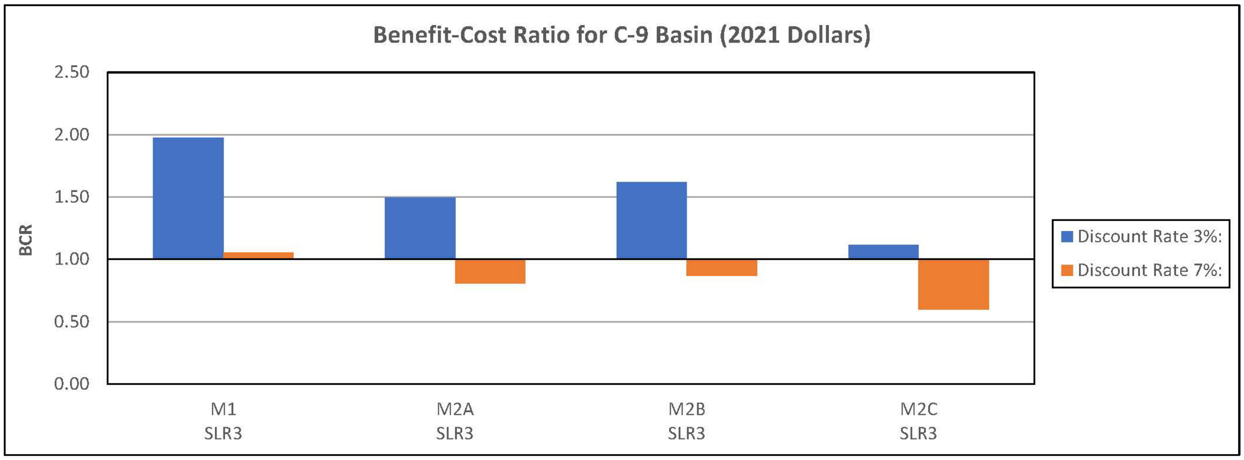

Figure 7.3 Benefit-Cost Ratio Graph for the C-9 Basin

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

7.2.1 M0 Projects

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

7.2.2 M1 Projects

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

7.2.3 M2 Projects

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

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

7.2.4 M3 Projects

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

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

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

7.2.5 Benefit-Cost Ratio Conclusions

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

7.2.6 Indirect Impact to Benefit-Cost Ratios

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

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

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

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

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

8.0 CONCLUSIONS

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

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

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

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

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

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

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

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

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

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REPORT

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TASK 4.1 TECHNICAL MEMORANDUM: DRAFT ADAPTATION PLANNING REPORT

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

Task 4.1 Technical Memorandum
Draft Adaptation Planning Report

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

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Draft

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1.0 INTRODUCTION

The South Florida Water Management District (SFWMD or District) is conducting a system-wide review of the regional water management infrastructure to determine which mitigation projects may maintain or improve the current flood protection level of service (FPLOS). The FPLOS Phase 1 Study describes the level of protection provided by the water management facilities within a watershed considering sea level rise (SLR), future development, and known water management issues in each watershed. This study is part of the FPLOS Phase 2 for the C-8 and C-9 basins. The District's objective of the Phase 2 studies is to identify mitigation activities that may reduce flooding impacts and predict reductions in economic consequences. This technical memorandum is Deliverable 4.1 of Task 4 Adaptation Pathway Planning and Workshops.

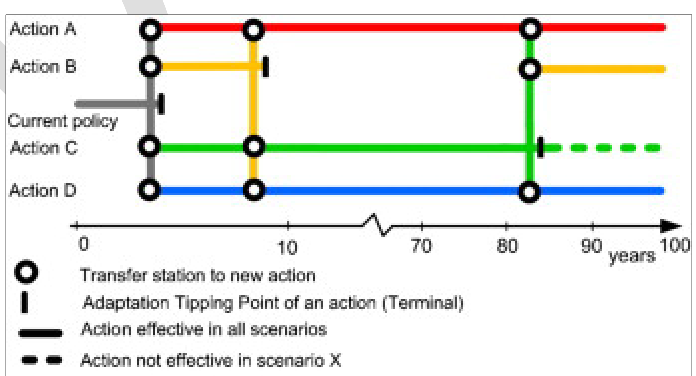
This memorandum details the application of the Dynamic Adaptive Policy Pathways framework (Haasnoot et al, 2013) and the use of the "Pathways Generator" (developed and copyrighted by Deltares and Carthago Consultancy) to the C-8 and C-9 basins, along with selected focus area census tracts.

2.0 DYNAMIC ADAPTIVE POLICY PATHWAYS: A POLICY AND PLANNING FRAMEWORK

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 (**Figure 2.1**) 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 technical memorandum.
- 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 forms a roadmap for future are known as a pathway on the Adaptations Pathway Map.



Adaptation Pathways Map

Figure 2.1 Example of an Adaptations Pathway Map

Adaptation pathways can represent multiple sequences of adaptation measures to adjust to changing conditions. In **Figure 2.1**, 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.

3.0 C-8/C-9 DAPP FRAMEWORK

For the C-8 and C-9 study, the DAPP analyzes 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 Basin study, the DAPP analysis includes these inputs:

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

3.1 Sea Level Rise Curves

The SLR projections (**Figure 3.1**) 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 (**Table 3.1**).

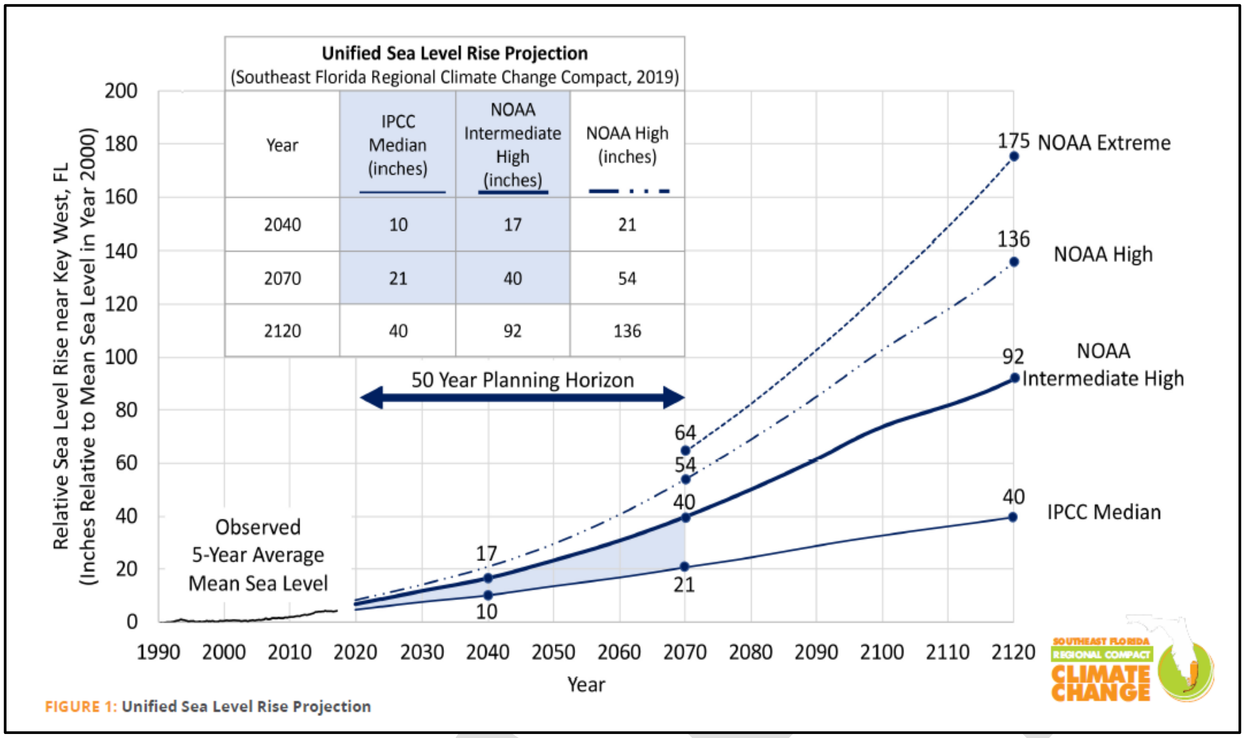


Figure 3.1 Southeast Florida Regional Climate Change Compact (2020)
Unified Sea Level Rise Projection: 2019 Update

Table 3.1 Estimated Year of Anticipated Sea Level Rise

SLR (ft above 2021)	NOAA 2017 Intermediate High Interpolated Year	NOAA 2017 High Interpolated Year
1	2044	2040
2	2060	2053
3	2073	2063

Source: Southeast Florida Regional Climate Change Compact (2020)

3.2 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.*

The EADs produced by the SFWMD-FIAT can also highlight the differences in the effectiveness of the mitigation alternatives by basins or another geographic boundary. For this study, we selected some focus areas by census tracts within each basin.

3.2.1 Census Tract Focus Areas

Focus area analysis provides a method to examine trends in EAD differences based on the effects of different mitigation scenarios in different geographic areas. There are several options to examine when considering geographic boundaries to determine comparative analysis areas, such as subbasin boundaries, census tract boundaries, or equal area grids (1km x 1km). District staff and project team decided on the analysis of areas using census tract boundaries given the familiarity of this designation in current political jurisdictions and broader economic studies.

The team originally selected census tracts with the highest EADs, based on the SFWMD-FIAT aggregated outputs. This method exposed the limitations when selecting census tracts with large geographic areas containing a small number of structures and roads relative to a small census tract with a large number of structures and roads. Analysis showed that the density within different census tracts caused disparate EADs and could not be compared. Further discussion with District staff concluded that it would be best to analyze census tracts based on an area-weighted EAD (EAD per acre).

EAD per acre calculations were performed for each census tract using the following steps:

1. Output shapefiles from the SFWMD-FIAT were grouped using ESRI's Dissolve tool to merge all structures and roads by common census tract name.
2. ESRI's Calculate Geometry tool was used to determine the acreage of all structures and roads within each census tract area. Using this calculated developed area as a ratio of each census tract provides more accurate area-weighted calculations because of the varied density of census tract land use.
3. A final calculation was performed to define the area-weighted EAD of each census tract using the acreage of merged structures and roads.

To select the final census tracts for this task, the project team examined area-weighted EAD to find census tracts with the highest EAD per acre. In this analysis, several census tracts with extremely high EAD per acre were excluded. Some of these outliers include census tracts whose edges do not coincide with the basin boundaries, resulting in high density small areas (> 0.01 acre) with extremely high EAD per acre.

3.2.2 Mitigation Strategies included in DAPP

There are 4 levels of mitigation strategies included in the FPLOS program. Three of those mitigation strategies (M0, M1, and M2) were included in the DAPP analysis (**Table 3.2**). A fourth level of strategies, M3, were included at planning level mitigation studies, but not included in the DAPP analysis. M3 strategies involve land elevation changes that can be either regional or local in nature. Examples may include raising buildings, finished floor elevations, seawall or flood wall elevations, raising roadways, or other administrative or regulatory changes. Because the M3 scenarios did not exceed the thresholds under 1-, 2-, or 3- ft of SLR, they were not included in the adaptive pathways.

The M0 strategy reflects the current conditions with no changes to existing infrastructure or regulations and no mitigation improvements. M1 strategy mitigates flooding within the secondary or tertiary flood control system and is implemented by the local partners. The M2 mitigation actions are regional and are implemented as part of the primary flood control system which allows the basin to store during peak runoff or discharge to tide under flooding conditions, including SLR.

Table 3.2 Mitigation Strategies Included in DAPP Analysis

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

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

For each basin, 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. The thresholds used for the C-8 and C-9 Basins, shown as a dashed line in **Figure 3.2** and **Figure 3.3**, respectively, are:

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

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 basin-wide. **Appendix A** contains the mitigation strategies with their thresholds, and SLR at which the thresholds are surpassed for both basins.

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.

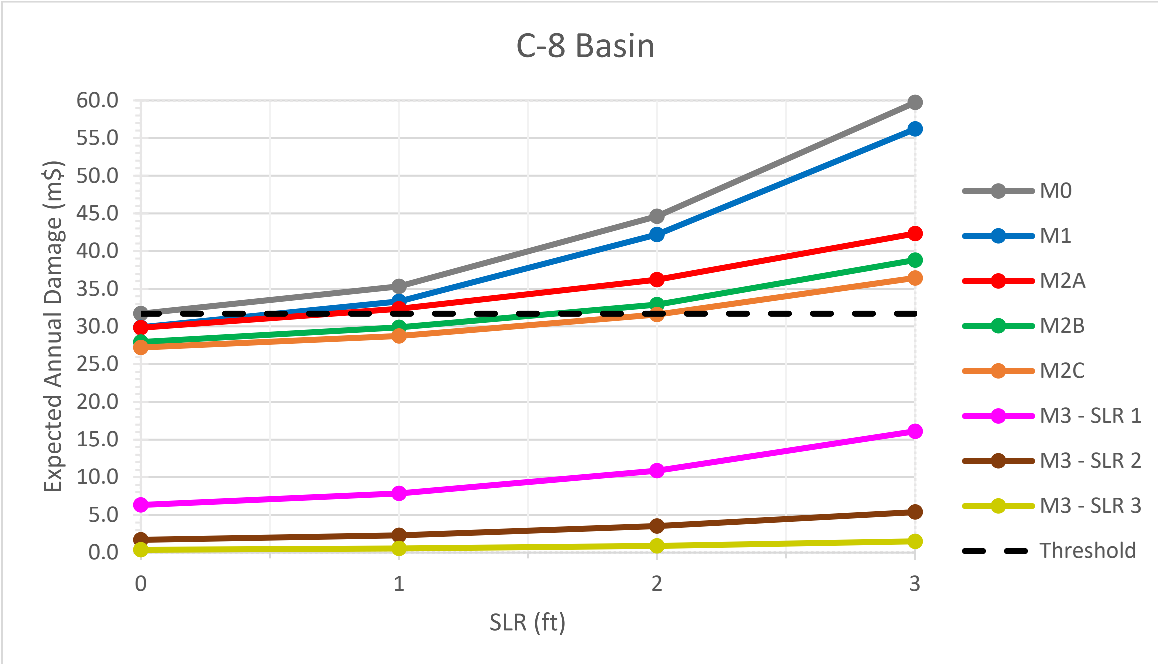


Figure 3.2 C-8 Basin Estimated Annual Damages for Flood Mitigation Strategies With 1-, 2-, 3-ft Sea Level Rise (ft, msl)

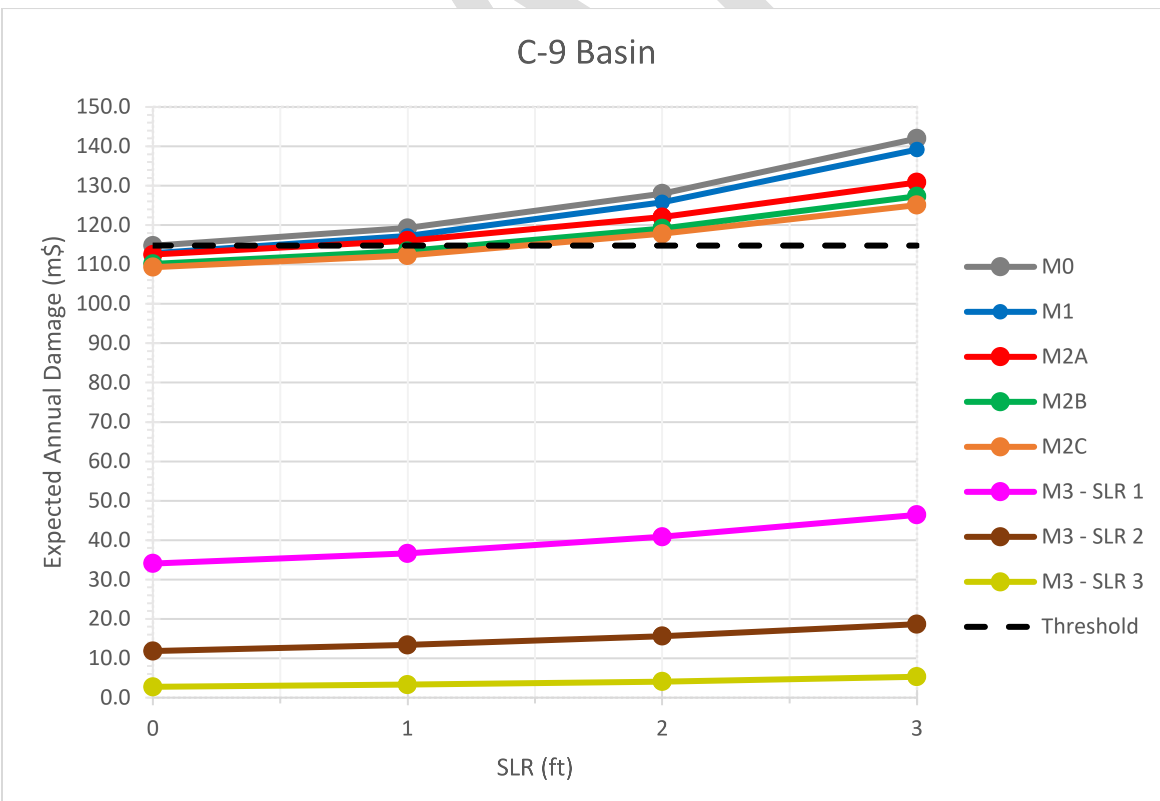


Figure 3.3 C-9 Basin Estimated Annual Damages for Flood Mitigation Strategies With 1-, 2-, 3-ft Sea Level Rise (ft, msl)

4.0 ADAPTIVE PATHWAY MAPS

This section contains the results of the C-8 and C-9 DAPP Analysis, as performed with the Pathways Generator. Basin-wide results are presented first, followed by census tract areas.

4.1 Basin-wide Pathways

The adaptation pathways map for C-8, **Figure 4.1**, indicates that all strategies accommodate some degree of SLR with M2B and M2C providing long-term risk reduction.

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).

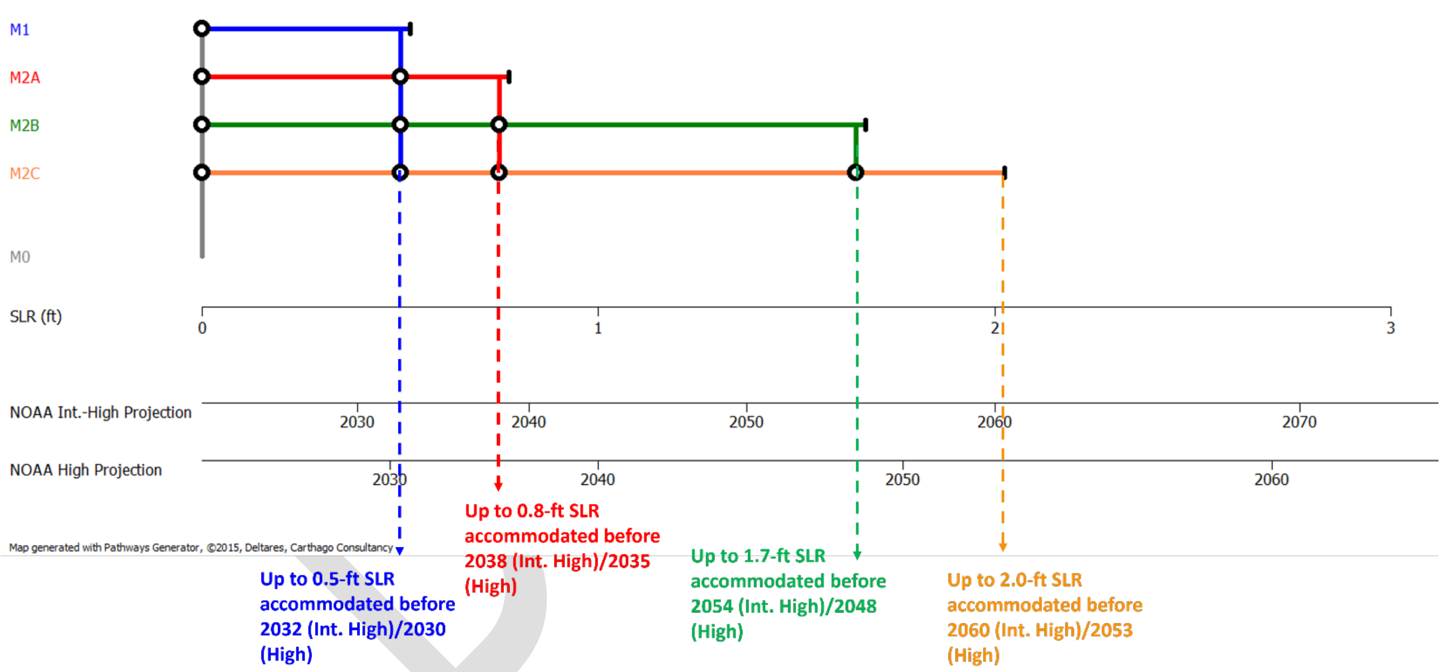


Figure 4.1 C-8 Basin-Wide Adaptation Pathway Map

The adaptation pathways map for C-9, **Figure 4.2**, indicates that all strategies accommodate 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).

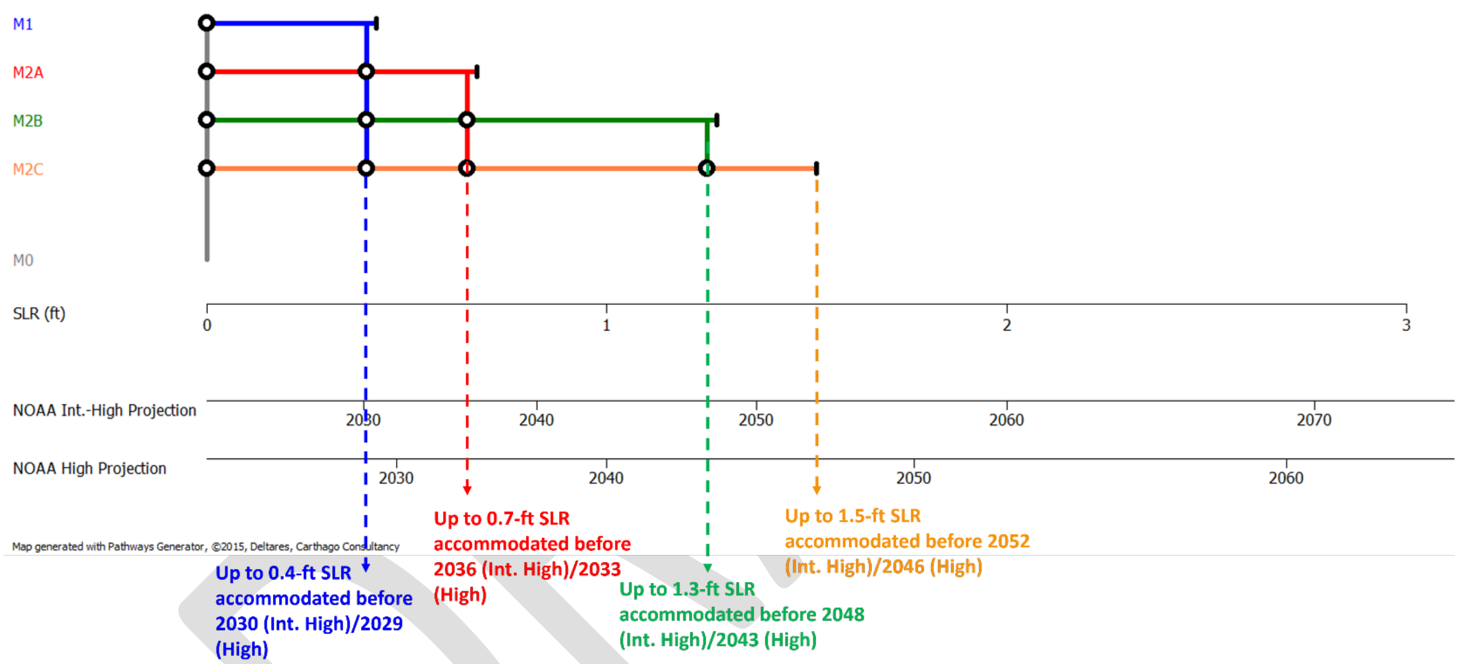


Figure 4.2 C-9 Basin-Wide Adaptation Pathway Map

4.2 Census Tract Pathways

The impacts of the alternative mitigation strategies vary spatially. To illustrate this spatial variability, this section contains the pathway maps for specific C-8 and C-9 census tracts. For C-8, census tracts 309, 310, and 312 were selected. For C-9, census tracts 213, 225, and 9602 were selected. These are representative tracts of highest EAD per acre, consistently throughout various return periods. Census tracts where the total area was very small were not included. Based on the damages to roads and structures that were calculated from the FIAT model within each of the selected census tracts, the anticipated SLR tipping points were determined. **Appendix A** includes the tipping points for each census track; they were derived with the same methodology used for the basin-wide analysis.

4.2.1 C-8 Census Track Pathway Maps

Figure 4.3 shows the location of the census tracks included in the analysis, with the 3 census tracts adjacent to each other and the C-8 canal.

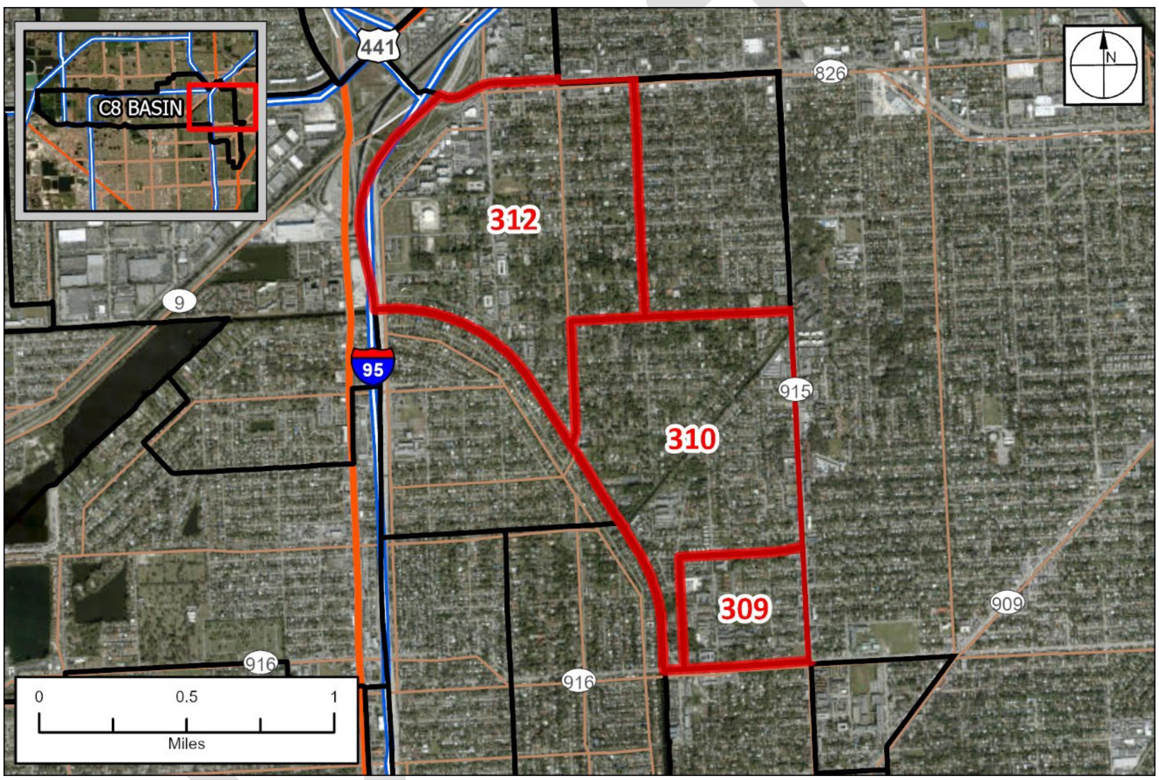


Figure 4.3 C-8 Basin Focus Area Census Tracts 309, 310, and 312

For census tract 309 (**Figure 4.4**), implementing the M1 (local strategy) is not sufficient much past current levels. M2A provides a short-term impact but only accommodates up to 0.2-ft of SLR. Implementation of M2B (increasing pump flow to 2,550 cfs) reduces risk levels by accommodating 2.1-ft of SLR, which is slightly greater than at basin scale. Consequently, for this census tract, M1 and M2A are not effective. Implementation of M2B would reduce risk to approximately 2061 (NOAA Intermediate High) and 2054 (NOAA High). M2C could be considered for additional risk reduction. One potential option could be to design and implement M2B such that M2C's increased pump capacity can be later added.

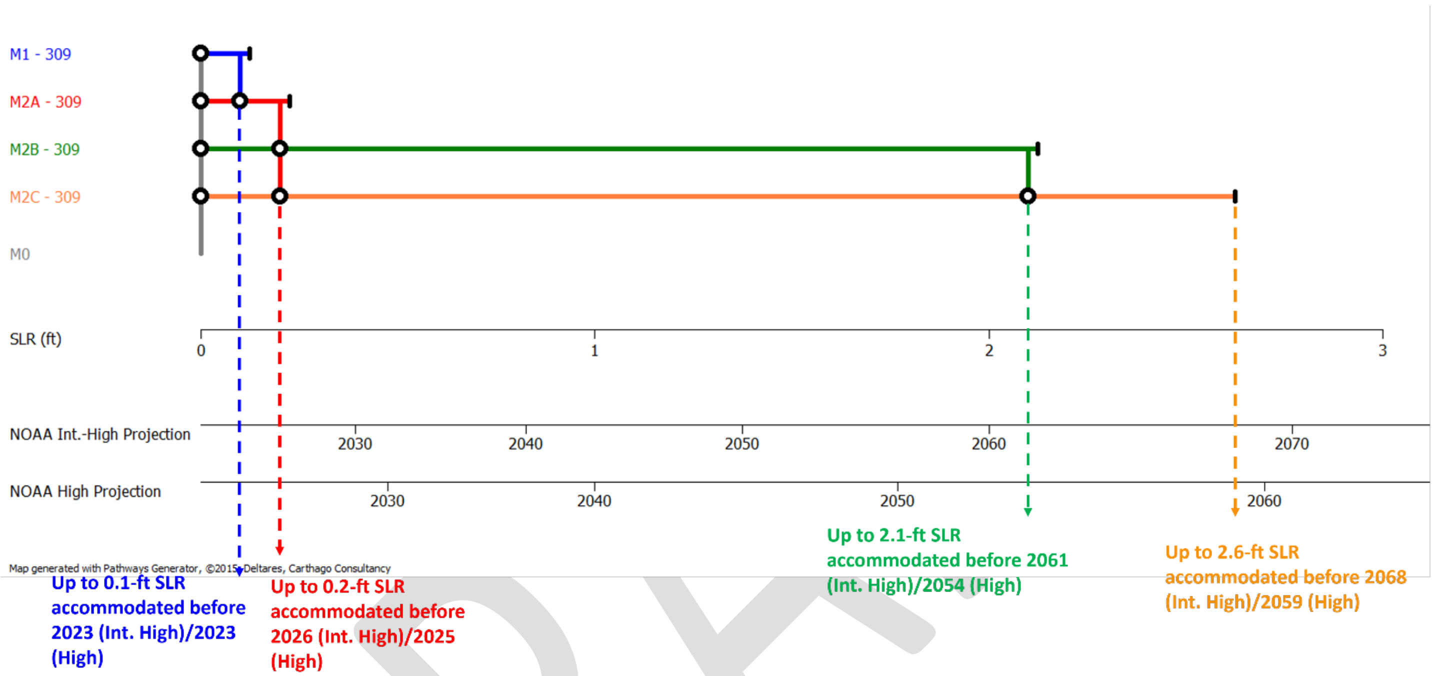


Figure 4.4 Census Tract 309 Adaptation Pathways Map

For census tract 310 (**Figure 4.5**), implementing the M1 strategy accommodates 0.5-ft SLR, 0.2-ft more than M2A. This highlights the importance of localized actions. At the census tract level, M2A accommodates less SLR than at the basin scale. Implementation of M2B (increasing pump flow to 2,550 cfs) reduces risk levels by accommodating up to 1.6-ft of SLR, same as the basin scale. The additional increase in pumping capacity of M2C accommodates 2.3-ft of SLR.

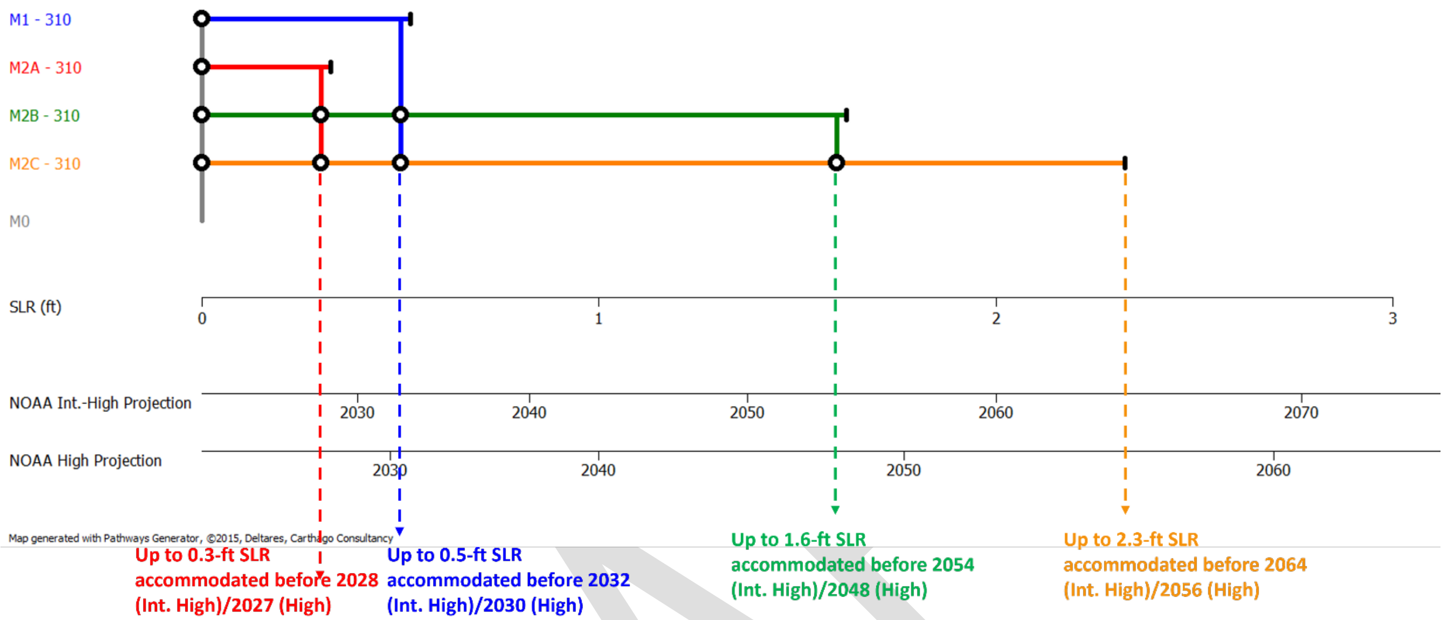


Figure 4.5 Census Tract 310 Adaptation Pathways Map

For census tract 312 (**Figure 4.6**), implementing M1 may provide risk reduction up to 1-ft SLR, double the basin-scale. M2A alone effectively does not provide *any* risk reduction, when considering the time scale. While our modeling and other analyses were not geared toward determining the cause of this localized condition, it could be that given that the topography is very low in census tract 312, the proposed pump capacity is insufficient. The location of the coastal structure where the potential pump would be located is approximately 3.3 miles to the southeast along the canal. The 1550 cfs anticipated for M2A is possibly not enough to reduce the risk to this low-lying area. Immediate implementation of strategy M1 would provide time (approximately 20 years based on the NOAA Intermediate High SLR projections) for planning and implementation of M2B or M2C in the future.

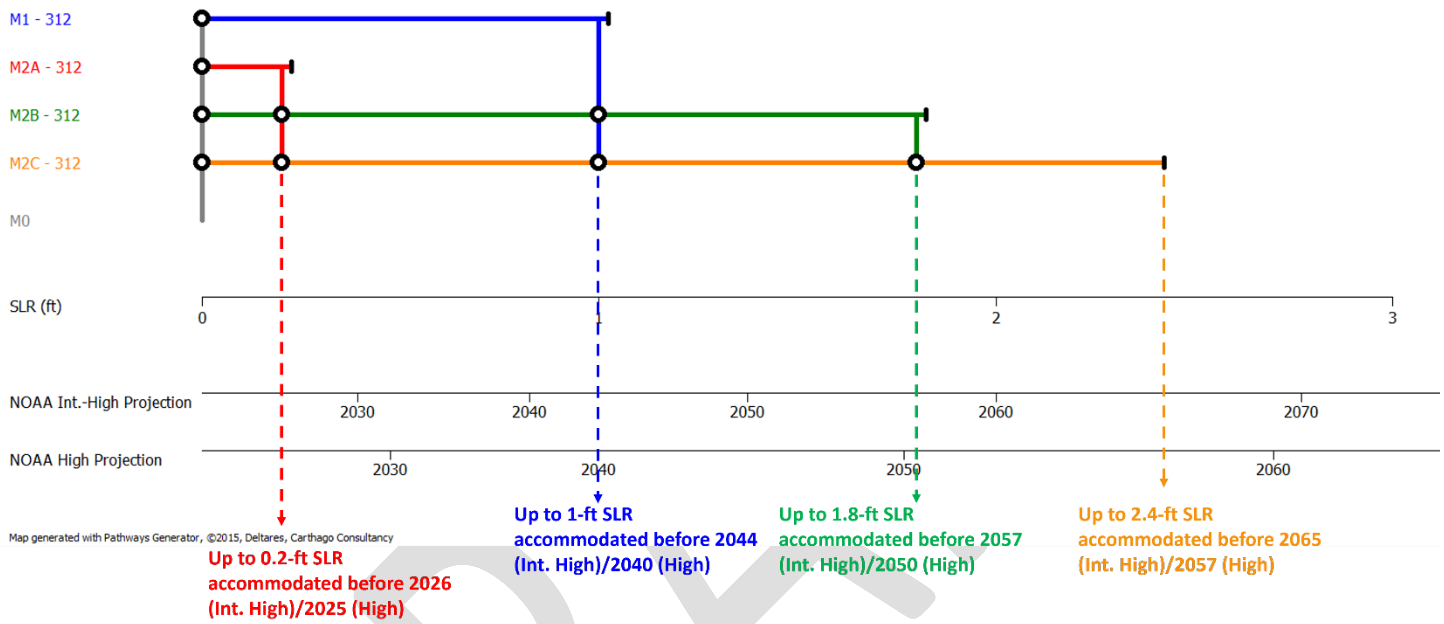


Figure 4.6 Census Tract 312 Adaptation Pathways Map

4.2.2 C-9 Census Track Pathway Maps

For the C-9 Basin, census tracts 213, 225, and 9602 were selected for DAPP, based on the EAD/acre derived from the FIAT model, described in Section 3.2.1 of this technical memorandum (**Figure 4.7**).

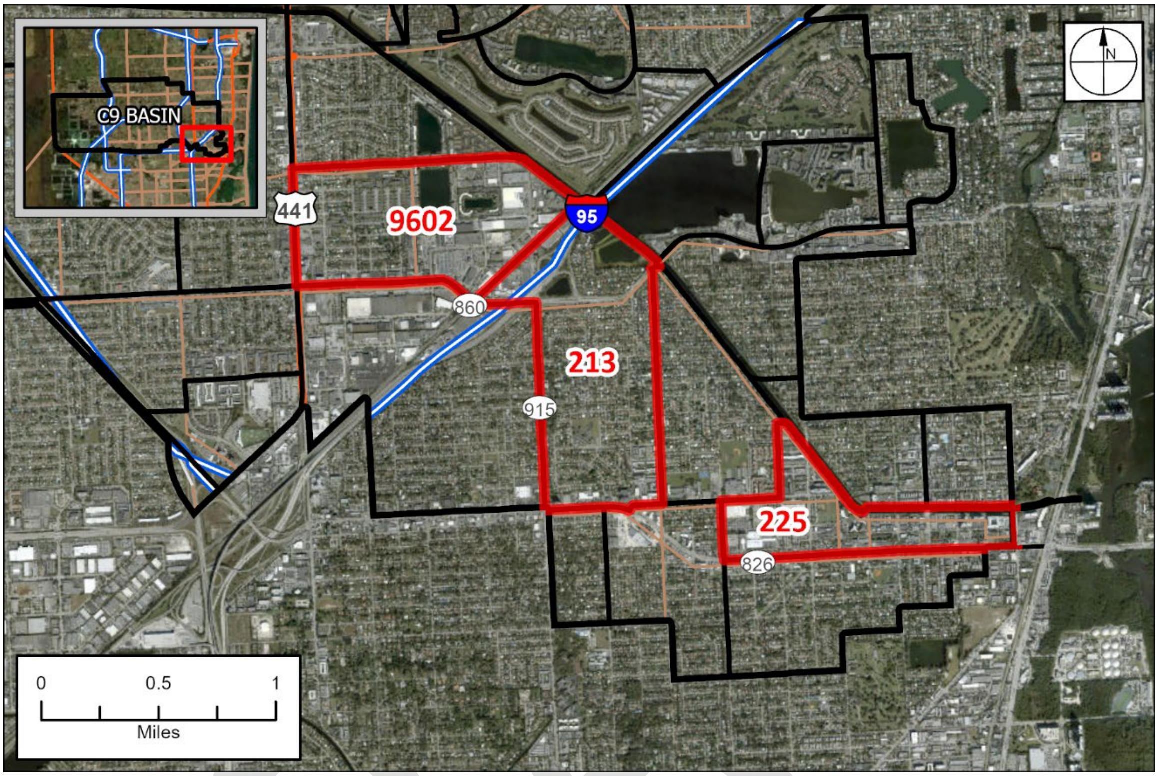


Figure 4.7 C-9 Basin Focus Area Census Tracts 213, 225, and 9602

For census tract 213 (**Figure 4.9**), implementing the M1 strategy accommodates approximately 1-ft of SLR, which is double the basin scale. Implementation of M2A reduces risk levels considerably to 1.25-ft of SLR to nearly 2040 (NOAA Intermediate High), which is greater than at basin scale. Immediate implementation of strategy M2A would provide time (over 20 years based on the NOAA Intermediate High SLR projection) for planning and implementation of M2C in the future. Interestingly M2A and M2B accommodate the same amount of SLR.

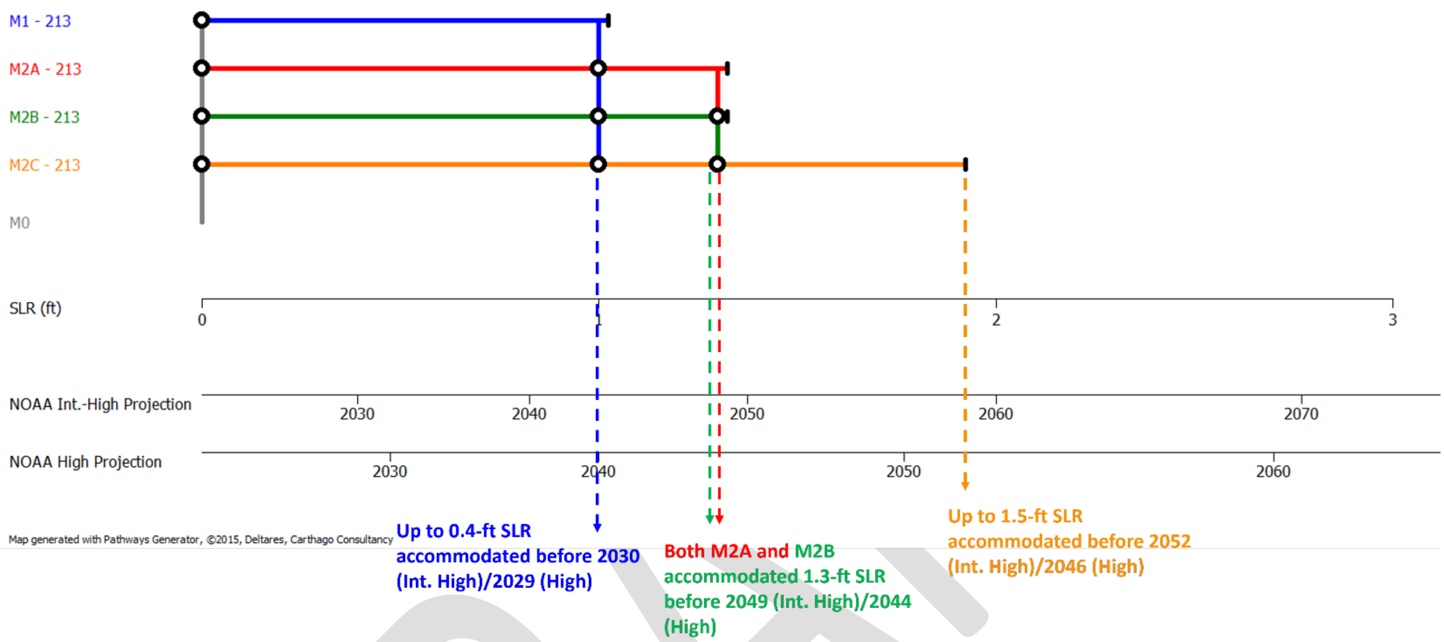


Figure 4.8 Census Tract 213 Adaptation Pathways Map

For census tract 225 (**Figure 4.9**), implementing the M1 strategy accommodates only 0.2-ft of SLR, which is less than at basin scale. Implementation of M2A reduces risk levels considerably to 1.3-ft of SLR to nearly 2049 (NOAA Intermediate High), which is much greater than at basin scale. Immediate implementation of strategy M2A would provide time (approximately 25 years based on the NOAA Intermediate High SLR projections) for planning and implementation of M2B or M2C in the future. Both M2B and M2C provide risk reduction over 2-ft of SLR.

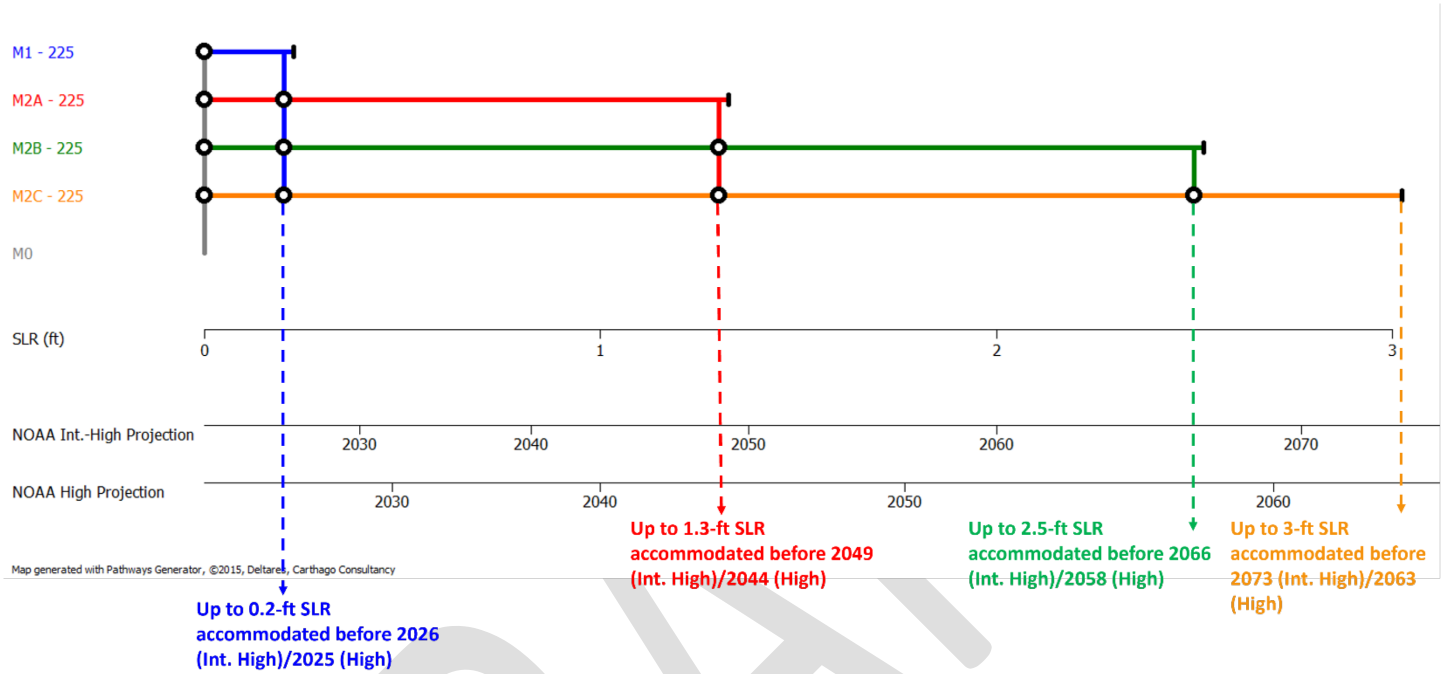


Figure 4.9 Census Tract 225 Adaptation Pathways Map

For census tract 9602 (**Figure 4.10**), implementing the M1 strategy accommodates only 0.1-ft of SLR, while M2A accommodates only up to 0.2-ft SLR, which is less than at basin scale. Implementation of M2B (increasing pump flow to 2,550 cfs) reduces risk levels considerably up to 2.1-ft of SLR to nearly 2061 (NOAA Intermediate High), approximating basin scale results.

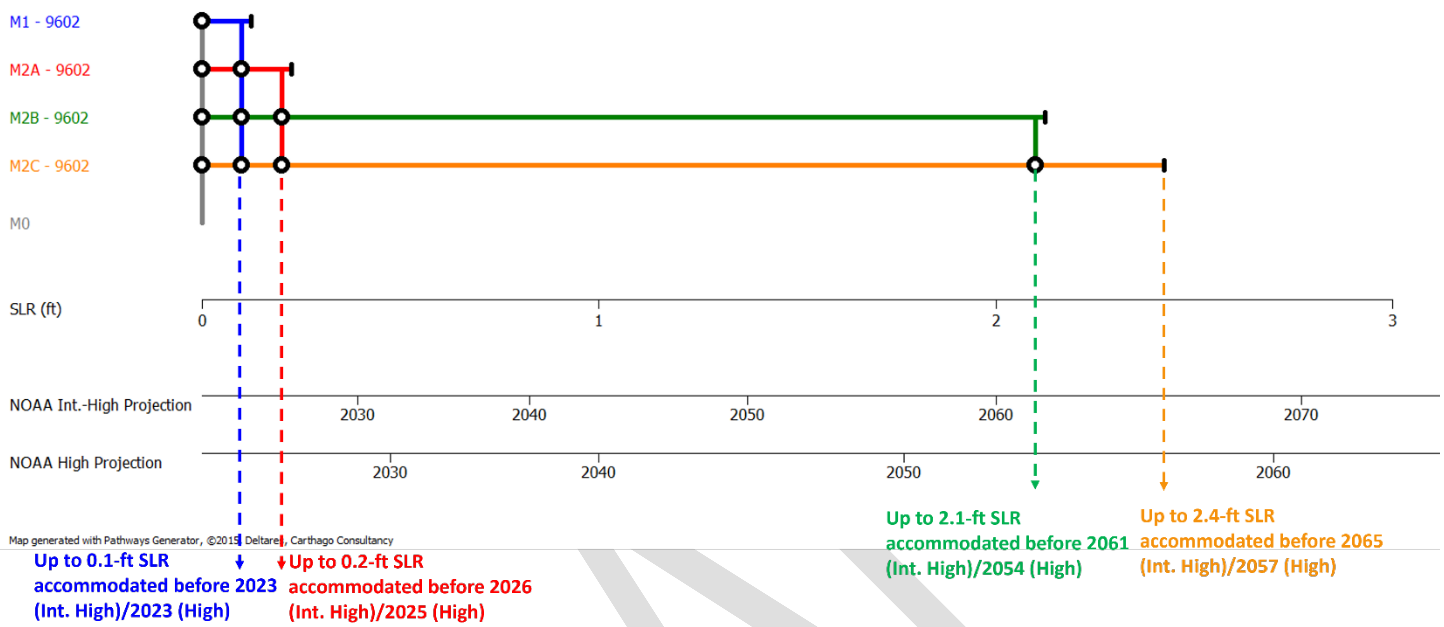


Figure 4.10 Census Tract 9602 Adaptation Pathways Map

5.0 DISCUSSION

One of the strengths in using the DAPP framework is the level of transparency available to decision makers. As previously mentioned, 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. The data can be viewed with different time scales, varied geographic or jurisdictional boundaries, or different SLR projection. Each lens can yield valuable information on the anticipated impact and duration of the mitigation actions.

We cannot overstate the importance of having regional and local projects and initiatives that can complement each other. Our analysis showed the impact of the mitigation actions differs if considered at the basin scale or at the census tract. Some alternatives can be very effective up to a high sea level rise in some census tracts but can only accommodate a limited amount of sea level rise in others before the risk thresholds are reached again. Smaller, targeted actions that can reduce flooding risk at the neighborhood or census tract scale may prove to be highly effective in providing near-term relief. For example, the benefits of M1 actions may not be effectively captured at the larger basin scale because they do not influence the basin. However, their local influence may be highly beneficial to specific communities. They may also provide the near-term risk reduction sufficient for the duration necessary for the larger projects to be planned and implemented.

This analysis also supports two approached implementation for adaptation strategies:

1. Adaptable mitigation solutions, i.e., those mitigation actions that can be adapted over time and space, and,

2. Phased implementation approaches, i.e., match the timing of mitigation actions with the timing of actual risk.

For example, for the C-8 and C-9 Basins, the M2C accommodates higher levels of SLR under both NOAA scenarios. However, implementing the mitigation strategy under M2C, which includes hardening and elevating of structures downstream and increasing pump output to 3,550 cfs may not be immediately possibly to implement due to funding constraints. It could be that M2B (2,550 cfs) may be a more attainable option while some shorter-term options, such as M1 and M2A, are implemented. Also, in all cases, new pump stations can be designed and built with the intent of future expansion to M2C. This allows for the adaptability of the additional pumping capacity to match flood risk posed with the future conditions of higher sea level.

Future analyses can incorporate changes to any of the inputs and would benefit from a sensitivity analysis to understand what variables influence the outcomes in the different scenarios. For example, in this task, the mitigation strategies contain various elements (e.g., distributed storage, pumping and structural changes, etc.), yet the elements were not analyzed individually but rather as one cohesive strategy. There may be benefits for individual projects to be analyzed and potentially combined for an increased level of detail for each strategy. Also, while the analyses rely on the FIAT to derive EADs, it would be beneficial to expand the definition of "estimated annual damages" to arrive at a more comprehensive benefits analysis of the mitigation activities. Presently, the EADs do not include other flood induced losses such as lost workforce productivity or preservation/decline of a tax base. Expanding the categories that derive risk reduction benefits would more clearly represent the benefits of the SFWMD investments.

Finally, the analyses show there are areas that are presently, or forecast to be, flooding more extensively. It would be beneficial for the stakeholders that have jurisdiction over portions of the secondary and tertiary system to continue to explore the data generated from this study. As they review the data, the added level of granularity may yield information on local mitigation strategies that can work better for them.

6.0 REFERENCES

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APPENDIX A
MITIGATION STRATEGIES WITH THEIR THRESHOLDS AND SLR TIPPING POINTS

The threshold for the C-8 basin is based on the EAD at the M0 with 0-ft of SLR, which in this case is $31.7 million. **Table A.1** lists the EADs for each foot of SLR per strategy. It also lists the amount of SLR the strategy can accommodate before it reaches the tipping point of the threshold value.

Table A.1 Threshold and SLR Tipping Points for C-8 Basin Mitigation Strategies

Mitigation Strategy	SLR (ft)	EAD (m $)	Tipping Point/SLR (ft) at Threshold
M0	**0**	**31.7 (threshold)**	N/A
	1	35.3	
	2	44.6	
	3	59.7	
M1	**0**	29.9	0.5
	1	33.3	
	2	42.2	
	3	56.2	
M2A	**0**	29.8	0.8
	1	32.4	
	2	36.2	
	3	42.3	
M2B	**0**	27.9	1.7
	1	29.9	
	2	32.9	
	3	38.8	
M2C	**0**	27.2	2
	1	28.7	
	2	31.6	
	3	36.4	
M3 (1ft)	**0**	6.3	>3
	1	7.8	
	2	10.9	
	3	16.1	
M3 (2ft)	**0**	1.7	>3
	1	2.3	
	2	3.5	
	3	5.4	
M3 (3ft)	**0**	0.4	>3
	1	0.5	
	2	0.9	
	3	1.5	

The threshold for the C-9 basin is based on the EAD at the M0 with 0-ft of SLR, which in this case is $114.8 million. **Table A.2** lists the EADs for each foot of SLR per strategy. It also lists the amount of SLR the strategy can accommodate before it reaches the tipping point of the threshold value.

Table A.2 Thresholds and SLR Tipping Points for C-9 Basin Mitigation Strategies

Mitigation Strategy	SLR (ft)	EAD (m $)	Tipping Point/SLR (ft) at Threshold
M0	**0**	**114.8 (threshold)**	N/A
	1	119.3	
	2	128.0	
	3	142.0	
M1	**0**	112.9	0.4
	1	117.3	
	2	125.7	
	3	139.2	
M2A	**0**	112.5	0.7
	1	116.1	
	2	122.0	
	3	130.8	
M2B	**0**	110.1	1.3
	1	113.4	
	2	119.1	
	3	127.3	
M2C	**0**	109.3	1.5
	1	112.3	
	2	117.8	
	3	125.1	
M3 (1ft)	**0**	34.1	>3
	1	36.6	
	2	40.8	
	3	46.4	
M3 (2ft)	**0**	11.8	>3
	1	13.4	
	2	15.6	
	3	18.7	
M3 (3ft)	**0**	2.8	>3
	1	3.3	
	2	4.1	
	3	5.3	

Table A.3 Thresholds and SLR Tipping Points for Census Tract 309, C-8 Basin

Mitigation Strategy	SLR (ft)	EAD (k $)	Tipping Point/SLR (ft) at Threshold
M0	**0**	**682.7 (threshold)**	N/A
	1	997.8	
	2	1620.8	
	3	2824.8	
M1	**0**	682.7	0.1
	1	997.8	
	2	1620.8	
	3	2824.8	
M2A	**0**	649.0	0.2
	1	830.3	
	2	1130.0	
	3	1584.0	
M2B	**0**	416.1	2.1
	1	516.4	
	2	660.9	
	3	1052.8	
M2C	**0**	378.6	2.6
	1	441.5	
	2	556.6	
	3	781.9	

Table A.4 Thresholds and SLR Tipping Points for Census Tract 310, C-8 Basin

Mitigation Strategy	SLR (ft)	EAD (k $)	Tipping Point/SLR (ft) at Threshold
M0	**0**	**881.4 (threshold)**	N/A
	1	1234.2	
	2	2003.9	
	3	3533.5	
M1	**0**	731.3	0.5
	1	1052.5	
	2	1744.1	
	3	3090.5	
M2A	**0**	807.6	0.3
	1	1022.1	
	2	1352.9	
	3	1899.4	
M2B	**0**	570.2	1.6
	1	719.9	
	2	962.4	
	3	1477.7	
M2C	**0**	519.1	2.3
	1	610.8	
	2	801.2	
	3	1134.0	

Table A.5 Thresholds and SLR Tipping Points for Census Tract 312, C-8 Basin

Mitigation Strategy	SLR (ft)	EAD (k $)	Tipping Point/SLR (ft) at Threshold
M0	**0**	**971.8 (threshold)**	N/A
	1	1261.0	
	2	1759.6	
	3	2753.2	
M1	**0**	755.5	1
	1	972.8	
	2	1379.3	
	3	2186.2	
M2A	**0**	937.2	0.2
	1	1128.1	
	2	1411.5	
	3	1775.2	
M2B	**0**	659.3	1.8
	1	783.0	
	2	996.3	
	3	1424.8	
M2C	**0**	619.7	2.4
	1	695.7	
	2	858.4	
	3	1135.1	

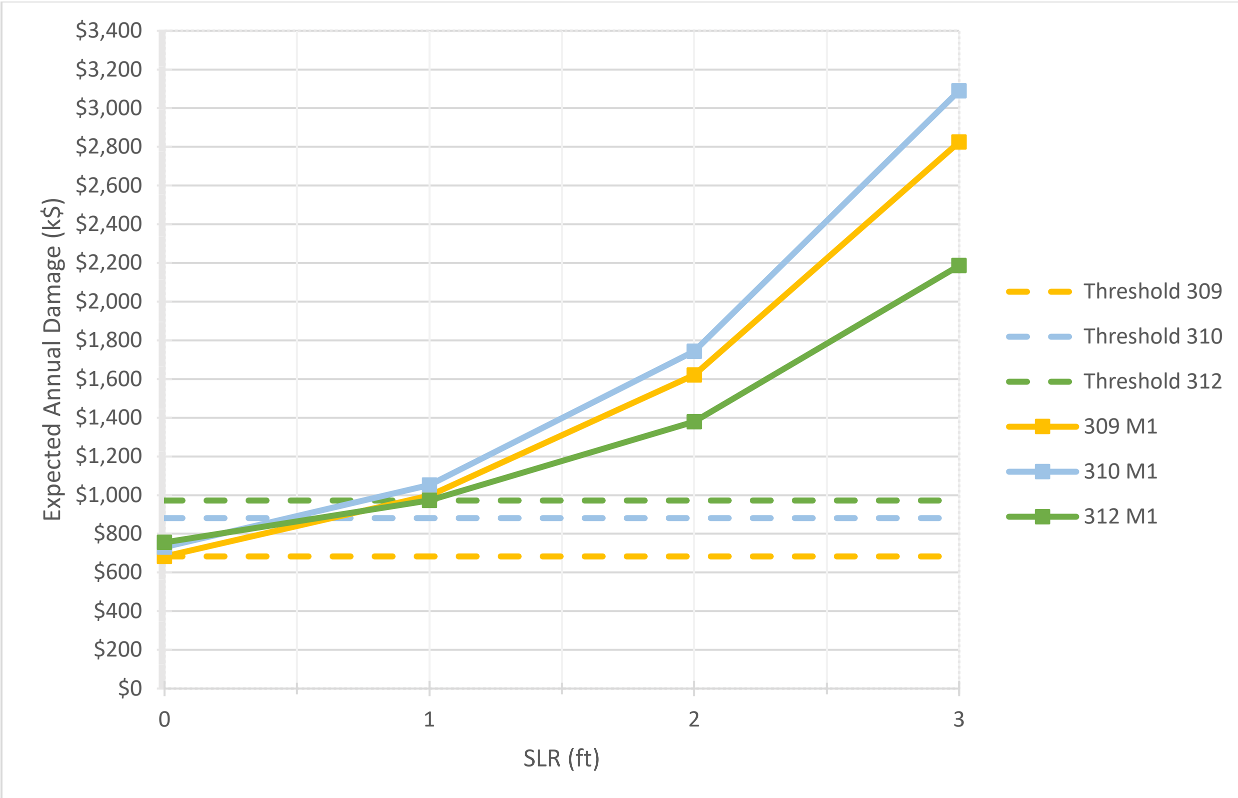

Figure A.1 C-8 Basin Census Tracts Estimated Annual Damages for Strategy M1 with 1-, 2-, 3-ft Sea Level Rise (ft, msl)

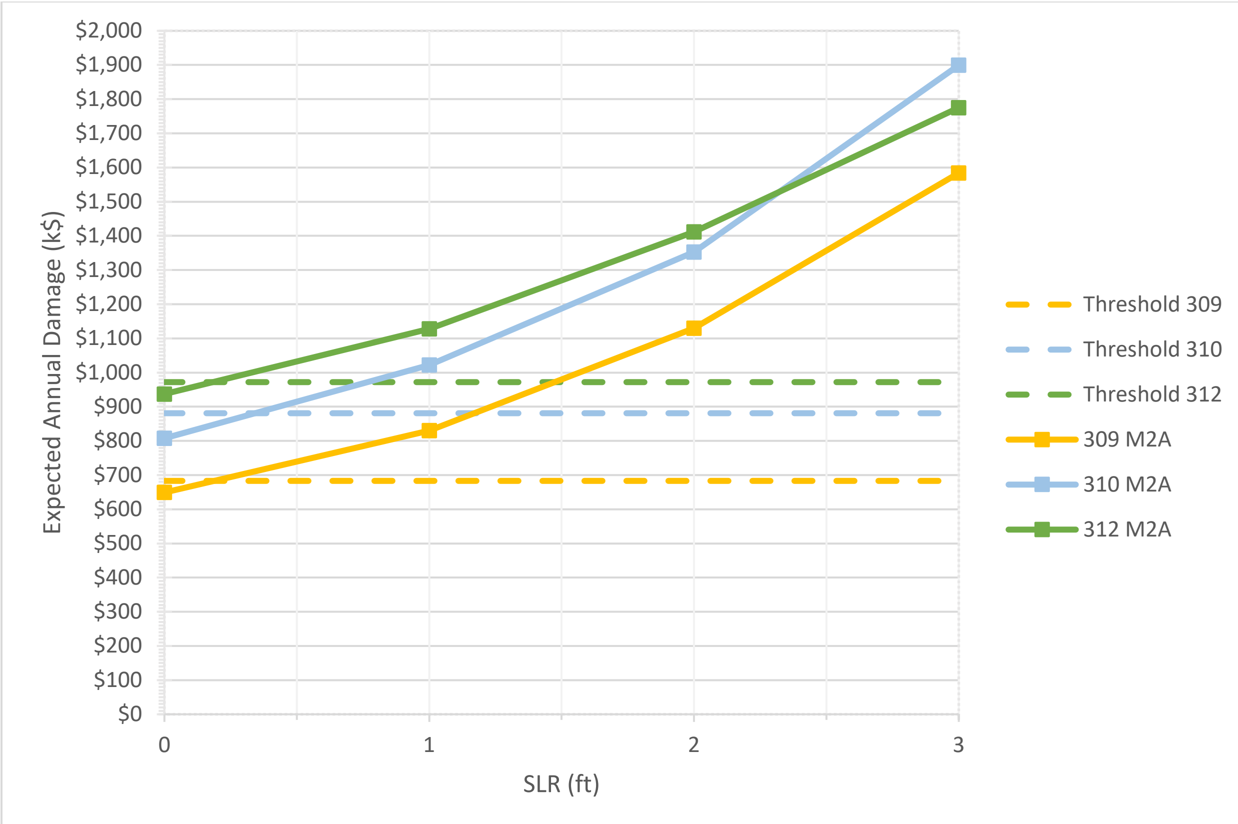

Figure A.2 C-8 Basin Census Tracts Estimated Annual Damages for Strategy M2A with 1-, 2-, 3-ft Sea Level Rise (ft, msl)

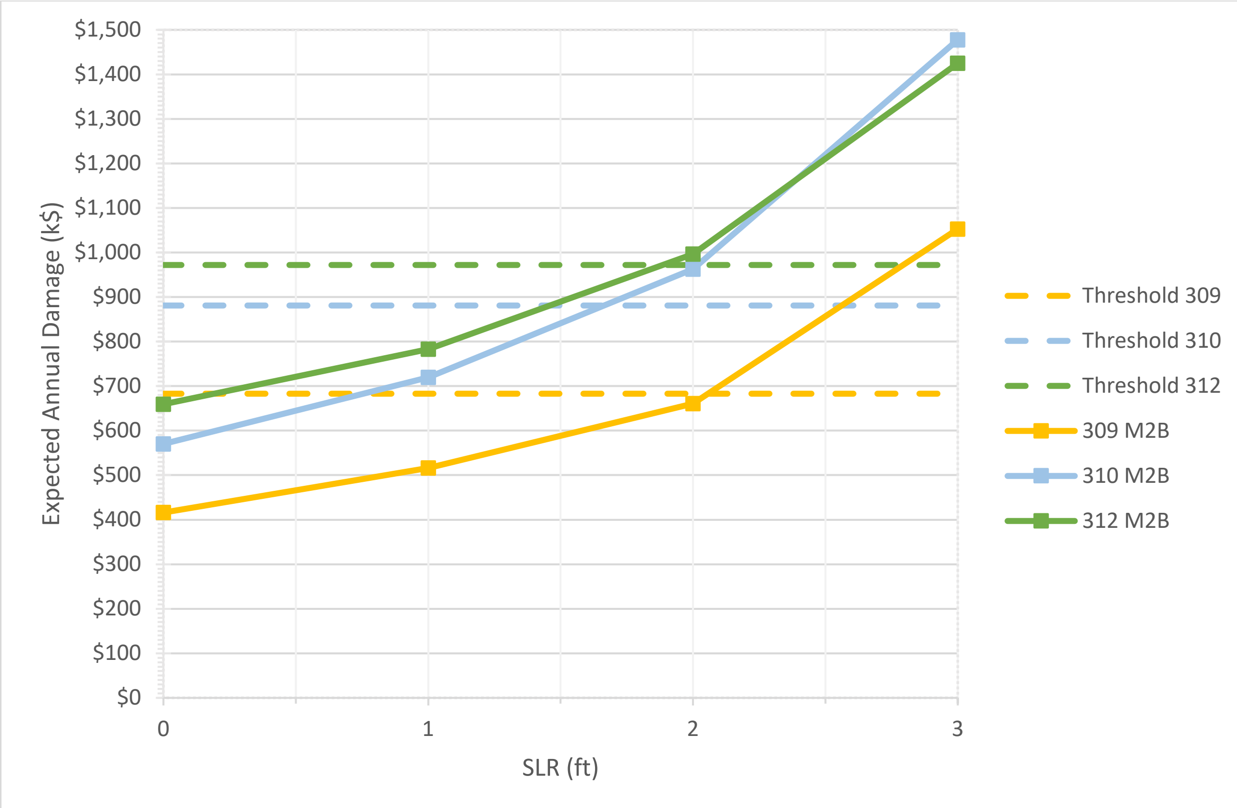

Figure A.3 C-8 Basin Census Tracts Estimated Annual Damages for Strategy M2B with 1-, 2-, 3-ft Sea Level Rise (ft, msl)

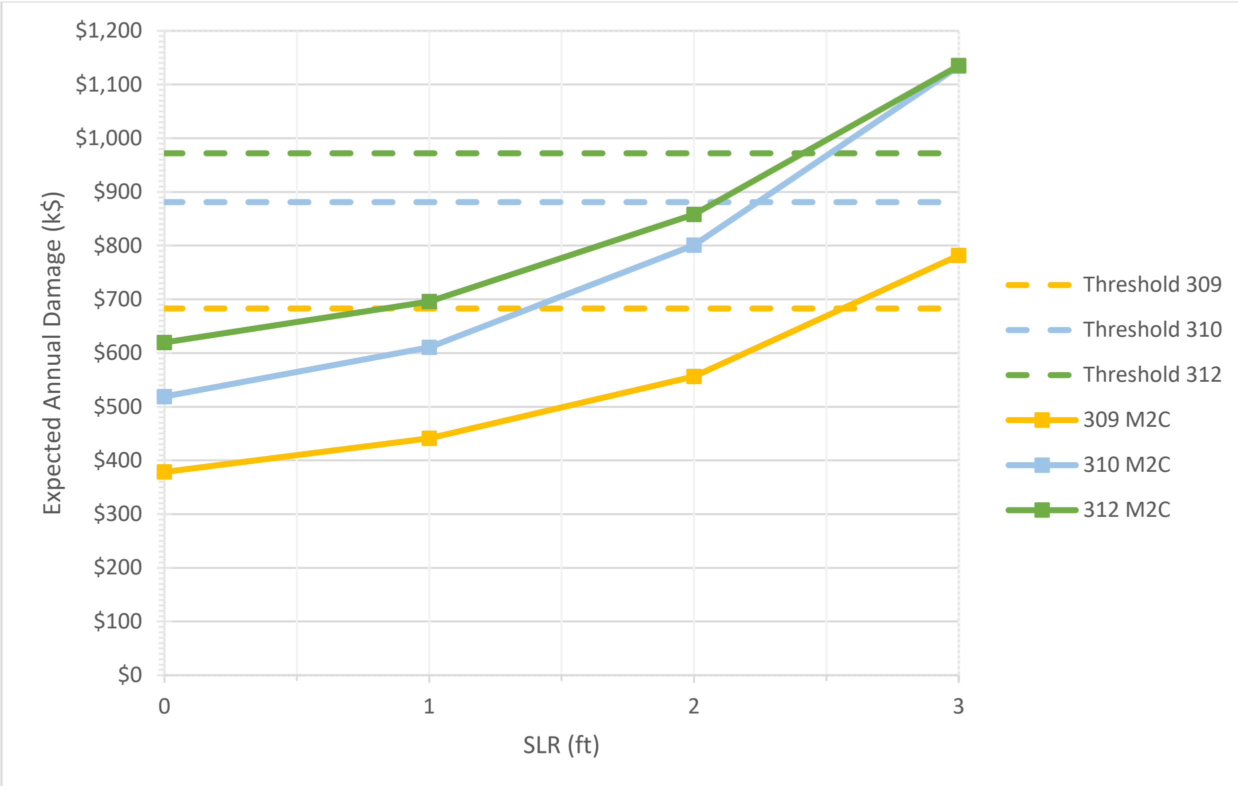

Figure A.4 C-8 Basin Census Tracts Estimated Annual Damages for Strategy M2C with 1-, 2-, 3-ft Sea Level Rise (ft, msl)

Table A.6 Thresholds and SLR Tipping Points for Census Tract 213, C-9 Basin

Mitigation Strategy	SLR (ft)	EAD (k $)	Tipping Point/SLR (ft) at Threshold
M0	**0**	**831.1 (threshold)**	N/A
	1	833.5	
	2	846.9	
	3	881.4	
M1	**0**	831.1	1
	1	833.5	
	2	846.9	
	3	881.4	
M2A	**0**	830.0	1.3
	1	832.4	
	2	837.2	
	3	845.9	
M2B	**0**	821.5	1.3
	1	825.1	
	2	829.8	
	3	830.1	
M2C	**0**	820.8	1.9
	1	823.0	
	2	829.6	
	3	830.9	

Table A.7 Thresholds and SLR Tipping Points for Census Tract 225, C-9 Basin

Mitigation Strategy	SLR (ft)	EAD (k $)	Tipping Point/SLR (ft) at Threshold
M0	**0**	**543.9 (threshold)**	N/A
	1	639.3	
	2	1050.7	
	3	2001.1	
M1	**0**	526.6	0.2
	1	623.6	
	2	1034.1	
	3	1980.7	
M2A	**0**	495.1	1.3
	1	524.0	
	2	596.0	
	3	862.3	
M2B	**0**	452.8	2.5
	1	455.0	
	2	489.0	
	3	605.6	
M2C	**0**	452.1	3
	1	452.9	
	2	466.5	
	3	537.5	

Table A.8 Thresholds and SLR Tipping Points for Census Tract 9602, C-9 Basin

Mitigation Strategy	SLR (ft)	EAD (k $)	Tipping Point/SLR (ft) at Threshold
M0	0	**1263.0 (threshold)**	N/A
	1	1549.9	
	2	2062.3	
	3	3018.1	
M1	0	1263.0	0.1
	1	1549.9	
	2	2062.3	
	3	3018.1	
M2A	0	1229.2	0.2
	1	1423.1	
	2	1773.7	
	3	2293.9	
M2B	0	985.6	2.1
	1	1049.9	
	2	1240.0	
	3	1563.3	
M2C	0	982.5	2.4
	1	1040.7	
	2	1169.7	
	3	1394.5	

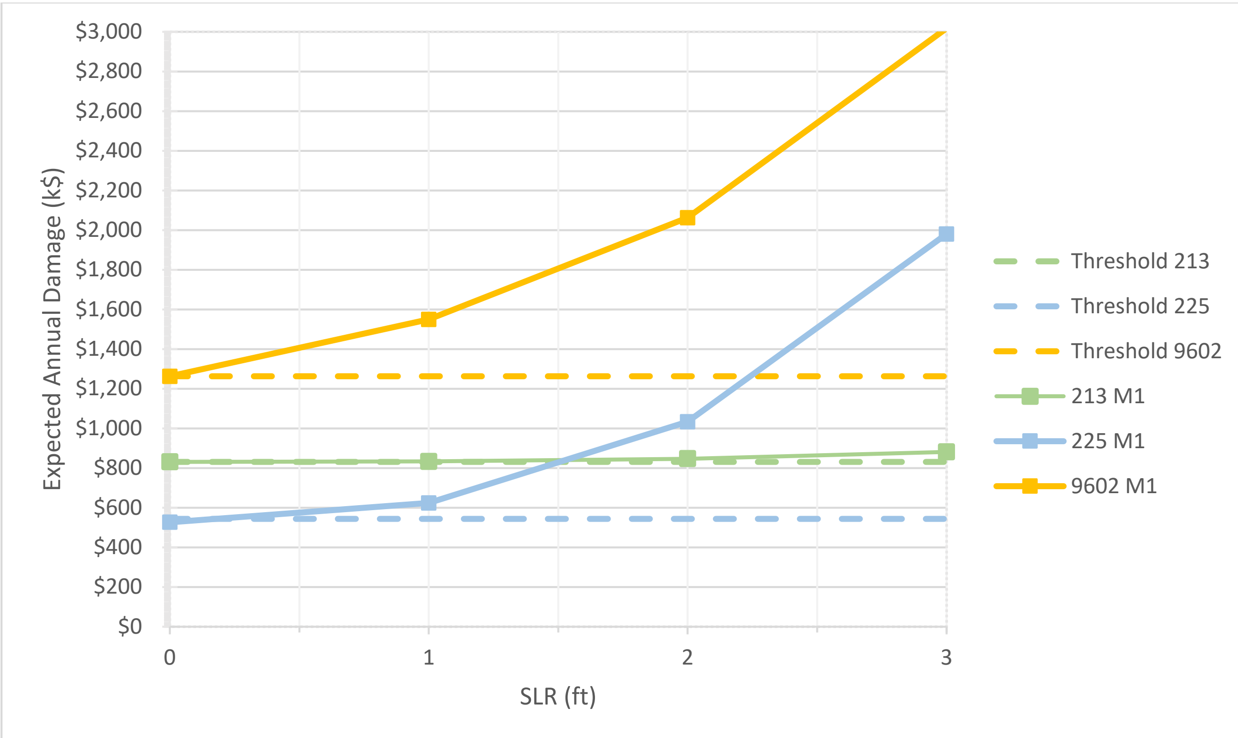

Figure A.5 C-9 Basin Census Tracts Estimated Annual Damages for Strategy M1 with 1-, 2-, 3-ft Sea Level Rise (ft, msl)

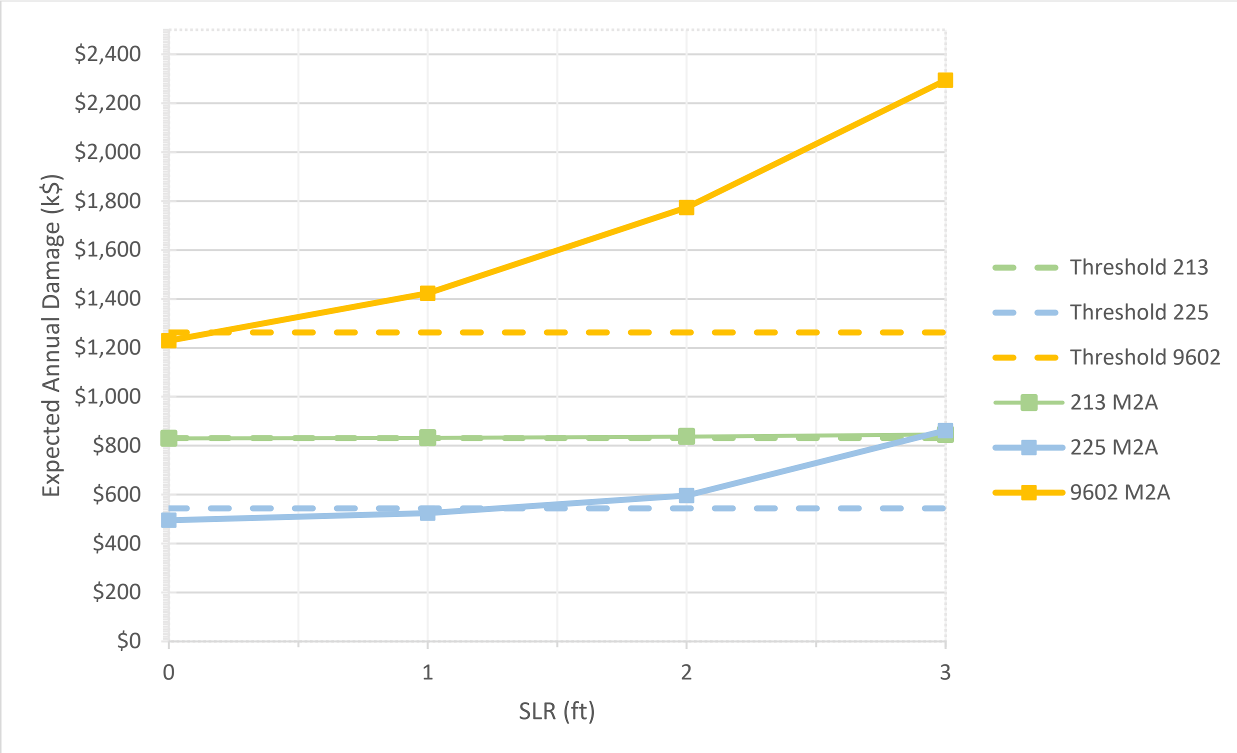

Figure A.6 C-9 Basin Census Tracts Estimated Annual Damages for Strategy M2A with 1-, 2-, 3-ft Sea Level Rise (ft, msl)

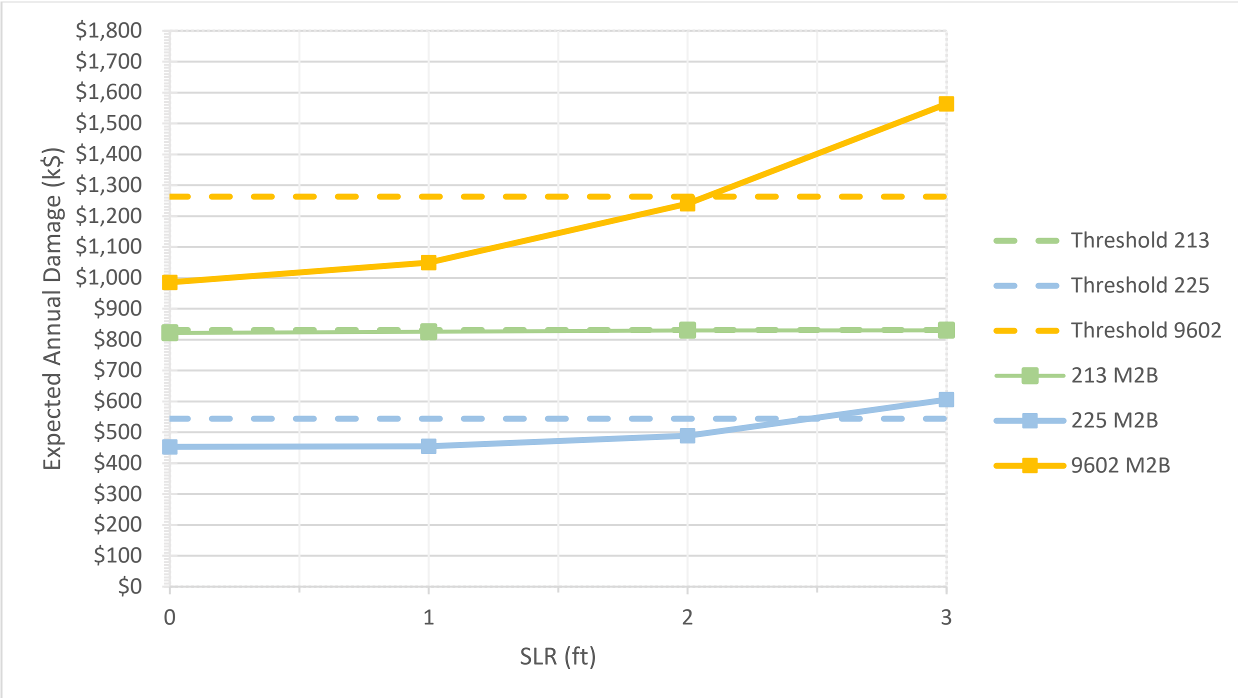

Figure A.7 C-9 Basin Census Tracts Estimated Annual Damages for Strategy M2B with 1-, 2-, 3-ft Sea Level Rise (ft, msl)

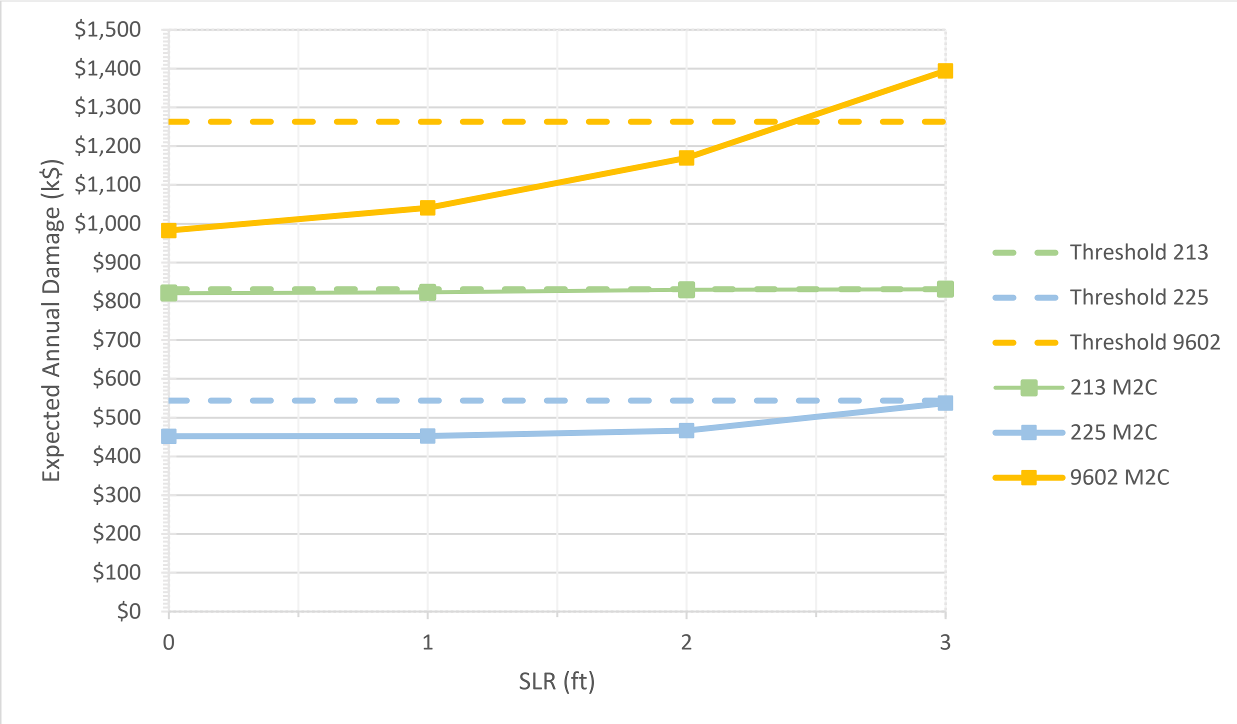

Figure A.8 C-9 Basin Census Tracts Estimated Annual Damages for Strategy M2C with 1-, 2-, 3-ft Sea Level Rise (ft, msl)

ASSESSMENT OF C-8 AND C-9 POTENTIAL WATER QUALITY IMPACTS TO NORTH BISCAYNE BAY

DRAFT TECHNICAL MEMORANDUM

TASK 4B – WATER QUALITY IMPACT ANALYSIS OF MITIGATION STRATEGIES ON NORTH BISCAYNE BAY

PREPARED FOR

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SFWMD Work Order No. 450004085-WO5

May 1, 2023

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1.0 OBJECTIVE AND SCOPE

The South Florida Water Management District (SFWMD or District) is conducting a system-wide review of the regional water management infrastructure to determine what mitigation projects would maintain or improve the current Flood Protection Level of Service (FPLOS). Phase II of this FPLOS assessment for the C-8 and C-9 watersheds in Miami-Dade County is currently in progress. Phase II consists of a comprehensive examination of different flood adaptation strategies and mitigation projects, together with sequencing of certain selected projects for implementation. 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 will also be evaluated.

This memorandum comprises Amendment No. 1 to Taylor Engineering Contract Number C2021-033. The scope of work for this Task is summarized below:

- 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 fifty-two (52) flow scenarios will be utilized for these assessments. This totals one-hundred and four (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.

2.0 INTRODUCTION AND BACKGROUND

2.1 Biscayne Bay

Biscayne Bay abuts the Miami metropolitan area in southeast Florida with an area of 702 km^2 and depths ranging between 0.5 and 3.0 m. It is a shallow estuary significantly affected by nutrient loading resulting from regional population growth and accelerated coastal development (Harlem, 1979; Alleman et al. 1995). Primary drivers of circulation in the bay include tides, inlets, water depth, salinity, and wind speed/direction (BFA, 2004).

2.2 North Biscayne Bay

North Biscayne Bay is located between mainland Miami and the barrier island of Miami Beach, adjacent to the most developed areas of metropolitan Miami. North Biscayne Bay extends from Dumfoundling Bay to the Rickenbacker Causeway. Astronomical tides, canal inflows, and wind stress influence flows in North Biscayne Bay, where ocean exchange occurs every 7 to 14 days on average (Chin 2020).

Approximately 40% of North Biscayne Bay has been dredged or filled, with average depths ranging from 1.1 to 2.2 m (excluding dredged areas). The federal navigation channels in Biscayne Bay consist of three major channels: Biscayne Channel, Fisher Cut, and Jones Lagoon Channel. Biscayne Channel is the largest of the three and runs along the eastern side of the bay. Fisher Cut connects Biscayne Channel to the western side of the bay, and Jones Lagoon Channel runs along the northern side of the bay. The depths of the channels vary, but generally range from 20 to 35 feet. The Port of Miami and other industrial complexes surround North Biscayne Bay. Additionally, the Miami River (C-6 canal) is the largest source of freshwater inflow to North Biscayne Bay, which has a history of contamination from industrial runoff and untreated sewage effluent. Other major sources of freshwater flow to North Biscayne Bay include the Biscayne Canal (C8 canal), Snake Creek (C-9 canal), Arch Creek, and Little River (C-7 canal) (see **Figure 2-1**). Stormwater runoff has been identified as a source of contamination in discharges from these canals.

The Bay has been significantly impacted by modifications in land use and the transformation of creeks into canals. This is especially true in North Biscayne Bay, where the greatest amount of freshwater flow is received (Caccia and Boyer, 2005). The ramifications of these alterations include the deterioration of natural habitats, impaired water clarity, heightened levels of contaminants such as heavy metals and hydrocarbons, and an overabundance of nutrients.

Two primary contributors to nutrient loadings to North Biscayne Bay are the C-8 and C-9 canals. Average canal flows on water-sample collection dates (approximately monthly) are 173 cubic foot per second (cfs) and 376 cfs for C-8 and C-9, respectively (Chin 2020).

The main impairments to North Biscayne Bay are seagrass die-off (Avila et al. 2017) and elevated concentrations of chlorophyll *a* (Millette et al. 2019), which may be caused by nutrient loading originating in canal discharges (Chin 2020). North Biscayne Bay has the highest chlorophyll *a* levels in Biscayne Bay and historical measurements indicate that Biscayne Bay is an oligotrophic lagoon. From 1995-2014, chlorophyll *a* concentrations in North Biscayne Bay were increasing at an average rate of approximately 0.029 (µg/L)/year with a mean of 1.5-2 µg/L (Millette et al. 2019). It is likely that the increases in chlorophyll *a* are related to seagrass die-off (Zhang et al. 2003). Their die-off results in a feedback loop where the loss of seagrass causes re-suspension of nutrients and sediments, further shading surviving seagrasses and fueling phytoplankton blooms (Millette et al. 2019).

Total nitrogen (TN) and total phosphorus (TP) concentrations in the canals are generally higher than in the bay (Chin 2020; Brand 1988). Throughout North Biscayne Bay, a TN gradient was observed from the coast to the open bay. In contrast, there exists minimal difference in TP concentrations with distance from the shore (Caccia and Boyer 2005). However, TP concentrations in North Biscayne Bay are the highest out of all regions of the bay at all times of the year. Additionally, TP showed pronounced seasonal differences in areas receiving freshwater input from canals, such as North Biscayne Bay (Caccia and Boyer, 2005). The canals are the dominant sources of TN and TP loading in the bay, contributing approximately 95% of the TN load and approximately 90% of the TP load to the bay on an annual basis. (Chin 2020).

For this investigation, North Biscayne Bay was subdivided into two distinct regions: (i) Northern North Bay A (NNB-A), associated with the Snake Creek/Oleta River (C-9), and (ii) Northern North Bay B (NNB-B), associated with the Biscayne Canal (C-8) (**Figure 2-1**). Of interest to this study are eight SFWMD monitoring stations located within North Biscayne Bay, including two sites that measure flow and six sites that measure water quality (**Table 2-1**).

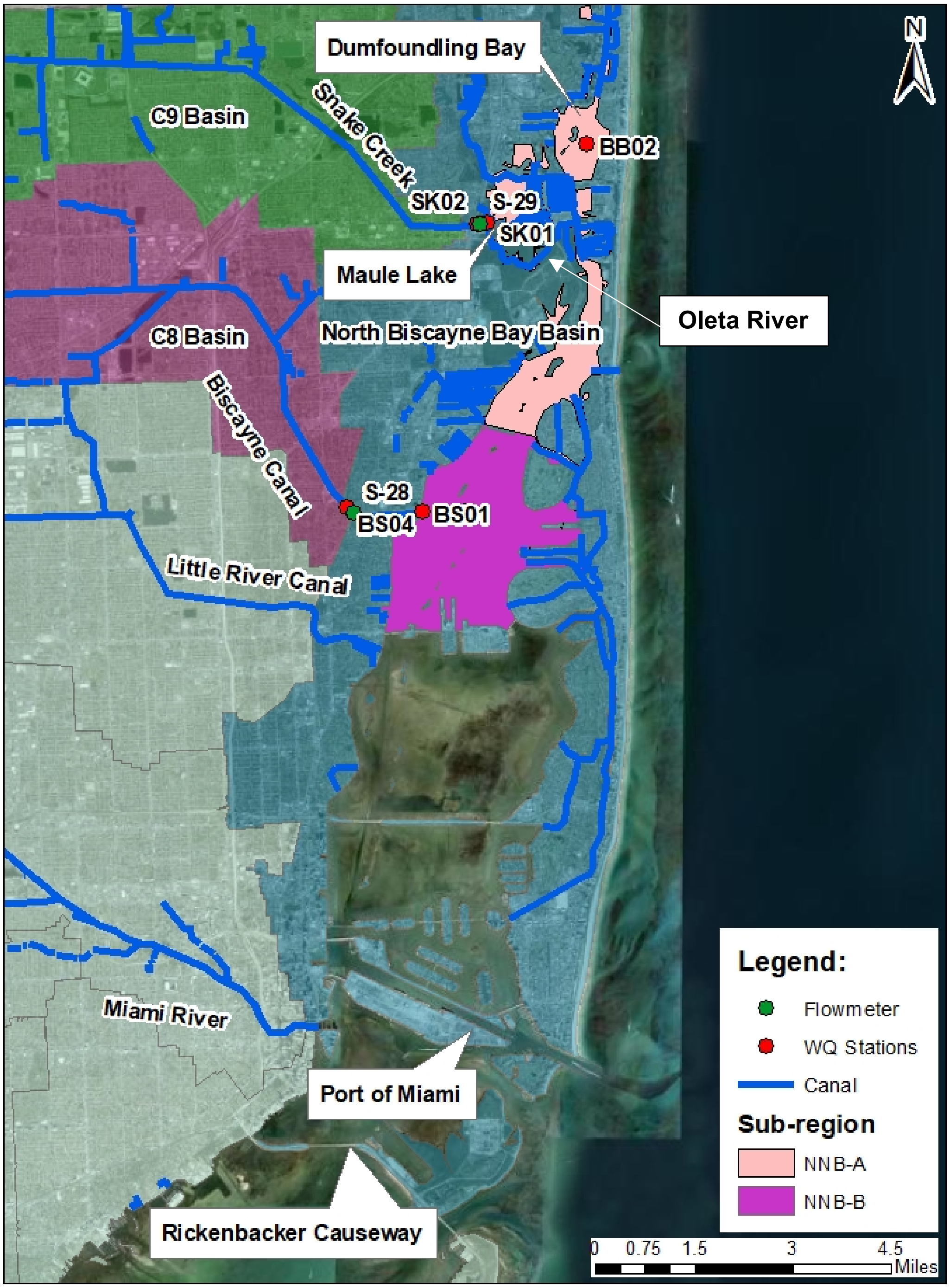

Figure 2-1: NNB -A and NNB -B in Relation to the WQ monitoring stations, Flowmeters, Canals, and Canal Basins

Table 2-1: List of Flowmeters and WQ Stations Associated with the C-8 and C-9 Canals and Basins

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

2.2.1 NNB-A

The subregion of NNB-A extends approximately seven miles from the Miami-Dade/Broward County line southwards to the Broad Causeway and Indian Creek Lake and is associated with the C-9 basin. Waterbodies and features within this sub-region include Dumfoundling Bay, Maule Lake, the Oleta River, and the Haulover inlet. The Haulover inlet serves as this region's only direct connection to the Atlantic Ocean. The width of this region of the bay varies from 0.1 to 1.5 miles. The most recent issue of the Biscayne Bay Report Card (2022), produced annually by Miami-Dade County (MDC), assessed the WQ of NNB-A as 'Fair', noting reduced seagrass coverage compared to the previous year, high levels of nutrient loading from the canals, and chlorophyll *a* concentrations that exceed the established baseline. The report card noted improvements in the bacteria enterococci and total nitrogen compared to 2021. Note that a 'Fair' rating (as opposed to a 'Poor' or 'Good' rating) describes a region experiencing degradation in its WQ, where 'essential ecological functions and species diversity are impacted and not able to perform beneficial functions at optimum levels'.

2.2.1.1 Water Quality

Chin (2020) performed a Load Duration Curve analysis for the canals discharging into North Biscayne Bay for the period 2008 – 2018 and found that the average concentration of TN at SK01 in the C-9 canal is 58 % higher under wet conditions than non-wet conditions. (Note that surface runoff is therefore the main driver of TN concentrations in the C-9.) Wet conditions are defined as high flow conditions, while dry conditions are defined as low flow conditions. The TN loading during wet conditions equaled 1,863 kg/day and for non-wet conditions equaled 381 kg/day. The average TN concentration during wet and non-wet conditions equaled 1.03 mg/L and 0.65 mg/L, respectively.

For TP loadings, Chin (2020) found no difference between wet and non-wet conditions, suggesting that stormwater runoff has little to no impact on TP loads at the C-9. The TP loading during wet conditions equaled 27 kg/day and for non-wet conditions equaled 7 kg/day. The average TP concentration equaled 13 µg/L for both wet and non-wet conditions.

2.2.2 NNB-B

NNB-B extends from the Broad Causeway south to the 79^{th} Street Causeway over approximately three miles and is associated with the C-8 basin. The width of this region of the bay varies from 1 to 2.5 miles. The 2022 MDC Biscayne Bay Report card outlined reduced seagrass coverage from die-off events and elevated chlorophyll *a* concentrations. Although chlorophyll *a* concentrations exceeded the established baseline, there was an improvement from 2021 concentrations. NNB-B received a ‘Fair’ rating on the 2022 report card.

2.2.2.1 Water Quality

For the C-8 canal, the average concentration of TN at BS04 is 15% higher under wet conditions than non-wet conditions. Stormwater runoff is therefore the main driver of TN concentrations in the C-8. The TN loading during wet conditions equaled 880 kg/day and for non-wet conditions equaled 191 kg/day. The average TN concentration during wet and non-wet conditions equaled 1.06 mg/L and 0.92 mg/L, respectively (Chin, 2020).

For TP loadings, Chin (2020) found that the average concentration of TP at BS04 is 10% higher under wet conditions than non-wet conditions, suggesting that stormwater runoff influences TP loads at the C-8. The average TP concentration during wet and non-wet conditions equaled 21 µg/L and 19 µg/L, respectively.

2.2.3 C-8 and C-9 Outfalls

The S-28 and S-29 structures are reinforced concrete gated spillways located at the mouth of the C-8 and C-9 canals, respectively. The S-29 structure lies approximately 500 ft west of Lake Maule’s shores, and the S-28 lies approximately one mile west of the shore of Biscayne Bay. These structures prevent saltwater intrusion when flood tides are high and maintain optimum upstream water control stages. The flood discharge rate (uncontrolled, submerged) equals 3,220 cfs and 4,780 cfs for the S-28 and S-29, respectively. The structures’ cable operated vertical lift gates are automatically controlled such that the hydraulic operating system opens or closes in accordance with the District’s operational criteria. Currently, they are operated to maintain an optimum headwater elevation of 1.8 ft NGVD29 at the S-28 and 2.0 ft NGVD29 at the S-29. In addition to maintaining optimum upstream freshwater control, the automatic controls have an overriding feature which closes the gates, regardless of the upstream water level in the event of a high flood tide, whenever the differential between the head and tailwater pool elevations reaches 0.3 feet. During the simultaneous occurrence of high tide and heavy rainfall, structure control is manually operated and the gates open when the headwater elevation exceeds the tailwater elevation.

3.0 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. Refer to **Appendix C** for a record of the correspondence.
- 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 C8 and C9 Watersheds, 2022*).

Where available, data were collected and analyzed for the period 1996 – 2022. Refer to **Appendix C** for the data/document control log, records of the associated correspondence, and further detail regarding the data collection effort.

4.0 METHODS

4.1 General

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 2-1**. **Figure 4-1** describes the general steps taken to assess the impact of proposed FPLOS scenarios on each WQ variable at North Biscayne Bay, which are further described in the subsequent sections. Refer to **Appendix A** for further detail regarding the methods shown in **Figure 4-1**.

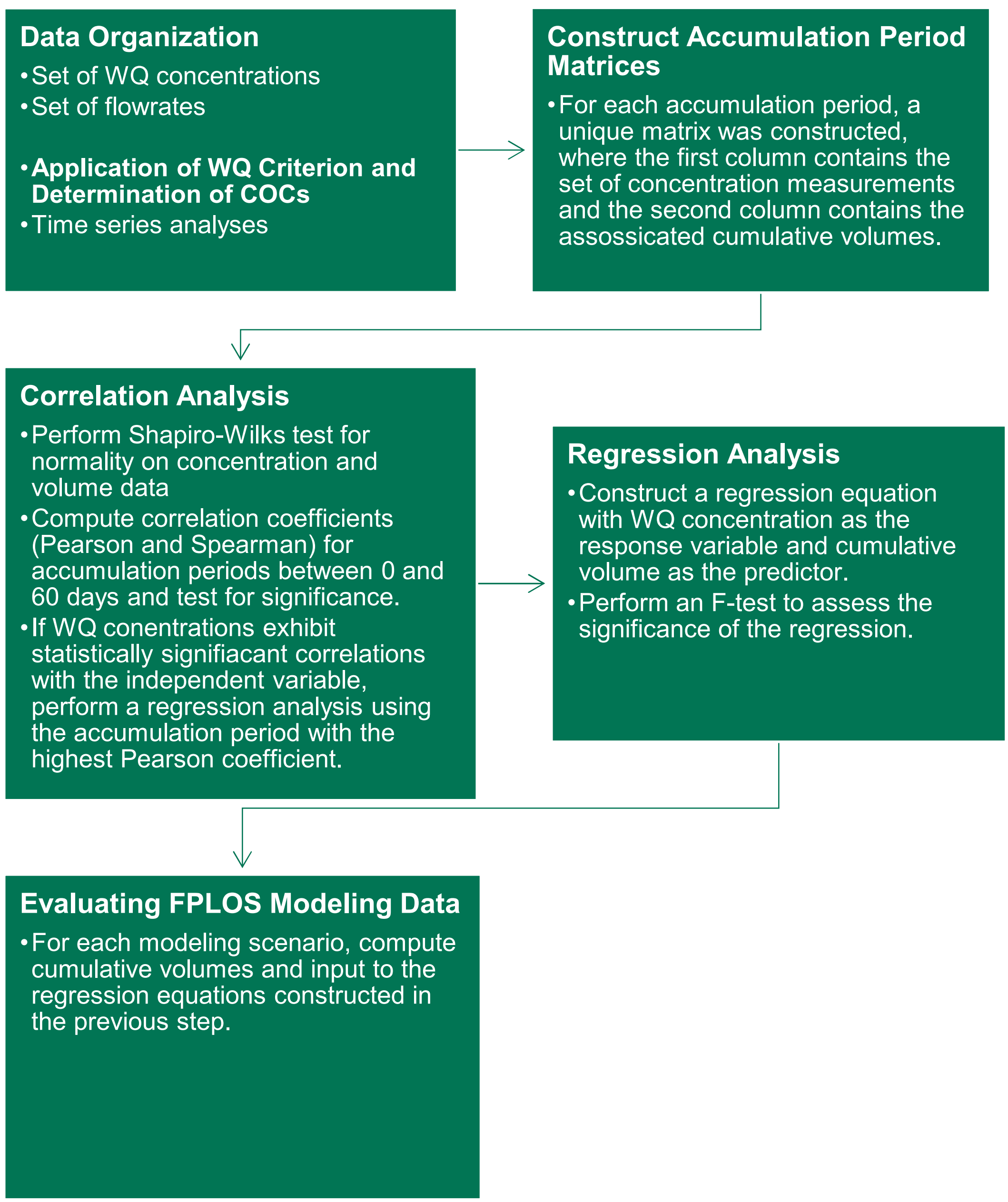

Figure 4-1: Flowchart of Methods used for the Cumulative Volume Analysis

4.2 Time Series Analyses

Time series were constructed for each WQ variable flagged as a contaminant of concern (COC). (Refer to **Section 5.0** for the determination of COCs.) For those variables whose regulatory standards utilize minimum/maximum statistics, a time series of instantaneous data was constructed for the period of interest. For those variables whose regulatory standards utilize geometric means (GMs), these means were computed and plotted for each year of the study period. The Mann-Kendall test (Kendall 1975; Mann 1945) was used on all applicable time series data to assess the direction and statistical significance of temporal trends at the 95% confidence level.

4.3 Cumulative Volume Analyses

For a given WQ variable, flow data was combined with the available WQ concentration data set by matching the time of flow measurement with the time of the contaminant concentration measurement in the bay. Then, for each contaminant concentration measurement, cumulative volumes were computed for volume accumulation periods between 0 and 60 days prior to the date of that concentration measurement. See **Appendix A** for the mathematical details associated with computing cumulative volumes for various accumulation periods.

4.3.1 Correlation Analyses

The magnitude and significance of the correlation between cumulative volume discharges from a given structure versus bay COC concentrations were assessed. **Table 4-1** summarizes the investigated variable pairs.

Table 4-1: Variable Pairs of Interest for the Correlation Analysis

Pair #	Variable 1	Variable 2	Analysis Type	Watershed
1	Cumulative Volume from S-29 (Flow Station)	WQ Variable Concentrations at BB02	Pearson/Spearman	C-9
2	Cumulative Volume from S-28 (Flow Station)	WQ Variable Concentrations at BB09	Pearson/Spearman	C-8

Correlation coefficients were computed for accumulation periods in the range of 0 to 60 days. This range was chosen because the residence time in North Biscayne Bay on average ranges between 7 and 14 days (Chin, 2020), and a 46-day buffer was added to capture the effects of unknown processes that work to distribute/retain contaminants within North Biscayne Bay, such as sediment resuspension and marine vegetation die-off acting as a source of contamination rather than a sink.

The statistical distribution of each WQ variable was evaluated using the Shapiro-Wilks test (Shapiro and Wilk, 1965) to determine whether each pair is bivariate normal. For pairs with at least one non-normally distributed variable, Spearman correlation coefficients were computed for each accumulation period and used to (i) to evaluate whether the relationship between cumulative volume and contaminant concentrations have non-linear characteristics (i.e., how closely their curve is described by a monotonic function) and (ii) whether the correlation coefficients computed based on ranks peak at an accumulation period different from that of non-ranked data. In addition, for each accumulation period, Pearson correlation coefficients were computed to provide information about the fit of linear regression relationships. For all coefficients, significance tests were performed at the 95% confidence level. Depending upon the value of the Pearson or

Spearman correlation coefficients, relationships were defined from a range of very weak to perfect (**Table 4-2**).

Table 4-2: Interpretation of the Pearson's and Spearman's Correlation Coefficients

Correlation Coefficient (+)	Correlation Coefficient (-)	Description of Strength of Correlation
0 to 0.2	-0.2 to 0	Very Weak
0.2 to 0.4	-0.4 to -0.2	Weak
0.4 to 0.6	-0.6 to -0.4	Moderate
0.6 to 0.8	-0.8 to -0.6	Strong
0.8 to 0.99	-0.99 to -0.8	Very Strong
1	-1	Perfect

4.3.2 Regression Analyses

The data set associated with the accumulation period that exhibited the highest Pearson correlation was chosen for further analysis. One regression equation was constructed per WQ variable per watershed. F-tests were performed at the 95% confidence level for all regressions. Refer to **Appendix A** for detailed reports of the regression results. In addition, refer to **Appendix B** for a regression analysis decision matrix for the C-8 and C-9 basins.

The aforementioned modeling flow data was provided by Taylor Engineering for a total of 16 days (6/2/2017 to 6/17/2017), where 6/2/2017 was set to day 0 and 6/17/2017 was set to day 15. This data was analyzed using the accumulation periods established in the correlation analyses. If an accumulation period greater than 15 days was found to coincide with the maximum/minimum correlation coefficient, then the 15-day accumulation period was used for the regression analysis.

5.0 CONTAMINANTS OF CONCERN

5.1 Standards and Criteria

The waters of the Biscayne Bay Aquatic Preserve (BBAP) are designated as Outstanding Florida Waters (OFW) and Class III waters for recreation, fishing, and wildlife protection under Chapter 62-302, FAC. Effective August 5, 2010, the definition of Class III waters was amended to distinguish those that are "predominantly fresh" or "predominantly marine." BBAP waters in MDC are regarded as "predominantly marine" in that the chloride concentration in its surface water is greater than or equal to 1,500 mg/L. Class III-Limited waters have at least one Site Specific Alternative Criterion as established under Rule 62-302.800, F.A.C.

The FDEP's Environmental Regulatory Commission (ERC) began adopting Numeric Nutrient Criteria (NNC) for Biscayne Bay WQ thresholds in 2011. Several NNCs are expressed as annual GM concentrations which cannot be exceeded more than once in a three-year period. The allowable concentrations for the Northern North Bay (comprising NNB-A and NNB-B) are as follows: 0.30 mg/L for total nitrogen (TN); 0.012 mg/L for total phosphorus (TP); and 1.7 µg/L for chlorophyll *a*. In addition, Chapter 62-302, FAC lists WQ criteria for Class III Marine Waters for additional parameters.

5.2 Evaluation of COCs

An analysis was conducted to determine current COCs in NNB-A (C-9 Basin) and NNB-B (C-8 Basin). WQ analyses for Station BB02 (NNB-A) and Station BB09 (NNB-B) were conducted, when possible, for the period 1996 - 2022. WQ criteria analysis for the parameters analyzed were based on various statistics (minimums, maximums, and annual GMs. Note that for several WQ parameters there exists limited data. **Table 5-1** and **Table 5-2** present the COCs evaluated for NNB-A and NNB-B, respectively. Parameters identified as COCs are presented in red font, parameters not in violation of their respective WQ criteria are in green font, and parameters that did not violate any WQ criteria but because of their importance to the bay's ecological health were flagged for further analysis are identified in purple font. Salinity levels were also evaluated because changes in salinity concentrations have historically had significant impacts to marine life in the bay.

Table 5-1: COC Analysis in NNB-A

Parameter[1]	Station ID	Critical Statistic (Observed)	Statistic Type	Water Quality Criteria	Units
Salinity	BB02	NA[6]	NA	NA	ppt
Chlorophyll *a*[2]	BB02	4.15	Annual GM	≤1.7	µg/L
Total Nitrogen[2]	BB02	0.47	Annual GM	≤0.30	mg/L
Total Phosphorus[2]	BB02	0.007	Annual GM	≤0.012	mg/L
Dissolved Oxygen[3,4]	BB02	3.70	Minimum	> 4.0	mg/L
Turbidity[3,5]	BB02	1.3	Maximum	≤ 1.3 NTU	NTU
Copper[3]	BB02	4	Maximum	≤3.7	µg/L
Cadmium, Total[3]	BB02	2.0	Maximum	≤8.8	µg/L
Selenium, Total[3]	BB02	8.0	Maximum	≤71	µg/L
Silver, Total[3]	BB02	1.0	Maximum	<2.3	µg/L
Lead[3]	BB02	3.6	Maximum	≤8.5	µg/L

[1] Insufficient data was provided for arsenic and chromium.
[2] Numeric Nutrient Criteria for Biscayne Bay, FAC 62-302.532.
[3] Surface Water Quality Criteria for Class III Marine Waters, FAC 62-302.530.
[4] Dissolved Oxygen criteria represents stressful conditions for most fish species.
[5] Turbidity was used as a measure of water clarity since it is measured more frequently than TSS.
[6] Not applicable.
Red font indicates the parameter was identified as a COC for NNB-A.
Purple font indicates the parameter was not a COC but was flagged for further study.
Green font indicates the parameter was not identified as a COC for NNB-A.

Table 5-2: COC Analysis in NNB-B

Parameter[1]	Station ID	Critical Statistic (Observed)	Statistic Type	Water Quality Criteria	Units
Salinity	BB09	NA[7]	NA	NA	ppt
Chlorophyll *a*[2]	BB09	2.06	Annual GM	≤1.7	µg/L
Total Nitrogen[2]	BB09	0.34	Annual GM	≤0.30	mg/L
Total Phosphorus[2]	BB09	0.008	Annual GM	≤0.012	mg/L
Fecal Coliform[3]	BB09	410	Maximum	≤800	CFU
Dissolved Oxygen[4,5]	BB09	3.73	Minimum	> 4	mg/L
Turbidity[5,6]	BB09	2	Maximum	≤ 1.3 NTU	NTU

[1] Insufficient data was provided for copper and zinc.
[2] Numeric Nutrient Criteria for Biscayne Bay, FAC 62-302.532.
[3] Note that in 2016, the Florida Department of Environmental Protection (FDEP) revised the human health-based surface water quality criteria in Chapter 62-302 and replaced the Fecal Coliform standard with Escherichia coli (E. coli) in Class III waters. No E. Coli data exists at BB09, and therefore all analyses were performed on Fecal Coliform.
[4]Dissolved Oxygen criteria represents stressful conditions for most fish species.
[5] Surface Water Quality Criteria for Class III Marine Waters, FAC 62-302.530.
[6] Turbidity was used as a measure of water clarity since it is measured more frequently than TSS.
[7] Not applicable
Red font indicates the parameter was identified as a COC for NNB-B.
Purple font indicates the parameter was not a COC but was flagged for further study.
Green font indicates the parameter was not identified as a COC for NNB-A.

6.0 DISCHARGES INTO NORTH BISCAYNE BAY

Modeling scenarios provided by Taylor Engineering for use in assessing potential WQ impacts to North Biscayne Bay focused on evaluating several sea level rise conditions over different design storms together with flood mitigation projects (**Table 6-1**). Data associated with a combination of mitigation strategies, storm events, and sea level rise scenarios was provided for the period 6/2/2017 to 6/17/2017.

Table 6-1: Modeling Scenarios for the FPLOS WQ Impact Assessment

Scenario Type	Sea Level Rise (ft)	Storm Events (yr.)	Number of Scenarios
M0 (No mitigation)	+0	5, 10, 25, 100	4
	+1	5, 10, 25, 100	4
	+2	5, 10, 25, 100	4
	+3	5, 10, 25, 100	4
M2A	+1	5, 10, 25, 100	4
	+2	5, 10, 25, 100	4
	+3	5, 10, 25, 100	4
M2B	+1	5, 10, 25, 100	4
	+2	5, 10, 25, 100	4
	+3	5, 10, 25, 100	4
M2C	+1	5, 10, 25, 100	4
	+2	5, 10, 25, 100	4
	+3	5, 10, 25, 100	4

Note that M0 represents scenarios without mitigation. M2A, M2B, and M2C comprise sets of regional adaptation or mitigation strategies implemented as part of the primary flood control system, as listed below.

Scenario M2A includes the following mitigation projects:

- S-28 and S-29 forward pumps (1,550 cfs).
- Gate improvements: raised overtopping elevation to 9.0 ft NGVD29.
- Tieback levees/floodwalls.
- Total of 500 acre-ft of distributed storage (gravity-driven drainage areas only).
- Optimized operational controls.

Scenario M2B includes the following mitigation projects:

- S-28 and S-29 forward pumps (2,550 cfs).
- Gate improvements: raised overtopping elevation to 9.0 ft NGVD29.
- Tieback levees/floodwalls.
- Total of 500 acre-ft of distributed storage (gravity-driven drainage areas only).
- Canal improvements: improved geometries and raised banks.
- Internal drainage system along primary canal to drain water through raised banks.
- Optimized operational controls.

Scenario M2C includes the following mitigation projects:

- S-28 and S-29 forward pumps (3,550 cfs).
- Gate improvements: raised overtopping elevation to 9.0 ft NGVD29.
- Tieback levees/floodwalls.
- Total of 500 acre-ft of distributed storage (gravity-driven drainage areas only).
- Canal improvements: improved geometries, widened cross sections, and raised banks.
- Internal drainage system along primary canal to drain water through raised banks.
- Optimized operational controls.

6.1 C-9 Watershed

6.1.1 Historical Flows

Figure 6-1 shows the time series of historical average daily flows at the S-29 for the period 1/1/1996 to 1/1/2022. The average for this period equaled 286 cfs (solid green line), inclusive of days with zero flow, while the maximum flowrate equaled 3,616 cfs (4/2/2000). For the subset of data comprising non-zero flows, the average daily flow equaled 467 cfs (dashed green line).

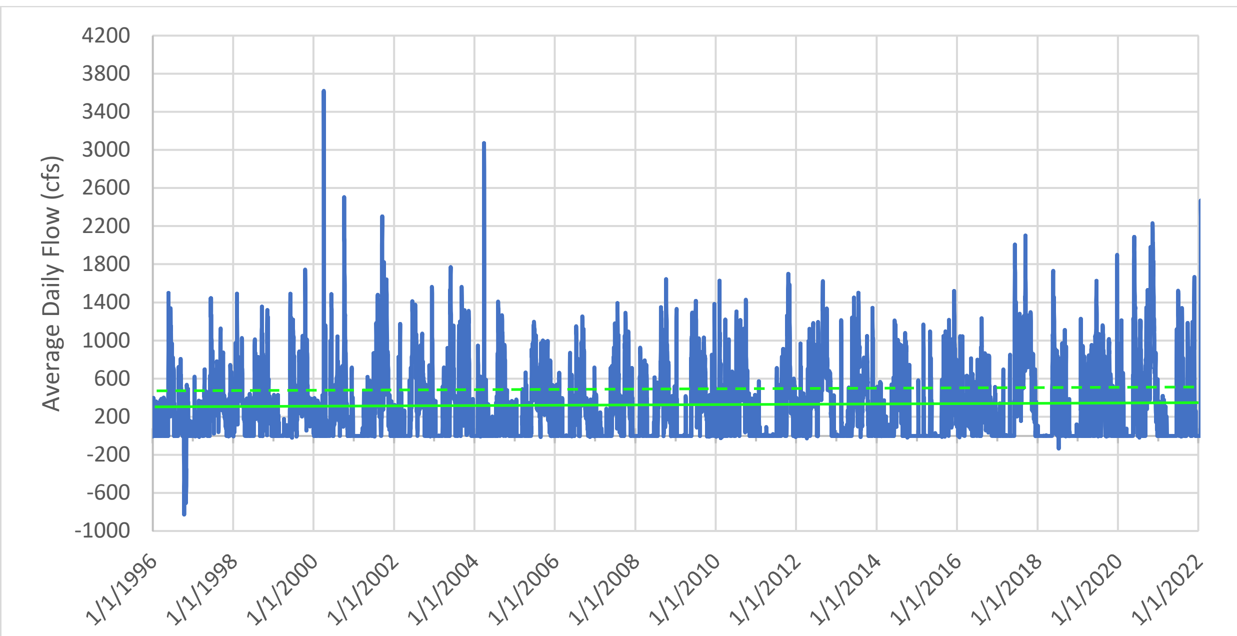

Figure 6-1: Historical Average Daily Flows at the S-29 for the Period 1/1/1996 to 1/1/2022

Figure 6-2 shows the time series of historical average daily flows for the period 6/2/2017 to 6/17/2017, which corresponds to the period utilized for the simulations presented in **Table 6-1**. Note that the peak flow of 1,913 cfs corresponds to the 99th percentile for both the set of all flows and the subset of non-zero flows.

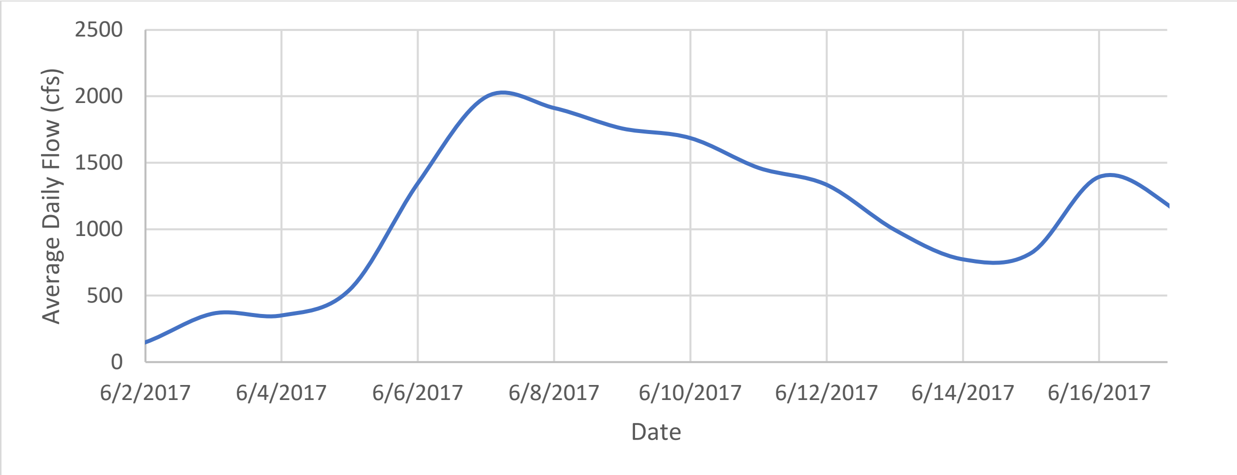

Figure 6-2: Historical Average Daily Flows at the S-29 for the Period 6/2/2017 to 6/17/2017

6.1.2 Hydraulic Modeling Flows

Figures 6-3 and **6-4** show modeled average daily flows provided by Taylor (2022) for the period 6/2/2017 to 6/17/2017 for the combination of scenarios summarized in **Table 6-1** at the S-29 on Snake Creek. Note that peak flows for M2C scenarios are generally higher than those without mitigation, for fixed SLR, across all return periods. M2A scenarios exhibit either equivalent or lower peak flows compared to M0 scenarios, for fixed SLR. Scenarios simulating 2 and 3 ft of sea level rise exhibit negative flows (backflow), which is expected to affect cumulative volume inputs. M2B peak flows generally lie between M2C and M2A peak flows. These flows were the basis for the WQ analysis performed for NNB-A.

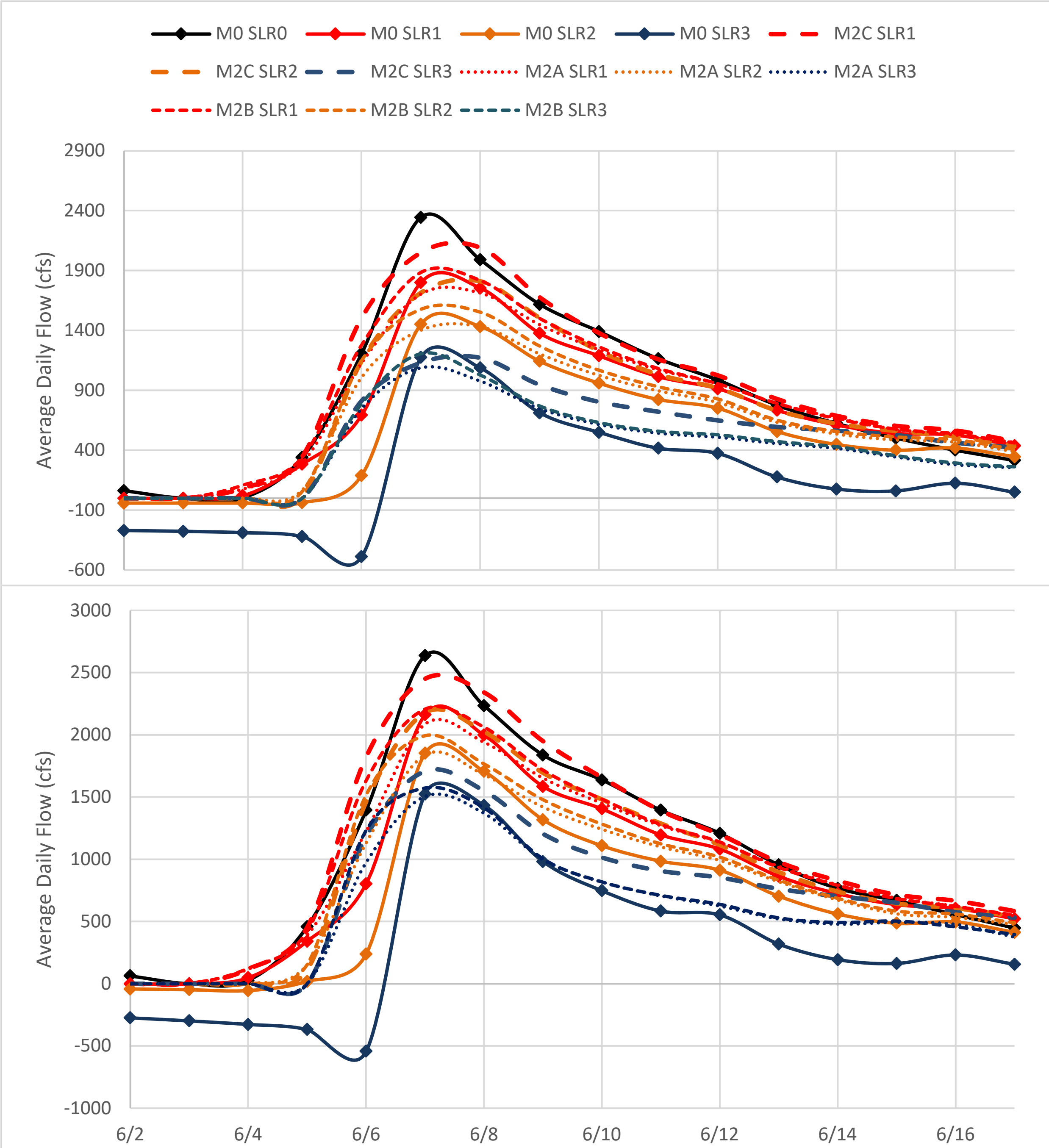

Figure 6-3: Simulated Average Daily Flows at the S-29 for All Combinations of Mitigation Strategy and Sea Level Rise Scenarios for a 5-year (top panel) and 10-Year (bottom panel) Return Period Design Storm

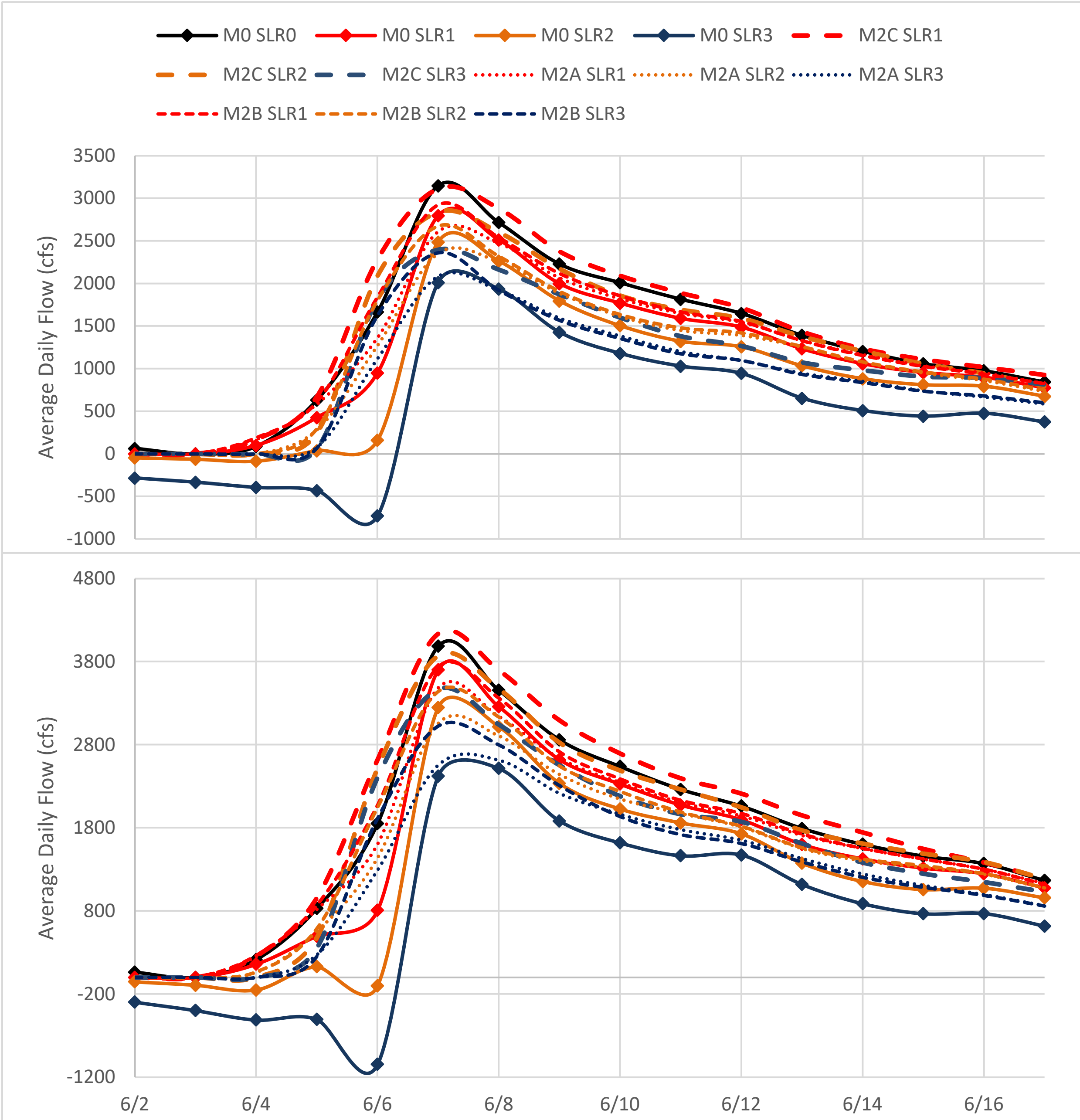

Figure 6-4: Simulated Average Daily Flows at the S-29 for All Combinations of Mitigation Strategy and Sea Level Rise Scenarios for a 25-year (top panel) and 100-Year (bottom panel) Return Period Design Storm

Figure 6-5 shows the relationship between modeled cumulative volume discharges at the S-29 and (i) mitigation strategy; (ii) sea level rise elevations; and (iii) storm return period for the period 6/2/2017 to 6/17/2017. Mitigation strategies are distinguished by shape (a square for M0, a triangle for M2A, a cross for M2B, and a circle for M2C), while sea level rise elevations are distinguished by color (red, green, and blue for 1 ft, 2 ft, and 3 ft, respectively). The following observations cane be drawn from **Figure 6-5**:

- M2A scenarios exhibit lower cumulative volumes across all return periods compared to M2C scenarios.
- M2B cumulative volumes are observed to lie between M2C and M2A for fixed SLR. Note that these volumes, however, are closer to M2A than to M2C.
- M0-SLR3 exhibits the lowest cumulative volumes compared to the other scenarios.
- M2C-SLR1 produced the highest cumulative volumes, followed by M0-SLR0. All other scenarios produce cumulative volumes lower than that of M0-SLR0 for every storm return period.

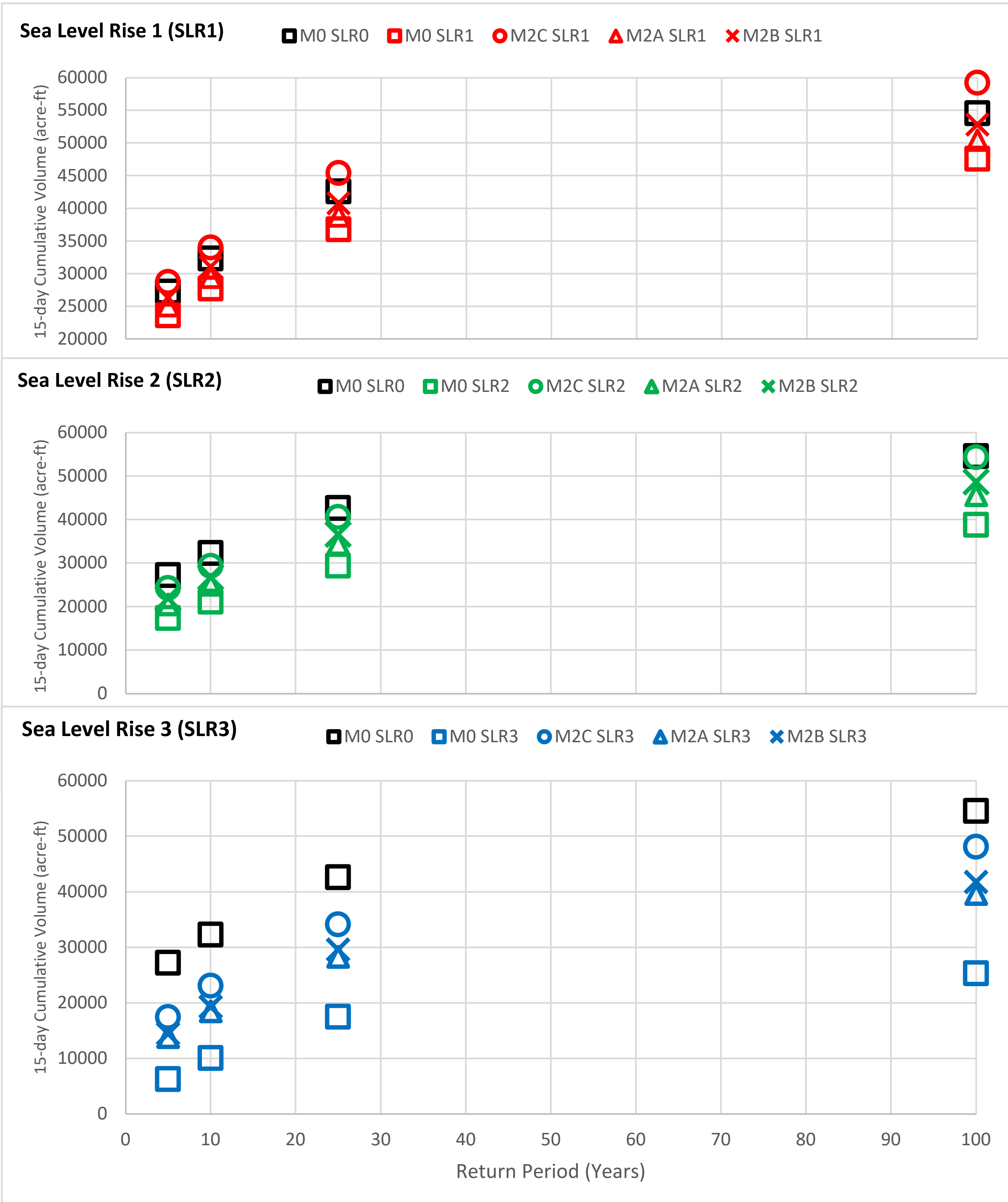

Figure 6-5: Cumulative Volume Discharges at the S-29 for Combinations of Mitigation Strategies, Sea Level Rise Scenarios, and Storm Return Periods for 6/2/2017 to 6/17/2017 (Event Simulation Period)

6.2 Biscayne Canal and Watershed (C-8)

6.2.1 Historical Flows

Figure 6-6 shows the time series of historical average daily flows at the S-28 for the period 1/1/1996 to 1/1/2022. The average for this period equaled 106 cfs, inclusive of zero flows, while the maximum flow equaled 1,757 cfs (10/4/2000). For the subset of data comprising non-zero flows, the average daily flow equaled 193 cfs.

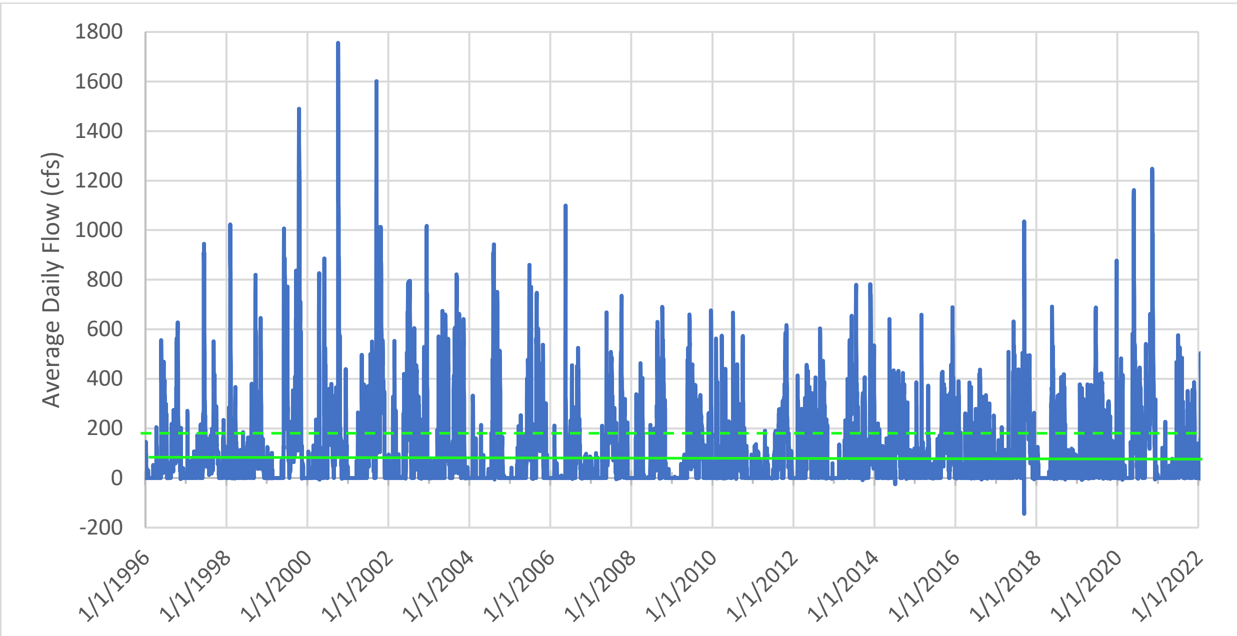

Figure 6-6: Historical Average Daily Flows at the S-28 for the Period 1/1/1996 to 1/1/2022

Figure 6-7 shows the time series of historical average daily flows for the period 6/2/2017 to 6/17/2017. Note that the peak flow of 603 cfs for this period corresponds to the 98th percentile of all flows and the 97th percentile of non-zero flows.

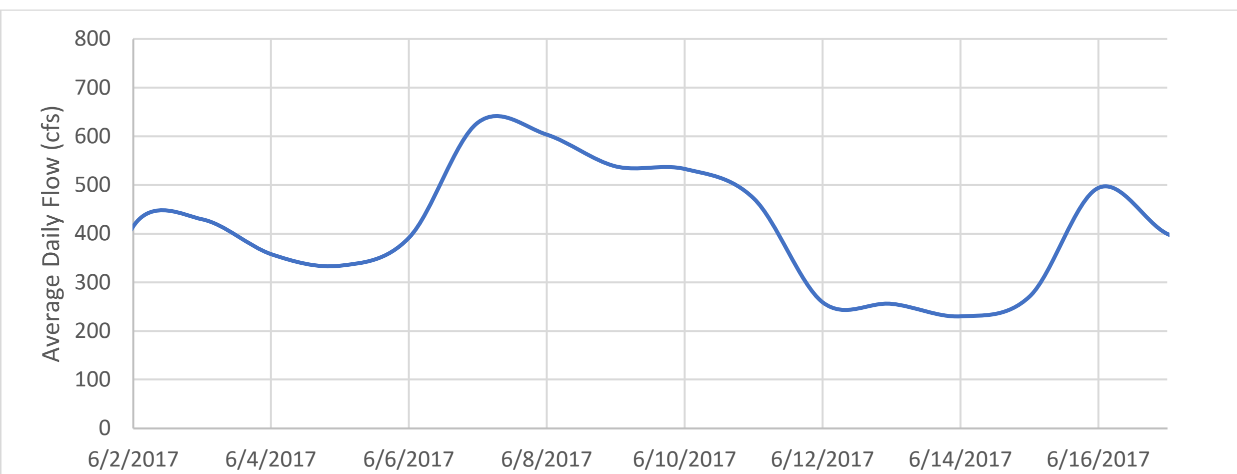

Figure 6-7: Historical Average Daily Flows at the S-28 for the Period 6/2/2017 to 6/17/2017

6.2.2 Hydraulic Modeling Flows

Figures 6-8 and **6-9** show modeled average daily flows for the period 6/2/2017 to 6/17/2017 for the combination of scenarios summarized in **Table 6-1** at the S-28 on Biscayne Canal (C-8). Note that peak flows for M2C scenarios are generally higher than those without mitigation across all return periods and M2A peak flows are lower compared to M0-SLR0. Part of the M2C mitigation strategy involves the installation of a 3,550 cfs pump at the S-28 and, therefore, M2C flows are expected to be higher than M0 flows, which consist of only gravity flow. In addition, scenarios simulating 2 and 3 ft of sea level rise exhibit negative flows (backflow), which is expected to affect cumulative volume inputs to NNB-B. Across storm return period, M2C peak flows are larger than M2B and M2A peak flows, with M2B lying between M2C and M2A.

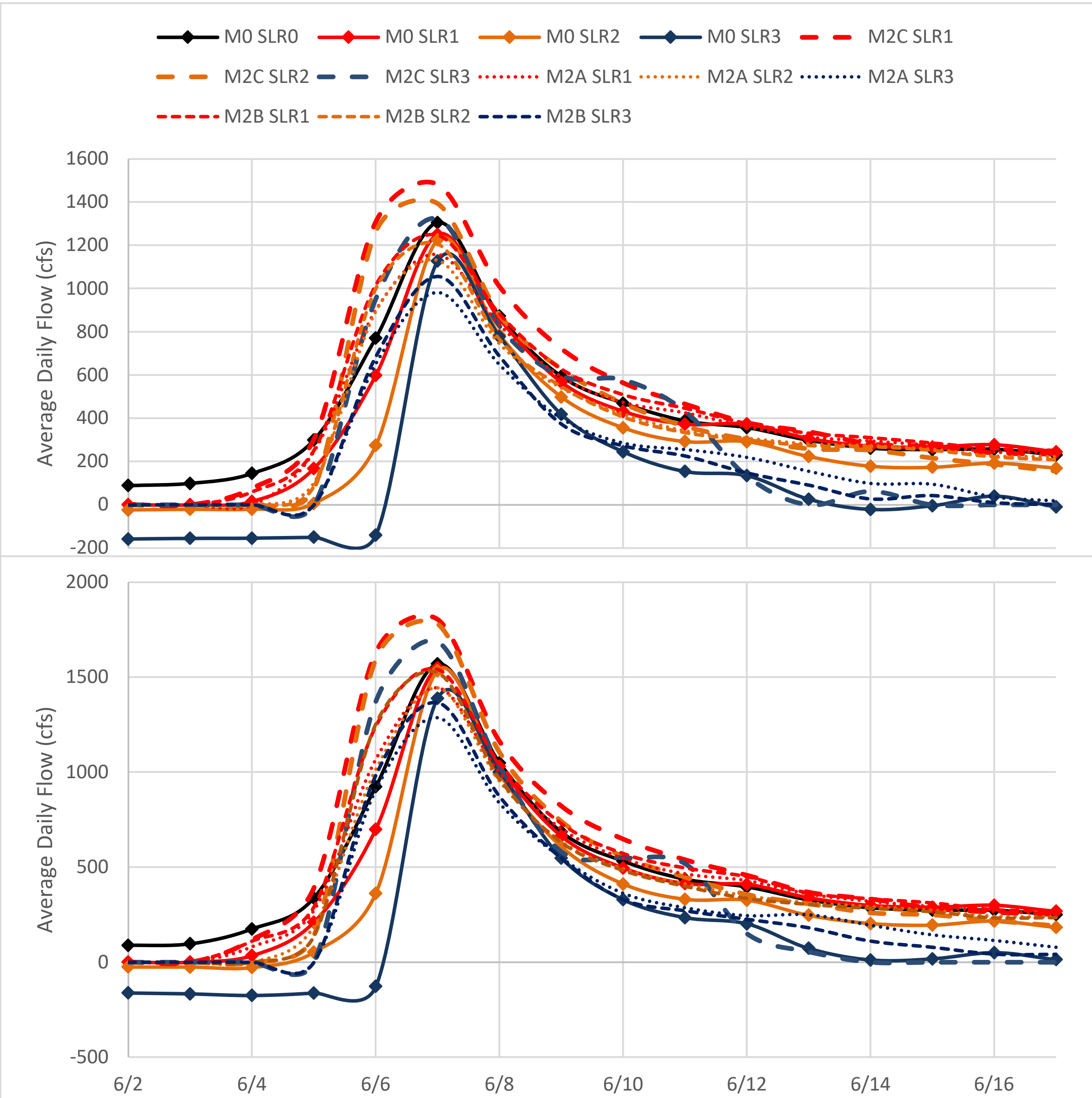

Figure 6-8: Simulated Average Daily Flows at the S-28 for All Combinations of Mitigation Strategy and Sea Level Rise Scenarios for a 5-year (top panel) and 10-Year (bottom panel) Return Period Design Storm

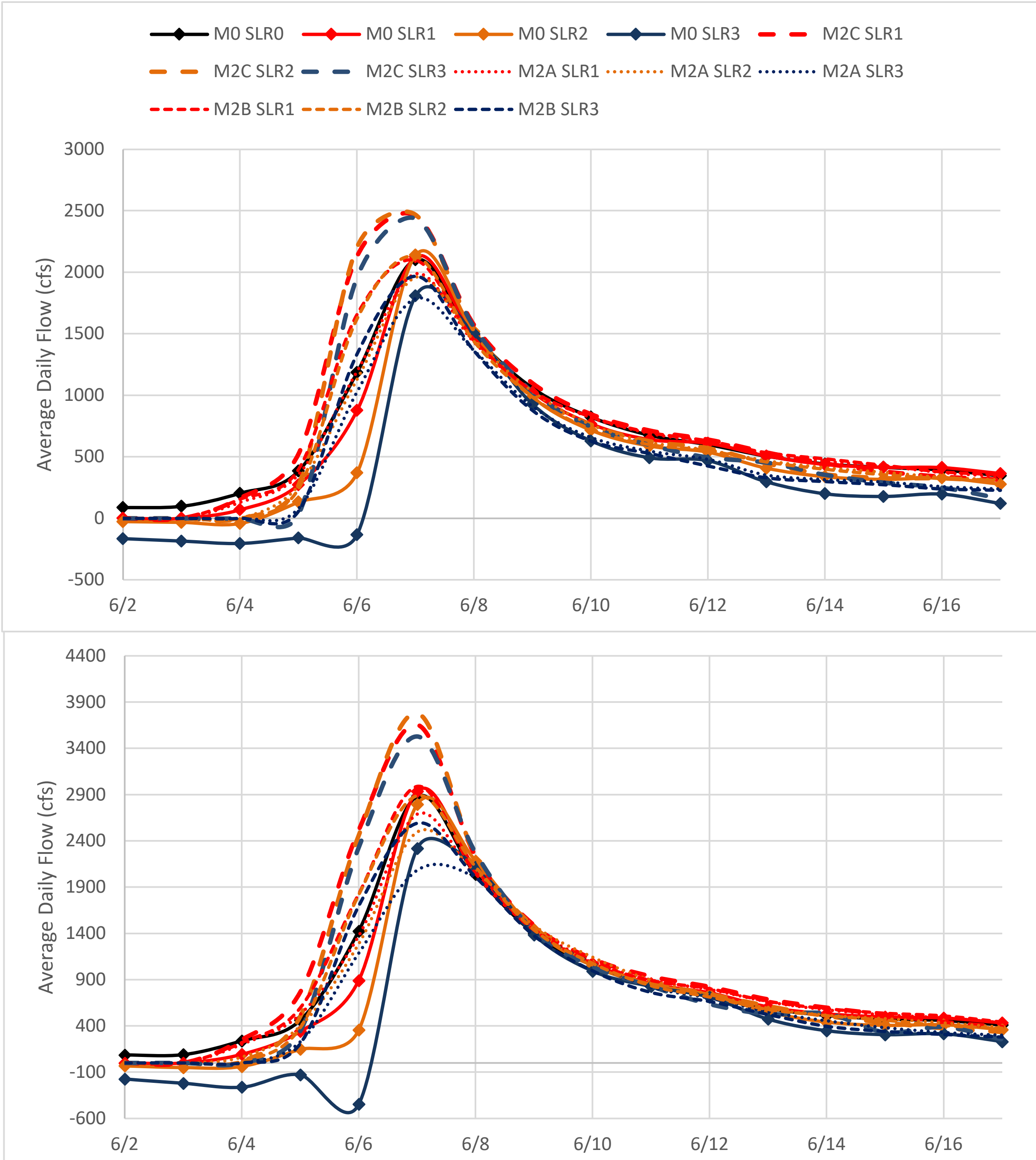

Figure 6-9: Simulated Average Daily Flows at the S-28 for All Combinations of Mitigation Strategy and Sea Level Rise Scenarios for a 25-year (top panel) and 100-Year (bottom panel) Return Period Design Storm

Figure 6-10 shows the relationship between cumulative volume discharges at the S-28 and (i) mitigation strategy; (ii) sea level rise elevations; and (iii) storm return period for the period 6/2/2017 to 6/17/2017. The following observations cane be drawn from **Figure 6-10**:

- Between M0, M2A, M2B, and M2C scenarios, results show that the difference in cumulative volume discharges becomes more pronounced with increasing return period.
- Compared to M2C, M2A scenarios exhibit lower cumulative volumes across all return periods.
- M2C-SLR1 exhibits the highest cumulative volumes of all scenarios across all return periods, and M0-SLR3 exhibits the lowest cumulative volumes.
- M2B cumulative volumes generally lie closer to M2A volumes compared to M2C volumes for fixed SLR.

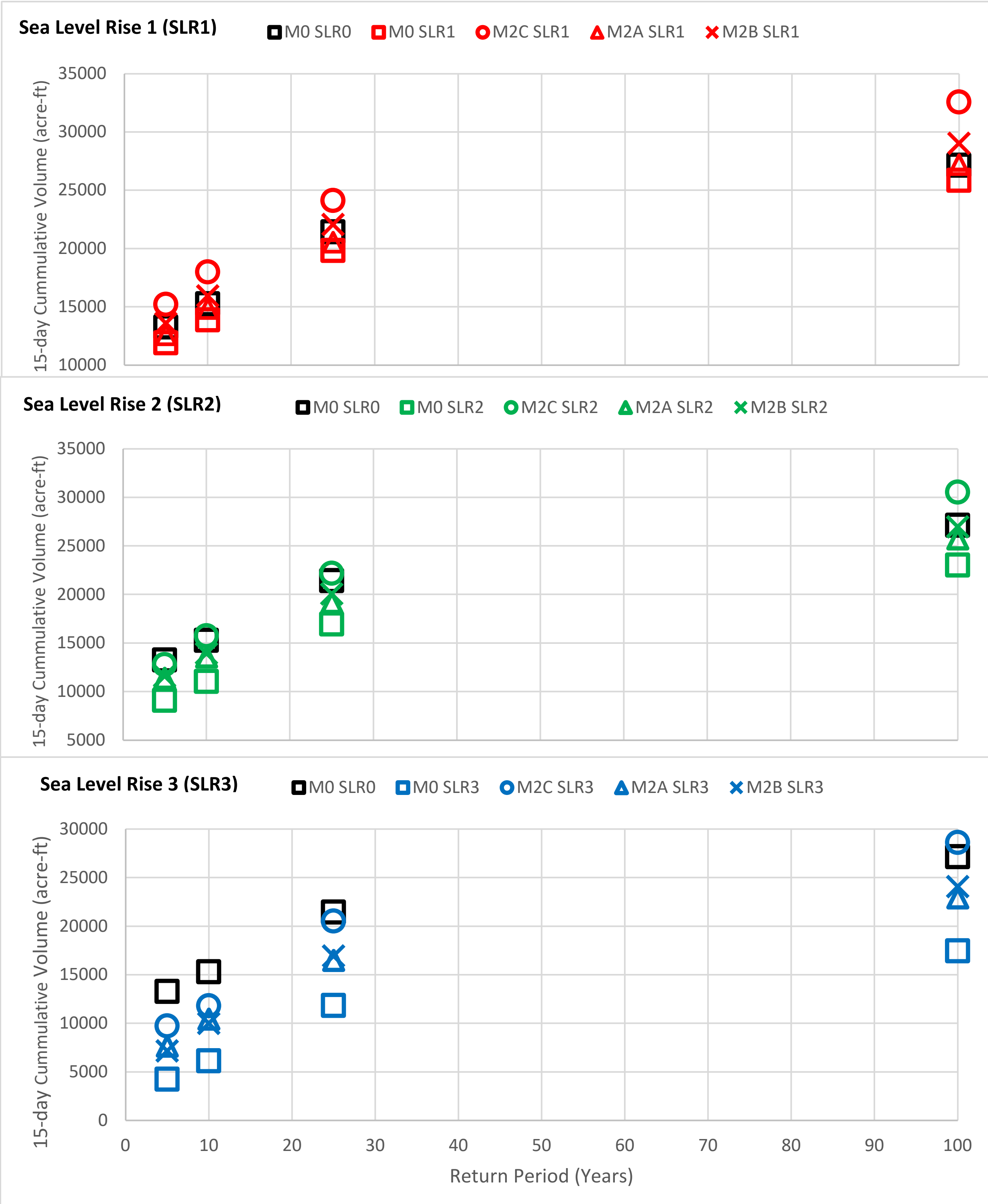

Figure 6-10: Cumulative Volume Discharges at the S-28 for Combinations of Mitigation Strategies, Sea Level Rise Scenarios, and Storm Return Periods for 6/2/2017 to 6/17/2017 (Event Simulation Period)

7.0 C-9 RESULTS AND MITIGATION SCENARIO IMPACTS ON WATER QUALITY

7.1 C-9 Time Series Results

Table 7-1 summarizes the Mann-Kendall test results for each COC at BB02 and at SK02. Note that the symbol '+' denotes a temporally increasing trend, '-' denotes a temporally decreasing trend, and 0 denotes no trend.

Table 7-1: Mann-Kendall Test Results for COCs at BB02 and SK02

WQ Parameter	Trend	Significance	Time Series Type	Station ID
Salinity	0	$p > 0.05$	Annual Mean	BB02
Salinity	0	$p > 0.05$	Annual Minimum Series	BB02
Chlorophyll a	0	$p > 0.05$	Annual GM	BB02
TN	0	$p > 0.05$	Annual GM	BB02
TN	-	$p < 0.05$	Annual GM	SK02
TP	0	$p > 0.05$	Annual GM	BB02
TP	+	$p < 0.05$	Annual GM	SK02
Dissolved Oxygen	0	$p > 0.05$	Annual Mean	BB02
Dissolved Oxygen	0	$p > 0.05$	Annual Mean	SK02
Turbidity	0	$p > 0.05$	Annual Mean	BB02
Copper	0	$p > 0.05$	Annual GM	BB02

7.1.1 Salinity

Figure 7-1 shows available annual salinity concentration means at BB02 for the period 1996 to 2019. (Note that salinity at BB02 is measured infrequently and that there exist data gaps in the time series.) The means range from 21 to 33 ppt, which is characteristic of a polyhaline regime, typical of the middle to lower part of an estuary dominated by marine influence.

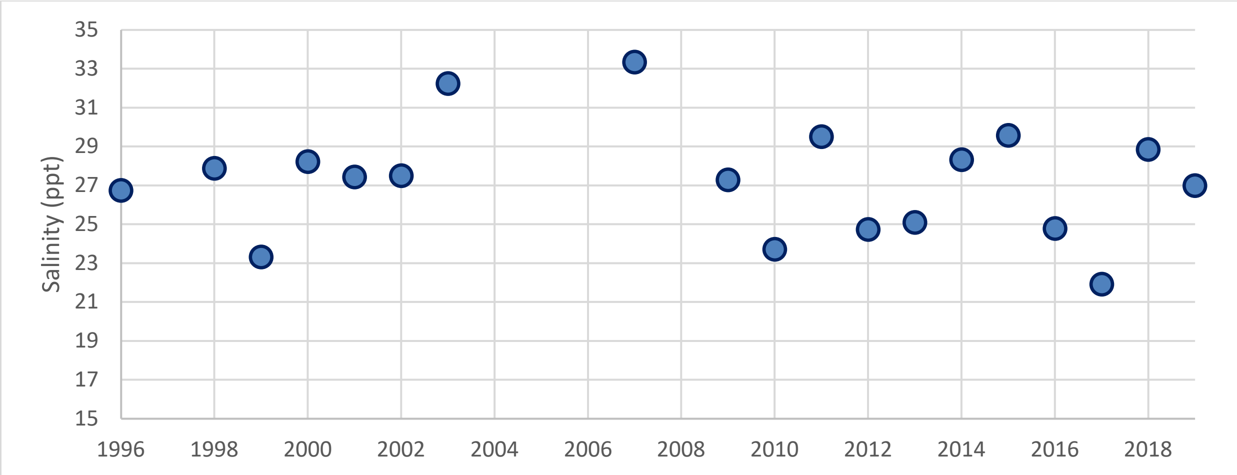

Figure 7-1: Annual Series of Average Salinity Concentrations at BB02

Figure 7-2 shows the annual minimum series (AMS) of salinity concentrations at BB02. This data represents the minimum concentration recorded for each year. In certain cases, shifts in salinity regime at BB02 are notable, since most annual minima are characteristic of a mesohaline system (5 – 18 ppt), and in 2018 there occurred an instance of 2.9 ppt, characteristic of an oligohaline system typically found near the mouths of freshwater rivers or streams. No statistically significant trends in salinity levels were detected at BB02 for both the annual average and annual minimum series.

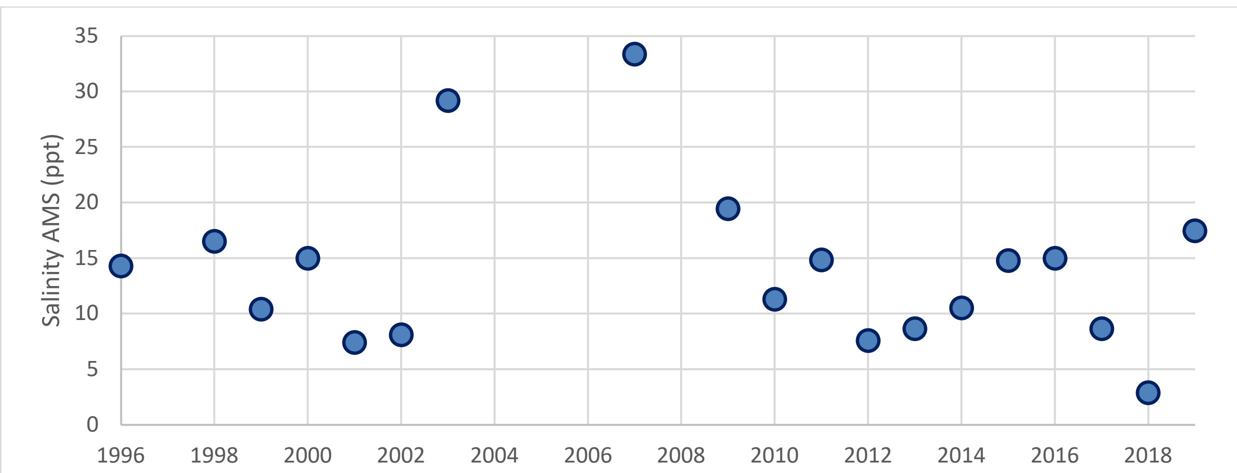

Figure 7-2: Annual Minimum Series of Salinity Concentrations at BB02

7.1.2 Chlorophyll a

Figure 7-3 shows annual GM s for chlorophyll a for the period 1996 to 2021 at BB02, plotted against the WQ criterion of 1.7 μg/L. Chlorophyll a concentrations in every year (except 2004) exceed the WQ criterion at BB02, indicating that this area of the bay shows signs of degradation. The USEPA (1974) defines a mesotrophic system as one exhibiting chlorophyll *a* concentrations between 4 and 10 μg/L. The most recent measure at BB02 equaled 4.2 μg/L, and BB02 has frequently exhibited GMs greater than 4 μg/L. No statistically significant trends in chlorophyll a levels were detected at BB02.

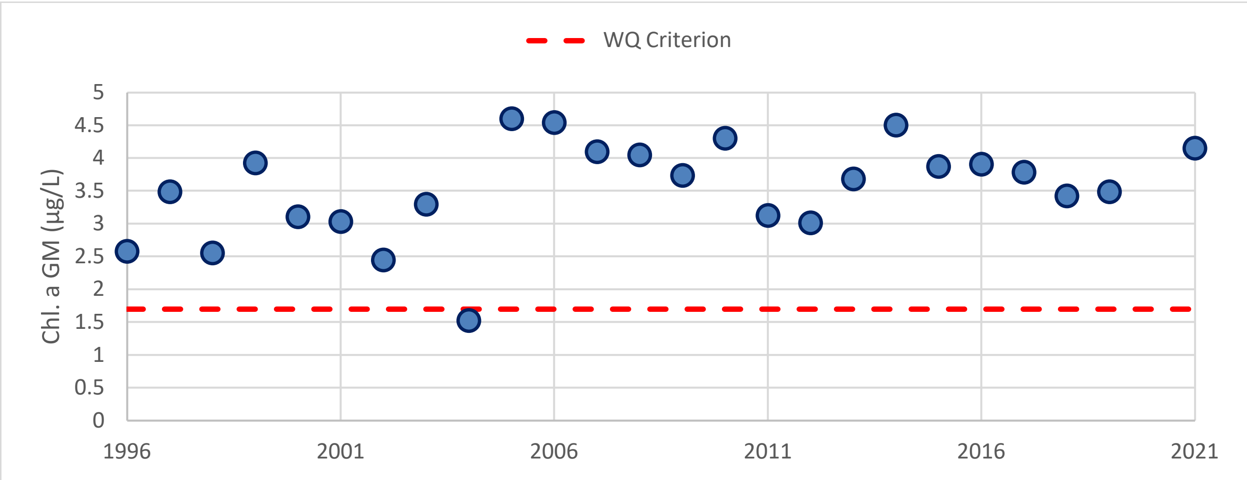

Figure 7-3: Annual GMs of Chlorophyll a Concentrations at BB02

7.1.3 Total Nitrogen

Figure 7-4 shows annual GMs for TN at BB02 and SK02 plotted against the WQ criterion of 0.30 mg/L. (Note that at BB02 data before 2008 and after 2015 is limited.) At BB02, the last two measures for which there is available data (2015 and 2019) exceeded the WQ criterion. At SK02, the WQ criterion is exceeded in every instance. The data show that TN concentrations at the discharge of the C-9 are higher on average than those measured at BB02, suggesting that flows may be acting as a concentrative force to NNB-A TN concentrations. TN annual GMs at BB02 exhibited no statistically significant trend. At SK02, however, there occurs a statistically significant decreasing trend ($p < 0.05$). For the period where data at BB02 and SK02 overlap (i.e., from 2008 to 2019), annual GMs at SK02 exhibited no statistically significant trend ($p > 0.05$).

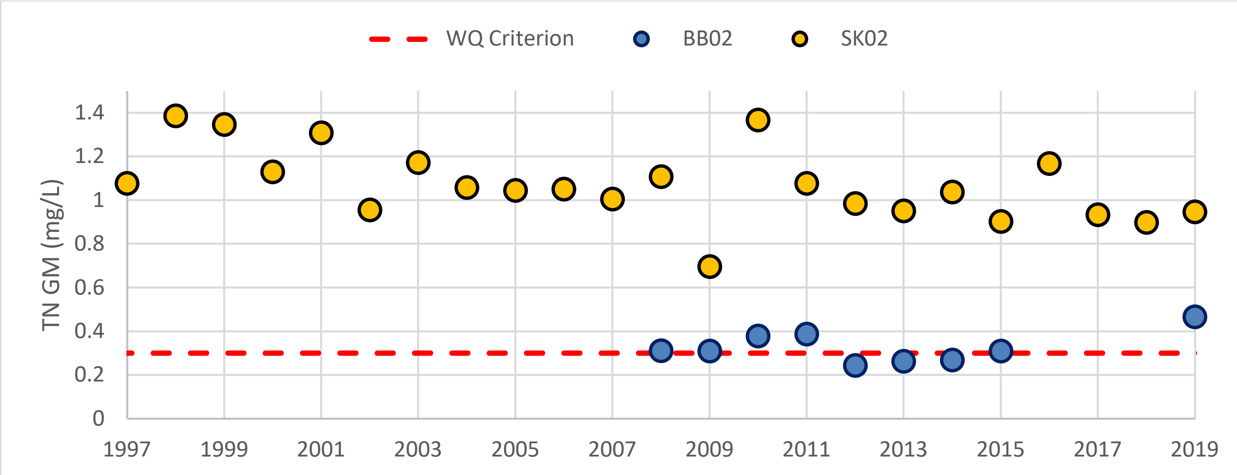

Figure 7-4: Annual GMs of TN Concentrations at BB02 and SK02

7.1.4 Total Phosphorus

Figure 7-5 shows annual GMs for TP at BB02 and SK02 plotted against the WQ criterion of 0.012 mg/L. Note that data after 2019 was not available for TP at BB02. Only in 2017 did TP concentrations at BB02 exceed the WQ criterion of 0.012 mg/L. The first instance of threshold exceedance at SK02 occurred in 2019 and then again in 2021.

TP annual GMs at both BB02 and SK02 exhibited statistically significant increasing trends ($p < 0.05$). TP concentrations at the discharge of the C-9 are approximately equal to those measured at BB02, suggesting that C-9 discharges may not have a dilutive nor a concentrative effect on BB02 concentrations. Note that increased concentrations at SK02 generally result in increased concentrations at BB02. Although no data at BB02 for the years 2020 – 2022 is available, it is likely that the WQ criterion has been exceeded for those years, given the increasing trends at both the bay and canal stations.

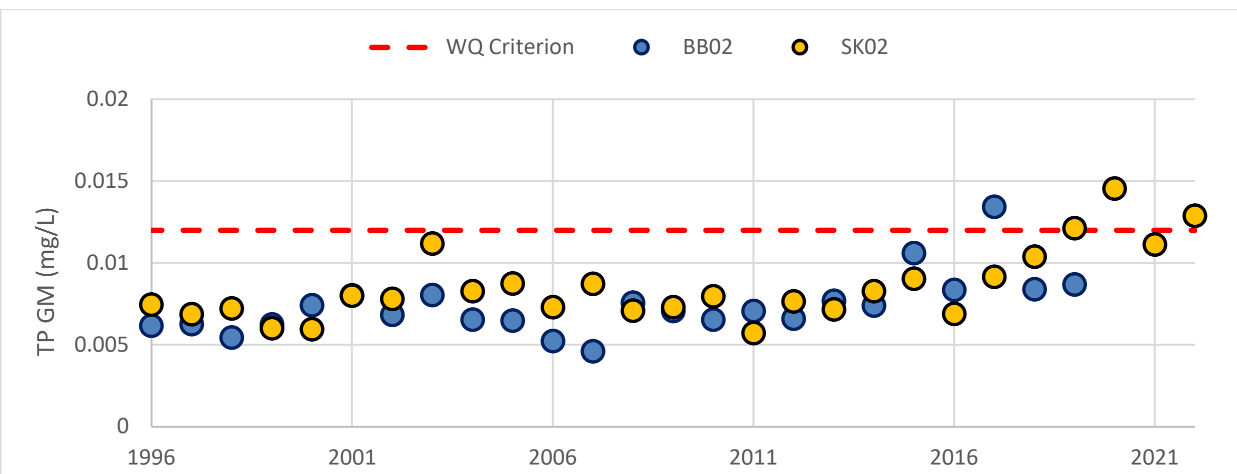

Figure 7-5: Annual GMs of TP Concentrations at BB02 and SK02 Dissolved Oxygen

7.1.5 Dissolved Oxygen

The NNC for dissolved oxygen (DO) are defined in terms of percent DO saturation, which is a function of both temperature and salinity. At BB02, DO concentrations are measured monthly, although the WQ criteria are based on daily averages, 7-day averages, and 30-day averages. DO saturation concentrations are not measured. Given the discrepancy between the current monitoring regime and NNC statistical criteria, this investigation used an alternative method of assessing DO levels using general tolerances for fish species. Note that a data gap exists at BB02 for the years 2004 to 2008.

The annual distributions of instantaneous DO concentrations taken monthly at BB02 are plotted in **Figure 7-6** against general tolerance thresholds for fish (Francis-Floyd, 2019). Stressful conditions are defined as a DO concentrations between 2.0 and 4.0 mg/L, while critically low conditions, under which most fish species cannot survive, are defined as being less than 2.0 mg/L. Optimal conditions are defined as being greater than or equal to 5.0 mg/L. Concentrations less than 5.0 mg/L comprise 15.0% of all data at BB02. Concentrations that lie between 2.0 and 4.0 comprise 6.0% of all data at BB02. Note that the critically low threshold of 2.0 mg/L has been exceeded just once (2013).

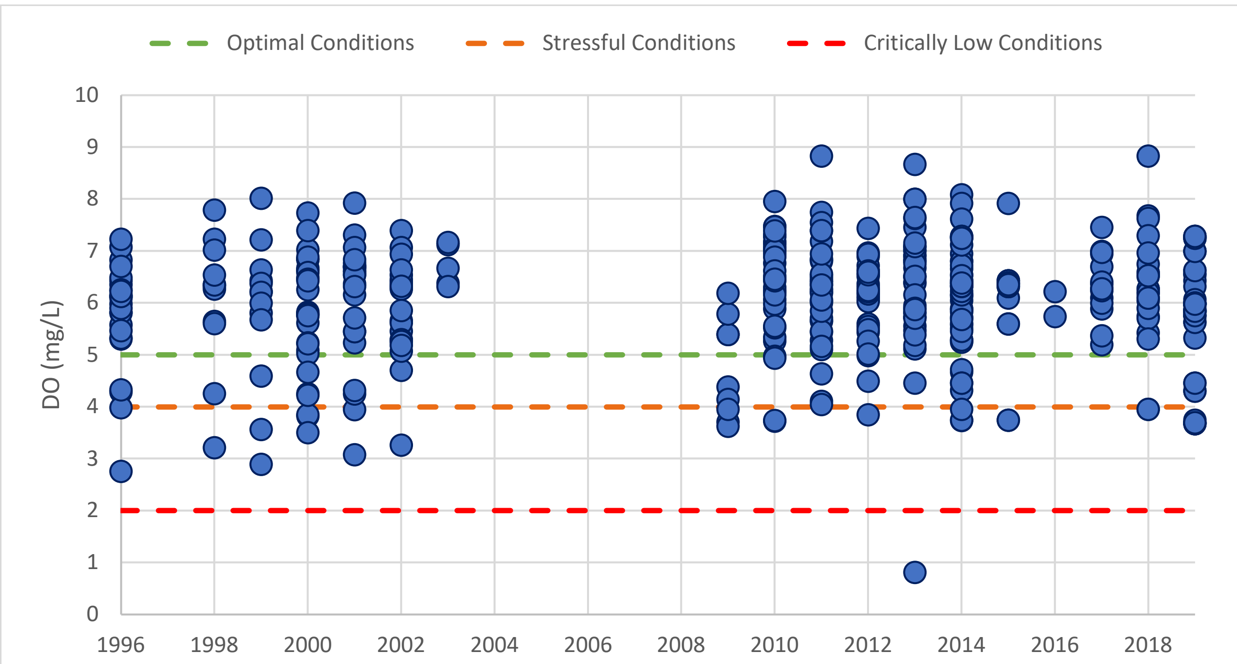

Figure 7-6: Annual Distributions of Instantaneous DO Concentrations at BB02 (1996 – 2019)

Figure 7-7 shows the annual means for DO at BB02 from 1996 to 2019. No statistically significant trend was detected for either BB02 or SK02. The average DO concentration remained above the optimal threshold of 5.0 mg/L throughout the study period at BB02, except for 2009 where it dropped below optimal but remained above the stressful threshold. Although DO concentrations are optimal on average, it has importance to the bay's ecological health and shows instantaneous occurrences of stressful conditions as well as one violation of the critical threshold in the instantaneous data. Further investigation of these occurrences are beyond the scope of this study.

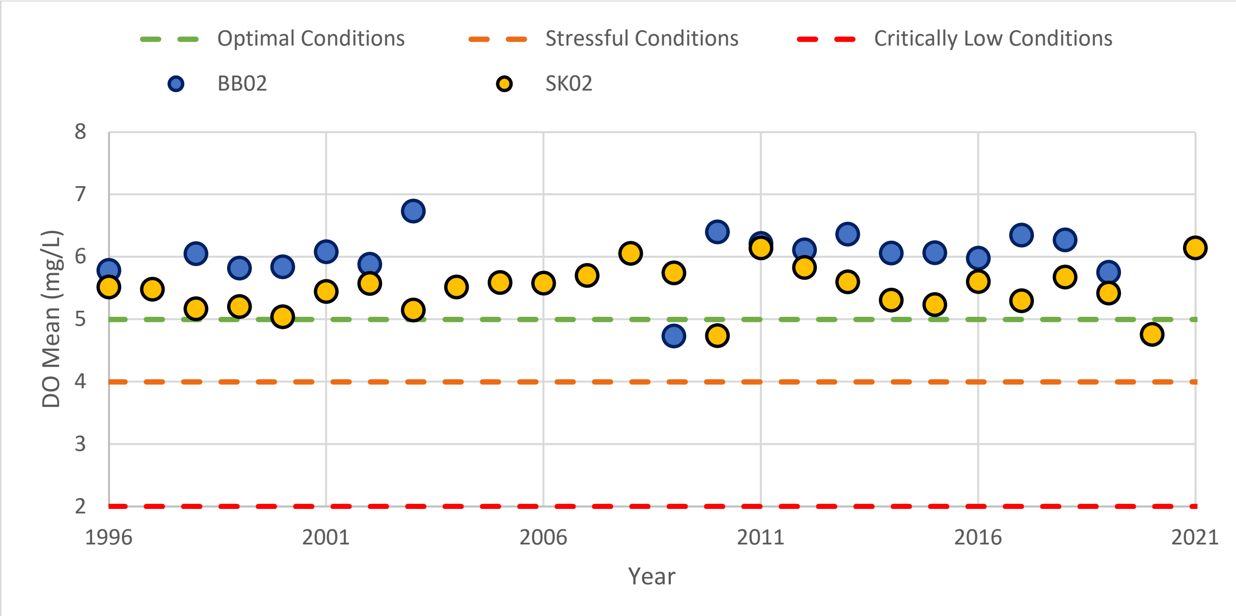

Figure 7-7: Annual Means of DO Concentrations at BB02 and SK02

7.1.6 Copper

Figure 7-8 shows available instantaneous measures of copper at BB02 and SK02 for the period 1996 to 2019. Cooper concentrations have exceeded the WQ criterion of 3.7 µg/L at BB02 five times since 1998, with a high of 26.8 µg/L in 2014 and most recently in 2019 with a recorded concentration of 4 µg/L. SK02 has not shown an exceedance of the WQ criterion during this period.

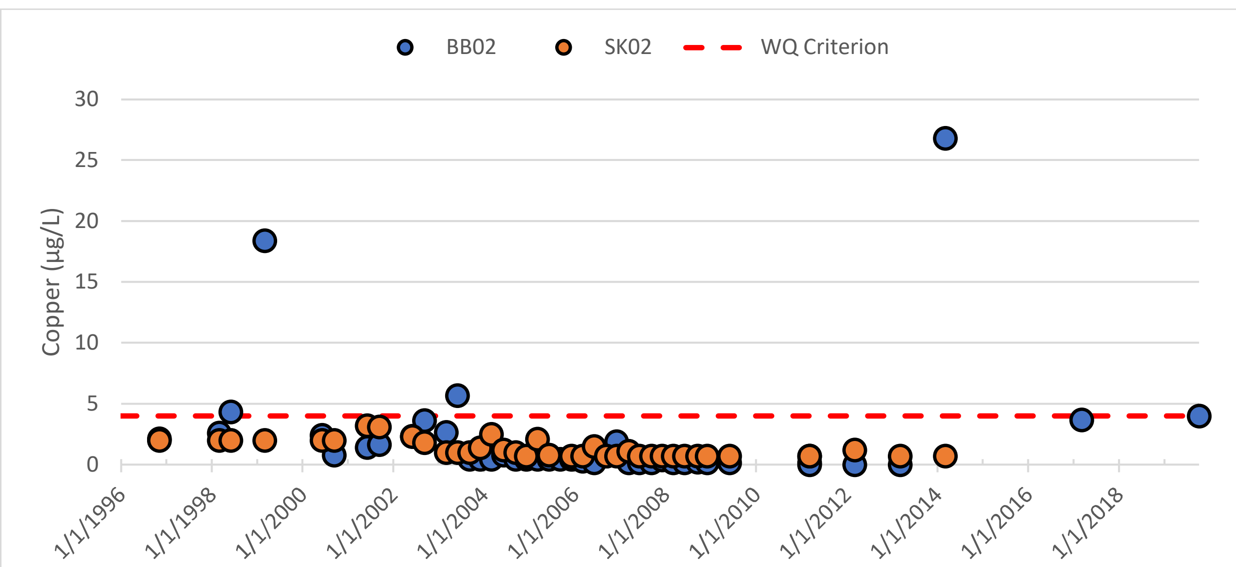

Figure 7-8: Instantaneous Copper Concentrations at BB02 and SK02

No statistically significant trend in copper concentrations was detected at BB02. Comparing instantaneous measures at BB02 with SK02 suggests that extreme concentrations at BB02 do not coincide with extreme concentrations at SK02 (3/1/1999 and 3/3/2014), and that there is likely no correlation between high canal flows and high copper concentrations in the bay.

7.1.7 Turbidity

The distribution of instantaneous turbidity measurements at BB02 is shown in **Figure 7-9**. The baseline is defined as the turbidity level associated with what has been defined in the literature as ecologically ideal conditions in Biscayne Bay (1.3 NTU, *MDC, 2022*). Within the last seven years, turbidity levels have exceeded the 1.3 NTU threshold at least once, although conditions have significantly improved compared to the 1996 to 2005 period. No statistically significant trend in turbidity levels was detected at BB02.

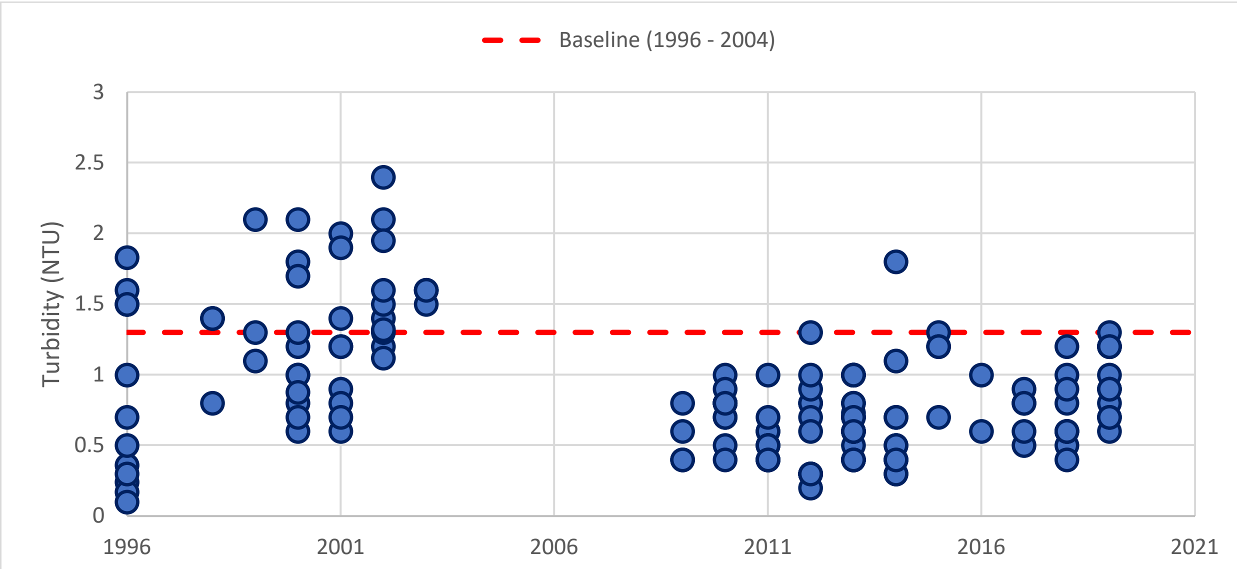

Figure 7-9: Annual Distributions of Instantaneous Turbidity Concentrations at BB02

7.2 C-9 Correlation Analysis Results

Table 7-2 reports the correlation coefficients between cumulative volumes from the S-29 (C-9 canal) and WQ variable concentrations in the bay at BB02 (refer to Variable Pair #1 in **Table 4-1**). For each WQ variable, the accumulation periods (days) associated with the highest coefficient of each type were reported. The accumulation period represents the number of days over which volumes are summed before a concentration measurement to obtain the cumulative volume. Variables in green font were determined to be adequate for regression analyses; those in red, inadequate. In the following sections, the statistical significance of correlation is shown graphically via a dotted line (insignificant, $p > 0.05$) and solid line (significant, $p < 0.05$).

Table 7-2: Correlation Analysis Results for Variable Pair #1 in the C-9

WQ Variable	Pearson r	Spearman r	Pearson Accumulation Period (days)	Spearman Accumulation Period (days)	Station ID
Salinity	-0.408	-0.518	5	4	BB02
Chlorophyll *a*	0.484	0.532	19	19	BB02
TN	0	0	NA	NA	BB02
TP	0	0.244	NA	58	BB02
Dissolved Oxygen	-0.288	-0.310	43	43	BB02
Turbidity	0.210	0.260	29	29	BB02
Copper	0	0	NA	NA	BB02

7.2.1 Salinity

Figure 7-10 shows Pearson and Spearman correlation coefficients for accumulation periods between 0 and 30 days at BB02 for salinity. Note that at BB02, coefficients of both types are statistically significant for all days. A minimum in the Pearson coefficient of -0.408 occurred on day 5. The Spearman coefficient exhibited a minimum on day 4 of -0.518. Salinity concentrations at BB02 exhibit a moderate negative association with freshwater inflow from the S-29. Freshwater inflows begin to influence salinity concentrations at BB02 on the same day of initial release, but this influence peaks after 4 to 5 days of accumulation.

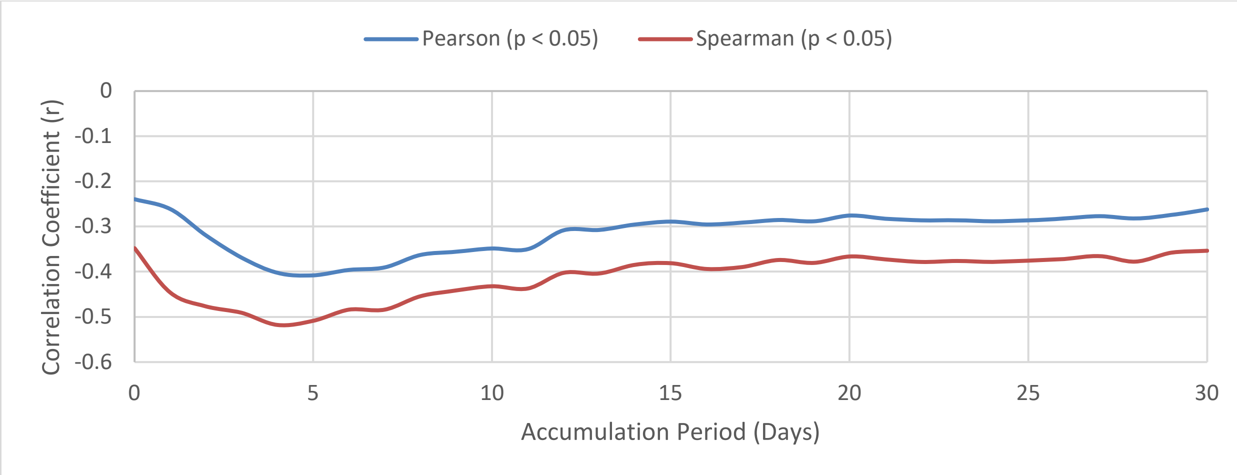

Figure 7-10: Pearson and Spearman Correlation Coefficients for Salinity versus Accumulation Period at BB02

7.2.2 Chlorophyll a

Pearson and Spearman correlation coefficients are shown in **Figure 7-11** at BB02 for chlorophyll *a*. Note that coefficients of both types are statistically significant for all accumulation periods. At BB02, there is agreement on day 19 between both types regarding the occurrence of the maximum coefficient. On day 19 the Pearson coefficient equaled 0.484 and the Spearman coefficient equaled 0.532. Chlorophyll *a* concentrations exhibit a moderate positive association with freshwater inflows from the S-29. The influence of canal flows is significant starting on the day of release and peaks at day 19, after which both correlation types become asymptotical.

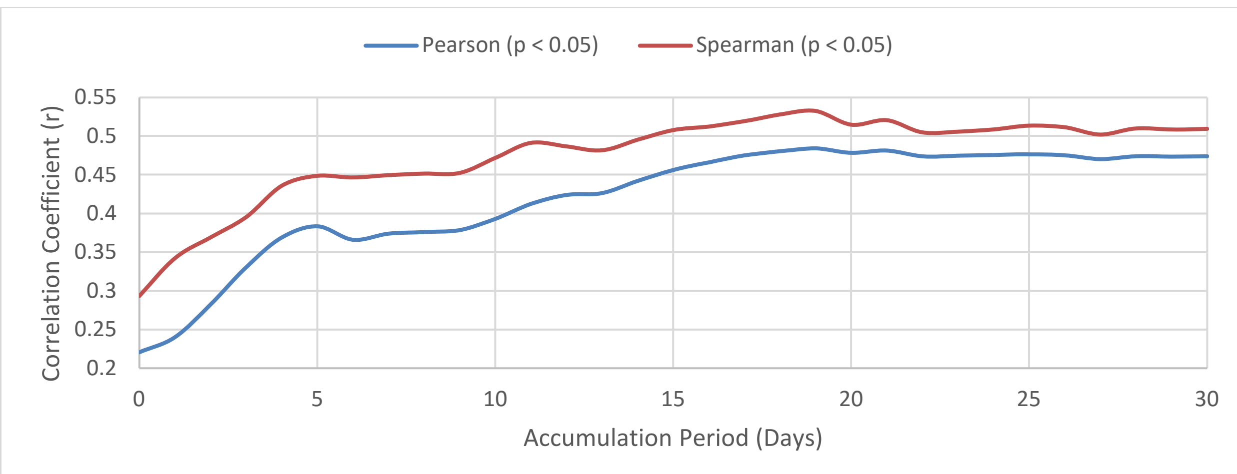

Figure 7-11: Pearson and Spearman Correlation Coefficients for Chlorophyll a versus Accumulation Period at BB02

7.2.3 Total Nitrogen

Pearson and Spearman correlation coefficients were computed for accumulation periods between 0 and 60 days. At no time did these coefficients exhibit magnitudes statistically different from zero, indicating TN concentrations at BB02 are uncorrelated with cumulative volume discharges from the S-29. Therefore, regression analyses between these variables could not be performed.

7.2.4 Total Phosphorus

For TP, Pearson and Spearman correlation coefficients were computed for accumulation periods between 0 and 60 days at BB02 (**Figure 7-12**). At no time during this period did the Pearson coefficient exhibit statistical significance. Statistical significance for the Spearman coefficient manifested on day 28, peaking on day 58 at a magnitude of 0.244 ($p < 0.05$). TP concentrations at BB02 are therefore correlated with cumulative volume discharges from the S-29 only on a rank-ordered basis (i.e., a non-linear relationship may exist). Because the Pearson coefficient exhibited no statistical significance, no regression analysis can be performed.

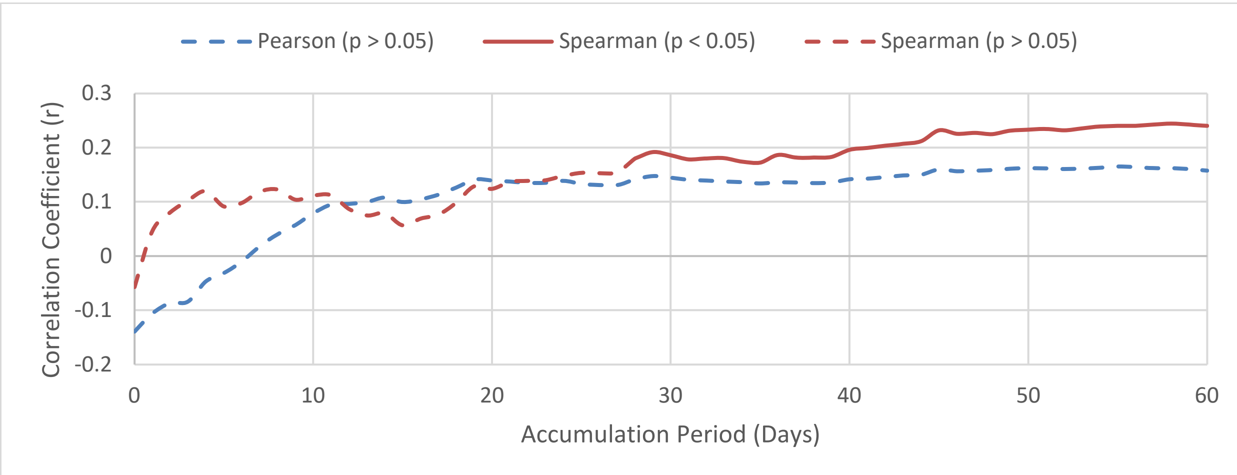

Figure 7-12: Pearson and Spearman Correlation Coefficients for TP versus Accumulation Period at BB02

7.2.5 Dissolved Oxygen

For DO, Pearson and Spearman correlation coefficients were computed for accumulation periods between 0 and 60 days at BB02 (**Figure 7-13**). For both correlation types, there occurs a statistically significant response in DO concentrations on day 0. Between days 0 and 11, the results alternate between significance and insignificance. At day 43 there is agreement for both correlation types on the occurrence of a minimum coefficient (-0.288 and -0.310 for Pearson and Spearman, respectively), after which time the strength of correlation diminishes. DO concentrations at BB02 exhibit a weak negative association with volumes from the S-29. Note that regression analyses are possible but only up to accumulation periods of 15 days due to the modeling data limitation. At this 15-day period, the Pearson coefficient equaled -0.180, which corresponds to a very weak negative association.

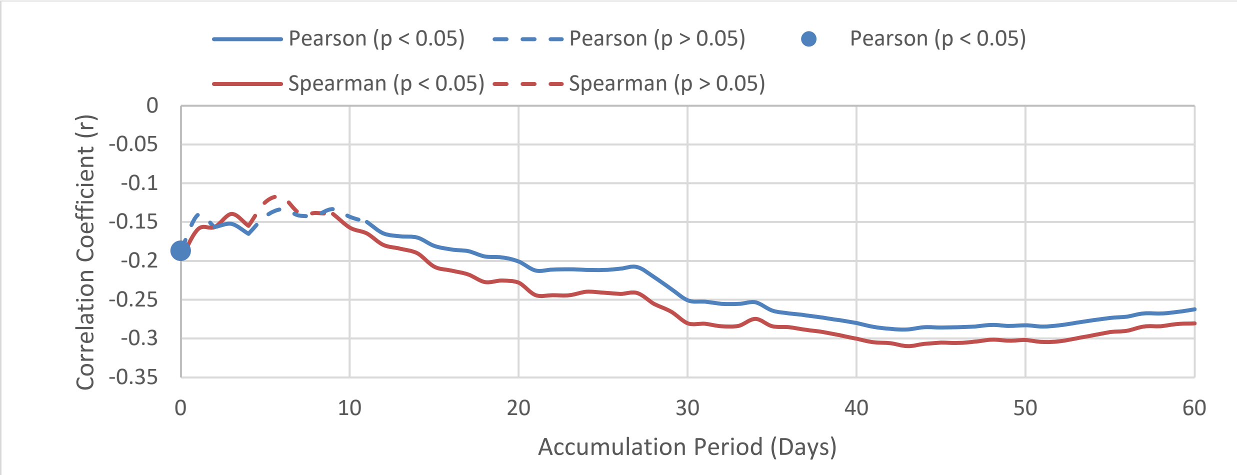

Figure 7-13: Pearson and Spearman Correlation Coefficients for DO versus Accumulation Period at BB02

7.2.6 Turbidity

For turbidity, Pearson and Spearman correlation coefficients were computed for accumulation periods between 0 and 60 days (**Figure 7-14**). A statistically significant signal in the Spearman coefficient occurs on day two, suggesting that for accumulation periods under 12 days there may exist a weak and undetectable association between turbidity at BB02 and S-29 flows. Statistical significance for the Pearson coefficient manifests beginning on day 16, and the coefficient peaks on day 29 at 0.210, indicating a weak positive association between turbidity and S-29 flows. The Spearman coefficient also peaks on day 29 at a magnitude of 0.260, bolstering evidence of a weak positive association. Because no occurrence of statistical significance in the Pearson coefficient occurs before day 16, no regression analyses can be performed.

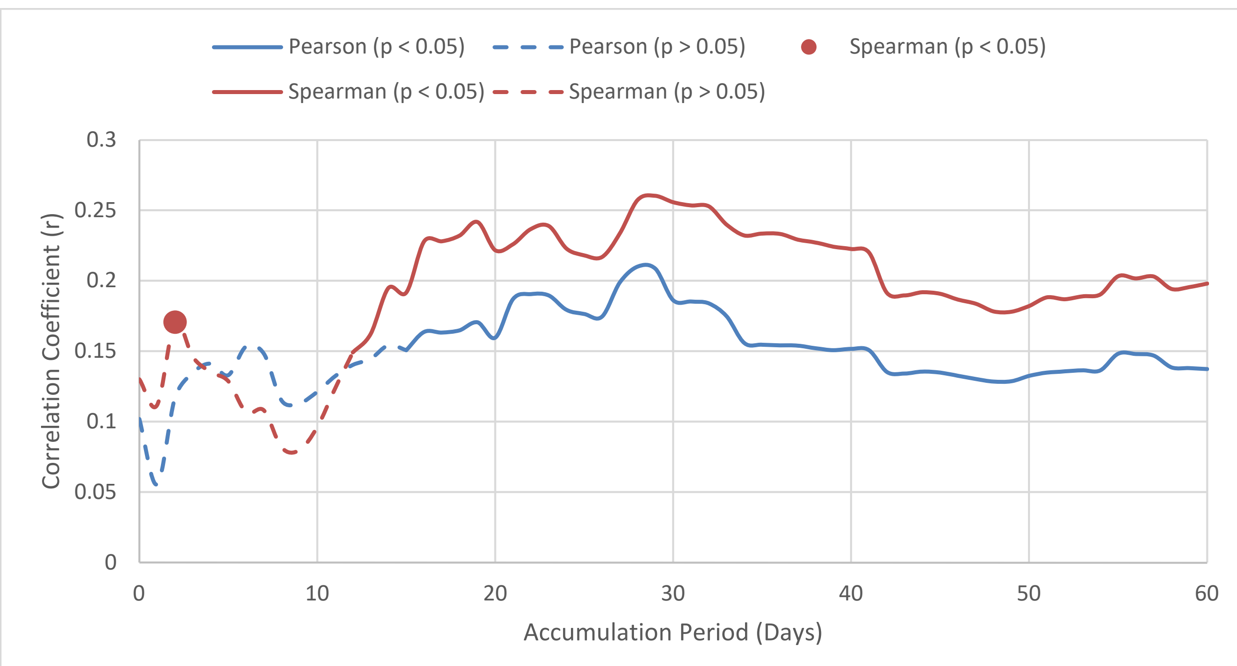

Figure 7-14: Pearson and Spearman Correlation Coefficients for Turbidity at BB02

7.2.7 Copper

For Copper, Pearson and Spearman correlation coefficients were computed for accumulation periods between 0 and 60 days. At no time did these coefficients exhibit magnitudes statistically different from zero. Copper concentrations at BB02 were determined to be uncorrelated with cumulative volume discharges from the S-29, and therefore regression analyses between these variables cannot be performed.

7.3 C-9 Regression Analyses Results

Table 7-3 provides a results summary of the regression analyses performed on WQ variable concentrations at BB02 (represented by the variable y) and cumulative volume discharges (represented by the variable V) at the S-29. Standard errors of the estimate follow the symbol '$\pm$', allowing for the construction of the 95% confidence for the response variable.

Table 7-3: Regression Results for the NNB-A Cumulative Volume Analyses

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

7.3.1 Salinity

The relationship between salinity concentrations at BB02 and 5-day cumulative volumes from the S-29 is shown in **Figure 7-15**. The coefficient of determination equaled 0.17, indicating that 17% of the variance in salinity concentrations is explained by 5-day cumulative volume discharges. The salinities shown in **Figure 7-15** are characteristic of three separate salinity regimes: (i) mesohaline (5 – 18 ppt); (ii) polyhaline (18 – 30 ppt); and (iii) euhaline (30 – 40 ppt). **Figure 7-1** shows that, on average, conditions at BB02 are consistent with a polyhaline regime. Measures of salinities in the mesohaline region likely coincide with instances of high freshwater input.

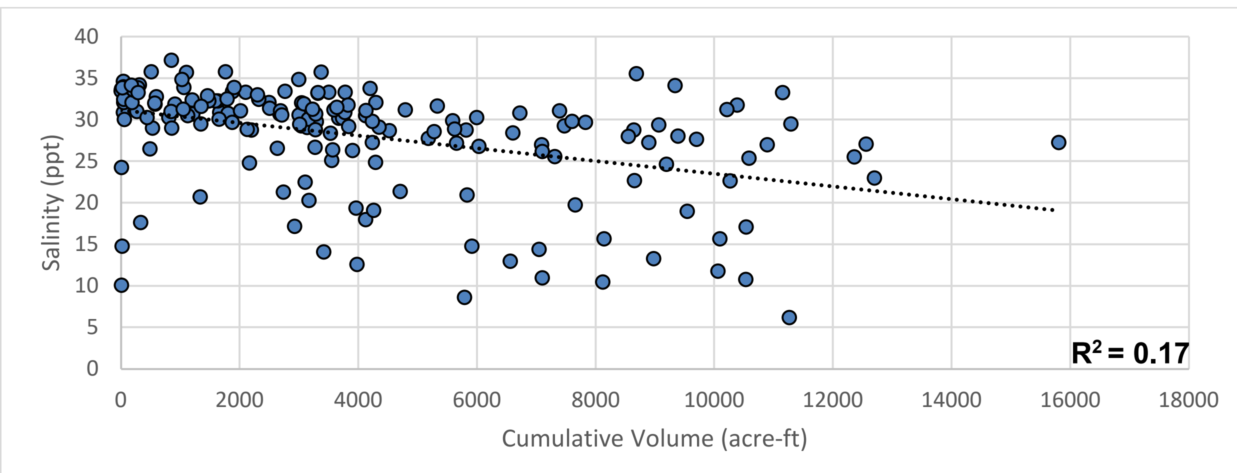

Figure 7-15: Salinity Concentrations at BB02 against 5-day Cumulative Volumes from S-29

Figure 7-16 shows projected salinity concentrations at BB02 for the modeling scenarios outlined in **Table 4-1**. At BB02, projections indicate that the scenarios are mixed between polyhaline and mesohaline salinity regimes. Increasing return period increases the number of scenarios that project a shift from a polyhaline to a mesohaline state.

At BB02, for all return periods, M2C-SLR1 is projected to result in lower salinity levels relative to M0-SLR0 (Existing Conditions), while the M0 scenarios with non-zero SLR are projected to result in higher salinity levels relative to M0-SLR0.

For the 5-year storm, the M0 scenarios exhibit slightly higher salinity concentrations than scenarios with mitigation for fixed SLR. M2B and M2C scenarios exhibit lower salinity concentrations compared to M2A and M0. Among the M2X scenarios, M2A consistently presents the highest salinity concentrations, followed by M2B and M2C.

For higher return period storms, the differences in salinity between the M2X scenarios increase with increasing return period. For the 100-year storm, the trend slightly differs as M2A scenarios exhibit slightly higher salinity concentrations than the corresponding M0 scenario for SLR1. M2B and M2C scenarios show lower concentrations compared to M0 for fixed SLR. Among the M2X scenarios for the 100-year storm return period, M2C-SLR1 results in the lowest salinity level, and M2C-SLR2 exhibits a lower salinity compared to M0-SLR0.

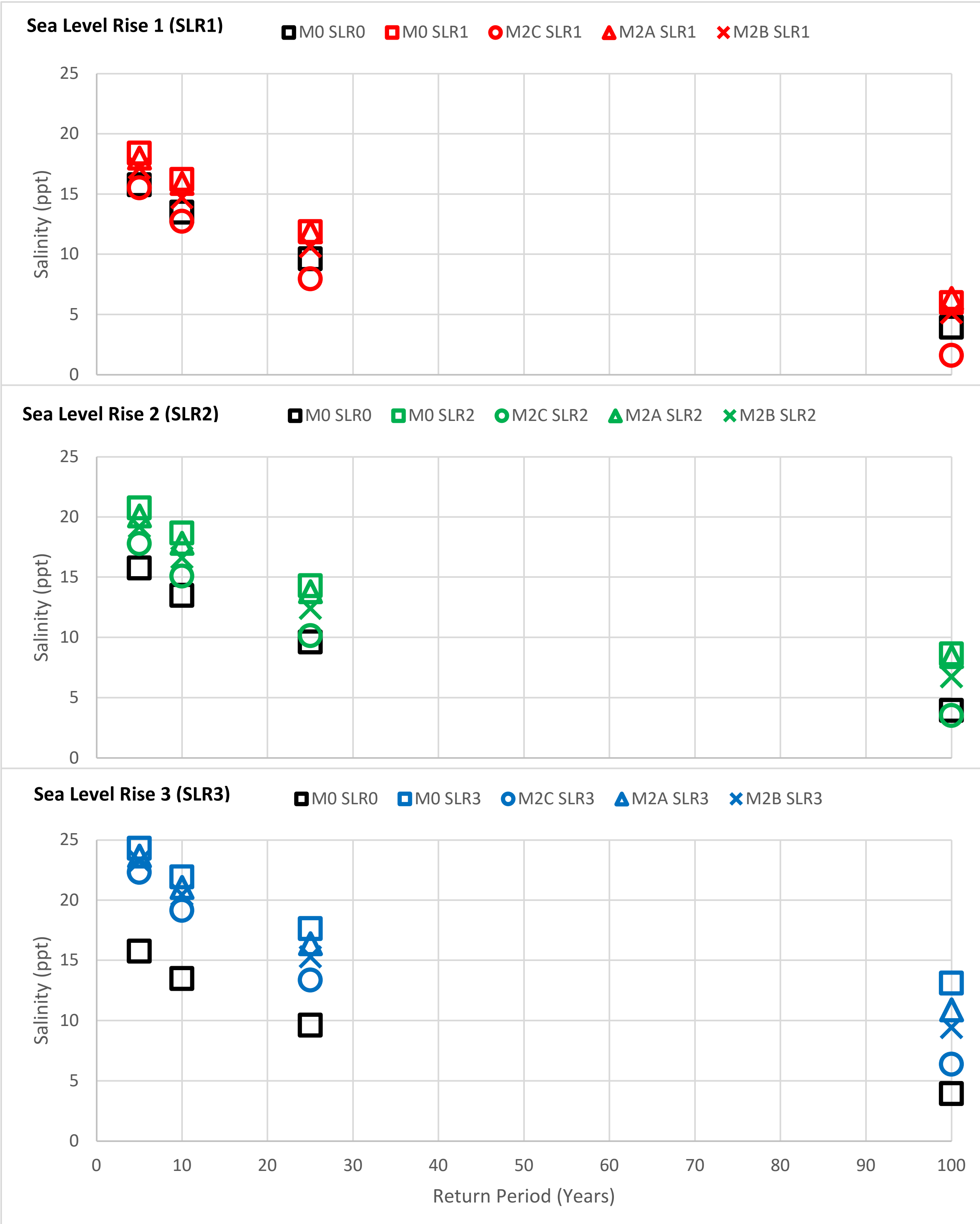

Figure 7-16: Projected Salinity Concentrations at BB02 for All Modeling Scenarios

7.3.2 Chlorophyll a

Chlorophyll *a* concentrations are plotted against 15-day cumulative volumes from the S-29 in **Figure 7-17**. At BB02, the coefficient of determination equaled 0.21, indicating that 21% of the variance in chlorophyll *a* concentrations is accounted for by the accumulation of water from the C-9 over a 15-day period. Note that 45% of concentrations equal or exceed 4 µg/L at BB02, which is characteristic of a mesotrophic system. Hence, water volume input from the C-9 is likely a significant (moderate, positive) driver of phytoplankton growth near BB02.

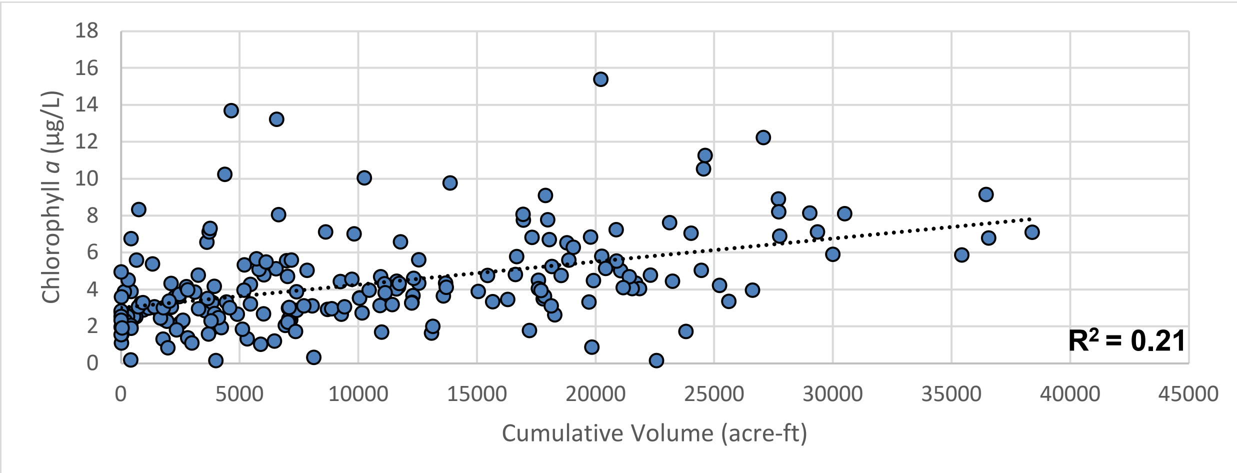

Figure 7-17: Chlorophyll a Concentrations at BB02 against 15-day Cumulative Volumes from S-29

Figure 7-18 shows projected chlorophyll *a* concentrations at BB02 for the modeling scenarios outlined in **Table 4-1**. For all return periods and of all scenarios, M2-SLR1 is projected to result in the greatest increase in chlorophyll *a* concentrations at BB02 and is the only one to exceed M0-SLR0 baseline conditions. All other scenarios, however, project a diminished effect compared to M0-SLR0 (Existing Conditions). Only M0-SLR3 (5-year storm) is projected to result in chlorophyll *a* concentrations below 4 µg/L (orange dashed line), and all scenarios would exceed the NNC of 1.7 µg/L.

Figure 7-18: Projected Chlorophyll a Concentrations at BB02 for All Modeling Scenarios

For the 5-year storm, the M2A scenarios exhibit lower chlorophyll a concentrations than M0-SLR0. M2B and M2C scenarios project higher chlorophyll *a* concentrations compared to M0 and M2A for fixed SLR. Among the M2X scenarios, M2C consistently presents the highest chlorophyll a concentrations, followed by M2B and M2A.

For the 10- and 25-year storm return periods, both M2B and M2C scenarios have higher concentrations compared to M0 and M2A for fixed SLR. Among the M2X scenarios, M2C has the highest chlorophyll *a* concentrations, followed by M2B and M2A.

For the 100-year storm return period, M2B and M2C scenarios show higher concentrations compared to M0 and M2A for fixed SLR. Among the M2X scenarios, M2C-SLR1 results in the highest chlorophyll *a* level.

7.3.3 Dissolved Oxygen

Figure 7-19 shows the relationship between DO concentrations and 15-day cumulative volumes from the S-29. At BB02, a coefficient of determination of 0.03 indicated that only 3% of the variance in DO concentrations is explained by 15-day cumulative volumes.

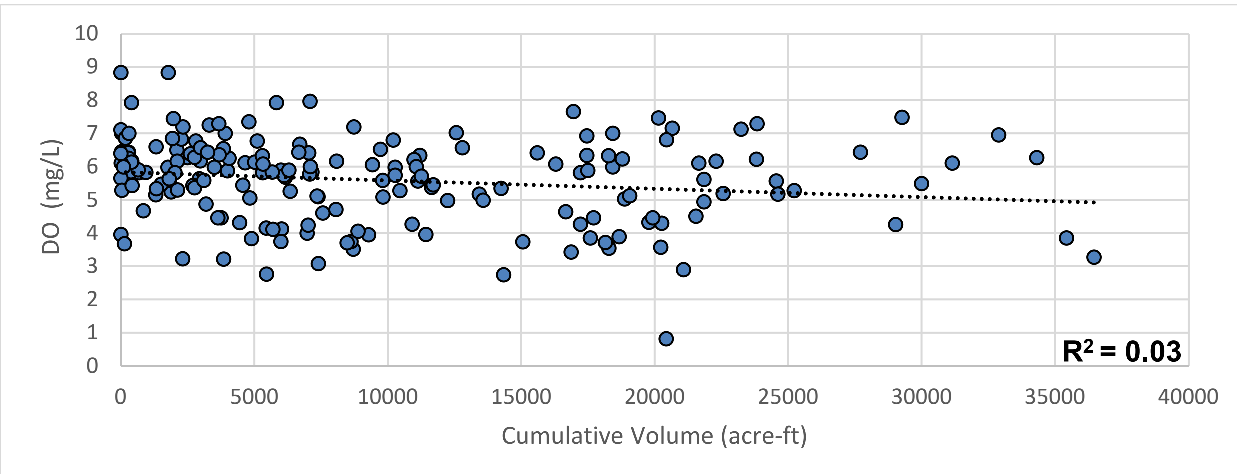

Figure 7-19: DO Concentrations at BB02 against 15-day Cumulative Volumes from S-29

The inverse relationship between DO concentrations and cumulative volume may be due to increased nutrient loadings associated with higher volume discharges at the structures. These increased nutrient loadings may cause excessive aquatic plant and algal growth in North Biscayne Bay. On cloudy days and at night these organisms consume oxygen via respiration, thereby decreasing DO levels in the bay. As these organisms die and decompose, the bacterial breakdown consumes dissolved oxygen, further depleting oxygen in the water column.

One method to evaluate whether excessive aquatic plant and algal growth may be causing decreased DO concentrations is to investigate whether depressed DO levels are associated with increased concentrations of chlorophyll *a*. **Figures 7-20** displays the relationship between DO and chlorophyll *a* concentrations measured on the same day at BB02.

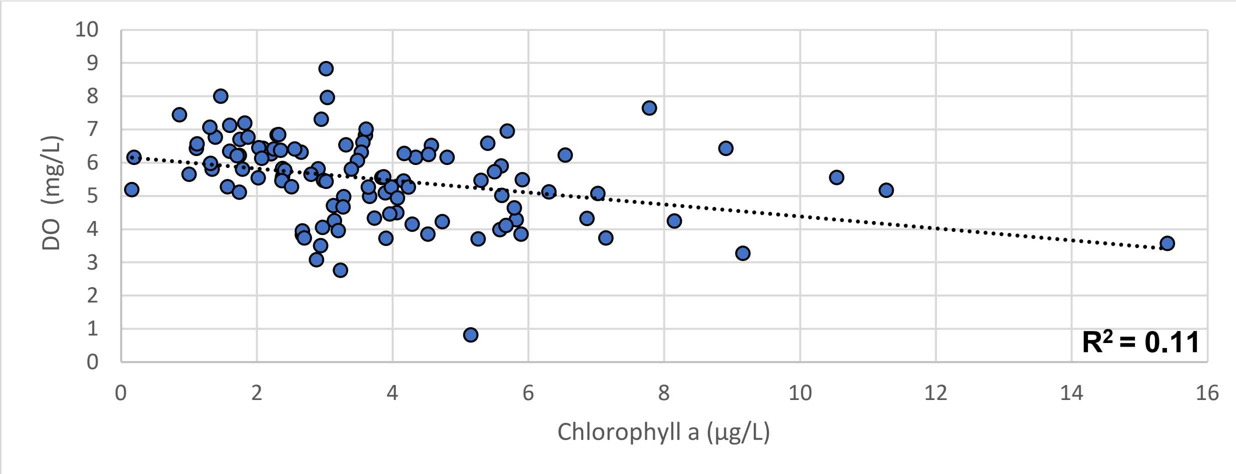

Figure 7-20: DO Concentrations Against Chlorophyll a Concentrations at BB02

A correlation coefficient of -0.33 was computed, indicating that there exists a weak negative association between DO and chlorophyll *a* concentrations at BB02. Hence, chlorophyll *a* levels account for 11% of the variance in DO concentrations. This suggests that the increased presence of phytoplankton in part drives the depletion of DO levels. Aquatic plants and other microorganisms such as attached macro-algae and drift macro-algae may also be in competition for DO. Other factors, however, are likely to be more significant than chlorophyll *a* in influencing DO concentrations, given the weakness of correlation.

Figure 7-21 shows projected DO concentrations at BB02 for the modeling scenarios outlined in **Table 4-1**. At BB02, optimal conditions for fish (above 5 mg/L— green dashed line) are achieved for every scenario for the 5- and 10-year storms. M2C-SLR1 is the only scenario projected to result in lower DO levels relative to the M0-SLR0 baseline scenario.

For the 5-year storm return period, the M2A scenarios exhibit slightly higher DO concentrations compared to M0-SLR0. M2B and M2C scenarios project lower DO concentrations compared to M0 for fixed SLR. Among the M2X scenarios, M2A consistently presents the highest DO concentrations, followed by M2B and M2C. Among the M2X scenarios for the 100-year storm return period, M2A-SLR1 results in the highest DO level, and M2C-SLR1 results in the lowest DO level.

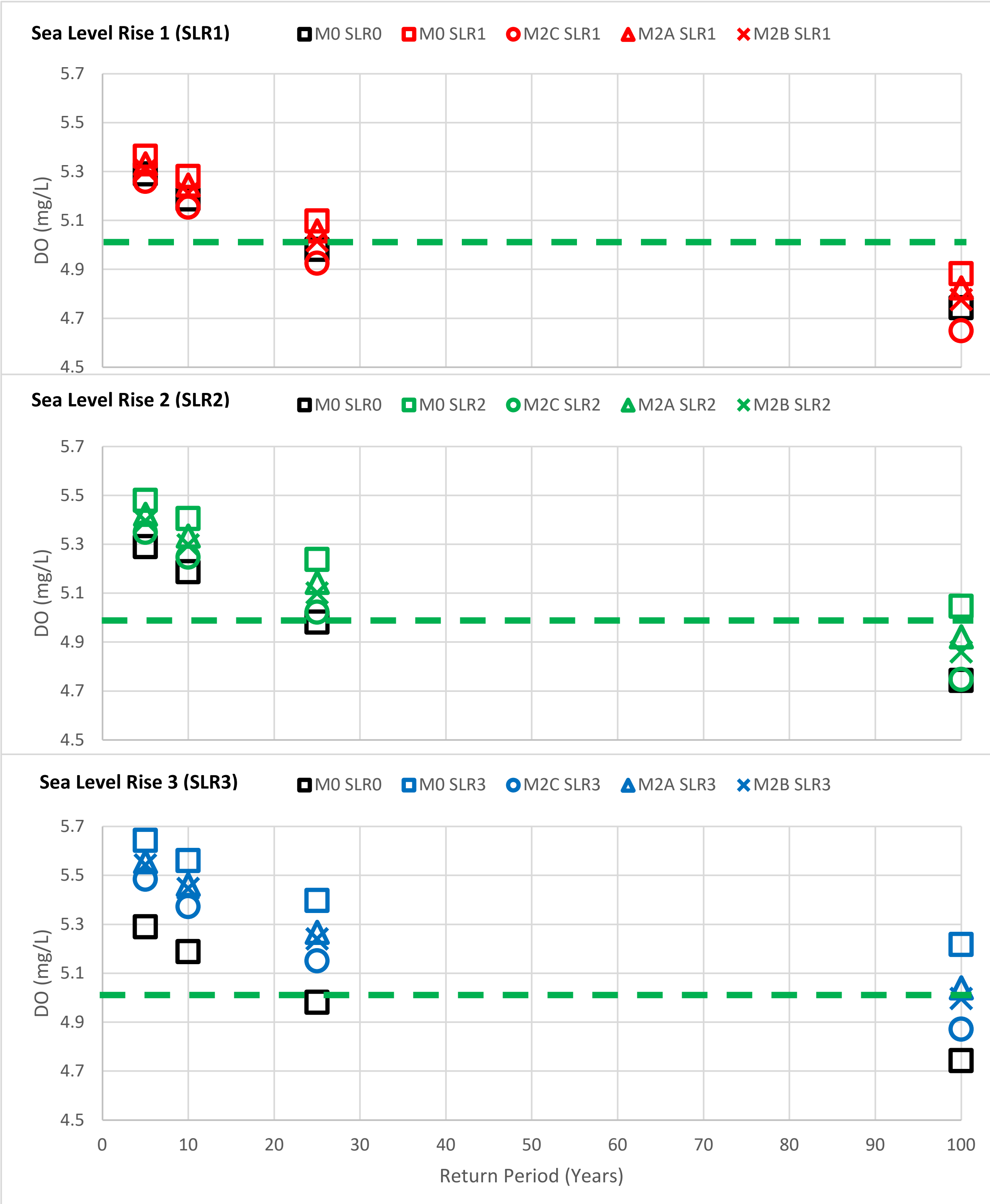

Figure 7-21: Projected DO Concentrations at BB02 for All Modeling Scenarios

7.4 NNB-A (C-9) Cumulative Volume Analysis Conclusions

Sections 7.2 and **7.3** demonstrated the feasibility of establishing useful regression relations between cumulative volume discharges from the C-9 canal and WQ parameter concentrations in the bay as the response variables. It was shown that the peak time of response (determined by the accumulation period where the maximum/minimum correlation coefficient is observed) varies among parameters, even at a fixed location. Salinity, for instance, exhibits a maximum response to cumulative volume inputs at BB02 after 4 to 5 days, while chlorophyll *a*, at that same location, exhibits a maximum response after 19 days. This difference is due to the nature of the variables in question. Salinity concentrations at BB02 reflect almost immediately the injection of freshwater to its vicinity, while the area surrounding BB02 must first assimilate the cumulative load of nutrients discharged from the canals, which are then taken up by phytoplankton and other organisms, causing a lag between times of initial canal discharge and the manifestation of chlorophyll *a.* Note that nutrient uptake in the vicinity of BB02 is further complicated by the presence of a mangrove forest (along the Oleta River) that acts as a sink to nitrogen/phosphorus prior to entering the bay. These mangroves likely distort the signal of nutrient concentration measurements at downstream WQ stations (e.g., BB02).

Table 7-4 summarizes the results of the correlation analysis between cumulative volume and several WQ variables for NNB-A. Refer to **Table 4-2** for descriptions of the strength of correlation and the color-coding key.

Table 7-4: NNB-A Correlation Analysis Results

WQ Variable	Max Pearson r	Max Spearman r	Station ID
Salinity	-0.41	-0.52	BB02
Chlorophyll *a*	0.48	0.53	BB02
Dissolved Oxygen	-0.29	-0.31	BB02

Note: Correlation Analyses were conducted only for variables that were determined to be COCs or flagged for further study.

Tables 7-5 to **7-8** summarize the results of the WQ analysis for NNB-A. For each variable and scenario, the percent change in WQ projections relative to existing conditions (M0-SLR0) was computed. Note that values highlighted in green indicate instances of short term WQ improvements; those in red, short term negative impacts to WQ; and those in orange are undetermined due to the uncertainty of impacts to the environment. The impact of changes in salinity concentrations on the local ecology, for instance, is not well understood. In addition, if the absolute value of a percentage change was computed to be less than or equal to 2%, the potential impact of the result was considered as undetermined due to statistical uncertainty of the regression.

Legend:

Undetermined
Short Term Negative Impact
Short Term WQ Improvement

Table 7-5: Results for the 5-Year 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	16.8	31.7	54.3	14.2	27.6	50.2	8.9	21.8	47.6	-1.5	12.9	41.5
Chlorophyll a	-6.3	-16.6	-30.9	-3.7	-11.7	-23.3	-1.6	-9.3	-22.1	2.6	-5.1	-17.0
DO	1.5	3.7	7.7	0.9	2.6	5.0	0.1	1.8	4.5	-0.4	1.2	3.8

Table 7-6: Results for the 10-Year 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	20.1	38.3	62.4	17.8	32.0	56.0	8.8	23.1	51.5	-5.6	11.8	41.9
Chlorophyll a	-7.4	-17.4	-29.9	-4.5	-11.7	-22.1	-2.0	-8.9	-20.7	2.7	-4.8	-14.8
DO	1.8	4.3	8.3	1.2	2.8	5.2	0.1	1.8	4.6	-0.6	1.2	3.6

Table 7-7: Results for the 25-Year 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 7-8: Results for the 100-Year 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**

The following summarizes observations from **Tables 7-5** to **7-8**.

- Compared to M0-SLR0, the M2A, M2B, and M2C scenarios exhibit differences in water quality variable outcomes (salinity, chlorophyll *a*, and DO).

<u>Salinity</u>

- Compared to M0-SLR0, the M2A, M2B, and M2C scenarios exhibit decreases in salinity, with the largest decrease observed in M2C-SLR1 during the 100-year storm return period.
- Salinity increases with increasing sea level rise (SLR1, SLR2, SLR3) for a given mitigation strategy.

<u>Chlorophyll *a*</u>

- The M2C-SLR1 scenario during the 100-year storm return period shows the largest increase in chlorophyll *a*, which is likely to cause short term negative impacts to chlorophyll *a* for all storm periods.
- Of the mitigation strategies, M2A-SLR3 scenario during the 5-year storm return period shows the largest decrease in chlorophyll *a,* which indicates the largest WQ benefit.
- Chlorophyll *a* concentrations decrease with increasing sea level rise (SLR1, SLR2, SLR3) for a given mitigation strategy.

<u>Dissolved Oxygen</u>

- The M2C-SLR1 scenario during the 100-year storm return period shows the largest decrease in DO, but the WQ impact for all storm periods is undetermined.
- Of the mitigation strategies, M2A-SLR3 scenario during the 5-year storm return period shows the largest increase in DO*,* which indicates the largest WQ benefit.
- DO concentrations increase with increasing sea level rise (SLR1, SLR2, SLR3) for a given mitigation strategy.

Generally, the M2C scenarios are associated with more frequent short term negative or uncertain impacts, while M2A scenarios are associated with less frequent negative impacts. However, specific trends may vary depending on the variable and sea level rise scenario being considered.

8.0 C-8 RESULTS AND MITIGATION SCENARIO IMPACTS ON WATER QUALITY

8.1 C-8 Time Series Results

Table 8-1 summarizes the Mann-Kendall test results for each COC at BB09 and at BS04. Note that the symbol '+' denotes a temporally increasing trend, '-' denotes a temporally decreasing trend, and 0 denotes no trend.

Table 8-1: Mann-Kendall Test Results for COCs at BB09 and BS04

WQ Parameter	Trend	Significance	Time Series Type	Station ID
Salinity	0	$p > 0.05$	Annual Mean	BB09
Salinity	0	$p > 0.05$	Annual Minimum Series	BB09
Chlorophyll a	0	$p > 0.05$	Annual GM	BB09
TN	+	$p < 0.05$	Annual GM	BB09
TN	0	$p > 0.05$	Annual Maximum Series	BB09
TN	-	$p < 0.05$	Annual GM	BS04
TP	+	$p < 0.05$	Annual GM	BB09
TP	0	$p > 0.05$	Annual GM	BS04
Dissolved Oxygen	+	$p < 0.05$	Annual Mean	BB09
Dissolved Oxygen	0	$p > 0.05$	Annual Mean	BS04
Turbidity	0	$p > 0.05$	Annual Mean	BB09

8.1.1 Salinity

Annual salinity concentration means for the period 1996 to 2021 at BB09 are shown in **Figure 8-1**. These means range from 29 to 33 ppt, which is consistent with a euhaline salinity regime, typical of the marine environment.

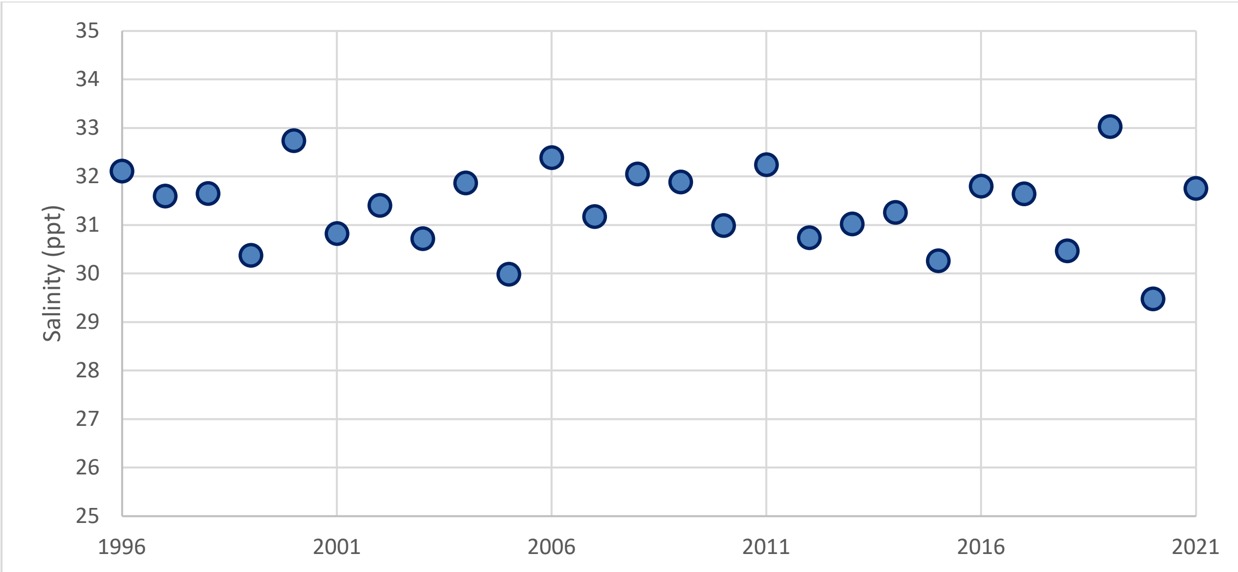

Figure 8-1: Annual Series of Average Salinity Concentrations at BB09

The AMS of salinity concentrations at BB09 is shown in **Figure 8-2**. No statistically significant trend was detected for this series. In 2005, there occurred a minimum concentration of 3.7 ppt. Note that several tropical cyclones passed over South Florida in 2005. No statistically significant trends in salinity levels were detected at BB09 for both the annual average and annual minimum series.

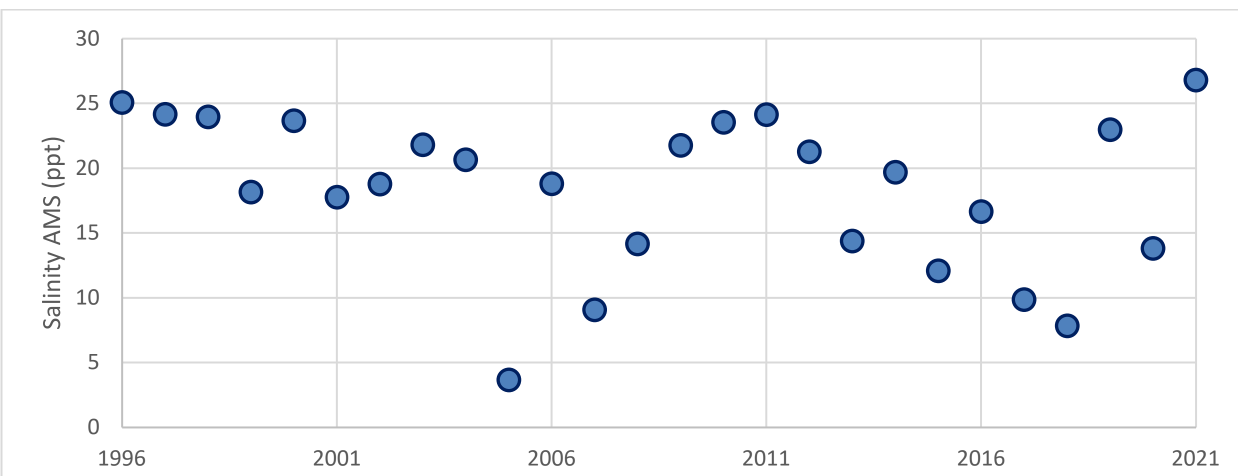

Figure 8-2: Annual Minimum Series of Salinity Concentrations at BB09

8.1.2 Chlorophyll a

Figures 8-3 shows annual GMs for chlorophyll *a* for the period 1996 to 2021 at BB09, plotted against the WQ criterion of 1.7 µg/L. Note that measures of chlorophyll *a* regularly exceed the criterion at BB09, especially from 2006 onwards. The WQ criteria was also exceeded twice in the last three years (2019 and 2020) for which data is available. These concentrations are typical of an oligotrophic system.

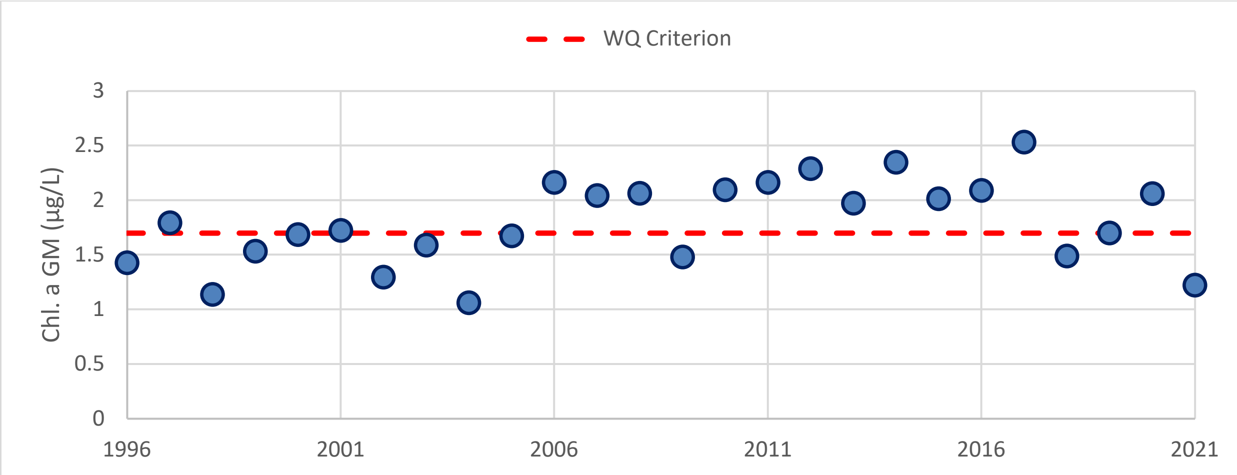

Figure 8-3: Annual GMs of Chlorophyll a Concentrations at BB09

No statistically significant trend in chlorophyll *a* levels was detected at BB09. This result is consistent with Chin (2020), who evaluated chlorophyll *a*, TN, and TP annual GMs at BB09 and found no significant trend in chlorophyll *a* concentrations between 2008 and 2018. Chin noted that, although TN and TP concentrations exhibited statistically significant increasing trends at BB09, their concentrations remain too low to significantly affect chlorophyll *a* concentrations.

Increasing trends in nutrient concentrations and none in chlorophyll *a* may be due to the nature of nutrient assimilation at the location of BB09. Phytoplankton, which produce chlorophyll *a*, may be in competition for nutrients with other organisms like attached and drift macro-algae, such that chlorophyll *a* levels remain depressed during a significant algal response (Fong et al. 1993; Harlin 1995; Nixon et al. 2001). The growth of these other algal populations can also negatively effect seagrass coverage negatively.

8.1.3 Total Nitrogen

Figure 7-4 shows annual GMs for TN for the period 1996 to 2021 at BB09 and BS04. In the last two years (2020 and 2021) the WQ criterion was exceeded at BB09, and a statistically significant increasing trend in annual TN GMs was detected. This result is consistent with Chin (2020), who analyzed this data from 2008 to 2018. A statistically significant decreasing trend was detected at BS04 ($p < 0.05$). This result suggests that factors other than C-8 canal TN loadings may be causing the increase in TN concentrations at BB09.

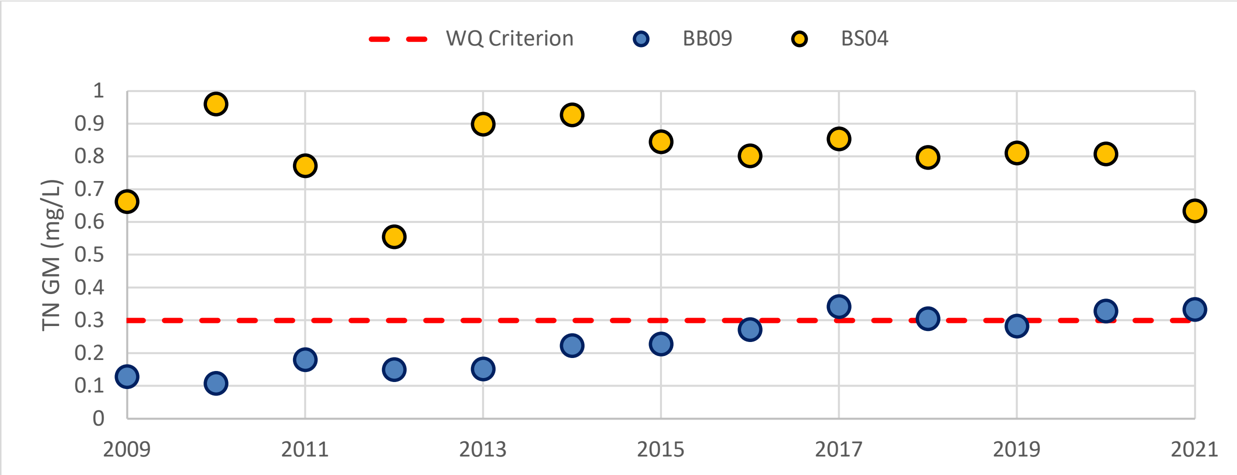

Figure 8-4: Annual GMs of TN Concentrations at BB09

8.1.4 Total Phosphorus

Figure 8-5 shows annual GMs for TP at BB09 and BS04 plotted against the WQ criterion of 0.012 mg/L. No WQ criterion exceedances have been recorded at BB09 between 2008 and 2018. Note that concentrations in the canal (BS04) are higher than concentrations in the bay (BB09) and frequently exceed WQ criterion. TP annual GMs at BB09 exhibited a statistically significant increasing trend ($p < 0.05$), while those at BB04 exhibited no statistically significant trend.

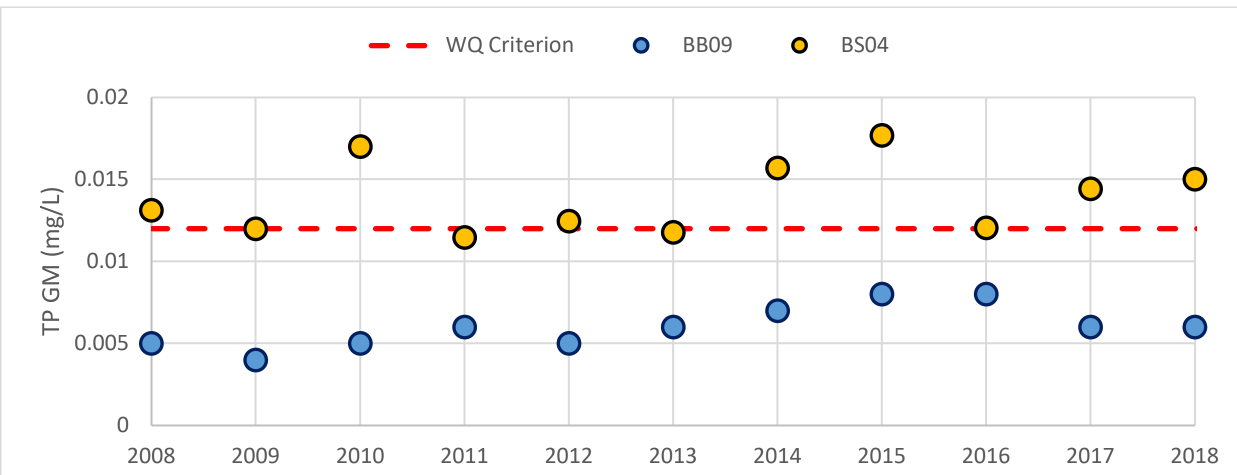

Figure 8-5: Annual GMs of TP Concentrations at BB09 and BS04

8.1.5 Dissolved Oxygen

The annual distributions of instantaneous DO concentrations are plotted at BB09 in **Figure 8-6** against general tolerance thresholds for fish (Francis-Floyd, 2019). At BB09, concentrations less than 5.0 mg/L comprise 8.0% of all data. Concentrations that lie between 2.0 and 4.0 comprise 1.2% of all data. Note that the critically low threshold of 2.0 mg/L has not been exceeded.

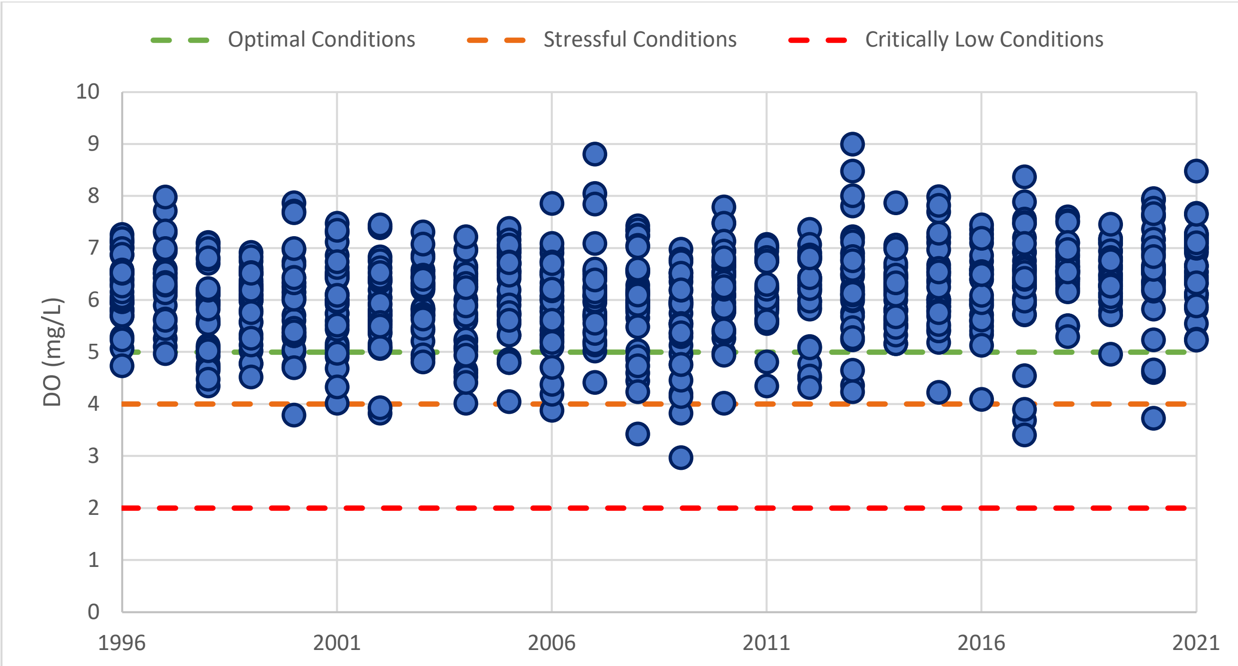

Figure 8-6: Annual Distributions of Instantaneous DO concentrations at BB09 (1996 – 2021)

Figure 8-7 shows the annual means for DO at BB09 from 1996 to 2021. A statistically significant increasing trend was detected at BB09. No statistically significant trend was detected at BS04. At BB09, the average DO concentration remained above the optimal threshold of 5.0 mg/L throughout the study period, while concentrations at BS04 were frequently below optimal.

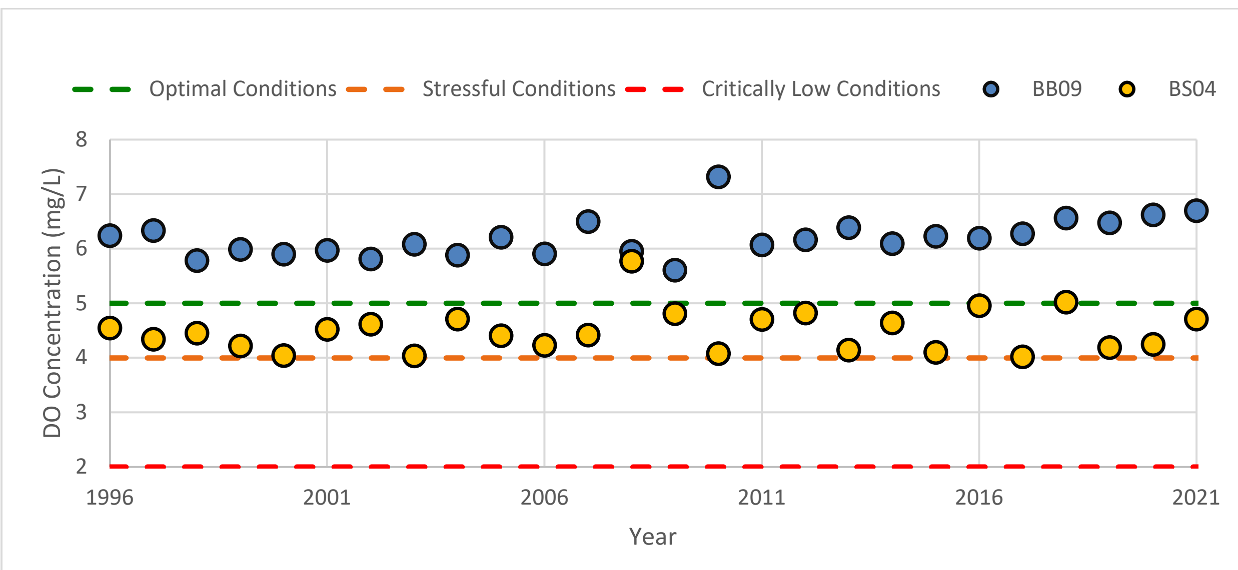

Figure 8-7: Annual Means of DO Concentrations at BB09

8.1.6 Turbidity

The distribution of instantaneous turbidity measurements at BB09 is shown in **Figures 8-8**. At BB09, in each of the last seven years, turbidity levels have exceeded the 1.3 NTU threshold at least once, although conditions have significantly improved compared to the 1996 to 2005 period.

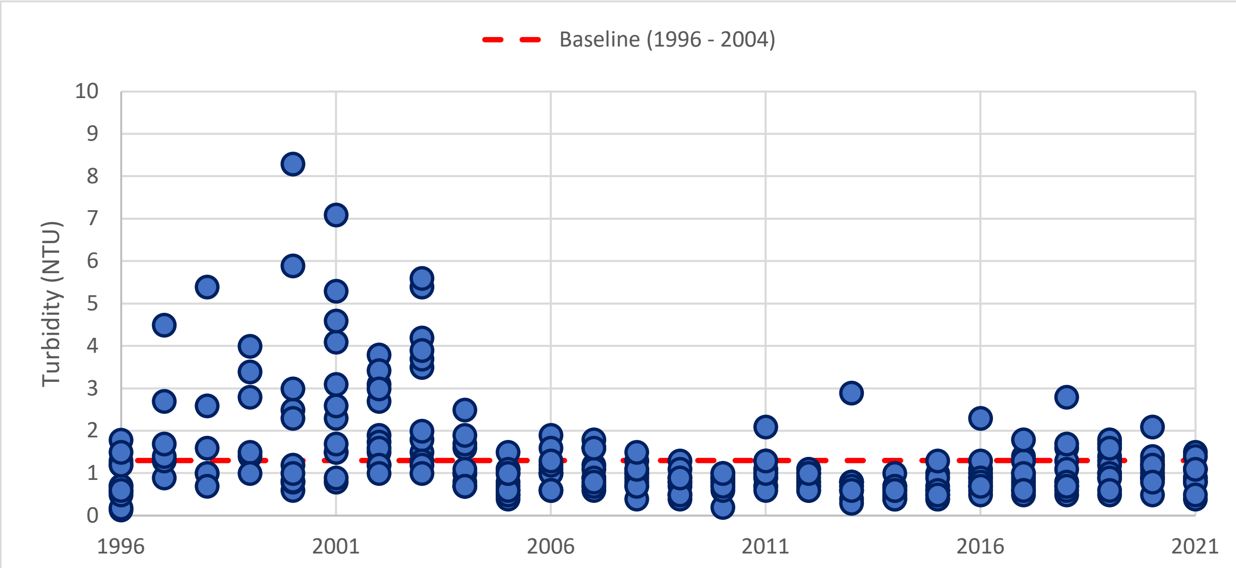

Figure 8-8: Annual Distributions of Instantaneous Turbidity Concentrations at BB09

8.2 C-8 Correlation Analysis Results

Table 8-2 reports the correlation coefficients between cumulative volumes from the S-28 and WQ variable concentrations in the bay (refer to Variable Pair #2 in **Table 4-1**). For each WQ variable, the accumulation periods (days) associated with the highest coefficient of each type were reported. The accumulation period represents the number of days over which volumes are summed before a concentration measurement to obtain the cumulative volume. Variables in green font were determined to be adequate for regression analyses; those in red, inadequate. In the following sections, the statistical significance of correlation is shown graphically via a dotted line (insignificant, $p > 0.05$) and solid line (significant, $p < 0.05$). Note that for TN, station BS01 was analyzed due to inconclusive results for station BB09.

Table 8-2: Summary of Correlation Analysis Results for Variable Pair #2 in the C-8

WQ Variable	Pearson r	Spearman r	Pearson Accumulation Period	Spearman Accumulation Period	Station ID
Salinity	-0.294	-0.464	5	26	BB09
Chlorophyll *a*	0.436	0.482	13	13	BB09
TN	0	0.283	NA	3	BB09
TN	0.660	0.707	39	39	BS01
TP	NA	NA	NA	NA	BB09
Dissolved Oxygen	-0.309	-0.389	15	11	BB09
Turbidity	0	0	NA	NA	BB09

8.2.1 Salinity

Figure 8-9 shows Pearson and Spearman correlation coefficients for accumulation periods between 0 and 30 days at BB09 for salinity. A minimum in the Pearson coefficient occurs on day 5, while Spearman coefficients decrease monotonically to day 30, where an asymptote is reached. Statistical significance in the Pearson coefficient manifests after one day of cumulative volume input from the S-28, while on a rank basis statistical significance is achieved on day 0. This suggests that the effect of continuous freshwater volume input from the S-28 on salinity concentrations peaks after 5 days of accumulation, after which time the effect of additional volume inputs remains significant but diminished. Salinity concentrations at BB09 exhibit a weak to moderate negative association with cumulative volumes from the S-28.

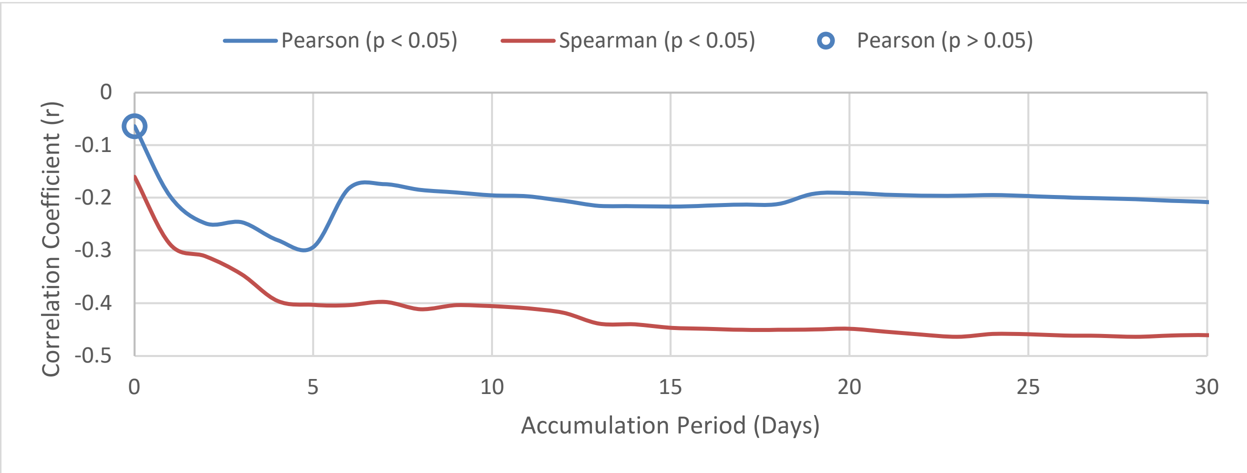

Figure 8-9: Pearson and Spearman Correlation Coefficients for Salinity versus Accumulation Period at BB09

8.2.2 Chlorophyll a

Pearson and Spearman correlation coefficients are shown in **Figure 8-10** at BB09 for chlorophyll *a*. Note that coefficients of both types are statistically significant for all accumulation periods. At BB09, for both the Pearson and Spearman coefficients, maximums of 0.436 and 0.482 occur, respectively, on day 13. At around day 4, for both correlation types, the rate of increase in correlation coefficients diminishes with increasing accumulation period for both correlation types. Hence, concentrations of chlorophyll a at BB09 exhibit a moderate positive association with cumulative volume inputs from the S-28.

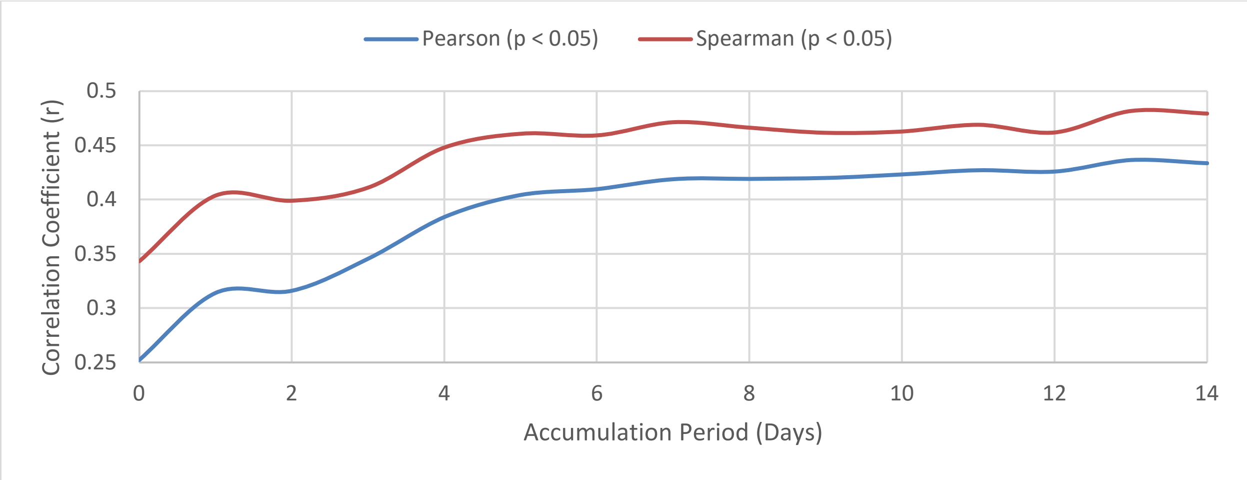

Figure 8-10: Pearson and Spearman Correlation Coefficients for Chlorophyll a versus Accumulation Period at BB09

8.2.3 Total Nitrogen

Pearson and Spearman correlation coefficients were computed for accumulation periods between 0 and 60 days. **Figure 8-11** shows Pearson and Spearman correlation coefficients for accumulation periods between 0 and 14 days at BB09. There was a lack of statistically significant correlation for both types, except on day 3 for the rank-ordered correlation. This potentially significant correlation led to the investigation of TN concentrations at WQ station BS01, which lies at the mouth of the C-8 canal, closer to the S-28 discharge point.

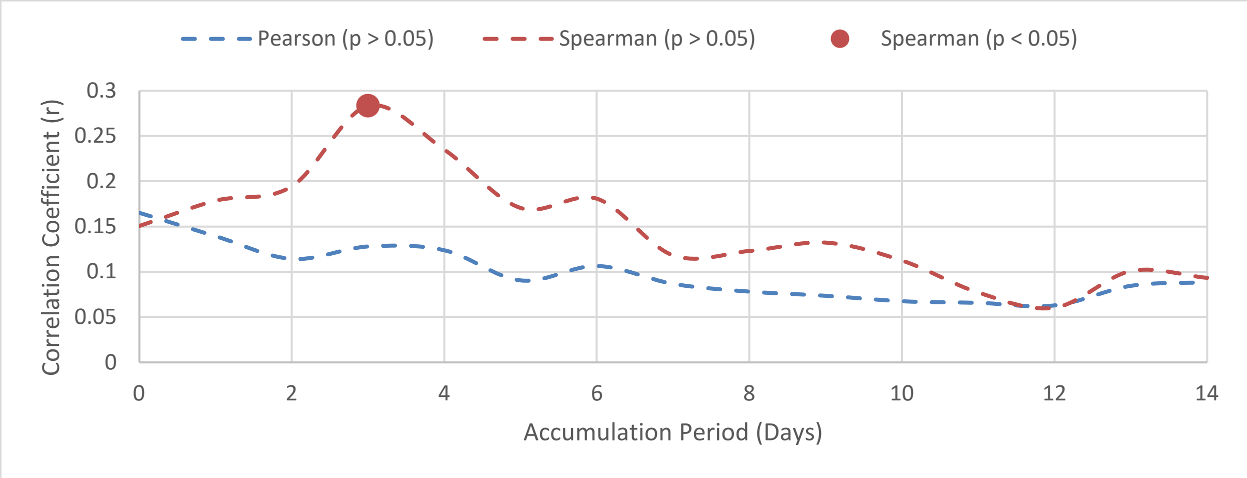

Figure 8-11: Pearson and Spearman Correlation Coefficients for TN versus Accumulation Period at BB09

Figure 7-23 shows Pearson and Spearman correlation coefficients for accumulation periods between 0 and 60 days at BS01. Within the first fifteen accumulation periods, a maximum in the Pearson coefficient of 0.567 occurred on day 3, while a global maximum of 0.660 occurred on day 39. A maximum in the Spearman coefficient of 0.707 occurs on day 39. Therefore, there exists a moderate to strong positive association between TN concentrations at BS01 and cumulative volume discharges from the S-28.

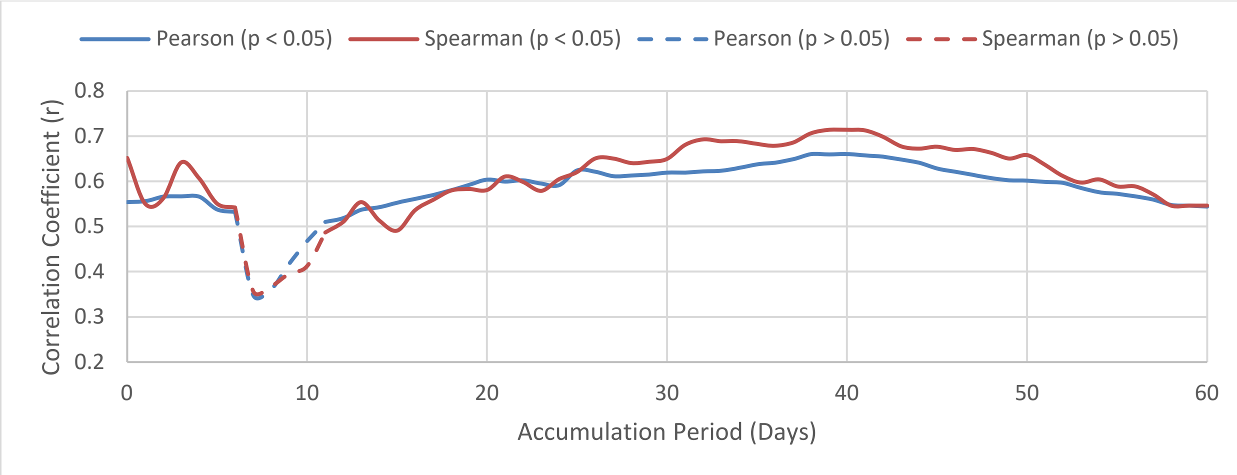

Figure 8-12: Pearson and Spearman Correlation Coefficients for TN at BS01

8.2.4 Total Phosphorus

Instantaneous TP data at BB09 was deemed insufficient for any correlation/regression analyses due to data gaps and imprecision in the available data. In addition, TP concentrations at BB09 have not exceeded the WQ criterion described by the time series in **Section 8.1.4**.

8.2.5 Dissolved Oxygen

For DO, Pearson and Spearman correlation coefficients were computed for accumulation periods between 0 and 60 days at BB09 (**Figure 8-13**). A minimum in the Pearson coefficient of -0.311 occurs on day 17, while a minimum in the Spearman coefficient of -0.389 occurs on day 11. Hence, DO concentrations at BB09 and cumulative volume inputs from the S-28 exhibit a weak negative association, and the maximum effect of cumulative volume inputs manifests between 11 to 17 days after the start of accumulation.

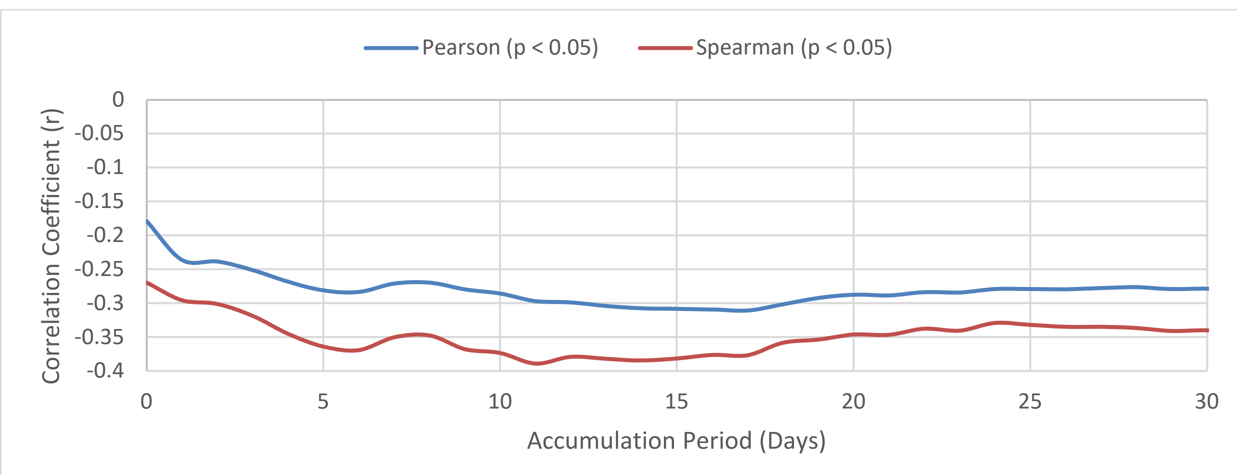

Figure 8-13: Pearson and Spearman Correlation Coefficients for DO versus Accumulation Period at BB09

8.2.6 Turbidity

For turbidity, Pearson and Spearman correlation coefficients were computed for accumulation periods between 0 and 60 days. At BB09, these coefficients never exhibited magnitudes statistically different from zero. Turbidity concentrations at BB09 are uncorrelated with cumulative volume discharges from the S-28, and therefore regression analyses between these variables cannot be performed.

8.3 C-8 Regression Analysis Results

Table 8-3 provides a results summary of the regression analyses performed on WQ variable concentrations at BB09 and BS01 (represented by the variable y) and cumulative volume discharges (represented by the variable V) at the S-28. Standard errors of the estimate follow the symbol '$\pm$', allowing for the construction of the 95% confidence for the response variable.

Table 8-3: Regression Results for the NNB-B Cumulative Volume Analyses

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

8.3.1 Salinity

The relationship between salinity concentrations at BB09 and 5-day cumulative volume discharges at the S-28 is shown in **Figure 8-14**. The coefficient of determination equaled 0.09, indicating that 9% of the variance in salinity concentrations are explained by 5-day cumulative volume discharges. Average salinity conditions at BB09 are characteristic of a Euhaline salinity regime (**Figure 8-1**). Polyhaline conditions are at times observed at BB09, which may be caused by the interplay between freshwater inflow from the C-8 canal and tidal phases.

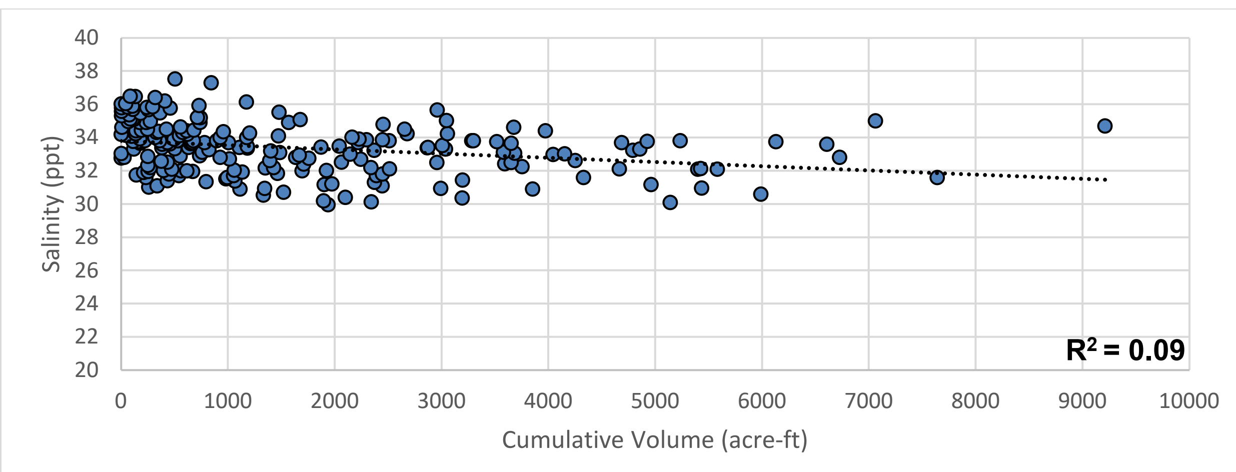

Figure 8-14: Salinity Concentrations at BB09 against 5-day Cumulative Volumes from the S-28

Figure 8-15 shows projected salinity concentrations at BB02 for the modeling scenarios outlined in **Table 4-1**. At BB09, for all return periods, the M2C scenarios are projected to result in lower salinity levels relative to M0-SLR0, while the M0 scenarios with non-zero SLR are projected to result in higher salinity levels relative to M0-SLR0.

For the 5-year storm, M2A scenarios exhibit slightly higher salinity concentrations than the corresponding M2B and M2C scenarios for fixed SLR. M2B scenarios display lower salinity concentrations compared to M0 and M2A, while M2C scenarios show the lowest salinity concentrations among all scenarios.

For the 10- and 25-year storm, a similar trend is observed. For the 100-year storm return period, the M2A scenarios exhibit higher salinity concentrations than M0-SLR0. M2B scenarios display lower salinity concentrations compared to M0 and M2A, while M2C scenarios show the lowest salinity concentrations among all scenarios.

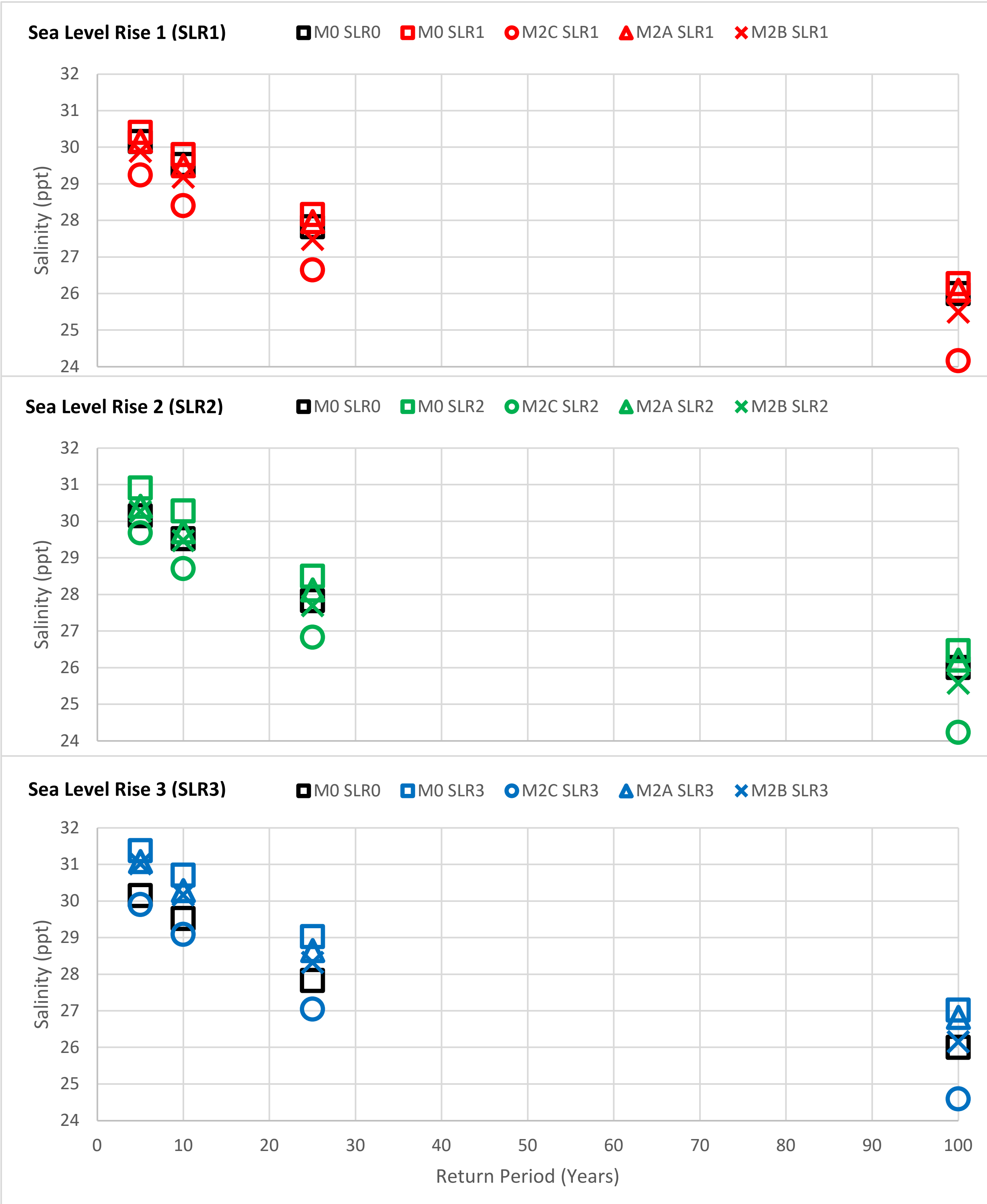

Figure 8-15: Projected Salinity Concentrations at BB09 for All Modeling Scenarios

8.3.2 Chlorophyll a

Chlorophyll *a* concentrations are plotted against 13-day cumulative volumes from the S-29 in **Figure 8-16**. At BB09, the coefficient of determination equaled 0.19, indicating that 19% of the variance in chlorophyll *a* concentrations are explained by 13-day cumulative volume discharges. Hence, water volume input from the C-8 is likely a significant (moderate positive) driver of phytoplankton growth near BB09.

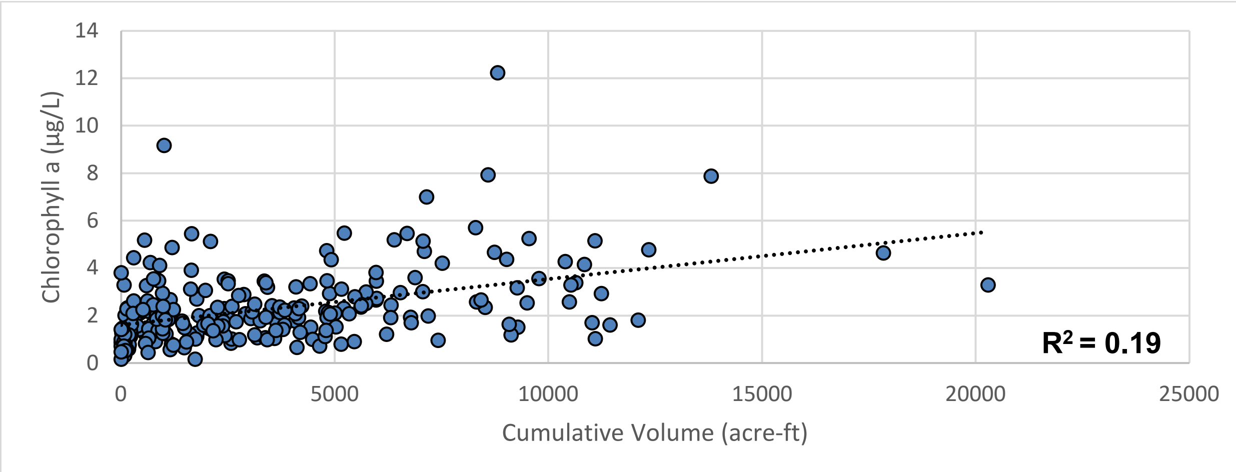

Figure 8-16: Chlorophyll a Concentrations at BB09 against 13-day Cumulative Volumes from the S-28

Figure 8-17 shows projected chlorophyll *a* concentrations at BB09 for the modeling scenarios outlined in **Table 4-1**. Note that M2C scenarios are generally projected to cause higher chlorophyll *a* levels than those without mitigation (M0), especially at higher return periods. For all return periods, M2A scenario projections are equivalent (M2A-SLR1) or less than M0-SLR0. For the 100-year storm, all M2C scenario projections are higher than M0-SLR0. Several scenarios at each SLR are projected to result in chlorophyll *a* concentrations above 4 µg/L (orange dashed line).

For the 5-year storm, M2A scenarios exhibit lower chlorophyll *a* concentrations than the corresponding M2B and M2C scenarios for fixed SLR. M2B scenarios display higher chlorophyll *a* concentrations compared to M0 and M2A, while M2C scenarios show the highest chlorophyll *a* concentrations among all scenarios.

For the 10- and 25-year storm, a similar trend is observed. For the 100-year storm return period, M2A-SLR1 exhibits slightly higher chlorophyll *a* concentrations than M0-SLR0. M2B scenarios display higher chlorophyll *a* concentrations compared to M0 and M2A for fixed SLR, while M2C scenarios show the highest chlorophyll *a* concentrations among all scenarios.

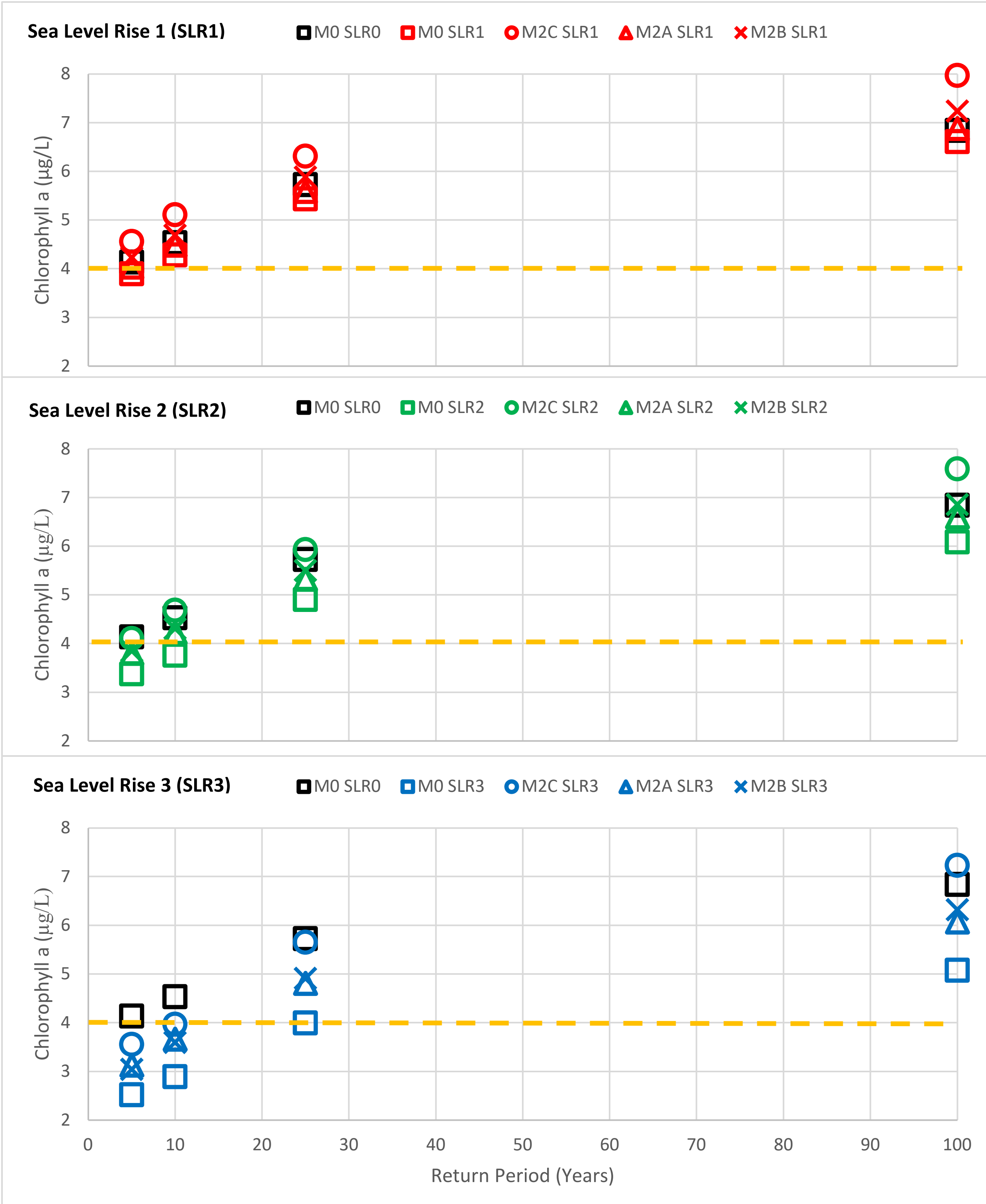

Figure 8-17: Projected Chlorophyll a Concentrations at BB09 for All Modeling Scenarios

8.3.3 Total Nitrogen

Pearson correlation coefficients were not statistically significant for the range of accumulation periods investigated at BB09; therefore, regression analyses were performed between TN concentrations at BS01 and cumulative volume discharge from the S-28. **Figure 8-18** shows the relationship between TN concentrations at BS01 and 15-day cumulative volumes. A coefficient of determination equal to 0.31 was computed, indicating that 31% of the variation in TN concentrations is explained by cumulative volume inputs.

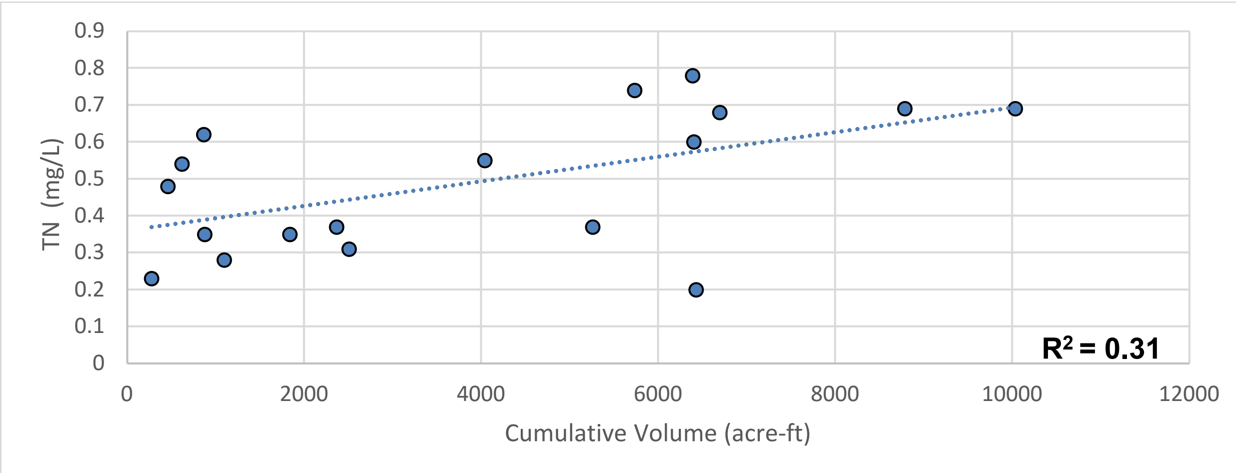

Figure 8-18: TN Concentrations at BS01 against 15-day Cumulative Volumes from the S-28

Figure 8-19 shows projected TN concentrations at BS01 for the modeling scenarios outlined in **Table 4-1**. Note that M2C scenarios are generally projected to result in higher TN concentrations than those without mitigation (M0), especially at higher return periods. In all cases the NNC of 0.3 mg/L is exceeded. Across all return periods, M2A scenario projections are equivalent (M2A-SLR1) or less than M0-SLR0. For the 100-year storm, all M2C scenario projections are higher than M0-SLR0.

For the 5-year storm, M2A scenarios exhibit lower TN concentrations than the corresponding M2B and M2C scenarios for fixed SLR. M2B scenarios display higher TN concentrations compared to M0 and M2A, while M2C scenarios show the highest TN concentrations among all scenarios.

For the 10- and 25-year storm, a similar trend is observed. For the 100-year storm return period, the M2A-SLR1 exhibits slightly higher TN concentrations than M0-SLR0. M2B scenarios display higher TN concentrations compared to M0 and M2A for fixed SLR, while M2C scenarios show the highest TN concentrations among all scenarios.

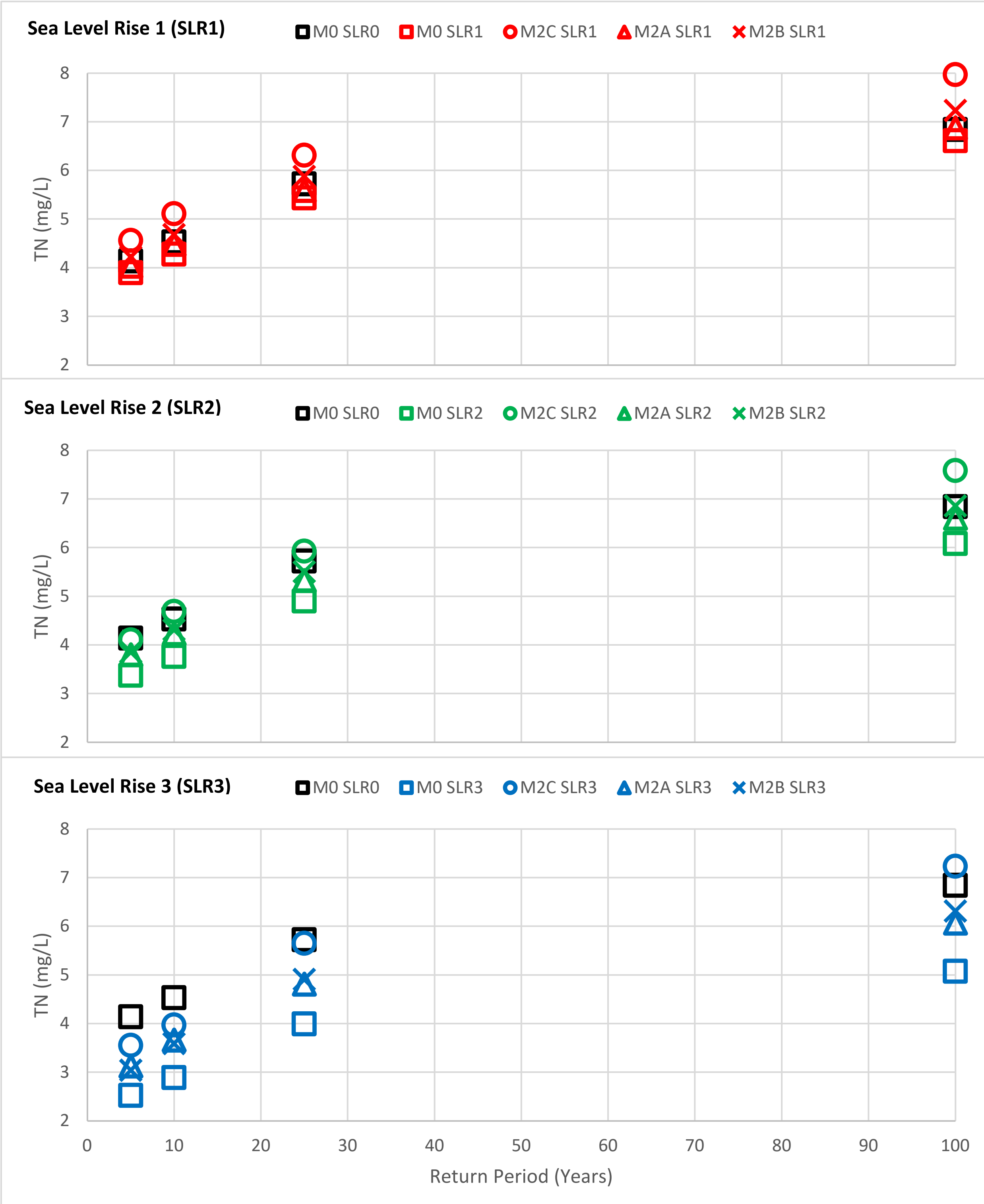

Figure 8-19: Projected TN Concentrations at BS01 for All Modeling Scenarios

8.3.4 Dissolved Oxygen

Figure 8-20 shows the relationship between DO concentrations and 15-day cumulative volumes from the S-28. At BB09, a linear function best fits the data. A coefficient of determination of 0.10 was computed, suggesting that 15-day cumulative volumes account for 10% of the variance in DO concentrations.

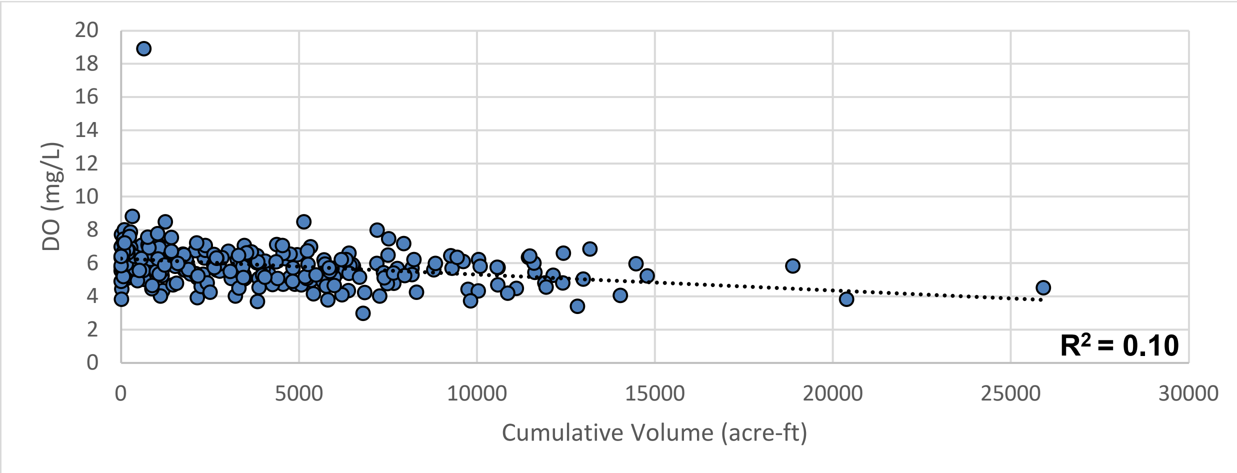

Figure 8-20: DO Concentrations at BB09 against 15-day Cumulative Volumes from the S-28

As presented for BB02, the inverse relationship between DO concentrations and cumulative volume may be due to increased nutrient loadings associated with higher volume discharges at the structures resulting in excessive aquatic plant and algal growth and eventual die-off in North Biscayne Bay. **Figures 8-21** displays the relationship between DO and chlorophyll *a* concentrations measured on the same day at BB09.

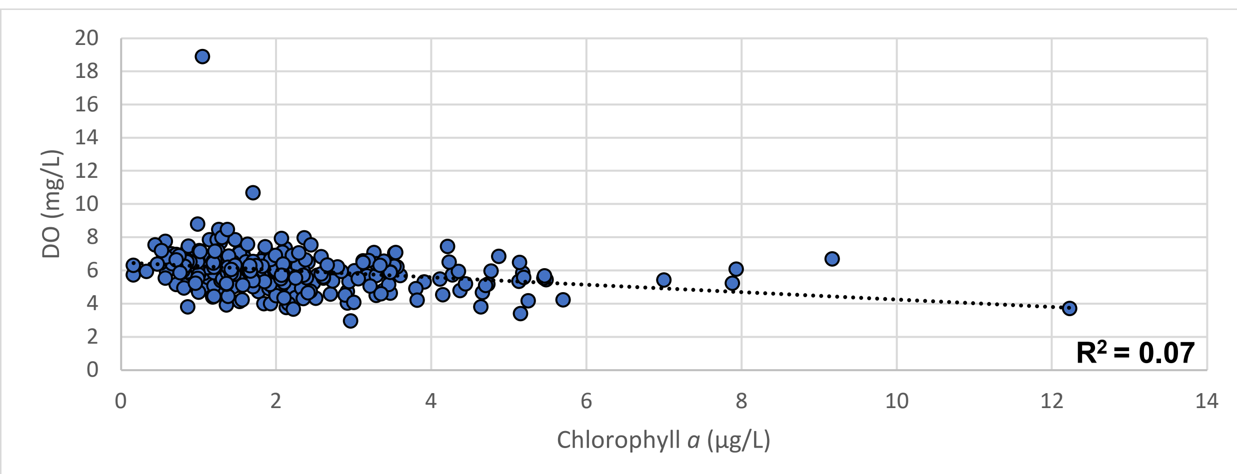

Figure 8-21: DO Concentrations versus Chlorophyll a Concentrations at BB09

A coefficient of determination equal to 0.07 was computed, suggesting that 7% of the variance in DO concentrations is explained by chlorophyll *a*. This corresponds to a Pearson coefficient equal to -0.26, indicating a statistically significant weak negative association between these variables. This indicates that oxygen depletion at BB09 is at least in part influenced by the increased presence of aquatic plants and organisms, given that chlorophyll *a* is an indicator of algal biomass. Other factors, however, are likely to be more significant than chlorophyll *a* in influencing DO concentrations.

Figure 8-22 shows projected DO concentrations at BB09 for the modeling scenarios outlined in **Table 4-1**. At BB09, optimal conditions (green dashed line) are achieved for all scenarios for the 5-year storm, except for M2C-SLR1. Several scenarios are projected to cause stressful conditions (orange dashed line) for the 25- and 100-year storm.

For the 5-year storm, M2A scenarios exhibit slightly DO salinity concentrations than the corresponding M2B and M2C scenarios for fixed SLR. M2B scenarios display lower DO concentrations compared to M0 and M2A, while M2C scenarios show the lowest DO concentrations among all scenarios for fixed SLR.

For the 10- and 25-year storm, a similar trend is observed. For the 100-year storm return period, the M2A scenarios exhibit equivalent or higher DO concentrations than M0-SLR0. M2B scenarios display lower DO concentrations compared to M0 and M2A, while M2C scenarios show the lowest DO concentrations among all scenarios.

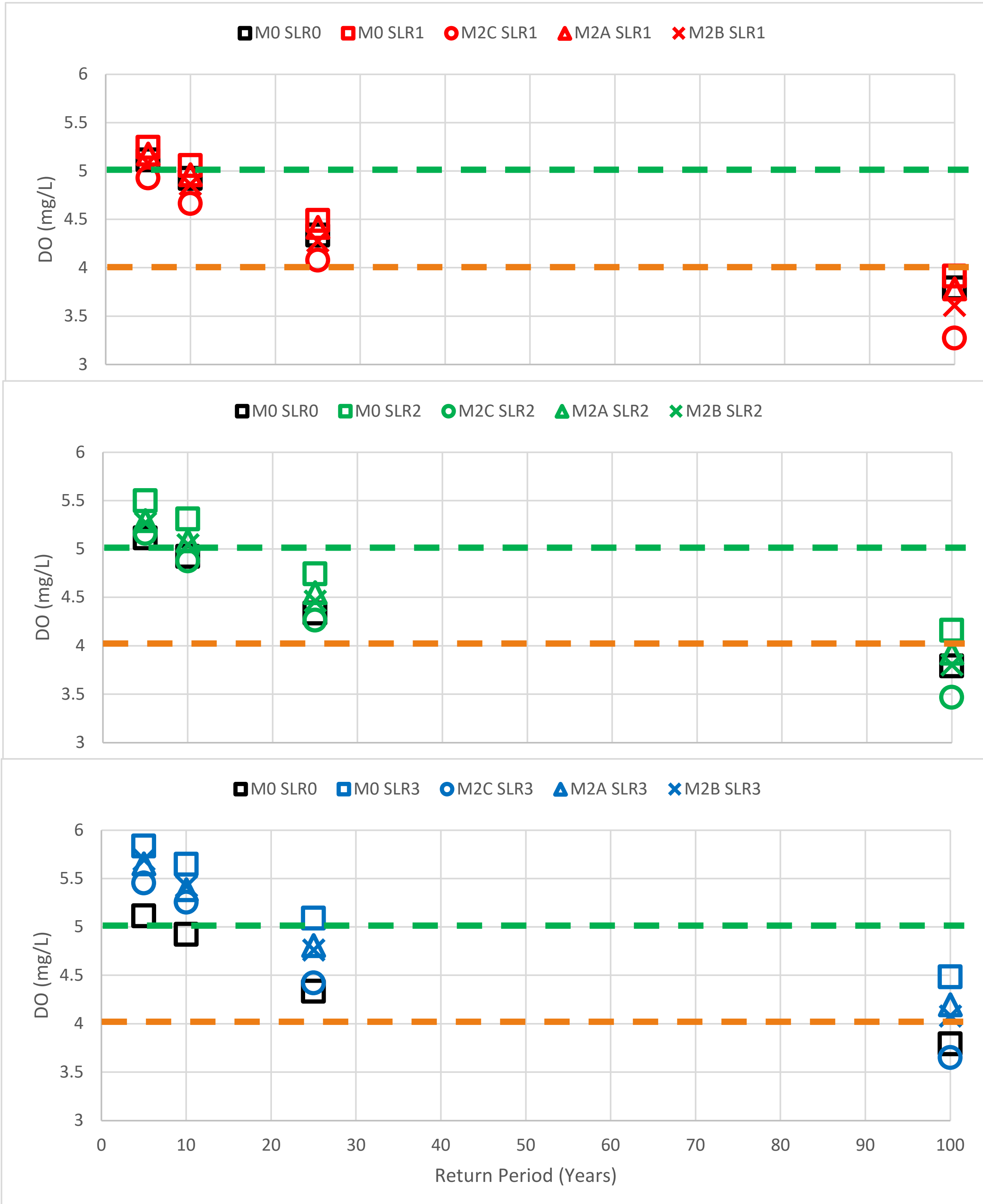

Figure 8-22: Projected DO Concentrations at BB09 for All Modeling Scenarios

8.4 NNB-B (C-8) Cumulative Volume Analyses Conclusions

Sections 8.2 and **8.3** demonstrated the feasibility of establishing useful regression relations between cumulative volume discharges from the C-8 canal and WQ parameter concentrations in the bay as the response variables. **Table 8-4** summarizes the results of the correlation analysis for NNB-A. Refer to **Table 4-2** for descriptions of the strength of correlation and the color-coding key.

Table 8-4: NNB-B Correlation Analysis Results

WQ Variable	Max Pearson r	Max Spearman r	Station ID
Salinity	-0.29	-0.46	BB09
Chlorophyll *a*	0.44	0.48	BB09
TN	0.66	0.71	BS01
Dissolved Oxygen	-0.31	-0.39	BB09

Note: Correlation Analyses were conducted only for variables that were determined to be COCs or flagged for further study.

Tables 8-5 to **8-8** summarize the results of the WQ analysis for NNB-B. For each variable and scenario, the percent change in WQ projections relative to existing conditions (M0-SLR0) was computed. Note that values highlighted in green indicate instances of WQ improvements; those in red, WQ degradation; and those in orange are undetermined due to the uncertainty of impacts to the environment. The impact of changes in salinity concentrations on the local ecology, for instance, is not well understood. In addition, if the absolute value of a percentage change was computed to be less than or equal to 2%, the potential impact of the result was considered as undetermined due to statistical uncertainty of the regression.

Legend:

Undetermined
Short Term Negative Impact
Short Term WQ Improvement

Table 8-5: Results for the 5-Year 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	0.8	2.5	4.1	0.1	0.9	3.1	-0.9	0.4	2.9	-3.0	-1.6	-0.8
Chlorophyll a	-5.9	-18.4	-39.1	-2.5	-8.2	-24.4	2.2	-6.9	-26.4	10.2	-0.8	-14.1
TN	-5.7	-16.7	-31.4	-2.7	-7.8	-23.4	1.4	-6.8	-25.3	8.1	-2.1	-14.7
DO	2.5	7.5	14.1	1.2	3.5	10.5	-0.6	3.1	11.4	-3.6	0.9	6.6

Table 8-6: Results for the 10-Year 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	0.9	2.6	4.0	-0.1	0.7	2.6	-1.2	-0.2	2.2	-3.8	-2.8	-1.5
Chlorophyll a	-5.5	-17.0	-36.2	-1.0	-6.6	-19.1	3.5	-4.8	-20.6	12.8	3.4	-12.4
TN	-5.3	-15.5	-29.1	-1.5	-6.5	-18.6	2.5	-5.0	-20.2	10.4	1.9	-13.4
DO	2.7	7.9	14.7	0.8	3.3	9.4	-1.3	2.5	10.2	-5.3	-0.9	6.7

Table 8-7: Summary of Results for the 25-Year 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 8-8: Summary of Results for the 100-Year 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

The following summarizes observations from **Tables 8-5** to **8-8**.

- Compared to M0-SLR0, the M2A, M2B, and M2C scenarios exhibit differences in water quality variable outcomes (salinity, chlorophyll *a*, TN, and DO).

Salinity

- Compared to M0-SLR0, the M2A, M2B, and M2C scenarios exhibit decreases in salinity, with the largest decrease observed in M2C-SLR1 during the 100-year storm return period.
- Salinity increases with increasing sea level rise (SLR1, SLR2, SLR3) for a given mitigation strategy.

Chlorophyll *a*

- The M2C-SLR1 scenario during the 100-year storm return period shows the largest increase in chlorophyll *a*, which is likely to cause short term negative impacts to chlorophyll *a* for all storm periods.
- Of the mitigation strategies, M2B-SLR3 scenario during the 5-year storm return period shows the largest decrease in chlorophyll *a,* which indicates the largest WQ benefit.
- Chlorophyll *a* concentrations decrease with increasing sea level rise (SLR1, SLR2, SLR3) for a given mitigation strategy.

Total Nitrogen

- The M2C-SLR1 scenario during the 100-year storm return period shows the largest increase in TN, which is likely to cause short term negative impacts to chlorophyll *a* for all storm periods.
- Of the mitigation strategies, M2B-SLR3 scenario during the 5-year storm return period shows the largest decrease in TN*,* which indicates the largest WQ benefit.
- TN concentrations decrease with increasing sea level rise (SLR1, SLR2, SLR3) for a given mitigation strategy.

Dissolved Oxygen

- The M2C-SLR1 scenario during the 100-year storm return period shows the largest decrease in DO, which is likely to cause short term negative impacts to DO for all storm periods.
- Of the mitigation strategies, M2B-SLR3 scenario during the 5-year storm return period shows the largest increase in DO*,* which indicates the largest WQ benefit.
- DO concentrations increase with increasing sea level rise (SLR1, SLR2, SLR3) for a given mitigation strategy.

Generally, the M2C scenarios are associated with more frequent short term negative or uncertain impacts, while M2A scenarios are associated with less frequent negative impacts. However, specific trends may vary depending on the variable and sea level rise scenario being considered.

9.0 MITIGATION SCENARIO IMPACTS ON MARINE LIFE AND SEAGRASS

Major ecosystems present in Biscayne Bay include mangrove forests, tidal marshes, seagrass meadows and macroalgae, oyster bars, hardbottom habitats, and softbottom habitats. The species of seagrass that populate the bay include: turtlegrass (*Thalassia testudinum*), shoal grass (*Halodule wrightii*), manatee grass (*Syringodium filiforme*), paddlegrass (*Halophila decipiens*), stargrass (*Halophila englemanii*), Johnson's Seagrass (*Halophila johnsonii*), and wigeon grass (*Ruppia maritima*). NNB-A is characterized by sparse seagrass (of which turtle grass is dominant). Shoal and manatee seagrass characterize the distribution of seagrasses within NNB-B. Other marine species in the bay include caridian shrimp, penaeid shrimp, crabs, clams, snails, and fish (BFA, 2004).

North Biscayne Bay is a critical component of the local ecosystem, is designated as Critical Habitat for the manatee by the United States Fish and Wildlife Service (USFWS), and has been identified as USFWS Consultation Areas for the American crocodile, piping plover, and Atlantic Coastal Plant. It is also designated as Essential Fish Habitat (EFH) by the National Oceanic and Atmospheric Administration (NOAA) for several important species including Snapper, Grouper, Spiny Lobster, Corals, Skipjack Tuna, Sailfish, and 10 species of sharks. The area's corals, coral reefs, and hard bottom habitats are identified as NOAA Habitat Areas of Particular Concern (HAPC) for Snapper, Grouper, and Penaeid Shrimp.

Oyster bars comprised of the American oyster (*Crassostrea virginica*), Black drum oysters (*Pogamias cromis*), and red drum oysters (*Sciaenops occelatus*) inhabited NNB-A until the construction of Haulover Cut, which is a man-made channel connecting Biscayne Bay and the Atlantic Ocean. It was constructed in 1925 to improve navigation and increase water flow between the two bodies of water. The construction of the Haulover Cut had significant impacts on the oyster habitats in the surrounding area. Before its construction, oyster reefs were abundant in Biscayne Bay and provided important habitat and food for a variety of marine organisms. Its construction altered the natural flow of water in the Bay, leading to changes in salinity levels and increased sedimentation. These changes, along with other factors such as pollution and over-harvesting, contributed to the decline of oyster reefs in the area.

Oyster reefs currently exist primarily at the mouth of the Oleta River. The health of oysters in the bay depends on salinity fluctuations, and changes in freshwater flow to the bay have inhibited oyster reef formation (BFA, 2004). Salinities below 15 ppt must be attained at some level of frequency for the formation of oyster beds. These low salinities protect oysters from gastropods, starfish, and other predators acclimated to more saline waters. Note that oyster beds at the mouths of canals/rivers can act as filters and nutrient sinks, and the disappearance of oysters in NNB-A may be a contributor to increased nutrient loads to the bay.

The installation of the canals that deliver freshwater to the bay altered the natural salinity gradient, thereby disturbing the habitat of species local to the estuary. Freshwater inputs as a result assumed a pulsed nature, which caused high variations in salinity concentrations at short time scales near the mouths of the canals. Alterations to timing, volume, and the concentration of freshwater discharges have undermined the viability of ecosystems in the bay (Caccia and Boyer, 2007).

A 2004 report by BFA Environmental Consultants (BFA) identified various indicator species for each of the sub-regions of Biscayne Bay to monitor ecological health as part of the Minimum Flows and Levels rule development process. In the following sections, each sub-region of the bay and their associated indicator species will be investigated.

9.1 NNB-A

In NNB-A, the American Oyster, the West Indian Manatee, and Johnson's Seagrass were identified as indicator species. BFA (2004) notes that no general mapping exists of the oyster beds in this area and that the state of their health is unknown. Oyster habitat is found at the mouth of the Snake Creek Canal, and these oysters prefer salinities ranging between 5 to 20 ppt. Uncertainty surrounds the potential impacts of freshwater flows on the health of these species. Seagrass coverage in this sub-region is mostly patchy/discontinuous. No seagrass has been reported in Maude Lake, while Dumbfounding Bay contains primarily patchy seagrass. See **Figure 9-1** for a schematic of the seagrass habitat in NNB-A. The following table lists the indicator species for NNB-A and their salinity/habitat requirements.

Table 9-1: Indicator Species of NNB-A and their Characteristics (BFA, 2004)

Species	Salinity Range (ppt)		Substrate/Habitat	Characteristics
	Juvenile	Adult		
American Oyster	15 – 26	14 – 30	Solid substrate	Tolerant of varying salinity, temperature, and WQ conditions
West Indian Manatee	0 – 35+		Open water, seagrasses	Inhabit fresh water, estuaries & marine environments. In Biscayne Bay, combination of warm water and fresh water in a predominately marine system causes aggregations
Johnson's Seagrass	15 - 43		Soft sand/mud	Submerged, herbaceous. Distribution only north of Virginia Key

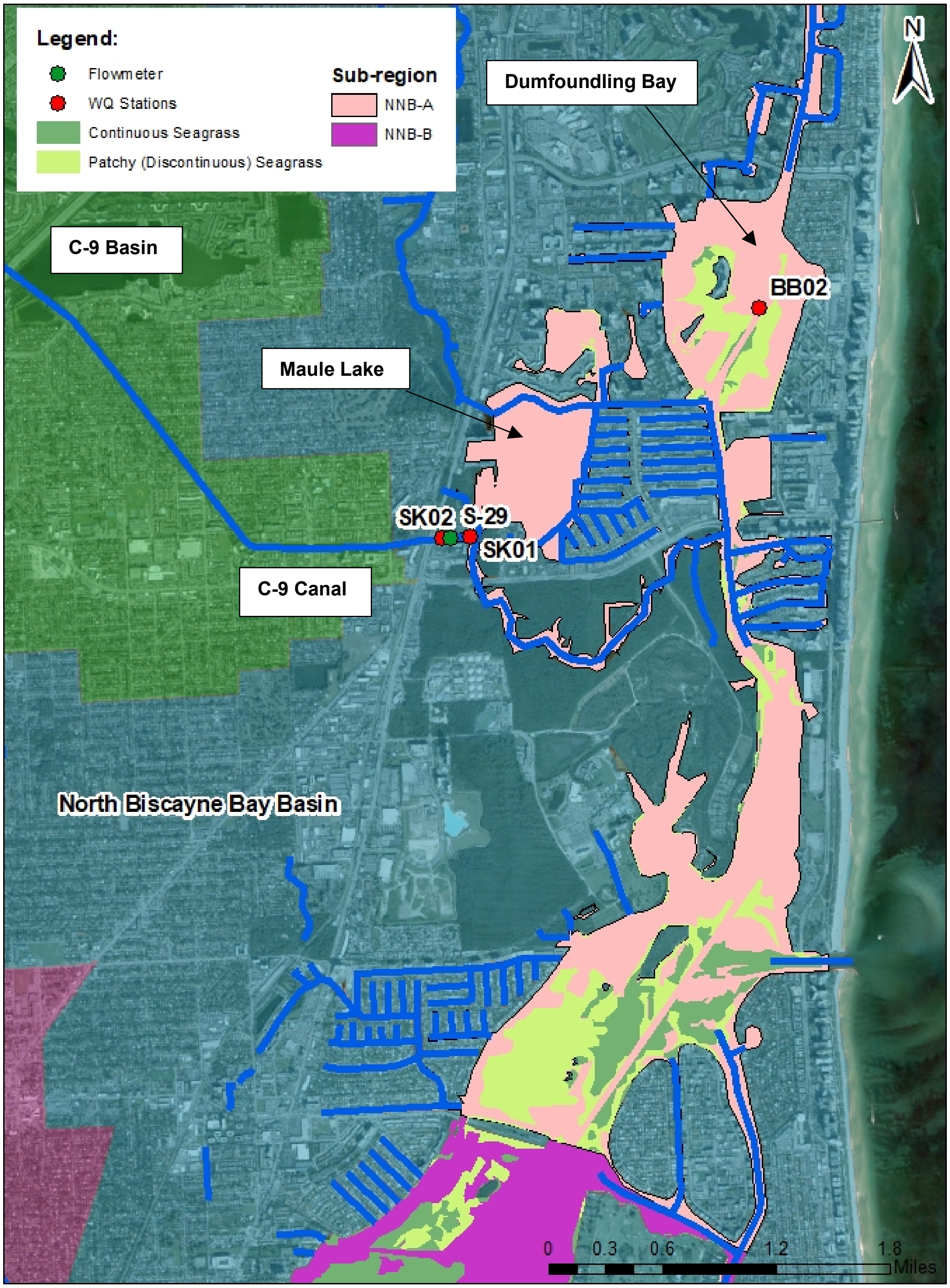

Figure 9-1: Seagrass Habitat in NNB-A (as of 2022)

9.1.1 Salinity Considerations

Salinity concentrations measured at BB02 are shown in **Figure 9-2** and plotted against the upper and lower limit salinity preferences of the American Oyster (AO) for both juveniles (red lines) and adults (green lines). Average salinities at BB02 range between 21 and 33 ppt. Note that the upper bounds for both AO juveniles and adults have been frequently exceeded. For the 25- and 100-year return period storms, salinity projections begin to violate the lower bound for the AO. Mitigation scenario projections do not violate the upper thresholds (**Figure 7-16**).

The West Indian Manatee tolerates a wide range of salinities from fresh to marine waters and proposed mitigation scenarios would not negatively impact this species. The lower threshold for Johnson's seagrass has been crossed at times in the empirical data, and salinity projections show that for the 25-year and 100-year design storms, this threshold may continue to be crossed, depending on the scenario (**Figure 7-16**). The orange box in **Figure 9-2** represents the range of salinity concentrations projected for the 100-year storm across all M0, M2A, M2B, and M2C scenarios.

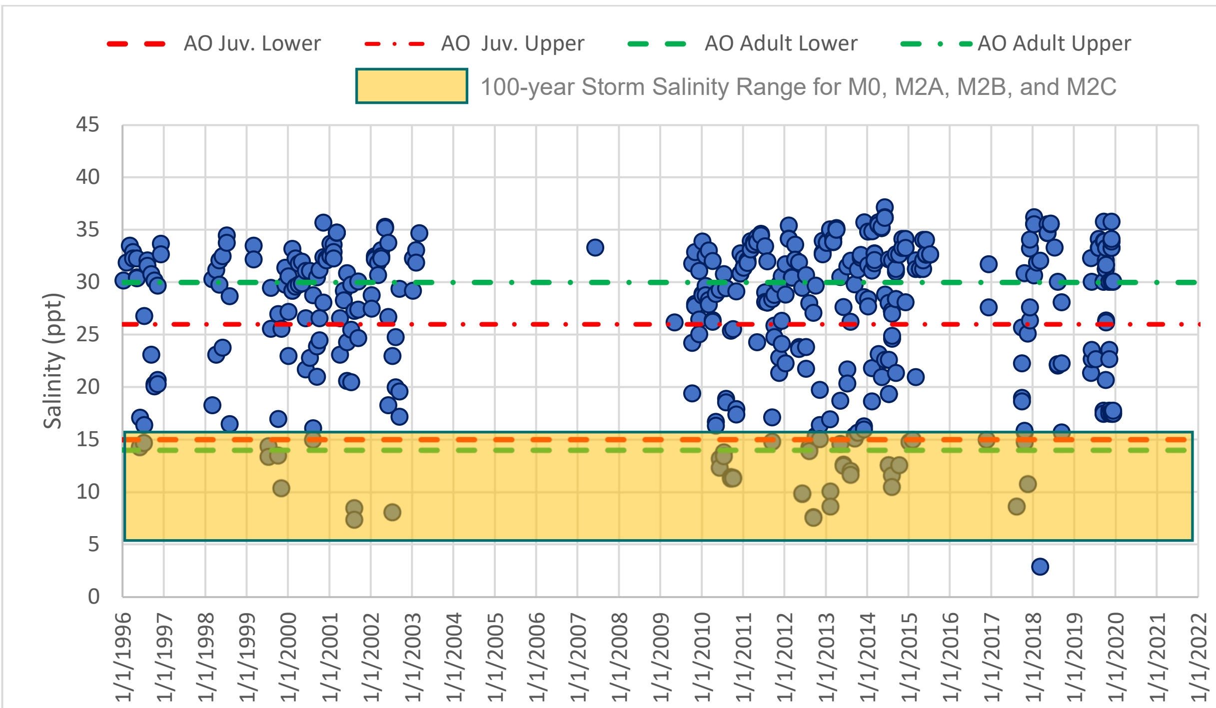

Figure 9-2: Salinity Concentrations at BB02 with 100-year Storm Mitigation Scenario Projection Range (Orange Box)

9.1.2 Nutrient Loading Considerations

Empirical TN mass fluxes were evaluated using flow data from structure S-29 and concentration data from WQ station SK02 and normalized using the NNB-A sub-region area (approximately 1,092 ha). The average normalized TN loading for the C-9 canal equaled 432.4 kg N/yr/ha for the period of record (1/6/1997 to 4/4/2022). **Figure 9-3** shows historical normalized TN mass loadings for this period.

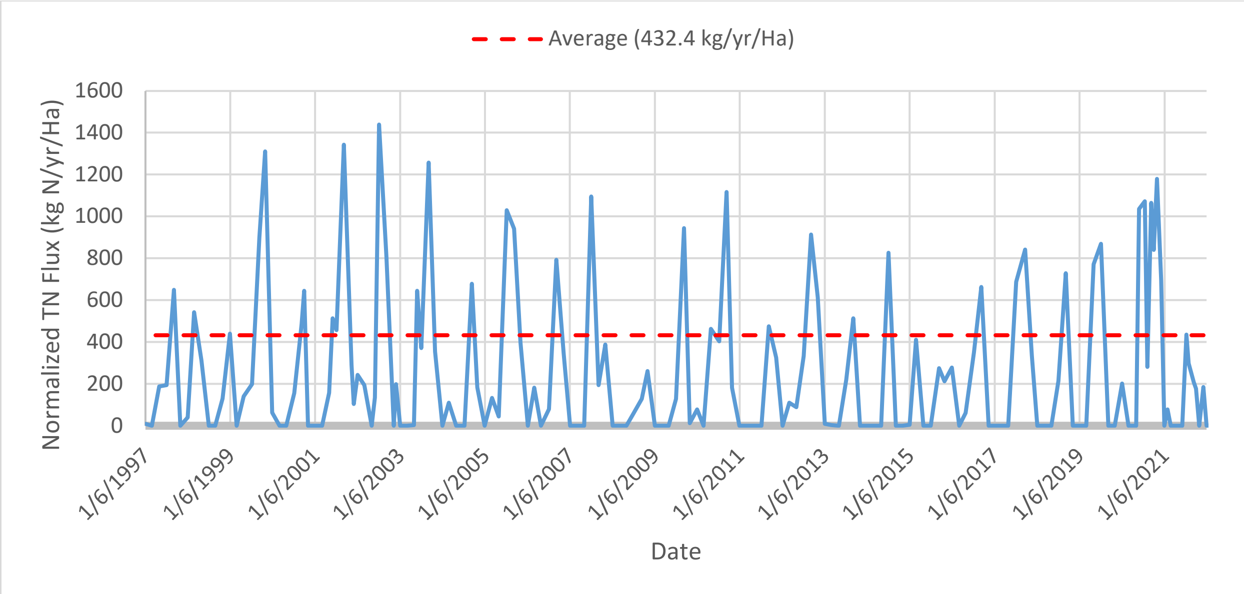

Figure 9-3: Empirical TN Mass Fluxes into NNB-A (1/6/1997 – 4/4/2022)

Steward and Green (2007) related the percent loss of seagrass to nitrogen loading rates normalized to estuary areas for several estuaries globally, which is shown in **Figure 9-4**.

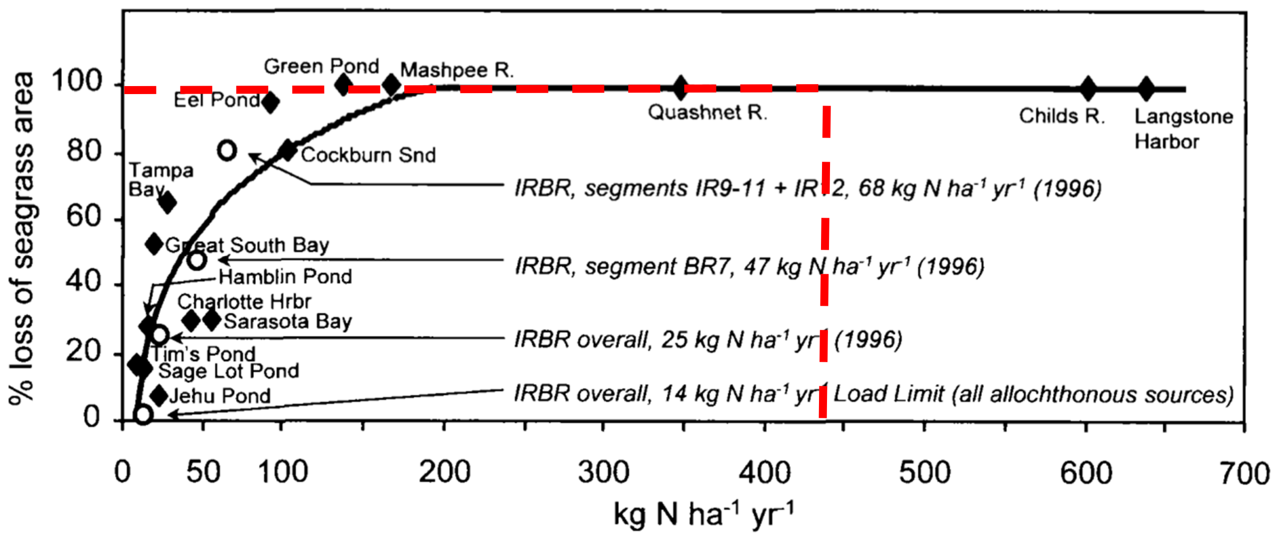

Figure 9-4: Best-fit Line for Percentage Seagrass Loss versus Normalized TN Loading Rates for Several Estuaries Applied to the C-9 (Steward and Green, 2007)

The dotted red lines on **Figure 9-4** indicate that a TN loading rate of 432.4 kg N/yr/ha corresponds to a 100% decrease in seagrass. TN mass loadings may therefore account for the complete disappearance of seagrass from Maude Lake (see **Figure 9-1**) and the patchiness of seagrass in Dumfoundling Bay. The presence of seagrass in the remainder of NNB-A may be due to the presence of a mangrove forest surrounding the Oleta River, which likely functions as a sink for TN as flow travels from the C-9 canal to the bay.

Work by Driscolla et al. (2003) indicates that a TN load limit of less than 20 kg/yr/ha is required to recover and maintain lost seagrass beds. In the C-9 canal, this would require a 95% decrease in the average TN mass loading rate to the bay. Valeria and Cole (2002) found that significant losses in seagrass coverage occur when TN loads exceed 30 kg/yr/ha in several estuaries worldwide. This corresponds to a 93% reduction in TN loading from the average in NNB-A.

9.2 NNB-B

For NBB-B, spotted seatrout (*Cynoscion nebulosus*) and manatee grass were identified by BFA (2004) as indicator species where the spawning of seatrout depends on the stability of low salinity areas and manatee grass appears to grow in areas with stable salinities and tolerates lower levels of light (i.e., high turbidity). This region of the bay is characterized by more dense continuous stretches of seagrass in the western portion. Note that station BB09 lies adjacent to the channel, surrounded by the largest seagrass beds growing in NNB-B (see **Figure 9-6**).

Table 9-2: Indicator Species of NNB-B and their Characteristics (BFA, 2004)

Species	Salinity Range (ppt)		Substrate/Habitat	Characteristics
	Juvenile	Adult		
Spotted Seatrout	1 – 25	5 – 37	Estuarine waters and seagrass	Prefers seagrass habitats
Manatee Grass	5 – 45		Soft sand/mud	Submerged, herbaceous.

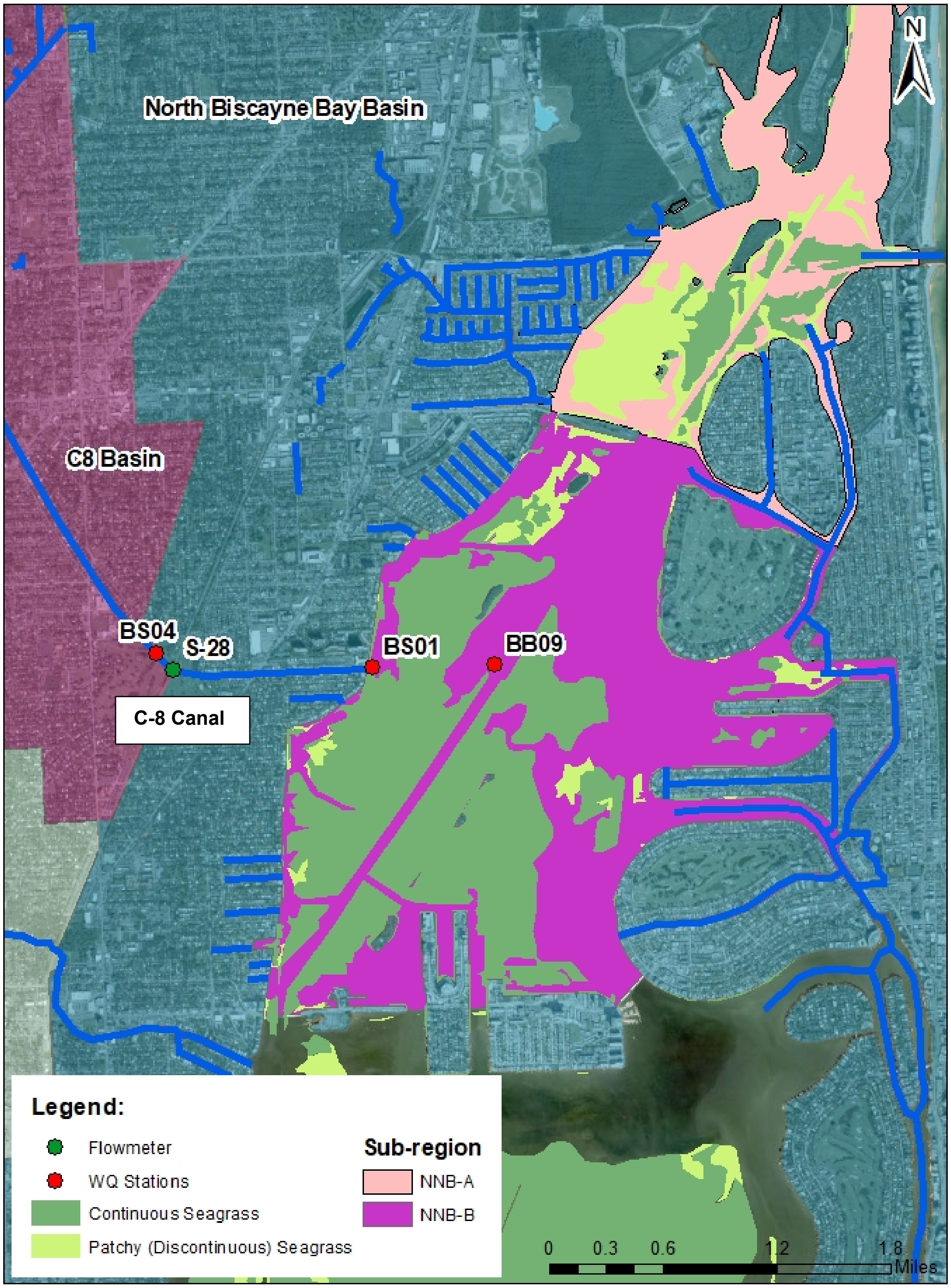

Figure 9-5: Seagrass Habitat in NNB-B (as of 2022)

9.2.1 Salinity Considerations

Salinity concentrations measured at BB09 are shown in **Figure 9-6** and plotted against the upper and lower limit salinity preferences of spotted seatrout (SS) for both juveniles (red line) and adults (green line). It is apparent that salinity concentrations lie within the tolerance range of adult SS with few exceptions, but that concentrations often exceed the tolerance range of juvenile SS. It may be that juvenile SS exist closer to the mouth of C-8 canal, where salinities are generally lower and are influenced more by freshwater flow. The orange box in **Figure 9-6** represents the range of salinity concentrations projected for the 100-year storm across all M0, M2A, M2B, and M2C scenarios.

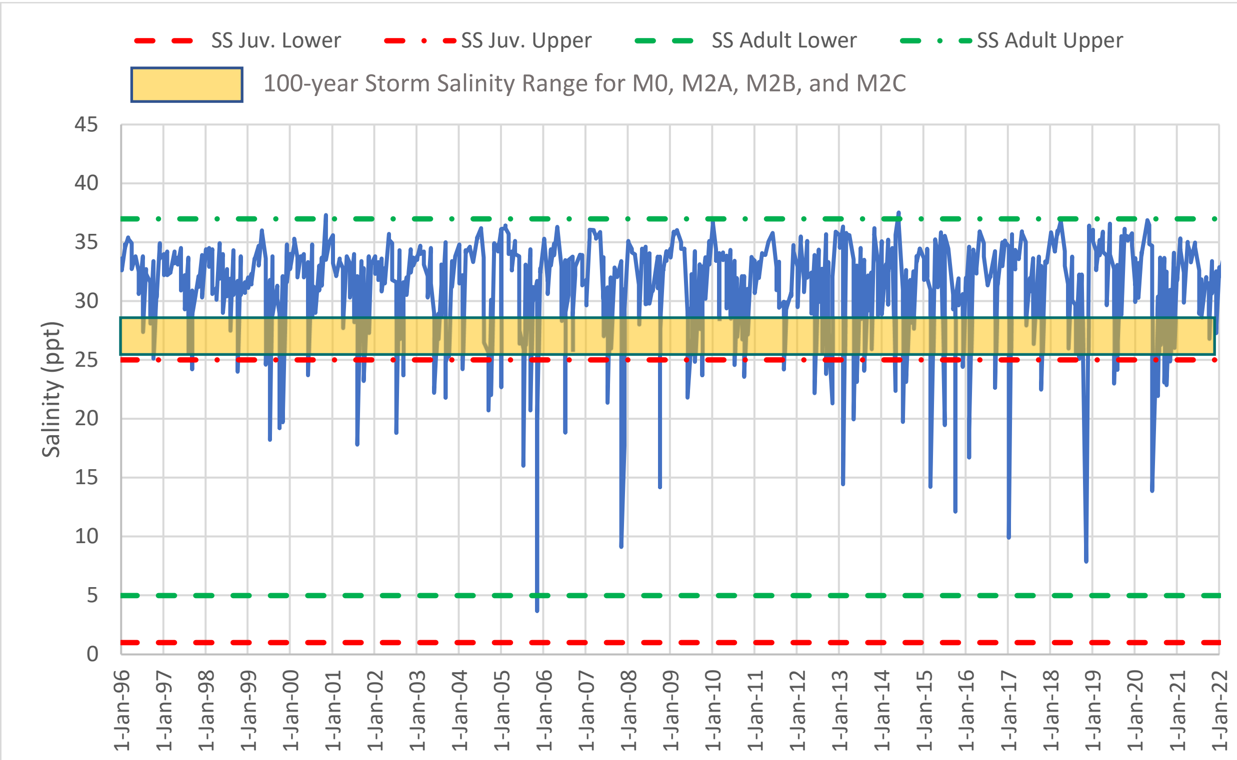

Figure 9-6: Salinity Concentrations at BB09 (1/1/1996 – 1/1/2022) with 100-year Storm Mitigation Scenario Projection Range (Orange Box)

From **Figure 8-15**, the impact to salinity from even the worst-case mitigation scenario (100-year M2-SLR1) is on the order of 25 ppt, which is within the range of tolerances for adult SS and just touches the upper bound for juveniles.

Given that manatee grass is tolerant to a wide range of salinities (5 – 45 ppt), changes in absolute salinity levels likely do not affect manatee grass coverage as much as other factors such as nutrient loadings, chlorophyll *a* concentrations, and temperature. BFA (2004) however notes uncertainties regarding the impact of freshwater flows on manatee grass health. For instance, the effects on manatee grass from salinity pulses and large variations in salinity concentrations at short time scales have not been investigated.

9.2.2 Nutrient Loading Considerations

TN mass loadings were evaluated using flow data from structure S-28 and concentration data from WQ station BS04 and normalized using the NNB-B sub-region area (approximately 1,463 ha). The average normalized TN loading for the C-8 canal equaled 115.3 kg N/yr/ha for the period of record (1/6/1997 to 4/4/2022). **Figure 9-7** shows historical normalized TN mass loadings for this period.

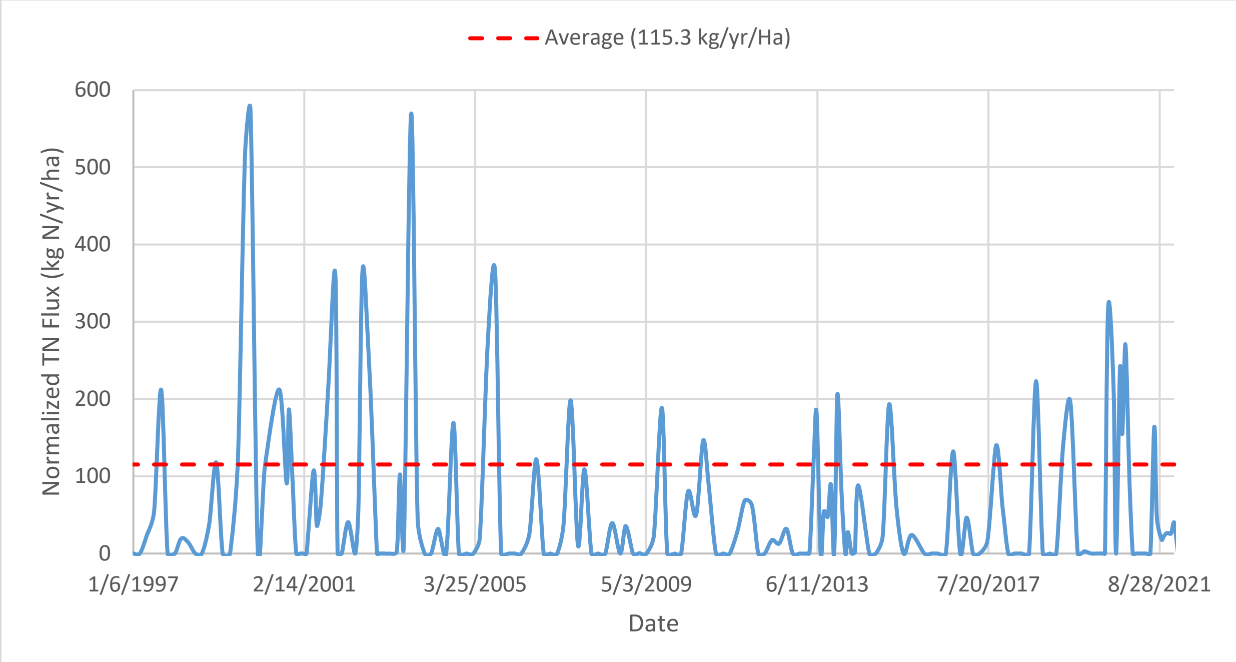

Figure 9-7: Empirical TN Mass Fluxes into NNB-B (1/6/1997 – 4/4/2022)

A 2019 report produced by MDC titled 'Report on the Findings of the County's Study on the Decline of Seagrass and Hardbottom Habitat in Biscayne Bay' (hereon referred to as the 2019 MDC Seagrass Report) reported that there has occurred an approximately 89.61% decrease in seagrass coverage in the 79th Street Basin (i.e., the NNB-B sub-region). TN mass fluxes into NNB-B were applied to the following figure taken from Steward and Green (2007) (see **Section 9.1.2**).

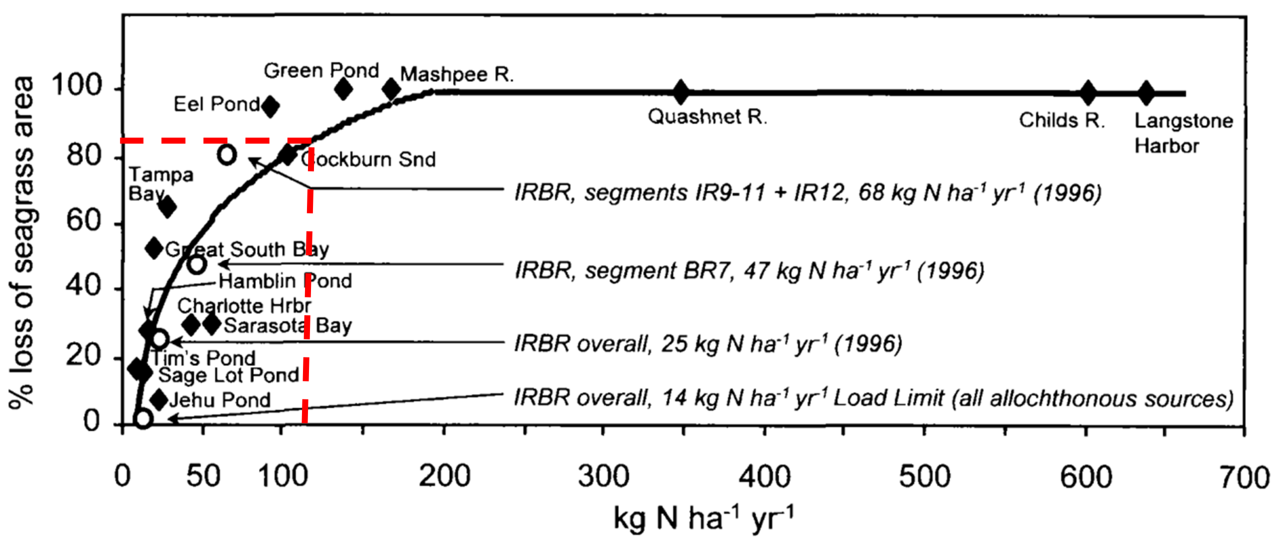

Figure 9-8: Best-fit Line for Percentage Seagrass Loss versus Normalized TN Loading Rates for Several Estuaries Applied to the C-8 (Steward and Green, 2007)

The dotted red lines on **Figure 9-8** indicate that a TN loading rate of 115.3 kg N/yr/Ha (x-axis) corresponds to approximately an 85% decrease in seagrass coverage (y-axis). This value is close to the historically observed value of 89.61%, suggesting that TN loadings from the C-8 significantly influence seagrass coverage in NNB-B. **Figure 9-8** further demonstrates that TN loadings from the C-8 are highly variable and frequently exceed the average. Applying the work by Driscolla et al. (2003) and Valeria and Cole (2002) to the C-8 led to the estimation that a 73 to 82% reduction in average TN mass fluxes is required to recover lost seagrass beds in NNB-B.

10.0 CONCLUSIONS

This memorandum 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 mitigation scenarios described in **Table 4-1**. 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 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. 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. Positive/negative impacts are addressed in bullets 3 and 4 of **Sections 10.1** and **10.2**.

10.1 C-9 Basin (NNB-A)

- 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.

- 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 (**Section 7.4**).
    - 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 in **Section 9.0**.
  - The higher return period storms are anticipated to violate the salinity tolerances of American Oyster and Johnson's Seagrass, two indicator species for NNB-A. Regarding TN loads, only scenario M2C-SLR1 would result in increased TN loads compared to M0-SLR0 for all return periods.

10.2 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 <u>**weak to moderate negative**</u> association exists between cumulative volume inputs from the S-28 and salinity concentrations at BB09.
  - Chlorophyll *a*
    - A <u>**moderate positive**</u> association exists between cumulative volume inputs from the S-28 and Chlorophyll *a* concentrations at BB09.
  - TN
    - A <u>**moderate to strong positive**</u> 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 <u>**weak negative**</u> association exists between cumulative volume inputs from the S-28 and DO concentrations at BB09.
  - Turbidity
    - <u>**No statistically significant**</u> 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 (**Section 8.4**). 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, while M2A scenarios are associated with less frequent negative impacts.
- Mitigation scenario impacts to marine life and seagrass were estimated in **Section 9.0**.

- 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.

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APPENDIX A

The following sections serve as a guide to the methods described in **Section 4.0**.

Time Series Analyses

WQ criteria for the parameters analyzed were based on various statistics (maximums, annual geometric means). COCs for NNB-A and NNB-B were determined in accordance with the NNC thresholds and water quality criteria for Class III waters. To determine the geometric mean, μ_{geo}, the following equation was applied to annual data for the appropriate WQ parameters (e.g., chlorophyll a, TN, and TP):

$$\mu_{geo} = \left(\prod_{i}^{n} x_i\right)^{\frac{1}{n}}$$

where x_i equals the magnitude of the ith element in the data set and n equals the data set's total number of elements.

The Mann-Kendall test for monotonic trends was applied to the time series presented in **Section 7.1** and **8.1**. It is a non-parametric test that compares relative magnitudes of a sample's data rather than their absolute magnitudes (Gilbert, 1987). The test evaluates sample values as an ordered time series, where a given data value is compared to all subsequent data values. The test statistic, S, is initially assumed to be nil. S is incremented by 1 if the subsequent data value is higher than the initial value; decremented by 1 if lower. A final value for S is the result of all increments/decrements over the sample period. The Python package pyMannKendall was utilized to obtain test statistics as well as to test for statistical significance. Refer to the following link for more information regarding this statistical package: https://pypi.org/project/pymannkendall/.

Cumulative Volume Analyses

Let C represent the set of concentration values for a given WQ variable, such that $C = \{C_1, C_2, \ldots, C_N\}$, where C_1 equals the concentration at time t_{C_1} and where N equals the number of elements in set C. Similarly, let F represent the set of average daily flowrates, such that $F = \{F_1, F_2, \ldots, F_P\}$, where P equals the number of elements in set F. An algorithm was constructed to perform the following operations between C and F for a given accumulation period (A_k). For each variable, accumulation periods between 0 and 60 days were evaluated.

The first iteration of the algorithm evaluated an accumulation period of zero ($A_k = 0$), meaning that each element of C was matched to the flowrate recorded on the same day as the concentration measurement. An $n\,x\,2$ matrix was thereby constructed, with each row of the first column containing all concentration data and each row of the second column containing the corresponding flowrates.

$$\begin{bmatrix} C_1 & F\left(t_{C_1}\right) \\ C_2 & F\left(t_{C_2}\right) \\ \ldots & \ldots \\ C_N & F\left(t_{C_N}\right) \end{bmatrix}_{A_k=0}$$

where $F\left(t_{C_i}\right)$ equals the flowrate associated with C_i.

The average daily flowrates were then converted to volumes, and correlation analyses were performed between columns 1 and 2.

The second iteration evaluated an accumulation period of one ($A_p = 1$), meaning that each element of C was matched to the average daily flowrate recorded on the same day in addition to that of the previous day of the concentration measurement. What resulted remained an $n\,x\,2$ matrix, but now each element of the second column contained the sum of the volumes associated with a given concentration measurement.

$$\begin{bmatrix} C_1 & F\left(t_{C_1}\right) + F(t_{C_1} - 1) \\ C_2 & F\left(t_{C_1}\right) + F(t_{C_1} - 1) \\ \dots & \dots \\ C_N & F\left(t_{C_N}\right) + F(t_{C_N} - 1) \end{bmatrix}_{A_k=1}$$

A general relation for any accumulation period was then derived.

$$\begin{bmatrix} C_1 & \sum_{i=0}^{A_k} F(t_{C_1} - A_k) \\ C_2 & \sum_{i=0}^{A_k} F(t_{C_2} - A_k) \\ \dots & \dots \\ C_N & \sum_{i=0}^{A_k} F(t_{C_N} - A_k) \end{bmatrix}$$

For each iteration, the Shapiro-Wilk test for normality was applied separately to columns 1 and 2. The test evaluates whether a random sample comes from a normal distribution. More information regarding this test can be found using the following link:

https://www.itl.nist.gov/div898/handbook/prc/section2/prc213.htm.

The scipy.stats.shapiro tool in Python was utilized to perform this test.

https://docs.scipy.org/doc/scipy/reference/generated/scipy.stats.shapiro.html

Pearson correlation coefficients between columns 1 and 2 were computed for each accumulation period. This coefficient is a measure of the linear correlation between two sets of data and equals the ratio between the covariance of two variables and the product of their standard deviations. The scipy.stats.pearsonr tool was utilized in Python to compute these coefficients and to perform tests of statistical significance.

Spearman rank-correlation coefficients were computed for each accumulation period between columns 1 and 2. This coefficient is a nonparametric measure of the monotonicity of the relationship between two variables. The Python tool scipy.stats.spearmanr was used to compute these coefficients

(https://docs.scipy.org/doc/scipy/reference/generated/scipy.stats.spearmanr.html.)

Ordinary Least Squares regression analyses were then performed for the accumulation period that exhibited the highest Pearson correlation coefficient. The numpy, pandas, and statsmodels.api packages in Python were used to perform these analyses. F-tests were performed to evaluate the statistical significance of the regression.

(https://www.statsmodels.org/dev/examples/notebooks/generated/ols.html.)

Variables for which statistically significant regression equations were constructed were then further evaluated for FPLOS impacts. Cumulative volumes were computed for each of the modeling scenarios listed in **Table 4-1**, and the accumulation period for which these modeling cumulative volumes were computed matched that of the occurrence of the maximum Pearson correlation coefficient. The following sections report the output of the OLS analyses and F-tests.

C-9 Salinity: OLS Regression Results

```
==============================================================================
Dep. Variable:          Concentration   R-squared:                       0.166
Model:                            OLS   Adj. R-squared:                  0.161
Method:                 Least Squares   F-statistic:                     34.29
Date:                Tue, 08 Nov 2022   Prob (F-statistic):           2.36e-08
Time:                        15:04:46   Log-Likelihood:                -555.30
No. Observations:                 174   AIC:                             1115.
Df Residuals:                     172   BIC:                             1121.
Df Model:                           1
Covariance Type:            nonrobust
=====================================================================================
                        coef    std err          t      P>|t|      [0.025      0.975]
-------------------------------------------------------------------------------------
const                31.1496      0.703     44.284      0.000      29.761      32.538
Cummulative Volume   -0.0008      0.000     -5.855      0.000      -0.001      -0.001
==============================================================================
Omnibus:                       43.779   Durbin-Watson:                   1.340
Prob(Omnibus):                  0.000   Jarque-Bera (JB):               69.467
Skew:                          -1.345   Prob(JB):                     8.23e-16
Kurtosis:                       4.533   Cond. No.                     8.45e+03
==============================================================================

Notes:
[1] Standard Errors assume that the covariance matrix of the errors is correctly
specified.
```

C-9 Chlorophyll a: OLS Regression Results

```
==============================================================================
Dep. Variable:          Concentration   R-squared:                       0.208
Model:                            OLS   Adj. R-squared:                  0.204
Method:                 Least Squares   F-statistic:                     55.15
Date:                Tue, 08 Nov 2022   Prob (F-statistic):           2.76e-12
Time:                        15:21:49   Log-Likelihood:                -469.17
No. Observations:                 212   AIC:                             942.3
Df Residuals:                     210   BIC:                             949.1
Df Model:                           1
Covariance Type:            nonrobust
=====================================================================================
                        coef    std err          t      P>|t|      [0.025      0.975]
-------------------------------------------------------------------------------------
const                 3.0079      0.230     13.066      0.000       2.554       3.462
Cummulative Volume    0.0001   1.68e-05      7.426      0.000    9.18e-05       0.000
==============================================================================
Omnibus:                       83.599   Durbin-Watson:                   1.802
Prob(Omnibus):                  0.000   Jarque-Bera (JB):              294.304
Skew:                           1.612   Prob(JB):                     1.24e-64
Kurtosis:                       7.788   Cond. No.                     2.06e+04
==============================================================================

Notes:
[1] Standard Errors assume that the covariance matrix of the errors is correctly
specified.
```

C-9 Dissolved Oxygen: OLS Regression Results

```
==============================================================================
Dep. Variable:          Concentration   R-squared:                       0.033
Model:                            OLS   Adj. R-squared:                  0.027
Method:                 Least Squares   F-statistic:                     6.332
Date:                Tue, 08 Nov 2022   Prob (F-statistic):             0.0127
Time:                        15:27:11   Log-Likelihood:                -308.32
No. Observations:                 190   AIC:                             620.6
Df Residuals:                     188   BIC:                             627.1
Df Model:                           1
Covariance Type:            nonrobust
======================================================================================
                        coef    std err          t      P>|t|      [0.025      0.975]
--------------------------------------------------------------------------------------
const                 5.8336      0.129     45.258      0.000       5.579       6.088
Cummulative Volume -2.498e-05   9.93e-06    -2.516      0.013   -4.46e-05    -5.4e-06
==============================================================================
Omnibus:                        5.667   Durbin-Watson:                   1.475
Prob(Omnibus):                  0.059   Jarque-Bera (JB):                5.272
Skew:                          -0.374   Prob(JB):                       0.0716
Kurtosis:                       3.328   Cond. No.                     1.87e+04
==============================================================================

Notes:
[1] Standard Errors assume that the covariance matrix of the errors is correctly
specified.
```

C-8 Salinity: OLS Regression Results

```
==============================================================================
Dep. Variable:          Concentration   R-squared:                       0.086
Model:                            OLS   Adj. R-squared:                  0.082
Method:                 Least Squares   F-statistic:                     20.97
Date:                Tue, 08 Nov 2022   Prob (F-statistic):           7.76e-06
Time:                        15:31:59   Log-Likelihood:                -482.79
No. Observations:                 224   AIC:                             969.6
Df Residuals:                     222   BIC:                             976.4
Df Model:                           1
Covariance Type:            nonrobust
======================================================================================
                        coef    std err          t      P>|t|      [0.025      0.975]
--------------------------------------------------------------------------------------
const                33.6384      0.194    173.139      0.000      33.255      34.021
Cummulative Volume   -0.0004   7.79e-05     -4.580      0.000      -0.001      -0.000
==============================================================================
Omnibus:                      110.371   Durbin-Watson:                   2.111
Prob(Omnibus):                  0.000   Jarque-Bera (JB):              668.994
Skew:                          -1.849   Prob(JB):                    5.37e-146
Kurtosis:                      10.616   Cond. No.                     3.46e+03
==============================================================================

Notes:
[1] Standard Errors assume that the covariance matrix of the errors is correctly
specified.
```

C-8 Chlorophyll a: OLS Regression Results

```
==============================================================================
Dep. Variable:          Concentration   R-squared:                       0.191
Model:                            OLS   Adj. R-squared:                  0.187
Method:                 Least Squares   F-statistic:                     59.13
Date:                Tue, 08 Nov 2022   Prob (F-statistic):           3.34e-13
Time:                        15:40:14   Log-Likelihood:                -441.60
No. Observations:                 253   AIC:                             887.2
Df Residuals:                     251   BIC:                             894.3
Df Model:                           1
Covariance Type:            nonrobust
=====================================================================================
                        coef    std err          t      P>|t|      [0.025      0.975]
-------------------------------------------------------------------------------------
const                 1.6117      0.121     13.353      0.000       1.374       1.849
Cummulative Volume    0.0002   2.51e-05      7.690      0.000       0.000       0.000
==============================================================================
Omnibus:                      146.018   Durbin-Watson:                   1.776
Prob(Omnibus):                  0.000   Jarque-Bera (JB):             1115.802
Skew:                           2.217   Prob(JB):                    5.09e-243
Kurtosis:                      12.284   Cond. No.                     6.63e+03
==============================================================================

Notes:
[1] Standard Errors assume that the covariance matrix of the errors is correctly
specified.
```

C-8 TN: OLS Regression Results

```
==============================================================================
Dep. Variable:          Concentration   R-squared:                       0.306
Model:                            OLS   Adj. R-squared:                  0.262
Method:                 Least Squares   F-statistic:                     7.051
Date:                Tue, 08 Nov 2022   Prob (F-statistic):             0.0173
Time:                        15:44:25   Log-Likelihood:                 8.4449
No. Observations:                  18   AIC:                            -12.89
Df Residuals:                      16   BIC:                            -11.11
Df Model:                           1
Covariance Type:            nonrobust
=====================================================================================
                        coef    std err          t      P>|t|      [0.025      0.975]
-------------------------------------------------------------------------------------
const                 0.3597      0.062      5.791      0.000       0.228       0.491
Cummulative Volume 3.331e-05   1.25e-05      2.655      0.017    6.72e-06    5.99e-05
==============================================================================
Omnibus:                        1.377   Durbin-Watson:                   1.905
Prob(Omnibus):                  0.502   Jarque-Bera (JB):                0.677
Skew:                          -0.475   Prob(JB):                        0.713
Kurtosis:                       2.971   Cond. No.                     8.13e+03
==============================================================================

Notes:
[1] Standard Errors assume that the covariance matrix of the errors is correctly
specified.
```

C-8 Dissolved Oxygen: OLS Regression Results

```
==============================================================================
Dep. Variable:          Concentration   R-squared:                       0.095
Model:                            OLS   Adj. R-squared:                  0.092
Method:                 Least Squares   F-statistic:                     28.58
Date:                Mon, 28 Nov 2022   Prob (F-statistic):           1.90e-07
Time:                        14:55:04   Log-Likelihood:                -437.03
No. Observations:                 274   AIC:                             878.1
Df Residuals:                     272   BIC:                             885.3
Df Model:                           1
Covariance Type:            nonrobust
=====================================================================================
                        coef    std err          t      P>|t|      [0.025      0.975]
-------------------------------------------------------------------------------------
const                 6.2776      0.100     63.043      0.000       6.082       6.474
Cummulative Volume -9.543e-05  1.78e-05     -5.346      0.000      -0.000   -6.03e-05
==============================================================================
Omnibus:                      299.992   Durbin-Watson:                   1.757
Prob(Omnibus):                  0.000   Jarque-Bera (JB):            23772.654
Skew:                           4.307   Prob(JB):                         0.00
Kurtosis:                      47.811   Cond. No.                     7.68e+03
==============================================================================

Notes:
[1] Standard Errors assume that the covariance matrix of the errors is correctly specified.
```

C-9 WQ Concentration FPLOS Estimates

Salinity Concentration Estimates with 95% Confidence Intervals (ppt)													
Storm Return Period	M0-SLR0	M0-SLR1	M0-SLR2	M0-SLR3	M2A-SLR1	M2A-SLR2	M2A-SLR3	M2B-SLR1	M2B-SLR2	M2B-SLR3	M2C-SLR1	M2C-SLR2	M2C-SLR3
5 Year	**15.7** (9.8-21.7)	**18.4** (12.5-24.3)	**20.7** (14.8-26.7)	**24.3** (18.4-30.2)	**18.0** (12.1-23.9)	**20.1** (14.2-26.0)	**23.7** (17.7-29.6)	**17.2** (11.2-23.1)	**19.2** (13.3-25.1)	**23.2** (17.3-29.2)	**15.5** (9.6-21.4)	**17.8** (11.9-23.7)	**22.3** (16.4-28.2)
10 Year	**13.5** (7.6-19.4)	**16.2** (10.3-22.1)	**18.7** (12.7-24.6)	**21.9** (16.0-27.8)	**15.9** (10.0-21.8)	**17.8** (11.9-23.7)	**21.0** (15.1-27.0)	**14.7** (8.8-20.6)	**16.6** (10.7-22.5)	**20.4** (14.5-26.4)	**12.7** (6.8-18.7)	**15.1** (9.2-21.0)	**19.1** (13.2-25.1)
25 Year	**9.6** (3.7-15.5)	**11.9** (5.9-17.8)	**14.3** (8.4-20.2)	**17.6** (11.7-23.5)	**11.9** (5.9-17.8)	**13.8** (7.9-19.7)	**16.4** (10.5-22.3)	**10.6** (4.7-16.5)	**12.4** (6.5-18.3)	**15.3** (9.4-21.2)	**7.9** (2.0-13.9)	**10.1** (4.2-16.1)	**13.3** (7.4-19.3)
100 Year	**3.9** (0 - 9.9)	**6.0** (0.1-11.9)	**8.6** (2.7-14.5)	**13.1** (7.2-19.0)	**6.3** (0.4-12.2)	**8.4** (2.5-14.3)	**10.9** (5.0-16.8)	**5.1** (0-11.1)	**6.7** (0.8-12.7)	**9.4** (3.5-15.3)	**1.6** (0.0-7.5)	**3.5** (0 -9.4)	**6.4** (0.5-12.3)

Chlorophyll a Concentration Estimates with 95% Confidence Intervals (µg/L)													
Storm Return Period	M0-SLR0	M0-SLR1	M0-SLR2	M0-SLR3	M2A-SLR1	M2A-SLR2	M2A-SLR3	M2B-SLR1	M2B-SLR2	M2B-SLR3	M2C-SLR1	M2C-SLR2	M2C-SLR3
5 Year	**5.7** (3.5-7.9)	**5.4** (3.1-7.6)	**4.8** (2.6-7.0)	**4.0** (1.7-6.2)	**5.5** (3.3-7.7)	**5.1** (2.8-7.3)	**4.4** (2.2-6.6)	**5.6** (3.4-7.9)	**5.2** (3.0-7.4)	**4.5** (2.2-6.7)	**5.9** (3.7-8.1)	**5.4** (3.2-7.7)	**4.8** (2.5-7.0)
10 Year	**6.2** (4.0-8.5)	**5.8** (3.6-8.0)	**5.1** (2.9-7.4)	**4.4** (2.2-6.6)	**6.0** (3.7-8.2)	**5.5** (3.3-7.7)	**4.9** (2.6-7.1)	**6.1** (3.9-8.3)	**5.7** (3.5-7.9)	**4.9** (2.7-7.2)	**6.4** (4.2-8.6)	**5.9** (3.7-8.2)	**5.3** (3.1-7.5)
25 Year	**7.3** (5.0-9.5)	**6.7** (4.5-8.9)	**6.0** (3.8-8.2)	**5.2** (3.0-7.4)	**6.9** (4.7-9.1)	**6.5** (4.2-8.7)	**5.8** (3.6-8.1)	**7.1** (4.9-9.3)	**6.7** (4.4-8.9)	**6.0** (3.8-8.2)	**7.5** (5.3-9.8)	**7.1** (4.8-9.3)	**6.4** (4.2-8.6)
100 Year	**8.5** (6.2-10.7)	**7.8** (5.5-10.0)	**6.9** (4.7-9.2)	**6.1** (3.9-8.3)	**8.1** (5.8-10.3)	**7.6** (5.3-9.8)	**7.0** (4.8-9.2)	**8.3** (6.1-10.5)	**7.9** (5.6-10.1)	**7.2** (5.0-9.4)	**8.9** (6.7-11.2)	**8.4** (6.2-10.7)	**7.8** (5.6-10.0)

Dissolved Oxygen Concentration Estimates with 95% Confidence Intervals (mg/L)													
Storm Return Period	M0-SLR0	M0-SLR1	M0-SLR2	M0-SLR3	M2A-SLR1	M2A-SLR2	M2A-SLR3	M2B-SLR1	M2B-SLR2	M2B-SLR3	M2C-SLR1	M2C-SLR2	M2C-SLR3
5 Year	**5.3** (4.1-6.5)	**5.4** (4.1-6.6)	**5.5** (4.3-6.7)	**5.7** (4.5-6.9)	**5.4** (4.1-6.6)	**5.4** (4.2-6.7)	**5.6** (4.3-6.8)	**5.3** (4.1-6.5)	**5.4** (4.2-6.6)	**5.5** (4.3-6.8)	**5.3** (4.0-6.5)	**5.4** (4.1-6.6)	**5.5** (4.3-6.7)
10 Year	**5.2** (4.0-6.4)	**5.3** (4.1-6.5)	**5.4** (4.2-6.7)	**5.6** (4.4-6.9)	**5.3** (4.0-6.5)	**5.4** (4.1-6.6)	**5.5** (4.2-6.7)	**5.2** (4.0-6.4)	**5.3** (4.1-6.5)	**5.4** (4.2-6.7)	**5.2** (3.9-6.4)	**5.3** (4.0-6.5)	**5.4** (4.2-6.6)
25 Year	**5.0** (3.8-6.2)	**5.1** (3.9-6.4)	**5.3** (4.0-6.5)	**5.5** (4.3-6.7)	**5.1** (3.9-6.3)	**5.2** (3.9-6.4)	**5.3** (4.1-6.5)	**5.0** (3.8-6.2)	**5.1** (3.9-6.3)	**5.2** (4.0-6.5)	**5.0** (3.7-6.2)	**5.1** (3.8-6.3)	**5.2** (4.0-6.4)
100 Year	**4.8** (3.6-6.0)	**4.9** (3.7-6.2)	**5.1** (3.9-6.3)	**5.4** (4.1-6.6)	**4.9** (3.6-6.1)	**5.0** (3.7-6.2)	**5.1** (3.8-6.3)	**4.8** (3.5-6.0)	**4.9** (3.6-6.1)	**5.0** (3.8-6.2)	**4.7** (3.5-5.9)	**4.8** (3.6-6.0)	**4.9** (3.7-6.1)

C-8 WQ Concentration FPLOS Estimates

Salinity Concentration Estimates with 95% Confidence Intervals (ppt)													
Storm Return Period	M0-SLR0	M0-SLR1	M0-SLR2	M0-SLR3	M2A-SLR1	M2A-SLR2	M2A-SLR3	M2B-SLR1	M2B-SLR2	M2B-SLR3	M2C-SLR1	M2C-SLR2	M2C-SLR3
5 Year	**30.2** (24.2-36.1)	**30.4** (24.5-36.3)	**30.9** (25.0-36.8)	**31.4** (25.5-37.3)	**30.2** (24.2-36.1)	**30.4** (24.5-36.3)	**31.1** (25.2-37.0)	**29.9** (23.3-35.2)	**30.3** (23.8-35.6)	**31.0** (24.0-35.8)	**29.2** (23.3-35.2)	**29.7** (23.8-35.6)	**29.9** (24.0-35.8)
10 Year	**29.5** (23.6-35.4)	**29.8** (23.9-35.7)	**30.3** (24.4-36.2)	**30.7** (24.8-36.6)	**29.5** (23.6-35.4)	**29.7** (23.8-35.6)	**30.3** (24.4-36.2)	**29.2** (22.5-34.3)	**29.5** (22.8-34.6)	**30.2** (23.2-35.0)	**28.4** (22.5-34.3)	**28.7** (22.8-34.6)	**29.1** (23.2-35.0)
25 Year	**27.8** (21.9-33.7)	**28.2** (22.2-34.1)	**28.5** (22.6-34.4)	**29.0** (23.1-34.9)	**28.0** (22.0-33.9)	**28.1** (22.2-34.0)	**28.7** (22.7-34.6)	**27.5** (20.7-32.6)	**27.7** (20.9-32.7)	**28.3** (21.1-33.0)	**26.6** (20.7-32.6)	**26.8** (20.9-32.7)	**27.0** (21.1-33.0)
100 Year	**26.0** (20.1-31.9)	**26.3** (20.3-32.2)	**26.5** (20.5-32.4)	**27.0** (21.1-32.9)	**26.1** (20.2-32.0)	**26.2** (20.3-32.1)	**26.8** (20.9-32.7)	**25.5** (0.0-30.1)	**25.6** (18.3-30.1)	**26.2** (18.7-30.5)	**24.2** (0.0-30.1)	**24.2** (18.3-30.1)	**24.6** (18.7-30.5)

Chlorophyll a Concentration Estimates with 95% Confidence Intervals (µg/L)													
Storm Return Period	M0-SLR0	M0-SLR1	M0-SLR2	M0-SLR3	M2A-SLR1	M2A-SLR2	M2A-SLR3	M2B-SLR1	M2B-SLR2	M2B-SLR3	M2C-SLR1	M2C-SLR2	M2C-SLR3
5 Year	**4.1** (1.9-6.4)	**3.9** (1.7-6.1)	**3.4** (1.2-5.6)	**2.5** (0.3-4.7)	**4.0** (1.8-6.3)	**3.8** (1.6-6.0)	**3.1** (0.9-5.3)	**4.2** (2.3-6.8)	**3.9** (1.9-6.3)	**3.0** (1.3-5.8)	**4.6** (2.3-6.8)	**4.1** (1.9-6.3)	**3.6** (1.3-5.8)
10 Year	**4.5** (2.3-6.8)	**4.3** (2.1-6.5)	**3.8** (1.5-6.0)	**2.9** (0.7-5.1)	**4.5** (2.3-6.7)	**4.2** (2.0-6.5)	**3.7** (1.4-5.9)	**4.7** (2.9-7.3)	**4.3** (2.5-6.9)	**3.6** (1.7-6.2)	**5.1** (2.9-7.3)	**4.7** (2.5-6.9)	**4.0** (1.7-6.2)
25 Year	**5.7** (3.5-7.9)	**5.4** (3.2-7.7)	**4.9** (2.7-7.1)	**4.0** (1.8-6.2)	**5.6** (3.4-7.8)	**5.3** (3.1-7.5)	**4.8** (2.6-7.0)	**5.9** (4.1-8.5)	**5.5** (3.7-8.1)	**4.9** (3.4-7.9)	**6.3** (4.1-8.5)	**5.9** (3.7-8.1)	**5.6** (3.4-7.9)
100 Year	**6.8** (4.6-9.1)	**6.6** (4.4-8.8)	**6.1** (3.9-8.3)	**5.1** (2.9-7.3)	**6.9** (4.7-9.1)	**6.6** (4.4-8.8)	**6.1** (3.8-8.3)	**7.2** (5.7-10.2)	**6.9** (5.4-9.8)	**6.3** (5.0-9.5)	**8.0** (5.7-10.2)	**7.6** (5.4-9.8)	**7.2** (5.0-9.5)

Dissolved Oxygen Concentration Estimates with 95% Confidence Intervals (mg/L)													
Storm Return Period	M0-SLR0	M0-SLR1	M0-SLR2	M0-SLR3	M2A-SLR1	M2A-SLR2	M2A-SLR3	M2B-SLR1	M2B-SLR2	M2B-SLR3	M2C-SLR1	M2C-SLR2	M2C-SLR3
5 Year	**5.1** (3.9-6.3)	**5.2** (4.0-6.5)	**5.5** (4.3-6.7)	**5.8** (4.6-7.1)	**5.2** (3.9-6.4)	**5.3** (4.1-6.5)	**5.7** (4.4-6.9)	**5.1** (3.7-6.2)	**5.3** (3.9-6.4)	**5.7** (4.2-6.7)	**4.9** (3.7-6.2)	**5.2** (3.9-6.4)	**5.5** (4.2-6.7)
10 Year	**4.9** (3.7-6.2)	**5.1** (3.8-6.3)	**5.3** (4.1-6.5)	**5.6** (4.4-6.9)	**5.0** (3.7-6.2)	**5.1** (3.9-6.3)	**5.4** (4.2-6.6)	**4.9** (3.4-5.9)	**5.0** (3.6-6.1)	**5.4** (4.0-6.5)	**4.7** (3.4-5.9)	**4.9** (3.6-6.1)	**5.3** (4.0-6.5)
25 Year	**4.3** (3.1-5.6)	**4.5** (3.3-5.7)	**4.7** (3.5-6.0)	**5.1** (3.9-6.3)	**4.4** (3.2-5.6)	**4.5** (3.3-5.8)	**4.8** (3.6-6.0)	**4.3** (2.8-5.3)	**4.5** (3.0-5.5)	**4.8** (3.2-5.7)	**4.1** (2.8-5.3)	**4.3** (3.0-5.5)	**4.4** (3.2-5.7)
100 Year	**3.8** (2.6-5.0)	**3.9** (2.7-5.1)	**4.2** (2.9-5.4)	**4.5** (3.3-5.7)	**3.8** (2.6-5.0)	**3.9** (2.7-5.2)	**4.2** (3.0-5.4)	**3.6** (2.0-4.5)	**3.8** (2.2-4.7)	**4.1** (2.4-4.9)	**3.3** (2.0-4.5)	**3.5** (2.2-4.7)	**3.7** (2.4-4.9)

Total Nitrogen Concentration Estimates with 95% Confidence Intervals (mg/L)													
Storm Return Period	M0-SLR0	M0-SLR1	M0-SLR2	M0-SLR3	M2A-SLR1	M2A-SLR2	M2A-SLR3	M2B-SLR1	M2B-SLR2	M2B-SLR3	M2C-SLR1	M2C-SLR2	M2C-SLR3
5 Year	**0.8** (0.6-1.0)	**0.8** (0.6-0.9)	**0.7** (0.5-0.8)	**0.5** (0.4-0.7)	**0.8** (0.6-0.9)	**0.7** (0.6-0.9)	**0.6** (0.5-0.8)	**0.8** (0.7-1.0)	**0.7** (0.6-0.9)	**0.6** (0.5-0.8)	**0.9** (0.7-1.0)	**0.8** (0.6-0.9)	**0.7** (0.5-0.8)
10 Year	**0.9** (0.7-1.0)	**0.8** (0.7-1.0)	**0.7** (0.6-0.9)	**0.6** (0.5-0.8)	**0.9** (0.7-1.0)	**0.8** (0.7-1.0)	**0.7** (0.5-0.9)	**0.9** (0.8-1.1)	**0.8** (0.7-1.0)	**0.7** (0.6-0.9)	**1.0** (0.8-1.1)	**0.9** (0.7-1.0)	**0.8** (0.6-0.9)
25 Year	**1.1** (0.9-1.2)	**1.0** (0.9-1.2)	**0.9** (0.8-1.1)	**0.8** (0.6-1.0)	**1.0** (0.9-1.2)	**1.0** (0.8-1.2)	**0.9** (0.7-1.1)	**1.1** (1.0-1.3)	**1.0** (0.9-1.3)	**0.9** (0.9-1.2)	**1.2** (1.0-1.3)	**1.1** (0.9-1.3)	**1.0** (0.9-1.2)
100 Year	**1.3** (1.1-1.4)	**1.2** (1.1-1.4)	**1.1** (1.0-1.3)	**1.0** (0.9-1.2)	**1.3** (1.1-1.4)	**1.2** (1.1-1.4)	**1.1** (1.0-1.3)	**1.3** (1.3-1.6)	**1.3** (1.2-1.5)	**1.2** (1.2-1.5)	**1.4** (1.3-1.6)	**1.4** (1.2-1.5)	**1.3** (1.2-1.5)

APPENDIX B

C-9 Regression Analysis Decision Table

Parameter	Regression Analysis Performed	No statistically significant correlation trends. p > 0.05 for cumulative volume correlations within the modeling period	Parameter within Class III Marine Water Criteria. Not identified as a COC. Further analysis not warranted	Insufficient/No data received
Salinity	X			
Chlorophyll *a*	X			
Total Nitrogen		X		
Total Phosphorus		X		
Dissolved Oxygen	X			
Turbidity		X		
Fecal Coliform				X
Copper		X		
Cadmium, Total			X	
Selenium, Total			X	
Silver, Total			X	
Lead			X	

C-8 Regression Analysis Decision Table

Salinity	X			
Chlorophyll *a*	X			
Total Nitrogen	X			
Total Phosphorus				X
Dissolved Oxygen	X			
Turbidity		X		
Fecal Coliform			X	
Copper				X
Cadmium, Total				X
Selenium, Total				X
Silver, Total				X
Lead				X

APPENDIX C

C-8/C-9 Water Quality Data Request Log

Last Updated: **2/6/2023**

Date Requested	Data Requested	Requested From	Contact	Received Date	Parameter	Data Period (Provided by County)
8/11/2022	SK01 (all parameters)	Georgio Tachiev	georgio.tachiev@miamidade.gov	8/13/2022		
8/11/2022	BS01 (all parameters)	Georgio Tachiev	georgio.tachiev@miamidade.gov	8/13/2022		
8/11/2022	BB02 (all parameters)	Georgio Tachiev	georgio.tachiev@miamidade.gov	8/13/2022		
8/12/2022	BB09 (all parameters)	Valentina Caccia	valentina.caccia@miamidade.gov	8/23/2022	Chlorophyll a	1980 - 2022
				8/23/2022	Fecal Coliform	1979 - 2017
				8/23/2022	Total Coliform	1979 - 2009
				8/23/2022	Copper	1989, 2019
				8/23/2022	DO	1979 - 2022
				8/23/2022	Lead	1989, 2019
				8/23/2022	TN	2020 - 2022
					TKN	None
					N-N	None
				8/23/2022	TP	1979 - 2022
				8/23/2022	Salinity	1979 - 2022
				8/23/2022	Turbity	1979 - 2022
				8/23/2022	Zinc	1989
					Temperature	None
8/26/2022	BB10 (TN)	Valentina Caccia	valentina.caccia@miamidade.gov	9/12/2022	TN	2020-2022
				9/16/2022	TKN	2018-2022
				9/16/2022	N-N	2018-2022
8/29/2022	S28 S29 M0 and M2C Model Flows	Michael Del Charco	mdelcharco@taylorengineering.com	9/13/2022		
8/30/2022	BS04 (all parameters)	Valentina Caccia	valentina.caccia@miamidade.gov	9/21/2022		
8/30/2022	SK02 (all parameters)	Valentina Caccia	valentina.caccia@miamidade.gov	9/21/2022		
8/30/2022	BB03 (all parameters)	Valentina Caccia	valentina.caccia@miamidade.gov	9/21/2022		
9/7/2022	WQ Standards	Valentina Caccia	valentina.caccia@miamidade.gov	9/16/2022		
9/23/2022	BB09 (TN, TKN, N-N, Temperature)	Sherea Higgs	Sherea.Higgs@miamidade.gov	9/30/2022	TN	2020-2022
				9/30/2022	TKN	2020-2022
				9/30/2022	N-N	2020-2022
				9/30/2022	Temperature	2020-2022
10/24/2022	•BB09 (TKN, NOx, TN, TP, Copper, Lead, Zinc, Temperature) •BS04 (TP) •BB02 (Chlorophyll a, TP, Copper) •BB03 (TKN, NOx, TN, TP, Copper, Lead, Zinc, Temperature) •SK02 (TP)	Omar Abdelrahman	Omar.Abdelrahman@miamidade.gov	10/25/2022	BB02 (Chlorophyll a, Copper, TP) BB03 (Temperature) BB09 (TKN, NOx, TN, Copper, Lead, Temperature) BSO4 (TP) SK02 (TP)	BB02: 1996-2022 (Chlorophyll a, TP) 1996-2019 (Copper) BB09: 1996-2022 (NOX, Temperature) 2009-2022 (TKN) 2020-2022 (TN) 2019 (Copper, Lead) BB03: 1996-2009 BS04: 1996-2022 SK02: 1996-2022
10/26/2022	BB09 (TP)	David Chin	dchin@miami.edu	11/19/2022	TP (Geometric means only)	2008 - 2018
1/13/2023	S28 S29 M2A Model Flows	Joseph Wilder	jwilder@taylorengineering.com	1/19/2023		