CITY OF Hollywood FLORIDA

Citywide Comprehensive Stormwater Master Plan

DRAFT **REPORT** **February 2024**

CDM Smith

FINAL DRAFT

City of Hollywood, FL

City Project 20-11053

Comprehensive City-Wide Stormwater Master Plan

February 2024

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Executive Summary

This document is the compiled Final Report summarizing the findings and recommendations of the analysis of the City of Hollywood's stormwater management system and is submitted as the deliverable for City Project 20-11053, *Comprehensive Citywide Stormwater Master Plan* (SWMP).

ES.1 Report Organization

This report is organized as follows:

- *Executive Summary* – Summary of the project and results.
- *Section 1 – Model Development Technical Memorandum* – Stand-alone document deliverable describing the development of the stormwater models and data used for the analysis.
- *Section 2 – Model Application Technical Memorandum* - Stand-alone document deliverable describing the application of the models to determine the existing conditions flooding and their roots causes.
- *Section 3 – Stormwater Master Plan and Capital Improvement Program* – Development of conceptual capital improvements projects (CIP) citywide to meet two City-desired alternative levels of service for flooding conditions, benefit cost analyses, sea level rise analyses, seawall and tidal flooding analysis, and implementation recommendations.

The stand-alone technical memorandums (TMs) in Sections 1 and 2 describe the development and approach taken to create, validate, and apply the hydrologic and hydraulic (H&H) models for this project, and use of the model for analysis under current conditions. Section 3 describes the SWMP results – Two alternative CIPs, performance evaluation of the integrated stormwater management systems and budgetary projected costs, as well as identification of the locations and elements of the proposed improvements to meet the City's two LOS goals. Details of the proposed conceptual projects for each CIP Area to address flooding issues to the LOS including conceptual layouts, approximate quantities, capacities, sizes, and the hydraulic parameters are provided in the figures, tables, and appendices for designers to use as a guide in the implementation of final designs.

ES.2 Introduction and Background

Due to development and re-development, changes in land use, increasing sea level rise, resiliency, vulnerability, and sustainability initiatives, and the changing regulatory requirements over time, 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 developed a detailed stormwater model of the city wide primary stormwater management system in the extended study area simulating present and future conditions including predicted tidal fluctuations and groundwater levels, which was validated to existing conditions for actual past storms and then used as the engineering tool to conceptually design and plan the stormwater capital improvements to meet the City's level of service and resiliency goals citywide. This SWMP was coordinated with other City and local agency initiatives including vulnerability studies, shoreline protection master plans, stormwater pump station condition assessments, parks and golf course master plans, water and wastewater master plans, and other in-progress capital improvement projects such as City stormwater, FDOT, and CRA projects.

ES.3 Use of This Document

This document and its models are intended to be used by engineers and planners as the supporting data and conceptual design guide for the final design of stormwater management projects, stormwater permit applications, grant applications, capital budget planning, and as a reference for coordination of other stormwater-related endeavors throughout the City. The model can be used to test and verify partial or phased designs to expedite permitting and coordination as projects are constructed.

The City intends to adopt, conceptually permit, fund, and implement the recommendations developed in the SWMP over time in a 20-30 year multi-phased, prioritized, stormwater management capital improvements program. Projects are intended to be distributed throughout the City as funding becomes available from various sources including potential future general obligation (GO) bonds, stormwater utility funds, local, state, and federal grant and loan programs, public-private partnerships, and joint project agreements with other entities such as neighboring municipalities, State and County agencies, and the adjacent drainage and water control districts. The SWMP CIP projects must also be coordinated with stormwater-related resiliency and flood protection projects from other in-progress, parallel, sustainability and vulnerability studies or initiatives, which includes shoreline armoring, tidal backflow prevention, pipe lining, critical structure hardening, and flood proofing.

ES.4 SWMP Project Work Phases

The SWMP project was implemented in five major work phases (Tasks):

1. *Data Collection and Evaluation Phase* – Development and production of the hydrologic and hydraulic data for surface and sub-surface conditions for the City and surrounding contributing area's Primary Stormwater Management System (PSMS) and the creation of the interconnected storm systems and boundary conditions for the models and field survey of missing data required for the models. The deliverable for this task was a Data Gap Analysis TM providing a summary of what data was available, what data was still needed, the data sources used and proposed, and what data was entered directly into the models versus what needed to be created for the models. An updated City Stormwater Infrastructure Geographic Information System (GIS) Database was developed as part of the project to store and memorialize all of the gathered data for "one-click" access in a single, searchable, archived location, merged with the City's most current GIS data and provided to the City for its future use.

2. *Stormwater Model Development Phase for Existing Conditions (EC)* – Development of the rainfall simulations and the detailed Storm Water Management Model (SWMM) to determine the EC Level of Service (LOS), validation of the models to actual rainfall events for flooding depth, duration and extent, with an analysis and determination of the root causes of the

flooding predicted in each neighborhood. The deliverable for this task was the Model Development TM and the Model Application TM (Sections 1 and 2 of this report).

3. *Prioritized Capital Improvement Plan Phase and Benefit-Cost Analysis Phase* – Analysis developing proposed CIP Citywide to meet the two alternative City-desired flooding levels of service (LOS), and development of a conceptual layout plan of the proposed new stormwater infrastructure, accounting of budgetary costs, and a benefit cost analysis (BCA) return on investment (ROI) analysis for the two alternatives, collated by Commission District.

4. *Sea Level Rise Evaluation, Climate Change and Resiliency Considerations Phase* - Projection of climate change effects on the proposed Capital Improvements Program (CIP) due to worsening boundary conditions and groundwater levels, a shoreline vulnerability and seawall height analyses, an interim conditions model of the proposed CIP without seawall improvements, and a simulation of future-projected higher intensity, larger storms.

5. *Stormwater Master Plan Support Services* - Other related ongoing support services to coordinate the SWMP guidance including: a public information program, the Recapture the Swales campaign, grant funded pilot programs, guidance and design assistance for SWMP coordination for other consultants' and internal City stormwater projects from DPU, DCM, CRA, and Parks, technical assistance and SWMP coordination with stormwater grant applications, meetings and workshops with stakeholders presenting the progress and findings of the on-going work, coordination with the two drainage districts with the City limits (SBDD and CBWCD), coordination with Broward County Surface Water Licensing and Resiliency divisions, and a conceptual City-wide permit application of the plan with the regulators.

ES.5 Local Stormwater Management Issues and Constraints

Factors which add to the complexity, cost, and magnitude of the City of Hollywood's CIP solutions for stormwater management are many, as local and state regulatory agencies impose significant restrictions on both stormwater quantity (limiting of allowable runoff, flows, and stages) and water quality (requirements for pollution control measures) as follows:

- <u>Regulatory Protection of Local Waterways</u> – Broward County Surface Water Licensing Division (BC SWLD) via delegation of authority from the South Florida Water Management District (SFWMD) regulates the water quality and limits the quantity of stormwater permitted to reach the receiving water bodies and enforces the implementation of allowable treatment measures to both protect the condition of the waters as well as prevent flooding in other areas due to the new discharge. This often results in the addition more stormwater management infrastructure or requires dedicated stormwater management lands to treat and attenuate runoff, and oftentimes, the restrictions may result in no appreciable reduction to the desired flooding LOS goal in many areas, as the stormwater runoff cannot be moved at a rate sufficient to reduce the existing conditions flooding within the constraints of the discharge requirement limitations.

- <u>Regulatory Protection of Local Groundwater</u> - Broward County Underground Injection Control Licensing Division restricts the allowable areas and quantity/rate of injection of stormwater into the aquifers via stormwater recharge wells in accordance with FDEP regulations, requiring pre-treatment, limiting the practice to only areas east of the 10,000 TDS isochlor (more saline groundwater existing approximately east of US-1), and prohibited in areas surrounding known underground contamination where plumes could be potentially migrated, and from areas in the potable wellfield protection zones. Special restrictions may also be imposed in areas of septic tanks on a case-by-case basis. These restrictions limit the options for the CIP in many areas of the City, and makes some areas cost prohibitive to meet the City's LOS goals due to the long distances the water must be conveyed before it can be released.

- Regulatory Pre-Post Project Demonstration of No Adverse Impact – SFWMD and Broward County regulations both require the demonstration (through engineering analysis) of no adverse impact to the receiving waterway's stages and flows from existing conditions. This rule is in place to prevent the resolution of flooding in one area from exacerbating flooding in another area, either up- or down-stream, which could result in potential damages and litigation, as most of the canals and conveyance structures are already at or near their full capacities, and conditions are projected to worsen due to the impacts of sea level rise. As the Hollywood regional area drainage system inland is "discharge permit restricted" and the receiving waters are essentially at their capacity, and flooding is currently widespread in many low-lying areas both within and outside of the City limits, simply installing new infrastructure in the form of new large pipes, pumps, and outfalls to move water out at the required rate to meet the City's desired LOS is permissible. Instead, complex combinations of other more costly methods in many areas, all working in concert synergistically, is required to balance flood control while meet discharge permit restrictions.

- Regulatory Requirements for Maintaining Historic Flows Through the City – To be permittable, stormwater projects are also required to demonstrate that they additionally maintain existing historic stormwater flow paths, thus the proposed improvement does not result in adverse impacts upstream or downstream. The detailed models developed for this SWMP have identified these flows will provide this support information for responses to regulators. As some areas of the City are lower than their surrounding municipalities and communities, during large rainstorms, significant flow can enter the City's system from other "off-site" areas exacerbating the flooding within the City and resulting in required larger capacity City infrastructure capital improvements requirements, as a portion of the system capacity is being occupied by other non-City flow. In many situations, due to local hydraulic conditions, further increasing the capacity of the City's stormwater infrastructure results in more flow entering from off-site areas and little further positive impact to the City's LOS, diminishing the effectiveness of the City's CIP to address its own flooding. These areas were flagged in the SWMP CIP areas for potential joint cost-sharing projects with the other communities as it benefits both entities.

- 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 low finished grade elevations within the many natural flood plains and from infill of lands over time without compensating floodplain storage, or subsidence of the land area over time, 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, most of the generated runoff to meet the LOS alternatives must all be handled with constructed retrofit conveyance, treatment, and disposal infrastructure. A list of potential currently vacant areas for future stormwater detention were identified in the report. Some areas of the City may be candidates for buyouts and creation of stormwater storage area in their place. Several identified low-lying, repetitive loss areas were provided to the City for consideration of potential future relocation and conversion to stormwater management areas.

- Low Topography, Undulating Terrain with High Groundwater Table – A significant amount of the built-out land area in City lies at an elevation near sea level affording few opportunities for the hydraulic conditions required for standard gravity collection system piping to waterway outfalls. Further, much of the low-lying land area topography is a series of small ridges and valleys which tend to capture the stormwater runoff in the "bottoms of the bowls" which accumulates as flooding. As the low ground becomes saturated rapidly during a rainstorm, the already high groundwater table rises further, reducing available infiltration into the ground, resulting in more runoff and stormwater accumulation, further exacerbating the flooding problems. Since many of the City's streets are constructed at too low an elevation for the current flood conditions and many of the houses in these older areas are built too low, structure flooding is predicted. Raising roads in existing neighborhoods creates geometry problems at the interface to driveways and entrances, and if done without creating directly connected compensating floodplain storage or a connection to a positive gravity or pumped collection system, (which in existing neighborhoods is sometimes not available) it will exacerbate the flooding at the low-lying homes. Certain areas of the City have been identified for roadway raising, but importantly, only in conjunction with other positive collection system improvements to resolve low spots in roadways roads during storms where additional infrastructure did not provide additional flood reduction benefit. Road raising is not recommended in areas where other improvements are not being installed as the loss of floodplain storage will exacerbate flooding in the structures on either side of the roadway being raised.

- Sea Level Rise Issues – Although not directly a stormwater issue, the fact that most of the stormwater runoff in the City flows in directly connected pipes to waterway outfalls tidally influenced by the ocean, the effect of high tides that rise above the hydraulic grade line of the stormwater system becomes an issue for the level of service of the stormwater system of the connected service areas. Accordingly, all outfall pipes into tidally influenced areas must have operational backflow prevention devices installed to prevent the migration of the receiving waters into the streets up through the stormwater inlets, and must be sealed (i.e., pipes and joints leak-free) such that rising groundwater does not infiltrate into the system past the backflow prevention devices. As the high tide elevations trend to an increase over time, outfalls below this high tidal elevation become ineffective until the tide recedes again. These devices also inherently impart additional headlosses (flow restrictions) into the outfall piping systems, requiring additional force (greater water surface elevation) to open, thus potentially further increasing the depth of the water (surface flooding) in the streets upstream. Eventually, the low elevation outfalls will need to be converted to pumped outfalls to overcome the sea level differential. In addition, as sea levels rise, the groundwater elevation rises accordingly, which impacts the future effectiveness of proposed/installed highly cost-effective CIP such as exfiltration which rely on a differential head to groundwater to function.

- Shoreline Armoring - The models demonstrate that the seawalls/berms must be leak free and at a contiguous elevation above the current king tide elevation, as even the largest practicable pumping systems are not sufficient to keep the sea from tidal flooding into the low-lying neighborhoods. This includes seawalls that extend into other neighboring municipalities that may flood overland back into the City from offsite. Low spots, leaks, or breaches will allow significant volumes of seawater into the rights of way, and the proposed stormwater CIP which was design for rainfall runoff flooding, cannot pump out the sea.

ES.6 SWMP Project Goals and Objectives

Stormwater management is not confined by jurisdictional boundaries. A SWMP helps stakeholders understand the big picture of the natural conditions, constraints, and the potential cost and magnitude of the opportunities to manage stormwater in a safe, regulatory compliant, and sustainable manner. The SWMP considers design storm flooding predictions using stormwater models simulating topography and land use, the physical attributes of the stormwater management system, rainfall patterns, and tidal and groundwater influences, and its controls and limitations of the runoff generated in various magnitude storms, to identify deficiencies and recommend corrective actions.

The primary objective for the project was to develop detailed and validated hydrologic and hydraulic (H&H) models of the City of Hollywood's drainage basins and stormwater management system thus providing a detailed 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 were then able to be conceptually designed and tested in the models until the City's desired LOSs were achieved and a conceptual project cost could be assigned. As CIP is constructed and installed, the model will need to be continually updated to the interim condition so the City will always have the most current system for permit reporting. The up-to-date models will also be used to perform back-check reviews on other designers' CIP projects citywide for conformance to the master plan objectives.

This SWMP provides the City:

- A detailed, dynamic, and comprehensive Citywide stormwater model to simulate predicted rainfall flooding and the effects of sea level rise and storm surge on the existing and proposed stormwater management system. The model can be modified and enhanced in the future as new projects come online or system conditions change.

- A Citywide CIP to cost-effectively mitigate flooding issues for two alternative levels of service and a prioritized list of project areas and improvements with planning-level budgets at the neighborhood scale.

- Increased aquifer recharge to reduce saltwater intrusion for future potable water supply and water quality treatment improvements to protect the receiving waters.

- A benefit-cost analysis for the proposed improvement alternatives.

- A modern GIS database with digital mapping and metadata to archive and access the City's vast stormwater assets and data linked to the stormwater model.

- A foundation and roadmap plan for stormwater and coastal resiliency in the future.

- National Flood Insurance Program Community Rating System (NFIP-CRS) flood insurance premium rate credits toward resident's discounts resulting from the City's efforts addressing the Federal goals of: Reducing and avoiding flood damage to insurable property, strengthening and supporting the insurance aspects of the National Flood Insurance Program, and fostering comprehensive floodplain management.

- A comprehensive, Citywide planning-level stormwater management strategies which are permittable and can be implemented in a prioritized, phased program. These strategies help address the City's chronic flooding, improve stormwater and coastal resiliency, and provide strategies for sea level rise. The end result is a cost-benefit balanced suite of both conventional and innovative approaches, which protects and utilizes the natural environment as an asset.

ES.7 Identification of Historic Flooding Problem Areas

The City experiences significant flooding from rainfall and from tidal events as identified in the "known historic flooding documentation" Citywide which was obtained from several sources:

- Repetitive Loss Areas: These locations have been attributed as repetitive loss areas based on the FEMA flood disaster database.

- Recorded Citizen Complaints: The City and County maintain a database of flooding complaints. The data shown in the flood location maps have been filtered to those that were specifically tagged "Flood" with a follow up survey of high-water marks.

- Department of Public Utilities flooding "hot spots" mapping: DPU keeps records of flooding areas around the City observed during recent major rainfall events which are used by maintenance personnel to concentrate system cleaning, pump operations, and identify potential "early-out" projects for partial, local, relief.

- Community Workshops for Resident Flood Complaints and Commission Flooding Workshops: For this project, two interactive community workshops were held to discuss flooding issues and the stormwater master plan. As part of the workshop, community members and leaders were asked to locate problematic rainstorm, hurricane, and tidal flooding locations on their neighborhood map. These locations are the cumulative accounting of these exercises. A separate, interactive workshop was held with Commission to identify each District's primary areas of concern.

- Available post-storm news and media documentation and other storm-related photographs from citizens, City staff, first responders, and the consultant's post-storm site visits.
- Meetings with City Stormwater Operations and Public Utilities: Operating procedures for road closures, temporary pumping, pre- and post-storm preparation and historical flooding areas were discussed with City staff and located on the map.

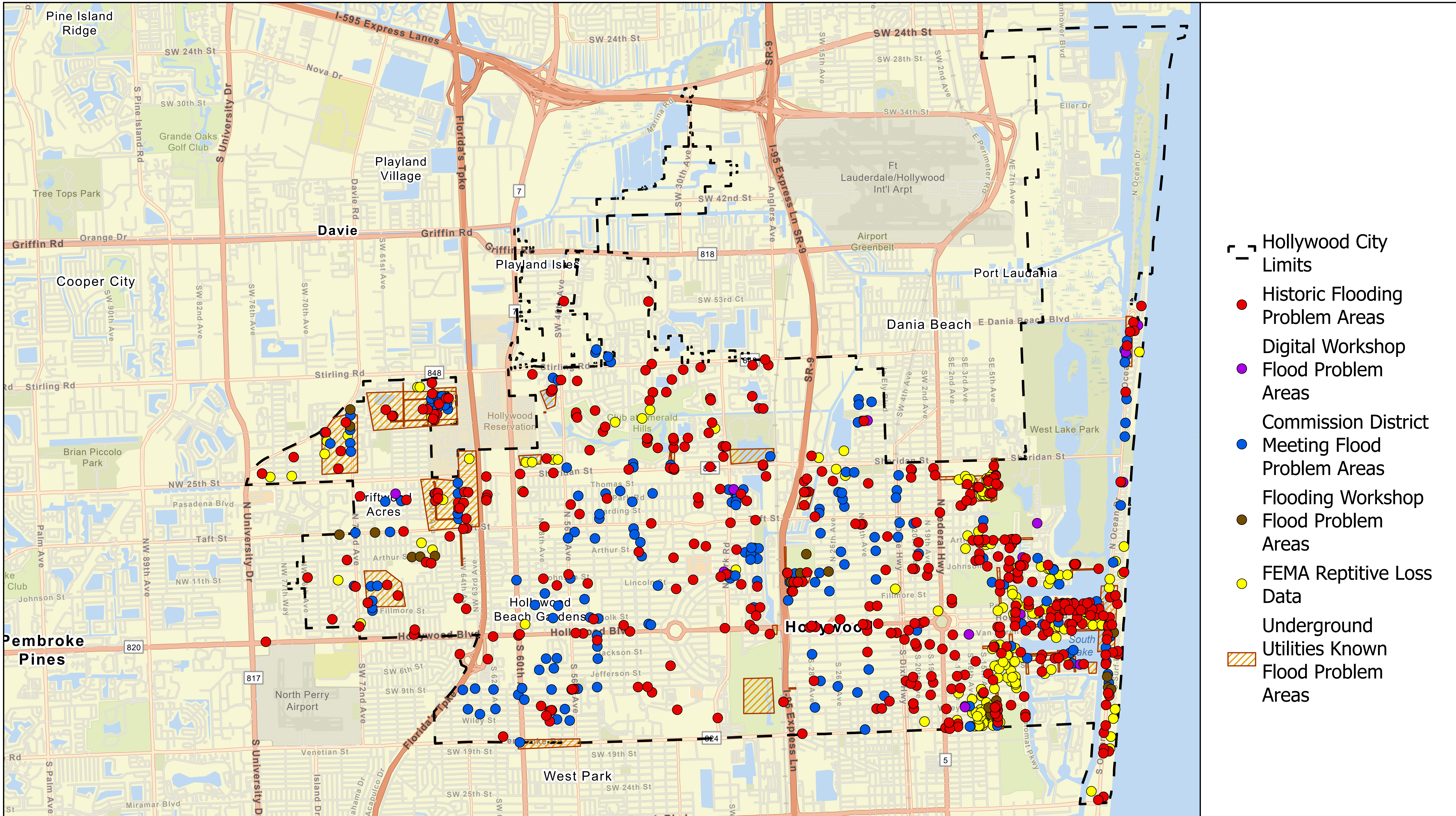
A Citywide flood complaints map is provided on **Figure ES-1**. As shown, complaints of flooding are widespread throughout many areas of the City and clusters of repetitive complains exist in the lowest-lying areas and/or areas with insufficient or no positive drainage systems.

ES.8 Flood Control Level of Service Goals

The analysis of two alternative LOSs was performed for the SWMP so that the benefit-cost analysis (BCA) comparisons can be determined over a wider range of LOS, and to provide an alternate, less costly, and potentially more practicable LOS goal, due to the anticipated high cost of implementing a CIP that fully meets the primary LOS goal in any existing area given the City's low topography, tidal and hydrologic characteristics, constraining permit requirements, and lack of land area for regional-scale stormwater management. The implemented LOS in any area may be a mix of LOS goals based on the area of the City and what the City can afford to fund to keep the major roadways passable for emergency and evacuation traffic.

- Alternative 1 – Primary LOS Goal – Up to 3 inches of flooding over the road crowns in the 10-year, 24-hour recurrence interval design storm for the major roadways and evacuation routes; and up to 3-inches above secondary and arterial residential streets for a 5-year, 24-hour storm; and flooding maintained below building finished-floor elevations in the 100-year recurrence interval design storm wherever practicable.
- Alternative 2 – Secondary LOS Goal – Up to 6 inches of short-duration flooding allowable over the road crowns in the 10-year, 24-hour recurrence interval design storm for major evacuation routes; up to 6-inches of flooding for a short duration above residential streets for a 5-year, 24-hour storm event; and flooding maintained below building finished-floor elevations in the 100-year recurrence interval design storm wherever practicable.

It should be noted that the Alternative 2 LOS goal is a comparatively robust and aggressive CIP and is a significant improvement Citywide over existing flooding conditions in terms of structural flooding reduction, reduction in depth and extent of flooding, and in the duration and dissipation of flooding post-storm.



City-wide Flood Complaints Map

City of Hollywood Stormwater Master Plan
Figure ES-1
4/6/2022

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ES.9 Flooding Reduction Analysis - Post CIP Installation

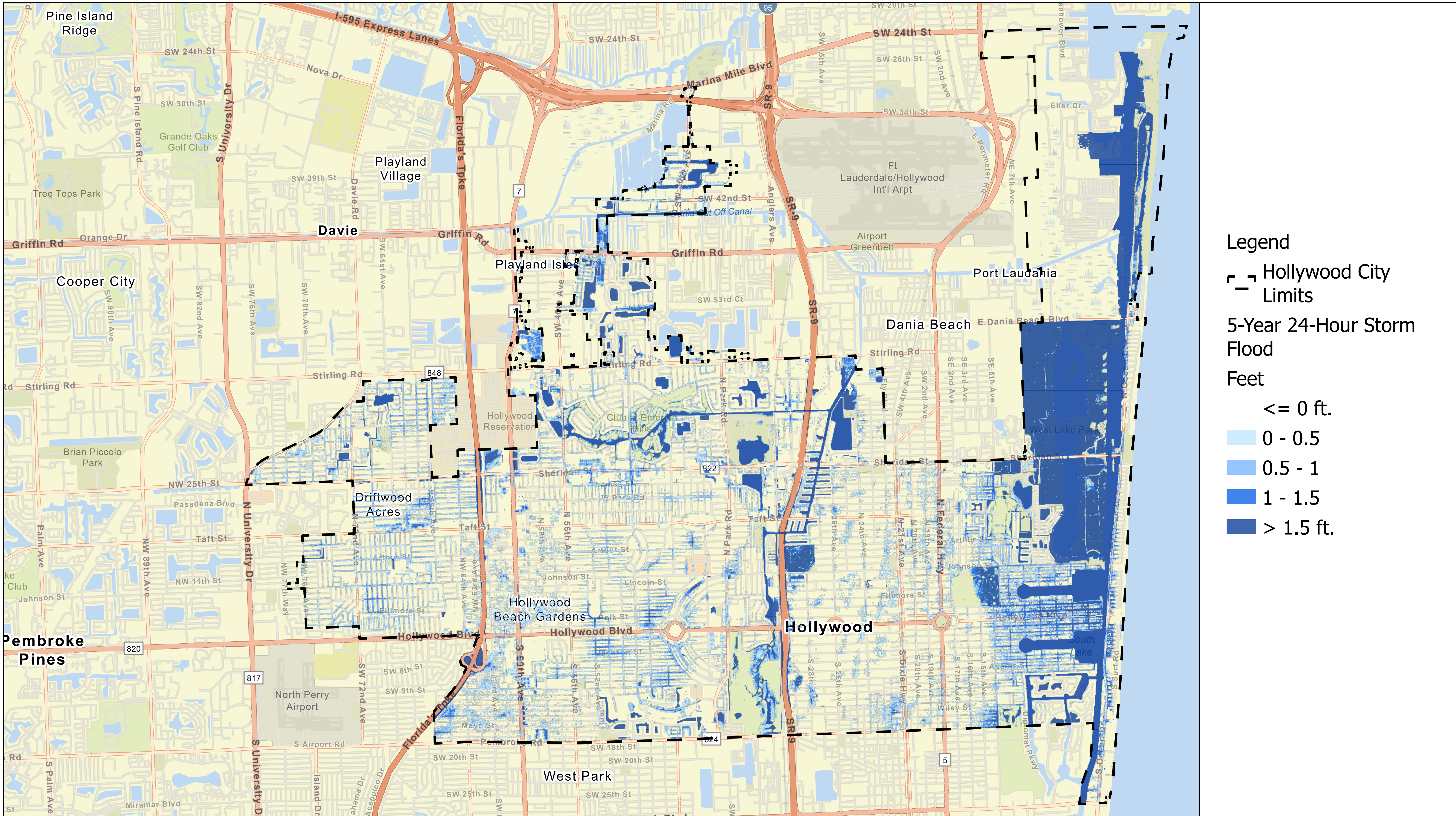
A range of simulations were performed using the USEPA SWMM v5 Model which was verified with sensitivity analyses to two past large storms and associated recorded flooding conditions in the City. Simulations include the 5-year and 10-year, 24-hour design storm; and the 25-year and 100-year, 72-hour design storms. Additionally, simulations were performed with a future climate change increased rainfall for the 100-year storm.

Figure ES-2 provides the flooding simulation map of the existing conditions current predicted flooding in the 5-year recurrence interval design storm, i.e., the intensity and quantity of rainfall for a storm that is statistically expected to occur only once every five years. For comparative purposes, the typical afternoon thunderstorm experienced in the City where some street flooding reported and roads may be required to be closed until the flood waters receded in the lowest areas is usually less than a 1-year event, as this condition statistically reoccurs in the City on the order of several times per year. As shown in the darker blue on the figure, deep flooding is widespread in the residential neighborhoods and in the City streets throughout the City, and some structures in low-lying areas are predicted to be close to, or inundated and this flooding can last for a significant amount of time post-storm. **Figure ES-3** shows the same storm with the proposed Alternative 2 (a less stringent LOS and less costly program) stormwater infrastructure CIP in place. As shown, this Alternative 2 CIP program addresses the majority of the City's flooding concerns and reduces the deepest areas to short duration shallow ponding at the storm peak that dissipates quickly. Similar maps for the larger 10- and 100-year storm vents events are provided in report Section 3.

It is important to note that, at the time of this SWMP, the City is in the process of completing a *Citywide Vulnerability Assessment and Adaptation Plan Update* in parallel that will address the flood-hardening of the majority of its critical facilities through local measures such as shoreline armoring, waterproofing, raising structure entrance drives, elevating or relocating sensitive electrical equipment out of the floodplain, strengthening or sealing structures to withstand water inundation, or adding or adjusting finished-floor access to the structures above the future 100-yr and/or 500-yr flood zones depending on code. Thus importantly, it is not necessary for the City to rely solely on additional or larger, more costly, citywide stormwater infrastructure CIP to address the individual, on-site flooding problems at each of its critical facilities, and can concentrate its Stormwater CIP expenditures on reducing the depth and duration of inundation of the public roadways, rights of way, and in the neighborhoods to the chosen LOS goal's available funding over time.

ES.10 Capital Improvement Areas Delineations

The entire City study area was analyzed and grouped logically into 40 discrete improvement regions (CIP Areas) considering, in-common connected topography, contiguous flooding extents, and the PSMS elements of adjoining neighborhoods, and was assigned a unique numerical name for this analysis. A CIP Area delineation thus represents the minimum boundary that improvements will need to extend into to address a common, connected area of flooding. The CIP areas will likely be further sub-phased into smaller projects during CIP execution, however, to meet the LOS goal fully, all of the proposed improvements in a CIP Area must eventually be constructed, or the LOS goal for the area relaxed.



Flooding Simulation Existing Conditions 5-Year 24-Hour Design Storm

City of Hollywood Stormwater Master Plan
Figure ES-2
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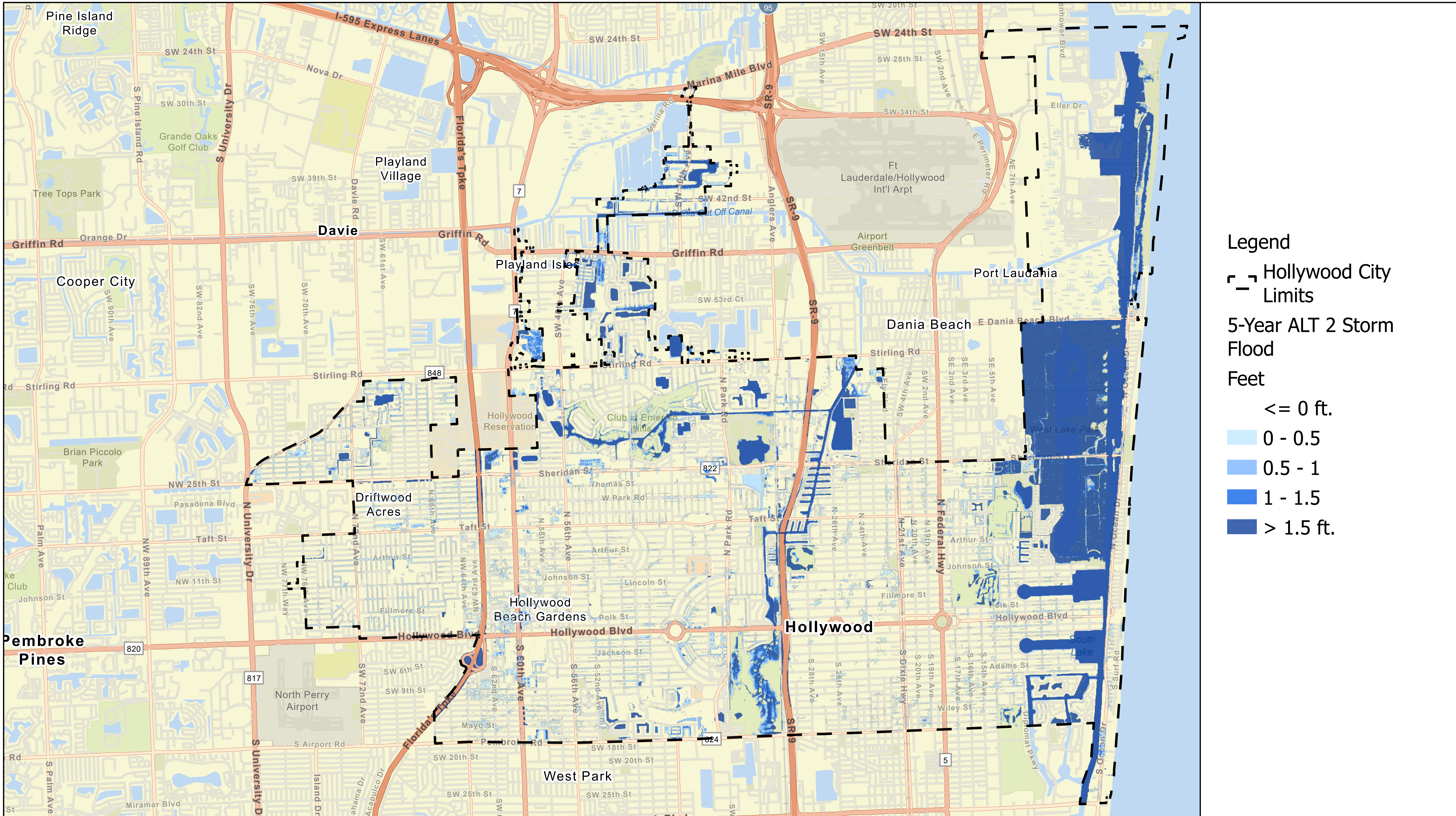

City of Hollywood Stormwater Master Plan

Figure ES-2

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Flooding Reduction for the 5-Year Design Storm with Alternative 2 CIP Installed

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The CIP Areas were and ranked for severity of flooding into the top three tiers shown with the colored circles by considering number of flood complaints, length of major and minor roads flooded, number of inundated structures, required road closures, time to dissipate, and commission priorities and vetted by City Staff.

It is important to note that this initial ranking is not to be confused with the CIP program prioritization or order of project schedule which will be dynamically influenced as the program proceeds by many other additional factors such as: funding availability, permitability, Commission direction, coordination with other City projects such as seawalls and other underground utility work, coordination with FDOT and neighboring municipalities and drainage districts for shared projects, etc.

Figure ES-4 presents the CIP Areas delineation map, commission district boundaries, assigned CIP area names, and the initial comparative flooding rankings. **Table ES-1** provides the budgetary planning-level cost for CIP achieving a LOS of Alternative 1 and Alternative 2 by CIP area.

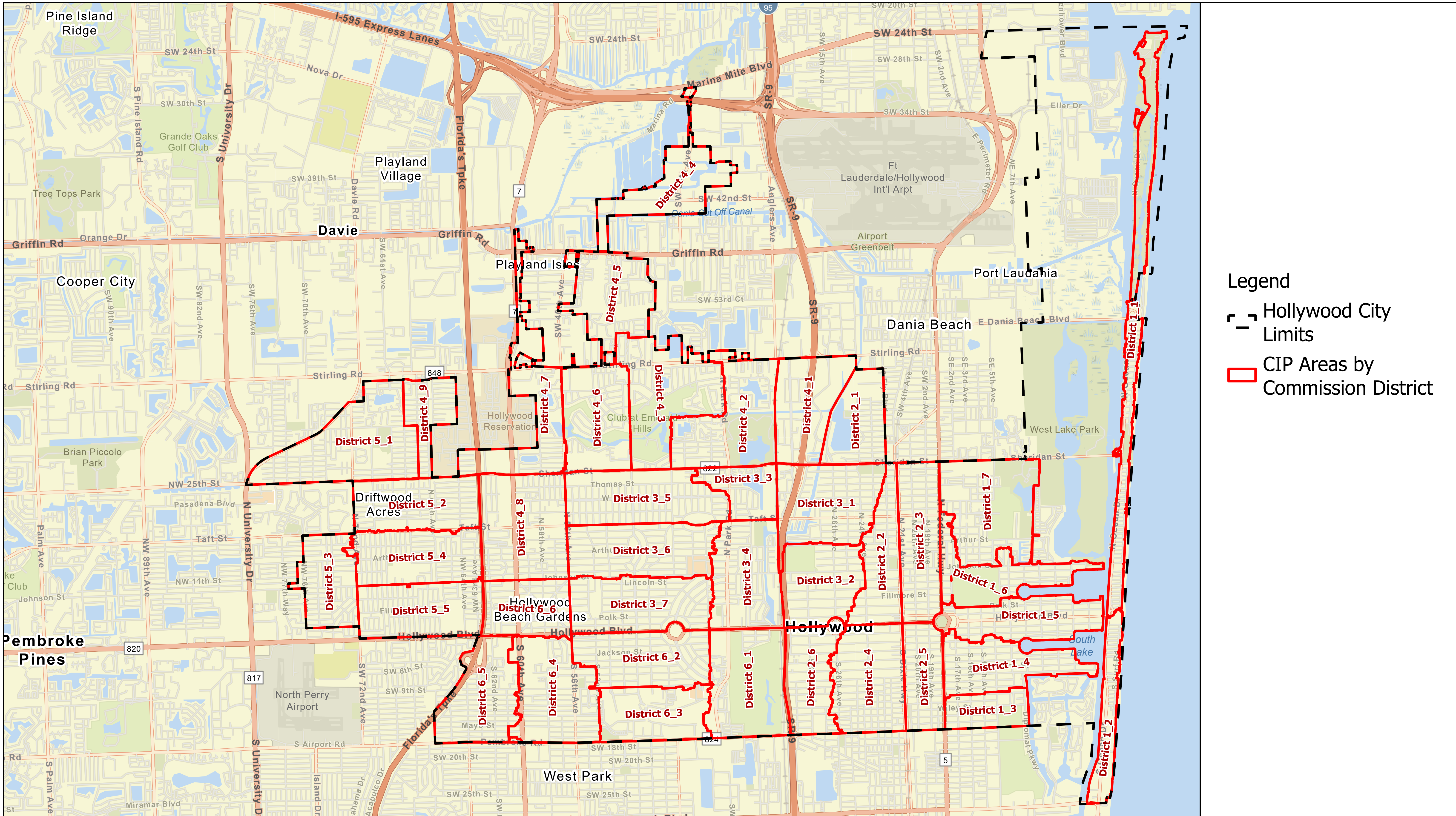
It should be noted that:

- Many of these proposed stormwater CIP systems will need to work in conjunction to meet the chosen LOS goals in the areas as each provides a portion of the overall water quantity and water quality solution.
- During the SWMP analysis, FDOT initiated its independent plan and funding to address the flooding on their roadway (SR-A1A) which includes the installation of a phased series of new stormwater pump stations, collection systems, and backflow prevention within City CIP Areas D1-1 and D1-2 in coordination with grant funding and the City’s CRA road raising projects. An alternative plan was developed for these two CIP Areas on Hollywood Beach in the City's SWMP only for comparative purposes; however, FDOT’s plan is in place and is moving forward in five-year funded increments, allowing the City to re-allocate its SWMP CIP funding to other flooding areas.
- During the SWMP analysis, the City commenced the shoreline protection project for the Lakes area, moving this area forward in priority as the new seawalls will result in exacerbated flooding beyond the initial SWMP existing conditions analysis in these areas.

The individual improvements for each CIP area are provided in the report. Stormwater CIP elements include:

1. Exfiltration trenches where hydraulically applicable to capture water “uphill” before it enters the primary system to the outfalls and to meet or enhance required water quality.
2. Systems of connected street-level grate inlets and gravity conveyance piping and ditches to direct the stormwater away from flooding areas toward the outfalls.
3. Gravity Stormwater Recharge Wells where permittable and hydraulically feasible to supplement the catchment of stormwater runoff and divert it from the outfalls.

Figure ES-4 CIP Areas Delineation and Relative Flooding Severity



CIP Areas by Commission District

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City of Hollywood Stormwater Master Plan
Figure ES-4
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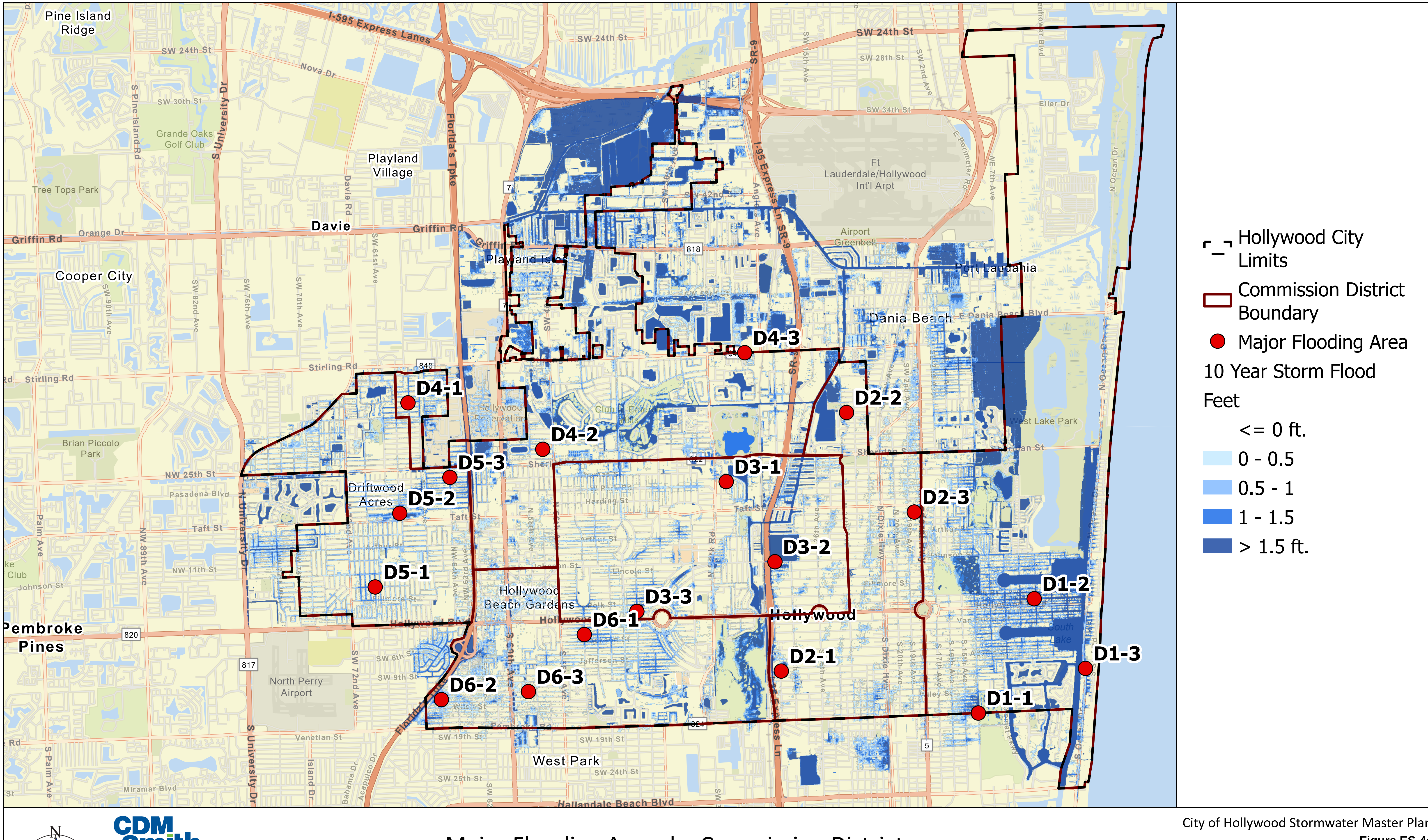


Major Flooding Areas by Commission District

City of Hollywood Stormwater Master Plan

Figure ES-4a

2/21/2021

Table ES-1: Budgetary Planning-Level Costs for Stormwater Infrastructure to Meet LOS by CIP Area

DISTRICT	CIP AREA NAME	NEIGHBORHOOD	ALT 1 PLANNING-LEVEL COST ($M)	ALT 2 PLANNING-LEVEL COST ($M)
1	HE-D1-1	North Beach and South Central Beach	$35.88	$26.87
1	HE-D1-2	South Central Beach	$38.06	$25.29
1	HE-D1-3	Hollywood Lakes South	$48.80	$16.89
1	HE-D1-4	Hollywood Lakes - South Lake	$64.30	$31.06
1	HE-D1-5	Hollywood Lakes - Central	$65.35	$30.43
1	HE-D1-6	Hollywood Lakes - North Lake	$68.53	$38.33
1	HE-D1-7	Hollywood Lakes North	$50.13	$26.84
		Subtotal D1	***$371.04***	***$195.72***
2	HC-D2-6	Highland Gardens	$30.00	$3.69
2	HC-D2-1	Liberia	$42.04	$27.05
2	HE-D2-2	North Central - East	$11.61	$4.31
2	HE-D2-3	Royal Poinciana	$80.27	$34.98
2	HE-D2-4	Highland Gardens East	$41.81	$9.35
2	HE-D2-5	Parkside	$35.75	$18.32
		Subtotal D2	***$241.48***	***$97.71***
3	HC-D3-5	Hollywood Hills North	$92.77	$19.89
3	HC-D3-6	Hollywood Hills North Central	$49.31	$7.35
3	HC-D3-7	Hollywood Hills South Central	$33.27	$15.65
3	HC-D3-3, 4	Parkeast North	$73.75	$48.96
3	HC-D3-2	North Cental South	$46.28	$18.36
3	HC-D3-1	North Cental North / Parkeast	$79.52	$42.35
		Subtotal D3	***$374.90***	***$152.55***
4	HW-D4-9	Driftwood	$100.50	$58.63
4	HW-D4-8	441 Cooridor Central / Hollywood Gardens West	$43.89	$28.54
4	HW-D4-7	Playland / 441 Corridor North	$19.62	$12.73
4	HC-D4-4	Alandco	$0.00	$0.00
4	HC-D4-5	Oakridge / Mapleridge	$1.76	$1.33
4	HC-D4-6	Emerald Hills / Playland / 441 Corridor Central / Hollywood Hills	$30.17	$18.41
4	HC-D4-3	Emerald Hills / Stirling Commercial District	$33.58	$18.98
4	HC-D4-2	Emerald Hills / TY Park	$25.11	$15.56
4	HC-D4-1	Oakwood Hills	$45.02	$32.92
		Subtotal D4	***$299.66***	***$187.11***
5	HW-D5-1	Driftwood / Carriage Hills	$41.94	$20.85
5	HW-D5-2	Driftwood	$53.40	$16.82
5	HW-D5-3, 4, 5	Boulevard Heights	$257.97	$111.25
		Subtotal D5	***$353.32***	***$148.92***
6	HW-D6-6	Hollywood Gardens West / 441 Cooridor South	$8.13	$3.22
6	HW-D6-5	Beverly Park	$157.03	$48.83
6	HW-D6-4	Lawn Acres / Washington Park	$12.51	$5.72
6	HC-D6-2, 3	Hillcrest / Hollywood Hills South	$65.66	$44.67
6	HC-D6-1	Parkeast South	$16.02	$4.16
		Subtotal D6	***$259.35***	***$106.60***
			ALT 1	***ALT 2***
		CIP TOTAL CITYWIDE	**$1,899.76**	**$888.62**

4. New pump stations and discharge forcemains in areas that are too low to positively drain by gravity and uphill catchment is not sufficient due to topography, and in areas where new required seawalls will block and catch historic overland flows and result in new flooding.

5. New Pumped Stormwater Recharge Wells in areas where water quality or water quantity needs were required to be addressed and to lower discharges in receiving water bodies to make volume available for new flows or meet regulated discharge limits.

6. Regional Storage, Control Gates, and Pre-Storm Forward Pumping –

    1) Dry detention storage within the Orangebrook Golf Course is a critical element of both the current and future SWMP (additional volume is required) to meet allowable discharges and reduce flooding westside of the City as well as storage proposed in a few other City and County parks.

    2) The CS-22 gate structure resides on the C-10 Canal at NW 46th Avenue. The gate was previously operated by Broward County, has not been used for salinity control for many years, and has been offered to the City for its use. Due to the location of the gate, the SWMP analysis is investigated the feasibility of lowering stages in the canals and lakes to the west of the structure by the use of a pump to create additional stormwater storage and provide additional LOS increases to several CIP areas to the west for ATL 1 and conversion to a weir with backflow prevention for ALT 2. Both create necessary storage upstream and help achieve the LOS goals.

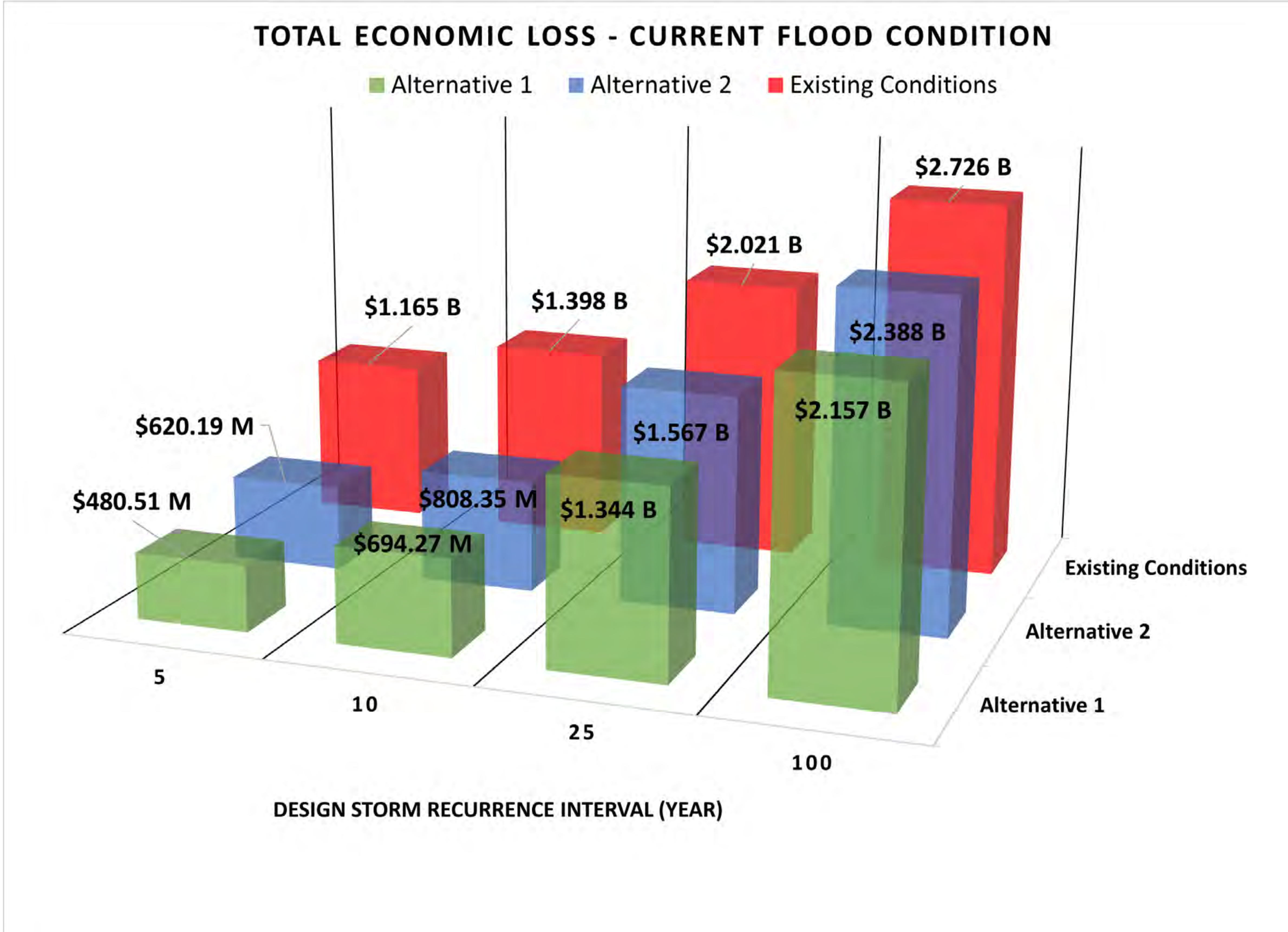
ES.11 Benefit-Cost Analysis

The Federal Emergency Management Agency (FEMA) Hazard-US (HAZUS) Benefit-Cost Analysis (BCA) model is a standardized tool for estimating monetary risk and economic loss from flooding. The HAZUS flood model calculates physical damage and economic loss due to coastal and/or riverine inundation. Losses are calculated using functions that relate the depth and type of flooding to the degree of damage for various categories of buildings using data in the Federal database. The numerical model was run for both Alternatives 1 and 2 CIP Citywide investments.

The flood damage analysis shows that the existing conditions in the City have significant potential economic losses associated with flood events for both rainfall and tidal flood sources. The FEMA HAZUS model predicts benefits of 1.7:1 to 2.5:1 return on the CIP investment for each dollar spent on CIP as the net result of the avoided damages by recurrence interval storm. **Figure ES-5** provides the graphical BCA per storm.

ES.12 Water Quality Analysis

To be permittable for construction, individual projects must be designed to meet state (FDEP and SFWMD) and local (Broward County Surface Water Management Licensing Division, BC SWLD) requirements. A Citywide water quality analysis was performed for current conditions and post-CIP conditions for both Alternatives 1 and 2. The post-CIP conditions meet or exceed the permit water quality requirements Citywide with the identified improvement in place. Phased projects



Benefit Cost Analysis by Storm

City of Hollywood Stormwater Master Plan
Figure ES-5
4/10/2023

may be required to meet additional interim water quality requirements for each phase which will be determined by regulators. It should be noted that water quality projects may be required to be installed in areas of lesser flooding to offset projects in higher flooding areas concurrently. As part of the SWMP, the City implemented the "Recapture the Swale" program through grant funding with Broward County and the State of Florida. The pilot program results showed that swales implemented Citywide are effective in capturing pollutants and the "first-flush" of runoff from areas, adding storage for flooding in smaller storms and treatment equal to a much larger and costlier dedicated system, helping to protect the receiving waters.

ES.13 Pre-Post CIP Conveyance Canal Flows and Stages

To be permittable for the Broward County / SFWMD conceptual ERP, pre-post CIP stages flows in the canal system must demonstrate no impact in the 25-year design storm. The combination of exfiltration, retention storage peak attenuation, and gravity/pumped recharge wells Citywide is able to offset the increases in flow to the interior canal systems and demonstrate no adverse impact for ALT 2, and a minor impact for ALT1. This means that in a phased program such as this, in order to be permittable, at some point CIP in other areas of the City which attenuate or eliminate existing flow to the canals (detention areas, exfiltration or stormwater wells) will be required to be implemented prior to (or in parallel with) CIP in the desired flood priority areas to offset flows discharged to the canal system, and that the ALT 1 CIP LOS may not be permitted to be retrofit everywhere.

ES.14 Long-Term Resiliency Planning and Sea Level Rise Adaptation

Sea Level Rise Considerations

Model simulations were performed for multiple heights of projected sea level rise required for future resiliency grant funding identified by FDEP and the Southeast Florida Regional Compact for Climate Change, and to determine the effect on the proposed CIP in the future. Continued sea level rise will diminish the effectiveness of the City's stormwater management systems for flood control over time due to the detrimental effect that the rising boundary conditions of both the receiving waters (sea and tidally influenced canals) and groundwater levels will have on the primary system's hydraulic performance for the gravity-based systems of exfiltration, gravity recharge wells, and gravity piping to outfalls.

The City ordinance-required raising of the City's low seawalls or adding seawalls where currently none exist, coupled with concurrently adding back flow prevention devices and raising the low surface elevations of roadways in many areas are imminent additions for resiliency to prevent the sea from flowing onto the land and flooding during the rising tides. As a result, both of these requirements deplete existing topographical storage areas and will exacerbate stormwater flooding if compensation storage or additional flood control measures are not put in in place concurrently as proposed in this SWMP. Many locations do not have the available lands to accomplish these compensatory storage requirements fully. Inundation maps with sea level rise are presented in are provided in the report Appendix. The CIP as proposed works effectively for future sea levels up to 5 ft NAVD (near the end of the century on most sea-level rise projections).

Living with Water and Long-Term Adaptation

Long-term resiliency measures include both structural and non-structural activities. Most long-term measures for resiliency are conceptual in nature because they require funding and policy decisions beyond what the City can realistically generate or implement today and they also include joint decisions that could significantly affect the South Florida population, way of life, and local economy, and would require coordination and agreement amongst multiple stakeholders. Often, the long-term stormwater flooding and sea level rise proposed solutions compete with environmental protection initiatives. Because climate change cycles occur over such a long period of time, in general it is sometimes difficult for municipal officials and regulators to begin to commit funding, adopt, or enforce, long-term solutions now, as there are many competing more pressing current interests for available funding. It is speculated that future Federal initiatives, bank mortgage and development lending risk, flood insurance rates and availability, long-term municipal land leasing, and the real estate market will ultimately drive the urgency for implementing long-term resiliency action.

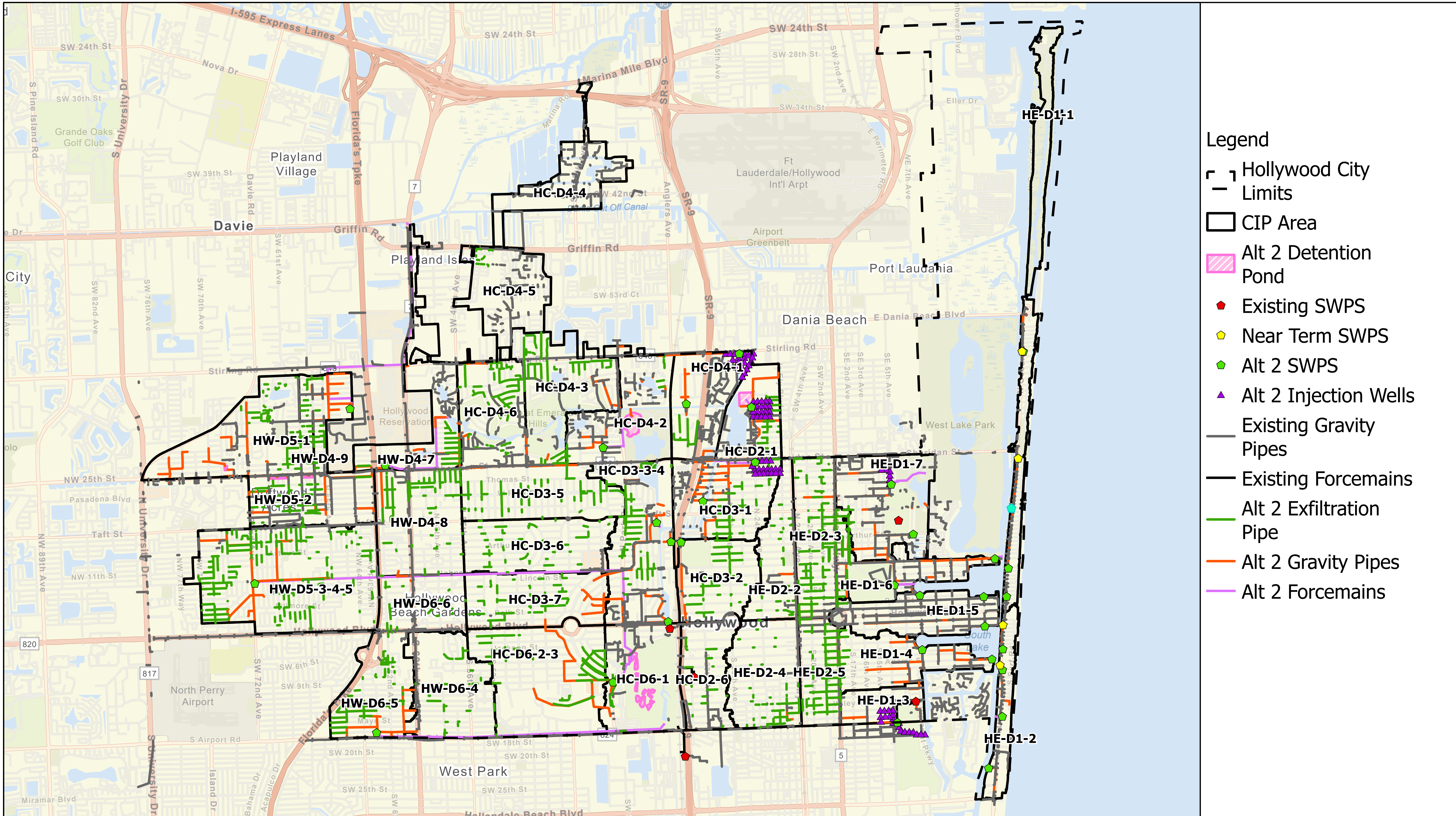
The City is undertaking forward-thinking resiliency conceptual analyses, attending expert symposiums, and performing vulnerability studies and resiliency studies in conjunction with preparations for co-existing with stormwater flooding, and adaptation to future sea level rise. Some of these concepts may re-imagine the basic design of the City itself by considering building code changes for eventual sacrificial first-floor with a contingency for a “main second floor”, requirements for Low Impact Development/Green Infrastructure (LID/GI) which would retain more stormwater on each site, and exploring the possibility of conceptual measures such as future elevated pile roadway networks, elevated houses, floating houses, floating neighborhoods and/or platform communities in the lowest-lying areas, conversion of low-lying streets to interconnected canals for water transportation and flood control, conversion of flood prone lands to stormwater management lands, elevating critical infrastructure, eventual potential relocation; and reginal solutions such as adding dikes, locks, floodwalls, and large-scale regional pumping systems for future sea level rise conditions.

ES.15 CIP Implementation

Figure ES-6a and 6b provide schematic representative figures of the overall Citywide CIP to meet the Alternative 1 & 2 LOS respectively using a mix of exfiltration, gravity conveyance piping, SWPSs and FMs, gravity and pumped recharge wells, and new dry-detention storage, in conjunction with contiguous seawalls. Detailed proposed CIP is provided in the report for each neighborhood.

The order of the eventual implementation of stormwater infrastructure capital improvements and the prioritization of implementation will be discussed in subsequent workshops with the City and will be driven by several influencing factors discussed below:

1. Funding Availability – Availability of funding will be the ultimate driver of the CIP over time. It is common that the funding initially available may be less that the anticipated funding needs for the stormwater CIP to meet the desired LOS goal in most areas. It is likely that a future CIP bond will need to be issued for the program in conjunction with stormwater utility fees, as the Stormwater Utility Funds are usually sufficient for covering



Citywide CIP for Alternative Two

City of Hollywood Stormwater Master Plan
Figure ES-6
4/10/203

operations and maintenance of the expanding existing stormwater system and smaller emergency-type projects, as well as debt service. An Immediate Action Plan (IAP) can be developed and tailored to available funding, and made equitable if desired among geographic, land use, and economic income-level areas. These IAP projects can be labeled as “Phase I” of larger, comprehensive, multi-phased CIP projects for the contiguous CIP area and be seamlessly integrated into the larger project as the SWMP implementation program progresses.

2. Grant Funding – Certain projects may qualify for various grant monies and economic stimulus funding due to their type, location, or economic zone, including resiliency and hardening, green infrastructure, and infrastructure renewal. These projects may be required to be accelerated to meet the deadlines imposed for submission of “shovel-ready” contract documents to qualify for the funding.

3. Coordination with Other Utility Work and Joint Projects – CIP projects may be accelerated or moved to an alternate schedule to coordinate with other utility work or projects being performed by the City of Hollywood, Broward County, FDOT, partnerships with neighboring municipalities, drainage districts, and with private developers. The SWMP results show that the City’s proposed CIP also improves the LOS in other neighboring areas in several locations due to natural topography and system interconnectivity. Coordination meetings between the City and the other agencies and stakeholders should occur immediately after the CIP is adapted to discuss the timing and coordination of the projects in common or overlapping/connecting areas. The GIS layers of the Stormwater Infrastructure CIP projects can be superimposed with the work from other entities to quickly determine and identify conflicts and commonality.

4. New Seawalled Areas – Areas where seawall shoreline armoring are sealing up the neighborhoods will require an acceleration of the stormwater CIP as the seawalls not only keep out the rising tides but will also trap stormwater which used to flow naturally off the land into the sea behind the walls, exacerbating the existing flooding conditions.

5. Sociopolitical and Policy Decisions – The City may have other influencing factors originating at the City Commission level that will raise or lower the priority of project(s) depending on the location or initiatives set in place by local governance under equity initiatives or disparity studies.

6. Public-Private-Partnerships (PPP) – PPPs involve collaboration between a government agency and private-sector companies that can be leveraged to finance, build, and operate projects, such as public utilities. As the private entity takes on a significant amount of the risk, the PPPs typically result in faster project completions and reduced delays by including time-to-completion as a measure of performance and therefore of profit, thus they are in control of the timing and schedule of the design and construction.

7. Development Impact and Concurrency – The City may require large developments to improve City streets and utilities within their planned areas that may contain stormwater CIP projects, or portions of CIP projects, resulting in acceleration or deceleration of these portions of planned projects.

8. Design and Permitting Constraints – Some projects may require other projects to be implemented first (or in parallel) to be permittable in order to reduce the impact of the flows and stages on the receiving waters of the primary project. Additionally, depending on the type or size of the Stormwater CIP project, the time to design and the complexity of applying for and receiving the permit to construct will vary by project, sometimes significantly. Long lead-time projects may be desired to be phased and scheduled differently to allow for other immediate relief type projects to be implemented.

9. NPDES/MS4 Program Requirements – Areas of lesser water quality identified in the City's NPDES/MS4 sampling program affecting stormwater discharge to the canals, lakes, or waterways or designated protected areas may be required by imposed regulatory mandate to accelerate certain Best Management Practices (BMP) retrofit CIP projects for water quality specific improvements within a time schedule to avoid fines.

10. Low Impact Development Local Building Code Modifications and Enforcement – Building code modifications which may include the use of porous pavement, grass pavers, zero discharge retention of stormwater on site, etc. can be implemented immediately if desired.

ES.16 Design Considerations

The following items should be carefully monitored and prioritized by the City:

ES.16.1 Living Model and Version Currency

It is critical to the long-term the success of the program that the SWMM model be kept current as projects are phased into the system to:

1) Test the final designs for necessary mid-course corrections as any of the above factors begin to result in deviations from the initial SWMP planning CIP,

2) Expedite demonstration of meeting permitting requirements of individual projects, and

3) Determine equitable shared costs with partners in joint projects

4) Allow the City to "see" the bigger picture for potential impact in other areas that pre-post partial CIP will impart that may not be readily evident during individual designs and help avoid litigation of adverse interim impact until the full proposed system is in place.

ES.16.2 Design Implementation Guidelines

The SWMP provides an "equivalent system" proposed to meet the LOS goal. From a masterplan perspective for new infrastructure, it is equivalent in the analysis results if an existing pump station or piping system is expanded/increased or if a new facility with the appropriate capacity is placed next to it or installed somewhere else nearby in the existing service area with equivalent piping installed to it for no change in the headlosses. This decision will be the designer's choice based on local constraints at the time of design which are not able yet to be analyzed at the detail required on a Citywide conceptual scale (i.e., coordination with other projects, system changes, continued development, local architectural review boards, availability of land or rights of way, etc.). The SWMP provides the planning-level improvements to the stormwater PSMS to meet the goal LOSs, and the associated engineering data for design flexibility including system stages, flows, capacity, basic geometry, critical elevations, service area delineation, equivalent pipe sizing, and the hydrology and hydraulics. The engineer of record for a particular project will then evaluate other influencing factors at the time of implementation based on local conditions such as available land and/or easements, available utility corridors for piping routes, neighborhood architectural review board modifications to location, appearance, or functionality, final costs and available funding, phasing within the basin and with CIP from other basins considering project prioritization, and also the operational condition of the existing system components.

ES.16.3 Design Standards

Design standards for materials, instrumentation, electronics, communications protocols, and standard equipment should be updated prior to the program construction so that all of the components are similar throughout the City's facilities reducing spare parts and operator training. Operations staff should be consulted as to their preferences from field experience on manufacturers and technologies.

ES.16.4 System Automation

Importantly, the supervisory control and data acquisition system (SCADA) for remote control and monitoring should be reviewed for expandability and capability as more stations will be added to the system. The City should set a goal to minimize its use of its limited O&M Staff who currently must venture out during storms to verify or change the operational state of critical system equipment that can be monitored and operated remotely from a hardened, emergency operations control room.

ES.17 Funding Alternatives

To determine funding needs, an expenditure cashflow can be produced from the planning-level budget for the proposed CIP for the chosen LOS alternative provided in the report, and using industry standard times of performance for design, permitting, procurement, and construction phases and applying percentage of total cost factors to each phase, an annual cost can be obtained. Projects can be re-prioritized and plotted over time for different program durations (i.e., 20, 25, and 30+ years). The projected annual expense is then compared to the stormwater-related capital and operations budget, and any shortfall can be calculated. The difference in funding and projected expenditures can then be obtained from an optimum combination of stormwater utility fee increases, bonds, loans, partnerships, and grant supplements, or by limiting the number of projects let annually, or desired in total, or by extending the total program duration.

The urrentt stormwater utility should be reviewed and updated as necessary for the average square footage of the basic unit of measure (ERU, equivalent residential unit), current impervious calculations by parcel for non-residential and other land uses, and accuracy of the billing file, to ensure the utility is collecting the full revenue per ordinance.

Section 1

Model Development Technical Memorandum

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Technical Memorandum

Stormwater Model Development Methodology and Existing Conditions Model Results

City Project 20-11053
Comprehensive Citywide Stormwater Master Plan

April 2022

1.0 Introduction

This Technical Memorandum (TM) is provided as the deliverable for the Year 1 Services Scope item *Task 3* of City Project 20-11053, *Stormwater Master Plan Modeling and CIP Development Phase* and presents a summary of the development of the Citywide stormwater models for existing conditions, their verifications to actual past storms, and presents an overview of the current major flooding areas throughout the City and their probable root causes. This Model Development TM 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, and presents the results of the model validation to the calibration storms, and the existing conditions model runs flooding inundation simulations.

Project Work Phases

The full project is divided into four major work phases:

1. *Data Collection and Evaluation Phase* – Developing and producing the hydrologic and hydraulic data for surface and sub-surface conditions for the City and surrounding contributing area's Primary Stormwater Management Systems (PSMS) system and the boundary conditions for the models, and field survey of missing data required for the models. The deliverable for this task was the Data Gap Analysis TM providing a summary of what data was available, the sources used, what was entered directly versus created, and the Updated City Stormwater Infrastructure Database (GIS). This effort has been complete under Year 1 services.
2. *Stormwater Model Development Phase for Existing Conditions (EC)* – Developing the rainfall simulations and the detailed Storm Water Management Model (SWMM) to determine the EC Level of Service (LOS), validation of the models to actual rainfall events, and determining the root causes of the flooding inundation extent and depth predicted. This effort has been complete under Year 1 services. The deliverable for this task is this TM.

3. *Sea level Rise Evaluation and Considerations Phase* (Year 2 Services) – Projection of climate change effects on the proposed CIP.
4. *Prioritized Capital Improvement Plan Phase with Benefit Cost Analysis Phase* (Year 2 Services) – Analysis of proposed CIP to meet two alternative LOSs desired by the City.

Other ongoing work for both years' services includes a public information program and the final report, which will compile the results and summarize the recommendations of the prioritized CIP and costs.

1.1 Background Information

Statement of Need

As a result of development and re-development over time, changes in land use, sea level rise, climate change, and the changing regulatory environment, the development of a new and comprehensive Citywide SWMP was desirable to address chronic citywide flooding issues with effective capital improvements and assist the City in establishing a policy framework so that the integrity and resiliency of the City's future is protected and enhanced over time.

Previous stormwater planning work has analyzed several smaller or isolated flooding issues individually and has been partially successful primarily addressed only the smaller storm events. To fully understand the root causes of the flooding Citywide, meet the City's desired level of service for both smaller and larger storms, and to be able to determine a resultant cost of the expected improvements, all areas of the City should be analyzed concurrently and in greater detail to account for the interaction of runoff between adjacent areas and offsite contributions overland into the City at its topological boundaries (well beyond the City limits). These collective conditions all affect the City's system capacity, the canal stages, the groundwater levels, and in turn the resultant flooding in the City. Often, capital improvements in one neighborhood greatly improve flooding conditions in other remote neighborhoods because of the connected topography that can only be seen in a detailed comprehensive model simulation, and the Stormwater Master Plan analyses were designed to accomplish that goal.

Study Area Overview

The City of Hollywood (City) is located in south Florida in the southern portion of Broward County on the coastal plain of the Atlantic Ocean. The City limits encompass approximately 30.8 square miles (27.34 of which is land, 3.46 is water). Hollywood is home to a seasonally-fluctuating population of approximately 153,000 (in 2020). Of the total area, approximately 10 square miles are located in relative upland areas along the coastal ridge east of I-95, and also between Park Road and the Florida Turnpike. The remaining 20 square miles are found in lower-lying areas in the western part of the City, west of the Florida Turnpike, within the historic floodplains of the Hollywood Canal and C-10 Canal. The easternmost portion of the City lies east of the south Florida coastal ridge and west of the Intracoastal Waterway (ICW). Additionally, there are approximately 7 miles of Atlantic Ocean beachfront land situated on a narrow barrier island with a natural raised beach dune/coastal berm on the oceanside, sloping downhill approximately one block toward the

ICW to the west. There is also a large wetland area that exists in the northeast between the ICW and the mainland.

Climate Description

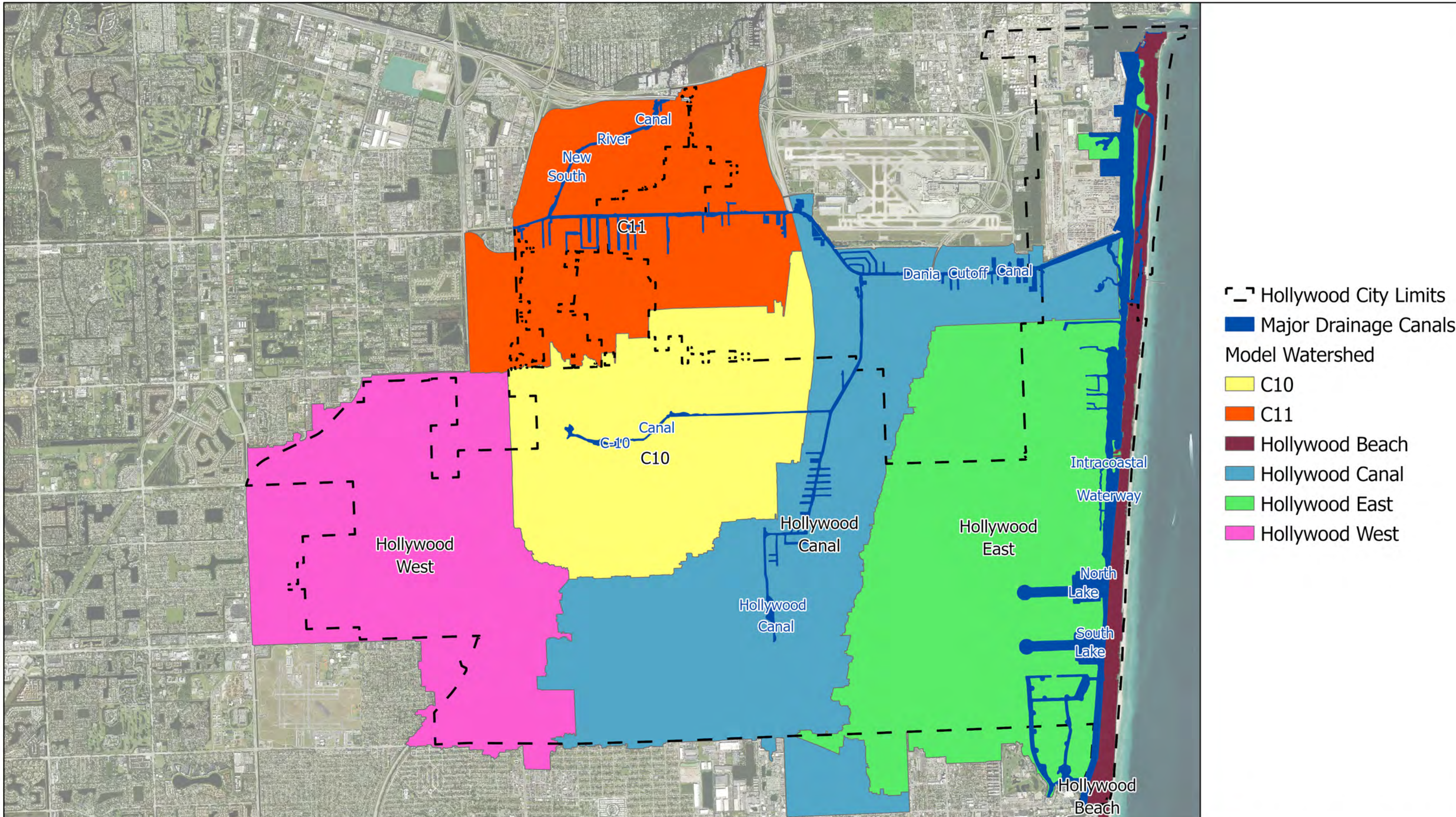
The City of Hollywood experiences an annual average rainfall total of 64 inches (compared to 38 inches nationally) and receives precipitation on 133 days per year on average. The “wet season” or “rainy season” takes place from May through October annually.

The winter months bring wet cold fronts from the western United States that clash with the warmer moist southern climate air that can stall over South Florida, resulting in extended periods of steady rainfall over the City. The summer months bring strong, convective, high-intensity, shorter duration thunderstorms that are fueled by high humidity, saturated air masses created by the moist sea breezes generated by the temperature differential between the east and west coast waters of the Gulf of Mexico and Atlantic Ocean, and the solar heating of the Florida land mass in between.

Additionally, an annual cycle of tropical systems ranging from broad areas of sustained waves of tropical low pressure to tropical storms and major hurricanes that are created in the warm waters of the Atlantic Ocean, Caribbean Sea, and Gulf of Mexico can form and move over the area depending on the steering currents in the atmosphere, delivering storm surge and large amounts of wind-driven rainfall in short periods of time.

Stormwater Service Area

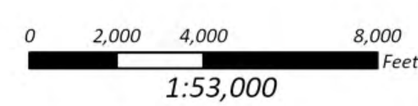
The City’s stormwater service area is divided by natural and man-made riverine/canal floodplains, elevation and topography and major conveyance infrastructure into five major “Basins” as shown on **Figure 1-1**. There are areas of the City that are served by installed “positive” drainage system infrastructure (i.e., non-over land sheet flow) such as catch basins, pipes, pumps, and outfalls, others that are served by exfiltration systems that recharge the stormwater into the ground, and many other areas with no stormwater infrastructure. As Hollywood is a coastal city rising only approximately 10–12 feet above sea level or lower (many areas are only 1–3 ft above sea level), there are many areas that are particularly susceptible to flooding as stormwater flows naturally into these low elevation depressional areas from the surrounding slightly higher neighborhoods. With inadequate or non-existent stormwater infrastructure in place, the result is that flooding frequently occurs at the “bottoms of the bowls” whenever large amounts of rain fall. The flooding extent, depth, and duration can increase when the ground is already saturated from previous storms, or when rainfall coincides with a high tide event as explained further below. Photographs of this flooding around the City are included in the Model Verification Analysis in **Appendix A**.



CDM Smith

CITY OF Hollywood FLORIDA

City Limits, Major Drainage Canals and Major Basins



City of Hollywood Stormwater Master Plan

Figure 1-1

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Stormwater System Tidal Connection

Because most of the City's stormwater system drains by gravity ultimately to the ocean through open pipes known as "outfalls," when rainfall occurs coincident with a high tide, the effect of the higher ocean levels, and the directly connected ICW and the City's inland canals, will prevent the City's storm system from draining freely by gravity until the tide elevation subsides and the stormwater can again flow out to the ocean. Pumped systems are not hydraulically affected by the high tide, but their effectiveness is greatly lessened, as a portion of the station capacity is used up by pumping out the tide in lieu of the intended stormwater runoff. As climate change effects result in increasingly higher high tides, the situation will continue to worsen over time.

In general, most areas (such as Hollywood) have two high tides and two low tides each day. As the Earth rotates, two tidal "bulges" occur during the lunar day and coastal areas experience two high and two low tides every 24 hours and 50 minutes. High tides occur 12 hours and 25 minutes apart. It takes 6 hours and 12.5 minutes for the water at the shore to go from high to low, or from low to high. When the two highs and the two lows are about the same height, the pattern is called a semi-daily or semidiurnal tide. This cycle is mathematically predictable, available digitally by geographic location, and can be entered as a boundary condition in the SWMM models to include the hydraulic tidal effects on the stormwater system.

"King Tides" are the non-scientific name given to the highest predicted high tide of the year at a coastal location, and it is at an elevation above the highest water level reached at high tide on an average day. King Tides are also known as perigean spring tides. In the United States, they are predicted by the National Oceanic and Atmospheric Administration (NOAA) and occur when the orbits and alignment of the Earth, moon, and sun combine to produce the greatest tidal effects of the year. King Tides are a normal occurrence once or twice every year in coastal areas. When a King Tide occurs concurrent with a weather pattern resulting in winds from the east, the wind tends to push water inland, further raising the apparent tide elevation.

In response to tidal flooding caused by the ocean water entering the stormwater system gravity outfalls at high tides and flowing out into the streets through the stormwater catch basin inlets, backflow prevention devices (BFPs), also referred to as "one-way tidal valves" have been installed in the majority of the City's outfalls. The valve's mechanism shuts automatically when the high tide water flows inland from the outfall and opens only to let water out toward the sea. The BFPs are closed by a mechanism or weight that adds headloss, and requires additional hydraulic driving head on the land side to open during a storm, adding potentially an inch or more of additional water surface height be able to push it open, which must be accounted for in the design. Thus, when the backflow preventers are closed during the high tide, stormwater drainage is hindered because of the back pressure of the ocean tide elevation, so additional improvements to the stormwater system are required in conjunction to offset the condition and not exacerbate existing stormwater flooding levels. The BFPs are also subject to the harsh marine environment and require regular maintenance to ensure a tight seal and full functionality when needed.

With current sea level rise predictions, the increasing tide elevations, while stopped by the tidal valves from entering the stormwater system, can also overtop the existing low shoreline areas along the connected coastal waterways and also result in tidal flooding of seawater into the streets. This includes non-sea walled, low sea walled, failed sea walls, and any non-bermed low lying areas. Additionally, low, non-armored areas of adjacent municipalities will need to be addressed, as water can flow into the City from other areas.

As seawalls are constructed or raised to the required ordinance height in areas where there are currently none exist and stormwater previously flowed freely off the land area as the primary drainage mechanism, other measures such as pump systems will be required to be installed concurrently so to not increase flooding levels trapped behind the new seawalls. The flooding of public rights of way at high tides in the low-lying areas will continue until the seawalls or shoreline (both public and private) can be raised to a contiguous barrier higher than the highest tide, and all of the tidal valves at the outfalls are all working. In the lowest areas, additional pumps will still likely be required to meet the City LOS during coincident high tide and rainfall events. The SWMP model will be able to identify these areas and will be used as a tool to propose the capital improvements in the engineering analyses that will address these issues.

Current Stormwater Infrastructure Overview

The City's stormwater management infrastructure is operated and maintained by Public Utilities and includes approximately 130 miles of pipes, 380 outfalls, many interconnected open channels and ditches, public right of way swales, natural waterways, drainage easements, thousands of manholes and catch basin inlets, and includes 10 City stormwater pump stations (SWPS), 2 Florida Department of Transportation (FDOT) SWPSs, and several retention and detention basins.

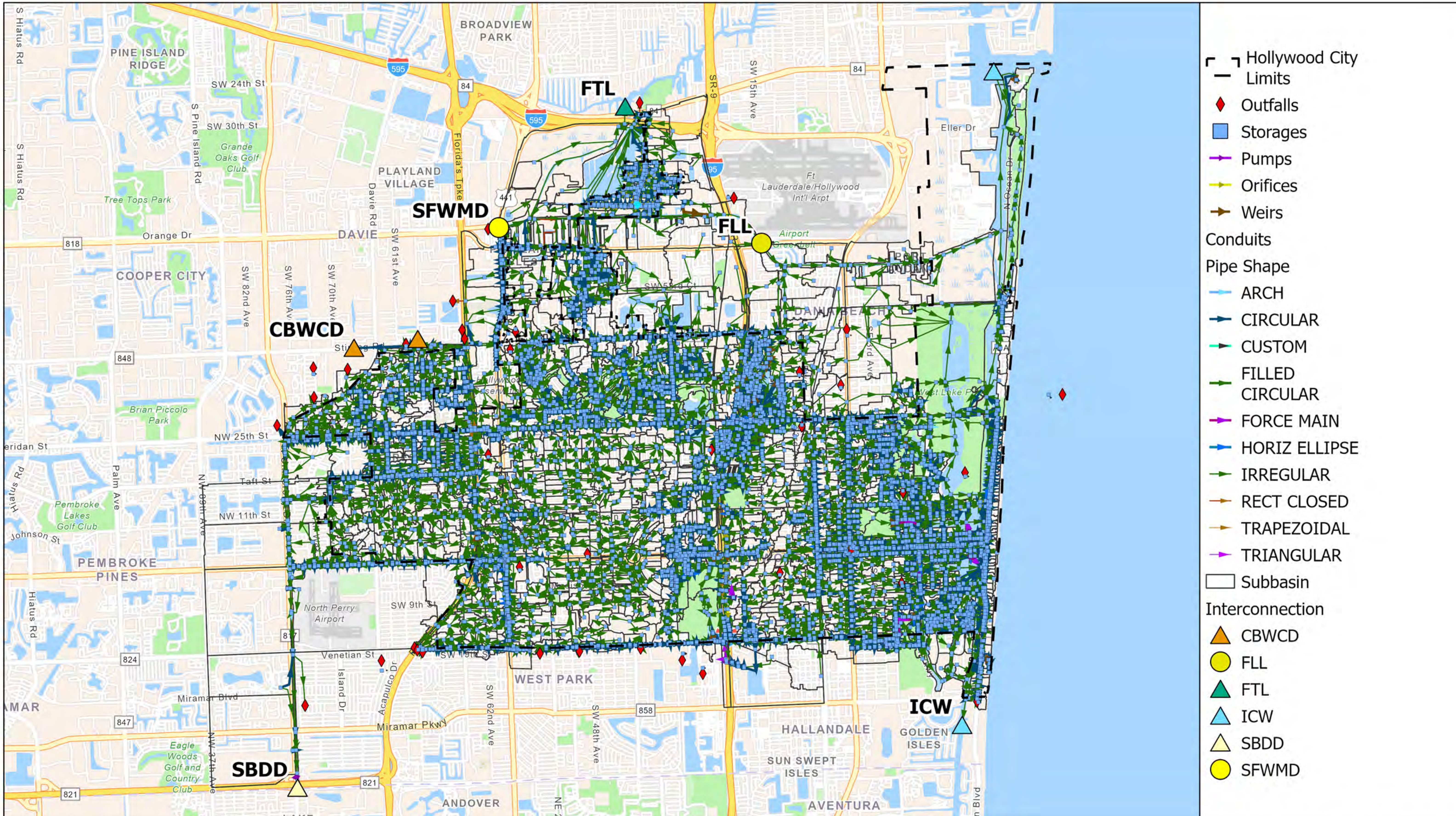
Hollywood enforces the Broward County stormwater design standards and permitting process through the Surface Water Licensing Division such that properly permitted, constructed, operated, and maintained drainage systems are in place in areas of the City that remove pollutants from storm runoff prior to discharging into Broward County's surface waters, and provides some approved level of flood protection in accordance with established criteria for proposed development. Stormwater management systems do not fully extend into all areas of the City to provide positive drainage to every neighborhood, nor is the existing system sized to handle larger storms. Currently, when heavy rains are forecast and there is the potential for flooding, City crews are dispatched pre-storm to assigned areas to clear catch basin inlets, check and maintain pump stations, deploy portable pumps if necessary to help clear standing water, and to temporarily close impassable roads.

The City's stormwater management system is highly interconnected with both County-maintained systems and FDOT-maintained systems, and the drainage area is topographically connected to the neighboring municipalities of Dania Beach to the North and Hallandale Beach to the South. Stormwater flow in the central-western and south-western portion of the City is controlled by the Central Broward Water Control District (CBWCD) and South Broward Drainage District (SBDD) respectively, which have their own PSMS and permitted discharge limits and restrictions with South Florida Water Management District (SFWMD), controlling the LOS that is provided in those areas of the City. New positive connections to those systems will need to demonstrate no pre-post impact to flows and levels of their systems. The water control districts may be of assistance for joint projects but have limited budget for new infrastructure.

Figure 1-2 presents an overview of the extents of full model schematic representing the PSMS elements of the drainage system, along with the neighborhood-level subbasin delineations, overland flow channels, and the interconnections with the boundaries influencing the system performance. The detailed schematic used in the SWMM model and discussed in the following sections is provided in **Appendix B**.

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 area into flood zones ranging from Moderate to High Flooding risk. According to FEMA data, currently approximately 40 percent (%) of the homes in Hollywood 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. Hollywood has been required to keep records of these certificates on file since it began participating in the Community Rating System (CRS). The current FEMA Flood Map showing the various flood zones for the City of Hollywood Study Area is provided on **Figure 1-3.**



Stormwater Management System and Interconnects

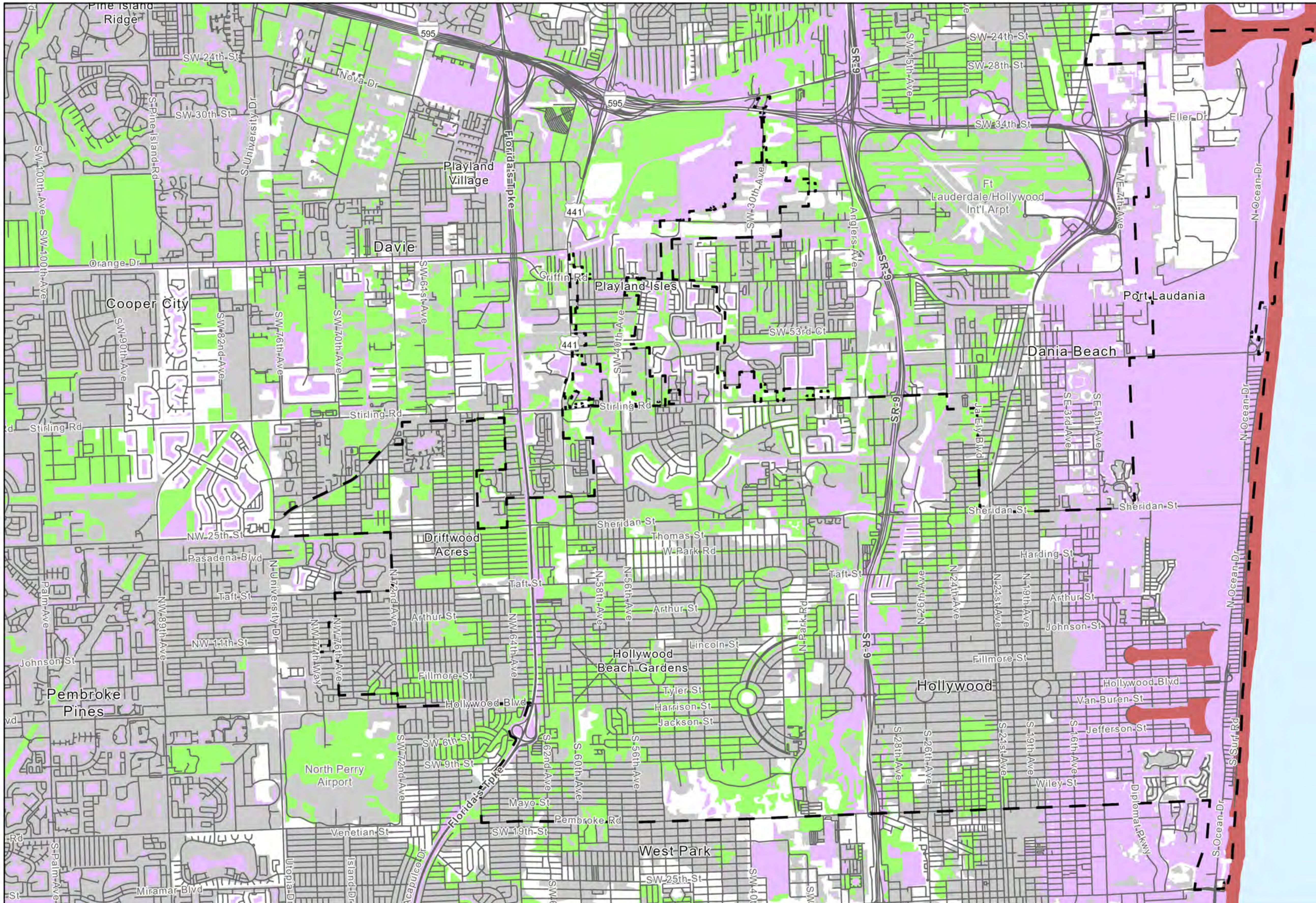
0 2,500 5,000 10,000 Feet

1:65,000

City of Hollywood Stormwater Master Plan

Figure 1-2

2/21/2021



Hollywood City Limits

Raods

FEMA Flood Zone

D - Conservation Area

VE - Coastal Flood Zone

AO - Flood Depths 1 to 3 Feet from Sheet Flow

AH - Flood Depths of 1 to 3 Feet, areas of ponding

AE - 1% Annual Chance Flood

X - Areas of 0.2% Chance Annual Flood (Moderate Risk)

X - Areas outside 0.2% Annual Chance Flood (Minimal Risk)

N

CDM Smith

City of Hollywood Florida

FEMA Flood Zones

0 2,000 4,000 8,000 Feet

1:53,000

City of Hollywood Stormwater Master Plan

Figure 1-3

2/21/2022

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2.0 Model Development

2.1 Stormwater Model

The primary objective for developing a detailed hydrologic and hydraulic (H&H) model of the City's drainage basins is to provide a tool suitable for evaluating the performance of the City's stormwater management system and establishing a baseline against which to evaluate alternative improvements to meet a desired level of service for flood control on a neighborhood scale. The following sections 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, the developed models focus on the 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 waterbodies (i.e., the boundary conditions). The PSMS is defined as open channels and pipes of 24-inch diameter and larger, except where the model analysis specifically required smaller, or more detailed infrastructure to be considered for the analysis.

Dynamic 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 simultaneously in a time series 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. These dynamic water quality specialty routines were not required to be applied in this project.

The City's stormwater models follow the interconnected stormwater management system (City-owned and County/State-owned as necessary) downstream through pipes, channels, offsite and on-site overland flow, and ditches through to the point of discharge into a major canal, river, ground, pump station, or Intracoastal Waterway (outfall). The major canals and lakes are explicitly included in the master plan models with the final downstream boundary conditions located in the ICW for the eastern portion of the City, and the in the SBDD and Central Broward Drainage District (CBDD) Canals in the west.

The stormwater models for this analysis use the U.S. Environmental Protection Agency (EPA) Storm Water 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. 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.

For expediency, the stormwater models for this particular analysis were initially created using a commercially available program/pre-processor PCSWMM by CHI (Computational Hydraulics International) due to the program's large data manipulation and GIS capabilities. PCSWMM also includes a custom graphical user interface (GUI) and offers other advanced GIS functionality, model building, calibration, and post processing tools that expedited the initial builds and report figures and is fully compatible with the EPA SWMM running the EPA SWMM numerical engine. The EPA SWMM model software is also capable of creating the same model input files as a standalone product. The master plan models will also need to be maintained to address future needs and incorporate the changes that occur in the system over time as development/re-development occurs or drainage improvements are constructed.

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 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 the City's Operations and Maintenance (O&M) needs, and to coordinate implementation.

For the scale of this Citywide planning-level analysis, the required 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, as they do not affect the outcome of the alternatives. However, where drainage areas of reasonably large size were served by pipes smaller than 24 inches in diameter or additional detail was necessary for model accuracy, smaller pipes were necessarily included in the model to allow for accurate characterization of the area. Generally, all pipes in the primary system have a runoff element loaded to the upstream terminus and thus help define sub-basin delineation.

To accurately represent drainage basin hydrology, the rainfall interval used 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 available source data. The runoff wet weather time step was set to 1 minute with no significant impact on run times; and the runoff dry weather time step should be equal to the same 1 minute for simulations shorter than 1 week.

With respect to hydraulics, the time step used in the models for flow routing will 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 2 seconds was used for routing to reduce instabilities in the model simulations.

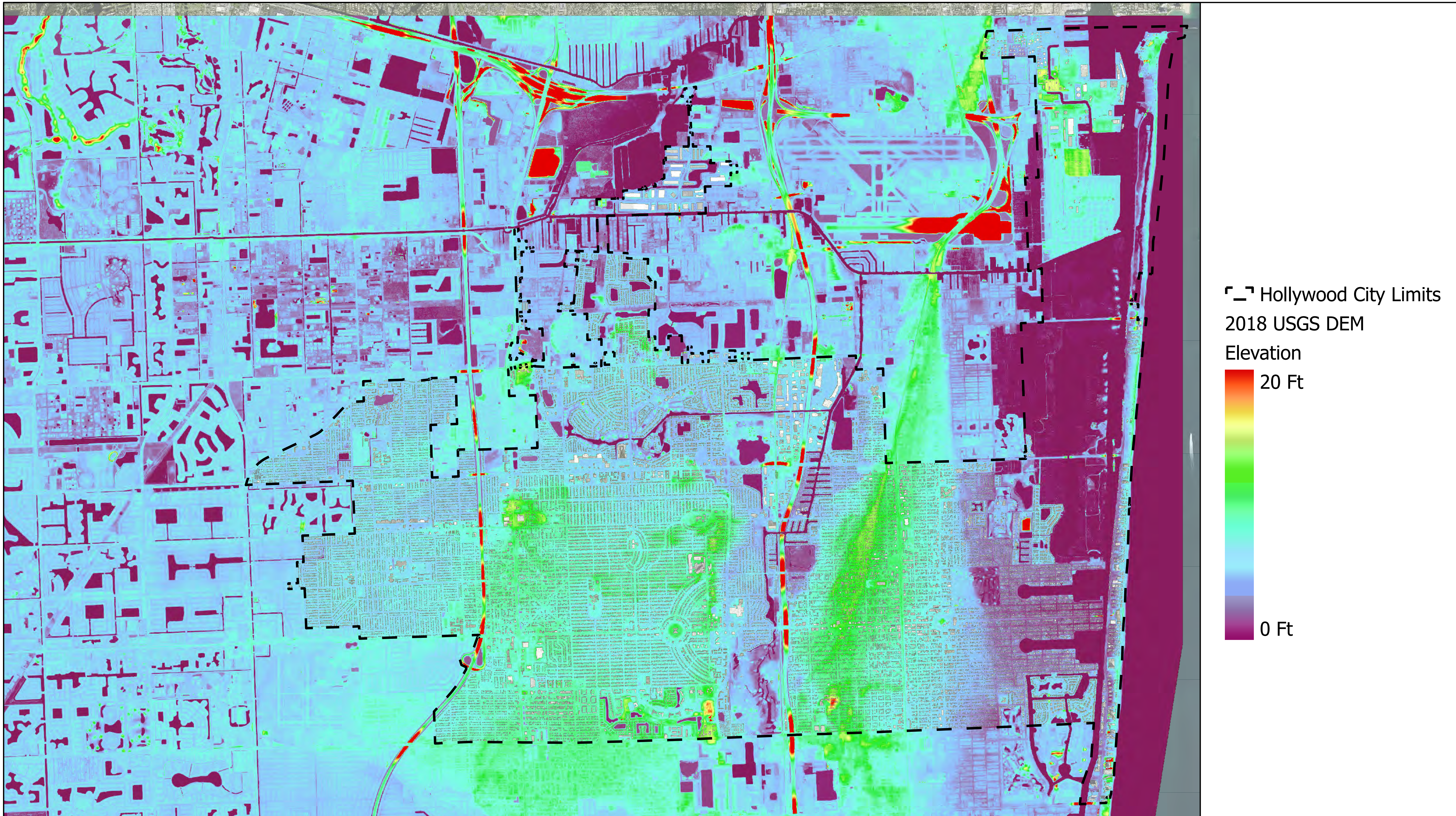
2.3 Data Collection and Characterization of the Drainage Basins

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 Topographic Data

The primary Digital Elevation Model (DEM) used for this SWMP has been prepared from Light Detection and Ranging (LiDAR) data acquired from USGS for 2018 at a 5-ft pixel QL1 accuracy. Sources of elevation data was geo-processed by USGS to make a composite bare earth DEM. The fundamental vertical accuracy for bare earth elevations is 0.64 feet, the horizontal resolution of the LiDAR grid is 1.64 feet in length and width. The bare earth DEM excludes buildings, trees, bridges, etc. by using last return and ground classification features from the LIDAR point cloud. CDM Smith further processed the DEM by erasing building footprints, so that the stage storage is not overestimated, and the results do not show false positives of building flooding. A second, raw DEM acquired from USGS with LiDAR grid resolution of 5.0 feet in length and width was used in the initial model development. A third DEM layer was acquired from FDOT for 2017 with resolution of 0.5 feet in length and width was used in some areas for higher resolution in the model development; however, was not available city-wide. Natural land surface in the LiDAR data ranges from a high elevation of approximately 14 ft-NAVD to a low of 0 ft-NAVD.

Figure 2-1 provides the DEM. As shown in the color scale, the higher elevations are generally located along the coastal ridge (approximately follows area line from north of Pembroke Rd and South 26th Avenue to the City boundaries between Sheridan Street and North Dixie Hwy). Other "relative" upland areas occur between Pembroke Road and Taft Street, between Park Road and the Florida Turnpike.



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City of Hollywood Elevation

0 2,000 4,000 8,000 Feet
1:53,000

City of Hollywood Stormwater Master Plan
Figure 2-1
11/8/2021

The upland areas between about 8 ft-NAVD and 14 ft-NAVD generally provide better natural soils infiltration (less runoff) as well as higher exfiltration capacities in exfiltration systems (French Drains and gravity wells) because of larger depths to water table and greater available hydraulic driving head. The exfiltration capacities are also determined by the hydraulic conductivity of the underlying aquifer, which may be independent of topography. The City topography is characterized by very low-lying land areas both east and west of the coastal ridge, as well as west of the Florida Turnpike and north of Sterling Road. Elevations drop off relatively rapidly east of U.S. Highway 1 (Federal Hwy) toward the ICW, especially between North and South Lakes, where road crowns are routinely found to be near or below 1 ft-NAVD. East of the Intracoastal, Ocean Drive (A1A) and multiple side streets also have very low road crowns in the 1-2 ft elevation range. Within the interior of the City, neighborhoods adjacent to the Hollywood Canal and C-10 Canal are also low-lying. In particular, there are multiple roads with road crowns below 3 ft-NAVD east of I-95 from south of Sunset Golf Course to Sheridan Street. Additionally, west of the Florida Turnpike, there are multiple neighborhoods with road crowns below 5 ft-NAVD.

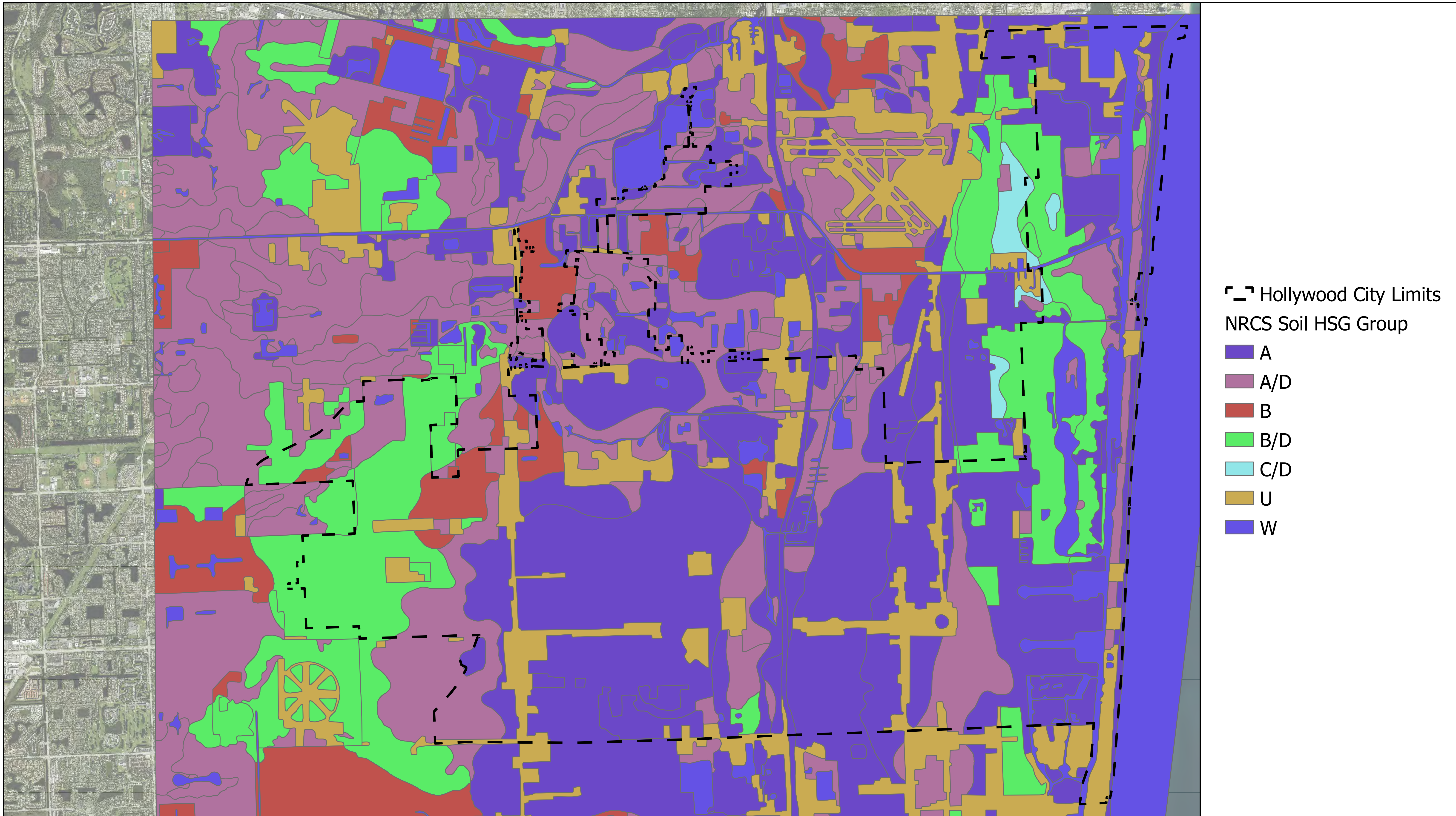
2.3.2 Soils Data

Two categories of soil parameters are used in the model. The infiltration rates of the upper soils layers and the saturated hydraulic conductivity (K_{sat}) of the upper aquifer.

Soils Classification

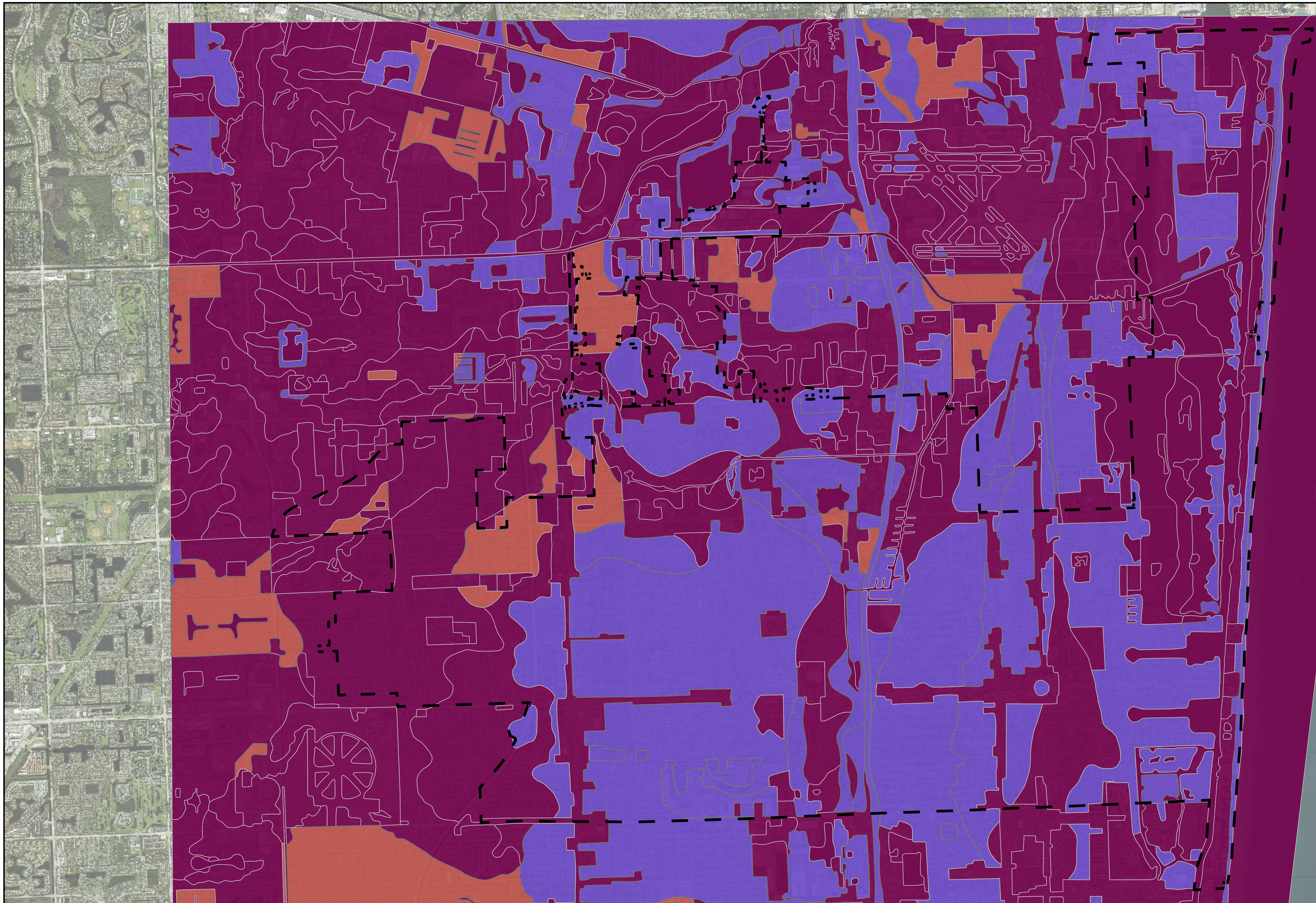
The National Resources Conservation Services (NRCS) Soil Survey Geographic database (SSURGO) data for Broward County East Area FL606, generated by the United States Department of Agriculture (USDA), was downloaded from the NRCS website (https://sdmdataaccess.nrcs.usda.gov) and reviewed to determine dominant 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 and vicinity. One of the soil types found in the City is classified as 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 a 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. **Figure 2-3** displays the NRCS Soils adjusted map for the City used for modeling purposes.



NRCS Soils Map

City of Hollywood Stormwater Master Plan
Figure 2-2
11/8/2021



NRCS Soils Adjusted Map

City of Hollywood Stormwater Master Plan
Figure 2-3
11/8/2021

0 2,000 4,000 8,000 Feet
1:53,000

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Aquifer Permeability Geotechnical Field Testing

Two categories of soil parameters are used in the model. The infiltration rates of the upper layers described above, and the saturated hydraulic conductivity (K_{sat}) of the upper aquifer. A database search was conducted to find local field permeability tests of the latter.

A total of 135 tests scattered throughout the City have been included in the SWMP:

- 84 K_{sat} t data points were researched and found from inspection of Broward County permit records.
- 6 K_{sat} data points were obtained through a Geotechnical Report in areas located in the North and South Lake, City of Hollywood Tidal Flooding Mitigation Phase 1.
- 45 K_{sat} data points were obtained through surveyed aquifer percolation tests.

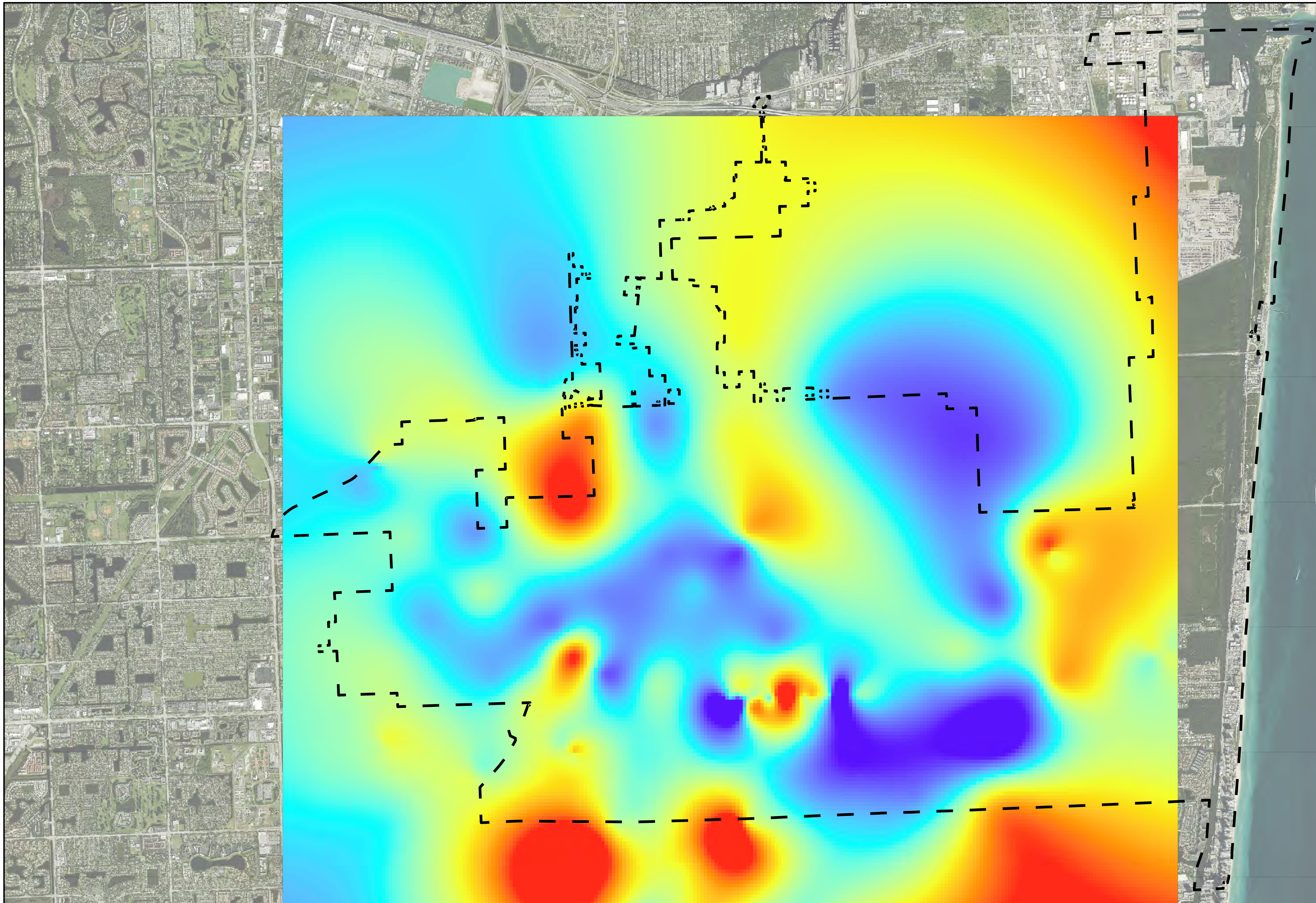
These tests measure the permeability of the underlying Biscayne Aquifer. Open boreholes are drilled or augured deep enough to penetrate the aquifer (typically 10–15 feet below land surface), and water is pumped into the hole. The falling head test estimates the K_{sat} of the aquifer by measuring the 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 data point. 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. 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^{-5} to 4.0 x 10^{-2} from permit data values and from 1.0 x 10^{-5} to 4.0 x 10^{-3} from survey data, with a log mean value of 3 x 10^{-4} cfs/ft^2 per foot of head. 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 good 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 (cut into the aquifer) to recognize the increased performance. For proposed exfiltration systems, additional site-specific testing will be necessary to provide more precise local values of exfiltration capacity.

2.3.3 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 SFWMD Existing (2014–2016) Land-use map.



Hollywood City Limits

KSAT

cfs/ft per ft of head

High: 10^-2

Low: 10^-5

Saturated Hydraulic Conductivity (KSAT)

0 2,000 4,000 8,000 Feet

1:53,000

City of Hollywood Stormwater Master Plan

Figure 2-4

4/8/2022

CDM Smith

City of Hollywood Florida

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Published values were compared to 50 selected locations of actual GIS takeoffs for impervious area in test tracts for representative areas of the City and the results were found to be statistically similar, so no further refinements or adjustments were required to be made to the published data.

USGS Impervious Coverage

Imperviousness values that affect the runoff calculation were obtained from USGS based on remote sensing data from the 2016 and 2019 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 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. An overlay comparison of more recent aerials of the City was performed, and imperviousness of areas of new development and construction shown on the latest aerials were adjusted manually where necessary to account for new impervious areas.

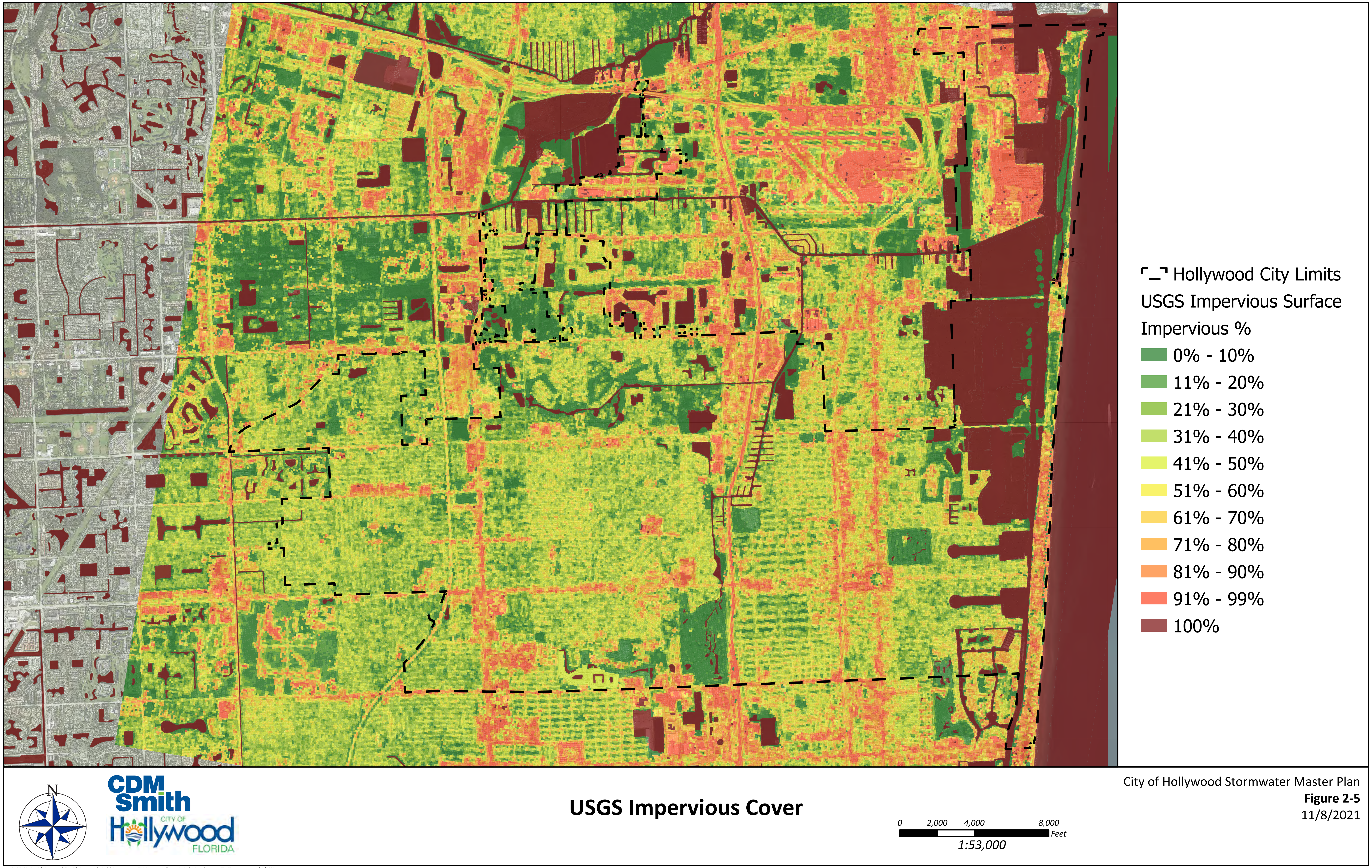
SFWMD Land Use Coverage

Existing land-use coverage is used for secondary parameters such as pervious roughness and is published as a layer on the SFWMD website SFWMD_LCCLU_2014_2016. There are approximately 101 different land use codes in the SFWMD 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. **Figure 2-6** displays the land-use data for the City.

2.4 Stormwater Infrastructure

The physical stormwater infrastructure used in the model PSMS was compiled from a mosaic of City archives (existing available GIS, atlases, survey, as-builts/record drawings), and data from the SFWMD, FDOT records, Central Broward Water Control District, South Broward Drainage District, Broward County, as well as extensive field surveys, and various other publicly available published data sources.

The compiled data were geospatially translated into a new City of Hollywood stormwater layer in GIS format and customized for the City. The new geodatabase is developed with the Esri Municipal Standards for ArcGIS Utilities Databases and the Local Government Information Data Model Standards. The stormwater management specific data features include: inlets/catch basins, manholes, drainage wells, exfiltration trenches, valves, pipes, culverts and ditches, conveyance swales, stormwater pump stations and associated discharge force mains, outfalls, weirs, gates, BFPs, and other pertinent stormwater structures.



CDM Smith

City of Hollywood Florida

USGS Impervious Cover

City of Hollywood Stormwater Master Plan

Figure 2-5

11/8/2021

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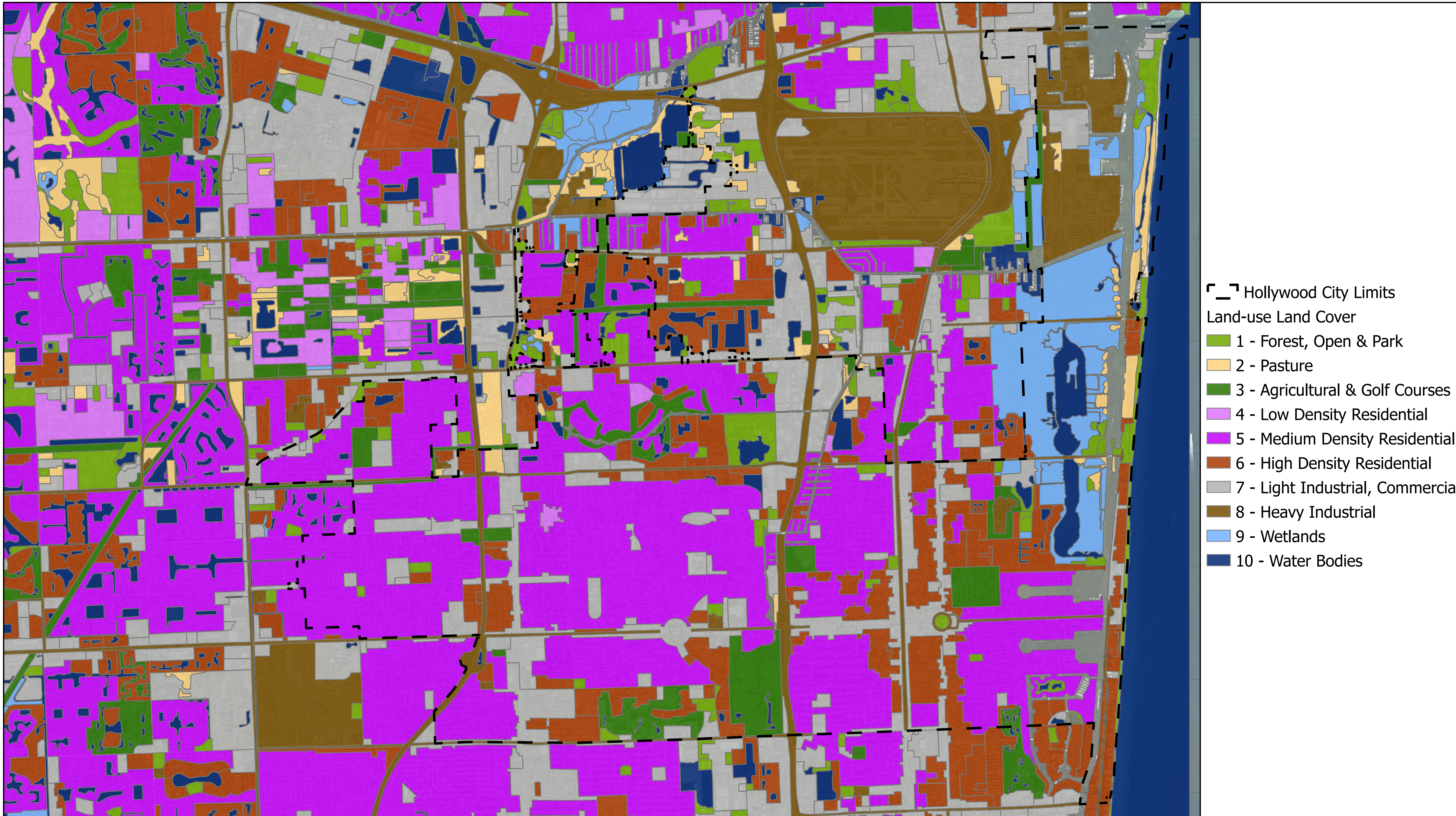

City of Hollywood Landuse

City of Hollywood Stormwater Master Plan
Figure 2-6
11/8/2021

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The PSMS is explicitly modeled for all pipes 24 inches in diameter and larger, ditches/swales 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 (SSMS) and are not explicitly modeled, except where needed for accuracy or connectivity of the model. Critical attributes in the stormwater layers, aside from coordinates, include Facility Identification (FACILITYID) 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).

2.4.1 Naming Convention

For model nomenclature, the FACILITYID is combined with a neighborhood prefix to develop a model ID used for all storages and outfalls. A list of the neighborhood abbreviations provided in **Table 2-1**.

For nodes representing inlets, manholes and discharge points without a City FACILITYID, a unique ID was provided to the element for modeling purposes. For model nodes representing above ground elements (such as ponds, low-lying areas without PSMS, etc.), a unique "AGE" ID was provided in the model. Additionally, unique IDs were provided for nodes representing ends of canal links.

For pipes, the naming convention is to use the upstream node name as the pipe name. If there is more than one pipe leaving a given node, suffixes "_1", "_2", etc. are used. A prefix of "C" is added to the FACILITYID or equivalent user supplied unique ID for canal sections, a prefix of "C" is used for 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. 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.

Table 2-1. Neighborhood Abbreviations

Neighborhood	Prefix	Neighborhood	Prefix	Neighborhood	Prefix
441 Corridor	441	Hollywood Hills	HH	Park East	PKE
Alandco	AL	Hollywood Lakes	HL	Park Side	PS
Arapahoe Farms	AF	Lake Eden	LE	Playland	PL
Beverly Park	BP	Lakes of Emerald Hills	LEH	Port Everglades	PE
Boulevard Heights	BH	Lawn Acres	LA	Royal Poinciana	RP
Carriage Hills	CH	Liberia	LB	South Central Beach	SCB
Driftwood	DW	Maple Ridge	MR	Stirling Commercial	SC
Emerald Hills	EH	North Beach	NB	Ty Park	TP
Highland Gardens	HG	North Central	NC	Washington Park	WP
Hillcrest	HC	Oakridge	OR	Broward County	BC

Neighborhood	Prefix	Neighborhood	Prefix	Neighborhood	Prefix
Hollywood Gardens West	HGW	Oakwood Hills	OH	South Broward Drainage District	SBDD

2.4.2 Model Schematic Preparation

Creation of an accurate, interconnected and detailed model schematic involved the following steps:

1. Initial Basic Layout of Infrastructure – The first step was to prepare a model schematic based on the defined levels of detail. The model schematics were organized and created by major drainage basin with standard symbology on a GIS base map for each 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.

2. Nodal Placement – 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 that 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.

3. Sub-Basin Delineation – 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.

4. Overland Flow Channels – The next step is 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.

5. Boundary Conditions Definition – The final step is to create the boundary conditions for the stormwater system evaluation and other boundary control structures. A 1-year stillwater of 2.5 ft-NAVD for Port Everglades is used. Sea Level Rise (SLR) analyses are performed at an additional 1.5 feet (4.0 ft-NAVD) and 2.5 feet (5.0 ft-NAVD) on top of the boundary conditions. A more detailed discussion of the development of model boundary conditions is presented below.

2.4.3 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 and statistically significant fit with available data and within the accuracy of the model. The detailed model validation analysis is provided as a standalone document in **Appendix A**.

2.5 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.

2.5.1 Measured Rainfall Data

Two separate validation storms were necessary to be used City-wide to analyze and validate the models as there was no one historical recorded storm that provided the necessary uniform rainfall data of the entire City area.

The following two validation storms were selected for the analysis:

1. Hurricane Eta – Eta was a slow moving and wet tropical storm as it approached Florida that resulted in 5-10 inches of precipitation in Hollywood over approximately 72 hours from November 7, 2020 through September 10, 2020, with the majority of the rainfall falling within a 24-hour period. This was used for the western portions of the City. For TS Eta, the month prior to the storm was extremely wet, with over 30 inches of precipitation in some areas; therefore, the soils were saturated and groundwater flows were significant, especially in the western canals.

2. December 23, 2019 Storm – This storm that ranged from 2.4 inches to 10.5 inches of precipitation in approximately 4 hours was used for the eastern portions of the City.

For both storms, data from a nearby precipitation gauge was provided by SFWMD through the DBHYDRO portal at https://www.sfwmd.gov/science-data/dbhydro. The S-13 gauge for stage elevations was used for this project and is located on the SFWMD C-11 Drainage Canal, near U.S. 441, north of Griffin Road.

Since the rainfall volumes varied substantially throughout the City, NEXRAD rainfall estimates from the SFWMD (https://apps.sfwmd.gov/nexrad2/nrdmain.action) were used as model input. All SFWMD datasets are provided in 15-minute increments.

The precipitation data for Validation Storms are presented in **Table 2-2**. The cumulative rainfall hyetographs for TS Eta and the December 2019 Storm are presented on **Figure 2-7 and Figure 2-8**. The spatial distributions of the two storms are presented in **Figure 2-9** for TS Eta and **Figure 2-10** for the December 2019 Storm.

As shown in the NEXRAD mosaic volume data sets, precipitation volumes were significantly higher in the west of the City during TS Eta and for the December 2019 storm, precipitation volumes were significantly higher in the eastern portion of the City than in the west.

Table 2-2 Validation Storm Statistics

Gage	Date	Rainfall Depth (inches)	Peak 15-min Intensity (inches/hr)	Peak Hour (inches)
Eta				
S-13	November 7-10, 2020	9.6	0.6	1.4
NEXRAD	November 7-10, 2020	5.0-9.0	0.5	1.4
December 2019				
S-13	December 23, 2019	5.6	0.9	3.2
NEXRAD	December 23, 2019	2.4-10.5	1.6	4.3

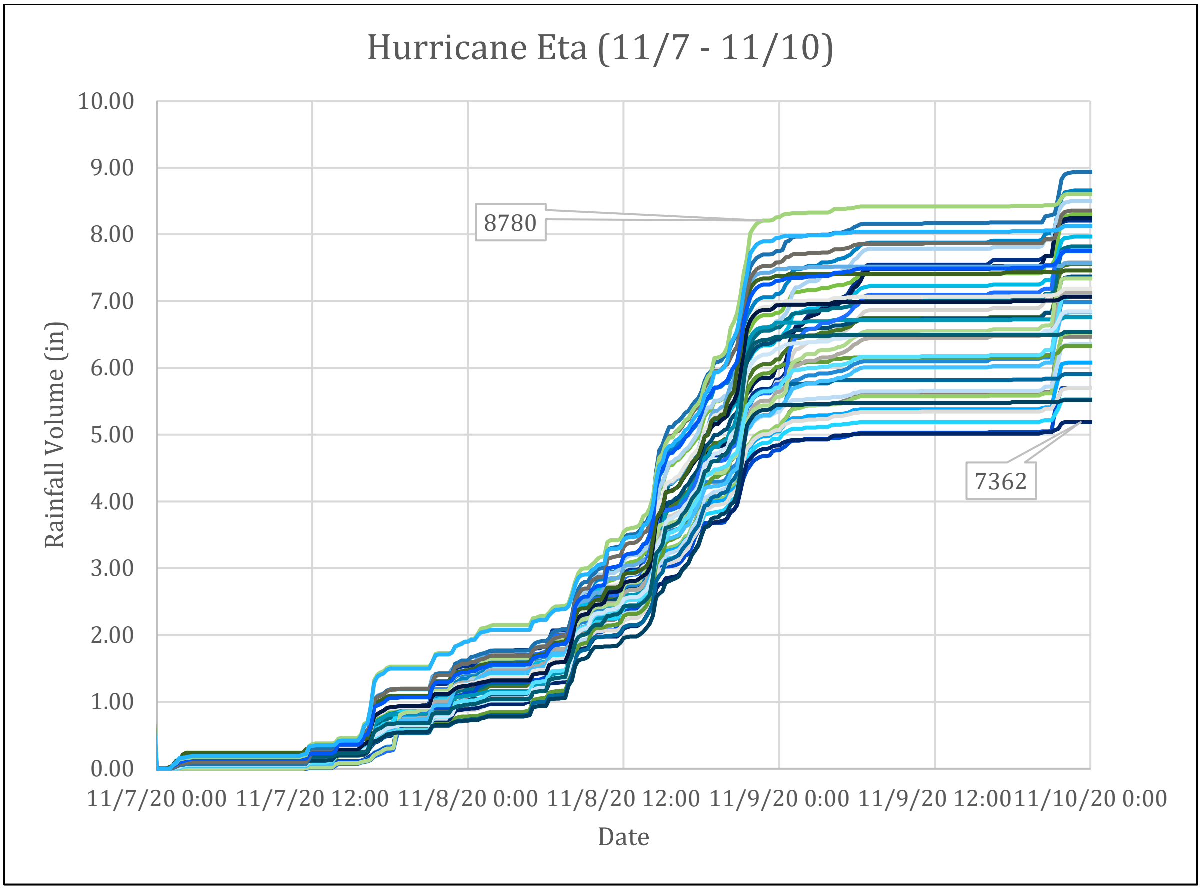


Figure 2-7 Cumulative Rainfall Hyetograph for Validation Storm: Eta

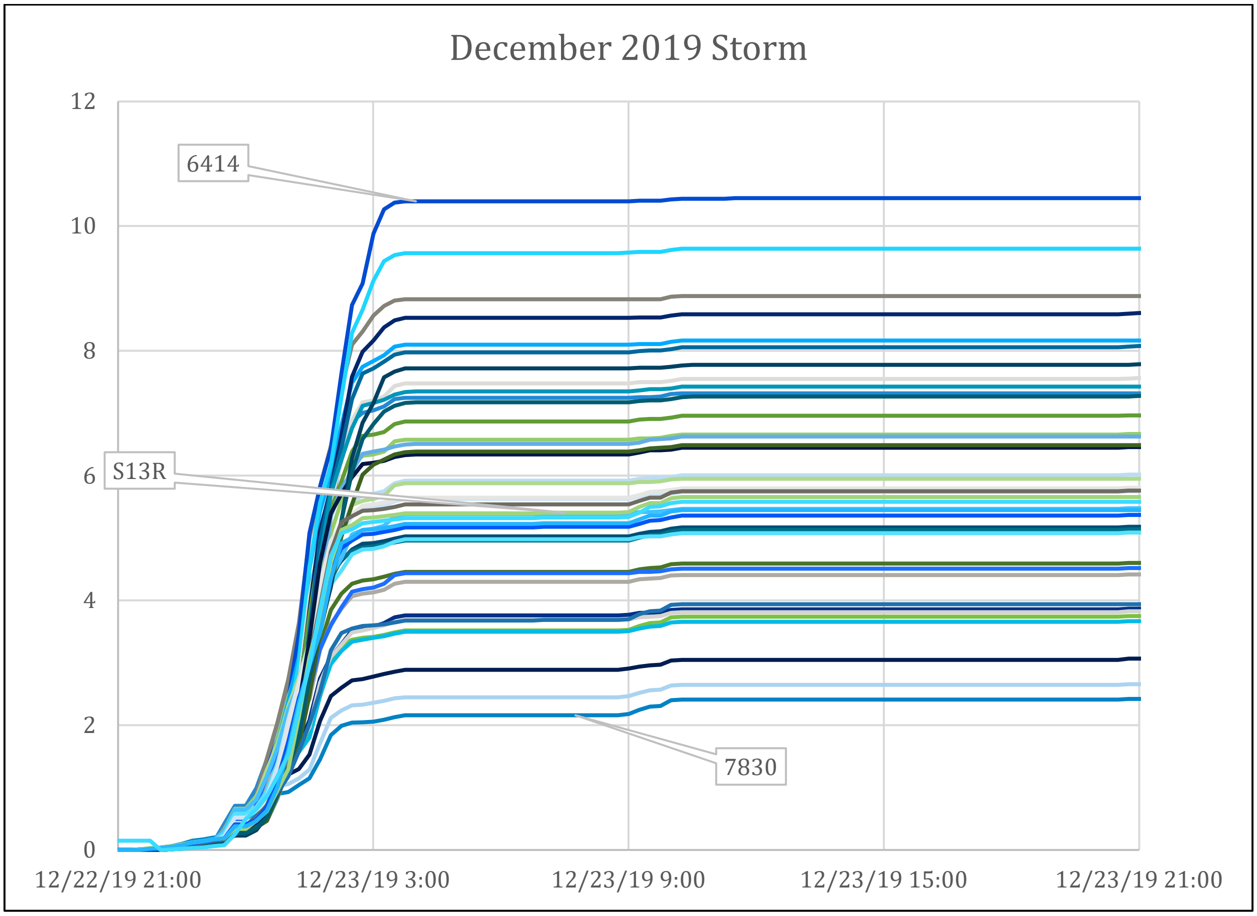
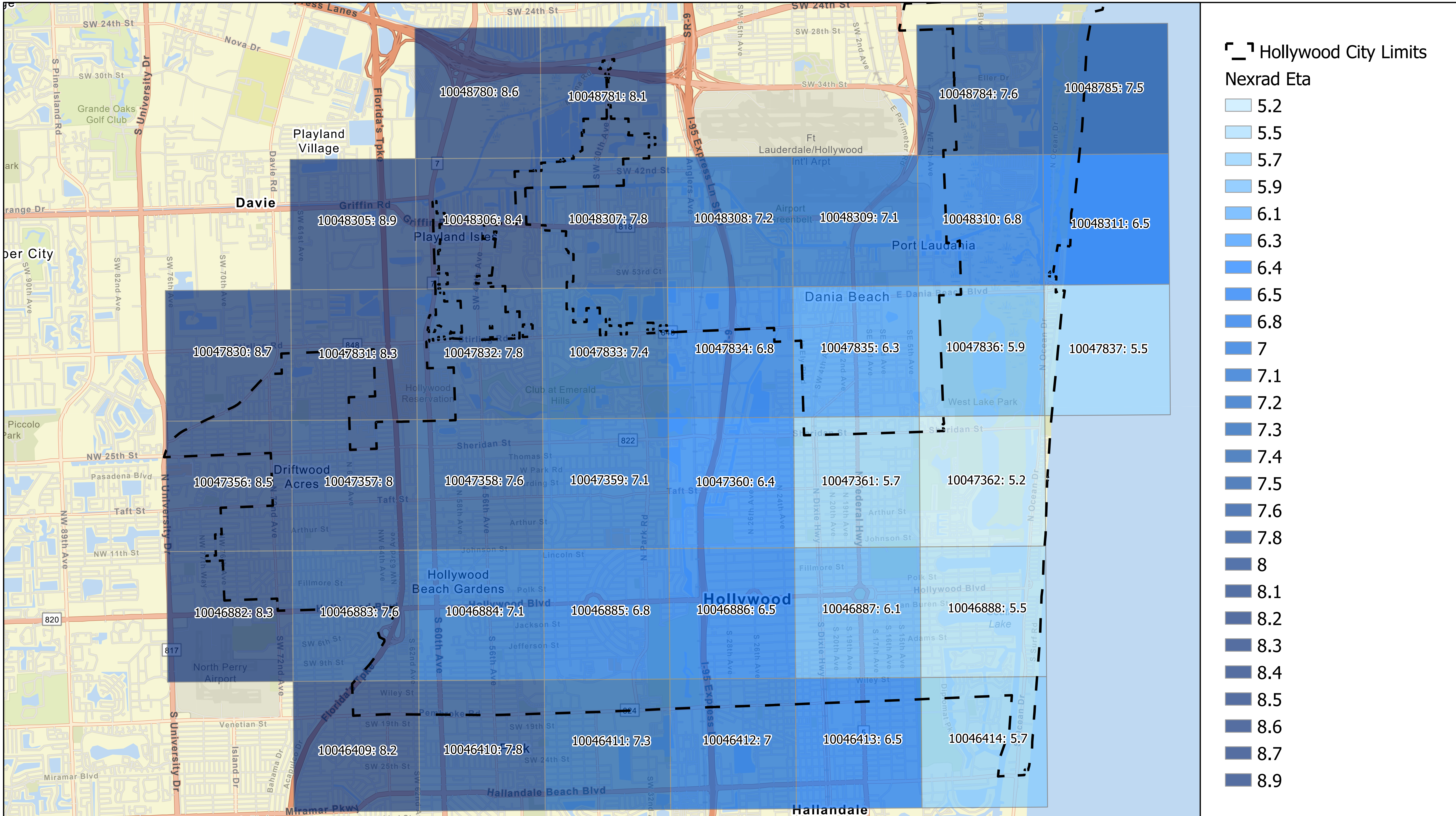


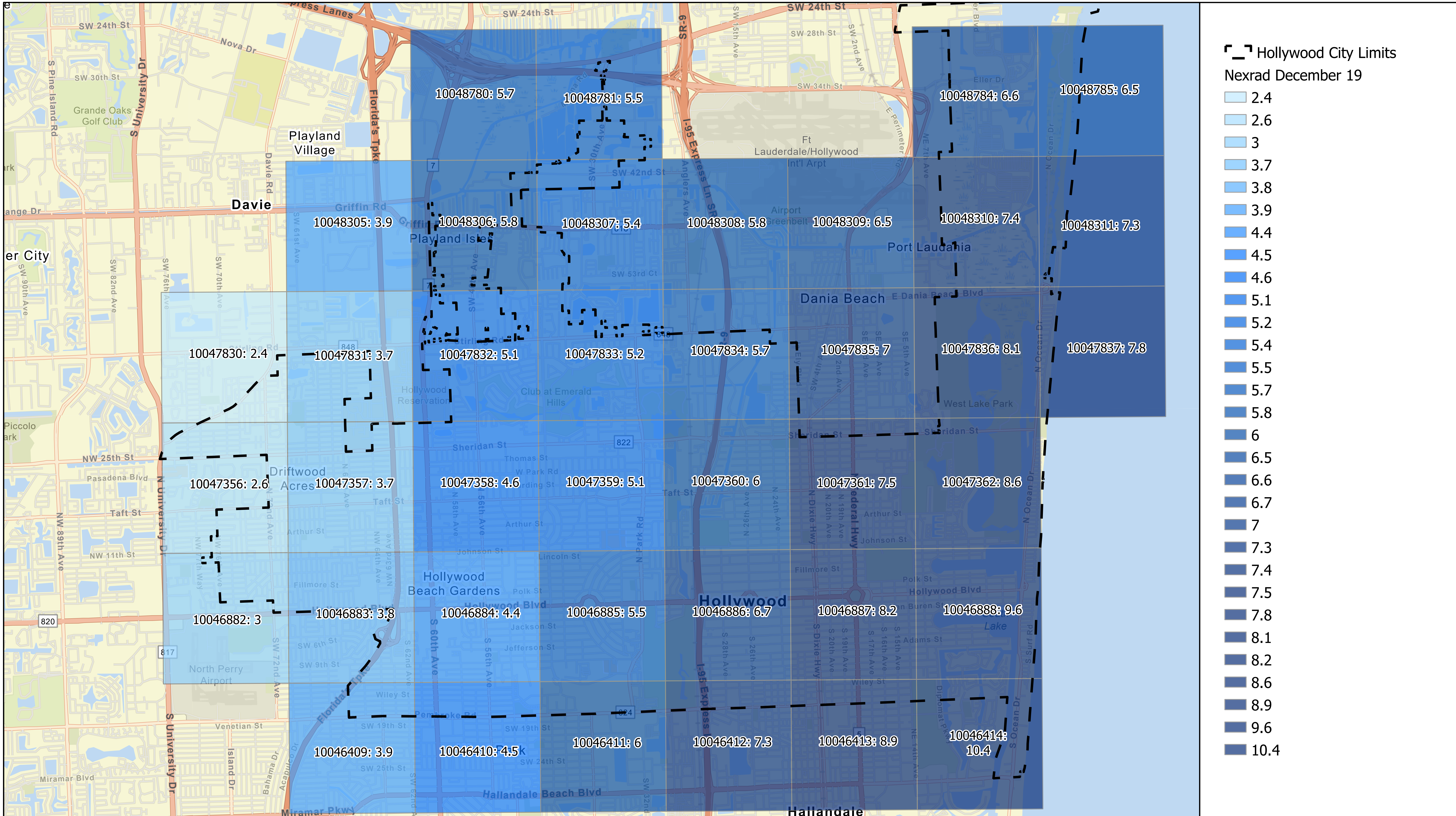
Figure 2-8 Cumulative Rainfall Hyetograph for Validation Storm: December 2019



Nexrad Volumes for Tropical Storm Eta

City of Hollywood Stormwater Master Plan
Figure 2-9
11/8/2021

0 2,000 4,000 8,000 Feet
1:53,000



Nexrad Volumes for December 2019 Storm

0 2,000 4,000 8,000 Feet
1:53,000

City of Hollywood Stormwater Master Plan
Figure 2-10
11/8/2021

SUSINOBM D:\Hollywood SWMP\Hollywood Model Development TM Figures\Hollywood Model Development TM Figures.aprx 4/12/2022

2.5.2 Design Storm Rainfall Data

Design Storm rainfall data are 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 the following parameters:

- Volume/depth (measured in inches)
- Intensity (measured in inches per hour)
- Return period (measured years)
- Event duration (measured in hours)
- Spatial distribution (the locational variance)
- Temporal distribution (the time variance)

Design storm events are designated to reflect the return period of the rainfall depth and the event duration, or how often, statistically based on data records, that size of a storm can be expected to occur in this region. For example, a 25-year, 72-hour design event describes a rainfall depth over a 72-hour period that has a 1 in 25 (or 4 percent = 1/25) chance of occurring at a particular location in any given year. The 24-hour design storm has its peak centered at 12 hours while the 72-hour design storms have their peak intensities at 60 hours. The 72-hour distribution applies the SFWMD 24-hour distribution from hours 48–72, with continuous lower intensity rainfall over the first 48 hours. The ratio between the 72-hour volume and the 24-hour volume for a given storm is 1.359. Design Storm distributions were taken from the SFWMD Permit Information Manual, Volume IV.

In addition to the storms required by SFWMD, the local Broward County Resilient Environment Department Environmental Permitting Division (EEPD) Surface Water Management Licensing division permit requires a 10-year, 24-hour storm be included for permitting purposes. A delegation agreement from the State to Broward County has transferred the authority for the Environmental Resource Permit (ERP) program. The County EEPD's Surface Water Management Program issues two types of licenses: a formal Surface Water Management License and a Surface Water Management General License, as well as SFWMD and FDEP ERP's. Model simulations were performed for the following design storms:

1. 5-year, 24-hour (potential goal LOS event for secondary roads)
2. 10-year, 24-hour (potential goal LOS event for primary roads including but not limited to evacuation routes)
3. 10-year, 72-hour (use TBD)

4. 25-year, 72-hour (SFWMD pre-post flows and stages/levels requirement for regulated canals)
5. 100-year, 72-hour (FEMA minimum finished-floor elevation requirement)

The 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 digital rainfall gage data than the isohyetal maps in the SFWMD Permit Information Manual, as District maps were developed in the 1990s. SFWMD confirmed previously that NOAA Atlas 14 volumes are acceptable for permitting purposes.

Design Storm rainfall volumes may be found for select gages in the NOAA atlas, or an interpolated volume estimate may be estimated for point locations. For this project, point location estimates were made for each model basin. To be conservative, the highest volume for a given basin was used as the rainfall volume over the entire basin. For the 10-yr, 25-yr, and 100-yr 72-hour storms, the 24-hour volumes were extracted from the map and multiplied by a factor of 1.359 to produce 72-hour volumes, to match the SFWMD distributions. The resulting volumes are typically higher than the 72-hour volumes in the tables. The Design Storm volumes and intensities will be provided in the individual basin reports in the Model Application TM.

Rainfall depths and intensities are provided for the East (EB) Basin in **Table 2-3** below as an example:

Table 2-3 East Basin Design Storm Volumes and Intensities

Storm	Rainfall Depth (inches)	Peak Hour (inches)
5-year, 24-hour	7.4	3.0
10-year, 24-hour	9.0	3.7
10-year, 72-hour	12.2	3.7
25-year, 72-hour	15.5	4.7
100-year, 72-hour	21.2	6.5

2.5.3 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 LiDAR DEM. 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 1.6 feet in length and width. The fundamental vertical accuracy for bare earth elevations is 0.64 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).

2.5.4 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). Where relatively large areas are served by smaller systems, the level of service was expanded to include the size of the smaller pipe. For modeling purposes, some 24-inch pipes were necessarily not included in the model. Situations where (1) the tributary area to the end of the pipe was significantly smaller than the rest of the City areas (areas smaller than 1 acre are instead combined together at a higher resolution), or (2) multiple parallel pipes needed to be combined into one multi-barrel pipe for 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 subsequently performed on these areas. Additional edits to sub-basin delineations were occasionally performed as the model hydraulics were developed for greater accuracy of the simulation.

Runoff typically does not stop at the City's municipal boundaries, so major portions of Broward County beyond the City limits are necessarily included in the basin models, wherever these areas were tributary to the City's PSMS or where local topography allows overland flow to enter the City (see previous Figure 1-1). For the portions of Broward County that are outside the City boundaries but drain to the City PSMS, sub-basin delineation was performed beyond the City limits similar to the City sub-basins, but on a larger, coarser scale to be able to account for the off-site runoff conditions.

Some locations of note are:

- North of Stirling Road in the C-11 Basin Model, the City boundary is irregular and often narrow. The adjoining County neighborhoods are included in the model both east and west of the City.
- Along the northern boundary of the City, east of I-95 (in the Hollywood Canal Basin Model), County neighborhoods that drain to the Hollywood Canal or the Dania Cutoff Canal have been added to the model in order to estimate flow in these canals.

- The neighborhood east of SW 4th Avenue and north of Sheridan Street (East Basin Model) has been added at a rough level of detail to estimate stages in West Lake.
- Along the southern boundary of the model, parts of Hallandale have been modeled to because they share PSMS with the Eastern Basin and Hollywood Canal Basin Models.
- SBDD sub-basins have been added to the West Basin Model to estimate stages in the SBDD drainage ditch along University Drive.
- Some county sub-basins have been added to the model northwest of the City along the Davie Road Extension and north of the City to Stirling Road (west of the Florida Turnpike) to estimate flows along these systems.
- The Seminole Reservation has been added to the model north of Atlanta Street between NW 64th Avenue and N 58th Avenue, and from Sheridan to Charleston Street between NW 64th Avenue and NW 6th Avenue.
- A portion of the Port Everglades is within the City boundary and it is not included in the model, as it has a separate SWMP and Master Plan from Broward County.

Once the sub-basin delineation was established at both the refined City level and coarser County level, each sub-basin was given specific individual 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.

Table 2-4 Basin Delineation Data

Basin	Type	Area (Acres)	Number of Sub-basins	Average Size (Acres)
East	**City**	**4372**	**495**	**8.8**
	County	2086	49	42.6
	Total	6448	544	11.9
West	**City**	**3456**	**423**	**8.2**
	County	1426	75	19.0
	Total	4882	498	9.8
Hollywood Canal (HWC)	**City**	**4725**	**471**	**10.0**
	County	1872	49	38.2
	Total	6597	520	12.7
C-10	**City**	**3164**	**332**	**9.5**
	County	610	20	30.5
	Total	3774	352	10.7
C-11	**City**	**708**	**102**	**6.9**
	County	3105	93	33.9
	Total	3858	195	19.8
Beach	**City**	**624**	**109**	**5.7**
	County	30	4	7.5
	Total	654	113	5.8

2.5.5 Land Use Parameters and Impervious Areas

Two City-wide database layers were used to estimate the hydrologic model parameters excluding the soils parameters: the total impervious area within each sub-basin was estimated from the USGS NLCD Figure 2-5, and the SFWMD Land-use database, Figure 2-6. 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

Land Use Description	Abbreviation
Commercial, Light Industrial, and Institutional	Comm
Heavy Industrial and Transportation	HInd
Wetlands	Wetlnd
Waterbodies	Water

Land Use Dependent Parameters

Land use coverage is 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:

1. Surface Roughness (Pervious n and Impervious n) – The Manning's n Roughness Coefficient along the representative flow path.
2. 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.

Typical depression storage values range from 0.05 inches to 0.5 inches and vary by sub-basin and land cover. A relatively small value of 0.1 inches is used for this project, since swales and much of the larger depressions are accounted for in the hydraulic model with the stage-storage curves. The portion of the impervious area given zero depression storage is set to 25%, which is the SWMM default value unless the modeler adjusts during a model calibration (the default value is used for this project). This value is 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

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.

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[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.

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.

Impervious Area

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 Hollywood 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-County C-100 Basin models, City of Miami Comprehensive SMWP, City of New Orleans SWMP).

CDM Smith conducted a test of the database versus aerial inspection over multiple areas within the city ranging from low density residential to high density residential/commercial. For this test, every impervious surface including buildings, roads, parking lots, sidewalks, etc. in the inspection areas were delineated in GIS and then compared to the USGS coverage. Comparison of the coverage with the aerial inspection indicated that the database was often underestimating impervious area.

For the draft models, the impervious values found from the USGS database were adjusted higher based on a linear average of the differences between the aerial inspections and the database. However, after simulating both validation storms, the model runoff and subsequent flood depths were consistently high, for both storms and throughout the City. Therefore, the adjustments were removed from the model pre-processing and the USGS database values used directly.

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.

2.5.6 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. 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 that 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:

1. Sub-basin Area – The total sub-basin area calculated in GIS.
2. Representative runoff flow paths – Paths 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:
    - Sub-basin widths – The sub-basin area divided by the area-weighted average length of the runoff flow paths within the sub-basin.
    - 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, up to three 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.

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, up to three representative flow paths were drawn in GIS from the edge of the subbasin to a point on the PSMS. Weighted averaging was used to combine the inlet flow paths to one representative sub-basin flow path, by normalizing over the tributary areas. The upstream and downstream elevation levels are included in each flow path, so weighted average slopes were estimated as well.

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 SWMM, 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
- 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 are presented 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 that 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 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	4.7	0.33	2.2
B	1.0	0.30	7.0
C	0.5	0.25	10.0
D	0.1	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.

2.5.7 Groundwater Data

Groundwater baseflows supply a significant portion of the flows in the SFWMD Canal systems, as much of the flow is generated in western Broward County and flows west to east from the Everglades to the ICW and the Atlantic Ocean. These regional, horizontal baseflows are modeled in Broward County IWRP models as seepage into the county canals.

The City of Hollywood is generally at higher elevations than the surrounding neighborhoods, except in the far eastern portion of the City and in the C-10 and Hollywood Canal floodplains. For the higher elevations, groundwater baseflow should not be significantly affected by regional Everglades to Intracoastal/Ocean flows. For the lower elevation areas, groundwater baseflow into the Intracoastal waterway is not likely to affect peak stages in the adjacent neighborhoods in the Eastern Basin and these flows should be relatively small compared to tidal fluctuations in the waterway.

As part of the model sensitivity analysis, groundwater inflows to the Hollywood Canal and C-10 Canal extracted from the Broward County integrated surface water and groundwater models were analyzed to determine if the base flows were significantly high enough to alter the peak stages during design storms. The sensitivity analysis indicated that adding regional (from outside the city) baseflows would not significantly alter results.

In addition to the regional County-wide groundwater movement, local groundwater interactions also affect the results, as local infiltration in large storm events causes the groundwater table to rise toward the ground surface, potentially impacting the local canal systems and lakes. The Green-Ampt infiltration method that was used to simulate soils infiltration processes provides an input hydrograph to the model's groundwater routines. The groundwater level (water table) 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.

The following local groundwater simulations are included in the model:

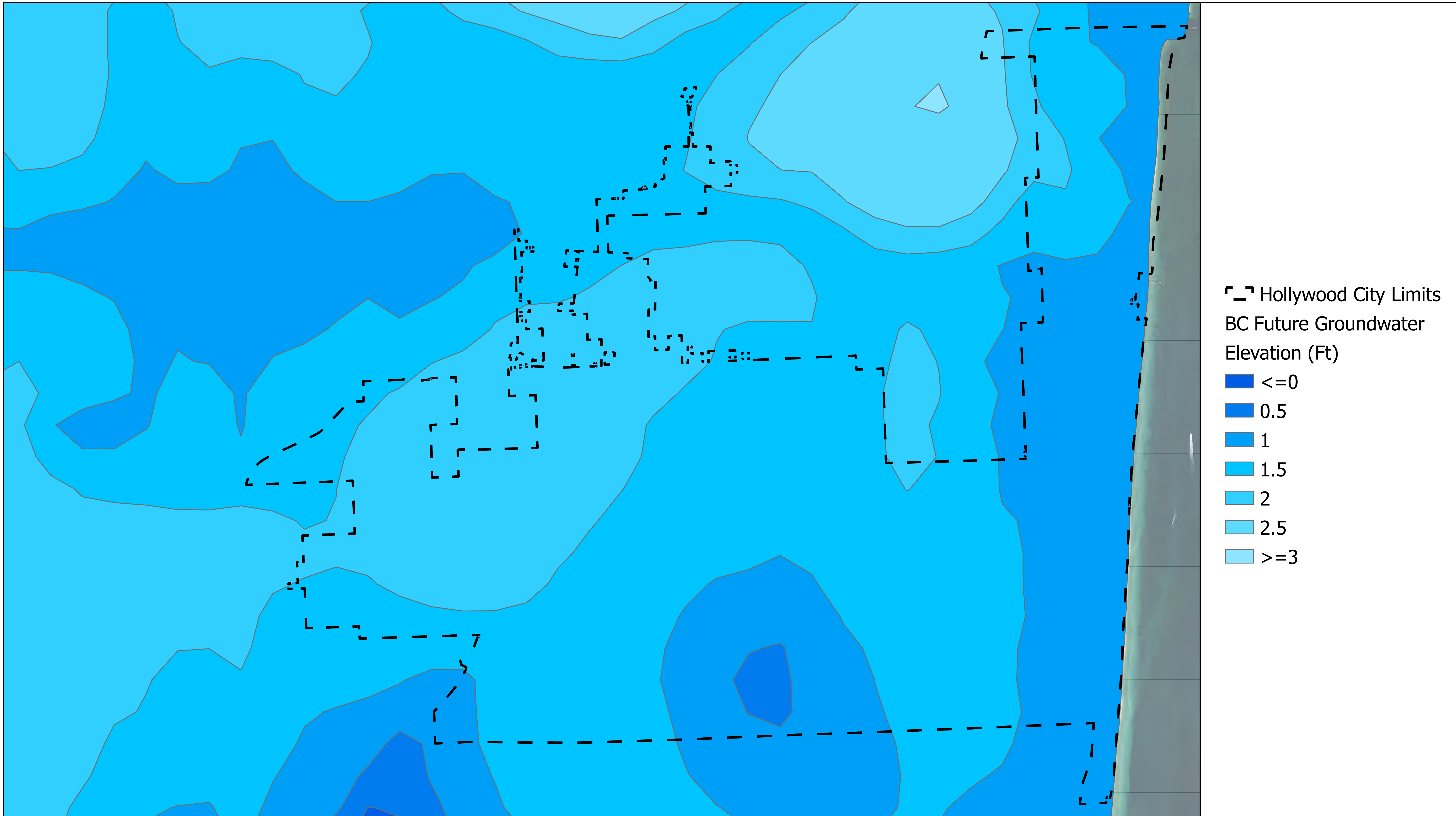
1. In the West Basin Model, sub-basins west of the ridge of higher elevations between the Florida Turnpike and U.S. 441 and south of approximately Taft Street are directed to the SBDD canals along University Drive; the SBDD sub-basins are also directed to the SBDD Canals. This baseflow is especially needed for the Eta Validation Model as baseflows are a significant portion of the total flows for this storm. Groundwater flows from the northern sub-basins are directed to a CBDD outfall.
2. In the Hollywood Canal Basin model, groundwater flows are directed to nodes dispersed along the Hollywood Canal, in an approximate downhill direction from the sub-basin.
3. In the C-10 Basin model, groundwater flows are directed to nodes dispersed along the C-10 Canal, in an approximate downhill direction from the sub-basin.
4. In the C-11 Basin model, groundwater flows are directed to nodes dispersed along the C-11 Canal and the South New River Canal, in an approximate downhill direction from the sub-basin.
5. In the East Watershed model, groundwater flows are directed to the ICW and do not significantly affect outfall flows. However, where sandy (Type "A") soils are located near the Intracoastal, and the depth to groundwater is very shallow, the groundwater routines raise the water table to the surface in the model and cut off infiltration.

For all but the East Watershed model, sub-basins with large waterbodies have groundwater flows directed to the sub-basin itself (i.e., the groundwater outflow is combined with the sub-basin runoff). The sub-basins surrounding the large waterbodies are often also directed to the water body node, unless one of the canals is also nearby and a more likely receiving body. The Eastern and Beach Basin Models do not have the local groundwater routines simulated, since the receiving waterbodies would be the ICW and/or the Atlantic Ocean and therefore groundwater flows do not affect design storm simulation results.

The SWMM groundwater parameters were developed using engineering judgement and previous experience with models in Broward 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 routines in SWMM were also used to estimate the receiving body stages for the exfiltration systems (described in Section 2.5.9). Exfiltration systems, including gravity recharge wells, remove floodwaters at rates that are a function of the driving head. The driving head is generally the depth from the inlet grate, or flood elevation in the storms causes flooding above the grate, to the aquifer elevation. In South Florida, as the groundwater elevations rise rapidly in response to large storm events, the inflow rates taper off as the driving head drops. For exfiltration systems built at relatively low elevations, the driving head may effectively be shut off early in the storm and the exfiltration systems may not work at all. This is simulated in the SWMP watershed models with virtual aquifer nodes representing groundwater response to rainfall, similar to the local groundwater response discussed above. The difference is in this case, the large virtual sub-basins are used to mimic a more regional groundwater response. The runoff from these virtual sub-basins is discarded from the models to not double count any areas, while the baseflow is directed to a node representing the underlying aquifer. Elevations rise in the aquifer due to the baseflow and fall based on a rating curve that has been developed based on experience with the Biscayne aquifer recedence rates.

Since the elevation of the groundwater table at the start of the simulation is important to the driving head, spatial variations in the wet season water table elevation are used in the SWMP. Broward County published a map of wet season water table elevations from 2000 that shows the entire City of Hollywood within the 0.5 ft-NAVD contour (as approximate and converted from NGVD). Broward County also created future expected wet season groundwater elevations for use in all stormwater design projects shown on **Figure 2-11.** For validation simulations, an average of the year 2000 elevations (0.5 ft-NAVD) and the future wet season elevations were used for the exfiltration modeling of the 2019 and 2020 storms. For existing conditions, the future wet season water table elevations calculated from the data provided from Broward County was used (See Figure 2-11), in accordance with Broward County policy. For reference, existing (Year 2000) GWELs published by Broward County is provided in **Appendix C**.



Groundwater Elevation

City of Hollywood Stormwater Master Plan
Figure 2-11
11/8/2021

SUSINOBM D:\Hollywood SWMP\Hollywood Model Development TM Figures\Hollywood Model Development TM Figures.aprx 4/12/2022

2.6 Hydraulic Data and Parameters

The H&H model uses a node/link (junction/conduit) representation of the PSMS. Model node types include junctions, storages, and outfalls. Model link types include - conduits (pipes and open channels), weirs, orifices, pumps, and outlets (rating curves).

For this study, the PSMS conduits were primarily circular pipes greater than 24 inches in diameter. In some cases, smaller pipes down to 8 inches in diameter or less were necessarily included as follows:

1. In locations that are topographically isolated, where the smaller pipe is all that drains the area
2. 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
3. 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
- 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)
- The confluence of streams or ditches represented as open channels

2.6.1 Model Nodes

Junction Nodes

Junctions are not used in the SWMP, as storages with relatively small, constant storage values are more stable in large models. In SWMM, “Junctions” are provided area from connecting links in the mass balance equation. However, when the HGL at a manhole increases above the crowns of the connecting pipes, the lack of additional area in the Junction may cause a spike that would allow the maximum numerical HGL to be higher than what would be expected.

Storage Nodes

The parameters defining model storage nodes are invert elevation, rim elevation, initial depth, and the storage type: "FUNCTIONAL" for constant or "TABULAR" for a stage-storage area curve in the node. Nodes in the hydraulic system where runoff is loaded are provided the 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. Model node rim elevations were set 10 feet above ground elevation, so as 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.

Stage Area Relationships

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 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 that was obtained from the latest available data using Microsoft Bing© Maps Florida Statewide 2018. 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 near 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; however, for some lakes, the stage-area below the LiDAR level was estimated in the model. 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 "TP_AGE999635@-10" for storage node "TP_AGE999635," 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.

Nodes with Functional 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 Intercoastal Waterway, to account for the out-of-channel storage in marinas, for instance. Small amounts of constant storage are added at manholes for computational stability. As opposed to using the junction node described above, numerical instabilities may be mitigated by using a functional storage node with a small amount of constant storage applied up to the rim elevation. The value 12.56 square feet is used for this purpose, which is what would be expected in a 4-ft diameter manhole.

2.6.2 Outfalls

Outfall nodes are used to provide boundary conditions to the model. Based on project specific survey, as-builts, and the GIS coverage of stormwater pipes provided by the City, stormwater PSMS points of final discharge from the system were identified and simulated as outfalls that discharge to ICW or other water bodies. In SWMM, an outfall node may only attach to a single link in the model, whether a pipe link or an overflow link. Therefore, some outfall locations have adjacent pipe outfalls and overland flow link outfalls. Note that some model nodes have use Inflow Time Series as boundary conditions as opposed to using an outfall node.

Model outfalls are provided at the following locations:

ICW Outfalls (Eastern, Beach, C-10, C-11, and Hollywood Canal Basins)

- ICW at Port Everglades and at Hallandale Beach Boulevard were classified as outfalls and use a fixed boundary condition for tides, design storms, and time series boundary conditions for the validation events. The data for Port Everglades stages was extracted from the National Oceanic and Atmospheric Administration (NOAA) for the South Port Everglades Station (https://tidesandcurrents.noaa.gov/stationhome.html?id=8722956#available).

West Basin Model Outfalls

- Florida Turnpike and Pembroke Road both turnpike side ditches – Fixed stage boundary conditions are used in both ditches since further data is unavailable. City ground elevations near the outfall are significantly higher than likely ditch stages; therefore, the boundary condition should not significantly alter results.

- Intersection of the SBDD Canal adjacent to University Drive and Riviera Boulevard (SBDD S-1 Pump Station) – For design storms and all validation simulations other than Hurricane Eta, the S-1 PS operations (rates and trigger elevations) are used as the boundary condition. Though there is also a gated structure at this location, the gate is set closed when the tailwater in the C-9 Canal is above the reference elevation. For design storms, the 1-year stillwater used as the ICW fixed stage boundary is higher than this reference stage, thus we should expect the gate to remain closed throughout the simulation. For Eta, the S-1 PS headwater data has been provided by SBDD and used as a time series BC.

- Intersection of University Drive and Sheridan Street outfall of the double barrel 6-ft diameter culvert under the intersection to the CBDD conveyance ditch – A time series has been extracted from the CBDD's ICPR stormwater model for each design storm simulation and applied at this location.

- Three locations north of Stirling Road (SW 67th Ave, SW 58th Ave, and adjacent to the Florida Turnpike) – these outfalls represent locations where the Stirling Road FDOT pipes outfall to CBDD conveyance ditches. Stages in the Stirling Road FDOT system may have a minor impact on City flood elevations in the northwest corner of the City. A time series has been extracted from the CBDD's ICPR stormwater model for each design storm simulation and applied at these locations.

C-11 Basin Model Outfalls

- Intersection of U.S. 441 and the C-11 Canal FDOT outfall to the upstream side of the SFWMD S-13 Structure – for the validation storms, the observed headwater elevation data is input as a time series boundary condition. For design storms, a time series has been extracted from the CBDD's ICPR stormwater model for simulation and applied at this location.

- South New River Canal at State Road 84 and the north end of the culvert under State Road 84, immediately east of the South New River Canal – time series boundary conditions have been developed at this location (at the confluence of the South New River Canal and the South Fork of the New River) for both design storms and the validation storm using a regional version of SWMM, built by CDM Smith for the City of Fort Lauderdale stormwater master plan in 2008.

Free Outfalls

Additionally, there are multiple locations of "Free" outfalls where excess flooding may sheet flow out of the model through overland flow links. Because of 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. It is not expected that higher boundary conditions (either fixed or time series) are needed at these locations, because the model boundaries have already been extended outside the City at locations where such boundaries would cause significant issues within the City.

2.6.3 Model Links

Model link types include conduits, weirs, orifices, pumps, and outlets (rating curves). Model conduits may be separated into closed conduits: pipes, culverts, and force mains; and open conduits: generally irregular channels, but also triangular, trapezoidal, and open rectangular channels. Pipes and culverts may be modeled with a large number of shapes, including a custom conduit, but are primarily circular.

Conduits - Pipes, Culverts, and Force Mains

The 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 National Geodetic Vertical Datum of 1929 (NGVD) and 1988 NAVD. Elevation adjustments were applied to the GIS pipe inverts, so that they were all expressed in the NAVD datum. The adjustment factor from NGVD to NAVD varies slightly 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. The National Oceanographic Atmospheric Association (NOAA) provides a vertical datum conversion tool known as VDATUM at: https://vdatum.noaa.gov/.

Where data gaps were present and necessary for model connectivity, survey crews were dispatched to inspect the pipes and manholes and record estimated geometry and connectivity to provide the necessary size data for the stormwater pipes and structures that define 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.

System maintenance is a high-priority, critical service to keep the City's stormwater system functioning as designed, with consequences being potential wide-spread flooding. Under the purview of the City of Hollywood's Public Utilities, the stormwater system operations and maintenance staff's assigned duties are to receive and process complaints and perform regular 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. Sensitivity analyses were specifically performed for percent siltation and as expected, the system is highly sensitive to clogging, exacerbating flooding upstream, due to the flat hydraulic grade of the City's system. It is important to note, the model parameters were adjusted to match existing conditions flooding for the validation storm models that inherently included any pipe clogging; however, the existing conditions design storm LOS and future CIP models will necessarily assume a clean, well-maintained system, so that the system hydraulic sizing is accurately depicted and selected. Accordingly, for the purposes of model development, pipe roughness values in the model are estimated for a clean, well-maintained system.

Accordingly, 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. Hydraulic losses were developed as follows:

- Exit loss k values were set to 0.2 for inlets and manholes
- 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;
- Minor losses for fittings, 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 2.8 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 near between 2 and 3 over the range of flows and velocities expected for this system.
- Force mains in the models were assigned a Hazen-Williams C-factor of 130.

Conduits – 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 Hollywood most of the historic floodplains are typically separated from the canals with seawalls, which are to be raised in future scenarios per recent resiliency ordinance. Therefore, City sub-basins along canals and the ICW are modeled with sub-basin delineation boundaries along the seawalls, or where a potential seawall will be built.

Often 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 the detail required using 2-D and 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, essentially simulating the same 2D information but in a more efficient manner. The cross-section of the overland flow link represents the top of the seawall, generally for the length of the adjacent model sub-basin.

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 that 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 0.02 to 0.1 based on vegetation and engineering judgment. The center channel roughness for the major canal links (the Dania Cutoff Canal, the Hollywood Canal, and the C-10 Canal) are set to 0.33, based on the Broward County Model. Roughness in the overbanks ranged from 0.015 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 set high enough to convey the largest flows to be modeled, or else the transect area is cut off (limited by the highest elevation in the cross-section). Generally, this requires extracting the transects wide enough to reach higher elevations. For canals with seawalls, the banks are artificially raised high enough to contain the highest possible HGL to not limit 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.

Swale transects were extracted from the LiDAR DEM. Typically, swales represent dry conveyances pre-storm, i.e., they should have no standing water in an aerial photo. The LiDAR DEM is generally a good representation of the swale; however, in some cases the bottom of the swale is obscured by vegetation and the must therefore be estimated. Ditch transects typically are slightly deeper than swales, and may have standing water pre-storm, which reflects LIDAR and does not allow for the bottom to be extracted from the DEM. A combination of survey, field visits, culvert invert data and engineering judgement is used to estimate the ditch center channels. The bank data is extracted from the LiDAR DEM.

The canal (channel) transects were extracted from the Broward County, SBDD, and CBDD models, and corrected by field survey sampling, where appropriate. Where necessary, bank data was extracted from the LiDAR DEM. For North and South Lakes, bathymetric data was provided by the City from a parallel study and used to develop channel cross-sections from the western ends of the lakes to the ICW. For the ICW, bathymetric data was extracted from NOAA (NOAA Maps ICW 11467 WPB to MIA).

Conduits – Overland Flow Links

For the Hollywood Basin models, depth of flooding and movement of flood waters is controlled by two methods:

- Depth-storage area curves in the storage nodes, 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 (simulating a 2D model). 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, an overland flow link, with a cross-section representative of the street or other defined boundary between the sub-basins, is used. The length of these channels is typically short (~20 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.

Conduits – 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, parking lot entrances, 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. 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
7. Small Road "W" Half: half the above section, for when the overflow includes only one side of the road crown
8. Wide Road "W": Characteristic of a typical major road section (U.S. 1, Hollywood Blvd, Sterling Rd, etc.) – multiple road transects were extracted from LiDAR and averaged to produce the section; and
9. Wide Road "W" Half: half the above section, for when the overflow includes only one side of the road crown

Conduits – Bridges (Custom Conduits)

Bridges are modeled similarly to a short section of channel if flow under the bridge cannot become pressurized because the lower chord of the bridge deck is above the likely peak flood level in the canal. 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 to the model. This option allows for an irregular shaped closed conduit, which can 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. Generally, the cross-sectional area of bridge piles is removed from the channel cross-section to estimates the area of conveyance under the bridge.

2.6.4 Stormwater Control Structures

The Regional primary drainage system for South Florida consists of the large drainage canals and associated features that are managed by the South Florida Water Management District (SFWMD) and United States Army Corps of Engineers (USACE). SFWMD is a regional governmental agency that manages the water resources in the southern half of the state, covering 16 counties from Orlando to the Florida Keys and serving a population of approximately 9 million residents. It is the oldest and largest of the state's five water management districts, created in 1949. The agency is responsible for managing and protecting water resources of South Florida by balancing and improving flood control, water supply, water quality and natural systems. This primary system of canals and natural waterways connects to municipal and community drainage districts and hundreds of smaller neighborhood systems to manage floodwaters during heavy rain events. These 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.

SFWMD's regional structures are large-scale hydraulic works (i.e., spillways, culverts, weirs, gates, and pump stations) located in the main drainage canals to control water surface elevation or flow and are generally incorporated as the boundary conditions in the Citywide 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 to support natural ecosystems, and in the case of the coastal canals, to control saltwater intrusion.

Secondary systems operate under permits issued by SFWMD that restrict the flow volume and discharge to their regional systems—these include the SBDD, CBWCD for this model.

Tertiary systems consist of local 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 SFWMD or locally, by a Surface Water Discharge License issued by Broward County.

In SWMM, control structures are modeled as link elements, even though the upstream and downstream sides of the structure may be co-located or very close in space. In the GUI, these sides are often artificially separated so the structure link may be seen in the schematic. This SWMP includes the following control structure link types: pumps, weirs, orifices, and outlets (rating curves). For the SWMP model development, CDM Smith reviewed and incorporated stormwater structure related information provided by the County, the two Drainage Districts, and SFWMD for inclusion within the models.

Stormwater Pump Stations (SWPSs)

SWPSs are located as indicated on the model schematic.

City SWPSs – The City provided data for the 10 City-owned pump stations and the 4 temporary portable pumps used in emergency flood conditions. The available data generally included the pump station design capacities and design on/off set point elevations. The SWPS sites were visited and inspected and the plan sets were reviewed for the pump stations to determine current operational and maintenance modifications, and weir levels and bypasses where appropriate. Pump station design capacities as provided are sufficient for the input data for the master plan modeling as the flow rates are not expected to vary much over the heads expected in the design storm models.

SFWMD Pump Station – There is one SFWMD Pump Station included in the Citywide models. This Station parallel to the S-13 Gated Structure on the C-11 Canal. The capacity of this pump station is approximately 580 cubic feet of water per second (cfs). The SFWMD Structure Booklet indicates there are 3 pumps at 180 cfs, i.e. 540 cfs, though the observed recorded data flows are consistently 580 cfs. The S-13 pump station is designed to be used by SFWMD when tailwaters are high and the S-13 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 is included for validation simulations, using data from the DBHYDRO database. For design storm simulations, since this location is at the boundary of the C-11 Basin Model, inflows were extracted from the CBDD model, therefore, this station was not explicitly modeled.

Broward Drainage District SWPSs – There is one SBDD Pump Station included in the Citywide models located near the intersection of University Drive and Riviera Boulevard in the SBDD Canal adjacent and parallel to University Drive. The capacity of this pump station is approximately 425 cfs and is designed to be used by SBDD when tailwaters are high in the C-9 Canal. The bleed down pump is 87 cfs and is turned on when upstream stages reach 3 ft NGVD (approximately 1.45 ft-NAVD). The remaining two pumps are turned on when stages reach 3.2 and 3.3 ft NGVD (1.65 and 1.75 ft-NAVD), respectfully. In practice, the SBDD gate is expected to be closed in the design storm simulations because the one-year stillwater used for the boundary condition is higher than the operational trigger of the gate (2.5 ft NGVD, 0.95 NAVD). Observed data for this station is included for the Hurricane Eta validation (data provided by SBDD).

FDOT SWPS – There are two FDOT SWPS in the model. The first is located in the west right of way of I-95 just south of Pembroke Road that brings flow into the City's system. The station takes suction from Chaves Lake that is used partially for FDOT drainage. The station capacity was shown in FDOT records as approximately 120 cfs discharging into a lined ditch along I-95, flowing northward to a structure just south of Hollywood Blvd, and discharging in the canal just downstream of the City's SWPS No. SW04, and ultimately through the City to the Dania Cutoff Canal. A second FDOT SWPS is part of the same system and is located farther west at Lake Trinity (Beehan Lake), with a station capacity of 40 cfs, manifolding into the other SWPS discharge.

Gated Structures

There is one gated control structure in the Basin models; namely, the CS-22 Structure at the intersection of N 46th Avenue and the C-10 Canal (immediately south of Casper Court). The structure is currently owned and maintained by Broward County and has not been opened or operated since 2012 and is therefore closed in the existing condition models. The County has offered relinquishing this gate to the City for ownership and operation if needed.

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 detention ponds in Oakwood Plaza, or Corporate Park in Alandco. Weirs are also used to limit flows, such as the two-level weir in Broward County limiting flow from the 6-ft outfall culvert across SW 42nd St to the Dania Cutoff Canal. 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 and low flow openings in weir structures. Additionally, the many weep holes in the I-95 sound wall are models as orifices. Orifice data includes, but is not limited to, shape, dimensions (length and width for rectangular orifices, diameter for circular), invert elevation, and discharge coefficient.

Outlets – Exfiltration Systems and Aquifer Recharge Wells

In SWMM, outlets are used to route flow from one model node to another using rating curves, i.e. tables of flow versus head difference (between the nodes). For this SWMP, outlets are used to model the City's exfiltration systems. The City of Hollywood uses multiple 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:

- 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 3–5 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 solid connection pipes, though usually they are not designed to move water far. Exfiltration design is well defined by SFWMD and local as further described below.

- Aquifer Recharge (Drainage) Wells: There are two types of drainage aquifer recharge wells used in the South Florida, 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 only permitted and 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 Hollywood are east of I-95, while those farther to the west have casing opening that are deeper, to a depth where the aquifer is greater 10,000 mg/L TDS.

1. 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. 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.

2. Injection wells work at any elevation because the pump station provides the driving head. There are no injection wells in the City of Hollywood GIS, though they are likely to be added as part of the FDOT mitigation along the beach and will be part of the alternative mitigation solutions for flooding in this SWMP. Injection wells are regulated by FDEP and require specific restrictions be met regarding location near water supply wells or known contamination plumes, and the minimum TDS of the receiving groundwater (>10,000 TDS).

The SFWMD Environmental Resources Permit (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 Hollywood has a large amount of exfiltration trench designed in this manner. To represent the exfiltration systems 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 in the records, the permit default sizes were implemented.

The K_{sat} was determined for each model sub-basin using the permeability surface developed for this project described previously (Figure 2-4). 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 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 South Florida. 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, a SWMM 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 the simulated 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 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 low-lying areas may eventually rise to 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 typically 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.

2.6.5 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 Hollywood 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 (Geom2): 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 that 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.

2.7 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 at the boundaries and can adopt fixed-stage boundaries or time series boundaries as necessary. Boundary Conditions may also include User Defined Inflow, as either a constant flow value or a time series, which may be applied to any model junction or storage node.

2.7.1 Design Storms: Primary Outfall Boundary Condition

At the time of this analysis, no comprehensive rainfall-tide correlated stage recurrence analysis has been performed for the City of Hollywood. 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 NOAA Virginia Key Gage with a continuous 27-year record, and the SFWMD S-40 Control Structure, Tailwater Gage with a continuous 36-year record. The data were compared to the NOAA Port Everglades gage used for the validation storms (see below); however, the Port Everglades Gage is limited to a 3.7-year record. The S-40 Structure (in Boca Raton) is more than 20 miles north of Port Everglades in the ICW, while the Virginia Key gage is over 25 miles to the south, on Bear Cut adjacent to the Atlantic Ocean. There are closer SFWMD salinity barrier structures to the project, but they are located inland along the canals and may not accurately reflect the tailwater in the ICW. The Virginia Key Gage provides a 1-year recurrence elevation of about 1.6 ft-NAVD, while the S-40 gage provides a value of about 2.5 ft-NAVD. However, over the last decade, the gages produce 1-year recurrence elevations of 1.9 ft-NAVD and 2.7 ft-NAVD, respectively. The weighted average of this data at Port Everglades suggests a 1-year recurrence of about 2.3 ft-NAVD. Inspection of the Port Everglades Gage indicates that there have been 11 days of high tides 2.3 ft or greater in the 3.7-year record of the Port Everglades Gage, over 5 different King Tide cycles. The 1-year recurrence for the Port Everglades data is 2.5 ft-NAVD, which is between the last-decade 1-year recurrences for the nearest coastal gages, but more conservative than the average of the gages. Therefore, the value of 2.5 ft-NAVD is used as the 1-year stillwater for this SWMP.

For resiliency planning purposes, model simulations will also include scenarios representing at least 1.5 feet and 2.5 feet of Sea Level Rise. These increments are directly added to the 1-year stillwater fixed stage. The historical observed data versus recurrence intervals are plotted on **Figures 2-12 and 2-13** for the Virginia Key Gage and the S-40 Structure, respectively.

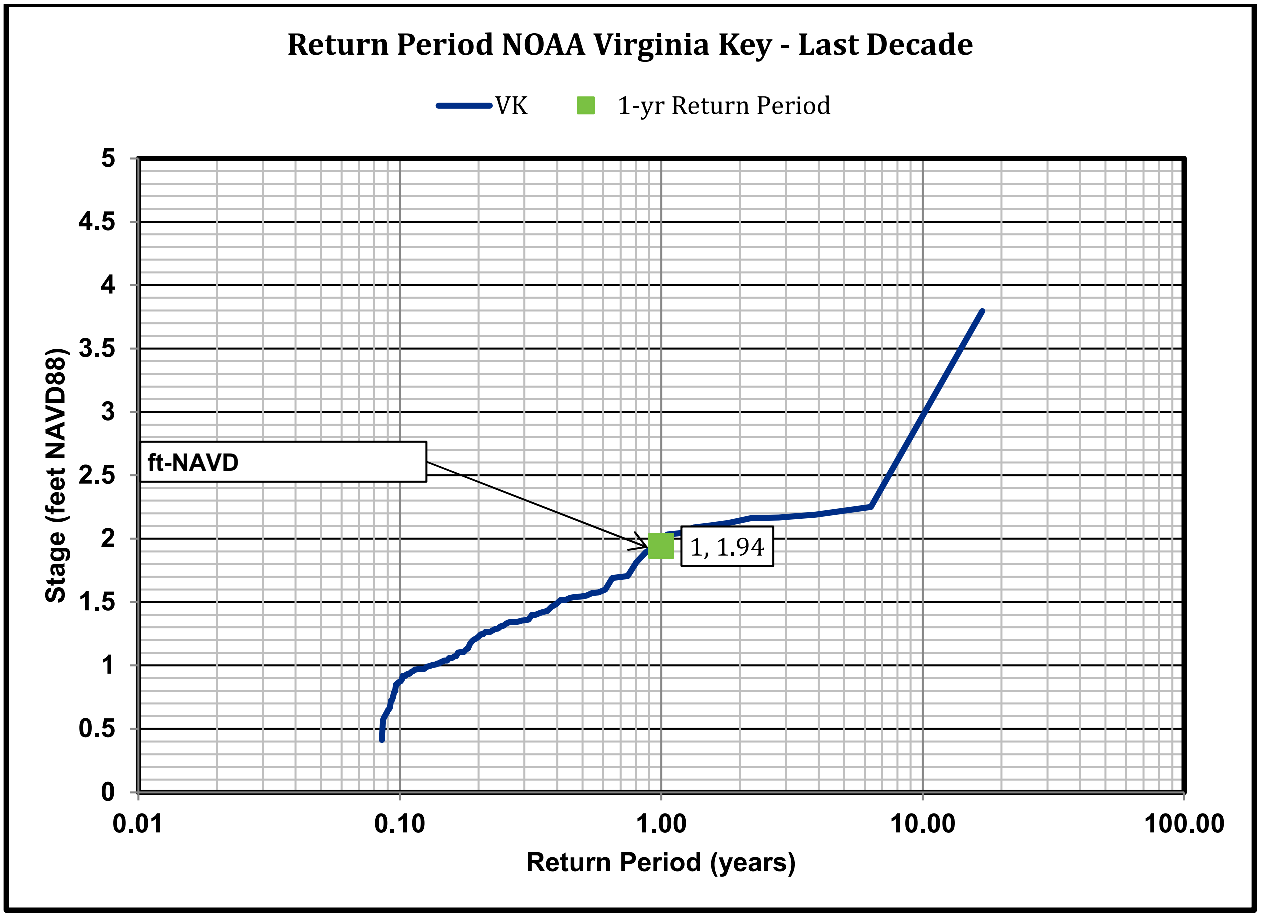


Figure 2-12
Return Period for NOAA Virginia Key Gage

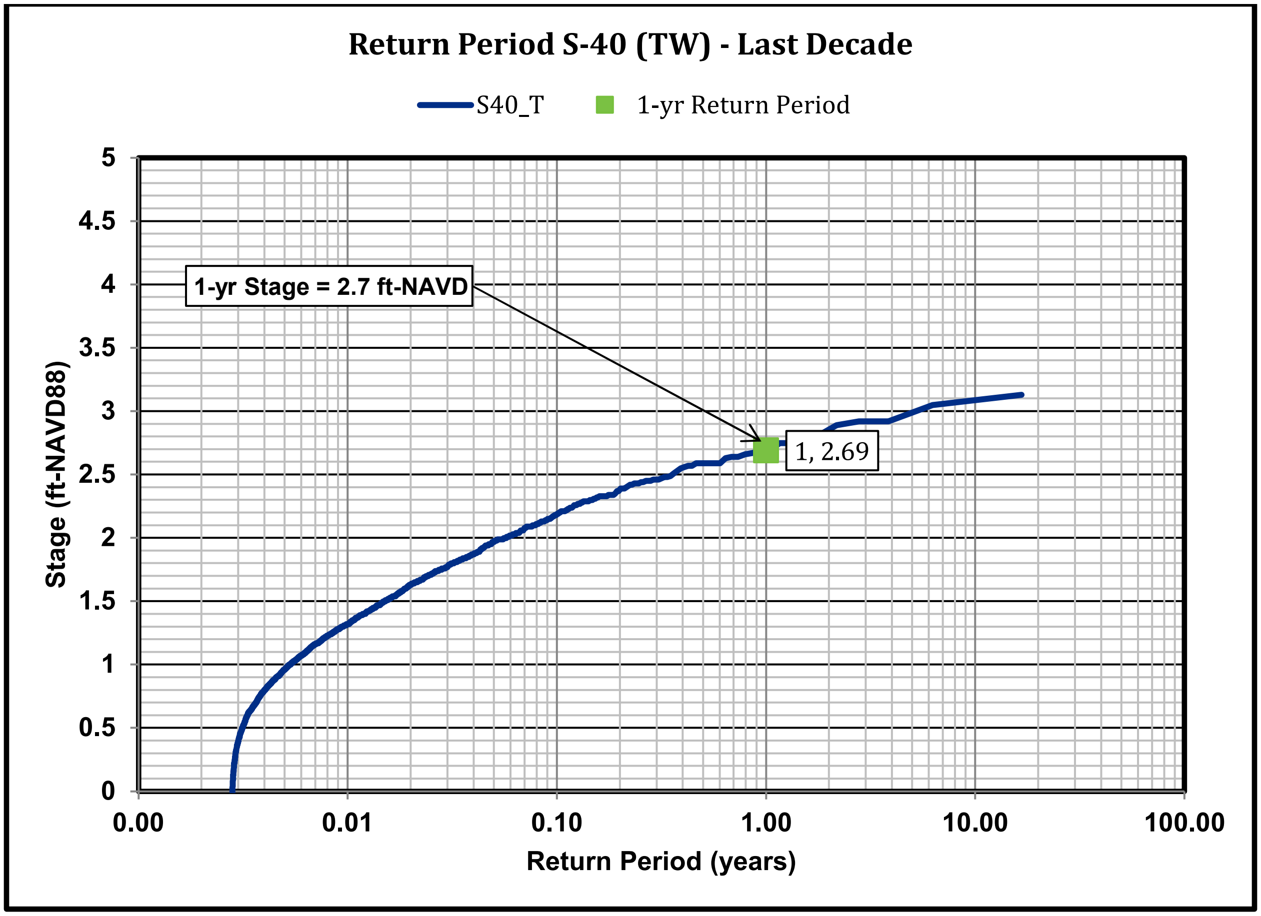


Figure 2-13
Return Period for SFWMD S-40 Tailwater

2.7.2 Design Storms: Additional Boundary Conditions

Individual Basin Models have boundary conditions set at major interflow locations along the individual model boundaries, such as at the confluence of the C-10 Canal and the Hollywood Canal. There are, however, several major interflow locations between the modeled City of Hollywood Watershed including adjacent Broward County neighborhoods that have been added to the model and the non-modeled areas west, north, and south of the watershed. For design storms, these boundary conditions are represented by both fixed stages at outfalls, time series at outfalls, and "User Inflow Time Series" at model storages.

West Basin

- At the Florida Turnpike and Pembroke Road both turnpike side ditches: Fixed stage boundary conditions at the same elevation as the Primary Outfall Boundary Condition (2.5 ft-NAVD). As discussed in Section 2.5.1.3, boundary stages in these ditches are unlikely to affect neighboring flood elevations.

- At the intersection of the SBDD Canal adjacent to University Drive and Riviera Boulevard (the SBDD S-1 Pump Station): the S-1 PS operations (See Section 2.5.3.1) are used as the boundary condition. Though there is also a gated structure at this location, the gate is set closed when the tailwater in the C-9 Canal is above the reference elevation. For design storms, the C-9 Canal stage should be as high or higher than the Primary Outfall Boundary Condition, thus it is expected the gate remains closed throughout the simulation.

- At the intersection of University Drive and Sheridan Street: the outfall of the double barrel 6-ft diameter culvert under the intersection to a CBDD ditch. A stage time series has been extracted from the CBDD ICPR model for each design storm simulation and applied at this outfall.

- At three locations north of Stirling Road (SW 67th Ave, SW 58th Ave, and adjacent to the Florida Turnpike): these outfalls represent locations where the Stirling Road FDOT pipes outfall to CBDD ditches. Stages in the Stirling Road FDOT system may have a minor impact on City flood elevations in the northwest corner of the City. Stage time series have been extracted from the CBDD ICPR model for each design storm simulation and applied at these outfalls.

C-11 Basin

- At the intersection of U.S. 441 and the C-11 Canal at the SFWMD S-13 Control Structure: The S-13 is a gated salinity structure with a parallel pump station used when tailwaters in the Dania Cutoff Canal are higher than headwater stages in the C-11 Canal. A flow time series has been extracted from the CBDD ICPR model for each design storm and applied as a User Supplied Inflow to a storage node at this location.

- Immediately upstream of the intersection of U.S. 441 and the C-11 Canal: a relatively small FDOT outfall to the upstream side of the SFWMD S-13 Structure. A stage time series has been extracted from the CBDD ICPR model and applied at this outfall.

- Along the South New River Canal at State Road 84 and at the north end of the culvert under State Road 84, immediately east of the South New River Canal: stage time series boundary conditions have been developed at this location (at the confluence of the South New River Canal and the South Fork of the New River) for each design storm using a regional version of SWMM, built by CDM Smith for the City of Fort Lauderdale in 2008.

Hollywood Canal Basin

- At the intersection of Griffin Road and the Dania Cutoff Canal: flow time series have been developed at this location to represent outfall flows from Fort Lauderdale-Hollywood International Airport. A previous version of the Broward County Aviation Department (BCAD) SWMM simulation of the airport was used to develop outfall hydrographs. Though this version of the model was last revised in 2006, the peak flows match the permitted outfall flows for the airport. Further development of the airport since 2006 is mitigated prior to the Dania Cutoff Canal outfalls by internal BMPs and weir structures. The three airport outfall time series have been combined and loaded as a User Supplied Inflow at this location. Minor variances in the shape of the outfall hydrographs are not likely to significantly influence flood stages in the City of Hollywood. Simulations of the Dania Cutoff Canal with and without these inflows indicate an increase in tailwater stage for the Hollywood Canal of over 0.1 ft.

- The ICW at Hallandale Beach Boulevard is treated as a "no-flow" boundary so that the ICW is represented to the south. It is therefore expected that the ICW flows north to Port Everglades north of this bridge, and south to Haulover Cut south of the bridge. It is beyond the scope of this project to provide detailed estimates of flows in the ICW to the Haulover inlet.

There are also multiple overland flow links across the model boundary allowing flow out of the modeled area to outfalls where the boundary condition has been set to "free." As noted above, areas adjacent to the City boundary where outside flooding likely affects flood stages in Hollywood have been included in the model.

2.7.3 Validation Storms: Primary Outfall Boundary Conditions

The observed stage data at Port Everglades in the ICW was extracted from the NOAA South Port Everglades Station for both the December 2019 Storm and Hurricane Eta (https://tidesandcurrents.noaa.gov/stationhome.html?id=8722956#available). This boundary condition is used in both ends of the model in the ICW, as there is no gage data in the south.

Figure 2-14 shows the time series at this location for the December 2019 storm. The peak is approximately 1.5 ft-NAVD on December 23rd, near the peak of the rainfall event**. Figure 2-15** shows the time series at this location for Hurricane Eta. The peak stage is approximately 2.1 ft-NAVD on November 9th. Note that 2.1 ft-NAVD is higher than some of the seawall heights in the North and South Lakes region of the City.

In locations where the PSMS is below the peak 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 performed outside the model using spreadsheets.

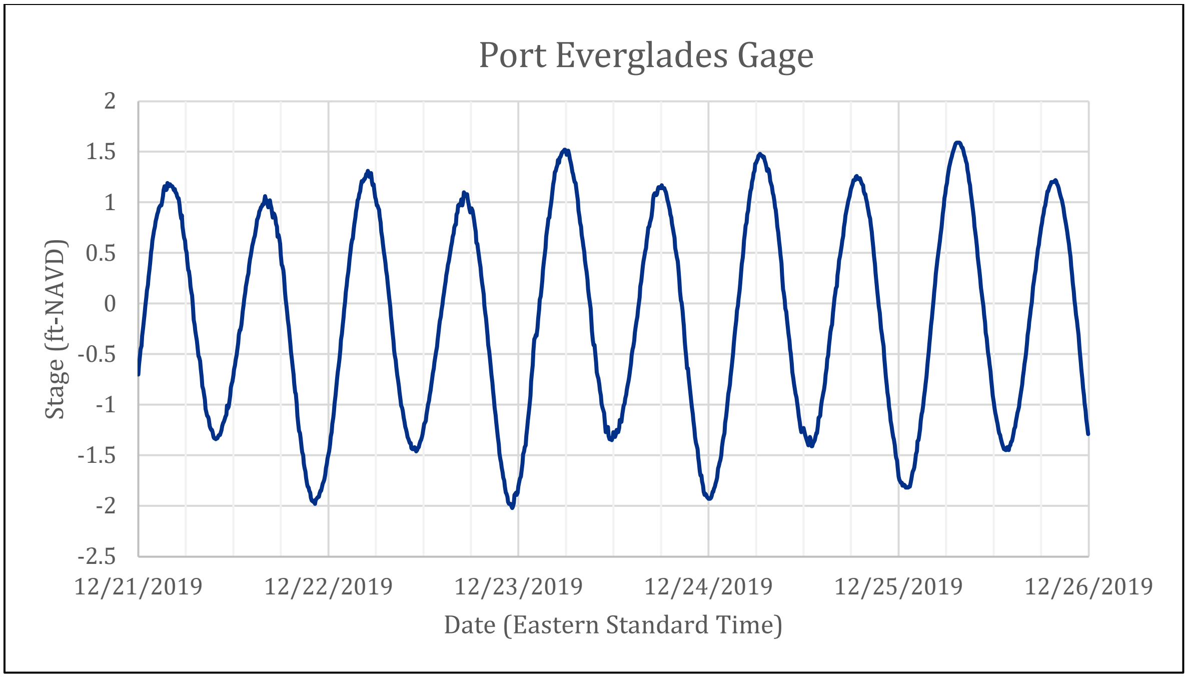


Figure 2-14
December 2019 Intracoastal Waterway Boundary Condition

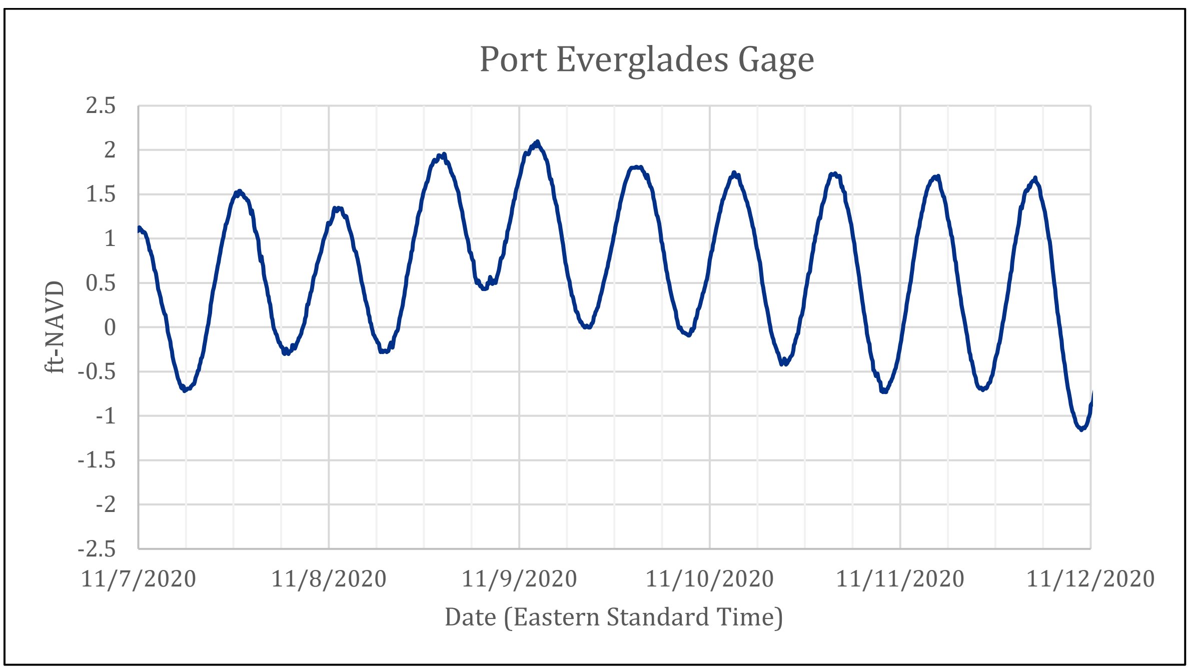


Figure 2-15
Hurricane Eta Intracoastal Waterway Boundary Condition

2.7.4 Validation Storms: Other Boundary Conditions

For the validation storms, many of the other boundary condition locations noted in Section 2.6.2 have no observed data and are therefore represented by the same fixed stages as in the design storms.

West Basin

- At the Florida Turnpike and Pembroke Road – both turnpike side ditches: No further data – fixed stage boundary conditions at the same elevation as the Primary Outfall Boundary Condition (2.5 ft-NAVD).
- At the intersection of the SBDD Canal adjacent to University Drive and Riviera Boulevard (the SBDD S-1 Pump Station): the SBDD provided headwater stage data for the time period covering Hurricane Eta, and the preceding 30 days, which was extremely wet. No data was provided outside of this time period, including non for the December 2019 Storm. The December 2019 validation storm was provided the S-1 Pump operations, similar to the design storm simulations.
- At the intersection of University Drive and Sheridan Street: the outfall of the double barrel 6-ft diameter culvert under the intersection to a CBDD ditch. The CBDD provided two observed stages: one at the peak of Hurricane Eta flooding, and one during the intense rainfall in the prior month (October 25, 2020). Both data points were approximately one foot above the peak stages in the SFWMD S-13 Structure observed headwater data (downstream of this location). Therefore, the S-13 Headwater Stage + 1.0 ft was used as a time series at this location. Note, the stages are likely high at off-peak times, though this is unlikely to affect flood stages in the City of Hollywood. The CBDD provided no data for the December 2019 Storm. However, rainfall was considerably less in the western portion of the city for this storm, as noted in Figure 2-12. Peak stages in the observed S-13 headwater were below typical wet season groundwater elevations (i.e., being controlled by the structure). Therefore, a fixed stage of 2 ft-NAVD was used at this location.
- Three locations north of Stirling Road (SW 67th Ave, SW 58th Ave, and adjacent to the Florida Turnpike): these outfalls have no additional data and therefore were provided the same boundary conditions as the other CBDD outfall discussed above.

C-11 Basin

- At the intersection of U.S. 441 and the C-11 Canal – the SFWMD S-13 Control Structure: The observed S-13 flows are used for all validation storms. Flow data for both the pump station and gate structure were extracted from DBHYDRO and combined as User Supplied Inflow time series at this location.

- Immediately upstream of the intersection of U.S. 441 and the C-11 Canal: The observed S-13 headwater stages are used for all validation storms at this location. Headwater stage data was extracted from DBHYDRO, converted to NAVD and input as an outfall time series boundary condition.

- Along the South New River Canal at State Road 84 and at the north end of the culvert under State Road 84, immediately east of the South New River Canal: stage time series boundary conditions have been developed at this location (at the confluence of the South New River Canal and the South Fork of the New River) for each validation storm using a regional version of SWMM, built by CDM Smith for the City of Fort Lauderdale in 2008.

Hollywood Canal Basin

- At the intersection of Griffin Road and the Dania Cutoff Canal: no data available for the validation storms. For the December 2013 storm, the 5-year, 24-hour design storm FLL Outfall hydrograph shape was used, adjusted in time to match the peak of the December 2019 Storm flows in neighboring modeled areas. For Hurricane Eta, the 10-year, 72-hour design storm FLL Outfall hydrograph shape was used, adjusted in time to match the peak of the Eta Storm flows in neighboring modeled areas. As noted in Section 2.6.2: though flows from the airport should not be neglected, it would require significantly higher outfall flows to impact the peak stages in the City of Hollywood.

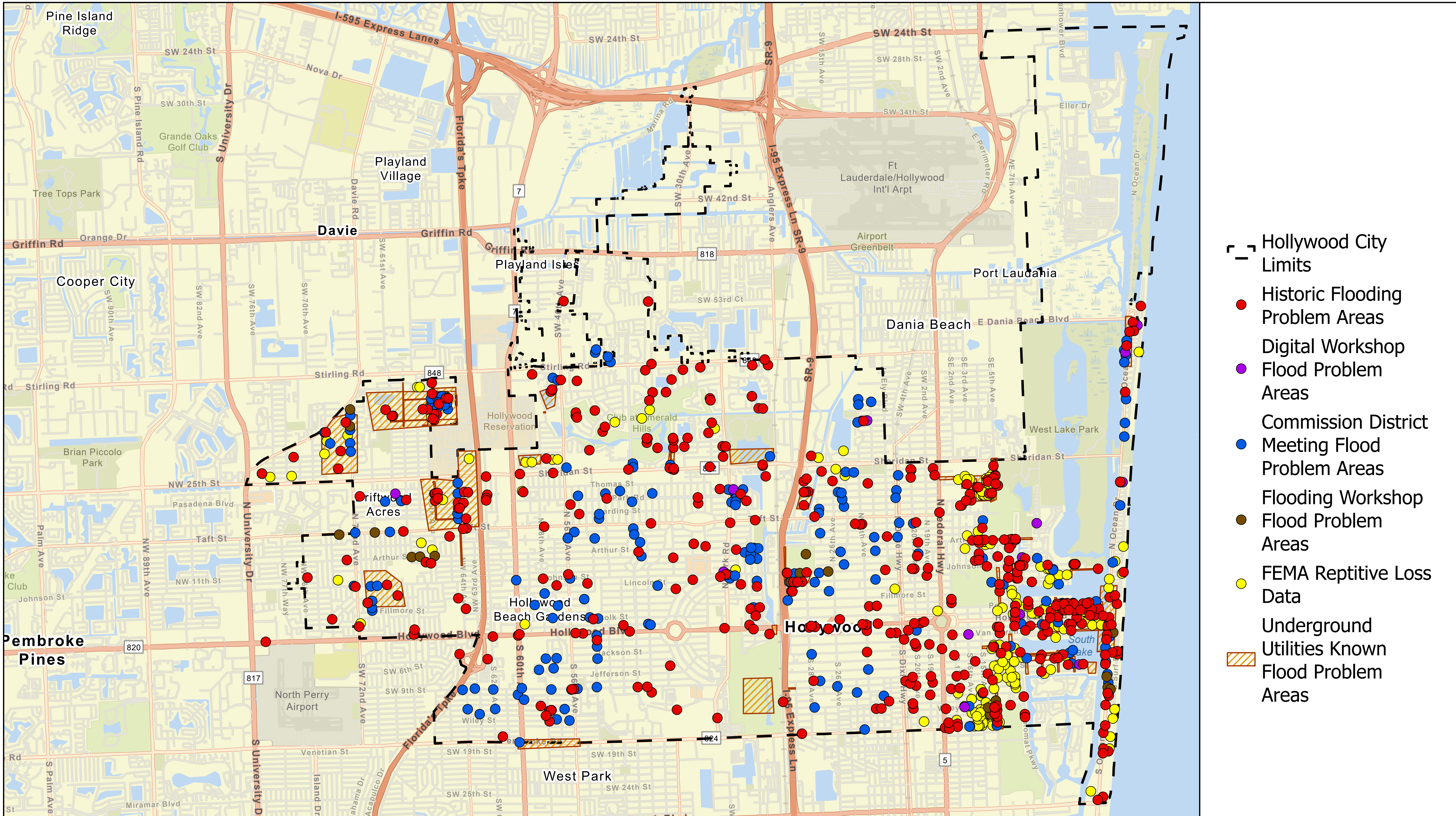
3.0 Model Validation

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. The detailed analysis is provided in **Appendix A**.

For each drainage basin, the locations and dates where complaints related to storms and/or flooding have been made were reviewed. **Figure 3-1** provides a map of flooding complaints from the various sources:

- FEMA repetitive loss properties.
- Public Utilities record for recurrent flooding areas.
- Citizen complaint databases where the City keeps maintenance records of service calls related to stormwater flooding complaints.
- Two Citizen Flooding Workshops were held, one on the westside and one on the east side of town. Following a presentation on the SWMP, citizens placed dots on maps for recurrent flooding complaints. A public website was also provided to place virtual dots on the map electronically and register a citizen flood complaint at any time.
- Commission input was solicited in a Commission Flooding Workshop where discussions were presented of chronic flooding areas and dots were placed on the same maps live and virtually for areas of known flooding to be addressed in each commission district.

Photographic records of flooding were collected and analyzed (including field survey for the high-water marks in some cases) 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. Model parameters were subsequently adjusted and models rerun until a statistically significant correlation was reached within the expected accuracy of the model for the depth, extent, and duration of the flooding predicted versus the actual flooding depicted in the photographs.



City-wide Flood Complaints Map

0 2,000 4,000 8,000 Feet
1:53,000

City of Hollywood Stormwater Master Plan
Figure 3-1
4/6/2022

SUSINOBM D:\Hollywood SWMP\Hollywood Model Development TM Figures\Hollywood Model Development TM Figures.aprx 4/6/2022

4.0 Model Results

The Existing Conditions (EC) simulation results predict that approximately 25% of the City's metropolitan land area will currently flood more than a half-foot deep in a 5-year recurring storm, and approximately 20% of the metropolitan land area will currently flood up to a foot or greater in a 10-year recurring storm event. The 100-year storm event (TS Eta was close to this type of event in rainfall volume in certain areas of the City) will deeply flood the eastern potions of the City inland to about 16th Avenue, areas west of US-1 in the C-10 Canal corridor, and many other widespread pockets of depressional areas in the western parts of the City.

Inundation maps are provided for the two LOS storms (5-yr/24-hr and 10-yr/24-hr) storms for existing conditions in **Appendix D.** The darker blue represents deeper flooding. The results of the EC LOS analysis also confirmed the City-reported areas that flood even in smaller rainstorms. Observation shows that the flooding areas are primarily attributed to the following common general factors:

1. Lack of a sufficient network of existing infrastructure such as positive drainage systems, too few pump stations in the numerous confined bowl areas, and existing pump stations that are undersized for the desired LOS.
2. Older areas of the City that were built within the low-lying natural flood plains and sloughs of the original riverine systems at near existing land surface elevations without consideration for higher floor elevation or drainage requirements. The roadways and homes in the N and S Lakes area are built at too low an elevation and flooding is exacerbated by sea level rise.
3. High impervious area occurring with buildout over the years and few dedicated lands for compensating storage areas created, generating more runoff overflowing into the lower lying areas.
4. Some historical sheet flow (or overland flow) is entering into the City from higher elevations from neighboring areas beyond the City's limits exacerbating the City's flooding problems.
5. Discharge limitations imposed on the drainage districts to the west are limiting the rate of allowable stormwater removal.

4.1 Level of Service Discussion

Stormwater Level of Service (LOS) is defined as the mechanism used to determine how well the stormwater management system is operating compared to a goal or standard appropriate to the needs and desires of the City. Higher levels of service will cost more to achieve, and in terms of almost all stormwater infrastructure, there is a point of diminishing returns where it becomes exponentially more costly for only small additional improvement in level of service to be realized. At some point, the proposed infrastructure becomes too large for the neighborhood or basin's capacity to supply the required power, necessary land, or comply with the zoning for the area.

Based on competing needs for available budget and funding, system owners and operators need to choose a balance between the cost of fully achieving the desired LOS goal, versus allowing some safe, short-duration ponding in known areas, for a known duration, select less frequent return interval design storm events, or deem certain areas as known flooding areas and allow them to flood in an identified design level event and return to being natural storage areas.

For a retrofit CIP such as this—meaning the structures and roadways are already built and in-place and the infrastructure needs to adapt to these existing conditions—the owning entity often chooses a primary LOS goal as its "general standard" but also recognizes that it likely cannot be achieved everywhere, and where it cannot be achieved or where it is not economically feasible to implement, a secondary LOS will necessarily be used. The secondary LOS should be chosen such that it is also a robust design goal such as a 5-year, 24-hour design storm where the peak rainfall intensity is compressed into a shorter period of time and as such, this goal will still provide the needed relief for the heavy afternoon thunderstorms that in many areas can be the majority of the storms causing many of the City's recurrent reported flooding problems.

The analysis of two alternative levels of service is being performed so that the cost-benefit comparisons can be determined over a wider range of LOS, and to provide an alternate, potentially more practicable and realistic LOS goal, due to the anticipated high cost of implementing a CIP that fully meets the Primary LOS goal in an existing area with the hydrologic characteristics of Hollywood, and without major land acquisition or regional-scale projects. The implemented LOS in any area will likely be a mix of the two LOS goals based on the area of the City, what the City can afford to implement to keep major roadways passable for emergency and evacuation traffic and keep flooding below most homes and buildings to the maximum extent practicable within the available funding constraints. This type of CIP implementation lends itself toward a phased, prioritized approach, as funding is available over time.

As described above, for this Stormwater Master Plan, analyses will be performed for the two separate levels of service goals for development of the CIP alternatives, to provide a wider range of potentially achievable LOSs and implementation affordability:

1. <u>Alternative 1 – Primary LOS Goal</u> – Up to 3 inches of flooding over the road crowns in the 10-year, 24-hour recurrence interval design storm for the major roadways and evacuation routes; and up to 3 inches above secondary and arterial residential streets for a 5-year, 24-hour storm; and flooding maintained below building finished-floor elevations in the 100-year recurrence interval design storm wherever practicable.
2. <u>Alternative 2 – Secondary LOS Goal</u> – Up to 6 inches of flooding allowable over the road crowns in the 10-year, 24-hour recurrence interval design storm for major evacuation routes; up to 6-inches of flooding above residential streets for a 5-year, 24-hour storm event; and flooding maintained below building finished-floor elevations in the 100-year recurrence interval design storm wherever practicable.

The City and CDM Smith may decide to alter the secondary LOS goal based on results of the primary goal. The implemented LOS in any area can also be a combination of the two LOS goals based on the applicable CIP for the location in the City, what the City can afford to implement to keep major roadways passable for emergency and evacuation traffic, and to keep flooding below most homes and buildings to the maximum extent practicable within the available funding constraints.

4.2 EC Flooding Discussion by Commission District

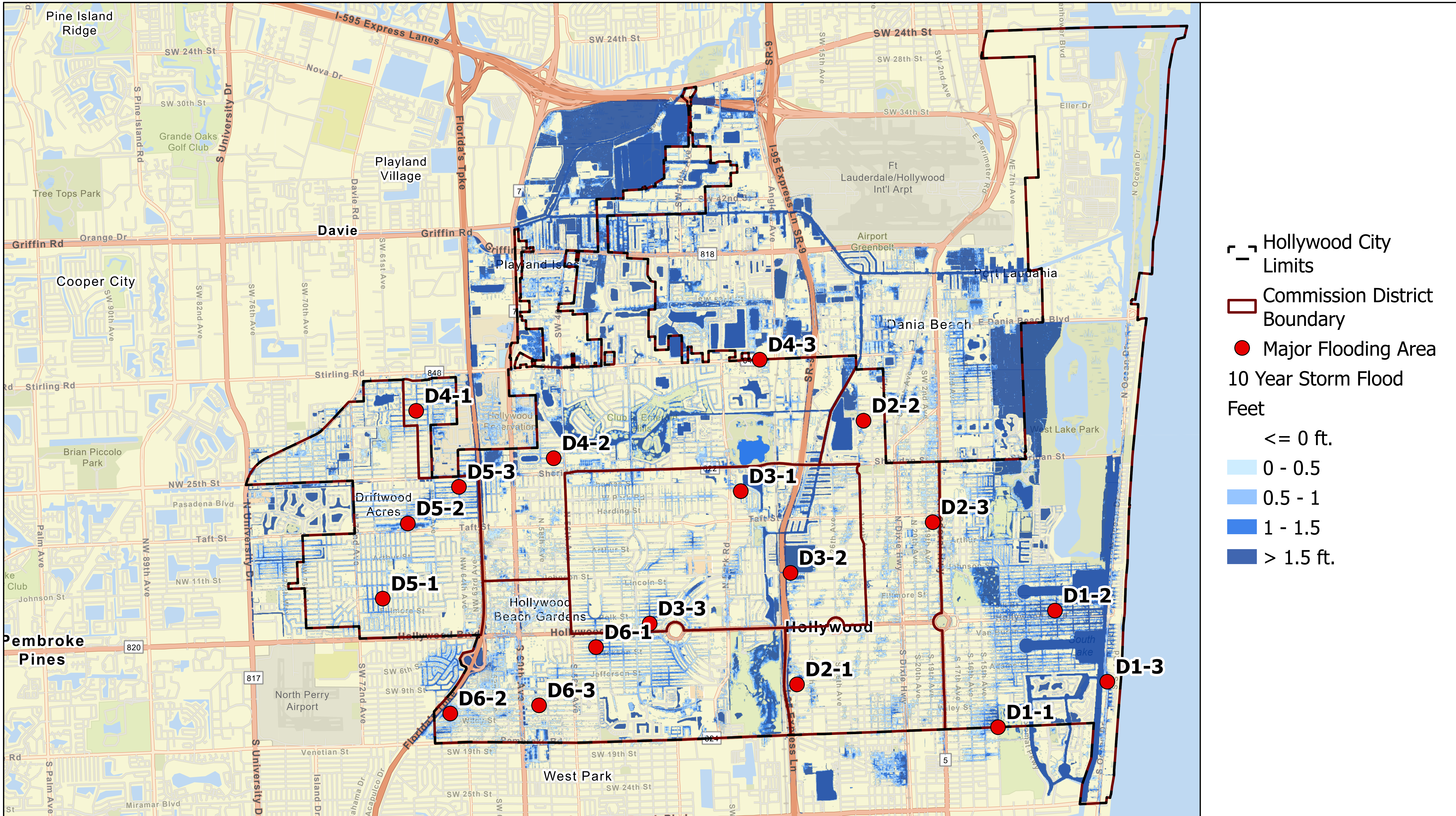
The two verification storms were simulated under the existing conditions (EC) land use scenario model, validated to actual reported flooding, and areas of major flooding inundation were identified along with an initial analysis of the probable root cause of the flooding.

Some of the major flooding problem areas of the several that were identified by each Commission for their District were selected for further discussion below. A description of each and the probable causes of the flooding from initial observations are presented in the following sections and are shown graphically on **Figure 4-1**, which provides the Citywide flooding inundation map as predicted for a 10-year recurrence interval storm with the locations identified at Commission-level during the project as notable areas of flooding to be addressed in the SWMP.

4.2.1 District 1 Noted Flooding Areas Discussion

1. S 14th Ave & Moffett Street

   This area is characterized by extremely low roadway elevations (road crowns at approximately 1 ft-NAVD). All of the surrounding areas slope into this area—from the west from US-1, from the south from the City of Hallandale Beach, and from the north from the residential areas. The area also has a high impervious cover (paved) generating runoff quickly that is exacerbated by a wet season water table near ground level, so the available soil storage is very low. The primary positive drainage element for the system in this area is SWPS#8 that is not sized at a large enough capacity to handle the required volume of runoff flow from the service area for the design storm and is further limited by the current configuration of an in-series re-pump connection to the smaller capacity SWPS#07. The flow able to be pumped out of the service area is less than the predicted runoff flow into the station from contributing areas, and the stormwater is backing up and flooding the neighborhoods. The SWMP will be investigating adding injection wells (IWs) and a new (or increasing the capacity of the existing) SWPS(s) and removing the current bottleneck of re-pumping through the lesser-capacity SWPS#07.



Major Flooding Areas by Commission District

0 2,000 4,000 8,000 Feet
1:53,000

City of Hollywood Stormwater Master Plan
Figure 4-1
2/21/2021

SUSINOBM D:\Hollywood SWMP\Hollywood Model Development TM Figures\Hollywood Model Development TM Figures.aprx 4/12/2022

2. N-S Lake (Hollywood Lakes) Neighborhoods

   This area is characterized by low elevations (road crowns at approximately 1 to 2 ft-NAVD) and runoff flowing downhill to the east from all areas as far west as US-1. Similar to the Moffett area, the relatively high imperviousness and a wet season water table elevation near ground level reducing available soil storage results in large amounts of runoff over a large area. Additionally, low seawalls elevations in the area (less than 2.5 ft-NAVD, which is the recent king tide elevation) allow tidal waters to enter the streets and fill up available stormwater system capacity. Water levels at high tide prevent stormwater from flowing by gravity out of the outfalls so even small storms tend to flood the area due to the head differential at until the tide subsides. The area is served primarily by SWPS#01 and SWPS#02, which cannot keep up with predicted flow capacity. The SWMP will be investigating adding new IWs, new or increased capacity SWPSs, raising the seawalls or perimeter berms to keep the tidal flooding out of the system, and verifying the installation and integrity of the BFPs at all outfalls. Farther east in this drainage basin, SWPS#06 located at the golf course appears to be undersized and will likely need to be increased in capacity, the golf course will be investigated for additional storage systems incorporated into the course design, SW#09 capacity will likely need to be increased, and potentially a new SWPSs will need to be added to the system.

3. SR A1A Vicinity of Crocus and Bougainvillea Terrace

   This area is characterized by a combination of low elevations along SR-A1A, a beach side coastal dune at a higher elevation running west to the east edge of SR-A1A being slightly lower than the roadway and forming a ridge trapping stormwater as it flows downhill toward SR-A1A, resulting in flooding in the side streets, all exacerbated by high tide preventing gravity flow out of the outfalls, and the outfalls being undersized restricting the flow. FDOT is installing four new SWPSs with shared City infrastructure to address the issues. If found not sufficient for the desired LOS in the future model, additional pumps, IWs, and new collection pipes will likely be recommended.

4. Hollywood Lakes Neighborhood – Approx. N 14th Street & South of Sheridan Street

   This neighborhood is characterized by low road crowns in the 1.5 ft-NAVD range, stormwater runoff flowing east into the neighborhood from as far away as the US-1 ridge, low soil storage due to high groundwater elevations, and an undersized, small existing outfall at west lake park that the City was told by the County cannot be increase due to an existing permit restriction to the wetland areas. Further exacerbating the conditions is the fact that this area's tailwater is tidally influenced and the elevation is higher than the roadways. The SWMP will be investigating a series of IWs with a new SWPS, and potentially a connection to and expanding the water features of the City's Eco Golf Course for additional stormwater storage.

4.2.2 District 2 Noted Flooding Areas Discussion

1. Highland Gardens Neighborhood, Washington Street & S 29th Ave

   This area is the bottom of a large topographic depression and is collecting stormwater runoff from overland flow from all sides for several blocks, and nowhere for the standing water to exit the area. A small SWPS#05 is ineffective for the required capacity. The SWMP will be investigating a series of IWs with a new greater capacity SWPS to address this and other nearby surrounding flooding areas together.

2. Liberia Neighborhood, N 24th Ave & Cody Street

   This area is characterized by relatively low land elevations and a natural ridge at a higher elevation farther to the east, resulting in runoff flowing downhill into the neighborhood from east from approximately the R/R tracks, which is also highly impervious, and then is trapped in this bowl, flooding the neighborhood. Additionally, the tailwater is tidally controlled in the lake at the area's outfalls and it is at a higher elevation when compared to the roads, so there is no gravity flow out at most of the tides. The SWMP will be investigating the potential implementation of a regional solution using the interconnected lakes system for pre-storm storage using control gates and pumps.

3. Royal Poinciana Neighborhood, Multiple Side Streets West of Federal Hwy (Taft, Roosevelt, Fillmore, Taylor, Sheridan)

   This area is characterized by the high roadway elevation of US-1 (located on the eastern edge of these neighborhoods) trapping stormwater runoff that is sheet flowing overland eastward from the higher areas from the ridge to the west. The US-1 FDOT system has few (if any) known connections to these neighborhoods, and their system would be undersized for the large additional flows from the City's areas, as it was likely designed for the roadway right of way only. The SWMP will be investigating catching water uphill with exfiltration in the western contributing areas, and if necessary, adding pumping or gravity systems extending downhill past US-1 toward the intracoastal.

4.2.3 District 3 Noted Flooding Areas Discussion

1. N 32nd Ave & Liberty St

   This area is characterized by a bottom of the bowl-type topography where overland sheet flow enters from the west, south, and north higher areas for multiple blocks. The roads in this area are at a relatively low elevation of 3 ft-NAVD with a high imperviousness, and the receiving small lake has no positive outfall that can be seen. The SWMP will likely be investigating a new SWPS discharging to the Hollywood canal for this area.

2. North Central Neighborhood, Johnson Street & N 29th Ave and Finger Islands north

   This area is characterized by low road elevations in the 2–3 ft-NAVD range, and a bottom of the bowl topography bounded by I-95 to the west, and a natural ridge to north, east, and south. There is no backflow prevention at SWPS#03 serving this area at the Sunset Golf Course, and the station is undersized for the required predicted capacity. The regional concept of utilizing the connected lakes system for floodplain storage with control gates and a pump station to lower the canal levels pre-storm, improving the outfalls, and add IWs will likely be investigated for this area in the SWMP.

3. Hollywood Hills Neighborhood, Tyler Steet & N 44th Ave

   This area is characterized by a bottom of bowl-type topography and no positive drainage system infrastructure. The SWMP will investigate the installation of exfiltration systems to catch the water uphill and address these issues due to the potentially favorable land elevation, soils, and aquifer transmissivity in this area.

4.2.4 District 4 Noted Flooding Areas Discussion

1. NE Driftwood Neighborhood and Carriage Hills

   This area is characterized by a bottom of the bowl-type topography compounded by an impervious privacy wall installed by the neighboring municipality to the east likely blocking historic overland stormwater flows and resulting in an accumulation of stormwater in this neighborhood. The SWMP will likely investigate a new expanded collection pipe system, and exfiltration systems. As the area is at the City limits, also to be considered would be a joint project solution with the Seminole Tribe of Florida, a joint project agreement with FDOT for drainage canal improvements and a positive connection, potential FM easements for the installation of IWs, or land acquisition off site for additional compensating floodplain storage.

2. Playland Neighborhood Vicinity and 441 Corridor

   This area is characterized by a bottom of the bowl-type topography on all sides. The County has closed the CS-22 structure so the receiving lake can never drain and stages can get high. The SWMP will likely investigate the effectiveness of the regional system concept here to lower stages pre-storm and create storage using gates and pumps.

3. Emerald Hills Neighborhood, Stirling Road & N 30th Ave

   This area is characterized by a depressional low spot in the area. The FDOT system to the north has a choke point in the conveyance piping system according to best available information that may be further restricting the flow. Initial investigations suggest runoff is flowing off the higher road into the neighborhood and accumulating in the depressional areas, and the small existing exfiltration system(s) are not adequate for this area. The SWMP will likely investigate adding additional exfiltration in this area to address the flooding.

4.2.5 District 5 Noted Flooding Areas Discussion

1. Boulevard Heights Neighborhood, N 70th Ave/Buchannan Street, N 72 Ave/Arthur St

This area is characterized by a localized low spot in the topography with no positive pipe systems to drain the overland sheet flow entering from the surrounding blocks. The SWMP will likely be investigating adding exfiltration systems in favorable areas to catch water up the hill, and potentially a new SWPS. The SBDD stated the City can use their canals as long as it can be demonstrated that there is no pre-post impact to stages and flows in their system

2. Driftwood Neighborhood near N 68th Ave

   This area is characterized by a low depressional topography and has some existing pipe conveyance systems. The stages and flows controlling the flooding levels in this area are limited by the CBWCD system and its discharge permit, so it is not likely more flow can be moved to the west without adding compensating attenuating storage to the CBWCD system through a joint project agreement, if that type of land area is even available. The SWMP will likely be investigating new exfiltration systems in the higher areas to catch water uphill, more pipe connections to the Sheridan Street system if feasible, and potentially a new SWPS.

3. N 64th Ave & Thomas Street

   This area is characterized by a low depressional neighborhood that drains to three small ponds that appear to be undersized for the capacity required, and a ditch along the Florida Turnpike that appears to end without a positive connection to another system. The SWMP will likely be investigating new exfiltration systems where feasible, and a conceptual discussion with FDOT for a joint project agreement to potentially extend the conveyance ditch northward to connect to the C-11 canal.

4.2.6 District 6 Noted Flooding Areas Discussion

1. Hollywood Hills near Van Buren Street & S 52nd Ave

   This area is characterized by a low depressional area with no positive drainage system out of the area. The SWMP will likely investigate adding exfiltration systems and a potential new SWPS to the Hollywood Canal.

2. Beverly Park Neighborhood, Pines Pkwy & Plunkett Street

   This area is characterized by a low depressional area trapped by the Florida Turnpike to the west and Pembroke Road with no positive system or exfiltration systems, and large sheet flows overland into the neighborhood from the surrounding areas. The SWMP will likely investigate adding exfiltration systems for this area.

3. Warehouse District near Washington Street and 60th Ave

   This area is characterized by a flat plateau trapped by slightly higher roadways on all perimeters with a very high impervious area. City O&M Staff report heavy industrial trash and sediments clogging the existing exfiltration systems due to the industrial activities in the area. The SWMP will likely investigate the thorough cleaning or replacement of these existing systems, adding additional exfiltration as necessary, enhanced maintenance, and enforcement of stormwater BMPs and SWPPPs. Due to the location and buildout of this area, other measures may not be feasible.

5.0 Model Stewardship

The City's stormwater system model will be an important planning tool for many years. The model must be regularly maintained through updating the asset data, hydrologic and hydraulic 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.

5.1 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:

- Correction of known problems
- Adaptation to keep a product usable in response to external changes
- Perfection to improve performance
- Prevention to correct faults before they cause problems

At the time of this publication, the drainage basin models were built using PCSWMM Version 7.4, with the base H&H engine in EPA SWMM 5.015. 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 backwards-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).

5.2 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
    - Precipitation data from NOAA Atlas 14, future updates from NOAA, or updates based on City design standards; precipitation time series distributions (unit hyetographs) from SFWMD
    - 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.

5.3 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.

5.3.1 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 4.

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.

5.4 Programmatic Maintenance Tasks

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

5.4.1 Model Re-validation

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 may want to 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. 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 10 years, and earlier if major changes to the PSMS have occurred. Recalibration is best achieved in conjunction with a database of high-water marks. Alternatively, recalibration can be performed on a rolling basis, with portions of the system targeted for assessment each year.

5.4.2 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, and smaller pipes included where necessary. 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.

5.4.3 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.

5.4.4 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 use only 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.

5.5 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 five 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 optional 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.

5.6 Model Updates

The City's drainage system model will be an important planning tool for many years. As discussed in Section 3, 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.

5.6.1 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 GIS 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.

For both PCSWMM and EPA SWMM editing, the user may wish to add/edit the model elements directly in the GUI. Generally, this is performed by importing a background map (such as a design drawing) that has been georeferenced to the model's coordinate system, though PCSWMM has built-in maps that may suffice. Typically edits or additions directly in the GUI are performed for a relatively small number of new entries. The process below is recommended for larger datasets.

It is recommended that a copy of the model be made prior to importing data. Once the edits to the nodes (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 "Storages"

Browse for "Source Layer…" to the newly created shapefile

Under "Import Options":

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 storages have not been edited, this will not harm the import. Any storages in the model not within the new GIS will be unaffected.

Update "Matching Entities" and "Selected Entities" should be left unchecked for this purpose.

Never check "Delete All Entities First" for this purpose.

Update coordinates is the default and is OK.

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 storage shapefile was used as a base, the source layer attributes should automatically align with the storage layer attributes. These should be checked prior to import.

Select "Finish."

Repeat for Outfalls (if any have been added or changed). Note the nodes (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. New storages and outfalls should import prior to adding conduits to ensure the inlet and outlet nodes are present in the model, otherwise the import will throw an error message.

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.

5.6.2 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.

5.6.3 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.

5.6.4 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. Prior to PCSWMM Version 7.4, these GIS files were written to a separate folder in the model's home directory and updated during each edit session. For Version 7.4 (and presumably later versions), the files are generated only when the "Export" function is applied, and the user selects the file destination. 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. Note also 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 PCSWMM Version 7.4 and later, editing the PCSWMM generated shapefiles can no longer directly interfere with the model files; however, it is still a good idea to only work on copies. 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.

5.6.5 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 Portable Network Graphic

(PNG, *.png) drawings, add them to the GIS and then use the georeferencing tools to place them properly in the map.

Once the CAD or georeferenced PNG 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.

5.7 Creating New or Revising Existing Model Elements

5.7.1 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 similar resolution.

5.7.2 Adding Nodes

Once the model resolution is chosen, the copied 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 storage nodes 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 nod. This node 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 there are existing model nodes 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.

5.7.3 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 that 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 node 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 matches the upstream node name. If there is more than one pipe with flow leaving the upstream node, suffixes of "_1", "_2", etc. are used. 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 2.5.2. For irregular channels, engineering judgement, and details and guidance described in Section 2.5.2 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.

ENTRYLOSSCO: entry loss for the pipe or culvert. This value is typically 0.3 for pipes and 0.5–1.0 for culverts (see Section 2.5.2).

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 0.5–1.0 for culverts (see Section 2.5.2).

AVGLOSSCO: additional losses for pipes, based on the bend losses within the pipe or the angle losses at the pipe end (see Section 2.5.2). Note: in many models the bend losses are added in the exit loss, and this value left at 0.

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.

5.7.4 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.

5.7.5 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 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 existing sub-basins with 40 design sub-basins, 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) discussed 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.

5.7.6 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).

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 0.2–0.45, 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 0.05 inch used in most models.

DSPERV: pervious depression storage in inches. This value is typically small, with 0.1 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 K_{sat} 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.

5.7.7 Adding or Modifying Storage Curves

To this point, storage nodes have been added to the model, but they are missing the storage curves that 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 that 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 node 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.

5.7.8 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 node 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.

5.7.9 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 2.5 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.

5.7.10 Adding or Modifying Overland Flow Links

The SWMP Basin models were built in a similar fashion as for the development addition described here. At this point in the model build, the SWMP 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 ft-NAVD and neighboring intersection B a flood stage of 9 ft-NAVD, if the lowest point in the transect separating the neighborhoods is 7 ft-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 ft-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 a Weir 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.

5.7.11 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.

Appendix A

Model Verification

Model Verification Methodology

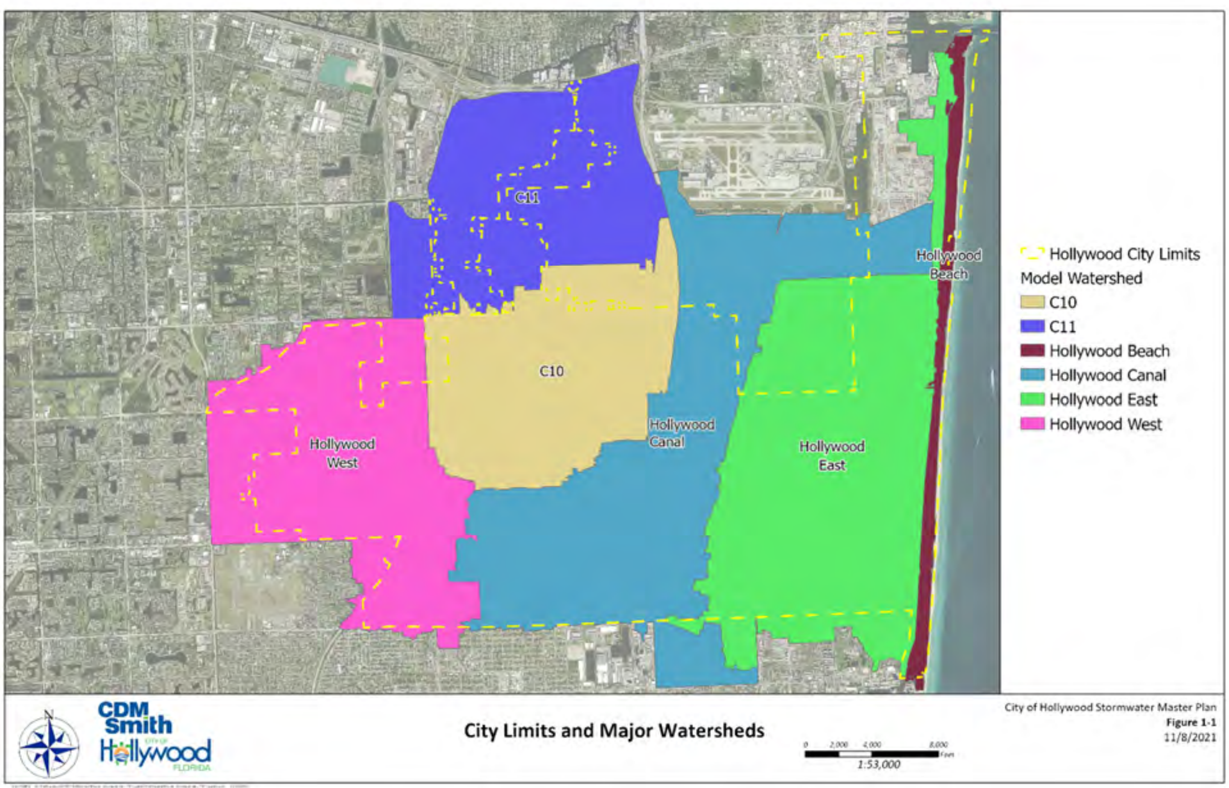
Introduction

Stormwater model verification techniques are used to compare model results to actual conditions for a known storm event for corresponding dates and times. Models are initially run with the best available or empirical data as a first pass and then iterative sensitivity analyses are run with small changes to the model input parameters to finetune the results to obtain a statistically significant match to best available recorded field data. The stormwater service area is naturally divided by elevation, topography, and interconnected infrastructure into eight major drainage areas or basins as shown in **(Figure A-1)**.

The field data collected for this project for verification included:

- Surveyed highwater marks
- Photographic and video recordings
- News media articles
- Weather reports
- First-responder public awareness posts
- Anecdotal evidence submitted to the City by residents during the flooding workshops
- City Public Works Operations Staff

Figure A-1 - City Limits and Major Watersheds



Verification Storm Data

Because a rainstorm is typically spatially diverse and varies in intensity and volume as it moves through an area, different verification storms were required to be used for verification of different areas depending on both the amount of rainfall that was recorded for the particular area and the available time-correlated visual evidence of the resultant flooding either from the City, private reports, or publicly available media sources. To simulate a verification storm within the models, rainfall volume, intensity, and spatial distribution over the study area are all required, as well as corresponding evidence of flooding, and the boundary conditions at the time of the storm event.

Two primary verification storms were available for use during the verification portion of this project for analysis in various levels of detail depending on the impact in the City and the availability of corresponding photographs or other evidence as follows:

1. December 23rd, 2019 Storm – This storm event produced concentrated areas of intense, high-volume rainfall in the areas of the eastern portion of the City and a few areas of the City not severely flooded in the Nov 7th storm. This storm recorded from 2.4 to 10 inches of rainfall in approximately 4 hours. The locations of the corresponding photos from this event 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. This storm was approximately a 50-year event in parts of the City but closer to a 10-year event overall.
2. November 7th – 10th, 2020 Storm – This storm event (Tropical Storm Eta) produced 5-10 inches of rainfall in a 72-hour period with most of the rainfall falling in a 24-hour period. Additionally, the eastern portion of the City of Hollywood had significantly higher volumes of precipitation when compared to other parts of the city. The locations of the corresponding photos from this event 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. This storm is approximately a 25-year event in parts of the City but also closer to a 10-year event overall.

Figure A-2 shows the spatial distribution of the NEXRAD rainfall grid and subbasin assignment within the City for the December 23rd, 2019 Storm. The Dec. 23rd storm was chosen because it included recent, intense precipitation and simulations of rainfall driven events rather than tide driven events provide better verification of the rainfall/runoff characteristics of the model and potential hydraulic bottlenecks or deficiencies and had the best storm data available for the area and included pictures and videos of flood levels during the event. For the December 23rd Storm, the total volume NEXRAD grid was researched and downloaded from the SFWMD using the DBHYDRO database and then corrected for the observed local gage values from published Weather Underground as described in detail in the Model Development Technical Memorandum. The sub-basins were then assigned by grid volume. There was significant variation in volume across the basin from 10.4 inches in the southeast of the City to 2.4 inches in the west. The boundary conditions for this storm were set to the observed stage data at Port Everglades in the Intracoastal Waterway was extracted from the NOAA South Port Everglades Station, which can be found at the following web location-(https://tidesandcurrents.noaa.gov/stationhome.html?id=8722956#available).

Figure A-3 shows the spatial distribution of the rainfall gages and subbasin assignment within the City for Hurricane (Tropical Storm) Eta which affected the City of Hollywood on November 7th through 10th, 2020. TS Eta was simulated with the model to show surge and tidal flooding because it was the only recent storm at the time of verification with City-wide coverage, and there were available pictures and videos of flood levels during and after the event. For Eta, the total volume NEXRAD grid was researched and downloaded from the SFWMD using the DBHYDRO database and then corrected for the observed local gage values from published Weather Underground as described in detail in the Model Development Technical Memorandum. The sub-basins were then assigned by grid volume. There was significant variation in volume across the basin from 5 to 10 inches with higher precipitation volumes occurring in the western part of the City. It should also be noted that the month prior to the storm was extremely wet, with over 30 inches of precipitation in some areas; therefore, the soils were saturated and groundwater flows were significant, especially in the western canals. The boundary conditions for this storm were set to the observed stage data at Port Everglades in the Intracoastal Waterway was extracted from the NOAA South Port Everglades Station, which can be found at the following web location-(https://tidesandcurrents.noaa.gov/stationhome.html?id=8722956#available).

Figure A-2 - Spatial and Volumetric Distribution of NEXRAD Grid for December 23rd, 2019 Verification Storm

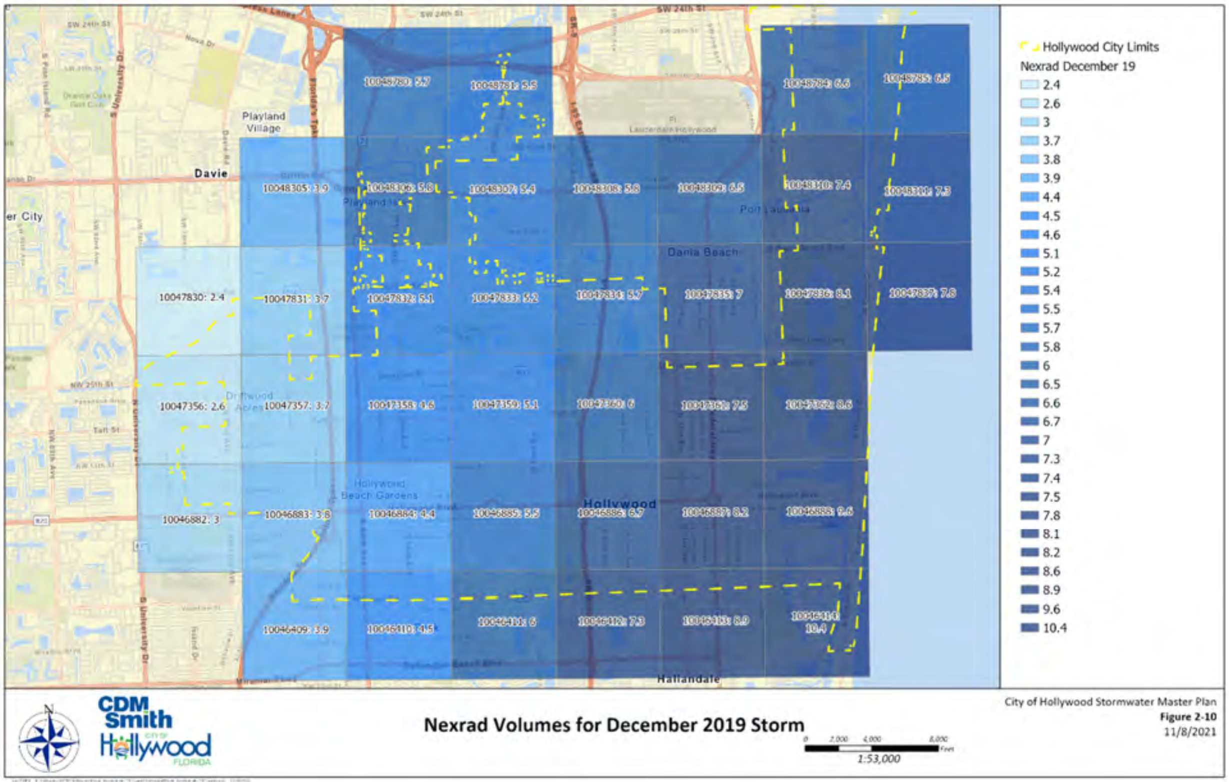
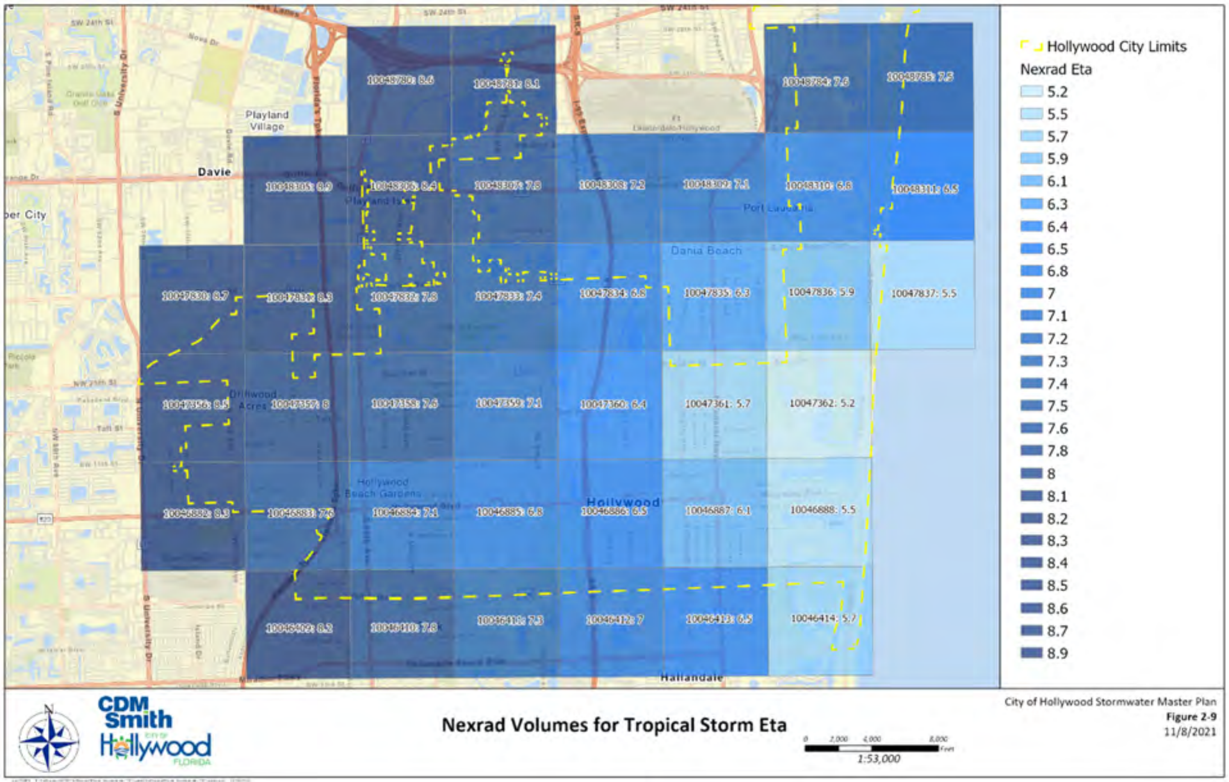


Figure A-3 - Spatial and Volumetric Distribution of NEXRAD Grid for Hurricane Eta



Model Verification Events and Locations

The accuracy of the results is considered high and within the limits of the accuracy of the model. For the below analyses, the photographic evidence of a verification location is shown as compared to the predicted model result for the same modeled storm in the same location and same conditions, blue representing the flooding, and the darker blue being deeper flooding.

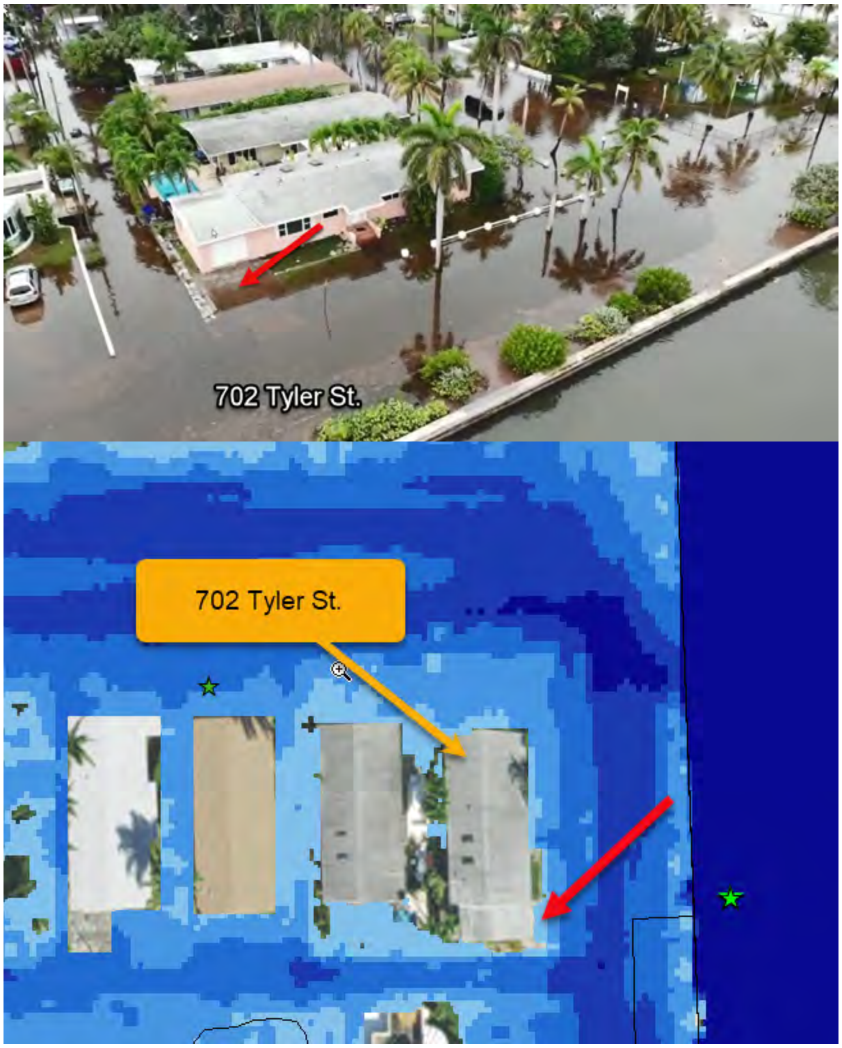
December 23rd, 2019 Storm Event

Photographs and videos of flooding for the Dec. 23rd, 2019, storm event was acquired from different sources for multiple neighborhoods in the City of Hollywood including City Staff, online media search, and by concerned citizens and local businesses.

Neighborhood: Hollywood Lakes

Multiple photos and drone footage were captured in the Hollywood Lakes Neighborhood post storm. The first is a screenshot taken from a drone video at SW corner of S. 7th Ave and Tyler St., as shown in **Figure A-4**. The corresponding model indicates a peak flood stage of 1.95 ft-NAVD, which is slightly higher than the approximate elevation of the flooding in the photograph based on the aerial extent and the LiDAR DEM. The photo was taken after the peak of the storm event and the higher modelled peak should be expected at this location.

Figure A-4 - Drone Footage at 702 Tyler St.

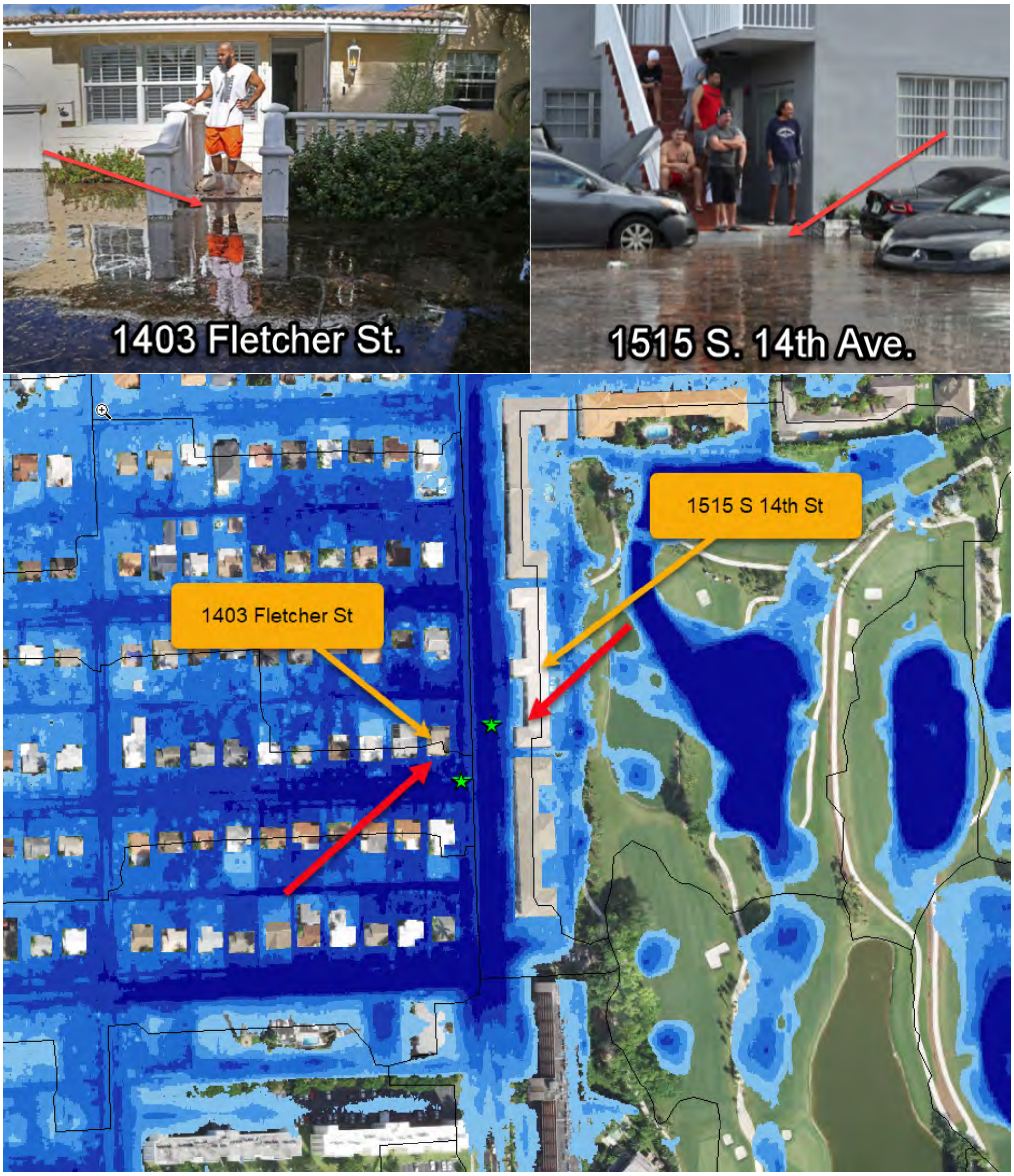


The second drone footage screenshot in the Hollywood Lakes Neighborhood was captured on the west side of 749 N. Southlake Dr., as shown in **Figure A-5.** The corresponding model indicates a peak flood stage of 2.02 ft-NAVD, which is slightly higher than the approximate elevation of the flooding in the photograph based on the aerial extent and the LiDAR DEM. The photo was taken after the peak of the storm event and the higher modelled peak should be expected at this location.

Figure A-5 - Drone footage at 749 N. Southlake Dr.

Numerous photographs were provided along S 14th Ave. between Moffet St. and Wiley St., as shown in **Figure A-6**. The corresponding model indicates a peak flood stage of 3.52 ft-NAVD, which is at the post-storm surveyed elevation of the flooding depicted in the photographs.

Figure A-6 - Flooding at 1403 Fletcher St. and 1515 S 14th Ave.



November 7-10th, 2020 Verification Storm Event (Hurricane Eta)

Photographs and videos of flooding for the November 7th -10th, 2020 Storm were acquired from different sources for multiple neighborhoods in the City of Hollywood including City Staff, online media search, and by concerned citizens and local businesses.

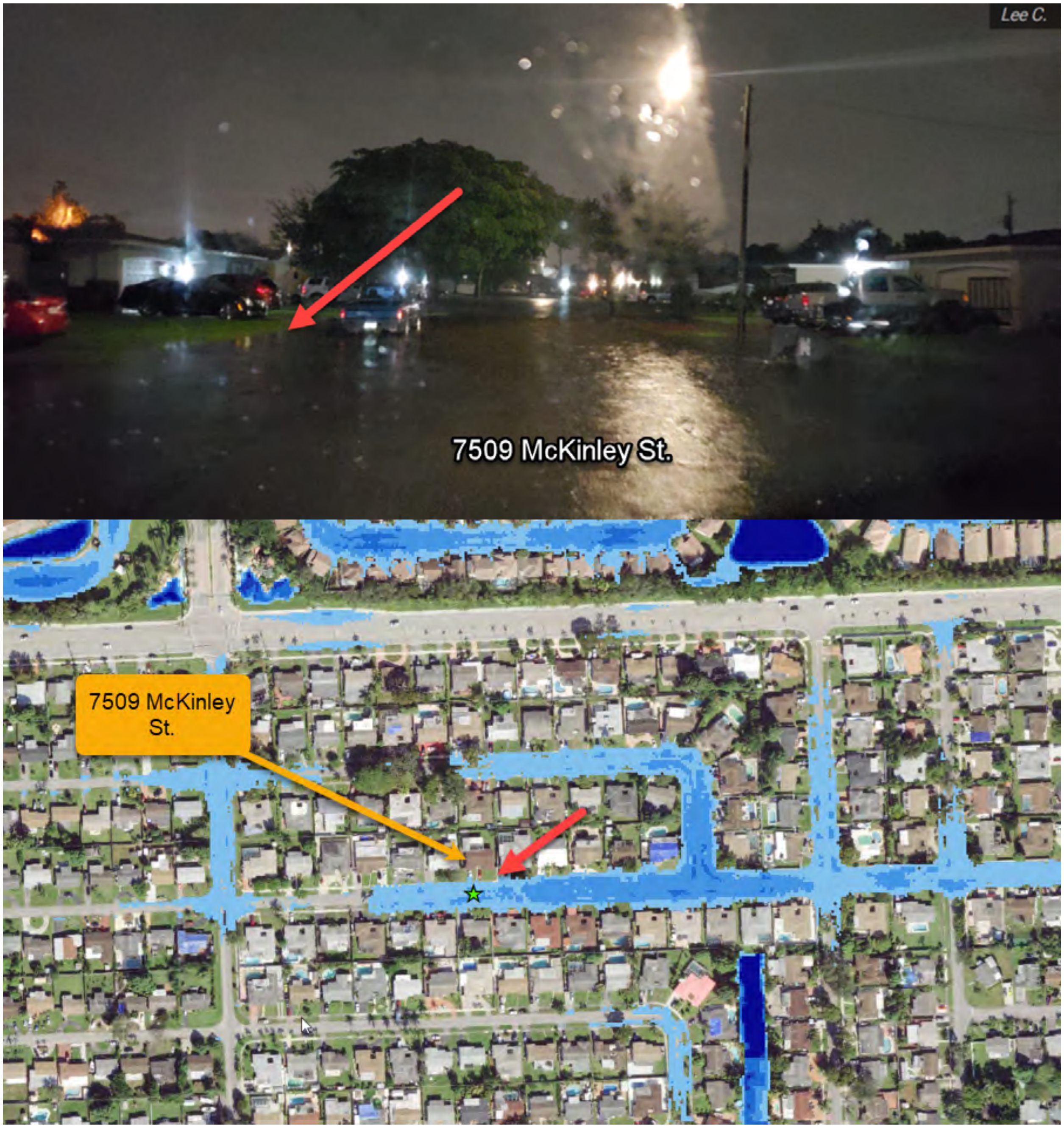
Neighborhood: Boulevard Heights

Three photographs were captured in the Boulevard Heights Neighborhood. The first is a screenshot taken from a video at the intersection of N 69th Way and Johnson Street (Hollywood Park Elementary School) as shown in **Figure A-7**. The corresponding model indicates a peak flood stage of 6.09 ft-NAVD, which is slightly higher than the approximate elevation of the flooding in the photograph based on the aerial extent and the LiDAR DEM. The photo was taken after the peak of the storm event and the higher modelled peak should be expected at this location.

Figure A-7 - Flooding Near N 69th Ave and Johnson Street (Hollywood Park Elementary)

The second photo in the Boulevard Heights Neighborhood was taken in front of 7509 McKinley St. looking east, as shown in **Figure A-8**. The corresponding model indicates a peak flood stage of 4.76 ft-NAVD. It should be noted that this photo was taken during the flood event and has poorer resolution so the exact extent of the pictured flood and stage was estimated.

Figure A-8 - Flooding Near 75 Ave and McKinley Street



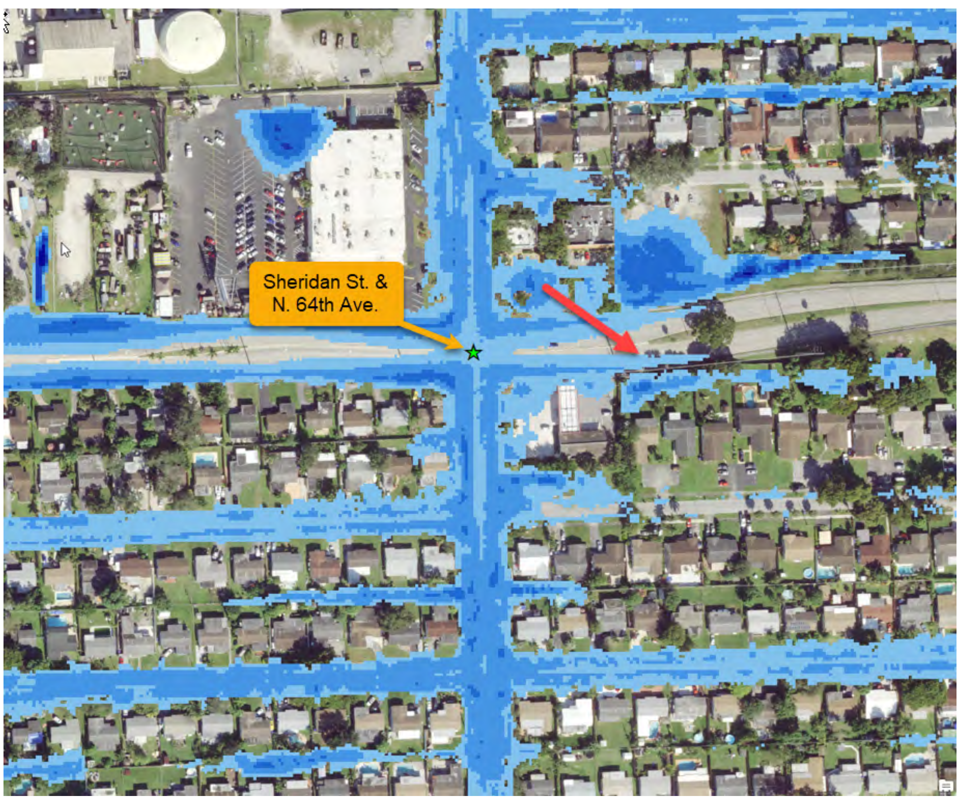
The third photo in the Boulevard Heights Neighborhood was taken in front of 741 N. 70th Terrace looking south, as shown in **Figure A-9**. The corresponding model indicates a peak flood stage of 6.09 ft-NAVD, which is slightly higher than the approximate elevation of the flooding in the photograph based on the aerial extent and the LiDAR DEM. The photo was taken after the peak of the storm event and the higher modelled peak should be expected at this location.

Figure A-9 - Flooding Near 741 N. 70th Terrace

<u>Neighborhood: Driftwood</u>

Two post Eta flood photos were taken in the Driftwood Neighborhood. The first photo shows flooding at the intersection of Sheridan St. and N. 64th Ave. looking east, as shown in **Figure A-10**. The corresponding model indicates a peak flood stage of 5.17 ft-NAVD, which matches the approximate elevation of the flooding in the photograph based on the aerial extent and the LiDAR DEM.

Figure A-10 Flooding Near Sheridan St. and N 64th Ave.



In the Driftwood Neighborhood a screen shot was taken from a video captured in the Fresca Y Mas parking lot (6775 Taft St.) looking south toward Taft St., as shown in **Figure A-11**. The corresponding model indicates a peak flood stage of 5.43 ft-NAVD, which is slightly higher than the approximate elevation of the flooding in the photograph based on the aerial extent and the LiDAR DEM. However, the picture was taken a short time after the storm event, therefore it is expected that the model peak stage would be slightly higher.

Figure A-11 Fresca Y Mas parking lot flooding, looking east toward Taft St.

Neighborhood: Hollywood Lakes

In the Hollywood Lakes Neighborhood, a photo was taken on Polk St. at the southwest corner of Jon B Kooser Park, as shown in **Figure A-12**. The corresponding model only indicates flooding on the south side of Polk St. with a modelled peak flood stage of 1.67 ft-NAVD. The photo also indicates flooding only on the south side of Polk St. It should be noted that it appears the flood water captured in the photo is moving, possibly due to a car recently passing through. Therefore, an accurate assessment of the pictured flood stage and extent is not available, and this data point was only used for reasonableness.

Figure A-12 - Polk St. and N. 14th Ave looking east

Neighborhood: Broward County East of 441 Corridor

East of the 441 Corridor, just outside of the city limits, a photo was taken at Griffin Rd. and SW 48th Ave., as shown in **Figure A-13**. While the photo indicates flooding outside of the city boundary, the area was modelled due to its potential to contribute overland flow to the City proper. The corresponding model indicates a peak flood stage of 5.15 ft-NAVD, which is slightly higher than the approximate elevation of the flooding in the photograph based on the aerial extent and the LiDAR DEM. The photo was taken after the peak of the storm event and the higher modelled peak should be expected at this location.

Figure A-13 - Griffin Rd. and SW 48th Ave. East of the 441-corridor looking south down SW 48th Rd.

Summary and Conclusions

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 and statistically significant fit with available data and within the accuracy of the model. Based on the model output for the two validation storms, the comparisons of the results to the available photographic evidence and surveyed high water marks, and a cross-check of the flood complaint database to the flood inundation maps, the model is considered to be ready for use for application of design storms and CIP modeling to meet the desired LOS.

Appendix B

Model Schematic – Existing System