FINAL REPORT

City of Miami

CITY PROJECT B-30632A
Service Order No. 01

Comprehensive City-Wide
Stormwater Master Plan

Final Report

March 2021

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Section 1

Introduction and Background

This document is the Final Report summarizing the findings and recommendations of the analysis of the City of Miami's primary stormwater management system (PSMS) and is submitted as the final deliverable for City Project B-30632A, *Comprehensive Citywide Stormwater Master Plan* (SWMP).

1.1 Introduction

Due to changes in land use, increasing sea level rise, and the changing regulatory environment over time, the development of a new and comprehensive Citywide SWMP was desirable to assist the City in establishing a policy framework so that the integrity of the City's future is protected and enhanced over time. This project planned and developed a newly updated and comprehensive Citywide stormwater model, SWMP, and the creation of a modern GIS database digitally mapping its PSMS stormwater assets.

The City of Miami is implementing the recommendations developed herein in a phased, prioritized citywide stormwater management Capital Improvements Program initially funded by a portion of its 2017 Miami Forever General Obligation Bond Program. The City's intent for the Miami Forever Bond is to build a stronger, more resilient future for Miami, alleviating existing and future risks to residents, economy, tourism, and the City's legacy. The Bond funds a series of immediate, near-term, and long-term projects with a goal of transforming the future of Miami in key categories which align with the City's most pressing needs including addressing sea-level rise and flood prevention. The objectives of the bond projects are to minimize flooding frequency, severity, duration, and impact, and to protect critical infrastructure and high-use areas, reducing financial and economic vulnerability.

The project work was divided into four major work phases in the contracted scope of services:

- <u>Task A – Data Collection and Evaluation Phase</u> - This phase developed and analyzed the required information describing the physical details of the existing stormwater management system, physical characteristics of the study area topography, rainfall, and groundwater, and established the boundary conditions for the models to be used. When all of the City's available data was analyzed, a data gap analysis was performed, and survey teams were deployed to fill-in the missing data. A new, modern Geographic Information System (GIS) was developed and the data was digitally converted to provide electronic, one-click visual access for all City departments to their stormwater system data. This effort included field surveys for missing or conflicting data and structures, acquired the finished floor elevations of the City's critical structures, created a digital elevation model (DEM) for topography, surveyed seawalls and shorelines, analyzed and digitized the City's paper stormwater atlases and record drawings, included acquisition of plans from other agencies, determined canal cross sections, local and regional pump station and gate operations, and created an electronic database and digital map of the City's primary stormwater assets and all of the spatial data used to create the stormwater models.

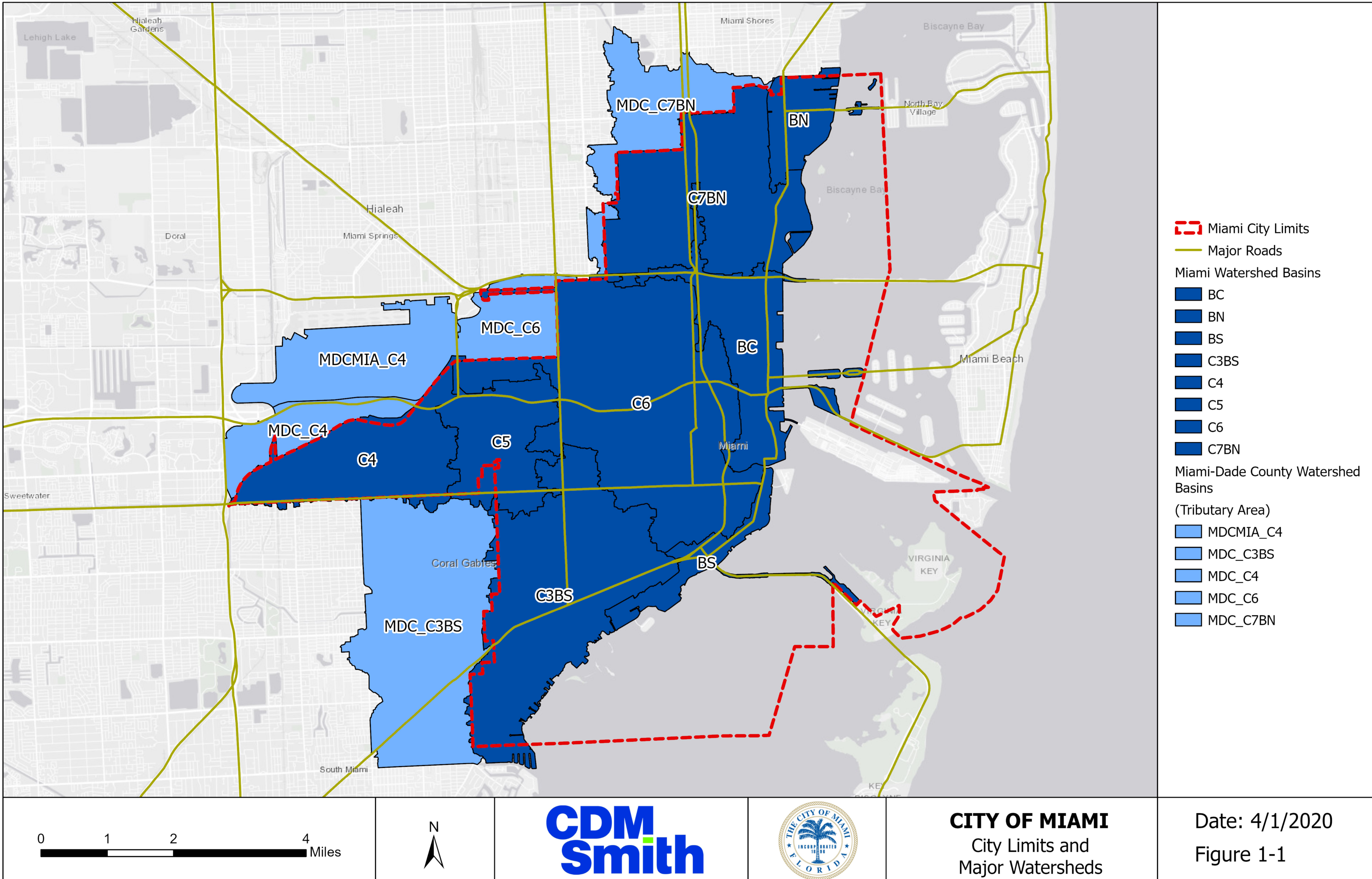
- Task B – Stormwater Modeling Phase - This phase developed the mathematical equations and routines to simulate rainfall, stormwater runoff, pipe and pump systems hydraulics, and groundwater reaction using actual City topography, interconnections with surrounding adjacent municipalities and systems, the receiving waters, and the current imposed permitting constraints for stormwater quality. The models were validated to actual conditions for past known storms, and then used to predict existing and future conditions flood depths and durations to determine the cause of the flooding so it can be resolved with new capital projects. This effort included the development of the digital representation of the physical stormwater system components and the application of the dynamic mathematical formulas for the hydraulics, hydrology, basin delineations, off-site tributary areas beyond the City's limits, set the model boundary conditions, tides, groundwater, and rainfall. Simulations were run in the EPA SWMM5 model engine for existing land use conditions and verified against recent actual recorded storm events for flooding depth, location, duration, and aerial extent. The models were then used to simulate the 5-yr/24 hr, 10-yr/72 hr, 25-yr/72 hr, and 100-yr/72 hr design storm events and predict flooding inundation around the City under the design conditions. Engineering analysis were performed by adding stormwater capital improvements to the models to reduce the flooding to the City's chosen levels of service.

- Task C – Sea Level Rise Evaluation and Resiliency Considerations Phase - This effort included a tidal surge analysis to determine the cost benefit of increasing seawall heights and superimposed two sea level rise conditions on the proposed CIP to determine the effect on the system and developed models to simulate future sea level rise to determine the impact on the existing and proposed stormwater management systems, and simulated storm surge events for resiliency planning.

- Task D – Capital Improvement Program Phase - This phase developed the Citywide CIP to address flooding for two alternate Levels of Service (LOS) for stormwater flooding - one more restrictive, one less restrictive; and created a cost-benefit analysis for each LOS to help decision makers plan the most beneficial projects under available budget. This effort ranked the areas of the City based on length of road inundated, number of structures inundated, and number of critical structures flooded, determined the planning-level cost of delineated proposed projects for the two levels of service, and listed the CIP for implementation based on City input to capture its priorities.

1.2 Background

The City of Miami (City) encompasses approximately 56 square miles. Of this total, approximately 36 square miles are located in upland areas while the remaining 20 square miles are found within coastal basins and Biscayne Bay. The stormwater service area is naturally divided by elevation, topography, and infrastructure into eight major drainage areas or basins **(Figure 1-1)**.


MDC_C7BN
BN
C7BN
MDC_C6
MDCMIA_C4
BC
C6
MDC_C4
C5
C4
BS
C3BS
MDC_C3BS
Lehigh Lake
Hialeah Gardens
Miami Shores
Biscayne Bay
North Bay Village
Hialeah
Doral
Miami Springs
Miami Beach
Miami
Sweetwater
Coral Gables
Virginia Key
South Miami
Miami City Limits
Major Roads
Miami Watershed Basins
BC
BN
BS
C3BS
C4
C5
C6
C7BN
Miami-Dade County Watershed Basins
(Tributary Area)
MDCMIA_C4
MDC_C3BS
MDC_C4
MDC_C6
MDC_C7BN
0 1 2 4 Miles
N
CDM Smith
THE CITY OF MIAMI INCORP ORATED 1896 FLORIDA
CITY OF MIAMI
City Limits and
Major Watersheds
Date: 4/1/2020
Figure 1-1

As a result of changes in land use, sea level rise, and changes in the regulatory environment over time, the development of a new and comprehensive Citywide SWMP was desirable to assist the City in establishing a policy framework so that the integrity of the City's future is protected and enhanced over time. The Citywide SWMP project encompasses planning and developing a newly updated and comprehensive master planning document and the creation of a modern GIS database of its stormwater assets.

To support the Citywide planning-level analysis required for the SWMP proposed CIP, the models and developed GIS focus on the identified primary stormwater management system (PSMS) for multiple design rainfall events and various downstream tidal boundary conditions. The PSMS includes constructed stormwater structures and facilities and overland flow paths that flow and outfall to the downstream receiving body. The PSMS is defined as the major open channels and pipes of 24-inch diameter and larger, except where the model analysis specifically required more detailed infrastructure to be considered for the analysis.

Factors which added complexity, cost, and magnitude specifically to the City's CIP solutions for stormwater management included:

- Protection of Biscayne Bay – The dynamic and diverse ecosystem of Biscayne Bay is governed by several sets of rules including the Historic Sites Act, Endangered Species Act, National Environmental Policy Act, Clean Water Act and other Title 36 rules, and further is designated as an impaired Water and an Outstanding Florida Waters (OFW) by FDEP/SFWMD - a water body that requires the highest protection and allows stricter scrutiny for permitting. As the Bay is the ultimate discharge point for above ground stormwater runoff for the City, whether by overland flow, or gravity piped or pumped outfalls, this regulatory situation results in restrictions on discharge of untreated water into the Bay, requirements for enhanced pollution control, limits shoreline development, and adds pre-post development flow constraints, thus limiting stormwater management options and increasing costs for conveyance and treatment.

- Compensation for Flows Entering the City from Off-Site and Maintaining Pre-Post Conditions – To be permittable, stormwater projects are required to demonstrate that they both maintain existing historic stormwater flow paths, and do not result in adverse impacts upstream or downstream of the proposed improvements. The detailed models developed for this Master Plan provide this support information for response to regulators. Several areas in the City are lower than their surrounding communities and, during large rainstorms, significant flow can enter from other "off-site" areas exacerbating the flooding within the City and resulting in required larger capacity City infrastructure capital improvement requirements, as a portion of the system capacity is being occupied by other non-City flows. In many situations, due to localized hydraulic conditions, further increasing the capacity of the City's stormwater infrastructure resulted in even more flow entering from off-site areas, diminishing the effectiveness of the City's CIP to address its own flooding LOS.

- Lack of Available Dedicated Stormwater Management Lands – The City is near buildout, and little, if any dedicated stormwater management lands exist to store stormwater runoff, attenuate the peak flows, and treat the runoff generated from the highly impervious land areas. This is exacerbated by historic development at, or near, existing grade elevations within the many natural riverine sloughs and flood plains of the feeder flow channels for the Miami River, and infill of lands over time without compensating floodplain storage, both resulting in increased runoff. At this time, the City is not creating or converting existing recurrent flood lands into dedicated storage areas as part of the initial CIP. Accordingly, all of the generated runoff to meet the LOS alternatives must all be handled with constructed retrofit conveyance, treatment, and disposal infrastructure.

1.3 Project Goals and Objectives

A primary objective for the project was to develop detailed hydrologic and hydraulic (H&H) models of the City of Miami's drainage basins and stormwater management system providing a tool suitable for evaluating the performance of the City's existing stormwater system, and establishing a baseline against which to evaluate proposed alternative improvements to meet the desired LOS for flood control under future simulated storms of varying intensity and duration, or meet an alternative secondary level of service as a compromise due to practical costs and regulatory constraints. Proposed capital improvements can then be tested, prioritized, and balanced to available funding over time.

The report describes the approach taken to create and apply the H&H models for this purpose, and the creation, validation, and use of the model for analysis under both simulated current conditions (available infrastructure and land use data up to Data Year 2017) and proposed alternatives CIP conditions. The report describes the determination of the current LOS, model verification techniques, performance evaluation of the integrated stormwater management systems, as well as proposed improvements to meet the City's desired LOS goals.

1.4 Regulatory and Intergovernmental Framework

Regulatory agencies impose restrictions on both water quantity (runoff flows and stages) and water quality (pollution control) for stormwater management.

1.4.1 Flood Control

For flood control, the State of Florida South Florida Water Management District (SFWMD) operates and maintains the regional southern peninsular water management system consisting of levees, berms, canals, and large spillways, gates, and pump stations with the intent of protecting south Florida's residents and businesses from both flood and drought, and moving water to meet varying conditions and needs is essential to sustaining South Florida's population, economy, and environment. This primary system of canals and natural waterways connects to community drainage districts and smaller neighborhood systems, which together must manage floodwaters during heavy rains. As a result of this interconnected drainage system, flood control in South Florida is a shared responsibility between SFWMD, County and City governments, local drainage districts, and on a neighborhood level by developers, homeowners' associations, and residents. The SFWMD regulates stormwater discharges from new development or projects through the Environmental Resource Permit (ERP) process. The permitting requires assurance that new projects do not impact (worsen) existing flood levels, do not impede historic flows, and meet the water quality treatment requirement for the receiving waters.

1.4.2 Water Quality Requirements and the Protection of Groundwater and Biscayne Bay

Locally, Miami-Dade County Department of Regulatory and Economic Resources (RER) and the Department of Environmental Resources Management (DERM), require a separate permit to control stormwater discharge and pollution to any surface water in Miami-Dade County. Similar to the District rules, at a minimum, the first inch of rainfall that is not absorbed by the ground is required to be retained on site, prior to discharge as studies have shown this first inch is typically where up to 90% of the pollution is picked up by rainfall runoff (a.k.a, "the first flush"). If the applicant indicates that they cannot reasonably contain the whole storm event on site after retaining the first inch, the County may allow a discharge to a body of water with additional alternate pollution control measures applied on an individual project basis.

Surface Water Discharges

The Florida Department of Environmental Regulation (FDEP) imposes regulatory water quality restrictions on discharges to surface waters, groundwater, and to Biscayne Bay. Nonpoint source pollution is described as stormwater pollution that results from the accumulation of contaminants from land surface, erosion of soils, debris, increased volumes of stormwater runoff, atmospheric deposition, suspended sediments, and dissolved contaminants. Rainfall dissolves and releases pollution and contaminants created by of urban activities, conveying pollutants, trash, oils, fertilizers, and other chemicals that wash off of the roads and ground surfaces. The initial few minutes, first flush of a storm, will release most the accumulated contaminants and holds the highest concentration of runoff pollution. Without dedicated treatment systems, the runoff can convey the pollutants and trash via stormwater systems to the receiving waters. Stormwater pollution can be harmful to aquatic plants and animals, and over time, can result in detrimental effects to marine ecosystems.

Citywide, this is regulated by the NPDES MS4 permitting process. As a part of the Federal National Pollutant Discharge Elimination System Program (NPDES) for Municipal Separate Stormwater Systems (MS4) permit, the City is required by penalty of law to treat stormwater flowing off the City land areas to the maximum extent practicable prior to discharge to the receiving waters. Due to topography, the ultimate receiving water for the greater Miami area's stormwater runoff is Biscayne Bay which is recognized by the State of Florida as a designated Outstanding Florida Water (OFW), providing for the highest levels of protection to assist in maintaining the quality of its waters. Protection of the water quality of Biscayne Bay can impose additional required treatment volumes of up to 1.5 times the normal required. Adding new treatment systems Citywide in addition to the infrastructure proposed to reduce flooding are costly and may result in certain projects being potentially cost-prohibitive or not implementable under the available budget. Discussions with regulators should be commenced early-on in the stormwater master planning effort to understand regulatory constraints and open a dialog for future requirements so the CIP is aligned with each regulatory jurisdiction.

Groundwater Discharge/Recharge

Restrictions on allowable locations where recharge/drainage wells to dispose of and treat stormwater runoff can be installed in the City is another constraint on City CIP projects. Two applicable FDEP/MDCRER regulatory rules govern where these stormwater management systems can be installed:

1. A saltwater/freshwater interface exists beneath the City where the ocean meets the inland freshwater aquifer (a situation commonly referred to as saltwater intrusion as it detrimentally affects the area's potable water supply), the exact location of which inland varies from North to South with seasonal rainfall, tides, canal operations, potable water well pumping, rainfall, and sea-level rise. The saltier layer, where stormwater is permitted to be injected into the ground, is defined as groundwater with a chloride concentration of 1,000 milligrams per liter (mg/L) (parts per million, ppm) or greater. This area is generally the eastern portions of the City from just west of I-95 to the Bay, nearer the ocean. Several government agencies publish salinity front data which is updated from time to time.

2. The use of Biscayne Aquifer for recharge/drainage wells is permittable in areas as long as injection of runoff is also restricted to zones where there are no impacts to Class G-II potable water supply aquifers, (i.e., water treatment plant wellfield potable water supply sources). These areas will normally coincide with the zones where chloride concentrations exceed the saltwater intrusion front rule from restriction 1 above as the brackish water is more expensive to treat. Well field "zones of influence" are published for public record in the individual well field permits.

CIP Construction Permitting Process

An Environmental Resource Permit (ERP) is required for development or construction activities to prevent flooding, protect the water quality of Florida's lakes and streams from stormwater pollution, and protect wetlands and other surface waters. The SFWMD, FDEP, and MDC RER/DERM regulates these activities. Projects developed or implemented in phases such as the citywide SWMP will be required to have an approved (commission adopted) stormwater master plan showing the applicant's contiguous land holdings and providing assurance that a funding mechanism is in place. The primary concerns of the regulatory agencies are to ensure continuity between phases and satisfactory completion and operation of individual phases if the overall project is not completed as planned. There is an imposed water quality treatment requirement of 2.5 inches over the project impervious area, or 1-inch over the full site area (whichever volume is greater) to be treated by an approved method before release into the conveyance system.

For multi-phased programs such as this, the District encourages/allows the submittal of a "Conceptual ERP". Issuance of a conceptual approval permit is a regulatory determination that the conceptual plan is, within the extent of detail provided in the application, consistent with applicable rules at the time of issuance. The conceptual approval permit then provides the permit holder (City) with a rebuttable presumption that, during the duration of the conceptual approval permit, the design and environmental concepts upon which the conceptual approval permit is based will meet applicable rule criteria for issuance of permits for subsequent phases of the project, barring any significant deviations. The purpose of obtaining the conceptual permit is to be able to expedite and reduce the information required for individual project construction permits as they are designed and constructed in accordance with the approved master plan conceptual ERP.

1.4.3 BMP Treatment Train Concept for Stormwater Quality

A stormwater Best Management Practice (BMP) is a method or combination of methods found to be the most effective and feasible means of preventing or reducing the amount of pollution generated by nonpoint sources to a level compatible with water quality goals or requirements.

BMPs are classified as either:

- Prevention - avoiding the generation of pollutants.
- Reduction - reducing or redirecting of pollutants.
- Treatment - capturing and treating pollutants.

Methods for controlling pollutants in stormwater runoff are further categorized as non-structural or structural BMPs and are often used in concert to control pollution in stormwater runoff.

- *Nonstructural BMPs* are practices that improve water quality by reducing the accumulation and generation of potential pollutants at or near their source and do not require physical construction of a facility but provide for the development of pollution control programs that include prevention, operations and maintenance, education, and regulation.
- *Structural BMPs* involve design and construction a facility for controlling quantity and quality of urban runoff. These structures treat runoff at either the point of generation or the point of discharge and require routine maintenance such as retention/detention system, aquifer recharge systems, oil water separators, trash screens, and grit chambers.

The effective combination of both types of BMPs is known as a BMP treatment train.

1.4.4 Stormwater Management and Septic Systems

Septic systems for residential sanitary waste disposal are still in use throughout Miami-Dade County. A septic system is a buried tank attached to the waste drains of a dwelling to capture and partially treat raw domestic sanitary wastewater and are usually used in more remote or limited-access areas where public municipal sewer service is not practical or available. The septic system's drainfield requires that the groundwater elevation be lower than it to function properly and not backup into the house or flood the ground with sewage. In November of 2018, MDC RER published a report (updated in December of 2020 as a Plan of Action Report) which analyzed the effect of sea level rise and rising groundwater elevations on septic systems. The report noted that there are approximately 105,000 parcels served by septic systems in the County, several of which are within the City of Miami. The report stated that improperly functioning septic systems can pose public health and environmental risks as the systems' treatment is compromised, and pollutants (human-host-specific fecal bacteria) may eventually migrate within the aquifer to the canals and into the Bay. The report concludes that increased initiatives to extend sanitary sewer services and eliminate septic tanks in areas vulnerable to failure from SLR and high groundwater tables to protect the health, safety, and environmental integrity of the community should be undertaken by MDWASD which serves the majority of the County for wastewater collection and treatment.

A large portion of the proposed stormwater infrastructure CIP relies on exfiltration and disposal of stormwater into the underground aquifer due to the constraints on new or direct discharge to the protected Bay. If septic systems are nearby these stormwater BMPs, there is the potential for movement of known areas of septic system bacteria – how far, at what concentration, or to where, is not known without further study. Close coordination of the City's SWMP CIP and the County's initiative to eliminate remaining septic tanks should be undertaken for potential coordination of projects and accelerated their scheduling in stormwater improvement neighborhoods.

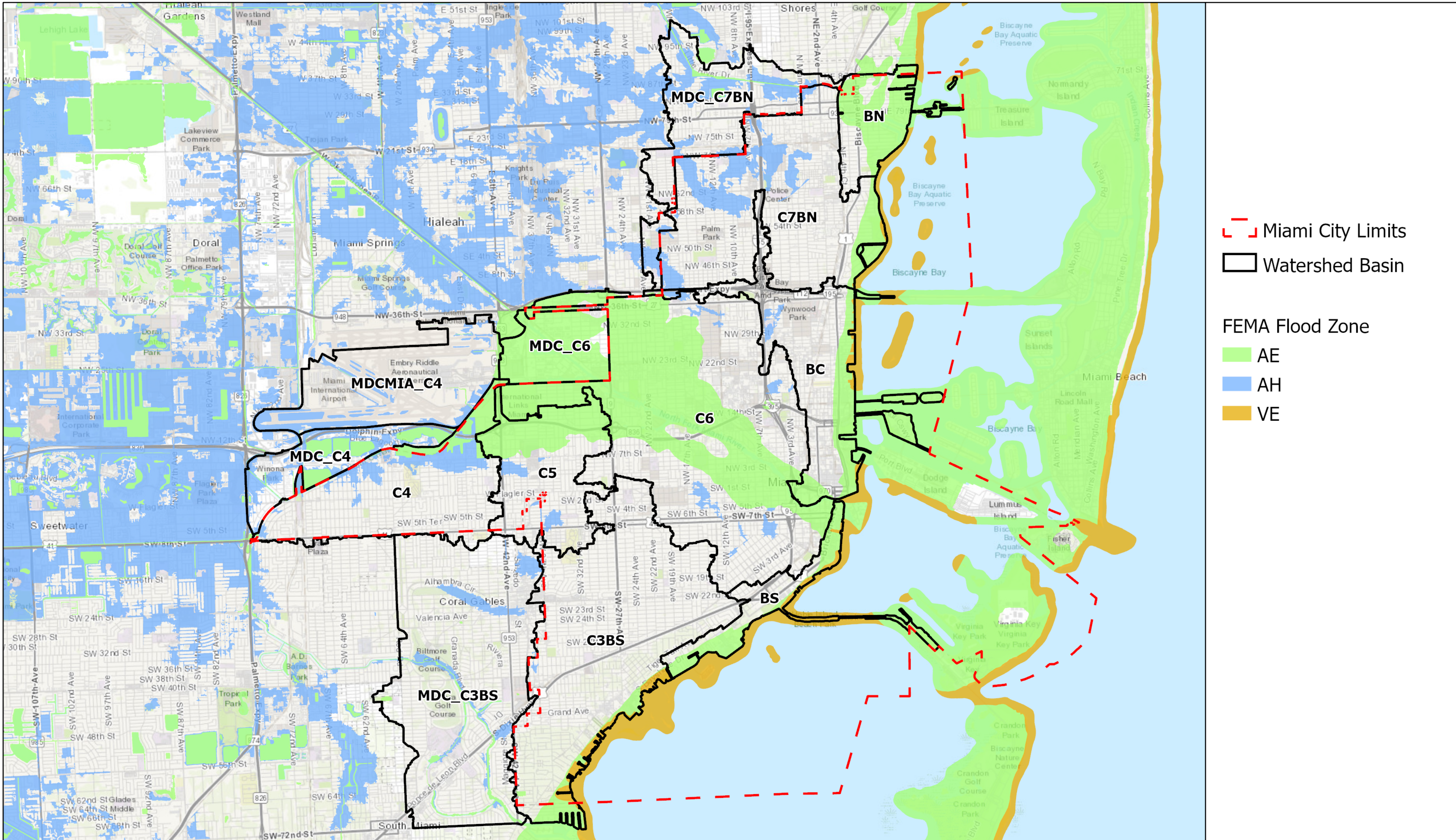
1.5 Historic Flooding Problem Areas

Known historic flooding documentation citywide was obtained from several sources:

- Repetitive Loss Areas: These locations have been attributed as repetitive loss areas based on the FEMA database.
- 311 Complaints: Miami Dade County maintains a 311 database of complaints. The data shown in the flood location maps have been filtered to those that were specifically tagged "Flood" with follow up survey of high water marks.
- Community Workshops for Resident Complaints: For this project, the City of Miami held six interactive community workshops to discuss flooding and the stormwater master plan, one in each commission district, during May and June 2019. As part of the workshop, community members were asked to locate rainfall, hurricane, and tide flood locations on their neighborhood map. These locations are the cumulative accounting of this exercise.
- Available post-storm media documentation and other storm-related photographs.

1.5.1 FEMA Flood Zones

The Federal Emergency Management Agency's (FEMA) flood hazard maps reflect current flood risks for metropolitan areas. FEMA flood maps divide the City into flood zones ranging from Moderate to High Flooding risk. According to FEMA data, approximately 40% of the homes in Miami are built upon floodplains and are considered within flood-risk zones. Flood Insurance Rate Maps (FIRMs) illustrate flood hazards throughout the City on a course scale and are used for determining flood insurance policy rates. Structures determined to lie in a flood zone usually obtain an Elevation Certificate that can be used to gage how high a structure was built in relation to that flood zone's recurrent flood elevation. Certificates are now required for all new construction, as well as for construction projects that involve making substantial improvements to a structure and are used to determine flood loss claims. Miami-Dade County has kept records of these Certificates on file since it began participating in the Community Rating System (CRS). The FEMA Flood Map showing the various flood zones for the City of Miami Study Area is provided on **Figure 1-2.**



CDM Smith

THE CITY OF MIAMI FLORIDA

FEMA Flood Map
City of Miami Study Area

Date: 12/17/2020

Figure 1-2

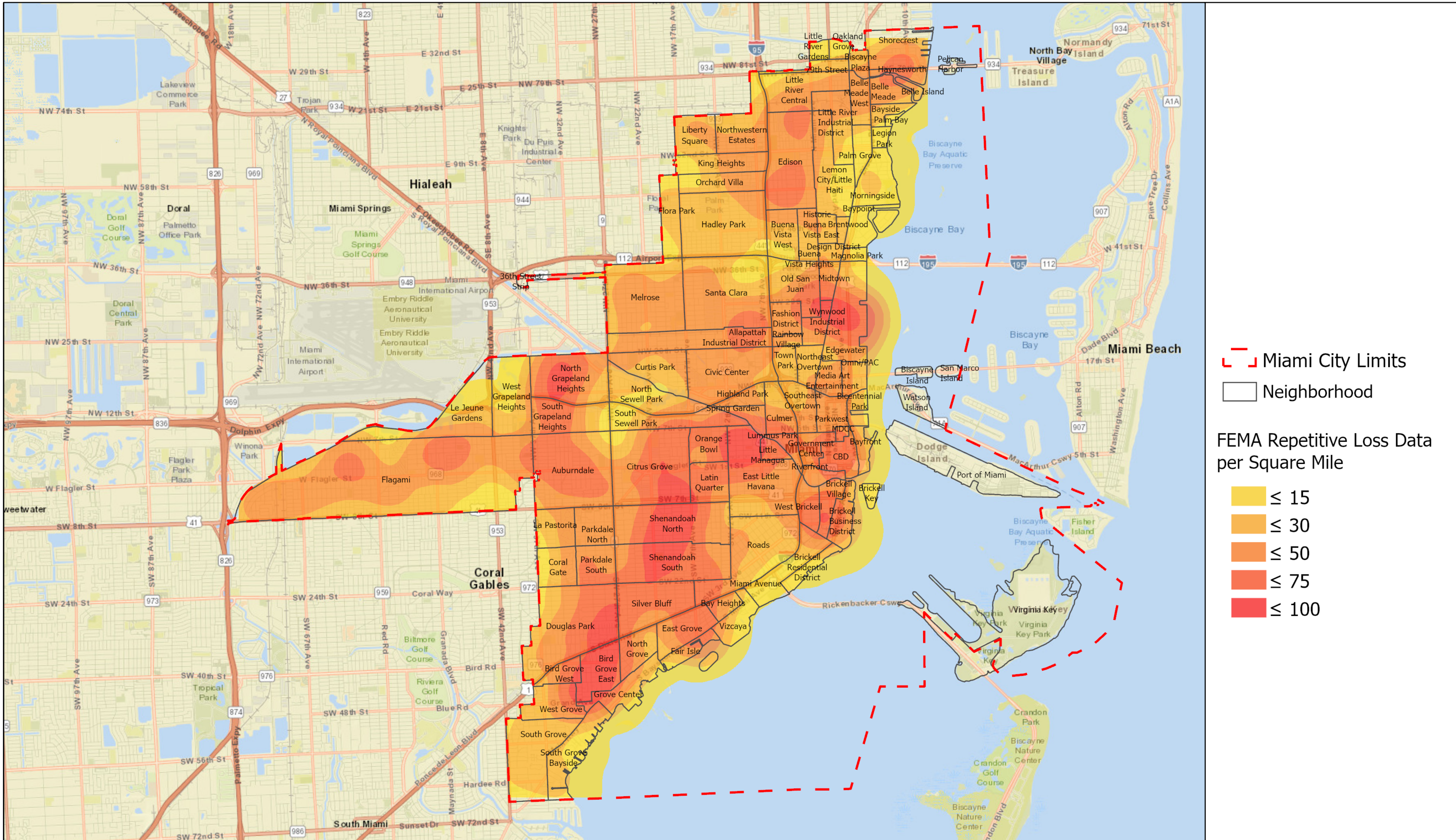
1.5.2 Flooding Areas and Documented Repetitive Loss Data

A digital map layer was created in the Geographical Information System (GIS) for this study plotting the historic recorded data for FEMA Repetitive Loss (RL) properties on the City map to get a geographic picture of the recorded recurrent flooding areas in the City. RL is currently defined by FEMA as "any insurable building for which two or more claims of more than $1,000 were paid by the National Flood Insurance Program (NFIP) within any rolling ten-year period, since 1978." The mapped data are used to develop potential positive correlations with influencing parameters such as topography, impervious development, extent of installed stormwater infrastructure, or any anomalies particular to the flooding areas.

Additional flooding data points were added from the Miami-Dade County 311 Contact Center flood complaints data and from the resident flooding complaint data obtained from the series of interactive, Citizen's Community Informational Flooding Workshops conducted Citywide in each commission district as part of this project. **Figure 1-3** shows the repetitive loss and flooding complaints map that resulted from the data gathering efforts. As shown, clusters or groupings of repetitive, historical flooding reports are evident. **Figure 1-4** shows the same repetitive loss and flooding complaint data plotted over the topographic map, which illustrates a positive correlation between the lowest lying and/or spatially confined areas and the repetitive historic flooding. The map also shows that many of the densely developed areas in the lower elevation upstream sloughs of the historic natural riverine systems throughout the City (pre-development) continue to be problematic for chronic flooding. Other areas correlate with the lack of positive draining stormwater management infrastructure including areas of over-development without integrating compensation for historic flood plain storage or dedicated water management lands.

1.5.3 Flooding Reports for Recent Storms and Model Verification

Stormwater model verification, calibration, and validation techniques are used to compare model results to actual conditions for a known storm event for corresponding dates and times. Calibration and validation are typically performed using measured gage data for stages and estimates of flows. The available gages are on the main SFWMD Canals and cannot be used to directly verify the model results within the City system at a neighborhood level of detail. Therefore, a verification technique was used to match observed flooding with recent events based on measured rainfall. In this approach, models are run with best available data as a first pass, and then iterative, sensitivity analyses are run with small changes to the model input parameters to fine-tune the results to obtain a statistically significant match to best available recorded field data. As a typical rainstorm is spatially diverse and varies in both intensity and volume as it moves through an area, different verification storms are used for different areas depending on the amount of rainfall that was recorded for the particular area and the available correlated visual evidence of the resultant flooding either from the City, private reports, or publicly available media sources. The field data used for this project for verification included surveyed highwater marks, photographic and visual recordings, and anecdotal evidence submitted to the City by residents or Staff, or a combination of all three. Rainfall and flooding data were not available in all areas of the City so other parameters such as time series of canal stages and flows were matched.



0 1 2 3 4 Miles

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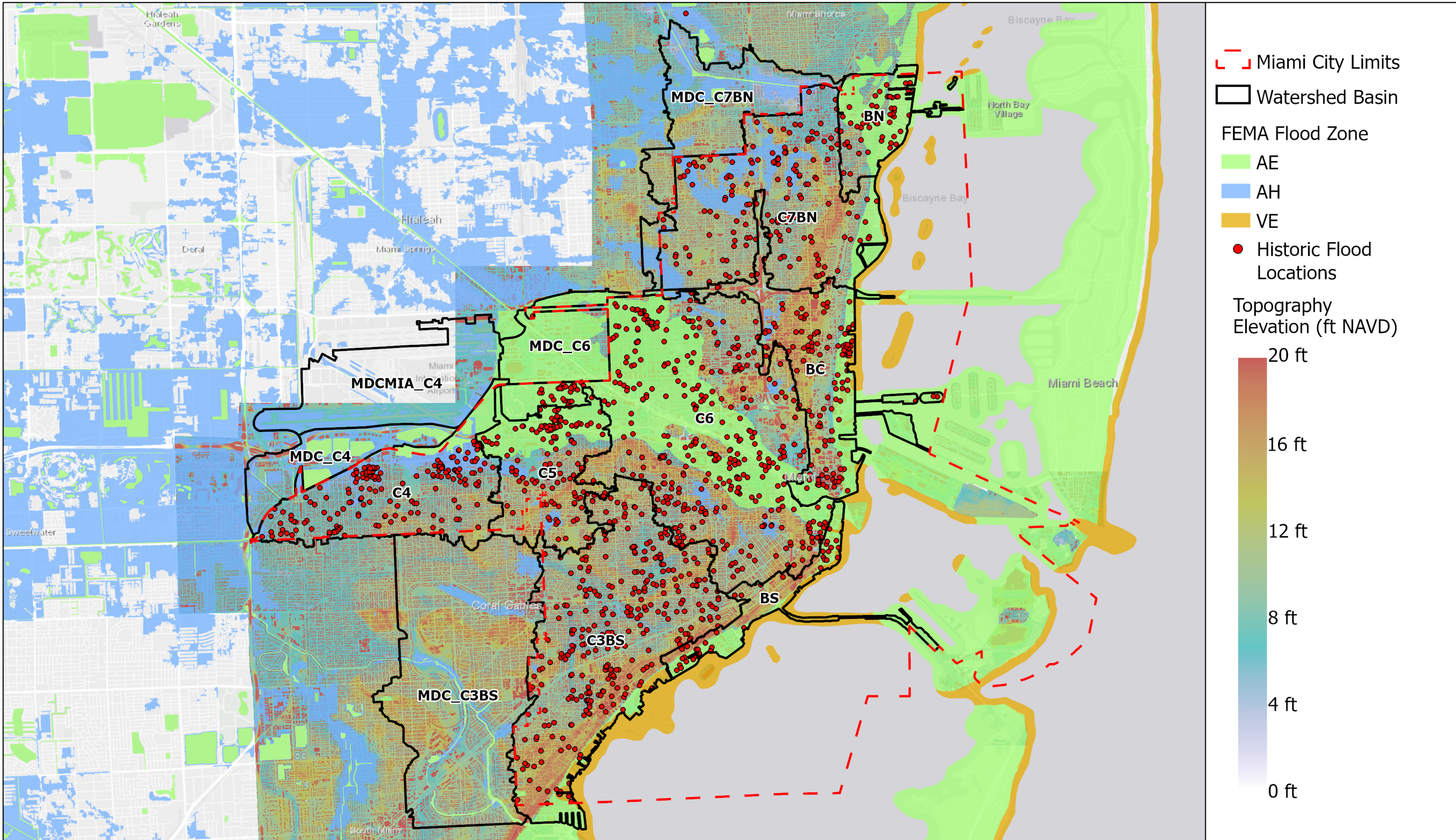
THE CITY OF MIAMI FLORIDA

FEMA Repetitive Loss Data

Date: 12/17/2020

Figure 1-3



0 1 2 3 4 Miles

N

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Historic Flooding Data and Topographic Map

Date: 12/17/2020

Figure 1-4

Data for three verification storms were available at the time of the model verification phase and a fourth storm occurring after model verification were analyzed in various detail in the eight watershed models depending on their impact in the City and the availability of corresponding photographs or other evidence:

- The May 5, 2019 storm produced a short (approximately 1-hour) intense precipitation event that covered most of the City of Miami and was used to verify the results of many of the models. There were no other storms that were able to be obtained with corresponding photographs. The locations of these photos were either surveyed for a high-water mark, or the flood level was estimated by inspection of the photo compared to the LiDAR DEM, or from anecdotal reports.

- The June 16, 2013 storm produced concentrated areas of intense, high-volume rainfall in many areas of Metropolitan Dade County, centered in the Coconut Grove Area. The storm recorded over 3 inches of rainfall in 3 hours, 2 inches of which fell in the first hour.

- Hurricane Irma was used as a third model verification data source. On September 10, 2017, Hurricane Irma hit Cudjoe Key, 20 miles north of Key West, as a Category 4 storm. Miami did not get the core of Irma, but still received severe storm conditions and was used to simulate storm surge and tidal flooding superimposed with rainfall. According to the National Weather Service (NWS) data, "in Miami-Dade County, an average of 3-5 feet of inundation occurred along the Biscayne Bay shoreline from Homestead to Downtown Miami/Brickell and extending inland 1-2 blocks, with peak surveyed inundation of slightly greater than 6 feet in isolated spots in Coconut Grove and Brickell. Inundation decreased north of Downtown Miami along the Biscayne Bay shoreline, with values generally around 2-3 feet. Along the Atlantic oceanfront, including Key Biscayne and Miami Beach, inundation was generally around 2-3 feet and confined to the immediate beachfront. The 72-hr rainfall total was wide-spread and ranged between 4-8 inches over the area."

- A fourth, high intensity, high volume, data-rich storm occurred from May 24-27, 2020 in the study area, affecting the majority of the City, but the schedule and timing of that event was such that the project had already moved into the CIP modeling and planning phase. This storm produced 8 to 10 inches of rainfall across a wide swath from Fort Lauderdale to the upper Keys over three days with rainfall in some places recording the most since Hurricane Irma in September 2017. The storm data were gathered, analyzed, and simulated in parallel with the ongoing work in the models, and the major flooding was well-correlated and of sufficient predicted accuracy to assist the City with the root causes, and design guidance parameters for early-out projects in the worst flooding areas.

A discussion of the full model verification with comparisons of model predicted inundation versus actual flooding is provided in **Appendix A.**

1.6 Critical City Structures

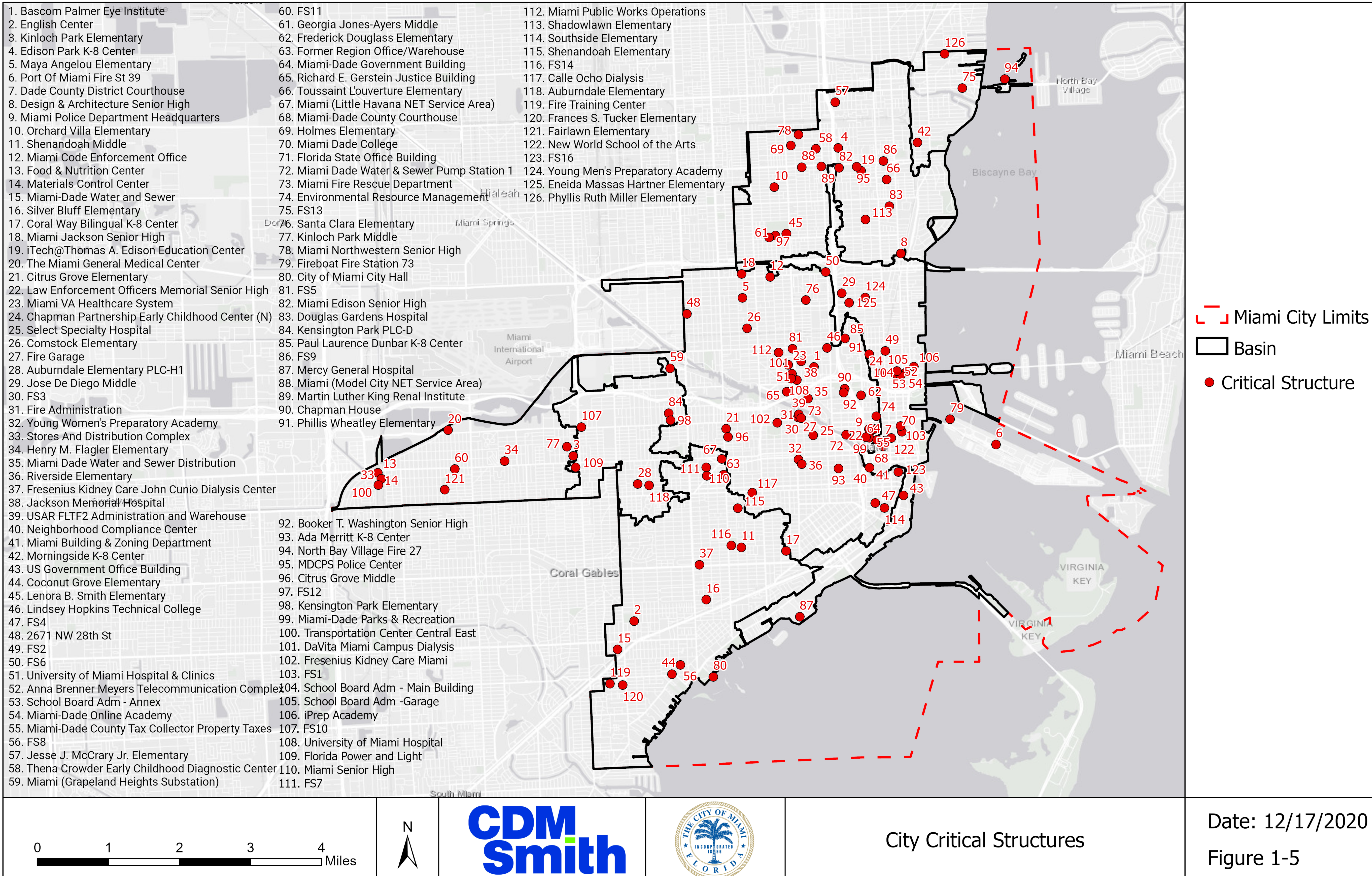
Critical structures, in terms of stormwater management analyses, are defined as structures, buildings, or facilities owned and/or operated by the municipality or others that are considered essential to the uninterrupted operation, health, safety, and welfare of the community in a storm-related emergency. For Miami, this includes emergency operations centers, police, fire rescue, hospital, utility, government, and evacuation centers such as schools and storm shelters. Structures such as treatment plants and power generation facilities are owned and operated by others. A Citywide list of 127 facilities was compiled matching this functional use type. Each of these buildings was then field surveyed for its finished floor-elevation so it can be compared to predicted flood elevations under the various simulations. A map of the citywide critical structures and their designation is provided on **Figure 1-5**, and again in **Appendix D** along with the City's Stormwater Pump Stations.

1.7 Current NFIP-CRS Review

As a part of the FEMA National Flood Insurance Program (NFIP), the Community Rating System (CRS) is a voluntary incentive program that recognizes and encourages community floodplain management activities that exceed the minimum program requirements. Congress established the NFIP with the passage of the National Flood Insurance Act of 1968. As a result, flood insurance premium rates are discounted to reflect the reduced flood risk resulting from the community actions meeting the three goals of the Community Rating System:

1. Reduce flood damage to insurable property
2. Strengthen and support the insurance aspects of the National Flood Insurance Program
3. Encourage a comprehensive approach to floodplain management

For National Flood Insurance Program Community Rating System participating communities, flood insurance premium rates are discounted in increments of 5 percent. Assignment of a Class 10 means the community is not participating in the Community Rating System and receives no discount, a Class 9 community would receive a 5 percent discount, up to a Class 1 community which would receive a 45 percent premium discount. The Community Rating System Classes for local communities are based on 19 creditable activities which fall under four categories: Public Information, Mapping and Regulations, Flood Damage Reduction, Flood Preparedness. The elements of the comprehensive citywide Stormwater Master Plan and CIP implementation should allow an increase in the NFIP Community Class and discount for the City's residents.



City Critical Structures

Date: 12/17/2020

Figure 1-5

The table below shows the credit points earned, classification awarded, and premium reductions given for the City under the NFIP CRS. The City's last cycle verification report was under the old manual (FIA-15/2013) and is in need of update. For comparison, Miami-Dade County is currently a Class 5 with a 25% discount for SFHA.

Table 1-1 City of Miami Current NFIP CRS Rating

Community No.	120650
Entry Date	10/01/1994
Current Effective Date	5/1/2010
Current Class	7
% Discount for SFHA	15
% Discount for non-FSHA	5
Status	C

1.8 Current NPDES Permit

The City is required to inspect and maintain its stormwater infrastructure in accordance with the frequency and requirements set forth in its National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) Phase I Permit No. FLS000002-004 which was issued by the Florida Department of Environmental Protection (FDEP) in November 2016. The City is currently a co-permittee with Miami-Dade County and 41 other municipalities. The City is required to produce and submit an annual report demonstrating compliance with the regulations, providing an updated outfall inventory and various water quality summaries, the goal being to eliminate non-stormwater discharges through the stormwater system and pollution reduction to the receiving waters to the maximum extent practicable.

1.9 Stormwater Utility and Development Impact Fees

The City of Miami Code of Ordinance Chapter 18 Sections 291 to 298, establishes the Stormwater Fees and Fund. According to provisions of F.S. Chapter 166 and the Florida Constitution, the City is authorized to construct, improve and extend the stormwater utility systems and to issue revenue and other debts if needed to finance in whole or in part the cost of such system. The City is also authorized to establish just and equitable rates, fees and charges for the services and facilities provided by the system. Fees collected go toward the planning, construction, operation and maintenance of stormwater management systems – such as canal and drainage improvement projects and secondary drainage systems, and toward reducing pollution caused by silt, oil, gasoline, fertilizers, pesticides and other litter carried by the stormwater to the drainage systems.

The stormwater utility fee (SWU fee) is imposed upon each developed lot and parcel within the City. The current (October 2020) City of Miami monthly stormwater utility fee is $3.50 for each the Equivalent Residential Unit (ERU) defined as the statistical average horizontal impervious area of all residences in the City of Miami which has been appraised as residences by the County property appraiser office. The total impervious are of each parcel of land includes all areas covered by structures and impervious amenities such as but not limited to roof tops, patios, porches, driveways and any hard surface. For comparative purposes, the Miami-Dade County SWU fee is currently $5.00 monthly/ERU. Parcels within the City are classified into Residential and Non-Residential customer classes. Residential single family detached homes, condominium units, apartments, townhouse units, and mobile homes are billed at a flat fee of 1 ERU per dwelling unit. Non-Residential properties such as businesses are billed based on the total impervious area of the property divided by 1,191 and then multiplied by $3.50/monthly. Vacant properties are considered 100% pervious and have no billing. The fees are assessed quarterly through a bill from Miami Dade Water and Sewer Department Invoice if there is a current water and sewer, or semi-annually through an invoice by the City of Miami Finance Department for properties that have no water and sewer account. There is a provision for fee adjustment upon further review if the special characteristics of the site allow it to accept additional stormwater and it is providing additional retention pond area or exfiltration beyond that which is required for its site. The SWU fees are not intended to finance major capital programs.

Chapter 13 of the City of Miami Code of Ordinances allows for fees to be imposed upon development which generates increased demands upon the City's public facilities and services. The amount of the impact fee is calculated based upon the average amount of public facility capacity demand attributable to the development and average costs of additional capital facilities, capital improvements, and capital equipment needed to provide additional capacity and vary by area. The fees are levied through the building permit process.

1.10 Citywide Flood Stage Monitoring Program

An analysis was performed on the feasibility of the implementation of a City-wide stage gauge monitoring network. This type of flood stage monitoring network is used in conjunction with other data to assist with the planning, trending, and analysis of flooding-related events whether by rainfall, storm surge, or tidal causes.

The monitor gauge network consists of a series of self-contained, reporting or recording, water surface elevation detection equipment located at critical points in the City either on land or within waterbodies. Specifically, the data can be used for hydraulic model calibration and refinement, trending pre- and post-installation of capital improvements to measure the effect of the improvements on flooding frequency, depth, and duration, and potentially providing an alert to emergency managers of live flooding conditions throughout the network during major storm events. The intent of the proposed Citywide stage gauge network differs from the existing canal level network in that flooding will be measured in the urban core overland as well, as opposed to only in open channel waterbodies. Ideally, the system will have the capability to measure flooding depth and duration due to both high tides (King Tides) and rainfall events and can be correlated to measured rainfall from convective storms and tropical events, and combinations thereof.

The proposed stage gauge network will be most useful if it has the capability to collect and record historic data over time to reveal trends, better quantify the depth, duration and spatial extent of smaller targeted flooding events, and have the capability to measure the larger events such as the 100-year storm. Moreover, the network should be able to document trends in inundation depth and extent due to sea level rise and show the impacts or improvements due to implemented stormwater control infrastructure projects. It is also envisioned that the stage gauge network is intended to be featured as an element of an overall program for stormwater management with City signage to that effect accompanying the devices in the congested public spaces where they will be deployed.

Twenty-two initial site locations were identified around the City for the flood monitors. The recommended technologies were narrowed down to either electroconductive sensors or optical infrared image sensors. Several vendors of the two types were provided to the City for the pilot testing and deployment. The data will be used for model refinement, measuring key performance indicators (KPIs) for the CIP program effectiveness, and a live link to the emergency management operations office for real-time flood depths around the City in a storm situation.

1.11 Miami Forever Bond Program Resiliency Initiative

The intent of the November 2017 Miami Forever General Obligation Bond is "to build a stronger, more resilient future for Miami, alleviating existing and future risks to residents, economy, tourism and the city's legacy". The Bond will fund a series of projects investing a total of $400 million in five categories which align with the City's most pressing needs: Sea-Level Rise and Flood Prevention, Roadways, Parks and Cultural Facilities, Public Safety and Affordable Housing. $192 million of the bond funding is slated to address the first few stormwater flooding-related projects. The first tranche of flood prevention projects will focus on low-cost high result investments such as tidal backflow prevention valves and additional capacity at current pump stations. Future funded projects will be guided by the Stormwater Master Plan CIP and will aim to minimize flooding frequency, severity, duration and impact; protect critical infrastructure and high-use areas; and reduce financial and economic vulnerability.

1.12 Public Information Program

In parallel with the technical work performed for the Citywide SWMP, a public information program has in place providing residents with updates on the progress and allowing community input into the process. Throughout the duration of the SWMP, the City has been engaging with residents and resiliency committees to hear their concerns and feedback and incorporated their input and concerns into the master plan recommendations.

The City has several dedicated areas of their website with updated information on the progress, interim findings, and public meetings on the SWMP. Interactive workshops were held in each commission district to gain resident input on flooding areas and answer questions on SWMP program. The City also hosted an interactive "Industry Experts" Workshop to discuss and gain input from local experts in their fields ranging from regulators, to engineering peer reviewers, to developers and environmentalists.

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Section 2

Data and Methodology

2.1 Introduction

This Section discusses the Model Development and describes the specific techniques, parameters, and input data used for the creation of the stormwater models being implemented in the analysis phase of the work.

2.1.1 Background Information

The primary objective for developing the hydrologic and hydraulic (H&H) models of the City of Miami's drainage basins is to provide a tool suitable for evaluating the performance of the City's stormwater system and establishing a baseline against which to evaluate alternative improvements to meet the desired level of service for flood control. The sections below describe the model development process, including data collection and evaluation, general model development considerations, summary of the modeling process, and development of H&H model parameters. The specifics of developing the individual drainage basin models, validation techniques, and performance evaluation is documented individually for each drainage basin.

To support the planning-level analysis required for the Capital Improvements Program (CIP), the developed models focus on the primary stormwater management system (PSMS) for multiple size design rainfall events and various downstream tidal boundary conditions. The PSMS includes constructed stormwater facilities and overland flow paths that flow and outfall to the downstream receiving waterbody (i.e., the boundary condition). The PSMS is defined as open channels and pipes of 24-inch diameter and larger, except where the model analysis specifically required more detailed infrastructure to be considered for the analysis.

2.2 Model Development

2.2.1 Stormwater Modeling Software

Stormwater computer models are tools used to determine the response of the stormwater management network to predefined precipitation events using a multitude of mathematical and engineering equations to simulate the response to variable input data. The models generally consist of a hydrologic component to estimate runoff flow rates and volume resulting from the precipitation applied; and a hydraulic component that routes flow through the PSMS and determines discharges, elevations, depths, travel times, volumes, and velocities throughout the system. Some models also support evaluation of water quality, including processes such as build-up and wash-off, uptake, transport, decay, deposition of pollutants and sediment, and Best Management Practice (BMP) pollutant removal.

Stormwater computer models are developed to support stormwater master planning, typically to evaluate performance of the City's stormwater infrastructure. The models follow the interconnected stormwater management system (City-owned and County/State-owned as necessary) downstream through pipes, channels, overland flow, and ditches to the point of discharge into a major canal, river, ground, pump station or Biscayne Bay. The major canals and the Miami River are included in the master plan models, with the final downstream boundary condition located in the tidally influenced Biscayne Bay. The master plan models will be maintained by the City to address future needs and incorporate changes that occur in the system.

The stormwater models for this analysis use the U.S. Environmental Protection Agency (EPA) Stormwater Management Model (SWMM) computational engine, which makes them fully compatible with the public domain software that may be downloaded without charge from the EPA website (https://www.epa.gov/water-research/storm-water-management-model-swmm).

As described on the EPA's website, the EPA SWMM is a dynamic rainfall-runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas. The runoff component of SWMM operates on a collection of subcatchment areas that receive precipitation and generate runoff and pollutant loads. The routing portion of SWMM transports this runoff through a system of pipes, channels, storage/treatment devices, pumps, and regulators. SWMM tracks the quantity and quality of runoff generated within each subcatchment, and the flow rate, flow depth, and quality of water in each pipe and channel during a simulation period comprised of multiple time steps. Running under Windows™, SWMM 5 provides an integrated environment for editing study area input data, running hydrologic, hydraulic and water quality simulations, and viewing the results in a variety of formats. These include color-coded drainage area and conveyance system maps, time series graphs and tables, profile plots, and statistical frequency analyses.

The stormwater models for this analysis were initially created using a commercially available program/pre-processor PCSWMM by CHI (Computational Hydraulics International) for expediency due to the program's large data manipulation capabilities. PCSWMM also includes a custom graphical user interface (GUI) and offers other advanced GIS functionality, model building, calibration, and post processing tools which expedited the initial builds, and is fully compatible with the EPA SWMM running the EPA SWMM numerical engine.

2.2.2 Levels of Detail, Temporal Scales, and Numerical Time Steps

The level of detail in the H&H models must be adequate to accurately define and characterize flooding and erosion problems and the level of detail must represent the local and sub-watershed effects of each master plan alternative and/or series of alternatives sufficiently to allow alternative projects to solve existing problems, to be sized cost-effectively, to support Operations and Maintenance (O&M), and to coordinate implementations. For the scale of this planning-level analysis, the adequate level of detail was determined to include the PSMS of 24-inch diameter pipes and larger. In general, this means that pipes smaller than 24 inches are considered secondary and are typically not modeled. However, where drainage areas of reasonably large size were served by pipes smaller than 24 inches in diameter, these pipes were necessarily included in the model to allow for accurate characterization of the area. Generally, all pipes in the primary system have runoff loaded to the upstream terminus and thus help define sub-basin delineation.

To accurately represent drainage basin hydrology, the rainfall interval should be less than or equal to the travel times within the smallest sub-basin. For this project, a 5-minute rainfall interval was used for simulation of design storms and 5- or 15-minute intervals were used for simulation of historical rainfall, depending on the source data. It is also recommended to set the runoff wet weather time step to 1 minute since it has no impact on run times; similarly, the runoff dry weather time step should be equal to the 1-minute for simulations shorter than 1 week. With respect to hydraulics, the time step for flow routing should provide appropriate computational iterations within the shortest travel time associated with system hydraulic conveyances, thereby maintaining continuity (shortest travel times are typically associated with relatively short sections of large diameter pipes). For these models, a maximum time step of 5 seconds is used for routing to reduce instabilities in the model simulations.

2.3 Model Development Process

This section presents an overview of the model development process that was applied for all the drainage basins included in this study.

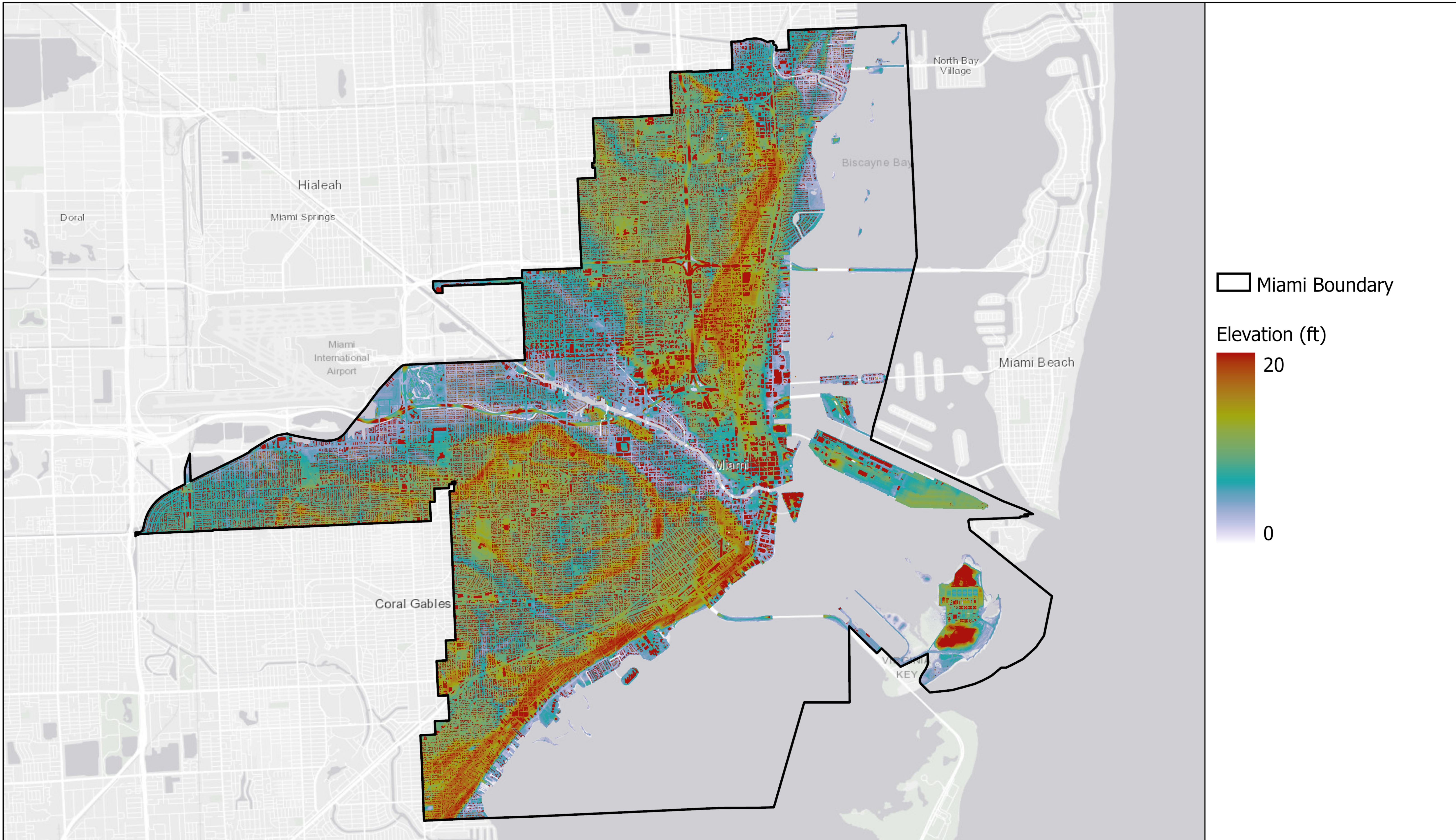
2.3.1 Data Collection and Characterization of the Drainage Basins

Data were collected and evaluated to compile the H&H parameters necessary to model the city watersheds. This section presents a description of the data obtained. Section 2.4 presents the role of each dataset in the modeling effort, and where applicable, the necessary modifications required for use in the watershed evaluation.

2.3.1.1 Topographic Data

The Digital Elevation Model (DEM) has been prepared from Light Detection and Ranging (LiDAR) data acquired from Miami-Dade County for 2015, along with coastal LAS (LASer format point cloud) data acquired through Quantum Spatial for 2018. Both sources of elevation data have been geo-processed to make a composite bare earth DEM. The fundamental vertical accuracy for bare earth elevations is 0.60 feet, the horizontal resolution of the LiDAR grid is 2 feet in length and width. The bare earth DEM excludes buildings, trees, bridges, etc.; however, the building footprints have been reintroduced by raster processing to create a new specific-use data layer (named CityOfMiami_CompositeDEM_Buildings) so that storage is not overestimated, and the results do not show false positives of building flooding. A second, raw DEM prepared from LAS data acquired from the Florida Division of Emergency Management for the year 2007, was used to evaluate the surfaces of elevated highways.

Figure 2-1 displays the topographic elevation with buildings included for the City of Miami in North American Vertical Datum of 1988 (NAVD). Natural land surface ranges from approximately 20 feet NAVD to 0 feet NAVD. Higher elevations are located along the coastal ridge (approximately follows the Flagler Railroad north of the Miami River, and is between U.S. Highway 1 and Bayshore Drive in the southern portion of the City), and a second ridge representing the southern bank of the Miami River historic floodplain (near NW 7th Street in South Grapeland Heights, running southeast to about SE 7th Street in Little Havana). The City is characterized by very low-lying land areas east of the coastal ridge and in the Miami River and Wagner Creek historic floodplains.



0 1 2 3 4 Miles

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CDM Smith

CITY OF MIAMI

Elevation

Date: 3/25/2020

Figure 2-1

2.3.1.2 Soils Data

The National Resources Conservation Services (NRCS) Soil Survey Geographic database (SSURGO) data for Miami-Dade County Area FL686, generated by the USDA (United States Department of Agriculture) was downloaded from the NRCS website (https://sdmdataaccess.nrcs.usda.gov) and reviewed to determine dominant soil types in the project area. The Hydrologic Soil Group (HSG) for each soil, if available, was extracted to the NRCS soil map database from NRCS tables using Soil Data Viewer 6.2 dominant condition aggregation.

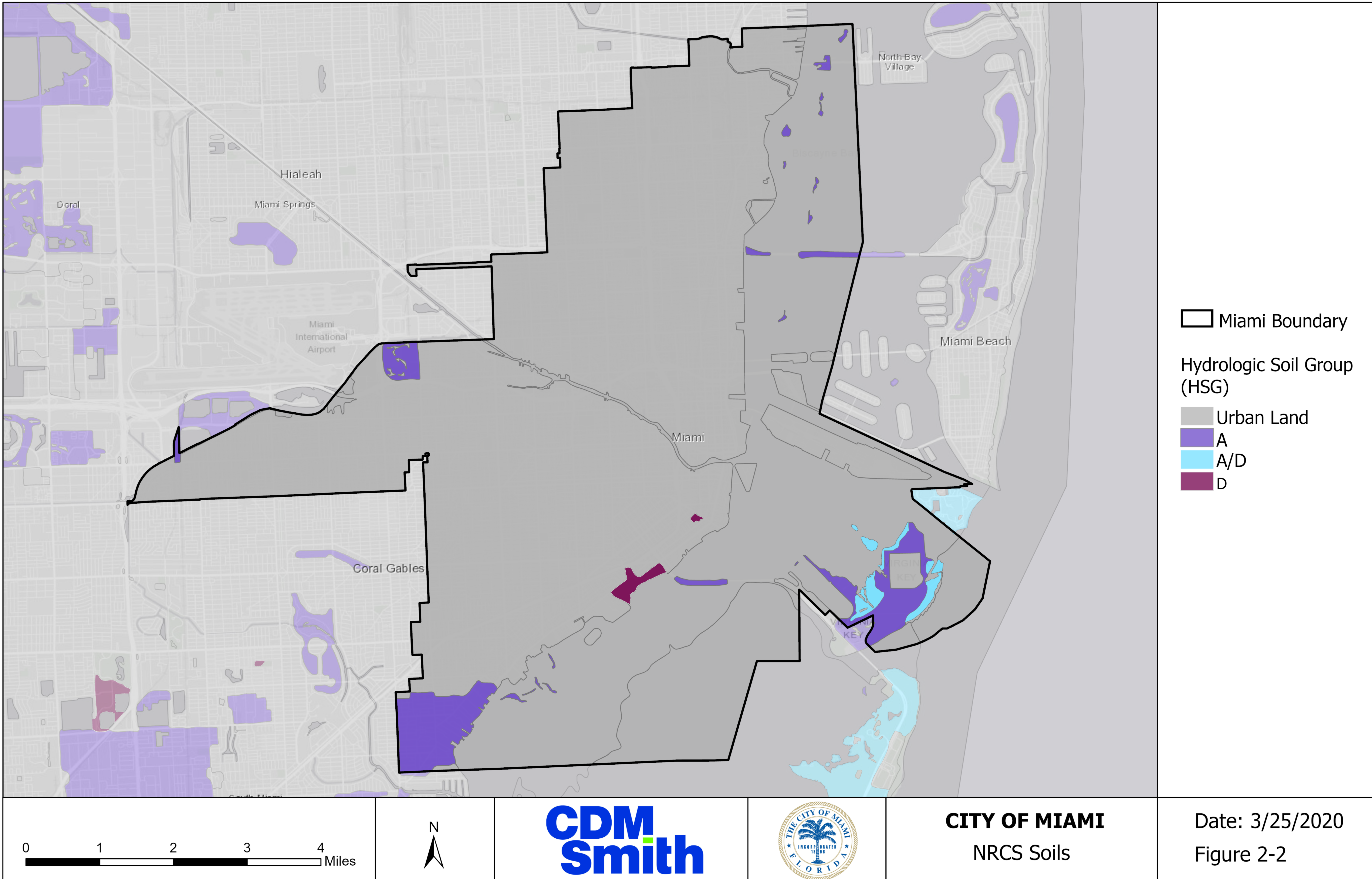
Figure 2-2 displays the NRCS soils map for the City. The dominant soil type in the City is Urban Land, which is defined as land covered by impervious urban development such as airports, shopping centers, parking lots, large buildings, streets, sidewalks and/or other structures, so that natural soil is not readily observed. Note that as result of urbanization, the underlying soil may be disturbed or covered by a new layer. In this case, utilizing the Type-D HSG classification for modeling is commonly recommended.

Soils types with dual classifications generally represent areas where there is a lens of poorly-drained soils lying above a section of better draining soils. Typically, the lower (Type-D) classification is used in H&H models, unless the soil is disturbed, such as a field of row crops where it is likely the upper lens has been penetrated. For this modeling effort, the dual class soils were provided a Type-D classification.

Double Ring Infiltration Tests

Ten double ring infiltrometer tests were conducted as part of this project, to test soil infiltration capacities where the NRCS HSG was Type "U," which represents urban land (i.e., to test whether a Type D classification is warranted). These tests use ringed cylindrical devices to measure the rate at which water moves into the topsoil.

The infiltration rates from the ten sites ranged from 0.1 inches per hour to17 inches per hour, ranging from a Type D soil to a Type A soil. The 10 tests were conducted in pairs at five sites to determine if the soils adjacent to a parking lot or street were more compacted than areas which were presumably less disturbed. However, the data did not show significantly lower values in the tests directly adjacent to impervious areas. The tests do show that the infiltration rates were more representative of Type A soils (sandy soils) at the higher elevations, and more representative of Type D soils (muck or clay) in the Miami River historic floodplain. Therefore, the coverage was adjusted for the soils map to provide data for the Type U coverage roughly based on location and topography, shown on **Figure 2-3**.



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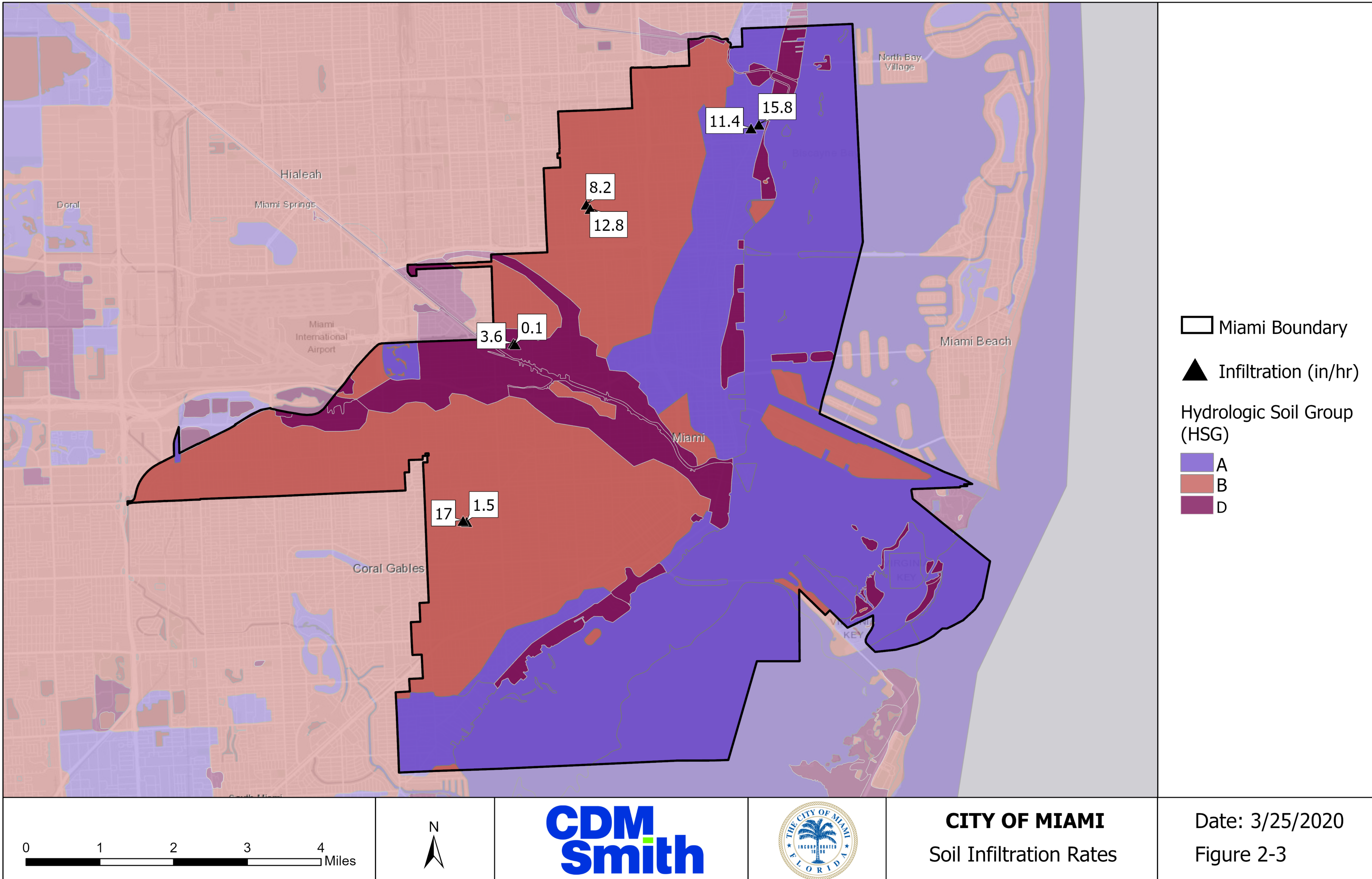
CITY OF MIAMI
NRCS Soils

Date: 3/25/2020
Figure 2-2



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CITY OF MIAMI

Soil Infiltration Rates

Date: 3/25/2020

Figure 2-3

Field Aquifer Permeability Tests

A database search was conducted to find local field permeability tests. A total of 37 tests scattered throughout the city were researched and found from inspection of Miami-Dade County permit records. These tests measure the permeability of the underlying Biscayne Aquifer. Open boreholes are drilled or augered deep enough to penetrate the aquifer (typically 10-15 feet below land surface), and water is pumped into the hole. The falling head test estimates the saturated hydraulic conductivity (K_{sat}) of the aquifer by measuring the time for the head to fall a given distance. The standing head test maintains the head at a given elevation and estimates K_{sat} by measuring the flow necessary to maintain the head over time.

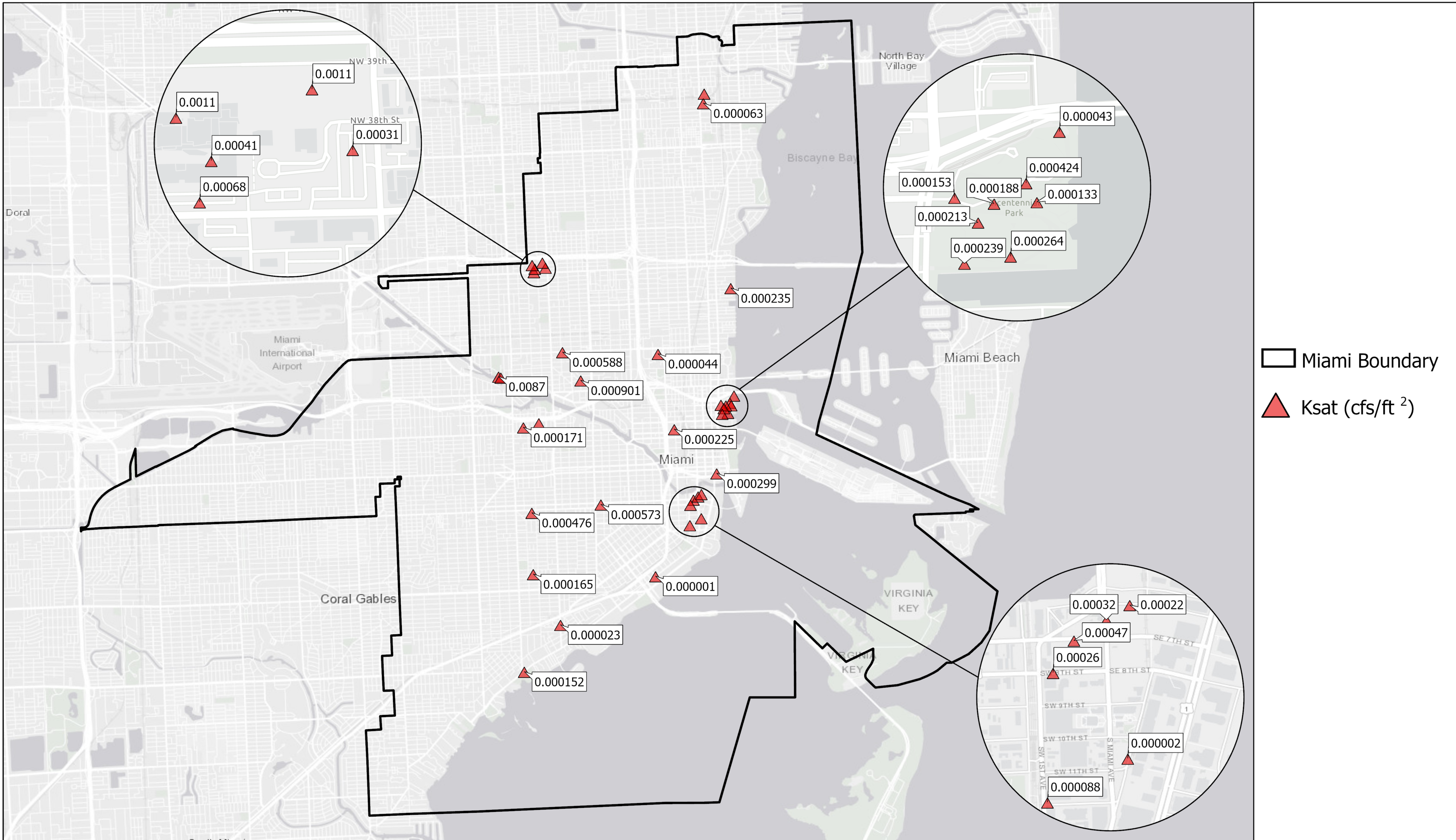
Figure 2-4 presents the location and estimated hydraulic conductivities from the geotechnical reports associated with each test. Hydraulic conductivities are measured in units of cfs/ft^2 per foot of head and often can vary by orders of magnitude across short distances. The measured values range from 1.0 x 10^{-6} to 8.7 x 10^{-3}, with a log mean value of 2 x 10^{-4}. Values on the order of 10^{-3}, as seen in some of these data points, represent very high permeability, which is not uncommon for the Biscayne Aquifer. These areas should provide excellent exfiltration (infiltration into the aquifer) for well-designed exfiltration systems cut into the aquifer. It is important to note that exfiltration systems must penetrate to a depth into the stratigraphy that demonstrates the high permeability to recognize the increased performance. Figure 2-4 also presents a raster surface of the interpolated values (on a log scale), which were used in providing potential exfiltration rates in the existing and proposed systems. For proposed exfiltration systems, additional site-specific testing will be necessary to provide more precise local values of exfiltration capacity.

2.3.1.3 Land-use and Impervious Data

Two land-use and impervious sources were used to develop the hydrologic model: a United States Geologic Survey (USGS) impervious cover map and the Miami-Dade County Existing (2014) Land-use map.

USGS Impervious Coverage

Imperviousness values were obtained from USGS based on remote sensing data from the 2016 National Land Cover Database (NLCD), as shown on **Figure 2-5**. This set of data found at (https://www.usgs.gov/centers/eros/science/national-land-cover-database?qt-science_center_objects=0#qt-science_center_objects), is based on 100-foot resolution and shows the impervious coverage of the City. The South Florida Water Management District (SFWMD) wetlands and water body coverages were merged with the USGS layer to augment the data. Water bodies and wetlands are modeled as 100% impervious in the H&H models as there is no expected soil storage under these areas.



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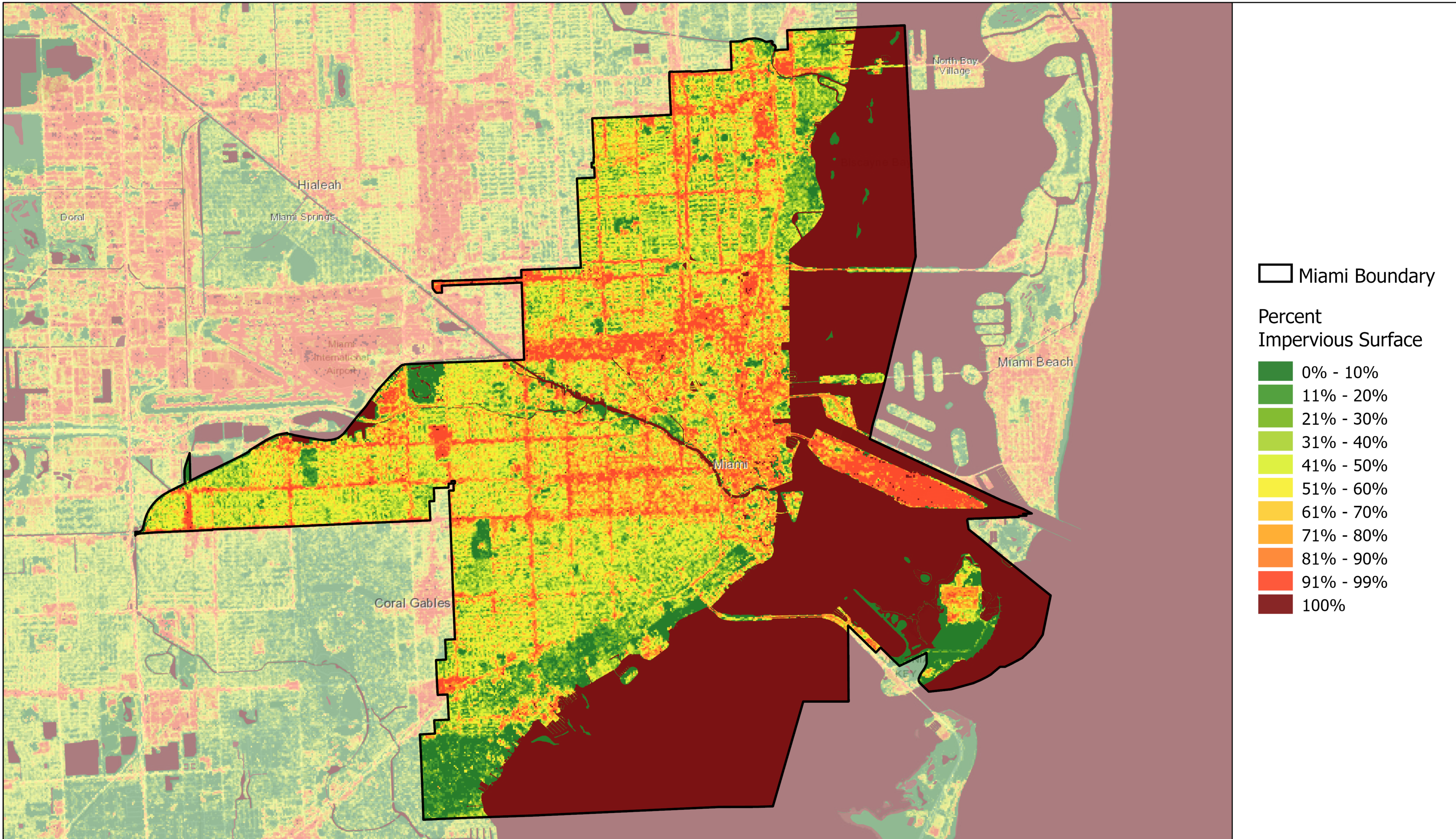
CDM Smith

THE CITY OF MIAMI INCORPORATED 1896 FLORIDA

CITY OF MIAMI
Saturated Hydraulic Conductivity (Ksat)

Date: 3/25/2020
Figure 2-4



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CDM Smith

CITY OF MIAMI

USGS Impervious Surface

Date: 3/25/2020

Figure 2-5

Land-use Coverage

Existing land-use coverage is published in the Miami-Dade County's Comprehensive Development Master Plan (CDMP). The CDMP is published as a geodatabase and as printable map (at http://www.miamidade.gov/planning/maps.asp). There are approximately 101 different land use codes in the Miami-Dade County classification system, which were grouped into 10 different classifications for use in this project: (1) Open & Park, (2) Pasture, (3) Agriculture & Golf Course, (4) Low Density Residential, (5) Medium Density Residential, (6) High Density Residential, (7) Commercial & Light Industrial, (8) Heavy Industrial & Transportation, (9) Wetlands, and (10) Waterbodies. The SFWMD wetlands and water body coverages were merged with the MDC land-use coverage to augment the data. **Figure 2-6** displays the land-use data for the City.

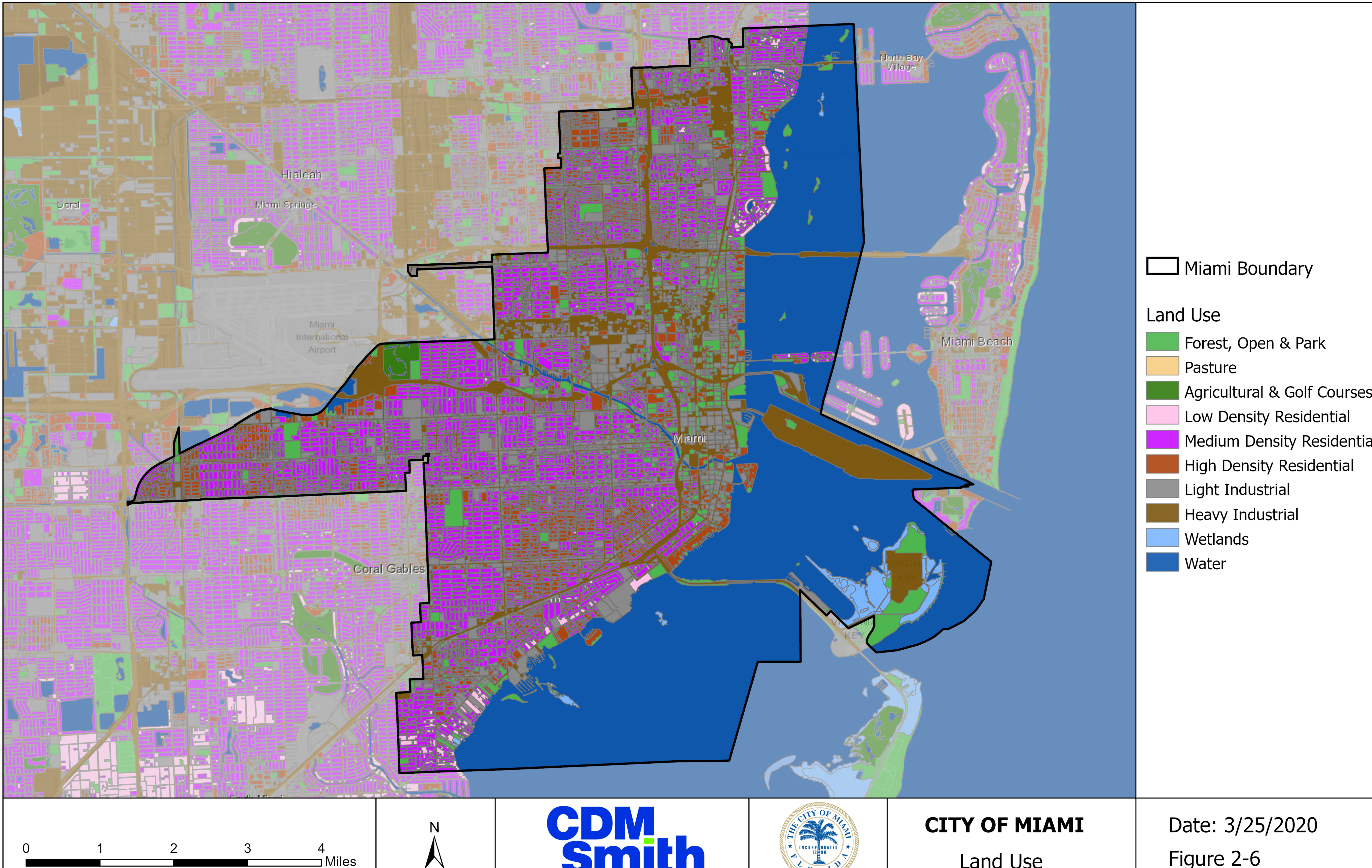
2.3.1.4 Stormwater Infrastructure

The stormwater infrastructure used in the model was compiled from a mosaic of City archives (atlases, survey books, as-built/record drawings), SFWMD, Florida Department of Transportation (FDOT), and Miami-Dade County drainage records, spot field surveys, and various other publicly available published data sources, and was geospatially translated into a new City of Miami stormwater atlas in GIS format, customized for the City, and based on the Esri municipal standards for ArcGIS utilities databases and the Local Government Information data model standards. The stormwater management specific data features inlets, manholes, drainage wells, exfiltration trenches, slab covered trench, valves, pipes, culverts, stormwater pump stations and associated discharge force mains, outfalls, weirs, and other pertinent stormwater structures.

The PSMS is explicitly modeled for all pipes approximately 24 inches in diameter and larger, ditches that connect model elements, and canals. Smaller pipes and ditches that serve as storage, but not significant conveyance, are considered part of the secondary system and are not explicitly modeled. Critical attributes in the stormwater layers, aside from coordinates, include Unit Identification (UNIQUEID) in the junctions (inlet, manholes, nodes, and misc.), pipe shape, pipe material, pipe diameter (or height), pipe width, and upstream and downstream inverts (converted to NAVD).

2.3.2 Naming Convention

For model naming, the UNIQUEID is combined with the atlas grid location to develop a "FACILITYID" used for all junctions and outfalls, and most storages (the exception being named lakes). For pipes, the naming convention is USN:DSN, where USN is the upstream node FACILITYID and DSN is the downstream node FACILITYID. For example, the 42-inch diameter pipe from the stormwater inlet with FACILITYID 37_IN-05731 to the manhole with FACILITYID 37_MH-02383 is named 37_IN-05731:37_MH-02383 in the Drainage Basin C-6 model. A prefix of "C" is used for canal sections, including bridges in the major canals, and a prefix of "D" is used for ditches. A suffix of "_O" is used for overland flow links, which are described in detail below.



CDM Smith

CITY OF MIAMI

Land Use

Date: 3/25/2020

Figure 2-6

In addition to the completed drainage basin models, CDM Smith provided the model sub-basin, junction, storage, outfall, conduit, weir, and pump data layers back to the City in GIS shapefile format. For the model sub basin names, a prefix of "HU" is applied to the sub basin outlet node name.

2.3.3 Model Schematic Preparation

Model schematic preparation involved the following steps. The first step was to prepare a model schematic based on the defined levels of detail. The model schematics (created by major drainage basin) were developed with standard symbology on a base map for the drainage basin. The schematics depict the layout and connectivity of the sub-basins, nodes (junction and storage), links (conduits, pipes and channels), and identification codes (alphanumeric) on an aerial photogrammetric base map.

In the preparation of the model schematic, model node placement helps define the level of detail for the overall stormwater model. Model node placement was primarily based upon the locations of inlets, manholes, and other miscellaneous nodes in the GIS layers. Nodes not depicted in the GIS were added to the model at topographic low points and locations of hydraulic elements along the stormwater system (e.g., storage, confluence of ditches, changes in stream cross-section, etc.). Note that since the level of detail for this project is a 24-inch diameter pipe and larger, feeder (collector) pipes from inlets to the primary system are often not explicitly modeled. Therefore, each modeled inlet may represent multiple real inlets. For example, an intersection may include multiple curb inlets which all feed to a 24-inch diameter pipe. At a stormwater management master plan level of detail for modeling, it is expected that the critical element (the control point in the system) is the 24-inch diameter pipe and not the individual curb/gutter inlets or the feeder pipes.

After the model network was defined, sub-basins were delineated based on available topographic data and local stormwater system maps. In general, sub-basins were delineated for the area tributary to each node and are sized on a "neighborhood" or smaller level of detail. Occasionally, nodes were adjusted and/or added to define sub-basins with relatively uniform hydrologic properties and/or to properly distribute the runoff from the sub-basin to the modeled stormwater systems. Each sub-basin defines a model node as load point (outlet) to route the corresponding runoff hydrograph along the modeled network. The load point generally corresponds to a node nearest to the lowest elevation in the sub-basin.

The next step was to define and add overland flow paths to the model to connect areas and account for the continuous flow of runoff on the surface in parallel with the stormwater system infrastructure. During high intensity storms, including the 100-year storm, it is expected that many roads and low-lying areas will be the first locations to flood. Above-ground model elements added include stage-storage area nodes and hydraulic overland flow links to estimate the above-ground movement of water in streets, parking lots, and yards.

The final step was to create the boundary conditions for the stormwater system evaluation and other boundary control structures. A 1-year stillwater of 2.0 feet NAVD for Biscayne Bay is used. Sea Level Rise (SLR) analyses are performed at an additional 1.5 feet (3.5 feet NAVD) and 2.5 feet

(4.5 feet NAVD) on top of the boundary conditions. A more detailed discussion of the development of model boundary conditions is presented below.

2.3.4 Model Validation

Following initial model development, the simulation results were compared against known flooding conditions within the drainage basin, and sensitivity analyses were run for each input parameter. Adjustments were made to model parameters to obtain a reasonable fit with available data. Appendix A provides the detailed model validation process that was undertaken for the project.

2.4 Hydrologic Data and Parameters

Two types of rainfall data are necessary for the analyses in this project, namely measured rainfall at nearby gauge stations to validate the models, and regulatory design storm depths and distributions for the forecast simulations.

2.4.1 Measured Rainfall Data

Two storms were used City-wide to analyze and validate the models: Hurricane Irma, which had 6-7 inches of precipitation over 24 hours from September 9th, 2017 through September 10th, 2017; and the May 5, 2019 Storm, which had as much as 5 inches of precipitation in a just over 1 hour.

For Hurricane Irma, data from a nearby precipitation gauges were provided by the SFWMD through the DBHYDRO portal at https://www.sfwmd.gov/science-data/dbhydro. The S-26 and S-27 rainfall gauges used for this project are located on the SFWMD C-6 and C-7 Drainage Canals, respectively. The rainfall volumes and temporal distributions do not vary substantially throughout the City, so no other gauges were used for this storm. The SFWMD dataset for this gauge is provided in 15-minute increments. The precipitation data for Hurricane Irma at SFWMD Stations S-26 and S-27 are presented in **Table 2-1**. The cumulative rainfall hyetographs are presented on **Figure 2-7**.

Table 2-1 Hurricane Irma Validation Storm

Gage	Date*	Rainfall Depth (inches)	Peak 5-min Intensity (inches/hr)	Peak Hour (inches)
S-26	September 9-10, 2017	7.52	4.0	0.9
S-27	September 9-10, 2017	6.82	4.8	1.7

*Note: model simulation from 9/7 through 9/14

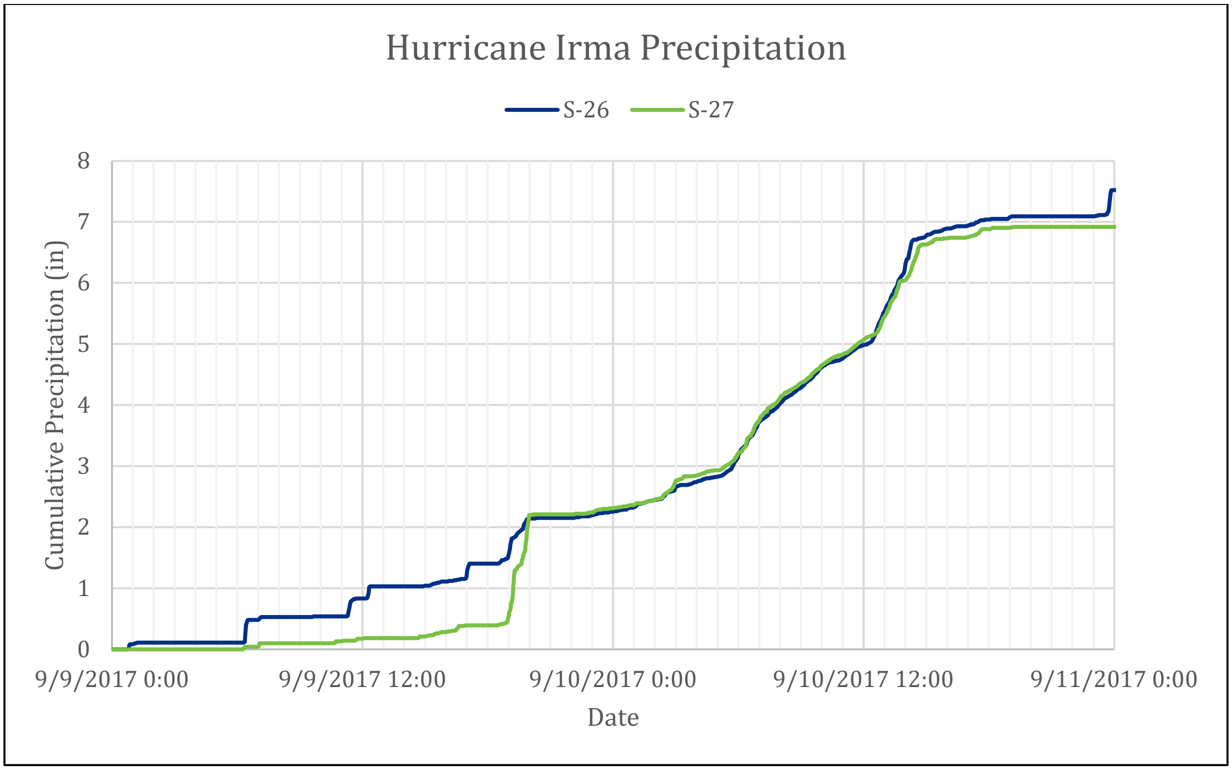


Figure 2-7
Cumulative Rainfall Hyetograph for Validation Storm

For the May 5th, 2019 Storm, precipitation intensities and volumes did vary significantly across the City. The SFWMD gage network was not dense enough to pick up this variation. Two datasets were used to develop the historical rainfall hyetographs for this storm: SFWMD NEXRAD rainfall grids in 15-minute increments, and rainfall gage data from published records from Weather Underground (http://www.wunderground.com). The precipitation data for the Weather Underground Stations are presented in **Table 2-2**. The rainfall intervals varied from 1- to 15-minute intervals, depending on station; therefore, peak intensities were interpolated. The cumulative rainfall hyetographs are presented on **Figure 2-8**.

Table 2-2 May 5th Validation Storm

Gage	Rainfall Depth (inches)	Peak 5-min Intensity (inches/hr)	Peak Hour (inches)
8th St & 54th Ave	3.30	8.3	3.0
SW 24th Ave & 21st St	4.05	6.0	3.7
Frost Museum	2.37	5.0	2.2
Bayshore at CGYC	3.31	8.2	3.2
Grove: Fair Isle	2.87	6.1	2.8
SW 22nd & SW 32nd Ave	3.64	7.4	3.3
Bird Rd & SW 59th Ave	4.45	7.8	3.8
Miami Shores	2.52	4.2	1.5
Univ. of Miami (Gables)	4.91	13.1	4.7

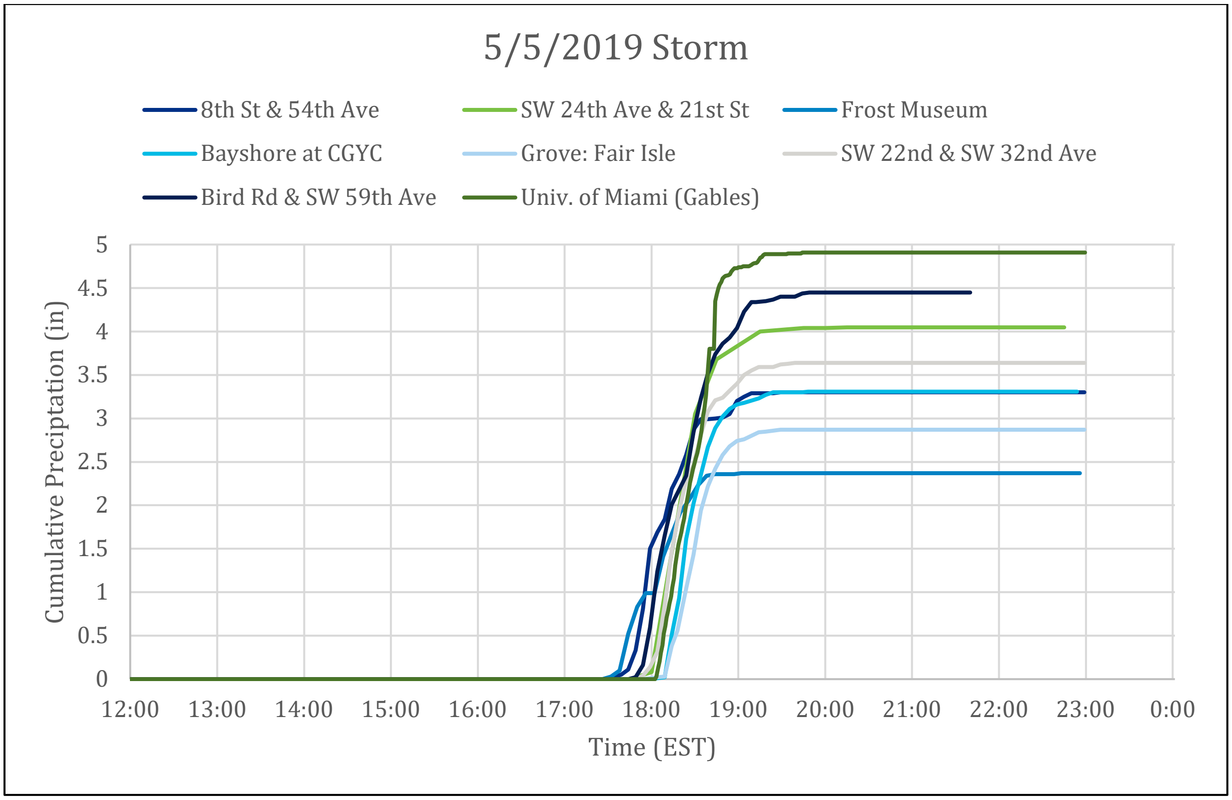


Figure 2-8
Cumulative Rainfall Hyetograph for Validation Storm

The NEXRAD data gives a better indication of where the most intense portions of the storm were located, since the gage data are still sparse, especially in the Midtown/Wynwood neighborhoods, which experienced significant flooding. However, the NEXRAD volumes didn't match the gage data everywhere. Therefore, the gage data were used to correct the radar data and produce a gage-corrected rainfall-radar grid of cumulative volumes for use in the models as shown on **Figure 2-9**. Sub-basins that mostly fall within one of the grids were provided the volume for that grid, with a unit hydrograph that was produced from one of the station distributions, since the distributions were similar at all gages.

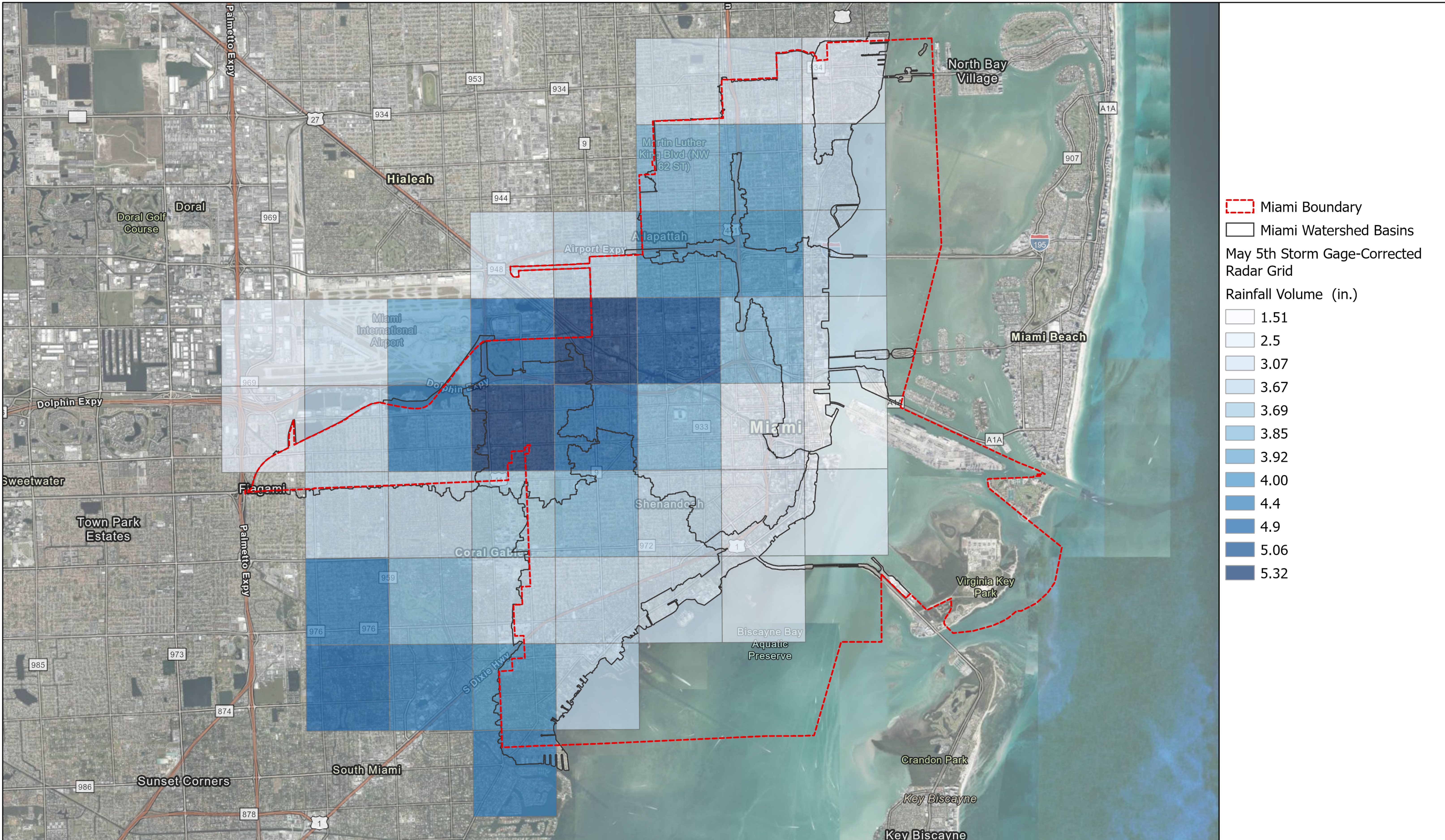
2.4.2 Design Storm Rainfall Data

Rainfall data were used to generate stormwater runoff hydrographs for each sub-basin represented in the design storm event hydrologic model. Design storm rainfall data are generally characterized by a depth (measured in inches), intensity (inches per hour), return period (years), event duration (hours), spatial distribution (locational variance), and temporal distribution (time variance).

Design storm events are usually designated to reflect the return period of the rainfall depth and the event duration. For example, a 25-year, 72-hour design event describes a rainfall depth over a 72-hour period that has a 4 percent (1/25) chance of occurring at a particular location in any given year.

Design Storm distributions were taken from the SFWMD Permit Information Manual, Volume IV. Model simulations are performed with the 5-year, 24-hour design storm; and the 10-year, 25-year, and 100-year, 72-hour design storms. The 24-hour design storm has a peak centered at 12 hours, while the 72-hour design storms have peak intensities at 60 hours. The SFWMD design storm distributions are sampled at 5-minute increments.

Design Storm volumes were found from the National Oceanic and Atmospheric Administration (NOAA) Atlas 14, Point Precipitation Frequency Estimates (https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=fl) for Florida. This website uses more recent rainfall gage data than the isohyetal maps in the SFWMD Permit Information Manual, as District maps were developed in the 1990s. SFWMD confirmed that NOAA Atlas 14 volumes are acceptable for permitting purposes. CDM Smith communicated with the Section Leader for Surface Water Management Environmental Resource Bureau South Florida Water Management District for concurrence on the acceptableness of this data set. The data were checked across all model watershed basins and found to be slightly greater than the District's at all locations, providing a more conservative approach.



CDM Smith

CITY OF MIAMI
Gage-corrected Rainfall Volume for May 5th Validation Storm

Date: 5/20/2020
Figure 2-9

Design Storm rainfall volumes may be found for select gages in the atlas, or an interpolated volume estimate may be found for point locations. For this project, point location estimates were made for each model basin. In order to be conservative, the highest volume for a given basin was used as the rainfall volume over the entire basin. The Design Storm volumes and intensities are provided in the individual basin reports; however, rainfall depths and intensities are provided for the Biscayne Central (BC) Basin in **Table 2-3** below as an example.

Table 2-3 BC Design Storm Volumes and Intensities

Storm	Rainfall Depth (inches)*	Peak 5-min Intensity (inches/hr)
5-year, 24-hour	6.99	5.4
10-year, 72-hour	10.6	6.1
25-year, 72-hour	13.1	7.5
100-year, 72-hour	17.6	10.1

* Atlas 14 provides 1-day volumes to the hundredths and 3-day volumes to the tenths of an inch

2.4.3 Topography and Vertical Datum

Topographic data are used to define hydrologic boundaries, runoff flow paths and slopes, out-of-bank channel cross-sections, overland hydraulic links, stage-area-storage relationships, and critical flood elevations.

For this study, the principal source of topographic data were the DEM provided by Miami-Dade County (see Section 2.3.1.1 and Figure 2-1). A DEM is a two-dimensional surface with elevation values at discrete points on the surface. These discrete points are tiles each having a specific elevation value and a resolution of 2 feet in length and width. The fundamental vertical accuracy for bare earth elevations is 0.60 feet.

The elevation data used in the computer models and provided in this report are referenced to the North American Vertical Datum of 1988 (NAVD88).

2.4.4 Sub-Basin Delineation

Sub-basins are defined by natural physical features, and by constructed stormwater conveyance systems that control and direct stormwater runoff to a common outfall. Delineation of the study area sub-basins was based primarily on the DEM and the stormwater collection system data.

ESRI ArcHydro tools were used to develop polygons around all inlets in the SWMP Atlas, based on the DEM; i.e., the tool determines the tributary from each load point. The polygons were then inspected by hand and combined to meet the scoped sub-basin level of service (approximately the area tributary to the upstream ends of 24-inch pipes and greater). The relatively large areas were served by smaller systems, the level of service was relaxed to the size of the smaller pipe. Additionally, some 24-inch pipe were not included in the model if: (1) the tributary area to the end of the pipe was significantly smaller than the rest of the city (typically areas smaller than 1 acre were combined at a higher resolution), or (2) multiple parallel pipes were combined into one multi-barrel pipe in the model (i.e., the parallel pipes would be co-located in the location of one of the barrels).

Once the sub-basin delineation was defined to the correct scale, the edges were cleaned up over building footprints. ArcHydro delineations tend to be erratic over the building footprints, so a smoothing adjustment was performed. Additional edits to sub-basin delineations were occasionally performed as the model hydraulics were developed.

Since runoff typically does not stop at municipal boundaries, parts of Miami-Dade County are necessarily included in the basin models, where these areas are tributary to the City's PSMS or overland flows (see Figure 1-1). For the C-3, C-4, and C-7canals, the Miami-Dade County Models were used to provide inflow time series hydrographs for historic storms and for design storms at the point where the canal intersects the City boundary. The C-5 Canal lies completely within the City boundary. For the C-6 Canal, the City boundary is near the SFWMD S-26 Structure, so the model boundary is set at the structure. Additionally, parts of Miami-Dade County that are outside the City boundary may drain to the same PSMS (whether City, County, or FDOT systems) that outfalls to the canals downstream of where the canal boundaries are set. The sub-basin delineation is performed similar to the City sub-basin, but on a much rougher scale (nearly an order of magnitude larger).

Once established, each sub-basin is given specific hydrologic values that describe the area's key hydrologic characteristics. These values are among the most critical inputs to the model. The hydrologic parameters assigned to each sub-basin include area, flow width, slope, impervious area, roughness, initial abstraction, and Modified Green-Ampt soil parameters of saturated hydraulic conductivity, capillary suction, and initial moisture deficit. Additionally, not all of the impervious surface is directly connected to the hydraulic system. The percent of the impervious surface routed to pervious is an additional input parameter and was estimated by land use and total impervious area. Sub-basin roughness and initial abstraction were also assigned according to the land use within the sub-basin. The total impervious area was estimated from the USGS impervious coverage, while soil parameters are estimated from the soil's coverage. Section 2.4.7 describes how these data were utilized in the model.

Table 2-4 provides the number and average size of the sub-basin delineation for each basin. More detailed information is provided in the individual basin report sections.

Table 2-4 Basin Delineation Data

Basin	Type	Area (Acres)	Number of Sub-basins	Average Size (Acres)
Biscayne North	City	880	171	5.1
Biscayne Central	City	2,170	359	6.1
Biscayne South	City	757	172	4.4
C-5	City	1,736	233	7.5
C-3	**City**	**4,561**	**461**	**9.9**
	County	4,698	21	223.7
	Total	9,260	482	52.8
C-4	**City**	**2,272**	**346**	**6.6**
	County	1,035	19	54.5
	Total	3,307	365	9.1
C-6	**City**	**6,240**	**844**	**7.4**
	County	950	14	67.9
	Total	7,190	858	8.4
C-7	**City**	**3,730**	**445**	**8.4**
	County	1,740	59	29.4
	Total	5,470	504	10.9

2.4.5 Land Use Parameters and Impervious Areas

Two Citywide database layers were used to estimate the remainder of the hydrologic model parameters: the total impervious area within each sub-basin was estimated from the USGS NLCD Figure 2-5, and the Miami-Dade County Land-use database, Figure 2-7. Land use is used to estimate a percentage of the total impervious area that is routed to pervious areas, surface friction factors, and initial abstractions for each sub-basin. For this project, the land uses were grouped into 10 categories of relatively homogeneous geophysical parameters. Present land uses within the study area are provided in **Table 2-5**.

Table 2-5 Land Use Types

Land Use Description	Abbreviation
Forests, Open Land, and Parks	Open
Pasture	Past
Golf Courses and Agriculture	Ag/GC
Low Density Residential	LDR
Medium Density Residential	MDR
High Density Residential and Mixed Use	HDR
Commercial, Light Industrial, and Institutional	Comm
Heavy Industrial and Transportation	HInd
Wetlands	Wetlnd
Waterbodies	Water

2.4.5.1 Land Use Dependent Parameters

Land use coverage was used to characterize the percent of the total impervious area routed to pervious areas (the "Routed %" parameter). Infiltration and runoff routing parameters for directly connected impervious area (DCIA) differs from the non-DCIA areas. Non-DCIA areas may include roof surfaces that are routed to pervious yards as opposed to directly to the stormwater system, for example. Some roads, airport taxiways and runways, and minor parking lots all may runoff to grassy swales prior to loading to the PSMS. Typically, about one-third of medium density residential impervious surfaces are routed to pervious while only 10% of commercial surfaces are routed to pervious.

Land cover was also used to characterize the surface roughness (Manning's n) of the runoff flow path and the depression storage within the sub-basin. Each modeled sub-basin requires values defined for the following land cover model parameters:

- Surface Roughness (Pervious n and Impervious n) – The Manning's n Roughness Coefficient along the representative flowpath.
- Depression Storage (Initial abstraction (Ia) divided into Pervious Ia and Impervious Ia) – the amount of rainfall at the beginning of a precipitation event that is trapped within areas (usually small) and does not become surface runoff.

The impervious surface roughness represents the composite roughness of rooftops, sidewalks, streets, gutters, inlets and collector pipes, if the pipes and gutters are not modeled explicitly in the hydraulic model. The pervious roughness is the composite roughness of sheet flow over pervious surfaces such as lawns and open areas.

Table 2-6 lists Manning's roughness coefficient ranges by land cover type. Manning's roughness coefficients are higher for runoff over pervious surfaces in the hydrologic model compared to similar surfaces in the hydraulic model. This is because the depth of flow for runoff is significantly less than the depth of flow in a canal, for instance. When the depth of flow is similar to the height of grass, roughness can be significant.

Depression storage characterizes the interception of runoff before it reaches the inlets of the collection system. In SWMM, depression storage is treated as an initial abstraction, such that the depression storage volume must be filled prior to surface runoff. Depression storage is expressed as a depth (in inches) over the entire sub-basin and values are required for both impervious and pervious areas. The volume of depression storage within a sub-basin represents the sum of depression areas including small cracks and voids in paved surfaces, puddles, sags in street profiles, rooftops, and interception due to vegetation. In SWMM, water that ponds in these depression areas either evaporates from the impervious surface area or infiltrates into the soil from pervious surface areas. The portion of the impervious area given zero depression storage is set to 25%, unless adjusted for validation. This SWMM default value was used to simulate impervious areas that are sloped and/or smooth enough to not allow ponding.

Table 2-6 Published Values of Manning's n Roughness Coefficients for Overland Flow

Source	Ground Cover	Manning n	Range
Crawford and Linsley (1966)[1]	Smooth asphalt	0.012	
	Asphalt of concrete paving Packed clay	0.014	
	Packed clay	0.03	
	Light turf	0.2	
	Dense turf	0.35	
	Dense shrubbery and forest litter	0.4	
Engman (1986)[2]	Concrete or asphalt	0.011	0.01-0.013
	Bare sand	0.01	0.01-0.16
	Graveled Surface	0.02	0.012-0.03
	Bare clay-loam (eroded)	0.02	0.012-0.033
	Range (natural)	0.13	0.01-0.32
	Bluegrass sod	0.45	0.39-0.63
	Short grass prairie	0.15	0.10-0.20
	Bermuda grass	0.41	0.30-0.48

Typical depression storage values range from 0.05 inches to 0.5 inches and vary by sub-basin and land cover. The parameters in **Table 2-7** were incorporated by intersecting the land use coverage with the sub-basin polygons in GIS, and the resulting values were area weighted by sub-basin to develop parameter values for inclusion in the model. Global values of land use dependent variables are compiled in Table 2-7. In the H&H models, water and wetland areas are treated as 100% impervious surfaces, therefore there are no pervious parameters for these land-use types in the table.

Table 2-7 Global Land Use Dependent Parameters

Parameter	Open	Past	Ag/GC	LDR	MDR	HDR	Comm	HInd	WetLnd	Water
Impervious n	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.1	0.024
Pervious n	0.4	0.3	0.3	0.25	0.25	0.25	0.25	0.25		
Impervious Ia	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.5	0.1
Pervious Ia	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25		
Routed	80%	80%	80%	50%	34%	21%	10%	10%	0%	0%

Note: Refer to Section 2.4.4 and Table 2-5 above for heading land use definitions.

2.4.5.2 Impervious Area

Any rainfall that occurs on impervious area becomes surface runoff once its depression storage is filled. The USGS NCLD coverages provides the most comprehensive impervious coverage database available for the City of Miami and has been found to be a more accurate estimate of impervious coverage than estimates based on land-use coverage (multiple CDM Smith Projects, including the Miami-Dade County C-100 Basin models, City of New Orleans SWMP). However,

[1] Crawford, N.H. and Linsley, R.K., "Digital Simulation in Hydrology: Stanford Watershed Model IV," Tech. Report No. 39, Civil Engineering Department, Stanford University, Palo Alto, CA, July 1966.

[2] Engman, E.T., "Roughness Coefficients for Routing Surface Runoff," Journal of Irrigation and Drainage Engineering, ASCE, Vol. 112, No. 1, February 1986, pp. 39-53.

comparison of the coverage with aerial inspection indicated that the database was consistently underestimating impervious area. Therefore, CDM Smith conducted a test of the database for the pilot model area, which included the Shorecrest neighborhood and surrounding areas. For this test, every impervious surface including buildings, roads, parking lots, sidewalks, etc. in the pilot area was delineated in GIS and then compared to the USGS coverage.

The comparison between directly measured total impervious area per sub-basin versus a spatial average of the USGS grid per sub-basin is presented on **Figure 2-10**. Though the R^2 value of the scatter plot is relatively good at 0.85, the comparison does indicate that the USGS estimate is consistently lower than a direct measurement. For example, where the analysis of the USGS coverage provides a total impervious area of 58%, the direct measurement provides a value of 65%. Therefore, for all City sub-basins, the following procedure was implemented:

1. The SFWMD water bodies and wetland coverage areas were intersected with the USGS NCLD coverage, to provide 100% impervious area for wetlands and water body areas.
2. The combined coverage was intersected with the subbasin delineation and area-weighted, to provide an estimate of total impervious area per sub-basin.
3. The correction formula is applied from the pilot model, y = 0.845 * x + 16.6; where x is the USGS estimate in percent and y is the final estimate. Any value greater the 100% is set to 100%.

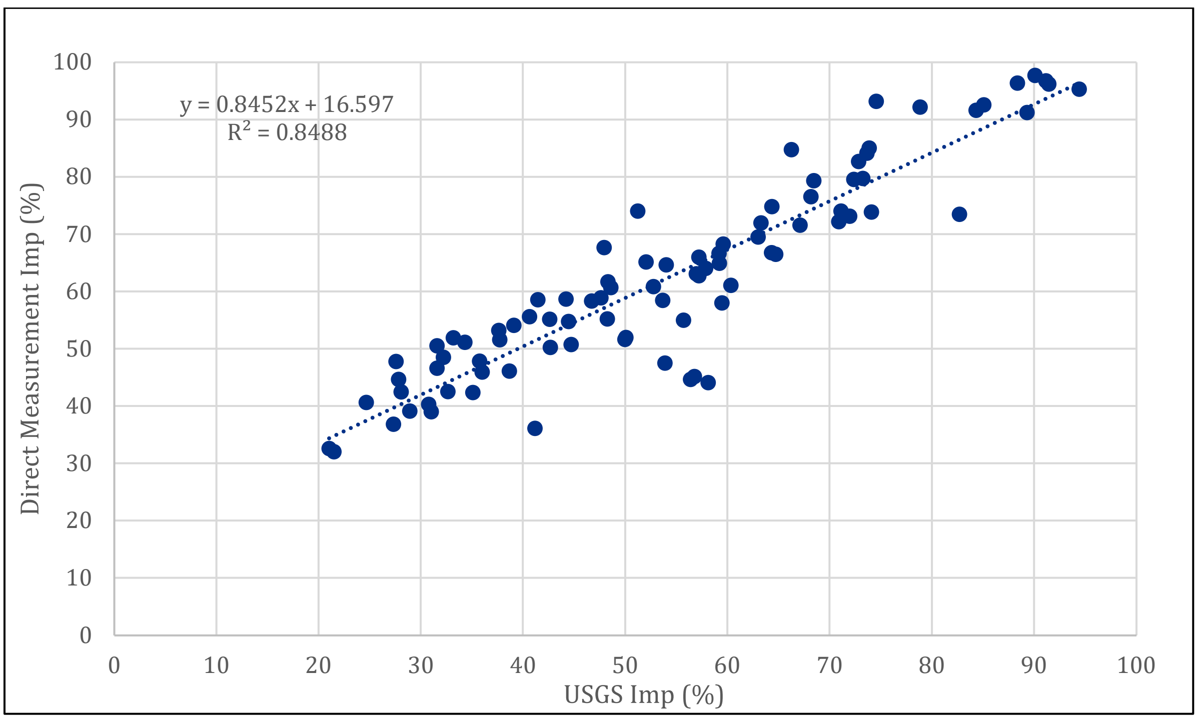


Figure 2-10
Impervious Percentage Comparison: Direct Measurement vs. USGS NCLD

2.4.6 Runoff Parameters

For this study, non-linear reservoir flow routing techniques (EPA SWMM RUNOFF methodology) have been used as opposed to more traditional unit hydrograph techniques for the following reasons:

- Unit hydrograph techniques have primary applicability on mid-size sub-basins, on the order of 1 to 400 square miles, whereas kinematic wave techniques become more accurate with decreasing sub-basin size.
- One of the model selection criteria was the ability to run continuous simulations. As discussed in Section 2.4.6, the Modified Green-Ampt infiltration methodology is much more applicable to continuous simulations than curve number methodologies.
- SWMM runoff is a more rigorous, parameter-based methodology which more readily lends itself to local, physical parameter changes (through calibration and/or detailed modeling of a drainage basin subset).
- The time of concentration calculation in SCS methodology does not vary by storm depth; however, real travel times are shorter in larger storms due to increasing depth of flow, which is estimated in SWMM.

With the SWMM methodology, runoff parameters that affect the timing and shape of the stormwater runoff hydrograph are defined as opposed to a unit hydrograph. Each model sub-basin requires the following runoff parameters:

- Sub-basin Area – The total sub-basin area calculated in GIS.
- Representative runoff flow paths, which are developed within each sub-basin that characterize the route runoff takes to the modeled stormwater network (to estimate the sub-basin width and slope parameters below):
    1. Sub-basin widths - The sub-basin area divided by the area-weighted average length of the runoff flow paths within the sub-basin.
    2. Average surface slopes – The area-weighted average slope of the sub-basin along representative runoff flow paths.

The timing of the runoff is dependent on the sub-basin geometry (average slope and average width), roughness of both the impervious and pervious surfaces, and total flow (developed from rainfall minus infiltration and initial abstraction). Therefore, times of concentration are not calculated or input directly in SWMM.

To develop representative parameters for modeling, flow paths were developed for each sub-basin, where each flow path was used to characterize routing of flow through an associated percentage of the sub-basin. Each of the portions of the sub-basins (pervious area and impervious) are idealized as a rectangular runoff area of length equal to the flow path and width equal to the area divided by the flow path length. Area-weighted averaging of the flow path parameters is then used in the model. These parameters, together with surface roughness and rainfall are used to calculate runoff hydrographs for each sub-basin.

The formulation of each model parameter is further discussed in the paragraphs below.

2.4.6.1 Length and Slope

The length (L) parameter is the average area-weighted travel length to the hydraulic model load point. For ponded or detention storage areas, the hydraulic model load point is typically the centroid of ponding. For areas where ponding does not occur, the hydraulic model load point is typically the downstream extent of the sub-basin area.

The slope parameter is the average slope over the flow path length and is calculated by dividing the difference in elevation by the length. Length and slope information was obtained using the LiDAR topographic data (DEM).

Typically, Esri ArcHydro tools were used to find the representative flowpath for each inlet in the GIS. As noted above, multiple inlets areas were combined to provide the sub-basin areas. Weighted averaging was used to combine the inlet flow paths to one representative sub-basin flow path, by normalizing by the inlet tributary areas. The upstream and downstream elevation levels are included in each flowpath, so weighted average slopes were estimated as well. The Esri ArcHydro data model standardizes water data structures so that data can be used consistently and efficiently to solve water resource problems at any spatial scale.

For sub-basins outside of the City GIS coverage (i.e., MDC sub-basins) and for locations where there are few inlets, the modelers would find representative flow paths per sub-basin by hand, using the LiDAR DEM and GIS tools.

2.4.7 Soils and Geotechnical Data

Soils in the pervious part of the sub-basin affect the rate and volume of water infiltration. The hydrologic model uses the Green-Ampt equations to determine infiltration and soil moisture accounting. In PCSWMM, the “Modified Green-Ampt” option was chosen, to avoid the inadvertent loss of infiltration capacity that can occur under certain conditions with the original SWMM Green-Ampt algorithm.

The Modified Green-Ampt equation was used because it is based on soil properties, and because it may be adopted for continuous simulation of weeks, months, and years since it provides a more accurate recovery of soil storage for multiple events over a long time period. This method for modeling infiltration assumes that a sharp wetting front exists in the soil column, separating soil with some initial moisture content below from saturated soil above. Required input parameters include initial moisture deficit of the soil; soil hydraulic conductivity, and suction head at the wetting front. The recovery rate of moisture deficit during dry periods is empirically related to the hydraulic conductivity.

The initial deficit for a completely drained soil is the difference between the soil's porosity and its field capacity. Estimated values for all of these parameters can be found in **Table 2-8**. Characteristics of various soils for the Green-Ampt Method were applied from EPA SWMM 5 Help, Green-Ampt Infiltration Parameters, Soil Characteristics Table; which in turn was developed from

Rawls, Brakensiek, and Miller, Green-Ampt Infiltration Parameters from Soils Data, Journal of Hydraulic Engineering, 109:1316 (1983). Since the adjusted NRCS soils coverage described previously (Section 2.3.1.2, Figure 2-4) provides soils data by HSG, estimates of the Modified Green-Ampt infiltration parameters by HSG type are provided in **Table 2-9**.

Table 2-8 Green-Ampt Parameter Estimates by Soil

Soil Texture	Hydraulic Conductivity (inches/hr)	Initial Moisture Deficit (fraction)	Suction Head (inches)
Sand	4.74	0.34	1.9
Loamy Sand	1.18	0.33	2.4
Sandy Loam	0.43	0.33	4.3
Loam	0.13	0.31	3.5
Silt Loam	0.26	0.32	6.7
Sandy Clay Loam	0.06	0.26	8.7
Clay Loam	0.04	0.24	8.3
Silty Clay Loam	0.04	0.26	10.6
Sandy Clay	0.02	0.22	9.5
Silty Clay	0.02	0.22	11.4
Clay	0.01	0.21	12.6

Table 2-9 Green-Ampt Parameter Estimates by HSG

Soil HSG	Hydraulic Conductivity (inches/hr)	Initial Moisture Deficit (fraction)	Suction Head (inches)
A	4.0	0.33	2.2
B	0.5	0.30	7.0
C	0.2	0.25	10.0
D	0.04	0.21	12.5

The map of HGS coverage is intersected with the sub-basin delineation to provide sub-areas of each soils type per sub-basin. The Suction Head and Initial Moisture Deficit are then assigned to each sub-basin by the weighted area of each soil type. Since Hydraulic Conductivity can vary by two orders of magnitude, the values are converted to logarithmic values, area-weighted, then converted back to inches per hour.

2.4.8 Groundwater Data

Groundwater baseflows supply a significant portion of the flows in the SFWMD Canal systems, especially in eastern Miami-Dade County. However, much of this flow is generated west of the City Basins, as the groundwater flows west to east from the Everglades to Biscayne Bay. These regional, horizontal baseflows are modeled in Miami-Dade County models as seepage into the canals. Since the Miami-Dade County models are used as boundary conditions, to provide inflow hydrographs at the western boundaries of the basin models, this regional baseflow is accounted for in the City models.

Additionally, local groundwater interactions may also affect the results, as infiltration causes the groundwater table to rise toward the ground surface. The Green-Ampt infiltration method that was used to simulate infiltration processes provides an input hydrograph to the model's groundwater routines. The groundwater (water table) level may be increased by the infiltration up to the ground surface, where infiltration then stops. Groundwater levels may also decrease due to groundwater outflows modeled by SWMM, which routes the groundwater flow to a previously defined node.

For sub-basins with large waterbodies, groundwater flows were directed to the sub-basin itself (i.e., the groundwater outflow is combined with the sub-basin runoff). For all other sub-basins, the groundwater outflow was directed to the receiving nodes that were the closest canal nodes in the groundwater flow direction. The SWMM groundwater parameters were developed using engineering judgement and previous experience with models in Miami-Dade County and South Florida to produce a groundwater table response that reasonable matches observed responses. Due to the extremely high transmissivity of the underlying Biscayne Aquifer, the groundwater response is relatively fast.

The groundwater elevations for existing conditions was provided by Miami-Dade County and is presented on **Figure 2-11**.

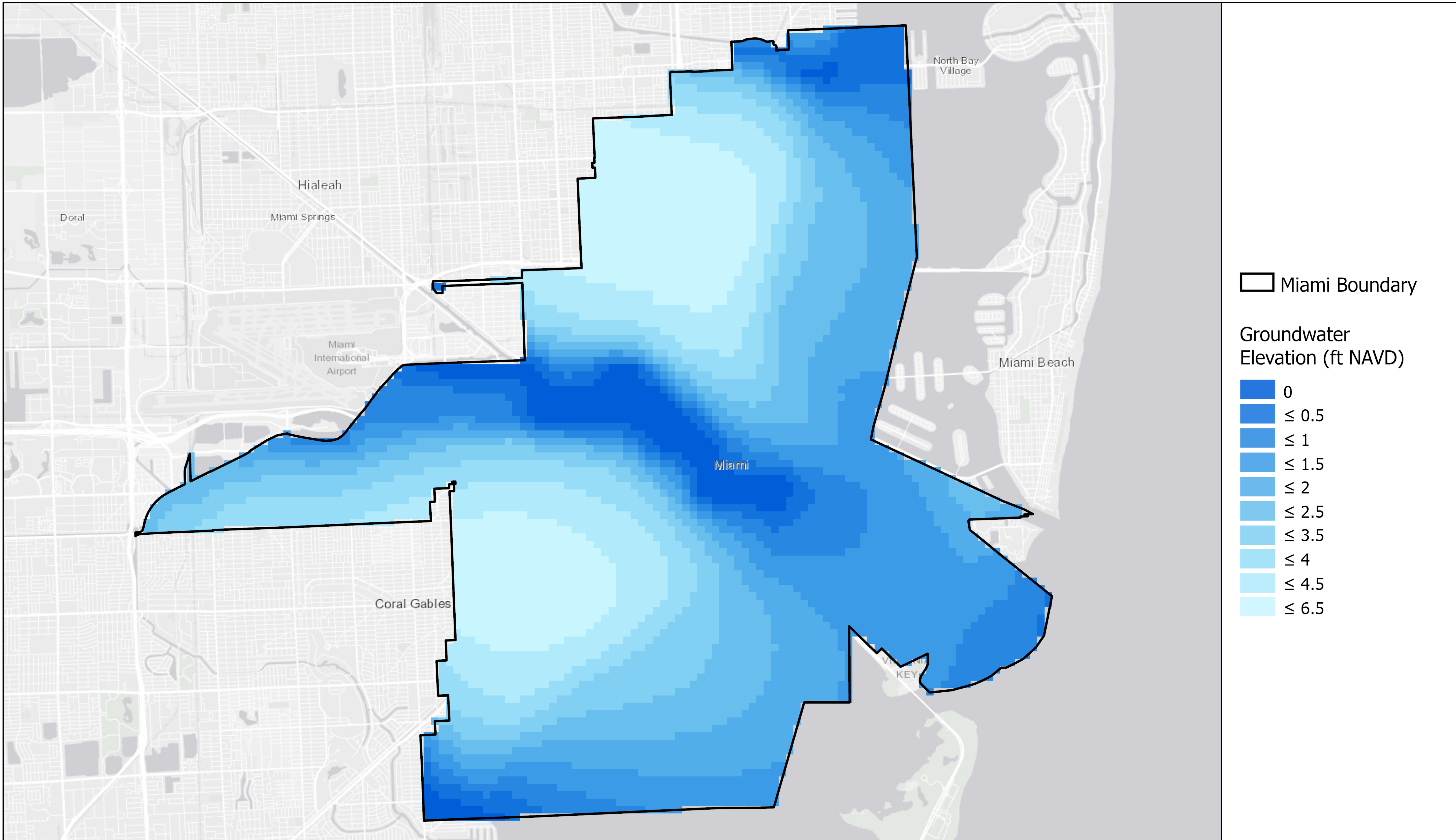
2.5 Hydraulic Data and Parameters

The H&H model uses a node/link (junction/conduit) representation of the PSMS. For this study, the PSMS links were primarily circular pipes greater than 24 inches in diameter. In some cases, smaller pipes down to 12 inches in diameter or less were necessarily included:

- In locations that are topographically isolated, where the smaller pipe is all that drains the area
- In portions of the system where pipes smaller than 24 inches connect two larger systems, which is often the case in areas of extensive exfiltration where the smaller pipes allow some conveyance between systems, and/or
- In locations where multiple smaller pipes connect across a hydraulic divide, such as multiple connectors across the crown of a major road, which otherwise would impede overland flow.

Nodes are located at:

- The ends of pipes or culverts
- Locations of inlets where the sub-basin runoff is loaded
- Manholes
- Locations where the stormwater pipes change diameter



0 1 2 3 4 Miles

N

CDM Smith

THE CITY OF MIAMI INCORPORATED 1896 FLORIDA

CITY OF MIAMI

Groundwater Elevation

Date: 5/19/2020

Figure 2-11

- Locations where irregular conduits are split to represent different cross sections if the geometry of the channel changes dramatically
- Points representing the sub-basin low surface elevations (storage units); and
- The confluence of streams or ditches represented as open channels

2.5.1 Model Nodes

The parameters defining model nodes are invert elevation, rim elevation, initial depth, the storage node data flag, and the outfall data flag. Nodes in the hydraulic system where runoff is loaded are provided stage-storage-area curves as discussed below. For manholes and inlets where runoff is not loaded, a small amount of constant storage (12.56 square feet) was used to provide numerical stability. The model nodes with outfall flags checked are used to provide boundary conditions to the model as described below. Model node rim elevations were set 10 feet above ground elevation, in order to not allow water to (computationally) flood out of the model. For this project, above ground features such as stage-storage junctions and overland links were used to not only keep flooding within model elements, but also to provide a relatively accurate estimate of flood depth. In SWMM, the node rim elevations need to be as high as the highest connecting link, and in the case of storage junctions, as high as the stage-storage curve. In the case of manholes, adding 10 feet to the rim effectively seals the manhole, by not allowing water to flood out of the model at that location. In the case of nodes representing points on ditches, stream, and canals, the rim may be set more than 10 feet above ground elevation because the connecting links may be more than 10 feet deep. A column has been added to the model files to include the estimated ground elevation at each node, based on the DEM.

2.5.1.1 Stage Area Relationships

In these models, storage is accounted for explicitly above inlets with stage-storage area relationships in storage nodes. Stage-storage area relationships are also used for ponds, lakes and low-lying areas that are not accounted for in the cross sections representing ditches or other open conduits. An accurate accounting of the storage and open conduit volumes is needed for accurate peak flood stage, flow, and velocity estimates. Actual initial water levels are also considered to account for “dead storage” for which the stormwater has no access, e.g., the “wet” volume of a pond below the normal water level.

Stage-storage area relationships were computed for each storage node using the topography from LiDAR and GIS. In general, the area attributed to each storage node is limited by the sub-basin boundary around that node, though in practice, the maximum stage in the curve is not always deep enough to extend to the sub-basin boundary. The stage-storage area relationships were determined by excluding the footprint of the buildings layer obtained from the City of Miami. The footprint of ditches and canals that are explicitly modeled as PSMS, i.e., the storage is already contained in these model links, were also excluded from the storage calculation. LiDAR measures topography of lakes and other waterbodies at the surface; therefore, the bathymetry is not included in the storage area curve. Generally, this means the model includes no storage volume below the normal water level. For design storm models, this is not an issue because this “dead” storage is not available for flood protection. Initial depths in nodes are also used to limit storage below normal or maintained water levels, where appropriate.

Storage nodes with stage-storage area relationships are provided depth/area curves as plan areas for stages measured in depth above node invert were calculated from the LiDAR surface. It is critical in SWMM that the node inverts are not revised without also adjusting the depth curve, else the storage may be translated up or down in error. Therefore, the invert depths are added as part of the curve name, such as the curve “25_SP-00307@-10” for storage node “25_SP-00307”, which has an invert of -10.0 ft NAVD. Typically, the storage nodes are given small sumps, with minimal storage below the bottom of the inlet or manhole structure, to allow for minor changes in link (connecting pipe) inverts to be made without having to change the curve. However, relatively large changes in pipe inverts, such as a proposed system that is much larger than the existing system, may require lowering storage node inverts and updating the curve to match.

2.5.1.2 Nodes with Function Storage

Storage nodes may be provided functional storage as opposed to a tabular depth/area curve. Typically, this is used to add constant storage to a node. Locations where constant storage areas are applied include in the Miami River, to account for the out-of-channel storage in marinas, for instance. Small amounts of constant storage are added at manholes for computational stability. In SWMM, junctions are provided area from connecting links in the mass balance equation. When the HGL at a manhole increases above the crowns of the connecting pipes, the lack of additional area may cause a spike which would allow the maximum numerical HGL to be higher than what would be expected. This may be mitigated with small amount of constant storage, such as 12.56 square feet, which is what would be expected in a 4-ft diameter manhole.

2.5.2 Outfalls

Based on project specific survey and the GIS coverage of stormwater pipes provided by the City, stormwater PSMS points of discharge were identified and simulated as outfalls that discharge to Biscayne Bay or other water bodies. The discharges to Biscayne Bay are classified as outfalls in SWMM and utilize fixed boundary conditions for design storms and time series boundary conditions for validation events. For the C-4 and C-5 Basin models, the point of discharge is to the Miami River through the SFWMD gated structures. Observed data from the SFWMD DBHYDRO public database is used as boundary conditions in the outfall for the validation events, where the C-6 Basin model is used for boundary conditions in the design events. DBHYDRO is the SFWMD's corporate environmental database that stores hydrologic, meteorologic, hydrogeologic, and water quality data. This database is the source of historical and up-to-date environmental data for the 16-county region covered by the District. The DBHYDRO browser allows you to search DBHYDRO, using one or more criteria, and to generate a summary of the data from the available period of record. Data sets of interest are selected, and the time series data are downloaded for use.

In SWMM, an outfall node may only attach to a single link in the model, whether a pipe link or a seawall overflow link. Since there are hundreds of pipe outfalls and seawall connections to Biscayne Bay, there could be hundreds of individual model outfalls. However, in order to simplify City future model upkeep and operation, for each model adjacent to the Bay (BN, C7/BN, BC, BS, C3/BS), the links to the Bay have been combined to a virtual node representing the Bay, with a final virtual link to a single outfall. Therefore, changes to the Bay boundary conditions may be performed at one outfall for each model. The final link is sized such that it generates no additional losses but remains computationally stable.

Additional outfalls in the models represent locations where excess flooding may sheetflow out of the model through overland flow links (described below in Section 2.5.5). Due to the relative flat topography of the City, the basin boundaries may be overtopped in the larger volume events. Therefore, in some cases, flow may leave the model at the edges through these outfalls and is thus accounted for.

2.5.3 Pipes, Culverts, and Force Mains

Pipe, culvert and force main data were developed and included in the new City GIS Stormwater Atlas. The pipe invert elevations in the source data records provided for the GIS were expressed in different datums depending on the year the pipes were designed and constructed – invert elevations varied from Miami Datum, National Geodetic Vertical Datum of 1929 (NGVD) and 1988 NAVD. Pipe invert data were considered to be on the NAVD datum, unless otherwise specified in plans. Elevation adjustments were applied to the GIS pipe inverts, so they were all expressed in the NAVD datum. The adjustment factor from NGVD to NAVD varies across the City, but generally ranges from -1.54 ft to -1.57 ft, i.e., NAVD values are about a foot and a half below NGVD values. Miami Datum values are another few tenths of a foot higher then NGVD; therefore, the adjustment factor from Miami Datum to NAVD is approximately -1.8 feet. The National Geodetic Survey (NGS) provides a vertical datum conversion tool known as VERTCON at: http://www.ngs.noaa.gov/cgi-bin/VERTCON/vert_con.prl.

Where data gaps were present, survey crews were dispatched to open manholes and record estimated geometry and connectivity and data were obtained to provide the necessary size data for the stormwater pipes and structures that defined the PSMS. The field survey sheets were scanned and recorded in the survey field of the geodatabase in the GIS. Where field survey and inspection of plans could not identify pipe size due to depth, siltation/trash, or accessibility of structure, or pipes were missing from areas entirely, the data gaps were estimated using the adjacent PSMS as a guide. Additionally, where invert elevations were missing, estimates were made based on the adjacent connecting stormwater system and relative depth to ground (cover).

Although out of the scope of this project, in subsequent phases of the GIS refinement, remote CCTV robotic cameras can be deployed and entered into pipes during routine system maintenance activities to determine exact system dimensions. Under the purview of the City of Miami's Resilience and Public Works Department, Maintenance Operations Division, the Storm Water Maintenance Team's assigned duties are to receive and process complaints and perform cleaning and removing debris of stormwater inlets and pipes, and outfalls, as well as minor repairs of storm drainage systems, damaged inlets and pipes, frames and covers. As this system maintenance function is a highest-priority, critical service to keep the City's stormwater system functioning as designed and the consequences are potential flooding, for the purposes of model development, pipe roughness values in the model thus assumed a clean, well maintained system. Therefore, reinforced concrete pipes (RCP) were assigned a Manning's roughness value of 0.013 and corrugated metal pipe (CMP) roughness values were set to 0.024. For HDPE and PVC pipes, a value of 0.011 was used. Pipe lengths were determined using the survey data and the GIS database. Minor losses were developed as follows: entrance loss k values were set to 0.3, exit loss k values were set to 0.2 for inlets and manholes; for pipes and culverts discharging into moving water, an exit loss k value of 0.5 was used, while an exit loss of 1.0 was used for pipes and culverts discharging into still water; for additional minor losses, a k value 0.7 was used for 90-degree bends and Tees, a value of 0.5 was used for 45 degrees and a value of 0.25 was used for 20-degree bends. Backflow preventer tidal valves at outfalls were assigned a k value of 2 from the manufacturer's literature of the most common typical type being installed by the City. Although the headloss through the units can vary by manufacturer and by fitting size, generally the k values were in the 2 range for the flows and velocities expected for this system. Force mains in the models were assigned a Hazen-Williams C-factor of 120.

2.5.4 Open Channels and Ditches

Open channels and ditches typically consist of an incised or main channel surrounding the channel centerline and a floodplain that stores and/or conveys flows that are greater than what the main channel can carry. However, in Miami historic floodplains are typically separated from the canals with seawalls, which are projected to be raised in future scenarios. Therefore, City Basins are modeled with sub-basin delineation boundaries along the seawalls, or where a potential seawall may be built, with adjacent storage nodes with depth-surface area stage-storage elevation curves representing the historic floodplain areas. Since the City-wide Basin models are too large to properly model in 2-D while maintaining all the functionality of SWMM, these canals are best modeled by using overland flow links to intermittently pass water back and forth between channels and floodplains over the seawalls. The cross-section of the overland flow link represents the top of the seawall, generally for the length of the adjacent model sub-basin. Overland Flow links are discussed in further detail in Section 2.5.5.

In SWMM, open channels are represented as prismatic segments, meaning that the hydraulic properties defined for the transect in each link are applied consistently throughout the length of the modeled link. Natural channel shapes are defined by cross-sections which are station/elevation pairs measured normal to the direction of flow. Stationing is from left to right as the observer is looking downstream. Multiple links may use the same transect (i.e., the same cross-section) if the depth, shape and roughness has not changed.

Open channel ditch, and canal segments were modeled as irregular cross-sections with a center channel representing the ditch or canal, and left and right overbank areas representing the floodplain, where applicable. Roughness values for center channels ranged from 0.03 to 0.05 based on vegetation and engineering judgment. Roughness in the overbanks ranged from 0.02 to 0.1 based on vegetation and engineering judgment. The roughness coefficients of an open channel specified in the transect editor takes precedence over the roughness coefficient listed in the attribute table of the model link.

Bank elevations of ditch transects need to be high enough to convey the largest flows to be modeled, else the transect area is cut off (limited by the highest bank). Generally, this requires extracting the transects wide enough to reach higher elevations. For canals, the banks are artificially raised high enough to contain the highest possible HGL without limiting the potential flow cross-section. Note that this in no way limits the flow over the seawalls, since that flow occurs at the model nodes through the overland flow links described above.

2.5.5 Overland Flow Links

For the Miami Basin models, depth of flooding and movement of flood waters is controlled by two methods: depth-storage area curves in the storage nodes (see Section 2.5.1), and overland flow links. Overland flow links convey flood waters when the subsurface stormwater system is overwhelmed by a large volume and/or a high intensity storm. In some neighborhoods, the storage and conveyance in streets is a feature of the stormwater system and therefore needs to be included in the model. Because the above-ground storage is accounted for in the storage nodes, the overland flow links have minimal storage and act as irregular weirs between sub-basins. There is generally a hydraulic boundary between two sub-basins, such as a (relative) high point in a road, a major road crossing, or the berm/seawall between a canal and its floodplain. A weir may be used to represent the boundary between the sub-basins, but typically the boundary is irregular and therefore, the overland flow link is a cross-section representative of the street or other defined boundary between the sub-basins. The length of these channels is typically short (< 50 feet) to minimize additional storage while maintaining computational stability. The cross-section widths are on the order of 50 to 300 feet (though some may be much wider). Flow occurs in these links when ponding on either side of the link reaches the height of the topographic boundary (e.g., road crown, curb, and landscape berm). During high intensity storm events, surface ponding is prevalent and flow transfer can occur from one sub-basin to another.

2.5.5.1 Template Transects

Since there are thousands of overland flow links in the Basin models, many of which are very similar, template transects have been developed for use where the overflows are relatively generic. SWMM allows input of the overflow link inverts to determine the absolute elevation of each transect, so generic station/elevation pairs may be used (i.e., the lowest point in the template transects is always 0.0). Additionally, wide flat overflows tend to produce numerical instabilities in the model, since very small changes in head, can produce relatively large changes in cross-sectional area. Therefore, wide flat overflows such as grass banks or road crowns have shallow slopes across the transect in the shape of a very flat triangle.

The following templates are used in the models:

1. Road Crown: characterized by a 500-ft wide, low-roughness overflow with a very shallow slope perpendicular to flow (0.1 ft/ 250 ft) – may also be used for parking lots or any wide flat concrete or asphalt area

2. Grass Bank: characterized by a 500-ft wide, high-roughness overflow with a very shallow slope perpendicular to flow (0.1 ft/ 250 ft)

3. Narrow Paved: characterized by a 24-ft wide, low-roughness overflow with a very shallow slope perpendicular to flow (0.1 ft/ 12 ft) – may be used for alleys or paved areas between houses

4. Narrow Grass: characterized by a 24-ft wide, high-roughness overflow with a very shallow slope perpendicular to flow (0.1 ft/ 12 ft) – may be used for grass areas between buildings or houses

5. Typical Backyard: characterized by multiple irregular openings between houses, not all at the same elevation – this template was taken from an actual cross-section between sub-basin that was representative of many of the type

6. Seawall Edge: characterized by a sloping grass bank (5 ft in 25 ft) to the seawall – may be used along Biscayne Bay where there is significant slope in the yards, down to a seawall, when connecting seawall adjacent sub-basins

7. Small Road "W": Characteristic of a typical road section (center top point represents high point at median and external top points represent top of curb) – multiple road transects were extracted from LiDAR and averaged to produce the section

8. Small Road "W" Half: half the above section, for when the overflow includes only one side of the road crown

9. Wide Road "W": Characteristic of a typical major road section (U.S. 1, Coral Way, 27th Avenue, etc.) – multiple road transects were extracted from LiDAR and averaged to produce the section; and

10. Wide Road "W" Half: half the above section, for when the overflow includes only one side of the road crown

2.5.6 Bridges

Bridges are modeled similar to a short section of channel if the lower chord of the bridge deck is above the likely peak flood level in the canal. Thus, the flow under the bridge cannot become pressurized. However, if the bridge deck is low enough to impede flow, the Custom Conduit option is used where a table of depth versus surface width is imported. This option allows for an irregular shaped closed conduit, which can be therefore be pressurized (an open channel may be pressurized in SWMM if the transect is not deep enough, but the wetted perimeter and surface width values would not be correct). Often a parallel overland flow link accompanies the bridge link to model potential flows over or around the top of the bridge deck.

2.5.7 Stormwater Control Structures

The primary regional drainage system for South Florida consists of the large drainage canals and associated features that are managed by the SFWMD and USACE. Secondary systems consist of canals and features that are managed by other designated drainage districts or private entities, such as the City, which may discharge to the coast or receiving lakes, or into the primary system. The regional structures are large-scale hydraulic works (i.e., spillways, culverts, weirs, gates, and pump stations) located in the main drainage designed canals to control water surface elevation or flow and are generally incorporated as the boundary conditions in the City wide SWMP models. Their primary function is to achieve a balance between discharging excess water during flooding conditions, maintaining environmentally desirable flows and level fluctuations, maintaining minimum water levels for water supply in the aquifers, canals and lakes preventing over-drainage, and in the case of the coastal canals, to control saltwater intrusion.

Secondary systems operate under permits issued by the District. Tertiary systems consist of canals and features generally located on private lands that provide localized drainage and discharge into retention/detention areas or into secondary systems and are regulated under an Environmental Resource Permit issued by the SFWMD. For the SWMP model development, CDM Smith reviewed and incorporated stormwater structure related information provided by the City and SFWMD for inclusion within the models.

2.5.7.1 Pump Stations

The City provided data for 15 of its City-owned Pump Stations, generally including pump station design capacities and design on/off set point elevations. Where available, CDM Smith also inspected plan sets for the pump stations to determine weir levels and bypasses, where appropriate. Pump capacities are sufficient for master plan modeling as the flow rates are not expected to vary much over the heads expected in design storm models. Many of the City pump stations are associated with injection wells, which are described in further detail below.

There are two SFWMD Pump Stations included in the Citywide models. One is parallel to the S-26 Gated Structure on the Miami River (C-6 Canal). The capacity of this pump station is approximately 650 cubic feet of water per second (cfs) and is designed to be used by SFWMD when tailwaters are high and the S-26 gates are closed. In practice, the SFWMD gate operational records database indicates that the pumps also remain on at times when the gates are open as well. Observed data for this station are included for validation simulation, using data from the DBHYDRO database. For design storm simulations, since this location is at the boundary of the models, inflows from the Miami-Dade County Boundary models include the station flows; therefore, this station is not explicitly modeled. The second station is parallel to the S-25B Gated Structure between the C-4 Canal and the C-6 Canal. Similar to the S-26 pump station, the purpose of the S-25B pump station is to maintain flows while the gates are closed, but again, in practice, it appears that the pumps are often found to be running when the gates are open in the observed data. The capacity of this station is also 650 cfs. The detailed modeled operation of the pump stations is described in the individual basin reports for the C-4 and C-6 Basin models in the Model Application TM.

2.5.7.2 Gated Structures

The following SFWMD Gated Canal Control Structures are included in the models:

- S-27 on the C-7 Canal in the C-7 and Biscayne North basin models
- S-26 on the C-6 Canal the C-6 basin models
- S-25B between the C-4 and C-6 Canals in the C-4 and C-6 basin models
- S-25 between the C-5 and C-6 Canals in the C-5 and C-6 basin models
- G-93 Structure on the C-3 Canal in the C-3/Biscayne South basin model

Observed data from the structures are used as inflows for the validation storm modeling and used as validation time series in some cases. For the design storm simulations, the SFWMD operations guidance is to fully open and lock the gates pre-storm; therefore, the models use full rectangular box culverts to simulate the open gates. Details of each structures are provided in the individual model reports.

2.5.7.3 Weirs and Orifices

Weirs and orifices are provided in the model where data were available in the record documents. Weirs are typically used for structures maintaining water levels in ponds, such as the FDOT pond at the I-95, I-195, S-112 interchange. Weirs are also used to divert flows at structures, such as pump stations where low-level flows go to treatment, but higher flows above the weir crest go directly to the pump. Weir data includes, but is not limited to, length (perpendicular to flow), invert (i.e., crest) elevation, height of weir opening relative to the weir crest, and discharge coefficient.

Orifices are typically used for drop inlets in dry detention basins. As there is a general uncertainty on the part of the City regarding the ability to acquire additional lands, whether by eminent domain or purchase for the creation of new storage basins for future BMPs currently programmed for other land uses, these structures may not appear in the models.

2.5.8 Model Link Summary

The following parameters are used for conduits in the hydraulic layer of SWMM:

- Cross-section: shape of pipe or link including circular, closed rectangular, open rectangular, arch, semi-circular, elliptical (both vertical and horizontal), irregular (for channels and overland flow links), trapezoidal, and custom (bridge). It should be noted that in this model, pumps, orifices, weirs, and outlets (rating curves) are all entered as separate elements from conduits.

- Length: The conduit length, in feet. This information was based on the City of Miami record data or was measured in GIS. Overland flow links have no actual length but are dimensionally set just long enough for computational stability, but not so long to where they could skew storage calculations (generally 20 feet).

- Diameter or Height (Geom1): Diameter of a circular conduit, in feet. This field also represents the height of the conduit for non-circular shapes (not used for irregular shapes). This information was based on the City's record drawings or field survey sheets.

- Width (Geom 2): width of pipe or conduit (not used for circular pipes or irregular shapes). This information was based on the City's record drawings or field survey sheets.

- Roughness Coefficient (Manning): Conduit roughness as described by Manning's n.

- Upstream and Downstream inverts: the upstream and downstream invert elevations for pipes and culverts were obtained through the City's records, other as-built drawings and special purpose spot surveys. The inverts for channels were estimated from the cross-sections, where available and special purpose bathymetric surveys. The upstream invert for the overland flow links were estimated from the lowest point of the topographically high hydraulic ridge between sub-basins. The downstream invert is typically set at a slightly lower elevation for numerical stability. It should be noted that the basin models are built in "Offsets: Elevation", which means inverts are provided as elevations in feet NAVD.

- Transect: the name of the transect used for irregular (channels, ditches, and overland flow links) conduits.

The following parameters are supplied in the transect data file for irregular conduits:

- Cross Section Coordinates: entered as an array of x-y coordinate positions in feet and elevations at each coordinate entry in feet. The arrays are taken from survey data for channel cross-sections, where available and from LiDAR for ditches and overland flow links. Note: SWMM does NOT uses the absolute elevations from the transect as the conduit inverts. SWMM builds a table of depth versus hydraulic parameter (area, hydraulic radius, surface width) from the low point of the transect. The model then applies this table at the upstream and downstream link inverts (see above), for each conduit that uses the transect.

- Left and Right Overbank Positions: the overbank positions (in feet) are the x-coordinate positions which are assigned as the top of the bank positions.

- Left and Right Overbank Manning's Roughness Coefficients: the Manning's roughness coefficient for the cross-sectional area from the left side of the transect to the left overbank station; and the Manning's roughness coefficient for the cross-sectional area from the right overbank station to the right side of the transect.

- Main Channel Manning's Roughness: The Manning's roughness coefficient for the cross-sectional area between the bank stations. Note that this value overrides the link roughness provided above.

2.5.9 Exfiltration Systems

The City of Miami uses extensive exfiltration techniques to reduce flooding and improve water quality by moving water from the PSMS into the ground to the Biscayne Aquifer. These systems include:

- Slab Covered Trenches: Slab covered trenches are characterized by rectangular boxes cut directly into the limestone aquifer, then covered with a concrete slab. Their sizes range from 3-ft by 3-ft boxes to as deep as 10 feet and wide as 8 feet (though smaller and large boxes are possible). The larger boxes can be used to covey large amounts of water similar to a pipe, as well as exfiltrate large amounts of water into the highly permeable aquifer. One issue with slab covered trenches is that they are hard to maintain, since the slabs can be paved over with time and the trenches become no longer accessible by maintenance equipment. Unless there is data to suggest that they are clogged, the model provides conveyance and exfiltration as though the trenches are in working order.

- French Drains (Exfiltration Trenches): French Drains are characterized by perforated pipe situated in a gravel-filled rectangular shaped excavation cut into the aquifer. Typically, the gravel-filled excavation is 3 to 5 feet wide, with a depth into the aquifer of a similar dimension. The perforated pipes are typically 24 inches in diameter, though sizes may vary. French Drains are cleaned similarly to solid pipes, using jets and vactor trucks at manholes. A French Drain may also have some conveyance when connected in series through an overflow connection pipe, though usually they are not designed to move water far.

Exfiltration design is well defined by the SFWMD and local Dade County RER as further described below.

- Drainage (Aquifer Recharge) Wells: There are two types of drainage aquifer recharge wells in the City Miami, gravity driven wells and injection (pumped) wells. Both are required to be located such that stormwater is not introduced to the fresh (drinking) water portion of the Biscayne Aquifer. Therefore, they are located east of the salinity interface defined as the interface/location where water quality exceeds 10,000 milligrams per liter (mg/L) total dissolved solids (TDS). Most of the shallow gravity drainage wells in the City of Miami are east of I-95, while those further to the west have casing opening that are deeper, to a depth where the aquifer is greater 10,000 mg/L TDS. Gravity recharge wells use the head difference between the flood levels in the street and the groundwater table elevation to drive water into the aquifer. Additionally, due to the density differences between freshwater and saltwater, the wells require an additional 2-3 feet of driving head to initiate flow. Therefore, gravity wells work better at higher elevations where the needed driving head is available. Injection wells work at any elevation because the pump station provides the driving head. There are over 2,000 drainage/recharge wells in the City. CDM Smith research indicates that the capacities of these wells range from 500 to 1,500 gallons per minute (gpm) per foot of driving head, with an average of 1,000 gpm/ft (2.2 cfs/ft). These rates are determined by the permeability of the aquifer and the limitations of the well size (typically 24 inches in diameter). Wells are typically preceded by a baffle box to capture floatables and trash.

The SFWMD ERP Information Manual has explicit formulas for designing acceptable, permittable exfiltration systems. The exfiltration designs are based on saturated hydraulic conductivity (K_{sat}), the geometry of the trench, and the depth of the water table. In practice, engineers enter the volume necessary to meet water quality criteria (or other storage criteria) and determine the length of the trench necessary to meet the criteria for the parameters given. The District equation solves for the volume by assuming an hour of flow at the rate determined by the K_{sat}, water table elevation, top of trench, and trench geometry. The City of Miami has a large amount of exfiltration trench designed in this manner. In order to represent the exfiltration in the model, the geometry (trench length and width) and K_{sat} have been used to back-calculate the flow rate using data from the City's records and field observation for length and size. Where size data were missing, default sizes were implemented.

The K_{sat} was determined for each model sub-basin using the permeability raster developed for this project described previously (Figure 2-5). The exfiltration rate also depends on the depth to water table and the depths of the trench that are saturated versus unsaturated. To compensate for the fact that the groundwater table rises during a storm, and thus the exfiltration rates drop, the model uses rating curves for each section of trench, as opposed to a constant flow rate. The hydrologic model was used to predict a regional groundwater response based on precipitation. The hydraulic model is used to convert the groundwater response into a simulated water table elevation using a large conceptual storage container element and an outfall to the deeper aquifer.

To estimate the depth to water table at any given time in the storm, the hydrologic model groundwater routines have been used for conceptualized sub-basins representing the general areas of the project. Neither the runoff nor the groundwater flows from the conceptual sub-basins contribute to modeled PSMS. These sub-basins are used only to estimate depth to water table for the during the storm event. The groundwater parameters, which simulate the timing and amplitude of the groundwater response to precipitation, were developed from previous CDM Smith projects in Miami-Dade County. Due to the high permeability of the Biscayne Aquifer, there is a relatively rapid response of the groundwater table to precipitation.

At locations where the stormwater system records indicate French Drains or Slab Covered Trenches, a model link outlet which routes flows based on a rating curve, provides connectivity between the PSMS node and the conceptual storage node representing the regional aquifer. This system allows flows out of the PSMS nodes connected to the exfiltration systems, at rates determined by the local K_{sat} and trench geometry.

The head used by SWMM to establish the exfiltration flow rate is calculated by the model as the difference between the head (water surface elevation, WSE) at the PSMS node and the head in the conceptual regional water table node, which becomes the driving head through the exfiltration system - as simulated, as the conceptual aquifer water table elevation rises, the head difference drops and the flow rate via exfiltration drops accordingly. Tables of head versus flow for the exfiltration outlet link are developed outside of the model using the regional K_{sat}, trench geometry, and summed exfiltration lengths per sub-basin. In the largest storms, the water table in areas may eventually rise to reach near the ground surface and the exfiltration rates drop to zero. Due to the lag between the peak of the precipitation and the peak of the water table rise, the exfiltration systems work as designed through the peak of the storm.

The exfiltration links are connected to multiple aquifer/outfall systems representing the groundwater aquifer. Therefore, the exfiltrated volume is removed from the model through these outfalls. Though there is potential for these flows to re-enter the basin PSMS in a canal, ditch or pond, it is expected that the regional behavior of the groundwater elevation, which is already being accounted for in the model, is not significantly affected by these flows (i.e., the water table is already simulated such that it rises rather quickly due to the storm).

The gravity wells use a similar methodology, except that the number of wells per sub-basin is used in place of trench length, the rating is based on the estimated 2.2 cfs per foot of driving head as noted above, and the driving head is adjusted to account for the density head difference.

2.6 Boundary Data and Conditions

Boundary conditions for the model are necessary to represent the influence from water levels in the downstream receiving water body. When the receiving water body level is low, the existing stormwater drainage system will be able to provide maximum conveyance, but when the receiving water body level is high, there will be portions of the existing drainage system that have reduced conveyance capacity or potentially even backflow. The modeling software provides flexibility for defining boundary conditions and can adopt fixed-stage boundaries or time series boundaries as necessary.

2.6.1 Design Storm Boundary Conditions

At the time of this writing, no comprehensive rainfall-tide correlated stage analysis has been performed for the City of Miami. The design storm style precipitation events are typically tropical, and may include storm surge; however, using a 10-year recurrence interval surge with the 10-year precipitation would produce an event that has a significantly lower chance of recurrence than 10% in a given year. Therefore, for the design storm simulations for this project, the 1-year tide (stillwater) is combined with the precipitation recurrence intervals to produce the recurrence events. Stillwater is defined as the flood level not including the effects of waves, but including storm surge and astronomic tide. A fixed stage boundary condition is used at the 1-year stillwater elevation to be conservative (i.e., since the timing of the storm is unknown versus high/low tide, using a fixed stage forces stages to be high at the peak of the storm). Note, a fixed stage boundary condition does affect the duration of flooding, as tides, even those accompanied by surge, allow flood levels to drain during the lower cycle.

The 1-year stillwater elevation was determined from observed data at the SFWMD S-22 and S-27 Control Structures and included 33 years of records at both structures. The S-22 Gage is approximate 3 miles south of the City, and 9 miles south of the mouth of the Miami River; while the S-27 gage is near the northern border of the City, approximately 5 miles north of the mouth of the Miami River. However, the S-27 gage is approximately 1 mile upstream of Biscayne Bay. The SFWMD stage gage at the mouth of the Miami River (MRMS4), has a shorter record and therefore was not as useful. The S-22 Gage provides a 1-year stillwater of about 2.0 feet NAVD, while the S-27 gage provides a value of about 2.1 feet NAVD. It is likely that most of Biscayne Bay experiences a 1-year Stillwater of 2.0 feet NAVD, considering the S-27 Structure is upstream of the Bay; therefore, this value is used for all models.

The historical observed data versus recurrence intervals are plotted on **Figures 2-12 and 2-13** for the SFWMD S-22 and S-27 Structures, respectively.

2.6.2 Validation Storm Boundary Conditions

The observed stage data at the SFWMD Gage at the mouth of the Miami River (MRMS4) was extracted from the SFWMD DBHYDRO database for the southern and central Basin models adjacent to Biscayne Bay (Biscayne Central, C-6, Biscayne South, and C-3/Biscayne South), for all validation storm models, including king tide events.

For the C-7 and Biscayne North models, an average of the MRMS4 gage and the S-27 tailwater gage observed data are used for the Hurricane Irma validation storm. This is because the S-27 tailwater gage is one mile inland from Biscayne Bay and there is some expected head loss between the gage and the Bay. However, the MRMS4 gage at the mouth of the Miami River had different timing and amplitude than the S-27 gage, so adjustments needed to be made.

For King Tide events and other validation storms, the S-27 observed tailwater data were used as the boundary condition because there were minimal losses in the C-7 Canal for these lower flow events. For the C-4 Basin model, observed stages at the SFWMD S-25B Headwater Gage are used for all validation events, while for the C-5 Basin, the SFWMD S-25 headwater gage is used.

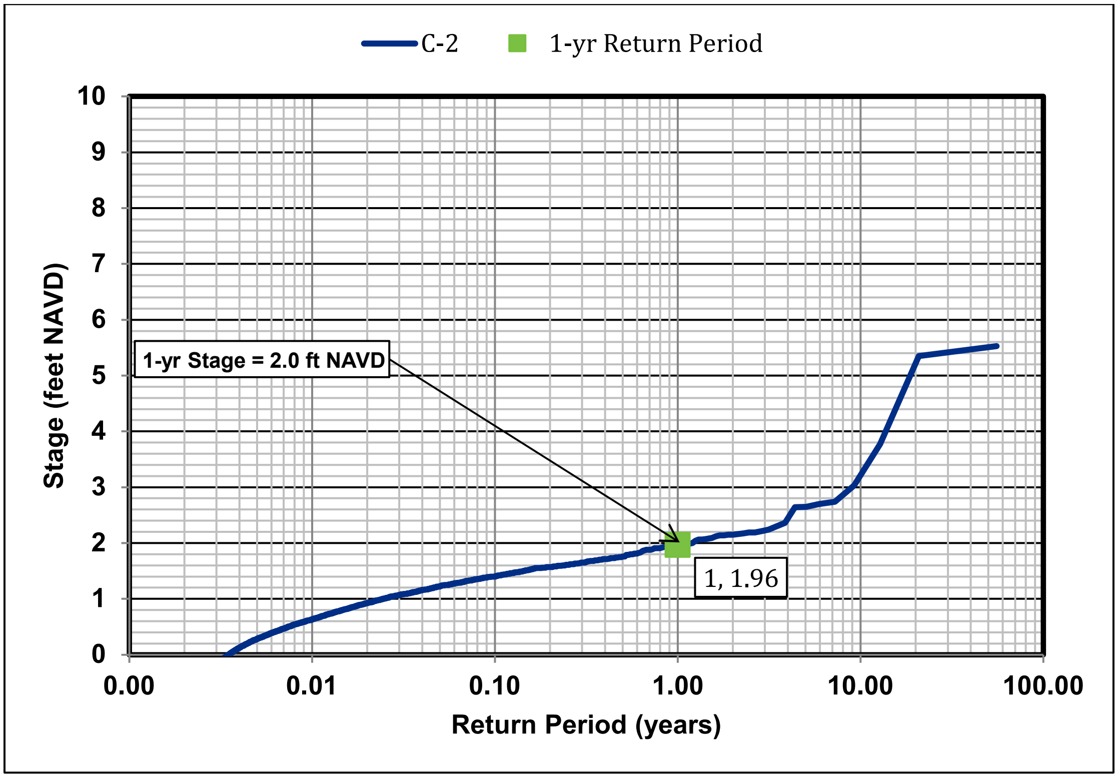


Figure 2-12
Return Period for SFWMD C-2 Canal, S-22 Tailwater

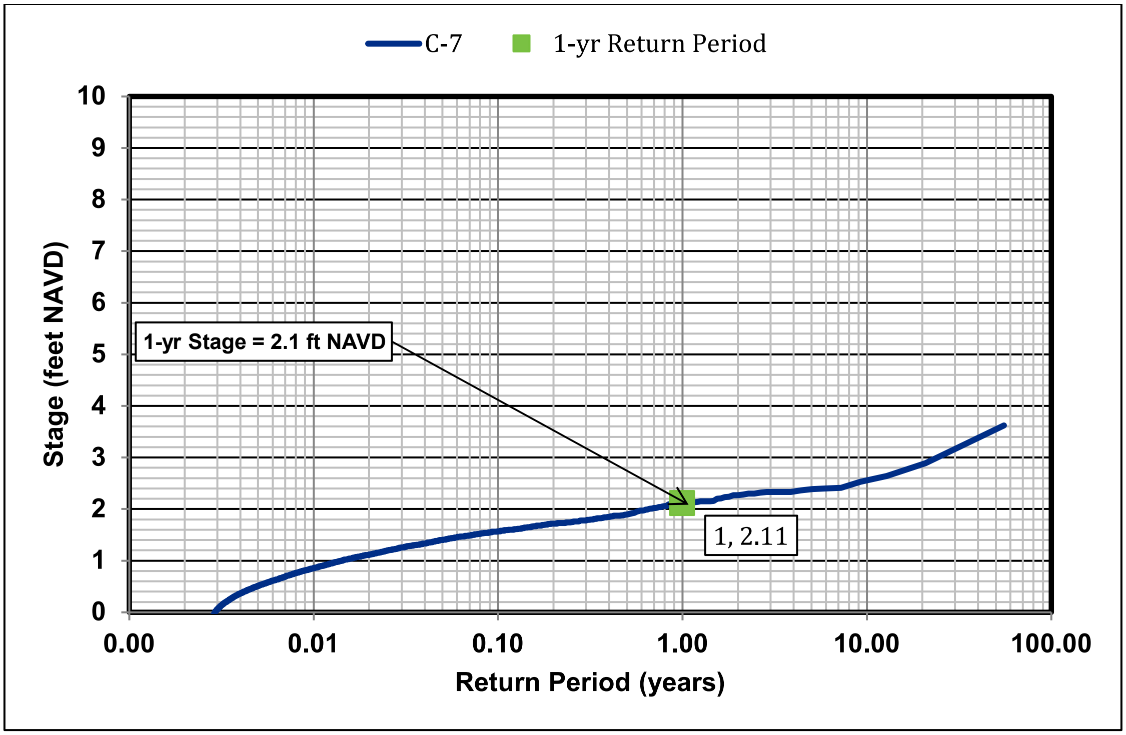


Figure 2-13
Return Period for SFWMD C-7 Canal, S-27 Tailwater

In locations where the PSMS is below the fixed stage and connected to the receiving water body by gravity (i.e., not pumped), initial depths were set in the model to match the boundary condition for each storm to prevent initial backflow at model startup. This calculation is generally performed outside the model using spreadsheets.

For resiliency planning purposes, model simulations will also include scenarios representing 1.5 feet and 2.5 feet of SLR. These increments are directly added to the fixed stage.

2.7 Model Validation

Following model development and debugging, drainage basin model results were compared to the best storm and flooding data available from the City for each basin. This included a date-sorted geodatabase of georeferenced flooding complaints that was created from citizen input and City field reports. For each drainage basin, the locations and dates where complaints related to storms and/or flooding have been made were reviewed. In particular locations of repetitive complaints and dates of the greatest number of complaints were noted. Photographs of flooding were collected and analyses (including field survey in some cases) of high-water marks were completed to estimate observed water levels corresponding to particular storms. Model results were then compared with observed water levels at the flood complaint locations for the same rain event data and the determination made whether the model produced reasonable results given the available data. Comparison results for each individual drainage basin model is provided separately in **Appendix A**.

The City is also in the process considering a pilot test for installing a network of permanent flood level sensors and real-time reporting gauges in various recommended locations throughout the City; this data should be utilized to continuously compare the model against rain events and peak stage response times for future verification efforts, identification of potential system maintenance problem areas, and to measure the pre-post effectiveness of installed CIP projects.

2.8 Model Stewardship

The City's drainage system model will be an important planning tool for many years. The model must be regularly maintained through updating the asset data, hydrologic and water quality parameters, and through periodic validation, hardware and software upgrades, and staff training. This section discusses model maintenance concepts and recommends protocols for model maintenance and support resources that will ensure the City's model returns maximum value.

2.8.1 Software Maintenance Concepts

Drainage system model maintenance is comparable to proprietary software modification and maintenance, which has been studied extensively. ISO/IEC 14764 (2006) defines four categories of software modification:

1. Correction of known problems
2. Adaptation to keep a product usable in response to external changes
3. Perfection to improve performance
4. Prevention to correct faults before they cause problems

At the time of this publication, the drainage basin models were built using PCSWMM Version 7.2, with the base H&H engine in EPA SWMM 5.013. Both the US EPA and Computational Hydraulics International (CHI, the maker of PCSWMM) provide regular updates and support of these products. New versions of the software are backward-compatible and changes are well documented. As new EPA SWMM software versions are released, they should be used for drainage basin models that are under development. As model updates are completed in the future, they should use the latest available software version. The model version for each drainage basin should be noted in the documentation for each model. Though PCSWMM provides many useful tools to build the models and visualize results, only the public domain EPA SWMM software is necessary to run and maintain the models.

The City's models will need ongoing maintenance for many reasons. Most may be classified as adaptive improvements:

- The physical assets in the drainage system change as the City implements capital improvements, and the City or other entities implement stormwater or resiliency control measures.
- The drainage system ages, leading to changes in infiltration, pipe roughness and sedimentation levels. Initially built models assumed a clean system for CIP purposes.

- Changes in operational protocols for modeled processes and pump station or structure operation.
- New precipitation, temperature, and tide data as needed to simulate recent conditions.
- Changes in land use.
- Removal of illegal connections or other illicit flow.

Other maintenance needs can be classified as corrective, perfective, or preventive:

- Find and correct discrepancies in the model network based on newer data (corrective).
- Regularly compare the model against observed stage gauge data to ensure its ongoing validity (perfective and/or corrective).
- Addition of features over time such as: secondary system smaller pipes in areas of interest or more concise refinement for the representation of hydrologic basins processes (perfective).
- Regular update of the model documentation to ensure that users other than the original developer and owner can understand it (perfective).
- Adjustment of the model naming conventions to maintain compatibility with the City's GIS or asset management upgrades (perfective).
- Archiving of older versions of the model and corresponding output (preventive).

2.8.2 Files

The model consists of items that will change with time:

- SWMM software
- The SWMM database describing the hydrology and hydraulics of the City's drainage system and the regional drainage network
- Environmental time series data
    1. Precipitation data from NOAA Atlas 14, future updates from NOAA, or updates based on City design standards; precipitation time series distributions (unit hyetographs) from the SFWMD
    2. Boundary Condition data
- City asset data in the City GIS
- Reference data including drawings, photographs and other documents
- Base maps and supporting GIS data such as buildings, roadways, and hydrography, etc.

- Model output
- Documentation describing model history and organization

General strategies for maintaining these computer files and documents are outlined below:

SWMM software. EPA has made an average of three upgrades per year to the underlying SWMM software since its release in 2005, while ESRI updates ArcGIS one to two times a year. The City may use EPA SWMM to view and run the model directly without GIS. The publicly available EPA program produces the same results as PCSWMM as both use the same computational engine and is easily installed and shared with others. The results from model simulations completed in EPA SWMM can be compared using the scenario manager in a third party program such as PCSWMM, or by simply exporting the results from the models output file into a spreadsheet.

SWMM database. The model database is an ArcGIS-compatible geodatabase that was developed with PCSWMM. The geodatabase updates immediately for changes made in PCSWMM; however, if changes to the model are made in EPA SWMM, contemporaneous edits to the geodatabase will need to be made in parallel as well. Additionally, the City's stormwater system asset data are provided in GIS, facilitating simultaneous display of both datasets and transfer of data into the model.

Environmental data. The model uses a 5-minute resolution precipitation data, though lower resolution datasets such as hourly data may be disaggregated to a shorter time step, if necessary, to run historic events and/or continuous precipitation time series. Model defaults may be used for evaporation values over a design storm; however, average monthly evaporation rates should be used for the continuous simulations. The outfall boundary conditions for design storms use fixed stages at the 1-year stillwater elevation. These data must be updated in the model if sea level rise causes this elevation to increase, or to test alternative SLR scenarios. Documentation should be maintained to describe the processes and updates to the precipitation, evaporation, and boundary conditions.

City asset data. A SWMM project can be viewed in conjunction with GIS asset data. The asset data are maintained within the model database with inverts, rim elevations, and pipe dimensions. The SWMM model elements are built from the City's GIS database, but not connected to it. Changes/additions to the City's asset database need to be imported into the SWMM database.

Reference data. Among the many sources used to build the model are record drawings, sketches, and photographs. These should be updated within the City's geodatabase as necessary to be kept current.

Output files. SWMM output files can be very large. It is recommended that all model files for a given simulation (i.e., drainage basin/recurrence interval storm/sea level rise option) be stored in an individual folder on a large capacity computer or external hard drive, and on a backup external hard drive. Further, it is recommended that all model simulations be stored without model results in a common location. In this manner, the models may be reviewed quickly, without results, to answer questions of connectivity for instance. If the user needs to review results, the *.out file from the backup may be copied to the common location and the model will show the results automatically as long as no names are changed. The models will need to be re-run if revisions are made to the model.

In general, it is important to track model input configurations, as output can be regenerated by performing a new simulation. Once the model simulation is complete, junction, pipe and sub-basin names should not be altered, or the output file will no longer be viable. If the model naming must be changed for any of the scenarios, the model output should be changed to match as well to remain viable. Unneeded alternatives and scenarios should be regularly purged from the model database to maintain manageable file sizes.

2.8.3 Frequent Model Maintenance Tasks

The following maintenance tasks should be performed monthly or quarterly, as needed based on activity within each drainage basin. Individual items are discussed in detail in subsequent text as appropriate.

Backup and Updates. If the City network drives are regularly backed up and the database is maintained on the network, there is no need to perform additional backups. Otherwise, the model caretaker should maintain a second copy of the current database separate from the live copy, and should keep older copies on hand. A protocol should be developed to communicate among staff and document when model updates are in progress. A backup copy should always be made before the principal database is edited.

Documentation. The City should maintain a narrative log of principal edits to the database. This file can be maintained as text narrative in a word processing file or in a database format. The documentation should describe changes to the model database and supporting source data. These reports should be considered core components of the model along with this report.

Update network, catchments, and land use. The model should be checked and updated on a drainage basin basis based on the availability of updated data, system improvements or new developments. At a minimum, the model for each drainage basin should be reviewed and updated annually. Several checks should be made after updates are completed, including:

- Model output files for each scenario should be free of warning messages or errors (note: the model produces warning messages from the SWMM engine about minimum elevation drops being used for flat conduits – these will necessarily remain).
- Results from a simulation should be checked following the City's quality control checklist and to ensure no unexpected flooding is indicated.

Environmental data update. Update of precipitation, and evaporation can generally be achieved by a straightforward replacement (cut and paste) of existing model data.

Software update. The SWMM model should be updated to current software at least annually to take advantage of improvements to its software, as well as in ArcGIS and EPA SWMM. More frequent upgrades can be helpful if newer features are needed; fewer upgrades can be preferable to limit time spent on software maintenance, and if changes in model results would cause inconsistent results in a planning study.

Archiving. Prior versions of the model should be archived with each update and at a minimum annually. Unneeded scenarios and supporting files should be culled to maintain a useful library of historical information, while important files should be cataloged and stored off-line.

2.8.3.1 Network Updates

The modeled network will need to be updated to correct, adapt, or perfect model representation of existing and future conditions: improved representation of existing system features and incorporation of future system modifications.

Improved representation of existing system features. The model can only be as accurate as the data that were used for development and verification. The model has primarily been developed using the City's available records and spot surveyed to fill in major data gaps. However, it is likely that future investigations and construction activities will further enhance/revise the City GIS, and model updates should be completed in parallel to maintain consistency with the GIS. In addition, as collection systems age, sediment levels and pipe roughness change even when basic infrastructure remains the same. For planning level CIP analyses, the drainage basins are modeled with clean, new pipes however, scenarios with localized sedimentation or higher roughness should be performed to analyze neighborhood-level isolated issues.

System modifications from refined data. The City should incorporate field verification of asset characteristics into its maintenance and inspection programs. Pipe configuration, invert elevations, sediment and flow constrictions are important to note. The following guidelines may be used to help prioritize field verification:

- Focus on key system features.
- Assess where model results are inconsistent with observed performance. As the model simulates how the system should perform if configured as represented, investigations can target locations where model results do not conform to observations. Variations can be due to blockages or other O&M issues.
- Plan field verification and re-calibration according to design and implementation schedules.
- Incorporate system modifications. The level of detail entered for each project can be evaluated on a case-by-case basis. As projects are completed, record drawings should be used to update the model.
- Pre- and post-construction monitoring can be used to assess the need for model recalibration.

Representing pipe replacements can be relatively simple. If existing manholes are retained, the task only requires data modification to pipe dimensions. If manholes are relocated, then the system data will need to replace the existing geometric data in the model.

System modifications from new developments and system improvements. As system improvements and new developments are planned and constructed both within the City and around the boundaries, the drainage basin models will need to be updated to reflect the system changes. Expanding the model to include new pipe systems/inlet locations requires more advanced modeling skills. Drainage sub-basins must be re-delineated to ensure that all drains have appropriate tributary areas. Hydrologic parameters must be assigned to each sub-basin. These parameters should correspond with system-wide average characteristics, land use and imperviousness unless data indicate otherwise. Technical aspects of system updates are discussed in Section 2.9.

Model versioning and supporting documentation should be maintained to distinguish drainage basin models updated with constructed improvements as opposed to updates completed for the purpose of evaluating new planned developments. In most cases, models to support evaluations of planned developments can be completed in association with each development. However, there may be cases where the cumulative effects of multiple planned developments should be evaluated. For these cases a separate planning version of the drainage basin model can be created and maintained for engineering evaluations, and then the existing conditions drainage basin model can be updated separately as improvements are constructed.

2.9 Programmatic Maintenance Tasks

The following maintenance tasks should be performed as needed and based on available supporting data.

2.9.1 Model Revalidation

The model has been validated based on available flooding information as provided by the City and collected under the data phase of this project; however, the content and detail of available data varied by drainage basin. The City should strive to develop a database of high-water marks for larger storms. The City should provide an email site or webpage where time-stamped and georeferenced photos of flooding may be submitted by residents. If a given photo provides a reasonable calibration point, the location may be surveyed at a later date. Additionally, the planned flood stage gage network will become a key data source to further advance the informational database and its response to storms over time. As a database of flood elevations per rainfall event is developed, refined validation of the models may be performed. Subsequently, annual validation should confirm that subsequent adjustments to the model yield sensible results.

The model should be fully recalibrated at least every ten years, and earlier if major changes to the PSMS have occurred or if the above stage gauge monitoring data become available. Recalibration is best achieved in conjunction with a database of high-water marks. Alternatively, recalibration can be performed on a rolling basis, with a portion of the system targeted for assessment each year.

2.9.2 Level of Detail

The model has variations in its existing level of detail, reflecting the projects under which each component was built. All of the City has a 24-inch diameter threshold for inclusion in the model. Over time, as new developments are constructed, model updates should include a similar minimum level of detail. Sub-basins should be targeted to be approximately 5 acres, pipes 24-inch and larger should always be included, smaller where necessary, and stormwater management facilities that affect system storage and attenuation should be included. The established level of detail is adequate for the purpose of master planning and representing refined flow contributions from new developments. However, additional detail may be added depending on anticipated analysis needs for select locations. Population of the City’s GIS with complete asset data over time will provide future flexibility for adding finer scales of detail to the model to help solve local issues where desired.

2.9.3 Hydrology

The model's hydrology should be periodically reconsidered as the City's needs evolve and modeling technology advances. While the model's configuration exceeds current standards of drainage system modeling, the "state-of-the-art" standard continually advances. For example, it is likely that in the future, a "rain on grid" hydrology method will be developed in conjunction with more intensive 2D modeling.

The existing Low Impact Development (LID) features are not directly represented in the model; storage and infiltration devices across the City are currently considered implicitly in each sub-basin's runoff characteristics. As the City continues its efforts to limit stormwater runoff and improve runoff water quality, it may be desirable to modify the model to explicitly represent storage and infiltration devices using SWMM's LID component.

2.9.4 Software

The model software platform should be reconsidered at least every 10 years. The City has the option of changing software vendors at any time, as the model uses standard SWMM 5 data structures that can be readily ported to SWMM platforms available from Innovyze, DHI, and others. The City could also choose to only use the public domain EPA SWMM interface, which, while possessing limited GIS functionality and not offering scenario management, can be adequate for most in-house potential uses of the model.

2.10 Staffing and Training

It is recommended that the City allocate adequate internal resources for upkeep and application of the model. This could include assigning one staff member to be the model custodian, which could be part of their existing job duties. The custodian should be a stormwater engineer (or certified flood plain manager) with a solid understanding of open and closed-conduit hydrology and hydraulics, and I/T and GIS background.

The City has options for performing modeling in-house, to perform some work in-house and contract for larger projects, or use contract resources to perform most modeling, as is done by many cities. If the City chooses to use in-house resources, CDM Smith recommends that at least two employees be trained in using the model and kept current by attending recurring SWMM training. Each should have at least 5 years previous modeling experience and requisite engineering skills. The redundancy is preferable due to the possibility of staff changes. Staffing needs should be reviewed annually to coordinate staff capacity with the anticipated frequency of model updates that will be needed.

To effectively understand the model contents and capabilities, the custodian(s) should have specific software training. Training in the following topics is required to be able to work with the model: 1) hydrologic, hydraulic, and water quality modeling using both EPA SWMM and ArcGIS. Training in the use of other third-party software such as PCSWMM is helpful but not required.

CDM Smith recommends that the model custodian should participate in the following training:

- 1 day of training in general use of SWMM models

- 1 day of training in EPASWMM
- 1 day learning about the contents of the City's model and interfacing with the City's GIS

In addition to the training being provided to the City by CDM Smith under the master plan scope, the use of SWMM for water quality modeling is described in the software user manual (Rossman, 2010), and a sample water quality application is described in the SWMM Applications Manual (Gironás, Roesner, and Davis, 2009). There is also a brief online tutorial included with the EPA SWMM software, available from its website (http://www2.epa.gov/water-research/storm-water-management-model-swmm).

Introductory ArcGIS training can be accomplished using the City's internal resources, or via online offerings such as the free nine-hour class "Getting Started with GIS" offered by ESRI.

2.11 Model Updates

The City's drainage system model will be an important planning tool for many years. As discussed in Section 2.8, the model will require regular maintenance, including updates to asset data, hydrologic and water quality parameters, and through periodic validation and recalibration, hardware and software upgrades, and staff training. In addition to the regular maintenance, the models will need to be modified to analyze and manage future developments. This section describes the steps necessary to be able to add future developments to the SWMM models.

2.11.1 Importing New Data into the Model

This section provides the steps necessary to import revised model GIS data into the PCSWMM interface to update the models. To incorporate this data into the EPA SWMM interface, the shapefiles must be exported to spreadsheets and the spreadsheet data pasted into the ASCII SWMM [model name].inp file. The complicated nature of where each attribute is entered in the [model name].inp file precludes describing it in this document.

It is recommended that a copy of the model be made prior to importing data. Once the edits to the nodes (junctions, storages, and outfalls), conduits, and sub-basins have been made, all editing sessions should be ended and the revised shapes are ready for import. The process is as follows:

- Go to File, Import, GIS/CAD
- Highlight the Import to Layer "Junctions"
- Browse for "Source Layer…" to the newly created shapefile
- Under "Import Options":
    1. The "Import New Entities" should typically be checked when appending new features (based on unique IDs) not already in the model. If unchecked, all the data in the GIS will overwrite the data in the model for junctions with the same name. If the remaining junctions have not been edited, this will not harm the import. Any junctions in the model not within the new GIS will be unaffected.

2. Update "Matching Entities" and "Selected Entities" should be left unchecked for this purpose.
3. Never check "Delete All Entities First" for this purpose.
4. Update coordinates is the default and is OK.
5. It is good practice to check "Tag Imported Entities" and provide a unique name if everything imported is new entities only. It will help define the entities later.

- Under "Attribute Matching", if the original junction shapefile was used as a base, the source layer attributes should automatically align with the junction layer attributes. These should be checked prior to import.
- Select "Finish."
- Repeat for Storages and Outfalls (if any have been added or changed). Note the nodes (junctions, storages, and outfalls) are added prior to conduits and sub-basins because the latter two call the node names.
- Repeat for Conduits: For conduits, it is critical that the Inlet Node and Outlet Node have been set and the attribute matching is correct. The model does not recognize that the conduit "starts" at the same location as a node, this information needs to be provided.
- Repeat for Sub-basins: if the names from the existing sub-basins are reused in the new set, "Import New Entities Only" should not be checked. If, however, the new sub-basins have completely new names, the old ones that cover the same area need to be manually removed from the model (even if the entire drainage basin sub-basin shapefile has been edited, the old ones would remain upon the new import, unless "Delete All Entities First" is applied, which is not recommended). It is not always easy to see overlapping sub-basins, so it is recommended that these be deleted prior to import.
- If pumps, weirs, orifices, or any other element was edited in GIS, repeat steps for these.

It is critical to review the model import and make sure all the entities have been added and connect to the existing system where needed. The model should show the sub-basin connections to the loading node. These should be confirmed as well. If elements from the existing system remain, but are to be plugged or abandoned, they need to be manually deleted. The existing model may also have had large storage nodes representing open fields (i.e., pre-development areas) and/or overland flow conduits covering the area, which also should be removed.

2.11.2 Adding Design Drawings or As-Built Records

Generally, three types of design or as-built drawings are needed to add a new development to the larger drainage basin stormwater models:

- A drainage plan, including a plan view of the stormwater system and development boundary, pipe type, diameter, and inverts along with details on any control or special structures. The cross-section view is not necessary if the pipe inverts and locations are provided on the plan view.

- A plan drawing of impervious coverage. This should include roads, driveways, parking lots, sidewalks, building footprints, water body footprints, and other pavement/ impervious coverage. For commercial developments, the approximate impervious coverage is often known in the design phase. If the impervious is unknown, an approximate impervious percent per parcel should be estimated.

- A grading plan, including proposed detention ponds or swales.

2.11.2.1 Incorporating New As-built Records

Typically, the final record drawings would be incorporated into a GIS environment first and the model features updated outside of the SWMM interface, prior to being installed in the model itself. This section describes the steps necessary to incorporate a new development using the ESRI ArcGIS interface; however, it is possible to upload geo-referenced image files into SWMM and then use SWMM editing tools to update the model manually with the program.

2.11.2.2 Export of Existing Model Elements

Software such as PCSWMM maintains GIS shapefiles of model elements including all conduits, pumps, weirs, and orifices; all nodes including regular junctions, storage junctions, and outfalls; and all sub-basins. The shapefiles have attributes that include nearly all of the model information. The transect information for irregular sections, the storage curves for storage nodes, and pump curves are some of the element information that is not stored in the GIS data and must be entered separately. However, since most of the model data were developed in PCSWMM, this represents an excellent resource for model revisions and updates. These shapefiles get updated every time the model is saved. Note, it is important that the model be properly geo-referenced prior to saving. The drainage basin models should already be in state plane coordinates of NAD83 HARN Florida East feet US. Further, it is recommended that the coordinate system of the GIS map file be the same as the one in the model. If the model is not georeferenced, search through the “Projected Systems” for this projection and then update all elements to this system and save the model. Also note the drainage basin models should be in “Offsets:Elevation” (this is in a drop-down box at the bottom left on the frame of both the EPA SWMM and PCSWMM interfaces). If this is set to “Offsets:Depth”, change this to “Elevation” and accept that all conduits will be updated.

Once the model has been georeferenced and saved, the model elements can be added to a GIS map in the same coordinate system. Generally, the map should also include the city-wide impervious coverage and land-use maps, the drainage basin DEM developed from LiDAR, and a soils coverage map. The map should also include existing GIS of survey data (pipes, inlets, etc.) for comparisons and connections to the new development.

After the model shapefiles have been added to the GIS map, each should be copied to another folder, as it is not necessary nor advisable to edit the original PCSWMM shapefiles directly. In larger models, it may be helpful to select the model elements included within and immediately adjacent to the new development and only copy these elements to the new folder. This can make the files to be edited more manageable.

2.11.2.3 Adding Drawings to the GIS

The drainage network, impervious coverage, and grading plans should be added to the map and GIS. If in the proper coordinate system, AutoCAD drawings often can be incorporated to GIS directly. However, it is typically necessary to save pdf drawings as a Tag Image File Format (TIFF, *.tif) drawings, add them to the GIS and then use the georeferencing tools to place them properly in the map.

Once the CAD or georeferenced TIFF images are placed in the map, they may be used as background images to guide the model revisions and additions. When the background image is uploaded and spatially georeferenced, the elements can be traced manually individually using the dropdown elements and tools within EPA SWMM.

2.12 Creating New or Revising Existing Model Elements

2.12.1 Revising Pipe Networks

In order to make revisions to the model, it is necessary to determine the resolution of the updated model in the vicinity of the new development. The drainage basin models have generally been built to a resolution where 24-inch pipe diameters and larger have been included in the model, while smaller pipes typically have been considered as secondary systems that are essentially incorporated into the hydrology. Smaller pipes have been added if they represent the only drainage from a low area or are necessary to convey flows from ponds or lakes (structure outlet pipes, for example). However, if an intersection contains multiple inlets to small diameter pipes, and these pipes all connect to a single 24-inch line, the small diameter leader pipes will not be in the model as the sub-basin will contain all the inlets but only drain to the end of the 24-inch pipe. This type of analysis assumes that the leader pipes are designed correctly, and the limiting system element is the 24-inch trunk line. For inlets along the trunk line of a system, not every inlet gets a separate sub-basin in the model.

The methodology described above should be sufficient for most new developments as well; however, if it is determined that the model resolution should include all pipes in the design, then the sub-basins must be delineated to the same resolution, i.e., every upstream end of pipe requires a separate sub-basin and intermediate sub-basins should have the same resolution.

2.12.2 Adding Nodes

Once the model resolution is chosen, the copied junction and storage node files should be edited and new model nodes should be added to the model. Initially, a storage node should be used in all locations that the sub-basins drain to. This includes any detention ponds, all upstream end of pipe networks, and the inlets along trunk lines at the lowest elevations according to the grading plans. If multiple inlets are expected at similar elevations, place the storage nodes at even intervals such that the sub-basin delineation size is similar to the ends. If every inlet and every pipe is to be modeled, all inlets should be storage nodes. All manholes, as well as inlets that runoff will not be loaded in the model, should be added as junctions (or as storage node with constant storage set to 12.5 square feet). Additionally, if the detention ponds or swales have outlet structures, the downstream side of the structure will require an additional junction. This junction also represents the upstream end of the discharge pipe. Since both nodes representing the structure may be located at the same x and y coordinates, one will have to be moved slightly so they both can be seen. Typically, the upstream side of the structure is moved toward the center of the pond.

In the model, the storage node for ponds, lakes, and dry detention represent planar areas. In GIS and in the model node/link schematic, the storage node must be implemented as a point in space. Therefore, the inlet(s) to the pond and the upstream side of the outlet structure or pipe all have to be represented by the same point in the model. The upstream end of the outlet structure or pipe should be set as the model storage node, and the downstream ends of the pipes outletting to the pond should be directly connected to the storage node.

If the development is on the edge of a drainage basin and the development is expected to drain to a waterbody that is considered an outfall (such as Biscayne Bay), the outfall file should be edited, and the end of pipe(s) should be added as an outfall(s) in the model.

If there are existing model nodes (either storage, junction, or outfall) within the new development that are parts of systems that will be abandoned, they may be deleted from the GIS input. However, if only new features are imported into the model, any abandoned portions will need to be deleted from the model after the import.

Once all new nodes have been added to the GIS, each should be named according to the City model nomenclature rules. If the new development has already been included in the City GIS system and IDs provided, the nodes should be named based on the provided ID. Other attributes that may be added at this time are invert elevation and rim elevation. The inverts need to be at or below the lowest connecting pipe invert. For ease of future model updates, storage node invert elevations are typically set below the lowest pipe invert (in intervals of 5 feet). The lowered storage node invert avoids having to recalculate depth-volume storage curves each time a pipe invert changes, minimizing subsequent model update efforts.

The rim elevation of new nodes should be ground elevation plus 10 feet. Rim elevations are set above ground to allow for above ground model elements such as storage curves in the storage nodes and overland flow channels between nodes. Ten feet has been added to create a matching offset to actual ground to aid in profile mapping. In some cases, the offset between the model and actual ground elevation needs to be greater than 10 feet. Examples include at the ends of ditches, streams, canals and some swales where the maximum depth between the “ground” at the node and the highest elevation of the connecting conduit (ditch, stream, etc.) is larger than 10 feet. In these cases, the maximum depth needs to be as high as the highest connecting conduit and the rim needs to be higher than 10 feet. If the offset defined in the model needs to be increased a warning will be issued during model simulation.

For all nodes, the X and Y coordinates need to be calculated so they may be added to the model in the correct location. For new storage nodes, the SHAPECURVE attribute can be set to “TABULAR” to prepare for the curve input, though it is not necessary.

2.12.3 Adding Conduits

The conduits within the drainage system that are considered primary and therefore modeled, should be added to the conduit shapefile from the drainage plan. It is generally a good practice to “snap” the ends of the conduits to the nodes which have already been added to the GIS. With the nodes edited the subsequent step of adding conduits is straight forward and includes adding the following attributes:

- INLETNODE: The conduits should be drawn in GIS in the direction of flow. Thus, the name of the node at the beginning of the conduit polyline should be given to the upstream node name ("inletnode") attribute.
- OUTLETNODE: The name of the node at the end of the conduit polyline should be given to the downstream node name ("outletnode") attribute. Pipes outletting to waterbodies (or dry detention) need to be connected to the storage node representing the water body or detention, not the junction representing the outfall. The downstream node name in this case must be the storage node representing the waterbody. If a conduit connects to a node from the existing model, the name of that node should be applied to this attribute.
- NAME: the conduit name for pipes usually is in the form "upstream node name: downstream node name"; however, if the downstream node is the storage junction of a pond, lake, etc., the actual outfall ID can be used as the second half of the name. Overland flow links, which will be discussed later, typically end with "_O" to differentiate from a potential parallel pipe. Ditches, canals, and swales may also have prefixes (check the underlying model nomenclature for guidance).
- LENGTH: length may be added from the drawings or measured in GIS. If measured, the drawn polyline should match the underlying drawing for changes in direction. Additionally, if the pipe outfalls to a pond, lake, etc., the length should match only the distance to the pipe outfall, not the distance to the storage node. It is not recommended that the Auto-Length feature in PCSWMM be used to find conduit length. Many pipes, such as those to pond storage nodes and overland flow conduits are drawn to a schematic length instead of a real length. If Auto-Length is turned on in PCSWMM, any edit of the line, such as moving vertices, will result in an errant length.
- ROUGHNESS: Pipe roughness should be set based on the Section 2.5.3. For irregular channels, engineering judgement, and details and guidance described in Section 2.5.4 to determine the roughness for center sections (main channel) and overbank areas.
- XSECTION: this attribute should include one of the following: CIRCULAR, ARCH, HORIZ_ELLIPSE, VERT_ELLIPSE, RECT_CLOSED, TRAPEZOIDAL, or IRREGULAR. There are additional conduit shapes available in SWMM. Check the model interface for additional types, or change the shape in the model.
- INLETELEV: This is the invert of the upstream end of the conduit. The drainage basin models are set up in SWMM as Offsets:Elevation; therefore, the inverts should be in absolute elevation in feet NAVD.
- OUTLETELEV: This is the invert of the downstream end of the conduit in feet NAVD.
- ENTRYLOSSC: entry loss for the pipe or culvert. This value is typically 0.3 for pipes and 0.5 to 1.0 for culverts (see Section 2.5.3).

- EXITLOSSCO: exit loss for the pipe or culvert. This value is typically 0.2 for pipes (1.0 for pipes outletting to standing water) and 0.5 to 1.0 for culverts (see Section 2.5.3).
- AVGLOSSCO: additional losses for pipes, based on the bend losses within the pipe or the angle losses at the pipe end (see Section 2.5.3).
- BARRELS: number of barrels of parallel pipe.
- GEOM1: pipe depth or diameter in feet.
- GEOM2: pipe width in feet (may be left blank for circular).

The remaining attributes should be populated within the model, though if there are numerous trapezoidal channels, GEOM3 and GEOM4 (which are used for the left- and right-side slopes) may be set in the GIS.

Additionally, irregular channels do not need the GEOM parameters set, but do require the TRANSECT value populated, which is easier to set up in the model. For conduits with "FLAPGATE" set to yes, flow direction is only allowed downstream; for these, entrance and exit losses should be defined.

2.12.4 Adding Weirs, Orifices, and Pumps

These other types of conduits may be edited in the GIS interface as well; however, typically there are not many to add and it is easier to set up within the model. If edits are made in GIS for these feature types, much of the same attribute data are populated as required for conduits.

2.12.5 Re-delineation of Sub-basins

The sub-basins from the existing model will need to be replaced by the new delineation (where conduits and nodes may simply be added to the model). When modifying existing sub-basins, the model import process (Section 2.9.5) overwrites data for sub-basins with the same name; therefore, if new sub-basin names are used, the original sub-basins will need to be manually removed from the model after the import.

For instance, if the new development replaces 4 sub-basins with 40, if the original 4 names are maintained in 4 catchments of the new 40; during the import of the new data, the old ones will be replaced. However, if 40 new names are used, the original 4 catchments will need to be deleted, either before or after the import.

The first step is to identify the sub-basins that cover the new development. It is important that any sub-basin that is affected by the development be re-delineated. Even if just a small area is affected, the attributes will need to be reset, particularly total area and impervious percentage.

The development's sub-basins should be delineated using the hydrologic inlets (at storage nodes) developed above and the development's grading plan. It may be useful to have a GIS expert incorporate the grading plan into the existing LIDAR DEM. The contours and/or point elevations may be used to develop a raster surface for the area, using the ArcGIS "Topo to Raster" (or other) tool. The existing DEM raster could then be replaced in this area with the proposed (or new) raster using the ArcGIS "Mosaic to New Raster" tool. This may aid in determining the hydraulic ridges that should be used. If a new DEM is not available, the best estimate of the boundary between sub-basins should be determined from the plan. The sub-basins containing detention ponds (or dry detention) should include all areas that sheet flow to the detention area, and areas that may be drained by smaller pipes, if they are not sub-delineated separately. Within residential neighborhoods, the highest point between street inlets for parallel streets is often at the houseline. There is no modeling reason to avoid cutting through the housing footprint in these cases. For industrial and commercial building footprints, if the direction of roof drainage is known, use that to determine the sub-basin delineation, otherwise, splitting the roof between sub-basins is a reasonable modeling assumption. The delineation should be set such that runoff can flow downhill to the chosen sub-basin inlet (storage) node.

2.12.6 Modifying Sub-Basin Parameters

The following parameters are best set in GIS, though they may be added inside SWMM, if calculated outside of GIS.

- NAME: The naming convention for the models is that the sub-basin name matches the sub-basin load point (outlet), with the attached prefix “HU”.
- OUTLET: The runoff will load to this node. This should be set to the storage node selected in the previous steps, though this may also be added once the sub-basins have been imported to the model.
- AREA: may be calculated with GIS polygon shapefile geometry calculation tool (Acres).
- WIDTH: this is a SWMM geometry term and may be derived as W = A/FL, where A is area in square feet and FL is average flow path length in feet (Width is input in feet). Typically, for larger sub-basins, three representative flow paths are chosen and averaged to find width and slope. For smaller sub-basins in highly refined developments, the flow path length and slope may be estimated from a typical parcel(s). In most cases, averaging three representative paths is still recommended.
- SLOPE: entered in percent as the slope along a typical flow path. Typically, this is calculated as an average of three representative flow paths as described above.
- IMPERV: this is the impervious coverage of the re-delineated sub-basin. If the impervious coverage of the development is provided, this should be intersected with the sub-basin delineation and the impervious areas calculated as a percentage of the total area. If the coverage plan is not set, the percent impervious must be estimated from the development plan. For example, it the developer plans to increase an existing 10-acre parcel from 0% impervious to 60% impervious, he will be adding 6 acres of impervious cover. If 2 acres are set aside for detention and open space, the remaining 8 acres should have 6 acres of impervious cover and average 75% impervious.
- NIMPERV: dimensionless Manning’s roughness for impervious areas. This will typically be set to 0.015 for all development impervious surface.

- NPERV: dimensionless Manning's roughness for pervious areas. Note, since the depth of flow for runoff over sub-basins is very shallow, these values should be significantly higher than for channels. Typical turf ranges from 0.2 to 0.45, though 0.25 is used throughout much of the drainage basin models, for residential and commercial areas.
- DSIMPERV: impervious depression storage in inches. This value is typically small, with 0.1 inch used in most models.
- DSPERV: pervious depression storage in inches. This value is typically small, with 0.25 inch used in most models.
- ROUTING: most of the drainage basin modeling routes to "PERVIOUS", which allows the percentage input below to be routed from impervious to pervious (such as a roof gutter directed onto a lawn) accounting for infiltration potential.
- PCTROUTED: Percent routed if the above parameter is set to "PERVIOUS". In the drainage basin models, this value is set by land use. For new developments, the modeler may be able to set this with more direct evidence. For instance, if parking lot flows are directed to grass areas prior to reaching the primary drainage system, then 100% of this impervious area could be directed to pervious. However, typical values are approximately 25–50%.
- CONDUCT: saturated hydraulic conductivity for Modified Green-Ampt infiltration (in/hr). This may be found by intersecting the sub-basin delineations with a soils coverage map and averaging by soils type (due to the range of values of this parameter, Log values of Ksat were averaged for the drainage basin models). If the development is completely within a single soil type, the values from the existing condition sub-basins may be used.
- SUCTIONHEA (in) and INITDEFICI (dimensionless) are the other Modified Green-Ampt Parameters and may be found from the same intersection as above.

2.12.7 Adding or Modifying Storage Curves

To this point, storage nodes have been added to the model, but they are missing the storage curves which will define them. Stage storage curves are typically developed for cross-sectional areas at quarter-foot increments for the entire depth of a given sub-basin, either based on the proposed DEM, or derived from the grading plans directly. Generally, detention areas should have contours which can be used for developing storage curves; however, there still will be a need to develop curves above the new inlets, unless the drainage system has been designed for the 500-year storm. For example, if the road is lower than the surrounding yards/homes, and a typical crown and gutter shape is given, a spreadsheet could be used to calculate the area for every depth above the inlet invert at the low point in the gutter for the length of road to the high point in the gutter. If the gutter is not deep, the profile of the crown and gutter may need to be extended into the neighboring yards at the proposed slope to accurately account for the area. If there are swales, ditches, streams, or canals adjacent to the storage areas, the footprint of the linear feature should be excluded from the storage calculation to not double count the storage.

The stage-storage area curves should always be set as depth from the storage junction invert versus planar area (in feet squared). It is good practice to add the invert elevation as part of the curve name. Therefore, if the invert changes and the curve is not similarly updated for the new depths, the invert and curve name will no longer match, which should be a flag for the modeler.

Each storage node with a stage-storage area curve should have Storage Curve : "Tabular" set. Under the Curve Name parameter, a dropdown box leads to the storage curve editor, where the name may be entered, and a table of depth/area pairs may be pasted from a spreadsheet.

2.12.8 Adding or Modifying Structures

Typically, it is easier to implement outlet structures directly in the model than in GIS. If the process above has been followed, there should be a storage node representing the upstream side of the structure, which includes the storage curve of the pond or detention area behind it. There also should be a junction representing the downstream side of the structure and the upstream end of the discharge pipe. Drop structures may be implemented as bottom rectangular orifice, though sometimes weirs are used if the orifice has stability issues. Typically, outfall structures also have bleeder elevations (smaller openings that discharge water during times of low inflow). The initial depth of the pond, and all elements upstream of the pond should be set to provide a flat initial surface upstream of the pond at this bleeder elevation.

2.12.9 Adding or Modifying Swales, Ditches, Streams, and Canals

If open, linear, features are part of the design, the conduits may be added in the GIS process, but the transects will need to be added separately.

It is always good practice to manually measure the length of open channel features, as actual length may vary from GIS length (or schematic length). The design should include an example cross-section and channel inverts. If roughness values are not provided, see Section 2.6 for guidance.

Typically, the drainage basin models have been designed to carry flows for extreme storms at extreme (and/or future) boundary conditions. This requires that irregular channel banks be extended to elevations well beyond what a typical design may show. For the purpose of adding a channel in a development, it may be necessary to extend the transect to higher elevations, using the grading plan adjacent to the channel and/or existing condition LIDAR. Note that if a floodplain is added to a channel, the footprint of the floodplain should be removed from the adjacent storage curve to avoid double counting storage volume.

2.12.10 Adding or Modifying Overland Flow Links

The drainage basin models were built in a similar fashion as described for the development addition described here. At this point in the model build, the models were run with the highest rainfall volumes and deepest boundary conditions that were expected in subsequent simulations. In locations where the resultant peak stages were at or near sub-basin boundaries (which should follow hydraulic boundaries), overland flow links were then provided. Overland flow links are used to equalize flood depths between neighboring areas where flooding breaches any boundary between the areas. For example, intersection A should not reach a peak flood stage of 8 feet NAVD and neighboring intersection B a flood stage of 9 feet NAVD, if the lowest point in the transect separating the neighborhoods is 7 feet NAVD. Under these conditions, the floodwater would travel down the road from intersection B to A until both were at nearly the same stage (probably near 8.5 feet NAVD). If the storage curves represent shallow “bowls” above each inlet, then the overland flow links are similar to irregular weirs at the edges of the bowl, where flood levels are allowed to equalize. It is not suggested that weirs be used for this purpose, since irregular shapes are not an option, and because they can be unstable when used for this purpose. Short, wide irregular sections at the highest transect between the “bowls” are used instead. At the drainage basin model scale, the typical length of an overland flow links is 20 feet.

Once the locations of the links are identified, the transect may be extracted from the proposed (or new) DEM if one has been built or developed from the grading plan. For example, if a curb and gutter standard shape is used, the standard shape may be added as the overland flow transect and the inverts set to the high point in the gutter as shown in the road grading plan. Since the link is acting like a weir, the upstream and downstream inverts can be set to the same elevation, though typically a small offset (0.1 feet) is used.

Note that it is possible, even likely, that existing adjacent neighborhoods connect to the new development through overland flow links, under the highest storm/ boundary condition.

2.12.11 Initial Depths

It is critical to provide reasonable initial depths in the models to provide accurate flood elevation projections. An initial depth is required for every junction and storage node in the model equal to the fixed stage boundary condition, or the simulation start-time elevation if time series are used (generally these are set to an elevation of 0.0 ft NAVD, though other portions of the model should be used for guidance). If structures are used to provide wet detention at elevations higher than the fixed boundary condition, the initial depths for all nodes and junctions upstream of the structure should provide even starting elevations equal to the control elevation of the structure.

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Section 3

Model Application and Stormwater Management Analyses

3.1 Introduction

This Section describes the specific techniques, parameters, and logic used for the verification and application of the developed stormwater models which are being implemented in the analysis phase of the work and focuses on analyzing existing conditions (EC) and determining the current level of service (LOS) being provided by the City's stormwater management system

3.1.1 Background Information

This Section describes the approach taken to apply the H&H models to develop the existing conditions level of service simulations for all eight basins citywide. The sections herein describe the use of the model for analysis under simulated current conditions (available infrastructure and land use data up to Year 2017) and determination of the current LOS with a detailed description of the components of each of the individual basin models, verification techniques, and performance evaluation of the integrated stormwater management systems.

To support the Citywide planning-level analysis required for the SWMP proposed CIP, the models focus on the identified primary stormwater management system (PSMS) for multiple design rainfall events and various downstream tidal boundary conditions. The PSMS includes constructed stormwater facilities and overland flow paths that flow and outfall to the downstream receiving body. The PSMS is generally defined as the major open channels and pipes of 24-inch diameter and larger, except where the model analysis specifically required more detailed infrastructure to be considered for the analysis.

3.2 Study Area Description

The greater Miami area is located on a broad plain extending from Lake Okeechobee southward to Florida Bay. The City of Miami study area is situated between the Everglades to the west and Biscayne Bay to the east. The average height of the City is approximately 6 feet above sea level in most neighborhoods with the highest points located along the Miami Rock Ridge, which lies under most of the eastern Miami metropolitan area. A densely populated and developed portion of the City is located along the shore of Biscayne Bay and the barrier island of Miami Beach defines the eastern edge of the Bay.

3.2.1 Local Geology, Hydrogeology, and Climatology

The South Florida Greater Miami Area has a unique geology, hydrogeology, and climate due to its geographic location and formation. The main bedrock under the Miami area is known as Miami oolite (which is a porous limestone) formed as the result of the drastic changes in historic sea levels associated with natural periods of glacial activity and ice ages. The bedrock is covered by a thin layer of topsoil generally varying from 12-20 feet thick. Beneath the surface and within the porous limestone is the groundwater layer known as the Biscayne Aquifer, a natural underground source of fresh water that extends from southern Palm Beach County to Florida Bay, which is currently the Miami metropolitan area's primary source of drinking water. As a result of the shallow aquifer, digging approximately 12 to 20 feet beneath the City will expose the groundwater table, which complicates underground construction often requiring dewatering systems, and restricts direct underground disposal of most wastes. However, the shallowness of this same limestone layer and the favorable hydraulic conductivity properties of the aquifer readily allow designed flow of stormwater into the ground, making exfiltration systems and shallow gravity recharge/drainage wells highly effective in areas where a small driving head elevation is available. Historic applications have termed these drainage wells; however, for this SWMP, the term recharge well is used since stormwater will be treated and recharged in locations to provide aquifer recharge and saltwater intrusion barriers.

The City's near sea-level elevation, close proximity to the both the coast and the warm Gulf Stream current offshore, and its latitudinal position above the Tropic of Cancer, result in its tropical monsoon climate, with a distinct wet season and dry season. The wet season typically begins in June and extends through October. The Miami area typically receives an average of approximately 62 inches of rainfall annually, most of which occurs during the wet season period. During this period, temperatures can typically range from the mid 80 degrees F to the low 90 degrees F, and is accompanied by high humidity from the sea breeze that develops off the Atlantic Ocean, which in conjunction with the heated inland area, fuels regular, strong afternoon convective thunderstorms. Propagating late season cold fronts from the north in the wet season tend to lose their energy as they pass through the region before stalling out in the area and can result in several consecutive days of moist unstable air and precipitation in the region.

Hurricane season officially runs from June 1 through November 30, although hurricanes can develop beyond those dates. Historically, Miami has been hit by 31 hurricanes since the early 1900s. Storm surges that can threaten life and property can occur when water from the ocean is pushed onshore by the force of tropical storm force winds and associated low pressures.

The area experiences various tidal events including King Tides, which are higher-than-normal tides that occur annually and predictably in September through November in Miami, resulting in the phenomenon of "sunny day flooding," where low lying streets or other areas temporarily flood from seawater as it rises and breaches low coastal barriers and seawalls, and/or backs up through the stormwater system pipes from the tidal outfalls. King Tides are caused by the alignment of the sun and the moon and their proximity to Earth where the combined gravitational pull causes unusually high-water levels. This can be exacerbated by coincidental, strong easterly coastal sea breezes that may accompany the high tide at certain times of the year, pushing water inland in the waterway channels.

Climate change may also be a major factor for the City as it is facing suspected climate-related increasing rates of sea level rise. Greater storm surge impacts, coastal erosion, deeper and more frequent tidal flooding, saltwater intrusion, and associated rising water surface elevations in the Biscayne Aquifer that will reduce the effectiveness of some of the stormwater exfiltration systems (one of the primary best management practices [BMPs] for stormwater collection, treatment, storage, conveyance, and beneficial disposal in this region), rendering the systems less effective in the future.

3.2.2 Study Area Topography

Miami-Dade County is located in a unique geographical area and is particularly susceptible to flooding from major rain events and storm surge, as it is surrounded by major water bodies - the Atlantic Ocean/Biscayne Bay, and many rivers, lakes, and controlled drainage canals. Therefore, major rain events sometimes leave rainwater nowhere to naturally drain, resulting in flooding in many areas of the City.

SFWMD operates and maintains the regional southern peninsular water management system consisting of levees, berms, canals, and large spillways, gates, and pump stations with the intent of protecting south Florida's residents and businesses from both flood and drought, and moving water to meet varying conditions and needs is essential to sustaining South Florida's people, economy, and environment. This primary system of canals and natural waterways connects to community drainage districts and smaller neighborhood systems, which together must manage floodwaters during heavy rains. As a result of this interconnected stormwater management system, flood control in South Florida is a shared responsibility between SFWMD, County and City governments, Florida Department of Transportation (FDOT), local drainage districts, and on a neighborhood level by developers, homeowners' associations, and residents.

Figure 3-1 shows the major canals that are within the study area:

1. Tamiami Canal (SFWMD S-25B Control Structure and Back Pump Station)
2. Comfort Canal (SFWMD S-25/S-25A Control Structure)
3. Little River Canal (SFWMD S-27 Structure)
4. Miami River
5. Lawrence Waterway
6. Wagner Creek
7. Seybold Canal

Figure 3-2 shows the topographic map of the study area from the Light Detection and Ranging (LiDAR) digital elevation model (DEM) imagery, using 1-foot contours at a 0.3-foot vertical accuracy, and a 2-½-foot pixel resolution that was used for the SWMP analysis. Of particular note are the many former wetland sloughs or areas defining the floodplain banks of creek beds and where rivers once naturally flowed prior to development, which are seen as the low, meandering areas upstream of the canals and rivers. As shown, elevations range from less than 1 ft North American Vertical Datum 1988 (NAVD 88) to just over 20 ft NAVD 88 on coastal ridges.

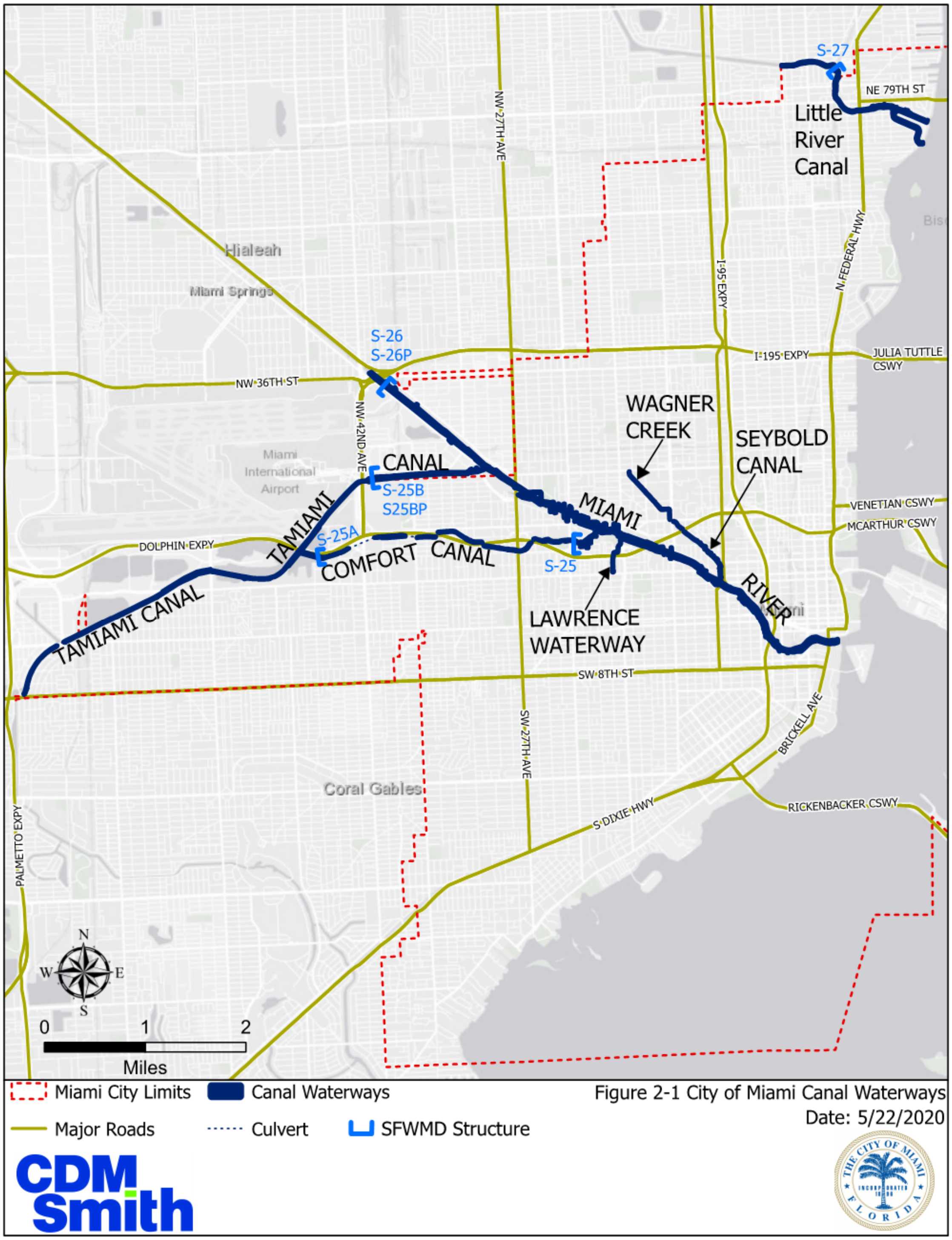
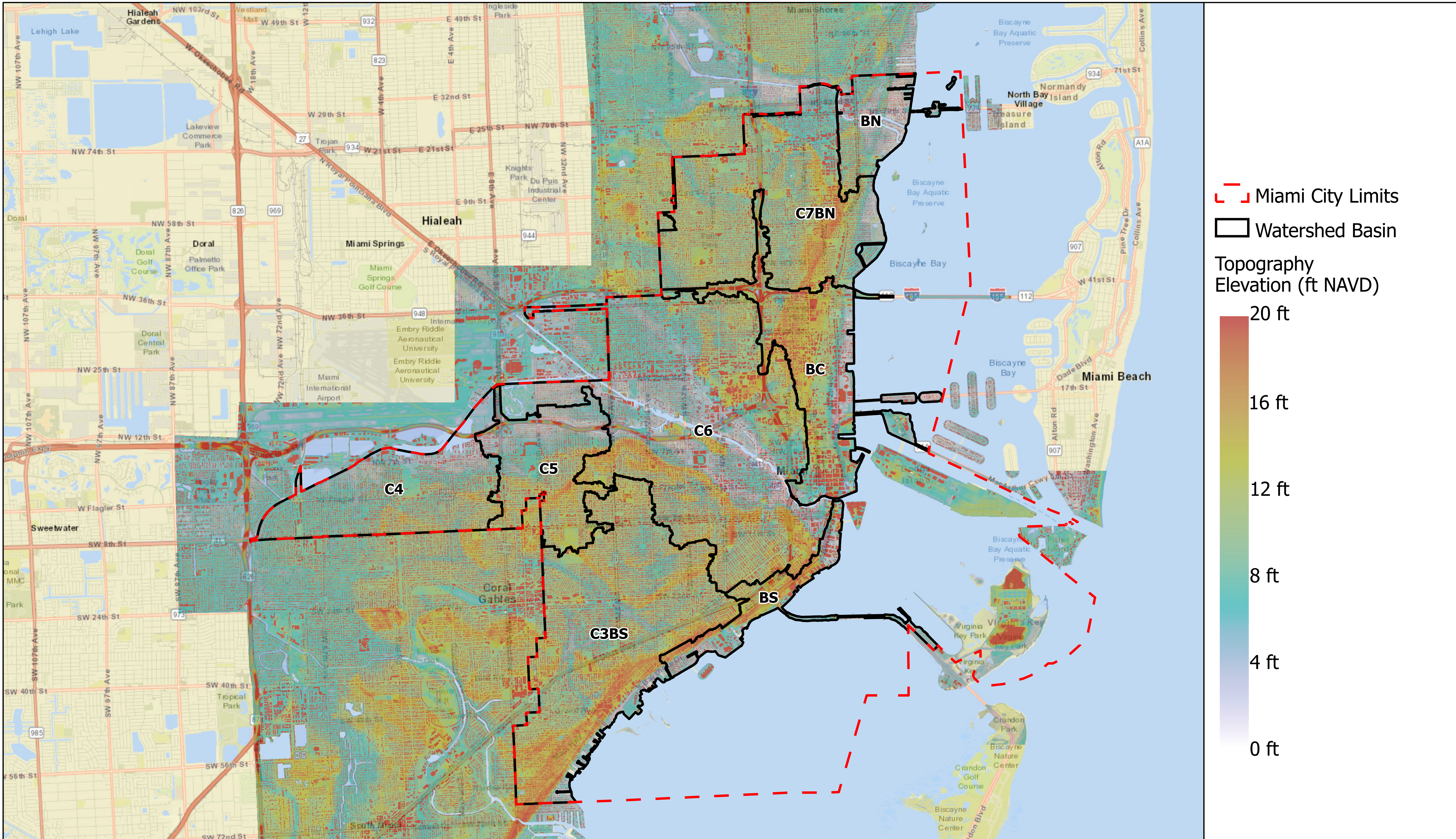


Figure 3-1
City of Miami Major Canal Waterways



CDM Smith

Study Area Topography (LiDAR Imagery)

Date: 3/25/2021

Figure 3-2

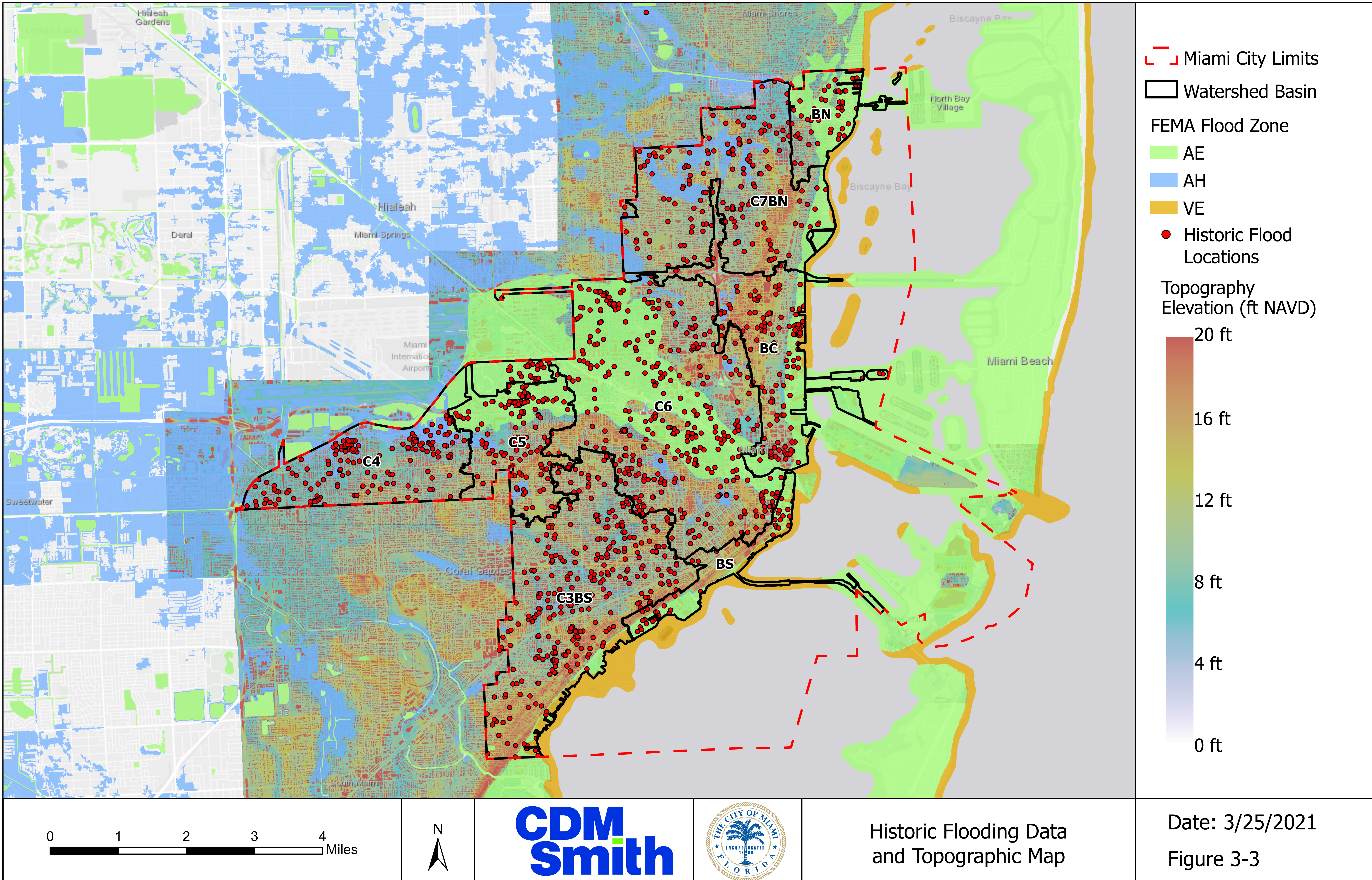
This flat local topography of the City makes it not only more susceptible to flooding, but, as a large portion of the study area is less than 5 or 6 feet above sea level, and the highest natural elevation is the limestone ridge (Miami Rock Ridge) that runs from Palm Beach to just south of the City and it averages only approximately 12 feet above sea level, small increases in sea-level rise above the land surface can begin to inundate significant areas of the City, if appropriate counter measures are not implemented in the near future. Of particular note is the fact that although approximately 90 percent (%) of the City's stormwater inlets on the main PSMS trunks are between 3 and 15-ft NAVD 88, over 1,600 inlets (7.3%) are located where the LiDAR indicates elevations are below 3 ft-NAVD 88, and the secondary system inlets, which are not included in this analysis, increase that percentage of low-lying infrastructure greatly.

Because several areas of the City of Miami are lower than the immediately adjacent surrounding areas, the overland storm runoff flow from off-site areas into the City exacerbates flooding problems with the City and complicates the City's ultimate goal of achieving its desired LOS—as stages are lowered by system improvements within the City, more flow can tend to enter from off-site, and since historic flows must be maintained and accounted for in the design of any stormwater improvements project to be permittable, many of Miami's proposed capital improvements must be "upsized" to handle not only the portion of the runoff contributed by the City, but the historic off-site flows into the City from off-site as well. This situation poses unique legal challenges and ultimately requires joint project agreements between many entities and further detailed study for equability and cost sharing, and parallel project coordination with Miami-Dade County, FDOT, and others. Additionally, if sea levels continue to rise over time as projected, the water surface in the underground aquifer will continue rise as well, and eventually, the exfiltration trenches and gravity recharge well components of the stormwater management system, which are the City's most cost effective stormwater management features, will begin to lose their effectiveness, worsening the flooding over time, and requiring larger-scale, regional solutions, such as floodwalls, large back- pump stations, navigable locks, dedicated storage and water conservation lands, and buyouts in low lying areas.

3.2.3 Identification of Historic Problem Areas Citywide

Known historic flooding documentation citywide was obtained from repetitive loss areas based on the FEMA database, Miami Dade County maintains a 311 database of complaints, and the six interactive community workshops to discuss flooding and the stormwater master plan, one in each commission district, during May and June 2019, and other publicly available storm documentation. A digital map layer was created in the Geographical Information System (GIS) for this study by adding the loss data, flooding data points were added from the Miami-Dade County 311 Contact Center flood complaints data and from the resident flooding complaint data obtained from the series of interactive, Citizen's Community Informational Flooding Workshops conducted citywide in each commission district as part of this project.

Figure 3-3 shows the data plotted over the topographic map, which illustrates the positive correlation between the lowest lying and/or spatially confined areas and the repetitive historic flooding. The map also shows that many of the densely developed areas in the upstream sloughs of the historic natural riverine systems throughout the City continue to be problematic for flooding. Other areas correlate with the lack of positive draining stormwater management infrastructure including areas of over-development without integrating compensation for historic flood plain storage or dedicated water management lands.



CDM Smith

Historic Flooding Data and Topographic Map

Date: 3/25/2021

Figure 3-3

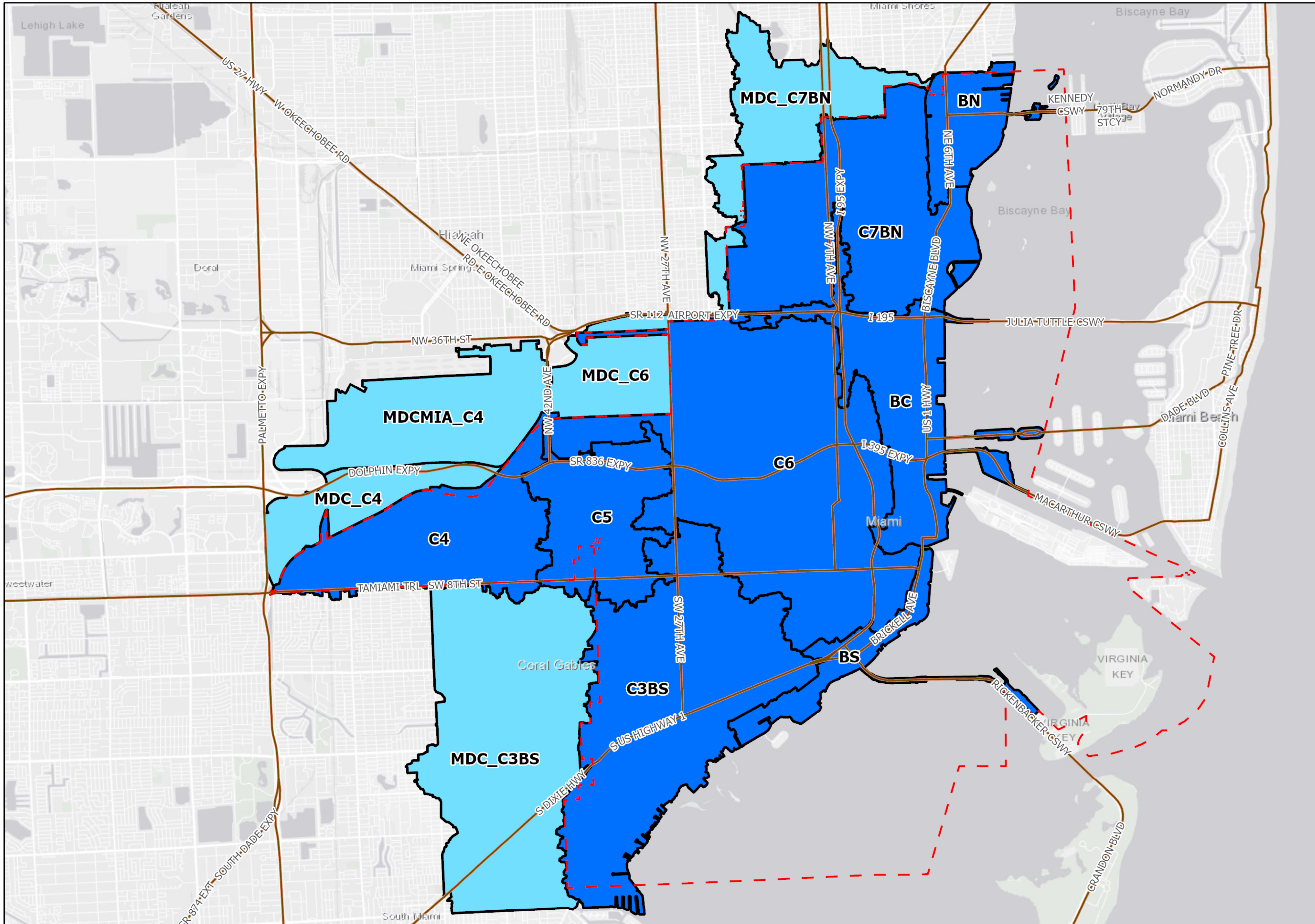
3.3 Stormwater Model Application

The following sections describe how the stormwater models are applied to obtain the baseline results and the framework for documenting the current LOS and serves as the foundation for the water quality analyses and stormwater infrastructure capital improvement planning. The figures presented in this Section are subsets of the City-wide maps of topography, land-use, impervious cover, soils, geotechnical data, and groundwater, which were described in detail in the data development sections of the previously Model Development Sections.

The major drainage basins for the City were defined by both topography and interconnected stormwater infrastructure into the geographic boundaries shown previously on Figure 1-1. As the models were built and the existing conditions (EC) analyses completed, it became apparent that due to the low-lying, flat topography of the City, combined with the intensity of the largest design rainfall events and the associated depths of flooding, overland flow channels between major drainage basins would also be required to account for and capture the runoff between the individual models. Eventually, all eight drainage major basin models were necessarily interconnected, and one large combined overall model created for the analyses of the City as a whole.

For the purposes of the 10-year primary LOS and the relaxed LOS modeling and CIP alternatives on a neighborhood scale, the individual models can still be used effectively. The output results are then confirmed in the combined Citywide model as the CIP alternatives were developed. The boundaries of each major basin model are delineated on **Figure 3-4** and is further described in the sub-sections below. The models were merged into one contiguous model for the CIP and SLR analyses. **Appendix B** provides the 8 model schematics for each major basin. **Appendix C** provides the model input parameters used for each major basin. The locations and names of Critical Structures that were identified Citywide that could be compromised if flooded or access was flooded are provided in **Appendix D**.

The compiled final merged schematic for the Citywide model and the output data from the model for peak stages flows was transmitted separately to the City in GIS format for formal publishing as a single source document for its use and provision to system designers. The information is retrieved by navigating to the desired project area in the on-line GIS map, selecting the existing or future CIP model scenario, selecting the desired design storm, and extracting the design guidance data for the primary stormwater management system stages and flows at the proposed point of attachment to the system.



Miami City Limits

Major Roads

Miami Watershed Basin

BC

BN

BS

C3BS

C4

C5

C6

C7BN

Miami Dade County Watershed Basin (Tributary Area)

MDCMIA_C4

MDC_C3BS

MDC_C4

MDC_C6

MDC_C7BN

0 1 2 3 4 Miles

N

CDM Smith

City of Miami
City Limits and
Major Watersheds

Date: 3/25/2021

Figure 3-4

3.3.1 Biscayne North Basin (BN)

3.3.1.1 BN Basin Description

The Biscayne North (BN) Basin consists of 876 acres of low-lying land that primarily discharges to Biscayne Bay. **Figure 3.3.1-1** includes a delineation of the BN Basin and a simplified representation of the PSMS within the basin. The BN Basin is characterized by PSMS discharge directly to Biscayne Bay south of 87th Street and north of NE 59th Street. The northern boundary is just south of the City's boundary with Miami Dade County. The southern boundary is delineated by NE 64th and NE 59th Streets following topography. The west boundary is delineated by topography and NW 4th Ave. The western and southern boundaries are adjacent to the C7BN Basin. The eastern boundary is Biscayne Bay. This model also includes Pelican Island and Pelican Harbor Marina within the City limits. The basin necessarily includes tributary areas beyond the City boundaries as shown on the figure.

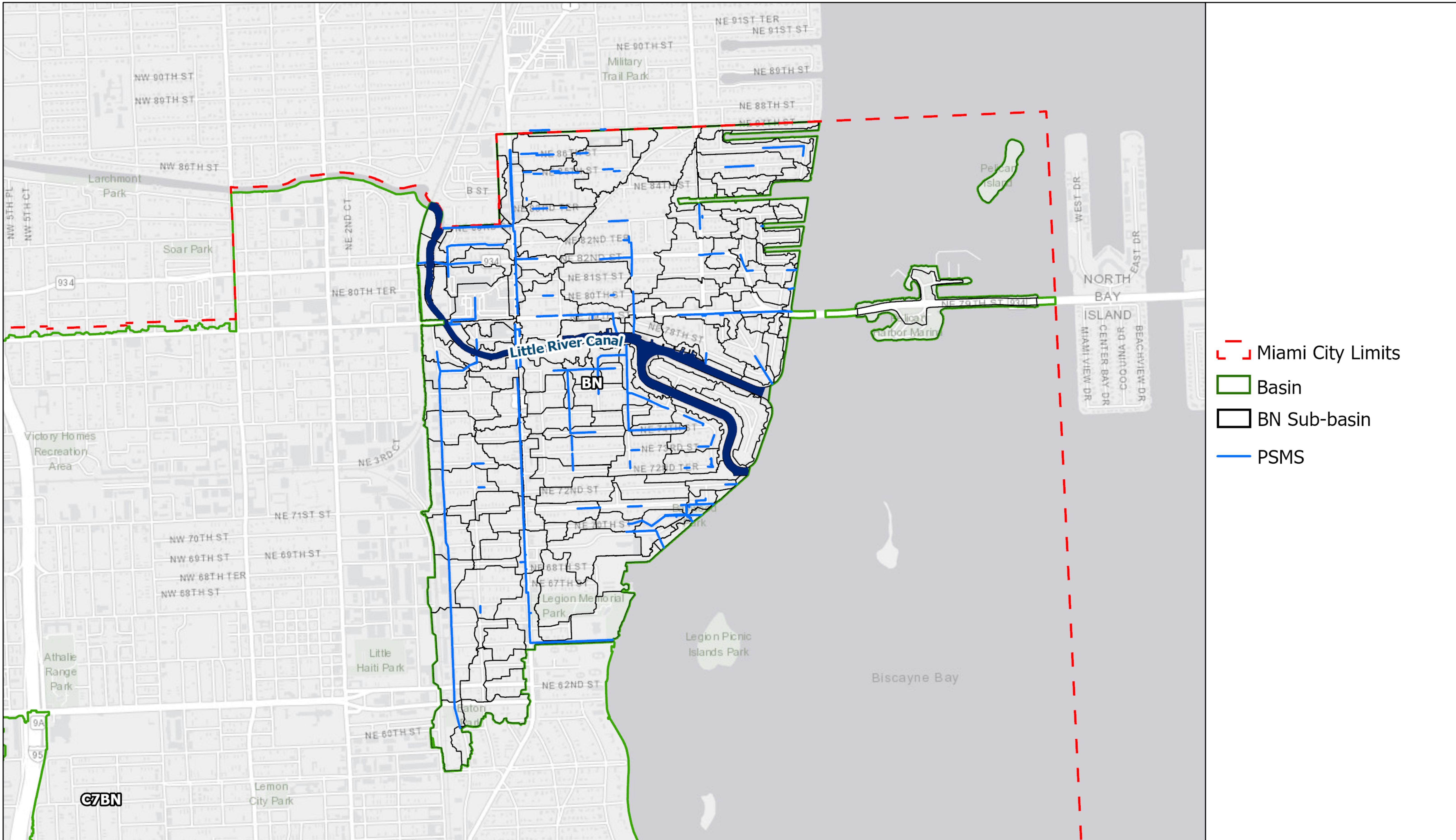
Figure 3.3.1-2 shows the Digital Elevation Model (DEM) for the BN Basin. Topographic elevations range from less than 1-ft NAVD in coastal areas near Biscayne Bay and the Little River (C7 Canal) to approximately 17-ft NAVD 88 along the coastal ridge in the southern corner of the basin. The coastal ridge section that falls within the basin is approximately 900 ft long by 800 ft wide just below NE 62nd Street and has elevations ranging from 11 to 17-ft NAVD 88. Approximately 64% of the BN Basin's stormwater inlets are between 3 and 15-ft NAVD 88; however, over 300 inlets (35.6%) on the PSMS are located where the LiDAR elevations are below 3 ft-NAVD 88. These lower elevations are all near the coast and are susceptible to storm surge and sea level rise. Further, the associated low street elevations preclude using gravity recharge wells or other exfiltration systems, since the driving heads are not sufficient for effective or efficient gravity discharge. Existing exfiltration systems are currently installed in these areas and are not expected to work well, either as simulated in the model or in actual operation.

Figure 3.3.1-3 presents a map of the impervious cover for the BN Basin based on the USGS NLCD coverage as discussed in the model approach memorandum, and **Figure 3.3.1-4** presents a map of the SFWMD land-use for the BN Basin.

As described in detail in the previous Model Development Sections, impervious coverages were intersected with the sub-basin delineations, adjusted using the developed USGS impervious weightings, and a percentage of the total impervious routed to pervious based on land-use parameters.

Figure 3.3.1-5 presents the total impervious percentage in the BN Basin, delineated by sub-basin, after the adjustment for pervious/impervious routing was applied.

CDM Smith



0 0.5 1 Miles

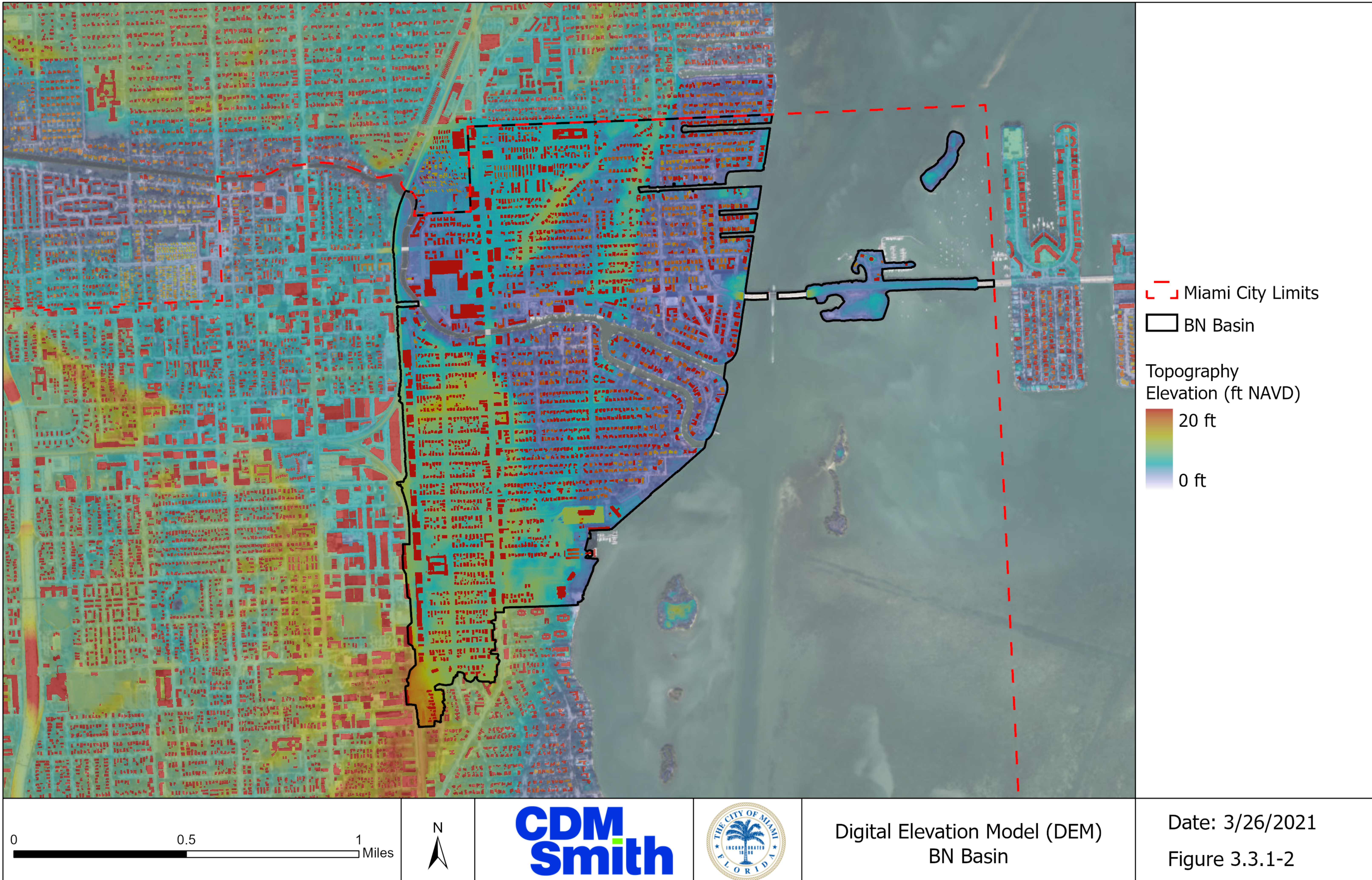
N

CDM Smith

Sub-basin Delineation and PSMS
BN Basin

Date: 3/26/2021

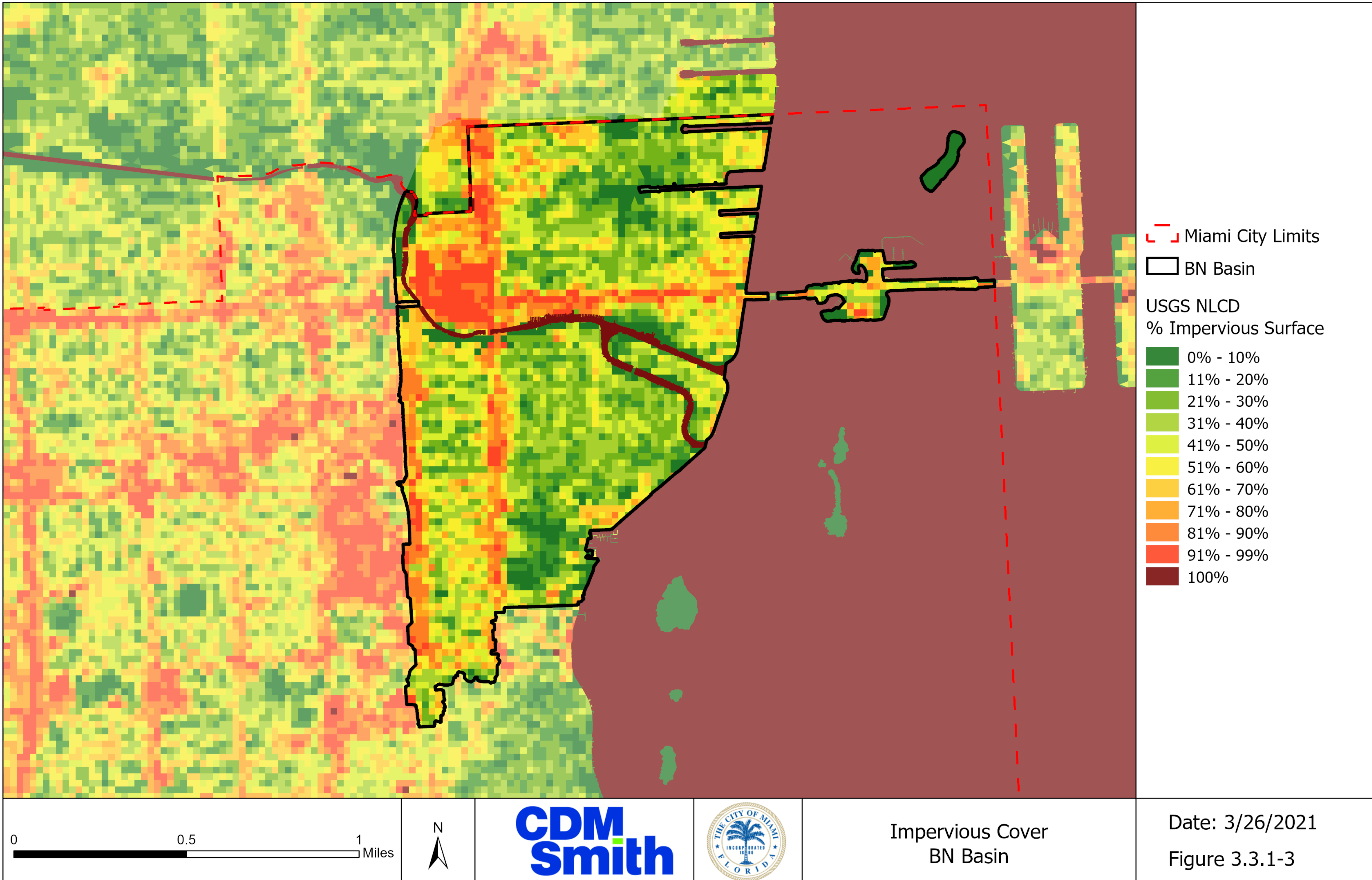
Figure 3.3.1-1



Digital Elevation Model (DEM)
BN Basin

Date: 3/26/2021

Figure 3.3.1-2

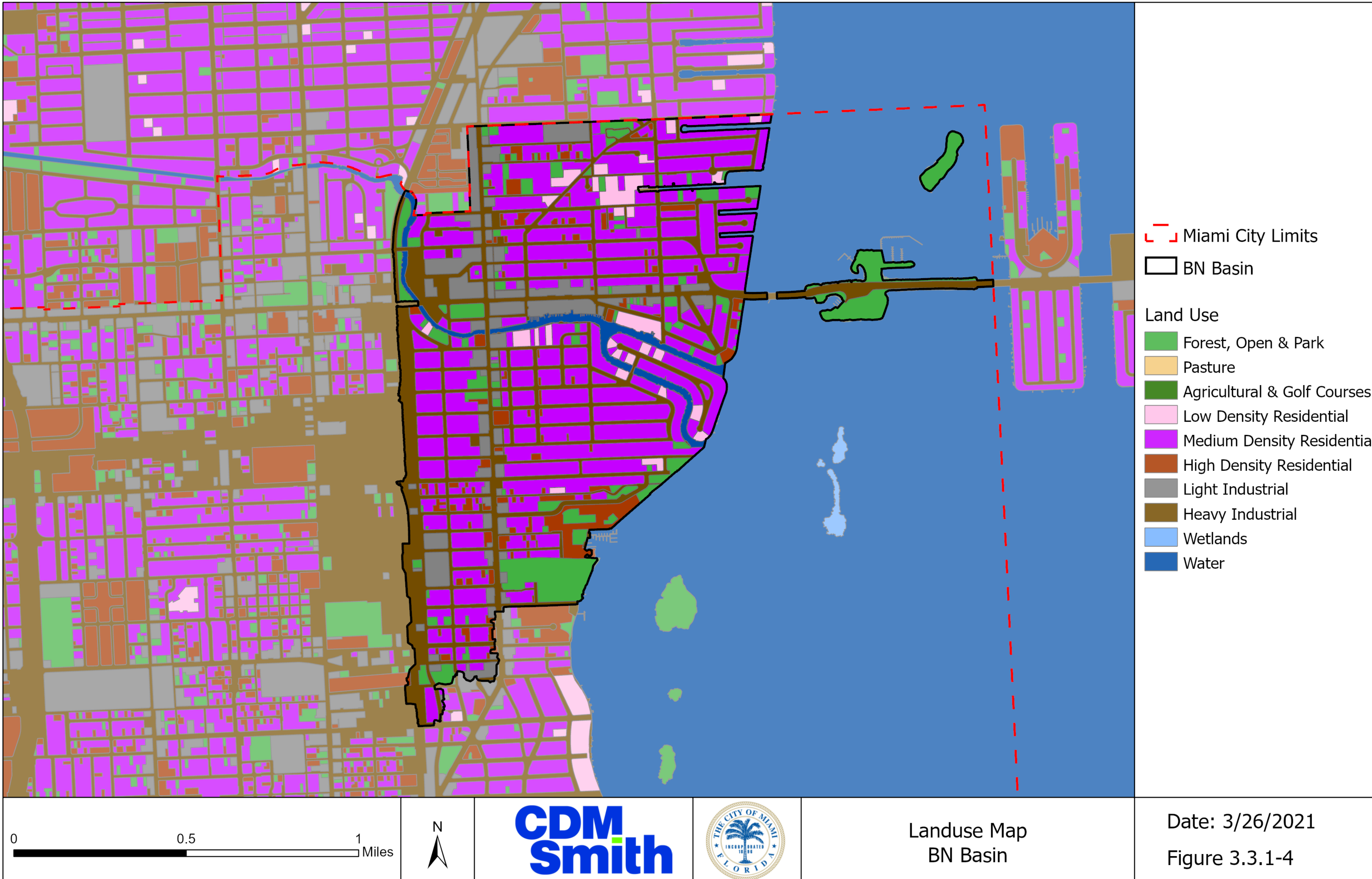


CDM Smith

Impervious Cover
BN Basin

Date: 3/26/2021

Figure 3.3.1-3

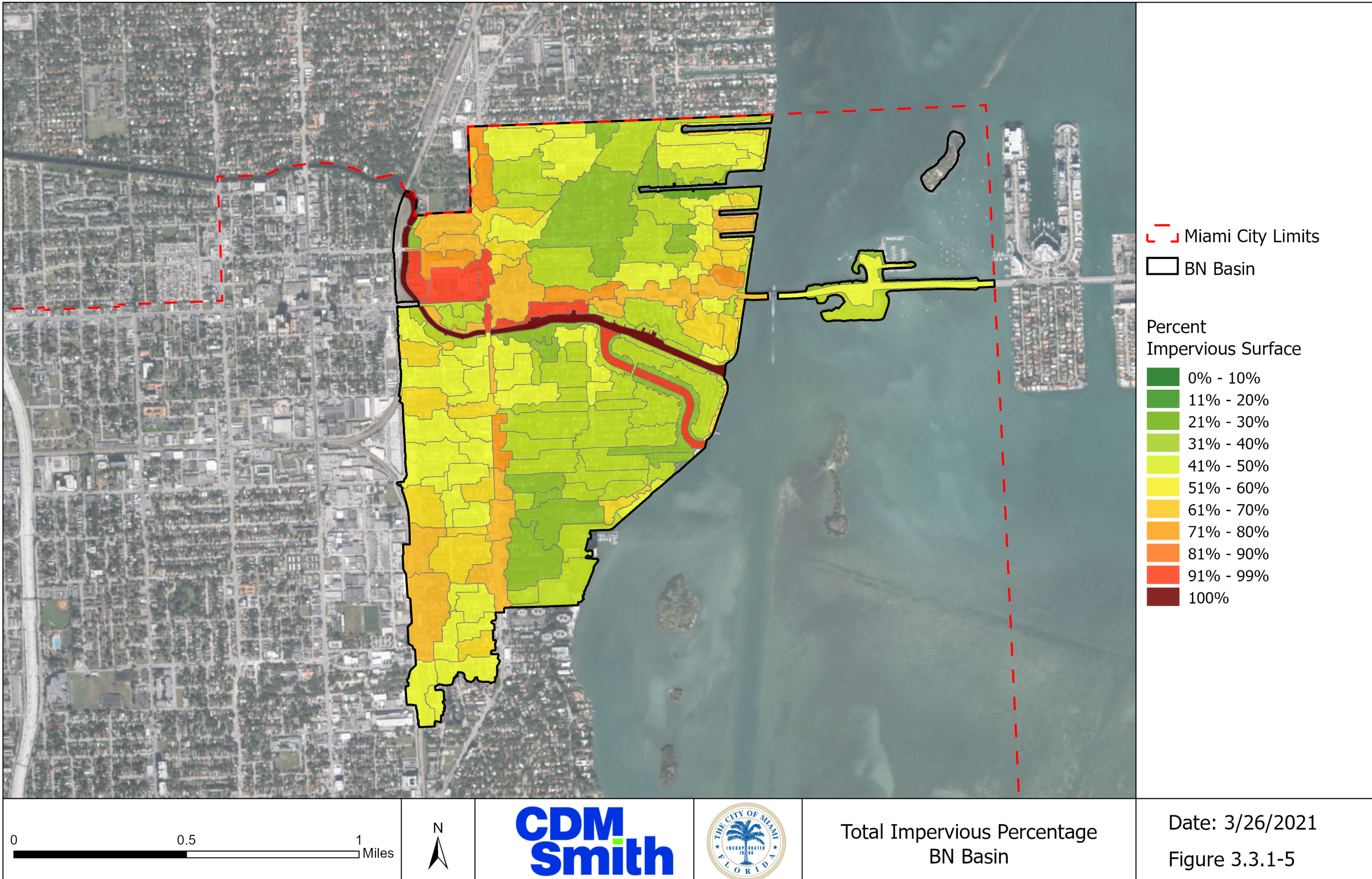


CDM Smith

Landuse Map
BN Basin

Date: 3/26/2021

Figure 3.3.1-4



CDM Smith

Total Impervious Percentage
BN Basin

Date: 3/26/2021

Figure 3.3.1-5

Figure 3.3.1-6 presents a breakdown of the land use by 10 standard consolidated categories, for use in the model. **Figure 3.3.1-7** presents a breakdown of the impervious cover in the model. The area-weighted total impervious percent of the BN Basin is estimated to be 55%; therefore, approximately 482 acres of the 876 acres are expected to be impervious surface. Of this, approximately 113 acres are expected to be routed to pervious surfaces prior to entry into the BN Basin PSMS. The routing of runoff to pervious surfaces does not affect the volume infiltrated to soils but does change the timing of the runoff hydrograph.

For design storm simulations, the SFWMD 24-hour and 72-hour unit hyetographs were used to simulate the rainfall distributions per storm. **Table 3.3.1-1** presents the volumes for the BN Basin for the 5-year, 24-hour; and 10-year, 25-year, and 100-year 72-hour design storms obtained from the NOAA Atlas 14. Design Storm rainfall volumes may be found for select gages in the atlas, or an interpolated volume estimate may be found for point locations. For this basin, point location estimates were made across the basin. In order to be conservative, the highest rainfall depth (volume) was used over the entire basin. In general, the western edge of the basin has slightly higher expected volumes than the coastal edge.

Table 3.3.1-1 Biscayne North Design Storm Volumes and Intensities

Storm	Rainfall Depth (inches)*	Peak 5-min Intensity (inches/hr)
5-year, 24-hour	7.01	5.4
10-year, 72-hour	10.6	6.1
25-year, 72-hour	13.1	7.5
100-year, 72-hour	17.6	10.1

* NOAA Atlas 14 provides 1-day volumes to the hundredths and 3-day volumes to the tenths of an inch

Surface soils in the BN Basin are uniformly described as “urban” with the exceptions of Pelican Island and Pelican Harbor Marina which are described as “group A” in the NRCS soils map included as shown on **Figure 3.3.1-8**. In order to apply the Modified Green-Ampt infiltration method in SWMM, the urban soils needed to be characterized in more detail. The project team performed a limited number of double-ring infiltrometer (DRI) tests in order to determine soil types throughout the project area. Miami-Dade County has performed similar tests. As discussed in the Model Development Sections, the tests indicated Type A (sandy, or well-draining soils) soils at higher elevations, Type D (clay, or poor-draining soils) in low areas, particularly in the Miami River Floodplain, and intermediate soils elsewhere.

CDM Smith

Figure 3.3.1-6 Landuse Category Breakdown for BN Basin

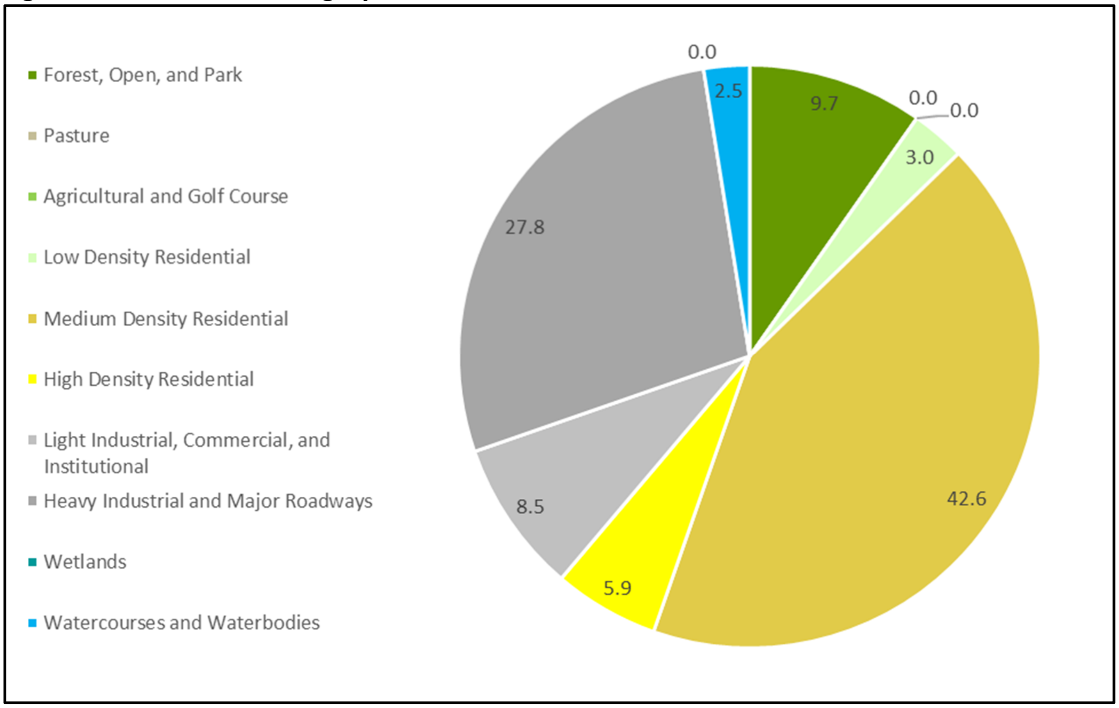
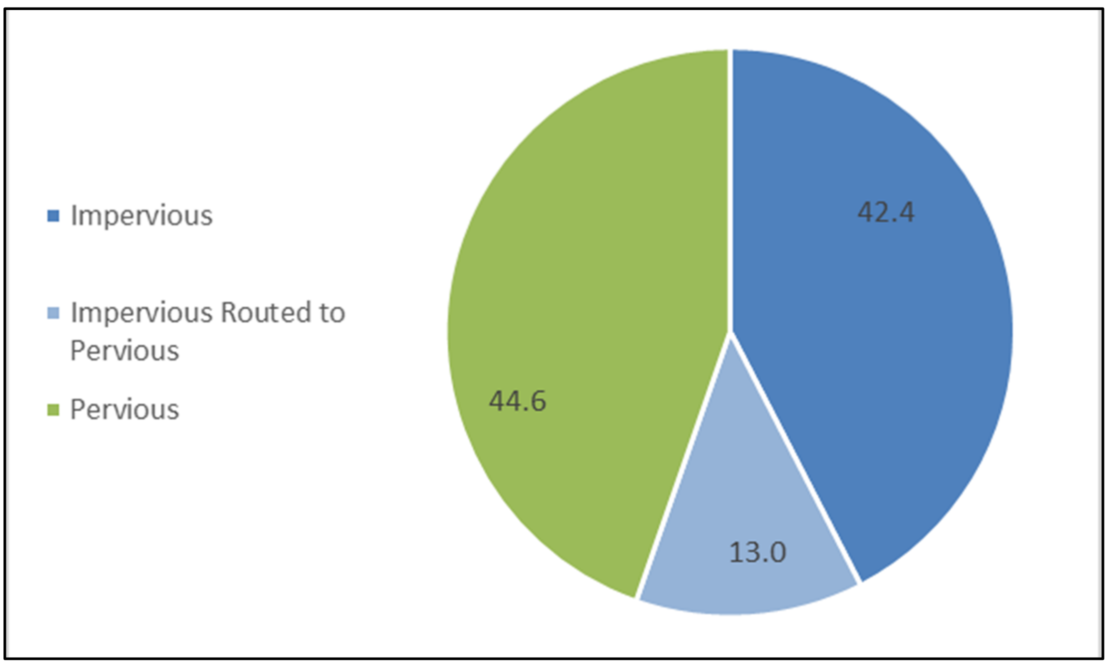
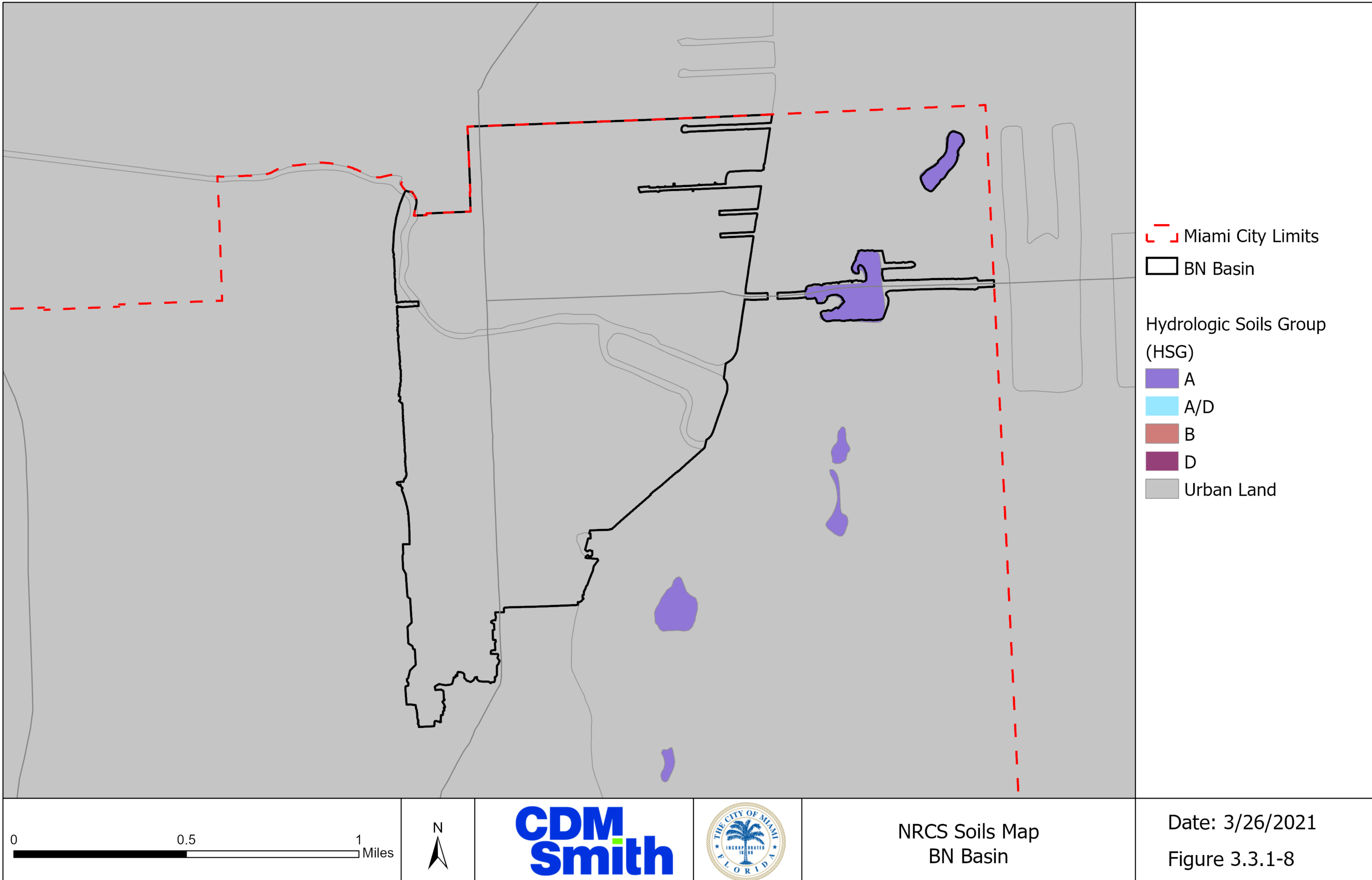


Figure 3.3.1-7 Breakdown of Adjusted impervious Cover for BN Basin





NRCS Soils Map
BN Basin

Date: 3/26/2021

Figure 3.3.1-8

Therefore, the BN Basin model uses Type A soil along the higher coastal Biscayne Area, Type D soils in the low-lying regions within C7 canal floodplain and coastal areas, and Type B (Intermediate) soil in the west region, as shown on **Figure 3.3.1-9**. Note that the rates on Figure 3.1-9, and the model parameter inputs, are Green-Ampt hydraulic conductivities, which do not directly correspond to the measured DRI soils infiltration rates.

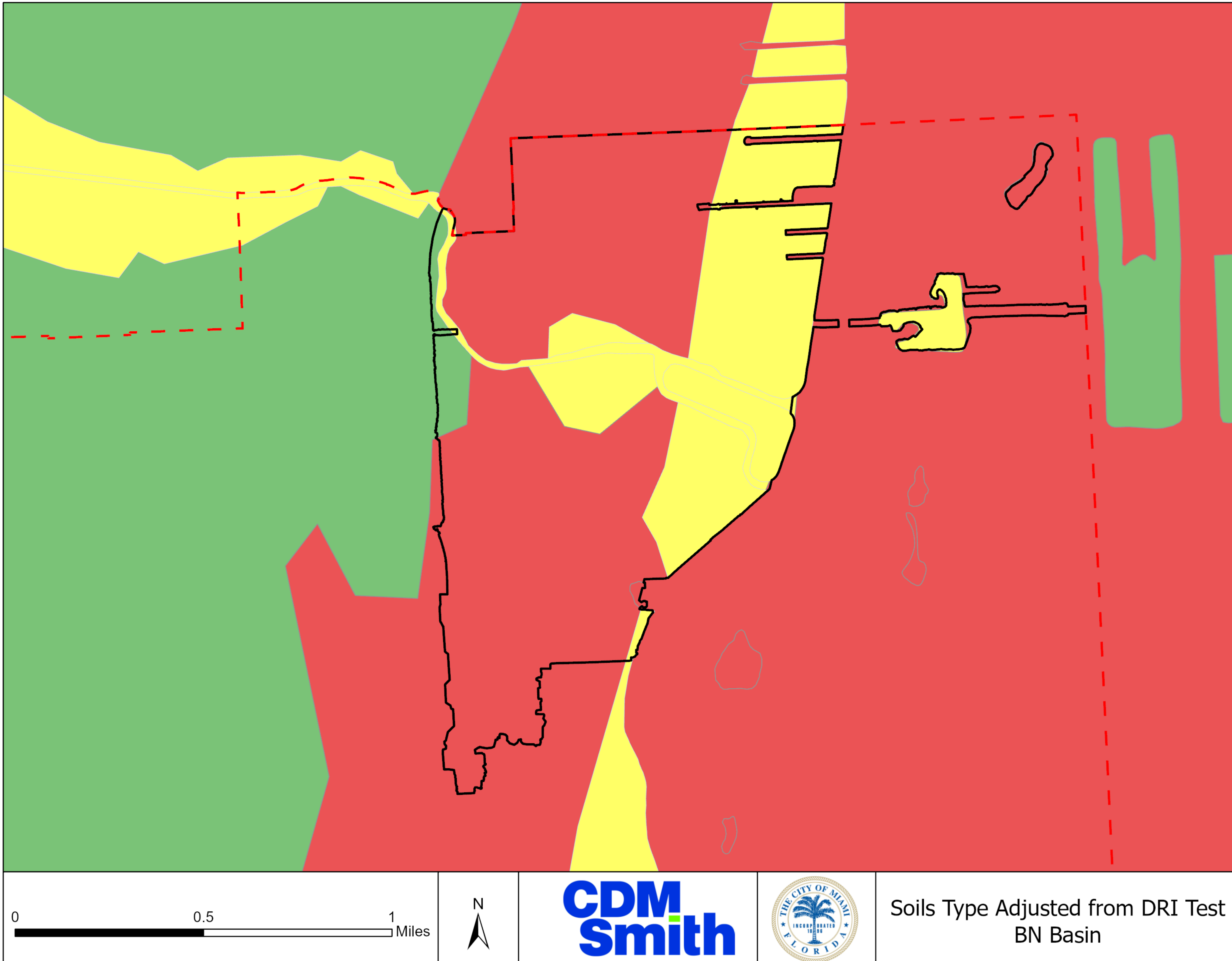
3.3.1.2 BN Hydrologic and Hydraulic Model Elements

The developed H&H models for the BN Basin stormwater management system were used to evaluate the performance of the City's existing stormwater management system and to analyze future capital improvement program (CIP) projects. Model analysis evaluated the PSMS for multiple size rainfall events and downstream tidal boundary conditions. The PSMS includes constructed stormwater facilities and overland flow paths that drain to the downstream waterbody (i.e., boundary condition). The PSMS generally includes open channels and pipes of 24-inch diameter and larger.

The BN Basin modeled area is 876 acres delineated into 171 sub-basins ranging in size from 0.5 acres to 37.0 acres with a mean size of 5.1 acres. Many of the smaller sub-basins delineate the area directly adjacent to the seawalls, which are necessary to model pre- and post-conditions for raised seawalls and backflow prevention but tend to be cut smaller than most of the citywide delineation. The largest sub-basin is in the Northwest Shorecrest neighborhood and is connected to a major depression in the LiDAR DEM. The second largest sub-basin within city limits represents 16.1 acres of an area located in the Palm Grove neighborhood. **Table 3.3.1-2** summarizes the BN model elements.

Table 3.3.1-2 Summary of BN Model Elements

Sub-basins		171
Junctions		11
Storages	Functional	270
	Tabular	167
Outfalls		1
Conduits	Circular	373
	Custom (Bridge)	4
	Ellipse	9
	Rectangular Closed	2
	Irregular Canal	12
	Irregular Outfall	1
	Irregular Overland	278



CDM Smith

Soils Type Adjusted from DRI Test
BN Basin

Date: 3/26/2021

Figure 3.3.1-9

Appendix B includes the BN Basin model schematic (**Figure BN-EC**) with standard symbology and Appendix C includes the detailed tables presenting the BN model element characteristics. These tables include the following:

- **Table BN-1** Hydrologic Parameters per Sub-basin
- **Table BN-2** Hydraulic Nodes Data
- **Table BN-3** Hydraulic Conduit Data
- **Table BN-4** Model Pump Data
- **Table BN-5** Model Weir Data
- **Table BN-6** Model Exfiltration Data

Model nodes representing manholes are modeled as functional storage nodes with a minimal amount of constant storage area (12.56 square feet, which is equivalent to a typical 48-inch diameter manhole). Pump Station wet wells are modeled as functional storage nodes with constant areas equivalent to the wet well area, if the station dimensions were provided, or 100 square feet if the dimensions were not provided.

The BN Basin model has one primary outfall representing Biscayne Bay (BiscayneBayBNC). Multiple pipe and seawall overland flow links have been combined at a virtual node (BiscayneBayN) to provide one link to this outfall because EPA SWMM only allows a single link per outfall. The outfalls have been co-located for ease in changing boundary conditions once the models have been turned over to the City. Additionally, 8 sub-basins, 8 storage nodes, and 8 outfalls were required to be used to simulate the exfiltration systems in the BN Basin. The groundwater table has been divided into 8 contiguous sections in the basin area because the initial level of the base groundwater varies depending on distance from Biscayne Bay and topography. The virtual systems representing groundwater are not included in the model schematic nor in the tables. The BN exfiltration systems are described in further detail in the section below.

The City's project-specific survey and the GIS coverage of stormwater pipes in the BN Basin identifies 25 stormwater points of discharge simulated as outfalls that discharge to Biscayne Bay, and another 13 that discharge to the Little River. There are an additional 21 outfalls representing the sheet flow to Biscayne Bay and another 14 to the River from the sub-basins along the shore. Generally, the overland sheet flow cross-sections represent the seawall surveyed in that area. If a seawall is not present over a portion of the shoreline, 0.0 ft-NAVD 88 is used as the overflow elevation. The topography behind the shoreline determines the opposite side of the seawall edge sub-basin, and the subsequent overland flow elevation to the rest of the neighborhood.

3.3.1.3 BN Pump Stations

In the SWMM, pumps are represented by stage-flow links connected to an inflow storage node that serves as the wet well. The outflow section of the link is connected to a node that serves as a force main to an outfall. The types of pumps represented in this model are in-line pumps where flow increases incrementally with inlet node depth (SWMM Type 2).

There is one existing stormwater pump station (SWPS) in the BN Basin that conveys stormwater flow from the low-lying areas out to the outfall as shown on Figure BN-EC. A wetwell with an underflow weir provides storage and treatment and screening of collected runoff for the station. Pumps are typically set to turn on at levels above the static water table and cycle off as water levels drop in the wetwell. Most pump stations have a control gate to bypass the station when offline for maintenance servicing, and some have an overflow weir to allow flow beyond the pump station capacity to continue out the outfall by gravity.

All pump station information was obtained from City-provided as-builts or other available plan sets.

1. <u>Belle Meade SWPS</u> has a total maximum capacity of 116 cubic feet per second (cfs) or 52,000 gallons per minute (gpm) and is located on NE 8th Avenue immediately south of the Little River (C-7 Canal). This pump station discharges water directly into the Little River via 2 outfalls. For flood modeling purposes, whether the flow leaves the model to the aquifer or the Bay is not relevant to the peak flood levels in the Belle Meade neighborhood, only to the water quality analysis as the wells provide treatment credit and saltwater intrusion mitigation. Accordingly, the pump station links directly to the outfall nodes representing the aquifer and the Bay are not explicitly modeled. For this station, the wetwell is set at -14.4 feet NAVD 88.

    - There are 3 pumps in the station. There are both lead and lag pumps in the Main pump, though in the model, they are combined to one link. There is a separate link for the duty pump.

    - Main pumps cycle on and off at -3.5 ft-NAVD 88 and -5.0 ft-NAVD 88, respectively, with a maximum flow of 96.2 cfs (43,200 gpm).

    - Duty pump cycles on and off at -5.0 ft-NAVD 88 and -6.5 ft-NAVD 88, respectively, with a maximum flow of 19.5 cfs (8,750 gpm).

3.3.1.4 BN Exfiltration

The BN Basin uses exfiltration systems as one of its primary methods to reduce flooding and improve water quality by moving water from the PSMS to the Biscayne Aquifer. These systems include:

- Slab Covered Trenches: Rectangular boxes cut directly into the limestone aquifer, then covered with a concrete slab. There is no slab covered trenches in the BN Basin.

- Exfiltration/French Drains: Perforated pipe situated in a gravel-filled rectangular shaped excavation into the aquifer. There are approximately 4.6 miles of exfiltration/French drains in the BN Basin.

- Recharge/Drainage Wells: There are 32 gravity drainage/recharge wells in the BN Basin. There are two types of recharge wells used in the Miami area - gravity driven wells and injection (pumped) wells. Injection wells are accounted for in the pumped flows to outfall representing the aquifer (see above) and therefore not included in the exfiltration rating curves. Gravity drainage wells use the differential driving head of the land surface water surface elevation and the aquifer ground water table elevation to overcome the well casing friction and any salinity interface density to push stormwater runoff out into the porous and highly transmissive limestone layer underground. The use of Biscayne Aquifer drainage wells is restricted to zones where chloride concentrations exceed the saltwater intrusion front identified as the location at the base of the aquifer of the 1,000 milligrams/per liter (mg/L) isochlor (lines of equal chloride concentrations) and there is no Class G-II (potable ground water source) aquifer impact.

As described earlier, in the BN Basin, the regional water table elevation is estimated for 8 separate regions. Each region has a specified initial water table level based on the Miami-Dade County base groundwater elevation database. Note, these initial levels are higher in the sea level rise scenarios. The regional water tables were designed to automatically rise in the model based on precipitation and infiltration using regional land-use estimates, i.e., the 8 model sub-basins ("GWBN" prefix), 8 storage nodes ("BiscayneAQBC" prefix), and 8 outfalls ("AQLossOut" prefix) are virtual elements designed solely to predict water table elevations and are not hydrologically or hydraulically connected to the model PSMS. The exfiltration rating curves are developed outside the model in a spreadsheet, based on length of system and count of wells per sub-basin, and other sub-basin specific parameters. The curves are head versus flow curves, where the head is internally calculated in the model by subtracting the regional groundwater elevation from the site-specific flood stage. As in actual conditions, in the large design storms, some of the low-lying exfiltration systems cease operations as the water table rises to ground surface. The Model Development TM provides more details on the exfiltration systems and how rating curves were developed for each type per model sub-basin.

3.3.1.5 BN Known Flooding Problem Areas

Known problem areas in BN Basin include the neighborhoods of Belle Meade, Belle Meade West, and Haynesworth around and within the C7 canal floodplain. Coastal neighborhoods that presented indication of flooding by local residents included Palm Bay and Bayside. Shorecrest displayed flooding problems following topography around low-lying areas. **Figure 3.3.1-10** indicates where complaints related to storms and/or flooding were made in the BN Basin.

3.3.1.6 BN Design Storm Simulations

A range of simulations were performed in the BN Basin model covering the multiple design storm intensities and an array of boundary conditions. **Table 3.3.1-3** presents all the simulation scenarios being run for the master plan analysis; only the Base Condition run was performed for this TM.

Design storm distributions were taken from the SFWMD Permit Information Manual, Volume IV. Model simulations are performed for the 5-year, 24-hour design storm; and the 10-year, 25-year, and 100-year, 72-hour design storms. The 24-hour design storm has a peak centered at 12 hours, while the 72-hour design storms have peak intensities at 60 hours. The SFWMD design storm distributions are sampled at 5-minute increments. Design Storm volumes were extracted for localized actual recorded rainfall data from the NOAA Atlas 14, as shown previously in Table 3.1-1. Initial depths for nodes in the model were set to match the boundary conditions to create an even starting surface within all areas of the models including pumped areas.

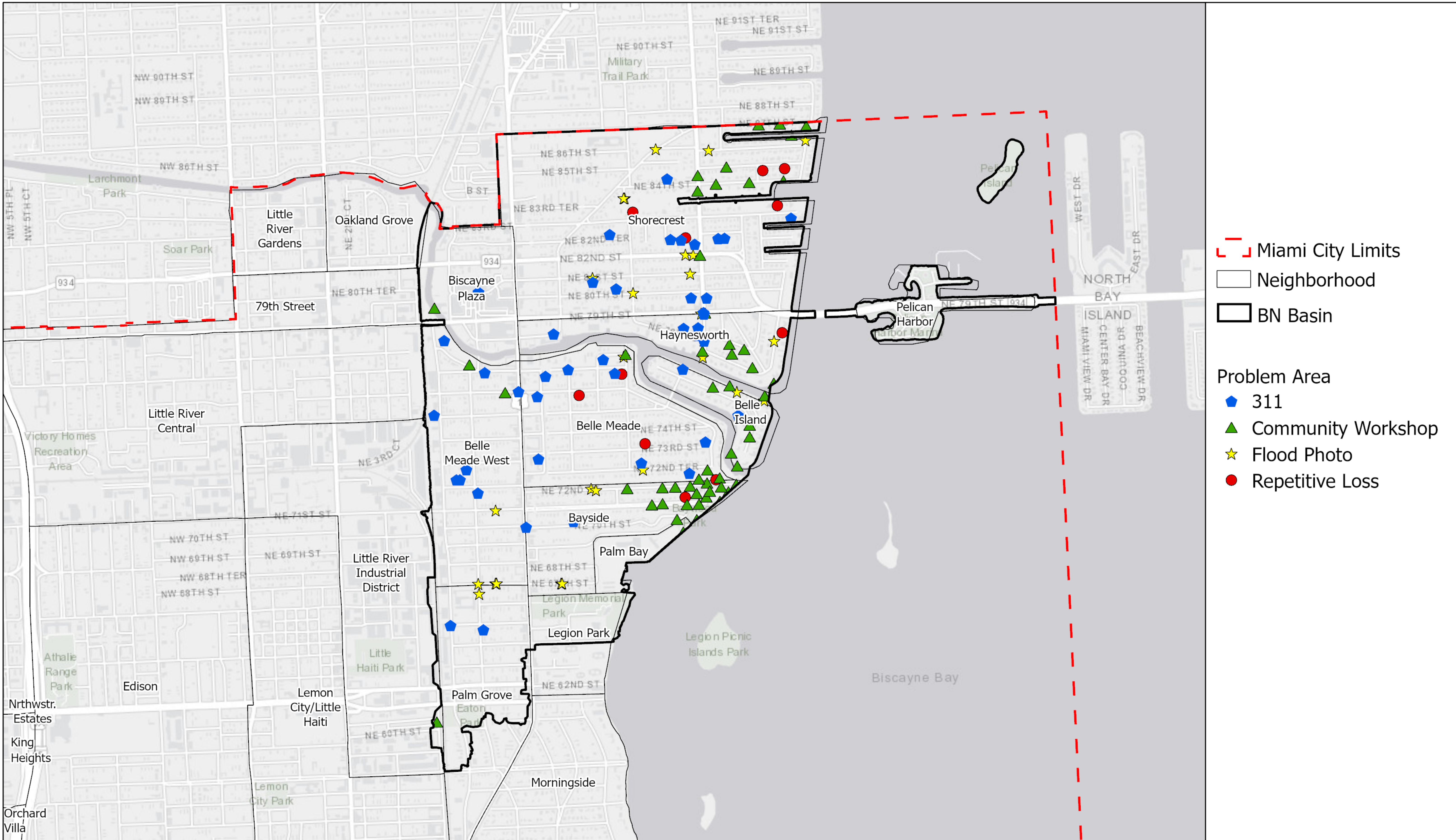
Table 3.3.1-3 Design Storm Simulations

Tailwater Condition	Tailwater Stage in Biscayne Bay (ft-NAVD 88)			
	5-yr, 24-hr	10-yr, 72-hr	25-yr,72-hr	100-yr, 72-hr
Base Condition*	2.0	2.0	2.0	2.0
Base Plus 1.5 feet Sea Level Rise (SLR)	3.5	3.5	3.5	3.5
Base Plus 2.5 feet SLR	4.5	4.5	4.5	4.5
10-year Storm Surge		6.0		

* Base condition represents the one-year stillwater tide elevation – see Model Development TM.

3.3.1.7 BN Existing Conditions (EC) Model Results and Design Storm Inundation Mapping

The verified BN Basin EC model was run for the base simulation for each design storm considering a well maintained, clean pipe condition. A summary of peak flood stages for the simulated EC model is provided in the on-line GIS tables published by the City**.** Flood mapping of the base simulations of existing conditions for the 5-year, 24-hour design storm; and the 10-year, 25-year, and 100-year, 72-hour design storms are presented on **Figures 3.3.1-11 through 3.3.1-14**.



0 0.5 1 Miles

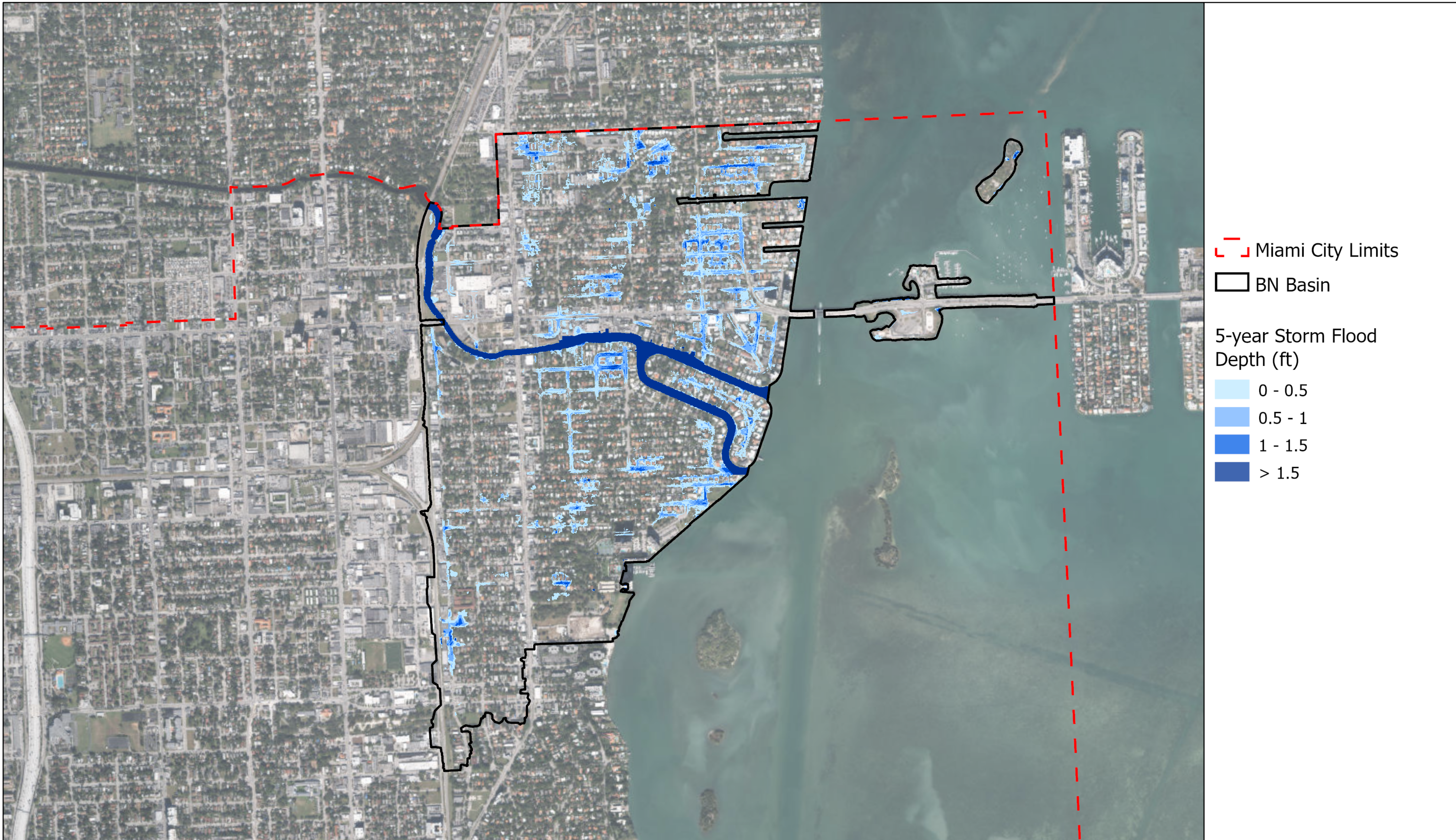
N

CDM Smith

Known Problem Areas
BN Basin (Neighborhoods)

Date: 3/26/2021

Figure 3.3.1-10

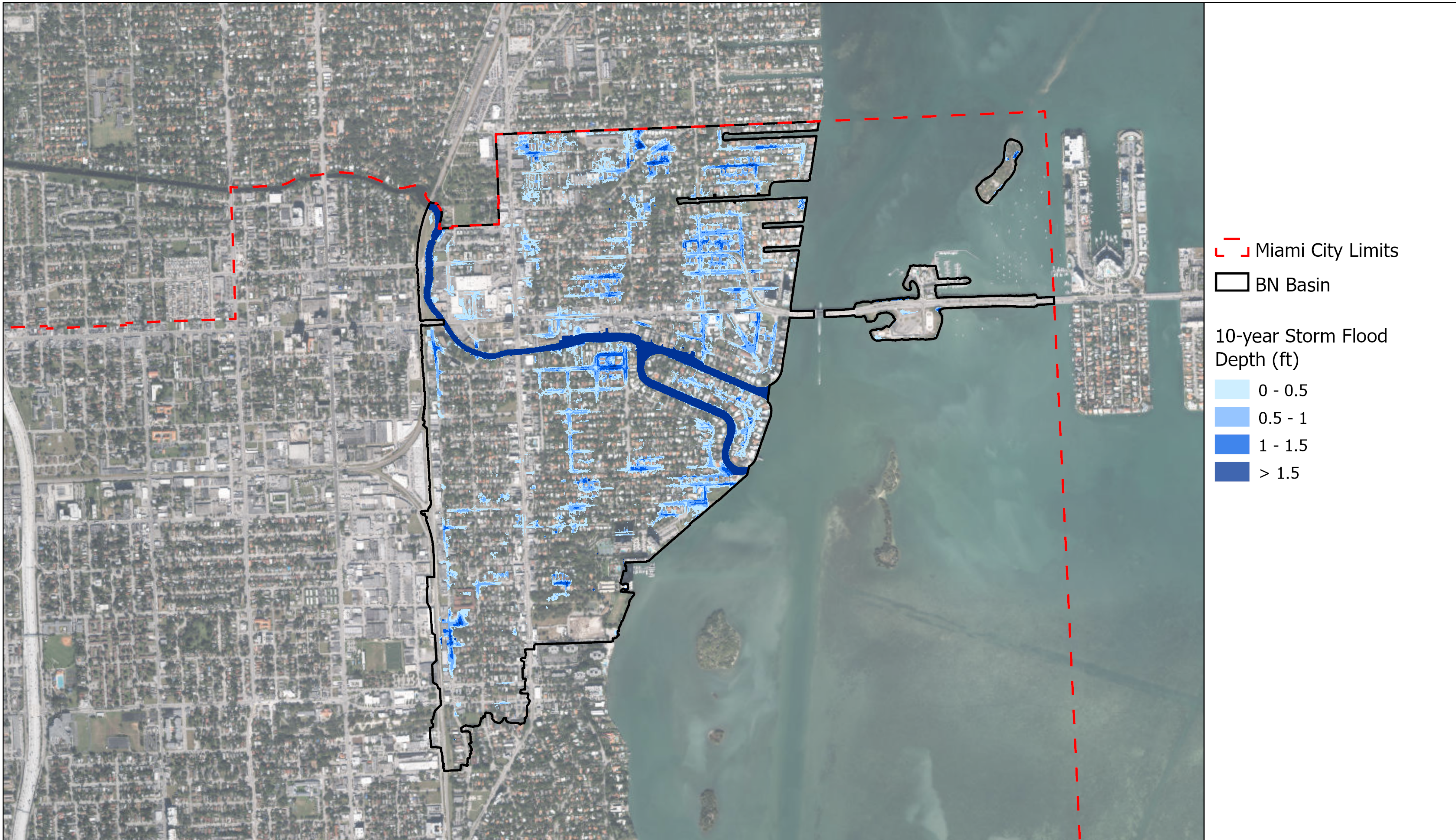


CDM Smith

Flood Map
5 yr/24 hr Design Storm
BN Basin Existing Conditions

Date: 3/26/2021

Figure 3.3.1-11



0 0.5 1 Miles

N

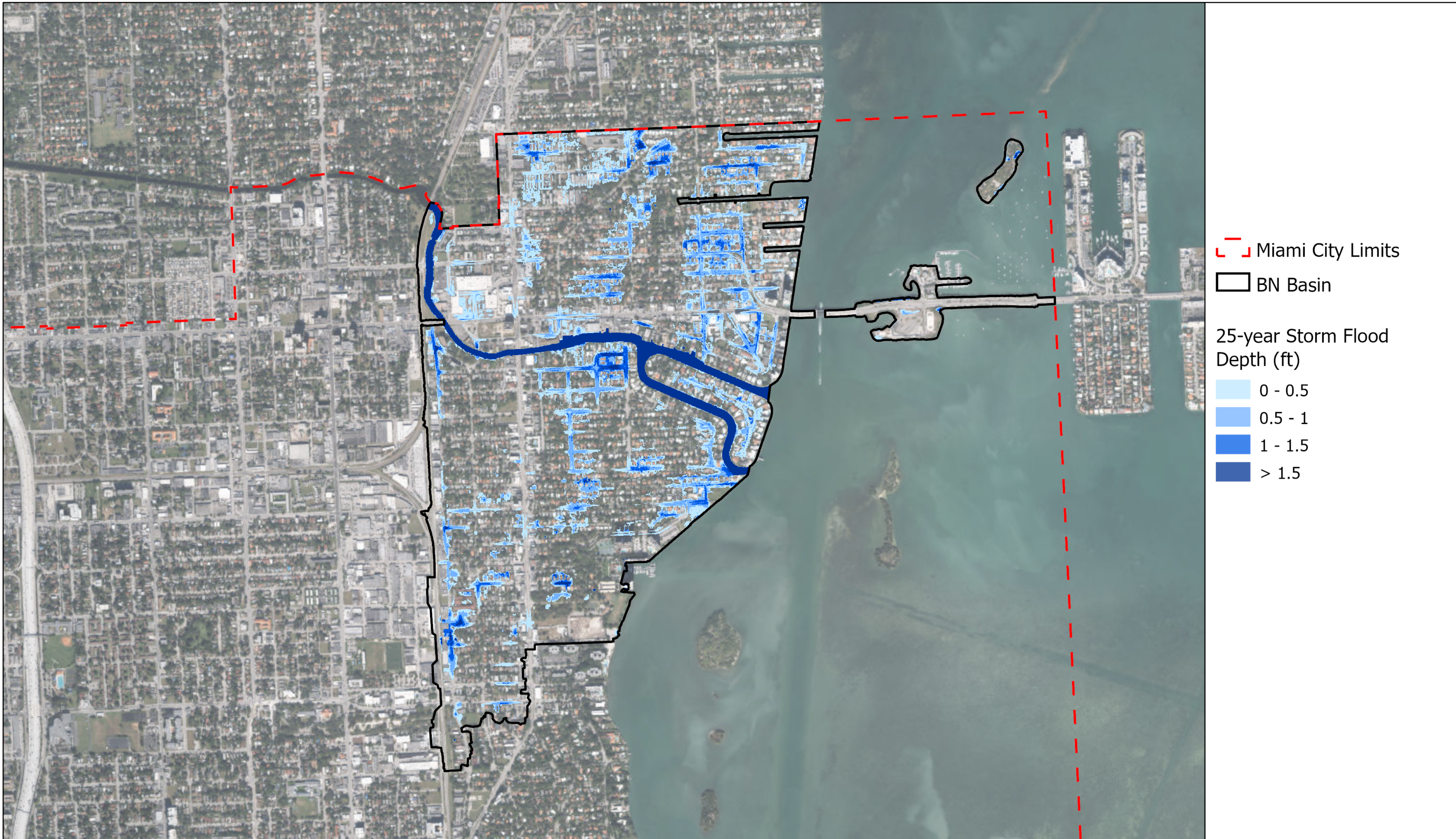
CDM Smith

THE CITY OF MIAMI INCORPORATED 1896 FLORIDA

Flood Map
10 yr/72 hr Design Storm
BN Basin Existing Conditions

Date: 3/26/2021

Figure 3.3.1-12



0 0.5 1 Miles

N

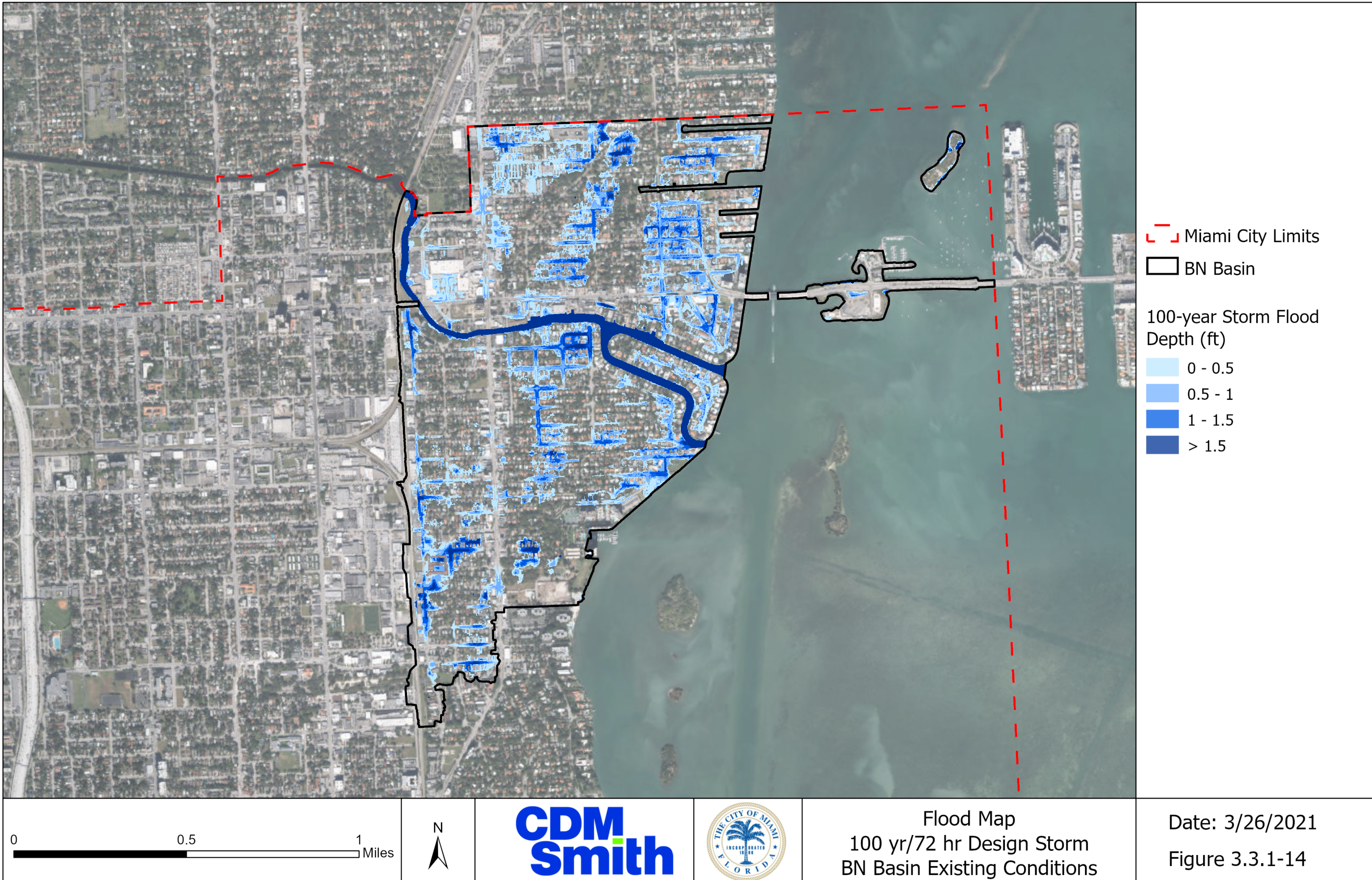
CDM Smith

THE CITY OF MIAMI INCORPORATED 1896 FLORIDA

Flood Map
25 yr/72 hr Design Storm
BN Basin Existing Conditions

Date: 3/26/2021

Figure 3.3.1-13



CDM Smith

Flood Map
100 yr/72 hr Design Storm
BN Basin Existing Conditions

Date: 3/26/2021

Figure 3.3.1-14

3.3.1.8 BN Model Result Summary and EC Level of Service (LOS) Scoring

Peak flood stages were compared to indicator elevations through the basin for the 10-year storm to determine the existing flood LOS for roads, and similar for the 100-year storm to determine the existing LOS for buildings.

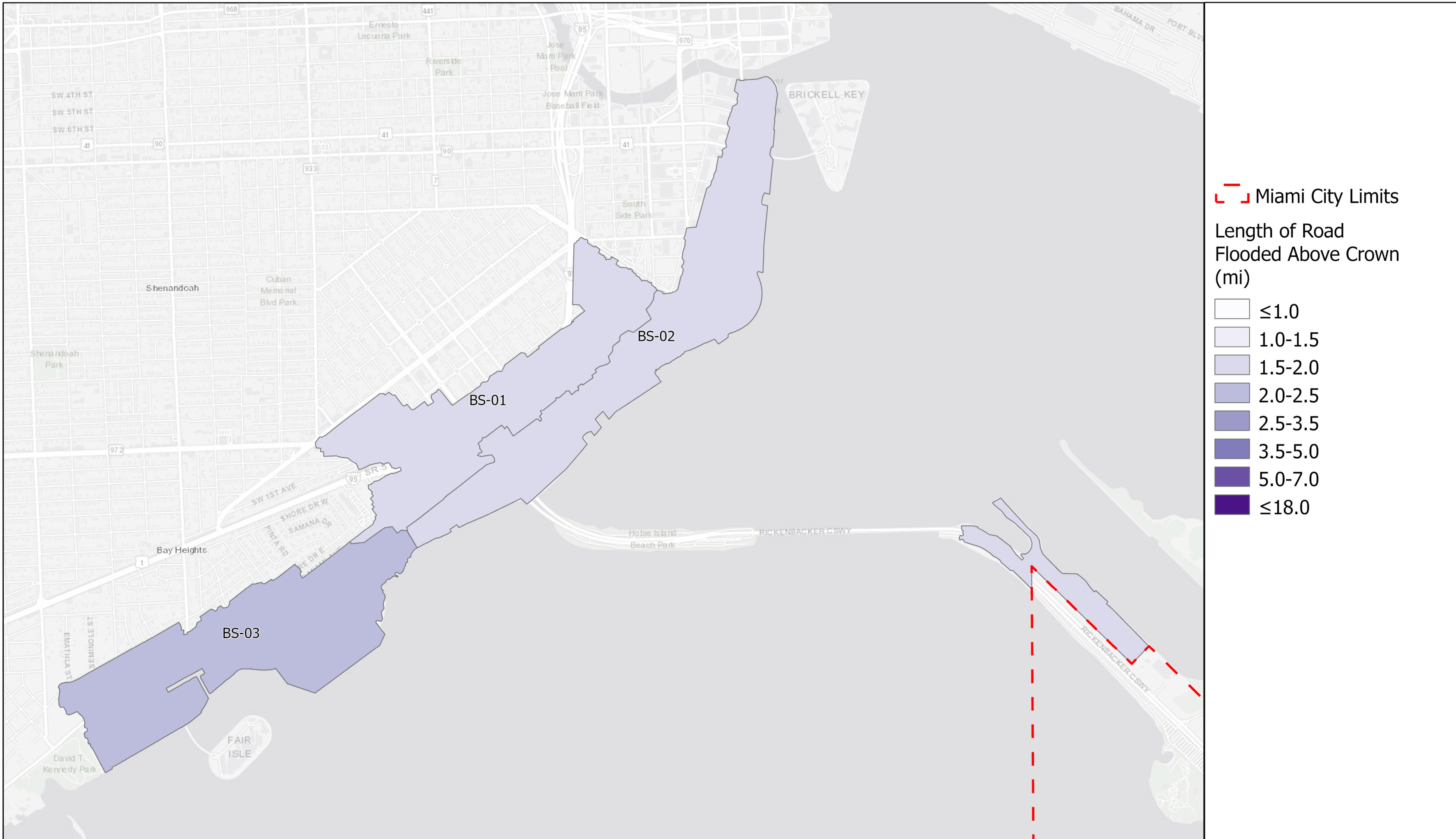
The BN Basin was analyzed and grouped logically into 6 improvement regions (LOS Areas) considering in-common topography and PSMS elements of adjoining neighborhoods. **Table 3.3.1-4** presents the length of road flooded above crown in each region for the 10-year storm, base condition, and the number of buildings expected to flood for the 100-year storm, base condition. Because the verification of each individual First Floor Elevation (FFE) for every building and residence property in Miami is not within of the scope of this project, a standard 1 foot above existing grade has been added to the LiDAR DEM around the periphery of each structure as a reasonable estimate of the minimum building FFEs. Approximately 300 FFEs were field verified in the deepest flooding areas by ground survey and the DEM numbers were adjusted accordingly as necessary. It is noted that Current Florida Building Code requires 1 foot or more above the base flood elevation (BFE) depending on the FIRM flood hazard zone within which the property is located. Future minimum FFEs may be required to include additional height provisions for sea level rise.

The LOS score for each region was determined by the following equation:

$S_{LOS} = C_1 * Len_{10} + C_2 * Bldg_{100} + C_3 * Str_{Crit}$;

Where S_{LOS} is the LOS score, Len_{10} is the length of road flooded above crown for the 10-year storm in linear feet and normalized by population, $Bldg_{100}$ is the number of buildings flooded above the estimated FFE for the 100-year storm, normalized by population, Str_{Crit} is the number of critical structures identified in the region with a flooding issue, and C_1, C_2, and C_3 are coefficients that may be adjusted by the City of Miami to help rank neighborhoods. Higher scores indicate worse predicted current LOS problems. These rankings are for initial evaluation purposes only, as the two proposed LOS alternatives attempt to mitigate all problem areas, not just those in the highest ranked areas.

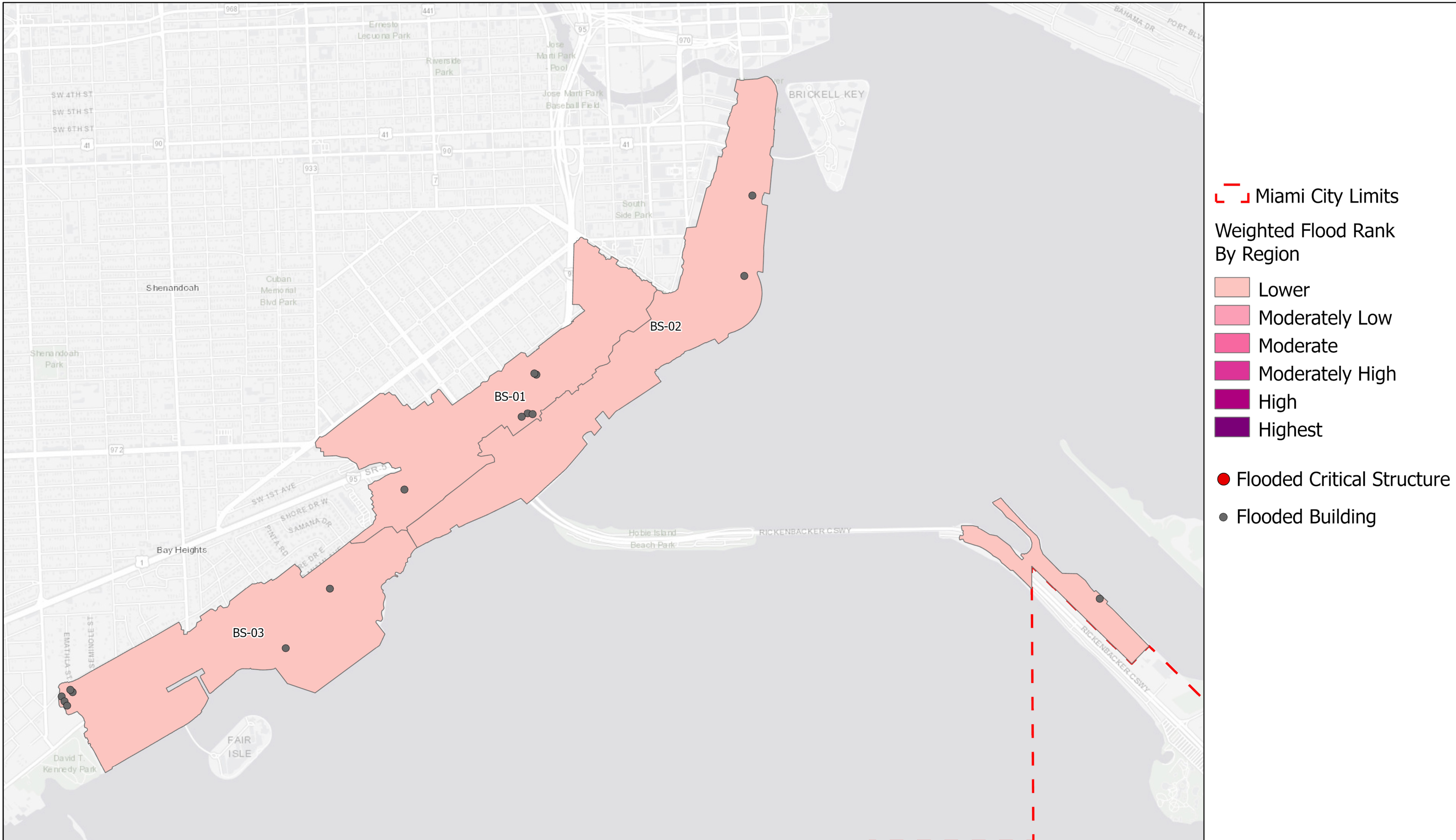
Figures 3.3.1-15 and 3.3.1-16 provide the relative existing conditions predicted LOS flooding of roadways and structures respectively for the BN Basin.



Length of Road Flooded Above Crown by Region 10-year storm BS Basin Existing Conditions

Date: 12/14/2020

Figure 3.3.8-15



0 0.8 1.5 Miles

N

CDM Smith

Number of Buildings & Critical Structures Flooded by Region 100-year storm BS Basin Existing Conditions

Date: 12/14/2020

Figure 3.3.8-16

Table 3.3.1-4 BN Basin Existing LOS Ranking

LOS Region	Primary Neighborhood in LOS Area	All Neighborhoods in LOS Area	Area (acres)	Flooded Area 100yr (acres)	Flooded Area/Total Basin Area	Population (2010)	Length of Street Flooded (mi)	Length of Street Flooded/Total Length of Street Flooded 10yr	Est # of Buildings Flooded (100 yr)	# of Buildings Flooded/Total # of Buildings Flooded (100 yr)	# of Critical Structures Flooded (100 yr)	# of Critical Structures Flooded/Total # of Critical Structues Flooded (100 yr)	Basin Relative Flood Ranking
								1		1		1	
BN-01	Northwest Shorecrest	Shorecrest, Oakland Grove, Biscayne Plaza, 79th Street	142.3	76.9	20.03%	1,875	1.49	16.51%	9	30.00%	0	0.05%	0.46561
BN-02	Shorecrest	Shorecrest, Biscayne Plaza, Pelican Harbor, Haynesworth	236.0	116.3	30.28%	2,669	3.30	36.65%	5	16.67%	0	0.05%	0.53367
BN-03	Belle Meade	Biscayne Plaza, Haynesworth, Belle Meade West, Little River Central, Belle Meade, Belle Island, Little River Industrial District, Bayside	172.0	78.7	20.49%	1,639	2.38	26.45%	2	6.67%	0	0.05%	0.33168
BN-04	Belle Meade West	Belle Meade West, Belle Meade, Little River Industrial District, Bayside, Palm Grove	70.5	37.0	9.63%	886	0.48	5.29%	0	0.00%	1	49.90%	0.55194
BN-05	Bayside	Belle Meade West, Belle Meade, Bayside, Palm Bay, Legion Park	95.5	39.5	10.28%	1,337	0.87	9.62%	8	26.67%	0	0.05%	0.36340
BN-06	Palm Grove	Belle Meade West, Little River Industrial District, Bayside, Palm Grove, Legion Park	73.5	35.7	9.29%	1,125	0.49	5.47%	6	20.00%	1	49.90%	0.75369
Totals	6		789.9	383.9	100%	9,531	9.0	100%	30	100%	2	100%	

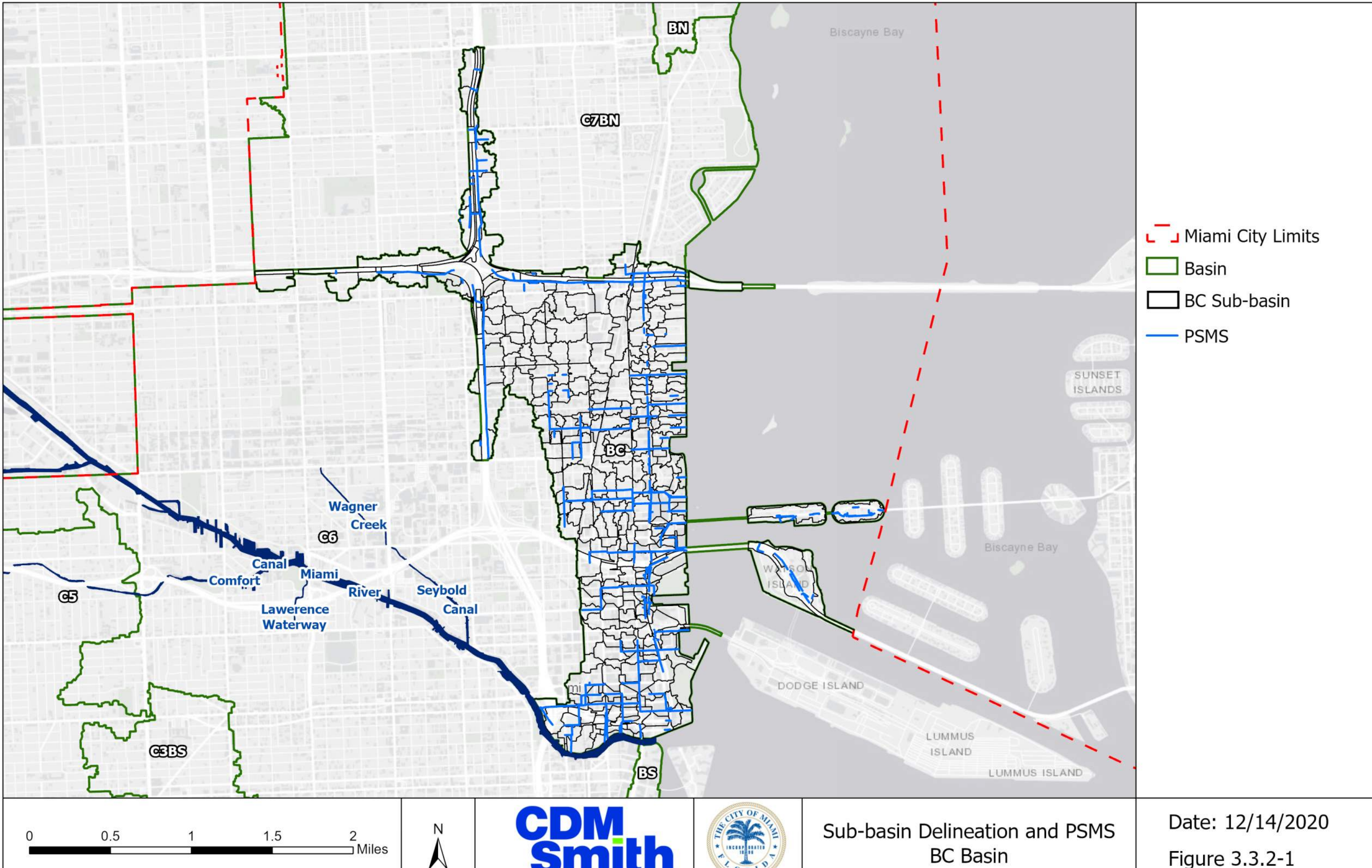
3.3.2 Biscayne Central Basin (BC)

3.3.2.1 BC Basin Description

The Biscayne Central (BC) Basin consists of 2,172 acres of low-lying land areas that primarily discharge to Biscayne Bay. **Figure 3.3.2-1** includes a delineation of the BC Basin and a simplified representation of the PSMS within the basin. The BC Basin is characterized by PSMS drainage directly to Biscayne Bay south of the Julia Tuttle Causeway (I-195) and north of the Miami River (C-6 Canal). Since there is an FDOT stormwater system that drains the large I-95/I-195 interchange pond systems, the FDOT pipes tributary to these ponds, and adjacent areas that share runoff to these systems, are necessarily included in the BC model. Divides in the FDOT system occur near I-95 and NW 62nd Street, at I-95 and NW 20th Street, and at SR-112 and NW 22nd Avenue. This produces the cross-shape of the northwest side of the basin boundary. The northern boundary is adjacent to the C7BN Basin, delineated between areas that flow to the FDOT system versus those that flow to City PSMS north of I-195. The western boundary is adjacent to the C-6 Basin and is delineated by topography and the local PSMS. To the south of the basin, the PSMS interconnects systems that outfall to Biscayne Bay with systems that outfall to the Miami River; therefore, a portion of the BC Basin also drains to the river, downstream of the Flagler Bridge. The eastern boundary is Biscayne Bay. The model also includes the Venetian Causeway islands within City limits and Watson Island.

Figure 3.3.2-2 shows the DEM for the BC Basin. Topographic elevations range from near 0 ft-NAVD in coastal areas near Biscayne Bay and the Miami River to approximately 20 ft-NAVD 88 along the coastal ridge near the center of the basin. In the BC Basin, the coastal ridge is relatively wide, approximately half a mile from Federal Highway to N.W. 2nd Avenue in the north. The ridge tapers off to the south, but in downtown Miami, the ridge elevations range from 9-13 ft-NAVD 88. Approximately 80% of the BC Basin's stormwater inlets are between 3 and 15 feet NAVD 88; however, over 300 inlets (11.8%) are located where the LiDAR elevations are below 3 feet NAVD 88. The lower elevations are all near the coast and are susceptible to storm surge and sea level rise. Further, low street elevations preclude using gravity recharge wells or other exfiltration systems in many areas, since the driving heads are small. Existing exfiltration systems in these areas are not expected to work well.

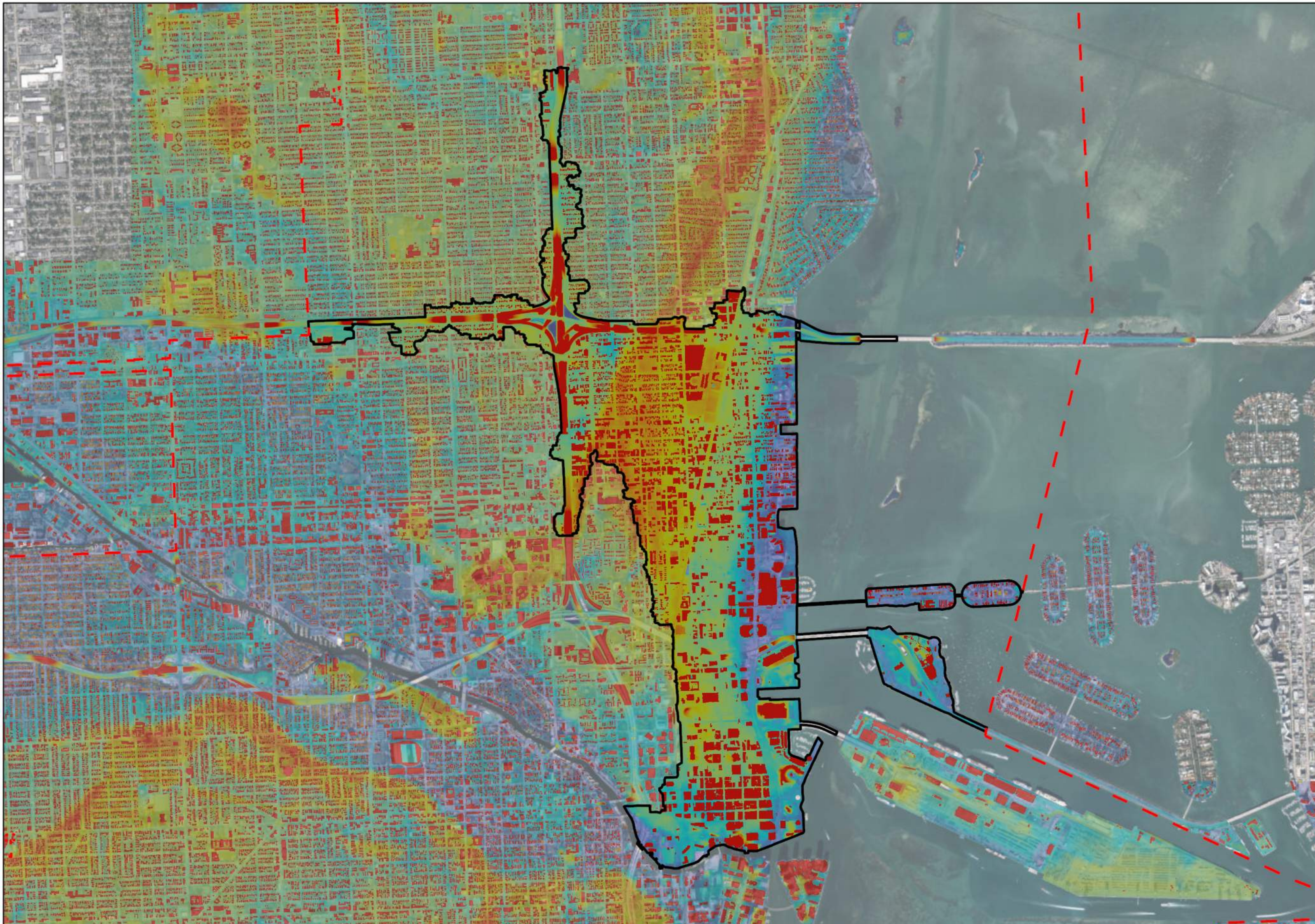
Figure 3.3.2-3 presents a map of the impervious cover for the BC Basin based on the USGS NLCD coverage as discussed in the Model Approach TM and **Figure 3.3.2-4** presents a map of the SFWMD land-use for the BC Basin.



Sub-basin Delineation and PSMS
BC Basin

Date: 12/14/2020

Figure 3.3.2-1



Miami City Limits

BC Basin

Topography
Elevation (ft NAVD)

20 ft

0 ft

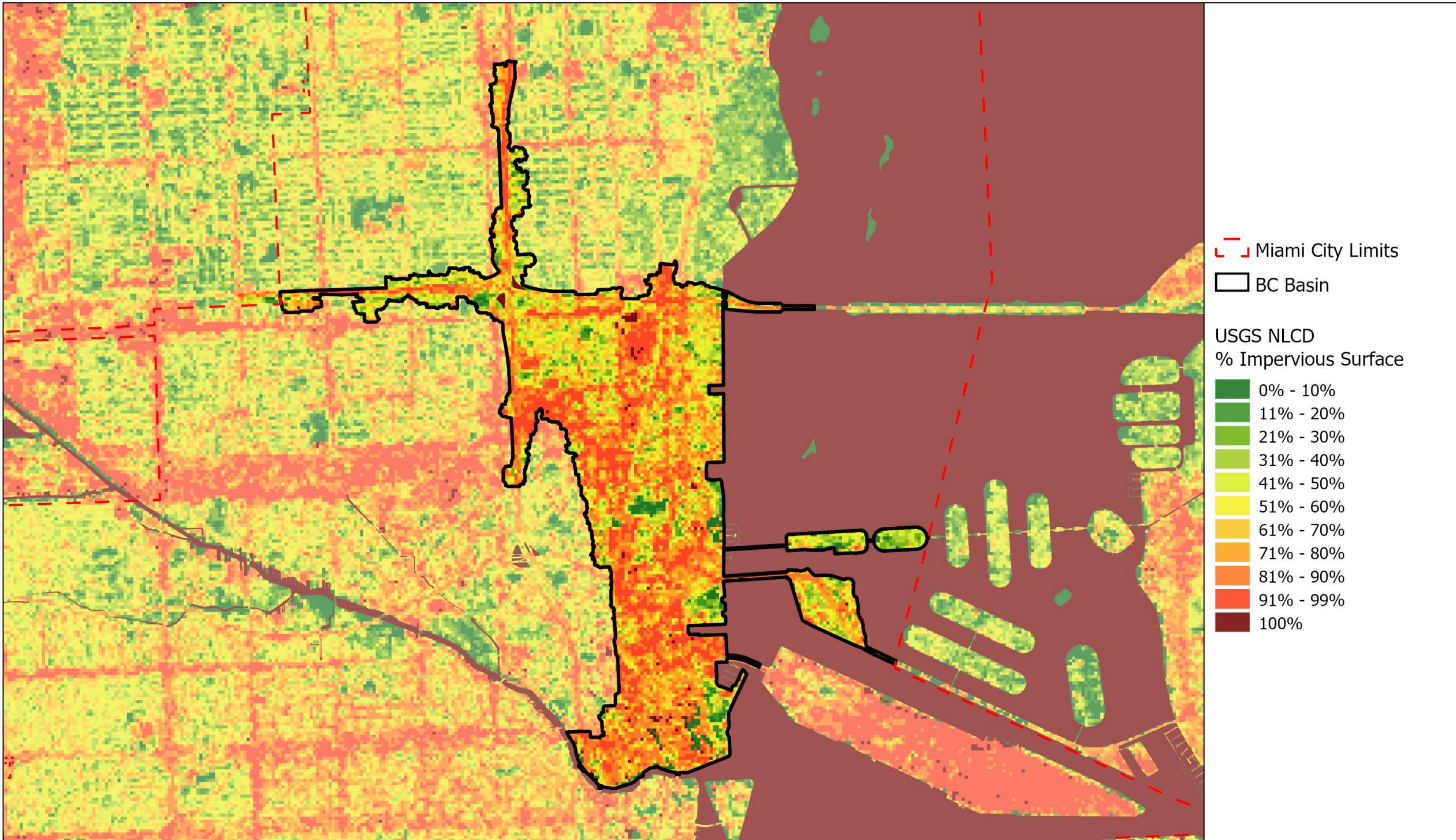
0 0.5 1 1.5 2 Miles

N

Digital Elevation Model (DEM)
BC Basin

Date: 12/14/2020

Figure 3.3.2-2



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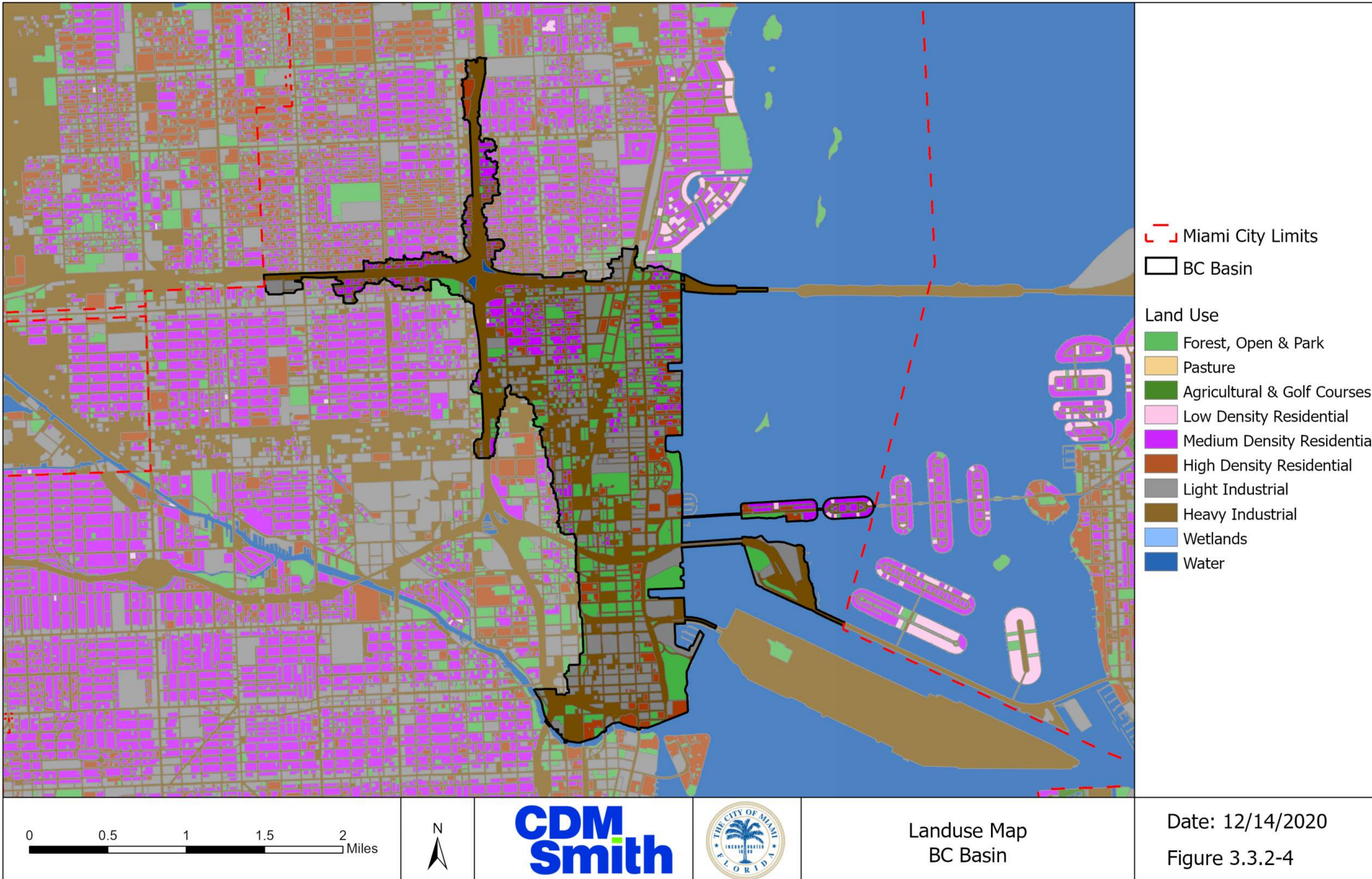
Impervious Cover
BC Basin

Date: 12/14/2020

Figure 3.3.2-3



Landuse Map
BC Basin

Date: 12/14/2020

Figure 3.3.2-4

As described in detail in the Model Development TM, impervious coverages were intersected with the sub-basin delineations, adjusted using the developed USGS impervious weightings, and a percentage of the total impervious routed to pervious based on land-use parameters. **Figure 3.3.2-5** presents the total impervious percentage in the BC Basin, delineated by sub-basin, after the adjustment for pervious/impervious routing was applied. **Figure 3.3.2-6** presents a breakdown of the land use by 10 standard consolidated categories, for use in the model. **Figure 3.3.2-7** presents a breakdown of the impervious cover in the model. The area-weighted total impervious percent of the BC Basin is estimated to be 74%; therefore, approximately 1,613 acres of the 2,172 acres are expected to be impervious surface. Of this, approximately 321 acres are expected to be routed to pervious surfaces prior to entry into the BC Basin PSMS. The routing of runoff to pervious surfaces does not affect the volume infiltrated to soils but does change the timing of the hyetograph.

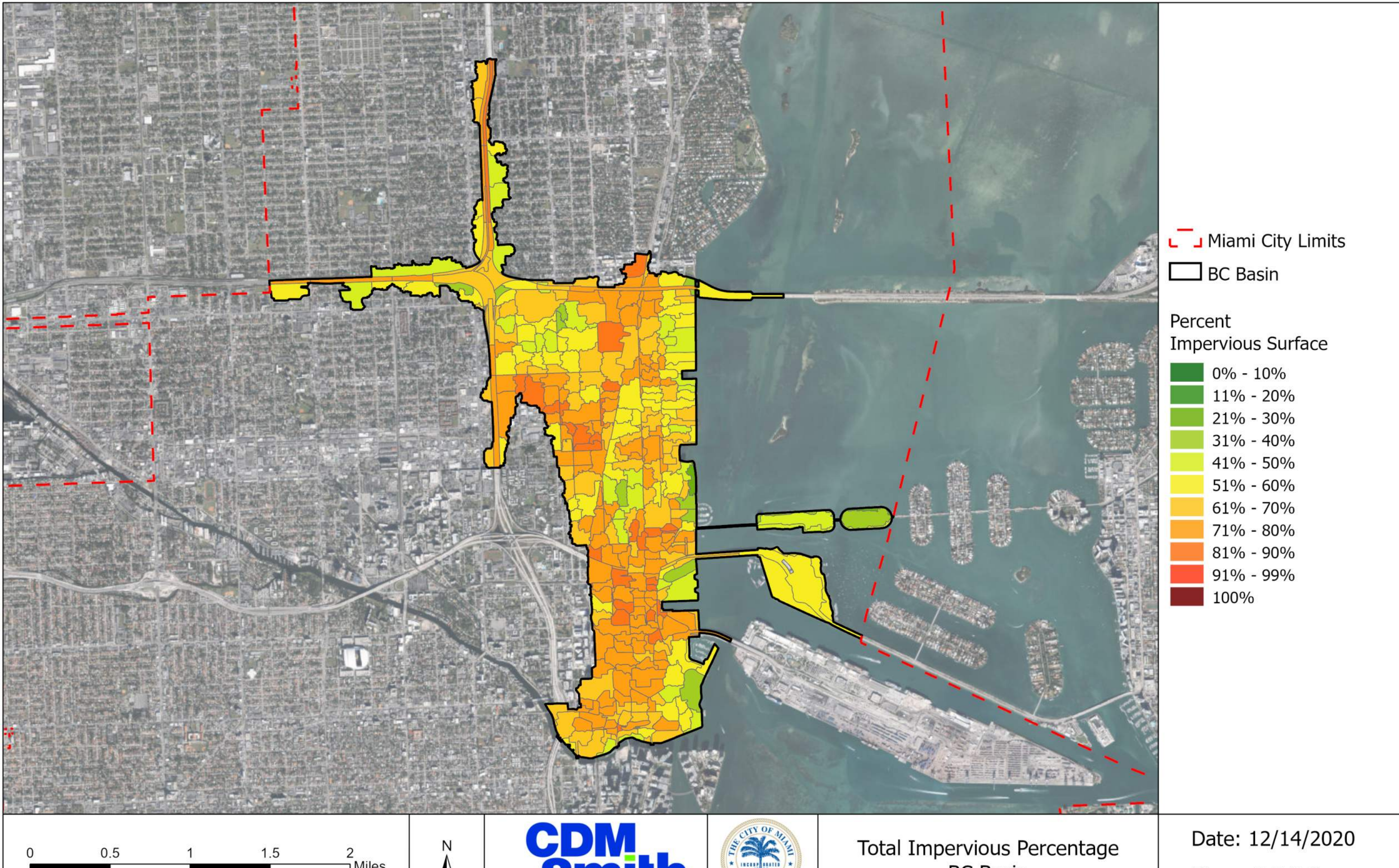
For design storm simulations, the SFWMD 24-hour and 72-hour unit hydrographs were used to implement the rainfall distributions per storm. **Table 3.3.2-1** presents the volumes for the BC Basin for the 5-year, 24-hour; and 10-year, 25-year, and 100-year 72-hour design storms that were obtained from the NOAA Atlas 14. Design Storm rainfall volumes were found for select gages in the atlas, and interpolated volume estimates were determined for point locations. For this basin, point location estimates were made across the basin. To be conservative, the highest volume was used as the design rainfall volume over the entire basin. In general, the western edge of the basin has slightly higher expected volumes than the coastal edge.

Table 3.3.2-1 Biscayne Central Design Storm Volumes and Intensities

Storm	Rainfall Depth (inches)*	Peak 5-min Intensity (inches/hr)
5-year, 24-hour	6.99	5.4
10-year, 72-hour	10.6	6.1
25-year, 72-hour	13.1	7.5
100-year, 72-hour	17.6	10.1

* NOAA Atlas 14 provides 1-day volumes to the hundredths and 3-day volumes to the tenths of an inch

Surface soils in the BC Basin are uniformly described as “urban” in the NRCS soils map included as shown on **Figure 3.3.2-8.** In order to apply the Modified Green-Ampt infiltration in SWMM, the urban soils needed to be characterized in more detail.



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THE CITY OF MIAMI FLORIDA

Total Impervious Percentage
BC Basin

Date: 12/14/2020

Figure 3.3.2-5

Figure 3.3.2-6 Landuse Category Breakdown for BC Basin

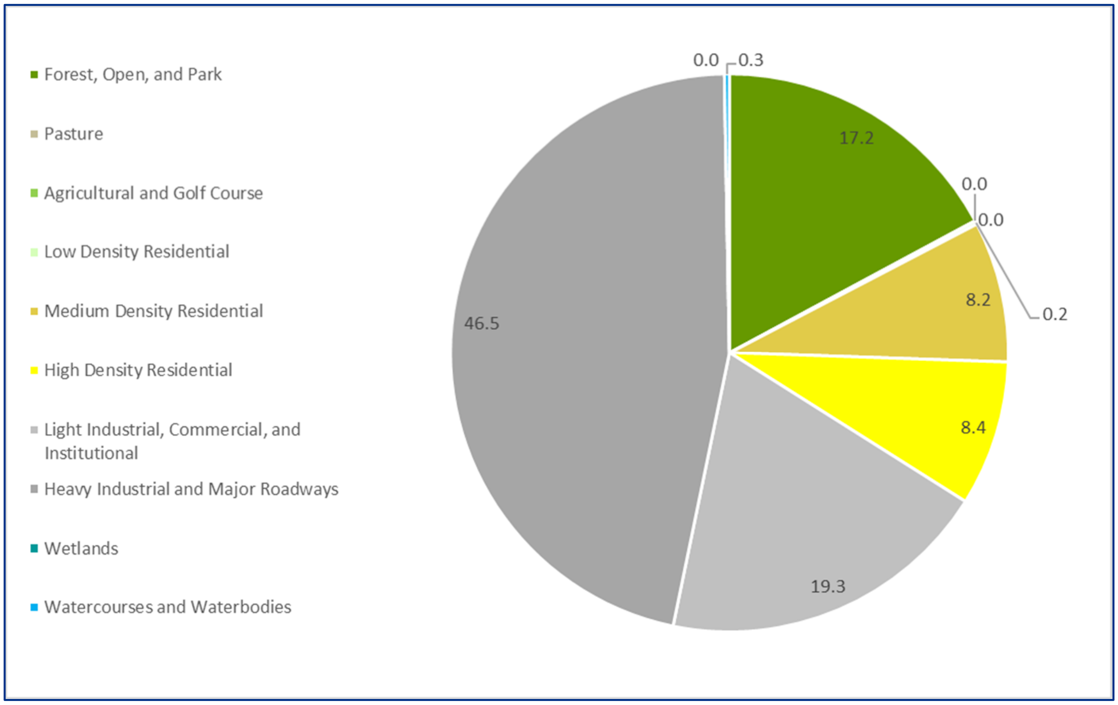
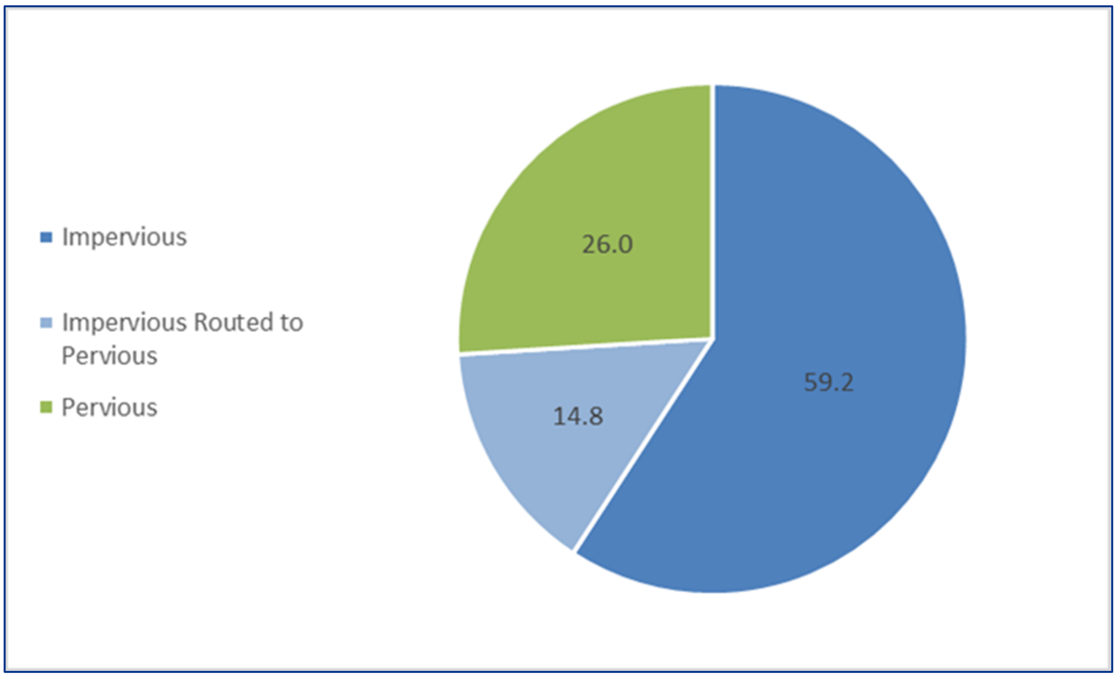
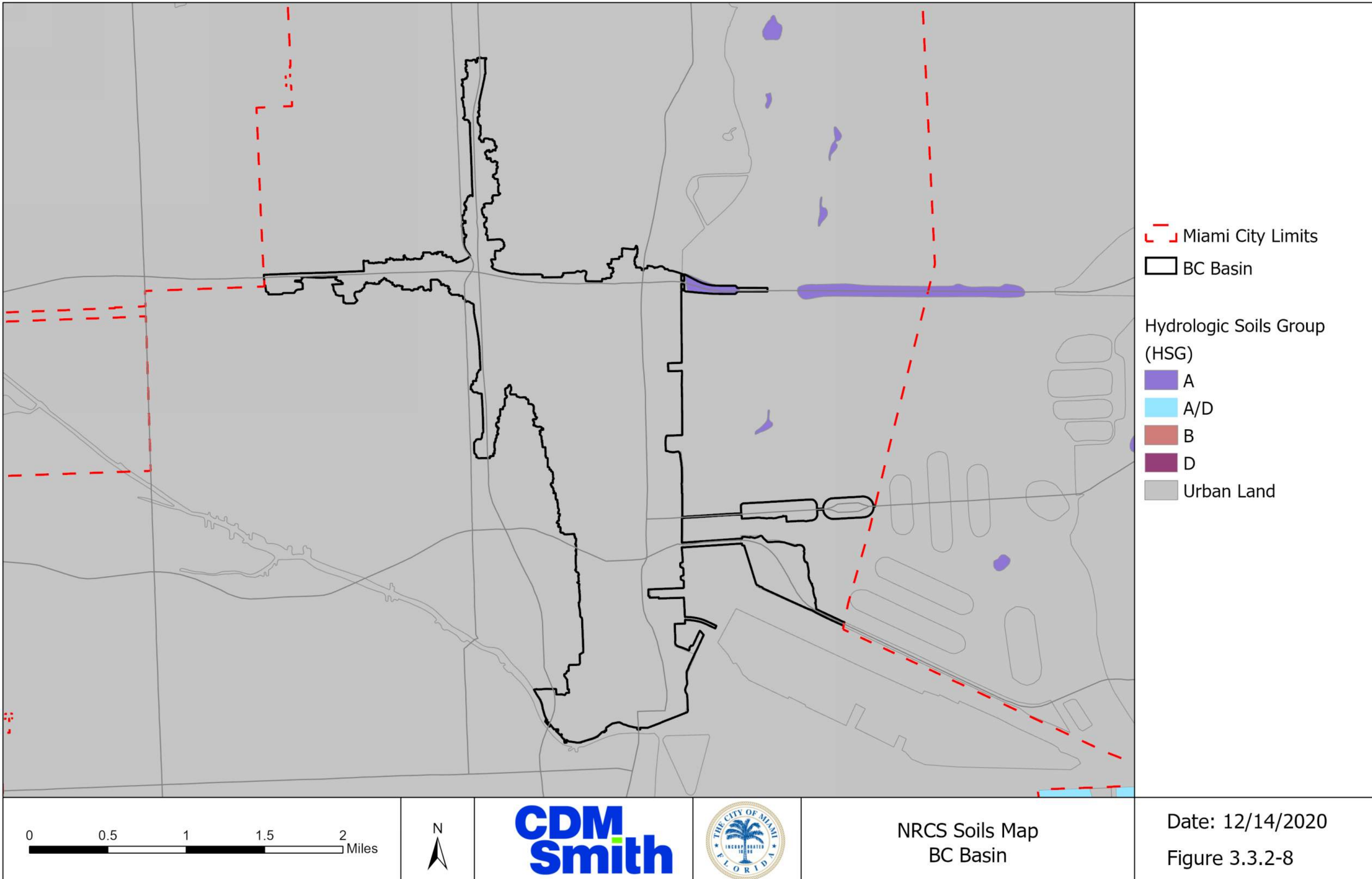


Figure 3.3.2-7 Breakdown of Adjusted impervious Cover for BC Basin





CDM Smith

NRCS Soils Map
BC Basin

Date: 12/14/2020

Figure 3.3.2-8

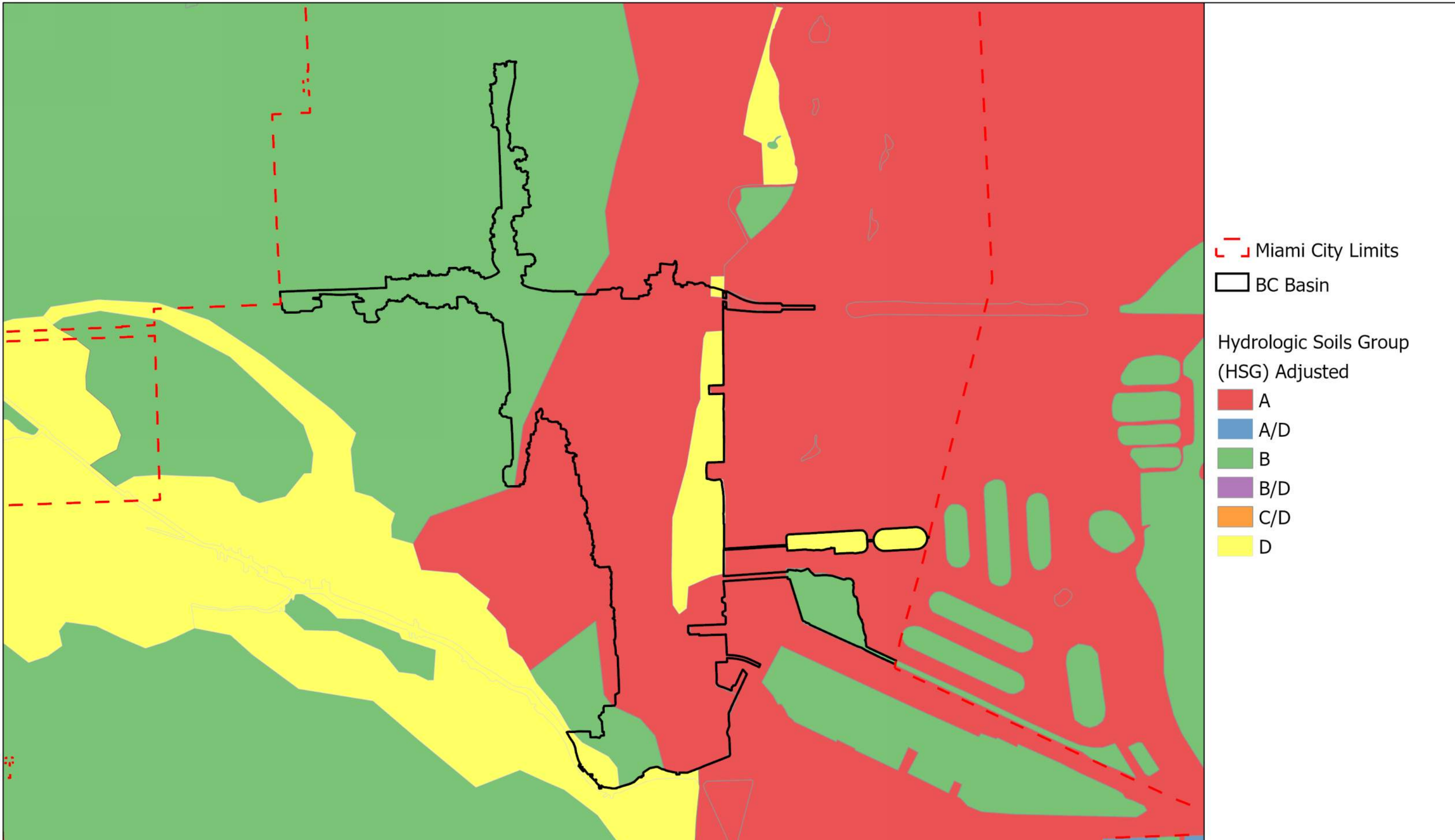
The project performed a limited number of double-ring infiltrometer tests in order to determine soil types throughout the project area. Miami-Dade County has performed similar tests. As discussed in the Model Development TM, the tests indicated Type A (sandy, or well-draining soils) soils at higher elevations, Type D (clay, or poor-draining soils) in low areas, particularly in the Miami River Floodplain, and intermediate soils elsewhere. Therefore, the BC Basin model uses Type A soils along the coastal ridge and higher coastal Biscayne Bay area, Type D soils in the low-lying regions within the Miami River floodplain, and Type B (intermediate) soils in the west, and between regions, as shown on **Figure 3.3.2-9**. Note that the rates on Figure 3.3.2-9, and the model parameter inputs, are Green-Ampt Hydraulic Conductivities, which do not directly correspond to the measured DRI soils infiltration rates.

3.3.2.2 BC Hydrologic and Hydraulic Model Elements

The developed H&H models for the BC Basin stormwater management system were used to evaluate the performance of the City's existing stormwater management system and to analyze future improvement projects (CIP). Model analysis evaluated the PSMS for multiple size rainfall events and downstream tidal boundary conditions. The PSMS includes constructed stormwater facilities and overland flow paths that drain to the downstream waterbody (i.e., boundary condition). The PSMS generally includes open channels and pipes of 24-inch diameter and larger. The BC Basin modeled area is 2,172 acres delineated into 359 sub-basins ranging in size from 0.8 acres to 49.2 acres with a mean size of 6.1 acres. Many of the smaller sub-basins delineate the area directly adjacent to the seawalls, which are necessary to model pre- and post-conditions for raised seawalls and backflow prevention but tend to be smaller than most of the City-wide delineation. The largest BC sub-basin is Watson Island. The second largest sub-basin represents approximately 30 acres of the Old San Juan neighborhood that is not connected to a major PSMS and represents a relatively large depression in the LiDAR DEM. **Table 3.2-2** summarizes the BC model elements.

Table 3.3.2-2 Summary of BC Model Elements

Sub-basins		359
Junctions		20
Storages	**Functional**	528
	Tabular	359
Outfalls		36
Conduits	**Circular**	725
	Ellipse	5
	Trapezoidal	1
	Rectangular Closed	110
	Irregular Canal	11
	Irregular Ditch	2
	Irregular Overland	813



Soils Type Adjusted from DRI Test
BC Basin

Date: 12/14/2020

Figure 3.3.2-9

Appendix B includes the BC Basin model schematic (**Figure BC-EC**) with standard symbology and Appendix C includes more detailed tables presenting the BC model element characteristics. These tables include the following:

- **Table BC-1** Hydrologic Parameters per Sub-basin
- **Table BC-2** Hydraulic Nodes Data
- **Table BC-3** Hydraulic Conduit Data
- **Table BC-4** Model Pump Data
- **Table BC-5** Model Weir Data
- **Table BC-6** Model Exfiltration Data

Model nodes representing manholes are modeled as functional storage nodes with a minimal amount of constant storage area (12.56 square feet, which is equivalent to a typical 48-inch diameter manhole). Pump Station wet wells are modeled as functional storage nodes with constant areas equivalent to the wet well area if the station dimensions were provided, or 100 square feet if the dimensions were not provided.

The BC Basin model has one primary outfall representing Biscayne Bay (BiscayneBayBC). Multiple pipe and seawall overland flow links have been combined at a virtual node (BiscayneBay) to provide one link to this outfall because EPA SWMM only allows a single link per outfall. The outfalls have been co-located for ease in changing boundary conditions once the models have been turned over to the City. Four outfalls represent injection wells, where the runoff is pumped directly into the Biscayne Aquifer. Additionally, 19 subbasins, 19 storage nodes, and 19 outfalls are used to model the exfiltration systems in the BC Basin. The virtual systems representing groundwater are not included in the model schematic nor in the tables. The groundwater table has been divided into 19 contiguous sections in the basin area because the initial level of the base groundwater varies depending on distance from Biscayne Bay and topography. The exfiltration systems are described in further detail in below.

The City's project-specific survey and the Geographic Information System (GIS) coverage of stormwater pipes identifies 47 stormwater points of discharge simulated as outfalls that discharge to Biscayne Bay and another nine that discharge to the Miami River in the BC Basin. There are an additional 35 outfalls representing sheet flow to Biscayne Bay and another seven to the river from the sub-basins along the shore. Generally, the overland sheet flow cross-sections represent the seawall surveyed in that area. If a seawall is not present over a portion of the shoreline, 0.0 ft-NAVD 88 is used as the overflow elevation. The topography behind the shoreline is determines the opposite side of the seawall edge sub-basin, and the subsequent overland flow elevation to the rest of the neighborhood.

3.3.2.3 BC Pump Stations

There are three existing pump stations in the BC Basin that convey stormwater flow from low-lying area to outfalls, as shown on Figure BC-EC. A wetwell with and under flow weir provides storage and treatment and screening of collected runoff for each station. Pumps are typically set to turn on at levels above the static water table and cycle off as water levels drop in the wetwell. Most pump stations have a control gate to bypass the station when offline for maintenance servicing, and some have an overflow weir to allow flow beyond the pump station capacity to continue out the outfall by gravity.

In the SWMM, pumps are represented by stage-flow links connected to an inflow storage node that serves as the wet well. The outflow section of the link is connected to a node that serves as a force main to an outfall. The types of pumps represented in this model are in-line pumps where flow increases incrementally with inlet node depth (SWMM Type 2). All pump station information was obtained from City-provided as-builts or other available plan sets.

1. <u>San Marco Island SWPS</u> has a total maximum capacity of 40 cfs or 18,000 gpm, and is located on San Marco Island, between Venetian Causeway and S. Venetian Way. This pump station injects water directly into the Biscayne Aquifer via two shallow injection wells. If the aquifer cannot accept the full 40 cfs, the flow is diverted over a weir through two 300-foot long, 16-inch diameter force mains to the south and east to Biscayne Bay. For flood modeling purposes, whether the flow leaves the model to the aquifer or the Bay is not relevant to the peak flood levels on San Marco Island, only to the water quality analysis as the wells provide treatment credit and saltwater intrusion mitigation. Accordingly, the force mains are not explicitly modeled at this site, and the pump station links directly to the outfall nodes representing the aquifer and the Bay. For this station, the wet well is set at -10.0 feet NAVD 88.

    - There are both lead and lag pumps in the station, though in the model, they are combined to one link.

    - Pump station cycles on and off at -3.4 ft-NAVD 88 and -8.5 ft-NAVD 88, respectively, with a maximum flow of 40 cfs (18,000 gpm).

2. <u>Omni SWPS</u> has a total maximum capacity of 20 cfs (9,000 gpm) and is located adjacent to Biscayne Boulevard, just north of N.E. 17th Terrace in the Omni/PAC neighborhood. This pump station injects water directly into the Biscayne Aquifer through five injection wells north of the station along Biscayne Boulevard. If the aquifer cannot accept the full 20 cfs, the flow is diverted back south to the station bypass structure, through a manually operated sluice gate to a gravity system that flows to Biscayne Bay. Note: the model uses a one-way flow direction option (flap gate) for bypass flows to outfall to the Bay, while preventing backflows from the Bay to the pump station. This option has been added in the model to determine the relative flows to the aquifer versus flows to the Bay for water quality purposes. however, the City has not provided data confirming that the station is being operated in this manner. The force main along Biscayne Boulevard is not explicitly modeled, as the pump station links directly to the outfall node representing the aquifer at this location, thus in terms of the model simulation, the water is disposed of either way. For this station, the wet well is set at -10.0 feet NAVD 88.

    - There are both lead and lag pumps in the station, though in the model they are combined to one link.

- Pump 1 cycles on and off at 0.65 ft-NAVD 88 and -4.65 ft-NAVD 88, respectively, with a maximum flow of 20 cfs (9,000 gpm).

3. Museum SWPS has a total maximum capacity of 25.4 cfs (11,400 gpm) and is located adjacent to Biscayne Boulevard in front of Museum Park, just north of N.E. 10th Street. This pump station injects water directly into the Biscayne Aquifer through three injection wells near the station along Biscayne Boulevard. If the aquifer cannot accept the full 25.4 cfs, the flow is diverted back south to the station bypass structure, through a manually operated sluice gate to a gravity system that flows to Biscayne Bay. Note: the model uses a one-way flow direction option (flap gate) for bypass flows to outfall to the Bay, while preventing backflows from the Bay to the pump station. This option has been added in the model to determine the relative flows to the aquifer versus flows to the Bay for water quality purposes, however, the City has not provided data confirming that the station is being operated in this manner. The force main along Biscayne Boulevard is not modeled as the pump station links directly to the outfall node representing the aquifer at this location. For this station, the wet well is set at -10.0 feet NAVD 88.

    - There are both lead and lag pumps in the station, though in the model, they are combined to one link

    - Pump 1 cycles on and off at -0.74 ft-NAVD 88 and -3.13 ft-NAVD 88, respectively, with a maximum flow of 25.4 cfs (11,400 gpm).

3.3.2.4 BC Exfiltration

The BC Basin uses exfiltration systems as one of its primary methods to reduce flooding and improve water quality by moving water from the PSMS to the Biscayne Aquifer. These systems include:

- Slab Covered Trenches: Rectangular boxes cut directly into the limestone aquifer, then covered with a concrete slab. There are approximately 6.4 miles of slab covered trench in the BC Basin.

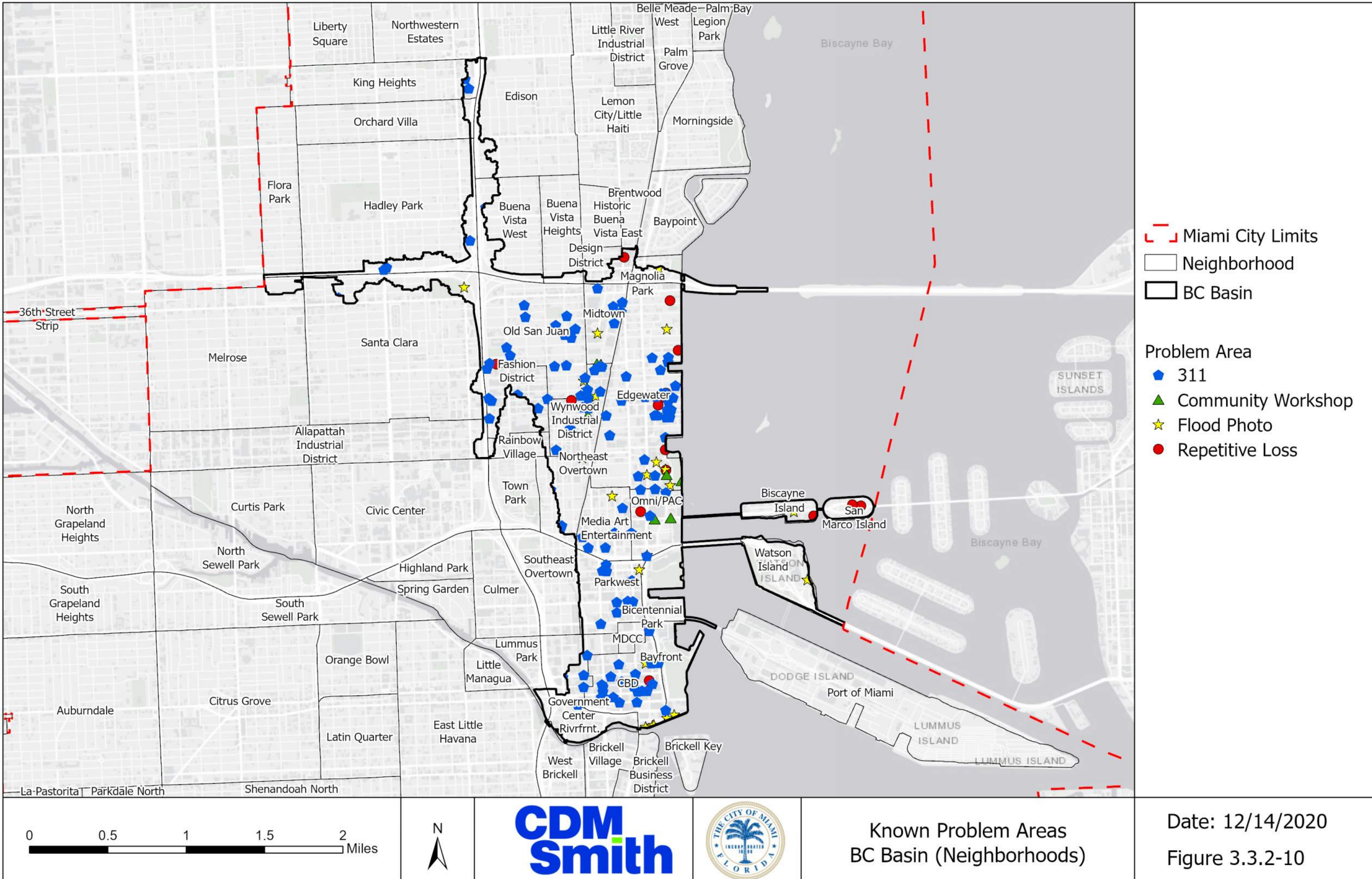
- French Drains: Perforated pipe situated in a gravel-filled rectangular shaped excavation into the aquifer. There are approximately 9.3 miles of French Drains in the BC Basin.

- Recharge/Drainage Wells: There are 79 gravity recharge/drainage wells in the BC Basin. There are two types of recharge wells used in the Miami area - gravity driven wells and injection (pumped) wells. Injection wells are accounted for in the pumped flows to outfall representing the aquifer (see above) and therefore not included in the exfiltration rating curves. Gravity wells use the differential driving head of the land surface water surface elevation and the aquifer ground water table elevation to overcome the well casing friction and salinity interface density to push stormwater runoff out into the porous and highly transmissive limestone layer underground. The use of Biscayne aquifer drainage wells is restricted to zones where chloride concentrations exceed the saltwater intrusion front identified as the location at the base of the aquifer, of the 1,000 mg/L isochlor and there are no impacts to Class G-II potable water supply aquifers.

In the BC Basin, the regional water table elevation is estimated for 19 separate regions. Each region has a specified initial water table level based on the Miami-Dade County base groundwater elevation database. Note, these initial levels are higher in the sea level rise scenarios. As in actual conditions, the regional water tables are designed in the model to rise based on precipitation and infiltration, using generic regional land-use estimates, i.e., the 19 model sub-basins ("GWBC" prefix), 19 storage nodes ("BiscayneAQBC" prefix), and 19 outfalls ("AQLossOut" prefix) are virtual elements designed solely to predict water table elevations and are not hydrologically or hydraulically connected to the model PSMS. The exfiltration rating curves are developed outside the model in a spreadsheet, based on length of system and count of wells per sub-basin, and other sub-basin specific parameters. The curves are head versus flow curves, where the head is internally calculated in the model by subtracting the regional groundwater elevation from the site-specific flood stage. In the large design storms, some of the low-lying exfiltration systems cease operations as the water table rises to ground surface. The Model Development TM provides more details on the exfiltration systems and how rating curves were developed for each type per model sub-basin.

3.3.2.5 BC Known Flooding Problem Areas

Known problem areas in Biscayne Central Basin include the neighborhoods of Edgewater, Wynwood, and Midtown. During Hurricane Irma, storm surge caused flooding in nearly all the coastal neighborhoods (Edgewater, Omni/PAC, Bicentennial Park, Bayfront, CBD) and the Riverfront and Lummus Park neighborhoods along the river. **Figure 3.3.2-10** indicates where complaints related to storms and/or flooding were made in the BC Basin.



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Known Problem Areas
BC Basin (Neighborhoods)

Date: 12/14/2020

Figure 3.3.2-10

3.3.2.6 BC Design Storm Simulations

A range of simulations were performed in the BC Basin model covering the multiple design storm intensities and an array of boundary conditions. **Table 3.3.2-3** presents all the simulation scenarios being run for the master plan, only the Base Condition run was performed for this TM.

Design storm distributions were taken from the SFWMD Permit Information Manual, Volume IV. Model simulations are performed for the 5-year, 24-hour design storm; and the 10-year, 25-year, and 100-year, 72-hour design storms. The 24-hour design storm has a peak centered at 12 hours, while the 72-hour design storms have peak intensities at 60 hours. The SFWMD design storm distributions are sampled at 5-minute increments. Design Storm volumes were extracted for localized actual recorded rainfall data from the NOAA Atlas 14, as shown previously in Table 3.2-1. Initial depths for nodes in the model were set to match the boundary conditions to create an even starting surface within all areas of the models including pumped areas.

Table 3.3.2-3 Design Storm Simulations

Tailwater Condition	Tailwater Stage in Biscayne Bay (ft-NAVD 88)			
	5-yr, 24-hr	10-yr, 72-hr	25-yr,72-hr	100-yr, 72-hr
Base Condition*	2.0	2.0	2.0	2.0
Base Plus 1.5 feet Sea Level Rise (SLR)	3.5	3.5	3.5	3.5
Base Plus 2.5 feet SLR	4.5	4.5	4.5	4.5
10-year Storm Surge		6.0		

* Base condition represents the 1-year stillwater tide elevation – see Model Development TM.

3.3.2.7 BC Existing Conditions Model Results and Design Storm Inundation Mapping

The verified BC Basin EC model was run for the base simulation for each design storm considering a well maintained, clean pipe condition. A summary of peak flood stages for the simulated EC model is provided in the City-published GIS model output tables. Flood mapping of the base simulations of existing conditions for the 5-year, 24-hour design storm; and the 10-year, 25-year, and 100-year, 72-hour design storms are presented on **Figures 3.3.2-11 through 3.3.2-14**.

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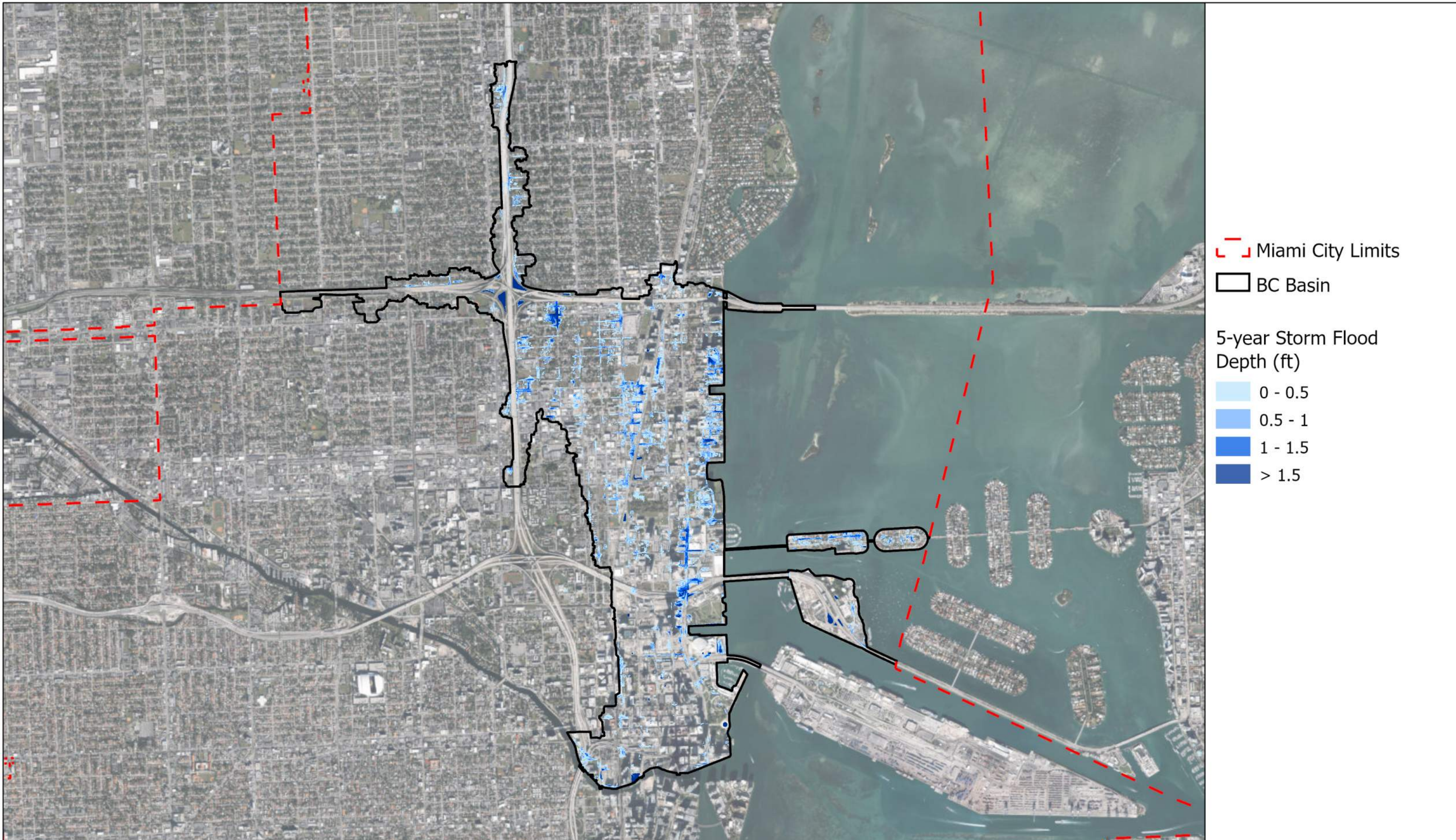

0 0.5 1 1.5 2 Miles

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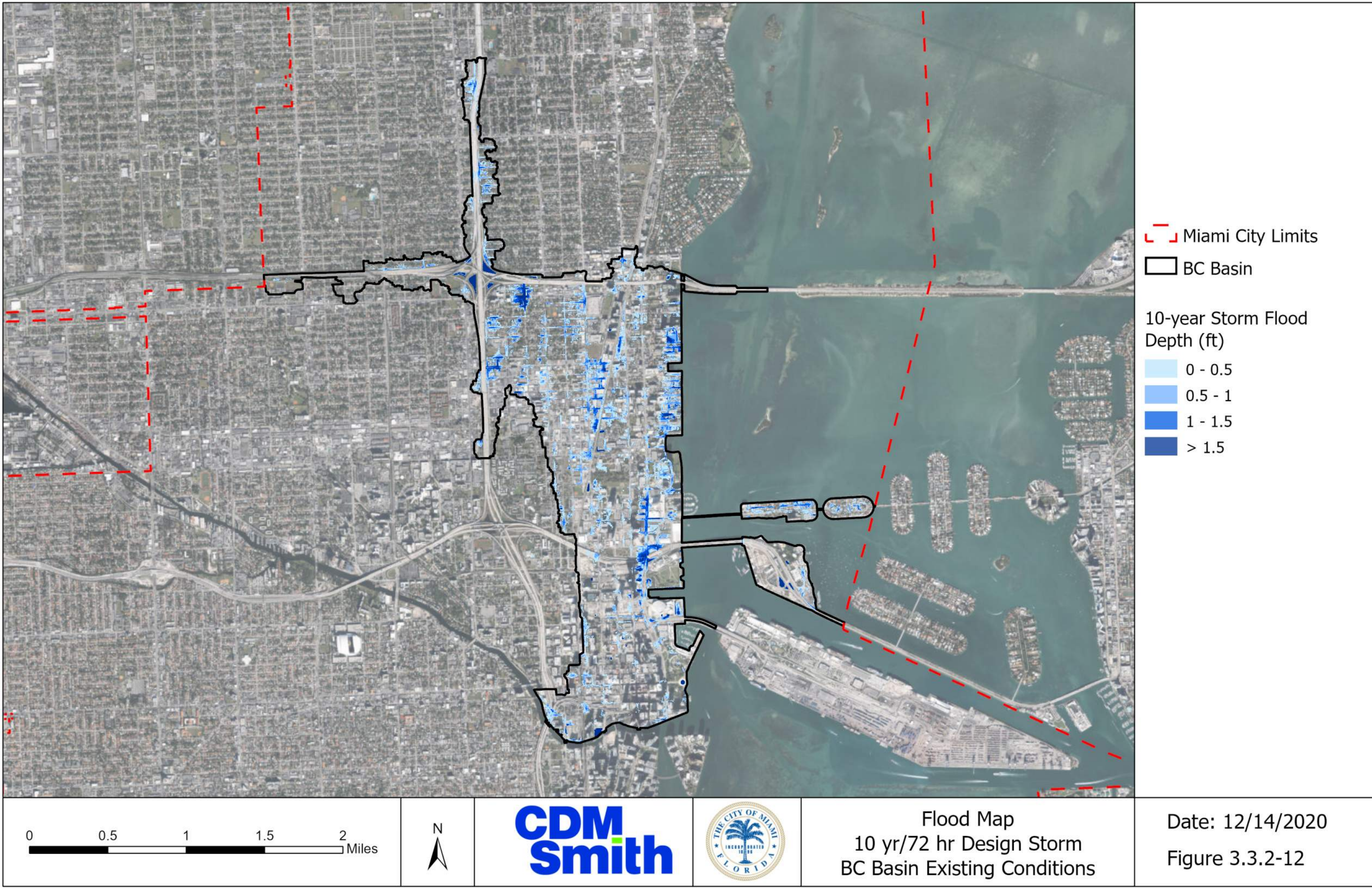
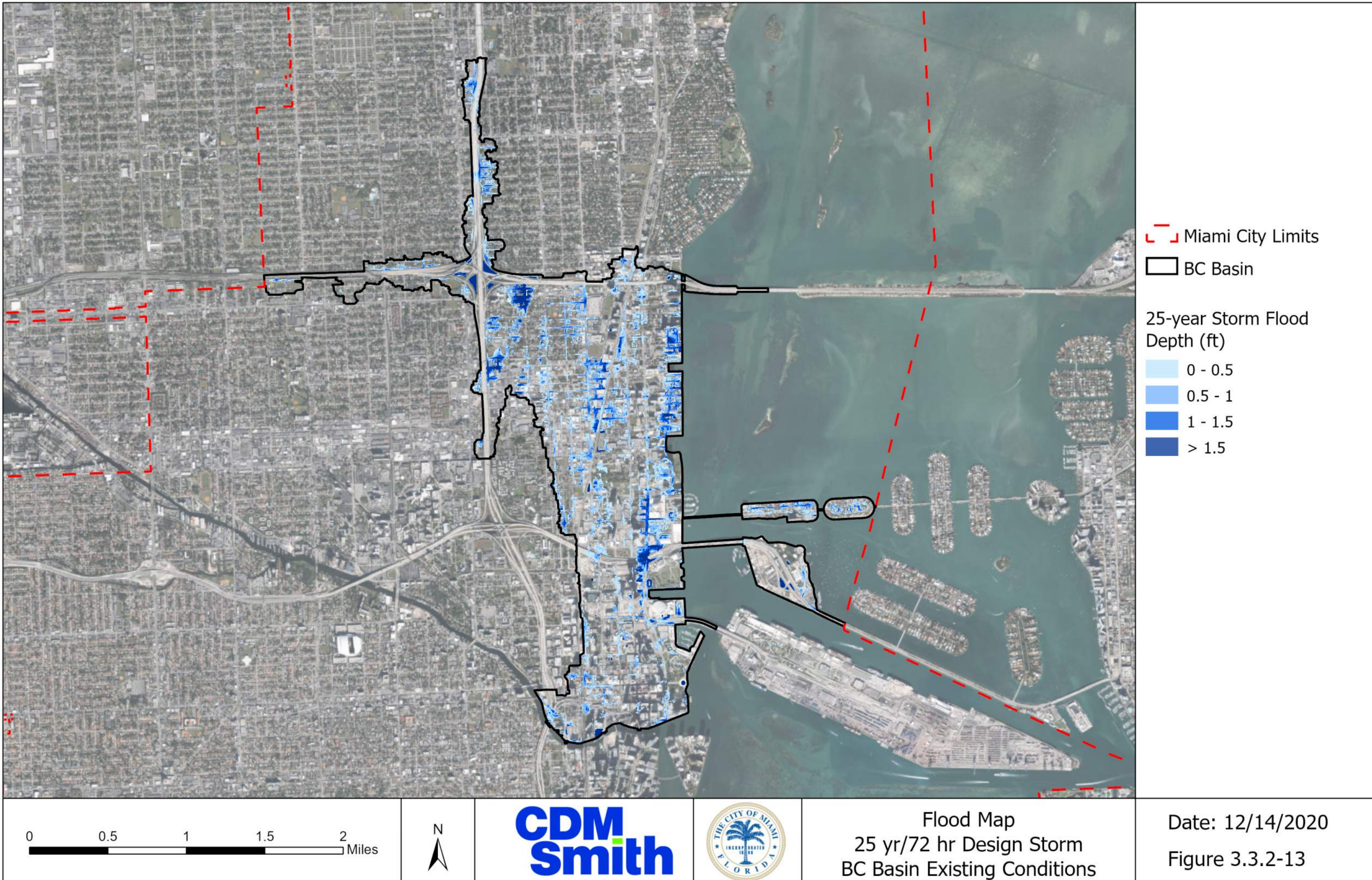
THE CITY OF MIAMI FLORIDA

Flood Map
5 yr/24 hr Design Storm
BC Basin Existing Conditions

Date: 12/14/2020

Figure 3.3.2-11


Miami City Limits
BC Basin
10-year Storm Flood Depth (ft)
0 - 0.5
0.5 - 1
1 - 1.5
> 1.5
0
0.5
1
1.5
2
Miles
N
CDM Smith
THE CITY OF MIAMI
FLORIDA
Flood Map
10 yr/72 hr Design Storm
BC Basin Existing Conditions
Date: 12/14/2020
Figure 3.3.2-12



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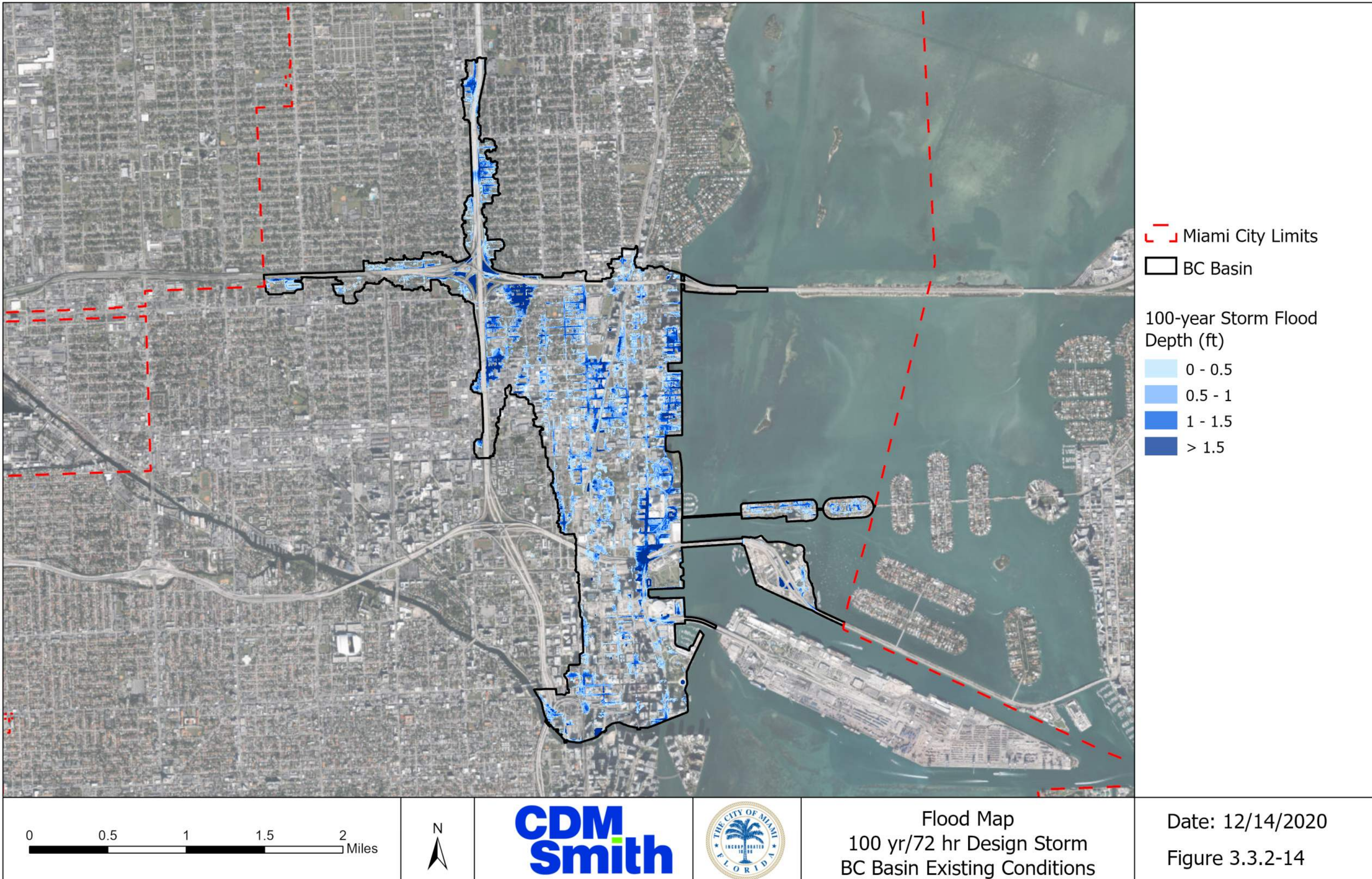
Flood Map
25 yr/72 hr Design Storm
BC Basin Existing Conditions

Date: 12/14/2020

Figure 3.3.2-13



CDM Smith

Flood Map
100 yr/72 hr Design Storm
BC Basin Existing Conditions

Date: 12/14/2020

Figure 3.3.2-14

3.3.2.8 BC Model Result Summary and Existing Conditions Level of Service Scoring

Peak flood stages were compared to indicator elevations through the basin for the 10-year storm to determine the existing flood LOS for roads, and for the 100-year storm to determine the existing LOS for buildings.

The BC Basin was analyzed and grouped logically into 11 improvement regions (LOS Areas) considering in-common topography and PSMS elements. **Table 3.3.2-4** presents the length of road flooded above crown in each region for the 10-year storm, base condition, and the number of buildings expected to flood for the 100-year storm, base condition. Because the verification of each individual FFE for every building and residence property in Miami is not within of the scope of this project, a standard 1 foot above existing grade has been added to the LiDAR DEM around the periphery of each structure as a reasonable estimate of the minimum building FFEs. Approximately 300 FFEs were field verified in the deepest flooding areas by ground survey and the DEM numbers were adjusted accordingly. It is noted that Current Florida Building Code requires 1 foot or more above the BFE depending on the FIRM flood hazard zone within which the property is located. Future minimum FFEs may be required to include additional height provisions for sea level rise.

The LOS score for each region was determined by the following equation:

$S_{LOS} = C_1 * Len_{10} + C_2 * Bldg_{100} + C_3 * Str_{Crit}$;

Where S_{LOS} is the LOS score, Len_{10} is the length of road flooded above crown for the 10-year storm in linear feet and normalized by population, $Bldg_{100}$ is the number of buildings flooded above the estimated FFE for the 100-year storm, normalized by population, Str_{Crit} is the number of critical structures flooded identified in the region, and C_1, C_2 and C_3 are coefficients that may be used by the City of Miami to help rank neighborhoods. Higher scores indicate worse predicted Current LOS problems. These rankings are for initial evaluation purposes only, as the two proposed LOS alternatives attempt to mitigate all problem areas, not just those in the highest ranked areas.

Figures 3.3.2-15 and 3.3.2-16 provide the relative existing conditions predicted LOS flooding of roadways and structures respectively for the BC Basin. Additionally, 144 critical structures were identified in the study area (emergency operations, police, fire, hospital, evacuation shelter, government, etc.) and added to the surveyed FFEs.

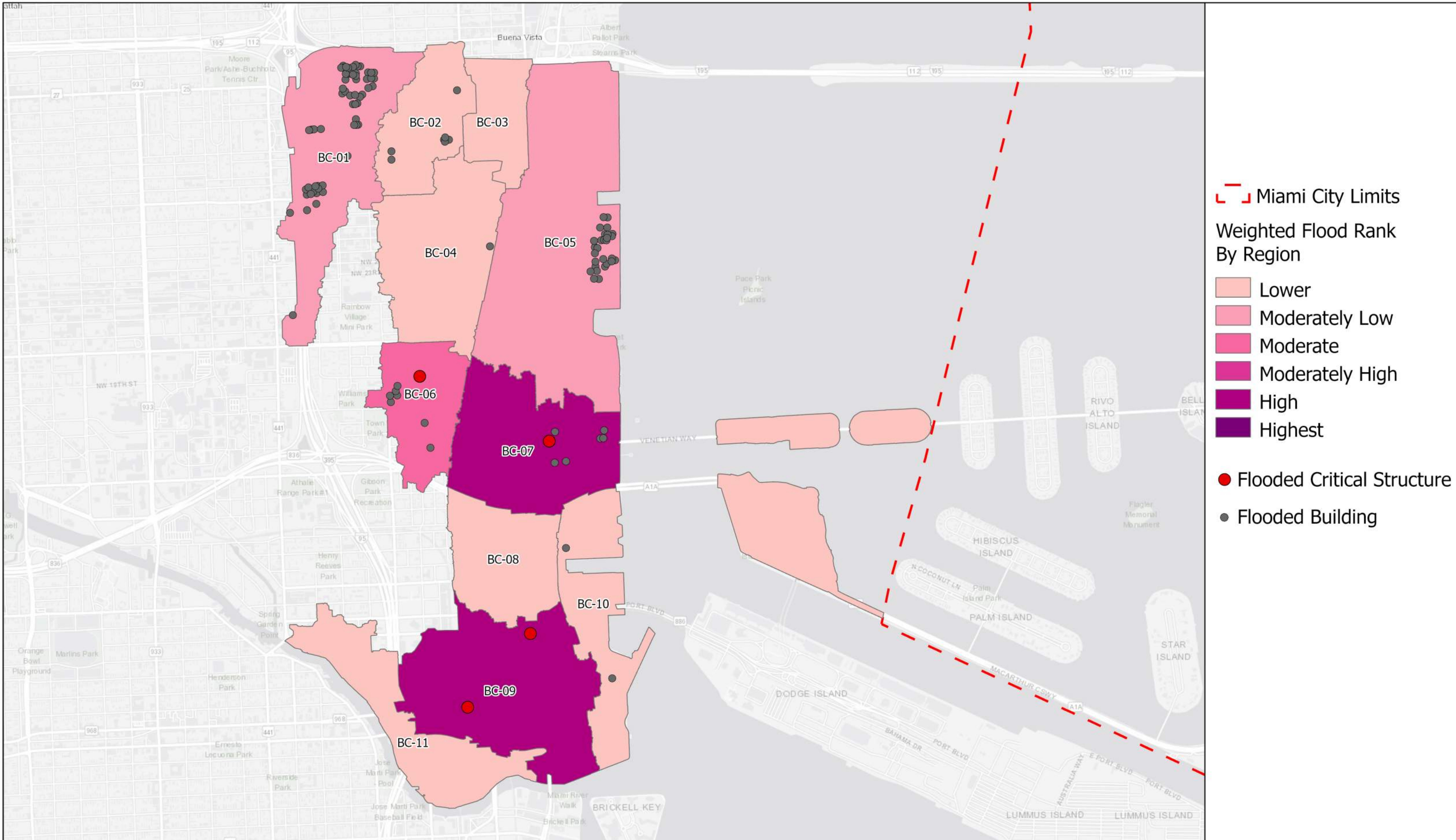
Table 3.3.2-4 BC Basin Existing LOS Ranking

								1		1		1	
LOS Region	Primary Neighborhood in LOS Area	All Neighborhoods in LOS Area	Area (acres)	Flooded Area 100yr (acres)	Flooded Area/Total Basin Area	Population (2010)	Length of Street Flooded (mi)	Length of Street Flooded/Total Length of Street Flooded 10yr	Est # of Buildings Flooded (100 yr)	# of Buildings Flooded/Total # of Buildings Flooded (100 yr)	# of Critical Structures Flooded (100 yr)	# of Critical Structures Flooded/Total # of Critical Structues Flooded (100 yr)	Basin Relative Flood Ranking
BC-01	Old San Juan West	Buena Vista Heights, Buena Vista West, Santa Clara, Old San Juan, Fashion District, Allapattah Industrial District, Rainbow Village	205.3	79.8	8.67%	2,469	2.16	9.89%	60	52.17%	1	9.09%	0.71147
BC-02	Old San Juan East	Buena Vista Heights, Design District, Old San Juan, Midtown	98.5	58.0	6.29%	1,610	1.95	8.94%	7	6.09%	0	0.01%	0.15032
BC-03	Midtown	Design District, Magnolia Park, Old San Juan, Edgewater, Midtown	67.4	25.6	2.77%	1,448	0.41	1.87%	0	0.00%	0	0.01%	0.01884
BC-04	Wynwood Industrial District	Old San Juan, Midtown, Wynwood Industrial District, Fashion District, Rainbow Village, Northeast Overtown	180.7	104.7	11.37%	1,690	2.54	11.64%	1	0.87%	0	0.01%	0.12517
BC-05	Edgewater	Edgewater, Midtown, Wynwood Industrial District, Northeast Overtown, Omni/PAC	367.1	190.6	20.70%	12,519	4.61	21.15%	29	25.22%	0	0.01%	0.46376
BC-06	Northeast Overtown	Wynwood Industrial District, Rainbow Village, Northeast Overtown, Town Park, Media Art Entertainment, Southeast Overtown	98.2	58.6	6.36%	1,986	1.26	5.79%	7	6.09%	1	9.09%	0.20960
BC-07	Omni/PAC	Edgewater, Northeast Overtown, Media Art Entertainment, Omni/PAC, Bicentennial Park, Parkwest	188.5	100.8	10.95%	1,994	2.29	10.53%	6	5.22%	1	9.09%	0.24829
BC-08	Parkwest	Northeast Overtown, Media Art Entertainment, Southeast Overtown, Bicentennial Park, Parkwest, MDCC	113.9	50.6	5.50%	3,370	0.90	4.15%	0	0.00%	0	0.01%	0.04158
BC-09	CBD	Southeast Overtown, Bicentennial Park, Parkwest, Bayfront, CBD, MDCC, Government Center, Lummus Park, Riverfront	243.2	102.5	11.13%	4,866	2.04	9.34%	0	0.00%	8	72.68%	0.82018
BC-10	Parks & Causeways	San Marco Island, Biscayne Island, Omni/PAC, Bicentennial Park, Parkwest, Bayfront, CBD, Watson Island	271.2	97.5	10.59%	1,837	1.93	8.84%	4	3.48%	0	0.01%	0.12330
BC-11	Riverfront	West Brickell, Culmer, East Little Havana, CBD, Government Center, Lummus Park, Riverfront	133.2	52.1	5.66%	3,425	1.72	7.87%	1	0.87%	0	0.01%	0.08750
Totals	11		1,967.1	920.9	100%	37,214.0	21.8	100%	115.0	100%	11	100%	

Length of Road Flooded Above Crown
by Region 10-year storm
BC Basin Existing Conditions

Date: 12/14/2020

Figure 3.3.2-15



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Number of Buildings & Critical Structures
Flooded by Region 100-year storm
BC Basin Existing Conditions

Date: 12/14/2020

Figure 3.3.2-16

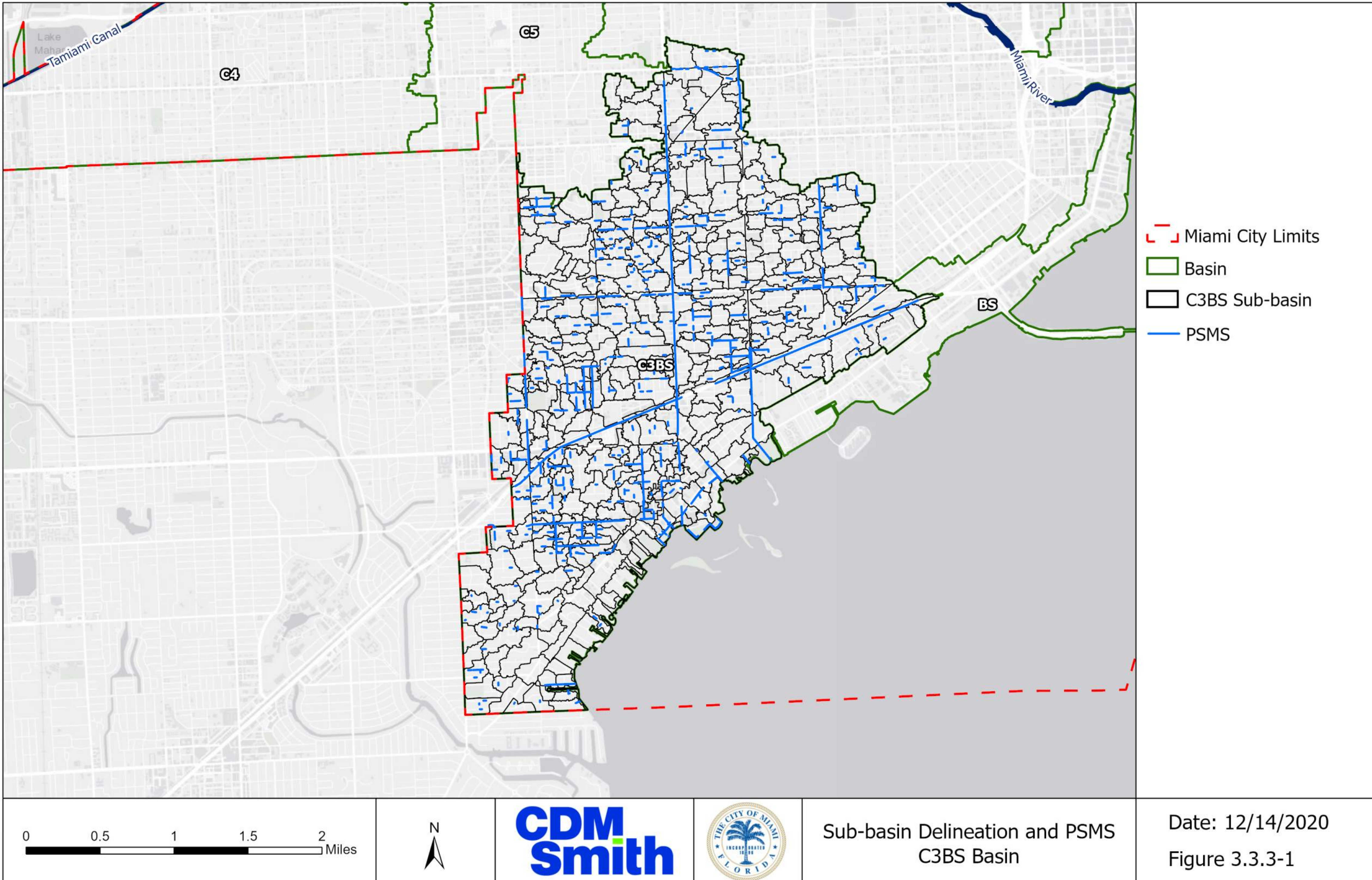
3.3.3 C-3 Biscayne South (C3BS) Basin

3.3.3.1 C3BS Basin Description

The C-3 Biscayne South (C3BS) Basin consists of 9,260 acres of low-lying land that primarily discharges to Biscayne Bay through the SFWMS C-3 Canal. The entire SFWMD C-3 (Coral Gables Canal) basin has an area of approximately 18 square miles and is located in eastern Miami-Dade County. C-3 begins as an open channel connection with C-4. Flow is normally to the south from C-4 to C-3. Water flow in C-3 is to the southeast, with discharge to Biscayne Bay through G-97. **Figure 3.3.3-1** includes a delineation of the C3BS Basin and a simplified representation of the PSMS within the basin. The C3BS Basin is characterized by PSMS discharge directly to Biscayne Bay south of NW 3rd Street and the Citrus Grove neighborhood. The Basin is north of the Sunrise Harbor Waterway. The Basin necessarily includes tributary beyond the City boundaries west of SW 42nd Avenue. The northern boundary is adjacent to the C5 and C6 Basins and delineated following topography. The western boundary is delineated by SW 42nd Avenue and S. Dixie Highway following topography. The southern boundary is delineated by the Sunrise Harbor Waterway following topography. The eastern boundary is Biscayne South Basin and Biscayne Bay.

Figure 3.3.3-2 shows the Digital Elevation Model (DEM) for the C3BS Basin. Topographic elevations range from near 0 feet North American Vertical Datum of 1988 (NAVD 88) in coastal areas near Biscayne Bay and the Sunrise Harbor Waterway to approximately 20 ft-NAVD 88 along the coastal ridge located in the southeast portion of the basin. In the C3BS Basin, the coastal ridge runs along the basin for approximately 4 miles, from 42nd Avenue to S Miami Avenue. The ridge elevations range from 12 to 20 ft-NAVD 88. Another coastal ridge runs along the center of the basin from SW 23rd Terrace to SW 15th Street for about 1.2 miles. Approximately 95% of the C3BS Basin's stormwater inlets are between 3 feet and 15 feet NAVD 88; however, over 50 PSMS inlets (1.5%) are located where the LiDAR elevations are below 3 feet NAVD 88. The lower elevations are all near the coast, east of the high coastal ridge and are susceptible to storm surge and sea level rise. Further, low street elevations in many areas preclude using gravity recharge wells or other exfiltration systems, since the driving heads are small. Existing exfiltration systems in these areas are not expected to work well, either in the model or actual operation.

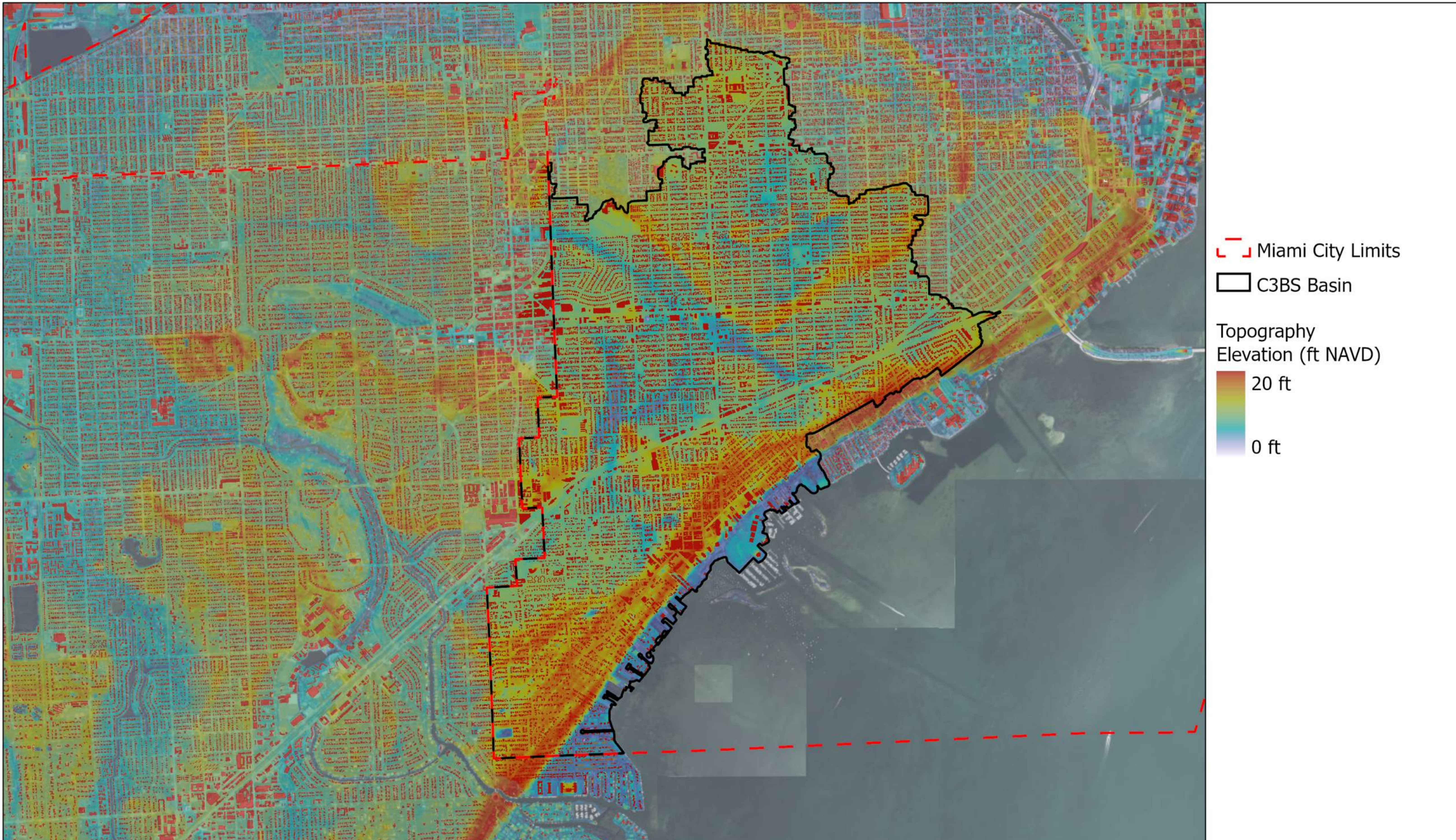
Figure 3.3.3-3 presents a map of the impervious cover for the C3BS Basin based on the USGS NLCD coverage as discussed in the Model Development Technical Memorandum and **Figure 3.3.3-4** presents a map of the SFWMD land-use for the C3BS Basin.



Sub-basin Delineation and PSMS
C3BS Basin

Date: 12/14/2020

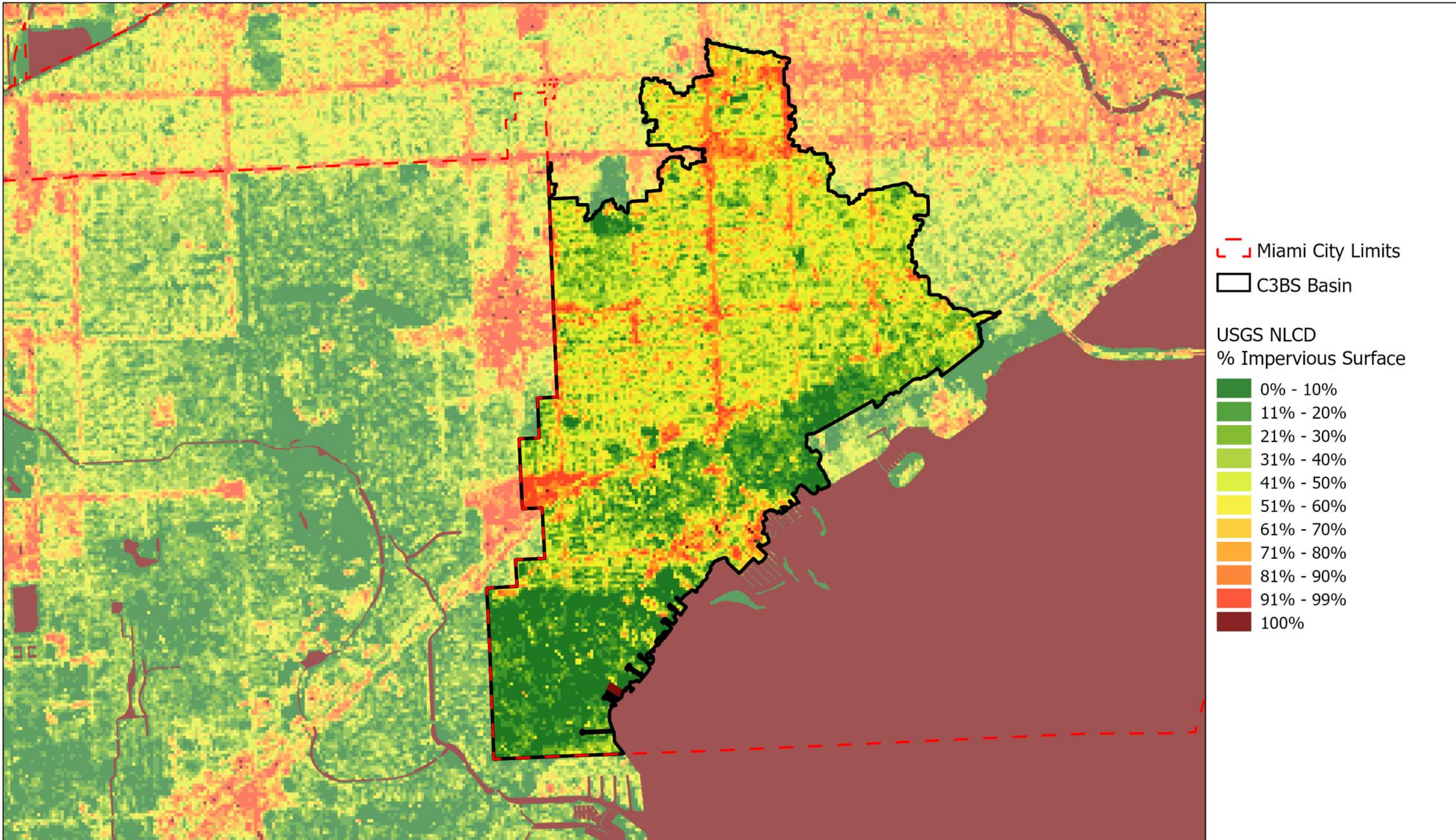
Figure 3.3.3-1



Digital Elevation Model (DEM)
C3BS Basin

Date: 12/14/2020

Figure 3.3.3-2



0 0.5 1 1.5 2 Miles

N

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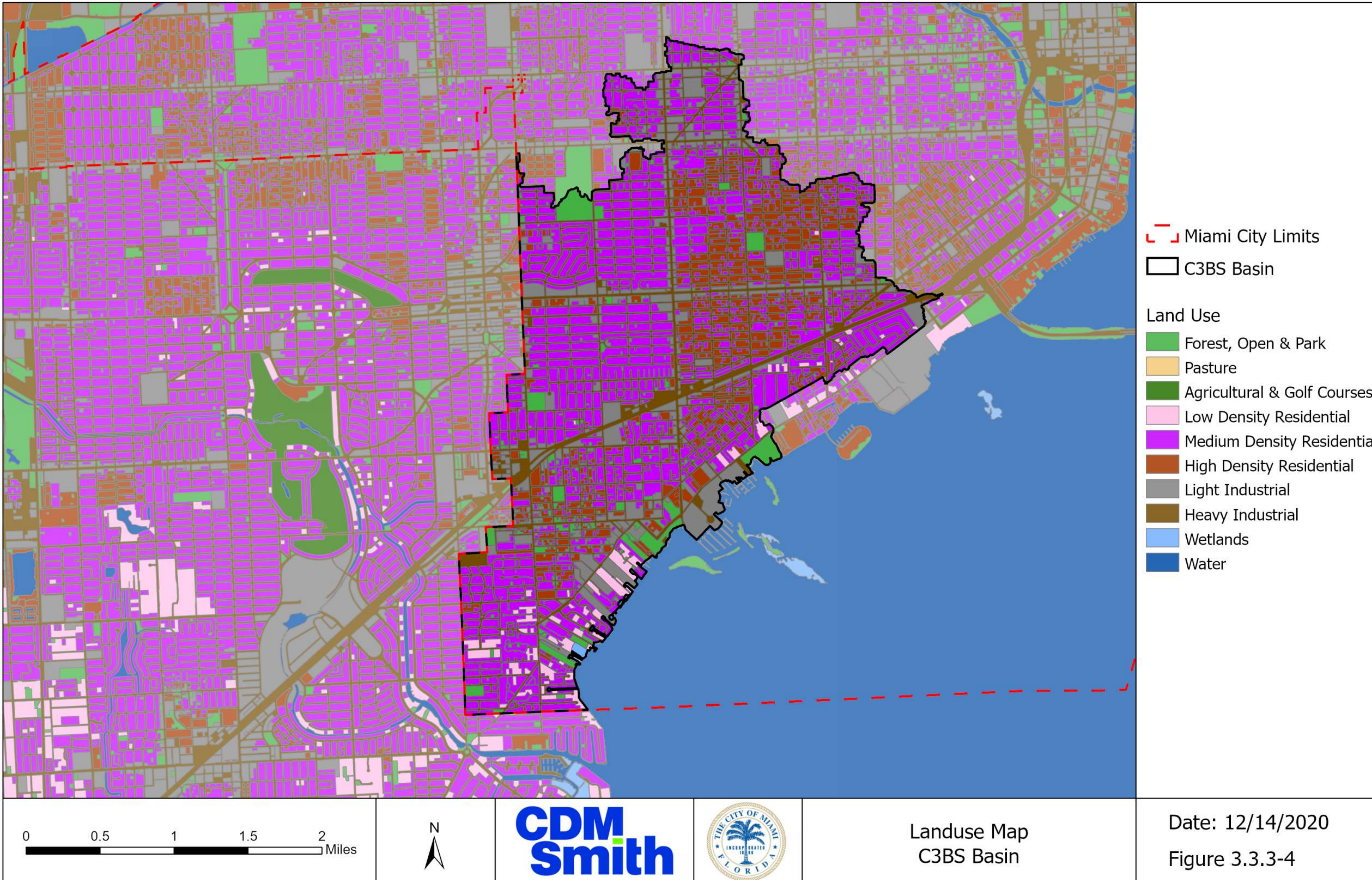
Impervious Cover
C3BS Basin

Date: 12/14/2020

Figure 3.3.3-3



Landuse Map
C3BS Basin

Date: 12/14/2020

Figure 3.3.3-4

As described in detail in the Model Development TM, impervious coverages were intersected with the sub-basin delineations, adjusted using the developed USGS impervious weightings, and a percentage of the total impervious routed to pervious based on land-use parameters. **Figure 3.3.3-5** presents the total impervious percentage in the C3BS Basin, delineated by sub-basin, after the adjustment for pervious/impervious routing was applied. **Figure 3.3.3-6** presents a breakdown of the land use by 10 standard consolidated categories, for use in the model. **Figure 3.3.3-7** presents a breakdown of the impervious cover in the model. The area-weighted total impervious percent of the C3BS Basin is estimated to be 47%; therefore, approximately 4,353 acres of the 9,260 acres are expected to be impervious surface. Of this, approximately 1,182 acres are expected to be routed to pervious surfaces prior to entry into the C3BS Basin PSMS. The routing of runoff to pervious surfaces does not affect the volume infiltrated to soils but does change the timing of the hyetograph.

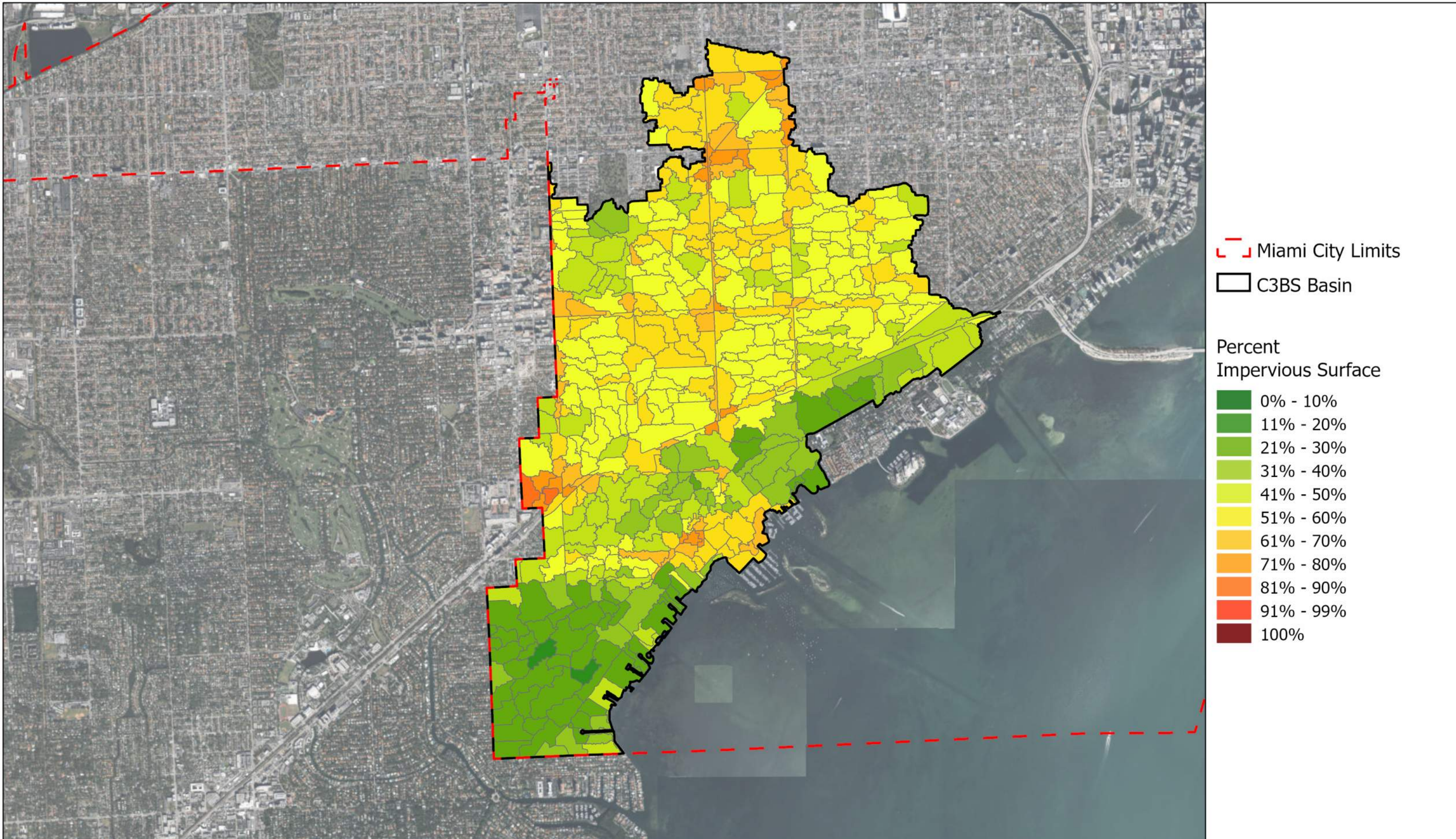
For design storm simulations, the SFWMD 24-hour and 72-hour unit hydrographs were used to implement the rainfall distributions per storm. **Table 3.3.3-1** presents the volumes for the BN Basin for the 5-year, 24-hour; and 10-year, 25-year, and 100-year 72-hour design storms that were obtained from the NOAA Atlas 14. Design Storm rainfall volumes may be found for select gages in the atlas, or an interpolated volume estimate may be found for point locations. For this basin, point location estimates were made across the basin. In order to be conservative, the highest volume was used as the design rainfall volume over the entire basin. In general, the western edge of the basin has slightly higher expected volumes than the coastal edge.

Table 3.3.3-1 C3BS Basin Design Storm Volumes and Intensities

Storm	Rainfall Depth (inches)*	Peak 5-min Intensity (inches/hr)
5-year, 24-hour	7.0	5.4
10-year, 72-hour	10.5	6.0
25-year, 72-hour	13.1	7.5
100-year, 72-hour	17.6	10.1

* NOAA Atlas 14 provides 1-day volumes to the hundredths and 3-day volumes to the tenths of an inch

Surface soils in the C3BS Basin are mostly described as “urban” with a southern portion classified as “group A” in the NRCS soils map included as shown on **Figure 3.3.3-8.** In order to apply the Modified Green-Ampt infiltration in SWMM, the urban soils needed to be characterized in more detail.



0 0.5 1 1.5 2 Miles

N

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Total Impervious Percentage
C3BS Basin

Date: 12/14/2020

Figure 3.3.3-5

Figure 3.3.3-6 Landuse Category Breakdown for C3BS Basin

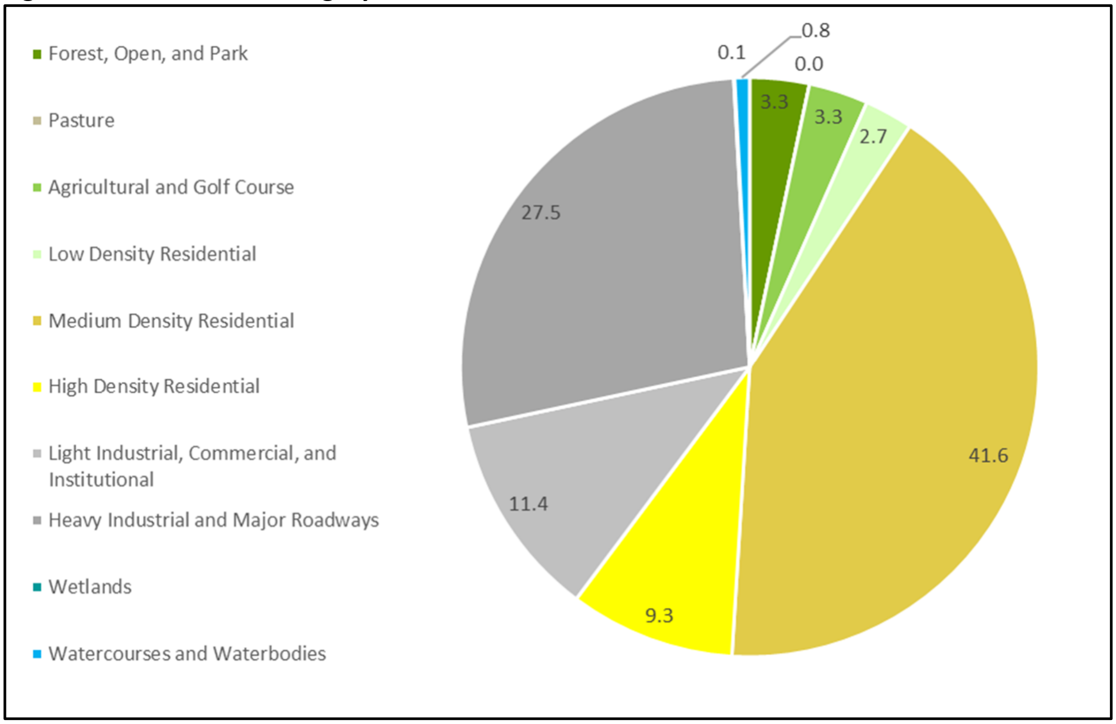
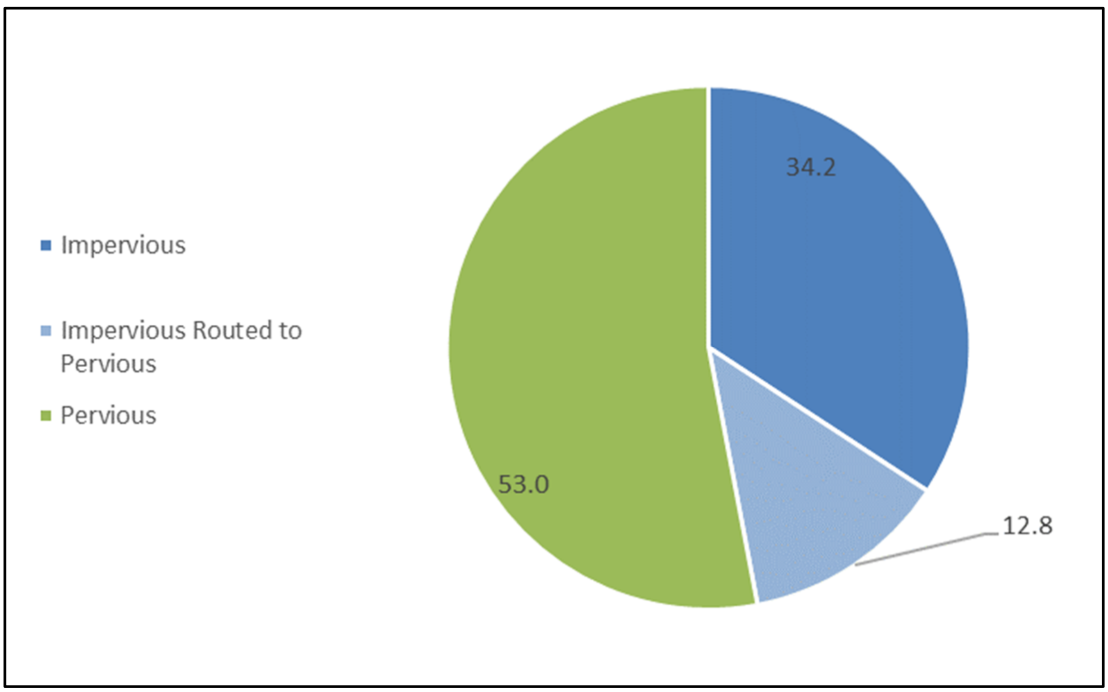
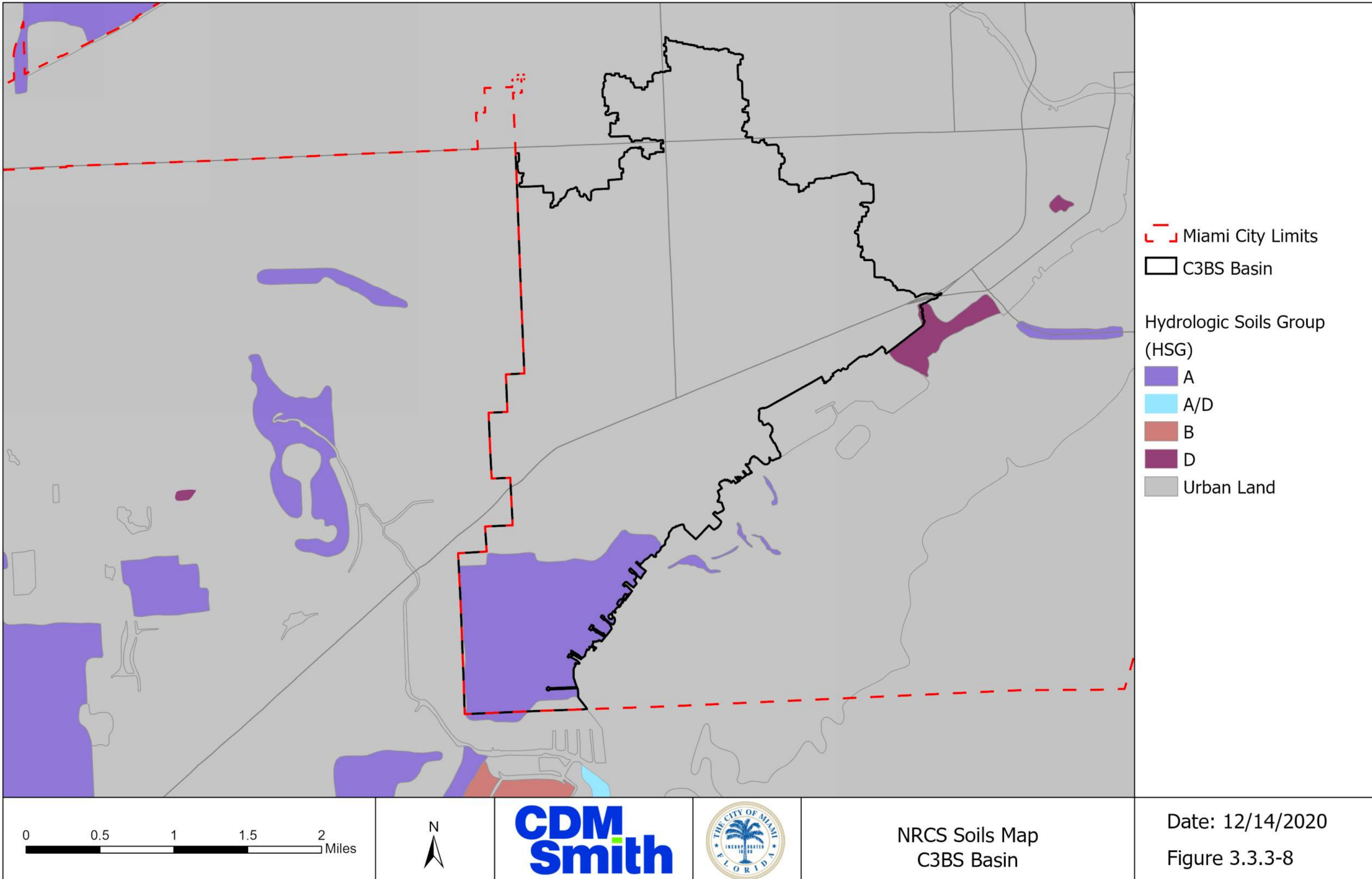


Figure 3.3.3-7 Breakdown of Adjusted impervious Cover for C3BS Basin





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NRCS Soils Map
C3BS Basin

Date: 12/14/2020
Figure 3.3.3-8

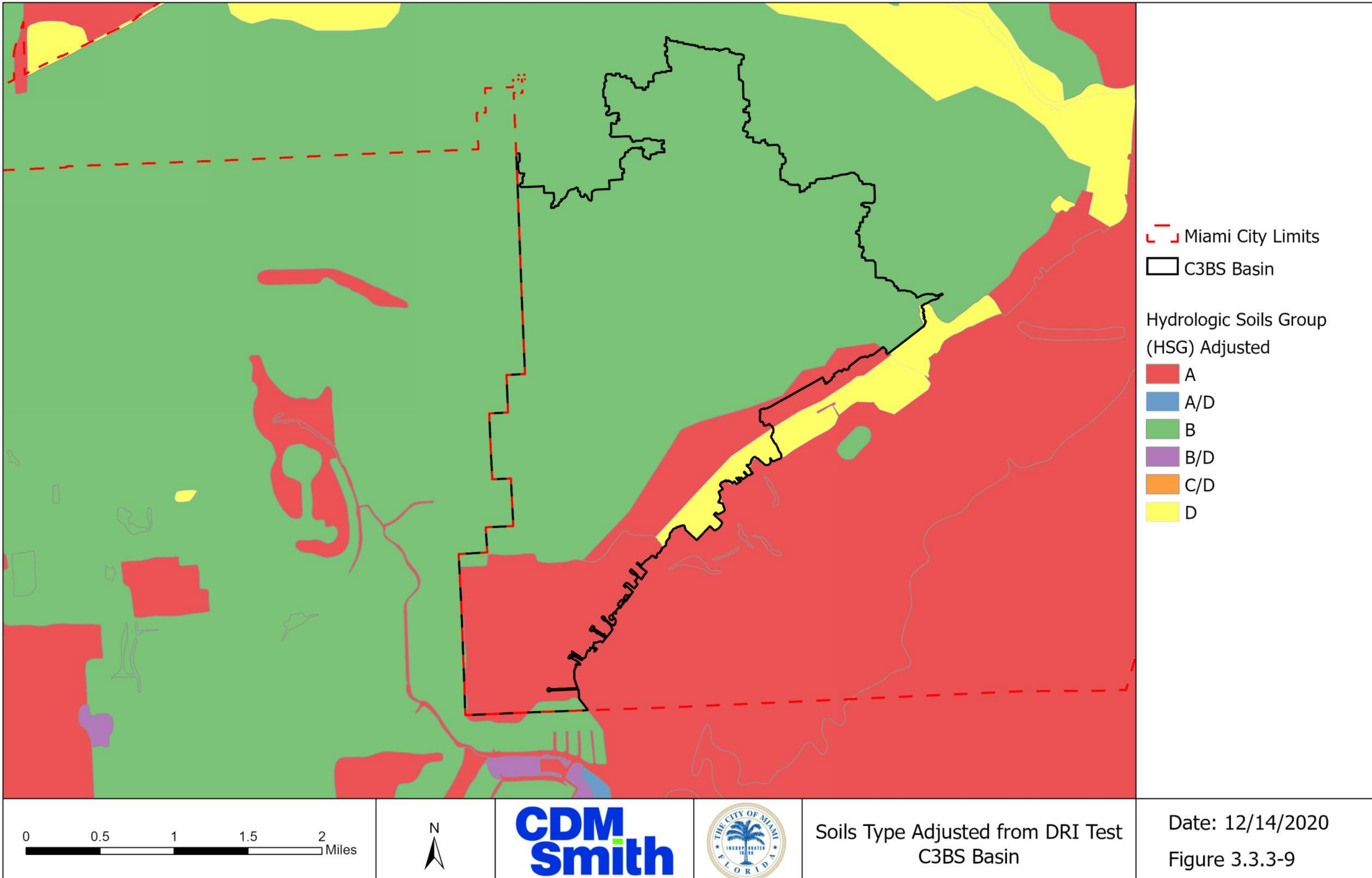
The project performed a limited number of double-ring infiltrometer tests in order to determine soil types throughout the project area. Miami-Dade County has performed similar tests. As discussed in the Model Development TM, the tests indicate Type A (sandy, or well-draining soils) soils at higher elevations, Type D (clay, or poor-draining soils) in low areas, particularly in the Miami River Floodplain, and intermediate soils elsewhere. Therefore, the C3BS Basin model uses Type A soils along the coastal ridge and higher coastal Biscayne area, Type D soils in the area encompassed by the David Kennedy Park, Kenneth Myers Park and S Bayshore Drive, and Type B (intermediate) soils in the low-lying regions within the C3BS Basin and the floodplain of the Sunrise Harbor waterway, as shown on **Figure 3.3.3-9**. Note that the rates on Figure 3.3-9, and the model parameter inputs, are Green-Ampt Hydraulic Conductivities, which do not directly correspond to the measured DRI soils infiltration rates.

3.3.3.2 C3BS Hydrologic and Hydraulic Model Elements

The developed H&H models for the C3BS Basin stormwater management system were used to evaluate the performance of the City's existing stormwater management system and to analyze future improvement projects (CIP). Model analysis evaluated the PSMS for multiple size rainfall events and downstream tidal boundary conditions. The PSMS includes constructed stormwater facilities and overland flow paths that drain to the downstream waterbody (i.e., boundary condition). The PSMS generally includes open channels and pipes of 24-inch diameter and larger. The C3BS Basin modeled area is 9,260 acres delineated into 482 sub-basins ranging in size from 0.7 to 490.1 acres with a mean size of 19.2 acres. Many of the smaller sub-basins delineate the area directly adjacent to the seawalls, which are necessary to model pre- and post-conditions for raised seawalls and backflow prevention but tend to be smaller than most of the City-wide delineation. The largest sub-basin within city limits is 34.2 acres and is located south of S. Dixie Highway and east of SW 22nd Avenue. The second largest sub-basin within city limits represents approximately 32.3 acres of an area north of S. Miami Avenue and South of S. Dixie Highway. **Table 3.3.3-2** summarizes the C3BS model elements.

Table 3.3.3-2 Summary of C3BS Model Elements

Sub-basins		482
Junctions		26
Storages	**Functional**	598
	Tabular	482
Outfalls		1
Conduits	**Circular**	535
	Arch	1
	Custom (Bridge)	2
	Ellipse	2
	Trapezoidal	1
	Rectangular Closed	273
	Irregular Canal	29
	Irregular Overland	855



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Soils Type Adjusted from DRI Test C3BS Basin

Date: 12/14/2020

Figure 3.3.3-9

Appendix B includes the C3BS Basin model schematic (**Figure C3BS-EC**) with standard symbology and Appendix C includes more detailed tables presenting the BC model element characteristics. These tables include the following:

- **Table C3BS-1** Hydrologic Parameters per Sub-basin
- **Table C3BS-2** Hydraulic Nodes Data
- **Table C3BS-3** Hydraulic Conduit Data
- **Table C3BS-4** Model Pump Data
- **Table C3BS-5** Model Weir Data
- **Table C3BS-6** Model Exfiltration Data

Model nodes representing manholes are modeled as functional storage nodes with a minimal amount of constant storage area (12.56 square feet, which is roughly equivalent to a typical 48-inch diameter manhole). Pump Station wet wells are modeled as functional storage nodes with constant areas equivalent to the wet well area, if the station dimensions were provided, or 100 square feet if the dimensions were not provided.

The C3BS Basin model has one primary outfall representing Biscayne Bay (BiscayneBay_South). Multiple pipe and seawall overland flow links have been combined at a virtual node (C3_BS_BC) to provide one link to this outfall because EPA SWMM only allows a single link per outfall. The outfalls have been co-located for ease in changing boundary conditions once the models have been turned over to the City. Additionally, 13 subbasins, 13 storage nodes, and 13 outfalls are used to model the exfiltration systems in the C3BS Basin. The virtual systems representing groundwater are not included in the model schematic nor in the tables. The groundwater table has been divided into 13 contiguous sections in the basin area because the initial level of the base groundwater varies depending on distance from Biscayne Bay and topography. The exfiltration systems are described in further detail in below.

The City's project-specific survey and the GIS coverage of stormwater pipes identifies 19 stormwater points of discharge simulated as outfalls that discharge to Biscayne Bay and another five that discharge to C3 canal in the C3BS Basin. There are an additional 18 outfalls representing sheet flow to Biscayne Bay and another 15 to the C3 canal from the sub-basins along the shore. Generally, the overland sheet flow cross-sections represent the seawall surveyed in that area. If a seawall is not present over a portion of the shoreline, 0.0 ft-NAVD 88 is used as the overflow elevation. The topography behind the shoreline is determines the opposite side of the seawall edge sub-basin, and the subsequent overland flow elevation to the rest of the neighborhood.

3.3.3.3 C3BS Pump Stations

There are no existing pump stations in the C3BS Basin.

3.3.3.4 C3BS Exfiltration

The C3BS Basin uses exfiltration systems as one of its primary methods to reduce flooding and improve water quality by moving water from the PSMS to the Biscayne Aquifer. These systems include:

- Slab Covered Trenches: Rectangular boxes cut directly into the limestone aquifer, then covered with a concrete slab. There are approximately 21.2 miles of slab covered trench in the C3BS Basin.

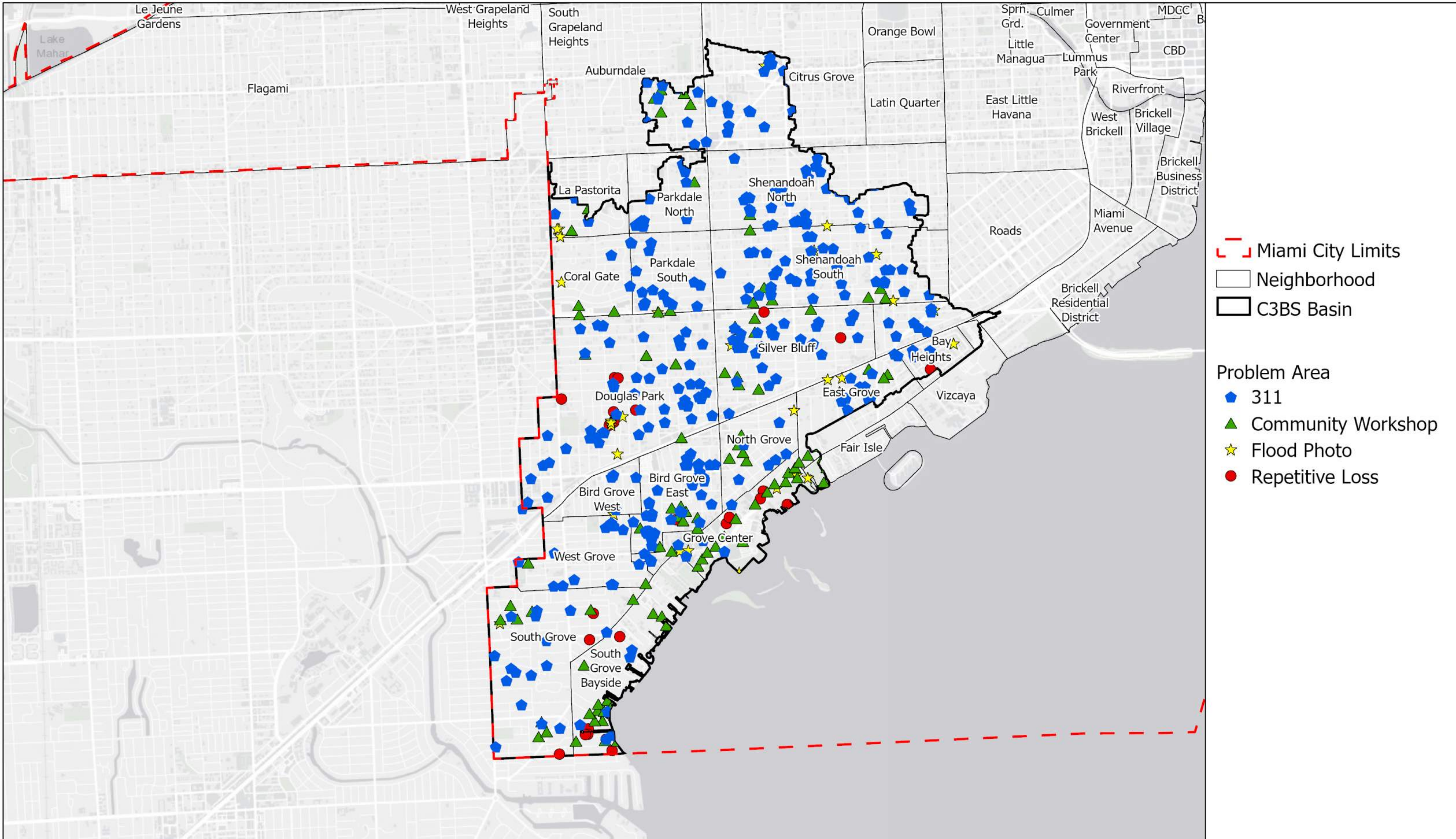
- French Drains: Perforated pipe situated in a gravel-filled rectangular shaped excavation into the aquifer. There are approximately 25.1 miles of French Drains in the C3BS Basin.

- Recharge/Drainage Wells: There are 64 gravity drainage/recharge wells in the C3BS Basin. There are two types of recharge wells used in the Miami area - gravity driven wells and injection (pumped) wells. Injection wells are accounted for in the pumped flows to outfall representing the aquifer (see above) and therefore not included in the exfiltration rating curves. Gravity drainage wells use the differential driving head of the land surface water surface elevation and the aquifer ground water table elevation to overcome the well casing friction and any salinity interface density to push stormwater runoff out into the porous and highly transmissive limestone layer underground. The use of Biscayne aquifer drainage wells is restricted to zones where chloride concentrations exceed the saltwater intrusion front identified as the location at the base of the aquifer, of the 1,000 mg/L isochlor and there are no impacts to Class G-II potable water supply aquifers.

In the C3BS Basin, the regional water table elevation is estimated for 13 separate regions. Each region has a specified initial water table level based on the Miami-Dade County base groundwater elevation database. Note, these initial levels are higher in the sea level rise scenarios. The regional water tables are designed to simulate actual conditions and rise in the model based on precipitation and infiltration, using generic regional land-use estimates, i.e. the 13 model sub-basins ("GWC3" prefix), 13 storage nodes ("BiscayneAQC3" prefix) and 13 outfalls ("AQLossOut" prefix) are virtual elements designed solely to predict water table elevations and are not hydrologically or hydraulically connected to the model PSMS. The exfiltration rating curves are developed outside the model in a spreadsheet, based on length of system and count of wells per sub-basin, and other sub-basin specific parameters. The curves are head versus flow curves, where the head is internally calculated in the model by subtracting the regional groundwater elevation from the site-specific flood stage. In the large design storms, some of the low-lying exfiltration systems cease operations as the water table rises to ground surface. The Model Development TM provides more details on the exfiltration systems and how rating curves were developed for each type per model sub-basin.

3.3.3.5 C3BS Known Flooding Problem Areas

Known problem areas in C3BS Basin include the neighborhoods of Shenandoah North, Shenandoah South, Silver Bluff, Parkdale North, Parkdale South, Douglas Park, East Grove, Bird Grove East, West Grove and South Grove. Neighborhoods with flooding problems along the coast include South Grove Bayside and Grove Center. **Figure 3.3.3-10** indicates where complaints related to flooding were made in the C3BS Basin.



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Known Problem Areas
C3BS Basin (Neighborhoods)

Date: 12/14/2020

Figure 3.3.3-10

3.3.3.6 C3BS Design Storm Simulations

A range of simulations were performed in the C3BS Basin model covering the multiple design storm intensities and an array of boundary conditions. **Table 3.3.3-3** presents all the simulation scenarios being run for the master plan, only the Base Condition run was performed for this TM.

Design storm distributions were taken from the SFWMD Permit Information Manual, Volume IV. Model simulations are performed for the 5-year, 24-hour design storm; and the 10-year, 25-year, and 100-year, 72-hour design storms. The 24-hour design storm has a peak centered at 12 hours, while the 72-hour design storms have peak intensities at 60 hours. The SFWMD design storm distributions are sampled at 5-minute increments. Design Storm volumes were extracted for localized actual recorded rainfall data from the NOAA Atlas 14, as shown previously in Table 3.3-1. Initial depths for nodes in the model were set to match the boundary conditions to create an even starting surface within all areas of the models including pumped areas.

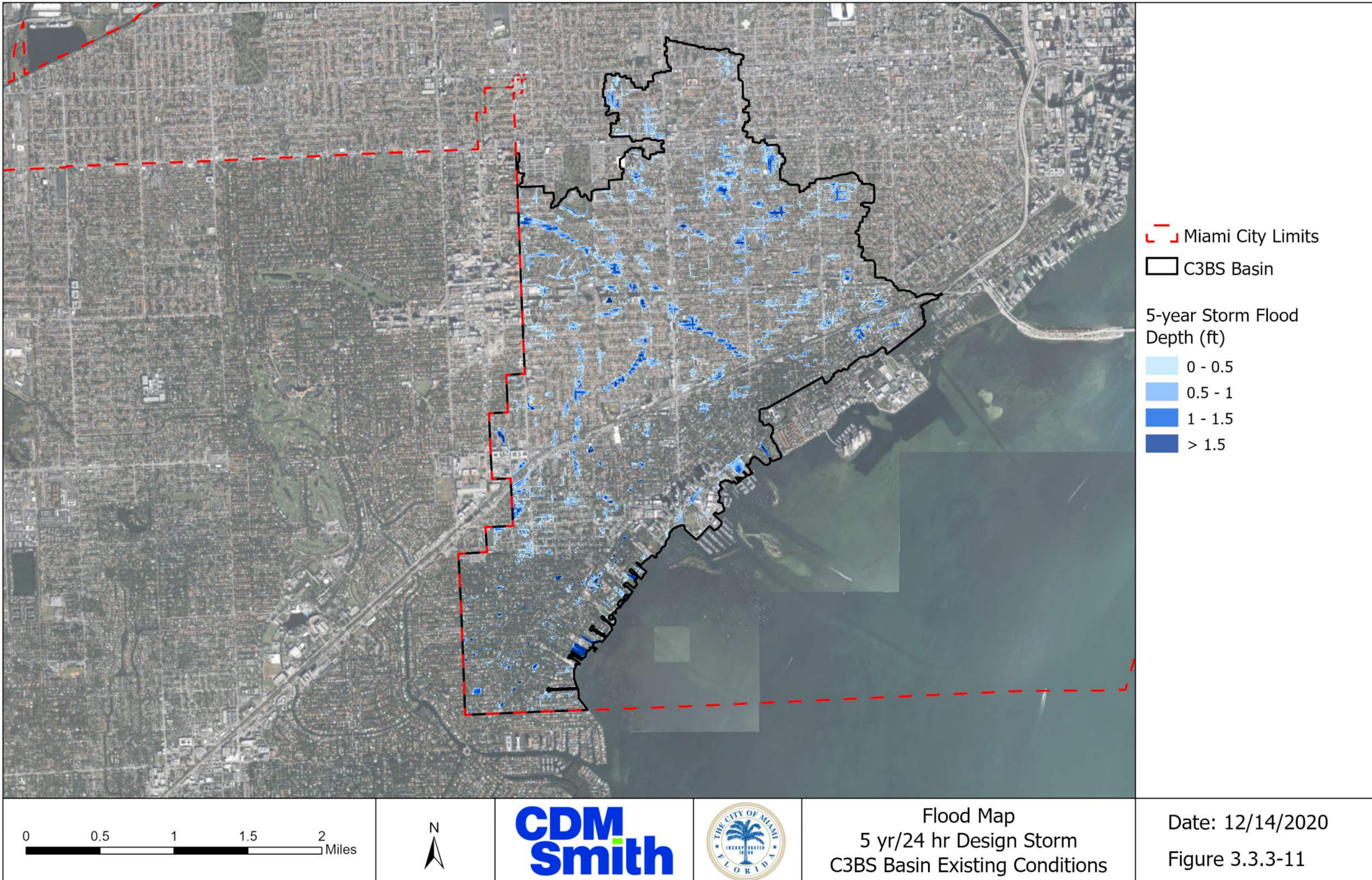
Table 3.3.3-3 Design Storm Simulations

Tailwater Condition	Tailwater Stage in Biscayne Bay (ft-NAVD 88)			
	5-yr, 24-hr	10-yr, 72-hr	25-yr,72-hr	100-yr, 72-hr
Base Condition*	2.0	2.0	2.0	2.0
Base Plus 1.5 feet Sea Level Rise (SLR)	3.5	3.5	3.5	3.5
Base Plus 2.5 feet SLR	4.5	4.5	4.5	4.5
10-year Storm Surge		6.0		

* Base condition represents the one-year stillwater tide elevation – see Model Development TM.

3.3.3.7 C3BS Existing Conditions Model Results and Design Storm Inundation Mapping

The verified C3BS Basin EC model was run for the base simulation for each design storm considering a well maintained, clean pipe condition. A summary of peak flood stages for the simulated EC model is published by the City in the tables for the on-line stormwater GIS. Flood mapping of the base simulations of existing conditions for the 5-year, 24-hour design storm; and the 10-year, 25-year, and 100-year, 72-hour design storms are presented on **Figures 3.3.3-11 through 3.3.3-14**.



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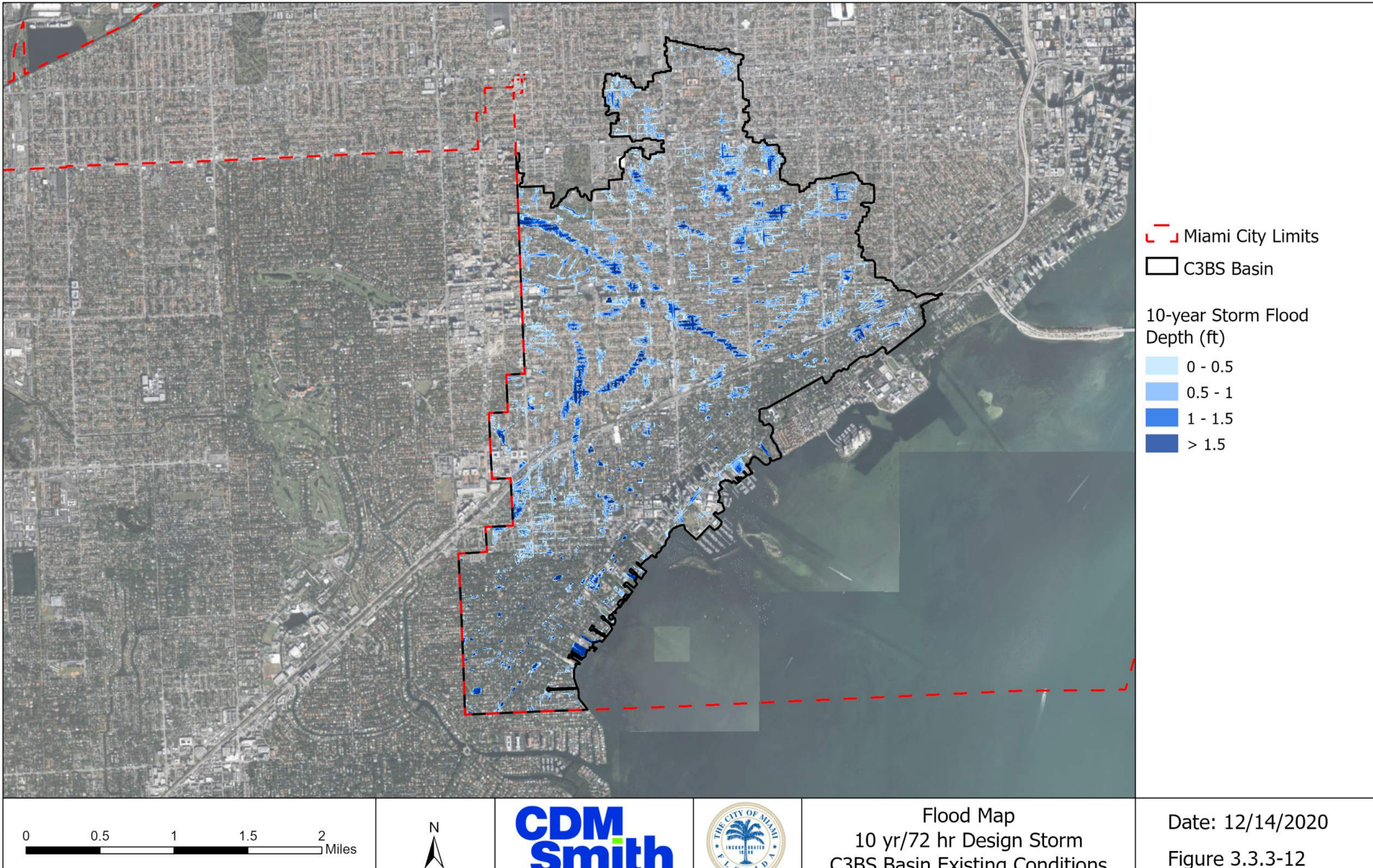
Flood Map
5 yr/24 hr Design Storm
C3BS Basin Existing Conditions

Date: 12/14/2020

Figure 3.3.3-11



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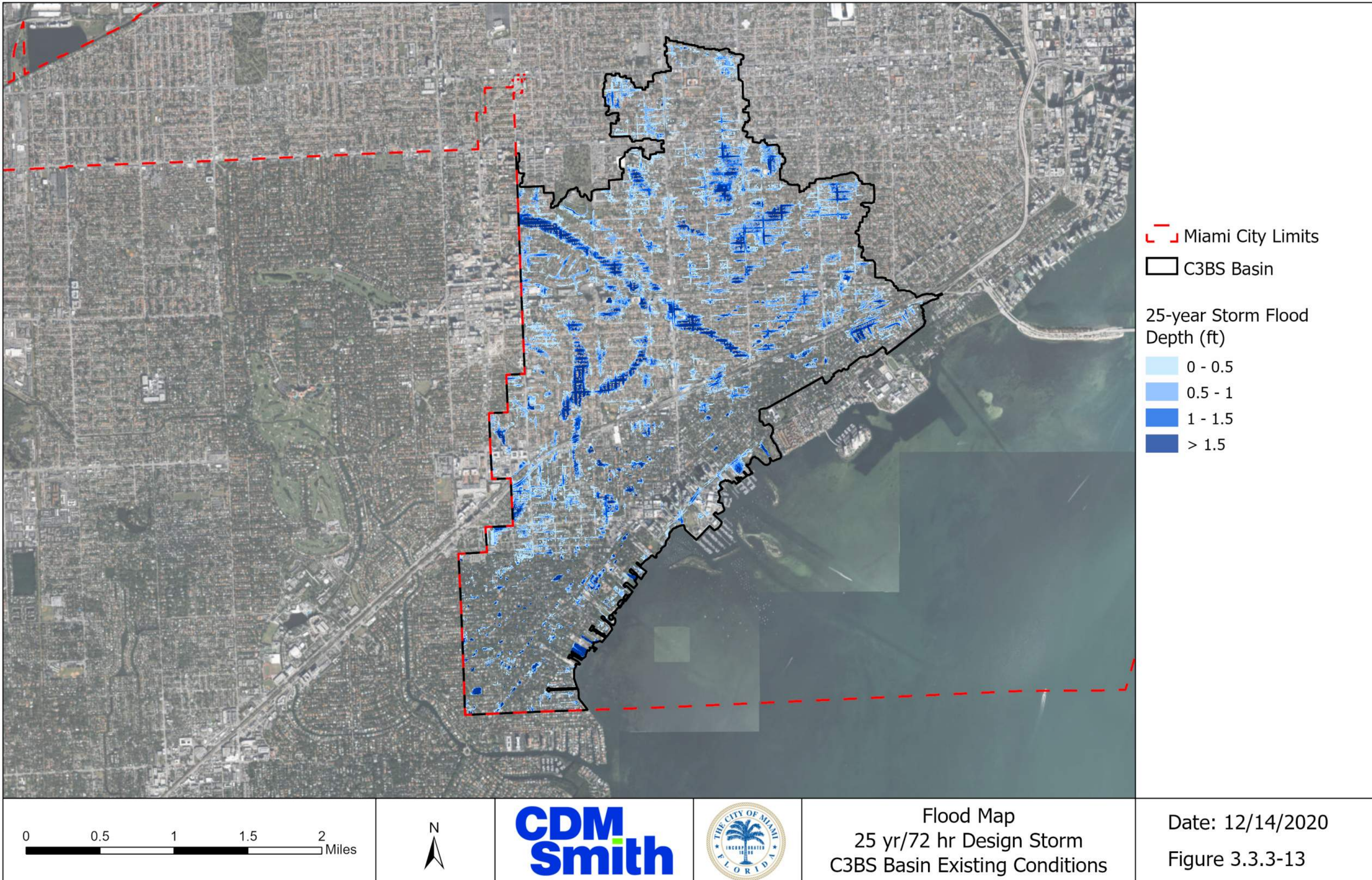
Flood Map
10 yr/72 hr Design Storm
C3BS Basin Existing Conditions

Date: 12/14/2020

Figure 3.3.3-12

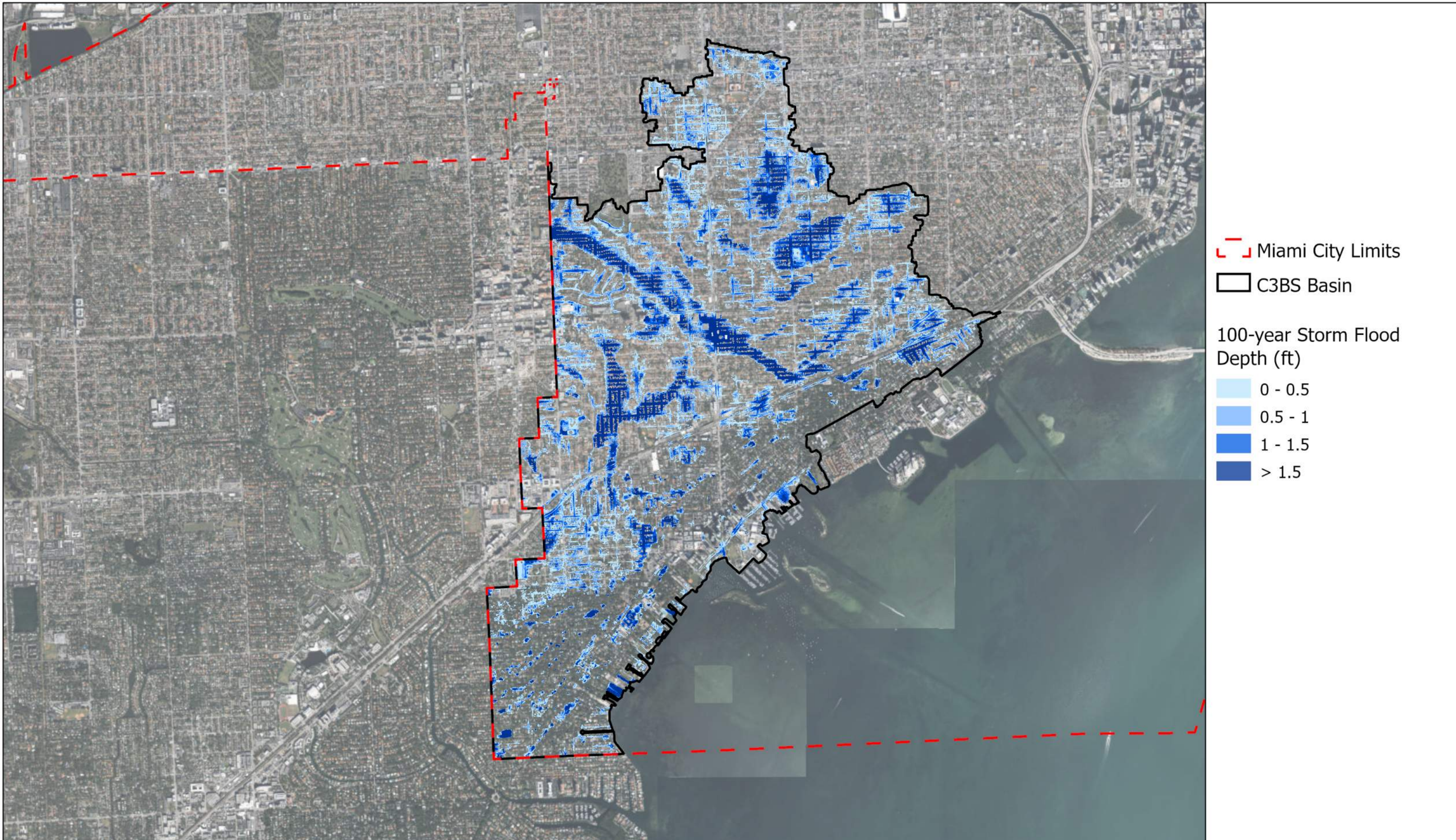


CDM Smith

Flood Map
25 yr/72 hr Design Storm
C3BS Basin Existing Conditions

Date: 12/14/2020

Figure 3.3.3-13



0 0.5 1 1.5 2 Miles

N

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Flood Map
100 yr/72 hr Design Storm
C3BS Basin Existing Conditions

Date: 12/14/2020

Figure 3.3.3-14

3.3.3.8 C3BS Model Result Summary and Existing Conditions Level of Service Scoring

Peak flood stages were compared to indicator elevations through the basin for the 10-year storm to determine the existing flood LOS for roads, and for the 100-year storm to determine the existing LOS for buildings.

The C3BS Basin was analyzed and grouped logically into 16 improvement regions (LOS Areas) considering in-common topography and PSMS elements. **Table 3.3.3-4** presents the length of road flooded above crown in each region for the 10-year storm, base condition, and the number of buildings expected to flood for the 100-year storm, base condition. Because the verification of each individual FFE for every building and residence property in Miami is not within of the scope of this project, a standard one-foot above existing grade has been added to the LiDAR DEM around the periphery of each structure as a reasonable estimate of the minimum building FFEs. Approximately 300 FFEs were field verified in the deepest flooding areas by ground survey and the DEM numbers were adjusted accordingly. It is noted that Current Florida Building Code requires 1 foot or more above the BFE depending on the FIRM flood hazard zone within which the property is located. Future minimum FFEs may be required to include additional height provisions for sea level rise.

The LOS score for each region was determined by the following equation:

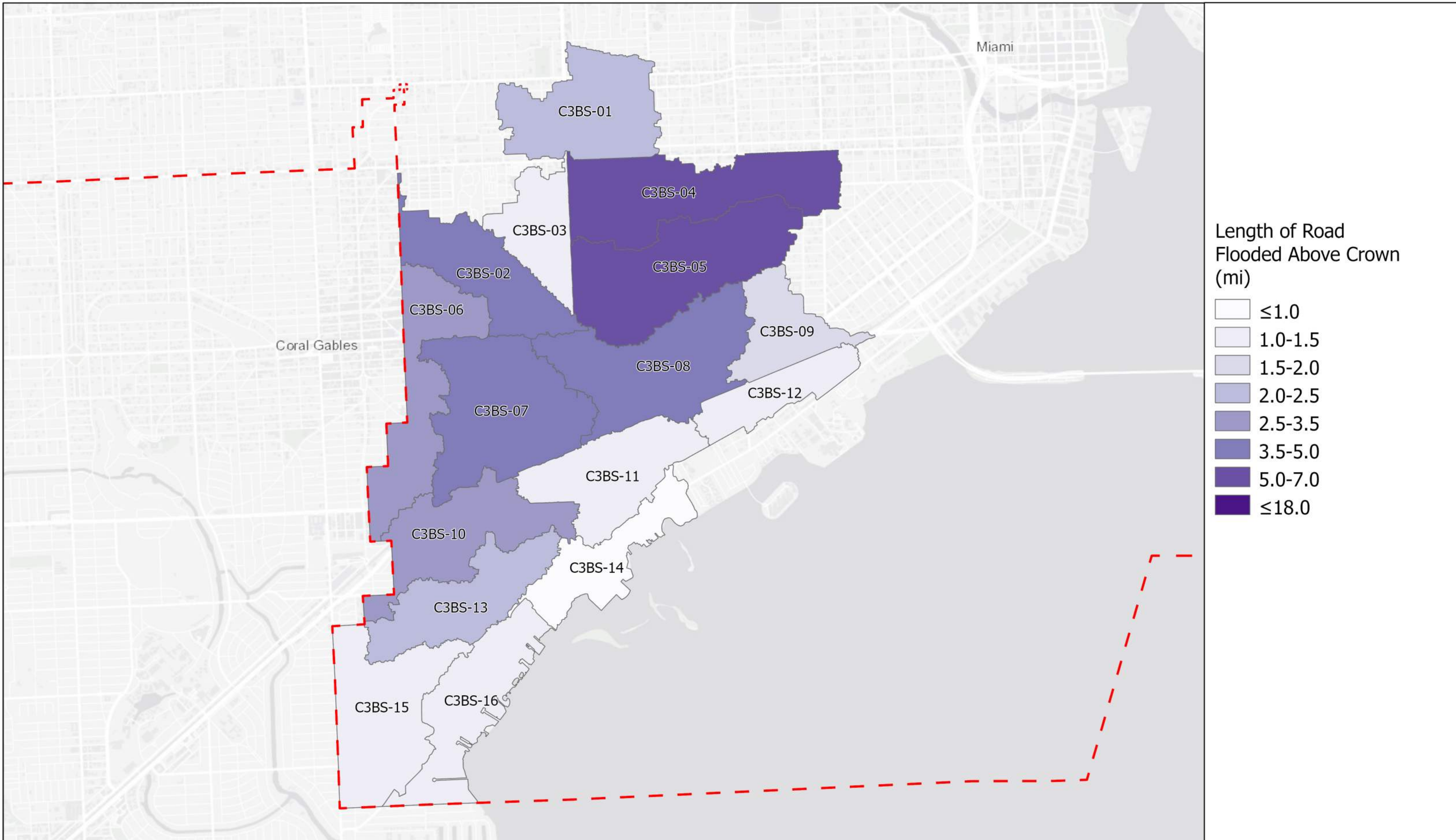
$S_{LOS} = C_1 * Len_{10} + C_2 * Bldg_{100} + C_3 * Str_{Crit}$;

Where S_{LOS} is the LOS score, Len_{10} is the length of road flooded above crown for the 10-year storm in linear feet and normalized by population, $Bldg_{100}$ is the number of buildings flooded above the estimated FFE for the 100-year storm, normalized by population, Str_{Crit} is the number of critical structures identified in the region, and C_1, C_2 and C_3 are coefficients which may be used by the City of Miami to help rank neighborhoods. Higher scores indicate worse predicted Current LOS problems. These rankings are for initial evaluation purposes only, as the two proposed LOS alternatives mitigate all of the problem areas, not just those in the highest ranked areas.

Figures 3.3.3-15 and 3.3.3-16 provide the relative existing conditions predicted LOS flooding of roadways and structures respectively for the C3BS Basin. Additionally, 144 critical structures were identified in the study area (emergency operations, police, fire, hospital, evacuation shelter, government, etc.) and added to the surveyed FFEs.

Table 3.3.3-4 C3BS Basin Existing LOS Ranking

LOS Region	Primary Neighborhood in LOS Area	All Neighborhoods in LOS Area	Area (acres)	Flooded Area 100yr (acres)	Flooded Area/Total Basin Area	Population (2010)	Length of Street Flooded (mi)	Length of Street Flooded/Total Length of Street Flooded 10yr [1]	Est # of Buildings Flooded (100 yr)	# of Buildings Flooded/Total # of Buildings Flooded (100 yr) [1]	# of Critical Structures Flooded (100 yr)	# of Critical Structures Flooded/Total # of Critical Structues Flooded (100 yr) [1]	Basin Relative Flood Ranking
C3BS-01	Citrus Grove West	Citrus Grove, Auburndale	310.6	198.1	8.17%	6,344	2.10	4.82%	5	0.29%	3	74.74%	0.79851
C3BS-02	Parkdale South	Parkdale North, La Pastorita, Shenandoah South, Parkdale South, Coral Gate, Silver Bluff, Douglas Park	253.9	170.8	7.05%	4,444	3.41	7.83%	248	14.54%	0	0.02%	0.22395
C3BS-03	Parkdale North	Citrus Grove, Auburndale, Shenandoah North, Parkdale North, La Pastorita, Shenandoah South, Parkdale South	166.3	102.1	4.21%	3,235	1.28	2.94%	38	2.23%	0	0.02%	0.05193
C3BS-04	Shenandoah North	Citrus Grove, Auburndale, Latin Quarter, Shenandoah North, Parkdale North, Roads, Shenandoah South, East Little Havana	396.7	245.6	10.13%	9,037	5.73	13.17%	195	11.43%	1	24.91%	0.49509
C3BS-05	Shenandoah South	Shenandoah North, Shenandoah South, Parkdale South, Silver Bluff	427.8	233.9	9.65%	7,837	6.90	15.84%	283	16.59%	0	0.02%	0.32452
C3BS-06	Coral Gate	Parkdale South, Coral Gate, Douglas Park	300.5	178.0	7.34%	5,666	3.40	7.82%	24	1.41%	0	0.02%	0.09251
C3BS-07	Douglas Park	Parkdale South, Coral Gate, Silver Bluff, Douglas Park	424.6	240.0	9.90%	10,577	4.25	9.76%	458	26.85%	0	0.02%	0.36631
C3BS-08	Silver Bluff	Roads, Shenandoah South, Parkdale South, Silver Bluff, Douglas Park, East Grove	394.4	223.1	9.20%	5,758	4.52	10.38%	232	13.60%	0	0.02%	0.24002
C3BS-09	Southwest Roads	Roads, Miami Avenue, Shenandoah South, Silver Bluff, Vizcaya, Bay Heights, East Grove	167.2	105.5	4.35%	2,422	1.56	3.58%	13	0.76%	0	0.02%	0.04368
C3BS-10	Bird Grove	Douglas Park, Bird Grove East, Bird Grove West, West Grove	292.1	161.7	6.67%	4,291	2.80	6.42%	68	3.99%	0	0.02%	0.10434
C3BS-11	North Grove	Silver Bluff, Douglas Park, East Grove, North Grove, Bird Grove East, Grove Center	272.5	74.5	3.07%	3,295	1.01	2.32%	12	0.70%	0	0.02%	0.03053
C3BS-12	East Grove	Roads, Miami Avenue, Vizcaya, Bay Heights, East Grove	148.2	54.5	2.25%	1,089	1.26	2.89%	45	2.64%	0	0.02%	0.05551
C3BS-13	West Grove	Bird Grove East, Grove Center, Bird Grove West, West Grove, South Grove Bayside, South Grove	258.1	138.3	5.71%	3,851	2.14	4.91%	65	3.81%	0	0.02%	0.08743
C3BS-14	Grove Center	East Grove, North Grove, Fair Isle, Bird Grove East, Grove Center, West Grove, South Grove Bayside	200.7	60.8	2.51%	1,602	0.53	1.22%	1	0.06%	0	0.02%	0.01301
C3BS-15	South Grove	West Grove, South Grove Bayside, South Grove	342.6	127.2	5.25%	2,151	1.27	2.93%	10	0.59%	0	0.02%	0.03536
C3BS-16	South Grove Bayside	West Grove, South Grove Bayside, South Grove	279.4	109.9	4.53%	1,191	1.38	3.18%	9	0.53%	0	0.02%	0.03731
Totals	16		4,635.4	2,424.2	100%	72,790.0	43.5	100%	1706	100%	4	100%	



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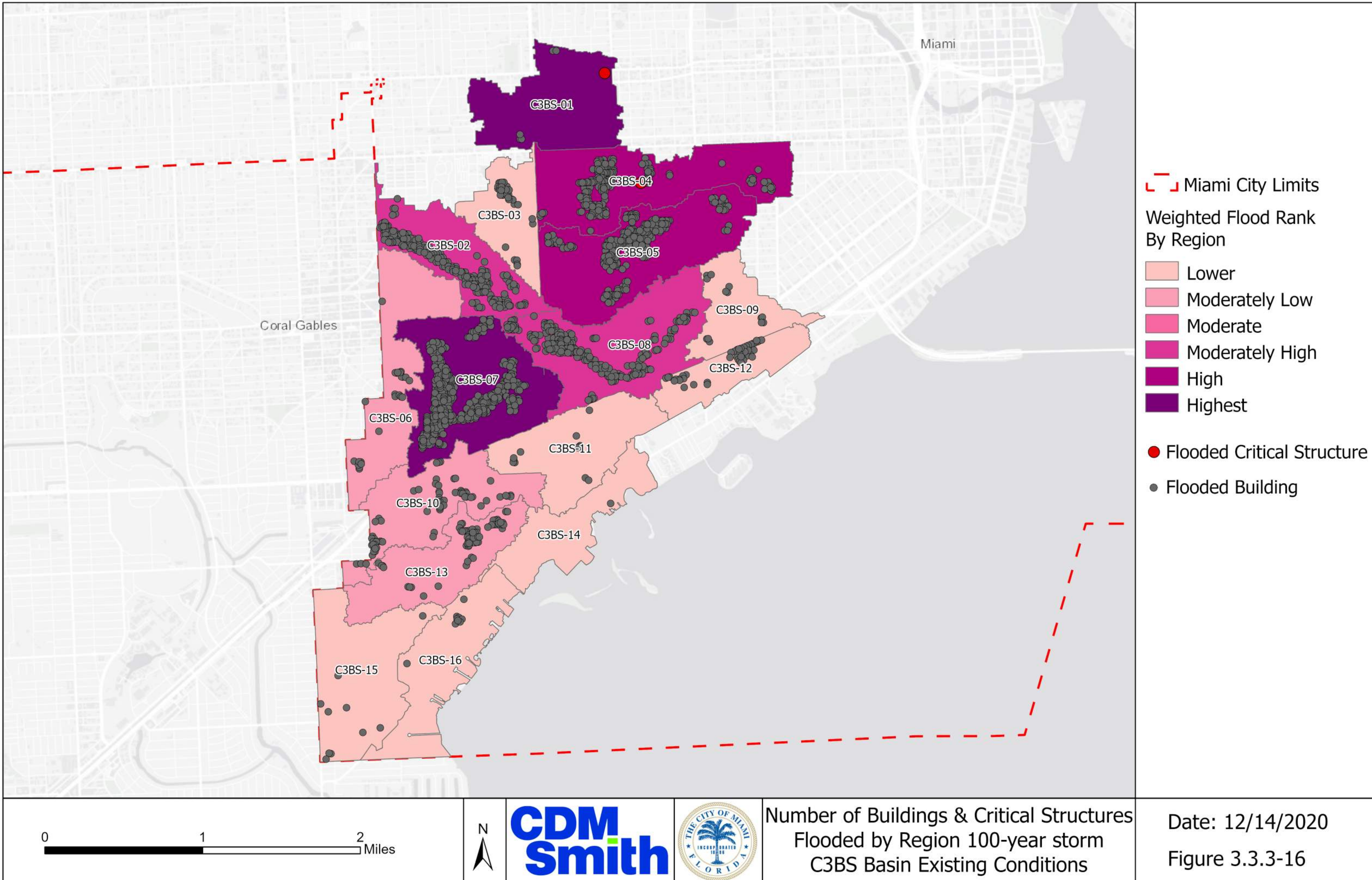
Length of Road Flooded Above Crown by Region 10-year storm C3BS Basin Existing Conditions

Date: 12/14/2020

Figure 3.3.3-15



Number of Buildings & Critical Structures Flooded by Region 100-year storm C3BS Basin Existing Conditions

Date: 12/14/2020

Figure 3.3.3-16

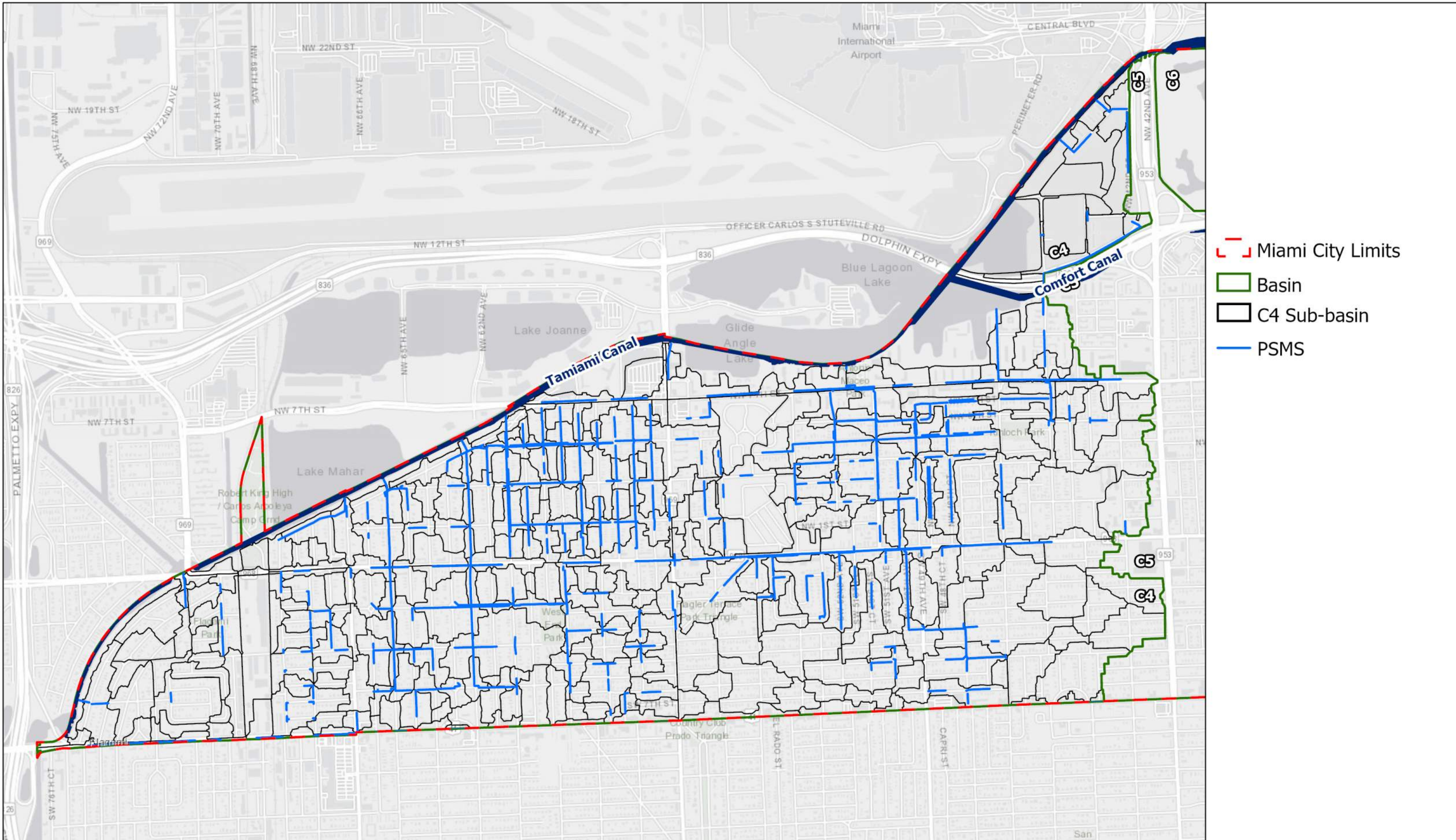
3.3.4 C-4 Basin (C4)

3.3.4.1 C4 Basin Description

The C-4 (C4) Basin consists of 3,284 acres of low-lying land that primarily discharges to Biscayne Bay. **Figure 3.3.4-1** includes a delineation of the C4 Basin and a simplified representation of the PSMS within the basin. The C4 Basin is characterized by PSMS discharge south of the C-4 canal and north of SW 8th Street. The basin necessarily includes tributary beyond the City boundaries. The northern boundary is delineated by the C-4 Canal, the Glide Angle Lake and Miami International Airport. The western boundary is delineated by the C-4 Canal following topography. The Southern boundary is adjacent to the C3BS Basin and delineated by SW 8th Street following topography. The eastern boundary is adjacent to the C-5, C-6 and C7BN Basins and delineated by 42nd Avenue following topography.

Figure 3.3.4-2 shows the DEM for the C4 Basin. Topographic elevations range from near 0 ft-NAVD 88 in areas near C4 canal and the Glide Angle Lake to approximately 15 ft-NAVD 88 in small areas in the southeastern portion of the basin. In the C4 Basin, there is a large low-lying area running along the northwest portion of the basin with elevations below 5 ft-NAVD 88. Approximately 97% of the C4 Basin's stormwater inlets are between 3 feet and 15 feet NAVD 88; however, over 70 PSMS inlets (2.9%) are located where the LiDAR elevations are below 3 feet NAVD 88. Over 300 inlets (12.0%) are located where the LiDAR elevations are below 4 fee NAVD 88. The lower elevations are all near the lake system and C4 canal. These inlets are susceptible to storm surge. Further, low street elevations preclude using gravity recharge wells or other exfiltration systems, since the driving heads are small. Existing exfiltration systems in these areas are not expected to work well, either in the model or actual operation.

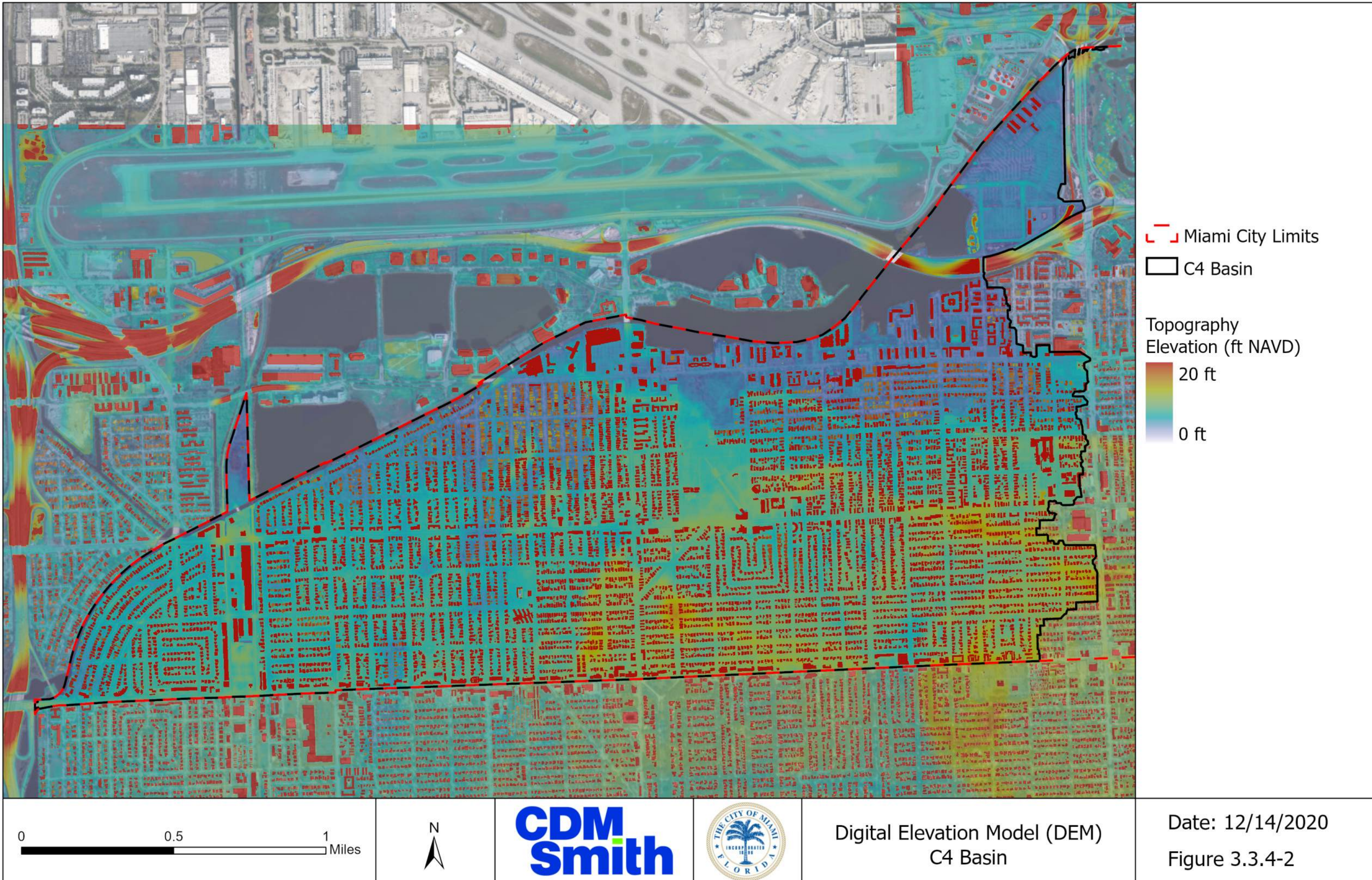
Figure 3.3.4-3 presents a map of the impervious cover for the C4 Basin based on the USGS NLCD coverage as discussed in the Model Development Technical Memorandum and **Figure 3.3.4-4** presents a map of the SFWMD land-use for the C4 Basin.



Sub-basin Delineation and PSMS
C4 Basin

Date: 12/14/2020

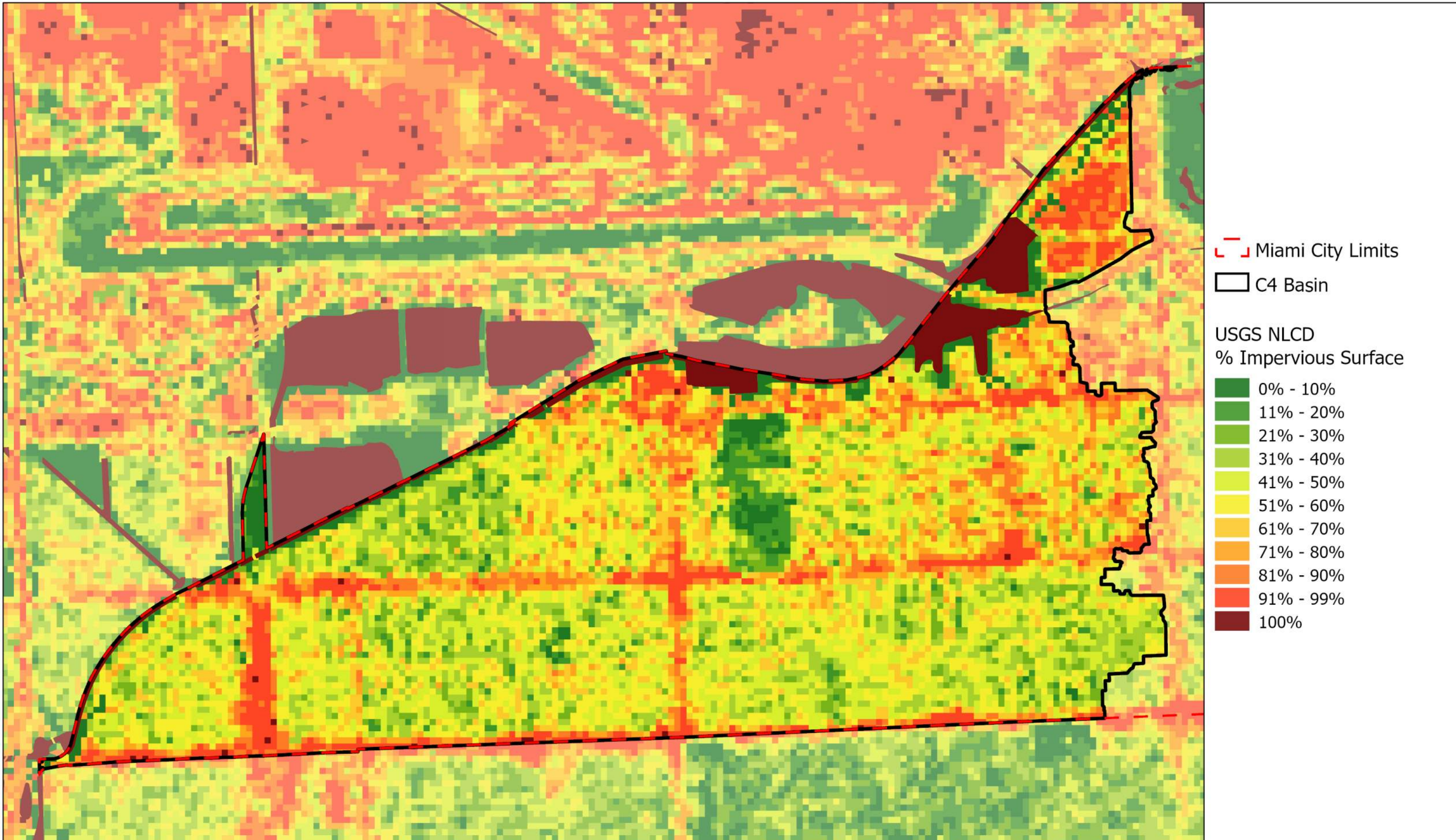
Figure 3.3.4-1



Digital Elevation Model (DEM)
C4 Basin

Date: 12/14/2020

Figure 3.3.4-2



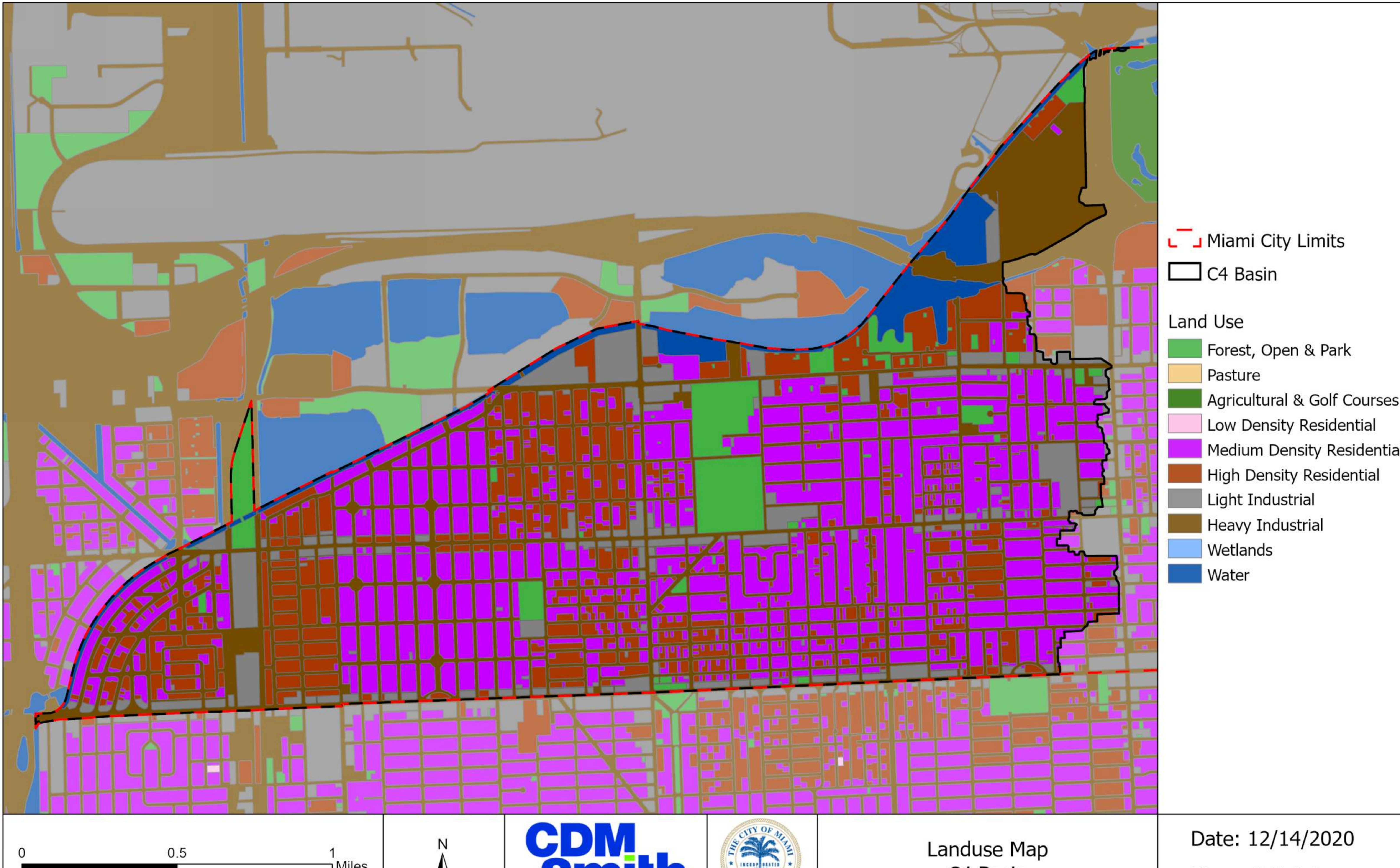
0 0.5 1 Miles

N

Impervious Cover
C4 Basin

Date: 12/14/2020

Figure 3.3.4-3



Landuse Map
C4 Basin

Date: 12/14/2020

Figure 3.3.4-4

As described in detail in the Model Development TM, impervious coverages were intersected with the sub-basin delineations, adjusted using the developed USGS impervious weightings, and a percentage of the total impervious routed to pervious based on land-use parameters. **Figure 3.3.4-5** presents the total impervious percentage in the C4 Basin, delineated by sub-basin, after the adjustment for pervious/impervious routing was applied. **Figure 3.3.4-6** presents a breakdown of the land use by ten standard consolidated categories, for use in the model. **Figure 3.3.4-7** presents a breakdown of the impervious cover in the model. The area-weighted total impervious percent of the C4 Basin is estimated to be 65%; therefore, approximately 2,141 acres of the 3,282 acres are expected to be impervious surface. Of this, approximately 499 acres are expected to be routed to pervious surfaces prior to entry into the BN Basin PSMS. The routing of runoff to pervious surfaces does not affect the volume infiltrated to soils but does change the timing of the hyetograph.

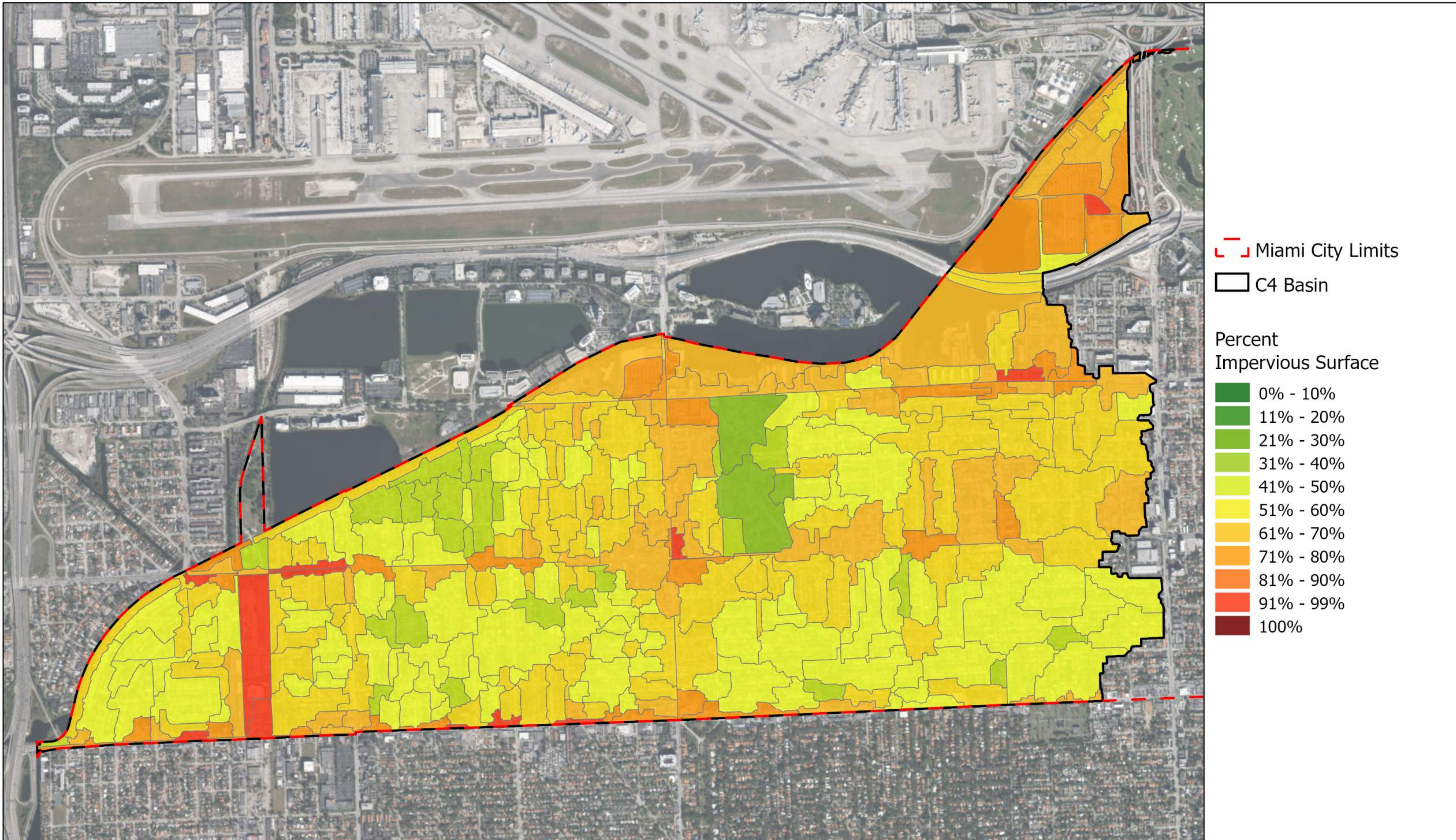
For design storm simulations, the SFWMD 24-hour and 72-hour unit hydrographs were used to implement the rainfall distributions per storm. **Table 3.3.4-1** presents the volumes for the C4 Basin for the 5-year, 24-hour; and 10-year, 25-year, and 100-year 72-hour design storms that were obtained from the NOAA Atlas 14. Design Storm rainfall volumes may be found for select gages in the atlas, or an interpolated volume estimate may be found for point locations. For this basin, point location estimates were made across the basin. In order to be conservative, the highest volume was used as the design rainfall volume over the entire basin. In general, the western edge of the basin has slightly higher expected volumes than the coastal edge.

Table 3.3.4-1 C-4 Basin Design Storm Volumes and Intensities

Storm	Rainfall Depth (inches)*	Peak 5-min Intensity (inches/hr)
5-year, 24-hour	7.1	5.5
10-year, 72-hour	10.6	6.1
25-year, 72-hour	13.2	7.5
100-year, 72-hour	17.7	10.1

* NOAA Atlas 14 provides 1-day volumes to the hundredths and 3-day volumes to the tenths of an inch

Surface soils in the C4 Basin are mostly described as “urban” with a western portion classified as “group A” in the NRCS soils map included as shown on **Figure 3.3.4-8.** In order to apply the Modified Green-Ampt infiltration in SWMM, the urban soils needed to be characterized in more detail.



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THE CITY OF MIAMI FLORIDA

Total Impervious Percentage
C4 Basin

Date: 12/14/2020

Figure 3.3.4-5

Figure 3.3.4-6 Landuse Category Breakdown for C4 Basin

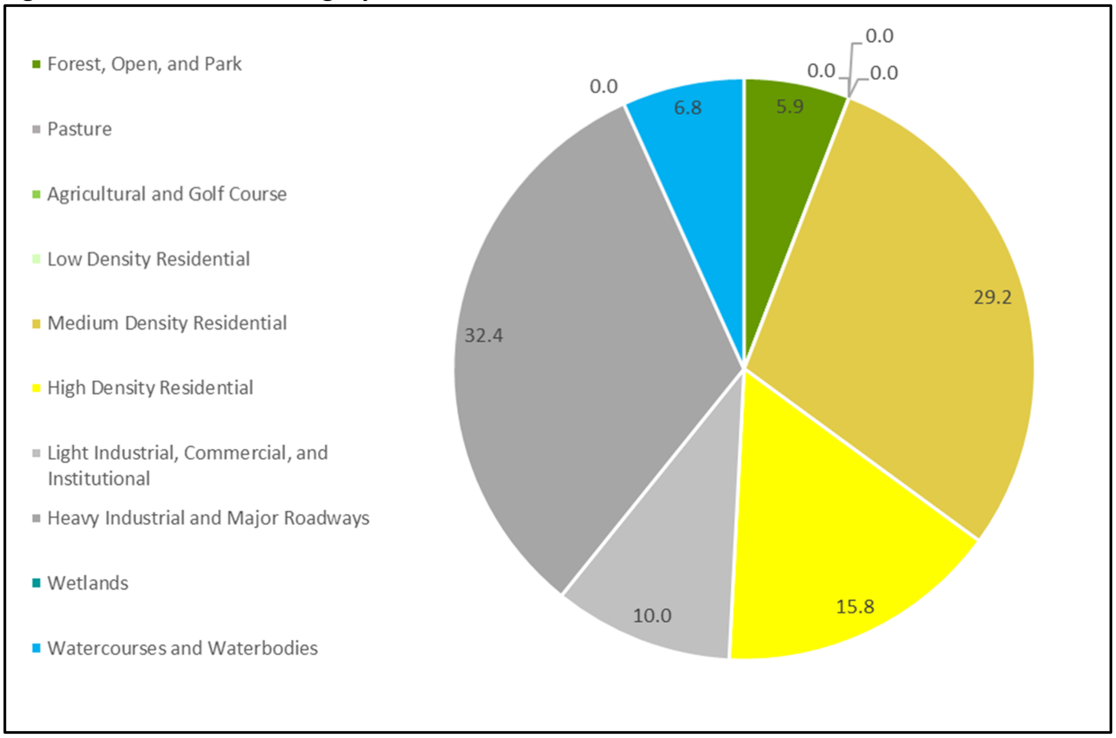
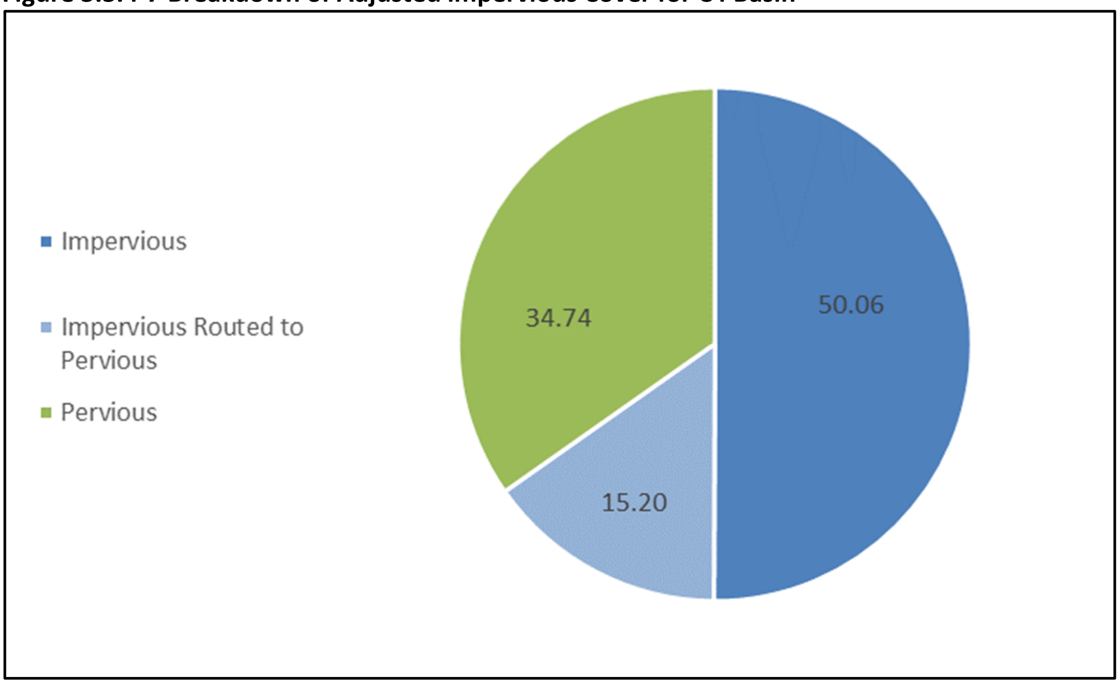
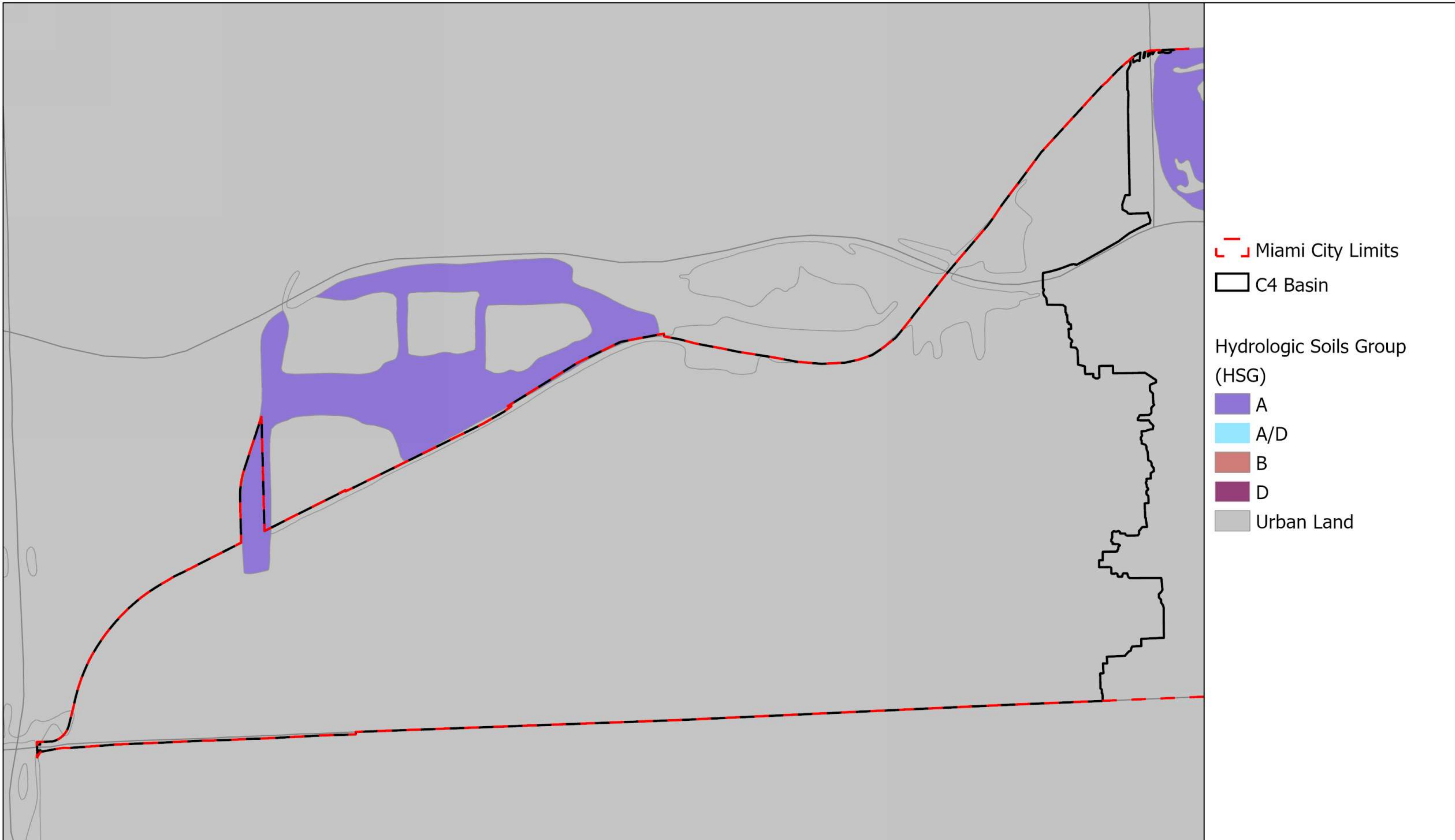


Figure 3.3.4-7 Breakdown of Adjusted impervious Cover for C4 Basin





CDM Smith

NRCS Soils Map
C4 Basin

Date: 12/14/2020

Figure 3.3.4-8

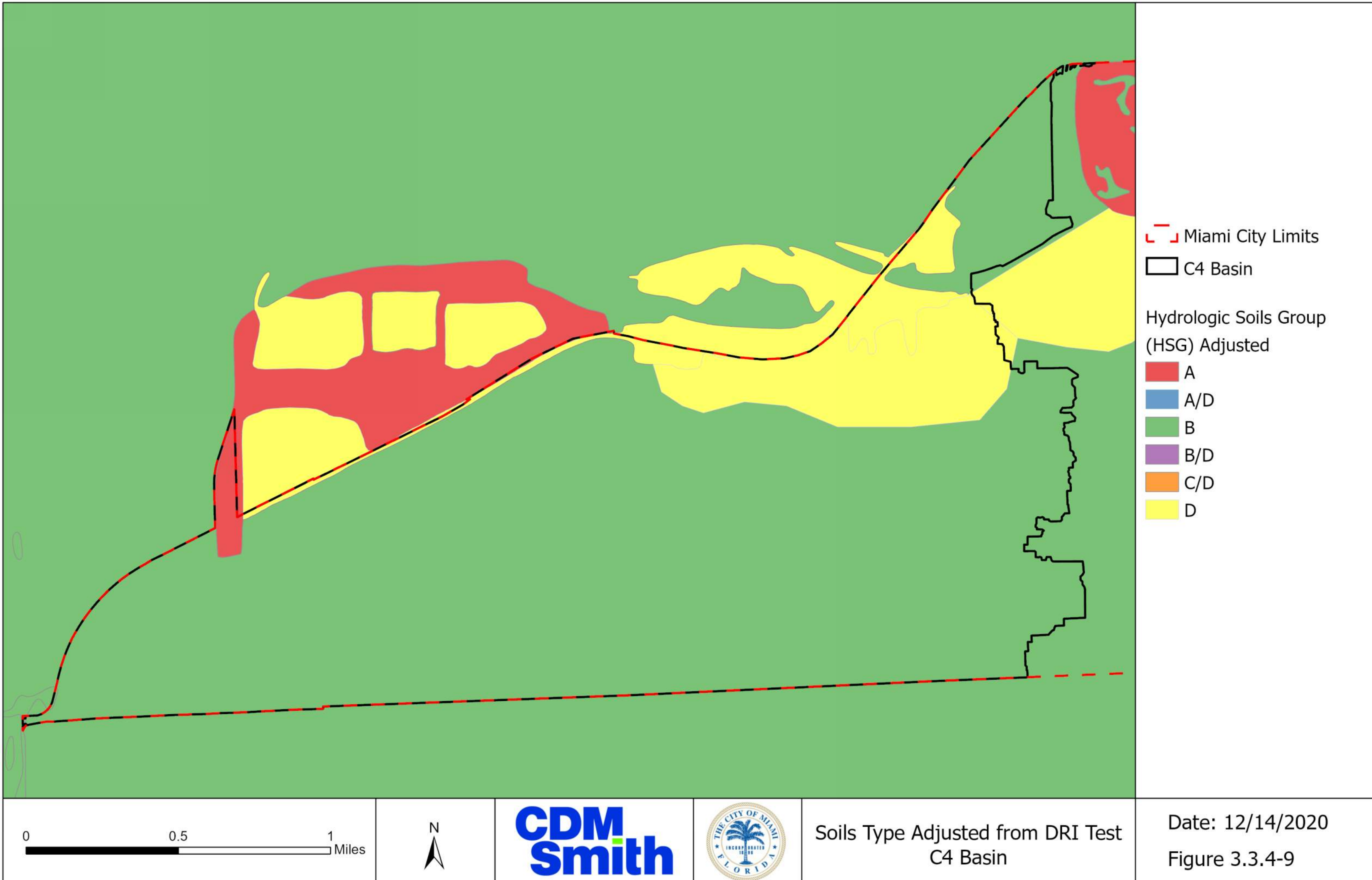
The project performed a limited number of DRI tests in order to determine soil types throughout the project area. Miami-Dade County has performed similar tests. As discussed in the Model Development TM, the tests indicate Type A (sandy, or well-draining soils) soils at higher elevations, Type D (clay, or poor-draining soils) in low areas, particularly in the Miami River Floodplain, and intermediate soils elsewhere. Therefore, the C4 Basin model uses Type D soils in the low laying areas adjacent to the Glide Angle and Blue Lagoon Lakes, Type A soils in the area north of the Tamiami Canal, and Type B (Intermediate) soils in the Flagami West, Flagami Central and south portion of Le Jeune Gardens neighborhoods, as shown on **Figure 3.3.4-9**. Note that the rates on Figure 3.3.4-9, and the model parameter inputs, are Green-Ampt Hydraulic Conductivities, which do not directly correspond to the measured DRI soils infiltration rates.

3.3.4.2 C4 Hydrologic and Hydraulic Model Elements

The developed H&H models for the C4 Basin stormwater management system were used to evaluate the performance of the City's existing stormwater management system and to analyze future improvement projects (CIP). Model analysis evaluated the PSMS for multiple size rainfall events and downstream tidal boundary conditions. The PSMS includes constructed stormwater facilities and overland flow paths that drain to the downstream waterbody (i.e., boundary condition). The PSMS generally includes open channels and pipes of 24-inch diameter and larger. The C4 Basin modeled area is 3,282 acres delineated into 365 sub-basins ranging in size from 0.4 acres to 162.1 acres with a mean size of 9.0 acres. Many of the smaller sub-basins delineate the area directly adjacent to the seawalls, which are necessary to model pre- and post-conditions for raised seawalls and backflow prevention but tend to be smaller than most of the City-wide delineation. The largest sub-basin within city limits is 36.1 acres and is located south of W Flagler Street and north of SW 5th Terrace. The second largest sub-basin within city limits represents approximately 35.6 acres located north of W Flagler St and west of NW 43rd Avenue. **Table 3.3.4-2** summarizes the C4 model elements.

Table 3.3.4-2 Summary of C4 Model Elements

Sub-basins		365
Junctions		18
Storages	Functional	1008
	Tabular	363
Outfalls		1
Conduits	Circular	1306
	Force Main	11
	Rectangular Closed	10
	Irregular Canal	40
	Irregular Ditch	1
	Irregular Overland	387



Soils Type Adjusted from DRI Test
C4 Basin

Date: 12/14/2020

Figure 3.3.4-9

Appendix B includes the C4 Basin model schematic (**Figure C4-EC**) with standard symbology and Appendix C includes more detailed tables presenting the C4 model element characteristics. These tables include the following:

- **Table C4-1** Hydrologic Parameters per Sub-basin
- **Table C4-2** Hydraulic Nodes Data
- **Table C4-3** Hydraulic Conduit Data
- **Table C4-4** Model Pump Data
- **Table C4-5** Model Weir Data
- **Table C4-6** Model Exfiltration Data

Model nodes representing manholes are modeled as functional storage nodes with a minimal amount of constant storage area (12.56 square feet, which is roughly equivalent to a typical 48-inch diameter manhole). Pump Station wet wells are modeled as functional storage nodes with constant areas equivalent to the wet well area, if the station dimensions were provided, or 100 square feet if the dimensions were not provided.

The C4 Basin model has one primary outfall representing the Tamiami C4 Canal (27_CJ-99401). The outfalls have been co-located for ease in changing boundary conditions once the models have been turned over to the City. Additionally, 11 subbasins, 11 storage nodes, and 11 outfalls are used to model the exfiltration systems in the C4 Basin. The virtual systems representing groundwater are not included in the model schematic nor in the tables. The groundwater table has been divided into 11 contiguous sections in the basin area because the initial level of the base groundwater varies depending on distance from Biscayne Bay and topography. The exfiltration systems are described in further detail in below.

The City's project-specific survey and the GIS coverage of stormwater pipes identifies 49 stormwater points of discharge simulated as outfalls that discharge to Tamiami C4 Canal. There are an additional 40 outfalls representing sheet flow to the canal from the sub-basins along the shore. Generally, the overland sheet flow cross-sections represent the seawall surveyed in that area. If a seawall is not present over a portion of the shoreline, 0.0 ft-NAVD 88 is used as the overflow elevation. The topography behind the shoreline is determines the opposite side of the seawall edge sub-basin, and the subsequent overland flow elevation to the rest of the neighborhood.

3.3.4.3 C4 Pump Stations

There are five existing pump stations in the C4 Basin which convey stormwater flow from low-lying area to outfalls as shown on Figure C4-EC. A wetwell with and under flow weir provides storage and treatment and screening of collected runoff for each station. Pumps are typically set to turn on at levels above the static water table and cycle off as water levels drop in the wetwell. Most pump stations have a control gate to bypass the station when offline for maintenance servicing, and some have an overflow weir to allow flow beyond the pump station capacity to continue out the outfall by gravity.

In the SWMM, pumps are represented by stage-flow links connected to an inflow storage node that serves as the wet well. The outflow section of the link is connected to a node that serves as a force main to an outfall. The types of pumps represented in this model are in-line pumps where flow increases incrementally with inlet node depth (SWMM Type 2). All pump station information was obtained from City-provided as-builts or other available plan sets.

1. West End PS #1 has a total maximum capacity of 30 cubic feet per second (cfs) or 13,464 gallons per minute (gpm), and is located on the northeast corner of the roundabout between SW 63rd Court and SW 6th Street. This pump station discharges water in the C4 canal via outfall. The flow is discharged through a 1692-foot long, 48-inch diameter force mains that later outfall through a 37-foot, 84-inch diameter force main south of NW 64th Avenue in the C4 Canal. For this station, the wet well is set at -13.9 feet NAVD 88.
    - There are two pumps in the station, and both are in separate links.
    - Pump A cycles on and off at 3.10 ft-NAVD 88 and 4.50 ft-NAVD 88, respectively, with a maximum flow of 15 cfs (6,732 gpm).
    - Pump B cycles on and off at -3.15 ft-NAVD 88 and 4.50 ft-NAVD 88, respectively, with a maximum flow of 15 cfs (6,732 gpm).
2. West End PS #2 has a total maximum capacity of 60 cfs (27,000 gpm), and is located on the northeast corner of the roundabout between SW 63rd Court and SW 2nd Street. This pump station discharges water into the C4 Canal via outfall. The flow is discharged through a 375-foot long, 36-inch diameter force main that connects to a 1,897-foot long, 54-inch diameter force main, that then outfalls through a 37-foot section of 84-inch diameter force main south of NW 64th Avenue into the C4 Canal. For this station, the wet well is set at -13.8 feet NAVD 88.
    - There are three pumps in the station, and all are in separate links.
    - Pump A cycles on and off at 3.25 ft-NAVD 88 and 2.90 ft-NAVD 88, respectively, with a maximum flow of 20 cfs (9,000 gpm).
    - Pump B cycles on and off at 0.60 ft-NAVD 88 and 2.90 ft-NAVD 88, respectively, with a maximum flow of 20 cfs (9,000 gpm).
    - Pump C cycles on and off at -4.40 ft-NAVD 88 and 2.90 ft-NAVD 88, respectively, with a maximum flow of 20 cfs (9,000 gpm).
3. West End PS #3 has a total maximum capacity of 40 cfs (18,000 gpm) and is located immediately south of Tamiami Canal Road between NW 3rd Street and NW 64th Court. The pump station discharges water into the C4 Canal via outfall. The flow Is discharged through a 528-foot long, 36-inch diameter force main that connects to a 190-foot long, 60-inch force main, that outfalls through a 37-foot section of 84-inch diameter force main

south of NW 64th Avenue in the C4 Canal. For this station, the wet well is set at -13.85 feet NAVD 88.

- There are three pumps in the station, and all are in separate links.
- Pump A cycles on and off at -4.40 ft-NAVD 88 and 6.55 ft-NAVD 88, respectively, with a maximum flow of 13.3 cfs (6,000 gpm).
- Pump B cycles on and off at -4.40 ft-NAVD 88 and 6.55 ft-NAVD 88, respectively, with a maximum flow of 13.3 cfs (6,000 gpm).
- Pump C cycles on and off at 2.15 ft-NAVD 88 and 6.55 ft-NAVD 88, respectively, with a maximum flow of 13.3 cfs (6,000 gpm).

4. West End PS #4 has a total maximum capacity of 54 cubic feet per second (cfs) or 24,000 gallons per minute (gpm), and is located immediately south of the Tamiami Canal Road between NW 5th Street and NW 62nd Court. This pump station discharges water into the C4 Canal via outfall. The flow is discharged through a 331-foot long, 30-inch diameter force main that outfalls through a 190-foot, 72-inch circular pipe. For this station, the wet well is set at -14.0 feet NAVD 88.:

   - There are three pumps in the station, and all are in separate links.
   - Pump A cycles on and off at -4.45 ft-NAVD 88 and -1.15 ft-NAVD 88, respectively, with a maximum flow of 18 cfs (8,000 gpm).
   - Pump B cycles on and off at 0.55 ft-NAVD 88 and -1.15 ft-NAVD 88, respectively, with a maximum flow of 18 cfs (8,000 gpm).
   - Pump C cycles on and off at 2.10 ft-NAVD 88 and -1.15 ft-NAVD 88, respectively, with a maximum flow of 18 cfs (8,000 gpm).

5. Antonio Maceo SWPS has a total maximum capacity of 15 cubic feet per second (cfs) or 6,732 gallons per minute (gpm), and is located immediately north of NW 7th Street on the Southwest corner of the Antonio Maceo Park. This pump station discharges water into the C4 Canal via outfall. The flow is discharged through a 350-foot long, 24-inch diameter force main that connects to a 40-foot long, 36-inch diameter circular pipe. For this station, the wet well is set at -11.9 feet NAVD 88.:

   - There are two pumps in the station, and both are in separate links.
   - Pump A cycles on and off at -4.40 ft-NAVD 88 and 1.20 ft-NAVD 88, respectively, with a maximum flow of 7.5 cfs (3,366 gpm).
   - Pump B cycles on and off at 0.60 ft-NAVD 88 and 1.20 ft-NAVD 88, respectively, with a maximum flow of 7.5 cfs (3,366 gpm).

3.3.4.4 C4 Exfiltration

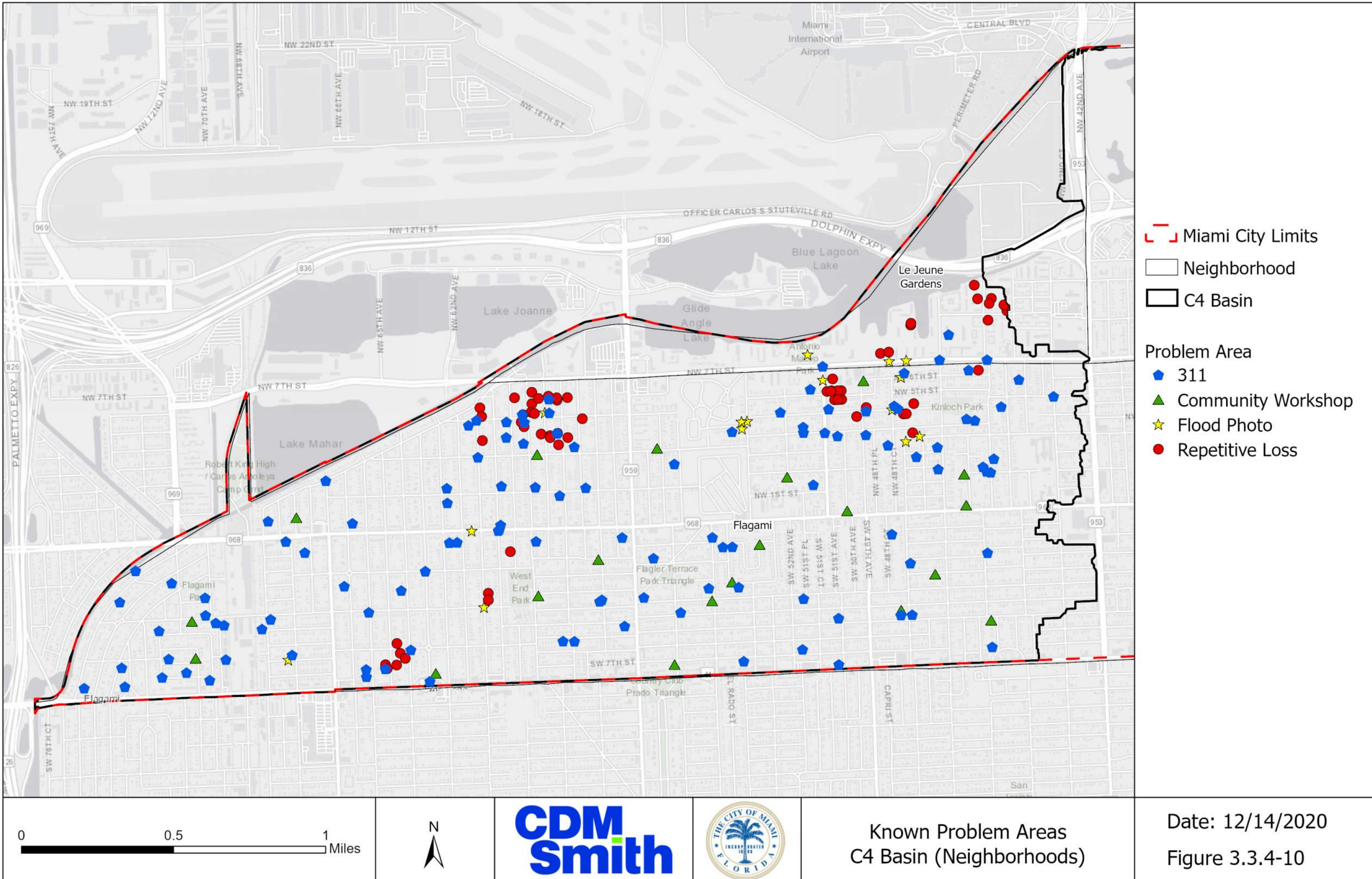
The C4 Basin uses exfiltration systems as one of its primary methods to reduce flooding and improve water quality by moving water from the PSMS to the Biscayne Aquifer. These systems include:

- Slab Covered Trenches: Rectangular boxes cut directly into the limestone aquifer, then covered with a concrete slab. There are approximately 0.8 miles of slab covered trenches in the C4 Basin.
- French Drains: Perforated pipe situated in a gravel-filled rectangular shaped excavation into the aquifer. There are approximately 21.5 miles of French Drains in the C4 Basin.
- Recharge/Drainage Wells: There are 2 gravity drainage/recharge wells in the C4 Basin. There are two types of recharge wells used in the Miami area - gravity driven wells and injection (pumped) wells. Injection wells are accounted for in the pumped flows to outfall representing the aquifer (see above) and therefore not included in the exfiltration rating curves. Gravity wells use the differential driving head of the land surface water surface elevation and the aquifer ground water table elevation to overcome the well casing friction and salinity interface density to push stormwater runoff out into the porous and highly transmissive limestone layer underground. The use of Biscayne aquifer drainage wells is restricted to zones where chloride concentrations exceed the saltwater intrusion front identified as the location at the base of the aquifer, of the 1,000 mg/L isochlor and does not impact any Class G-II potable aquifers.

In the C4 Basin, the regional water table elevation is estimated for 11 separate regions. Each region has a specified initial water table level based on the Miami-Dade County base groundwater elevation database. Note, these initial levels are higher in the sea level rise scenarios. The regional water tables rise based on precipitation and infiltration, using generic regional land-use estimates, i.e. the 11 model sub-basins ("GWBC" prefix), 11 storage nodes ("BiscayneAQBC" prefix) and 11 outfalls ("AQLossOut" prefix) are virtual elements designed solely to predict water table elevations and are not hydrologically or hydraulically connected to the model PSMS. The exfiltration rating curves are developed outside the model in a spreadsheet, based on length of system and count of wells per sub-basin, and other sub-basin specific parameters. The curves are head versus flow curves, where the head is internally calculated in the model by subtracting the regional groundwater elevation from the site-specific flood stage. In the large design storms, some of the low-lying exfiltration systems cease operations as the water table rises to ground surface. The Model Development TM provides more details on the exfiltration systems and how rating curves were developed for each type per model sub-basin.

3.3.4.5 C4 Known Flooding Problem Areas

Known problem areas in C4 Basin include the western and northern low-lying areas of the Flagami neighborhood. Known flooding problems also include the southern portion of Le Jeune Gardens neighborhood in proximity to the Blue Lagoon Lake and C4 canal. **Figure 3.3.4-10** indicates where complaints related to storms and/or flooding were made in the C4 Basin.



CDM Smith

Known Problem Areas
C4 Basin (Neighborhoods)

Date: 12/14/2020

Figure 3.3.4-10

3.3.4.6 C4 Design Storm Simulations

A range of simulations were performed in the C4 Basin model covering the multiple design storm intensities and an array of boundary conditions. **Table 3.3.4-3** presents all the simulation scenarios being run for the master plan, only the Base Condition run was performed for this TM.

Design storm distributions were taken from the SFWMD Permit Information Manual, Volume IV. Model simulations are performed for the 5-year, 24-hour design storm; and the 10-year, 25-year, and 100-year, 72-hour design storms. The 24-hour design storm has a peak centered at 12 hours, while the 72-hour design storms have peak intensities at 60 hours. The SFWMD design storm distributions are sampled at 5-minute increments. Design Storm volumes were extracted for localized actual recorded rainfall data from the NOAA Atlas 14, as shown previously in Table 3.4-1. Initial depths for nodes in the model were set to match the boundary conditions to create an even starting surface within all areas of the models including pumped areas.

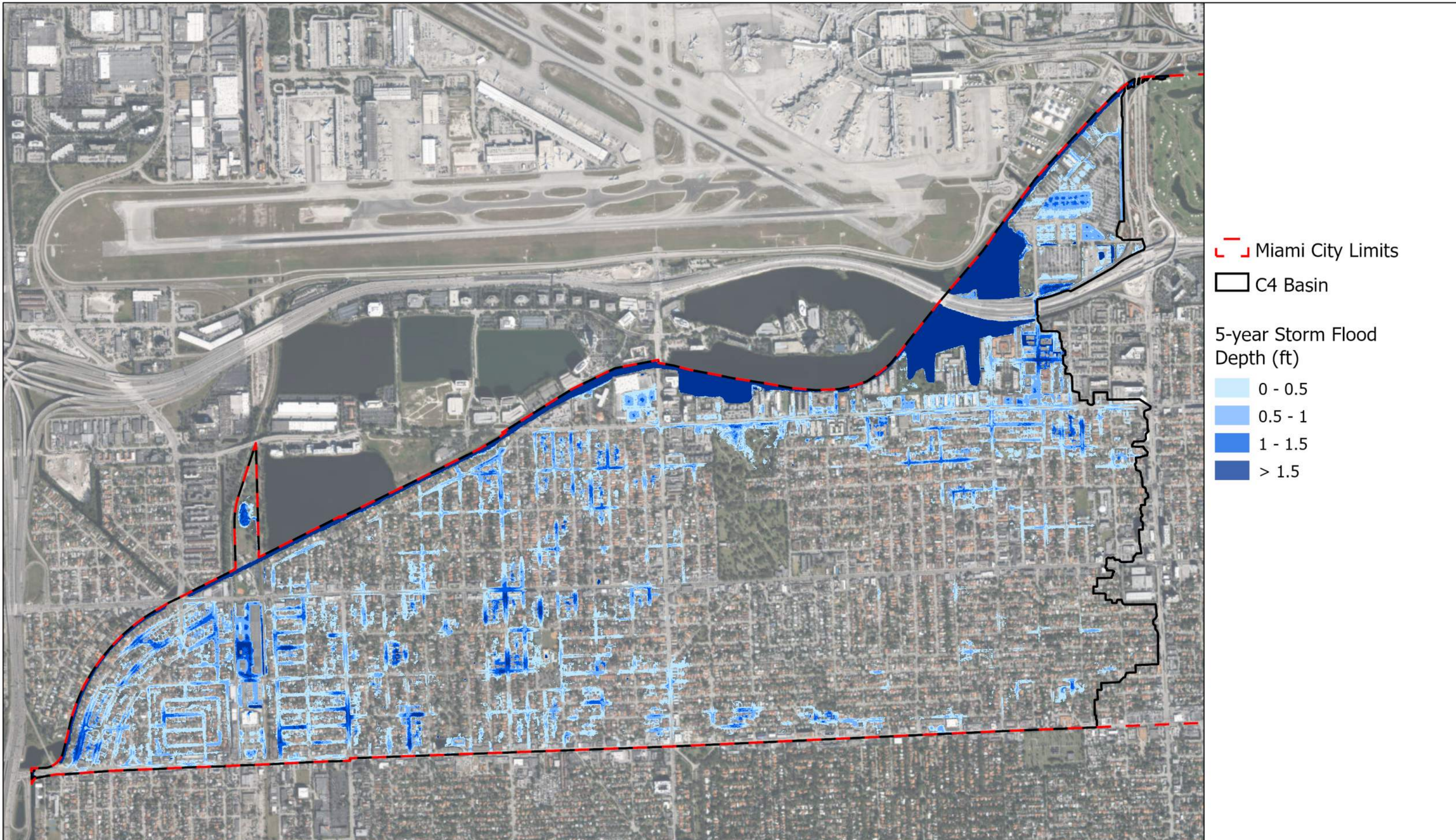
Table 3.3.4-3 Design Storm Simulations

Tailwater Condition	Tailwater Stage in Biscayne Bay (ft-NAVD 88)			
	5-yr, 24-hr	10-yr, 72-hr	25-yr,72-hr	100-yr, 72-hr
Base Condition*	2.0	2.0	2.0	2.0
Base Plus 1.5 feet Sea Level Rise (SLR)	3.5	3.5	3.5	3.5
Base Plus 2.5 feet SLR	4.5	4.5	4.5	4.5
10-year Storm Surge		6.0		

* Base condition represents the one-year stillwater tide elevation – see Model Development TM.

3.3.4.7 C4 Existing Conditions Model Results and Design Storm Inundation Mapping

The verified C4 Basin EC model was run for the base simulation for each design storm considering a well maintained, clean pipe condition. A summary of peak flood stages for the simulated EC model is published by the City in the on-line GIS model output tables**.** Flood mapping of the base simulations of existing conditions for the 5-year, 24-hour design storm; and the 10-year, 25-year, and 100-year, 72-hour design storms are presented on Figure**s 3.3.4-11 through 3.3.4-14**.

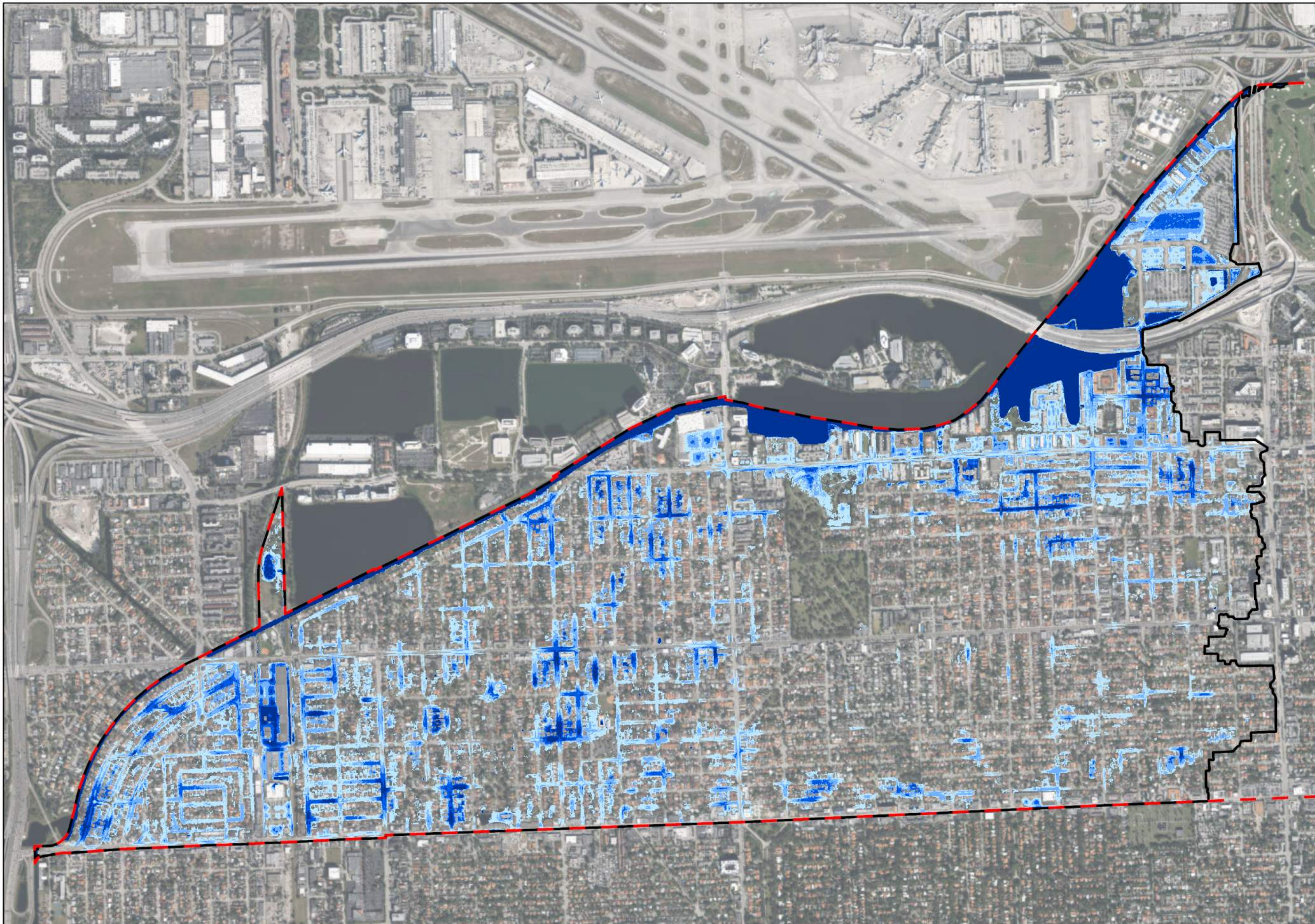


CDM Smith

Flood Map
5 yr/24 hr Design Storm
C4 Basin Existing Conditions

Date: 12/14/2020

Figure 3.3.4-11

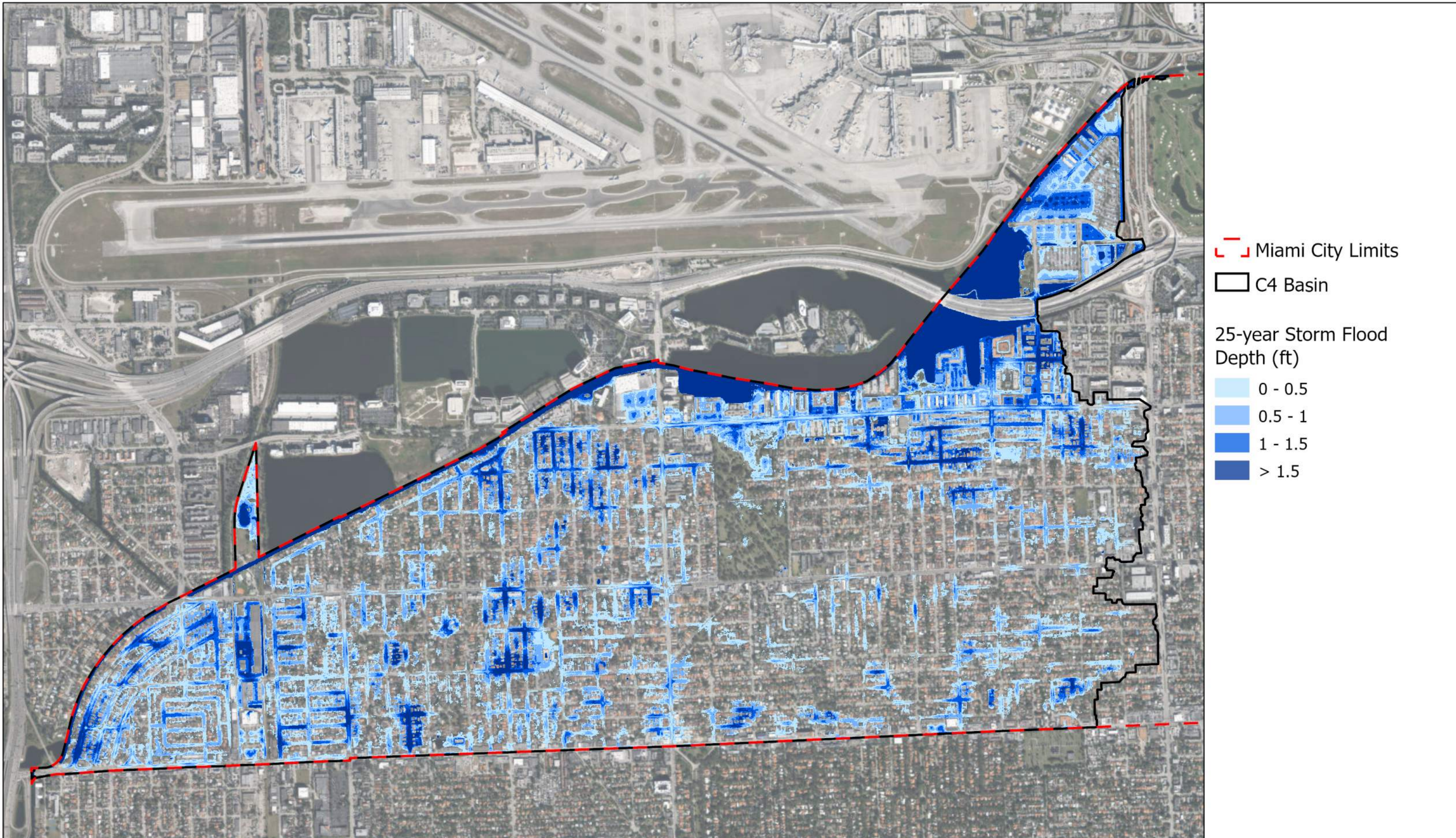


CDM Smith

Flood Map
10 yr/72 hr Design Storm
C4 Basin Existing Conditions

Date: 12/14/2020

Figure 3.3.4-12



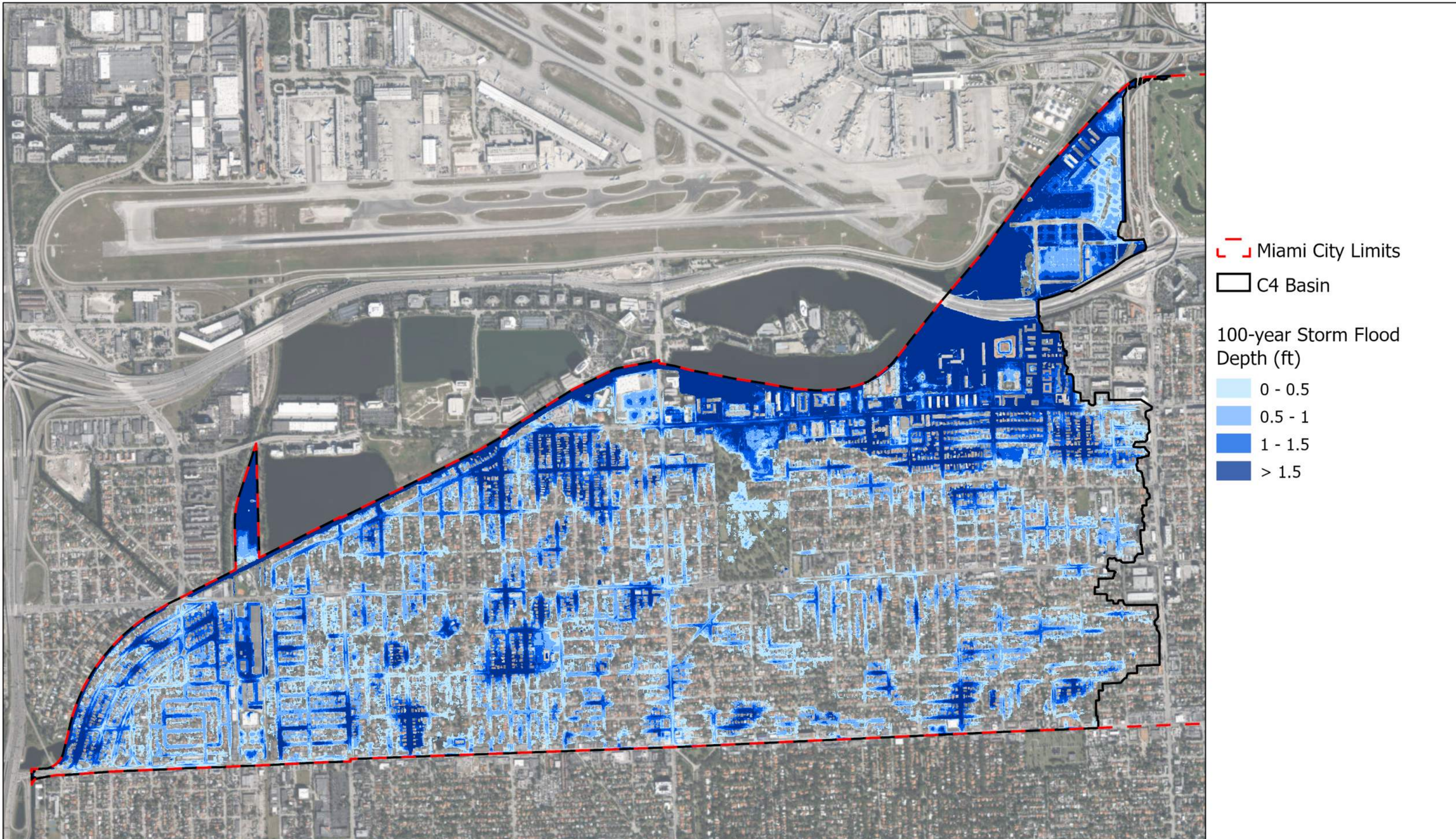
CDM Smith

THE CITY OF MIAMI FLORIDA

Flood Map
25 yr/72 hr Design Storm
C4 Basin Existing Conditions

Date: 12/14/2020

Figure 3.3.4-13



0 0.5 1 Miles

N

Flood Map
100 yr/72 hr Design Storm
C4 Basin Existing Conditions

Date: 12/14/2020

Figure 3.3.4-14

3.3.4.8 C4 Model Result Summary and Existing Conditions Level of Service Scoring

Peak flood stages were compared to indicator elevations through the basin for the 10-year storm to determine the existing flood LOS for roads, and for the 100-year storm to determine the existing LOS for buildings.

The C4 Basin was analyzed and grouped logically into 3 improvement regions (LOS Areas) considering in-common topography and PSMS elements. **Table 3.3.4-4** presents the length of road flooded above crown in each region for the 10-year storm, base condition, and the number of buildings expected to flood for the 100-year storm, base condition. Because the verification of each individual FFE for every building and residence property in Miami is not within of the scope of this project, a standard one-foot above existing grade has been added to the LiDAR DEM around the periphery of each structure as a reasonable estimate of the minimum building FFEs. Approximately 300 FFEs were field verified in the deepest flooding areas by ground survey and the DEM numbers were adjusted accordingly. It is noted that Current Florida Building Code requires 1 foot or more above the BFE depending on the FIRM flood hazard zone within which the property is located. Future minimum FFEs may be required to include additional height provisions for sea level rise.

The LOS score for each region was determined by the following equation:

$S_{LOS} = C_1 * Len_{10} + C_2 * Bldg_{100} + C_3 * Str_{Crit}$;

Where S_{LOS} is the LOS score, Len_{10} is the length of road flooded above crown for the 10-year storm in linear feet and normalized by population, $Bldg_{100}$ is the number of buildings flooded above the estimated FFE for the 100-year storm, normalized by population, Str_{Crit} is the number of critical structures identified in the region, and C_1, C_2 and C_3 are coefficients that the City of Miami may use to help rank neighborhoods. Higher scores indicate worse predicted Current LOS problems. These rankings are for initial evaluation purposes only, as the two proposed LOS alternatives encompass all of the problem areas, not just those in the highest ranked areas.

Figures 3.3.4-15 and 3.3.4-16 provide the relative existing conditions predicted LOS flooding of roadways and structures respectively for the C4 Basin. Additionally, 144 critical structures were identified in the study area (emergency operations, police, fire, hospital, evacuation shelter, government, etc.) and added to the surveyed FFEs.

Table 3.3.4-4 C4 Basin Existing LOS Ranking

								1		1		1	
LOS Region	**Primary Neighborhood in LOS Area**	**All Neighborhoods in LOS Area**	**Area (acres)**	**Flooded Area 100yr (acres)**	**Flooded Area/Total Basin Area**	**Population (2010)**	**Length of Street Flooded (mi)**	**Length of Street Flooded/Total Length of Street Flooded 10yr**	**Est # of Buildings Flooded (100 yr)**	**# of Buildings Flooded/Total # of Buildings Flooded (100 yr)**	**# of Critical Structures Flooded (100 yr)**	**# of Critical Structures Flooded/Total # of Critical Structues Flooded (100 yr)**	**Basin Relative Flood Ranking**
C4-01	Le Jeune Gardens	West Grapeland Heights, Le Jeune Gardens, Flagami	493.0	377.7	25.70%	11,929	5.97	20.42%	291	40.25%	0	0.02%	0.60687
C4-02	Flagami West	Le Jeune Gardens, Flagami	931.1	667.7	45.43%	16,548	17.87	61.09%	370	51.18%	5	99.96%	2.12222
C4-03	Flagami Central	Flagami	751.8	424.5	28.88%	15,498	5.41	18.50%	62	8.58%	0	0.02%	0.27091
Totals	3		2,176.0	1,469.9	100%	43,975.0	29.3	100%	723	100%	5.002	100%	

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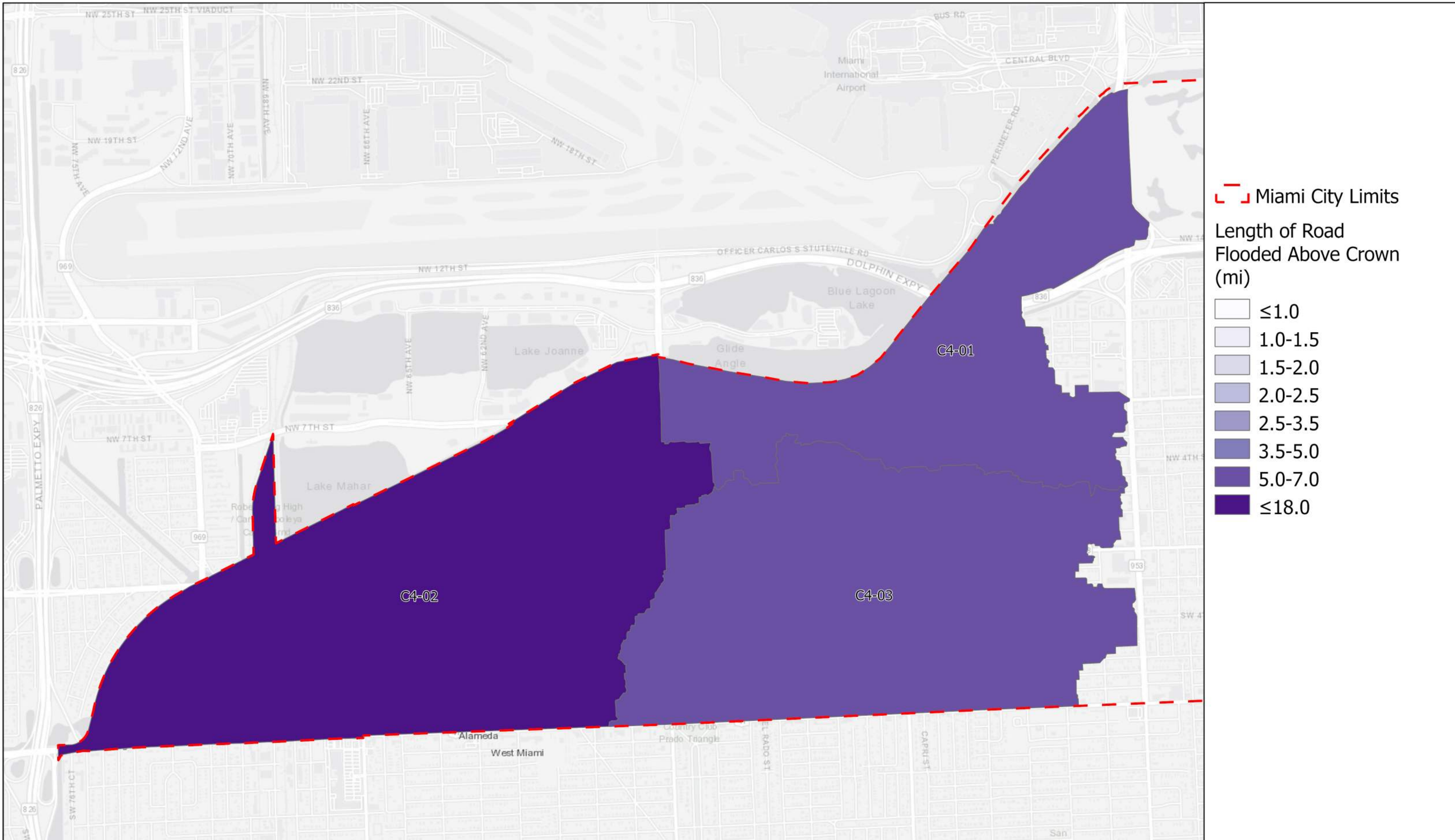
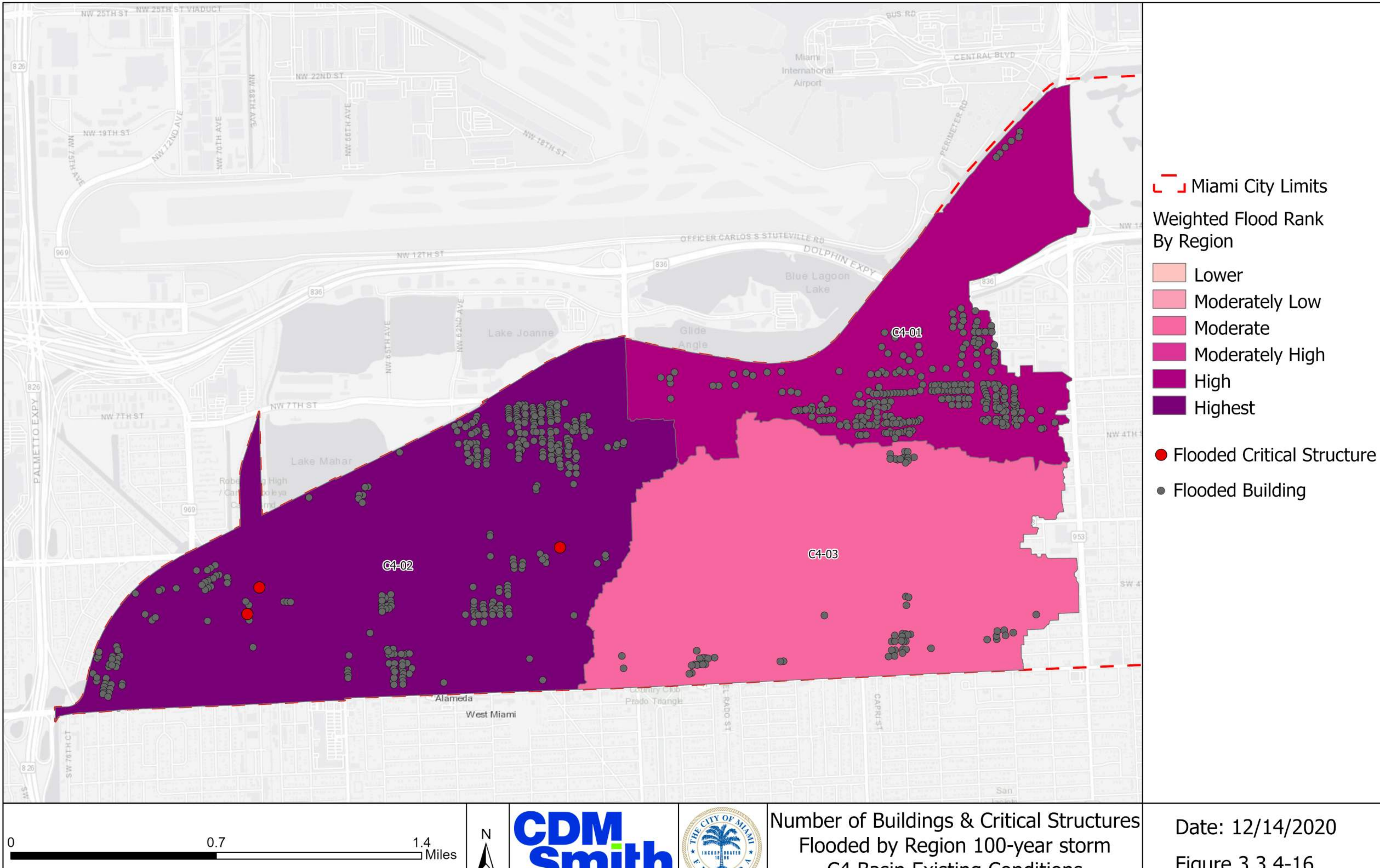


Length of Road Flooded Above Crown by Region 10-year storm C4 Basin Existing Conditions

Date: 12/14/2020

Figure 3.3.4-15



Number of Buildings & Critical Structures Flooded by Region 100-year storm C4 Basin Existing Conditions

Date: 12/14/2020

Figure 3.3.4-16

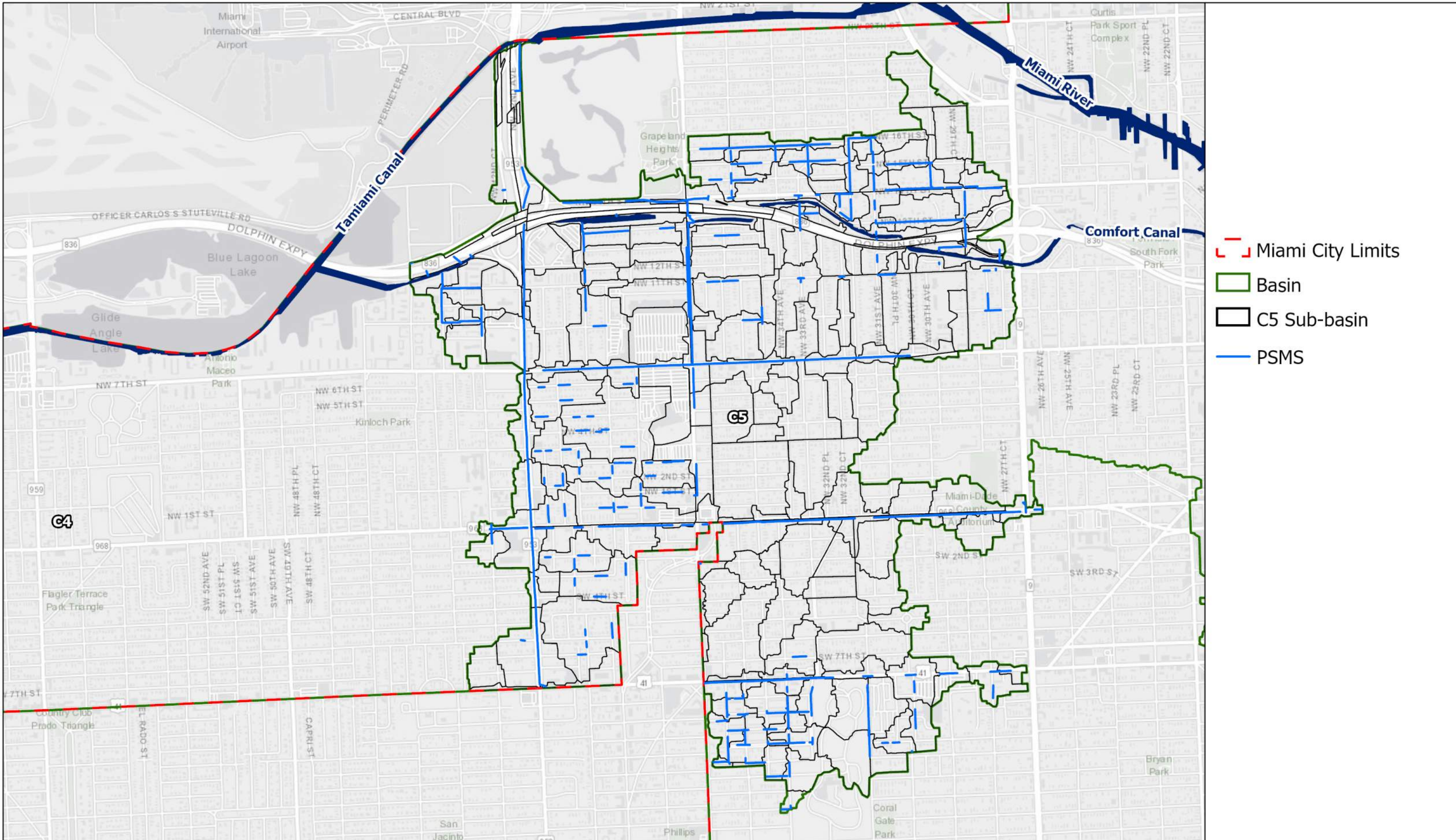
3.3.5 C-5 Basin (C5)

3.3.5.1 C5 Basin Description

The C-5 (C5) Basin consists of 1,734 acres of low-lying land that primarily discharges to Biscayne Bay. **Figure 3.3.5-1** includes a delineation of the C5 Basin and a simplified representation of the PSMS within the basin. The C5 Basin is characterized by PSMS discharge directly to C5 canal south of the C4 canal and the North Grapeland Heights neighborhood. The C5 Basin is north of SW 14th Street and Parkdale neighborhood. The stormwater system formed by the NW 42nd Avenue corridor from the C4 Canal to Dolphin Expressway is connected the C5 Basin in the northern boundary. The northern boundary is adjacent to the C6 Basin, delineated by the C4 Canal, NW 42nd Avenue, Dolphin Expressway, and C5 Canal following topography. The western boundary is adjacent to the C4 Basin following topography. The southern boundary is adjacent to the C3BS Basin and delineated following topography. The eastern boundary is adjacent to the C3BS and C6 Basins and delineated following topography west of 27th Avenue.

Figure 3.3.5-2 shows the DEM for the C5 Basin. Topographic elevations range from near 0 ft-NAVD 88 in areas near the C5 canal to approximately 19 ft-NAVD 88 along the coastal ridge that crosses the southeast portion of the basin. In the C5 Basin, the ridge are approximately 1.2 miles and runs from Calabria Avenue to NW 32nd Court. The elevation along the ridge ranges from 12 to 19 ft-NAVD 88. A substantial portion of the South Grapeland Heights neighborhood is low-lying areas below 5 ft NAVD 88. Approximately 89% of the C5 Basin's stormwater inlets are between 3 feet and 15 feet NAVD 88; however, nearly 200 PSMS inlets (9.4%) are located where the LiDAR elevations are below 3 feet NAVD 88. Nearly 400 PSMS inlets (19.3%) are located where the LiDAR elevations are below 4 feet NAVD 88. The lower elevations are all near the C5 canal and Miami River floodplain. These inlets are susceptible to storm surge and sea level rise. Further, low street elevations preclude using gravity recharge wells or other exfiltration systems, since the driving heads are small. Existing exfiltration systems in these areas are not expected to work well.

Figure 3.3.5-3 presents a map of the impervious cover for the C5 Basin based on the USGS NLCD coverage as discussed in the Model Development Technical Memorandum and **Figure 3.3.5-4** presents a map of the SFWMD land-use for the C5 Basin.



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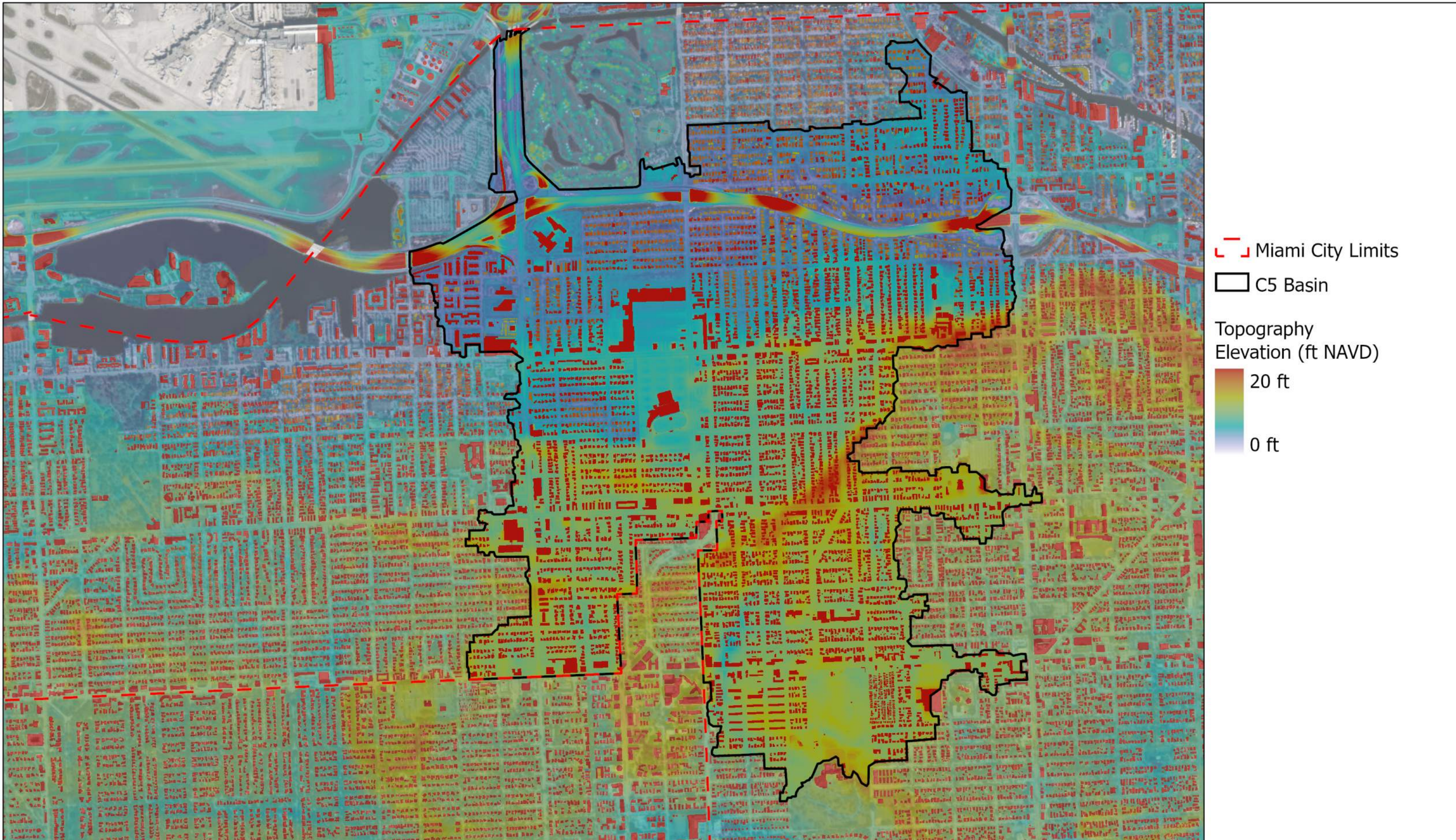
Sub-basin Delineation and PSMS
C5 Basin

Date: 12/15/2020

Figure 3.3.5-1



0 0.5 1 Miles

N

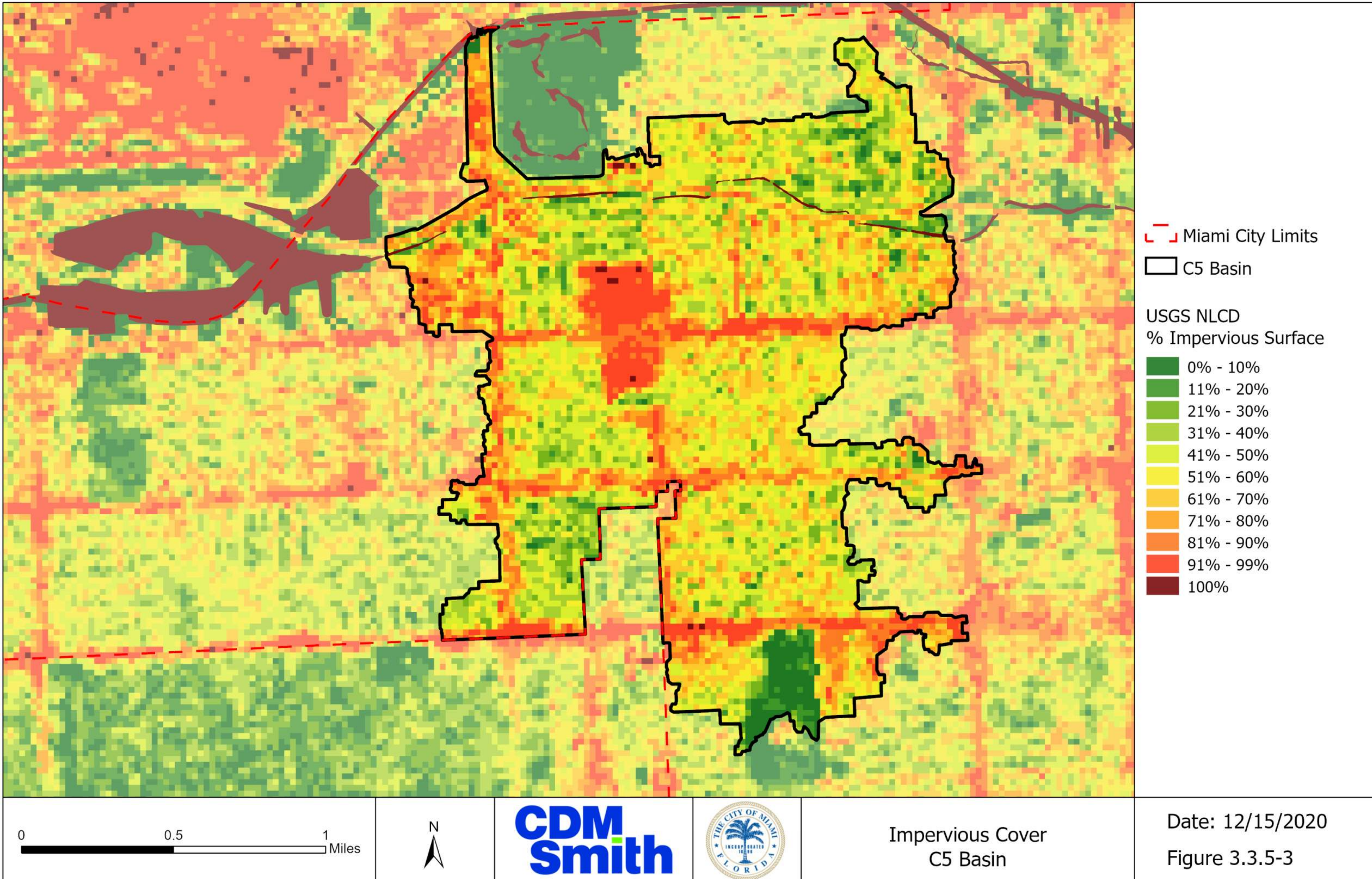
CDM Smith

THE CITY OF MIAMI
INCORPORATED 1896
FLORIDA

Digital Elevation Model (DEM)
C5 Basin

Date: 12/15/2020

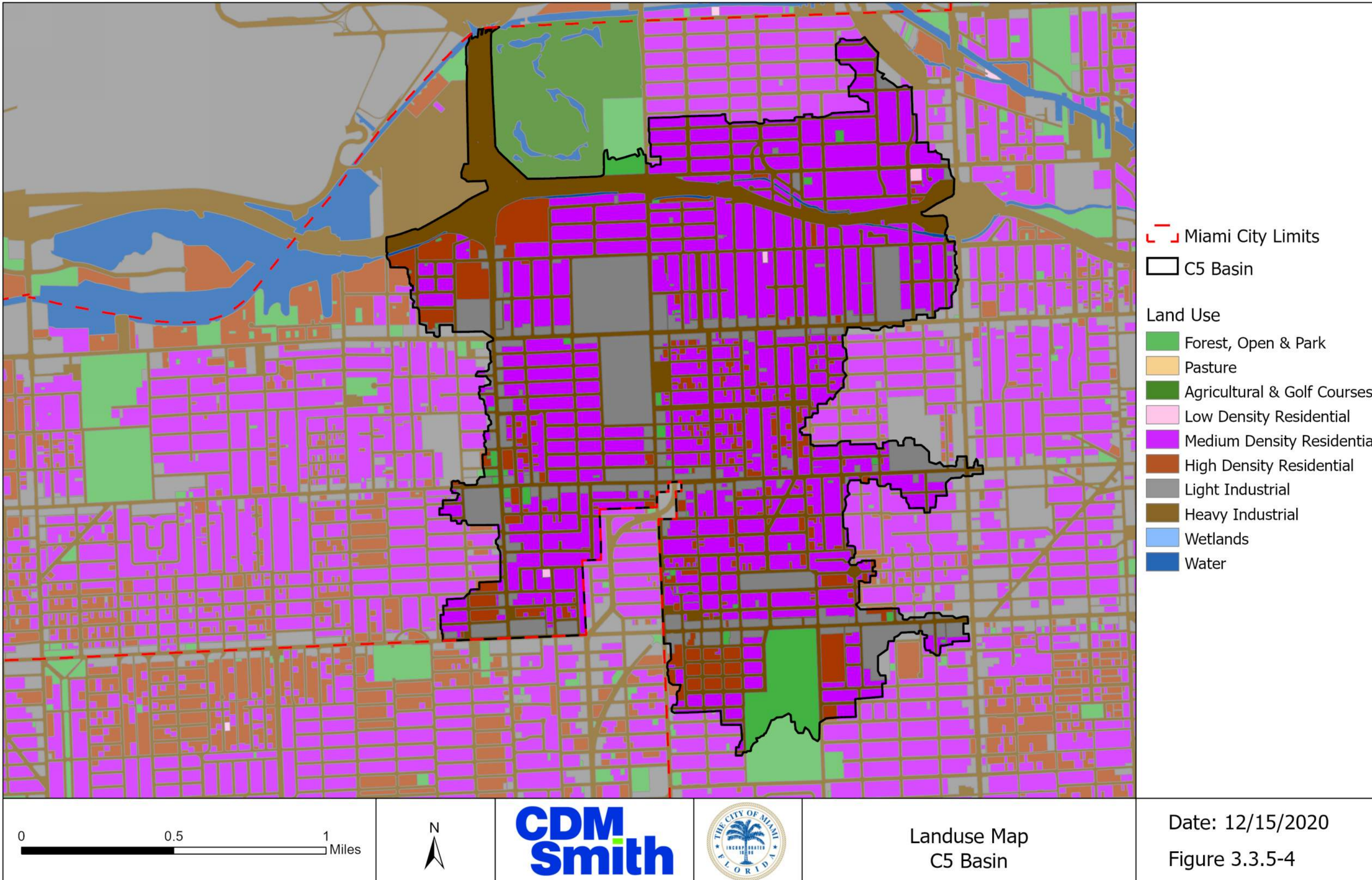
Figure 3.3.5-2



Impervious Cover
C5 Basin

Date: 12/15/2020

Figure 3.3.5-3



CDM Smith

THE CITY OF MIAMI FLORIDA INCORPORATED 1896

Landuse Map
C5 Basin

Date: 12/15/2020

Figure 3.3.5-4

As described in detail in the Model Development TM, impervious coverages were intersected with the sub-basin delineations, adjusted using the developed USGS impervious weightings, and a percentage of the total impervious routed to pervious based on land-use parameters. **Figure 3.3.5-5** presents the total impervious percentage in the C5 Basin, delineated by sub-basin, after the adjustment for pervious/impervious routing was applied. **Figure 3.3.5-6** presents a breakdown of the land use by ten standard consolidated categories, for use in the model. **Figure 3.3.5-7** presents a breakdown of the impervious cover in the model. The area-weighted total impervious percent of the C5 Basin is estimated to be 65%; therefore, approximately 1,131 acres of the 1,736 acres are expected to be impervious surface. Of this, approximately 262 acres are expected to be routed to pervious surfaces prior to entry into the BN Basin PSMS. The routing of runoff to pervious surfaces does not affect the volume infiltrated to soils but does change the timing of the hyetograph.

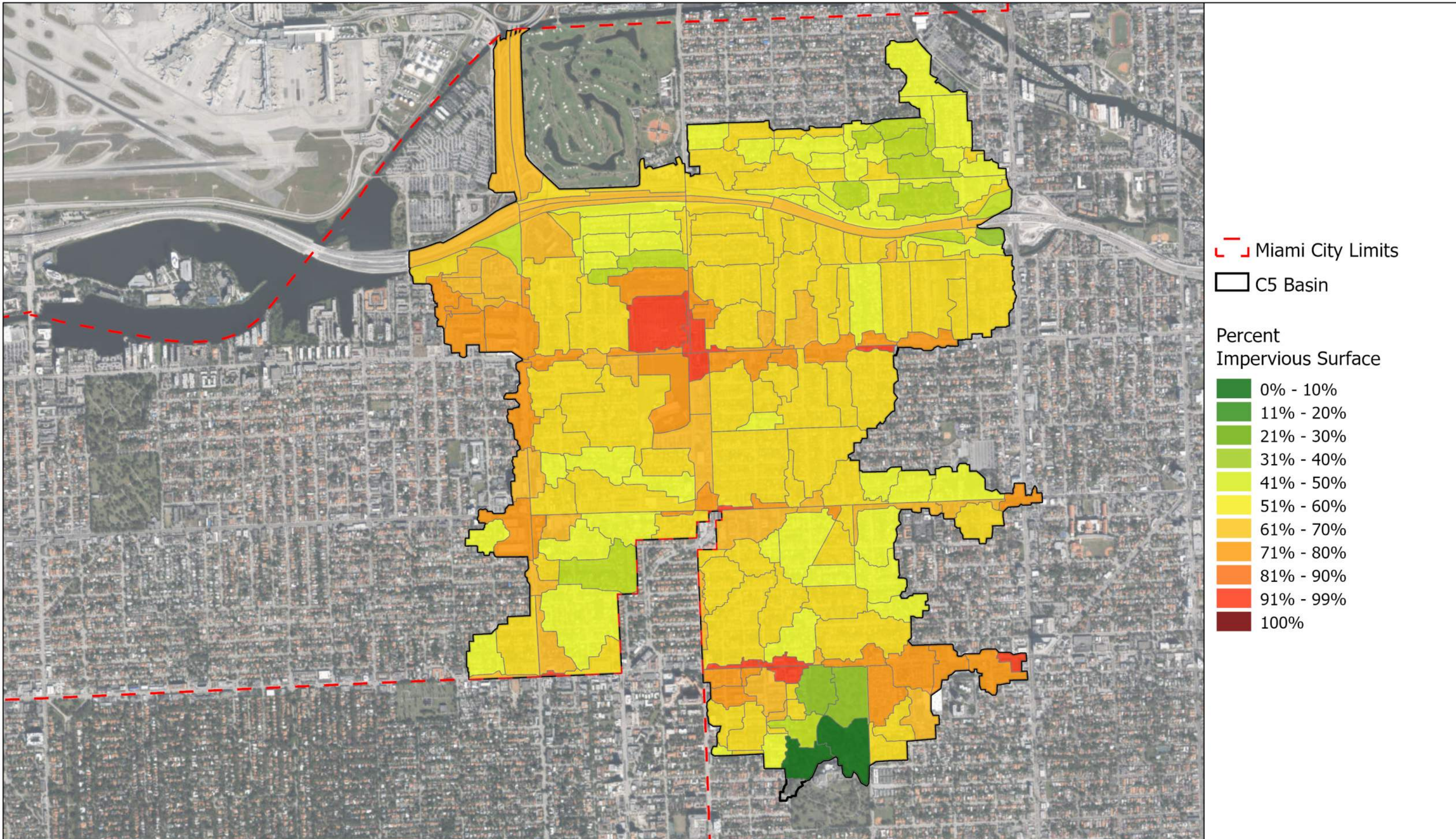
For design storm simulations, the SFWMD 24-hour and 72-hour unit hydrographs were used to implement the rainfall distributions per storm. **Table 3.3.5-1** presents the volumes for the C5 Basin for the 5-year, 24-hour; and 10-year, 25-year, and 100-year 72-hour design storms that were obtained from the NOAA Atlas 14. Design Storm rainfall volumes may be found for select gages in the atlas, or an interpolated volume estimate may be found for point locations. For this basin, point location estimates were made across the basin. In order to be conservative, the highest volume was used as the design rainfall volume over the entire basin. In general, the western edge of the basin has slightly higher expected volumes than the coastal edge.

Table 3.3.5-1 C-5 Basin Design Storm Volumes and Intensities

Storm	Rainfall Depth (inches)*	Peak 5-min Intensity (inches/hr)
5-year, 24-hour	7.1	5.5
10-year, 72-hour	10.6	6.1
25-year, 72-hour	13.2	7.5
100-year, 72-hour	17.7	10.1

* NOAA Atlas 14 provides 1-day volumes to the hundredths and 3-day volumes to the tenths of an inch

Surface soils in the C5 Basin are uniformly described as “urban” in the NRCS soils map included as shown on **Figure 3.3.5-8.** In order to apply the Modified Green-Ampt infiltration in SWMM, the urban soils needed to be characterized in more detail.



CDM Smith

Total Impervious Percentage
C5 Basin

Date: 12/15/2020

Figure 3.3.5-5

Figure 3.3.5-6 Landuse Category Breakdown for C5 Basin

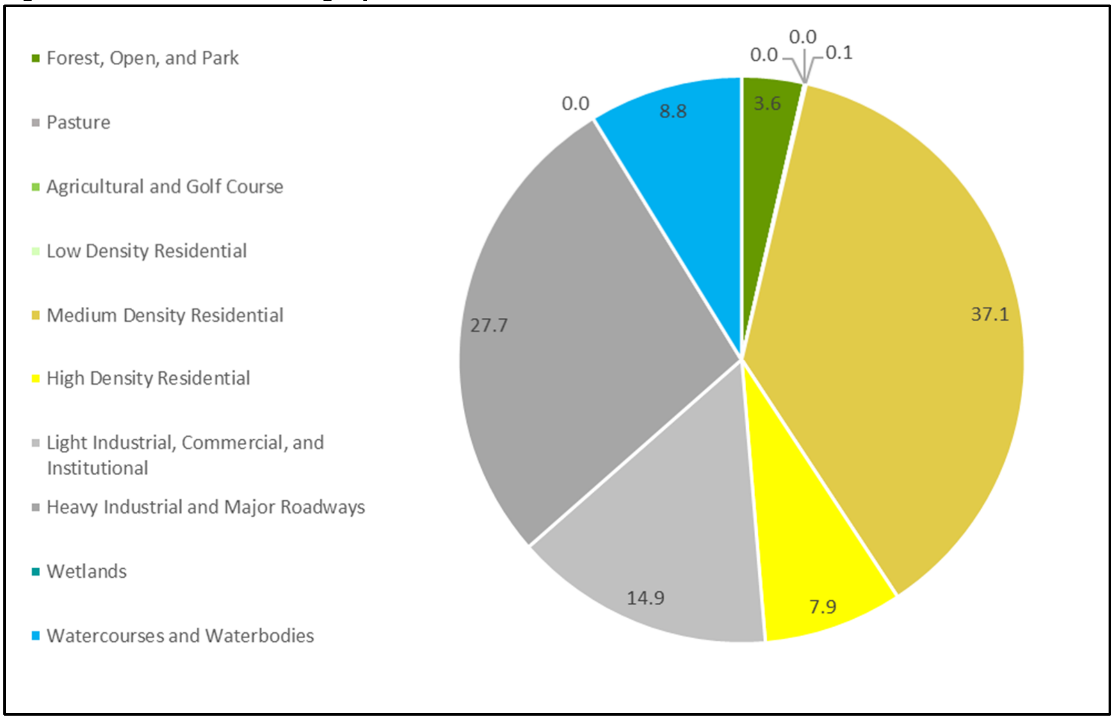
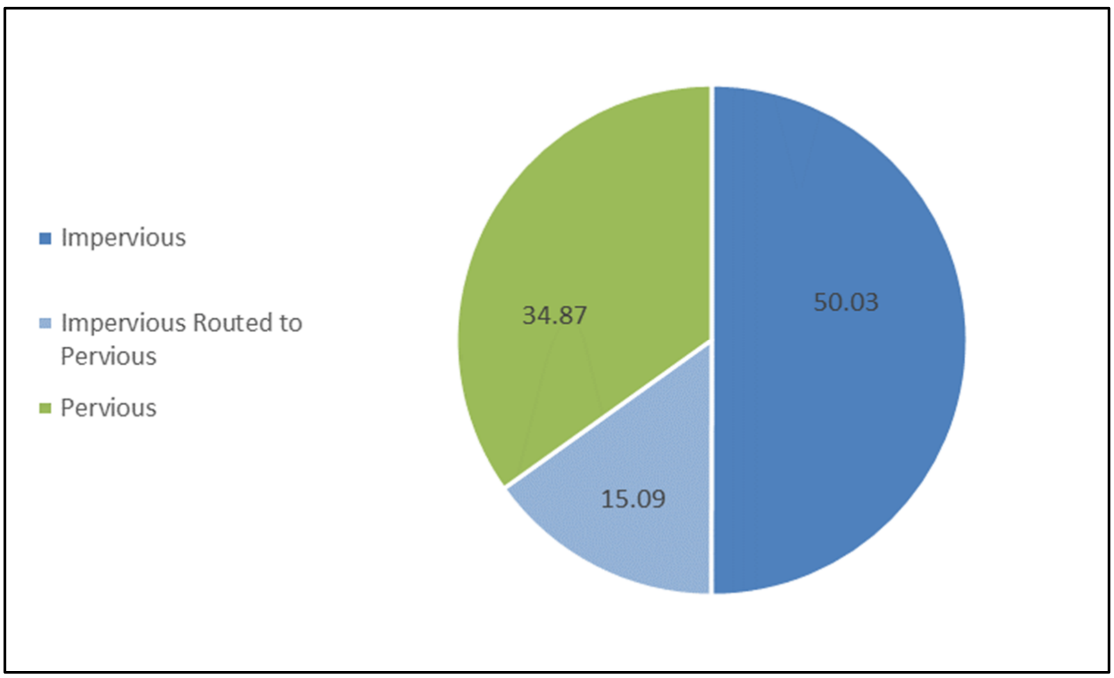
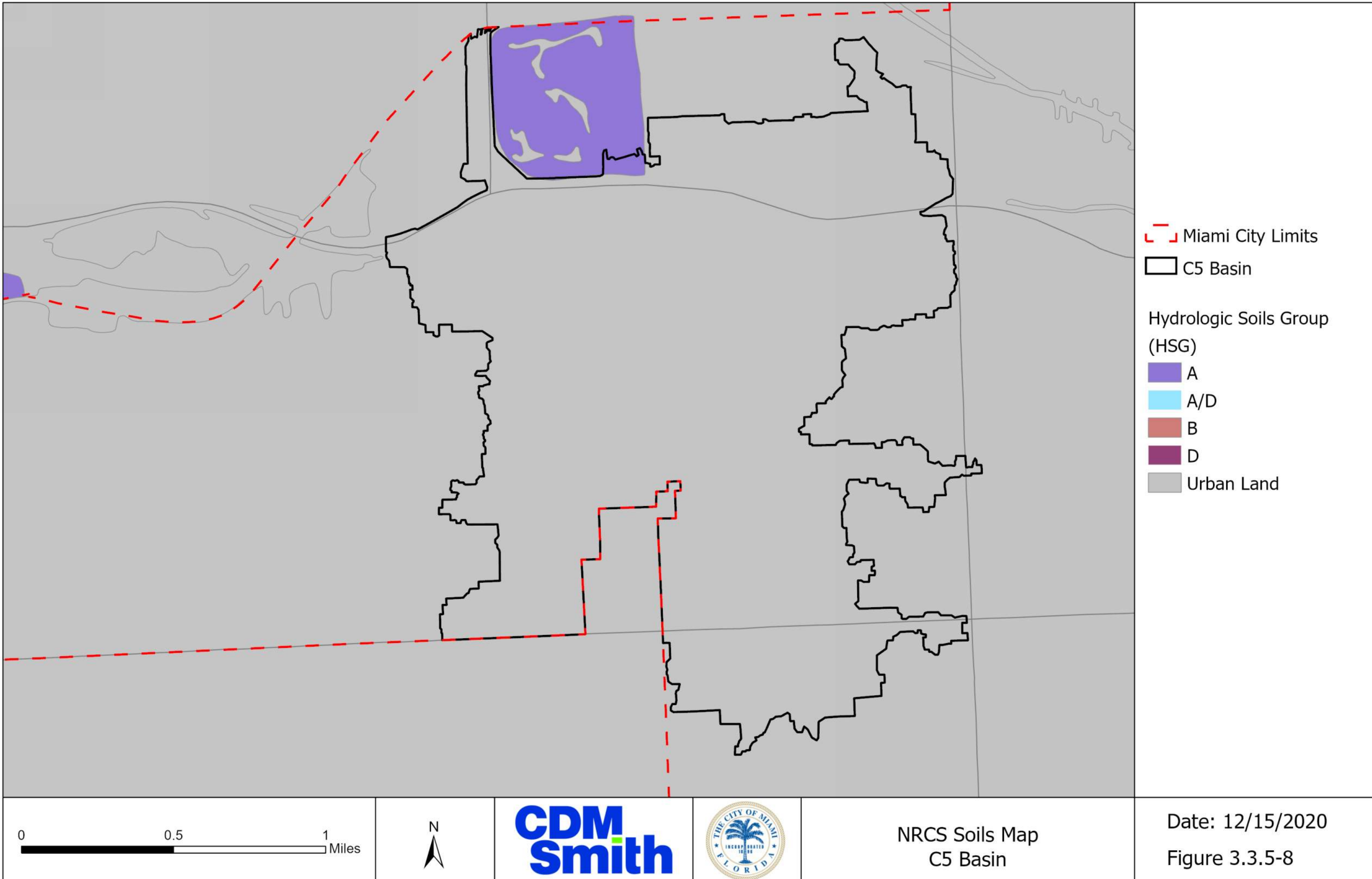


Figure 3.3.5-7 Breakdown of Adjusted impervious Cover for C5 Basin





NRCS Soils Map
C5 Basin

Date: 12/15/2020

Figure 3.3.5-8

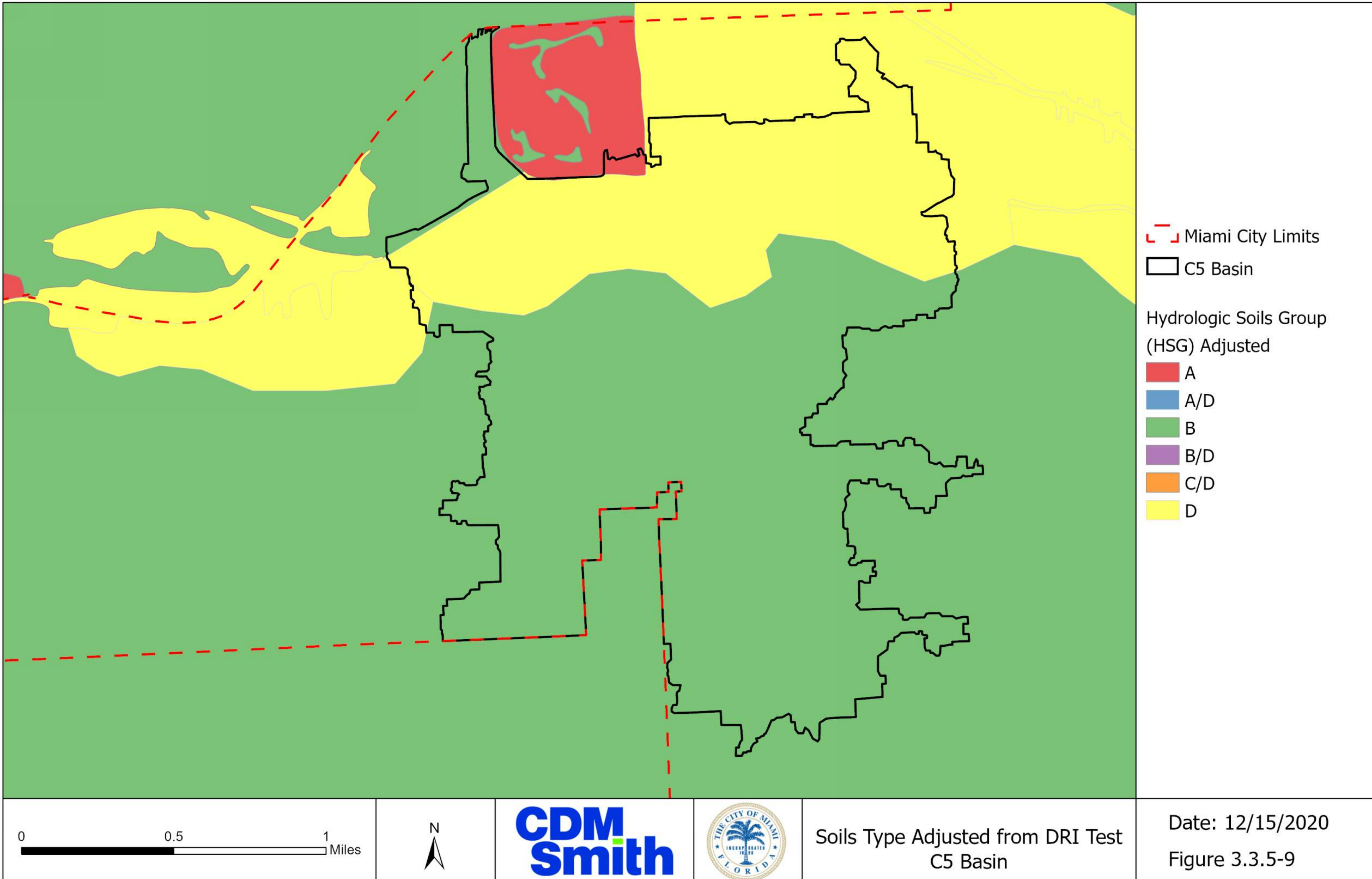
The project performed a limited number of double-ring infiltrometer tests in order to determine soil types throughout the project area. Miami-Dade County has performed similar tests. As discussed in the Model Development TM, the tests indicated Type A (sandy, or well-draining soils) soils at higher elevations, Type D (clay, or poor-draining soils) in low areas, particularly in the Miami River Floodplain, and intermediate soils elsewhere. Therefore, the C5 Basin model uses Type A soils in a small area north of the Dolphin Expressway, Type D soils in the low-lying regions adjacent to the C5 Canal, and Type B (intermediate) soils in the area south of the Grapeland Heights neighborhood and west region above Dolphin Expressway, as shown on **Figure 3.3.5-9**. Note that the rates on Figure 3.3.5-9, and the model parameter inputs, are Green-Ampt Hydraulic Conductivities, which do not directly correspond to the measured DRI soils infiltration rates.

3.3.5.2 C5 Hydrologic and Hydraulic Model Elements

The developed H&H models for the C5 Basin stormwater management system were used to evaluate the performance of the City's existing stormwater management system and to analyze future improvement projects (CIP). Model analysis evaluated the PSMS for multiple size rainfall events and downstream tidal boundary conditions. The PSMS includes constructed stormwater facilities and overland flow paths that drain to the downstream waterbody (i.e., boundary condition). The PSMS generally includes open channels and pipes of 24-inch diameter and larger. The C5 Basin modeled area is 1,736 acres delineated into 233 sub-basins ranging in size from 0.6 acres to 37.3 acres with a mean size of 7.5 acres. Many of the smaller sub-basins delineate the area directly adjacent to the seawalls, which are necessary to model pre- and post-conditions for raised seawalls and backflow prevention but tend to be smaller than most of the city-wide delineation. The largest and second largest sub-basins are located in the Flagami East neighborhood. The second largest sub-basin is approximately 37 acres and encompasses a depression as shown in the LiDAR DEM. **Table 3.3.5-2** summarizes the C5 model elements.

Table 3.3.5-2 Summary of C5 Model Elements

Subbasins		233
Junctions		15
Storages	Functional	580
	Tabular	233
Outfalls		1
Conduits	Circular	732
	Ellipse	2
	Force Main	2
	Rectangular Closed	28
	Irregular Canal	18
	Irregular Ditch	2
	Irregular Overland	228



Soils Type Adjusted from DRI Test C5 Basin

Date: 12/15/2020

Figure 3.3.5-9

Appendix B includes the C5 Basin model schematic (24 x 36 pullout) (**Figure C5-EC**) with standard symbology and Appendix C includes more detailed tables presenting the C5 model element characteristics. These tables include the following:

- **Table C5-1** Hydrologic Parameters per Sub-basin
- **Table C5-2** Hydraulic Nodes Data
- **Table C5-3** Hydraulic Conduit Data
- **Table C5-4** Model Pump Data
- **Table C5-5** Model Weir Data
- **Table C5-6** Model Exfiltration Data

Model nodes representing manholes are modeled as functional storage nodes with a minimal amount of constant storage area (12.56 square feet, which is roughly equivalent to a typical 48-inch diameter manhole). Pump Station wet wells are modeled as functional storage nodes with constant areas equivalent to the wet well area, if the station dimensions were provided, or 100 square feet if the dimensions were not provided.

The C5 Basin model has one primary outfall representing C5 Canal (S25_TW). The outfalls have been co-located for ease in changing boundary conditions once the models have been turned over to the City. Additionally, 9 subbasins, 9 storage nodes, and 9 outfalls are used to model the exfiltration systems in the C5 Basin. The virtual systems representing groundwater are not included in the model schematic nor in the tables. The groundwater table has been divided into 9 contiguous sections in the basin area because the initial level of the base groundwater varies depending on distance from Biscayne Bay and topography. The exfiltration systems are described in further detail in below.

The City's project-specific survey and the GIS coverage of stormwater pipes identifies 38 stormwater points of discharge simulated as outfalls that discharge to C5 Canal. There are an additional 40 outfalls representing sheet flow to the canal from the sub-basins along the shore. Generally, the overland sheet flow cross-sections represent the seawall surveyed in that area. If a seawall is not present over a portion of the shoreline, 0.0 ft-NAVD 88 is used as the overflow elevation. The topography behind the shoreline is determines the opposite side of the seawall edge sub-basin, and the subsequent overland flow elevation to the rest of the neighborhood.

3.3.5.3 C5 Pump Stations

There is one existing pump station in the C5 Basin which convey stormwater flow from low-lying area to outfalls as shown on Figure C5-EC. A wetwell with and under flow weir provides storage and treatment and screening of collected runoff for each station. Pumps are typically set to turn on at levels above the static water table and cycle off as water levels drop in the wetwell. Most pump stations have a control gate to bypass the station when offline for maintenance servicing, and some have an overflow weir to allow flow beyond the pump station capacity to continue out the outfall by gravity.

In the SWMM, pumps are represented by stage-flow links connected to an inflow storage node that serves as the wet well. The outflow section of the link is connected to a node that serves as a force main to an outfall. The types of pumps represented in this model are in-line pumps where flow increases incrementally with inlet node depth (SWMM Type 2). All pump station information was obtained from City-provided as-builts or other available plan sets.

1. FDOT NW 37th Avenue PS has a total maximum capacity of 22.2 cubic feet per second (cfs) or 10,000 gallons per minute (gpm) and is located immediately east of NW 37th Avenue and south of Dolphin Expressway. This pump station discharges water directly into South Fork Miami River via outfall. The flow is diverted over through two 60-foot long, 18-inch diameter force mains that merge into an 80-foot long, 18-inch diameter force main north of the South Fork Miami River. For this station, the wet well is set at -6.5 feet NAVD 88.:

    - There are two pumps in the station, and both are in separate links.
    - Pump A cycles on and off at -2.9 ft-NAVD 88 and -8.5 ft-NAVD 88, respectively, with a maximum flow of 11.2 cfs (5,000 gpm).
    - Pump B cycles on and off at -2.9 ft-NAVD 88 and -8.5 ft-NAVD 88, respectively, with a maximum flow of 11.2 cfs (5,000 gpm).

3.3.5.4 C5 Exfiltration

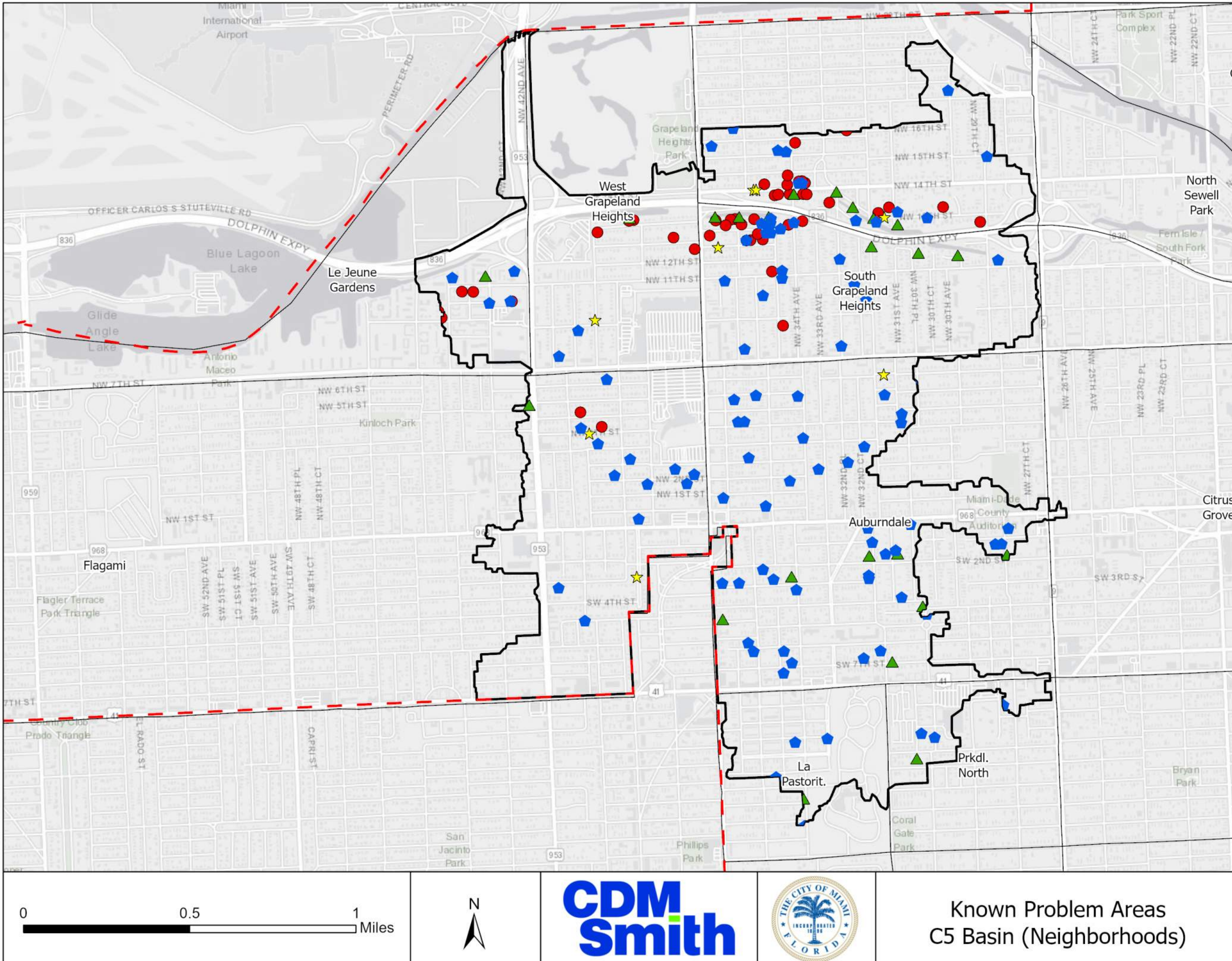
The C5 Basin uses exfiltration systems as one of its primary methods to reduce flooding and improve water quality by moving water from the PSMS to the Biscayne Aquifer. These systems include:

- Slab Covered Trenches: Rectangular boxes cut directly into the limestone aquifer, then covered with a concrete slab. There are approximately 1.5 miles of slab covered trench in the C5 Basin.
- French Drains: Perforated pipe situated in a gravel-filled rectangular shaped excavation into the aquifer. There are approximately 16.3 miles of French Drains in the C5 Basin.
- Recharge/Drainage Wells: There are 4 gravity drainage/recharge wells in the C5 Basin. There are two types of recharge wells used in the Miami area - gravity driven wells and injection (pumped) wells. Injection wells are accounted for in the pumped flows to outfall representing the aquifer (see above) and therefore not included in the exfiltration rating curves. Gravity drainage wells use the differential driving head of the land surface water surface elevation and the aquifer ground water table elevation to overcome the well casing friction and salinity interface density to push stormwater runoff out into the porous and highly transmissive limestone layer underground. The use of Biscayne aquifer drainage wells is restricted to zones where chloride concentrations exceed the saltwater intrusion front identified as the location at the base of the aquifer, of the 1,000 mg/L isochlor and does not impact any Class G-II potable aquifers.

In the C5 Basin, the regional water table elevation is estimated for 9 separate regions. Each region has a specified initial water table level based on the Miami-Dade County base groundwater elevation database. Note, these initial levels are higher in the sea level rise scenarios. The regional water tables rise based on precipitation and infiltration, using generic regional land-use estimates, i.e., the 9 model sub-basins ("GWBC" prefix), 9 storage nodes ("BiscayneAQBC" prefix) and 9 outfalls ("AQLossOut" prefix) are virtual elements designed solely to predict water table elevations and are not hydrologically or hydraulically connected to the model PSMS. The exfiltration rating curves are developed outside the model in a spreadsheet, based on length of system and count of wells per sub-basin, and other sub-basin specific parameters. The curves are head versus flow curves, where the head is internally calculated in the model by subtracting the regional groundwater elevation from the site-specific flood stage. In the large design storms, some of the low-lying exfiltration systems cease operations as the water table rises to ground surface. The Model Development TM provides more details on the exfiltration systems and how rating curves were developed for each type per model sub-basin.

3.3.5.5 CS5 Known Flooding Problem Areas

Known problem areas in C5 Basin include the neighborhoods South Grapeland Heights, Auburndale and West Grapeland Heights. Flooding problems are concentrated mainly in low-laying areas following topography. The majority of repetitive loses are located in the northwest portion of the South Grapeland neighborhood in the PSMS that directly outfalls to C5 canal. **Figure 3.3.5-10** indicates where complaints related to storms and/or flooding were made in the C5 Basin.



Known Problem Areas
C5 Basin (Neighborhoods)

Date: 12/15/2020

Figure 3.3.5-10

3.3.5.6 C5 Design Storm Simulations

A range of simulations were performed in the C5 Basin model covering the multiple design storm intensities and an array of boundary conditions. **Table 3.3.5-3** presents all the simulation scenarios being run for the master plan, only the Base Condition run was performed for this TM.

Design storm distributions were taken from the SFWMD Permit Information Manual, Volume IV. Model simulations are performed for the 5-year, 24-hour design storm; and the 10-year, 25-year, and 100-year, 72-hour design storms. The 24-hour design storm has a peak centered at 12 hours, while the 72-hour design storms have peak intensities at 60 hours. The SFWMD design storm distributions are sampled at 5-minute increments. Design Storm volumes were extracted for localized actual recorded rainfall data from the NOAA Atlas 14, as shown previously in Table 3.5-1. Initial depths for nodes in the model were set to match the boundary conditions to create an even starting surface within all areas of the models including pumped areas.

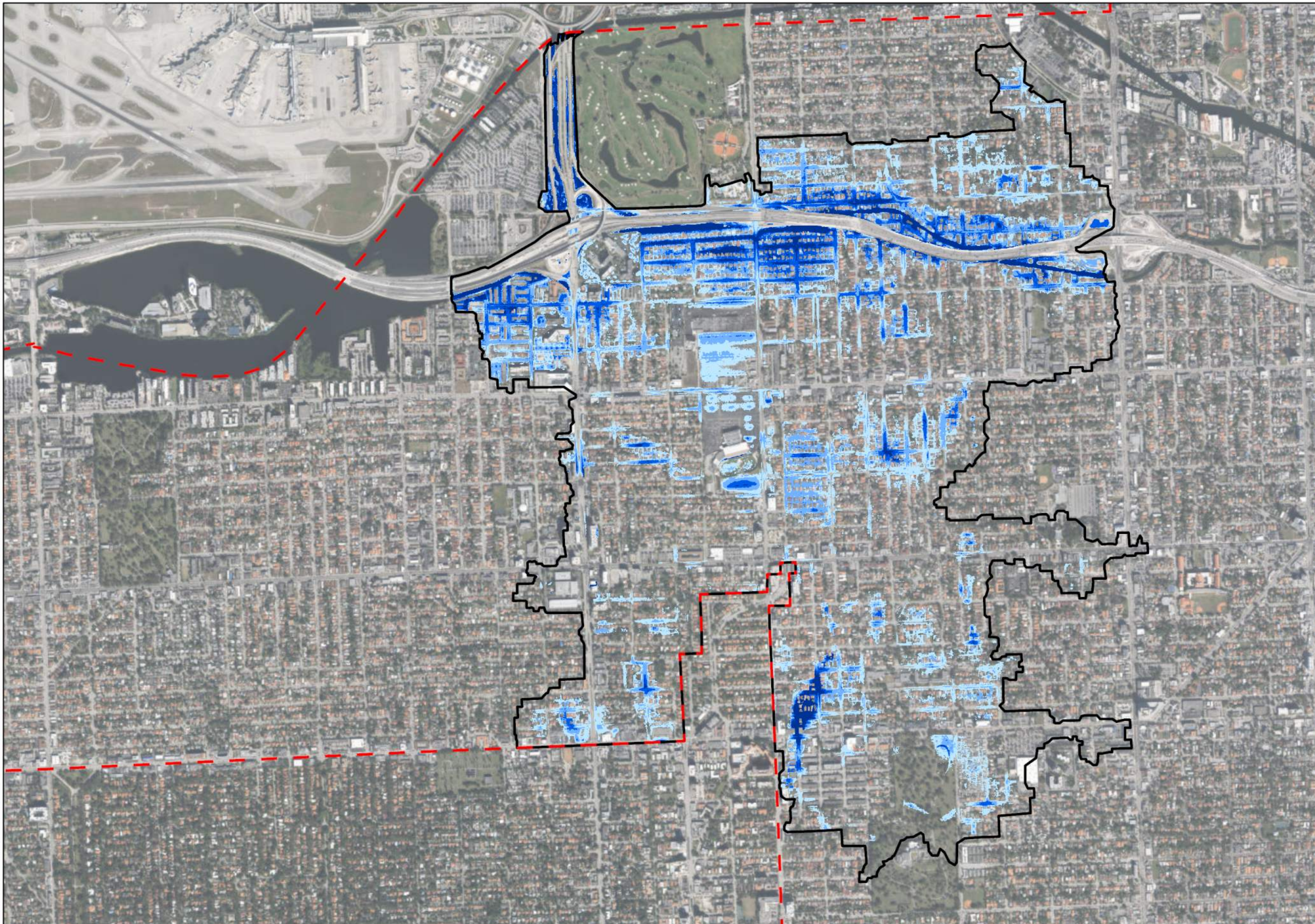
Table 3.3.5-3 Design Storm Simulations

Tailwater Condition	Tailwater Stage in Biscayne Bay (ft-NAVD 88)			
	5-yr, 24-hr	10-yr, 72-hr	25-yr,72-hr	100-yr, 72-hr
Base Condition*	2.0	2.0	2.0	2.0
Base Plus 1.5 feet Sea Level Rise (SLR)	3.5	3.5	3.5	3.5
Base Plus 2.5 feet SLR	4.5	4.5	4.5	4.5
10-year Storm Surge		6.0		

* Base condition represents the one-year stillwater tide elevation – see Model Development TM.

3.3.5.7 C5 Existing Conditions Model Results and Design Storm Inundation Mapping

The verified C5 Basin EC model was run for the base simulation for each design storm considering a well maintained, clean pipe condition. A summary of peak flood stages for the simulated EC model is published by the City in the tables in the stormwater GIS system on line**.** Flood mapping of the base simulations of existing conditions for the 5-year, 24-hour design storm; and the 10-year, 25-year, and 100-year, 72-hour design storms are presented on **Figures 3.3.5-11 through 3.3.5-14**.



Miami City Limits

C5 Basin

5-year Storm Flood Depth (ft)

0 - 0.5

0.5 - 1

1 - 1.5

> 1.5

0 0.5 1 Miles

N

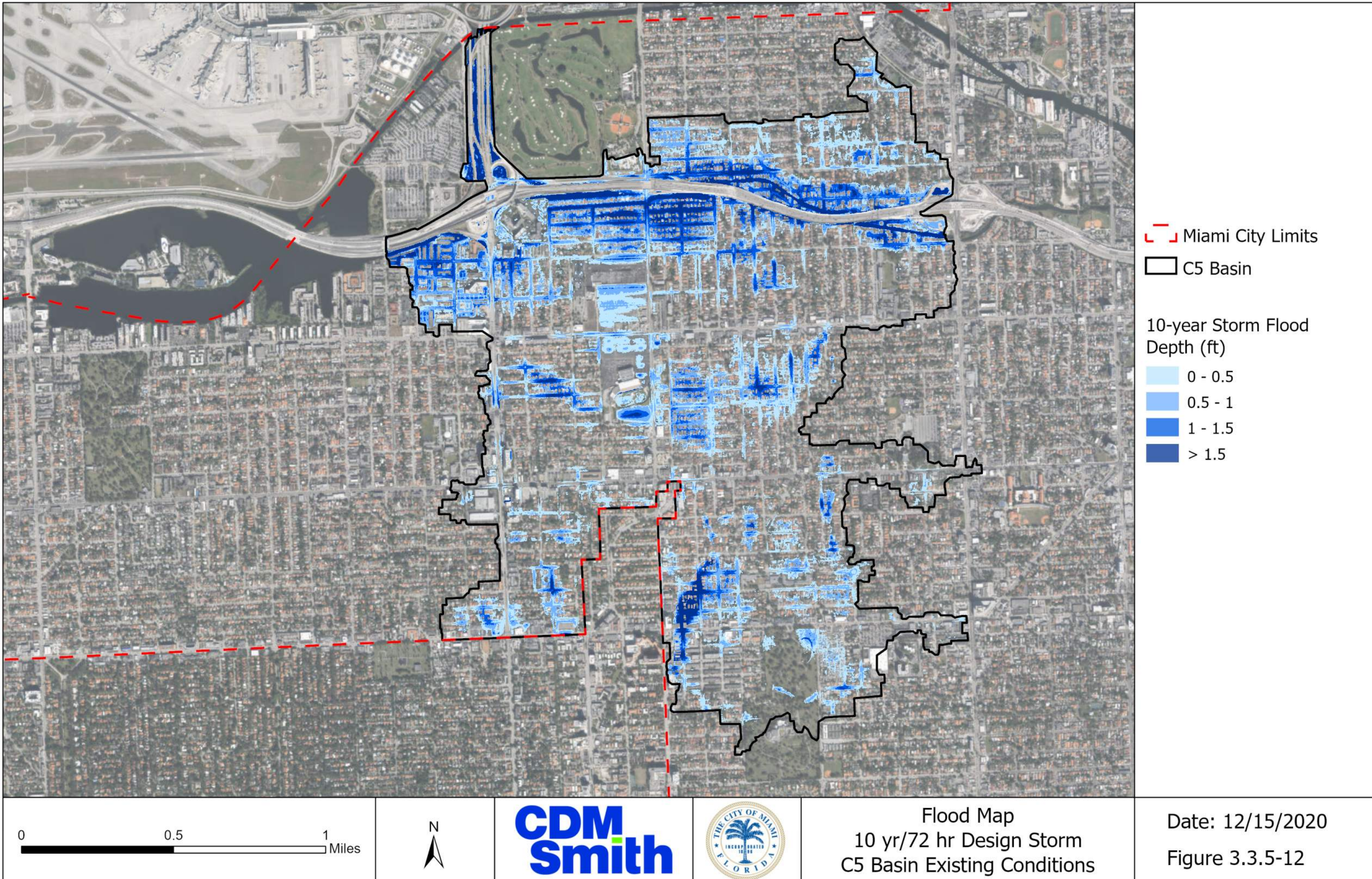
CDM Smith

THE CITY OF MIAMI INCORPORATED 1896 FLORIDA

Flood Map
5 yr/24 hr Design Storm
C5 Basin Existing Conditions

Date: 12/15/2020

Figure 3.3.5-11

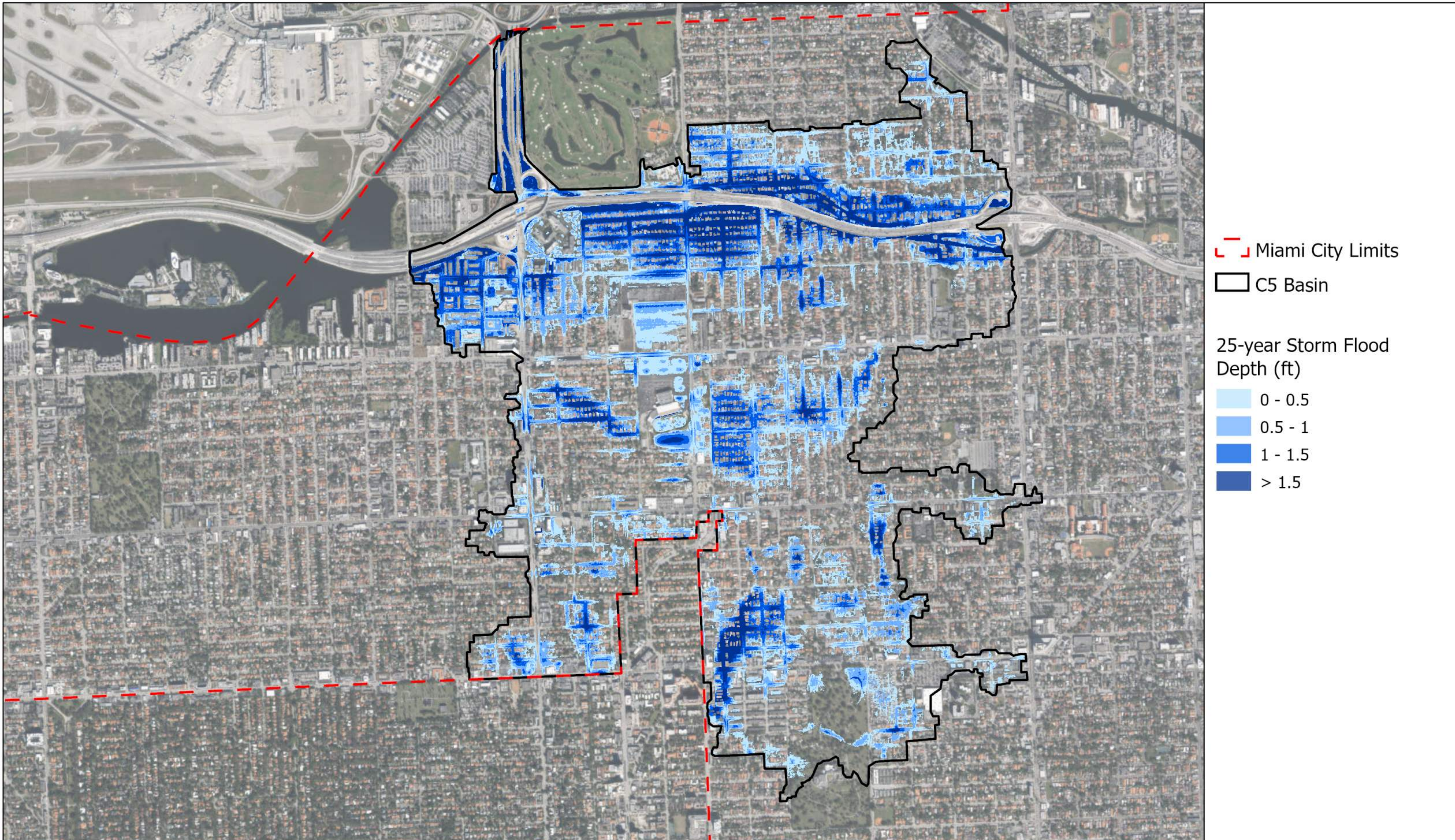


CDM Smith

Flood Map
10 yr/72 hr Design Storm
C5 Basin Existing Conditions

Date: 12/15/2020

Figure 3.3.5-12



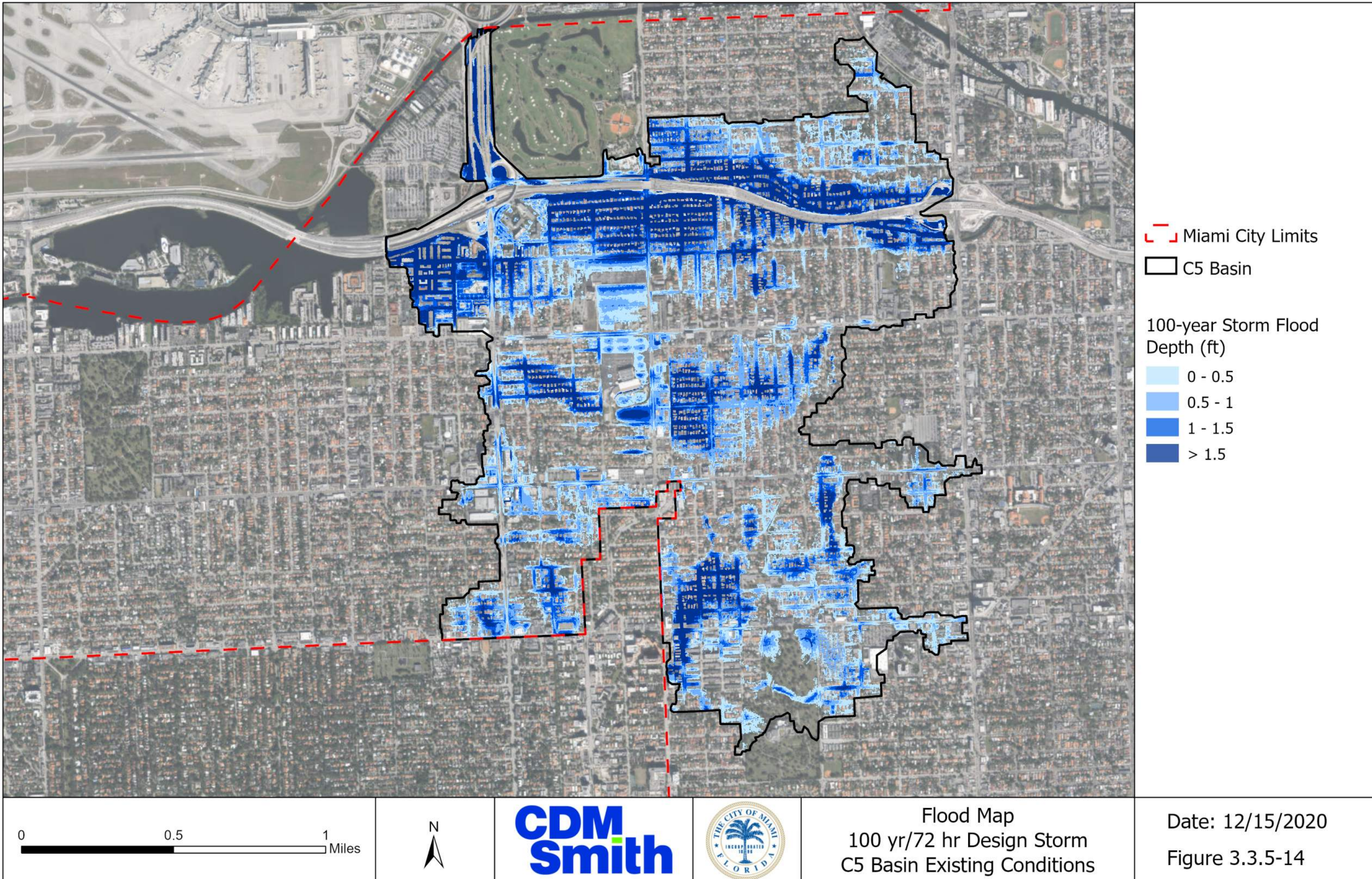
CDM Smith

THE CITY OF MIAMI FLORIDA

Flood Map
25 yr/72 hr Design Storm
C5 Basin Existing Conditions

Date: 12/15/2020

Figure 3.3.5-13



Flood Map
100 yr/72 hr Design Storm
C5 Basin Existing Conditions

Date: 12/15/2020

Figure 3.3.5-14

3.3.5.8 C5 Model Result Summary and Existing Conditions Level of Service Scoring

Peak flood stages were compared to indicator elevations through the basin for the 10-year storm to determine the existing flood LOS for roads, and for the 100-year storm to determine the existing LOS for buildings.

The C5 Basin was analyzed and grouped logically into 3 improvement regions (LOS Areas) considering in-common topography and PSMS elements. **Table 3.3.5-4** presents the length of road flooded above crown in each region for the 10-year storm, base condition, and the number of buildings expected to flood for the 100-year storm, base condition. Because the verification of each individual FFE for every building and residence property in Miami is not within of the scope of this project, a standard one-foot above existing grade has been added to the LiDAR DEM around the periphery of each structure as a reasonable estimate of the minimum building FFEs. Approximately 300 FFEs were field verified in the deepest flooding areas by ground survey and the DEM numbers were adjusted accordingly. It is noted that Current Florida Building Code requires 1 foot or more above the BFE depending on the FIRM flood hazard zone within which the property is located. Future minimum FFEs may be required to include additional height provisions for sea level rise.

The LOS score for each region was determined by the following equation:

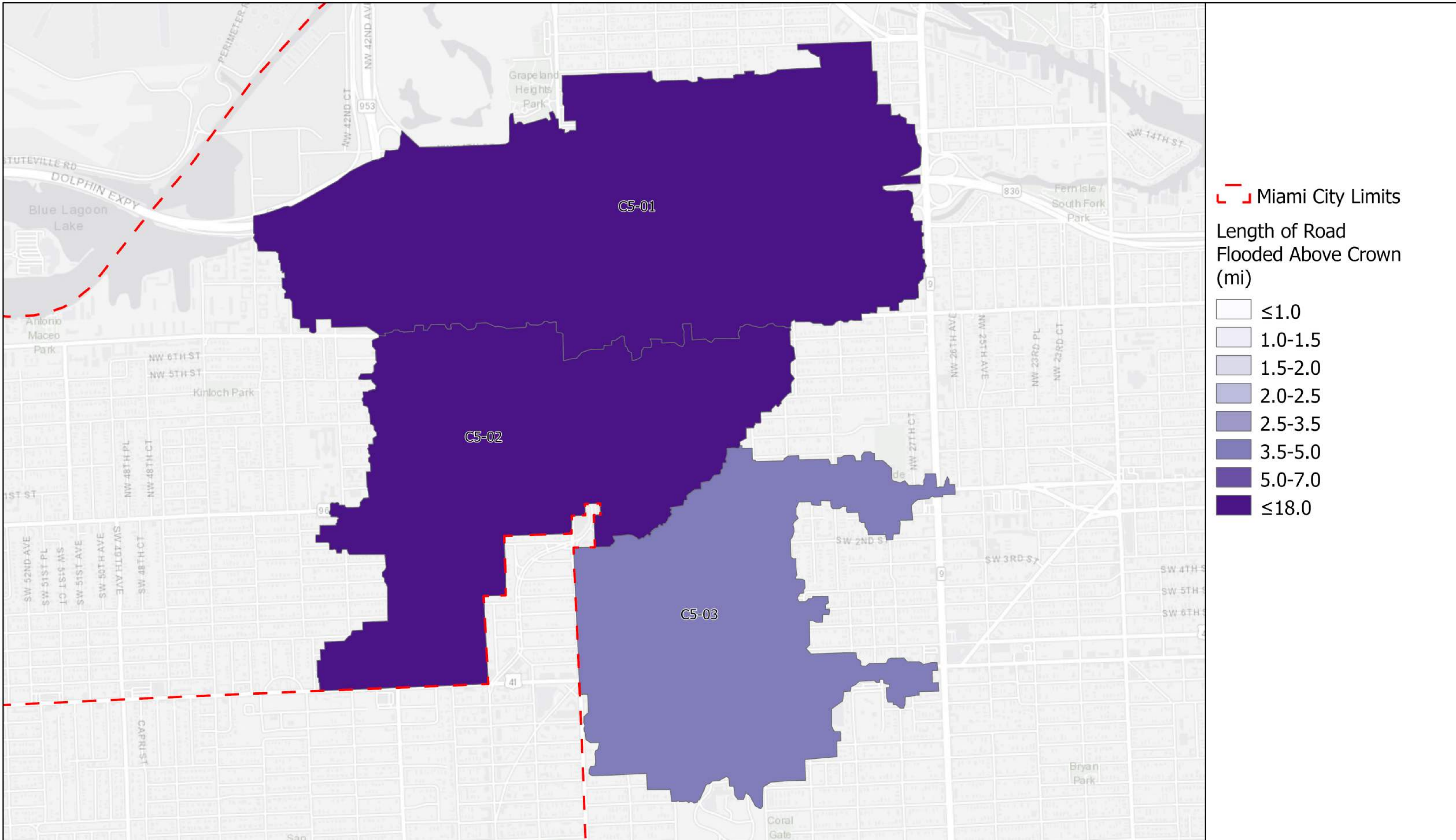
$S_{LOS} = C_1 * Len_{10} + C_2 * Bldg_{100} + C_3 * Str_{Crit}$;

Where S_{LOS} is the LOS score, Len_{10} is the length of road flooded above crown for the 10-year storm in linear feet and normalized by population, $Bldg_{100}$ is the number of buildings flooded above the estimated FFE for the 100-year storm, normalized by population, Str_{Crit} is the number of critical structures identified in the region, and C_1, C_2 and C_3 are coefficients the City of Miami may use to help rank neighborhoods. Higher scores indicate worse predicted Current LOS problems. These rankings are for initial evaluation purposes only, as the two proposed LOS alternatives encompass all of the problem areas, not just those in the highest ranked areas.

Figures 3.3.5-15 and 3.3.5-16 provide the relative existing conditions predicted LOS flooding of roadways and structures respectively for the C5 Basin. Additionally, 144 critical structures were identified in the study area (emergency operations, police, fire, hospital, evacuation shelter, government, etc.) and added to the surveyed FFEs.

Table 3.3.5-4 C5 Basin Existing LOS Ranking

LOS Region	Primary Neighborhood in LOS Area	All Neighborhoods in LOS Area	Area (acres)	Flooded Area 100yr (acres)	Flooded Area/Total Basin Area	Population (2010)	Length of Street Flooded (mi)	Length of Street Flooded/Total Length of Street Flooded 10yr	Est # of Buildings Flooded (100 yr)	# of Buildings Flooded/Total # of Buildings Flooded (100 yr)	# of Critical Structures Flooded (100 yr)	# of Critical Structures Flooded/Total # of Critical Structues Flooded (100 yr)	Basin Relative Flood Ranking
								1		1		1	
C5-01	South Grapeland Heights	North Grapeland Heights, West Grapeland Heights, Le Jeune Gardens, South Grapeland Heights, Auburndale, Flagami	700.3	422.9	43.97%	12,142	13.00	52.67%	587	63.53%	0	0.10%	1.16301
C5-02	Flagami East	West Grapeland Heights, Le Jeune Gardens, South Grapeland Heights, Auburndale, Flagami	480.7	294.7	30.64%	8,417	7.15	28.95%	210	22.73%	1	99.80%	1.51476
C5-03	Auburndale	Citrus Grove, Auburndale, Parkdale North, La Pastorita	385.7	244.3	25.39%	7,760	4.54	18.38%	127	13.74%	0	0.10%	0.32223
Totals	3		1,566.7	962.0	100%	28,319.0	24.7	100%	924.0	100%	1	100%	

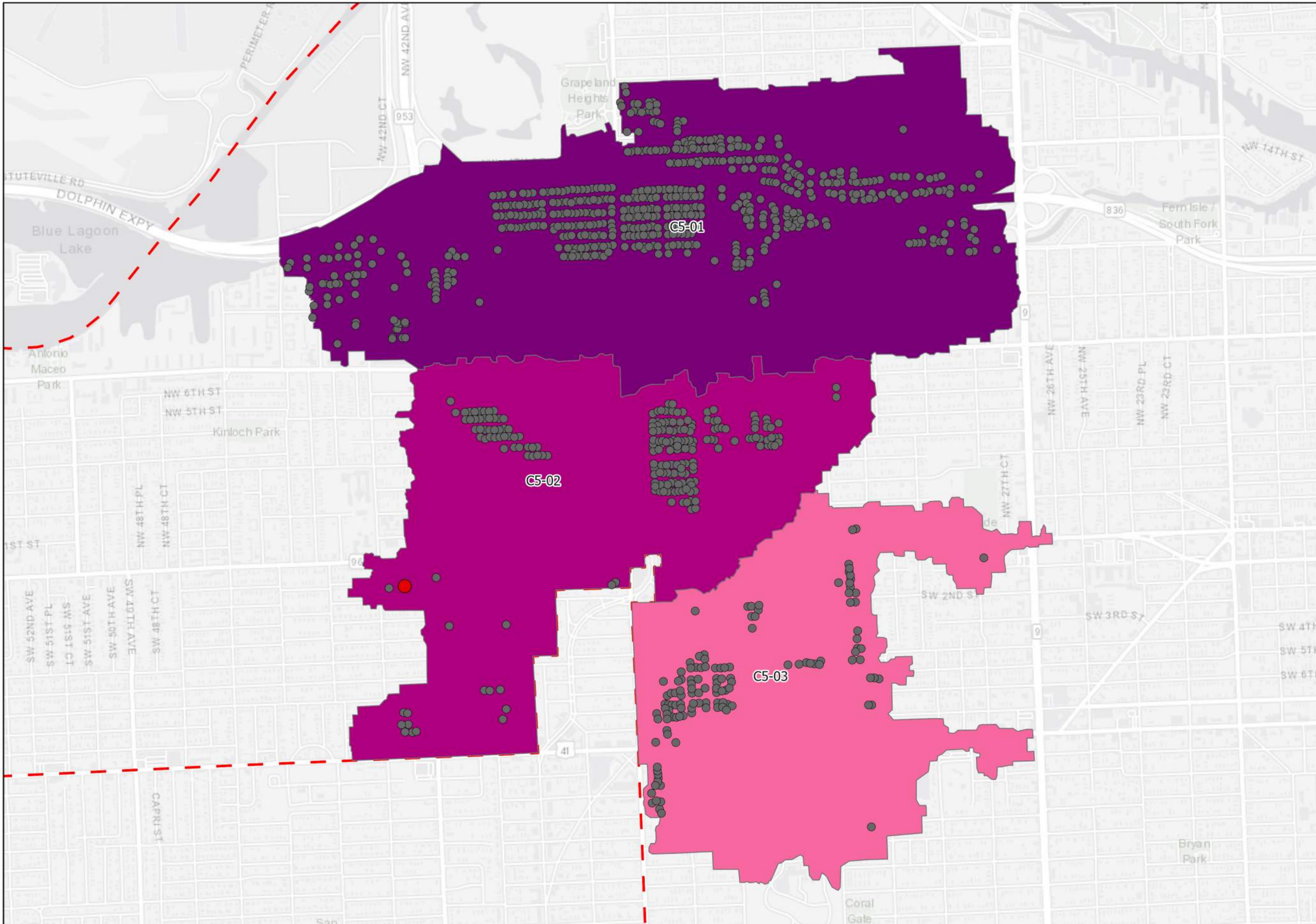


CDM Smith

Length of Road Flooded Above Crown by Region 10-year storm C5 Basin Existing Conditions

Date: 12/14/2020

Figure 3.3.5-15



Miami City Limits

Weighted Flood Rank By Region

- Lower
- Moderately Low
- Moderate
- Moderately High
- High
- Highest

- Flooded Critical Structure
- Flooded Building

CDM Smith

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Number of Buildings & Critical Structures Flooded by Region 100-year storm C5 Basin Existing Conditions

Date: 12/14/2020

Figure 3.3.5-16

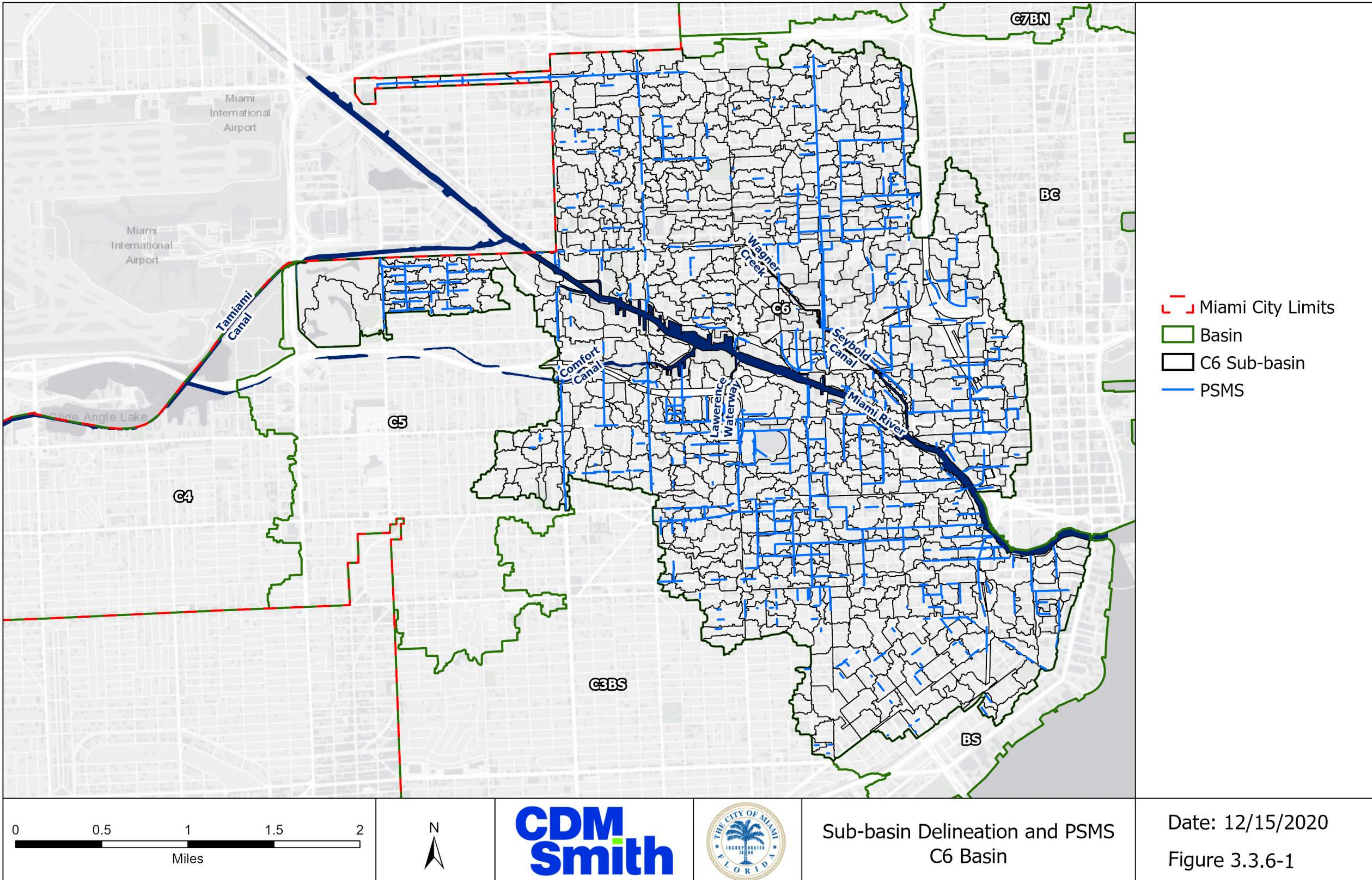
3.3.6 C-6 Basin (C6)

3.3.6.1 C6 Basin Description

The C-6 (C6) Basin consists of 7,194 acres of low-lying land that primarily discharges to the Miami River. **Figure 3.3.6-1** includes a delineation of the C6 Basin and a simplified representation of the PSMS within the basin. The C6 Basin is characterized by PSMS drainage directly to Miami River south of Julia Tuttle Causeway (I-195) and north of SW 3rd Avenue. The northern boundary is adjacent to C7BN and Biscayne Central Basins and is delineated by the I-195 expressway and NW 36th Street following topography. In the northwest portion of the basin, it necessarily includes tributary beyond city boundaries. The western boundary is delineated by NW 27th Avenue and NW 42nd Avenue following topography. The west portion of the basin also includes the NW 36th Street corridor and the North Grapeland Heights neighborhood west of NW 42nd Avenue. The southern boundary is adjacent to C5, C3BS and Biscayne South Basins and is delineated by topography south of the Citrus Grove, Latin Quarter and Roads neighborhoods. The eastern boundary is adjacent to Biscayne Central Basin and delineated by the Miami River, I-95 expressway, and NW 1st Avenue following topography.

Figure 3.3.6-2 shows the DEM for the C6 Basin. Topographic elevations range from near 0 ft-NAVD 88 in areas near Miami River to approximately 20 ft-NAVD 88 along the coastal ridge that surrounds the low-lying areas of the Miami River floodplain. In the C6 Basin, an isolated ridge adjacent to the Miami River extends for approximately a mile. The coastal ridge system connects south of the Miami River to the ridge present in C3BS and BS basin. Low laying areas in the basin include the Miami River floodplain, the adjacent area to the Wagner Creek Canal, and the area west of NW 27th Avenue in the North Grapeland Heights neighborhood. Approximately 89% of the C6 Basin's PSMS stormwater inlets are between 3 feet and 15 feet NAVD 88; however, over 500 PSMS inlets (8.2%) are located where the LiDAR elevations are below 3 feet NAVD 88. Over 1100 PSMS inlets (18.6%) are located where the LiDAR elevation are below 4 feet NAVD 88. The lower elevations are all near Miami River and are susceptible to storm surge and sea level rise. Further, low street elevations preclude using gravity recharge wells or other exfiltration systems, since the driving heads are small. Existing exfiltration systems in these areas are not expected to work well.

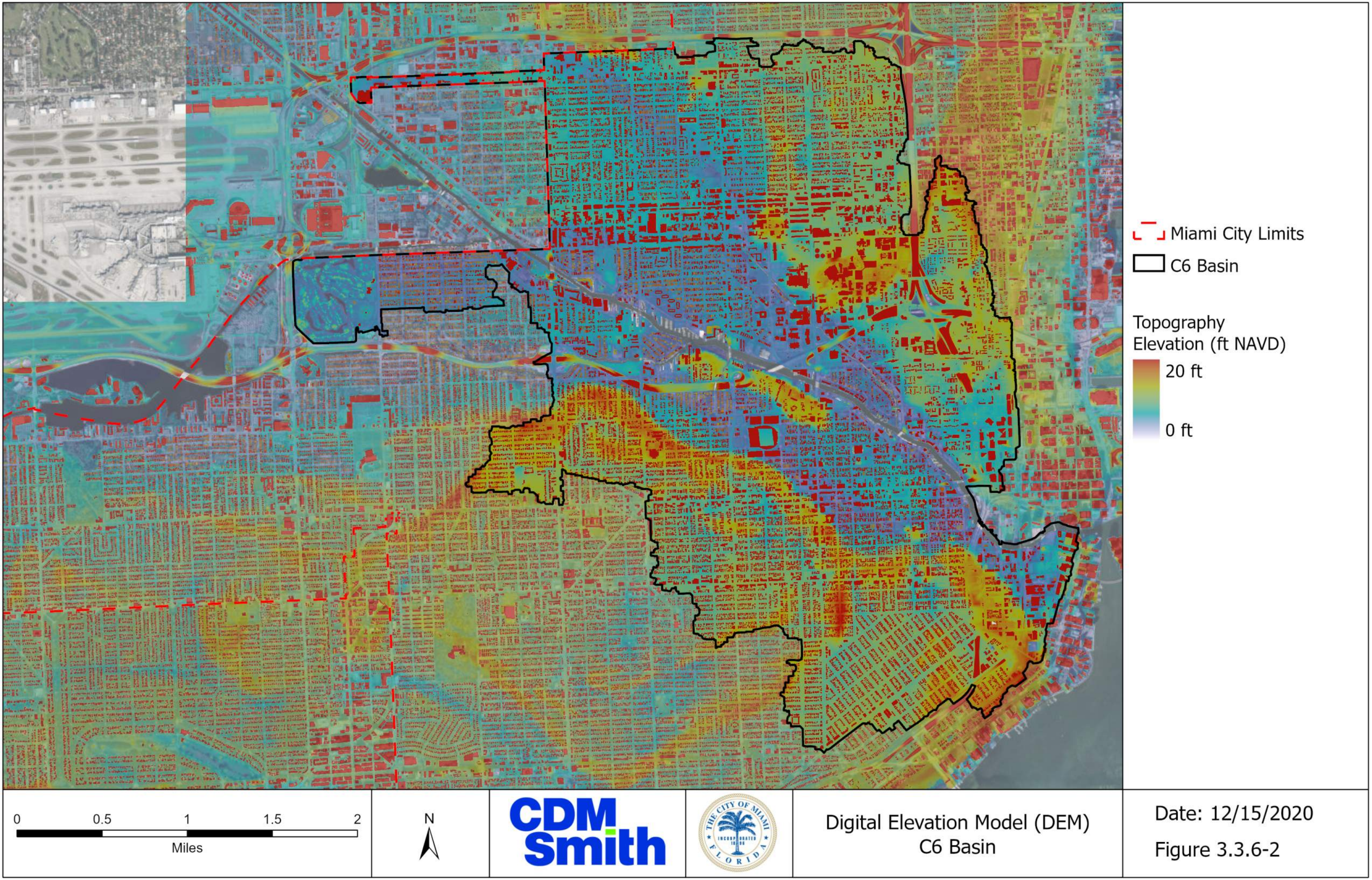
Figure 3.3.6-3 presents a map of the impervious cover for the C6 Basin based on the USGS NLCD coverage as discussed in the Model Development Technical Memorandum and **Figure 3.3.6-4** presents a map of the SFWMD land-use for the C6 Basin.



Sub-basin Delineation and PSMS
C6 Basin

Date: 12/15/2020

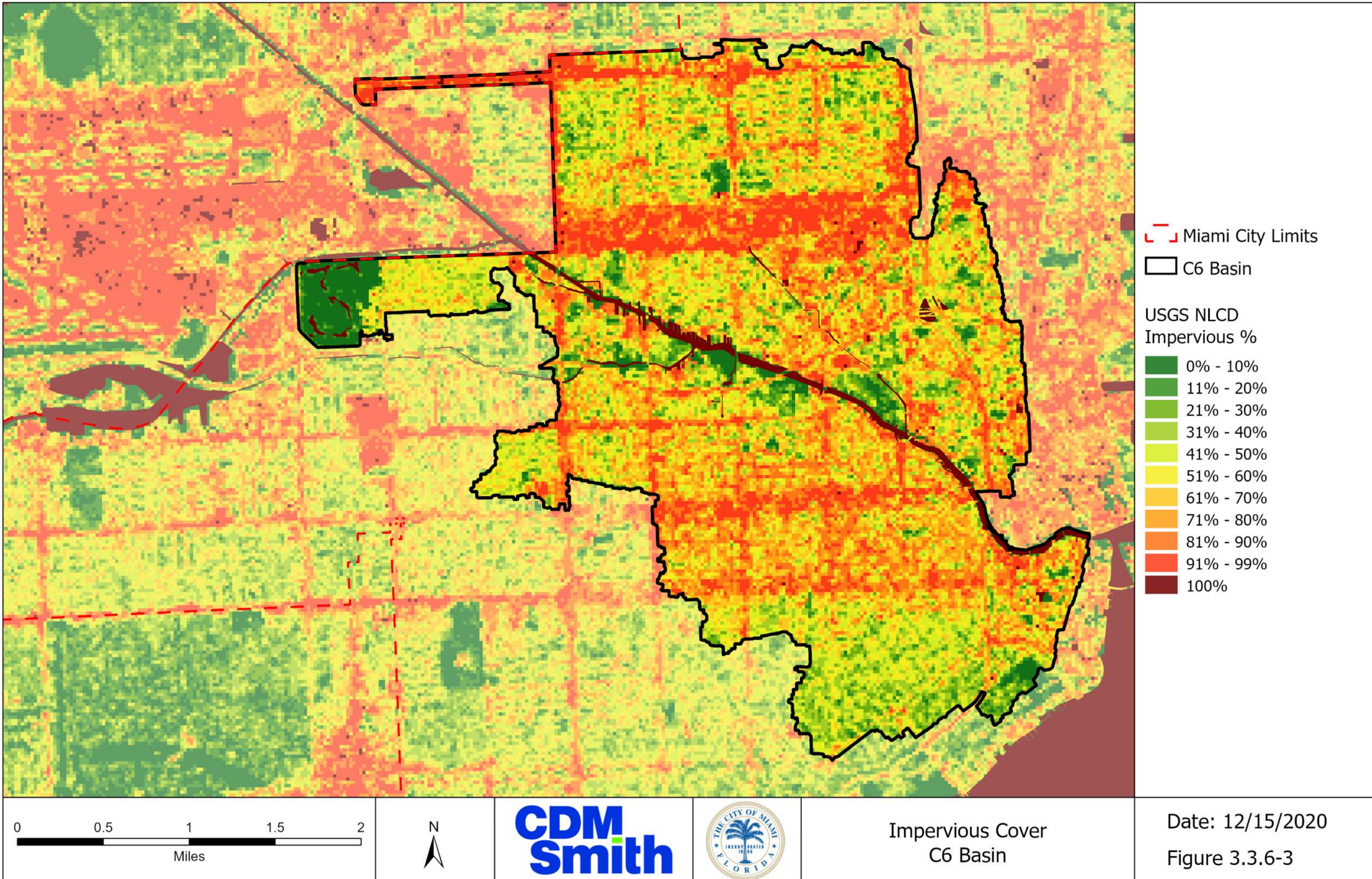
Figure 3.3.6-1



Digital Elevation Model (DEM)
C6 Basin

Date: 12/15/2020

Figure 3.3.6-2

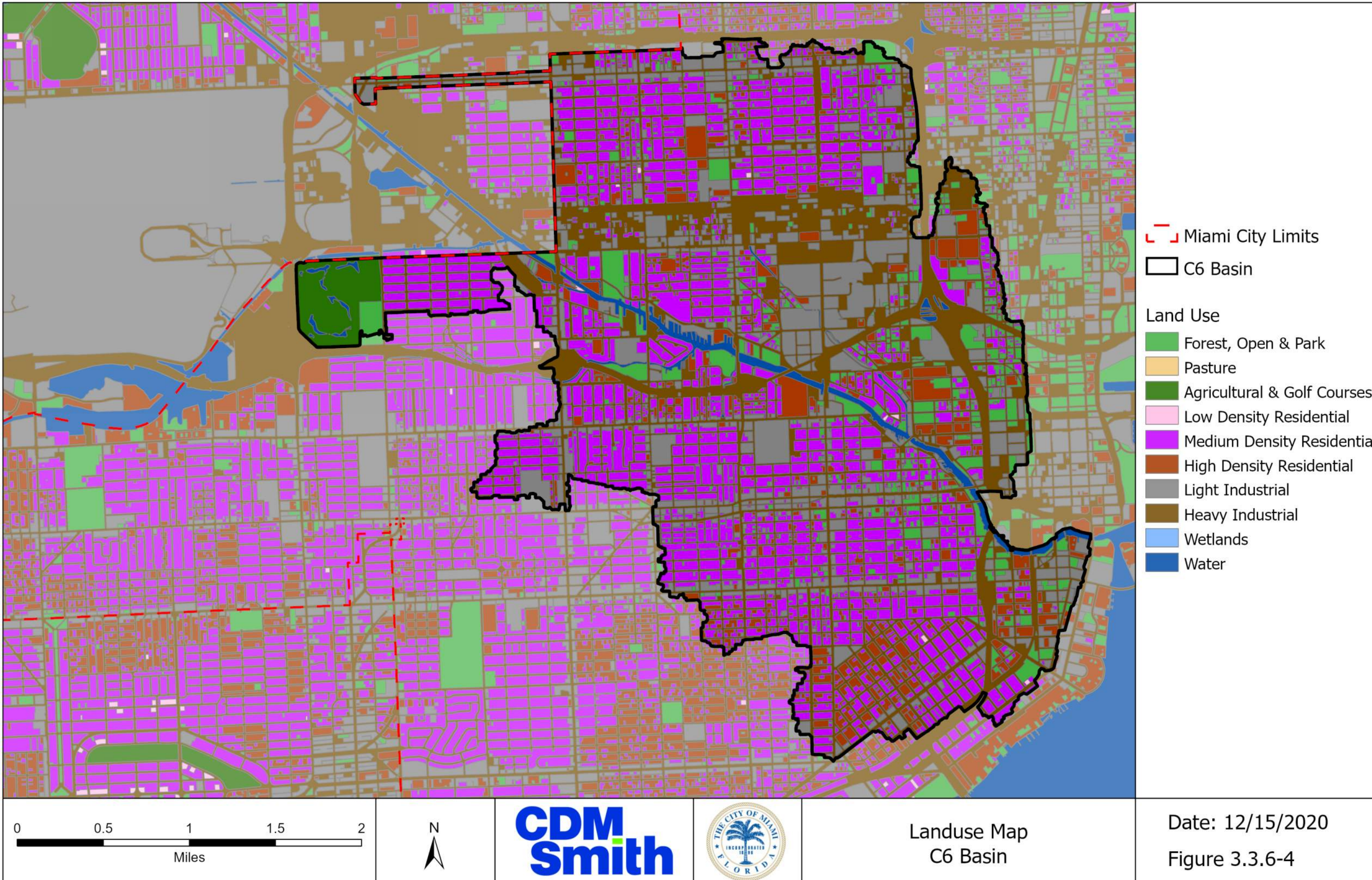


CDM Smith

Impervious Cover
C6 Basin

Date: 12/15/2020

Figure 3.3.6-3



CDM Smith

THE CITY OF MIAMI FLORIDA

Landuse Map
C6 Basin

Date: 12/15/2020

Figure 3.3.6-4

As described in detail in the Model Development TM, impervious coverages were intersected with the sub-basin delineations, adjusted using the developed USGS impervious weightings, and a percentage of the total impervious routed to pervious based on land-use parameters. **Figure 3.3.6-5** presents the total impervious percentage in the C6 Basin, delineated by sub-basin, after the adjustment for pervious/impervious routing was applied. **Figure 3.3.6-6** presents a breakdown of the land use by ten standard consolidated categories, for use in the model. **Figure 3.3.6-7** presents a breakdown of the impervious cover in the model. The area-weighted total impervious percent of the C6 Basin is estimated to be 70%; therefore, approximately 5,028 acres of the 7,194 acres are expected to be impervious surface. Of this, approximately 1,072 acres are expected to be routed to pervious surfaces prior to entry into the C6 Basin PSMS. The routing of runoff to pervious surfaces does not affect the volume infiltrated to soils but does change the timing of the hyetograph.

For design storm simulations, the SFWMD 24-hour and 72-hour unit hydrographs were used to implement the rainfall distributions per storm. **Table 3.3.6-1** presents the volumes for the C6 Basin for the 5-year, 24-hour; and 10-year, 25-year, and 100-year 72-hour design storms that were obtained from the NOAA Atlas 14. Design Storm rainfall volumes may be found for select gages in the atlas, or an interpolated volume estimate may be found for point locations. For this basin, point location estimates were made across the basin. In order to be conservative, the highest volume was used as the design rainfall volume over the entire basin. In general, the western edge of the basin has slightly higher expected volumes than the coastal edge.

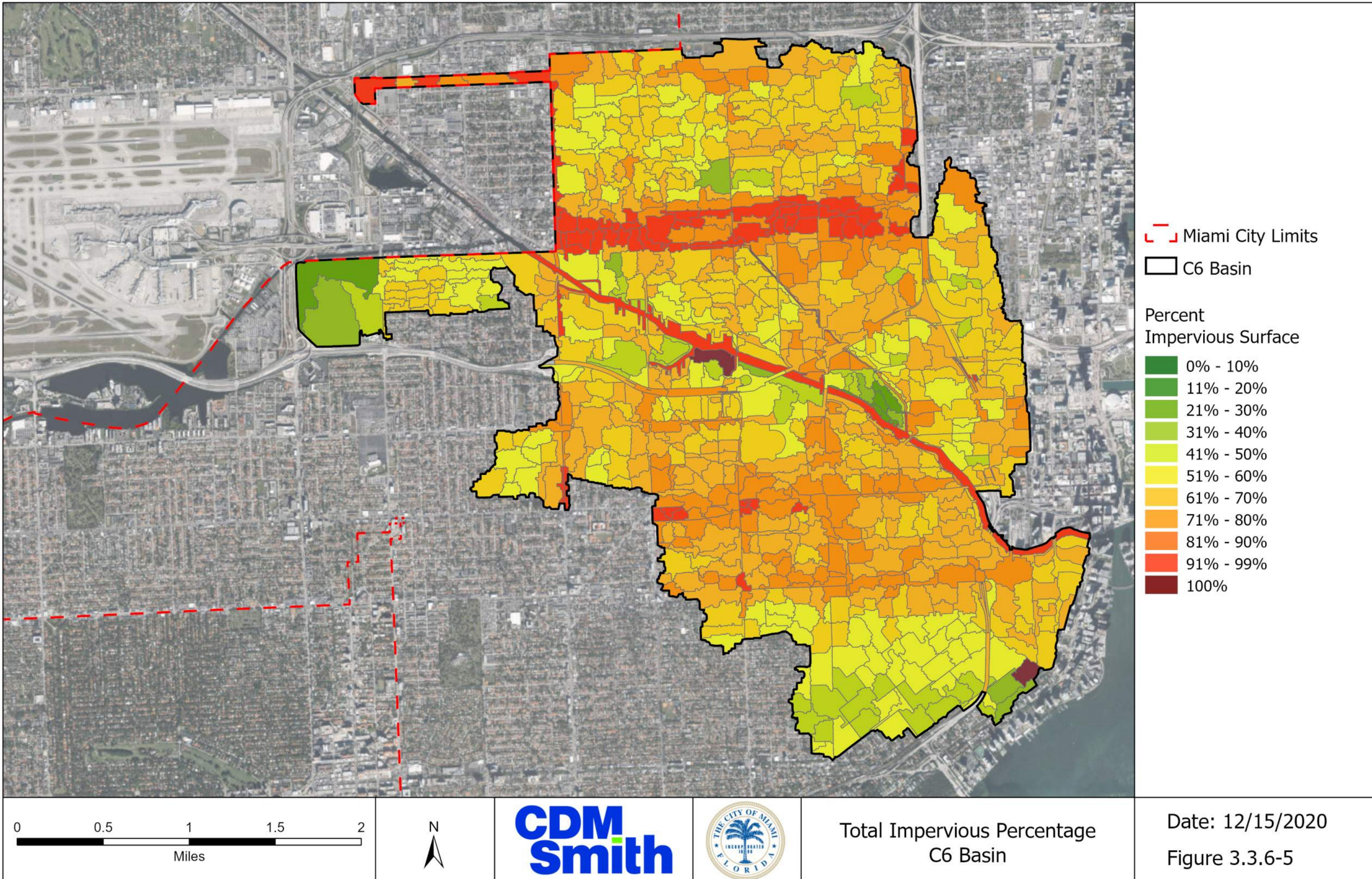
Table 3.3.6-1 C-6 Basin Design Storm Volumes and Intensities

Storm	Rainfall Depth (inches)*	Peak 5-min Intensity (inches/hr)
5-year, 24-hour	7.03	5.5
10-year, 72-hour	10.6	6.1
25-year, 72-hour	13.2	7.5
100-year, 72-hour	17.7	10.1

* NOAA Atlas 14 provides 1-day volumes to the hundredths and 3-day volumes to the tenths of an inch

Surface soils in the C6 Basin are uniformly described as “urban” with a western portion classified as “group A” in the NRCS soils map included as shown on **Figure 3.3.6-8.** In order to apply the Modified Green-Ampt infiltration in SWMM, the urban soils needed to be characterized in more detail.

The project performed a limited number of double-ring infiltrometer tests in order to determine soil types throughout the project area. Miami-Dade County has performed similar tests. As discussed in the Model Development TM, the tests indicated Type A (sandy, or well-draining soils) soils at higher elevations, Type D (clay, or poor-draining soils) in low areas, particularly in the Miami River Floodplain, and intermediate soils elsewhere.



Total Impervious Percentage
C6 Basin

Date: 12/15/2020

Figure 3.3.6-5

Figure 3.3.6-6 Landuse Category Breakdown for C6 Basin

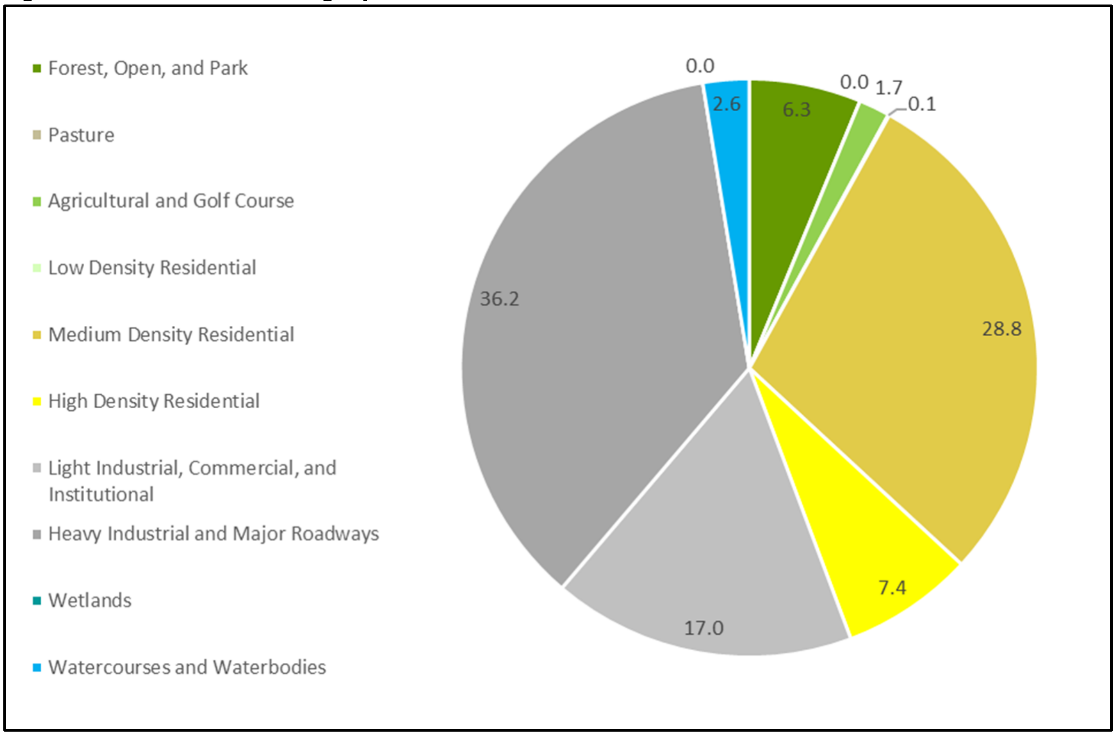
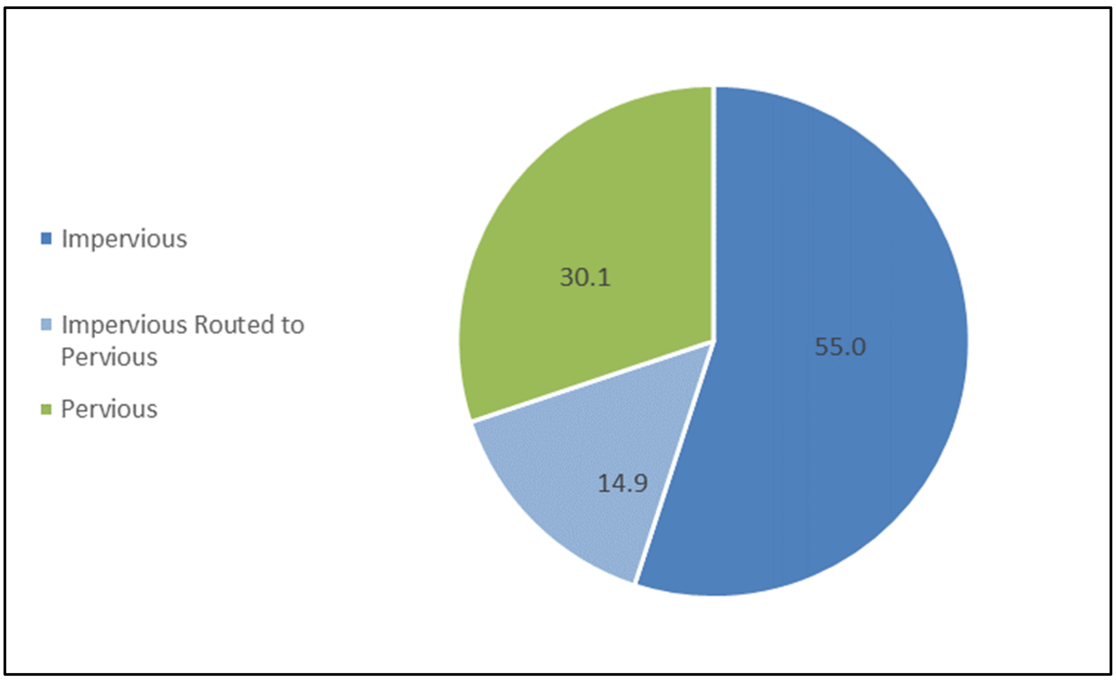
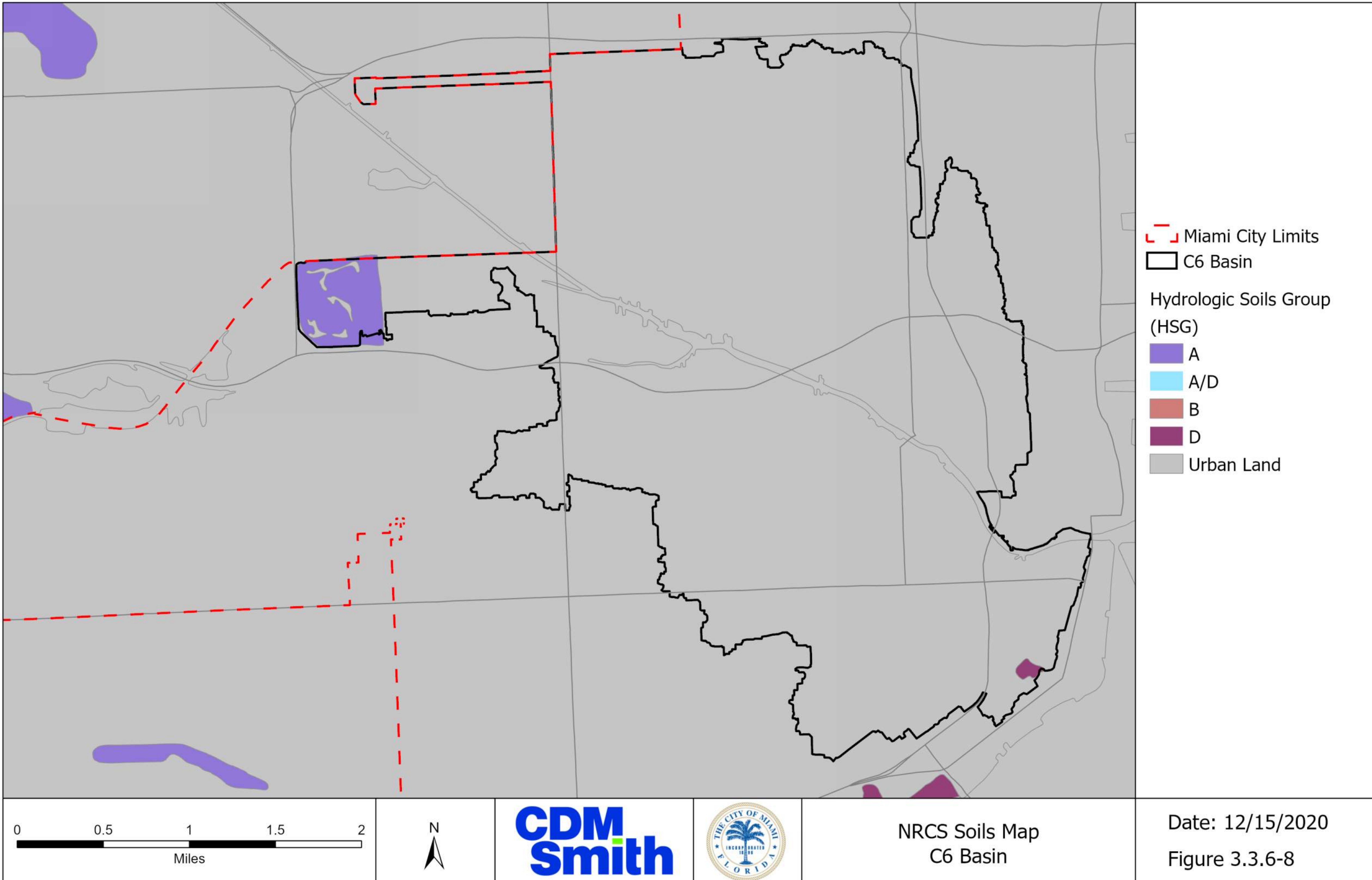


Figure 3.3.6-7 Breakdown of Adjusted impervious Cover for C6 Basin





NRCS Soils Map
C6 Basin

Date: 12/15/2020

Figure 3.3.6-8

Therefore, the C6 Basin model uses Type A soil in a region west to NW 37^{th} Ave and high coastal ridge areas, Type D soils along the low-lying areas within the Miami River floodplain, and Type B (intermediate) soils in the northern, southern portions of the basin and in between regions, as shown on **Figure 3.3.6-9**. Note that the rates on Figure 3.3.6-9, and the model parameter inputs, are Green-Ampt Hydraulic Conductivities, which do not directly correspond to the measured DRI soils infiltration rates.

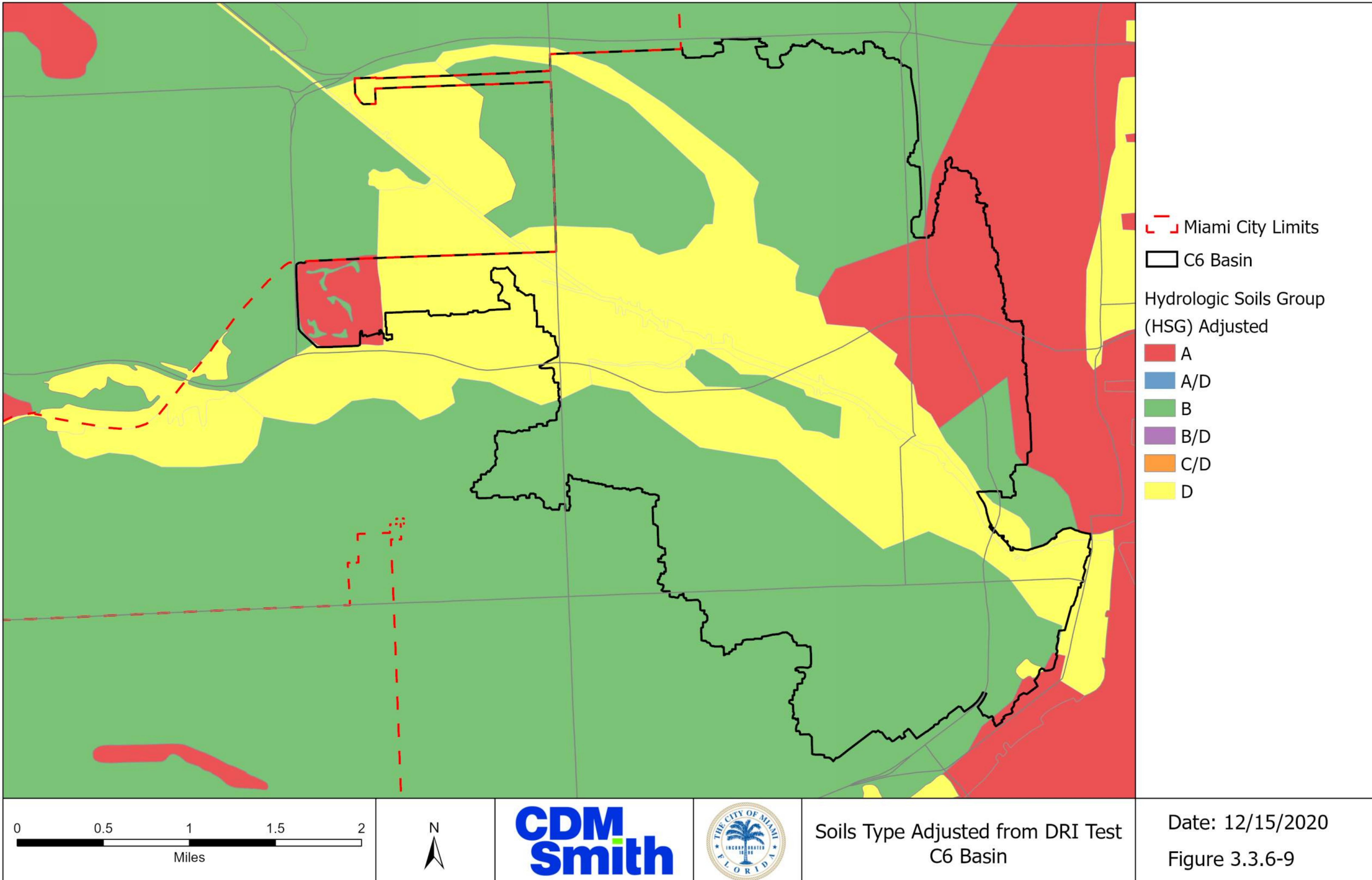
3.3.6.2 C6 Hydrologic and Hydraulic Model Elements

The developed H&H models for the C6 Basin stormwater management system were used to evaluate the performance of the City's existing stormwater management system and to analyze future improvement projects (CIP). Model analysis evaluated the PSMS for multiple size rainfall events and downstream tidal boundary conditions. The PSMS includes constructed stormwater facilities and overland flow paths that drain to the downstream waterbody (i.e., boundary condition). The PSMS generally includes open channels and pipes of 24-inch diameter and larger.

The C6 Basin modeled area is 7,194 acres delineated into 860 sub-basins ranging in size from 0.5 to 290.3 acres with a mean size of 8.4 acres. Many of the smaller sub-basins delineate the area directly adjacent to the seawalls, which are necessary to model pre- and post-conditions for raised seawalls and backflow prevention but tend to be smaller than most of the city-wide delineation. The largest sub-basin within city limits is 63.0 acres and located south of the Tamiami C-4 Canal and east of NW 42^{nd} Avenue. The second largest sub-basin within city limits is approximately 59.7 acres of an area immediately north of NW 14^{th} Street and east of NW 42^{nd} Avenue. **Table 3.3.6-2** summarizes the C6 model elements.

Table 3.3.6-2 Summary of C6 Model Elements

Sub-basins		860
Junctions		65
Storages	**Functional**	2043
	Tabular	865
Outfalls		6
Conduits	**Circular**	2316
	Custom (Bridge)	11
	Ellipse	20
	Force Main	5
	Trapezoidal	1
	Rectangular Closed	297
	Rectangular Triangular	1
	Irregular Bridge	17
	Irregular Canal	49
	Irregular Ditch	11
	Irregular Overland	1787



Soils Type Adjusted from DRI Test
C6 Basin

Date: 12/15/2020

Figure 3.3.6-9

Appendix B includes the C6 Basin model schematic (**Figure C6-EC**) with standard symbology and Appendix C includes more detailed tables presenting the C6 model element characteristics. These tables include the following:

- **Table C6-1** Hydrologic Parameters per Sub-basin
- **Table C6-2** Hydraulic Nodes Data
- **Table C6-3** Hydraulic Conduit Data
- **Table C6-4** Model Pump Data
- **Table C6-5** Model Weir Data
- **Table C6-6** Model Exfiltration Data

Model nodes representing manholes are modeled as functional storage nodes with a minimal amount of constant storage area (12.56 square feet, which is roughly equivalent to a typical 48-inch diameter manhole). Pump Station wet wells are modeled as functional storage nodes with constant areas equivalent to the wet well area, if the station dimensions were provided, or 100 square feet if the dimensions were not provided.

The C6 Basin model has one primary outfall representing Biscayne Bay (BiscayneBayBC). Only one irregular channel link has been connected to a virtual node (BiscayneBay). The outfalls have been co-located for ease in changing boundary conditions once the models have been turned over to the City. Five outfalls represent injection wells, where the runoff is pumped directly into the Biscayne Aquifer. Additionally, 20 subbasins, 20 storage nodes, and 20 outfalls are used to model the exfiltration systems in the C6 Basin. The virtual systems representing groundwater are not included in the model schematic nor in the tables. The groundwater table has been divided into 20 contiguous sections in the basin area because the initial level of the base groundwater varies depending on distance from Biscayne Bay and topography. The exfiltration systems are described in further detail in below.

The City's project-specific survey and the GIS coverage of stormwater pipes identifies 92 stormwater points of discharge simulated as outfalls that discharge to Miami River. There are an additional 76 outfalls representing sheet flow to the river from the sub-basins along the shore. Generally, the overland sheet flow cross-sections represent the seawall surveyed in that area. If a seawall is not present over a portion of the shoreline, 0.0 ft-NAVD 88 is used as the overflow elevation. The topography behind the shoreline is determines the opposite side of the seawall edge sub-basin, and the subsequent overland flow elevation to the rest of the neighborhood.

3.3.6.3 C6 Pump Stations

There are five existing pump stations in the C6 Basin which convey stormwater flow from low-lying area to outfalls as shown on Figure C6-EC. A wetwell with and under flow weir provides storage and treatment and screening of collected runoff for each station. Pumps are typically set to turn on at levels above the static water table and cycle off as water levels drop in the wetwell. Most pump stations have a control gate to bypass the station when offline for maintenance servicing, and some have an overflow weir to allow flow beyond the pump station capacity to continue out the outfall by gravity.

In the SWMM, pumps are represented by stage-flow links connected to an inflow storage node that serves as the wet well. The outflow section of the link is connected to a node that serves as a force main to an outfall. The types of pumps represented in this model are in-line pumps where flow increases incrementally with inlet node depth (SWMM Type 2). All pump station information was obtained from City-provided as-builts or other available plan sets.

1. Orange Bowl PS has a total maximum capacity of 124.7 cfs or 56,000 gpm, and is located on 1775 NW 7 Street. This pump station injects water directly into the Biscayne Aquifer via 2 injection wells and discharges water directly to the Lawrence Waterway via outfall. The Pump Station has a maximum capacity of 73.5 cfs or 33,000 gpm to inject water into the aquifer. If the aquifer cannot accept the 73.5 cfs, a maximum flow of 51.2 cfs or 23,000 gpm can also be diverted over a weir through a 240-foot long, 120-inch diameter force main immediately north of NW 7th Street into the Lawrence Waterway. For flood modeling purposes, since the flow leaves the model to the aquifer is not relevant to the peak flood levels on the South Sewell Park neighborhood, only to the water quality analysis as the wells provide treatment credit and saltwater intrusion mitigation. Accordingly, the force mains are not explicitly modeled, and the pump station links directly to the outfall nodes representing the aquifer. For this station, the wet well is set at -15.0 feet NAVD 88.:
   - There are three pumps in the station, and all are in separate links.
   - Pump 1 that injects into the aquifer cycles on and off at -6.8 ft-NAVD 88 and -10.3 ft-NAVD 88, respectively, with a maximum flow of 51.2 cfs (23,000 gpm).
   - Pump 2 that injects into the aquifer cycles on and off at -7.2 ft-NAVD 88 and -10.3 ft-NAVD 88, respectively, with a maximum flow of 22.3 cfs (10,000 gpm).
   - Pump 3 that discharges into the Lawrence Waterway cycles on and off at -6.0 ft-NAVD 88 and -10.0 ft-NAVD 88, respectively, with a maximum flow of 51.2 cfs (23,000 gpm).
2. NW 11th Street Fern Isle Park SWPS has a total maximum capacity of 20 cfs (9,000 gpm) and is located adjacent to Fern Isle Park, just north of N.W. 11th Street in the North Sewell Park neighborhood. This Miami Dade County Operated pump station injects water directly into the Biscayne Aquifer through one injection well. For flood modeling purposes, since the flow leaves the model to the aquifer, it is not relevant to the peak flood levels on the North Sewell Park neighborhood, only to the water quality analysis as the wells provide treatment credit and saltwater intrusion mitigation. Accordingly, the pump station link directly to the outfall node representing the aquifer is not explicitly model. For this station, the wet well is set at -10.0 feet NAVD 88.
   - There is one pump in the station.
   - Pump station cycles on and off at 0 ft-NAVD 88 and -5.0 ft-NAVD 88, respectively, with a maximum flow of 20 cfs (9,000 gpm).
3. Riverview PS has a total maximum capacity of 260 cfs (116,700 gpm) and is located at 1301 SW 6th Street. This pump station discharges water into the Miami River via 2

outfalls. The pump station discharges water into a 249-foot long, 84-inch diameter circular pipe north of NW 6th Street. This pipe connects to a 60-foot long, 84-inch pipe and the flow is diverted through a weir to two 950-foot long series of pipes that outfall in the Miami River. For this station, the wet well is set at -15.0 feet NAVD 88.

- There are four pumps in the station, and all are in separate links.
- Pump 1 cycles on and off at -6.5 ft-NAVD 88 and -7.44 ft-NAVD 88, respectively, with a maximum flow of 20 cfs (9,000 gpm).
- Pump 2 cycles on and off at -5.15 ft-NAVD 88 and -6.5 ft-NAVD 88, respectively, with a maximum flow of 80 cfs (35,900 gpm).
- Pump 3 cycles on and off at -3.62 ft-NAVD 88 and -5.15 ft-NAVD 88, respectively, with a maximum flow of 80 cfs (35,900 gpm).
- Pump 4 cycles on and off at -2.0 ft-NAVD 88 and -3.62 ft-NAVD 88, respectively, with a maximum flow of 80 cfs (35,900 gpm).

4. Lawrence PS has a total maximum capacity of 66.8 cfs (30,000 gpm) and is located at 342 SW 7th Avenue. This pump discharges water directly to the Miami River via outfall. The flow is discharged through a 2,200-foot long, 60-inch diameter force main where SW 4th Street meets the Miami River. For this station, the wet well is set at -15.0 feet NAVD 88.

   - There are two large duty pumps in the station rated at 15,000 and 20,000 gpm and a third small sump pump
   - Pump station cycles on and off at 0 ft-NAVD 88 and -10.0 ft-NAVD 88, respectively, with a maximum flow of 66.8 cfs (30,000 gpm).

5. Mary Brickell Village SWPS has a total maximum capacity of 64 cfs (28,724 gpm) and is located immediately west of SW 1st Avenue and south of SW 8th Street. This pump station injects water directly into the Biscayne Aquifer through two injection wells near the station along SW 1st Avenue. For flood modeling purposes, since the flow leaves the model to the aquifer, it is not relevant to the peak flood levels on West Brickell neighborhood, only to the water quality analysis as the wells provide treatment credit and saltwater intrusion mitigation. Accordingly, the pump station links directly to the outfall nodes representing the aquifer are not explicitly modeled. For this station, the wet well is set at -19.0 feet NAVD 88.

   - There are two pumps in the station, and all are in separate links.
   - Pump 1 cycles on and off at -0.2 ft-NAVD 88 and -13.0 ft-NAVD 88, respectively, with a maximum flow of 32 cfs (14,362 gpm).
   - Pump 2 cycles on and off at 0.3 ft-NAVD 88 and -13.0 ft-NAVD 88, respectively, with a maximum flow of 32 cfs (14,362 gpm).

3.3.6.4 C6 Exfiltration

The C6 Basin uses exfiltration systems as one of its primary methods to reduce flooding and improve water quality by moving water from the PSMS to the Biscayne Aquifer. These systems include:

- Slab Covered Trenches: Rectangular boxes cut directly into the limestone aquifer, then covered with a concrete slab. There are approximately 14.1 miles of slab covered trench in the C6 Basin.
- French Drains: Perforated pipe situated in a gravel-filled rectangular shaped excavation into the aquifer. There are approximately 37.4 miles of French Drains in the C6 Basin.
- Recharge/Drainage Wells: There are 124 gravity drainage/recharge wells in the C6 Basin. There are two types of recharge wells used in the Miami area - gravity driven wells and injection (pumped) wells. Injection wells are accounted for in the pumped flows to outfall representing the aquifer (see above) and therefore not included in the exfiltration rating curves. Gravity wells use the differential driving head of the land surface water surface elevation and the aquifer ground water table elevation to overcome the well casing friction and any salinity interface density to push stormwater runoff out into the porous and highly transmissive limestone layer underground. The use of Biscayne aquifer drainage wells is restricted to zones where chloride concentrations exceed the saltwater intrusion front identified as the location at the base of the aquifer, of the 1,000 mg/L isochlor and no impact to the Class G-II potable water supply aquifer.

In the C6 Basin, the regional water table elevation is estimated for 20 separate regions. Each region has a specified initial water table level based on the Miami-Dade County base groundwater elevation database. Note, these initial levels are higher in the sea level rise scenarios. The regional water tables rise based on precipitation and infiltration, using generic regional land-use estimates, i.e., the 20 model sub-basins ("GWBC" prefix), 20 storage nodes ("BiscayneAQBC" prefix) and 20 outfalls ("AQLossOut" prefix) are virtual elements designed solely to predict water table elevations and are not hydrologically or hydraulically connected to the model PSMS. The exfiltration rating curves are developed outside the model in a spreadsheet, based on length of system and count of wells per sub-basin, and other sub-basin specific parameters. The curves are head versus flow curves, where the head is internally calculated in the model by subtracting the regional groundwater elevation from the site-specific flood stage. In the large design storms, some of the low-lying exfiltration systems cease operations as the water table rises to ground surface. The Model Development TM provides more details on the exfiltration systems and how rating curves were developed for each type per model sub-basin.

3.3.6.5 C6 Known Flooding Problem Areas

Known problem areas in C6 Basin include the neighborhoods of North Grapeland Heights, Santa Clara, Allapattah Industrial District, Town Park, Citrus Grove, Latin Quarter and Roads. Flooding problems in the Miami River floodplain include neighborhoods of Curtis Park, North Sewell Park, South Sewell Park, Highland Park, Spring Park, Little Managua, East Little Havana and Riverfront. Neighborhoods with flooding problems in high coastal areas include West Brickell and Brickell Village. Flooding problems near Wagner Creek Canal include low-lying areas in the Melrose neighborhood. **Figure 3.3.6-10** indicates where complaints related to storms and/or flooding were made in the C6 Basin.

3.3.6.6 C6 Design Storm Simulations

A range of simulations were performed in the C6 Basin model covering the multiple design storm intensities and an array of boundary conditions. **Table 3.3.6-3** presents all the simulation scenarios being run for the master plan, only the Base Condition run was performed for this TM.

Design storm distributions were taken from the SFWMD Permit Information Manual, Volume IV. Model simulations are performed for the 5-year, 24-hour design storm; and the 10-year, 25-year, and 100-year, 72-hour design storms. The 24-hour design storm has a peak centered at 12 hours, while the 72-hour design storms have peak intensities at 60 hours. The SFWMD design storm distributions are sampled at 5-minute increments. Design Storm volumes were extracted for localized actual recorded rainfall data from the NOAA Atlas 14, as shown previously in Table 3.6-1. Initial depths for nodes in the model were set to match the boundary conditions to create an even starting surface within all areas of the models including pumped areas.

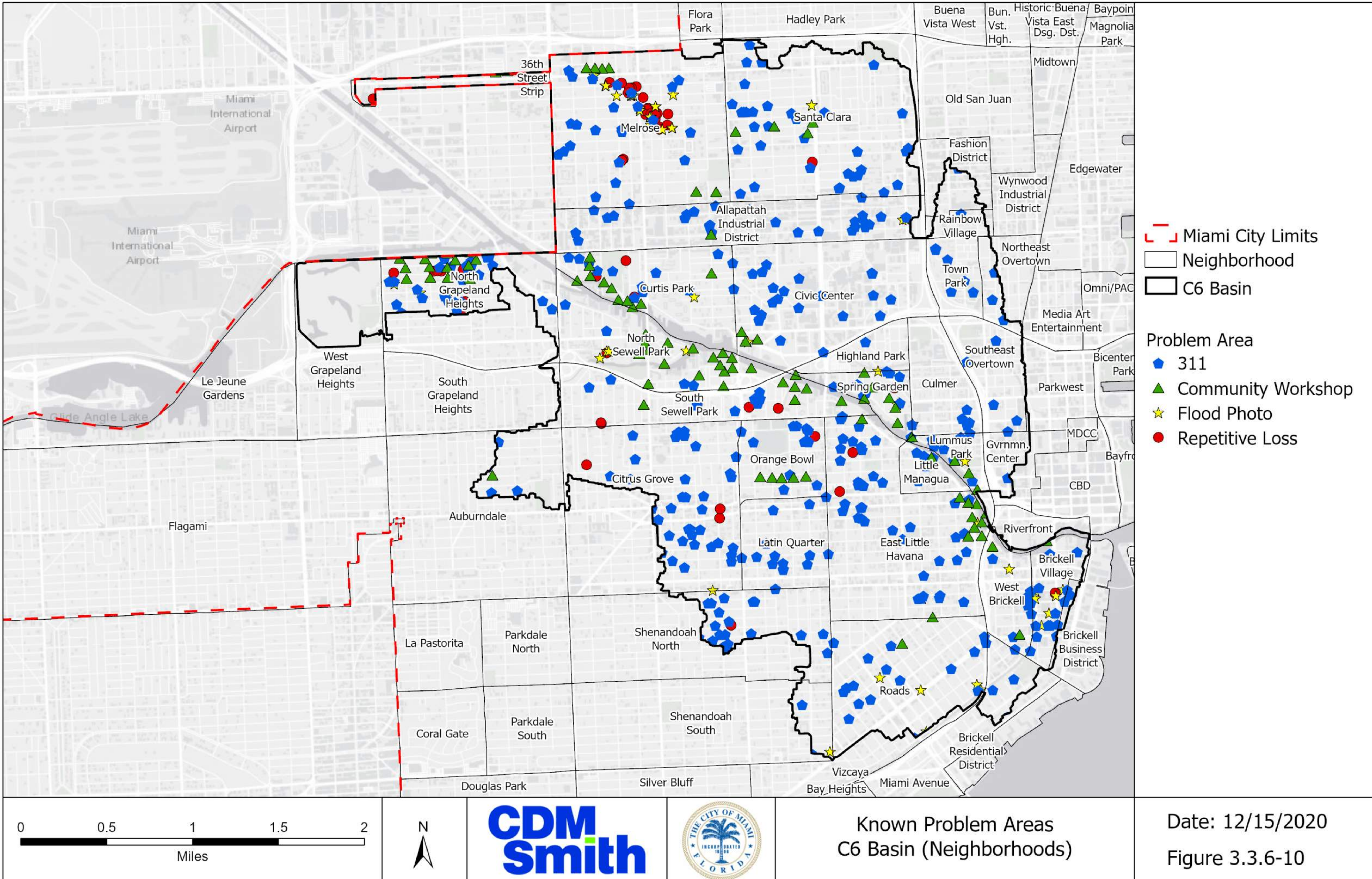
Table 3.3.6-3 Design Storm Simulations

Tailwater Condition	Tailwater Stage in Biscayne Bay (ft-NAVD 88)			
	5-yr, 24-hr	10-yr, 72-hr	25-yr,72-hr	100-yr, 72-hr
Base Condition*	2.0	2.0	2.0	2.0
Base Plus 1.5 feet Sea Level Rise (SLR)	3.5	3.5	3.5	3.5
Base Plus 2.5 feet SLR	4.5	4.5	4.5	4.5
10-year Storm Surge		6.0		

* Base condition represents the one-year stillwater tide elevation – see Model Development TM.

3.3.6.7 C6 Existing Conditions Model Results and Design Storm Inundation Mapping

The verified C6 Basin EC model was run for the base simulation for each design storm considering a well maintained, clean pipe condition. A summary of peak flood stages for the simulated EC model is published by the City in the tables of the on-line stormwater GIS. Flood mapping of the base simulations of existing conditions for the 5-year, 24-hour design storm; and the 10-year, 25-year, and 100-year, 72-hour design storms are presented on **Figures 3.3.6-11 through 3.3.6-14**.



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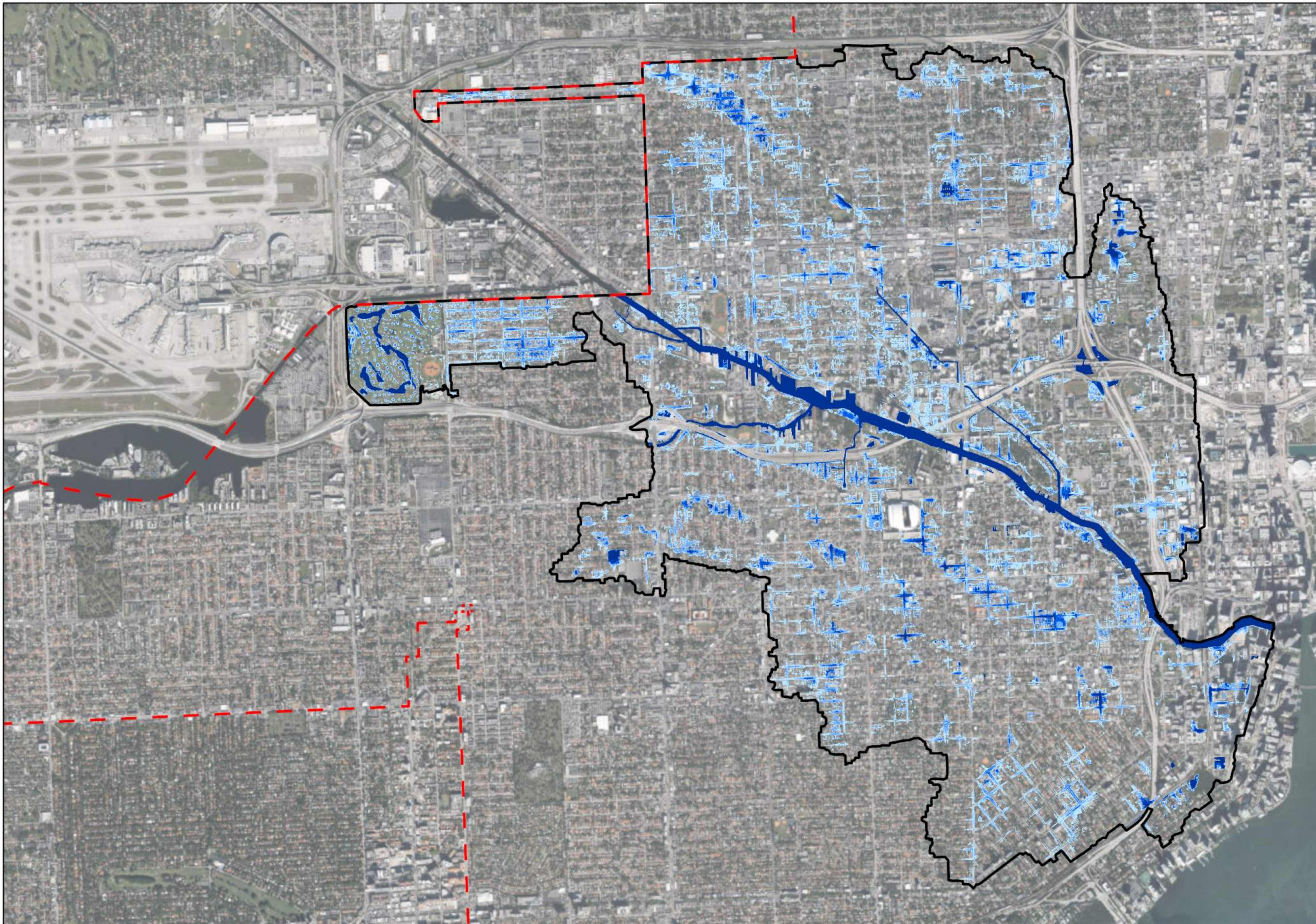
Known Problem Areas
C6 Basin (Neighborhoods)

Date: 12/15/2020

Figure 3.3.6-10



Miami City Limits

C6 Basin

5-year Storm Flood Depth (ft)

0 - 0.5

0.5 - 1

1 - 1.5

> 1.5

0 0.5 1 1.5 2

Miles

N

CDM Smith

THE CITY OF MIAMI
INCORPORATED 1896
FLORIDA

Flood Map
5 yr/24 hr Design Storm
C6 Basin Existing Conditions

Date: 12/15/2020

Figure 3.3.6-11