



Stormwater Master Plan Update

Stormwater Master Plan Update

Volume 1

Prepared by:



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1.0 EXECUTIVE SUMMARY

1.1 Background & Scope

The City of Delray Beach is approximately 16 square miles and located in Palm Beach County on the Atlantic Coast of southeast Florida. The location of the City is shown in **Figure 2-1**. The City spans from the Atlantic Ocean west to predominantly along South Military Trail. This City is bordered by the South Florida Water Management (SFWMD) C-15 Canal and Lake Worth Drainage District (LWDD) L-38 Canal to the south and predominantly by the LWDD L-30 Canal to the north. The City also contains LWDD L-32 and E-4 canals. The City's municipal boundary and major hydraulic features are shown in **Figure 2-2**.

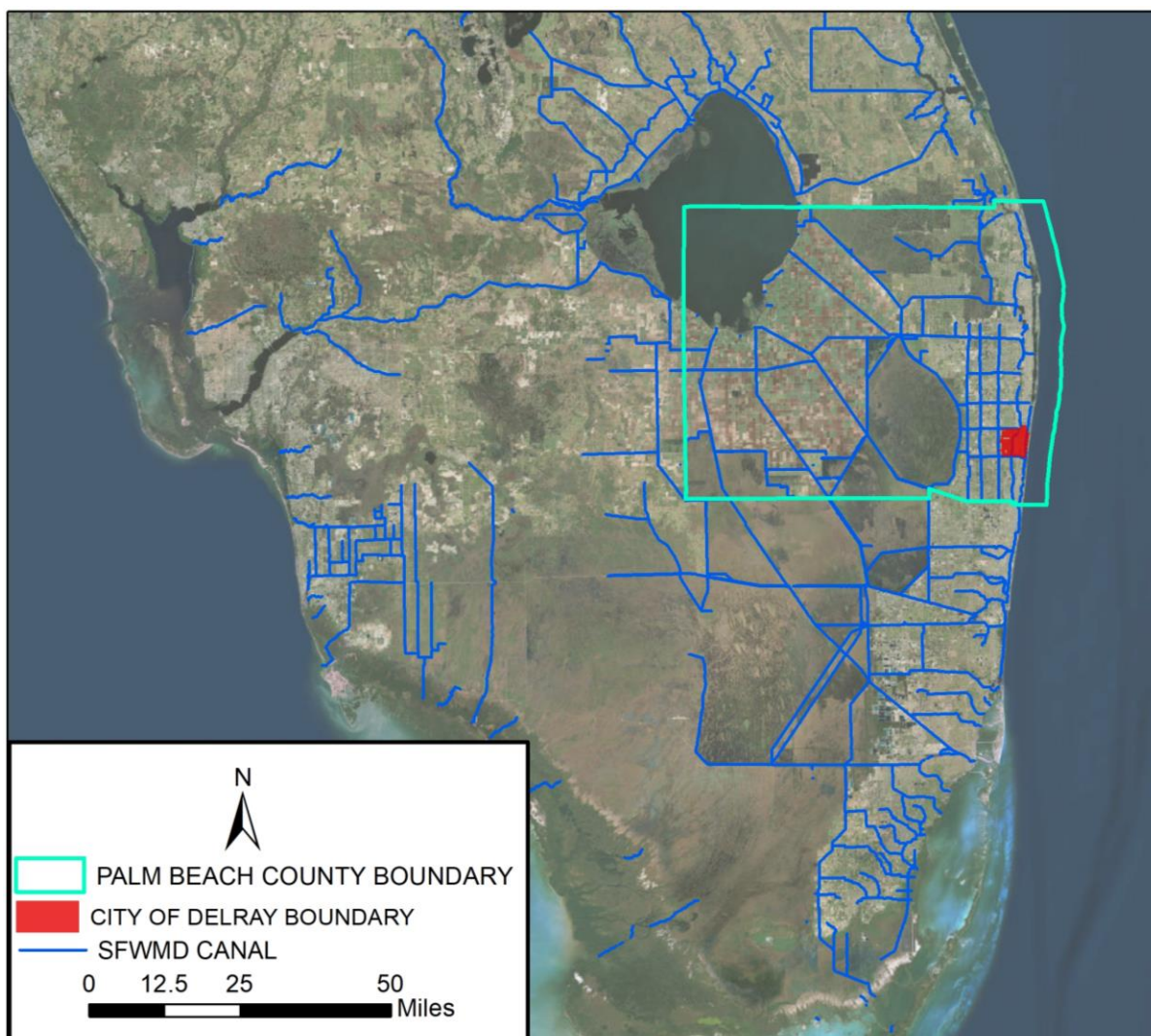


Figure 1-1 :City of Delray Beach Location

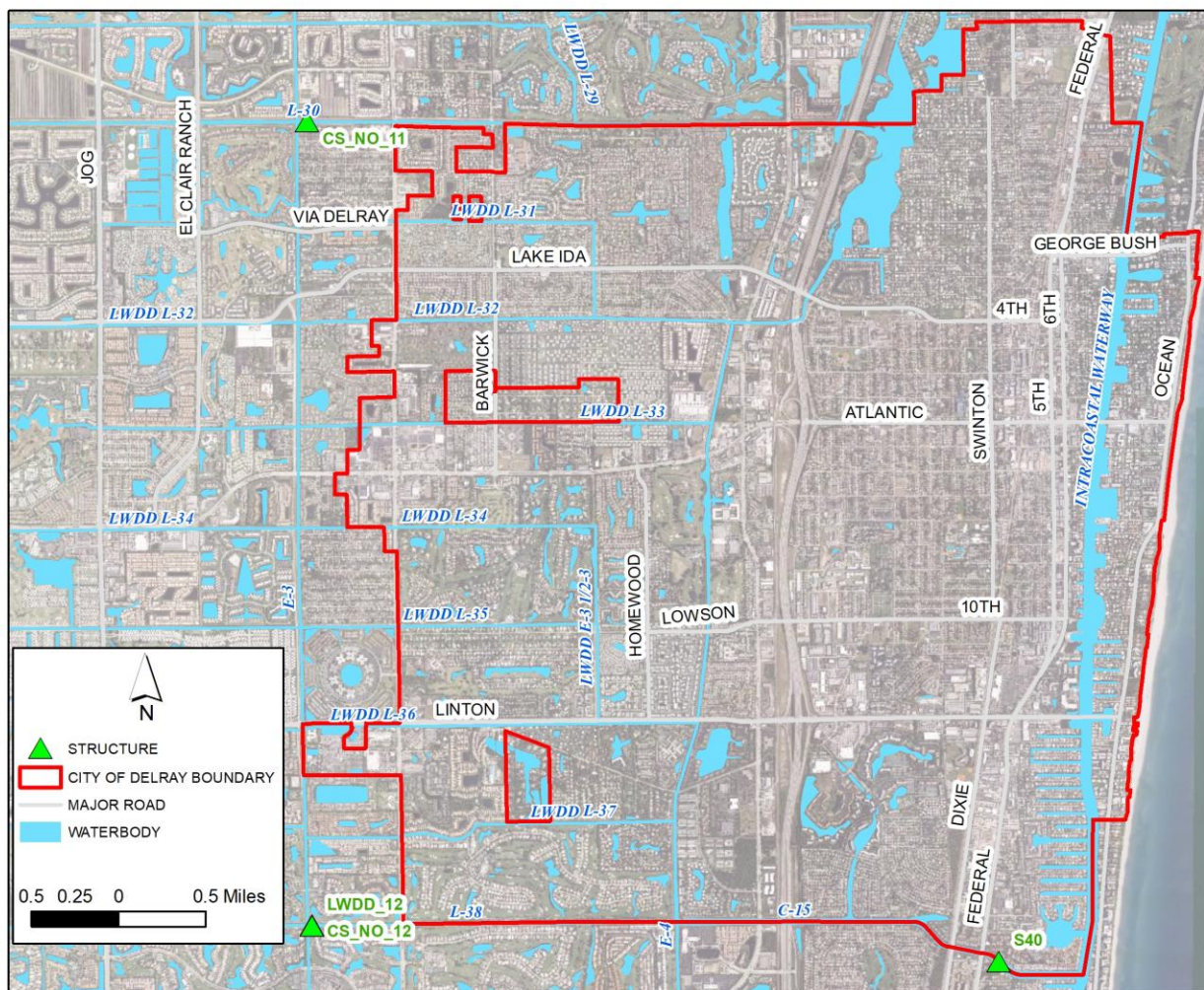


Figure 1-2 :City of Delray Beach Municipal Boundary and Major Hydraulic Features

The City's Stormwater Master Plan (SWMP) was originally created in 1993 by Mock, Roos & Associates, Inc. A revision was completed in 2000 by Kimley Horn & Associates, Inc. The last SWMP evaluated 11 known flood problem areas throughout the City and provided recommendations for improvements needed in the City's drainage system, which have only been partially completed to date.

The City retained A.D.A. Engineering, Inc. (ADA) under the Agreement for Professional Services (RFQ 2017-048), dated August 31, 2017 to perform an update to the City's SWMP. The goal of the SWMP update is to create a plan to address water resource issues and problems within the City. These issues include drainage problems, street flooding, tidal flooding, inadequate infrastructure, stormwater quality and recharge as well, impacts due to projected sea level and groundwater rise, as other stormwater related issues or problems. The Scope of Services was comprised of the following 10 tasks.

- Task 1 – Kickoff Meeting
- Task 2 – Data Acquisition and Evaluation
- Task 3 – Existing Conditions Hydrologic/Hydraulic Modeling (TM1)
- Task 4 – Existing Conditions Level of Service (TM2)
- Task 5 – Projected Sea Level Rise Impacts (TM3)
- Task 6 – Water Quality Assessment (TM4)
- Task 7 – Capital Improvement Projects (TM5)
- Task 8 – Stormwater Ordinance Review- Provided in separate deliverable
- Task 9 – Utility Rate Structure Review Assistance (Optional Task)
- Task 10 – NPDES Review (TM6)

Technical memorandums (TM) were prepared for some of the key tasks associated with SWMP Update Report. The tasks where TMs were prepared and associated TM number are outlined in the list above. TMs were submitted to the City for review, and applicable comments are included in this report.

These tasks are further explained and summarized in the text below labeled by its respective section within this SWMP Report, if applicable.

1.2 Task 1: Kickoff Meeting

The project kickoff meeting was held on January 25, 2018. The primary objectives of the kickoff meeting were to (1) introduce project team to City staff, (2) discuss the project approach for each of key scope of work elements of the Service Order, (3) discuss specific data requirements needed to prepare complete the Stormwater Master Plan update, and (3) discuss City of Delray Beach's (City's) expectations for other project components including deliverables, and schedule. The minutes of the project kickoff meeting are included in **Appendix 1A**.

1.3 Task 2: Section 3 – Data Acquisition and Evaluation

Data was requested and acquired from the various sources maintaining readily available data within Palm Beach County as well as from the City of Delray. The collected data was cataloged, evaluated, and utilized as needed to support the analyses and preparation of the Stormwater Master Plan Report. Data was requested and/or collected from the following agencies:

- City of Delray Beach
- South Florida Water Management District (SFWMD)
- National Oceanic and Atmospheric Administration (NOAA)
- Palm Beach County
- Lake Worth Drainage District (LWDD)

The largest portion of data was provided by the City of Delray Beach. This data includes but is not limited to: GIS files, locations of known drainage issues, LiDAR data, stormwater

and utility ordinances, and many other key components that were used in preparing this report. The data collected from these agencies is included in **Appendix 3A** and **Appendix 3B**.

Sufficient data was collected to develop a representative hydrologic/hydraulic model to evaluate the current and future flood protection level of service for the City and identify key projects to address future projected sea level and groundwater rise. The GIS data provided by the City along with permitting data collected through the SFWMD provided the basis for all modeling efforts. This data provided pipe sizes, inlet, manhole, and outfall locations, as well as parcel and right-of-way information that was used to create an appropriate capital improvements plan to be supplemented by modification of stormwater ordinances within the City of Delray. The provided data along with computational hydraulic modeling provided sufficient information to create this Stormwater Manager Master Plan.

1.4 Task 3: Section 4 – Existing Conditions Model

To build our representative existing conditions one dimensional (1D)/two dimensional (2D) hydrologic and hydraulic models, data was collected as part of Task 2. Spatial coverages for topography, land use, drainage systems, and rainfall were obtained for parameterizing the 2D model. A temporal tidal data set was obtained and analyzed for tidal boundary stages.

Drainage sub-basins were defined in the 1993 stormwater master plan. However additional infrastructure has been added since that time and better topography and drainage infrastructure information was available. Therefore, the sub-basin boundaries were adjusted and refined based on current conditions. In addition, sub-basins along the intracoastal were divided into much smaller sub-basins.

Problem areas were identified by the City of Delray Beach during the Data Acquisition task. The City provided at the project kickoff meeting a hard-copy list of drainage complaints, which was then subsequently converted into a GIS point shapefile. In addition, the City also identified other areas of known flooding based on observations during storm events, but where no official complaints have been voiced by residents. A total of 21 problem areas were identified by the City. These flood problem areas are depicted in **Figure 1-3**.

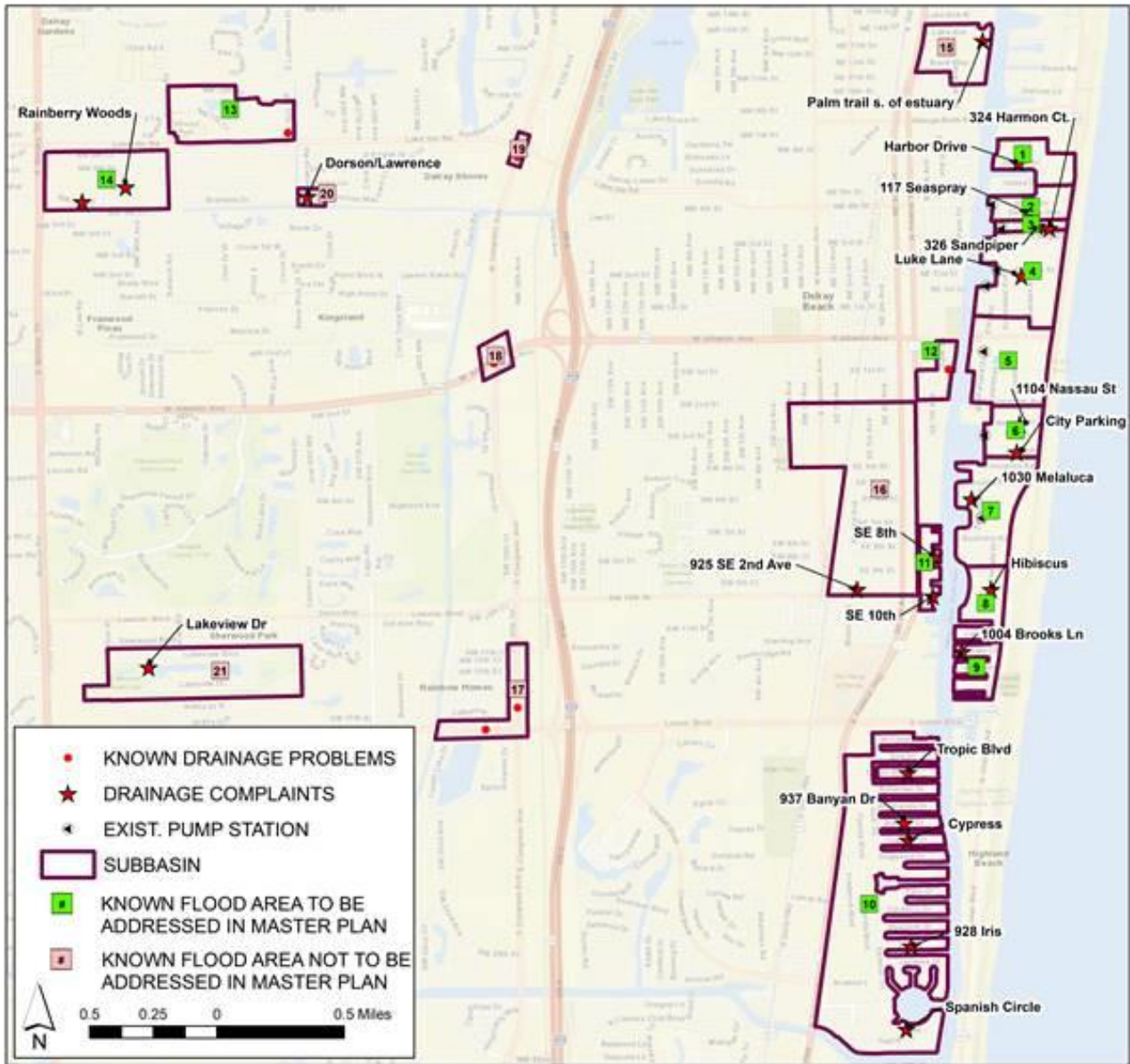


Figure 1-3: Identified Problem Areas

Based on the level of flood severity, the City concurred to evaluate as part of this stormwater management master plan update Problem Areas 1 through 11 and Problem Areas 13 and 14. Problem Areas 12, 15, and 16 are currently being addressed as part of ongoing City stormwater improvement projects. However, Problem Area 12 was evaluated through part of the stormwater master plan update, because the project for that problem areas was not started at the time the stormwater master plan update was started. Problems Areas 17 through 21 are in areas that are either within private, County, or State rights-of-way, and improvements cannot be funded by the City for those areas.

The ICPR4 Software was used for developing representative 1D/2D hydrologic/hydraulic models. Problem Areas 1 through 9 were modeled in a single model domain due to the interconnectivity between problem areas. Problem Areas 10, 11, 12, 13, and 14 were modeled separately. The 1D model components (pipes, manholes, inlets, control structures, pumps) were entered into each model based on GIS infrastructure coverages, City-provided infrastructure information, and SFWMD permit files. The 2D mesh was characterized by the DEM, a soil zone coverage, a land use zone coverage, and a rainfall zone coverage. The 2D mesh coverages were obtained from the City or SFWMD and were edited and formatted for incorporation into the model. Boundary conditions for the coastal models (Problem Areas 1-12) were assumed as intracoastal King Tide elevations based on the past five years of NOAA Tidal data. Boundary conditions for the upland models (Problem Areas 13 and 14) were the maintained based on the LWDD canal control elevations. The ICPR4 model node-link schematic and input file are included in **Appendix 4C** and **Appendix 4D**, respectively.

A validation model was run for the simulation period starting on June 1, 2017 and ending on June 10, 2017, because it was a well-documented rainfall event with known areas and levels of flooding. Validation inundation maps were developed to confirm the model's representation of the depth and extent of flooding. The validation model run inundation maps for Problem Areas 1 through 12 and Problem Areas 13 and 14 are included in **Appendix 4A**. The validation results were confirmed by the City to be sufficiently representative based on their observation of flooding during the June 2017 rainfall event.

Following the validation of the model, the 5-year 1-day, 10-year 1-day, 25-year 3-day, and 100-year 3-day storm simulations were executed. The inundation flood maps for the design storm events for Problem Areas 1 through 14 are included in **Appendix 4B**. The 100-year 3-day storm results were compared to the FEMA FIRM. Overall, there was good agreement between the 100-year, 3-day design storm event extent of flooding simulated by the ICPR4 model with the FEMA FIRM for the coastal areas of the City.

1.5 Task 4: Section 5 – Level of Service

After the hydraulic and hydrologic model was completed and the resulting data was compiled, the City's problem areas were ranked using a refined version of the scoring methodology developed and used by the Miami-Dade County's Department of Regulatory and Economic Resources (DRER, formerly DERM/PERA) as part of their stormwater master planning activities. The refined scoring methodology includes ranking sub-basins by establishing a Flood Protection Severity Score (FPSS). The FPSS is derived by scoring the results of two (2) Flooding Severity Indicators, weighting factor (WF) for applicable flooding severity indicators and an exceedance factor for each indicator. These scoring factors are summarized as follows:

1. **NS:** Number of structures anticipated to flood by a 100-year, 3-day design storm event, which can include commercial, residential, and public buildings. All structures and/or buildings are considered equivalent, regardless of their size or value. (**WF = 4**)

2. **MCLRS:** Miles of collector and local residential streets anticipated to be impassable during 5-year, 1-day design storm event. All collector and local residential streets are considered impassable if the depth of flooding exceeds the crown of the road during the 5-year, 1-day design storm event. (**WF = 2**)

The severity indicators are rated by an exceedance (E) value pursuant to the following severity score listed in the table below.

Depth of Flooding Above the FPLOS	E
Less than or equal to 6 inches	1
Greater than 6 inches and less than or equal to 12 inches	2
Greater than 12 inches	3

Given the definitions for the flooding severity indicators (NS and MCLRS), WF, and E, the FPSS for each problem area is calculated using the following formula, where $E_{(i)}$ relates to the degree of exceedance for each of the five severity indicators.

$$\text{FPSS} = \sum 4E_i \cdot \text{NS} + \sum 2E_i \cdot \text{MCLRS}$$

To account for the varying size of each problem area, the FPSS was divided by the area of the problem area to normalize the FPSS.

The level of service maps showing the NS and MCLRS not meeting the design criteria along with the amount of exceedance for Problem Areas 1 through 14 are included in **Appendix 5A**, and the FPSS score computation for each problem area is included in **Appendix 5B**. **Table 1-1** below lists the results of the ranking of each problem area based on the value of the Weighted FPSS Score.

The FPSS is used to determine the level of service and ranking of the top fourteen problem areas identified in **Task 3, Section 4.0**. These fourteen problem areas were identified as high priority in terms of capital improvement projects and are further evaluated in **Section 8.0** of this SWMP.

Table 1-1: FPSS Ranking by Problem Area

Rank	Problem Area Name	Problem Area	Sub-Basin Area (Acres)	FPSS	Weighted FPSS
1	Seasage Drive	7	61.22	731.4	11.95
2	Beach Drive	2	22.84	105.7	4.63
3	Basin Drive	4	67.34	234.4	3.48
4	Rainberry Woods	14	71.02	190.3	2.68
5	Hibiscus Road	8	28.53	63.4	2.22
6	Bay Street	6	27.42	55.2	2.01
7	Waterway Lane	3	7.85	4.6	0.59
8	Atlantic Ave	5	64.79	33.7	0.52
9	Spanish Circle	10	281.49	144.6	0.51
10	Harbor Drive	1	26.22	9.2	0.35
11	Banwick Park	13	59.92	17.9	0.3
12	7 th Avenue	11	14.65	1.6	0.11
13	Brooks Lane	9	19.54	1.4	0.07
14	Marine Way	12	15.28	0.8	0.05

1.6 Task 5: Section 6 – Projected Sea Level Rise Impact

Due to the fact that the City of Delray Beach has experienced increased levels of seasonal tidal flooding within the communities that are bound by the Intracoastal Waterway, this section of the report evaluates the vulnerability of the City's seawalls and surrounding structures, based on the anticipated sea level and groundwater rise during 30- and 75-year planning horizons. The *City of Delray Beach Intracoastal Waterway Water Level & Infrastructure Vulnerability Study – Phase 1a Report* prepared by Aptim Environmental & Infrastructure (Aptim), Inc in March 2018 was used to establish the anticipated 30- and 75-year projected sea level rise. In this study it was found that the expected peak tide elevation for the 30-year planning horizon is 3.9 to 4.4 feet relative to the North American Vertical Datum (ft-NAVD) of 1988, and the expected peak tide elevation for the 75-year planning horizon is 5.3 to 7.4 ft-NAVD. To determine the level of flooding for a 30-year and 75-year sea level rise planning horizons as part of the stormwater master plan update, peak sea level elevations of 4.2 and 7.4 ft-NAVD were used for tidal areas, respectively. Current peak tide elevations is approximately 2.5 ft-NAVD

The March 2018 Aptim report also included 773 surveyed points within the 12 coastal Problem Areas. These elevations were used to compare the current seawall top elevations to the projected 30- and 75-year sea level rise projections. It is estimated that for the 30-year planning horizon high tide elevation, approximately 12 miles of seawall within the City's Problem Areas will be overtopped. The location where the seawall would be overtopped are depicted in **Figure 1-4**. For the 75-year stop, 100% of the seawall within the 12 problem areas is overtopped. **Appendix 6A** includes profile comparison of

surveyed top of seawall elevation for Problem Areas 1 through 12 relative to current, 30-year, and 75-year peak tidal elevations.

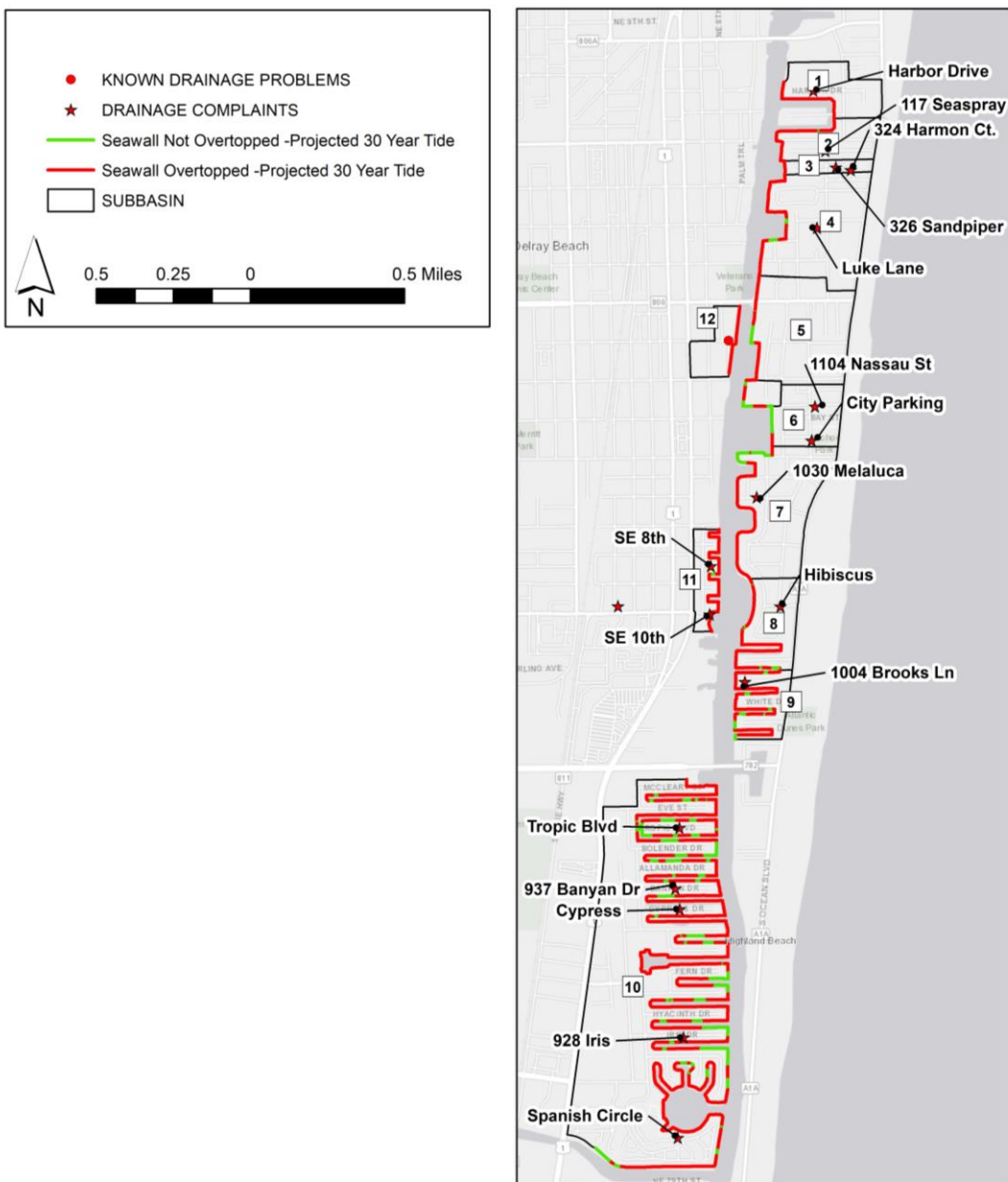


Figure 1-4: Seawall overtopped in 30-year Sea Level Rise Scenario

For western areas of the City (Problem Areas 13 and 14), there are currently no groundwater studies to determine the groundwater rise that can be anticipated for the 30- and 75-year planning horizons. Due to the fact that there is no groundwater rise projection study or data available for groundwater rise assumptions in this area of Palm Beach County, 1-ft (30-year horizon) and 2-ft (75-year horizon) of groundwater rise was

assumed for Problem Areas 13 and 14, respectively. The goal of assuming these values for groundwater rise was to illustrate the impact of reduced soil storage and increased canal stages on the flooding within these two problem areas, if future groundwater studies in Palm Beach County project higher groundwater rise in upland areas due to sea level rise.

The projected sea level and groundwater rise conditions were included in the existing condition model outlined in **Task 3, Section 4.0** as initial conditions, boundary conditions and reduced soil storage changes. The model was simulated under these sea level rise conditions for the 5-year, 1-day and 100-year 3-day design storm events. The flood inundation maps for Problem Areas 1 through 14 for the 30- and 75-year sea level rise planning horizons are depicted in **Appendix 6B**.

Once the data was modeled in ICPR4, the FPSS for the 30-year planning horizon was recalculated to determine the percent increase from existing conditions. The level of service maps showing the NS and MCLRS not meeting the design criteria along with the amount of exceedance for Problem Areas 1 through 14 for the 30-year planning horizon are included in **Appendix 6C**, and the FPSS score computation for each problem area is included in **Appendix 6D**. The results of that evaluation are outlined in the **Table 1-2**. The same analysis was not performed for the 75-year sea level planning horizon, because capital improvement projects will be implemented at this time to address a 30-year sea level rise condition.

FPSS Scores increased significantly in sea level rise scenarios, especially for the coastal Problem Areas where many areas experienced road and structural flooding with exceedance values of 3. This illustrates that these coastal areas, in particular are not outfitted with the infrastructure that is sufficient for the future tidal elevations predicted for the City of Delray Beach.

Table 1-2: Percent Increase of FPSS for 30-year Sea Level Rise Planning Horizon

Problem Area Name	NS		MCLRS		Composite Scores		
	4 Weighing Factor		2 Weighing Factor				
	Score		Score		FPSS		Percent Increase
	Exist	SLR	Exist	SLR	Exist	SLR	
1	8	56	1.20	1.40	9.20	57.40	524%
2	104	244	1.70	2.40	105.70	246.40	133%
3	4	60	0.60	1.00	4.60	61.00	1226%
4	228	1172	6.40	9.80	234.40	1181.80	404%
5	28	864	5.70	8.00	33.70	872.00	2488%
6	52	384	3.20	4.30	55.20	388.30	603%
7	56	524	7.40	11.60	63.40	535.60	745%
8	60	364	3.40	4.70	63.40	368.70	482%
9	0	380	1.40	2.70	1.40	382.70	27236%
10	124	648	20.60	25.20	144.60	673.20	366%
11	0	48	1.60	2.20	1.60	50.20	3038%
12	0	140	0.80	2.20	0.80	142.20	17675%
13	12	36	5.90	5.90	17.90	41.90	134%
14	184	288	6.30	6.50	190.30	294.50	55%

1.7 Task 6: Section 7 – Water Quality Assessment

The water quality assessment portion of this SWMP reviewed currently existing infrastructure and SFWMD Environmental Resources Permits (ERP). **Appendix 7A** includes a map with all current ERP permits within the City, and **Appendix 7B** includes the location of existing best management practices (BMPs). Areas where BMPs have currently not being implemented could be improved by implementing two types of site planning and BMPs. These site planning practices and BMPs are structural and non-structural methods that can be implemented in existing and future developments within the City of Delray Beach.

1.7.1 Non-structural Site Planning Practices

Implementation of non-structural site planning practices serve to manage stormwater runoff through the restoration and preservation of the natural drainage features present at the development site by applying source control.

The primary non-structural site planning practices and considerations that appear to be most applicable to the City of Delray Beach include the following:

1. **Pre-development topography and soil profile restoration and preservation-** to preserve the natural flow path and maximize filtration through permeable soils.
2. **Native and local vegetation preservation-** prevents erosion, reduces pollution levels, increases infiltration by decreasing runoff velocities, intercepts rainfall, and increases evapotranspiration rates.
3. **Open space design and conservation-** includes existing or designed pervious areas, including natural areas, recreational areas, common use areas, and buffer zones and is used to reduce impact to the watershed.
4. **Total impervious area minimization-** increases stormwater infiltration through pervious materials.
5. **Directly connected impervious area reduction-** Stormwater runoff should be directed to flow into natural areas, vegetated buffer zones, and soils with favorable infiltration.

1.7.2 Structural Site Planning Practices

Stormwater Management practices allow for the use of a wide array of simple, cost effective structural practices that focus on site-level hydrologic control. These practices should strive to have the same conditions or better for total and peak stormwater runoff volumes, runoff conveyance patterns, and infiltration and treatment capacity as were present before development. The selected structural BMPs, based on most cost-effective approach that can be utilized in the City of Delray Beach, are the management practices described and explained in detail in the following subsections. These include:

1. **Bioretention Basins or Rain Gardens-** are intended to manage and provide water quality treatment by using a conditioned planting soil bed and materials to filter the stored runoff.
2. **Tree Box Filters or Infiltration Planters-** performs as a filter if the bottom is open and stormwater is discharged through infiltration; and detention when the bottom is closed and the filtered stormwater flows into an underdrain to be discharged to another stormwater management or pipe system.
3. **Vegetated Swales (grass, infiltration, wet)-** reduce stormwater runoff, and provide many benefits including reduction in peak flow rates and slower runoff velocities.
4. **Filter Strips or Vegetated Buffers-** vegetated buffers slow runoff, reduce peak discharge, allow for infiltration and reduce stormwater volume.
5. **Exfiltration Trenches-** placed below paved or pervious surfaces or at the bottom of retention areas, exfiltration trenches offer a method of conveying stormwater runoff to the groundwater table in areas where impervious areas have been greatly increased.
6. **Infiltration Trenches-** when filter strips and grassed swales are used in combination as a form of pretreatment, infiltration trenches are highly effective at removing all targeted pollutants from stormwater runoff.
7. **Rain Harvesting (rain barrels/cisterns)-** runoff can later be used for non-potable activities including irrigation, toilet flushing, or industrial processes. This method is low-cost, effective and easily maintainable.

8. **Permeable Pavement**- unlike traditional pavements, this pavement allows water to pass through, reducing the volume and peak of stormwater runoff. They can be used as part of a treatment train to reduce stormwater volume and pollutant loads from parking lots and similar areas.
9. **Detention / Retention Ponds**- Using retention/detention systems in a watershed will help preserve or restore predevelopment hydrology, increase dry weather base flow, and reduce flooding frequency.
10. **Pollution Control Structures (i.e. Vortech/CDS Units)**- These units remove floatables, oil/grease, and reduce the total suspended solids (TSS) of the runoff prior to discharging to a waterbody or well.

It is suggested that the City of Delray set forth and implement at minimum of three of these Best Management Practices in order to improve the quality of its stormwater and maintain proper nutrient loading and pollution control within its bodies of water.

1.8 Task 7: Section 8 – Capital Improvement Projects

In accordance with the scope of work for the City of Delray SWMP development, conceptual stormwater capital improvement projects were developed for the top 14 Problem Areas identified and ranked in **Section 5.0**, except for Problem Area 12. Problem Area 12 is currently being addressed under a separate project and will not be included as part of the capital improvement project assessment.

Working in coordination with City staff, it was decided to conceptually design these projects to account for a 30-year sea level and groundwater rise due to the increasing effects of climate change. Along with this, the main goal when creating these conceptual designs was to remove as much flooding from the roads and structures as possible. To be able to address this level of projected flooding, the capital improvement projects will be comprised of one or combination of these stormwater management systems:

1. Raising existing seawalls or implementing new seawalls to a minimum top elevation of 4.2 ft-NAVD as documented in **Section 6.0**
2. Construction of new or rehabilitation of existing stormwater pump stations
3. Installation of backflow preventers for outfalls with positive discharge
4. Construction of exfiltration trenches
5. Lining existing stormwater pipes for projects within the coast areas
6. Implementing pollution control devices for systems discharging to LWDD canals, SFWMD canals, or the intracoastal
7. Raising the crown of road elevation as needed to be above the peak 5-year, 1-day flood elevation.

Projects were formulated to reduce the FPSS to 0, to the maximum extent possible. The capital improvement projects formulated for Problem Areas 1 through 11 and Problem Areas 13 and 14 are presented in **Appendix 8B**. The planning-level cost associated with

each capital improvement project is summarized in **Table 1-3**, and **Appendix 8D** includes a detailed estimate on how the costs were derived.

Table 1-3: Cost of Capital Improvements per Problem Area

Problem Area Name	Problem Area	Project Cost Estimate
Harbor Drive	1	\$10,343,628.80
Beach Drive	2	\$10,621,968.41
Waterway Lane	3	\$19,400,414.09
Basin Drive	4	\$42,085,705.66
Atlantic Avenue	5	\$27,975,112.98
Bay Street	6	\$21,087,575.32
Seasage Drive	7	\$32,943,700.48
Hibiscus Road	8	\$25,470,832.60
Brooks Lane	9	\$15,902,001.70
Spanish Circle	10	\$157,191,957.44
7 th Avenue	11	\$6,396,712.90
Banwick Park	13	\$3,743,110.48
Rainberry Woods	14	\$5,200,277.37
TOTAL		\$378,362,998.23

The FPSS reduction was computed for each of the capital improvement project with 30-year sea level and groundwater rise projected. The summary of FPSS score for each problem area is summarized in **Table 1-4**, and **Appendix 8C** includes the FPSS computation for each problem Area.

Table 1-4: FPSS for Current and Future Conditions

Problem Area Name	Problem Area (Acres)	Flood Protection Severity Score (FPSS)			FPSS Difference (30-Year Sea Level Rise FPSS minus Capital Improvements FPSS)	Percent Reduction of FPSS with Capital Improvements	Area-Weighted FPSS Difference (points reduced per acre)
		Current Tidal Conditions Existing Infrastructure	30-Year Sea Level Rise Existing Infrastructure	30-Year Sea Level Rise Capital Improvements			
1	26.22	9.20	57.40	0.00	57.40	100%	2.19
2	22.84	105.70	246.40	0.00	246.40	100%	10.79
3	7.85	4.60	61.00	0.00	61.00	100%	7.77
4	67.34	234.40	1181.80	12.00	1169.80	99%	17.37
5	64.79	33.70	872.00	12.00	860.00	99%	13.27
6	27.42	55.20	388.30	24.10	364.20	94%	13.28
7	61.22	731.40	535.60	0.00	535.60	100%	8.75
8	28.53	63.40	368.70	0.00	368.70	100%	12.92
9	19.54	1.40	382.70	0.00	382.70	100%	19.59
10	281.49	144.60	673.20	64.00	609.20	90%	2.16
11	14.65	1.60	50.20	0.00	50.20	100%	3.43
12	-	0.80	142.20	-	-	-	-
13	59.92	17.90	41.90	0.00	41.90	100%	0.70
14	71.02	190.30	294.50	8.00	286.50	97%	4.03

Once the cost was evaluated, the projects were ranked based on their percent reduction of FPSS with capital improvements. The purpose of this is to evaluate which problem area's improvement projects produced the greatest flood reduction in the most cost-effective manner. **Table 1-5** includes the problem areas capital improvement projects ranked by order of cost effectiveness. All problem areas are considered high priority areas. However, it is suggested that all capital improvements listed within this SWMP be implemented in order of priority, when possible.

Table 1-5: Ranking of Capital Improvement Projects by Cost Effectiveness

Rank	Problem Area	Problem Area Name	Dollars per Weighted FPSS Point Reduced per Acre
1	9	Brooks Lane	\$4,724,911.97
2	2	Beach Drive	\$ 984,601.29
3	14	Rainberry Woods	\$2,496,610.67
4	6	Bay Street	\$ 2,422,680.30
5	11	7 th Avenue	\$2,107,566.94
6	8	Hibiscus Road	\$ 1,587,647.76
7	5	Atlantic Avenue	\$3,765,521.55
8	4	Basin Drive/Thomas Street	\$ 1,970,932.61
9	3	Waterway Lane	\$811,928.70
10	7	Seasage Drive	\$72,632,902.33
11	1	Harbor Drive	\$1,866,769.80
13	13	Banwick Park	\$ 5,352,915.99
14	10	Spanish Circle	\$ 1,289,087.95
-	12	Marine Way	-
TOTAL COST			\$378,362,998.23

Figure 1-5 depicts each problem area and associated capital improvement project ranking.

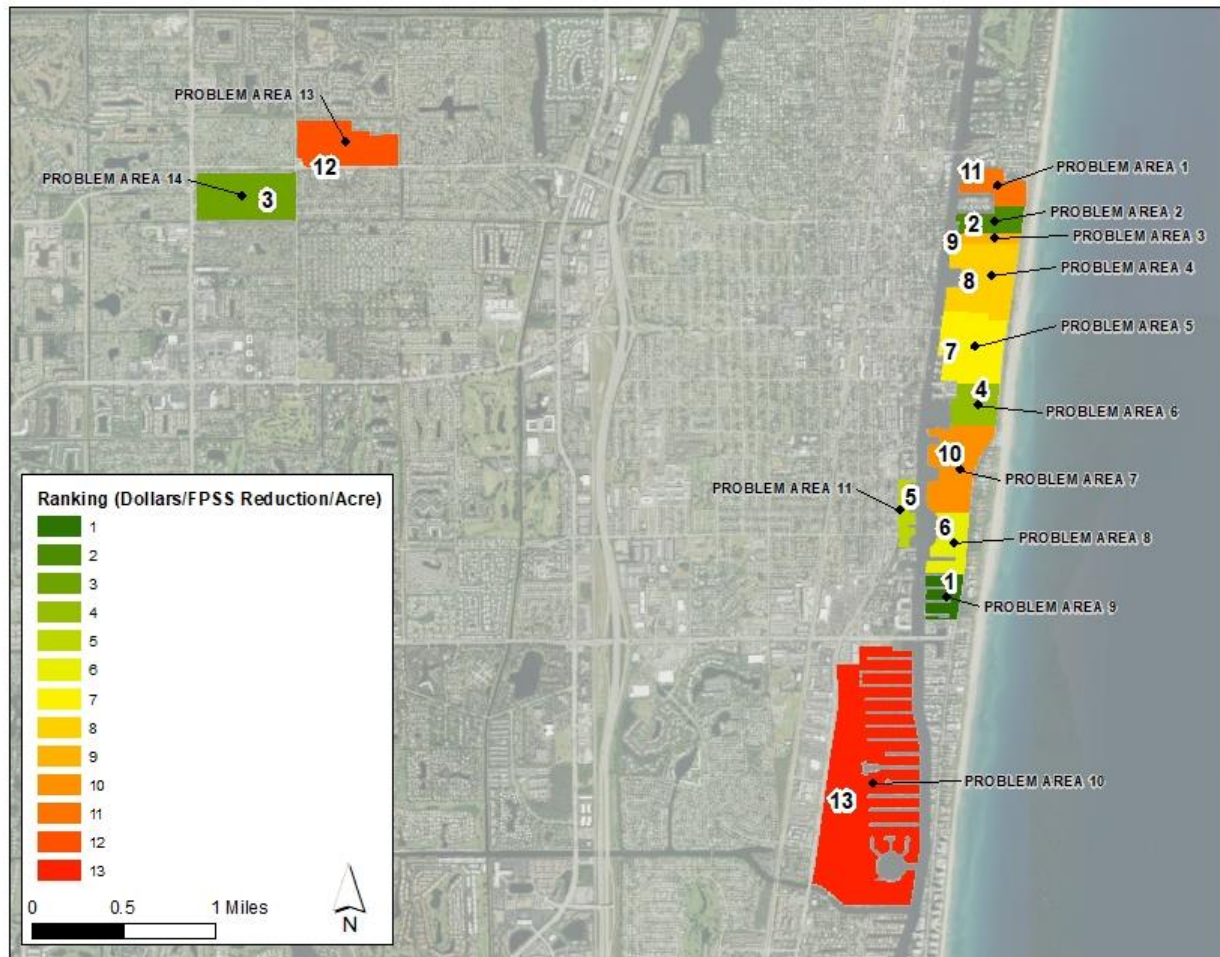


Figure 1-5: Problem Area and Capital Improvement Project Ranking

1.9 Task 8: Stormwater Ordinance Review

A review of existing stormwater ordinances for the City of Delray Beach was performed in accordance with Task 8 of the scope of work. This task reviewed existing stormwater ordinances and suggested modifications and additional ordinances to improve the quality and quantity requirements of stormwater within the city. The main ordinances the should be revised are:

1. An ordinance in which new or redeveloped residential commercial sites retain water quantities for a 5-year 1-day storm event on site.
2. Maximum lot coverage for single family residential should be maintained at 40% lot coverage.
3. Implement minimum open space requirements:
 - a. Commercial/Industrial: Min. 15%
 - b. Residential: Min. 25%

4. Developers shall implement three structural Best Management Practices outlined in **Section 7.0** of this SWMP.
5. On site erosion control practices
6. Post-development annual runoff shall not exceed pre-development annual runoff
7. Implement a 5-year permit recertification process or modify permit conditions every 5 years.
8. Sedimentation control BMPs should be implemented for every site.

These are just a few of the recommendations that were provided to the City and presented to City Staff comprised of Public Works Planning and Zoning and the Assistant City Manager on December 3, 2018. This task was done under a separate deliverable and will not be included within the text of this SWMP.

1.10 Task 9 – Utility Rate Structure Review Assistance (Optional Task)

Task 9 is an optional task to assist the City in reviewing the current Stormwater Utility Rate structure. The City is currently in the process of retaining a consultant to perform this review. Therefore, this task will not be part of the Stormwater Management Master Plan Update Report.

1.11 Task 10: Section 9 – NPDES Review

This task included a review of the current National Pollutant Discharge Elimination System (NPDES) permit requirements and develop a protocol that will satisfy the City's requirements for the existing Municipal Separate Storm Sewer System (MS4) - NPDES permit, and support the City in streamlining data collection methodologies for future annual reporting cycles. ADA met with the City staff and reviewed the current data collection process for developing the NPDES annual report. Information relating to the location, dimensions, installation dates, etc. of stormwater facilities within the City is currently stored in GIS Stormwater Infrastructure databases. However, maintenance activities and inspections of the facilities are recorded manually by field crews using paper records.

Upon reviewing the current methods used by the City to create their yearly NPDES reports, ADA identified several issues that could be improved. During the review of the SWMP Summary Table, it was found that some of the structural controls and stormwater collection systems were being inspected much more frequently than required as outlined in Table II.A.1.a of the State of Florida MS4 Permit FLS000018- 004 (see **Appendix 9A**). For example, only 10% of all pipes and culverts should be inspected each year. However, of the 20.3 miles of total pipes and culverts, the City inspected 52 miles in the 2016-2017 reporting period. That is more than two inspections per pipe or culvert per year. The same inspection rule applies for all inlets/ catch basins/ and grates. However, of the 2,630 reported facilities, there were 52 reported inspections, with a reported inspection percentage of 100%. The total number of inlets/ catch basins/ and grates that were inspected must be reported, even if a single inspection covers multiple structures.

Along with this, ADA understands that the City hasn't fully integrated their stormwater facilities database into GIS. However, it may be necessary to update the fields within the shapefiles to include data required for NPDES tracking and reporting. For example, the number of inspections or maintenance activities per stormwater facility for the reporting year. GIS training is recommended for all City staff to help maintain the stormwater databases and streamline the data collection process for the NPDES MS4 Permit annual reporting. Another option would be to outsource the database creation and data collection annual reporting process to a third-party sub-contractor.

2.0 INTRODUCTION

2.1 Background

The City of Delray Beach is approximately 16 square miles and located in Palm Beach County on the Atlantic Coast of southeast Florida. The location of the City is shown in **Figure 2-1**. The City spans from the Atlantic Ocean west to predominantly along South Military Trail. This City is bordered by the South Florida Water Management (SFWMD) C-15 Canal and Lake Worth Drainage District (LWDD) L-38 Canal to the south and predominantly by the LWDD L-30 Canal to the north. The City also contains LWDD L-32 and E-4 canals. The City's municipal boundary and major hydraulic features are shown in **Figure 2-2**.

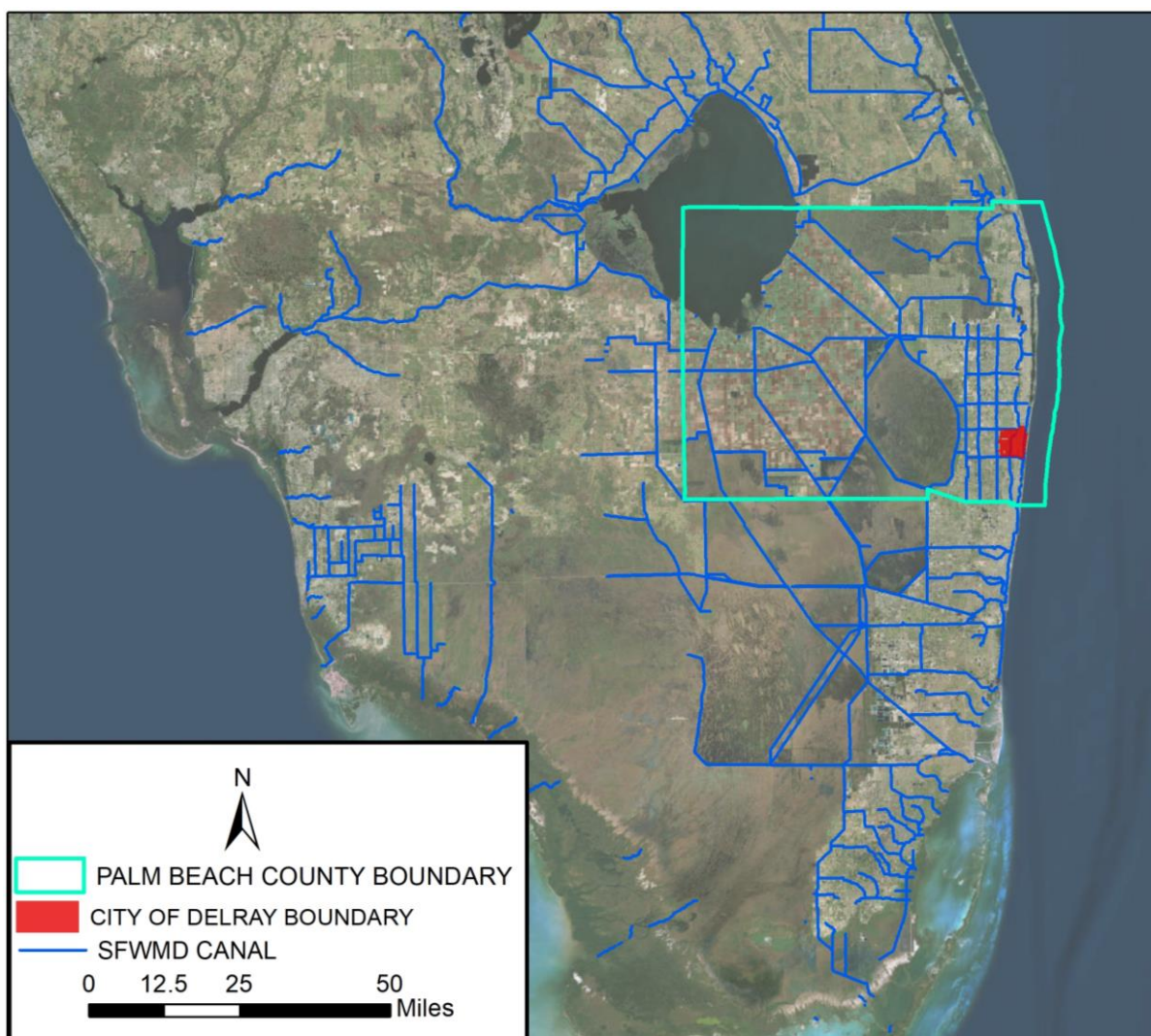


Figure 2-1: City of Delray Beach Location

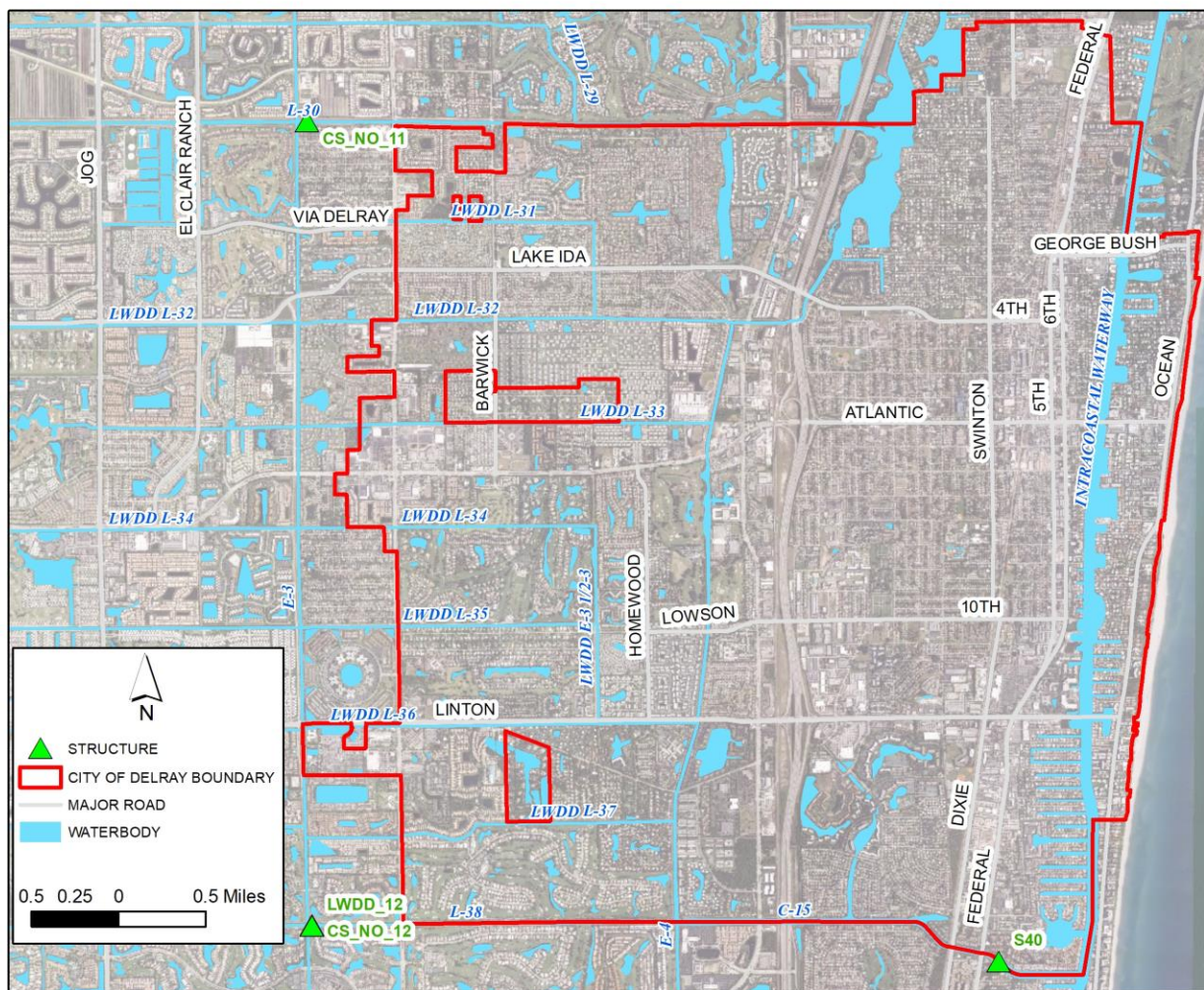


Figure 2-2: City of Delray Beach Municipal Boundary and Major Hydraulic Figures

The City's Stormwater Master Plan (SWMP) was originally created in 1993 by Mock, Roos & Associates, Inc. A revision was completed in 2000 by Kimley Horn & Associates, Inc. The last SWMP evaluated 11 known flood problem areas throughout the City and provided recommendations for improvements needed in the City's drainage system, which have only been partially completed to date.

The City, as with most of South Florida coastal communities, experiences stormwater management challenges and can be susceptible to impacts of sea-level rise and localized flooding. The projected rising of sea levels and groundwater can affect the intracoastal and canals within and adjacent to the City, which represent the primary drainage systems within the City. These issues, can in turn, compromise existing secondary drainage systems and ultimately reduce the capacity of these systems, which often results in flooding of streets and building, when coupled with frequent storm events. Identification of areas with the most vulnerability to sea level rise and groundwater rise within the City

will provide the City with an additional tool for evaluating future projects and partner with Palm Beach County, LWDD and the South Florida Water Management District (SFWMD) which control the regional drainage systems, to implement regional solutions to address potential impacts due to sea level.

The City retained A.D.A. Engineering, Inc. (ADA) under the Agreement for Professional Services (RFQ 2017-048), dated August 31, 2017 to perform an update to the City's SWMP. The goal of the SWMP update is to create a plan to address water resource issues and problems within the City. These issues include drainage problems, street flooding, tidal flooding, inadequate infrastructure, stormwater quality and recharge as well as other stormwater related issues or problems. The Scope of Services include reviewing the City's drainage infrastructure, evaluating the adequacy and condition of the drainage facilities, determining the Level of Service (LOS) for flood protection for the City's sub watersheds, identifying water resource and drainage issues/problems, and identifying and defining cost-effective solutions.

Included in this effort will be a review of the City's Stormwater Utility Ordinance and Fee structure, and recommend revisions to the fee structure to address the fairness and the fee distribution. Additionally, review of the City's National Pollutant Discharge Elimination System (NPDES) permit and requirements and development of an automated GIS system to collect inspection, sampling and other applicable data gathered by City staff to meet permit requirements. In addition, the updated SWMP will address the current and future needs of the City based on growth and climatological changes that have and will continue to impact the City's drainage system.

2.2 Stormwater Master Plan Purpose and Scope

ADA was contracted by the City to complete the Stormwater Master Plan update in accordance with Service Authorization No. 17-01, which is part of the Agreement for Professional Services (RFQ 2017-048) between the City and ADA. Service Authorization No. 17-01 was subdivided into 11 tasks with the final task consisting of preparing the SWMP Report.

The ADA Team scope of work to develop the City of Delray Beach Stormwater Master Plan was subdivided into the following key tasks:

- Task 1 – Kickoff Meeting
- Task 2 – Data Acquisition and Evaluation
- Task 3 – Existing Conditions Hydrologic/Hydraulic Modeling (TM1)
- Task 4 – Existing Conditions Level of Service (TM2)
- Task 5 – Projected Sea Leve Rise Impacts (TM3)
- Task 6 – Water Quality Assessment (TM4)
- Task 7 – Capital Improvement Projects (TM5)
- Task 8 – Stormwater Ordinance Review- Provided in separate deliverable
- Task 9 – Utility Rate Structure Review Assistance (Optional Task)
- Task 10 – NPDES Review (TM6)

Technical memorandums (TM) were prepared for some of the key tasks associated with SWMP Update Report. The tasks where TMs were prepared and associated TM number are outline in the list above. TM's were submitted to the City for review, and applicable comments are included in this report.

The scope of each tasks is further summarized in the text below labeled by its respective section within this SWMP Report, if applicable.

2.2.1 Task 1: Kickoff Meeting

The project kickoff meeting was held on January 25, 2018. The primary objectives of the kickoff meeting were to (1) introduce project team to City staff, (2) discuss the project approach for each of key scope of work elements of the Service Order, (3) discuss specific data requirements needed to prepare complete the Stormwater Master Plan update, and (3) discuss City of Delray Beach's (City's) expectations for other project components including deliverables, and schedule. The minutes of the project kickoff meeting are included in **Appendix 1A**.

2.2.2 Task 2: Section 3 - Data Acquisition and Evaluation

Data collection and evaluation involved requesting and collecting readily available data to support the development of and findings within the SWMP. Data was requested and acquired from the various sources maintaining data within the City as well as from the City. Limited field visits were also performed during rainfall events occurring during the development of this SWMP to physically observe the response of some of the City's stormwater management systems. The collected data was cataloged, evaluated, and utilized as necessary to support the analyses and preparation of this Stormwater Master Plan Report.

2.2.3 Task 3, Section 4 - Existing Conditions and Hydraulic Modeling

For this task, the purpose is to develop a representative one dimensional (1D)/two dimensional (2D) numerical hydrologic/hydraulic model of 14 known problem areas within the City to determine the current flood protection LOS in these areas, identify drainage issues and flooding problems, evaluate impacts of future projected sea level and groundwater rise conditions, and identify cost-effective solutions to improve the flood protection LOS to the maximum extent possible. The approach for selecting the 14 known problems areas is described in **Section 4.0**.

2.2.4 Task 4: Section 5 – Level of Service

The purpose of this task is to establish the LOS using documented procedures and requirements and will address minor, secondary and primary road systems as well buildings based on assumed finished floor elevations. Different storms will be established for each of these features based on common practices and coordination with the City. The results will be quantified by establishing a Flood Protection Severity Score (FPSS)

based on the linear feet of roadway meeting or not meeting the applicable LOS and number buildings meeting or not meeting the LOS. Maps will be produced showing the locations of areas of noncompliance and level of exceedance. The FPSS will be used to rank each of the Problem Areas based on level of flood severity.

2.2.5 Task 5: Section 6 - Projected Sea Level Rise Impacts

An important factor of evaluating flooding within any coastal area is to evaluate Sea Level Rise scenarios based on agreed upon source of anticipated ocean rise estimations. The scenario will reflect a timeframe as directed by the City such as 30 or 75 years into the future. The existing conditions model developed as part of **Section 4.0** will be revised to reflect the changes associated the projected higher sea level, including the boundary conditions and soil storage. The model will be run to assess the impacts of SLR by comparing the flooding depths and spatial extents to the results of the existing conditions model results, including reduction in overall level of service.

2.2.6 Task 6: Section 7 – Water Quality Assessment

The water quality assessment portion of this SWMP reviews currently existing infrastructure and SFWMD ERP permits. Areas where the water quality could be improved are identified and suggestions to improve these areas are outlined. Water quality features considered include swales, exfiltration trenches, ponds, and stormwater filters. One of the first steps in site planning involves taking inventory of the existing features on the site including topography, soil characteristics, flow paths, drainage features, building and stormwater infrastructure, impervious areas, open spaces, and vegetation. Both structural and non-structural site planning practices are identified that can be utilized to increase the amount of filtration through natural vegetation and percolation techniques. These stormwater management practices take an innovative approach to mitigate hydrologic, hydraulic and water quality impacts from future development and redevelopment and seeks to treat runoff and stormwater pollution at or near the source.

2.2.7 Task 7: Section 8 – Capital improvements Projects

To reduce all or most of the flooding within the 14 Problem Areas, flood reducing structures and practices may be implemented as capital improvement projects. The results obtained as part of **Sections 3.0** through **6.0** will be used to identify capital improvement projects to improve the flood protection level of service and flood protection severity score (FPSS) for existing roads and habitable buildings for the projected 30-year planning horizon sea level and groundwater rise. The capital improvement projects will be compared to projects identified on previous master plans that have not been constructed to date. Regulatory requirements for flood stages and allowable discharge rates will be evaluated in the development of alternatives and to meet current environmental permitting requirements and City ordinances. **Section 8.0** will also include conceptual illustrations of the proposed projects and opinion of probable construction costs to implement the projects. The capital improvement projects will then be ranked and

prioritized based on their cost effectiveness to improve the flood protection level of service and FPSS.

2.2.8 Task 8 – Stormwater Ordinance Review

The purpose of this task is to review existing stormwater ordinances and suggested modifications and additional ordinances to improve the quality and quantity requirements of stormwater within the city. Recommendations include modification of current city ordinances and implementing Best Management Practice requirements within the city for future developments. A list of structural and non-structural practices is not only listed within the PowerPoint presentation presented to the City by ADA, but also outlines in **Section 7.0** of this SWMP. The review of this task was presented to the city in a private board presentation on December 3, 2018. The deliverable materials are not included within the text of this SWMP Report.

2.2.9 Task 9 – Utility Rate Structure Review Assistance (Optional Task)

Task 9 is an optional task to assist the City in reviewing the current Stormwater Utility Rate structure. The City is currently in the process of retaining a consultant to perform this review. Therefore, this task will not be part of the Stormwater Management Master Plan Update Report.

2.2.10 Task 10, Section 10 – NPDES Review

The purpose of this task is to perform a review of City's National Pollutant Discharge Elimination System (NPDES) permit requirements, develop protocol that will satisfy the City's requirements for the existing Municipal Separate Storm Sewer System (MS4) - NPDES permit, and support the City in streamlining data collection methodologies for future annual reporting cycles. This permit requires that the City implement programs to protect waterbodies from pollutant loading and illicit discharges. As part of this task, recommendations will be provided for the requirements for inspection and maintenance of drainage facilities, reviewal of the current stormwater maintenance and inspection system, and streamlining and automation, to the maximum extent practical, the data collection effort using the City's current infrastructure database and potentially integrating GIS based facility management software.

3.0 DATA ACQUISITION AND EVALUATION

3.1 City of Delray Beach

ADA collected data associated with stormwater infrastructure, construction projects, previous permits, groundwater table data, and studies from the City of Delray Beach. The City provided files which include the City's current catch basins and outfalls, drainage structures, seawall analysis, as well as project cost estimates for various completed projects.

The data catalog presented in **Appendix 3A** provides a listing of the City's project data collected for incorporation into the hydrologic/hydraulic models. The data catalog in **Appendix 3A** also includes a section of pertinent GIS data collected from the City.

3.1.1 Existing Stormwater Infrastructures

The City of Delray Beach provided all readily available data, this data included digital and hard copy data of stormwater management related projects, reports, GIS shapefiles, CAD data, and digital PDF files. The data provided will support the development of the Stormwater Master Plan comprised of the following:

1. GIS shapefiles
 - a. City Limits
 - b. Water Mains, Nodes, Valves, and Hydrants
 - c. Existing and Future Land Use
 - d. Canals, Water Bodies and Outfalls
 - e. Delray drainage and manholes
 - f. Soil Data
 - g. Aerial images 2001
 - h. Water Canal Ownership
 - i. Swales, Ponds, and Basins
2. Locations of known drainage problems
3. LiDAR data for the City of Delray
4. Storm Drain Structures Description and Maintenance Cost
5. Drainage Improvement Projects
 - a. Reports
 - b. Cost Breakdown
6. MS4 NPDES permit and submittals to Countywide permitting coordinator
7. Stormwater ordinances
8. Utility rate structure studies
9. Seawall Analysis
 - a. Elevations
 - b. Vulnerability Analysis
10. Pump Station Operations

3.1.2 GIS Data

The City currently maintains stormwater infrastructure data in GIS shapefile format. This data includes but is not limited to: water mains, valves, nodes, canals, outfalls, drain inlets, manholes, pump stations, etc. Connectivity, pipes sizes and inverts of drainage systems were identified using the most up to date permitting available through the SFWMD website. This data was valuable in the development of the hydraulic modeling for the existing conditions and level of service tasks. This data was also useful in suggesting major improvements to the city's current drainage structures for the future.

3.2 Data from Other Sources

In addition to the main data contributions from the City of Delray Beach, other sources of information were accessed to help support the development of the Stormwater Master Plan. The following subsections provide a description of the entity and applicable data collected to support development of the City's SWMP.

3.2.1 South Florida Water Management District

Existing stormwater and environmental permitting information is available via the SFWMD ePermitting website. This website contains supporting documentation for Environmental Resources Permits (ERP) and applications submitted to and approved by the SFWMD. The website for ePermitting through the SFWMD is found below:

- SFWMD ePermitting portal:
 - <http://my.sfwmd.gov/ePermitting/MainPage.do>

In conjunction with the SFWMD permitting website, a GIS shapefile containing the location and extent of the SFWMD ERP permit can be found in the SFWMD GIS data catalog mentioned previously.

Additionally, the SFWMD data catalog is a viable source for additional data that is often directly available from other sources such as land use, soils, aerial imagery, etc. Although this data may not be maintained regularly, this data may be used if alternate resources are not readily accessible.

3.2.2 National Oceanic and Atmospheric Administration (NOAA)

Tide data is available from the National Oceanic and Atmospheric Administration (NOAA) and can be used to assess depth of high and low tides to evaluate potential overflow and flooding. NOAA monitors, assess, and distributes tidal data, current water level, and other coastal oceanographic data via their Center for Operational Oceanographic Products and Services (CO-OPS). NOAA's data is accessible via the web, at the following location:

- Main NOAA CO-OPS portal:
 - <http://tidesandcurrents.noaa.gov/>
- NOAA's Observational Data Interactive Navigation (ODIN) site for station data:
 - <http://tidesandcurrents.noaa.gov/gmap3/>

GIS data is also available from NOAA. GIS data for the NOAA stations can be obtained from the following location:

- NOAA GIS portal:
 - <http://www.nws.noaa.gov/gis/>

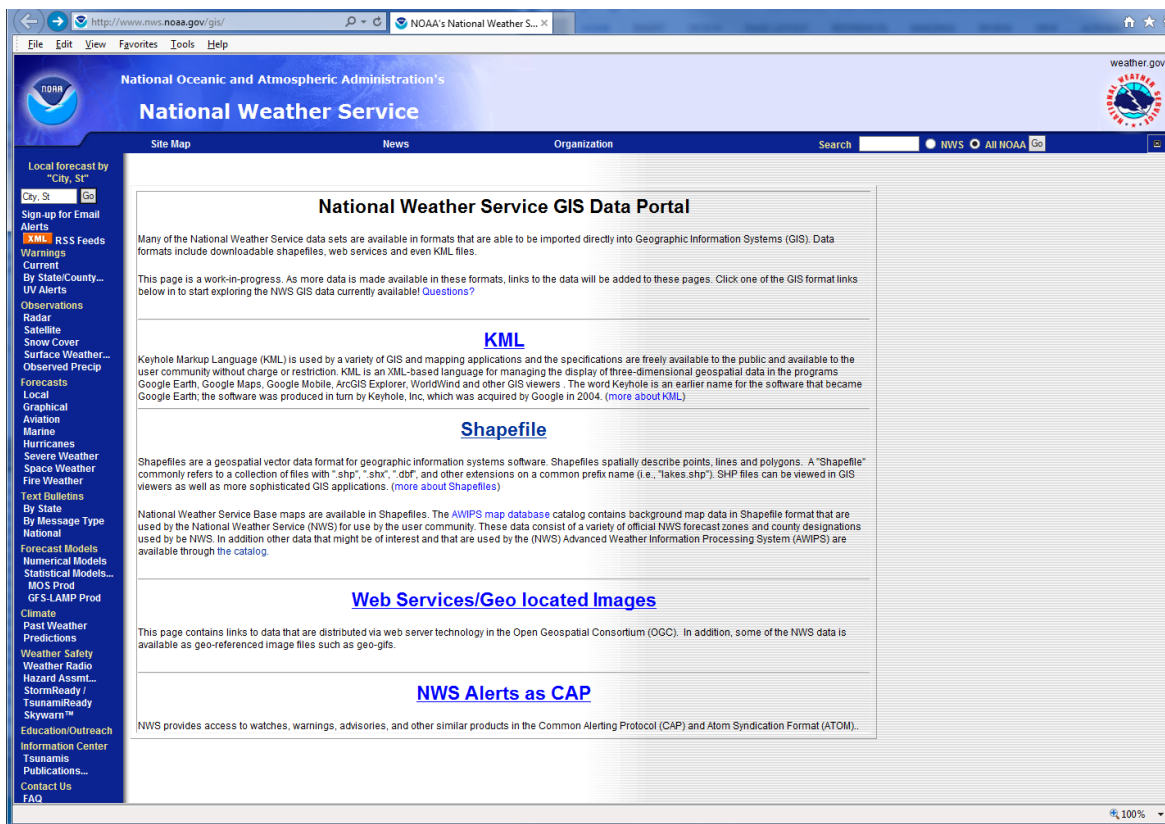


Figure 3-1: NOAA Website Homepage

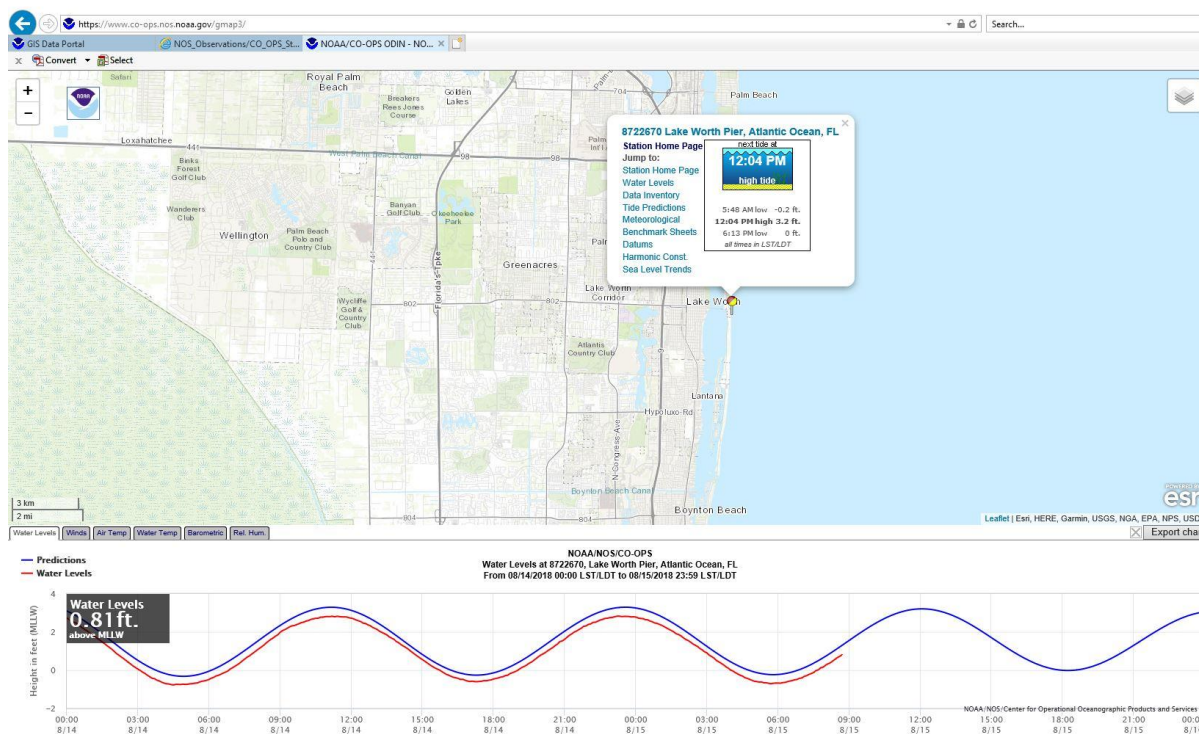


Figure 3-2: Tidal Data from NOAA on the City of Delray Beach

Figure 3-2 shown above is a graphical representation of tidal data taken every hour on the hour by NOAA. Various NOAA satellite stations around the country record and log hourly data that is available to the public directly through their website. This data is used to determine high tide, low tide, and king tide which proved useful in not only determining the Level of Service for the 14 problem areas but was used in the Sea Level Rise assessment (**Section 6.0**) of this SWMP.

3.2.3 Lake Worth Drainage District

Canal elevations and flow directions for all canals within the Lake Worth Drainage District (LWDD) service area are available through their website. This data encompasses areas ranging from West Palm Beach all the way to the Palm Beach County line. This data was used in the hydraulic modeling phase of this SWMP to determine peak flow rates and loading capacity's when determining flood zones for the specified problem areas.

Main LWDD Portal:

- <http://www.lwdd.net/>

Maintained Canal Elevations Map:

- <http://www.lwdd.net/wp-content/uploads/2014/08/District-Map.pdf>

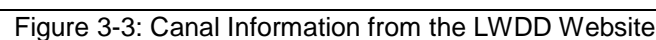


Figure 3-3 shown above is a map of existing canal elevations provided directly on the Lake Worth Drainage District website. These elevations were used in evaluating stage-storage relationships in problem areas 13 and 14 where existing pipe connections outfall into nearby LWDD canals.

4.0 EXISTING CONDITIONS HYDROLOGIC/HYDRAULIC MODELING

4.1 General Hydrologic/Hydraulic Model Setup and Methodology

The purpose of this task, *Existing Conditions Hydrologic/Hydraulic Modeling*, is to develop a representative numerical hydrologic/hydraulic model of 14 known problem areas within the City to determine the current flood protection LOS in these areas, identify drainage issues and flooding problems, evaluate impacts of future projected sea level and groundwater rise conditions, and identify cost-effective solutions to improve the flood protection LOS to the maximum extent possible. The approach for selecting the 14 known problems areas is described in **Section 4.9**.

The existing conditions hydrologic/hydraulic was developed using the ICPR 4 Expert Model, Version 4.03.02. The original scope of services requested development of a 1-D hydrologic/hydraulic model for the City. However, due limited elevation variations throughout the City and the subtle interconnectivity within drainage basins, an integrated 1-D and 2-D hydrologic/hydraulic model was developed using the ICPR 4 Expert Model. The model was developed for the top 14 identified problem areas within the City based on observed flooding and input from residents. Model data input include:

1. Measured rainfall and tidal data
2. Runoff curve numbers (CN)
3. Rainfall depths for design storm events
4. Digital terrain model from available LiDAR data
5. 2-D overland flow roughness coefficients
6. 1-D hydraulic nodes and links (stormwater infrastructure)
7. 1-D boundary conditions and 2-D overland flow boundary conditions

The 1-D hydraulics elements of the model include hydraulic nodes and links to represent the existing pipe network and stormwater pump stations, manholes where there are pipe size changes, and inlets where there is flow exchange between the 1-D and 2-D models. The 2-D model elements of the model were developed from the available digital terrain model from LiDAR data. Overland Boundary Stage Lines are included in the 2-D model where there are flow exchanges between land areas and the intercoastal or water bodies. The existing conditions model was tested using a known measured rainfall event and verified based on observed flooding and measured flow depth during that event, due to the lack of available calibration flow and stage data.

The validated model was then used to simulate the current flooding that can be anticipated during the following design storm events, with higher than normal measured tidal conditions (King Tides):

- 5-year, 24-hour
- 10-year, 24-hour
- 25-year, 72-hour
- 100-year, 72-hour

Inundation flood maps were created for each of these design storm events, for the top 14 identified problem areas.

4.2 Topography

A 5-foot (ft) resolution LiDAR topography was downloaded from the SFWMD GIS Database. The dataset is described as the 2007-08 Palm Beach East 5-ft digital elevation model (DEM) based on the North America Vertical Datum (NAVD) of 1988, Release Version 1. This is a 5-ft DEM of bare earth that covers most of eastern and urban Palm Beach County. The City of Delray Beach portion of the data is displayed in **Figure 4-1**. A 1-ft resolution LiDAR that covers the City of Delray Beach is being processed and was not available at the time the existing conditions models were developed.

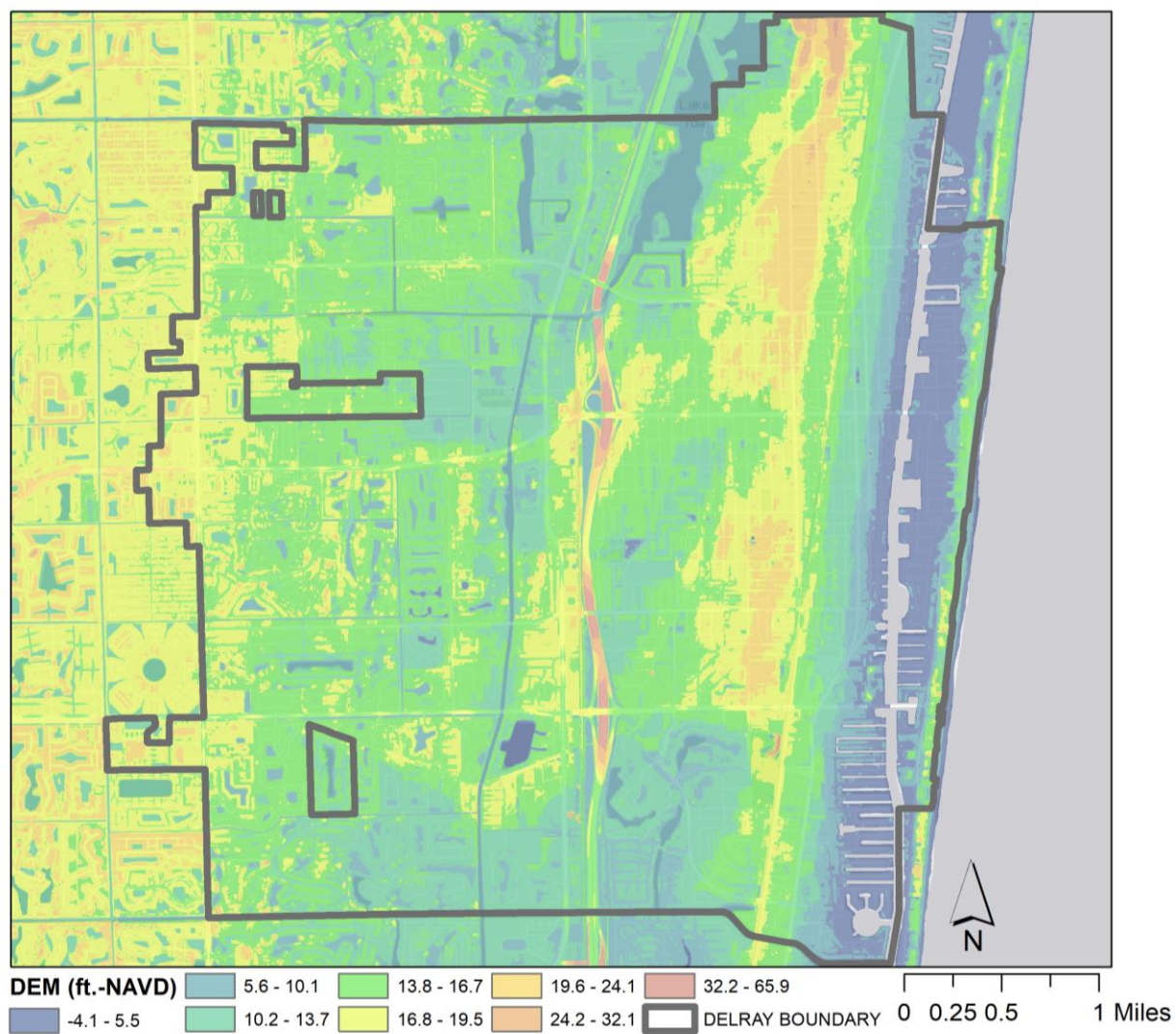


Figure 4-1: Topographic Map of the City of Delray Beach

4.3 Land Use

A land use coverage was obtained from the City of Delray Beach GIS Department. The land use classifications are shown in **Figure 4-2**.

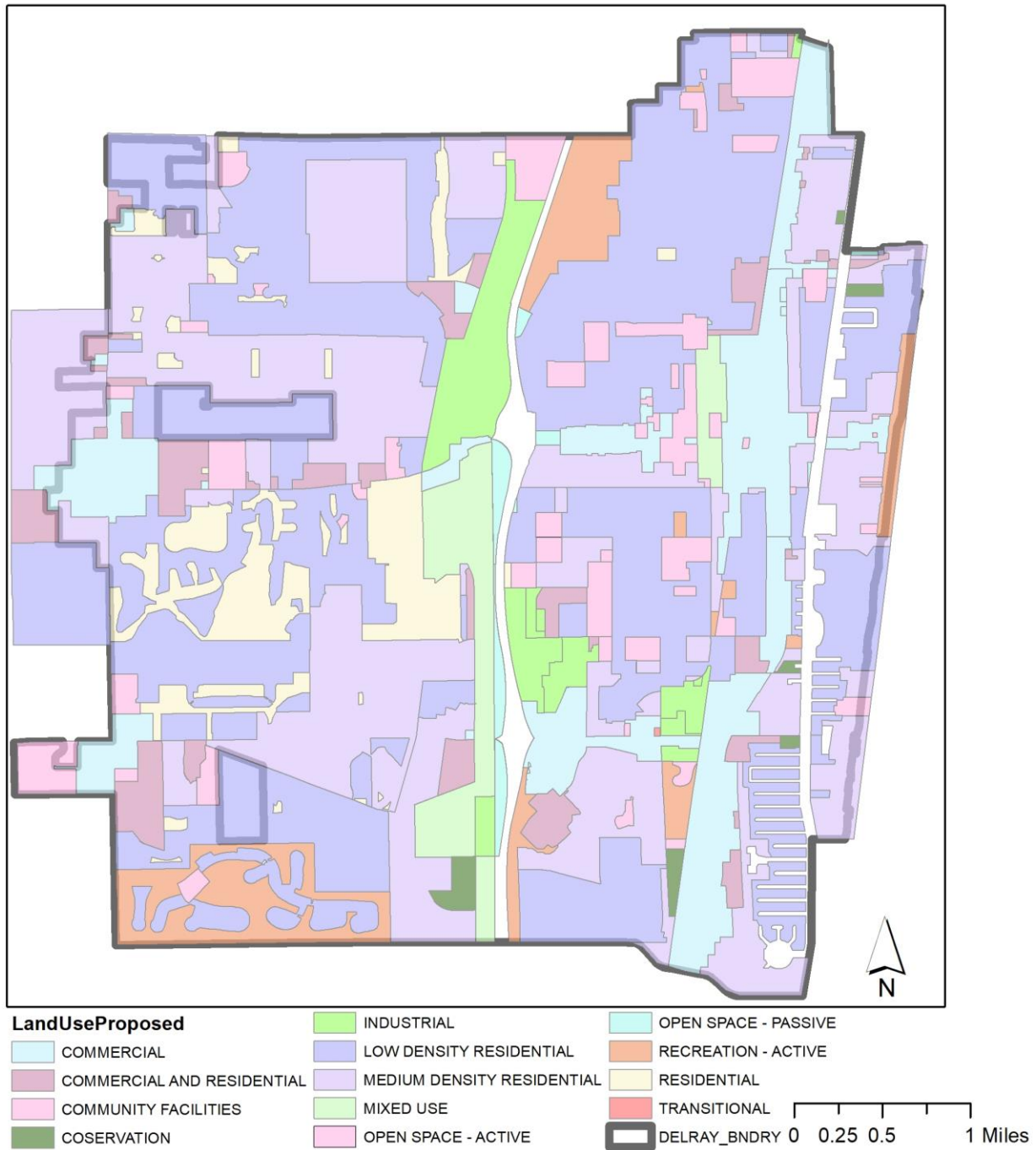


Figure 4-2: Land Use Map for the City of Delray Beach

4.4 Soils

Soil zones were defined according to the soil depth to seasonal high groundwater elevation versus water storage capacity relationship specified in the SFWMD

Environmental Resource Permit (ERP) Applicant's Handbook Volume II for coastal compacted soils, based on Soil Conservation Service estimates. Three soil zones (**Figure 4-3**) were defined for the study area based on the average pervious area elevations:

1. Elevations below 2 ft-NAVD
2. Elevations between 2 and 5 ft-NAVD
3. Elevations above 5 ft-NAVD.

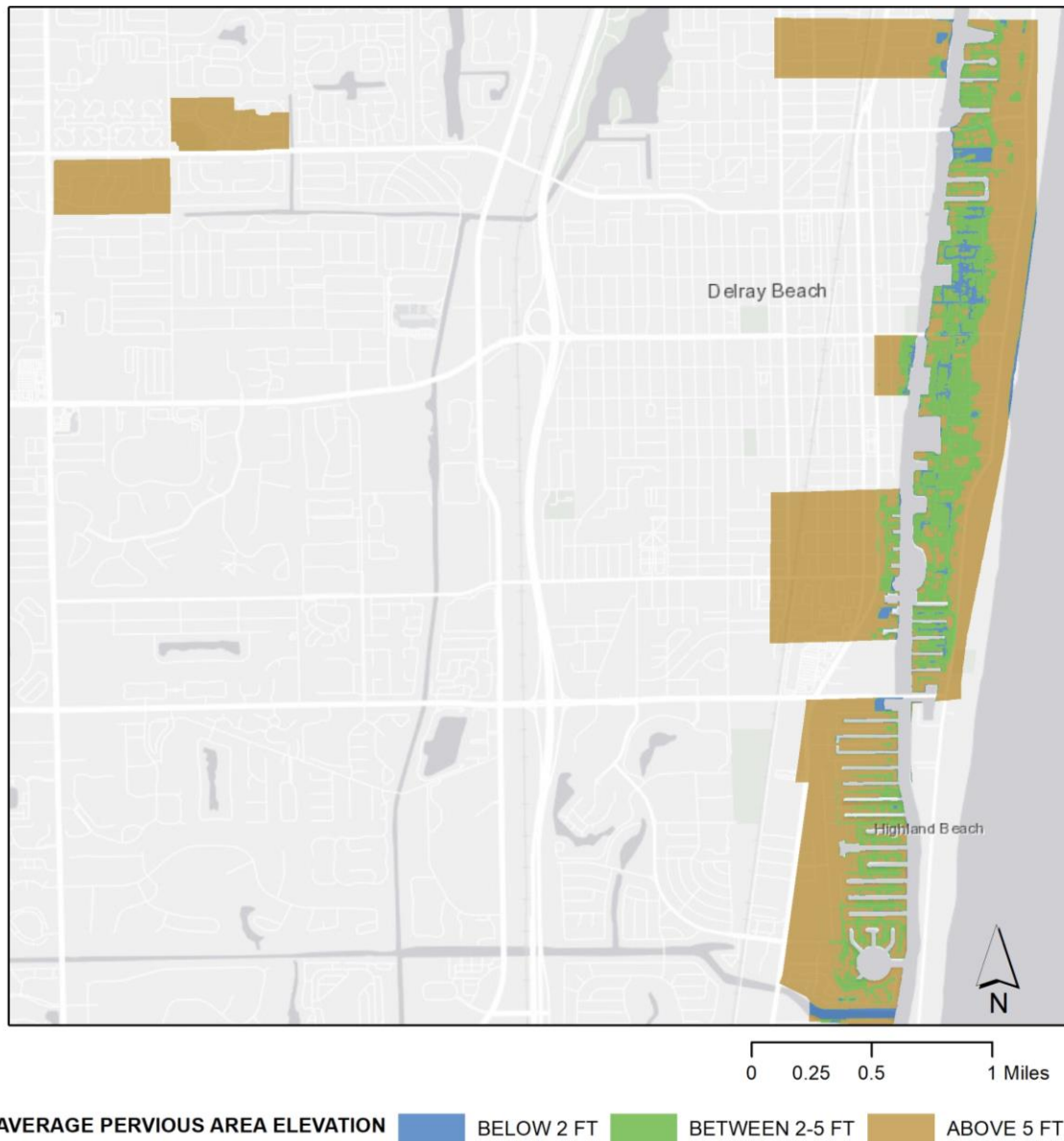


Figure 4-3: Soil Zone Map for the Proposed Model Areas in the City of Delray Beach

4.5 Stormwater Drainage System

Data for the stormwater drainage system was obtained from the City's stormwater infrastructure GIS database. The SFWMD permits database was also reviewed to obtain information on the stormwater system within the 14 identified problem areas. **Table 4-1** shows the ERPs that were obtained from the SFWMD ePermitting database to supplement the City's stormwater infrastructure GIS database.

Table 4-1: Permits Reviewed during Model Development

Permit No.	Application No.	Project Name
50-03383-S	940510-7	CITY OF DELRAY STORMWATER PUMP STATIONS
50-03383-S	120827-7	RECLAIMED WATER EXPANSION AREA 12A
NOT LISTED	170509-4	RECLAIMED WATER EXPANSION AREA 12C
50-03456-S	950221-7	EAST ATLANTIC AVENUE
50-03456-S	000530-13	VENETIAN DRIVE ROADWAY INFRASTRUCTURE IMPROVEMENTS
50-03658-P	960307-2	BARRIER ISLAND PUMP STATIONS
50-03658-P	060929-8	SEA SAGE/MELALEUCA/OLEANDER
50-09696-W	110317-1	CITY OF DELRAY BEACH RECLAIMED WATER EXPANSION – AREA 11B
50-09078-W	090514-3	CITY OF DELRAY BEACH AREA 11A RECLAIMED WATER SYSTEM
50-10238-W	130228-17	RECLAIM WATER EXPANSION – AREA 12A (PHASE 1)
50-10247-W	130226-2	LOWRY ST DRAINAGE
50-10470-W	140130-11	RECLAIMED WATER EXPANSION – AREA 12A PHASE 2 DELRAY BEACH
50-11053-W	160421-4	DELRAY RECLAIMED WATER EXPANSION AREA 12B
50-11489-W	180117-15	DELRAY BEACH RECLAIMED WATER EXPANSION: AREA 12C
50-01277-S	05184-A	PELICAN HARBOR
50-02771-S	911008-10	1991 ROAD RECONSTRUCTION
50-02707-S	910709-10	SOUTHEAST 8 TH STREET DRAINAGE IMPROVEMENTS
NOT LISTED	000814-2	MARINE WAY IMPROVEMENTS (SE 2 ND ST – SE 1 ST ST)

4.5.1 Inlets and Storm Drains

A selected number of inlets and storm drains were extracted from the Stormwater geodatabase provided by the City of Delray Beach GIS Department. Inlets were generalized based on the proposed model mesh size of 25 feet. Inlets in close proximity (less than 25 feet apart) were narrowed-down to a single inlet for modeling purposes. Only manholes where a change in pipe size or a significant change in pipe inverts were selected. **Figure 4-4** shows an example of some of the Selected Drainage Infrastructure selected for Problem Area 10 which is located at the southeast end of the City and west of the Intercoastal.

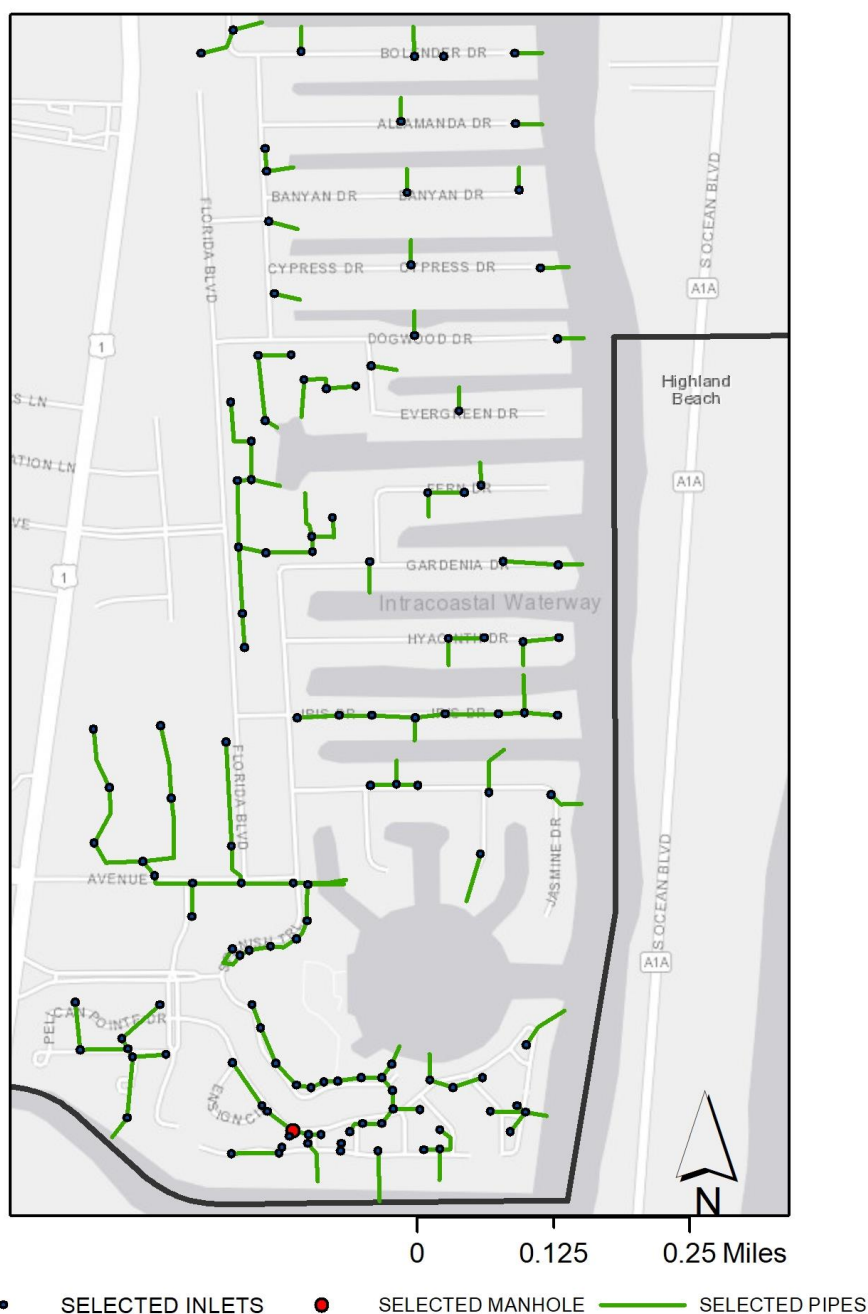


Figure 4-4: Example of Selected Drainage Infrastructure GIS Data for City of Delray Beach

4.5.2 Pump Stations

Seven pump stations exist on the barrier island portion of the City of Delray Beach. Pump on and off elevations were initially obtained from the City operation manual however, in most cases the operations given in the manual had unrealistically high on-elevations. For example, some pump station had on elevations higher than the ground elevation. Thus, adjustments were made based on the permitted on and off elevations as well as several

pump station off-elevations corresponding to the assumed/calculated *Design High Water* (DHW) elevation further discussed in the Model Setup portion of this report. **Table 4-2** shows the data sources used to represent the pump stations in the existing conditions models.

Table 4-2: Data Sources for Pump Station Information

Beach Operating Conditions	Pump station operations and geometry submitted with permit 50-03658-P.
Waterway Operating Conditions	Pump station operations and geometry submitted with permit 50-03658-P.
Thomas Operating Conditions	Pump station operations and geometry submitted with permit 50-03658-P.
Basin Operating Conditions	Pump station operations and geometry described in “Draft—Basin Drive Stormwater Pump Station Evaluation” prepared by WGI on 6-17-2016
Atlantic Operating Conditions	Pump station operations and geometry assumed to be the same as the Seasage (Tamarind) pump station per email to ADA Engineering from Jeffrey Needle on 5/11/18.
Bay Operating Conditions	Pump station operations and geometry submitted with permit 50-03383-P.
Seasage Operating Conditions	Pump station operations and geometry submitted with permit 50-03658-P.

4.6 Rainfall

Gauge rainfall data is available at the SFWMD S-40 spillway located at the southwest end of the City. Spatially distributed radar-based rainfall measurements (NEXRAD) were obtained from SFWMD for the duration of the validation period at 15-minute intervals.

Four design storm events were simulated to establish the existing conditions LOS in the problem area basins:

1. 5-year, 24-hour
2. 10-year, 24-hour
3. 25-year, 72-hour
4. 100-year, 72-hour

The SCSII-24 and SFWMD72 non-dimensional rainfall distributions were used for the 24-hour and 72-hour design storms, respectively. The rainfall depths were specified according to SFWMD design rainfall contours for each of the four storm frequencies. The rainfall depth varies throughout the City, based on the SFWMD rainfall contours. The rainfall depths for each of the 14 problems areas are outlined in **Section 4.12.4**.

4.7 Tide Stages

Measured tidal stages were obtained from the closest NOAA station to the study area which is located at the Lake Worth Pier. In addition, the City of Delray Beach measures tidal stage measurements at White Drive. Additional tidal data was obtained from the SFWMD S-40 spillway tailwater stages which is located at the southwest end of the City. **Table 4-3** shows the period of record of available data for the three stations.

Table 4-3: Tidal Stations Period of Record for Available Water Levels

Station	Start	End
NOAA at Lake Worth Pier	June, 2010	Present
City of Delray Beach at White Drive	January, 2018	Present
SFWMD S40 Spillway Tailwater	September, 1985	Present

4.8 Drainage Basin Delineation and Refinements

The Stormwater Master Plan prepared for the City of Delray Beach in 1993 subdivided the City into 45 drainage basins. **Figure 4-5** shows the 45 drainage basins defined in the 1993 Stormwater Master Plan.

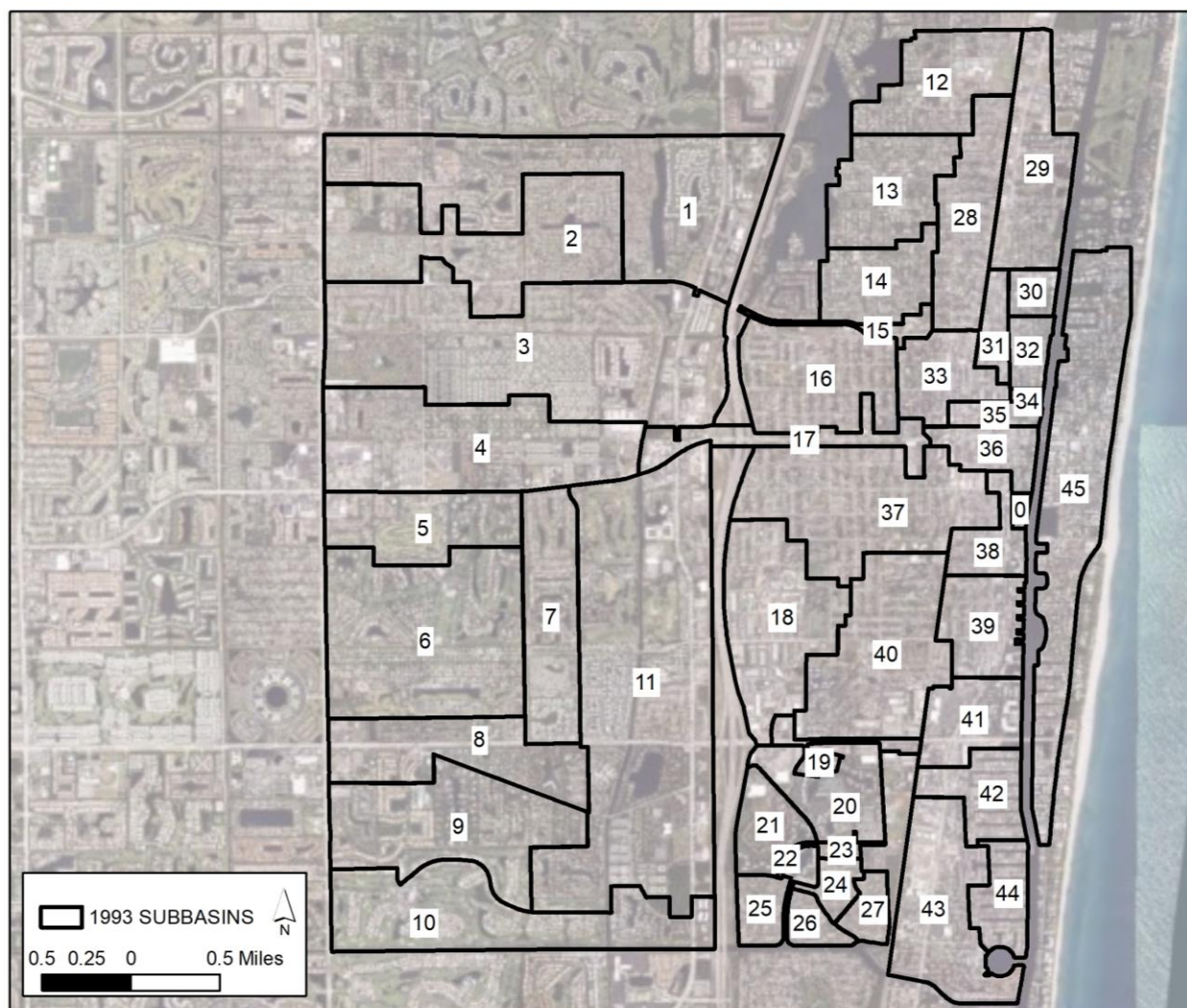


Figure 4-5: 1993 Stormwater Master Plan Drainage Basin Delineation

At the project kickoff meeting, it was agreed between the City and ADA that the drainage basin delineations east of I-95 should be further examined and refined because most of the known flooding issues occur east of I-95. Areas west of I-95 include recent developments that accommodate stormwater predominantly within the development stormwater management system.

The 1993 drainage basins east of I-95 were refined based on LiDAR topographic data and existing drainage infrastructure information. **Figure 4-6** shows the refined drainage basin delineations. The solid black lines in the figure depict the 1993 drainage basin boundaries, while the colored areas depict the refined drainage basin boundaries. The same numerical system used in the 1993 Stormwater Master Plan was maintained, with the refined drainage basins using a subset of the prior basin number. For example, in the 1993 Stormwater Master Plan, the barrier island of the City was subdivided into a single drainage basin (Basin 45). During the drainage basin refinement process, the barrier

island was subdivided into 14 drainage basins, and these basins were numbered 45-1 through 45-14. There were three areas in the 1993 master plan that were not included in the drainage basin delineations. These areas were included Drainage Basins 0-1 through 0-3 as shown in **Figure 4-6**.

After the drainage basin refinement process, there are now 76 drainage basins for the City of Delray Beach.

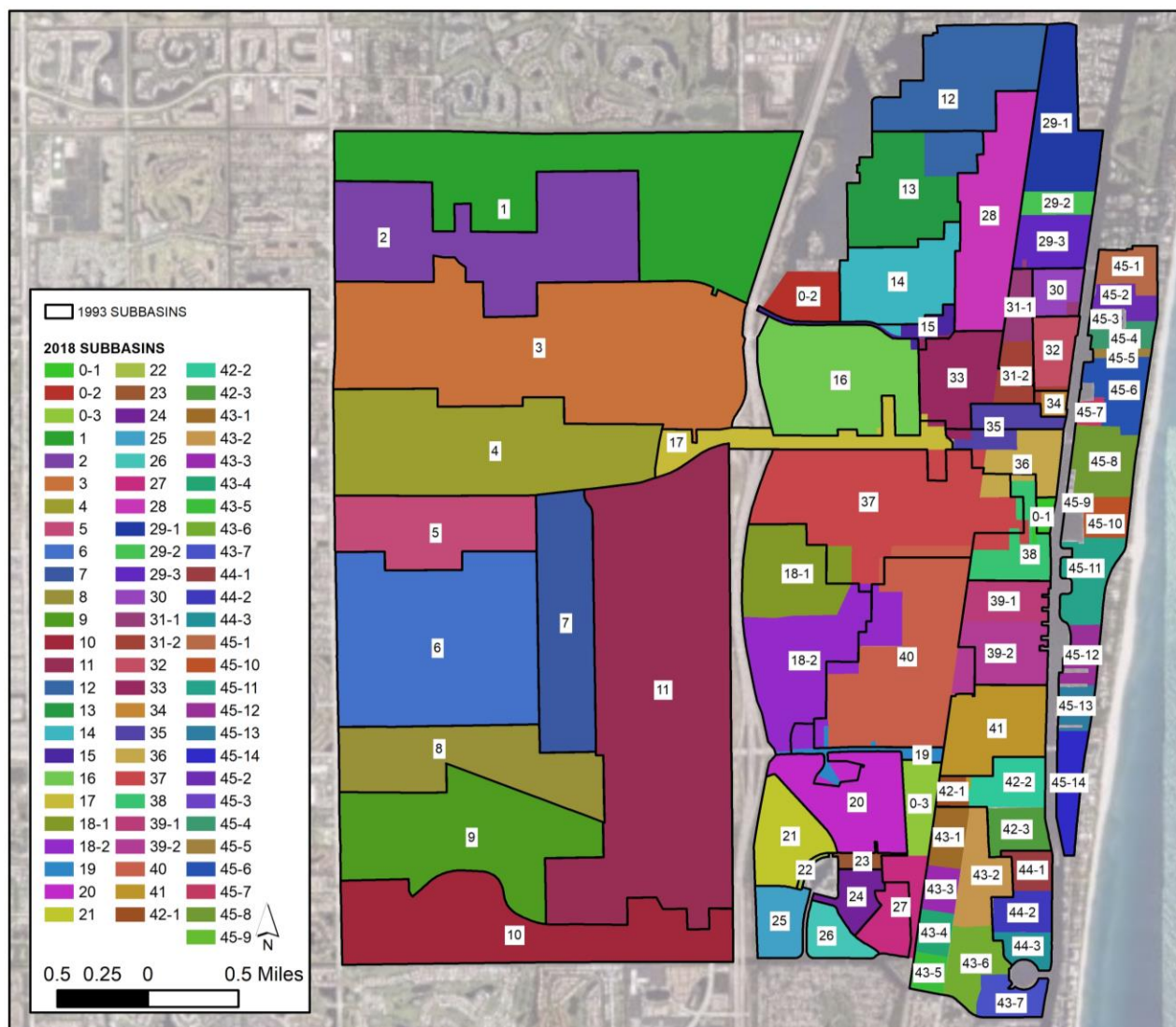


Figure 4-6: Stormwater Master Plan Update Refined Sub-Basin Delineation

4.9 Flood Problem Area Identification

Problem areas were identified by the City of Delray Beach during the Data Acquisition task. The City provided at the project kickoff meeting a hard-copy list of drainage complaints, which was then subsequently converted into a GIS point shapefile. In

addition, the City also identified other areas of known flooding based of observations during storm events, but where no official complaints have been voiced by residents. A total of 21 problem areas were identified by the City. These flood problem areas are depicted in **Figure 4-7**.

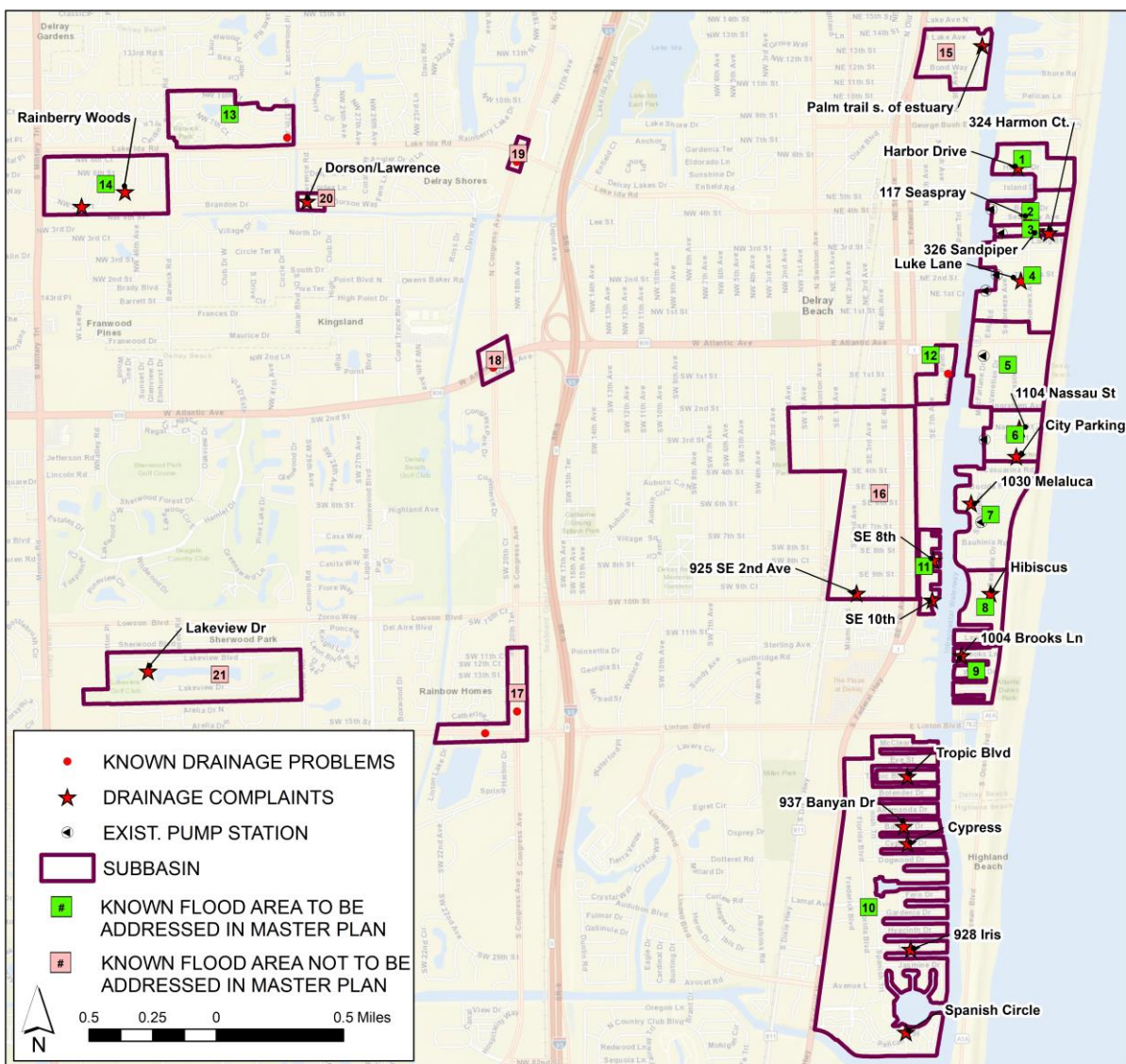


Figure 4-7: Identified Problem Areas

The City of Delray Beach narrowed-down the 21 problem areas into 14 areas that would be addressed in this update of the Stormwater Master Plan. These areas are depicted in green squares in **Figure 4-7**. The following is a description why the other seven areas will not be included in this version of the stormwater master plan update.

- Area 15 – Flooding problem is related to a localized low-lying area with no drainage infrastructure, and the City is in the process of implementing a stormwater infrastructure improvement project to address the flooding.
- Area 16 – This area is currently being addressed as part of the Osceola Park Neighborhood Improvement Project being performed by Mathews Consulting.
- Areas 17 through 19 – These areas include observed flooding within State and County roads, where the City will not be able to implement flood improvement projects in these areas.
- Area 20 – As for Areas 15, the flooding problem is related to a localized low-lying area with no drainage infrastructure, and the City is in the process of implementing a stormwater infrastructure improvement project to address the flooding.
- Area 21 – Flooding in this area is related to a pond equalization pipe that is damaged. The City is currently in the process of replacing this equalization pipe with a large diameter pipe.

4.10 Overview of Problem Areas

For future Level of Service tasks associated with the Stormwater Master Plan Update, the problem areas will be evaluated relative to each other to establish a level of service ranking and prioritization. However, refined drainage basins will be maintained and related to each of the 14 problem areas. **Table 4-4** relates the problem areas to their corresponding refined drainage basin, and **Figure 4-8** shows the problem areas overlaid on the refined drainage basin coverage.

Table 4-4: Drainage Basins Associated with Problem Areas

Problem Area	Area (Ac)	Associated Drainage Basin(s)
1	26.2	45-2
2	22.8	45-4
3	7.8	45-5
4	67.3	45-6, 45-7
5	64.8	45-8
6	27.4	45-10
7	61.2	45-11
8	28.5	45-12
9	19.5	45-13
10	281.5	42-2, 42-3, 43-2, 43-6, 43-7, 44-1, 44-2, 44-3
11	14.6	39-1, 39-2
12	15.3	36
13	59.9	2, 3
14	71.0	3

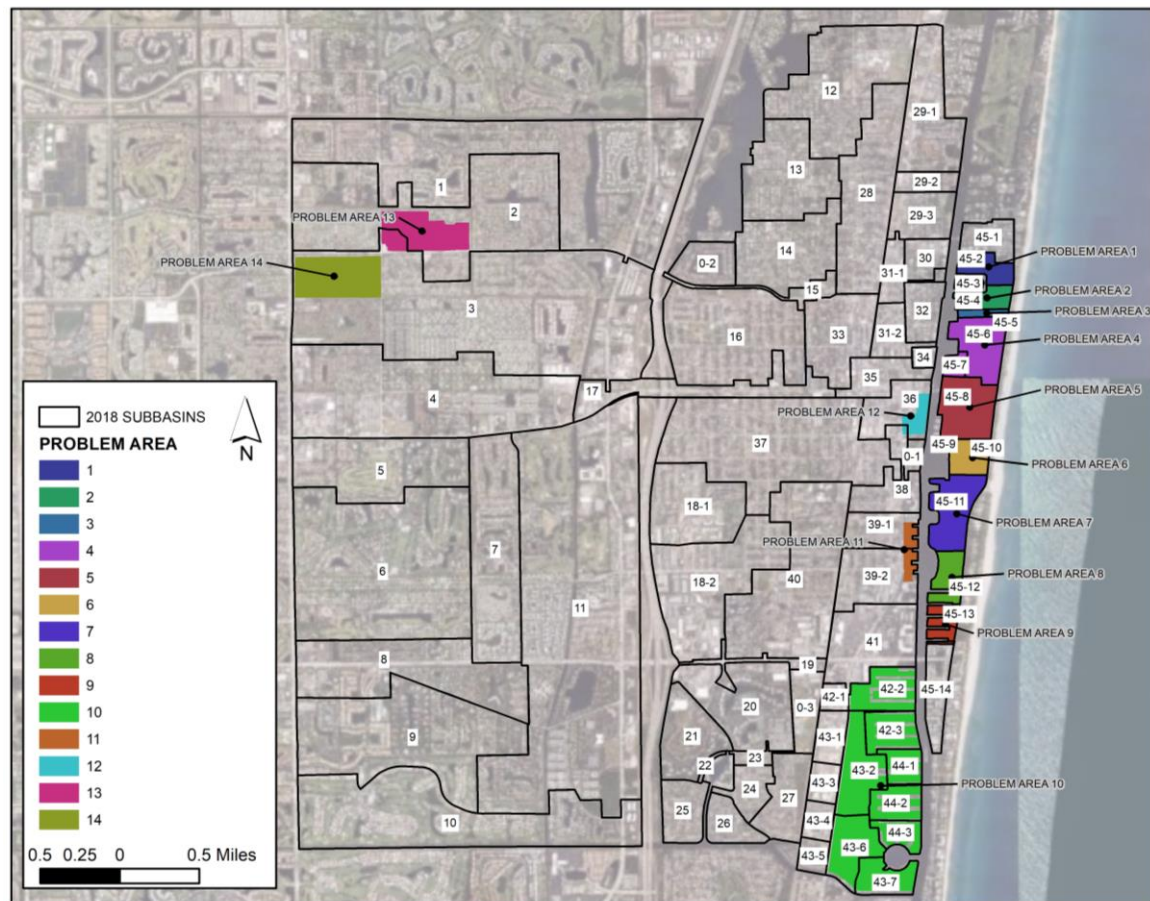


Figure 4-8 – Problem Areas and Refined Drainage Basins

4.10.1 Problem Area No. 1 – Harbor Drive Drainage Complaint

The City's list of Drainage complaints indicated that the Harbor Drive complaint was due to tidal backflow. The date associated with the complaint is September 12, 2017. **Figure 4-9** shows the topography and infrastructure within Problem Area 1.

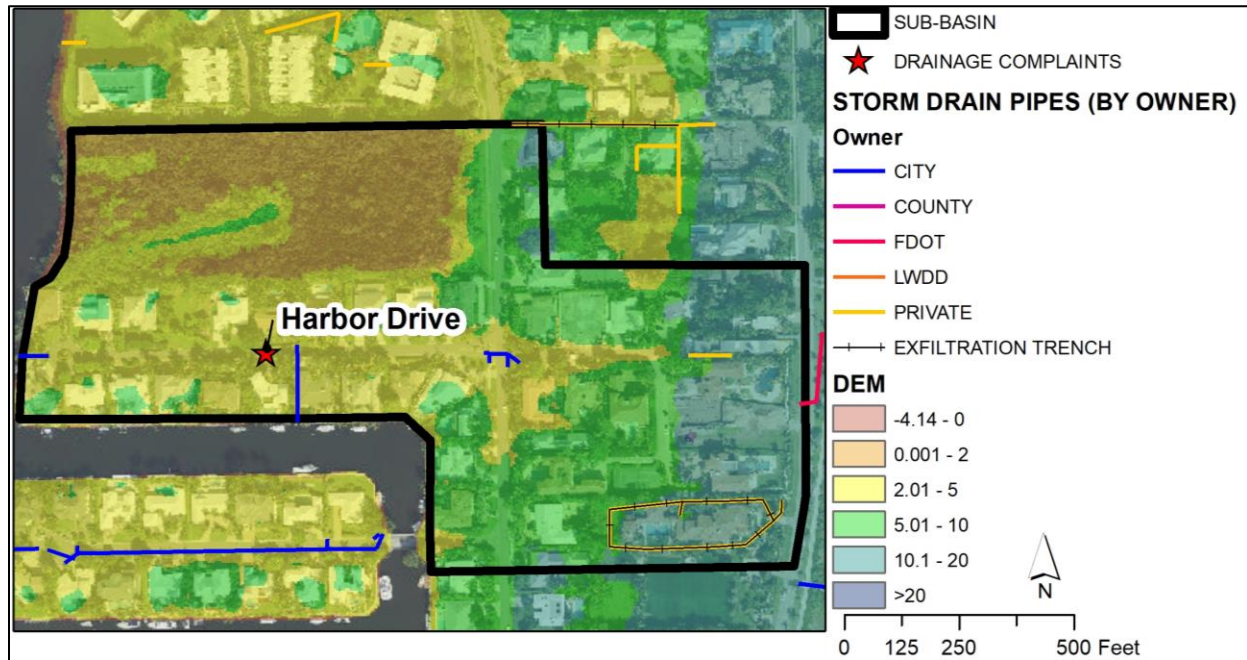


Figure 4-9: Problem Area 1 Topography and Infrastructure

4.10.2 Problem Area No. 2 – Seaspray Avenue Drainage Complaint / Beach Drive Pump Station

The City's list of drainage complaints indicated that ponding on Beach Road occurred at/near 117 Seaspray Avenue. The date associated with the complaint is December 19, 2017. Problem Area 2 is also served by the Beach Drive Pump Station. The City indicated that they would like all pump stations to be assessed in the Stormwater Master Plan Update. **Figure 4-10** shows the topography and infrastructure within Problem Area 2.

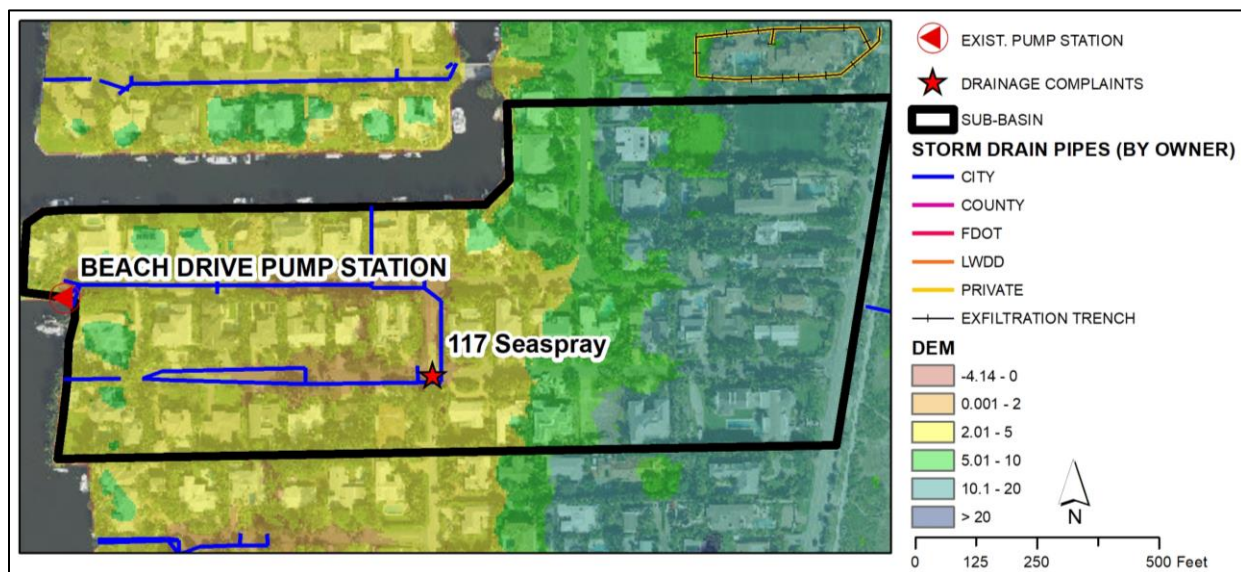


Figure 4-10: Problem Area 2 Topography and Infrastructure

4.10.3 Problem Area No. 3 – Sandpiper Lane and Harmon Court Drainage Complaint / Waterway Pump Station

A drainage complaint at 326 Sandpiper is associated with a date of December 4, 2016. The City suspects that the neighboring property altered their landscape, filled areas and removed drainage features. The City also indicated that Sandpiper needs a positive discharge connecting to a drainage line north or south along Andrews Ave.

Another drainage complaint within Problem Area 3 is the 324 Harmon Court flooding. The City suspects that the topography routes the water to the end of this cull de sac, and there are no drainage features in place to relieve the flooding.

Problem Area 3 is served by the Waterway Pump Station. The City indicated that they would like all pump stations to be assessed in the Stormwater Master Plan Update. **Figure 4-11** shows the topography and infrastructure within Problem Area 3.

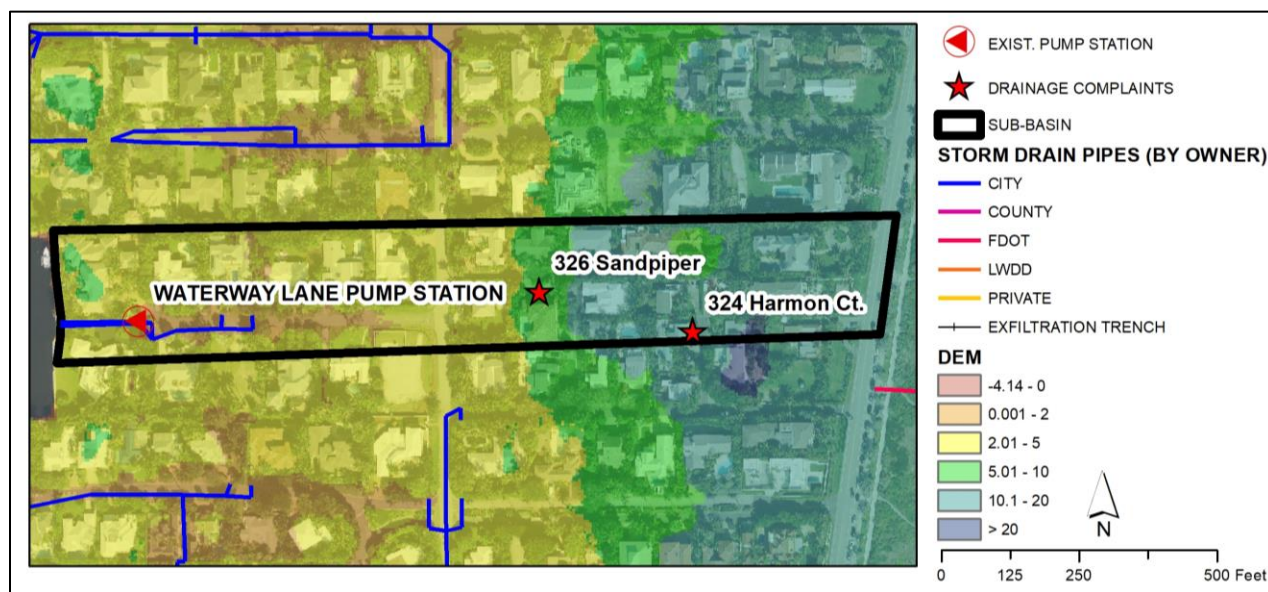


Figure 4-11: Problem Area 3 Topography and Infrastructure

4.10.4 Problem Area No. 4 – Luke Lane Drainage Complaint / Thomas Street Pump Station and Basin Drive Pump Station

Problem Area 4 has a complaint of street flooding on Luke Lane. The date associated with the drainage problem is December 12, 2017. The City installed a swale to relieve the drainage problem. However, flooding is still being observed in this area. In addition,

The Problem Area 4 area is also served by the Thomas Street Pump station and Basin Drive Pump Station. The City indicated that they would like all pump stations to be assessed in the Stormwater Master Plan Update. **Figure 4-12** shows the topography and infrastructure within Problem Area 4.

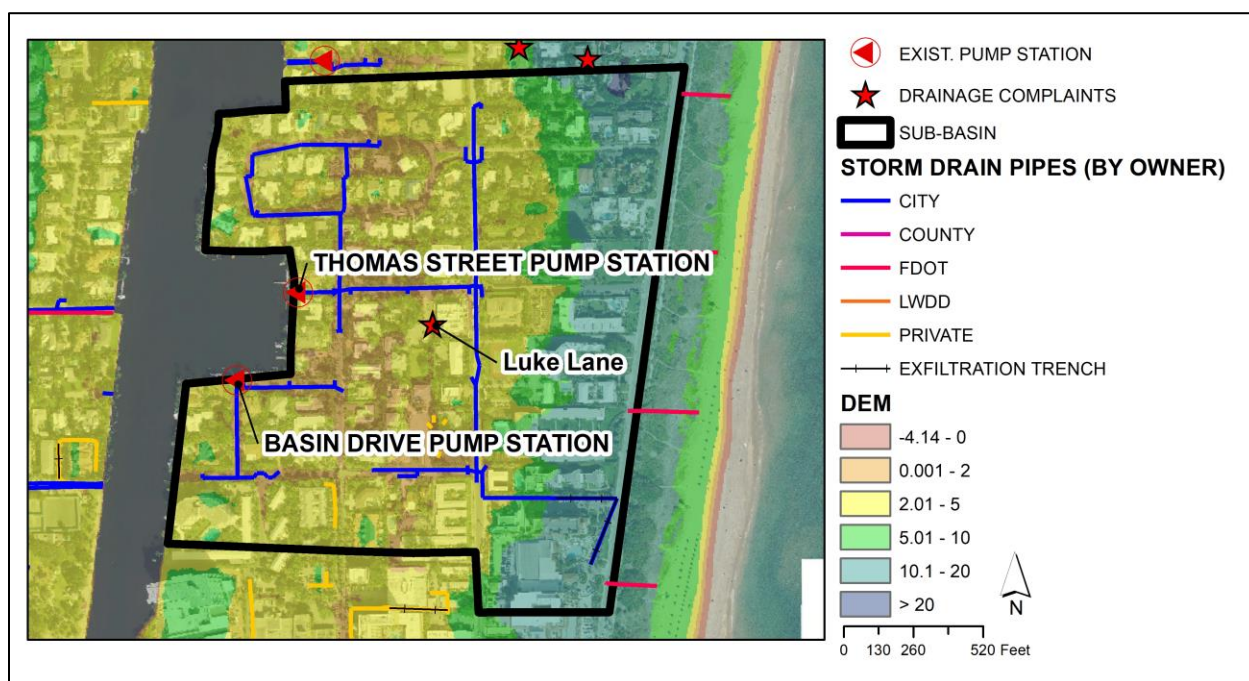


Figure 4-12; Problem Area 4 Topography and Infrastructure

4.10.5 Problem Area No. 5 – Atlantic Avenue Pump Station

Problem Area 5 served by the Atlantic Avenue Pump station. The City indicated that they would like all pump stations to be assessed in the Stormwater Master Plan Update. **Figure 4-13** shows the topography and infrastructure within Problem Area 5.

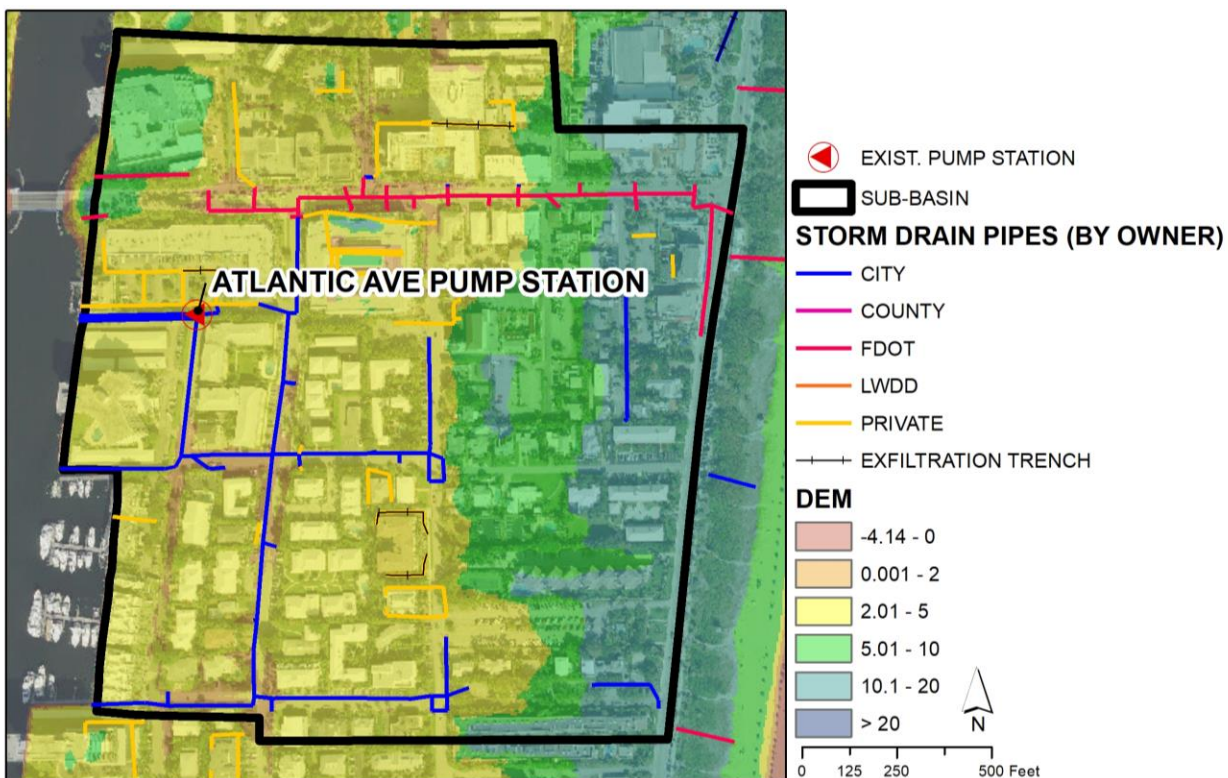


Figure 4-13: Problem Area 5 Topography and Infrastructure

4.10.6 Problem Area No. 6 – Nassau St. Flood Complaint and Bay Street Pump Station

Flooding of the finished floor at 1104 Nassau street was reported and noted by the City during project discussions. In addition, there is a City own parking facility the floods regularly at the southeast end of the problem area, west of Gleason Street.

Problem Area 6 is served by the Bay Street Pump Station. The City indicated that they would like all pump stations to be assessed in the Stormwater Master Plan Update. **Figure 4-14** shows the topography and infrastructure within Problem Area 6.

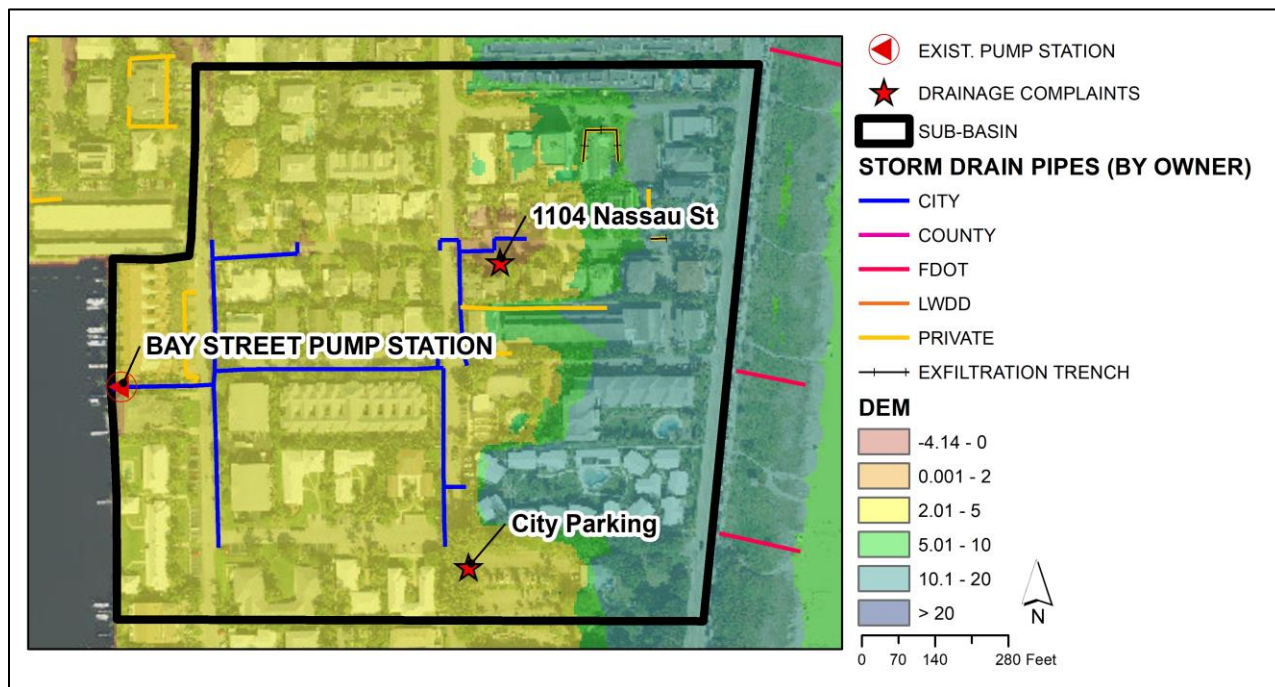


Figure 4-14: Problem Area 6 Topography and Infrastructure

4.10.7 Problem Area No. 7 – Melaluca Road Drainage Complaint / Seasage Drive Pump Station

The 1030 Melaluca Road drainage complaint in Problem Area 7 is from a flooded driveway. The City suggests in the list of drainage complaints that a swale is needed to relieve the ponding.

The Problem Area 7 6 is served by the Seasage Drive Pump Station. The City indicated that they would like all pump stations to be assessed in the Stormwater Master Plan Update sub-basin is the location of the. **Figure 4-15** shows the topography and infrastructure within Problem Area 7.

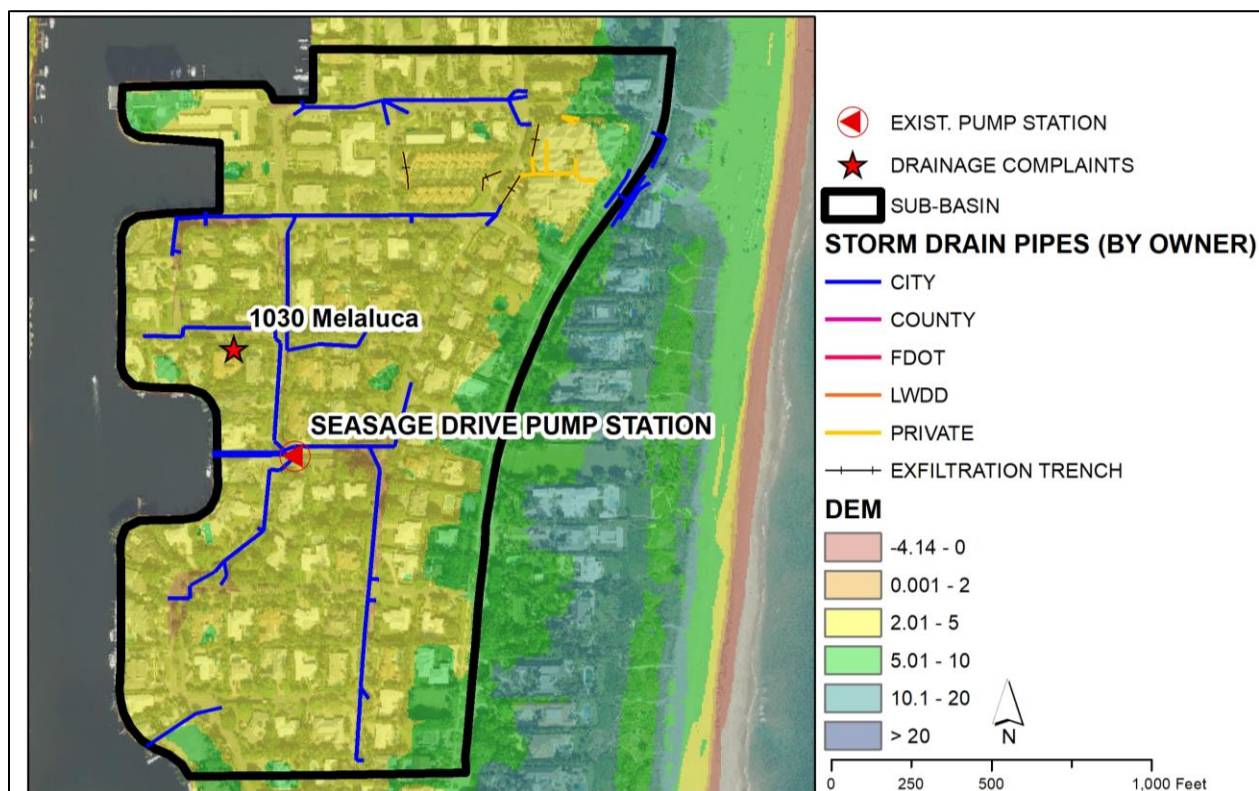


Figure 4-15: Problem Area 7 Topography and Infrastructure

4.10.8 Problem Area No. 8 – Hibiscus Road Drainage Complaint

A suspected tidal flooding drainage complaint at Hibiscus Road is noted in the City-provided list of drainage complaints as an ongoing issue. **Figure 4-16** shows the topography and infrastructure within Problem Area 8.

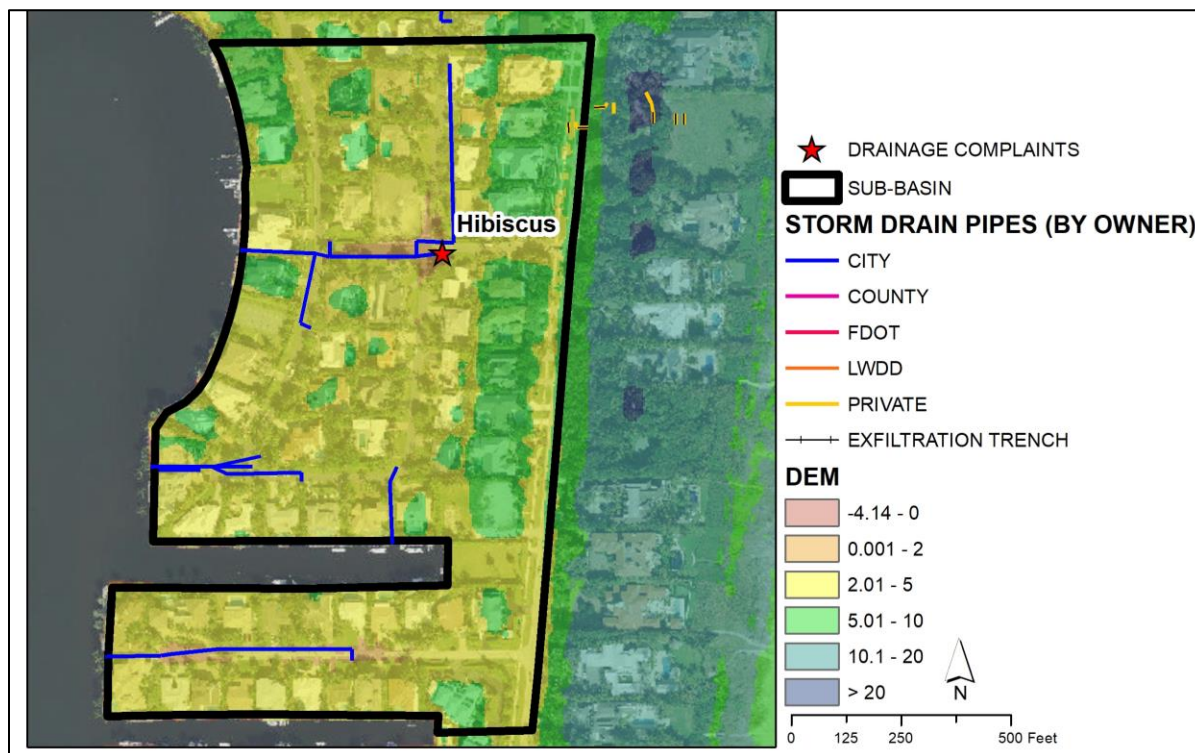


Figure 4-16: Problem Area 8 Topography and Infrastructure

4.10.9 Problem Area No. 9 – Brooks Lane Drainage Complaint

Soil loss near the pipe at 1004 Brooks Lane was noted on November 20, 2016. City inspected the nearby City-owned pipe and it appears to have no damage. In addition, the seawall at the east end of the canal between White Drive and Rhodes Villa Avenue is low and the parking facility east of the seawall flood regularly. **Figure 4-17** shows the topography and infrastructure within Problem Area 9.

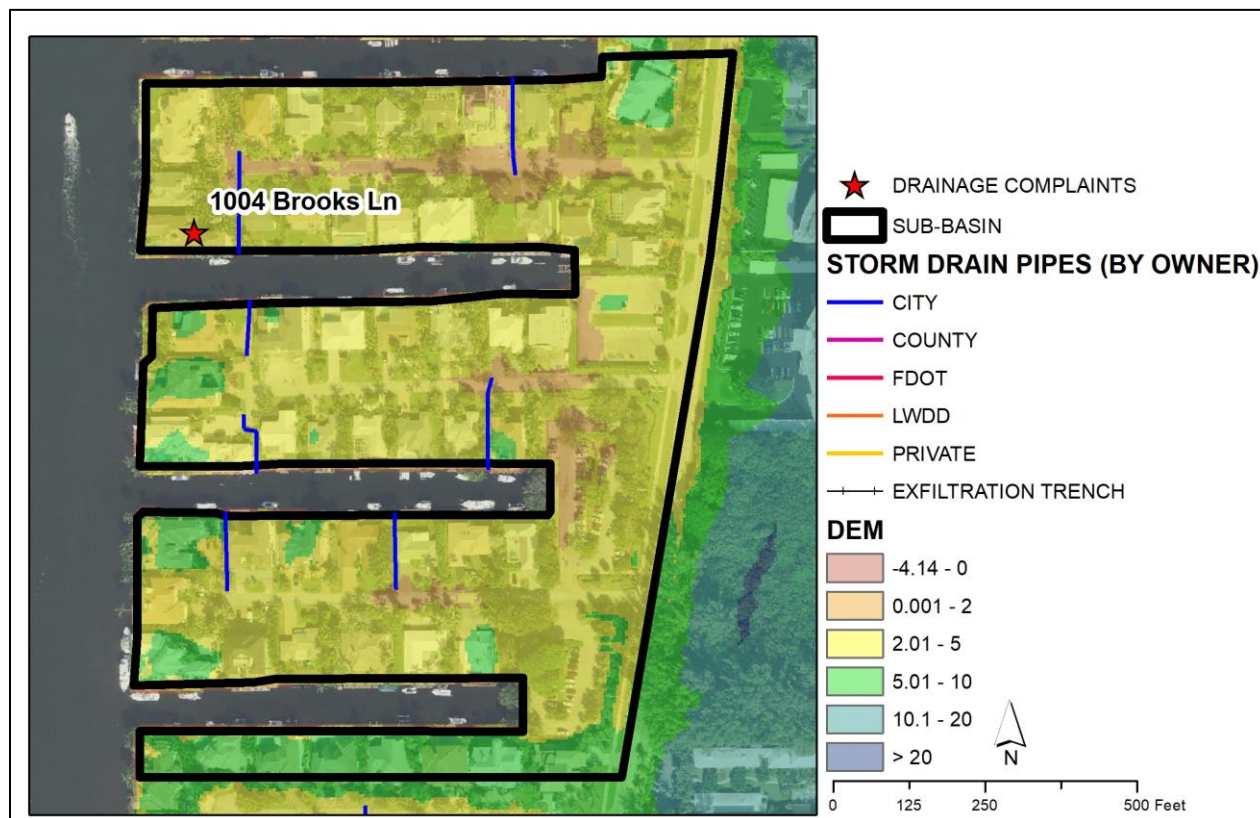


Figure 4-17: Problem Area 9 Topography and Infrastructure

4.10.10 Problem Area No. 10 – Spanish Circle, Iris Drive, and Banyan Drive Drainage Complaints

Three drainage complaints exist in Problem Area 10. The City indicated in their list of drainage complaints that the Spanish Circle complaint was due to an inadequate drainage design. According to the list of drainage complaints, an inlet and a swale was added.

The 928 Iris Drive and 937 Banyan Drive complaints are ongoing issues according to the City's list of drainage complaints. The City suspects that there are pipe failures at the seawalls in these locations. **Figure 4-18** shows the topography and infrastructure within Problem Area 10.

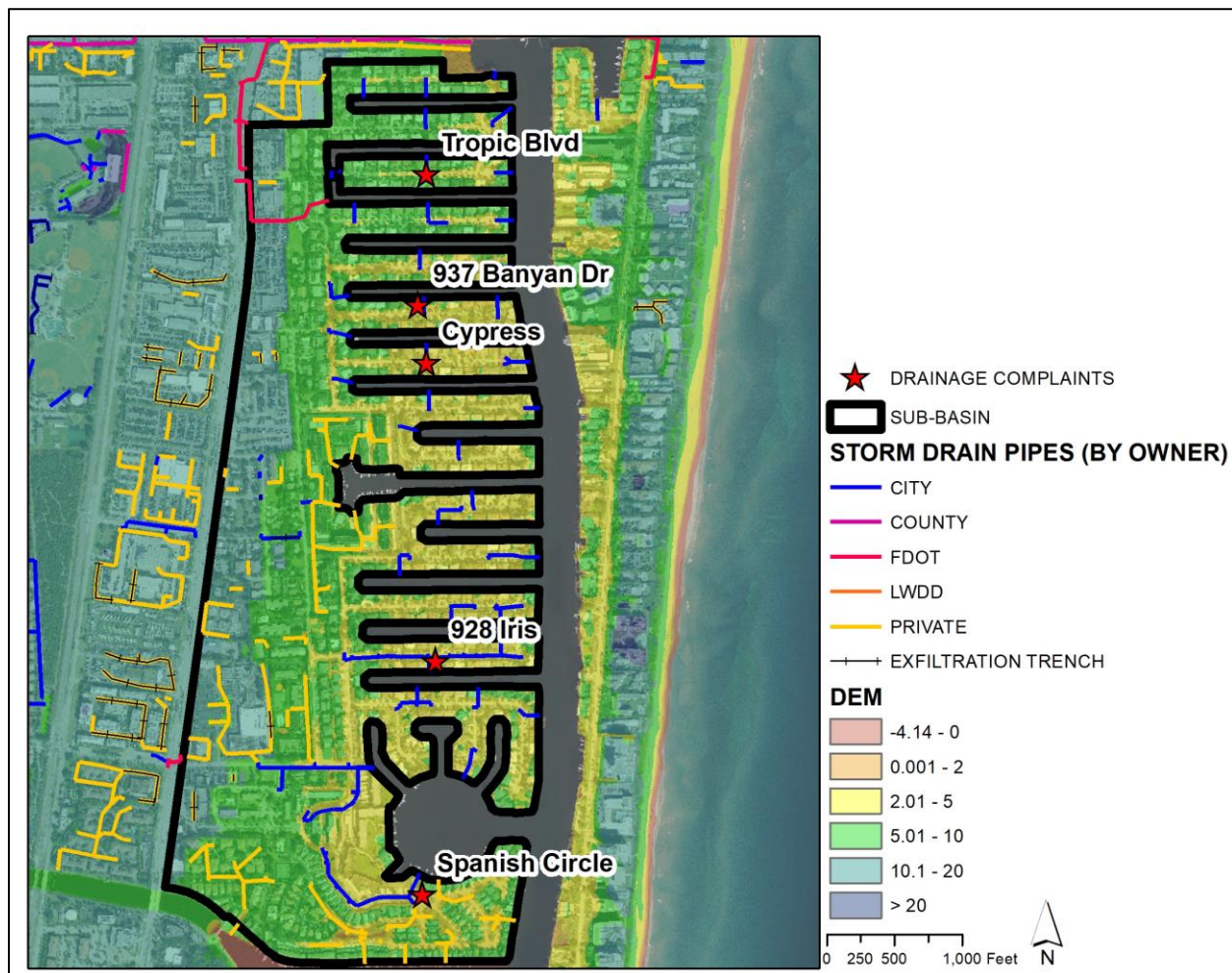


Figure 4-18: Problem Area 10 Topography and Infrastructure

4.10.11 Problem Area No. 11 – SE 8th Court and SE 10th Street Drainage Complaints

Problem Area 11 has drainage complaints on SE 8th Ct and SE 10th Ct where standing water was reported on the road. These drainage complaints both occur on cul de sacs where the City suspects an outfall is needed according to their list of drainage complaints **Figure 4-19** shows the topography and infrastructure within Problem Area 11.

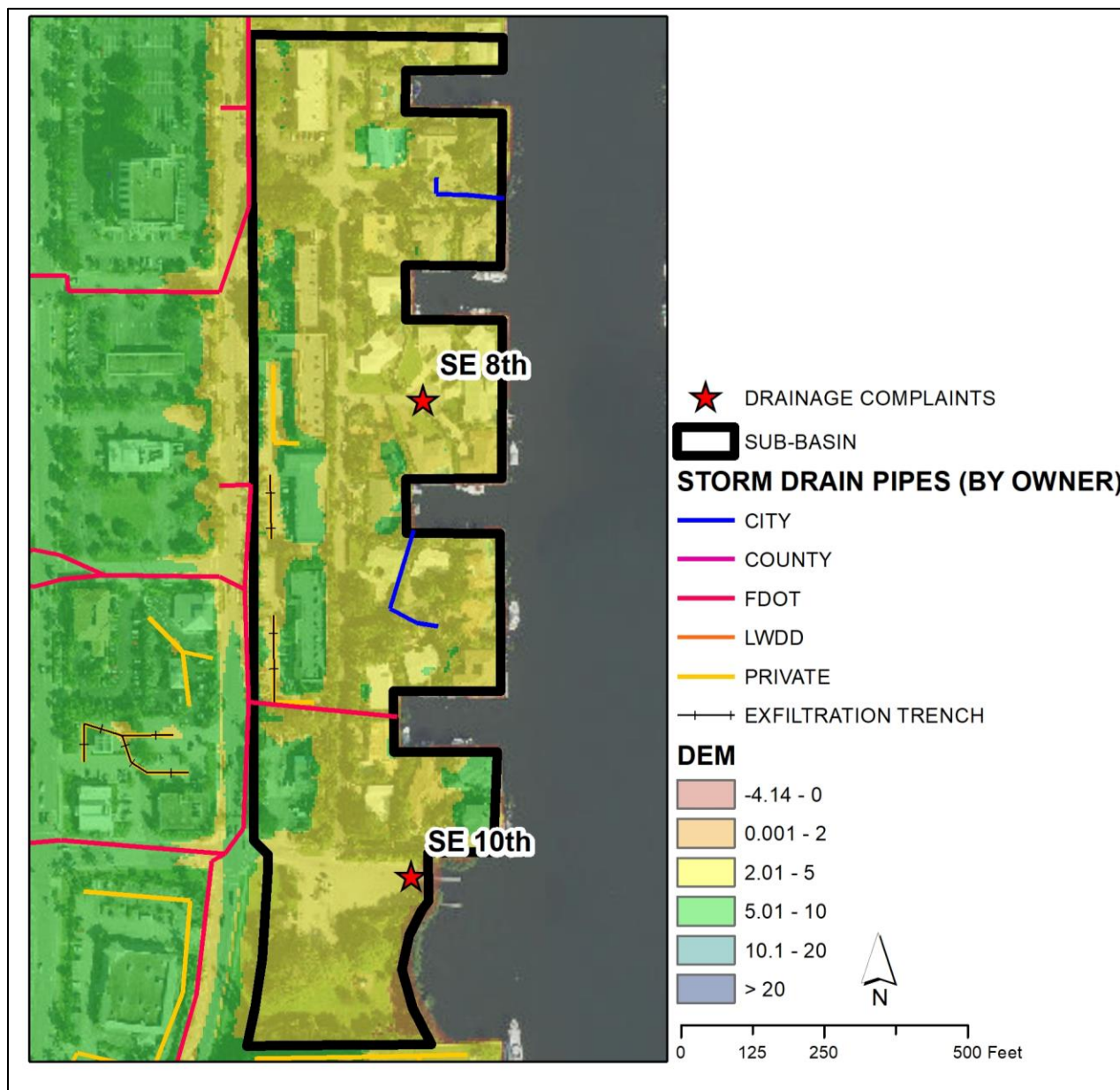


Figure 4-19: Problem Area 11 Topography and Infrastructure

4.10.12 Problem Area No. 12 –Drainage Problem on SE 1st Street and Intracoastal Waterway

The drainage problem located on SE 1st Street near the intracoastal for Problem Area 12 is not from the City-provided list of drainage complaints. However, it is a known drainage issue that the City indicated that further investigation was necessary. **Figure 4-20** shows the topography and infrastructure within Problem Area 12.

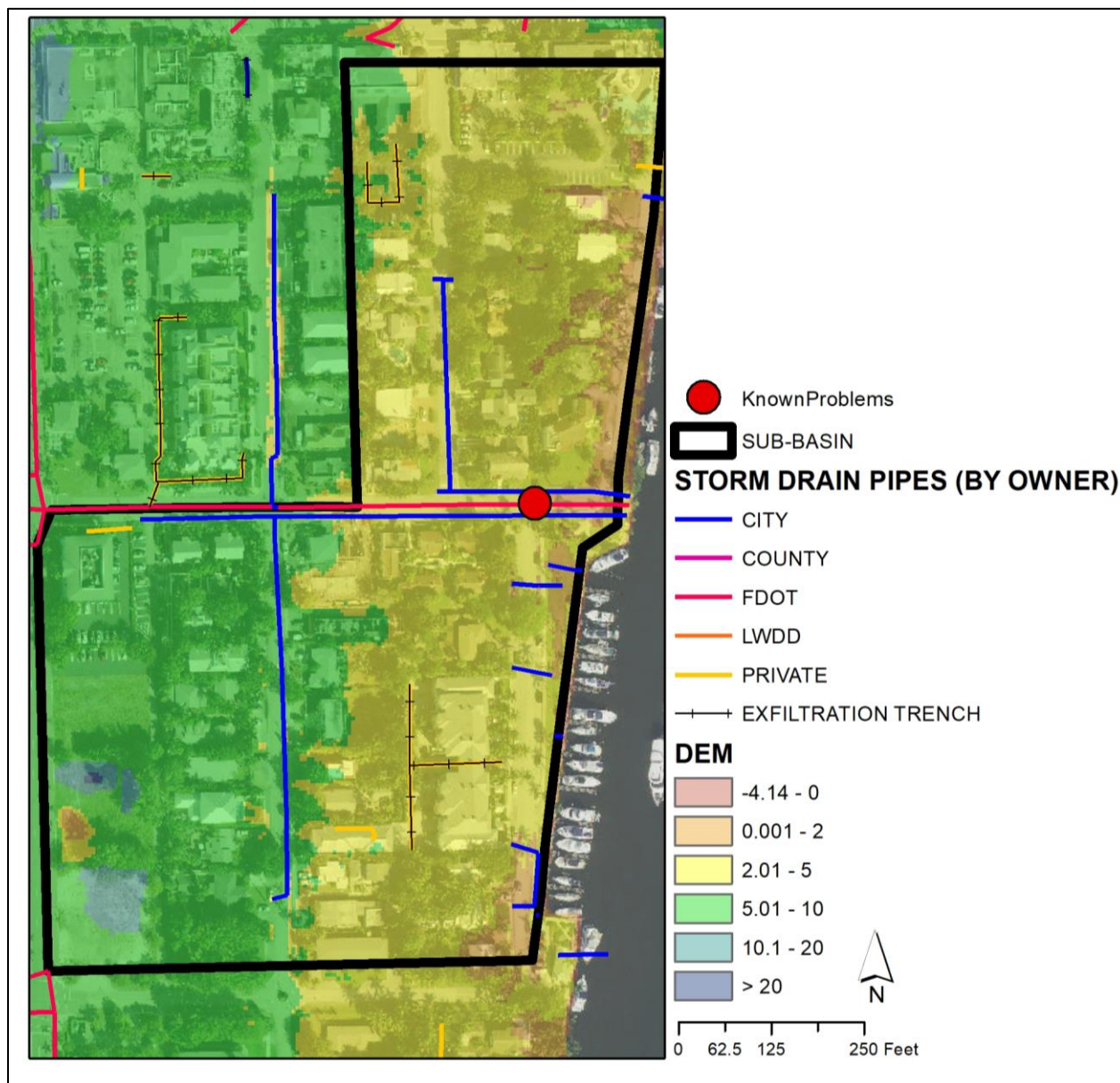


Figure 4-20: Problem Area 12 Topography and Infrastructure

This problem area is currently being evaluated under a separate contract.

4.10.13 Problem Area No. 13 – Drainage Problem on NW 37th Avenue and NW 7th Court

The drainage problem located on NW 37th Avenue in Problem Area 13 is not from the City-provided list of drainage complaints. However, it is a known drainage issue that the City indicated that further investigation was necessary. **Figure 4-21** shows the topography and infrastructure within Problem Area 13.

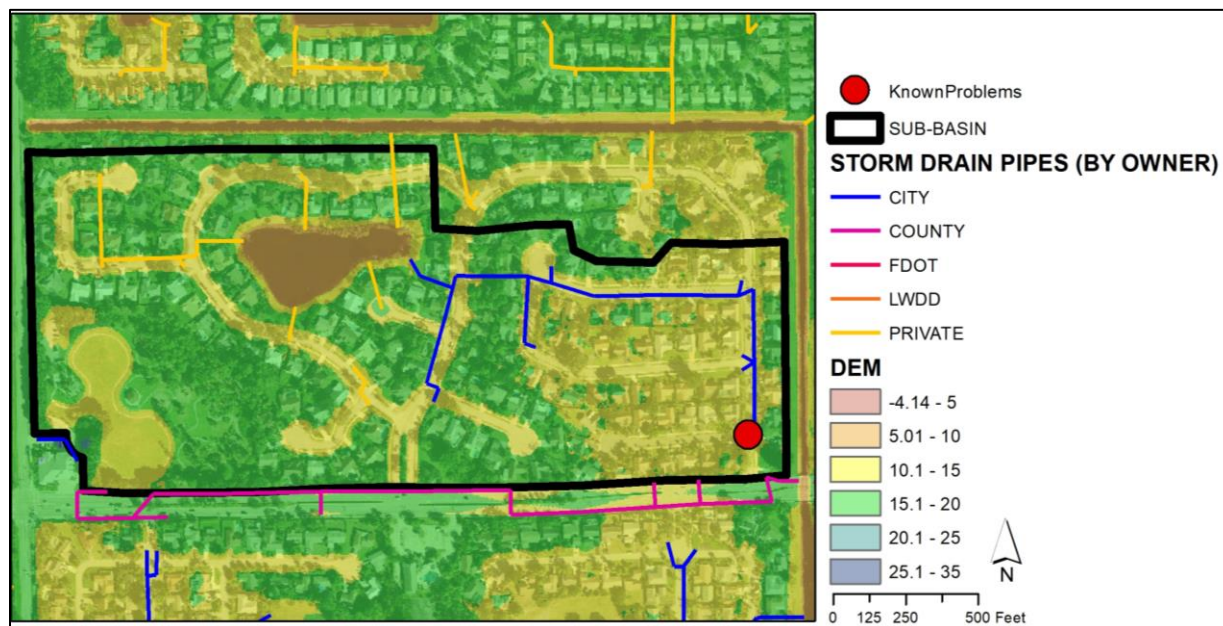


Figure 4-21: Problem Area 13 Topography and Infrastructure

4.10.14 Problem Area No. 14 – Rainberry Woods Drainage Problem

Several drainage complaints within the Rainberry Woods neighborhood on Lake Ida Road were raised to the City. Standing water was indicated to remain for two or more days near the intersection of NW 51st Avenue and NW 5th Street and on NW 46th Avenue near the tennis courts. **Figure 4-22** shows the topography and infrastructure within Problem Area 14.

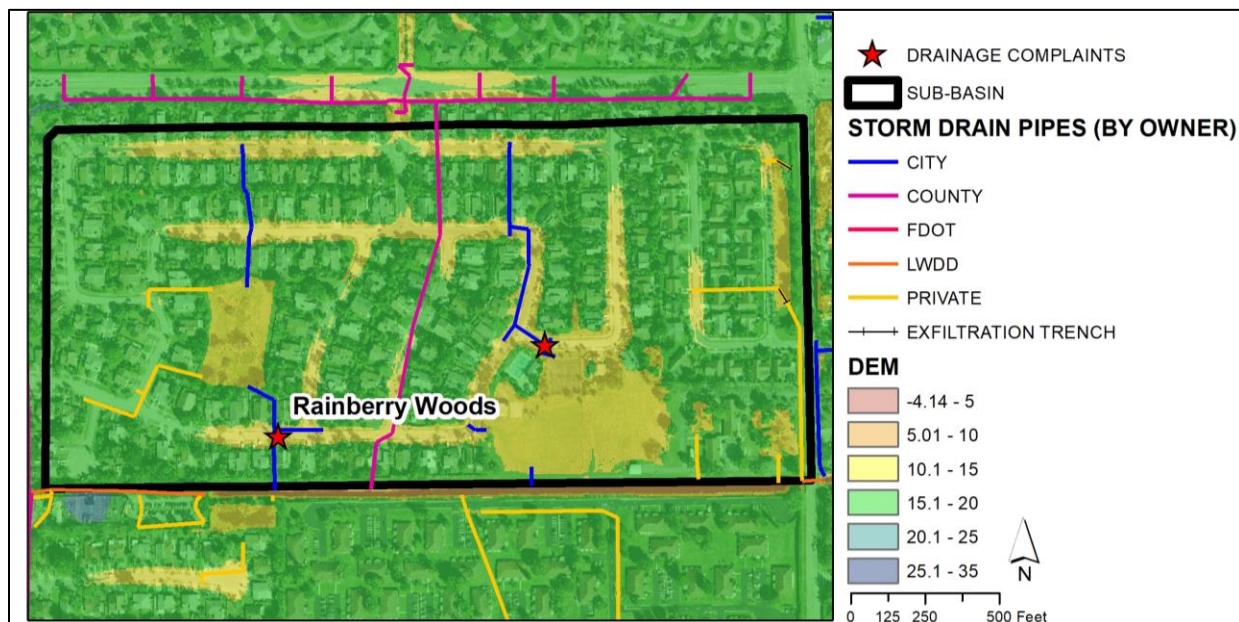


Figure 4-22: Problem Area 14 Topography and Infrastructure

4.11 Overview of the ICPR 4 Expert Model

The ICPR computer model is a hydrodynamic model developed by Streamline Technologies, Inc. that simulates hydrologic and hydraulic conditions by generating runoff hydrographs and dynamically routing these hydrographs through dendritic, diverging, looped and/or bifurcated stormwater management systems.

ICPR 4 Expert Model (ICPR4) includes 2-dimensional (2D) overland flow and groundwater components that are used instead as either a substitute or a complement to the traditional basin runoff method. These components generate a flexible triangular mesh based on a specified resolution and several types of landscape features. Honeycombs (or control volumes) are formed around the vertices of the triangles and produce different hydrological responses based on specified parameters the mapping of various landscape characteristics. Mass balance is accounted in each control volume to determine excess rainfall. The Manning's equation is used to calculate runoff velocity's using the slopes from the interpolated topography along the sides of the mesh triangles. Analogous to the 1D node-link computational schematic, the vertices of the triangles are treated as nodes and the sides of triangles are the overland flow links.

The layers that can be used to define the parameters which generate the overland flow hydrological unit response in each honeycomb are:

1. Ground elevations
2. Soil parameters
3. Land cover (% imperviousness)
4. Manning's roughness coefficients
5. Rainfall zones
6. Evapotranspiration parameters

4.12 Hydrologic Model Setup

For the models developed for this study, only the 2D overland flow component, as opposed to the traditional manual basin approach was used to generate runoff. The rainfall-runoff parameters specified in the models are described below.

The soil zone, land cover zone, and rainfall zone parameters are intersected to characterize the infiltration capabilities and precipitation amount for each 2D honeycomb basin. **Figure 4-23** illustrates the honeycomb basins (green), land use coverage (red outline), soil zone coverage (blue outline), and rainfall zone coverage (yellow outline) in a portion of the Area 10 Validation model. A mass balance for each honeycomb basin is performed which calculates the total precipitation minus the total infiltration for each honeycomb basin based on the soil zone, land cover zone, and rainfall zone.



Figure 4-23: 2D Honeycomb Basin Characterization

4.12.1 Model Domains

Due to hydraulic and hydrologic connectivity of certain problem areas, several problem areas were combined into a single model domain. A total of six (6) model domains were configured for the 14 problem areas. **Figure 4-24** shows the model domains and their corresponding problem area(s).

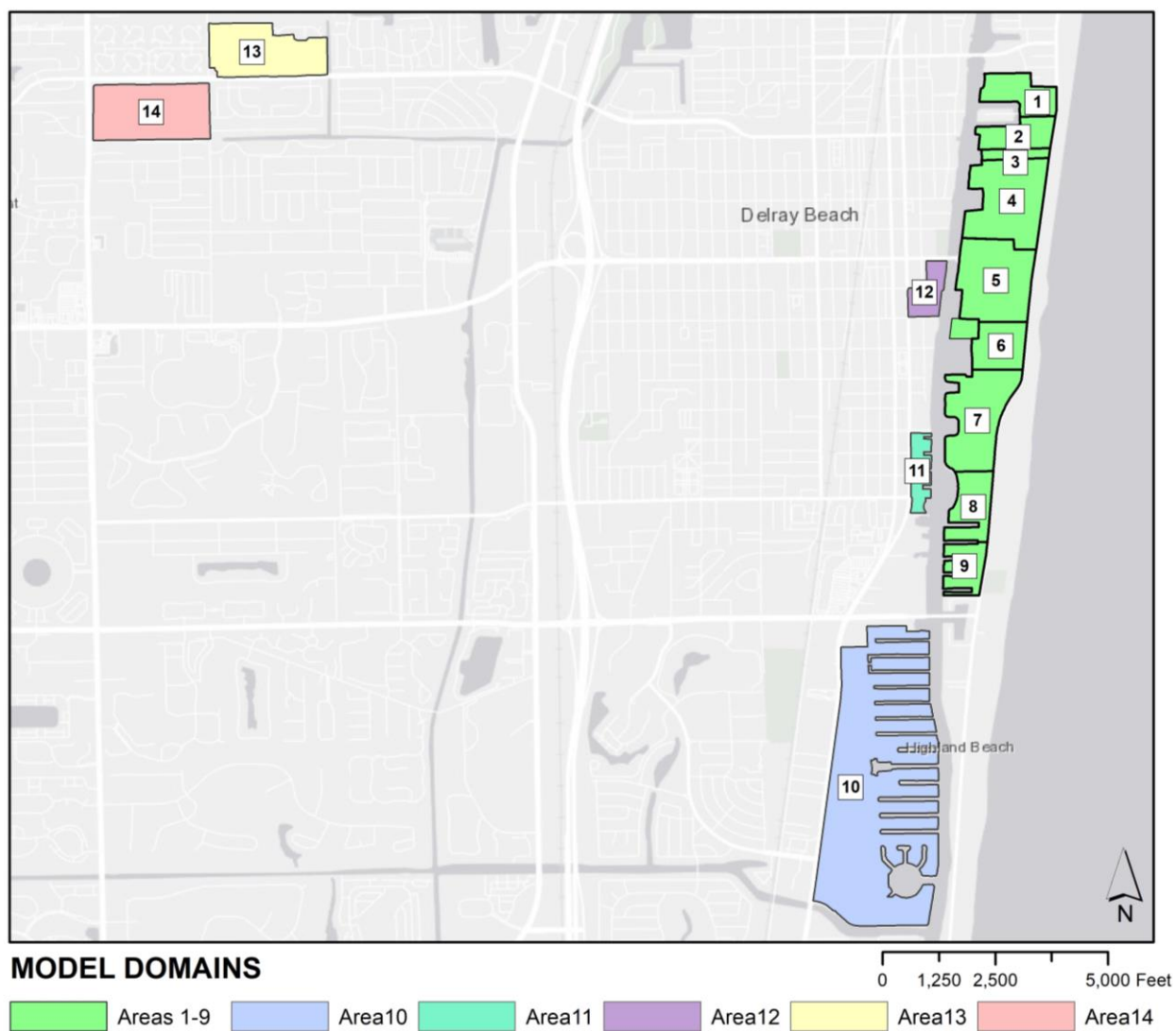


Figure 4-24: Model Domains and Problem Areas

4.12.2 Average Wet Season/Design High Water (DHW)

In order to set the initial condition parameters for the 2D mesh and 1D nodes, a DHW assumption was made. Since the model domains for Areas 1-9, Area 10, Area 11, and Area 12 are all coastal, it was assumed that the DHW in these areas was tidally

influenced. **Equation 4-1** describes the calculation of the Coastal DHW assumption value.

Equation 4-1: Coastal DHW Assumption

$$DHW = \frac{(Avg. of ten highest tides) + (Avg. of low tides corresponding to ten highest tides)}{2}$$

The ten highest tidal events from the past five years (2012-2018) at the NOAA Tidal Gage at Lake Worth Pier were examined. The mean elevation of the ten highest tides was averaged with the mean elevation of the corresponding low tide for those ten high tidal events. The resulting DHW assumption value was 0.37 ft-NAVD.

The initial stages for model domains for Areas 13 and 14 were set based on the nearest measured water table elevation on June 1st, 2017, approximately 10-ft NAVD. This value was obtained from the closest well with data for that time period, PB-1628. Although, the well is located approximately 2 miles north of Area 13, it is at a similar longitude and topographic elevation than Areas 13 and 14.

4.12.3 Curve Number

Curve number was calculated for each soil zone / land use combination. **Table 4-5** shows each calculated number.

Table 4-5: Curve Number for Land Cover Zone / Soil Zone Combinations

Land Cover Zone Abbr.	Land Cover Zone	Soil Zone	Curve Number
UCSS	Commercial	2	96
UIIN	Industrial	2	97
UOUN	Open Space	2	89
URSL	Low Density Residential	2	95
URSM	Medium Density Residential	2	95
USGF	Community Facilities	2	94
UCSS	Commercial	3	92
UIIN	Industrial	3	94
UOUN	Open Space	3	74
URSL	Low Density Residential	3	90
URSM	Medium Density Residential	3	91
USGF	Community Facilities	3	88
UCSS	Commercial	5	88
UIIN	Industrial	5	91
UOUN	Open Space	5	56
URSL	Low Density Residential	5	83
URSM	Medium Density Residential	5	85
USGF	Community Facilities	5	80

As described in **Section 4.4**, soil zone was based on the soil depth to water table versus water storage capacity relationship specified in the SFWMD Environmental Resource Permit Applicant's Handbook Volume II for compacted soils, based on Soil Conservation Service estimates. Land use was determined from the Proposed Land Use shapefile provided by the City of Delray Beach (**Section 4.3**). ICPR4 uses the spatial coverages of the land cover zones and the soil zones during the 2D overland flow runoff calculations.

4.12.4 Design Rainfall Depths

Rainfall depths for the Design Storms were estimated by the SFWMD isohyetal design rainfall contours and are as described in **Table 4-6**.

Table 4-6: Model Domain Rainfall Depths

Model Domain	5Y-1D	10Y-1D	25Y-3D	100Y-3D
Areas 1-9	8.5 in	11 in	15.6 in	18.5 in
Area 10	8.5 in	11 in	16.2 in	19.7 in
Area 11	8.5 in	11 in	15.5 in	18.8 in
Area 12	8.5 in	11 in	15.5 in	18.5 in
Area 13	8 in	10.5 in	14.3 in	17 in
Area 14	8 in	10.5 in	14.3 in	17 in

4.12.5 Runoff Extraction by Exfiltration Trenches

Where present, exfiltration trenches were represented as the estimated equivalent storage volume that is removed from the rainfall in portions of the drainage basins. Exfiltration trenches are typically designed to extract a runoff volume equal to the 5-year, 1-hour storm, which has a magnitude of 3.28 inches. The contributing area is determined by the length of the exfiltration trench, times the total contributing width on both sides of the exfiltration trench, as shown in **Figure 4-25**. A total width of 320 feet was used, which is based on random sampling of typical residential areas.



Figure 4-25: Exfiltration Trench Contributing Area

The exfiltration trenches were identified from the storm drain shapefile provided by the City. The shapefile's attribute table contained a CAD Label field that noted whether or not the line feature was representative of exfiltration trench or not. If the CAD description indicated that the length of pipe was perforated or exfiltration trench, then the feature was tagged as exfiltration trench using an additional single-character string field with "Y" for yes or "N" for no. The treatment areas are the areas within the sub-basins that are assumed to be affected by the exfiltration trench storage. **Figure 4-26** shows the exfiltration trenches and the treatment areas simulated.

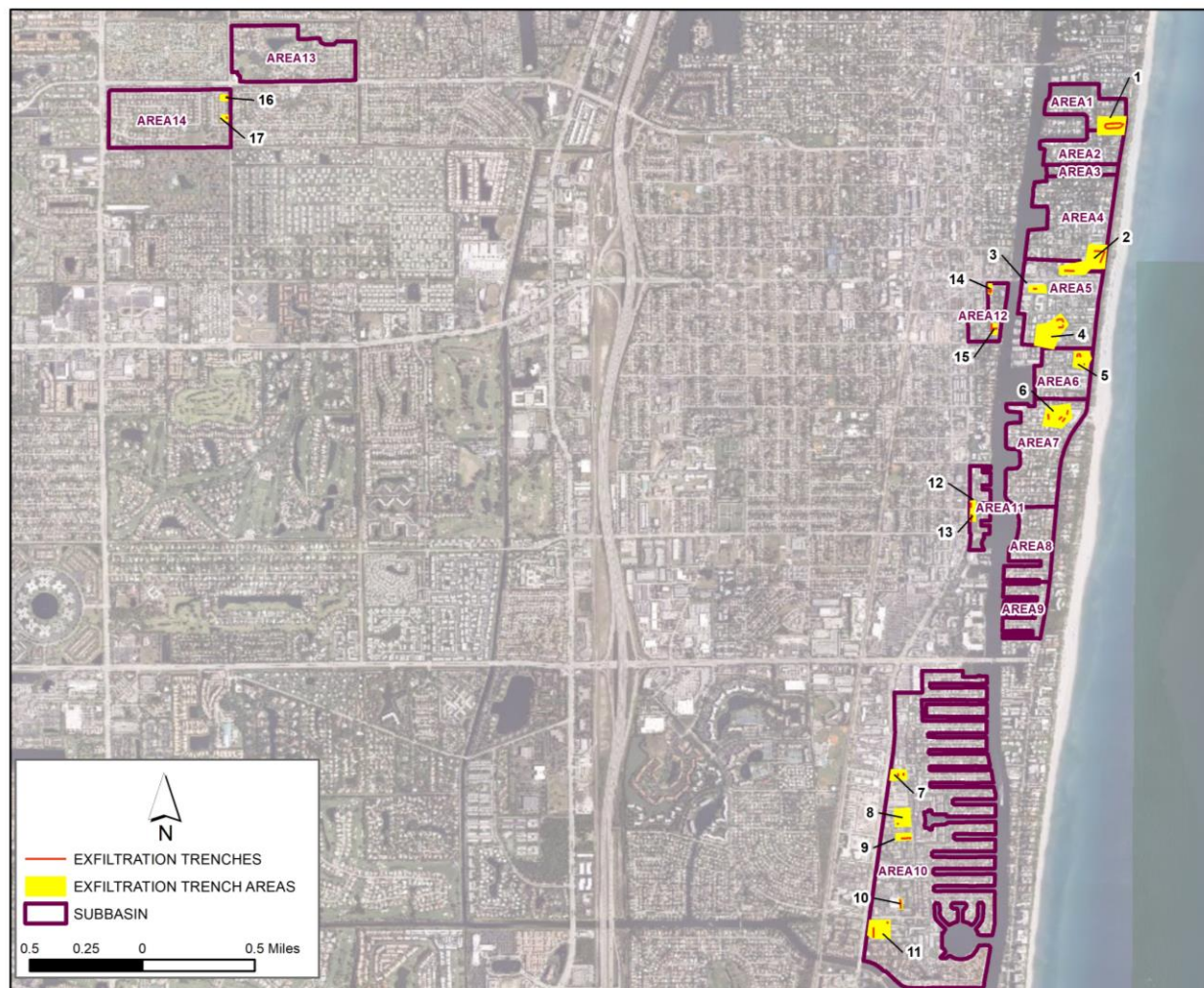


Figure 4-26: Exfiltration Trenches and Areas Simulated

The depth extracted from rainfall can be estimated with the following equation:

$$\text{Extraction Depth (inches)} = \frac{\text{Length Exfiltration Trench (ft)} \times 320 \text{ ft} \times 3.28 \text{ in}}{\text{Treatment Area (ft}^2\text{)}}$$

Table 4-7 shows the extraction depths for each of the exfiltration trench areas simulated. The Exfiltration Trench Area ID corresponds to the numbers shown in **Figure 4-26** above.

Table 4-7: Extraction Depths for each Exfiltration Trench Area Simulated

Exfiltration Trench Area ID	Problem Area	Length (ft)	Treatment Area (ft ²)	Extraction Depth (in)
1	Areas 1-2	928	234,406	2.1
2	Areas 4-5	714	354,385	1.1
3	Area 5	87	63,165	0.7
4	Area 5	366	329,885	0.6
5	Area 6	213	132,646	0.8
6	Area 7	428	255,938	0.9
7	Area 10	131	89,544	0.8
8	Area 10	39	141,114	0.1
9	Area 10	218	58,318	2.0
10	Area 10	200	20,727	5.1
11	Area 10	272	191,373	0.7
12	Area 11	111	27,001	2.2
13	Area 11	150	33,751	2.3
14	Area 12	177	23,137	4.0
15	Area 12	348	37,082	4.9
16	Area 14	57	27,342	1.1
17	Area 14	55	24,779	1.2

4.13 1-D Hydraulic Model Setup

In ICPR, a stormwater management system is modeled into a network of nodes or junctions and links. A node is a discrete location in the drainage system where runoff enters the system and conservation of mass or continuity is maintained. The nodes model the hydrologic conditions within the drainage system. Links represent connections between nodes and are used to transfer or convey stormwater runoff through the system. The links are used to model the hydraulic response of the management system for a defined hydrologic condition. A node-link schematic was developed to show the relationship between the nodes and links in the model setup that represent the existing and proposed designs. Node/link schematics for the 1D model setup for the existing conditions model are in **Appendix 4C**.

The stormwater pipe, manhole, and inlet spatial datasets obtained from the City of Delray Beach Geodatabase were used to define the 1D features of the hydraulic model. The stormwater pipes shapefile was used in the model for the 1D links, the manholes shapefile was used in the model for the 1D nodes, and the inlets shapefile was used in the model to define the locations of 1D node interface features. The 1D node interface features tie the 1-D and 2-D models together such that surface water flow will discharge into the 1D hydraulic network where it will be conveyed to the stormwater pumps stations and discharged out of the basins.

The type of node used for the manholes in the basin is referred to as the Stage/Area node. Nodes at the basin's outfalls are referred to as time/stage nodes set to an oscillating tidal schedule.

The pump stations are represented in the model by rating curve links with pump capacity's and operating tables with pump on and off elevations. This information is shown in **Table 4-8** and was obtained from South Florida Water Management District's permit files for the pump stations as described in **Section 4.5.2** and converted to the appropriate model units.

Table 4-8: Pump Station Capacity's and Operating Parameters

Beach Drive Pump Station			
Pump	On Elevation (ft-NAVD)	Off Elevation (ft-NAVD)	Capacity (cfs)
Pump 1	0.705	0.37	6.68
Pump 2	0.955	0.37	6.68
Waterway Drive Pump Station			
Pump	On Elevation (ft-NAVD)	Off Elevation (ft-NAVD)	Capacity (cfs)
Pump 1	0.705	0.37	6.68
Thomas Drive Pump Station			
Pump	On Elevation (ft-NAVD)	Off Elevation (ft-NAVD)	Capacity (cfs)
Pump 1	-0.545	-1.045	42.78
Basin Drive Pump Station			
Pump	On Elevation (ft-NAVD)	Off Elevation (ft-NAVD)	Capacity (cfs)
Pump 1	1.455	-0.545	6.68
Atlantic Drive Pump Station			
Pump	On Elevation (ft-NAVD)	Off Elevation (ft-NAVD)	Capacity (cfs)
Pump 1	0.705	0.37	22.28
Pump 2	0.955	0.37	22.28
Pump 3	0.955	0.37	22.28
Bay Drive Pump Station			
Pump	On Elevation (ft-NAVD)	Off Elevation (ft-NAVD)	Capacity (cfs)
Pump 1	-0.045	-6.545	6.68
Pump 2	0.955	-6.545	6.68
Seasage Drive Pump Station			
Pump	On Elevation (ft-NAVD)	Off Elevation (ft-NAVD)	Capacity (cfs)
Pump 1	0.705	0.37	11.14
Pump 2	0.955	0.37	11.14

Details about other 1-D hydraulic model setup parameters such as link and node parameters, curve number lookup tables, impervious and roughness lookup tables, and

boundary stage tables for design storm and validation events are included in **Appendix 4D**.

4.14 2-D Hydrologic Mesh Development

Each model domain described in **Section 4.12.1** was modeled as a separate Overland Flow Region in the 2D component of ICPR4. Overland Flow Regions are characterized by their land use classifications, soil zone classifications, elevation raster values, and rainfall zone values.

The 2D triangular mesh defines the computational resolution of the model, i.e., how accurately the model can read and use the information from the input DEM and the other model layers. Several 2D features can be used to define the mesh. For example, breaklines and breakpoints were the most common 2D features used in the models developed. Breaklines were incorporated into the 2D model to represent the roadways and ensure that the triangular mesh edges run along the correct paths to simulate flow. A road centerline shapefile provided by the City was imported into ICPR4 to delineate the breaklines. Breakpoints were placed evenly throughout the model domains 25 feet apart, which guarantees that there will be triangle vertices (2D nodes) every 25 feet. **Figure 4-27** shows an example of how the triangular mesh (blue) was set-up along one of the breaklines (yellow) and how the DEM establishes the down-gradient arrows along the mesh.



Figure 4-27: Triangular Mesh Formulation with Breaklines

Once the geometry of the mesh was defined, the links of the triangular mesh and the cells of the diamond and honeycomb meshes were given characteristics based on the DEM, soil zone map, land zone map, and roughness zone map. The soil zone, land cover zone, and roughness zone map layers each have a corresponding lookup table to further describe the hydrologic characteristics of the features in the map layers. **Figure 4-28**

shows the triangular (blue), diamond (pink), and honeycomb (green) meshes that characterize the 2D hydraulic model.

A single boundary stage line along any edge of a model domain that borders the intracoastal was used. The overland flow links coincident with the boundary stage lines are disabled, and the stage elevations along the boundary stage lines are forced as the tidal boundary stage elevation. This permits overland flow runoff into the Intracoastal Waterway eliminates the “wall” effect of the basin boundary edges that causes water buildup in some basin boundary locations and also allows for seawall overflows in the cases where tidal events are higher than intracoastal-front lot elevations.

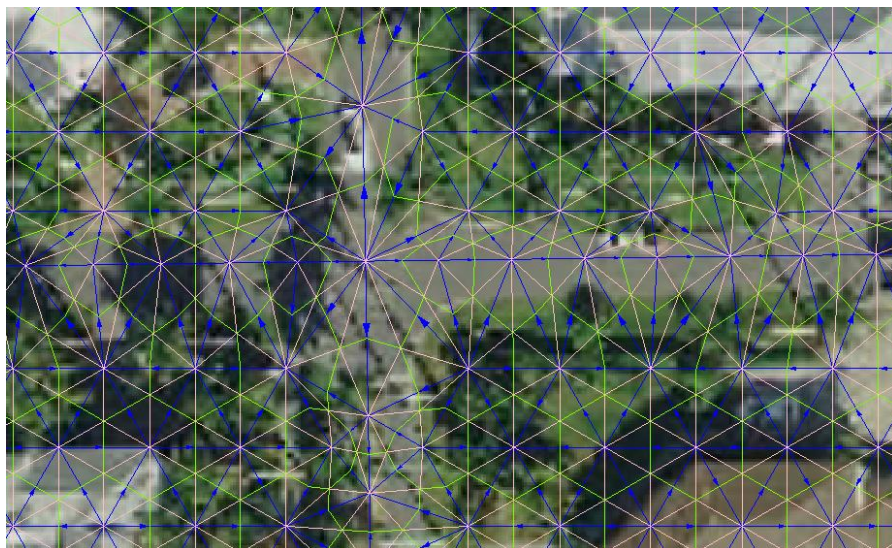


Figure 4-28: Diamond and Honeycomb Characteristic Meshes

The curve number rainfall excess method was used to model soil water storage and the corresponding runoff volume. The curve number for each of the honeycomb catchment areas is defined by the soils map layer and land cover map layer as described in **Section 4.12.3** and **Table 4-5**. Roughness zones characterize the diamond mesh and define the manning's n values for the overland flow links within the diamond-shaped cells. Roughness zones are spatially defined by the roughness zones map layer, which in the case of this model is identical to the land cover map layer. Roughness values for each land use type are described for each model in **Appendix 4D**.

4.15 Boundary Conditions

For the Validation Model, the stages measured at the NOAA tidal gage at Lake Worth Pier were specified at the downstream boundary. The tailwater stages at S40 structure were also considered, but the data seems to be missing the tidal peaks during the June 6-9, 2017 storm period. Measured water levels in the intercoastal within the City limits (at White Drive) are available starting in 2018. These stages were compared to the NOAA stages for the available overlapping period of time. Based on the resulting linear regression equation, an adjustment factor was applied to the NOAA stages to better

match the peaks and lows to the City data. The comparison is shown below in **Figure 4-29**.

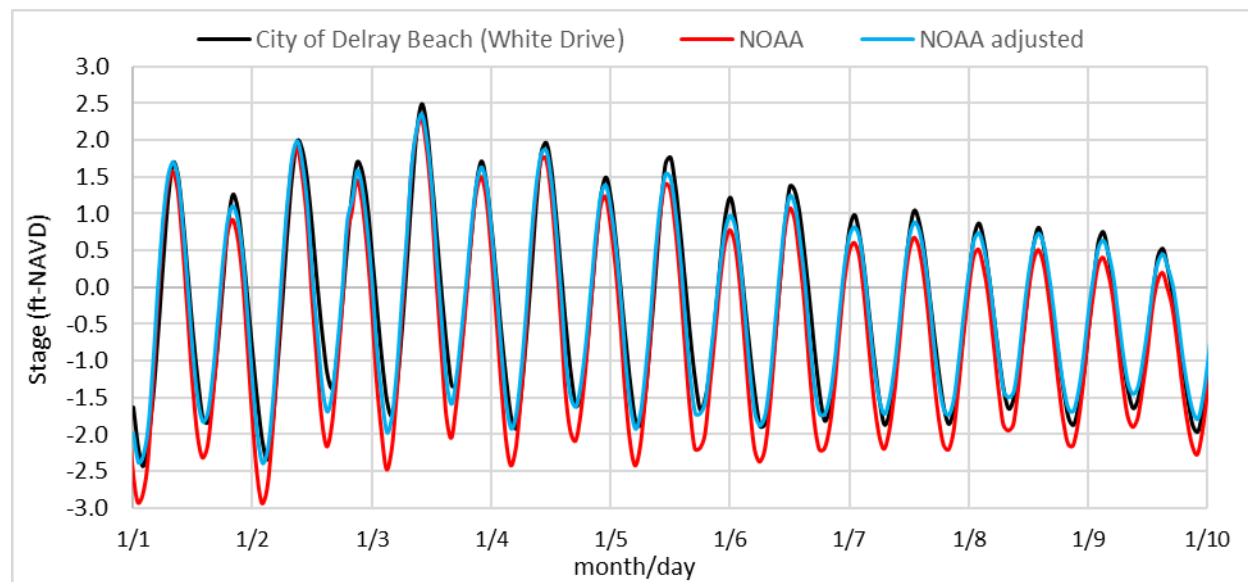


Figure 4-29: NOAA Stages at Lake Worth Pier versus Intracoastal Stages within the City Limits (White Drive) and NOAA Adjusted Stages

For the design storm event boundary conditions for any of the coastal models (Areas 1 through 12), conservative high tidal conditions were used. The highest tidal conditions from the past five years, measured at the NOAA Tidal Gage at Lake Worth Pier, were examined and averaged. The corresponding low tides for those ten high tidal events were averaged as well, and a 6-hour, oscillating tide was assumed for the 1-day and 3-day design events. The tidal elevations used were 2.5 ft-NAVD and -1.7-ft NAVD for high and low tides, respectively. **Appendix 4D** shows this boundary stage set for each design storm event.

To allow flow across the eastern boundary along A1A for the hydrologic model for Areas 1 through 9, the inlets on Ocean Blvd. were modeled and connected with a pipe to a time-stage node with a constant stage of 7 ft-NAVD, based on the average topography along the eastern boundary.

For the validation model, the downstream boundary conditions for Problem Areas 13 and 14 were set equal to the measured stages at Lake Ida, which is downstream of the L-31 and L-32 canals.

For the design storm event models, the downstream boundary condition for Problem Areas 13 and 14 was set to the downstream canal control elevation of 7 ft NAVD based on the control elevation documented by LWDD for the downstream canals. For area 14, there is a LWDD control structure (a fixed weir) that presents a flow constriction between the L-32 canal downstream of Problem Area 14 and Lake Ida. Thus, a fixed weir was added between the L-32 canal node and the downstream time-stage node. The weir crest

elevation was set to 8-ft NAVD, and the width was set 3.5 feet based on measurements taken of this fixed weir during a site visit.

4.16 Validation Storm Event Identification and Selection

A model validation period was selected based on rainfall data measured at the S40 station. Communications with City staff indicated that the summer of 2017 produced flooding conditions in some areas of the City. Thus, the largest rainfall event observed during this period of time was chosen as the validation period. **Figure 4-30** shows the largest event occurred during June 3rd to the 7th.

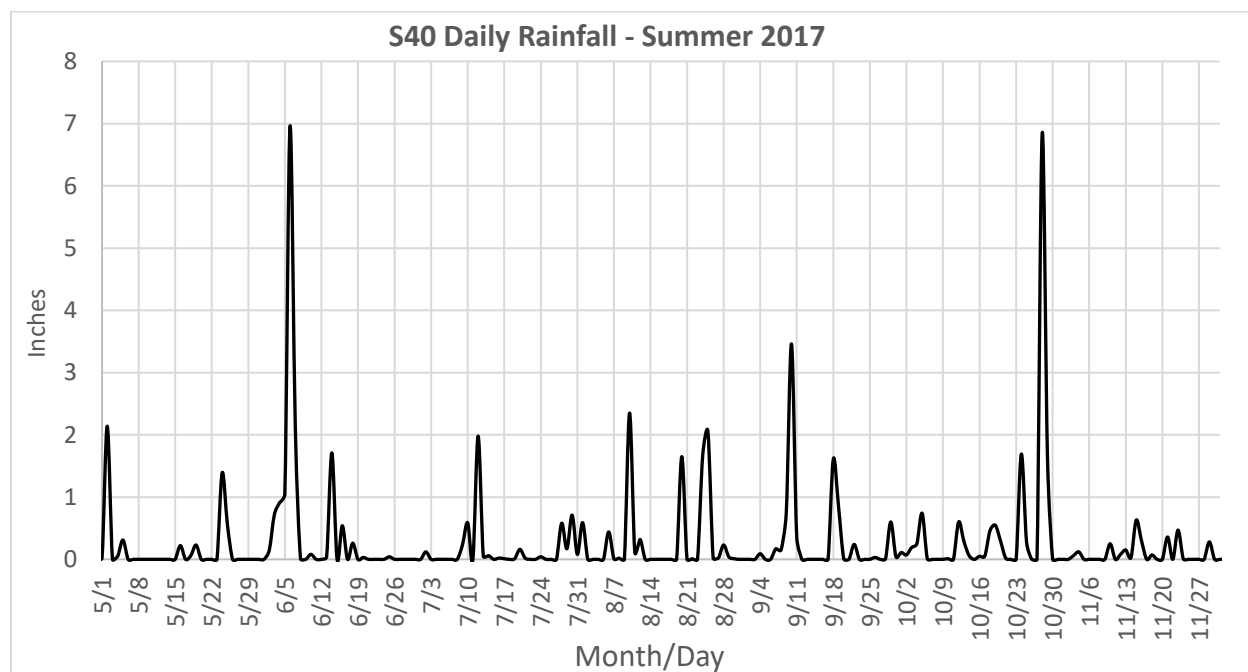


Figure 4-30: S40 Daily Rainfall for Summer 2017

4.17 Hydrologic and 2-D Model Setup for Validation Storm Event

The validation simulation period was set to run for 9 days, starting on June 1st, 2017 at 12 AM and stopping on June 10th, 2017 at 12 AM. The assumptions made to specify the initial and boundary conditions are described in **Sections 4.12.2** and **4.15**, respectively. The validation models use the NEXRAD radar rainfall processed for the corresponding cell(s) in each of the model areas. In addition, an estimated amount of rainfall depth was extracted in areas with exfiltration trenches representing the additional storage in those areas, as described in **Section 4.12.5**. Rainfall zone maps were defined to spatially distribute the varying rainfall amounts within each model area.

4.17.1 Validation Storm Event Results and Inundation Flood Maps

ICPR4 has the capability of exporting raster files of 2D model results at any time period. Maximum elevation and ground elevation raster files were exported from ICPR4. The

ground elevation raster was then subtracted from the maximum elevation raster to create a depth of flooding raster. The depth of flooding rasters for each problem area are included in **Appendix 4A**.

Validation flood maps were delivered to the City on July 6, 2018 for the City to compare the flood depths and extent of flooding predicted by the model to the observed flooding and known flooding complaints. Based on the City's review and comparison, the validation model inundation flood maps for the June 2017 rainfall event generates flooding very consistent with flooding complaints and observed flooding. Some minor discrepancies were observed between the flooding predicted by the model with known areas of flooding. These discrepancies are outlined below.

- For Problem Areas 1 through 9, the model shows some levels of flooding along Ocean Blvd. (A1A). However, A1A runs on the highest part of the dune through most of Delray Beach. Standing water has rarely been observed on that road. It has curb and gutter with frequent inlets. It appears that the predicted flooding in the model is due to the coarse nature of the LiDAR data that does not account for swale grading to the inlets along the road. Regardless, A1A is a State Road and alternatives will not be evaluated for these sections of these problem areas.
- For Problem Area 6, Atlantic Blvd between Gleason and Venetian did not have standing water in front of the Seagate Hotel. The model shows flooding in this section of Atlantic Blvd. As for flooding shown along some segments of A1A, alternatives will not be evaluated for because Atlantic Blvd is a state road.
- For Problem Area 10, standing water has been observed at the intersection of Spanish trail and near Tropic Blvd. However, the model shows limited flooding at this intersection. This discrepancy could also be due to the coarse nature of the available LiDAR data.

Considering the limited calibration and validation data available, there is consensus that the model represents very well the observed flooding and areas where there are documented flooding complaints. Therefore, it is assumed that this model is a valid representative model to be carried forward to assess the flood protection level of service for the 14 identified problem areas and to evaluate the required stormwater management improvements needed to address flooding in these areas and to address future predicted sea level and ground water rise.

4.18 Summary of Design Storm Event Results

The validated ICPR4 model documented in **Section 4.17** was used to simulate the level of flooding for the 14 problem areas using the design rainfall and boundary conditions documented in **Section 4.12**. **Table 4-9** summarizes the design storm event results with the range of flood depth for each area by design storm event and the location(s) where the worst flooding occurs. **Appendix 4B** has inundation maps for each design storm event for each of the 14 problem areas.

Table 4-9: Summary of Design Storm Event Results

Problem Area	Range of Depth of Flooding				Location(s) of Significant Flooding
	5Y-1D	10Y-1D	25Y-3D	100Y-3D	
1	0.1-3.4	0.3-3.5	0.3-3.5	0.3-3.5	Corner of Harbor Dr. and Andrews Ave.
2	0.1-2.8	0.1-3.1	0.3-3.3	0.4-3.8	Beach Dr., Seaspray Ave.
3	0.2-2.5	0.1-2.4	0.2-2.6	0.3-3.6	Waterway Ln.
4	0.3-3.1	0.2-3.5	0.4-3.7	0.4-4.0	Area near 1199 Lowry St.
5	0.2-2.7	0.2-2.9	0.2-2.9	0.3-3.1	1099 Miramar Dr.
6	0.2-3.0	0.3-3.4	0.3-3.9	0.5-4.8	Corner of Nassau St. and Gleason St.
7	0.2-5.9	0.4-6.3	1.0-6.8	1.0-7.1	1099 Tamarind Rd.
8	0.2-5.1	0.3-5.3	0.1-5.6	0.2-6.8	Corner of Hibiscus Rd. and Seasage Dr.
9	0.1-2.5	0.2-2.6	0.2-2.6	0.2-2.7	Rhodes Villa Ave, White Dr.
10	0.2-3.0	0.6-4.0	0.6-4.9	0.6-5.1	Eve St, Cypress St, Florida Blvd.
11	0.1-1.6	0.3-1.8	0.3-1.8	0.3-1.9	Near 800 SE 7th Ave.
12	0-0.9	0-1.2	0-1.2	0.1-1.4	Along Marine Way
13	0.2-1.8	0.2-2.1	0.2-2.2	0.2-2.4	Corner of NW 7th Ct. and 37th Ave.
14	1.2-4.1	0.3-5.3	0.4-6.0	0.5-6.7	NW 6th Ct., NW 6th St.

4.19 Flood Inundation Maps

Flood inundation maps for each problem area and design storm area included in **Appendix 4B**. Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps (FIRM) were visually compared to the 100-year 3-day storm event flood depth raster files for modeled areas 1 through 12. Modeled areas 13 and 14 did not have any property in the FEMA FIRM 1% annual chance flood area. **Figure 4-31** through **Figure 4-35** show the modeled 100-year 3-day storm maximum depth raster files superimposed on the FEMA FIRM maps.

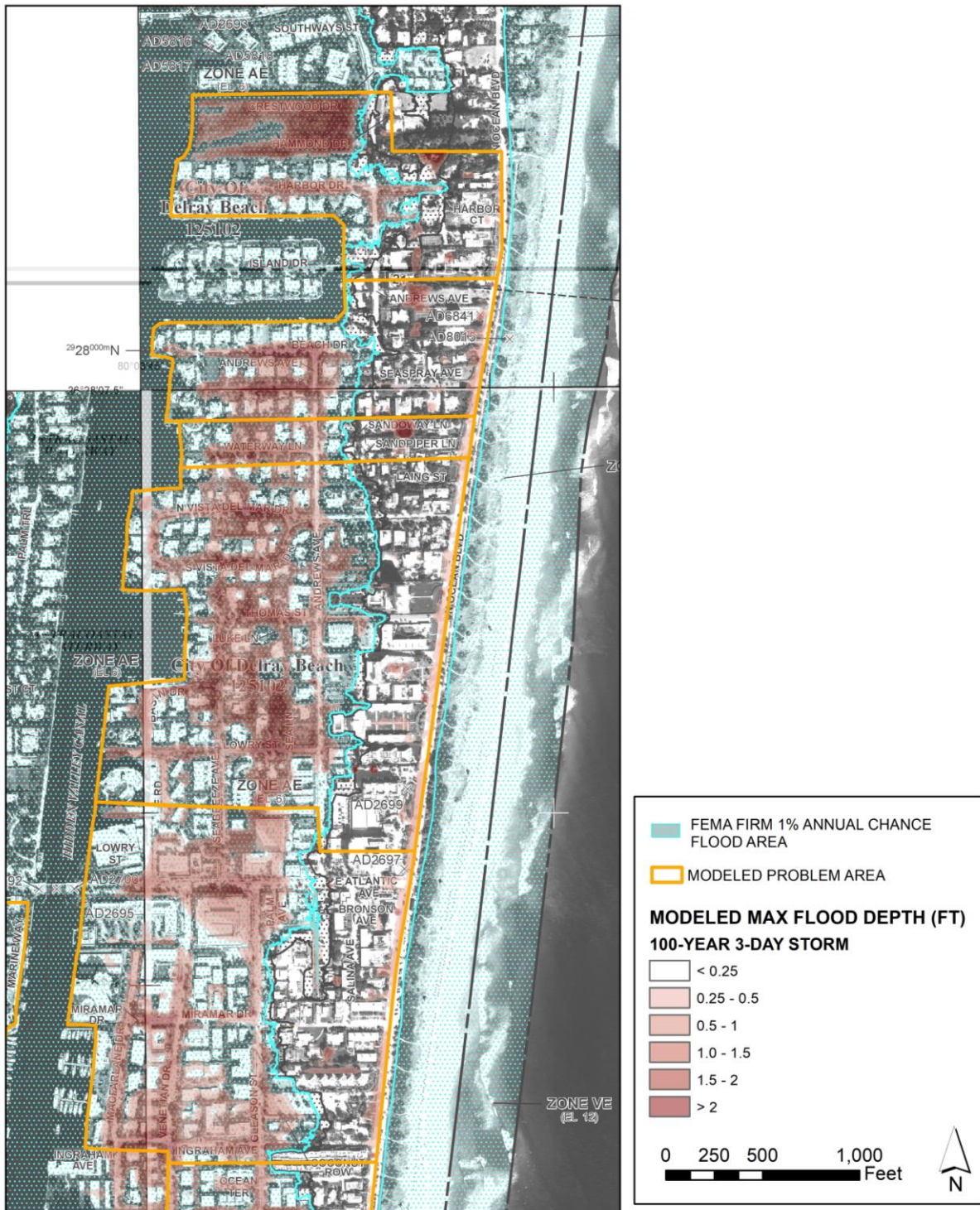


Figure 4-31: FEMA FIRM Compared to Modeled 100Y-3D Storm for Areas 1-5



Figure 4-32: FEMA FIRM Compared to Modeled 100Y-3D Storm for Areas 6-9

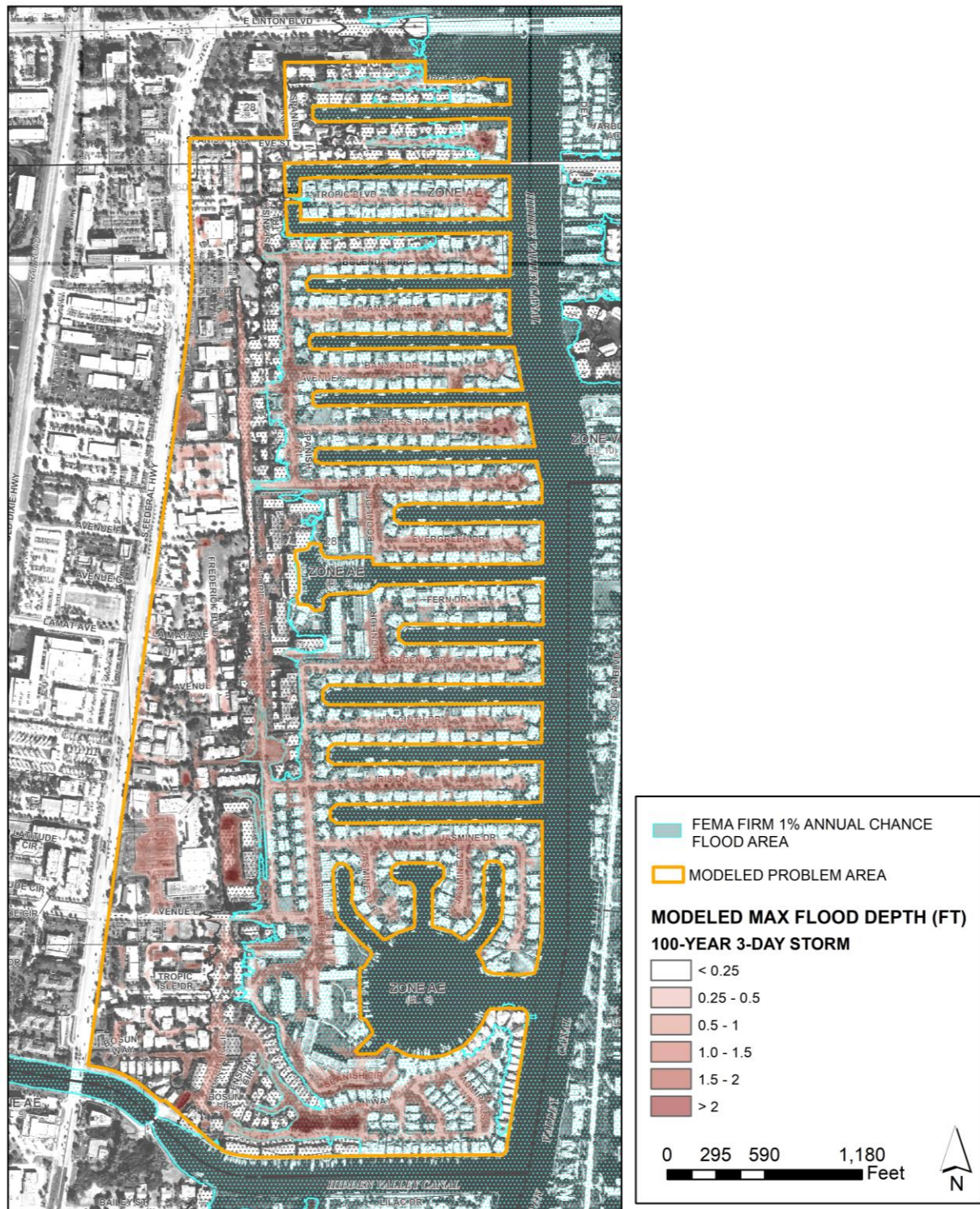


Figure 4-33: FEMA FIRM Compared to Modeled 100Y-3D Storm for Area 10

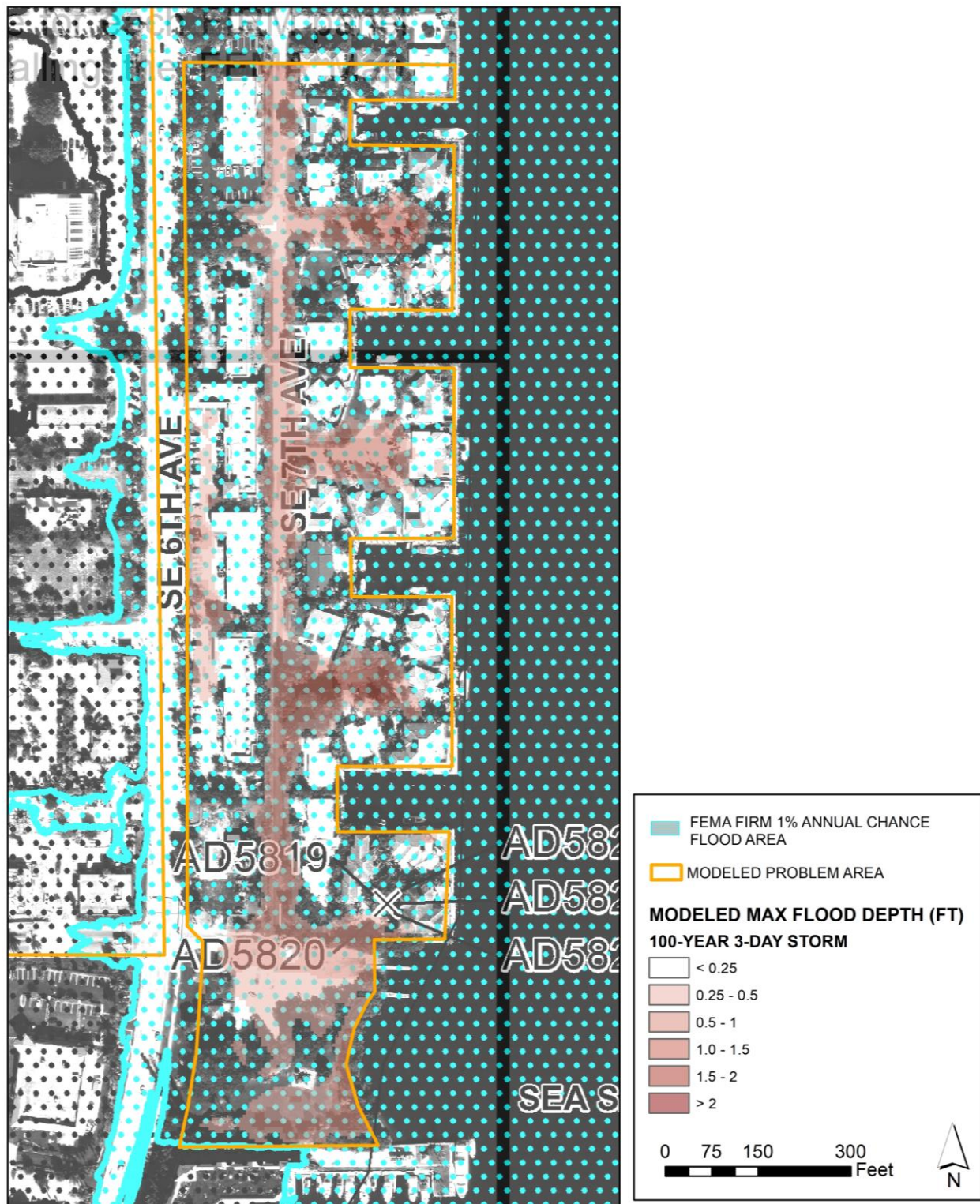


Figure 4-34: FEMA FIRM Compared to Modeled 100Y-3D Storm for Area 11

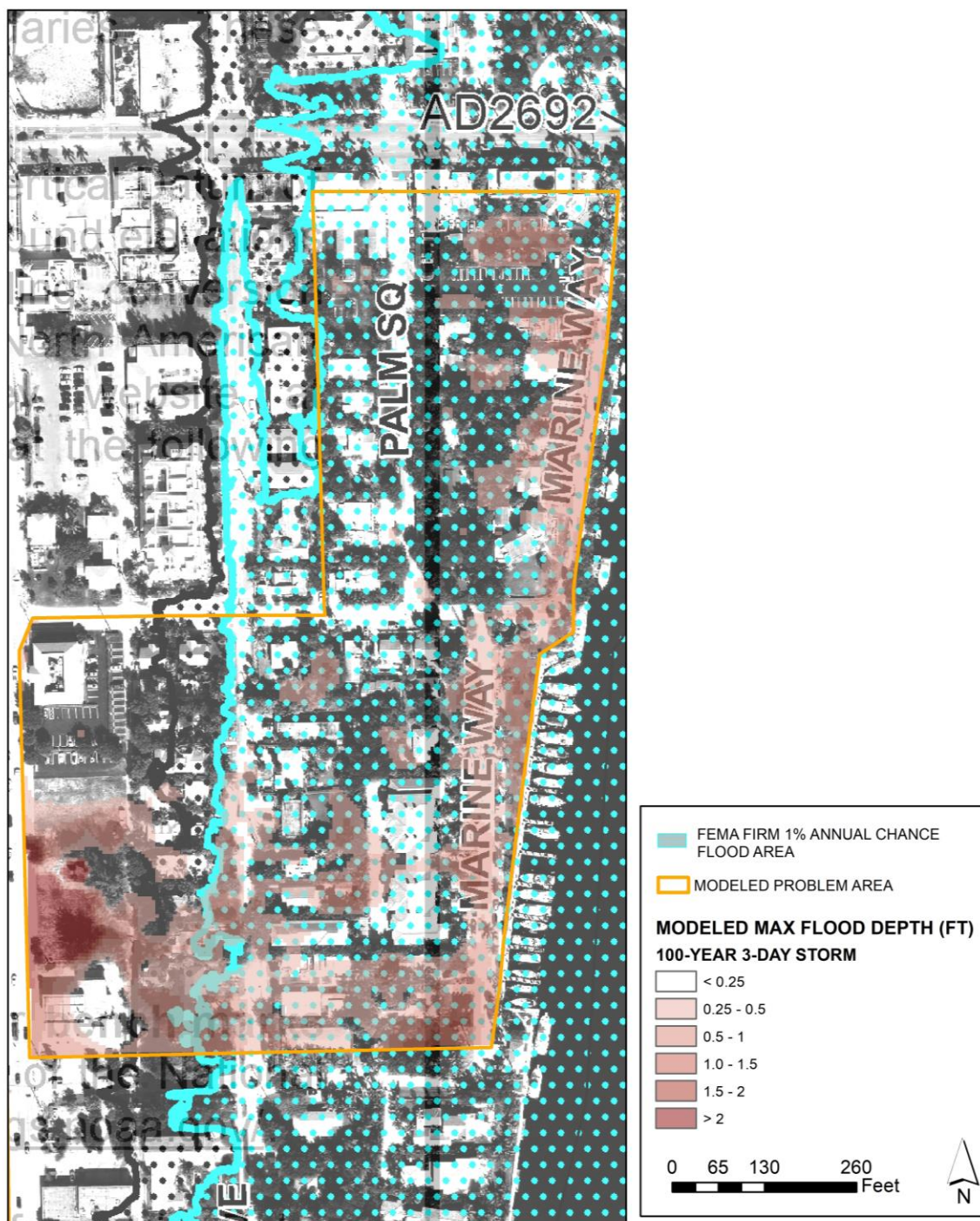


Figure 4-35: FEMA FIRM Compared to Modeled 100Y-3D Storm for Area 12

From **Figures 4-31 through 4-35**, overall there is good agreement between the 100-year, 3-day design storm event extent of flooding simulated by the ICPR4 model with the FEMA FIRM for the coastal areas of the City. This is another good indication that the existing

conditions ICPR4 model develop for this Stormwater Master Plan update is representative of the hydrologic/hydraulic conditions for the City.

5.0 LEVEL OF SERVICE

5.1 Background and Scope

The purpose of this task, *Level of Service (LOS)*, is to establish the existing LOS for the 14 problem areas outlined in TM 1. The LOS will be established using documented procedures and requirements and will address minor, secondary and primary road systems as well buildings based on assumed finished floor elevations. Different storms will be established for each of these features based on common practices and coordination with the City. The results will be quantified by establishing a Flood Protection Severity Score (FPSS) based on the linear feet of roadway meeting or not meeting the applicable LOS and number buildings meeting or not meeting the LOS. Maps will be produced showing the locations of areas of non-compliance and level of exceedance. The FPSS will be used to rank each of the Problem Areas based on level of flood severity.

5.2 Flood Problem Area Ranking Procedure

The ranking of flooding problem areas within the City will be related to the defined stormwater infrastructure level of service (FPLOS) as follows:

1. Building finished floor elevations shall be at or above the 100-year, 3-day design storm peak flood elevations (SFWMD ERP Applicant's Handbook, Volume II). Both tidal flooding and the 100-year, 3-day storm event shall be considered in determining the peak elevations.
2. City owned local collector roads and parking lots shall be at or above the 5-year, 1-day design storm peak flood elevations (SFWMD ERP Applicant's Handbook, Volume II). Both tidal flooding and the 5-year, 1-day storm event shall be considered in determining the peak elevations.

Within the 14 problem areas defined in TM 1, only one has a major collector road (Atlantic Avenue), and the coastal area has a major arterial/evacuation route (A1A) on the east end. However, A1A is elevated along the coastal ridge with little to no documented flooding, and the portion of Atlantic Avenue within Problem Area 5 also does not have frequently documented flooding. In addition, the proposed drainage improvement projects will only focus on flooding for City owned roads. Therefore, major collector and arterial roads will not be considered in determining the FPLOS for the 14 problem areas.

The severity of flooding within each problem area will be determined through the calculation of a flooding problem severity score (FPSS), which is a function of two "severity indicators" that are directly related to the FPLOS criteria described previously. These severity indicators are defined and summarized below. Each of these indicators also has an assigned "weighing factor" (WF), which is related to the relative importance of the flooding severity indicator.

3. **NS:** Number of structures anticipated to flood by a 100-year, 3-day design storm event, which can include commercial, residential, and public buildings. All

structures and/or buildings are considered equivalent, regardless of their size or value. **(WF = 4)**

4. **MCLRS:** Miles of collector and local residential streets anticipated to be impassable during 5-year, 1-day design storm event. All collector and local residential streets are considered impassable if the depth of flooding exceeds the crown of the road during the 5-year, 1-day design storm event. **(WF = 2)**

The severity indicators are rated by an exceedance (E) value pursuant to the following severity score listed in the table below.

Depth of Flooding Above the FPLOS	E
Less than or equal to 6 inches	1
Greater than 6 inches and less than or equal to 12 inches	2
Greater than 12 inches	3

Given the definitions for the flooding severity indicators (NS and MCLRS), WF, and E, the FPSS for each problem area is calculated using the following formula, where $E_{(i)}$ relates to the degree of exceedance for each of the five severity indicators.

$$\text{FPSS} = \sum 4E_i \cdot \text{NS} + \sum 2E_i \cdot \text{MCLRS}$$

Because the area of the problem areas varies significantly, the severity score is then weighted based on the approximate size of the problem area, to not have large problem areas skew the FPSS. Smaller problem areas are weighted less than larger problem areas due to a decrease in the number of streets as well as structures. Once the severity score is weighted per problem area, the area with the highest FPSS is given a ranking value of 1. Subsequent FPSS scores are then given ranking values of 2 through 14. Problem areas with equivalent FPSS are given the same ranking value. This approach will yield the area with the lowest FPLOS based on a quantifiable and mathematical basis.

5.3 Problem Area LOS Summary of Results and Ranking

Numerous GIS files were collected from the City of Delray Beach and the Palm Beach County online GIS Database to represent the roads, properties, and topography within the City limits. These files were modified and used to rank areas susceptible to flooding within the City based on the Design Storm ICPR4 Modeling results from **Section 4.0**. Only City-owned roadways and properties with structures were analyzed to establish the FPSS for each problem area. These updated files were then further defined using a topography file to include the elevation of their location. The defined roadway and

property files were combined with model results to quantify the values for each of each of the problem area flooding severity indicators and perform the level of service analysis.

5.4 Quantifying Methodology for Problem Area Flooding Severity Indicators

The various flood severity indicators of the FPSS equation outlined in **Section 5.2** were quantified using standard GIS tools to facilitate the analysis of the resulting model data versus the digital elevation model (DEM). The DEM used for this SWMP is described as the 2007-08 Palm Beach East 5-ft DEM in NAVD 1988, Release Version 1. This is a 5-ft digital elevation model (DEM) of bare earth that covers most of eastern and urban Palm Beach County.

As presented in **Section 4.0**, the modeled flood depths for the design storms were calculated by subtracting the modeled maximum elevation raster output, from ICPR4, from the modeled ground surface elevation raster output used by ICPR4. The resulting flood depth raster has cell dimensions of 5-ft by 5-ft and can be seen in **Figure 5-2**.

A 5-ft by 5-ft raster was also created from the road centerlines. All road centerline cells were given a value of 1 and all other cells were given a value of 0 as seen in **Figure 5-1**. This road centerline raster was multiplied by the 5-year, 1-day flood depth raster to produce a 5-ft grid along the road centerline with 5-year, 1-day flood depth values as seen in **Figure 5-3**. The road centerline raster was also multiplied by the 100-year, 3-day storm maximum elevation raster to produce a 5-ft grid along the road centerline with 100-year, 3-day flood elevation values to be used in the analysis of flooded structures.

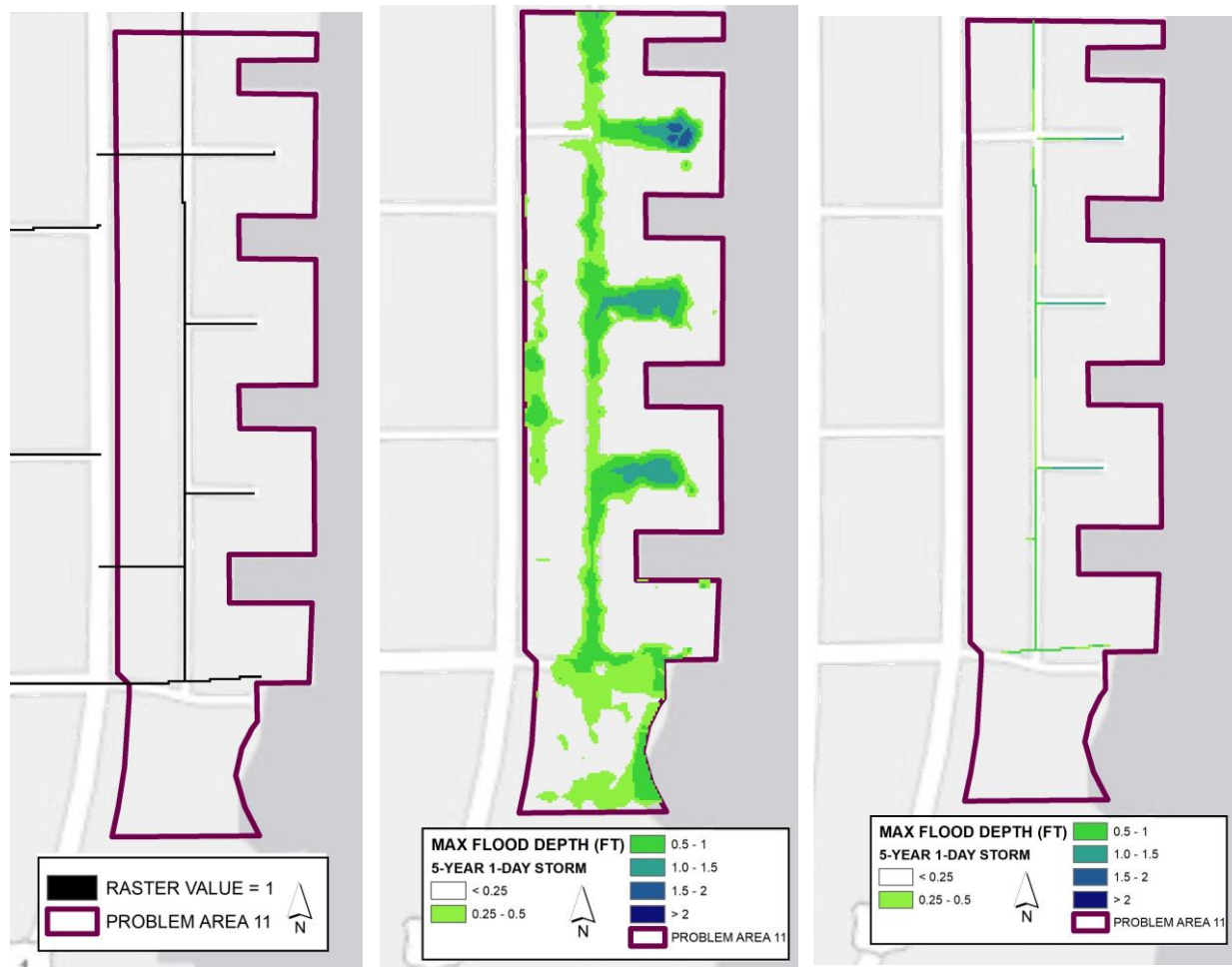


Figure 5-1: Road Centerline 5-ft by 5-ft Raster with a Value of 1

Figure 5-2: Maximum 5y-1d Flood Depth Raster

Figure 5-3: Result of Multiplying the Road Centerline (Value = 1) Raster with the Flood Depth Raster

5.4.1 Quantification of MCLRS

The 5-ft by 5-ft rasterized road centerline flood depth raster was reclassified using ArcMap tools. The reclassify tool was used to change any raster cell with a value less than 0.25 to zero, any raster cell with a value between 0.25 and 0.5 to a reclassified value of 1, any raster cell with a value between 0.5 and 1 to a reclassified value of 2, and any raster cell with a value above 1 to a reclassified value of 3. This created an Exceedance value for each 5-ft section of city roadway. **Appendix 5A** includes the MCLRS flooded and the exceedance values for the road raster in each problem area. The number of cells with each exceedance value was summed to give a count of 5-ft roadway sections for each flooding exceedance value. **Appendix 5B** shows the MCLRS count for each problem area.

5.4.2 Quantification of NS

Next, the number of structures flooded, or NS, was calculated using the existing property appraiser's coverage acquired from the Palm Beach County online GIS database. The parcel coverage included data about the land use for the property and whether the lot was vacant or not. A point shapefile was created by placing a point at the centroid of each polygon in the parcel shapefile that was not a vacant lot. The point shapefile was further edited visually using the 2017 aerial imagery to determine whether or not a building is truly located on the parcel.



Figure 5-4 – Property Polygons to Points

Per discussions with the City, finished floor elevations were assumed to be in accordance with the City regulation of 18 inches above the nearest crown-of road elevation. In order to assign each structure's point feature a finished floor elevation, a 5-ft by 5-ft crown of road elevation raster was first created along the centerlines of the City roads by multiplying the road centerline raster (Value = 1 along the road centerline, Value = 0 anywhere else in the City) with the DEM. This crown of road elevation raster was then converted into a point shapefile and spatially joined to the structure location point shapefile. The structure location point shapefile attribute table was then populated with the closest crown of road elevation. A field was added in the attribute table for the finished floor elevation and this field was calculated by adding 1.5-ft to the closest crown of road elevation. Problem Areas 13 and 14 had ERP permits with defined minimum finished floor elevations. Any structure in Area 13 or 14 that had a calculated finished floor

elevation (from the process described above) lower than the minimum finished floor elevation was edited to have at least the minimum finished floor elevation from the Permit.

Once the locations of the structures were delineated with a point shapefile in GIS, and finished floor elevations were assigned for each structure, the 5-ft by 5-ft road centerline 100-year, 3-day maximum elevation raster was further processed by converting it into a point shapefile. A spatial join was performed with the target raster set as the structures point shapefile and the join raster set as the road max flood elevation point shapefile. The structure location point shapefile attribute table was then populated with the closest road flood elevation.

Attribute table calculations were then performed for the depth of flooding of the structures. The finished floor elevation for each structure was subtracted from the maximum flood elevation for the nearest road. Negative values from this calculation were converted to 0 because this indicated that the road flood elevation was lower than the finished floor elevation. The flood depths were then assigned an exceedance value. As described earlier, any structure flooded less than 0.5-ft was assigned an exceedance value of 1. Any structure flooded between 0.5-ft and 1-ft was assigned an exceedance value of 2. Any structure flooded above 1-ft was assigned an exceedance value of 3. **Appendix 5A** shows the structure flooding and exceedance values for each problem area.

The number of flooded structures with each exceedance value was summed to give a count of structures for each flooding exceedance value for each problem area. **Appendix 5B** shows the number of structures flooded (NS) count for each problem area.

5.4.3 Summary of Results

The values quantified by the two (2) “severity indicators” determined the severity of flooding within each problem area and were used to establish the FPSS values for each problem area. These severity indicators are defined and summarized in **Section 5.4.3**. Each of these indicators also has an assigned recommended “weighing factor” (WF), which is related to the relative importance of the flooding severity indicator. The weighing factor of flooding structures is twice that of the miles of road flooded due to the inherent property loss and danger associated with flooded structures.

Once the severity score is calculated for each problem area and weighted against the acreage of the area, the areas are ranked from highest FPSS to lowest; 1 ranking highest and 14 ranking lowest. This approach will yield the areas with the highest flooding problems based on a quantifiable and mathematical basis. **Table 5-1** shows the ranking of problem areas based on their FPSS. The complete tables for calculation of FPSS are included in **Appendix 5B**.

Table 5-1: FPSS Ranking by Problem Area

Rank	Problem Area Name	Sub-Basin Area (Acres)	FPSS	Weighted FPSS
1	Beach Drive (2)	22.84	105.7	4.63
2	Thomas Street & Basin Drive (4)	67.34	234.4	3.48
3	Rainberry Woods (14)	71.02	190.3	2.68
4	Hibiscus (8)	28.53	63.4	2.22
5	Bay Street (6)	27.42	55.2	2.01
6	Seasage Drive (7)	61.22	63.4	1.04
7	Waterway Lane (3)	7.85	4.6	0.59
8	Atlantic Ave (5)	64.79	33.7	0.52
9	Spanish Circle (10)	281.49	144.6	0.51
10	Harbor Drive (1)	26.22	9.2	0.35
11	Banwick Park (13)	59.92	17.9	0.3
12	7 th Ave (11)	14.65	1.6	0.11
13	Brooks Lane (9)	19.54	1.4	0.07
14	Marine Way (12)	15.28	0.8	0.05

Analysis of FPSS ranking per problem area identified all problem areas as experiencing significant flood issues within the City of Delray. The FPSS predicts that all of the problem areas experience some significant road flooding and eleven out of the fourteen problem areas contain structures that may be at risk of flooding. These fourteen problem areas were identified by the City and are already considered high priority in terms of stormwater improvements; however, this ranking provides a quantifiable and mathematical way to prioritize improvements.

6.0 PROJECTED SEA LEVEL RISE IMPACTS

6.1 General

Due to the fact that the City of Delray Beach has experienced increased levels of seasonal flooding within the communities that are bounded by the Intracoastal Waterway, the City contracted a Water Level and Infrastructure Vulnerability Study with Aptim Environmental & Infrastructure, Inc. The study provides guidance on infrastructure at the 30-year and 75-year planning horizons. It also included a seawall elevation data and outfall data survey collection effort.

6.2 Prior and Ongoing Sea Level Rise Studies for Coastal Areas

The previously mentioned sea level rise study report, *City of Delray Beach Intracoastal Waterway Water Level & Infrastructure Vulnerability Study – Phase 1a*, was prepared by Aptim Environmental & Infrastructure, Inc in March 2018. The 2018 study analyzes available water level data, return periods of extreme events, and sea level rise projections and provides recommendations for the City's 30-year and 75-year planning horizons. In this study it was found that the expected peak tide elevation for the 30-year planning horizon is 3.9 to 4.4 ft-NAVD, and the expected peak tide elevation for the 75-year planning horizon is 5.3 to 7.4 ft-NAVD.

6.2.1 Seawall Survey

As a part of the seawall vulnerability analysis study by Aptim Environmental & Infrastructure, Inc., topographic survey of the seawall along the Intracoastal Waterway (ICW) was performed during the period of January 22, 2018 to May 22, 2018.

Applicable to this sea level rise assessment are 773 surveyed points within the 12 coastal Problem Areas. Problem areas are defined and described in **Section 3.0**. **Figure 6-1** shows the surveyed point locations and the 12 coastal problem areas.

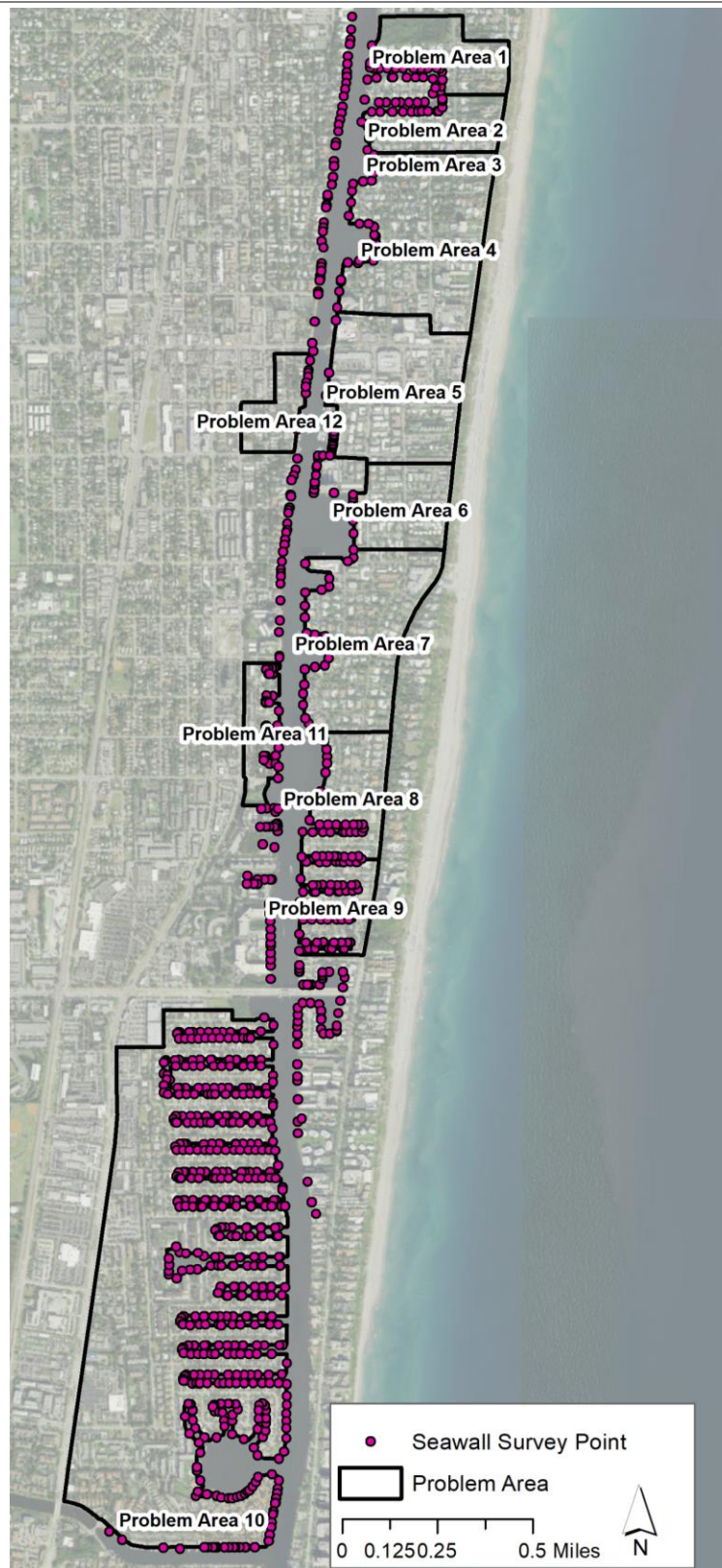


Figure 6-1: Seawall Survey Points for Coastal Areas

6.2.2 30-Year Sea Level Rise Planning Horizon Criteria for Coastal Areas

Per the discussion with the City of Delray Beach, the 30-year planning horizon sea level elevations are as outlined in **Table 6-1**. The previously described Aptim Environmental Water Level study estimates 30-year high tidal planning elevations between 3.9 ft-NAVD and 4.4 ft-NAVD. For the purpose of the modeling efforts described in this report, the high tide elevation for a 30-year planning horizon is assumed to be 4.2 ft-NAVD which is the average of 3.9 ft-NAVD and 4.4 ft-NAVD. Based on an approximate average of 4 feet of tidal difference between high and low tides, a low tide of 0.2 ft-NAVD is used. The groundwater level is assumed to be the mean of the high and low tidal elevations.

Table 6-1 : 30-Year Planning Horizon Criteria for Coastal Areas

30-Year Planning Horizon Model Parameter	Elevation (ft-NAVD)
High Tide Elevation (ft-NAVD)	4.2
Low Tide Elevation (ft-NAVD)	0.2
Avg Wet Season Groundwater Elevation (ft-NAVD)	2.2

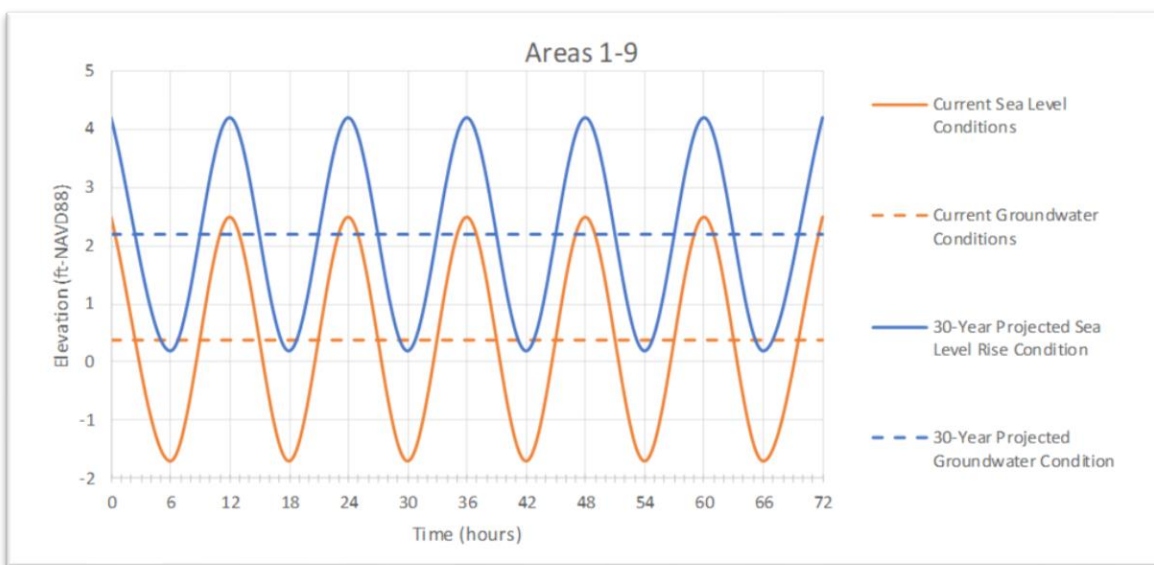


Figure 6-2: Coastal Problem Area (1-12) Tidal Boundary Conditions and Groundwater Level Assumptions

6.2.3 75-Year Sea Level Rise Planning Horizon Criteria for Coastal Areas

Per the discussion with the City of Delray Beach, the 75-year planning horizon sea level elevations are as outlined in **Table 6-2**. The previously described Aptim Environmental Water Level study estimates 75-year high tidal planning elevations between 5.3 ft-NAVD and 7.4 ft-NAVD. For the purpose of the modeling efforts described in this report, the worst-case scenario for high tide elevation for 75-year planning horizon is assumed. Based on an approximate average of 4 feet of tidal difference between high and low tides,

a low tide of 3.4 ft-NAVD is used. The groundwater level is assumed to be the mean of the high and low tidal elevations.

Table 6-2: 75-Year Planning Horizon Criteria for Coastal Areas

75-Year Planning Horizon Model Parameter	Elevation (ft-NAVD)
High Tide Elevation (ft-NAVD)	7.4
Low Tide Elevation (ft-NAVD)	3.4
Avg West Season Groundwater Elevation (ft-NAVD)	5.4

6.3 30-Year Sea Level Rise Seawall Vulnerability Assessment Summary

In order to determine the total length of vulnerable seawall within the 12 coastal problem areas, the elevation of the seawall sections between surveyed points was interpolated based on the two surveyed points that were geographically the closest. It was ensured that between a surveyed seawall point and a surveyed edge-of-pavement or no-seawall point, points were given the value of the seawall (if seawall extended to that location) or given the value of the closest edge-of-pavement point. Using the attributes table within GIS, the high tide elevation for a predicted 30-Year Sea Level Rise was compared to the seawall elevations and overtopping locations were determined. Plan and profile view plots of seawall vulnerability locations for the 30-year planning horizon can be found in **Appendix 6A**.

It is estimated that for the 30-year planning horizon high tide elevation, approximately 12 miles of seawall within the City's Problem Areas will be overtopped. **Table 6-3** describes the linear feet, per problem area, of overtopped seawall for the 30-year planning horizon. **Figure 6-3** shows the seawall within the 12 coastal Problem Areas that is predicted to be overtopped with the high tidal elevation for the 30-year planning horizon.

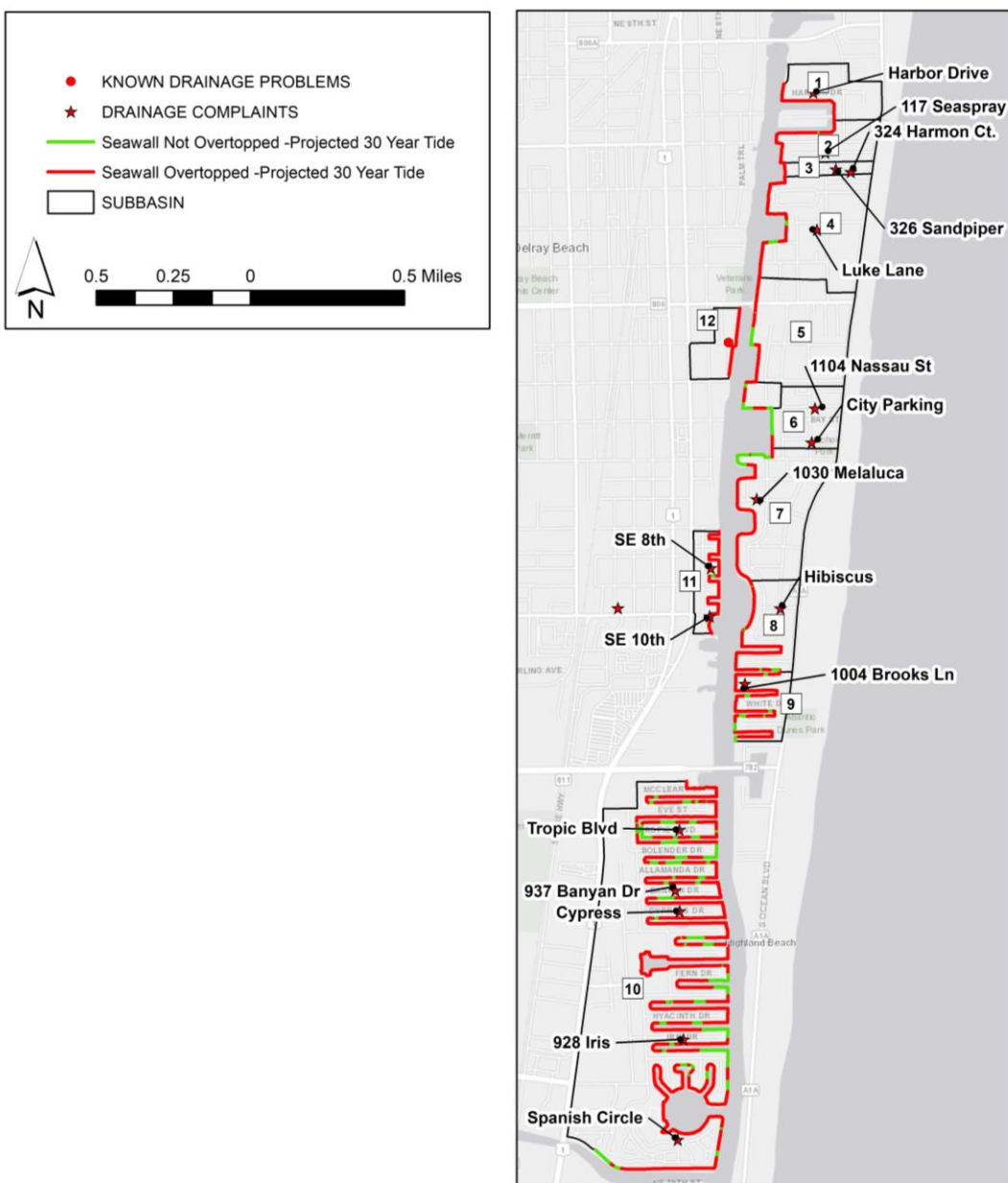


Figure 6-3 : Overall Seawall Overtopped in Projected 30-Year SLR Planning Horizon

Table 6-3: 30-Year Planning Horizon Length of Overtopped Seawall in Problem Areas

Problem Area	Problem Area Name	Linear Feet of Overtopped Seawall	Total Linear Feet of Seawall	Percent Overtopped
1	Harbor Drive	1495	1495	100%
2	Beach Drive	1790	1820	98%
3	Waterway Lane	235	235	100%
4	Basin Drive	2380	2635	90%
5	Atlantic Avenue	1580	1960	81%
6	Bay Street	890	1800	49%
7	Seasage Drive	3125	3995	78%
8	Hibiscus Road	3585	3840	93%
9	Brooks Lane	5285	5972	88%
10	Spanish Circle	39825	48452	82%
11	7 th Avenue	3170	3249	98%
12	Marine Way	1200	1200	100%

6.4 75-Year Sea Level Rise Seawall Vulnerability Assessment Summary

As previously described, in order to determine the total length of vulnerable seawall within the 12 coastal problem areas, the elevation of the seawall sections between surveyed points was interpolated based on the two surveyed points that were geographically the closest. **Appendix 6A** shows profile views of the problem area seawalls compared with the 75-year planning horizon predicted tide. The high tide used for the 75 Year Sea Level Rise Assessment is 7.4 Ft NAVD.

It is estimated that for the 75-year planning horizon high tide elevation, approximately 15 miles of seawall within the City's Problem Areas will be overtopped. **Table 6-4** describes the linear feet, per problem area, of overtopped seawall for the 75-year planning horizon.

Table 6-4: 75-Year Planning Horizon Length of Overtopped Seawall in Problem Areas

Problem Area	Problem Area Name	Linear Feet of Overtopped Seawall	Total Linear Feet of Seawall	Percent Overtopped
1	Harbor Drive	1495	1495	100%
2	Beach Drive	1820	1820	100%
3	Waterway Lane	235	235	100%
4	Basin Drive	2635	2635	100%
5	Atlantic Avenue	1960	1960	100%
6	Bay Street	1800	1800	100%
7	Seasage Drive	3995	3995	100%
8	Hibiscus Road	3840	3840	100%
9	Brooks Lane	5975	5972	100%
10	Spanish Circle	48452	48452	100%
11	7 th Avenue	3245	3249	100%
12	Marine Way	1200	1200	100%

6.5 Sea Level Rise Planning Horizons Model Setup

The ICPR4 models outlined in **Section 4.0** were copied and edited to include the sea level rise parameters discussed in **Sections 6.2.2, 6.2.3** and **6.6.1**. Changes to the model include boundary conditions, soil storage parameters, initial condition elevations, and a DEM that incorporates the surveyed seawall elevations.

Examination of the Palm Beach East 5-ft DEM raster (downloaded from the SFWMD GIS Database) showed that LiDAR was not precise enough to fully represent seawalls in the DEM. In order to ensure that seawalls are represented in the 2D mesh for the Overland Flow Region, the interpolated seawall elevation raster developed from the survey data described in **Section 6.2.1** was “burned” into the original 5-ft DEM. **Figure 6-4** shows an example of where the seawall is burned into the DEM. DEMs in the ICPR4 models were only edited to simulate surveyed seawall elevations for the coastal Problem Areas.

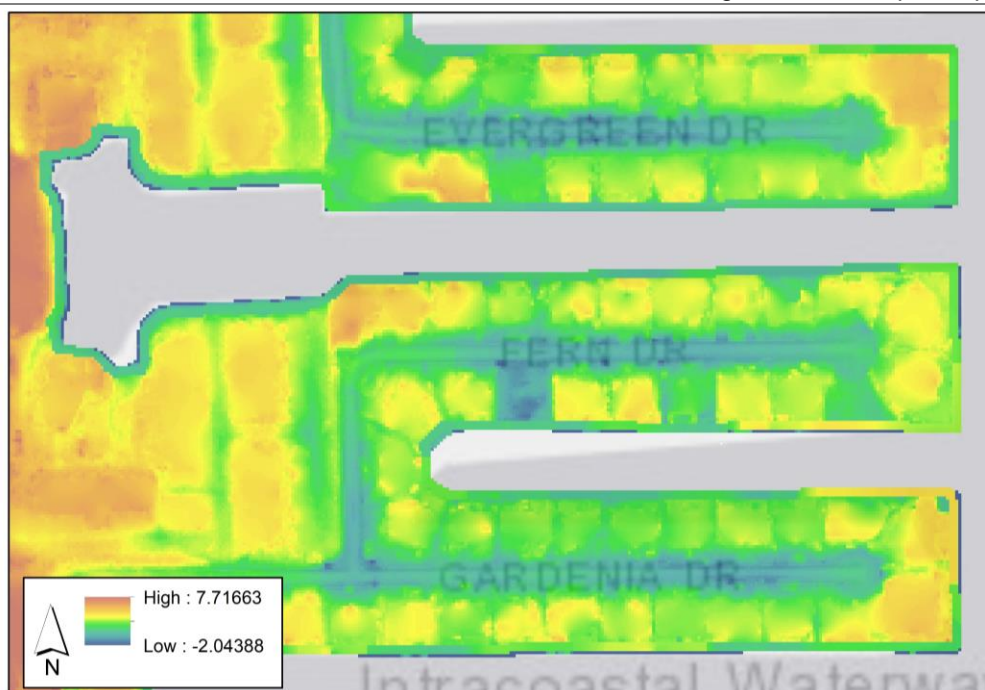


Figure 6-4: Surveyed Seawall Elevations Burned into DEM

6.6 Prior and Ongoing Groundwater Rise Studies for Upland Areas

Problem Areas 13 and 14 are approximately 3 miles from the Intracoastal Waterway. Palm Beach County does not have projected groundwater elevations as far inland as Problem Areas 13 and 14. The closest future groundwater level projections were done for Broward County for use in reviewing their surface water management license applications. These maps did not anticipate significant rise in groundwater in areas 3 miles inland.

6.6.1 Sea Level Rise Planning Horizon Criteria for Upland Areas

Due to the fact that there is no groundwater rise projection study or data available for groundwater rise assumptions in this area of Palm Beach County, 1-ft (30-year horizon) and 2-ft (75-year horizon) of groundwater rise was modeled for Problem Areas 13 and 14, respectively. The goal of assuming these values for groundwater rise was to illustrate the impact of reduced soil storage and increased canal stages on the flooding within these two problem areas, if future groundwater studies in Palm Beach County project higher groundwater rise in upland areas due to sea level rise.

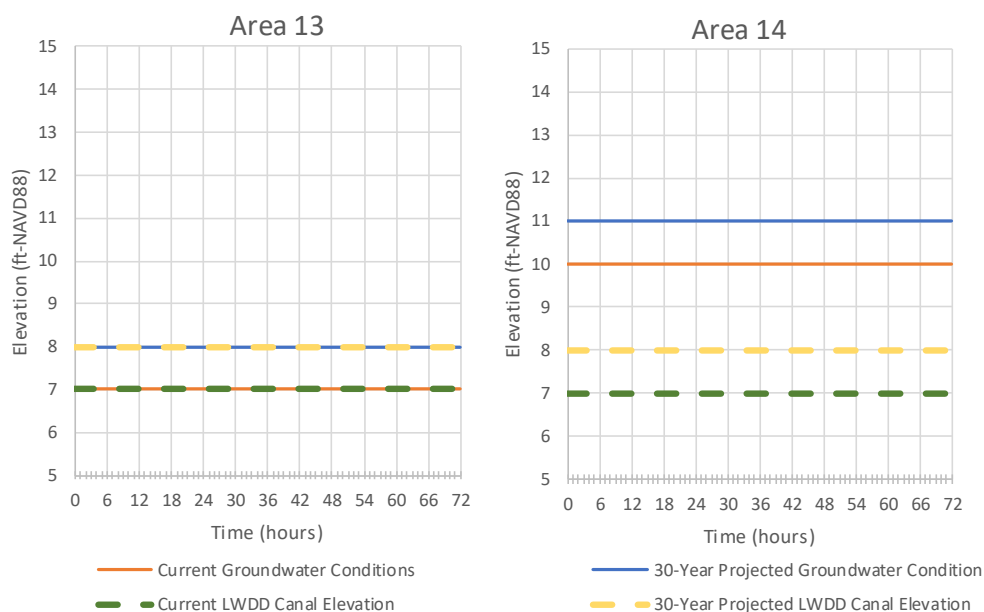


Figure 6-5: Upland Problem Area (13 - 14) Boundary Conditions and Groundwater Level Assumptions

6.7 30-year Sea Level Rise Planning Horizon Model Setup

Because of the differing impacts of Sea Level Rise between coastal areas and upland areas, sea level rise is modeled differently for the coastal Problem Areas (Areas 1-12) and upland Problem Areas (Areas 13-14). The following sections describe the soil storage, boundary condition, and initial condition parameter changes made from the Existing Conditions models to the 30-Year Planning Horizon Sea Level Rise models in order to simulate this degree of Sea Level Rise in Problem Areas 1-14.

6.7.1 Coastal Areas Model Setup (30-year SLR Planning Horizon)

Due to increased groundwater levels, the soil storage is lower in the sea level rise scenarios. Soil storage zones for areas with generalized elevations of 3, 4, 5, 6, 7, 8, and 9 ft-NAVD were defined for the coastal Problem Areas. **Figure 6-6** shows the soil zones defined for the sea level rise planning models for the coastal Problem Areas.

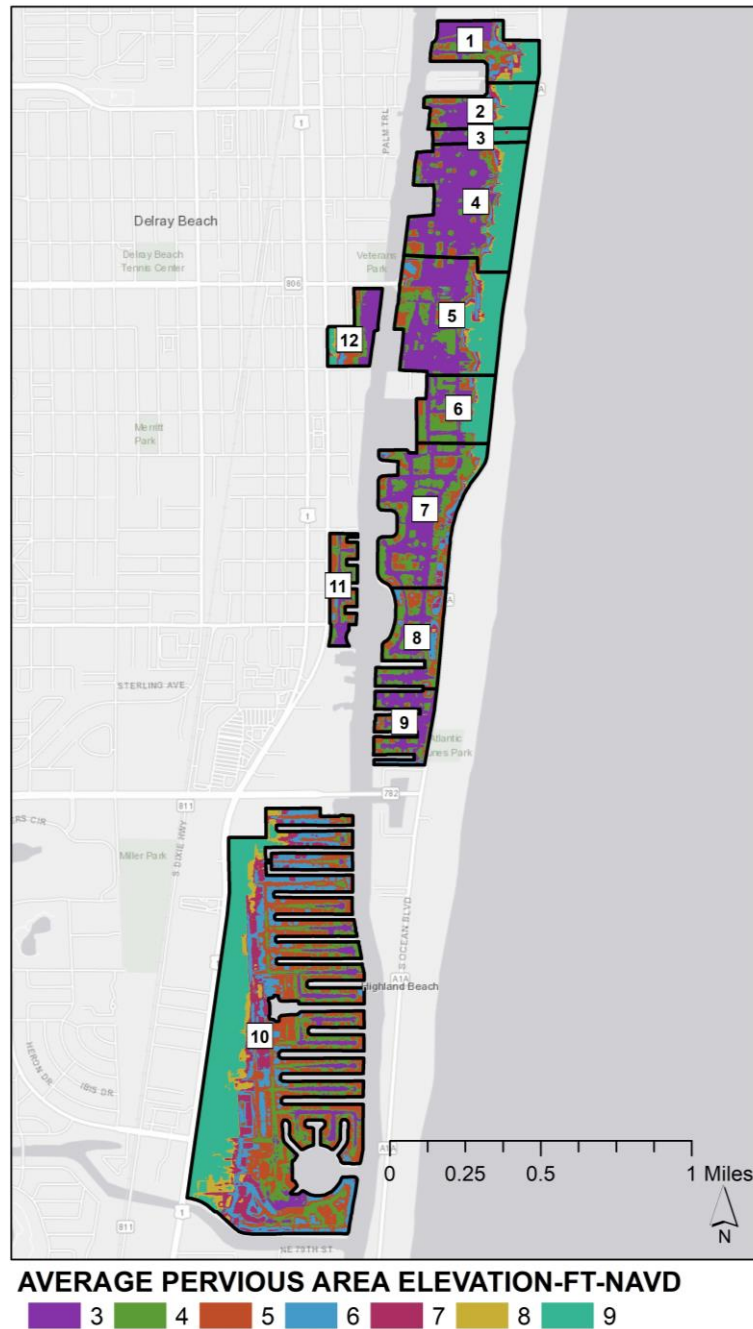


Figure 6-6 :Soil Zone Map for the Coastal Problem Areas Sea Level Rise Scenarios

In order to set the initial condition parameters for the 2D mesh and 1D nodes, a DHW assumption was made. Since the model domains for Problem Areas 1-12 are within coastal areas, it is assumed that the Design High Water (DHW) in these areas is tidally influenced. Therefore, the initial stage elevation is raised from 0.37 ft-NAVD in the Existing Conditions models to 2.2 ft-NAVD in the 30-year planning Horizon models to

represent an increased groundwater level along the coast, based on the 30-year SLR planning horizon average low and high tide elevations.

The intracoastal boundary stage line and boundary stage nodes were edited to have the high and low tidal conditions described in **Section 6.2.2**.

Curve numbers were re-calculated for each soil zone/land use combination. **Table 6-5** shows each re-calculated curve number for the 30-year sea level rise planning horizon for coastal Problem Areas.

Table 6-5: 30-Year Sea Level Rise Recalculated Curve Numbers for Coastal Problem Areas

Land Cover Zone Abbr.	Land Cover Zone	Soil Zone					
		3	4	5	6	7	8
UCSS	Commercial	98	96	92	88	88	88
UIIN	Industrial	98	97	94	91	91	91
UOUN	Open Space	98	88	71	58	56	56
URSL	Low Density Residential	98	95	89	84	83	83
URSM	Medium Density Residential	98	95	90	86	85	85
USGF	Community Facilities	98	94	86	81	80	80

6.7.2 Upland Areas Model Setup (30-year SLR Planning Horizon)

Soil storage zones for areas with generalized elevations of 10, 11, 12, and 13 ft-NAVD for Problem Areas 13 and 14 were defined for the upland Problem Areas. **Figure 6-7** and **Figure 6-8** show the soil zones defined for the groundwater rise planning models for the upland Problem Areas 13 and 14. As previously described, the DHW and boundary conditions in these upland areas was raised by 1-ft for the 30-year planning horizon scenario.

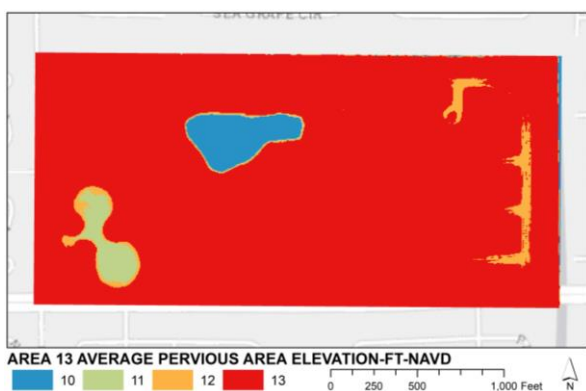


Figure 6-7 – Soil Zone Map for Area 13 Sea Level Rise Scenarios

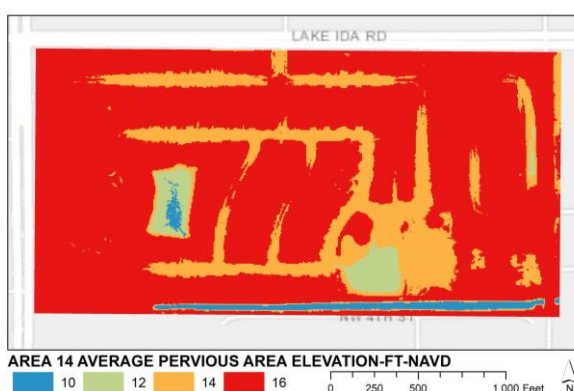


Figure 6-8 – Soil Zone Map for Area 14 Sea Level Rise Scenarios

Curve numbers were re-calculated for each soil zone/land use combination. **Table 6-6** and **Table 6-7** show each re-calculated curve number for the 30-year sea level rise planning horizon for upland Problem Areas.

Table 6-6:30-Year Sea Level Rise Recalculated Curve Numbers for Problem Area 13

Land Cover Zone Abbr.	Land Cover Zone	Soil Zone			
		10	11	12	13
UCSS	Commercial	95	91	88	88
UIIN	Industrial	96	93	91	91
UOUN	Open Space	85	68	56	56
URSL	Low Density Residential	94	88	83	83
URSM	Medium Density Residential	94	89	85	85
USGF	Community Facilities	92	85	80	80

Table 6-7: 30-Year Sea Level Rise Recalculated Curve Numbers for Problem Area 14

Land Cover Zone Abbr.	Land Cover Zone	Soil Zone			
		10	12	14	16
UCSS	Commercial	98	98	91	88
UIIN	Industrial	98	98	93	91
UOUN	Open Space	98	97	68	56
URSL	Low Density Residential	98	98	88	83
URSM	Medium Density Residential	98	98	89	85
USGF	Community Facilities	98	98	85	80

6.8 75-Year Sea Level Rise Planning Horizon Model Setup

As for the 30-year SLR Planning Horizon, impacts of Sea Level Rise between coastal areas and upland areas, sea level rise is modeled differently for the coastal Problem Areas (Areas 1-12) and upland Problem Areas (Areas 13-14). The following sections describe the soil storage, boundary condition, and initial condition parameter changes made from the Existing Conditions models to the 75-Year Planning Horizon Sea Level Rise model in order to simulate impacts of this degree of Sea Level Rise in Problem Areas 1-14.

6.8.1 Coastal Areas Model Setup (75-year SLR Planning Horizon)

The same soil zones that were used for the 30-year planning horizon models were used for the 75-year planning horizon models. However, curve numbers for these generalized elevations were recalculated. Curve numbers were calculated for each soil zone/land use combination assuming a raised DHW level of 5.4 ft-NAVD for the 75-year planning horizon as described in **Section 6.2.3**. **Table 6-8** shows each curve number for the 75-year planning horizon in coastal areas.

Table 6-8: 75-Year Sea Level Rise Recalculated Curve Numbers for Coastal Problem Areas

Land Cover Zone Abbr.	Land Cover Zone	Soil Zone					
		3	4	5	6	7	8
UCSS	Commercial	98	98	98	98	97	93
UIIN	Industrial	98	98	98	98	97	94
UOUN	Open Space	98	98	98	98	91	76
URSL	Low Density Residential	98	98	98	98	96	90
URSM	Medium Density Residential	98	98	98	98	96	92
USGF	Community Facilities	98	98	98	98	95	88

The intracoastal boundary stage line and boundary stage nodes were edited to have the high and low tidal conditions described in **Section 6.2.3**.

6.8.2 Upland Areas Model Setup (75-year SLR Planning Horizon)

The same soil zones that were used for the 30-year planning horizon models were used for the 75-year planning horizon models. However, curve numbers for these generalized elevations were recalculated. Curve numbers were calculated for each soil zone/land use combination assuming a DHW 2-ft higher than the Existing Conditions.

Table 6-9: 75-Year Sea Level Rise Recalculated Curve Numbers for Problem Area 13

Land Cover Zone Abbr.	Land Cover Zone	Soil Zone			
		10	11	12	13
UCSS	Commercial	98	95	91	88
UIIN	Industrial	98	96	93	91
UOUN	Open Space	97	85	68	56
URSL	Low Density Residential	98	94	88	83
URSM	Medium Density Residential	98	94	89	85
USGF	Community Facilities	98	92	85	80

Table 6-10: 75-Year Sea Level Rise Recalculated Curve Numbers for Problem Area 14

Land Cover Zone Abbr.	Land Cover Zone	Soil Zone			
		10	12	14	16
UCSS	Commercial	98	98	95	88
UIIN	Industrial	98	98	96	91
UOUN	Open Space	98	98	85	56
URSL	Low Density Residential	98	98	94	83
URSM	Medium Density Residential	98	98	94	85
USGF	Community Facilities	98	98	92	80

6.9 30-Year Sea Level Rise Modeling Results

Modeling results show that the sea level rise parameters incorporated into the ICPR4 model for the 14 problem areas has a profound impact for the 30-year planning horizon. Results are useful in determining the areas that are predicted to have the most severe flooding as well as the impact of isolated sea level rise without rainfall. Inundation maps for this 30-year predicted sea level rise are displayed in **Appendix 6B**.

Flood depth outputs for the inundation maps and the range of flooding depths in **Table 6-11** and **Table 6-12** were taken from time step 12.00 (hour 12) for the 1-day storm events and from time step 60.00 (hour 60) for the 3-day storm events.

6.9.1 30-Year Sea Level Rise Without Rainfall

A no-rainfall scenario was performed in order to isolate the flood severity of the predicted 30-year sea level rise tidal elevation. The coastal Problem Areas experienced significant flooding in this no-rainfall scenario indicating that seawall overtopping, higher groundwater levels, and outflow pipe backflow have the potential of causing inundation of these coastal problem areas. **Table 6-11** shows the range of depth of flooding in each problem area during the no-rainfall scenario with 30-year sea level rise planning horizon boundary conditions. Inundation maps for this 30-year predicted sea level rise during a day with no rainfall are displayed in **Appendix 6B**.

Table 6-11: Flooding Summary for No Rainfall 30-Year Sea Level Rise Scenario

Problem Area	Range of Depth of Flooding (feet)	Location(s) of Significant Flooding
	No Rainfall	
1	0.1-2.5	Harbor Drive
2	0.3-3.5	Central drainage inlet on Seaspray
3	0.1-4.0	Cul-de-sac on Waterway Lane
4	0.2-3.8	Drainage inlet near 1000 S Vista Del Mar Dr.
5	0.3-3.3	1009 Ingraham Avenue
6	0.1-2.2	246 Venetian Drive
7	0.2-3.1	100 Tamarind Road
8	0.3-3.3	Hibiscus Road drainage complaint
9	0.3-3.8	1047 Brooks Lane
10	0.3-2.4	Edge of Cypress Drive
11	0.2-1.8	SE 8 th Street
12	1.2-2.8	Northern area of Marine Way
13	N/A	N/A
14	0.1-1.2	5298 NW 6 th St.

6.9.2 30-Year Sea Level Rise with Rainfall

The design storm events described in **Section 4.0** were revisited and applied to models with the 30-year planning horizon sea level rise boundary conditions. As indicated with the no-rainfall scenario, the coastal Problem Areas experienced significant flooding due

to the seawall overtopping, higher groundwater levels, and outflow pipe backflow. Rainfall adds flood depth to the predicted inundation in the Problem Areas. **Table 6-12** describes the range of depth of flooding in the fourteen Problem Areas. **Appendix 6B** shows inundation maps for these 30-year Sea Level Rise Design Storm scenarios.

Table 6-12: Flooding Summary for Design Storm Event 30-Year Sea Level Rise Scenarios

Problem Area	Range of Depth of Flooding (feet)				Location(s) of Significant Flooding
	5Y-1D	10Y-1D	25Y-3D	100Y-3D	
1	0.3-3.5	0.4-3.6	0.4-3.5	0.4-3.5	Harbor Drive
2	0.3-3.8	0.3-3.8	0.3-3.9	0.3-4.8	Seaspray Avenue
3	0.1-3.7	0.3-3.8	0.3-3.7	0.3-4.0	Home near Sandpiper Lane
4	0.2-4.0	0.3-3.9	0.4-4.0	0.4-4.3	1022 Lowry Street, 1099 Basin drive
5	0.1-3.5	0.1-3.6	0.4-3.5	0.4-3.6	1010 Ingraham Ave, 991 Atlantic Ave
6	0.4-2.7	0.4-3.5	0.4-3.9	0.4-4.1	1104 Nassau St.
7	0.3-3.4	0.6-3.5	0.6-3.5	0.7-3.5	1099 Seasage Drive.
8	0.3-3.7	0.4-3.8	0.7-3.8	0.2-3.9	Hibiscus Rd.
9	0.3-3.8	0.3-3.8	0.3-3.8	0.6-3.8	1047 Brookes Lane
10	0.2-2.8	0.3-2.9	0.3-2.9	0.3-2.9	Spanish Trail, Jasmine Court, Banyan Drive
11	0.3-1.8	0.3-1.9	1-2.0	1.1-2.0	SE 10 th Street
12	1.1-2.8	1-2.8	0.8-2.8	1.1-2.8	SE 1 st Street, Marine Way
13	0.1-1.8	0.1-2.2	0.2-2.2	0.3-2.5	NW 7 th Court
14	0.3-1.9	0.4-3.6	0.4-4.6	0.7-5.0	4798, 5928 NW 6 th St.

6.10 Comparison with Existing Conditions Model

In order to have a numerical basis of comparing the Existing Conditions Model results to the Sea Level Rise scenarios, a Flood Protection Severity Score (FPSS) was calculated for the 30-year Sea Level Rise scenario. The FPSS calculation methods are the same as those described in **Section 5.0**. **Table 6-13** shows the Existing Conditions FPSS compared with the Sea Level Rise FPSS for each Problem Area. **Appendix 6D** shows the complete tables for calculation of the Sea Level Rise FPSS. **Appendix 6C** contains maps showing the exceedance values for both structures and streets used to calculate the FPSS.

FPSS increased significantly in sea level rise scenarios especially for the coastal Problem Areas where many areas experienced road and structural flooding with exceedance values of 3. This illustrates that these coastal areas, in particular are not outfitted with the infrastructure that is sufficient for the assumed future tidal elevations.

Table 6-14 describes the increased depth of flooding for the 30-year planning horizon sea level rise scenarios.

Table 6-13: Flood Protection Severity Score Changes with Sea Level Rise Projection

Problem Area	Problem Area Description	Existing Conditions FPSS	30-Year Sea Level Rise FPSS	Percent Increase of FPSS
1	Harbor Drive	9.2	57.4	524%
2	Beach Drive	105.7	246.4	133%
3	Waterway Lane	4.6	61	1226%
4	Basin Drive	234.4	1181.8	404%
5	Atlantic Avenue	33.7	872	2488%
6	Bay Street	55.2	388.3	603%
7	Seasage Drive	63.40	535.6	745%
8	Hibiscus Road	63.4	368.7	482%
9	Brooks Lane	1.4	382.7	27236%
10	Spanish Circle	144.6	673.2	366%
11	7 th Avenue	1.6	50.2	3038%
12	Marine Way	0.8	142.2	17675%
13	Banwick Park	17.9	41.9	134%
14	Rainberry Woods	190.3	294.5	55%

Table 6-14: Increased Depth of Flooding for 30-Year Sea Level Rise Scenario compared to Existing Conditions Model

Problem Area	Increased Depth of Flooding (feet)				Location(s) of Significant Flooding
	5Y-1D	10Y-1D	25Y-3D	100Y-3D	
1	0.3	0.3	0.3	0.2	Harbor Drive
2	1.2	0.9	1	1.7	Seaspray Avenue
3	1.5	1.4	1.3	1.4	Home near Sandpiper Lane
4	1.9	1.4	1.6	1.8	1022 Lowry Street, 1099 Basin drive
5	0.7	0.6	0.5	0.5	1010 Ingraham Ave, 991 Atlantic Ave
6	0.1	0.3	0.6	0.6	1104 Nassau St.
7	0.8	0.7	0.7	0.5	1099 Seasage Drive.
8	0.9	0.6	0.6	0.6	Hibiscus Rd.
9	1.6	1.6	1.6	1.6	1047 Brookes Lane
10	0.3	0.4	0.3	0.1	Spanish Trail, Jasmine Court, Banyan Drive
11	0.1	0.1	0.2	0.2	SE 10 th Street
12	1.5	1.5	1.5	1.5	SE 1 st Street, Marine Way
13	0.1	0.2	0.2	0.3	NW 7 th Court
14	0.2	1.7	2.6	2.8	4798, 5928 NW 6 th St.

6.11 75-Year Sea Level Rise Modeling Results

Modeling results show that the sea level rise parameters incorporated into the ICPR4 model for the 14 problem areas has an extremely severe impact for the 75-year planning horizon. Results indicate that many of the coastal areas will have greater than 3 feet of flooding due to the fact that the ground elevation is well below the predicted high tide event used for modeling and in many cases the ground elevation is lower than the assumed DHW level. Inundation maps for this 75-year predicted sea level rise are displayed in **Appendix 6B**.

Flood depth outputs for the inundation maps and the range of flooding depths in **Table 6-15** and **Table 6-16** were taken from time step 12.00 (hour 12) for the 1-day storm events and from time step 60.00 (hour 60) for the 3-day storm events.

6.11.1 75-Year Sea Level Rise Without Rainfall

As described previously for the 30-year planning horizon, a no-rainfall scenario was performed in order to isolate the flood severity of the predicted 75-year sea level rise tidal elevation. **Table 6-15** shows the range of depth of flooding in each problem area during the no-rainfall scenario with 30-year sea level rise planning horizon boundary conditions. Inundation maps for this 75-year predicted sea level rise during a day with no rainfall are displayed in **Appendix 6B**.

Table 6-15: Flooding Summary for No Rainfall 75-Year Sea Level Rise Scenario

Problem Area	Range of Depth of Flooding (feet)	Location(s) of Significant Flooding
	No Rainfall	
1	0.4-5.9	Harbor Drive
2	0.1-7.7	Central drainage inlet on Seaspray
3	0.2-7.4	Cul-de-sac on Waterway Lane
4	0.3-7.7	Drainage inlet near 1000 S Vista Del Mar Dr.
5	0.1-7.3	1009 Ingraham Avenue
6	0.1-6.7	246 Venetian Drive
7	0.3-7.2	100 Tamarind Road
8	0.8-7.7	Hibiscus Road drainage complaint
9	0.4-7.4	1047 Brooks Lane
10	0.1-6.0	Edge of Cypress Drive
11	0.2-5.5	SE 8 th Street
12	1.1-5.9	Northern area of Marine Way
13	NA	NW 7 th Court
14	0.1-1.1	5298 NW 6 th St.

6.11.2 75-Year Sea Level Rise with Rainfall

The design storm events described **Section 4.0** were revisited and applied to models with the 75-year planning horizon sea level rise boundary conditions. **Table 6-16** describes the range of depth of flooding in the fourteen Problem Areas. **Appendix 6B** shows inundation maps for these 75-year Sea Level Rise Design Storm scenarios.

Table 6-16: Flooding Summary for Design Storm Event 75-Year Sea Level Rise Scenarios

Problem Area	Range of Depth of Flooding (feet)				Location(s) of Significant Flooding
	5Y-1D	10Y-1D	25Y-3D	100Y-3D	
1	0.4-6.0	0.4-6.0	0.4-6.0	0.5-6.0	Harbor Drive
2	0.1-7.7	0.2-7.7	0.4-7.7	0.5-7.7	Seaspray Avenue
3	0.2-7.4	0.3-7.4	0.3-7.4	0.4-7.4	Home near Sandpiper Lane
4	0.3-7.7	0.4-7.7	0.4-7.7	0.4-7.9	1022 Lowry Street, 1099 Basin drive
5	0.2-7.3	0.4-7.3	0.4-7.3	0.4-7.3	1010 Ingraham Ave, 991 Atlantic Ave
6	0.1-6.7	0.1-6.8	0.2-6.8	0.2-6.8	1104 Nassau St.
7	0.3-7.2	0.3-7.2	0.4-7.2	0.6-7.2	1099 Seasage Drive.
8	0.8-7.7	0.8-7.7	0.8-7.7	0.8-7.7	Hibiscus Rd.
9	0.4-7.6	0.6-7.6	0.6-7.6	0.6-7.6	1047 Brookes Lane
10	1.0-6.0	1.2-6.0	1.6-6.0	1.8-6.0	Spanish Trail, Jasmine Court, Banyan Drive
11	0.2-5.5	0.2-5.5	0.2-5.5	0.2-5.5	SE 10 th Street
12	1.2-5.9	1.3-5.9	1.3-5.9	2.1-5.9	SE 1 st Street, Marine Way
13	0.1-1.8	0.2-2.2	0.3-2.3	0.3-2.5	NW 7 th Court
14	0.2-2.1	0.4-3.6	0.4-4.4	0.4-5.4	4798, 5928 NW 6 th St.

6.12 Comparison with Existing Condition Model

Visually, the inundation maps for the 75-year predicted sea level rise show that extreme amounts of flooding are predicted for the high tidal conditions at this point in the future. Most areas experienced greater than 3 feet of flooding which is beyond the scale of the FPSS exceedance factor. Therefore, FPSS was not calculated because of the fact that most coastal roads and structures showed flooding beyond the maximum exceedance value and this score would not provide additional information that is not already apparent from the inundation maps.

Table 6-17 describes the increased depth of flooding for the 75-year planning horizon sea level rise scenarios.

Table 6-17: Increased Depth of Flooding for 75-Year Sea Level Rise Scenario compared to Existing Conditions Model

Problem Area	Increased Depth of Flooding (feet)				Location(s) of Significant Flooding
	5Y-1D	10Y-1D	25Y-3D	100Y-3D	
1	2.8	2.7	2.8	2.7	Harbor Drive
2	5.1	4.8	4.8	4.6	Seaspray Avenue
3	5.2	5	5	4.8	Home near Sandpiper Lane
4	5.6	5.2	5.3	5.4	1022 Lowry Street, 1099 Basin drive
5	4.5	4.3	4.3	4.2	1010 Ingraham Ave, 991 Atlantic Ave
6	4.1	3.6	3.5	3.3	1104 Nassau St.
7	4.6	4.4	4.4	4.2	1099 Seasage Drive.
8	4.9	4.5	4.5	4.4	Hibiscus Rd.
9	5.4	5.4	5.4	5.4	1047 Brookes Lane
10	3.5	3.5	3.4	3.2	Spanish Trail, Jasmine Court, Banyan Drive
11	3.8	3.7	3.7	3.7	SE 10 th Street
12	4.6	4.6	4.6	4.6	SE 1 st Street, Marine Way
13	0.1	0.2	0.3	0.3	NW 7 th Court
14	0.4	1.7	2.4	3.2	4798, 5928 NW 6 th St.

7.0 WATER QUALITY ASSESSMENT

7.1 Water Quality and Site Planning Best Management Practices

The traditional engineering approach to storm water management is the rapid conveyance of runoff away from the development site into drainage structures and receiving water bodies designed to accommodate a large volume of stormwater. In contrast, Site Planning Practices take a different approach to conventional stormwater management by using the natural, pre-development features of the site to maximize on-site infiltration, storage, and treatment of runoff while reducing the disruptive effects of urban runoff patterns.

Implementation of water quality and Site Planning BMPs begin at the planning level of site development or redevelopment. One of the first steps in site planning involves taking inventory of the existing features on the site including topography, soil characteristics, flow paths, drainage features, building and stormwater infrastructure, impervious areas, open spaces, and vegetation. Through water quality and Site Planning techniques, developments are designed to be integrated with these existing features and to retain or simulate the pre-development site conditions.

Water quality and Site Planning design techniques include both structural and non-structural hydrologic controls that compliment traditional stormwater treatment and conveyance systems by utilizing pre-development hydrological features to decentralize and micromanage stormwater at its source. Throughout the site development process, alternative design options that include Site Planning techniques or Site Planning techniques combined with traditional stormwater management infrastructure are evaluated and integrated into the site plan to greatest extent possible. The overall water quality and site planning development process includes:

- Identification and compliance of existing site planning regulations and ordinances
- Assessment and inventory of pre-development site conditions
- Development of the preliminary site plan
- Minimization of directly connected impervious areas
- Evaluation and implementation of Integrated Management Practices (IMPs) water quality and Site Planning management techniques to achieve the desired post-development hydrologic condition
- Comparison of pre-development and post-development hydrology
- Completion of water quality and Site Plan

7.2 Non-Structural Site planning practices

When managed improperly, stormwater runoff contributes to water pollution, flooding, erosion, and groundwater recharge deficits. Implementation of non-structural site planning practices serve to manage stormwater runoff through the restoration and

preservation of the natural drainage features present at the development site by applying source control. The application of these practices throughout the site planning process reduce the use of traditional conveyance materials, such as steel and concrete, and often results in a more aesthetically pleasing site, lower development and maintenance costs, and additional recreational resources. The use of non-structural site planning practices uses native and natural features of the pre-development site to attenuate peak runoff and overall runoff volume, improves water quality, and increases groundwater recharge within the development site.

The primary non-structural site planning practices and considerations that appear to be most applicable to the City of Delray Beach include the following:

6. Pre-development topography and soil profile restoration and preservation
7. Native and local vegetation preservation
8. Open space design and conservation
9. Total impervious area minimization
10. Directly connected impervious area reduction

The following subsections provide details for the purpose, implementation, and benefits of each of the above practices.

7.3 Pre-Development Topography and Soil Profile Restoration and Preservation

Traditional site development typically requires adding grading fill material to create new drainage contours and infrastructure foundations. The drainage contours are traditionally designed to direct drainage away from the site into a pipe network and employs an end-of-pipe treatment system. The topography of the site, including natural slopes and depressions, define the natural flow path of stormwater runoff. With this non-structural site planning practice, the natural flow path is preserved and incorporated into the site plan as an existing open conveyance system where possible. To better preserve the pre-development topography, instead of using traditional slab-on-grade construction for building foundations, which requires alteration of the natural contours of the site and alteration of the natural soil conditions, the use of an alternative construction method should be used, when possible, as described below.

The soil profile includes the hydrologic soil groups, depth, extent, and infiltration capacity present throughout the site. The soil types present should be delineated within the site plan. Once delineated, the soil profiles should guide the placement of impervious areas, open or vegetated space, and stormwater management features. Locations of soil groups with low hydrologic function, such as clays and disturbed soils, are ideal for placement of buildings, parking areas, roadways, ponds, and other impervious structures. Areas with highly permeable soil groups are ideal for implementing stormwater management features relying on infiltration of runoff. Once the soil profiles have been established, construction activities must limit soil compaction in the areas of soils with higher permeability to protect the natural soil characteristics. If the natural properties of the soil are modified during construction through compaction or other activities, soil amendment

is recommended and may be required. Soil amendment involves changing the soils chemical or physical properties through the addition of other materials, or through mechanical means such as tilling or aeration. As a non-structural site planning practice, soil amendment is used to increase the infiltration capacity, storage capacity, or pollutant removal capacity of the soil, to add the nutrients needed for vegetation, and to stabilize sandy soils. For example, the addition of compost to compacted soils can increase the porosity and the permeability of the soil. However, soil amendment is not effective for restoring natural characteristics of soils altered by compaction during construction.

Additional preservation of site topography and soil profile non-structural site planning practices include:

- Selective grading and clearing
- Minimize soil disturbance and compaction
- Soil Amendment
- Reduce construction on highly permeable soils
- Locate new buildings, parking, and ponds in areas that have lower hydrologic function, such as clayey or disturbed soil
- Utilize stem wall construction and pier and beam/raised floor foundations when possible instead of slab-on-grade

7.4 Native and Local Vegetation Preservation

The pre-development site inventory and assessment should consider vegetation. Both Florida native and exotic plant species should be inventoried and considered when designing the initial site plan with existing vegetation buffers around bodies of surface water preserved. Vegetation prevents erosion, reduces pollution levels, increase infiltration by decreasing runoff velocity's, intercepts rainfall, and increase evapotranspiration rates. Traditional site development plans clear onsite vegetation, disturbing native soils and introducing new vegetation that demand greater water and nutrient levels to establish than the vegetation present on the site. Preserving pre-development vegetation on the site and using Florida native vegetation creates a longer-lasting landscape and reduces the effort and cost of maintenance.

Using hydrozones, plants are grouped into zones throughout the site based on sun requirements, water requirements, and nutrient demands. When designed and implemented, hydrozones minimize fertilizer, water, and pesticide use throughout the development. Whenever feasible, trees and native plants present on the site should be preserved and incorporated into the site design. The use of turfgrass should be limited to recreational areas, swales, and areas in need of erosion control that cannot be provided using other types of native ground cover. When included in the site design, the type of turfgrass used should be specific to the environmental conditions of the planting area. The *Florida-Friendly Landscaping Guide to Plant Section & Landscape Design* provides landscape design strategies, planning worksheets, and a plant list for plants recommended within the four regions of Florida. The *Florida-Friendly Landscaping*

Pattern Book, for USDA hardiness zones in South Florida, provides sample plants and designs based on site conditions specific for the South Florida Region. Both handbooks can be found at <http://fyn.ifas.ufl.edu/>. Vegetation types and species extracted from the *Florida-Friendly Landscaping Pattern Book* are provided in **Appendix 7C**. The tables provide specific examples of plants, flowers, and grass types recommended for South Florida, grouped by plant type, characteristics, and sun/shade requirements.

Additional preservation of native and local vegetation Site Planning practices includes:

- Preservation and incorporation of conservation areas and wetland habits
- Removal of exotic vegetation (recommended when greater than 5%)
- Retention of existing native vegetation
- Introducing native vegetation appropriate to existing site conditions
- Conservation of existing Tree Canopy
- Limit use of turfgrass and select turfgrass species with characteristics matching existing site conditions

7.5 Open Space Design and Conservation

Once the inventory and assessment of the site topography, soil profiles, and vegetation have been completed and delineated, the next step in the site planning is to design and outline the placement of open space and infrastructure such as roadways, sidewalks, lot layouts, buildings, driveways, and parking spaces. Open space includes existing or designed pervious areas, including natural areas, recreational areas, and common use areas, and buffer zones. When planning the layout of the site, employ the non-structural site planning practice of preserving the existing topography, soil zones with positive drainage benefits, and native plant communities by maximizing the area designed for open space. Larger open space areas and open spaces with smaller borders provide the maximum benefit for both stormwater management and wildlife.

Open spaces can be utilized for alternative non-structural stormwater management strategies that reduce the impact of the site development on the watershed. Open spaces maximize overland sheet flow with longer flow paths that reduce runoff velocity's, increase residence times, and provide space for planting native vegetation that take up heavy metals and remove nutrients from stormwater runoff. One method that maximizes the open space available is placing buildings with the cluster design approach. The cluster design approach increases the number of buildings or units per acre, which reduces overall infrastructure and development costs.

It is recommended that the City of Delray Beach consider revising the land development code to include an open space requirement and to provide flexibility in the development design which encourages the implementation of open space. The current Land development code, *Section 4.4.9 (f)(3)(c) Lot Coverage*, allows for a max coverage of commercial development of 75% with buildings, pavement, and/or other hardscapes resulting in 25% minimum open space requirement.

Lake Worth requires varying open space minimum percentages based on zoning land use and lot size. The maximum impervious area coverage ranges from 55% on large lots to 65% on small lots for both residential and commercial properties. Palm Beach County currently does not have any open space requirements in place, not do Boca Raton or the City of Boynton Beach. Based on the conditions of the City and on common practices of other municipalities, it is recommended that 25-30% open space be required for any new residential developments, or when existing developments undergo expansion or other substantial changes.

Additional open space design and conservation non-structural site planning practices include:

- Increase (or augment) the amount of vegetation on the site.
- Maximize use of open swale systems
- Maximize overland sheet flow
- Avoid total site clearing
- Reduce fill and grade operations

The recommended revisions to the land ordinance regarding open space requirements will be evaluated further under the Stormwater Ordinance Review.

7.6 Total Impervious Area Minimization

The greatest sources of impervious areas are the traffic distribution network and building rooftops. Alternative roadway layouts that implement shorter roadway lengths, such as the loops and “lollipops” layout, can reduce the overall roadway surface by 26% compared to implementation of the traditional grid layout. In some cases, the use of the T-shaped turn-about instead of the more common cul-de-sac design can decrease the roadway area needed, without adversely affecting the desired traffic access. Throughout the design of the traffic distribution network, pavement lengths and widths should be minimized to the extent that safety consideration allow.

When designing parking lots, use the smallest space dimensions with the fewest number of spaces, and use pervious areas for overflow parking needed for seasonal or rare events. Drainage from the impervious areas should be designed to direct runoff to vegetated, pervious areas such as swales or bioretention islands before entering a conventional pipe conveyance system.

Buildings should be designed to maximize the ratio of square footage to roof area. The application of high-density development strategies will reduce the stormwater runoff per building and decrease the total impervious area compared to low-density developments with the same number of units. A high-density development strategy also has less impact on the overall watershed and can improve the water quality of runoff generated on the site.

Additional minimization of total impervious area non-structural site planning practices includes:

- Alternative roadway, sidewalk, parking lot, and driveway design standards to minimize imperviousness
- Minimize width and lengths of traffic distribution networks
- Implement pervious shoulders and right-of-way's
- Limit the installation of sidewalks to one side of roadways

7.7 Directly Connected Impervious Area Reduction

Once the preliminary site plan has been developed that minimizes the total impervious area, preserves the sites natural hydrological characteristics and vegetation, and maximizes the areas of open space, the site plan should be evaluated to disconnect the unavoidable impervious areas. Stormwater runoff should be directed to flow into natural areas, vegetated buffer zones, and soils with favorable infiltration. The flow from large impervious areas should be broken up into smaller drainage areas with the flow directed to stabilized, vegetated areas.

This type of site planning practice is composed of several incremental structural and non-structural hydrologic controls. By disconnecting impervious areas from directly discharging into the offsite discharge system, the need for costly stormwater conveyance and treatment systems is reduced. Instead of large runoff volumes being drained into centralized basins and piped long distances to traditional end-of-pipe treatment facilities, runoff from individual roof tops is separated and treated using small basins located adjacent to the structure. Runoff from paved roads and parking areas are also separated using structural site planning controls, and the flow paths are directed to vegetated areas located within and adjacent to the impervious area. By reducing directly connected impervious areas, the negative impacts of a component failure have significantly less negative impact on the overall site and is often less costly to repair.

Additional reduction of directly connected impervious area non-structural site planning practices include:

- Direct drainage to stabilized vegetated areas.
- Site layout to break up flow directions from large paved surfaces
- Disconnect roof drains and drain to vegetated areas
- Site development to encourage sheet flow through vegetated areas (Locate impervious areas so that they drain to permeable areas)

7.8 Structural Practices and Stormwater Management

Stormwater Management practices allow for the use of a wide array of simple, cost-effective structural practices that focus on site-level hydrologic control. These practices should strive to have the same conditions or better for total and peak stormwater runoff volumes, runoff conveyance patterns, and infiltration and treatment capacity as were present before development.

In the previous section the site planning development process identified fundamental design techniques that can significantly minimize the hydrologic impacts of development. This section also identifies Site Planning BMPs which are structural stormwater management practices employed to achieve improved post-development water quality condition. Ideally IMP technologies would be located at the source (on-lot) on level ground within individual lots of the development thus eliminating the need for a large centralized system that will control the entire runoff from the development. Aside from the main characteristics of these stormwater management practices of providing quantity and quality control and enhancement, Site Planning BMPs must provide:

- Groundwater recharge through infiltration or exfiltration into the soil.
- Retention or detention of runoff for permanent storage or for later release.
- Pollutant settling and entrapment by conveying runoff slowly through vegetated swales and natural buffer strips.
- Aesthetic value to the property which enhances a sense of community lifestyle.
- Satisfaction of local government requirements for green or vegetated buffer space by implementing multiple landscaped areas on-lot.

The most effective type of design for maximum on-lot stormwater runoff control consists of placing source controls in series, this is especially effective at reducing volume and peak flow rates.

The selected structural BMPs, based on most cost-effective approach that can be utilized in the City of Delray Beach, are the management practices described and explained in detail in the following subsections. These include:

11. Bioretention Basins or Rain Gardens
12. Tree Box Filters or Infiltration Planters
13. Vegetated Swales (grass, infiltration, wet)
14. Filter Strips or Vegetated Buffers
15. Exfiltration Trenches
16. Infiltration Trenches
17. Rain Harvesting (rain barrels/cisterns)
18. Permeable Pavement
19. Detention / Retention Ponds
20. Pollution Control Structures (i.e. Vortech/CDS Units)

7.9 Bioretention Basins or Rain Gardens

Bioretention basins are small landscaped basins on-lot that hold and infiltrate stormwater. These are intended to manage and provide water quality treatment by using a conditioned planting soil bed and materials to filter the stored runoff. It is recommended that landscaped areas only use native species (see **Appendix 7C** for recommended species) to promote water conservation, benefits to native wildlife, aesthetic benefits to neighborhoods and increase in property values. The major components of Bioretention Basins or Rain Gardens systems include:

- Pretreatment area (optional – required for significant volumes)
- Ponding area
- Ground cover layer
- Plant Material and planting soil
- In situ soil
- Inlet and outlet controls
- Maintenance

This approach is very flexible as a method of source control for stormwater in residential developments, parking lot islands, or landscaped areas in commercial or public areas. In cases where soil permeability does not benefit infiltration, underdrains can carry the water downstream filtered through the Bioretention basin. An example of a typical Bioretention basin is shown in **Figure 7-1**.

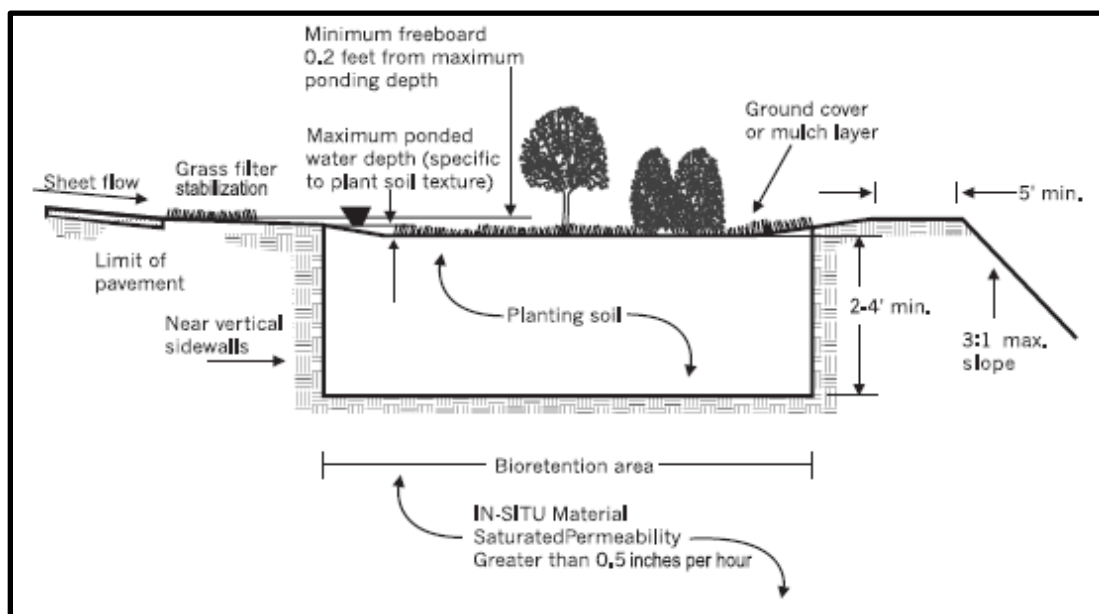


Figure 7-1: Typical Bioretention Basin Cross-section

A summary of design considerations for evaluating the suitability of Bioretention basins or Rain Gardens is shown in **Table 7-1**.

Table 7-1: Bioretention Basins and Rain Garden Design Considerations

Parameter	Consideration
Treatment Area	Individual lots in subdivisions or common areas, other landscaped areas and retrofit projects. Minimum surface area range 50 – 200 sq. ft. Minimum length to width ratio 2:1.
Pretreatment Area	Required when significant volume is anticipated from parking lots and commercial areas (i.e. grass buffer strip or vegetated swale).
Proximity to building Foundation	Minimum distance of 10 feet down gradient.
Soils	Infiltration rates < 0.1 inches/hour underdrains are required or soil augmentation.
Topography	May be difficult in areas with slopes > 10%.
Depth of Water Table	Not suitable if difference between seasonal high-water table and bottom of Bioretention area is < 2 feet. Unless, alternative design is appropriate for the specific area.
Groundcover Area	3 inches of mature mulch recommended.
Planting Soil	Depth = 4 feet / Clay content ≤ 10%. Soil mixture include sand, loamy sand, and sandy loam.
Inlet and outlet control	Non-erosive flow velocity's (0.5 ft/sec).
Plant Material	Minimum 3 native species. (see Appendix C)
Maintenance	Routine landscape – 5-7% of construction cost. Mulch should be replaced annually. Accumulated trash and sediment must be cleaned out. Infiltration capacity must be inspected (Total drawdown time 72-hr).
Hydrologic Design	Determined by State or Local agency

7.10 Tree Box Filters or Infiltration Planters

These are a small-scale variation of Bioretention basins. As the name implies, tree boxes use trees and infiltration planters use plants other than trees. There are basically two types: filter and detention boxes. The box performs as a filter if the bottom is open and stormwater is discharged through infiltration; and detention when the bottom is closed and the filtered stormwater flows into an underdrain to be discharged to another stormwater management or pipe system. Each consists of a ponding area or container filled with a layer of mulch, planting soils, plants or trees, and when needed an underdrain to discharge the treated stormwater runoff collected.

As with Bioretention basins it is recommended to use native species of trees and plants (see **Appendix 7C**) to promote water conservation, benefits to native habitat, aesthetic benefits and to reduce heat island effects. Plants reduce the volume of runoff and can enhance the quality of discharge or infiltrated water by amending the soil to assist in removing a particular pollutant present in the area. They are appropriate for new projects

and can be retrofit into existing stormwater systems. An example of a typical Tree Box Filter is shown in **Figure 7-2**.

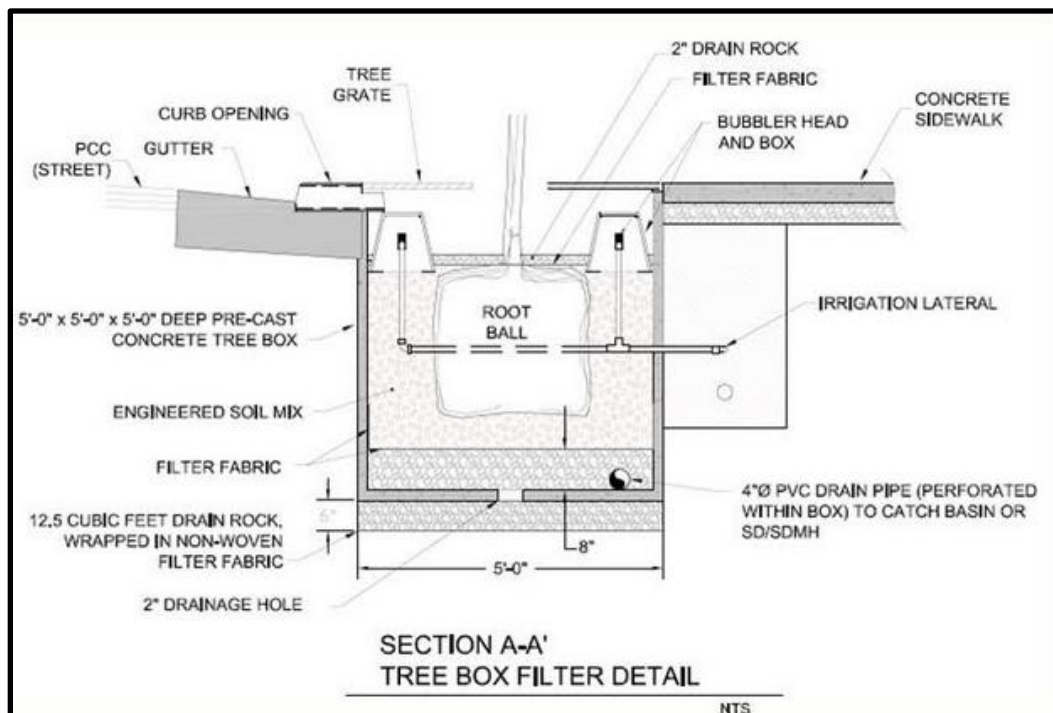


Figure 7-2: Typical Tree Box Filter

A summary of design considerations for evaluating the suitability of Tree Box Filters and Infiltration Planters is shown in **Table 7-2**.

Table 7-2: Design Considerations for Tree Box Filters and Infiltration Planters

Parameter	Consideration
Treatment Area	New Developments or retrofit into existing stormwater systems
Pretreatment Area	N/A
Proximity to building Foundation	Minimum distance of 10 feet down gradient if infiltration permitted. If located closer boxes should be contained with impermeable structures & with an underdrain.
Soils	Reduction of soil will directly impact the potential size of the tree. Avoid soil compaction.
Topography	N/A
Depth of Water Table	N/A
Groundcover Area	Bark mulch should be placed 4 inches deep. Pea gravel should be placed 2 inches deep.
Planting Soil	Typically amended to facilitate vigorous plant growth and not restrict performance requirements. Organic matter improves moisture retention and microbial action.
Inlet and outlet control	Curb cuts may be used as entry points of runoff Grading (surrounding pavement is graded towards box).

Parameter	Consideration
Plant Type and Species	See Appendix 7C .
Maintenance	Routine landscape. Maintaining the health of the plants, pruning and addition of mulch semi-annually. Trash and debris removal may be required based on location. If plant material dies, it must be replaced as part of regular maintenance.
Hydrologic Design	Determined by State or Local agency

7.11 Vegetated Swales (Grass, Infiltration, Wet)

Traditionally swales are commonly used to transport stormwater runoff away from roadways and rights-of-way, replacing standard curb and gutter and piped systems. The most common types of swales used today optimize stormwater drainage systems by reducing stormwater runoff, and provide many benefits including reduction in peak flow rates and slower runoff velocities.

Dry swales provide quantity and quality control by facilitating stormwater infiltration of all or a portion of design treatment volumes. Wet Swales use residence time and natural growth to reduce peak discharge and provide water quality treatment before discharge to another stormwater management or pipe system. Most likely, permeability of the soil will determine whether a dry or wet swale can be used. An example of a Vegetated Conveyance Swale is shown in **Figure 7-3**.

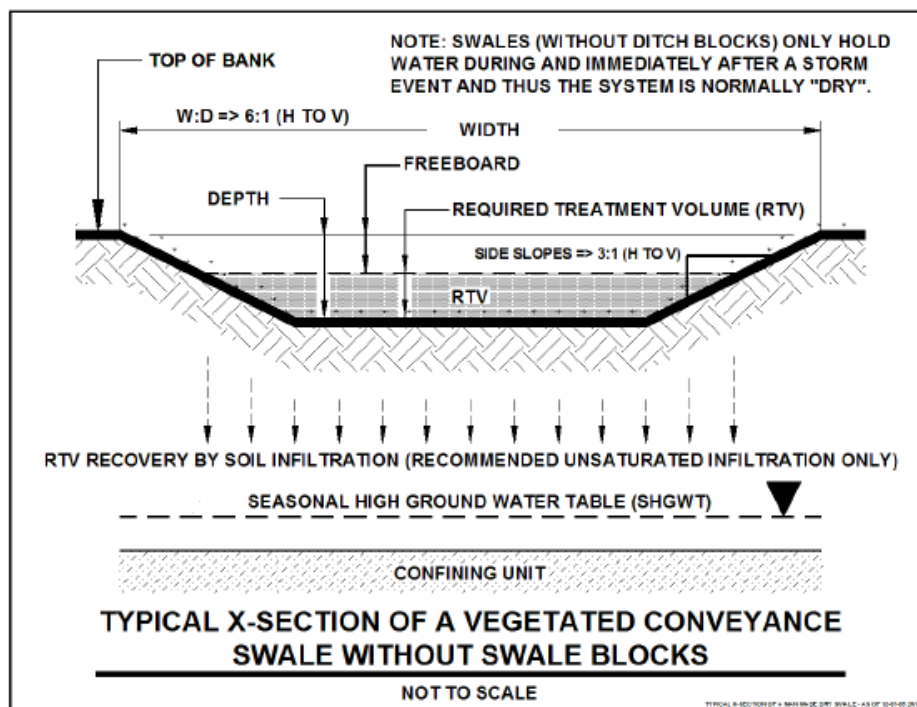


Figure 7-3: Typical Cross-section of a Vegetated Conveyance Swale without Swale Blocks

A summary of design considerations for evaluating the suitability of Vegetated Swales is shown in **Table 7-3**.

Table 7-3: Design Considerations for Vegetated Swales

Parameter	Consideration
Treatment Area	Along roadways and right-of-ways. Linear retention swales or conveyance swales. Top width to depth ratio of cross section \geq to 6:1 or side slopes \leq to 3H:1V
Pretreatment Area	N/A
Proximity to building Foundation	Minimum distance of 10 feet down gradient.
Soils	Permeability will determine whether dry or wet swale can be used. The minimum infiltration rate through the vegetation and soil shall be at least 1 inch per hour. Avoid soil compaction.
Topography	Trapezoidal or parabolic shape recommended
Depth of Water Table	Bottom of swale must be at least 2 feet above seasonal high-water table.
Groundcover Area	Design to account for soil erosion potential, soil percolation, slope, slope length, and drainage area to prevent erosion and reduce pollutant concentration.
Planting Soil	Typically, planted or has stabilized vegetation suitable for soil stabilization, stormwater treatment, and nutrient uptake.
Inlet and outlet control	Curb elimination, curb cuts, or curb replacements with raised knobs allow rainwater to enter vegetated swales.
Plant Material	See Appendix 7C .
Maintenance	Routine landscape. Inspected and maintaining to preserve adequate infiltration capacity in the soil. Trash and debris removal may be required based on location. Can become clogged with sediment deposits, overgrowth of alga, or overloading of oil and grease. Inspections should look for healthy vegetated slopes, erosion problems, blockage of flow path or any other damage.
Hydrologic Design	Determined by State or Local agency

7.12 Filter Strips or Vegetated Buffers

These vegetated buffers are planted or naturally vegetated zones around sensitive areas, or between pollutant sources and downstream receiving water bodies. These slow runoffs, reduces peak discharge, allows for infiltration and reduce stormwater volume. Although these should be used as a component of a broader management system and not intended to be the sole stormwater treatment system in residential areas. In some instances, they are recommended for treatment of runoff from backyards of residential developments.

Typically, vegetated buffers are composed of undisturbed native vegetation. If planted, only a diverse variety of native species should be used (See **Appendix 7C**). An example of a Vegetated Buffer/Filter Strip is shown in **Figure 7-4**.

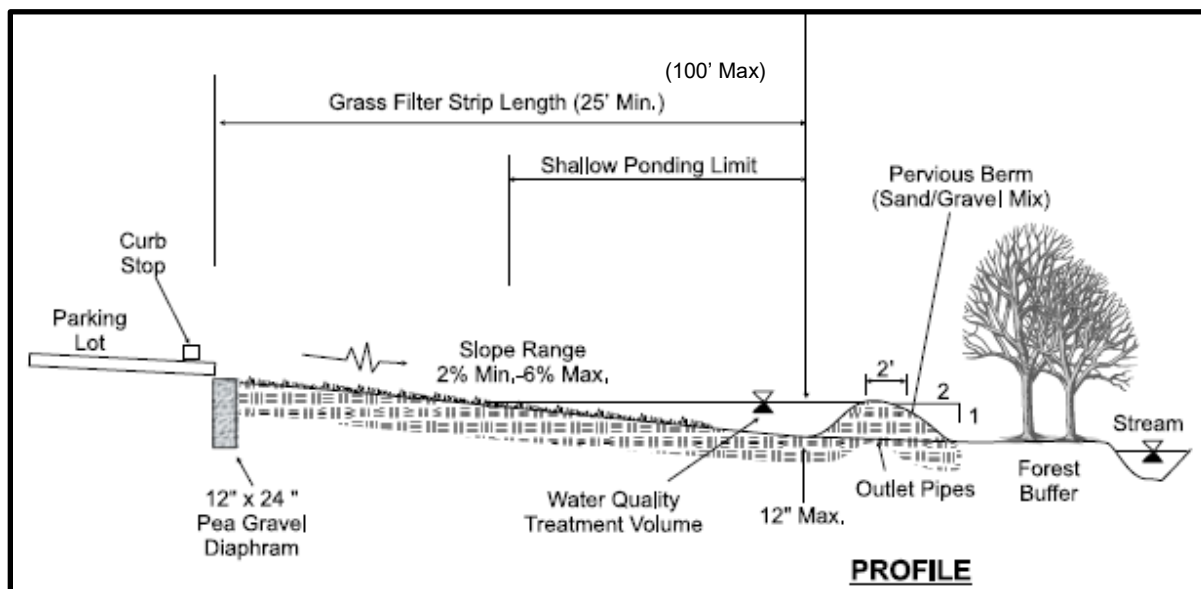


Figure 7-4: Typical Profile of a Filter Strip

A summary of design considerations for evaluating the suitability of Vegetated Buffers or Filter Strips is shown in **Table 7-4**.

Table 7-4: Design Parameters for Vegetated Buffers and Filter Strips

Parameter	Consideration
Treatment Area	Closed growing vegetation (natural or planted). Between pollutant source and downstream receiving water body. Sensitive areas (waterbodies, wetlands, erodible soils). Runoff from backyards of residential developments. Minimum dimensions recommended are 25 feet and maximum is 100 feet parallel to flow direction. The length perpendicular to the runoff must be at least as long as the contributing runoff area.
Pretreatment Area	Should be used as a part of a treatment train to reduce stormwater volume and pollutant
Proximity to building Foundation	Natural areas adjacent to rear-lots that have good infiltration potential.
Soils	The minimum infiltration rate through the vegetation and soil shall be at least 1 inch per hour.
Topography	Maximum slope shall not be greater than 6%
Depth of Water Table	Seasonal high groundwater table shall be at least two feet below the bottom of the vegetated natural buffer. Unless appropriate design demonstrates is suitable for the specific site conditions.

Parameter	Consideration
Groundcover Area	N/A
Planting Soil	Undisturbed native species, if planted See Appendix 7C.
Inlet and outlet control	Erosion control measures should be used to prevent erosion and sedimentation.
Plant Type and Species	Undisturbed native vegetation, if planted See Appendix 7C.
Maintenance	Inspection of sheetflow and infiltration of the required treatment, generally 24 to 72 hours after a storm. Must be inspected annually. Check damage by foot or vehicular traffic or encroachment by adjacent property owners. Inspect health and density of vegetation. Routine landscape if needed.
Hydrologic Design	Determined by State or Local agency

7.13 Exfiltration Trenches

An exfiltration trench consists of a perforated or slotted pipe laid in a bed of filter media, such as pea rock. It can be placed below paved or pervious surfaces or at the bottom of retention areas and offers a method of conveying stormwater runoff to the groundwater table in areas where impervious areas have been greatly increased. Typically, exfiltration trenches should not be placed below the travel lanes to prevent settlement, except in areas of low traffic volumes or loads.

Concerns of groundwater contamination and soil permeability restrict the use of exfiltration trenches. Examples of conditions where exfiltration trenches may not be appropriate to use include:

- Sites with low soil permeability
- Sites with contaminated soils
- Sites with unstable soils
- High groundwater table
- Sites with contaminated groundwater
- Terrain with steep slopes

To prevent exfiltration trenches from becoming plugged over time, oils, sediments, and floatables must be removed before stormwater enters the trench by means of a baffle and 4-foot sumps within all inlet structures directly connected to the exfiltration trench. An example of an Exfiltration Trench is shown in **Figure 7-6.**

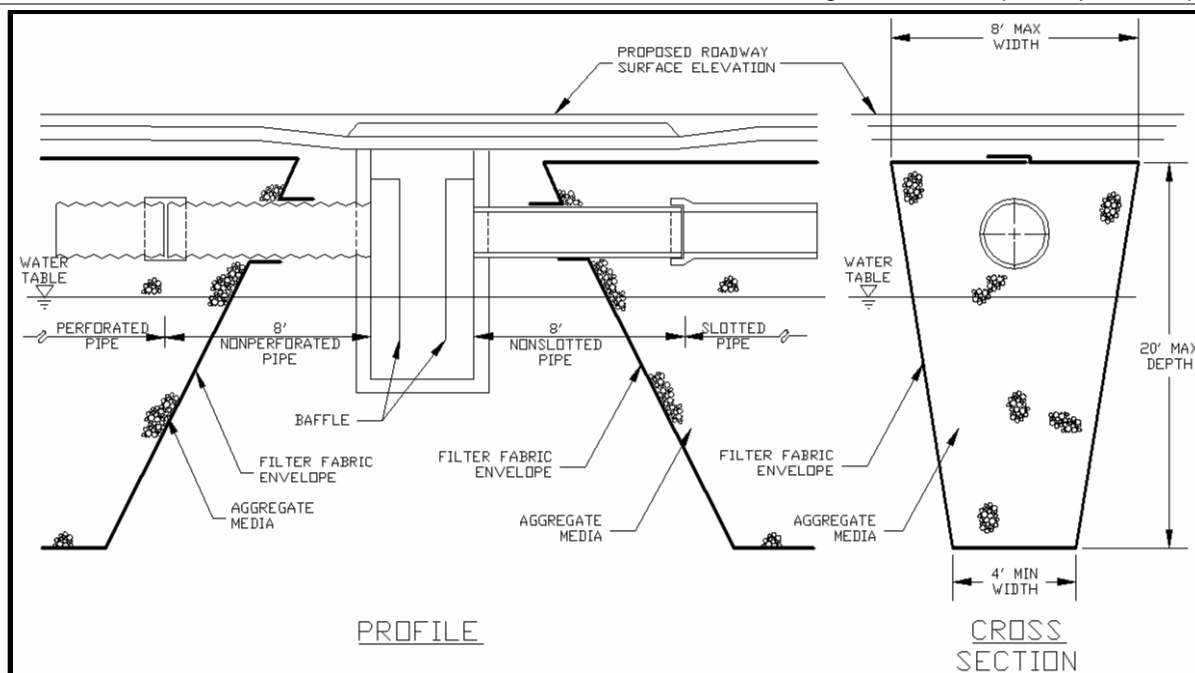


Figure 7-5: Typical Profile & Section View of an infiltration Trench

A summary of design considerations for evaluating the suitability of Exfiltration Trenches is shown in **Table 7-6**.

Table 7-5: Design Parameters for Infiltration Trenches

Parameter	Consideration
Treatment Area	Large impervious areas within public or private right-of-way, Roads, Parking Lots
Pretreatment Area	Use of Baffles prior to stormwater entering pipe.
Proximity to building Foundation	Minimum distance of 25 to 30 feet.
Soils	The soil hydraulic conductivity shall be greater than 1×10^{-5} cubic foot per second (cfs) per sq.ft. per ft of head
Topography	May be difficult in areas with steep slopes
Depth of Water Table	Present challenges in shallow seasonal high groundwater tables
Backfill	Clean aggregate $> \frac{3}{4}$ ", < 2 ", surrounded by geotextile filter fabric
Planting Soil	N/A
Inlet and outlet control	Baffles are used for inlet control Weirs may be used as an overflow device
Plant Material	N/A
Maintenance	Periodic monitoring Accumulated trash and sediment must be cleaned out Periodic pipe washout
Hydrologic Design	Determined by State or Local agency

7.14 Infiltration Trenches

Infiltration trenches consist of shallow excavated areas filled with rock material to create a subsurface reservoir layer. They store stormwater runoff until it can be infiltrated into the surrounding soil over a period of 72 hours. They are very adaptable, making them ideal for small urban drainage areas. When filter strips and grassed swales are used in combination as a form of pretreatment, infiltration trenches are highly effective at removing all targeted pollutants from stormwater runoff.

Concerns of groundwater contamination, soil permeability, and clogging at the site inflict restrictions on the use of infiltration trenches. Examples of conditions where infiltration trenches may not be appropriate to use include:

- Sites with low soil permeability
- Industrial locations where contaminated or toxic spills may occur
- Sites with unstable soils
- High groundwater table
- Sites with contaminated groundwater
- Excessively permeable soils as pollutants may affect groundwater quality
- Terrain with steep slopes

To prevent infiltration trenches from becoming plugged over time, sediment must be removed before stormwater enters the trench. It is important to consider other forms of pretreatment such as vegetated filter strips or grassed swales to remove and filter sediment. Refer to Florida Friendly Landscapes recommended vegetation, provided in **Appendix 7C**, for suitable vegetation to use. An example of an Infiltration Trench is shown in **Figure 7-6**.

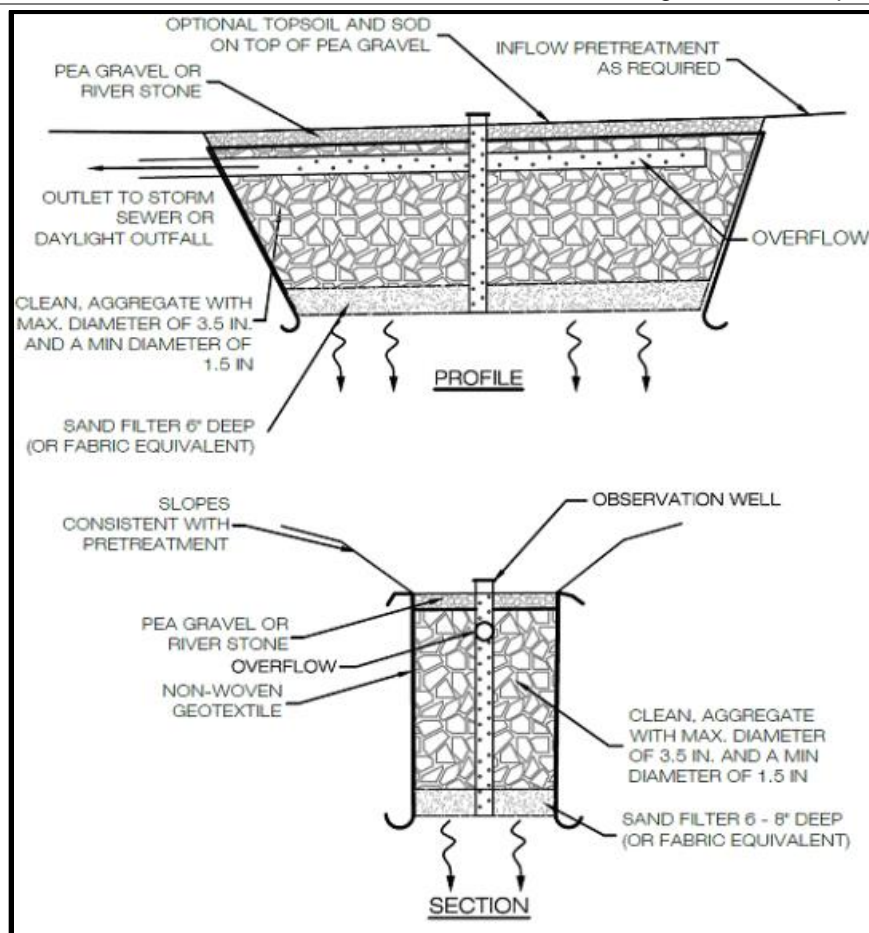


Figure 7-6: Typical Profile & Section View of an infiltration Trench

A summary of design considerations for evaluating the suitability of Infiltration Trenches is shown in **Table 7-6**.

Table 7-6: Design Parameters for Infiltration Trenches

Parameter	Consideration
Treatment Area	Small urban areas. Parking lots, recreational areas. Minimum surface area range: 8 – 20 sq.ft Minimum length to width ratio: 2:1
Pretreatment Area	Other form of pretreatment is ideal. Vegetated filter strips or grassed swales.
Proximity to building Foundation	Minimum distance of 10 feet down gradient.
Soils	The minimum infiltration rate through the vegetation and soil shall be at least 1 inch per hour.
Topography	May be difficult in areas with steep slopes
Depth of Water Table	Not suitable if difference between seasonal high-water table and bottom of Trench area is < 2 ft
Backfill	Clean aggregate > 1½", <3½", surrounded by geotextile filter fabric

Parameter	Consideration
Planting Soil	Pretreatment
Inlet and outlet control	Non-erosive flow velocity's (0.5 ft/sec). Overflow system must be identified.
Plant Material	Pretreatment native species (see Appendix 7C)
Maintenance	Periodic monitoring Accumulated trash and sediment must be cleaned out. Infiltration capacity must be inspected (Total drawdown time 72-hr)
Hydrologic Design	Determined by State or Local agency

7.15 Rain Barrels or Cisterns

Roof water management devices that collect and provide retention storage volume above-ground and underground. The runoff collected can later be used for non-potable activities including irrigation, toilet flushing, or industrial processes. The most common above-ground systems are rain barrels these are low-cost, effective and easily maintainable. Underground systems include a pipe to divert runoff to the cistern, overflow system for when the cistern is full, a pump, and a distribution system to supply non-potable water for the intended uses. Cisterns include, subsurface tanks, vaults and oversized pipes.

Also, they provide an opportunity for water conservation and reducing water utility costs. An example of Rain Barrels and underground Cisterns are shown in **Figure 7-7**.

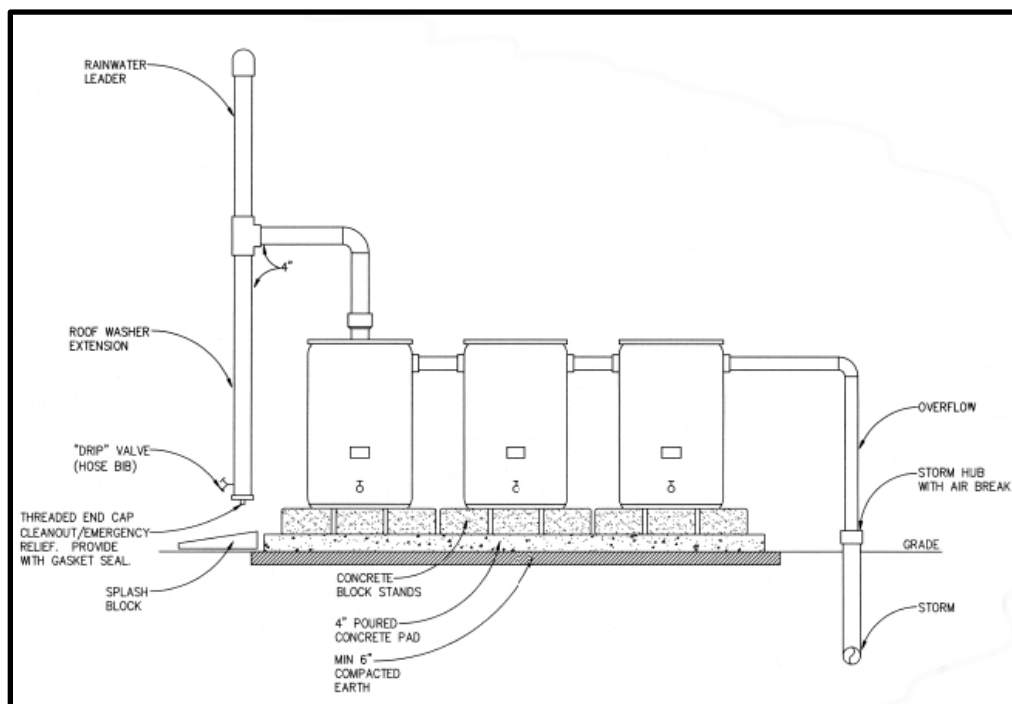


Figure 7-7: Typical Profile of a Rain Barrel System

A summary of design considerations for evaluating the suitability of Rain Barrels and Cisterns are summarized in **Table 7-7**.

Table 7-7: Design Considerations for Rain Barrels and Cisterns

Parameter	Consideration
Treatment Area	Rooftops and other small impervious areas. Size of Rain Barrels is a function of rooftop surface area & the inches of rainfall to be stored. Premanufactured residential cisterns come in sizes ranging from 100 to 1,400 gallons.
Pretreatment Area	Filter screens should be used on gutters to prevent clogging of debris.
Proximity to building Foundation	Beneath each downspout.
Soils	N/A
Topography	N/A
Depth of Water Table	N/A
Groundcover Area	N/A
Planting Soil	N/A
Inlet and outlet control	Downspout & gutters.
Plant Material	N/A
Maintenance	Should be located for easy maintenance & replacement. Inspect and repair/replace treatment area components.
Hydrologic Design	Determined by State or Local agency

7.16 Permeable Pavement

Permeable pavement, unlike traditional pavements, allow water to pass through, reducing the volume and peak of stormwater runoff. Some types can mitigate pollutants by allowing stormwater to percolate through the pavement and enter the soil below. Permeable surfaces include modular paving systems (concrete pavers, modular grass or gravel grids) or poured-in-place pavement (porous concrete, permeable asphalt). They work best on flat surfaces or with gentle slopes. Recent studies on the design, longevity and infiltration characteristics of pervious pavement systems are available on the University of Central Florida's website <http://stormwater.ucf.edu/>.

Pervious pavement systems are retention systems that should be used as part of a treatment train to reduce stormwater volume and pollutant loads from parking lots and similar areas. One of the major advantages of using these types of systems is that they reduce impervious areas and increases usable land/developable space. The treatment efficiency is based on the amount of the annual runoff volume infiltrated, which depends on the available storage volume within the pavement system, the soil permeability, and the ability of the system to readily recover this volume. Ideal locations are parking lots, driveways, sidewalks and areas with light traffic (<100 cars/day). An example of a pervious pavement system is shown in **Figure 7-8**.

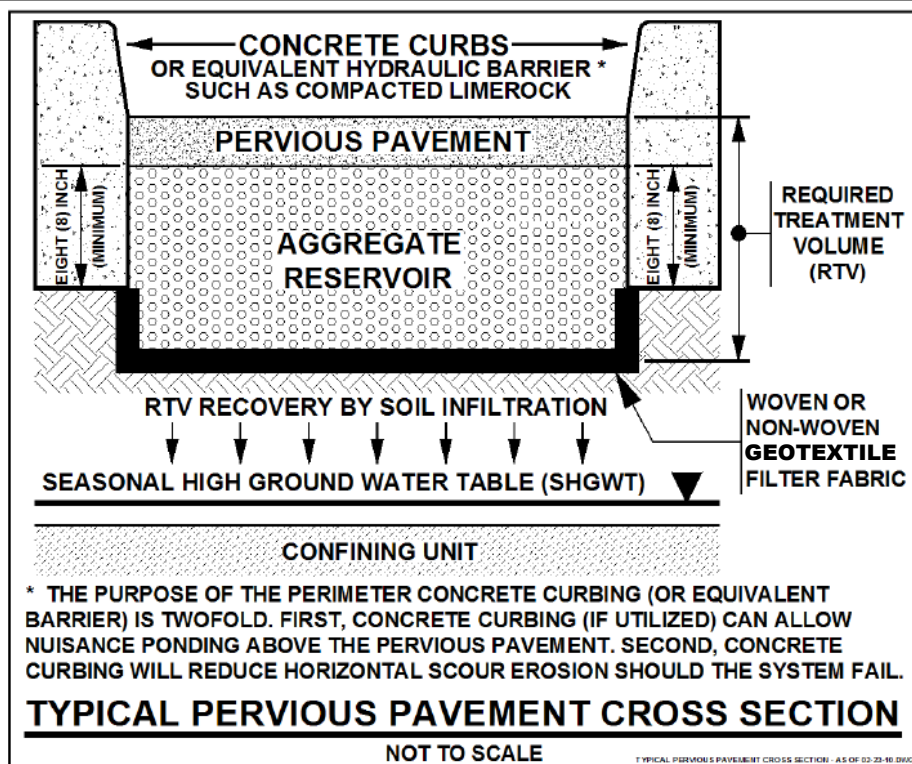


Figure 7-8: Typical Pervious Pavement Cross-section

A summary of design considerations for evaluating the suitability of implementing pervious pavement is shown in **Table 7-8**.

Table 7-8 : Pervious Pavement Design Considerations

Parameter	Consideration
Treatment Area	Parking lots, driveways, sidewalks and areas with light traffic. Avoid areas with high potential for hazardous material spills. Should consider potential for tripping hazards in areas used by pedestrians.
Pretreatment Area	Should be used as a part of a treatment train to reduce stormwater volume and pollutant loads
Proximity to building Foundation	Distance to foundation, septic systems, wells, needs to be verified onsite prior to construction.
Soils	Challenges include poorly draining soils, soils containing organic mucks
Topography	May be difficult in areas with steep slopes. Should not exceed 5.0%.
Depth of Water Table	Present challenges in shallow seasonal high groundwater tables and shallow confining units
Groundcover Area	Pervious surface.
Planting Soil	Pervious walks and bicycle paths must be placed over native upland soils or clean fill.

Parameter	Consideration
	For redevelopments, pervious pavements must be placed over rehabilitated soils.
Inlet and outlet control	Except for pervious walks and bike paths, curbing, edge constraint or other equivalent hydraulic barrier will be required to a minimum depth of 8 inches beneath the bottom of the pavement to prevent scouring from horizontal movement of water.
Plant Material	Native species. (see Appendix 7C)
Maintenance	Periodic vacuum sweeping is recommended annually and whenever the vertical hydraulic conductivity is less than 2.0 inches per hour or less than the permitted design percolation rate. Repair near edge constraints or overflows, and assure contributing area is stabilized and not a source of sediments.
Hydrologic Design	Determined by State or Local agency

7.17 Detention/Retention Ponds

7.17.1 Detention Ponds

Dry detention ponds detain a portion of urban runoff for a short period of time (72 hours after a storm based on SFWMD requirements) using a fixed opening to regulate outflow at a specified rate and allowing solids and associated pollutants time to settle out. Dry detention volume shall be provided equal to 75% of the amounts computed for wet detention. These systems in general are effective in removing total suspended solids but have low treatment efficiency for nutrients. They are normally dry between storm events. Siting requirements call for a minimum of one foot from control elevation to the bottom of the detention zone. Therefore, constructing dry detention ponds on wetlands and floodplains should be avoided. Where drainage areas are greater than 250 acres and ponds are being considered, inundation of upstream channels may be of concern.

Wet detention ponds are designed to maintain a permanent pool of water and temporarily store urban runoff until it is released at a controlled rate. Hydraulic holding times are relatively short, such as hours or days. These systems are more efficient in removing soluble pollutants (nutrients) than dry detention due to the biological activity in the vegetation and water column. Enhanced designs include a forebay to trap incoming sediment where it can be easily removed. A littoral zone can also be established around the perimeter of the pond. SFWMD Requires 20% Littoral Zone by area or 2.5% of the total basin area draining to the pond, whichever is less.

For wet detention systems, the bleed-down volume is defined between the elevation of the overflow weir and control elevation and shall be the first one inch of runoff from the contributing area, or the total runoff of 2.5 inches times the percentage of imperviousness, whichever is greater. The control elevation is the normal water level for the pond and it is established at the higher elevation of either the normal wet season tailwater elevation or the seasonal high groundwater table minus six inches. The maximum stage above the control elevation for providing bleed-down volume shall not exceed 18 inches unless alternative design is appropriate for the specific site conditions.

The permanent pool size shall be sized to provide a residence time that achieves the required nutrient removal efficiency. Resident time shall be based upon annual rainfall volumes. Maximum depth shall be no greater than 12 feet. The maximum allowable permanent pool depth as it relates to the aerobic zone is directly related to the anticipated algal productivity within the pond.

To ensure proper drainage, aerobic functioning and aeration, and vegetative health, regular inspections are needed. Also, regular maintenance should be performed to remove sediment, trash and debris. Ideal locations of wet detention ponds include downstream of catchment and runoff, usually constructed at the lowest point of the site.

An example of a typical wet detention system cross section is shown in **Figure 7-9**.

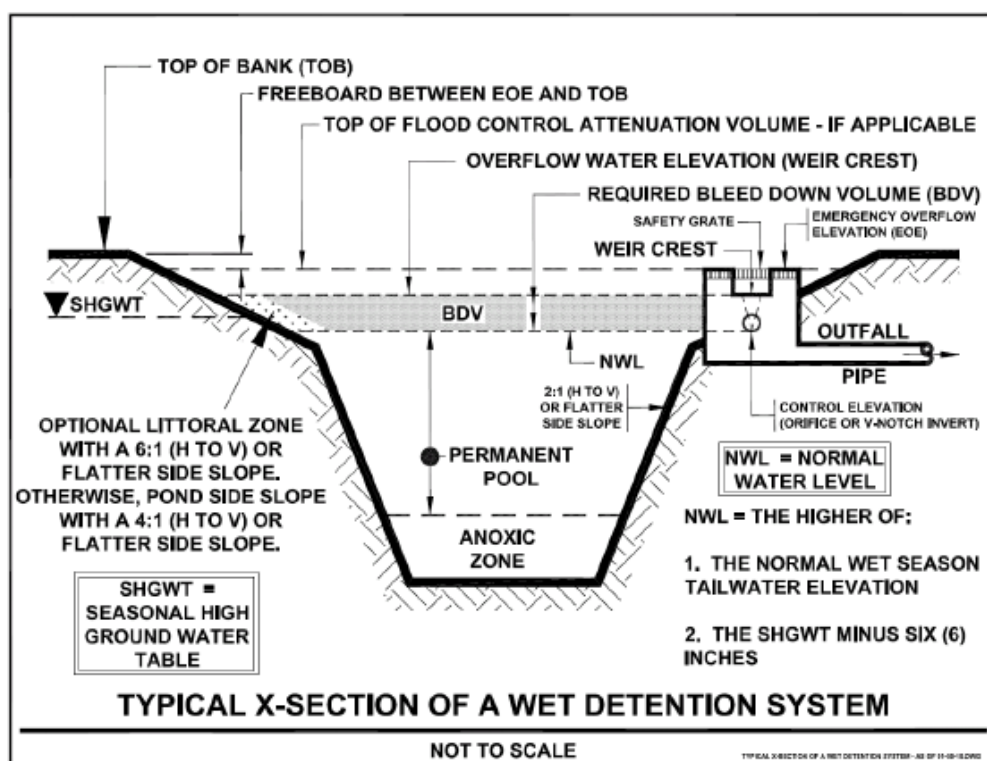


Figure 7-9: Typical Cross-section of a Wet Detention System

A summary of design considerations for evaluating the suitability of implementing a wet detention system is shown in **Table 7-9**.

Table 7-9: Wet Detention System Design Considerations

Parameter	Consideration
Treatment Area	Wet ponds designed to slowly release a portion of the collected stormwater runoff through an outlet structure. Most significant component is the storage capacity of the permanent pool.
Pretreatment Area	Provide removal of both dissolved and suspended pollutants by taking advantage of physical, chemical, and biological processes. Can be implemented also as a part of a BMP treatment train.
Proximity to building Foundation	Distance to foundation, septic systems, wells, needs to be verified onsite prior to construction.
Soils	Exotic or nuisance plant species shall be removed to prevent their long-term establishment.
Topography	Pond slopes shall be restricted from public access or contain slopes that are no steeper than 4:1. Deeper areas of the pond must maintain side slopes no steeper than 2:1.
Depth of Water Table	Moderate to high water table condition
Groundcover Area	Side slopes shall be stabilized by either vegetation or other materials to minimize erosion and sedimentation of the pond.
Planting Soil	Managed Aquatic Plant Systems (MAPS) are aquatic plant-based BMPs. Littoral Zones shall be gentle slopes (6:1) or flatter. 20% Littoral Zone by area or 2.5% of the total basin area drainage to the pond, whichever is less. Pond level shall be below 18 inches above control elevation to ensure vegetation can survive. Planting is recommended to meet 80% coverage requirement (MAPS) with no more than 10% consisting of exotic or nuisance species.
Inlet and outlet control	Outlet structure generally includes a drawdown device (orifice, "V" or square notch weir) set to establish a normal water control elevation and slowly release the bleed down volume.
Plant Material	Native species. (see Appendix 7C)
Maintenance	Ensure proper drainage, aerobic functioning and aeration. Vegetative regular inspections are needed to prevent erosion of side slopes and around inflow and outflow structures. Remove sediment, trash and debris. Inspect for potential mosquito breeding problems. Inspect littoral zone to assure invasive vegetation is not becoming established.
Hydrologic Design	Determined by State or Local agency

7.17.2 Retention Ponds

Retention systems rely on absorption of runoff to treat urban runoff discharges. Water is infiltrated through soils, where filtration and biological action remove pollutants. Systems that rely on soil absorption require a deep layer of permeable soils at separation distances

of at least 1 foot between the bottom of the structure and seasonal groundwater levels. Retention volumes shall provide equal to 50% of the above amounts computed for wet detention systems. Using retention systems in a watershed will help preserve or restore predevelopment hydrology, increase dry weather base flow, and reduce bankfull flooding frequency. Where groundwater requires protection, retention systems may not be appropriate.

Dry retention basins are depressed areas where incoming urban runoff is temporarily stored until it gradually infiltrates into the surrounding soil. These would gradually drain down to maintain aerobic conditions that favor bacteria which aid in pollutant removal and to ensure the basin is ready to receive the next storm. Runoff entering the basin is sometimes pretreated to remove coarse sediment that may clog the surface soil pores on the basin floor. Concentrated runoff should flow through a sediment trap. A vegetated filter strip may be used for sheet flow.

The required treatment volume to achieve the necessary efficiency shall be determined based on the percentage of directly connected impervious areas (DCIA) and the weighted curve number for non-DCIA areas. To avoid degradation of retention basin infiltration capacity, specific construction practices should be implemented. These include:

- Prevent unnecessary vehicular traffic to avoid soil compaction
- Excavation shall be done by lightweight equipment to minimize soil compaction
- Entire basin bottom must be deep raked and loosened for optimal infiltration once the basin has been excavated to final grade

Maintenance for regular trash and intermittent sediment removal should be performed, pollutants accumulate in soil and may require additional cleanouts. Ideal locations for a dry retention system include downstream of catchment and runoff, and upstream from off-site stormwater management systems.

An example of a typical dry retention system cross section is shown in **Figure 7-10**.

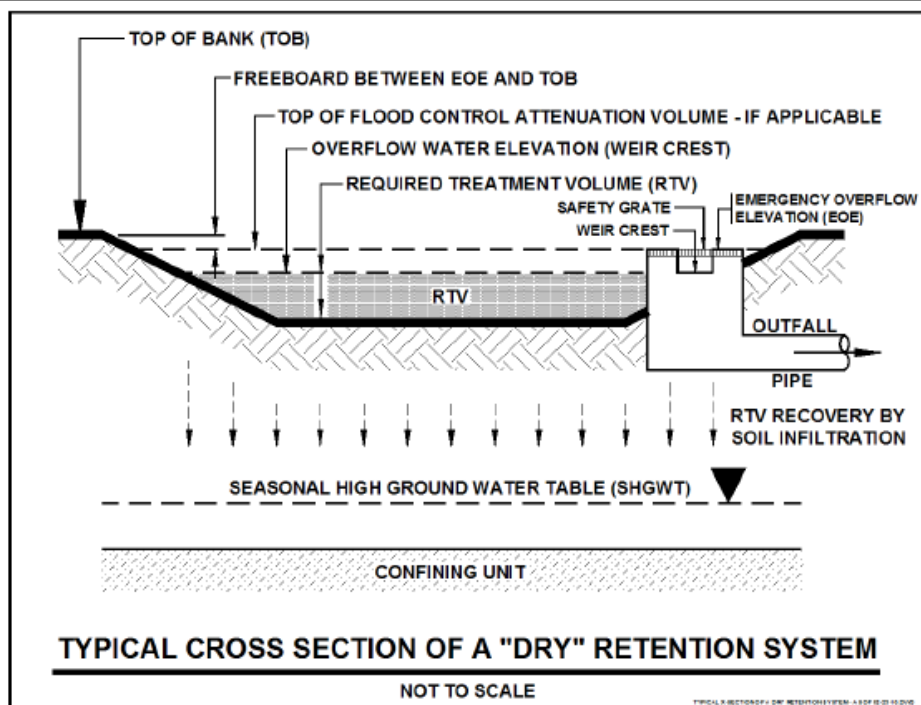


Figure 7-10: Typical Cross-section of a Dry Retention System

A summary of design considerations for evaluating the suitability of implementing a dry retention system is summarized in **Table 7-10**.

Table 7-10: Dry Retention System Design Considerations

Parameter	Consideration
Treatment Area	Must have the capacity to retain required treatment volume without a discharge and without considering soil storage. Constructed or natural depression areas, typically flat with turf, natural ground cover or other appropriate vegetation to promote infiltration and stabilize basin slopes. Side slopes of 1:4 are recommended. Bottom slopes of 2% or zero are recommended to maximize infiltration.
Pretreatment Area	Stormwater pollutants such as suspended solids, oxygen demanding materials, heavy metals, bacteria, some varieties of pesticides, and nutrients are removed as runoff percolates through the soil profile.
Proximity to building Foundation	Distance to foundation, septic systems, wells, needs to be verified onsite prior to construction. Shall not be constructed within 50 feet of public or private potable water supply well.
Soils	Turf, natural ground cover, or other appropriate vegetation.
Topography	Typically flat
Depth of Water Table	Seasonal high ground water table shall be at least 1 foot beneath the bottom of the retention basin.

Parameter	Consideration
	Unless alternative design is appropriate for the specific site condition.
Groundcover Area	Sides and bottom shall be stabilized with permanent vegetative cover, or pervious material to prevent erosion and sedimentation.
Planting Soil	Vegetation roots help maintain soil permeability. Grass needs to be mowed and grass clippings removed to reduce internal nutrient loadings.
Inlet and outlet control	Non-erosive velocities should be maintained to avoid resuspension of settled out solids.
Plant Material	Native species. (see Appendix 7C)
Maintenance	Remove accumulated sediments from retention basin bottom and inflow and outflow pipes. Remove trash and debris, trash racks and other components to prevent flooding and impeding flow. Maintain healthy vegetative cover to prevent erosion in the basin bottom, side slopes or around inflow and outflow structures.
Hydrologic Design	Determined by State or Local agency

7.18 Pollution Control Structures

Pollution control structures, such as CDS or Vortech units, are used to treat runoff in urban areas with limited right-of-way and/or poor soil infiltration rates. The units remove floatables, oil/grease, and reduce the total suspended solids (TSS) of the runoff prior to discharging to a waterbody or well. The units do not reduce the total volume of water discharged to the outfall. When used in conjunction, pollution control structures can reduce sedimentation in ponds, thus reducing the required maintenance needs of the pond.

Pollution control structures can be designed as in-line or offline structures. Offline control structures allow for the bypass of the system during large flow events while still providing the required treatment volume. Units are designed to handle peak flow events. An example of a pollution control structure is shown in **Figure 7-11** and **Figure 7-12**.

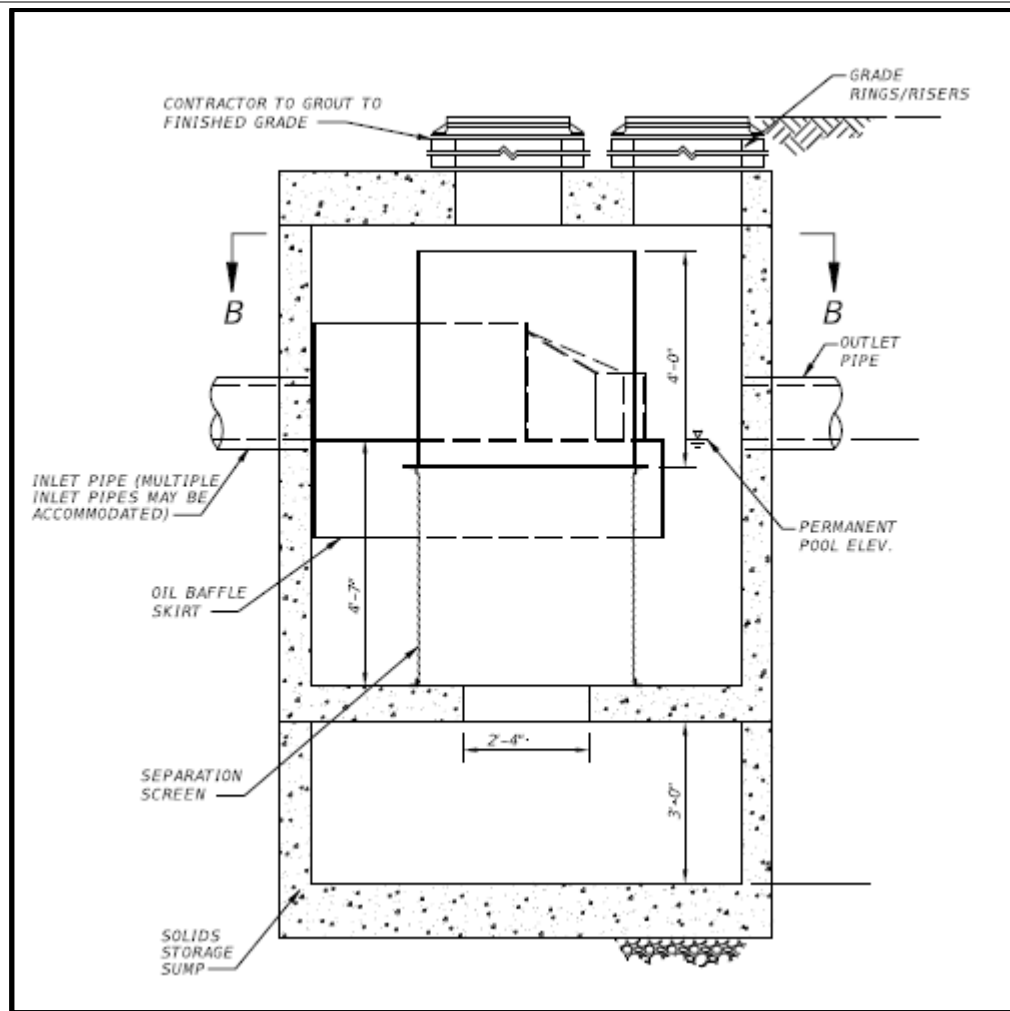


Figure 7-11: Typical Pollution Control Structure Cross-section

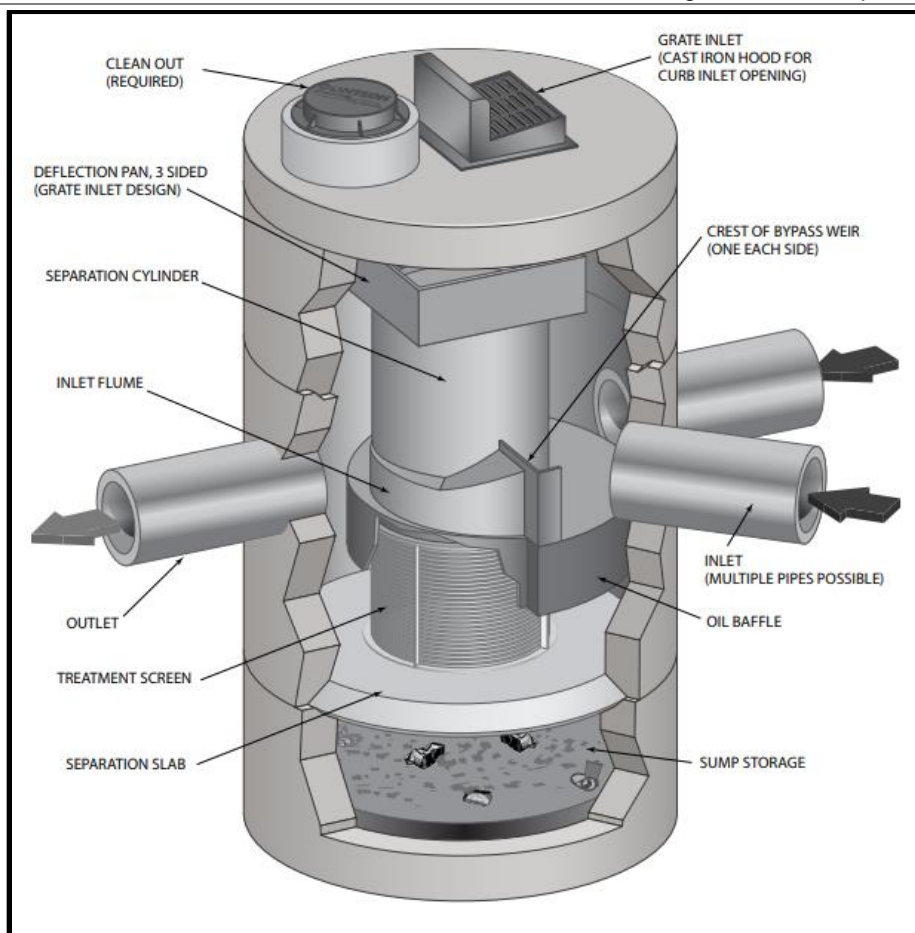


Figure 7-12: Typical Pollution Control Structure Cut Out (credit: www.conteches.com)

A summary of design considerations for evaluating the suitability of implementing a pollution control structure is summarized in **Table 7-8**.

Table 7-11: Pollution Control Structure Considerations

Parameter	Consideration
Treatment Area	Must be designed to meet peak flow rate of project area. Should be installed immediately upstream of outfall.
Pretreatment Area	Can be used independently or as part of a treatment train to reduce floatables and TSS.
Proximity to building Foundation	N/A
Soils	N/A
Topography	N/A
Depth of Water Table	Depth of water table shall be taken into account during design, but no specific requirements are needed.
Groundcover Area	N/A
Planting Soil	N/A

Parameter	Consideration
Inlet and outlet control	Inlet control is mandated by required treatment volume. Unit needs to be sized according to peak flow rates. Outlet control is subject to meeting pre vs. post outlet velocity's when discharging to offsite waterbodies or well capacity when discharging to an injection well.
Plant Material	Native species. (see Appendix 7C)
Maintenance	Periodic pump out is required. Maintenance schedule shall be determined by local agency based on floatable and pollutant loading. Locate pollution control structure for easy pump out without the need for maintenance of traffic, if possible.
Hydrologic Design	Determined by State or Local agency

7.19 Recommendations for Future Water Quality BMP and Stormwater Management Implementation

Due to the large percentage of area within the City of Delray Beach that currently has no water quality measures in place, vast improvements in water quality can be made through the various non-structural and structural BMPs outlined in the previous sections as future development, redevelopment, or City improvements take place. These stormwater management practices take an innovative approach to mitigate hydrologic, hydraulic and water quality impacts from future development and redevelopment and seeks to treat runoff and stormwater pollution at or near the source.

The City of Delray Beach currently has one ordinance mandating a max land coverage for commercial properties only. It is recommended that the City of Delray Beach consider revising the land development code to include revised open space requirement for both residential and commercial land uses. This will provide flexibility in the design of development or redevelopment projects, which will provide the opportunity to implement non-structural and structural stormwater BMPs based on project site size and type, and provisions for sites where these techniques may be technically infeasible. It is also recommended that the ordinance mandate all redevelopment and future development implement non-structural stormwater management practices to the maximum extent possible and implement a minimum of two structural BMPs.

In addition, it is recommended that provisions for long-term maintenance, monitoring, and enforcement be developed. Long-term maintenance and inspection plans are required for these types of structural stormwater management systems and the entity responsible for the maintenance and monitoring should be clearly defined. Site Planning Regulations should be evaluated to minimize the requirements for property setbacks, traffic distribution network widths, sidewalk widths, and rights-of-way.

Based on the data previously collected and evaluated, non-structural and structural stormwater management practices were identified that will naturally treat and retain

stormwater for new developments and redevelopment sites within public and private right-of-way. The site planning process should incorporate non-structural and structural stormwater management strategies throughout the planning process. The recommended priority for managing and capturing stormwater runoff is infiltration, evapotranspiration, capture and use, and treatment through biofiltration/bioretention systems.

The primary non-structural stormwater management practices and considerations that appear to be most applicable to the City of Delray Beach include the following:

1. Pre-development topography and soil profile restoration and preservation
2. Native and local vegetation preservation
3. Open space design and conservation
4. Total impervious area minimization
5. Directly connected impervious area reduction

The selected structural BMPs, based on most cost-effective approach that can be utilized in the City of Delray Beach, are the management practices listed below:

1. Bioretention Basins or Rain Gardens
2. Tree Box Filters or Infiltration Planters
3. Vegetated Swales (grass, infiltration, wet)
4. Filter Strips or Vegetated Buffers
5. Exfiltration Trenches
6. Infiltration Trenches
7. Rain Harvesting (rain barrels/cisterns)
8. Permeable Pavement
9. Detention / Retention Ponds
10. Pollution Control Structures (i.e. Vortech/CDS Units)

7.20 Private Areas

For private development, the use of non-structural BMP options is limitless; however, some applications are better suited for future development versus redevelopment.

7.20.1 Future Development

Future development allows for the implementation of any of the structural and non-structural BMPs. However, some of the non-structural practices are best suited for undeveloped sites. They use native and natural features of the existing site to attenuate peak runoff and overall runoff volume, improve water quality, and increase groundwater recharge within the development site.

1. Preservation of pre-development topography and soil profile
2. Preservation of native and local vegetation

7.20.2 Redevelopment

Redevelopment of existing sites, whether or not the site has an existing SWM Permit or ERP already, creates an opportunity for the betterment of the water quality of stormwater runoff. Any of the structural and many of the non-structural practices can be implemented as the sites are redeveloped. The BMPs should be selected based on each individual site conditions.

7.21 Barrier Island

Only one development within the City limits on the Barrier island has a retention/detention pond, another single development utilizes infiltration trenches, and swales are used in about 5 to 10% of the area. The remainder of the island currently has no water quality measures in place. However, the barrier island is almost entirely developed, which means water quality enhancements will need to take place alongside redevelopment. Pollution control structures are recommended for use since they provide water quality enhancements within a small footprint. Exfiltration trenches are also a viable option to provide additional attenuation within the limited space of the island.

7.22 City of Delray Beach Right-of-Way

When new projects are proposed within the City of Delray Beach right-of-way, it provides an opportunity to implement structural stormwater management practices to improve the quality of stormwater discharges to receiving water bodies. The most cost-effective water quality and quantity structural stormwater management practices are exfiltration trenches and pollution control structures. These BMPs can be easily implemented alongside roadway improvement/rehabilitation projects and kept within the City's right-of-way, eliminating the need to purchase additional land to improve stormwater discharge quality. Inline or offline pollution control structures can be implemented upstream of system outfall to significantly improve the quality of stormwater discharges to the receiving water body.

8.0 CAPITAL IMPROVEMENT PROJECTS

8.1 Capital Improvement Project Design Criteria and Regulatory Constraints

8.1.1 General

Capital improvement projects must adhere to strict water quality and quantity criteria set forth by various local, state, and federal agencies with jurisdiction within the City. All projects must adhere to these criteria prior to permitting and constructing the project. As such, all projects which are developed for the City will require full coordination with regulatory agencies and adherence to all local, state, and federal stormwater management regulations. As with any regulatory requirements, changes do occur over time, and all criteria must be verified with the applicable agency prior to the commencement of the design phase of a project.

8.1.2 Water Quality Regulatory Requirements

Because no additional impervious areas are being constructed as a part of the proposed capital improvement projects for the 14 Problem Areas, there are no water quality detention or retention required for these projects. In addition, the intracoastal is not designated as an impaired water body. Therefore, discharges into the intracoastal waterway will not require any pollutant load reductions. Regardless, for new stormwater improvement projects, the South Florida Water Management District (SFWMD) always encourages net water quality improvements for all new project to reduce the potential for the receiving water bodies from becoming impaired. Therefore, all capital improvement projects proposed to improve the flood protection level of service provide some level of water quality improvements to the maximum extent possible. The following sections outlined the water quality requirements by entities having jurisdiction with the City, for new projects where new impervious areas are part of the proposed improvements.

8.1.3 City of Delray Beach

The City of Delray has set standards for the quality of water discharged based on the SFWMD regulations. These criteria are summarized in **Section 8.1.5**. These criteria are normally met through exfiltration trenches, retention ponds and pollution control structures in residential and commercial development with high values of impervious area. Although this is the case for developed areas of the City, the Florida Department of Environmental Protection (FDEP) agency through the National Pollutant Discharge Illimitation System (NPDES) permit has also set standards for Total Maximum Daily Loads (TMDL) for stormwater discharges into Lake Ida. None of the Problem Areas discussed for Capital Improvements discharge into Lake Ida. Therefore, these TMDL requirements are not applicable to the proposed projects.

8.1.4 Lake Worth Drainage District

All water discharged into the Lake Worth Drainage District's (LWDD's) canal system must also meet water quality standards in accordance the SFWMD regulations. SFWMD water quality requirements are discussed in **Section 8.1.5**.

8.1.5 South Florida Water Management District

The SFWMD requires that all projects meet State of Florida water quality standards, as set forth in Florida Administrative Code (F.A.C.) Chapter 62-302. To assure that these criteria are met, projects must meet the following volumetric retention/detention requirements as described in the SFWMD Environmental Resource Permit Applicant's Handbook Volume II:

1. For wet detention systems:
 - a. A wet detention system is a system where the control elevation is less than one foot above the seasonal high groundwater elevation and does not bleed-down more than one-half inch of detention volume in 24 hours.
 - b. The greater of the following volumes must be detained on site:
 - i. the first one inch of runoff times the total project area
 - ii. 2.5 inches of total runoff from the impervious area
2. Dry detention systems must provide 75 percent of the required wet detention volume. Dry detention systems maintain the control elevation at least one foot above the seasonal high groundwater elevation.
3. Retention systems must provide at least 50 percent of the wet detention volume.
4. For projects with impervious areas accounting for more than 50 percent of the total project area, discharge to receiving water bodies must be made through baffles, skimmers, and/or other mechanisms suitable of preventing oil and grease from discharging to or from the retention/detention areas.

All of the proposed capital improvement projects will not include adding any new impervious areas. Therefore, these water quality requirements will not apply for these projects. However, many of the systems in the problem areas discharge stormwater to receiving water bodies with little to no treatment because many of these systems were constructed prior to stormwater management rules. Therefore, water quality will be provided to the maximum extent possible for stormwater runoff contributed from the City's right-of-way, to improve the quality of discharges into the receiving water bodies.

8.2 Water Quantity Regulatory and Permitting Requirements

8.2.1 City of Delray Beach

The City of Delray Beach has set criteria for setting the standards for various roads and finished floor elevations based on a variety of design storm events.

- Minimum Parking Elevation: 5-year -1 hour (peak stage)
- Collector Roads Centerline: 5-year - 1 day (peak stage)
- Minimum Perimeter Elevation: 25-year - 3 day (peak stage)
- Minimum Finished Floor Elevation: highest of the following:
 - 100 year – 3 day (peak stage) without offsite discharges
 - 18" Above adjected crown of road per Building Code (Section 7.1.3(2))
 - Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps (FIRM) established minimum finished floor elevation

8.2.2 Lake Worth Drainage District

According to the Lake Worth Drainage District Operating Policies, Chapter 3, Section 3.4 outlines the water quantity regulations set forth for all runoff into the LWDD basins. These allowable limits are listed in **Table 8-1**. Problem Areas 13 and 14 are located in the C-15 Basin.

Table 8-1: LWDD Allowable Discharge Limits

Basin	Rate	Frequency (yrs)
Hillsboro Canal	35 CSM	25
C-15	70 CSM	25
C-16	62.6 CSM	25
C-51	Subject to restrictions of SFWMD basin rule	

Note: CSM = cubic feet per second (cfs) per square mile.

In addition, the maximum allowable discharge from any newly constructed road or street, or improved roadway, must be limited to 2.5 cfs peak allowable discharge per half mile section during a 25-year design storm. As a basis of comparison, for Problem Areas 13 and 14 peak flows from the modeled Capital Improvements were compared to peak flows from the model with sea level rise and existing infrastructure to ensure that those peaks did not increase.

8.2.3 South Florida Water Management District

The SFWMD requires that off-site discharge rates be limited to rates not causing adverse impacts to existing off-site properties, and:

1. historic discharge rates,
2. rates determined in previous SFWMD permit action, or

3. basin allowable discharge rates.

For projects discharging to a SFWMD canal basin, the SFWMD Environmental Resource Permit Applicant's Handbook Volume II outlines basin allowable discharge rates. Capital projects along the coastal area will be discharging to the Intracoastal without increasing the amount of existing impervious areas. Therefore, the discharge volume for future conditions will be the same as existing conditions. The only variable for these projects will be that the discharge rate will increase, but the runoff volume will remain the same. However, overall the capital improvement projects will provide a net benefit due to the improvement of the quality of stormwater discharges to the receiving water bodies.

8.2.4 Federal Emergency Management Agency

The FEMA sets the standard for flood mapping in areas all over the country to ensure that city's and land developers have an accurate and appropriate expectation of flood elevations in any given area. FEMA identifies flood hazards and assesses flood risks to create FIRM to guide communities to mitigation actions. Problem Areas 1-11 fall in the flood zone AE which has a minimum Base Flood Elevation of 6 feet relative to the North American Vertical Datum of 1988 (ft-NAVD88). This flood elevation is based on a 100-Year design storm event and is used to determine safe elevations for construction. Because of this, all pump station control panels must set at or above 6 ft-NAVD88 elevation to ensure no electrical components will be flooded during extreme weather events.

8.3 Stormwater Management Systems

8.3.1 General

Capital improvement projects to be identified as part of this stormwater master plan update will be conceptually designed to address the projected 30-year sea level and groundwater rise flooding conditions documented in **Section 6.0**. **Figure 8-1** and **Figure 8-2** describe the projected tidal and groundwater changes for both the coastal Problem Areas (1-12) and the upland Problem Areas (13, 14), respectively.

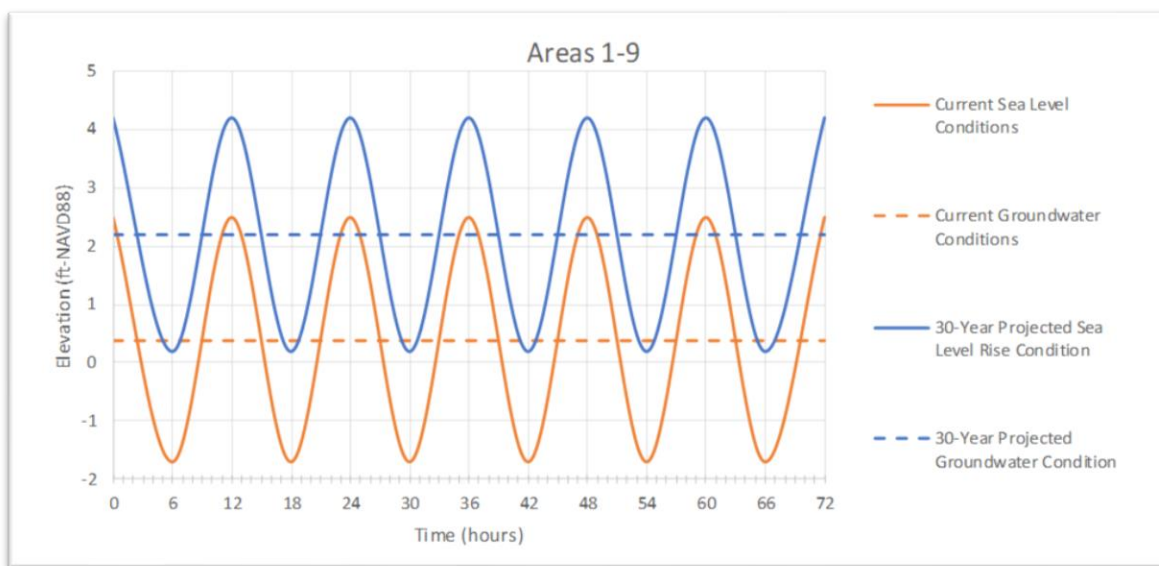


Figure 8-1: Coastal Problem Area (1-12) Tidal Boundary Conditions and Groundwater Level Assumptions

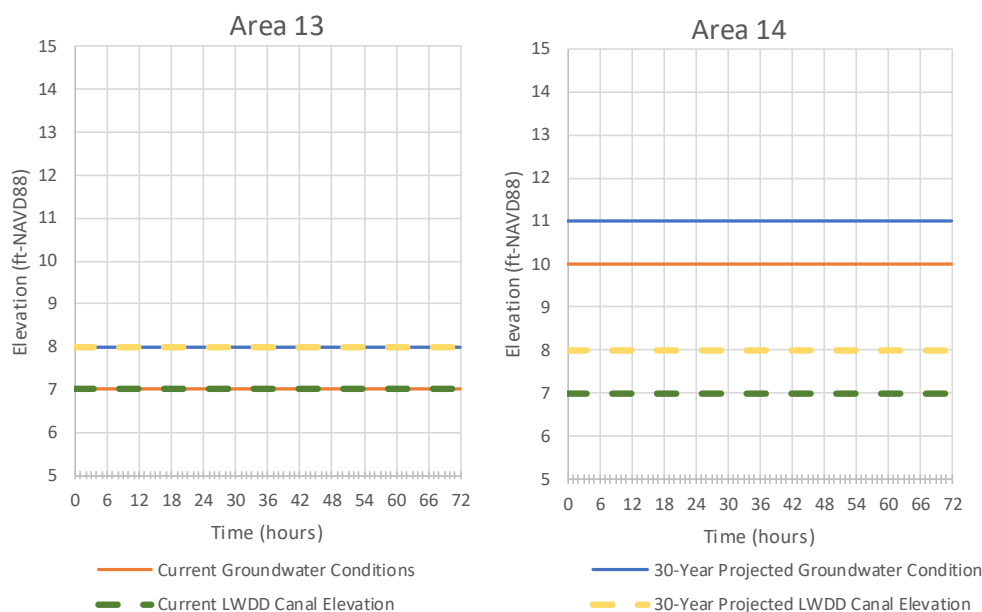


Figure 8-2: Upland Problem Area (13 - 14) Boundary Conditions and Groundwater Level Assumptions

To be able to address this level or projected flooding, the capital improvement projects will be comprised of one or combination of these stormwater management systems:

1. Raising existing sea walls or implementing new seawalls to a minimum top elevation of 4.2 ft-NAVD88 as documented in **Section 6.0**
2. Construction of new or rehabilitation of existing stormwater pump stations
3. Installation of backflow preventers for outfalls with positive discharge
4. Construction of exfiltration trenches
5. Lining existing stormwater pipes for projects within the coast areas
6. Implementing pollution control devices for systems discharging to LWDD canals, SFWMD canals or the Intracoastal
7. Raising the crown of road elevation as needed to be above the peak 5-year, 1-day flood elevation.

Over 95 percent of the seawalls within the City are privately owned. These seawalls will need to be raised by the property owners either via incentives or adoption of ordinances to require raising of the privately-owned walls. The City is currently in the process of raising the City-owned seawalls to the projected 30-year sea level elevation. For the proposed capital improvement projects for problem areas along the coastal areas, it will be assumed that the seawalls have been raised at the time of construction of the capital improvement project.

In addition to raising the seawalls, all positive outfall pipes to remain or proposed, whether private or public, must be retrofitted with a backflow prevention device. Because many

of the existing stormwater pipes are over 30 years old, even with backflow prevention devices, water could migrate inland through the pipe joints and into the inlets. Therefore, if after the backflow prevention device is installed and during high tides water enters the surface through existing inlets, all pipes connected to the outfall must be replaced or lined. For privately owned outfalls, the City will need to adopt ordinances to ensure that backflow prevention devices and pipe replacement or lining, if required, are implemented in privately-owned systems. As for the seawall, for the proposed capital improvement projects, it will be assumed that all gravity outfalls will have backflow prevention devices and the drainage system connected to the outfall is watertight.

8.4 Stormwater Pump Stations

Pump stations are used for expediting flows to a receiving water body or retention area. Although stormwater pump stations are expensive to install, operate, and maintain, their use is often required in areas where space is limited and no other practical gravity alternative is available. **Appendix 8A** shows typical details of a stormwater pump station and associated components. The main components of the stormwater pump station unit are:

- Off-line pollution control structure
- Trash rack
- Pump station and wet well
- Valve box
- Energy dissipator
- Electrical control panel

By separating each of the components into their respective locations, rather than placing them all within a centralized box, it allows for easier maintenance on a structure-specific basis. Numerous factors play a role in determining the size of the pump station and associated components. They include limits on rate/volume of receiving water body, conveyance capacity of contributing systems, and size constraints for the pump station wet well. Pump stations are a viable option for the City to mitigate the projected impacts of the anticipated 30-year sea level and groundwater rise.

Although the primary elements of the stormwater pump station will be located underground, the electrical panel will need to be located above ground, with a minimum elevation of 6 ft-NAVD88. In some areas this will create aesthetic challenges that will need to be addressed during the detailed design of these systems.

8.5 Backflow Preventer

Backflow preventers, also known as check valves, are devices that prevent the flow of water from one point backwards (negative) into a conveyance system, while still allowing for flow to continue in one direction (positive). These devices are typically applied in conjunction with positive discharge outfall structures that discharge to high tidal areas and canal systems with high surface water profiles and high tide conditions. During

positive flow discharge, these devices do increase the amount of head loss due to the pressure required to open the valve and reduced pipe diameter.

The recommended check valve that minimizes head losses and the possibility of being blocked or maintained opened by debris and marine growth are in-line backflow preventers. Several companies such as Red Valve, Inc.; WAPRO, Inc.; and others manufacture these type of backflow preventers. **Figure 8-3** and **Figure 8-4** show typical in-line backflow preventer devices and how they operate.

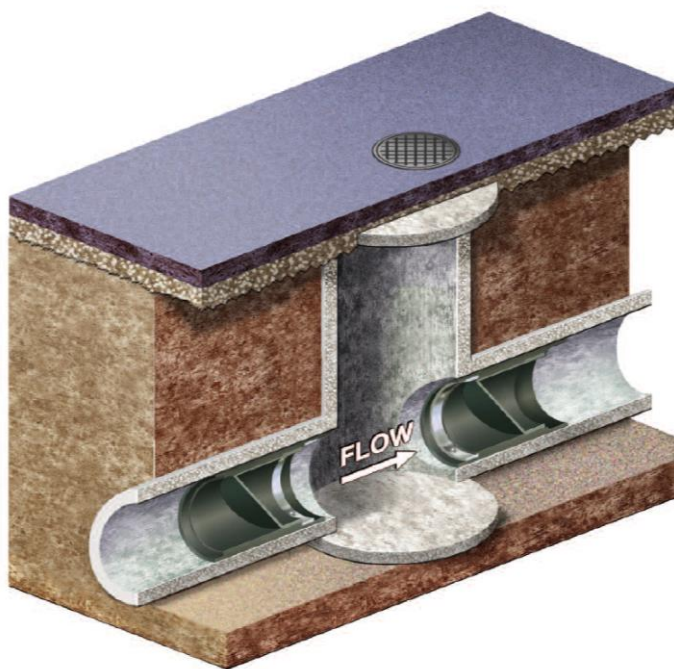


Figure 8-3: Typical in-line back-flow preventer installation

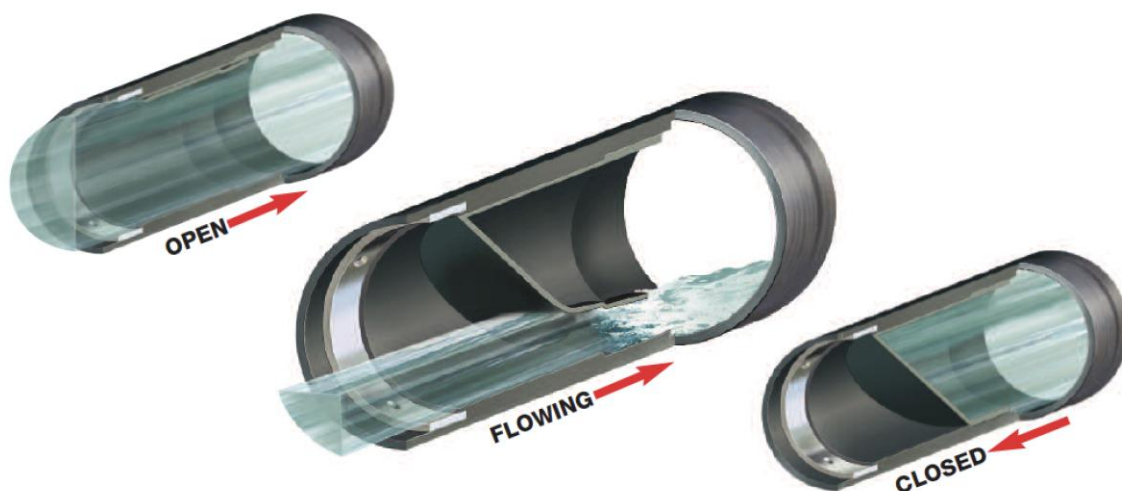


Figure 8-4: Typical in-line backflow preventer operation

8.6 Exfiltration Trenches

Exfiltration trenches have relatively low construction and maintenance costs and are one of the least land intensive stormwater drainage systems available. Their effectiveness is heavily dependent on acceptable soil hydraulic conductivity, groundwater table elevations, and available topographic elevations. The pipes associated with exfiltration trench systems can also provide additional interconnectivity within an area, as does a solid pipe system.

An exfiltration trench system consists of at least one catch basin or inlet that leads to a perforated or slotted pipe laid in a bed of aggregate filter media, such as ballast rock. They can be placed below paved surfaces or at the bottom of retention areas and offer a method of conveying stormwater runoff to the groundwater table in areas where impervious areas have been greatly increased. **Figure 8-5** shows a typical longitudinal profile and cross section of an exfiltration trench.

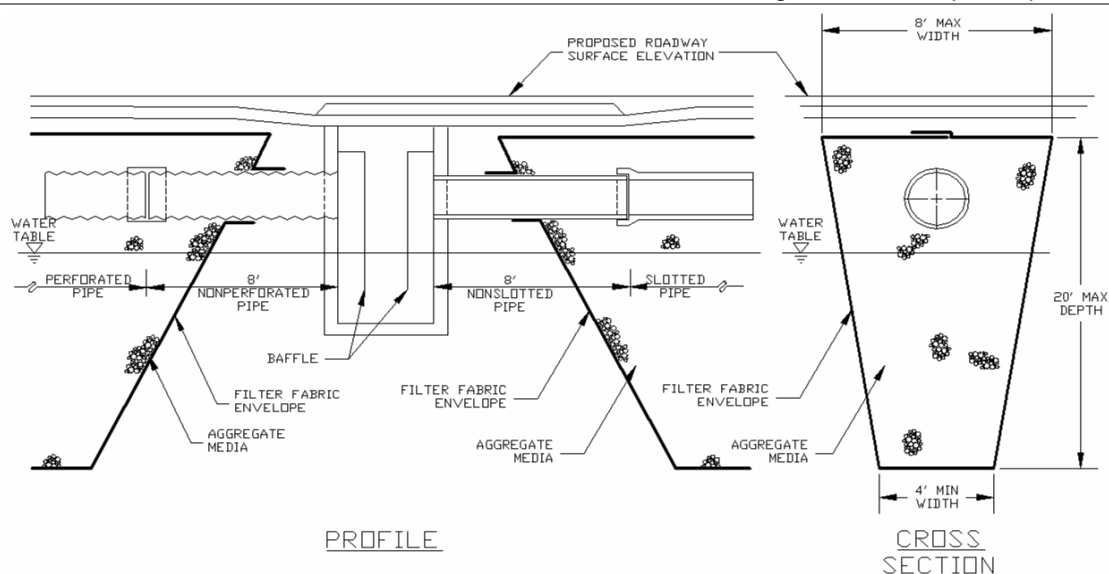


Figure 8-5: Typical Exfiltration Trench Sections

These types of systems typically include a weir or control structure which retain a certain amount of stormwater runoff and surcharges in the perforated pipe and trench to induce exfiltration into the surrounding native soil. Self-contained systems do not require a weir or control structure since the lowest inlet elevation acts as the target surge elevation, or control elevation of the system. Exfiltration trenches are not incorporated with systems with stormwater pump stations because it promotes pumping of groundwater, which makes the pump station inefficient.

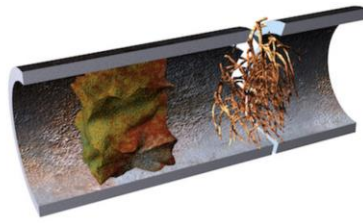
8.7 Existing Pipe Lining

Many of the pipes constructed in the City's coastal areas have been constructed over 30 to 50 years ago. Many of the joints of the existing pipe exhibit signs of leaking, which was evident during a King tide condition in 2017, where tidal waters were overtopping inlets connected to an outfall that had a backflow preventer. Therefore, existing pipes to remaining will need to be lined to maintain a watertight system to prevent groundwater intrusion into the new drainage system.

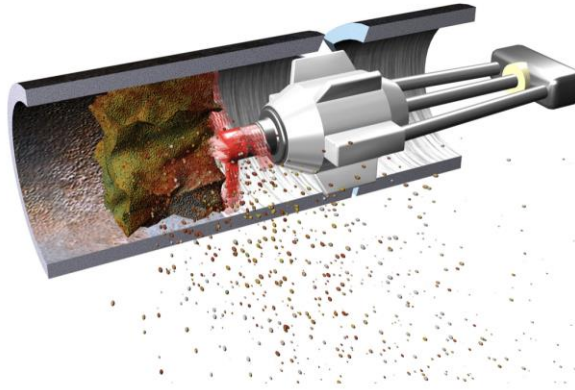
The recommended most cost-effective method to line the existing pipes to remain is via cured in place pipe (CIPP) pipe lining. CIPP lining is a technology that can save money on re-piping costs by reducing the need for an entirely new drainage pipe to be replaced or installed. The CIPP liner will provide a smooth wall with equal to less roughness to reinforced concrete pipe. However, once the liner is cured, it will typically reduce the diameter of the pipe by approximately two (2) inches.

CIPP lining process involves hydro jetting cleaning of the pipe to be lined, preceded by a camera inspection to locate problems and obstructions. Once the pipe is cleaned and pipe problems are identified, the lining process begins. The CIPP process uses an epoxy-based sleeve that is installed into the old pipe. The sleeve is inserted into the old pipe

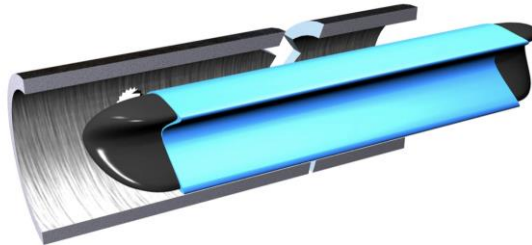
using a pull-in-place method, and once inflated, it is pushed into the pipe and allowed to seal off all holes and leaks. Then the epoxy dries, hardens, and the pipe is now watertight. **Figure 8-6** shows a graphic representation of the CIPP pipe lining process.



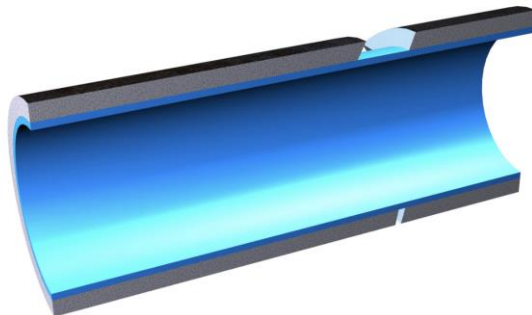
First, a SPT sewer camera reveals the waste buildup, breach, or possible root intrusion.



Then, a pneumatic cleaning tool cleans the pipe internally.



Next, a CIPP liner is pulled into place and the bladder is inflated.



After curing, the CIPP lining product is a structural "pipe within the original pipe."

Figure 8-6: CIPP lining process

8.8 Pollution Control Structures

Pollution control structures, such as CDS or Vortech units, are used to treat stormwater runoff in urban areas with limited right-of-way and/or poor soil infiltration rates. The units remove floatables, oil/grease, and reduce the total suspended solids (TSS) of the runoff prior to discharging to a waterbody or stormwater pump station wet well. The units do not reduce the total volume of water discharged to the outfall. Pollution control structures can be designed as in-line or offline structures. Offline control structures allow for the bypass of the system during large flow events while still providing the required treatment volume. Units are designed to handle peak flow events. The pollution control structures suggested for this project are comprised of an inlet, diversion weir, offline Vortech unit, baffle, and outlet. The purpose of this control box is to remove floatable pollution before dispersing the water to the pump station where it undergoes further pollution reduction before exiting into a nearby canal or, in this case, intracoastal. This reduces the required maintenance needs of the receiving water body and improves the quality of stormwater discharges into the water body.

Further analysis of these structures will be made during the design phase. **Figure 8-7** shows a schematic of the components of a vortex structure.

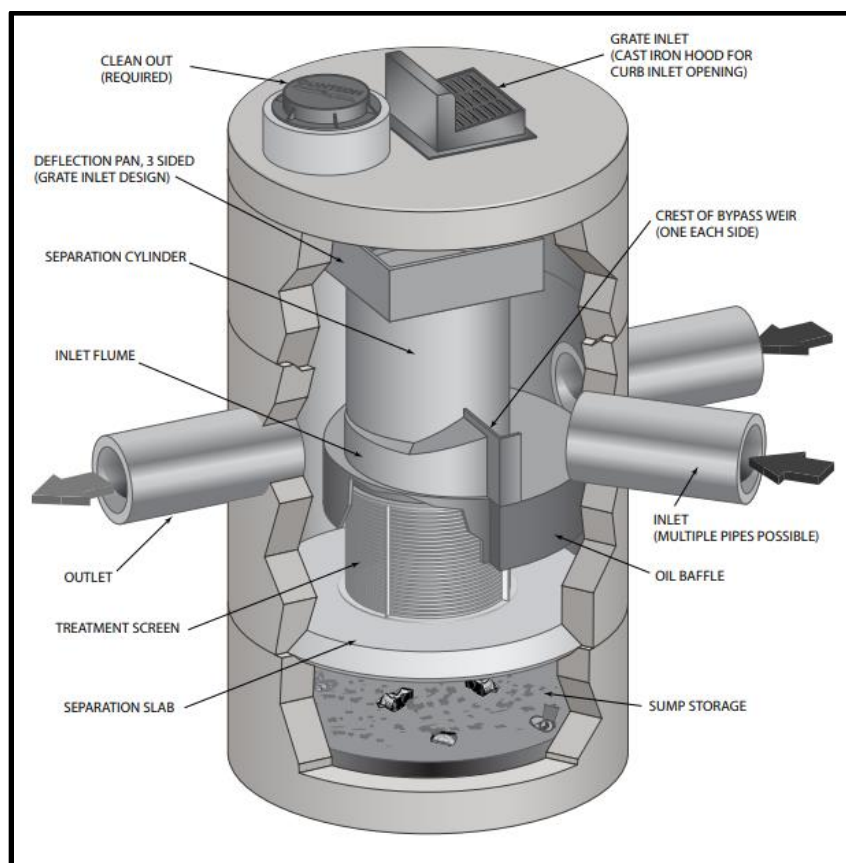


Figure 8-7: Vortex Pollution Control Structure Schematic

8.9 Raised Crown of Road

The current roadway system in the City of Delray has areas within the City where the crown of road is well below current tidal conditions and projected 30-year sea level elevations. These low elevations cause areas to experience extreme flooding during high tide events without rainfall (“sunny day flooding”). Areas closer to the intracoastal show drastically more flooding due to its close proximity to sea level. To reduce large amounts of flooding it is important to route the water from areas at high elevations to areas of low elevations where inlets to drainage structures can be found. By increasing the road crown and placing inlets on either side of the road, flooding can be routed from low lying elevations to the main trunk line where it will eventually be pumped out into the intracoastal through the proposed stormwater pump station explained above. Standard City grates and inlets will be located on both sides of the road to divert the water into an 18” pipe that is connected to a central trunk line of various dimensions depending on the current level of flooding in the area. A manhole connecting the structures allows for easier maintenance access. Further pipe sizing will be done during the design phase. **Figure 8-8** shows a profile of a typical raised crown of road and the added drainage. **Appendix 8A** also shows this detail.

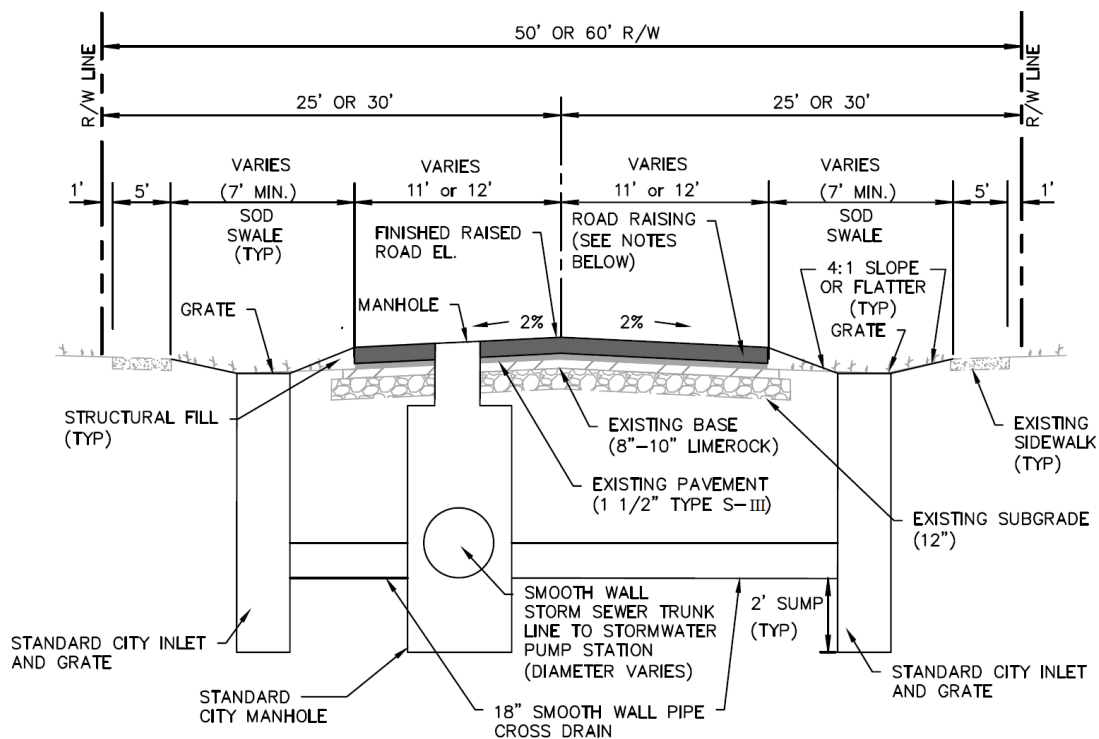


Figure 8-8: Raised Crown of Road and Added Drainage Profile

8.10 Capital Improvement Projects

8.10.1 General

As a starting point for formulating capital improvement projects as part of this project, the previous Stormwater Masterplans written by Mock, Roos, & Associates (1991), and Kimley Horn and Associates (2000) were reviewed. **Table 8-2** describes the stormwater pump stations recommended by these studies as well as the pump stations as they currently exist in the City. The suggested improvements from these prior master plans were implemented or upsized within the modeling to determine the needed capital improvement projects to mitigate the currently projected 30-year sea level and groundwater rise conditions.

Table 8-2: Existing and Previously Proposed Pump Stations

Pump Station Name	Problem Area	Prior Masterplan-Suggested Flow Capacity (gpm)	Current (As-Built) Flow Capacity (gpm)
Harbor Drive	1	5,000	-----
Beach Drive	2	4,500	3,000
Seaspray Avenue	2	4,500	-----
Waterway Lane	3	4,000	3,000
Thomas Street	4	36,000	19,000
Basin Drive	4	-----	3,000
Atlantic Avenue	5	13,000	10,000
Miramar Drive	5	8,000	-----
Bay Street	6	10,000	3,000
Bauhinia Road	7	13,000	-----
Seasage Drive	7	-----	5,000
Brooks Lane	9	2,500	-----
White Drive	9	2,500	-----

The first step to modeling the proposed capital improvements projects needed was to add to the models any pump capacity that was not built, but that was recommended by previous master plans. Then, iterations of capital improvements were performed by increasing pump capacity's, increasing pipe sizes, expanding the pipe network, and adding exfiltration trenches to accommodate the projected 30-year sea level and groundwater rise. These iterations of increasing the stormwater infrastructure capacity were performed until road flooding was reduced to 1 foot of flooding or less, and until structural flooding was eliminated as much as feasible. It was assumed that in locations with road flooding less than or equal to 1-foot of flooding, that roads could be raised to eliminate road flooding. In other words, in locations with 0.25 feet of flooding, roads would be raised by 0.25 feet, and the LOS FPSS would be reduced to 0; in locations of 0.5 feet of flooding, roads would be raised by 0.5 feet, and the LOS FPSS would be reduced to 0; and so-on.

In several locations, structure flood criteria could not be met by increasing infrastructure capacity's within the model without becoming cost-prohibitive. Therefore, LOS FPSS is not reduced to zero in all problem areas.

The proposed capital improvements projects conceptual designs required to mitigate a 30-year sea level and ground water rise are included in **Appendix 8B**. It is assumed that all seawalls have been raised by the City and private residents, and all private outfalls have been retrofitted with backflow prevention devices. The following sections outlined the proposed capital improvement projects for each of the problem areas and flood protection benefits to mitigate the projected 30-year sea level and groundwater rise.

8.11 Problem Area 1

Problem Area 1 was defined by the City due to a drainage complaint on Harbor Drive. The City attributed the flooding in that location to tidal backflow. There is no existing pump station in Problem Area 1, and drainage system is currently undersized to handle stormwater runoff and tidal backflows for the 30-year Sea Level Rise scenario flooding.

8.11.1 Stormwater Management Elements and Conceptual Design

Reduction of modeled flooding within Problem Area 1 is accomplished with added pipes, backflow preventers and inlets, increased pipe sizes, raised seawalls along the intracoastal, raised road elevations and a proposed pump station. **Figure 8-9** shows the details of the proposed capital improvements within Problem Area 1. The Problem Area 1 pump station is located on Harbor Drive and has a total capacity of 40,000 GPM (two 20,000 GPM pumps). See **Section 8.25** for the unit and cost breakdowns of the improvements and **Appendix 8A** for the pump station schematic.

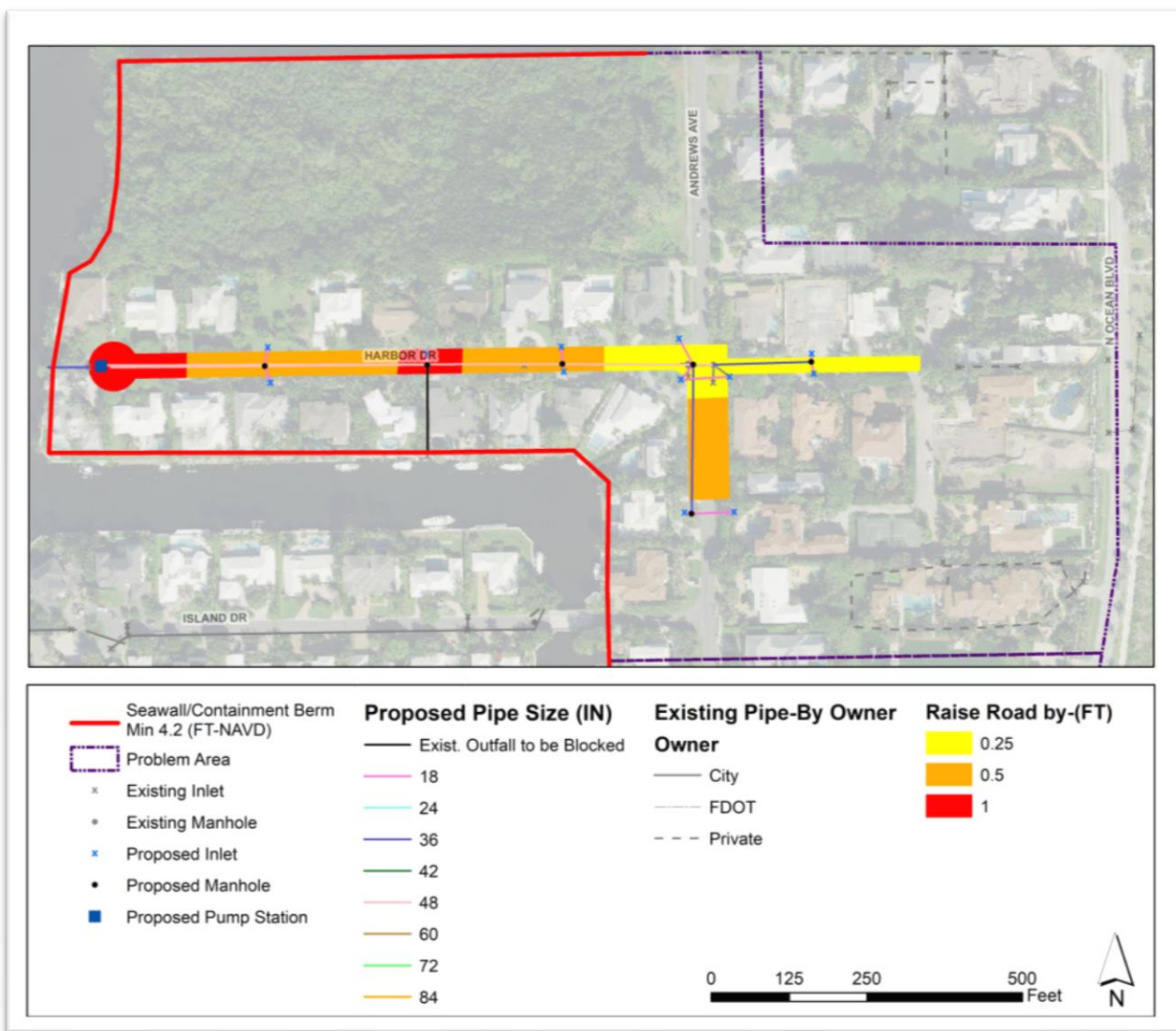


Figure 8-9: Proposed Capital Improvements for Problem Area 1

8.11.2 Flood Reduction Benefits

The infrastructure improvements within Problem Area 1 are predicted to reduce the FPSS to 0 in the sub-basin. No City-road centerlines had flooding greater than 0.25 feet and no structures showed flooding with the implementation of the proposed improvements within the model. The FPSS was reduced by 100% from the 30-year Sea Level Rise (SLR) scenario. **Appendix 8C** describes the detailed FPSS calculations. **Figure 8-10** is included to show differences in flooding before and after infrastructure improvements for the 30-Year Sea Level Rise Scenario and 100-year design storm event.

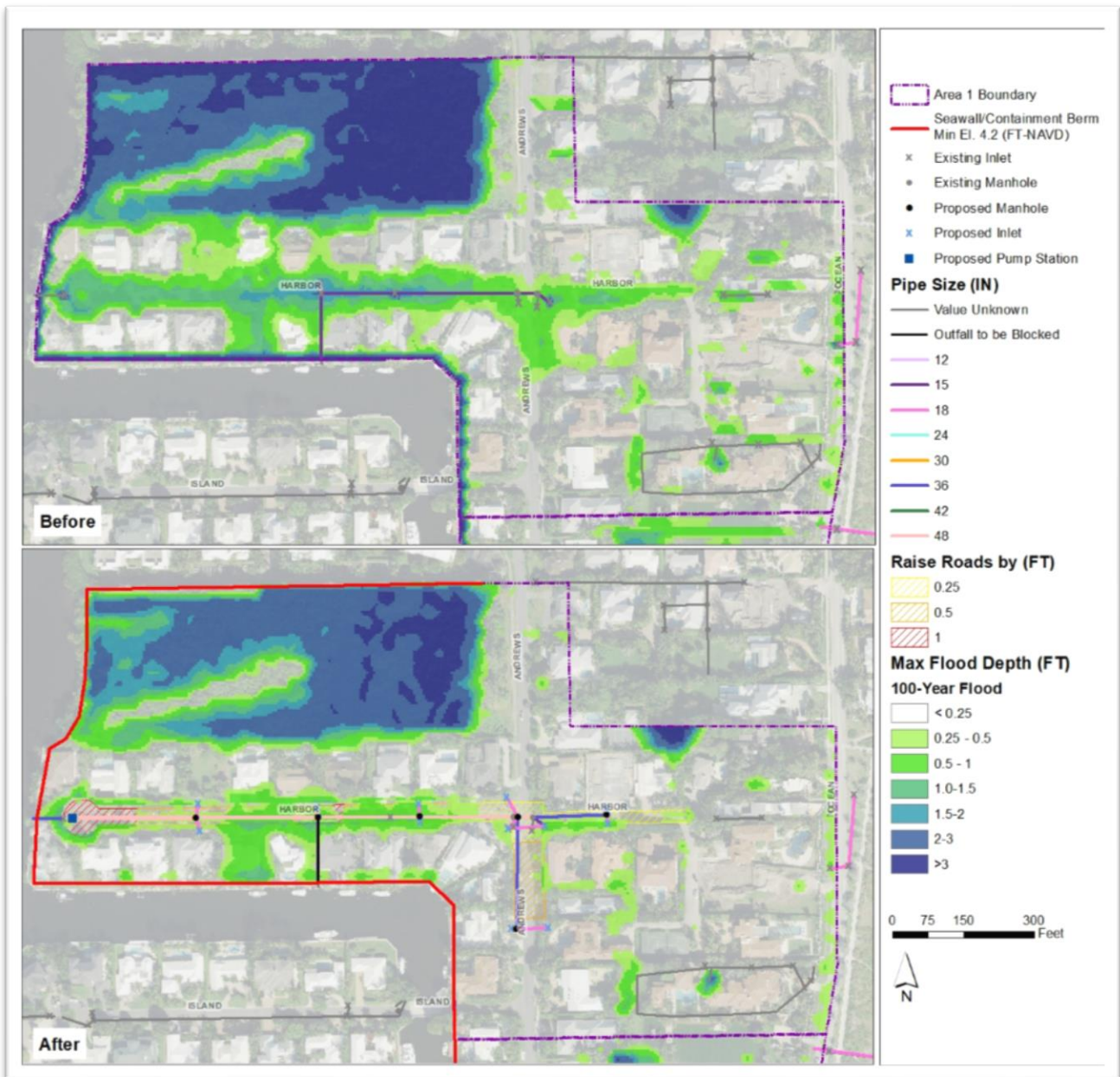


Figure 8-10: 100-Year Flood Depth Before and After Proposed Area 1 Capital Improvement Infrastructure

8.12 Problem Area 2

Problem Area 2 was defined by the City due to a drainage complaint at/near 117 Seaspray Avenue. There is an existing Beach Drive Pump Station, but the existing capacity and connecting pipes are undersized to carry stormwater for the 30-year Sea Level Rise scenario flooding.

8.12.1 Stormwater Management Elements and Conceptual Design

Reduction of modeled flooding within Problem Area 2 is accomplished with added pipes, backflow preventers and inlets, increased pipe sizes, raised seawalls along the intracoastal, raised road elevations and a proposed pump station. **Figure 8-11** shows the details of the proposed capital improvements within Problem Area 2. The Problem Area 2 pump station is located on Beach Drive and has a total capacity of 40,000 GPM (two 20,000 GPM pumps). See **Section 8.25** for the unit and cost breakdowns of the improvements and **Appendix 8A** for the pump station schematic.

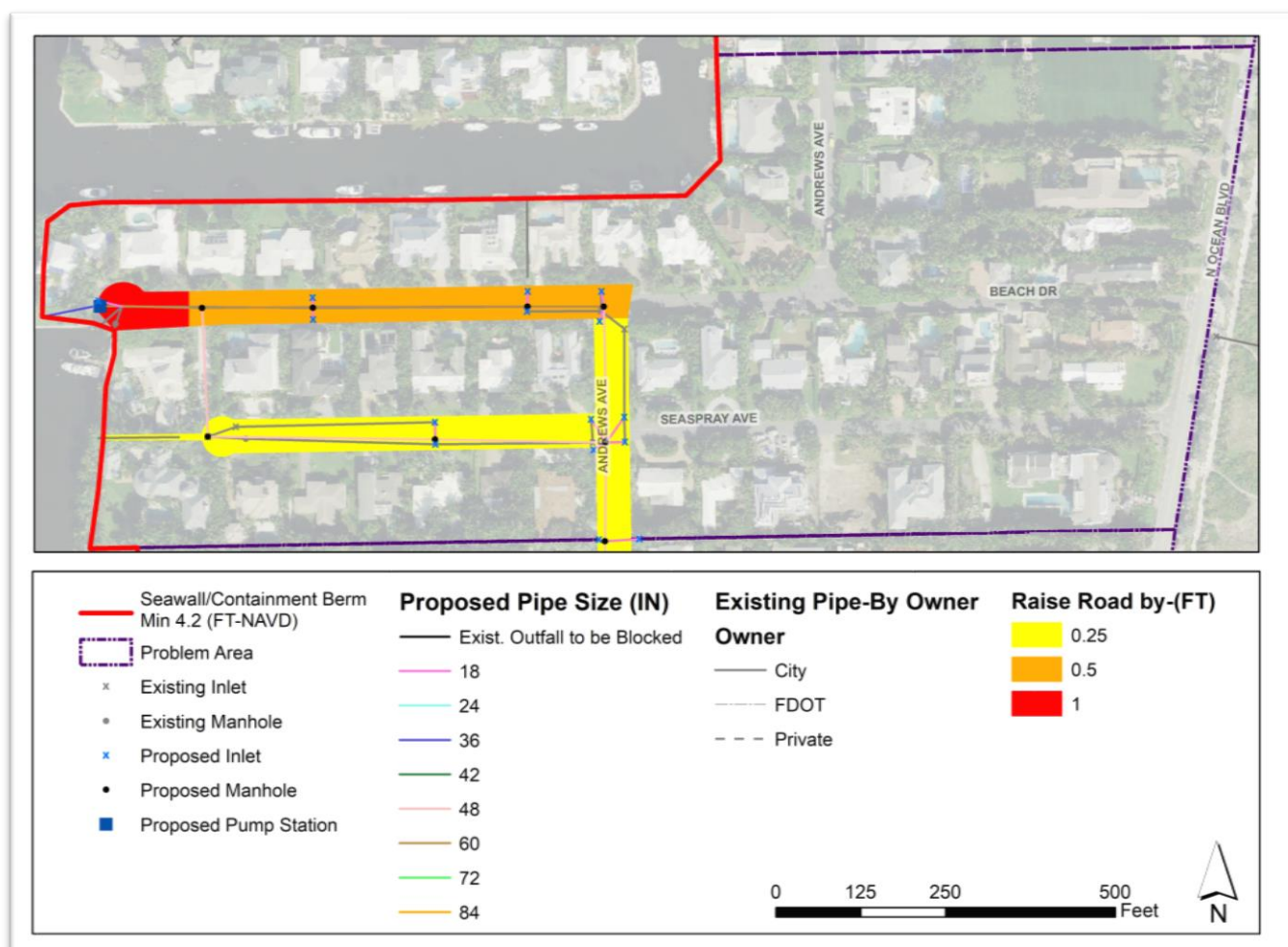


Figure 8-11: Proposed Capital Improvements for Problem Area 2

8.12.2 Flood Reduction Benefits

The infrastructure improvements within Problem Area 2 are predicted to reduce the FPSS to 0 in the sub-basin. No city-road centerlines had flooding greater than 0.25 feet and no structures showed flooding with the implementation of the proposed improvements within the model. The FPSS was reduced by 100% from the 30-year Sea Level Rise (SLR) scenario. **Appendix 8C** describes the detailed FPSS calculations. **Figure 8-12** is included to show differences in flooding before and after infrastructure improvements for the 30-Year Sea Level Rise Scenario and 100-year design storm event.

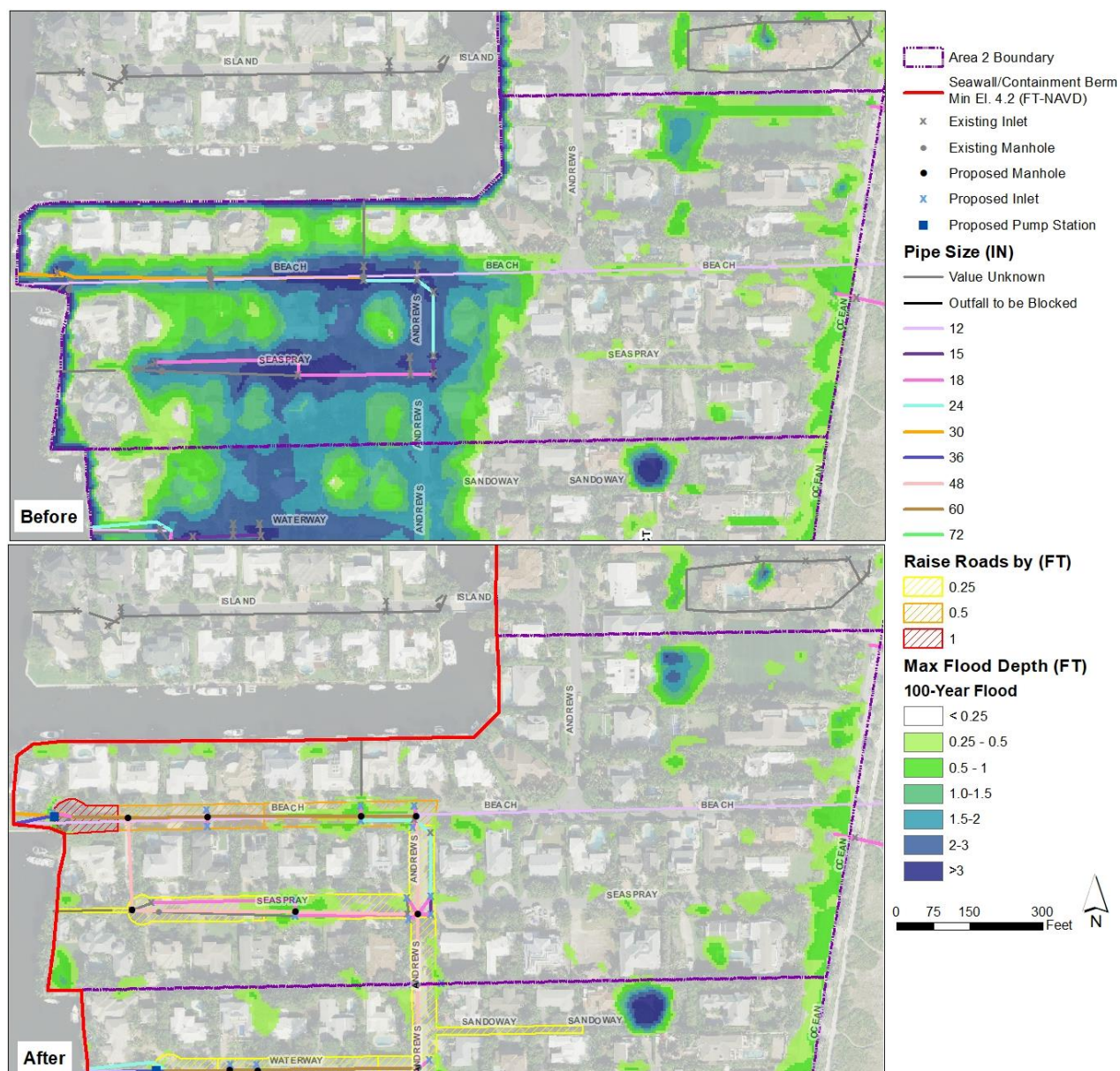


Figure 8-12: 100-Year Flood Depth Before and After Proposed Area 2 Capital Improvement Infrastructure

8.13 Problem Area 3

Problem Area 3 was defined by the City due to a drainage complaint at 326 Sandpiper Lane. It was suspected that the neighboring property altered their landscape, filled areas and removed drainage features. There is an existing pump station on Waterway Lane, but it is undersized and drainage does not extend far enough east to collect water near the drainage complaint and to carry stormwater for the 30-year Sea Level Rise scenario flooding.

8.13.1 Stormwater Management Elements and Conceptual Design

Reduction of modeled flooding within Problem Area 3 is accomplished with added pipes, backflow preventers and inlets, increased pipe sizes, raised seawalls along the intracoastal, raised road elevations and a proposed pump station. **Figure 8-13** shows the details of the proposed capital improvements within Problem Area 3. The Problem Area 3 pump station is located on Waterway Lane and has a total capacity of 80,000 GPM (two 40,000 GPM pumps). See **Section 8.25** for the unit and cost breakdowns of the improvements and **Appendix 8A** for the pump station schematic.

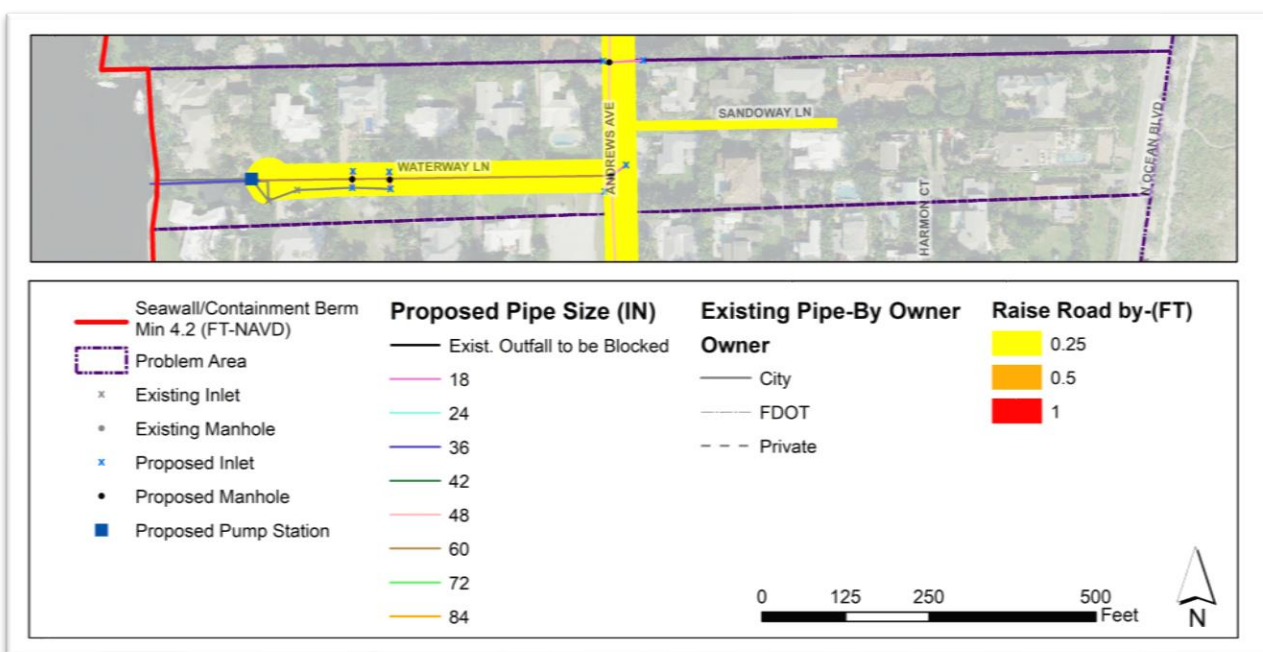


Figure 8-13: Proposed Capital Improvements for Problem Area 3

8.13.2 Flood Reduction Benefits

The infrastructure improvements within Problem Area 3 are predicted to reduce the FPSS to 0 in the sub-basin. No city-road centerlines had flooding greater than 0.25 feet and no structures showed flooding with the implementation of the proposed improvements within the model. The FPSS was reduced by 100% from the 30-year Sea Level Rise (SLR)

scenario. **Appendix 8C** describes the detailed FPSS calculations. **Figure 8-14** is included to show differences in flooding before and after infrastructure improvements for the 30-Year Sea Level Rise Scenario and 100-year design storm event.

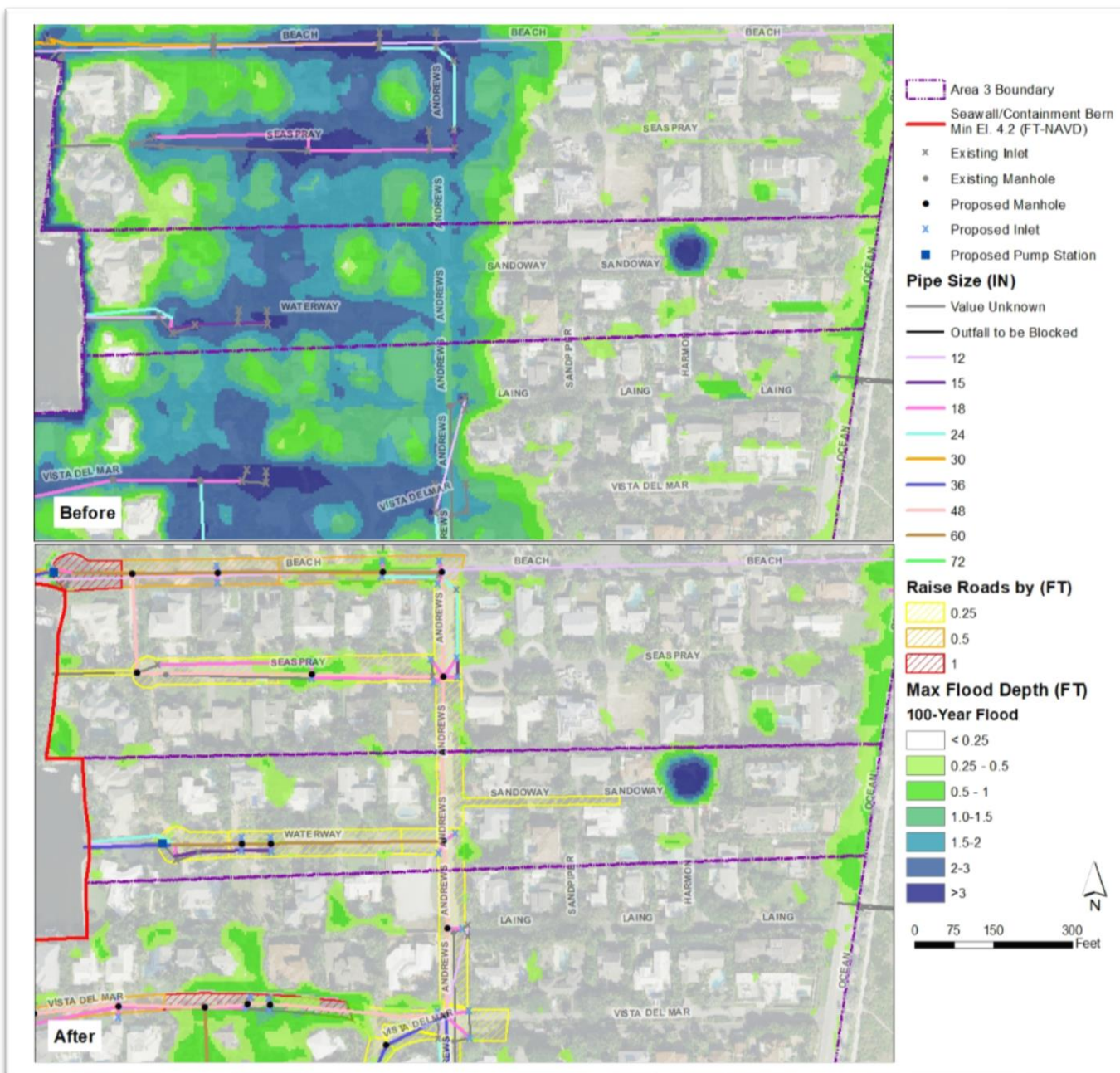


Figure 8-14: 100-Year Flood Depth Before and After Proposed Area 3 Capital Improvement Infrastructure

8.14 Problem Area 4

Problem Area 4 was defined by the City due to a drainage complaint of street flooding on Luke Lane. There are existing pump stations on Thomas Street and Basin Drive, but the capacities of the pump stations and the connecting pipes are undersized to carry stormwater for the 30-year Sea Level Rise scenario flooding.

8.14.1 Stormwater Management Elements and Conceptual Design

Reduction of modeled flooding within Problem Area 4 is accomplished with added pipes, backflow preventers and inlets, increased pipe sizes, raised seawalls along the intracoastal, raised road elevations and a proposed pump station. **Figure 8-15** shows the details of the proposed capital improvements within Problem Area 4. The Problem Area 4 pump station is located on Thomas Street and has a total capacity of 80,000 GPM (two 40,000 GPM pumps). Also included in Problem Area 4 are improvements to the Basin Drive Pump Station basin. The Basin Drive Pump station was upsized to a total capacity of 80,000 GPM (two 40,000 GPM pumps) and infrastructure was added to connect the Basin Drive Pump Station to the Thomas Street Pump station to alleviate some of the flooding in the area. See **Section 8.25** for the unit and cost breakdowns of the improvements and **Appendix 8A** for the pump station schematic.

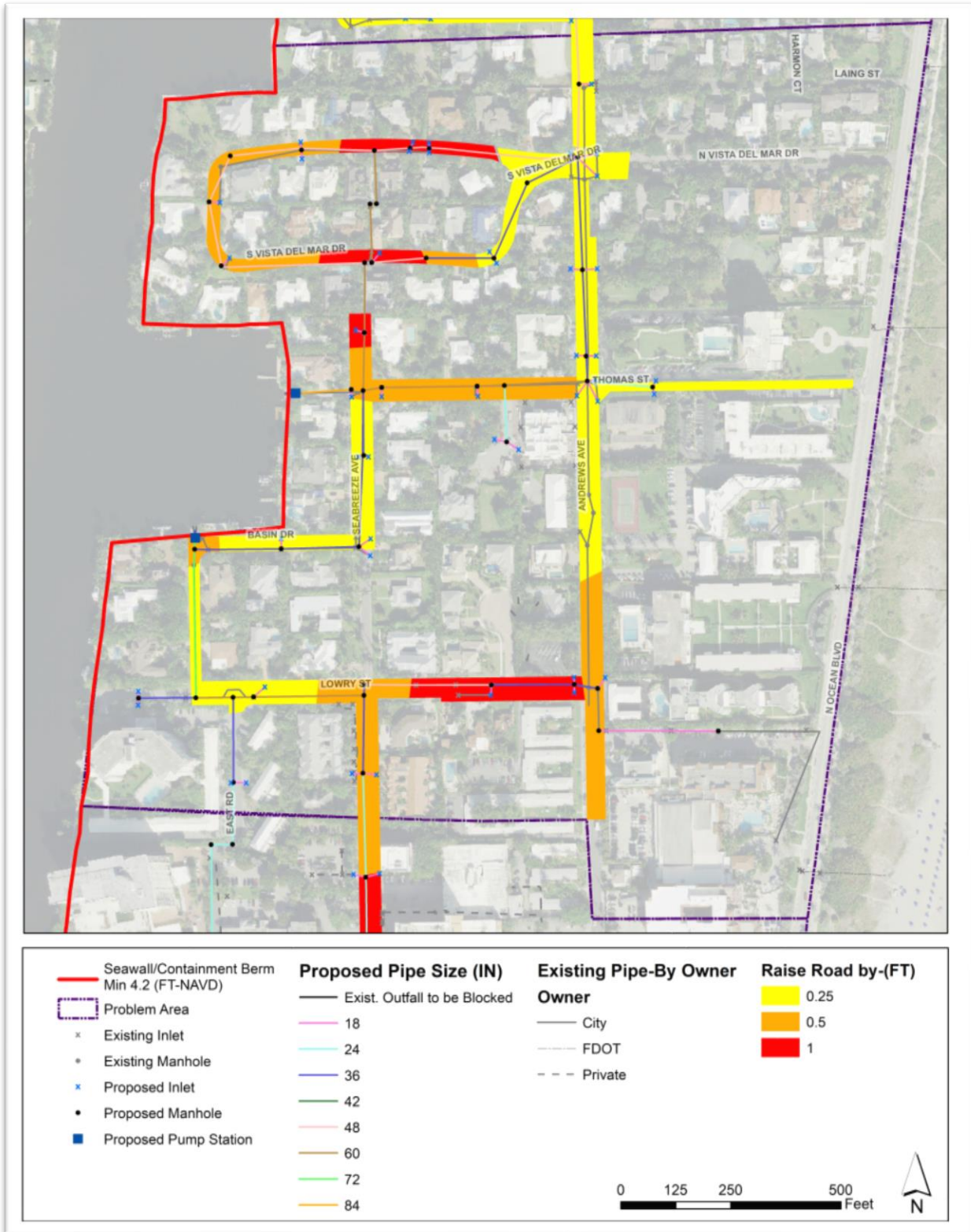


Figure 8-15: Proposed Capital Improvements for Problem Area 4

8.14.2 Flood Reduction Benefits

The infrastructure improvements within Problem Area 4 are predicted to reduce the FPSS from 1181 to 12 with the 30-year sea level rise and groundwater conditions. This is a 99% reduction in FPSS from the previous 30-year SLR scenario that was modeled without improvements. **Appendix 8C** describes the detailed FPSS calculations. A minor section of city-road centerline had flooding greater than 0.25 feet once improvements were modeled. The only city road to experience this flooding was Lowry Street. Three structures showed flooding after implementation of the proposed improvements within the model and all were located near Lowry Street and a private cul-de-sac where City-owned drainage was not extended in the proposed improvements. **Figure 8-16** details the roads and structures with LOS exceedance values. **Figure 8-17** is included to show differences in flooding before and after infrastructure improvements for the 30-Year Sea Level Rise Scenario and 100-year design storm event.

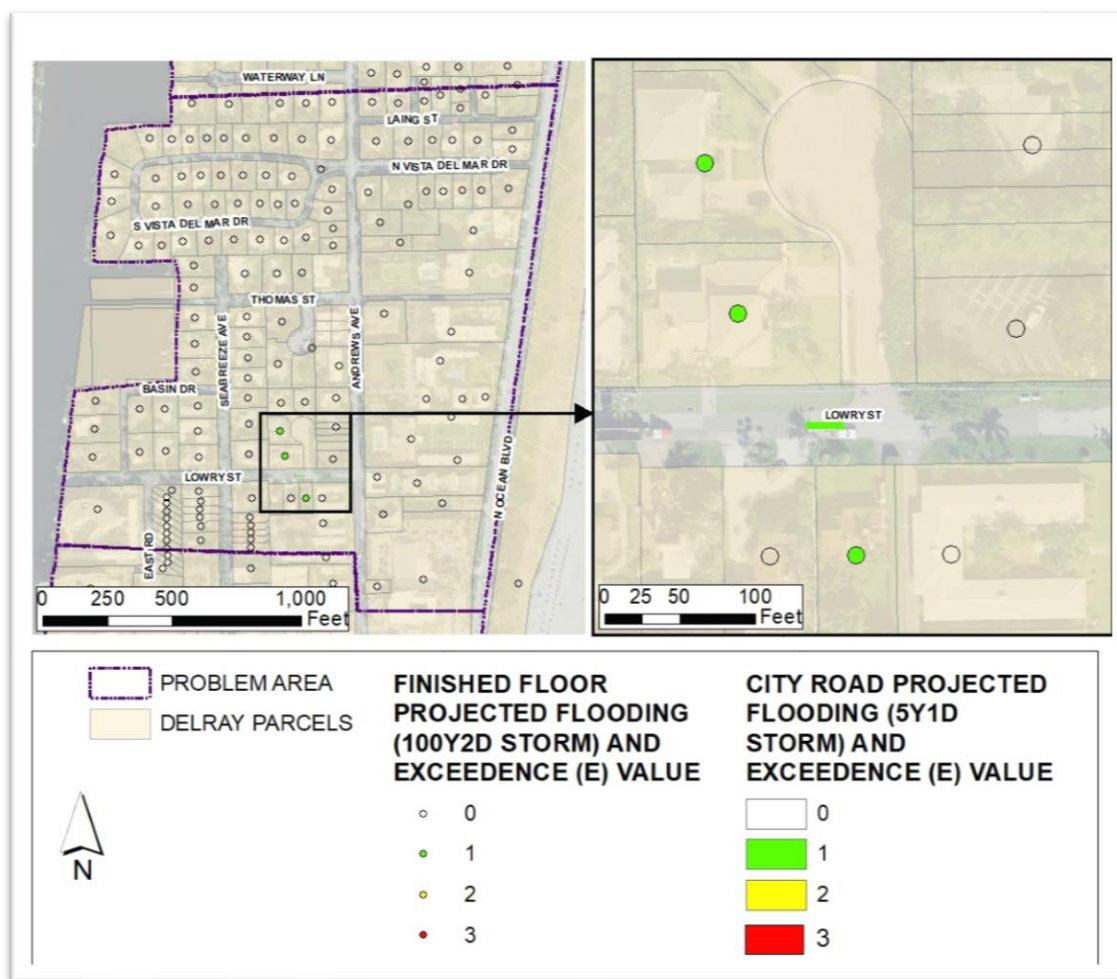


Figure 8-16: Level of Service Exceedance Values for Problem Area 4

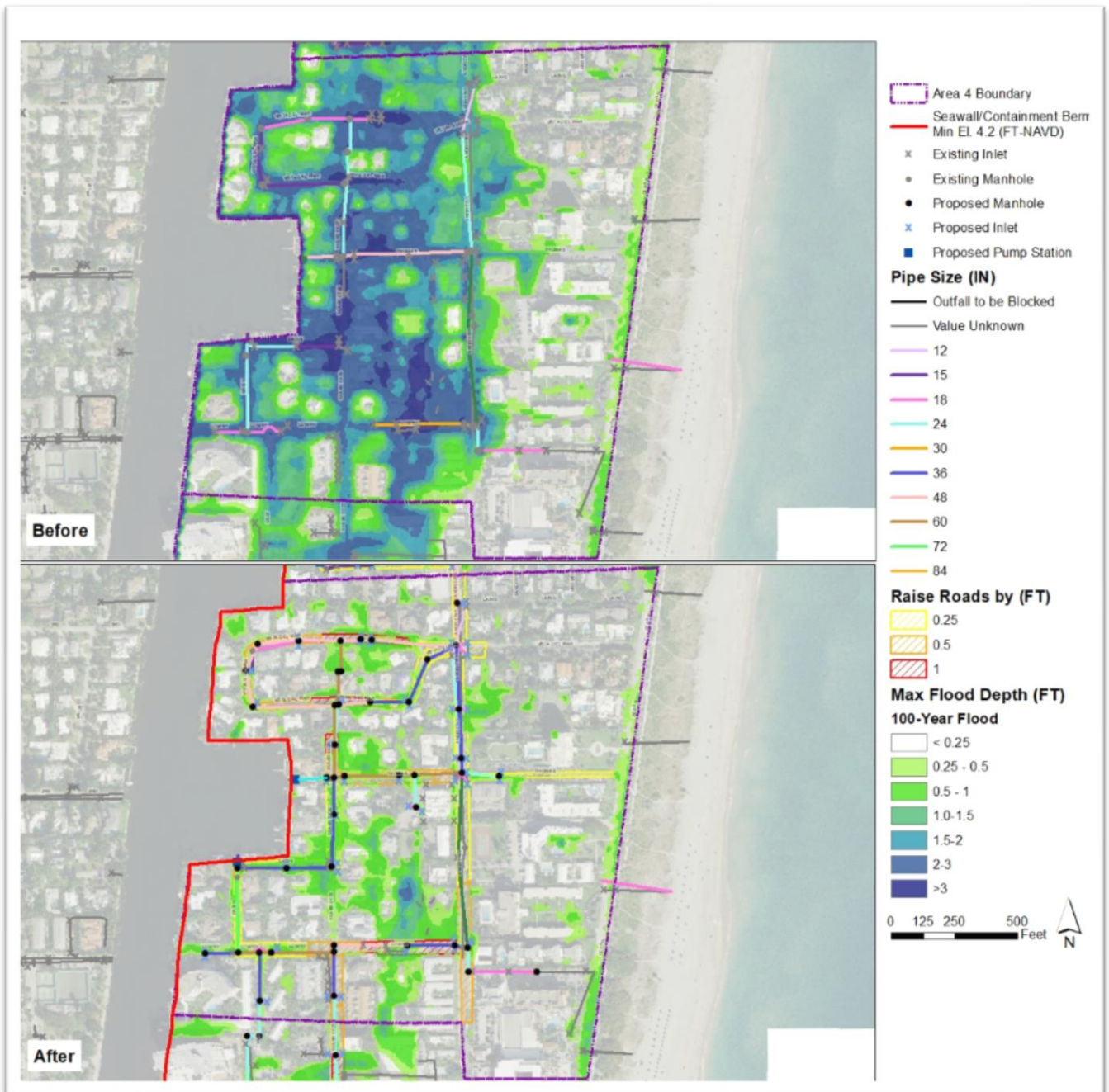


Figure 8-17: 100-Year Flood Depth Before and After Proposed Area 4 Capital Improvement Infrastructure

8.15 Problem Area 5

Problem Area 5 was included in the capital improvements assessment due to the fact that the City wanted the efficacy of the existing pump stations and their connecting infrastructure to be assessed. Pipes on Atlantic Avenue are not city-owned, but are connected to the Pump Station. These Atlantic Avenue pipes were not considered for the improvements.

8.15.1 Stormwater Management Elements and Conceptual Design

Reduction of modeled flooding within Problem Area 5 is accomplished with added pipes, backflow preventers and inlets, increased pipe sizes, raised seawalls along the intracoastal, raised road elevations and a proposed pump station. **Figure 8-18** shows the details of the proposed capital improvements within Problem Area 3. The Problem Area 3 pump station was historically called the Atlantic Avenue Pump station, but is located approximately 300 feet south of Atlantic Avenue. The proposed Atlantic Avenue Pump station has a total capacity of 80,000 GPM (two 40,000 GPM pumps). See **Section 8.25** for the unit and cost breakdowns of the improvements and **Appendix 8A** for the pump station schematic.

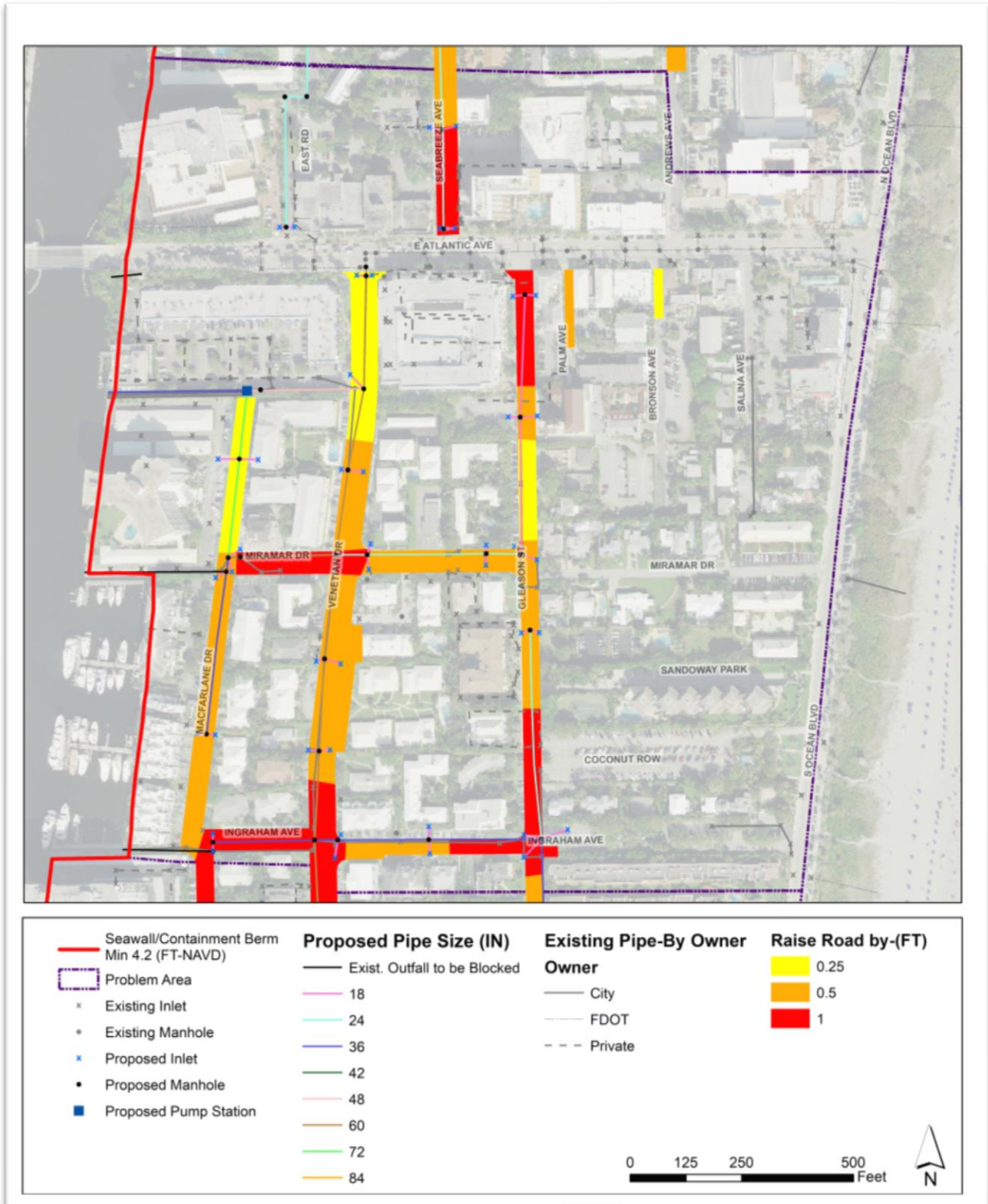


Figure 8-18: Proposed Capital Improvements for Problem Area 5

8.15.2 Flood Reduction Benefits

The infrastructure improvements within Problem Area 5 are predicted to reduce the FPSS from 872 to 12 with the 30-year sea level rise and groundwater conditions. This is a 99% reduction in FPSS from the previous 30-year SLR scenario that was modeled without improvements. Minor sections of city-road centerlines had flooding greater than 0.25 feet once improvements were modeled. The city roads which experienced this flooding were Gleason Street and Miramar Drive. Three structures showed flooding after implementation of the proposed improvements within the model. **Figure 8-19** details the roads and structures with LOS exceedance values. **Figure 8-20** is included to show differences in flooding before and after infrastructure improvements for the 30-Year Sea Level Rise Scenario and 100-year design storm event.

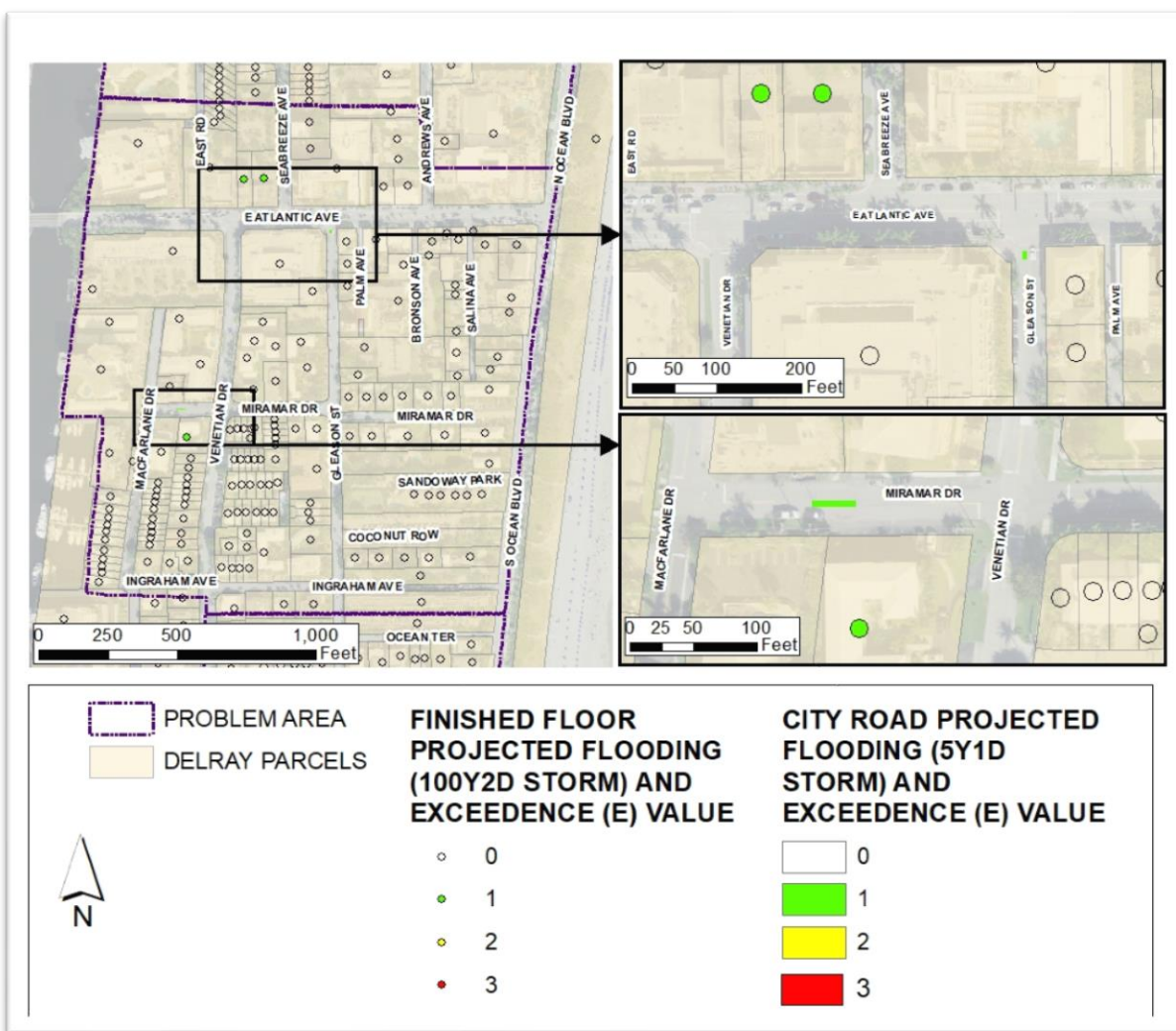


Figure 8-19: Level of Service Exceedance Values for Problem Area 5



Figure 8-20: 100-Year Flood Depth Before and After Proposed Area 5 Capital Improvement Infrastructure

8.16 Problem Area 6

Problem Area 6 was defined by the City due to a drainage complaint at/near 1104 Nassau Street and at the City-owned parking lot near Langer Way and Gleason Street. There is an existing Bay Street Pump Station but the existing capacity and connecting pipes are undersized to carry stormwater for the 30-year Sea Level Rise scenario flooding.

8.16.1 Stormwater Management Elements and Conceptual Design

Reduction of modeled flooding within Problem Area 6 is accomplished with added pipes, backflow preventers and inlets, increased pipe sizes, raised seawalls along the intracoastal, raised road elevations and a proposed pump station. **Figure 8-21** shows the details of the proposed capital improvements within Problem Area 6. The Problem Area 6 pump station is located on Bay Street and has a total capacity of 80,000 GPM (two 40,000 GPM pumps). To further alleviate flooding, pipes connect the Problem Area 6 Pump Station to the Problem Area 7 and Problem Area 5 Pump Stations. See **Section 8.25** for the unit and cost breakdowns of the improvements and **Appendix 8A** for the pump station schematic.

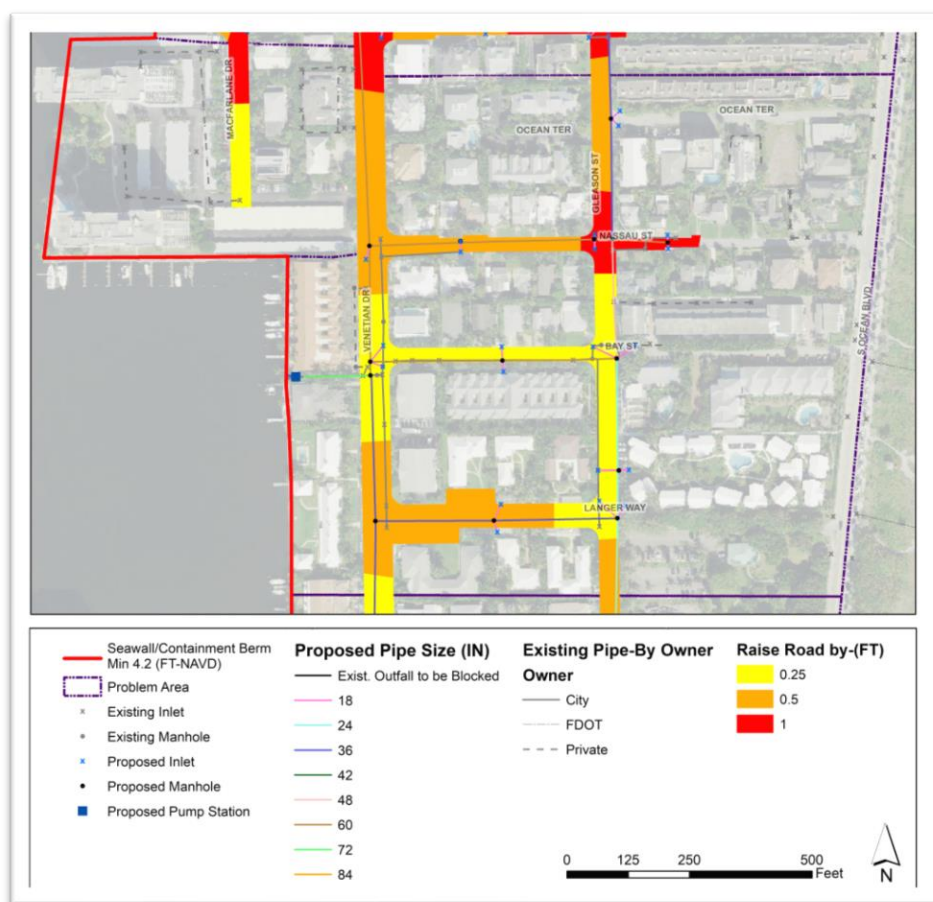


Figure 8-21: Proposed Capital Improvements for Problem Area 6

8.16.2 Flood Reduction Benefits

The infrastructure improvements within Problem Area 6 are predicted to reduce the FPSS from 388 to 24 with the 30-year sea level rise and groundwater conditions. This is a 94% reduction in FPSS from the previous 30-year SLR scenario that was modeled without improvements. **Appendix 8C** describes the detailed FPSS calculations. Minor sections of city-road centerlines had flooding greater than 0.25 feet once improvements were modeled. The only city road to experience this flooding was Nassau Street. Three structures showed flooding after implementation of the proposed improvements within the model and all were located on Nassau Street. **Figure 8-22** details the roads and structures with LOS exceedance values. **Figure 8-23** is included to show differences in flooding before and after infrastructure improvements for the 30-Year Sea Level Rise Scenario and 100-year design storm event.

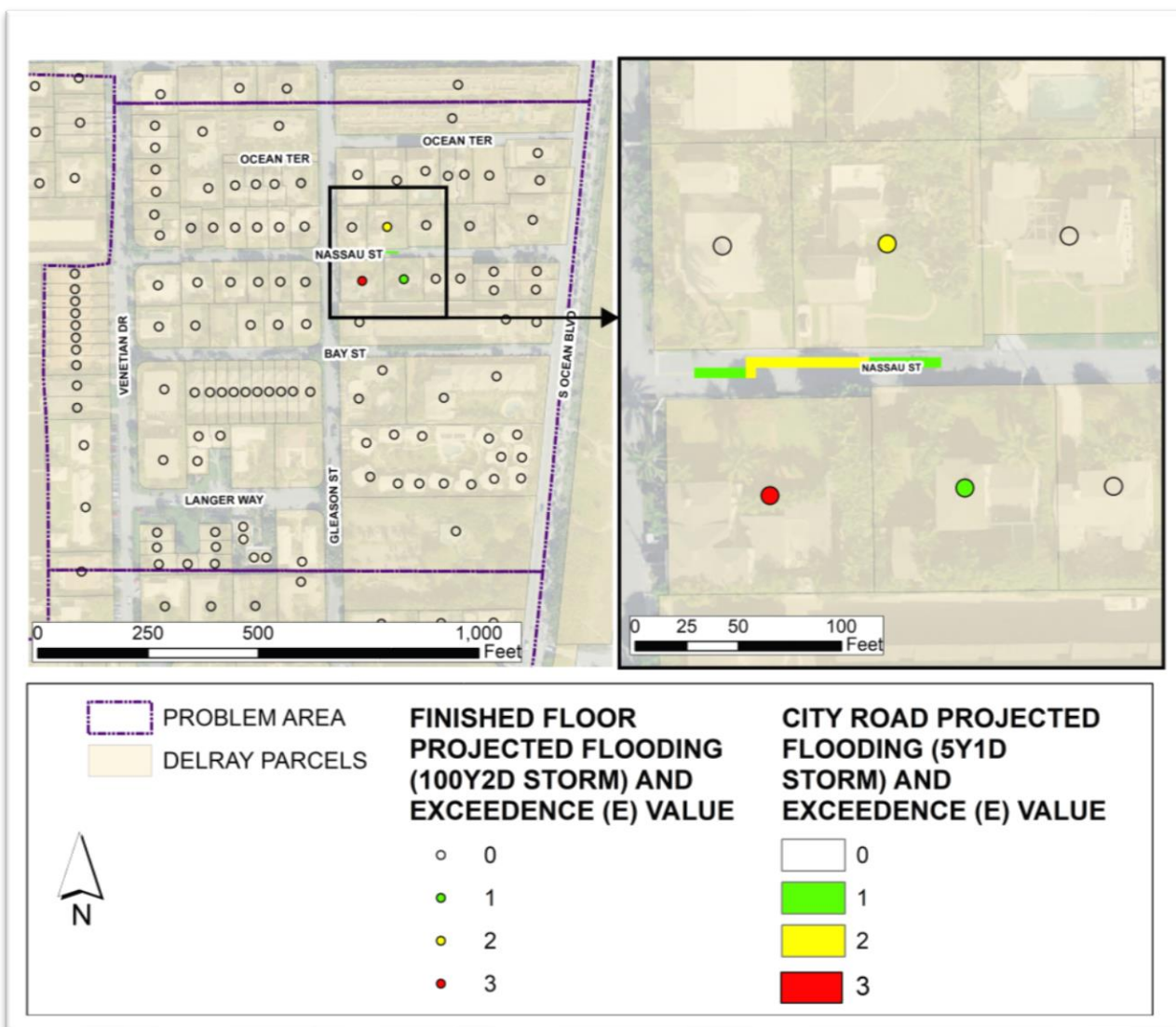


Figure 8-22: Level of Service Exceedance Value for Problem Area 6

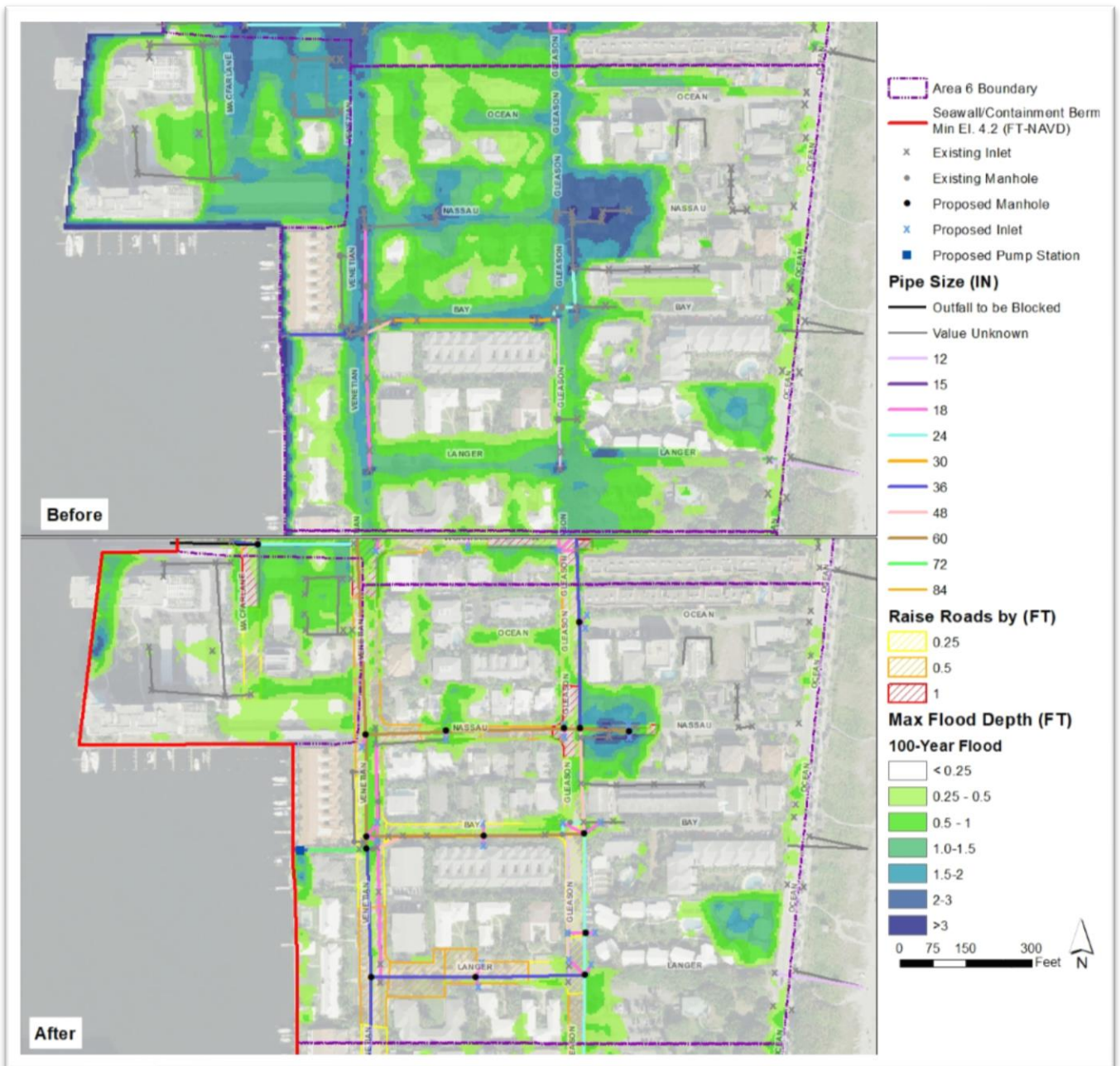


Figure 8-23: 100-Year Flood Depth Before and After Proposed Area 6 Capital Improvement Infrastructure

8.17 Problem Area 7

Problem Area 7 was defined by the City due to a drainage complaint at/near 1030 Melaluca Road. There is an existing Seasage Drive Pump Station but the existing capacity and connecting pipes are undersized to carry stormwater for the 30-year Sea Level Rise scenario flooding.

8.17.1 Stormwater Management Elements and Conceptual Design

Reduction of modeled flooding within Problem Area 7 is accomplished with added pipes, backflow preventers and inlets to the drainage network, increased pipe sizes, raised seawalls along the intracoastal, raising road elevations and proposed pump stations. **Figure 8-24** shows the details of the proposed capital improvements within Problem Area 7. The Problem Area 7 pump stations are located on Casuarina Road and Tamarind Road (Seasage Drive Pump Station). The Casuarina Road Pump Station has a total capacity of 40,000 GPM (two 20,000 GPM pumps) and the Tamarind Road/Seasage Drive Pump Station has a total capacity of 80,000 GPM (two 40,000 GPM pumps). Connectivity to the Problem Area 6 and Problem Area 8 pump stations is present to further alleviate flooding. See **Section 8.25** for the unit and cost breakdowns of the improvements and **Appendix 8A** for the pump station schematic.

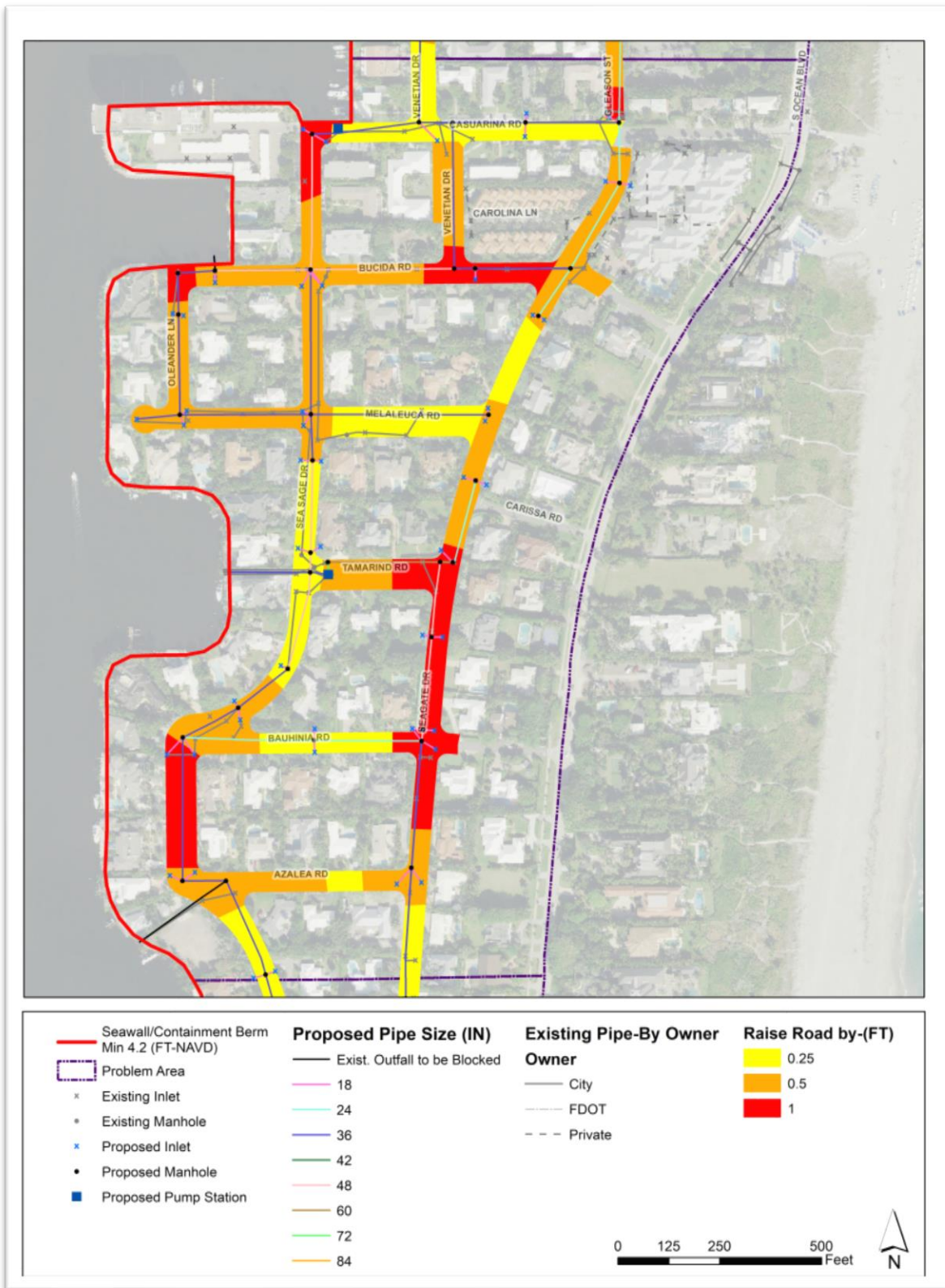


Figure 8-24: Proposed Capital Improvements for Problem Area 7

8.17.2 Flood Reduction Benefits

The infrastructure improvements within Problem Area 7 are predicted to reduce the FPSS to 0 in the sub-basin. No city-road centerlines had flooding greater than 0.25 feet and no structures showed flooding with the implementation of the proposed improvements within the model. Therefore, the FPSS was reduced by 100% from the 30-year Sea Level Rise (SLR) scenario. **Appendix 8C** describes the detailed FPSS calculations. **Figure 8-25** is included to show differences in flooding before and after infrastructure improvements for the 30-Year Sea Level Rise Scenario and 100-year design storm event.



Figure 8-25: 100-Year Flood Depth Before and After Proposed Area 7 Capital Improvement Infrastructure

8.18 Problem Area 8

Problem Area 8 was defined by the City due to a drainage complaint on Hibiscus Road. There is no existing pump station and the connecting pipes are undersized to carry stormwater for the 30-year Sea Level Rise scenario flooding.

8.18.1 Stormwater Management Elements and Conceptual Design

Reduction of modeled flooding within Problem Area 8 is accomplished with added pipes, backflow preventers and inlets, increased pipe sizes, raised seawalls along the intracoastal, raised road elevations and a proposed pump station. **Figure 8-26** shows the details of the proposed capital improvements within Problem Area 8. One Problem Area 8 pump station is located on Hibiscus Road and has a total capacity of 80,000 GPM (two 40,000 GPM pumps). To further alleviate flooding, pipes connect the Problem Area 8 Hibiscus Road Pump Station to the Problem Area 7 Pump Station. The second Problem Area 8 Pump Station is located on the peninsula of Lewis Cove Road and has a total capacity of 20,000 GPM (two 10,000 GPM pumps). See **Section 8.25** for the unit and cost breakdowns of the improvements and **Appendix 8A** for the pump station schematic.

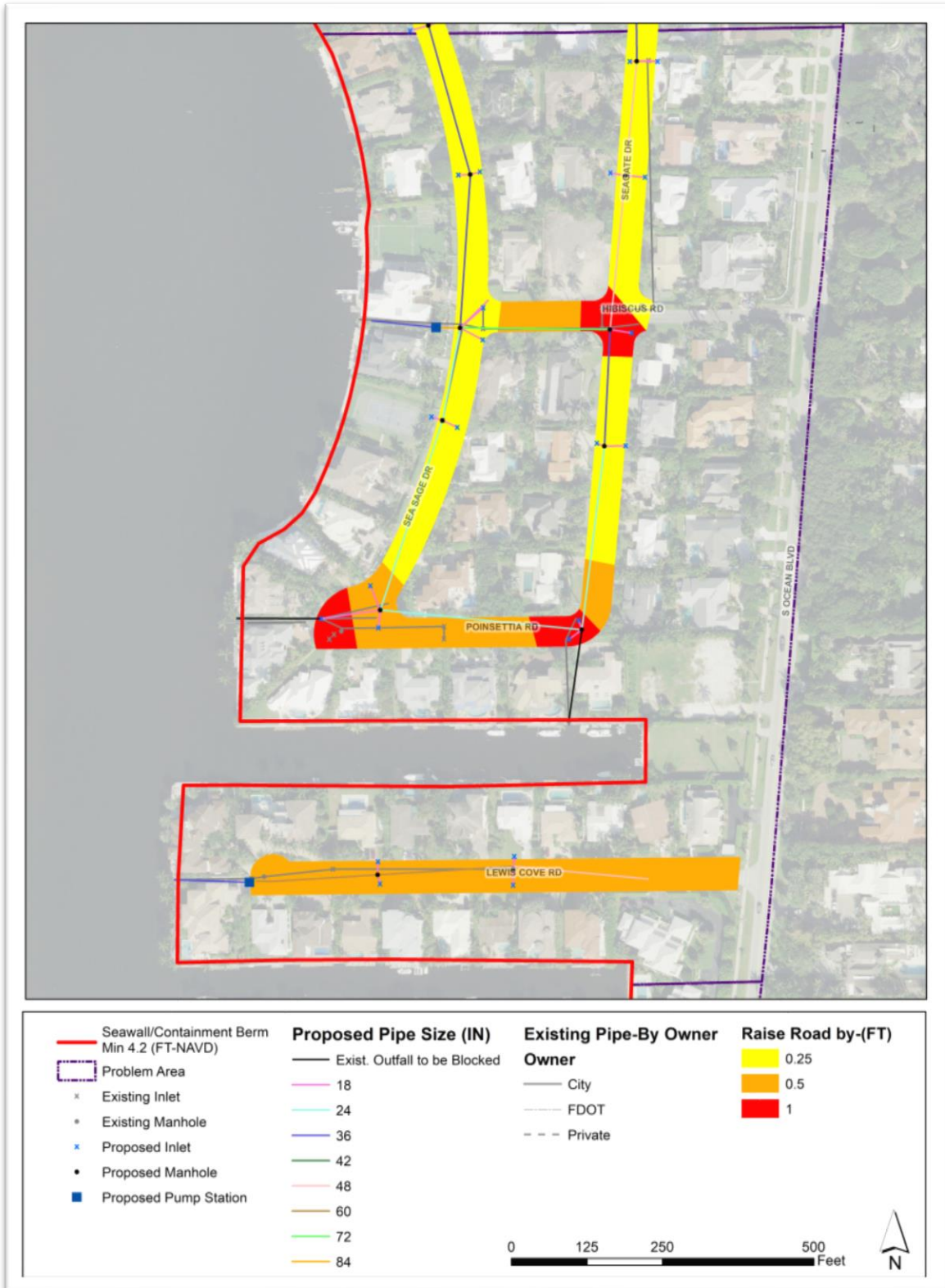


Figure 8-26: Proposed Capital Improvements for Problem Area 8

8.18.2 Flood Reduction Benefits

The infrastructure improvements within Problem Area 8 are predicted to reduce the FPSS to 0 in the sub-basin. No city-road centerlines had flooding greater than 0.25 feet and no structures showed flooding with the implementation of the proposed improvements within the model. Therefore, the FPSS was reduced by 100% from the 30-year SLR scenario. **Appendix 8C** describes the detailed FPSS calculations. **Figure 8-27** is included to show differences in flooding before and after infrastructure improvements for the 30-Year Sea Level Rise Scenario and 100-year design storm event.



Figure 8-27: 100-Year Flood Depth Before and After Proposed Area 8 Capital Improvement Infrastructure

8.19 Problem Area 9

Problem Area 9 was defined by the City due to a drainage complaint at/near 1004 Brooks Lane. There is no existing pump station and the existing outfalls in the model are not sufficient to carry stormwater for the 30-year Sea Level Rise scenario flooding.

8.19.1 Stormwater Management Elements and Conceptual Design

Reduction of modeled flooding within Problem Area 9 is accomplished with added pipes, backflow preventers and inlets, increased pipe sizes, raised seawalls along the intracoastal, raised road elevations and a proposed pump station. **Figure 8-28** shows the details of the proposed capital improvements within Problem Area 9. The Problem Area 9 pump stations are located on Brooks Lane and Rhodes Villa Lane. The proposed Brooks Lane Pump Station has a total capacity of 20,000 GPM (two 10,000 GPM pumps). The proposed Rhodes Villa Lane Pump Station has a total capacity of 40,000 GPM (two 20,000 GPM pumps) and is connected to the White Drive peninsula. See **Section 8.25** for the unit and cost breakdowns of the improvements and **Appendix 8A** for the pump station schematic.

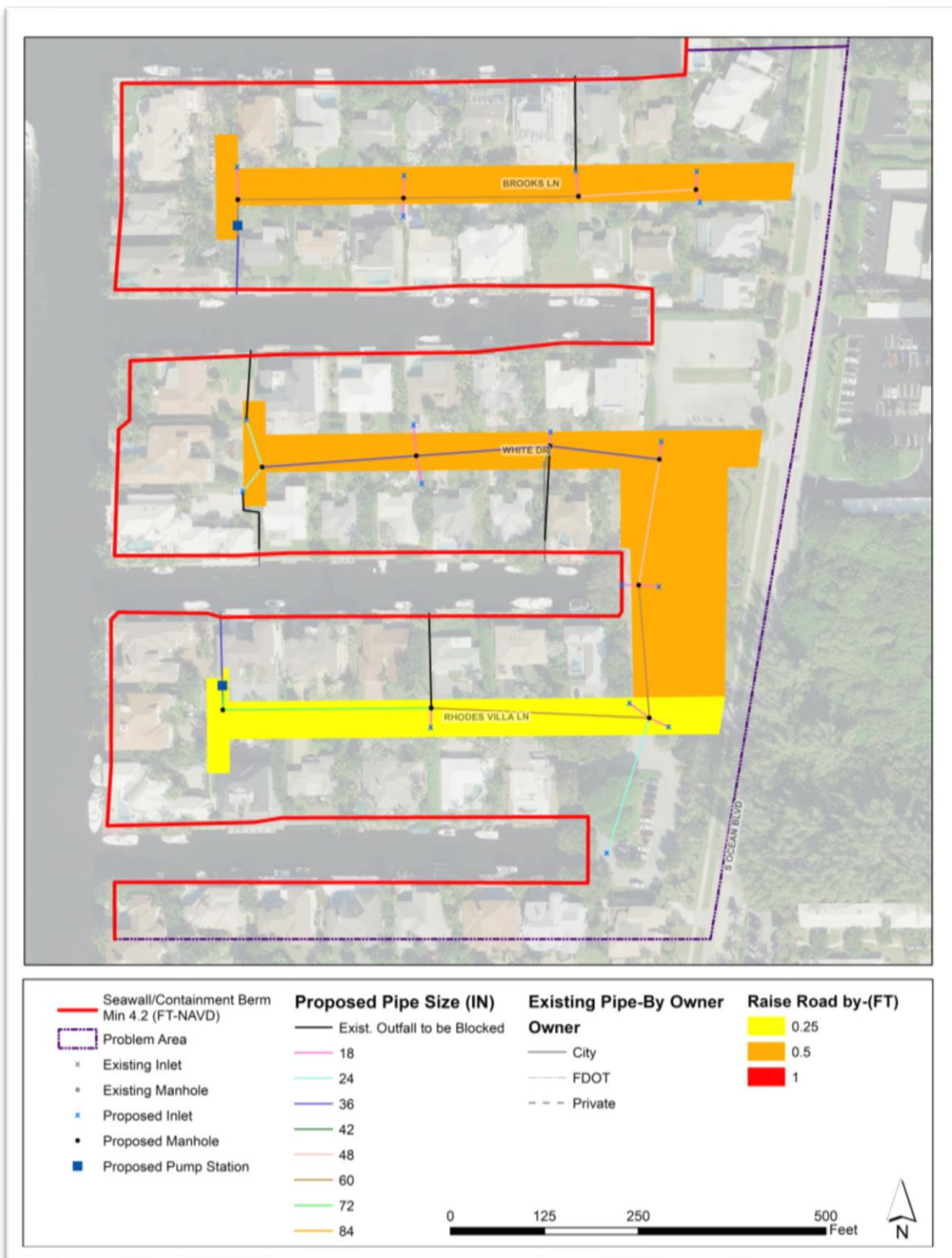


Figure 8-28: Proposed Capital Improvements for Problem Area 9

8.19.2 Flood Reduction Benefits

The infrastructure improvements within Problem Area 9 are predicted to reduce the FPSS to 0 in the sub-basin. No city-road centerlines had flooding greater than 0.25 feet and no structures showed flooding with the implementation of the proposed improvements within the model. Therefore, the FPSS was reduced by 100% from the 30-year Sea Level Rise (SLR) scenario. **Appendix 8C** describes the detailed FPSS calculations. **Figure 8-29** is included to show differences in flooding before and after infrastructure improvements for the 30-Year Sea Level Rise Scenario and 100-year design storm event.

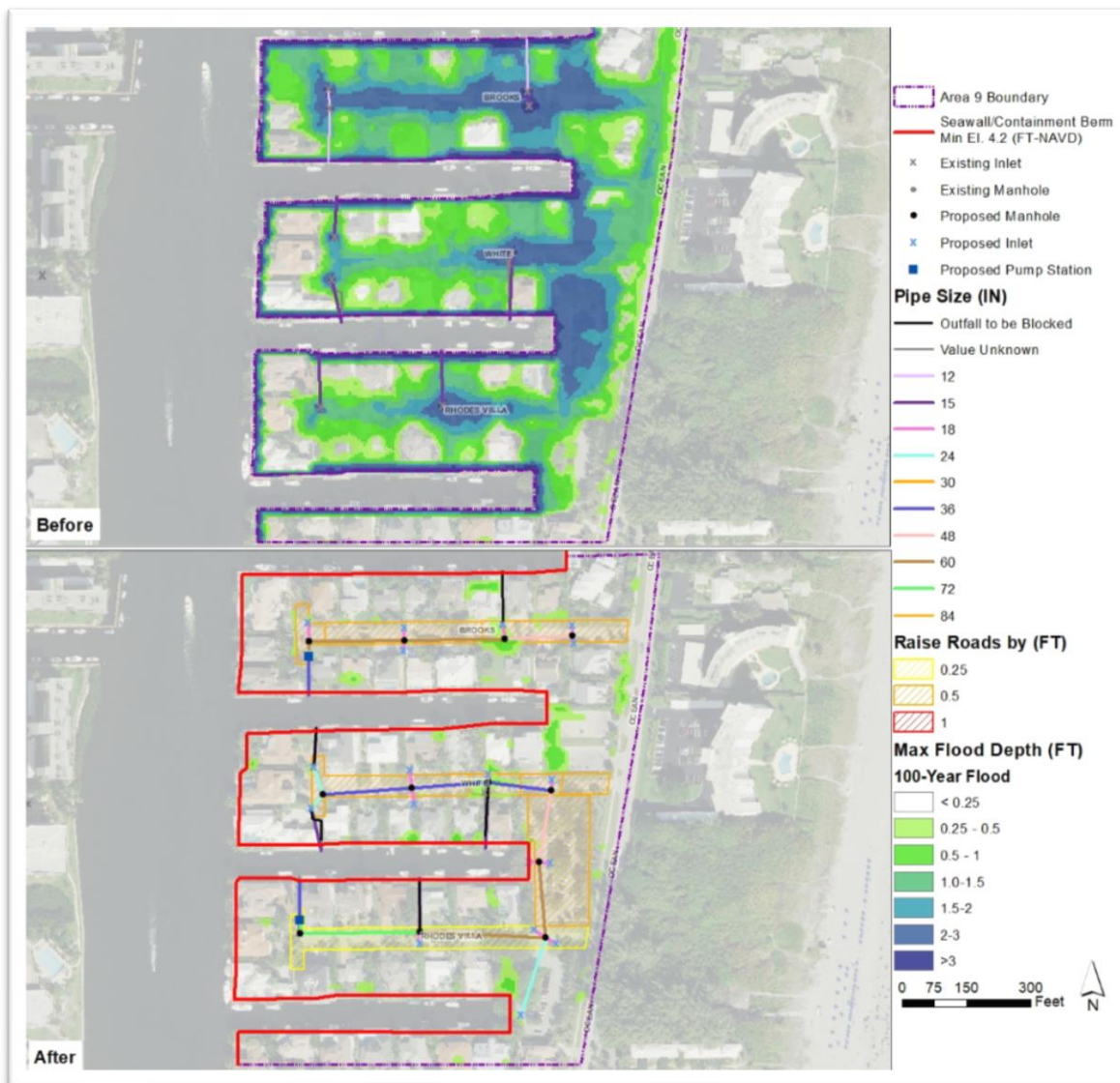


Figure 8-29: 100-Year Flood Depth Before and After Proposed Area 9 Capital Improvement Infrastructure

8.20 Problem Area 10

Problem Area 10 is the largest of the 14 defined problem areas. The drainage complaints within Problem Area 10 were defined by the City as flooding from deteriorated pipes. Complaints were located near the intracoastal at on Tropic Boulevard, Banyan Drive, Cypress Drive, and Iris Drive. There are no existing pump stations serving these areas, the streets have elevations that are vulnerable to high tides, and the existing outfalls and stormwater infrastructure are not sufficient to carry stormwater for the 30-year Sea Level Rise scenario flooding.

8.20.1 Stormwater Management Elements and Conceptual Design

Reduction of modeled flooding within Problem Area 10 is accomplished with added pipes, backflow preventers and inlets, increased pipe sizes, raised seawalls along the intracoastal, raised road elevations and 10 proposed pump stations. **Figure 8-30** and **Figure 8-31** show the details of the proposed capital improvements within Problem Area 10. The ten Problem Area 10 pump stations are located on Eve Street, Boleander Drive, Banyan Drive, Cypress Drive, Dogwood Drive, Gardenia Drive, Iris Drive, Jasmine Drive, Avenue L, and Pelican Way. **Table 8-3** describes each pump station and its capacity. Connectivity among the pump stations with north-south trunklines on Spanish Trail and Florida Boulevard was modeled to improve drainage. Existing outfalls are proposed to be grouted to prevent the potential for pump stations to pull seawater into the system. See **Section 8.25** for the unit and cost breakdowns of the improvements and **Appendix 8A** for the pump station schematic.

Table 8-3: Proposed Problem Area 10 Pump Stations

Label	Name	Flow Capacity (GPM)
1	Eve St	60,000
2	Bolender Dr.	60,000
3	Banyan Dr.	60,000
4	Cypress Dr.	20,000
5	Dogwood Dr.	80,000
6	Gardenia Dr.	60,000
7	Iris Dr.	60,000
8	Jasmine Dr.	60,000
9	Avenue L	60,000
10	Pelican Way	60,000

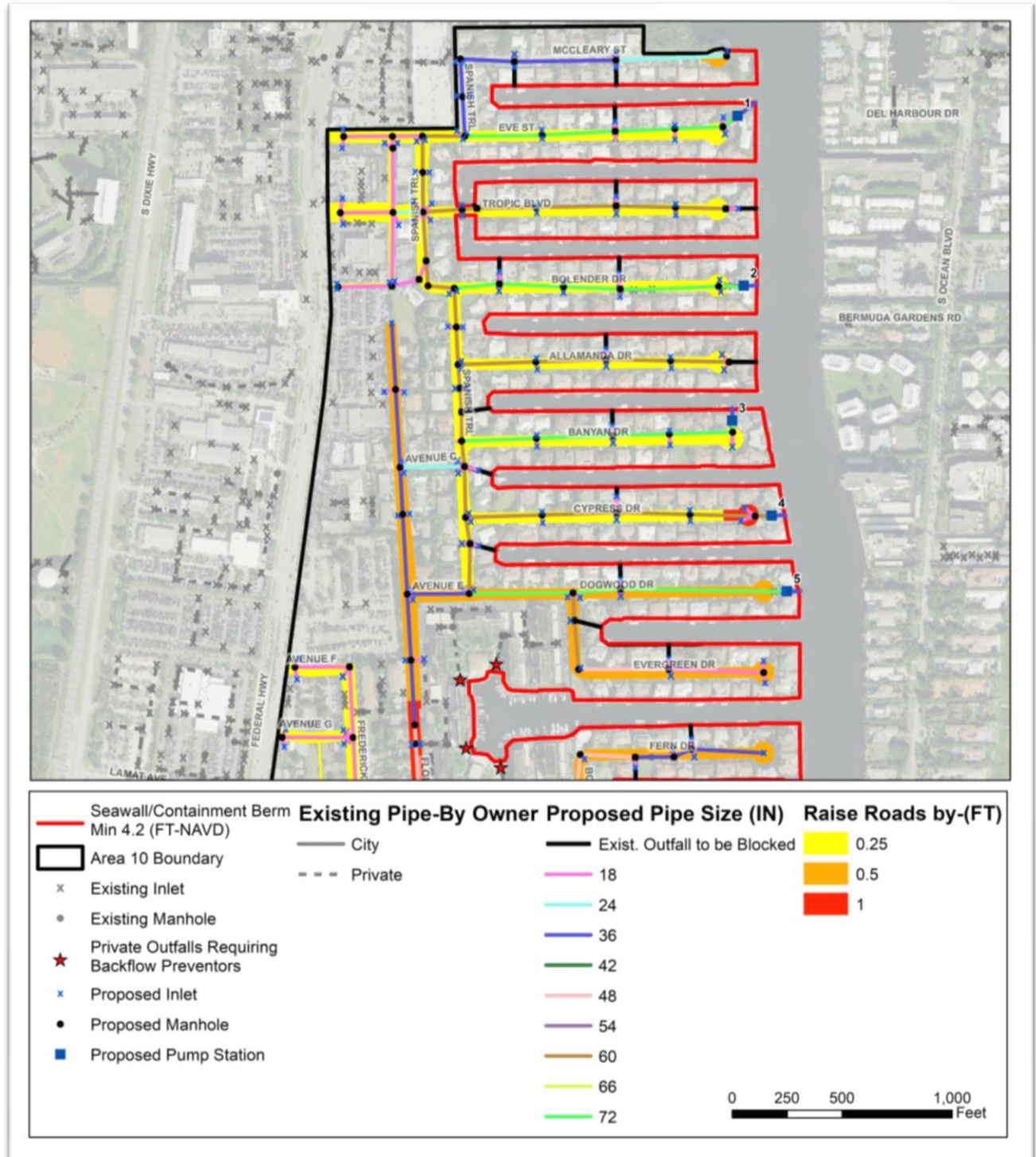


Figure 8-30: Proposed Capital Improvements for Problem Area 10-North

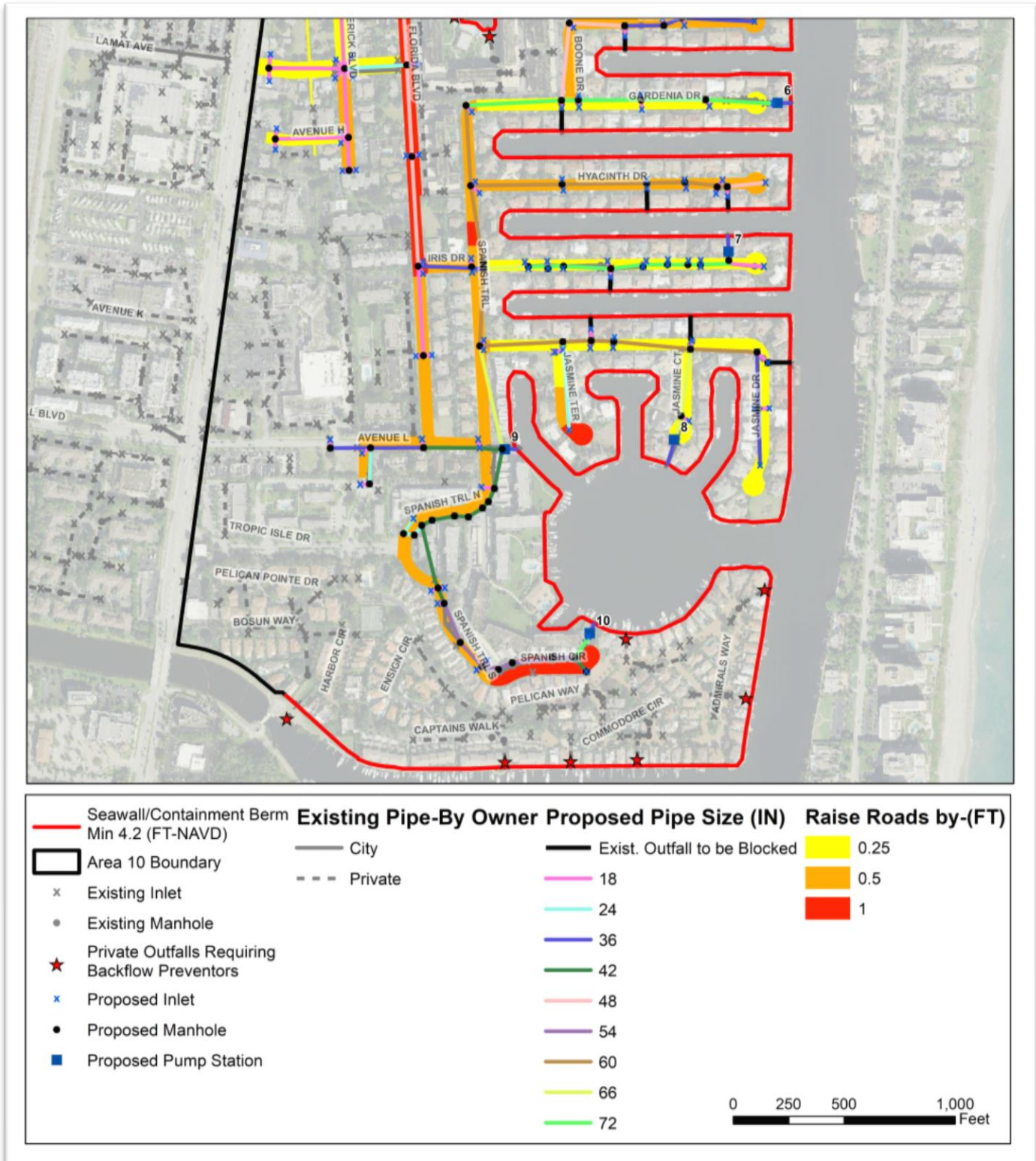


Figure 8-31: Proposed Capital Improvements for Problem Area 10-South

8.20.2 Flood Reduction Benefits

The infrastructure improvements within Problem Area 10 are predicted to reduce the FPSS from 673 to 64 with the 30-year sea level rise and groundwater conditions. This is a 90% reduction in FPSS from the previous 30-year SLR scenario that was modeled without improvements. **Appendix 8C** describes the detailed FPSS calculations. A small section of city-road centerline had flooding greater than 0.25 feet once improvements were modeled. This section of road was the corner of Avenue F and Frederick Boulevard. A total of eleven structures in the region showed flooding after implementation of the proposed improvements within the model. **Figure 8-32** details the roads and structures with LOS exceedance values. **Figure 8-33** and **Figure 8-34** are included to show differences in flooding before and after infrastructure improvements for the 30-Year Sea Level Rise Scenario and 100-year design storm event.

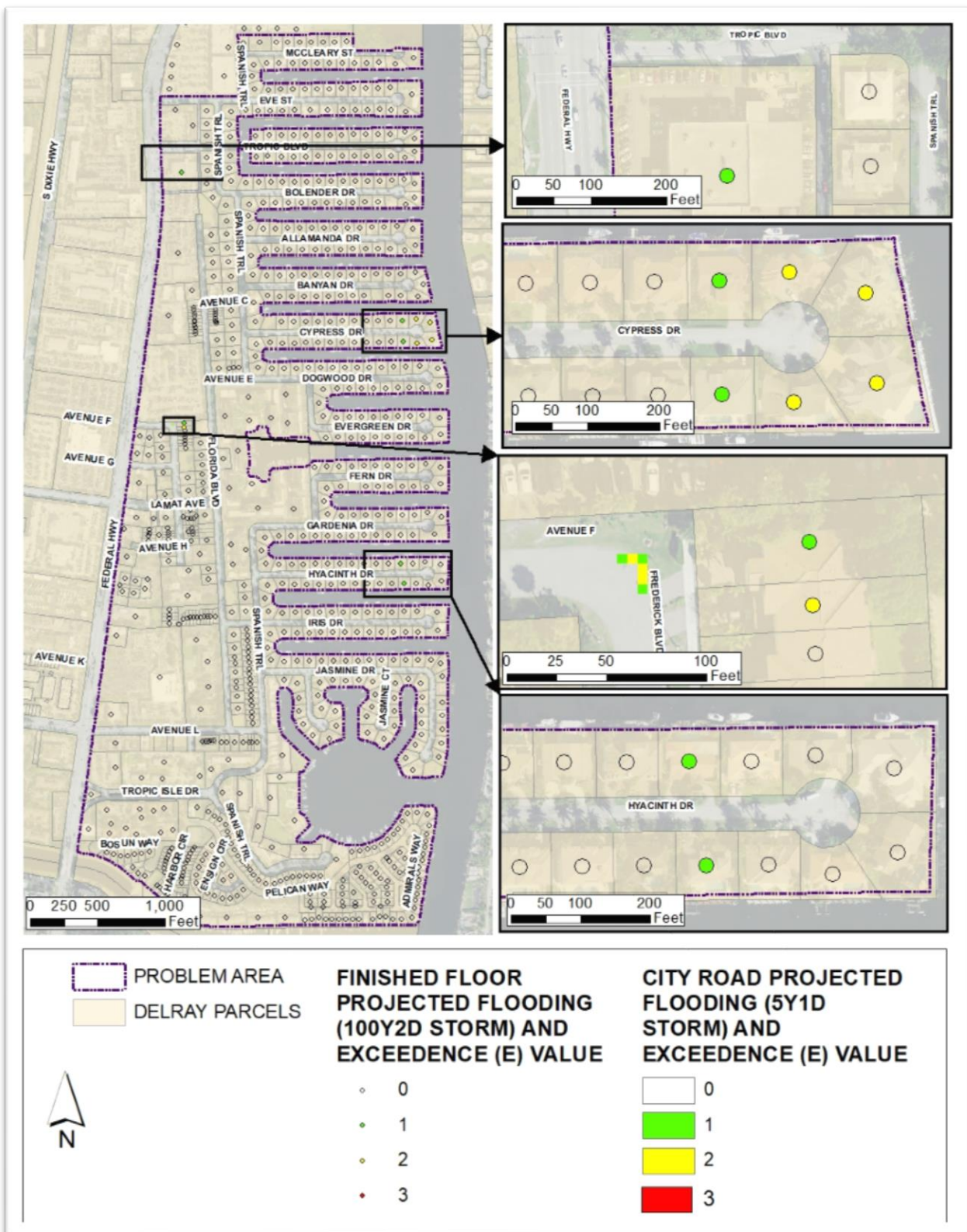


Figure 8-32: Level of Service Exceedance Value for Problem Area 10

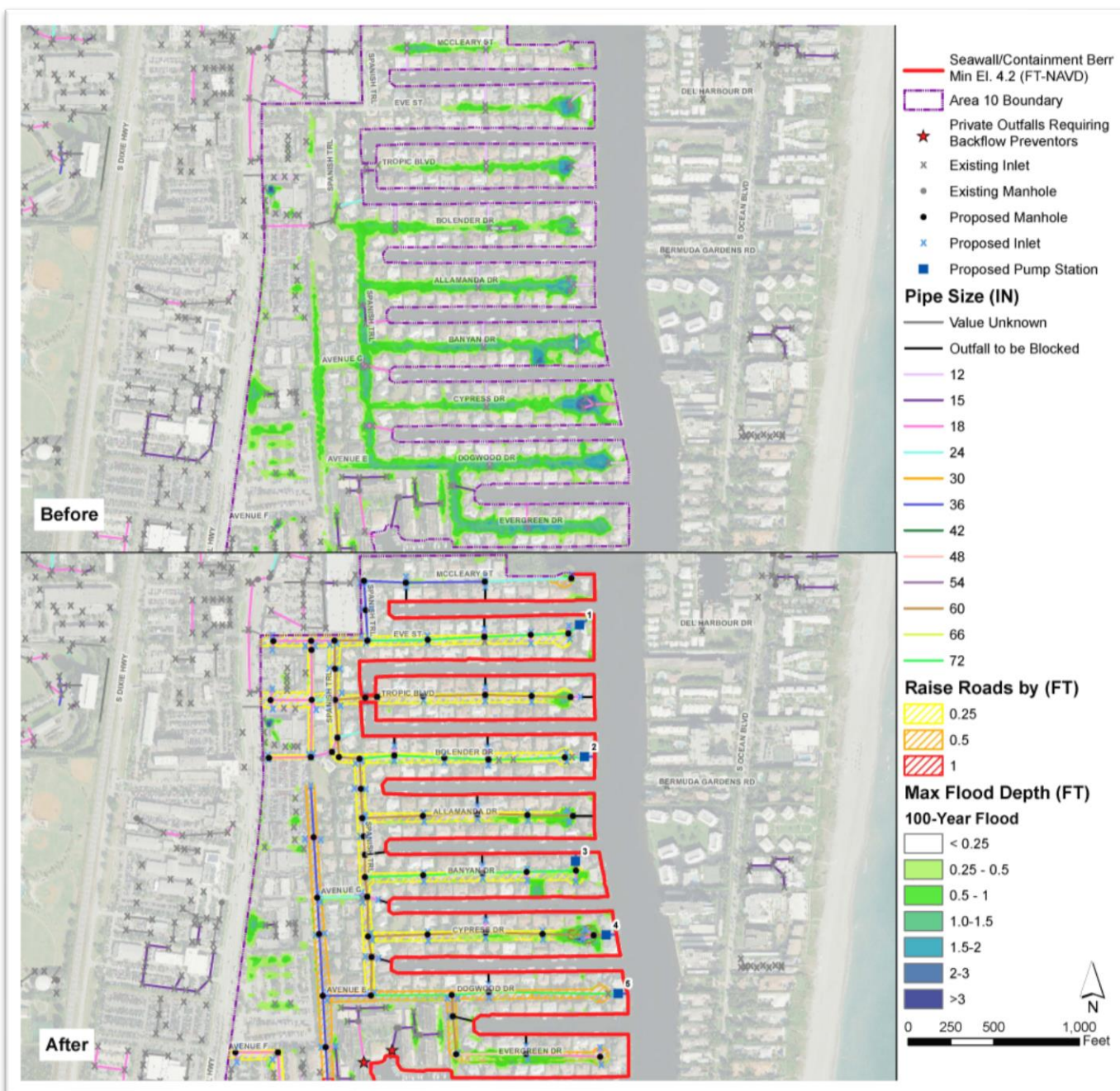


Figure 8-33: 100-Year Flood Depth Before and After Proposed Area 10-North Capital Improvement Infrastructure



Figure 8-34: 100-Year Flood Depth Before and After Proposed Area 10-South Capital Improvement Infrastructure

8.21 Problem Area 11

Problem Area 11 was defined by the City due to drainage complaints of standing water on the roads at the cul-de-sacs near SE 8th Ct and SE 10th Ct. There is no existing pump station and the existing outfalls in the model are not sufficient to carry stormwater for the 30-year Sea Level Rise scenario flooding.

8.21.1 Stormwater Management Elements and Conceptual Design

Reduction of modeled flooding within Problem Area 11 is accomplished with added pipes, backflow preventers and inlets, increased pipe sizes, raised seawalls along the intracoastal, raised road elevations and a proposed pump station. **Figure 8-35** shows the details of the proposed capital improvements within Problem Area 11. The Problem Area 11 pump station is located on SE 8th Street and has a total capacity of 20,000 GPM (two 10,000 GPM pumps). See **Section 8.25** for the unit and cost breakdowns of the improvements and **Appendix 8A** for the pump station schematic.

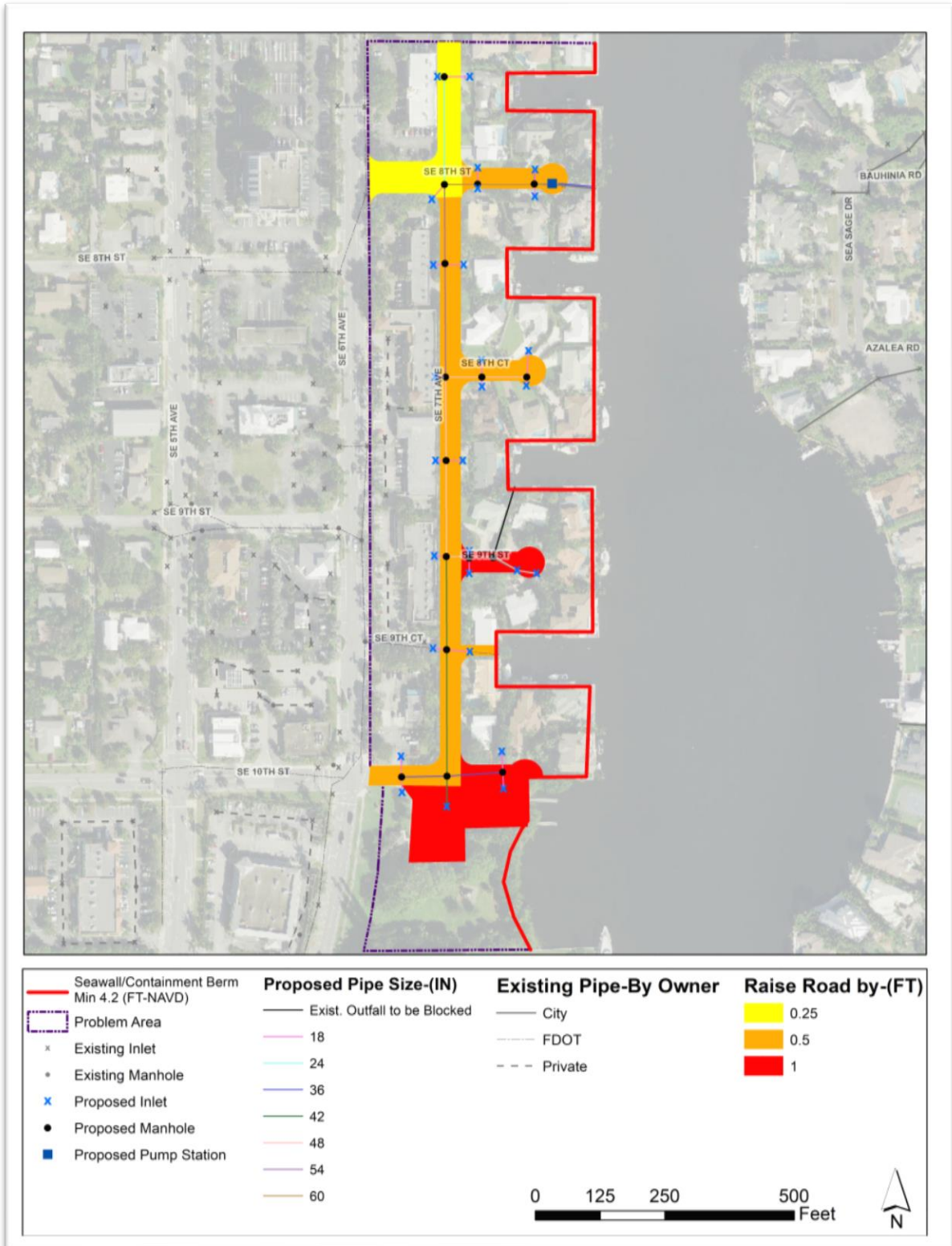


Figure 8-35: Proposed Capital Improvements for Problem Area 11

8.21.2 Flood Reduction Benefits

The infrastructure improvements within Problem Area 11 are predicted to reduce the FPSS to 0 in the sub-basin. No city-road centerlines had flooding greater than 0.25 feet and no structures showed flooding with the implementation of the proposed improvements within the model. Therefore, the FPSS was reduced by 100% from the 30-year Sea Level Rise (SLR) scenario. **Appendix 8C** describes the detailed FPSS calculations. **Figure 8-36** is included to show differences in flooding before and after infrastructure improvements for the 30-Year Sea Level Rise Scenario and 100-year design storm event.

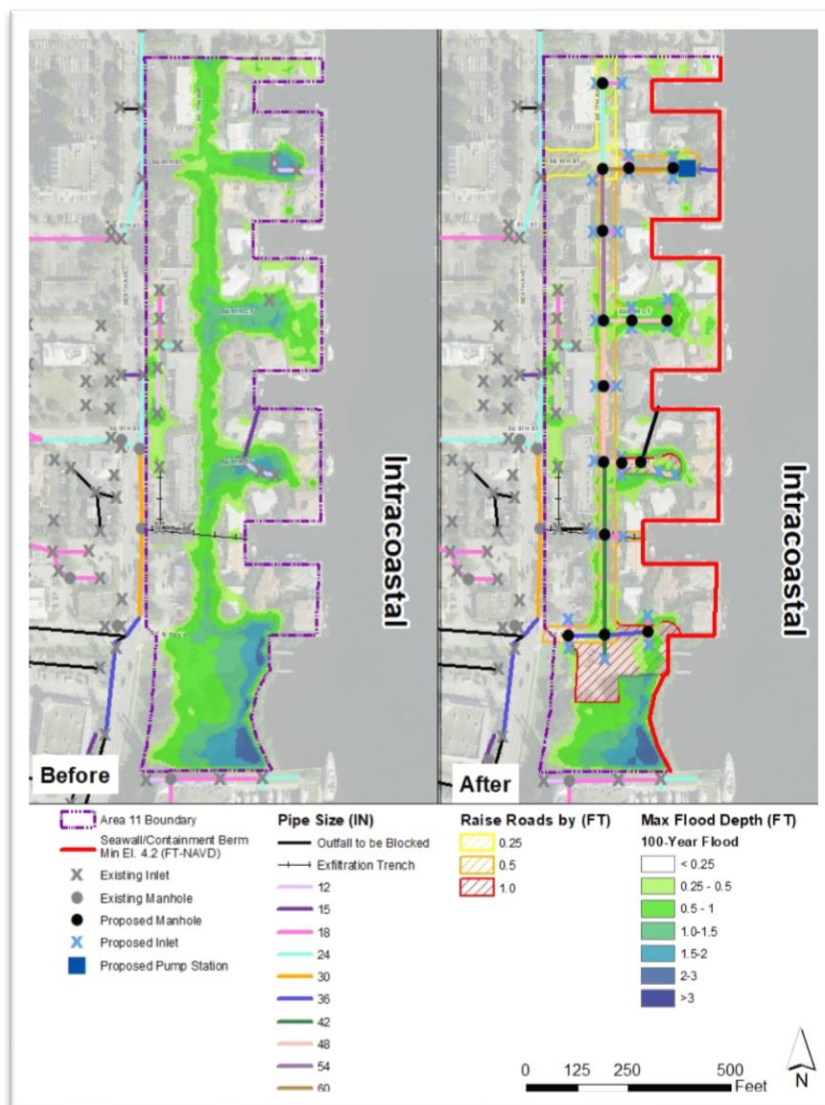


Figure 8-36: 100 Yr Flood Depth Before and After Proposed Area 11 Capital Improvement Infrastructure

8.22 Problem Area 12

Due to the fact that Watman Group is currently modeling and proposing improvements for the Marina Way area, this problem area was not analyzed for proposing capital improvement projects.

8.23 Problem Area 13

Problem Area 13 was defined by the City due to known flooding located on NW 37th Avenue just north of Lake Ida Road. Currently there is drainage infrastructure in the Problem Area that ultimately outfalls to a Lake Worth Drainage District Canal, but it is undersized to carry stormwater for the 30-year Sea Level Rise scenario flooding.

8.23.1 Stormwater Management Elements and Conceptual Design

Reduction of modeled flooding within Problem Area 13 is accomplished with added pipes, exfiltration trench, backflow preventers and inlets to the drainage network, increased pipe sizes, and raised road elevations. **Figure 8-37** shows the details of the proposed capital improvements within Problem Area 13. Per Miami-Dade County Regulatory and Economic Resources recommendations, it was assumed that exfiltration trench has the ability to exfiltrate 3.28 inches of the total rainfall depth produced by a rainfall event over the area contributing to the exfiltration trench. The total area contributing to the exfiltration trench in this basin is approximately 150 feet on each side of the centerline of the road which extends approximately to the back of the lot on each side of the road. Therefore, 3.28 inches of rainfall was abstracted from the rainfall amount within the region of the 150-foot buffer of the road centerlines with proposed exfiltration trench. See **Section 8.25** for the unit and cost breakdowns of the improvements.

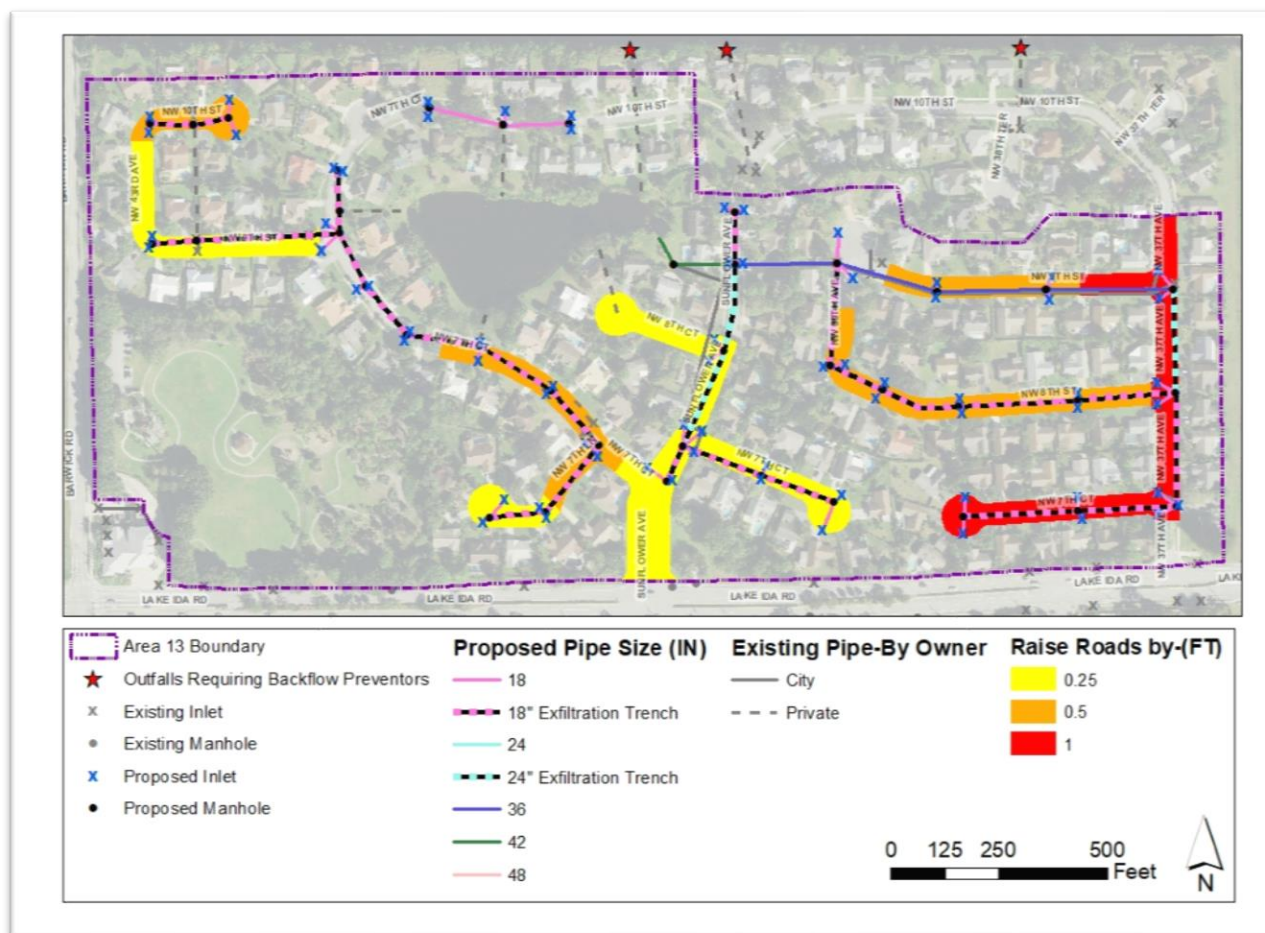


Figure 8-37: Proposed Capital Improvements for Problem Area 13

8.23.2 Flood Reduction Benefits

The infrastructure improvements within Problem Area 13 are predicted to reduce the FPSS to 0 in the sub-basin. No city-road centerlines had flooding greater than 0.25 feet and no structures showed flooding with the implementation of the proposed improvements within the model. Therefore, the FPSS was reduced by 100% from the 30-year Sea Level Rise (SLR) scenario. **Appendix 8C** describes the detailed FPSS calculations. **Figure 8-38** is included to show differences in flooding before and after infrastructure improvements for the 30-Year Sea Level Rise Scenario and 100-year design storm event.

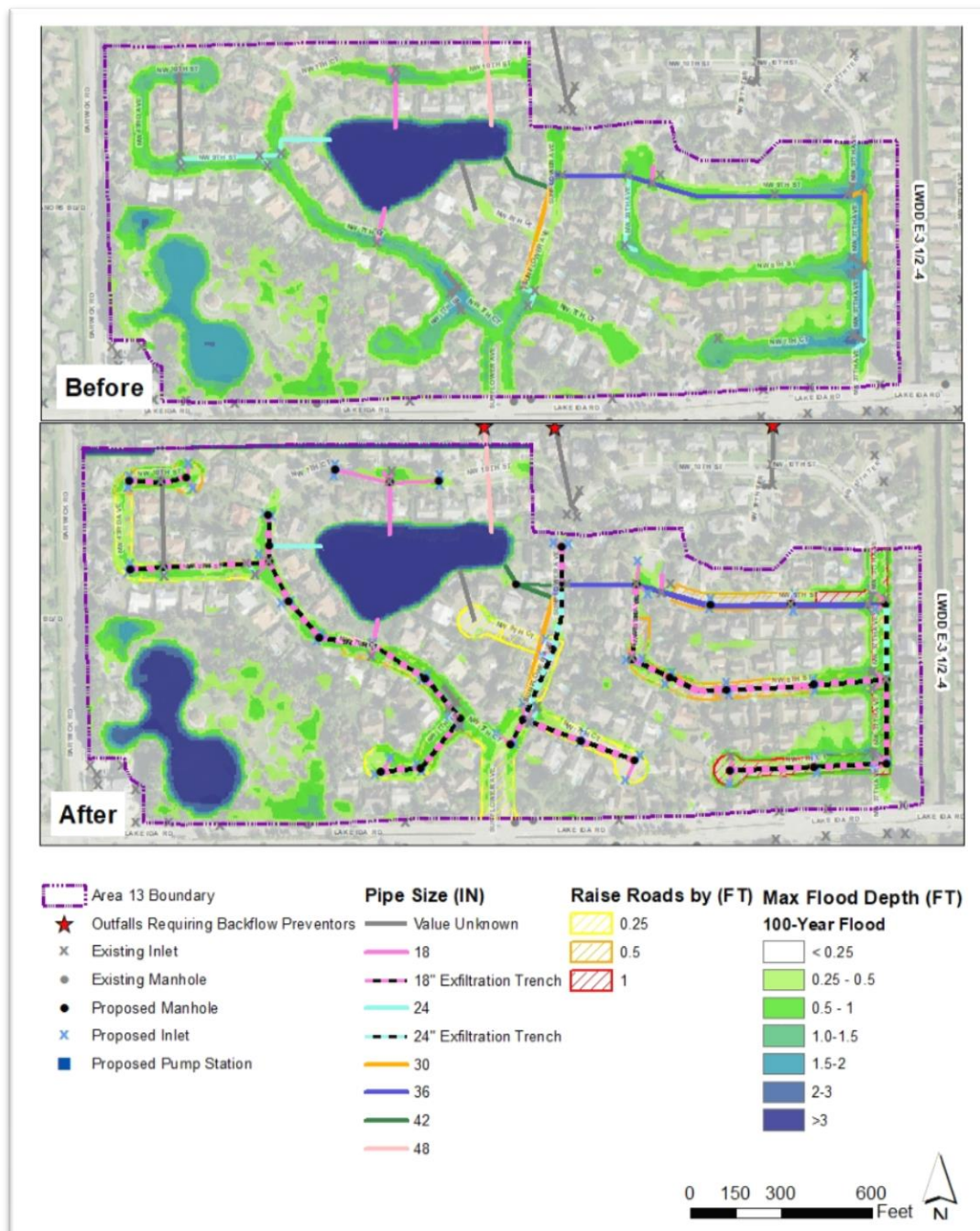


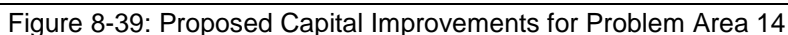
Figure 8-38: 100-Yr Flood Depth Before and After Proposed Area 13 Capital Improvement Infrastructure

8.24 Problem Area 14

Problem Area 14 was defined by the city due to several drainage complaints within the Rainberry Woods neighborhood. Standing water was indicated to remain for two or more days near the intersection of NW 51st Avenue and NW 5th Street and on NW 46th Avenue near the tennis courts. Currently there is drainage infrastructure in the Problem Area that ultimately outfalls to a Lake Worth Drainage District Canal, but it is undersized to carry stormwater for the 30-year Sea Level Rise scenario flooding.

8.24.1 Stormwater Management Elements and Conceptual Design

Reduction of modeled flooding within Problem Area 14 is accomplished with added pipes, exfiltration trench, backflow preventers and inlets to the drainage network, increased pipe sizes, and raised road elevations. **Figure 8-39** shows the details of the proposed capital improvements within Problem Area 14. Per Miami-Dade County Regulatory and Economic Resources recommendations, it was assumed that exfiltration trench has the ability to exfiltrate 3.28 inches of the total rainfall depth produced by a rainfall event over the area contributing to the exfiltration trench. The total area contributing to the exfiltration trench in this basin is approximately 150 feet on each side of the centerline of the road which extends approximately to the back of the lot on each side of the road. Therefore, 3.28 inches of rainfall was abstracted from the rainfall amount within the region of the 150-foot buffer of the road centerlines with proposed exfiltration trench. See **Section 8.25** for the unit and cost breakdowns of the improvements.



The infrastructure improvements within Problem Area 14 are predicted to reduce the FPSS from 295 to 8 with the 30-year sea level rise and groundwater conditions. This is a 97% reduction in FPSS from the previous 30-year SLR scenario that was modeled without improvements. **Appendix 8C** describes the detailed FPSS calculations. No city-road centerline had flooding greater than 0.25 feet once improvements were modeled. A total of two structures in the region showed flooding after implementation of the proposed improvements within the model. **Figure 8-40** details the roads and structures with LOS exceedance values. **Figure 8-41** is included to show differences in flooding before and after infrastructure improvements for the 30-Year Sea Level Rise Scenario.

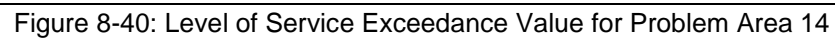




Figure 8-41: 100-Yr Flood Depth Before and After Proposed Area 11 Capital Improvement Infrastructure

8.25 Opinion of probable construction cost

As outlined in **Section 8.10**, the proposed projects consist of typically implemented stormwater infrastructure components as outlined in **Section 8.3**. Each project was assessed to mitigate the projected flooding with a 30-year sea level and groundwater rise. The 5-year, 1-day storm event was used to model flooding within the roadways to determine the height to raise the road, based on the flooding in that given location with the proposed stormwater management systems. The 100-year, 3-day storm was modeled and utilized to remove homes and buildings from the 100-year flood plain. **Appendix 8B** depicts the proposed conceptual designs for each of the problem areas.

Planning-level cost estimates were developed for each project based on the Florida Department of Transportation (FDOT) cost databases, costs from recent projects constructed within the City and ADA's own construction cost databases. The estimated cost for raising the crown of road is based on FDOT cost data assuming an average width of road of 23 feet. This cost takes into account the depth of limerock as well as depth of superpave SP-12.5 asphalt.

In addition to the average unit cost of the proposed improvements, provided in **Table 8-4**, the incidental expenditures including maintenance of traffic, mobilization, permitting contingency, design, and a construction administration were also calculated. The cost factors for the incidental expenditures used to calculate the final cost estimates for each of the proposed capital improvement projects are provided in **Table 8-5**.

Table 8-4: Average Unit Cost for Proposed Capital Improvement Projects

Description	Units	Average Unit Cost
ROADWAY PAY ITEMS		
CLEARING AND GRUBBING	AC	\$9,500
MILLING EXISTING ASPHALT (1" AVG. DEPTH)	SY	\$2.36
SUPERPAVE ASPHALTIC CONC, TRAFFIC C	TN	\$100.00
PERFORMANCE TURF (SOD)	SY	\$3.14
3" ASPHALT RAISE	LF	\$57.00
6" ASPHALT RAISE	LF	\$110.00
12" ASPHALT RAISE	LF	\$74.00
DRAINAGE ITEMS		
INLETS, DT BOT TYPE D, <10'	EA	\$4,100.00

Description	Units	Average Unit Cost
MANHOLE, J-7, >10'	EA	\$11,500.00
MANHOLE, P-7, >10'	EA	\$6,200.00
MANHOLE, P-7, <10'	EA	\$3,800.00
PIPE CULVERT, OPTIONAL MATERIAL, ROUND, 18" SD	LF	\$65.00
EXFILTRATION TRENCH, OPTIONAL MATERIAL, ROUND, 18" SD	LF	\$160.00
PIPE CULVERT, OPTIONAL MATERIAL, ROUND, 24" SD	LF	\$85.00
EXFILTRATION TRENCH, OPTIONAL MATERIAL, ROUND, 24" SD	LF	\$190.00
PIPE CULVERT, OPTIONAL MATERIAL, ROUND, 36" SD	LF	\$130.00
PIPE CULVERT, OPTIONAL MATERIAL, ROUND, 42" SD	LF	\$145.00
PIPE CULVERT, OPTIONAL MATERIAL, ROUND, 48" SD	LF	\$160.00
PIPE CULVERT, OPTIONAL MATERIAL, ROUND, 54" SD	LF	\$200.00
PIPE CULVERT, OPTIONAL MATERIAL, ROUND, 60" SD	LF	\$225.00
PIPE CULVERT, OPTIONAL MATERIAL, ROUND, 66" SD	LF	\$240.00
PIPE CULVERT, OPTIONAL MATERIAL, ROUND, 72" SD	LF	\$260.00
PIPE CULVERT, OPTIONAL MATERIAL, ROUND, 84" SD	LF	\$300.00
PUMP STATION	GPM	\$135.00
FLAP GATES, BACKFLOW PREVENTOR 36"	EA	\$20,000.00
CONCRETE FILL OF OUTFALL	CY	\$380.00

*AC=Acre, SY= Square Yards, TN=Tons , EA=Each, LF=Linear Feet, GPM= Gallons Per Minute

Table 8-5: Capital Cost Factors

Capital Cost Factors As Percentage of Total Material Cost					
Maintenance of Traffic	Mobilization	Permitting	Contingency	Design	Construction Administration
10%	10%	5%	30%	10%	10%

It should be noted that the planning-level cost estimates developed for this stormwater master plan update are intended as an adaptive planning tool for sea level rise and to help guide the City in prioritizing the location where stormwater improvement projects would immediately address current and observed areas of known flooding in a cost-effective manner. Costs were identified for placing stormwater management systems within the City right-of-way for the top 14 problem areas. Problem Area 12 was excluded because the City is currently implementing a flood protection project to also address a 30-year sea level and groundwater rise. **Appendix D** includes detailed planning-level cost estimate for each of the top 14 ranked problem areas, excluding Problem Area 12. A summary of the planning-level cost estimates for each of the top 13 ranked problem areas is provided in **Table 8-6**.

Table 8-6: Capital Improvement Project Planning-Level Cost Estimate

Problem Area Name	Problem Area	Project Cost Estimate
Harbor Drive	1	\$10,343,628.80
Beach Drive	2	\$10,621,968.41
Waterway Lane	3	\$19,400,414.09
Basin Drive	4	\$42,085,705.66
Atlantic Avenue	5	\$27,975,112.98
Bay Street	6	\$21,087,575.32
Seasage Drive	7	\$32,943,700.48
Hibiscus Road	8	\$25,470,832.60
Brooks Lane	9	\$15,902,001.70
Spanish Circle	10	\$157,191,957.44
7 th Avenue	11	\$6,396,712.90
Banwick Park	13	\$3,743,110.48
Rainberry Woods	14	\$5,200,277.37
TOTAL		\$378,362,998.23

These costs should be further refined during the final design and permitting phases of the capital improvement plan implementation process.

8.26 Capital Improvement Project Ranking and Prioritization

In **Sections 5.0** and **Section 6.0** Severity Score (FPSS) was computed as a basis of determining level of service and ranking problem areas based on the severity of flooding. The FPSS was also computed with the proposed stormwater management systems for each problem area. **Table 8-7** depicts FPSS for current conditions, 30-year sea level groundwater rise without stormwater management improvements and 30-year sea level groundwater rise with proposed capital improvement projects.

Table 8-7: FPSS for Current and Future Conditions

Problem Area Name	Problem Area (Acres)	Flood Protection Severity Score (FPSS)			FPSS Difference (30-Year Sea Level Rise FPSS minus Capital Improvements FPSS)	Percent Reduction of FPSS with Capital Improvements	Area-Weighted FPSS Difference (points reduced per acre)
		Current Tidal Conditions Existing Infrastructure	30-Year Sea Level Rise Existing Infrastructure	30-Year Sea Level Rise Capital Improvements			
1	26.22	9.20	57.40	0.00	57.40	100%	2.19
2	22.84	105.70	246.40	0.00	246.40	100%	10.79
3	7.85	4.60	61.00	0.00	61.00	100%	7.77
4	67.34	234.40	1181.80	12.00	1169.80	99%	17.37
5	64.79	33.70	872.00	12.00	860.00	99%	13.27
6	27.42	55.20	388.30	24.10	364.20	94%	13.28
7	61.22	731.40	535.60	0.00	535.60	100%	8.75
8	28.53	63.40	368.70	0.00	368.70	100%	12.92
9	19.54	1.40	382.70	0.00	382.70	100%	19.59
10	281.49	144.60	673.20	64.00	609.20	90%	2.16
11	14.65	1.60	50.20	0.00	50.20	100%	3.43
12	-	0.80	142.20	-	-	-	-
13	59.92	17.90	41.90	0.00	41.90	100%	0.70
14	71.02	190.30	294.50	8.00	286.50	97%	4.03

In order to prioritize projects, the capital improvements for each Problem Area were ranked based on the cost per FPSS area-weighted reduction as depicted in **Table 8-7**. In other words, the Problem Areas are ranked in order from least expensive Problem Area to improve FPSS by one point to most expensive Problem Area to improve FPSS by one point. The flood reduction benefits and FPSS for each Problem Area are described in **Section 8.10** of this report and **Appendix 8C**. **Table 8-8** below contains the project ranking by Problem Area based on the cost to lower the FPSS by one point, normalized by the area of the Problem Area.

Table 8-8: FPSS for Current and Future Conditions

Rank	Problem Area	Problem Area Name	Dollars per Weighted FPSS Point Reduced per Acre
1	9	Brooks Lane	\$4,724,911.97
2	2	Beach Drive	\$ 984,601.29
3	14	Rainberry Woods	\$2,496,610.67
4	6	Bay Street	\$ 2,422,680.30
5	11	7 th Avenue	\$2,107,566.94
6	8	Hibiscus Road	\$ 1,587,647.76
7	5	Atlantic Avenue	\$3,765,521.55
8	4	Basin Drive/Thomas Street	\$ 1,970,932.61
9	3	Waterway Lane	\$811,928.70
10	7	Seasage Drive	\$72,632,902.33
11	1	Harbor Drive	\$1,866,769.80
13	13	Banwick Park	\$ 5,352,915.99
14	10	Spanish Circle	\$ 1,289,087.95
-	12	Marine Way	-
TOTAL COST			\$378,362,998.23

Figure 8-42 depicts each problem area and associated capital improvement project ranking.

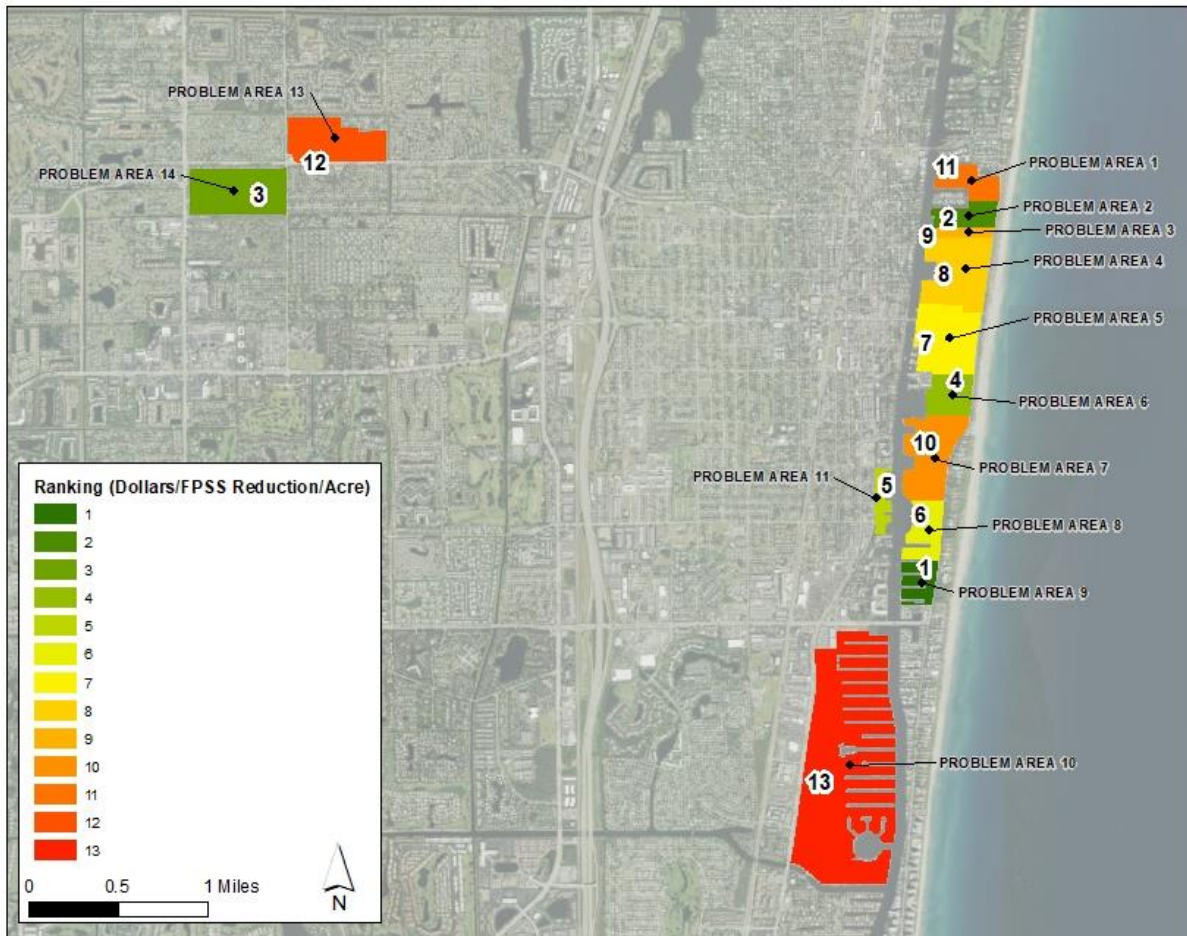


Figure 8-42: Problem Area and Capital Improvement Project Ranking

The project ranking will allow the City to focus funding for capital improvement projects in order of priority or cost-effectiveness. The entire stormwater management systems could be constructed overtime in order of priority as funding becomes available.

9.0 NPDES REVIEW

9.1 NPDES Annual Reporting REQUIREMENTS

The stormwater element of the National Pollutant Discharge Elimination System (NPDES) is implemented by the Department of Environmental Protection (DEP) and is mandated by the Clean Water Act (CWA). Palm Beach County Permit Number FLS000018-004 (**Appendix 9A**) allows municipalities within the County to discharge stormwater in accordance with the approved Stormwater Management Programs (SWMPs), effluent limitations, monitoring requirements, etc.

In addition to complying with the permit conditions and implementation of their own SWMPs, permittees must also submit annual reports to the DEP. Each report is due six months after the reporting period on March 31st. The reporting period covers a 12-month period beginning on October 1st of each year. A sample of the Annual Report Form is provided in **Appendix 9B**. In addition, the Annual Report must include, as an attachment, a report of the Assessment Program, which includes the status of the water quality monitoring plan implementation, a brief description of the assessment program results to date (i.e. water quality monitoring data and/or stormwater pollutant loading from previous reporting years), and an analysis of the data providing a summary of annual trends and a plan for targeting areas of pollutant loading within the MS4.

To-date the City has submitted the Year 1 Annual Report for Individual NPDES MS4 Permit for the reporting period of October 2016 through September 2017, submitted to the Florida Department of Environmental Protection (FDEP) in March of 2018. The City of Delray Beach Year 1 Annual Report is included in **Appendix 9C**.

The inspection and maintenance requirements are listed in Table II.A.1.a of the Palm Beach County MS4 Permit (full permit is provided in **Appendix 9A**). All stormwater structural controls operated by the City must comply with these requirements and must be included in each annual report. As described in Table II.A.1.a (**Appendix 9A**), all dry retention systems, underdrain filter systems, exfiltration trench / French drains, grass treatment swales, dry detention systems, and detention with filtration systems must adhere to the inspection schedule listed in **Table 9-1**. The frequency of inspection is dependent on the conditions of the control structure. All maintenance activities should be performed on an as-needed basis; no specific maintenance schedule is provided; however, regular vegetation removal / mowing, debris removal, and mosquito prevention are listed among the possible maintenance activities for these systems.

Table 9-1: Frequency of Inspection for Stormwater Systems

Condition	Frequency of Inspection
New	Annually for 2 years
Existing - no problems	Once every 3 years
Existing - chronic problems	Annually until problems are corrected

The frequency of inspection for stormwater control structures that are not dependent on the condition of the structure are listed in **Table 9-2**. All stormwater structures should be maintained on an as-needed basis. While no specific maintenance schedule is provided, suggested maintenance activities include removal of vegetation and debris, removal of sediments, and repairing damages. Where applicable, structures should be maintained according the manufacturer's recommendation.

Table 9-2: Frequency of Inspection for Stormwater Structures

Structural Control	Frequency of Inspection
Alum Injection Systems	Monthly unless historical records specify a different inspection frequency
Pollution Control Boxes	Quarterly, unless historical schedule indicates otherwise
Pump Stations	Semi-annually, or more as-needed
Major Outfalls	Annually, unless historic operation records specify a different frequency
Pipes / Culverts	Minimum of 10% of the total number of structures each year. All structures should be inspected at least once every 10 years.
Canals within the MS4 system	Annually
Inlets, Catch Basins, Grates, Ditches, Conveyance Swales, and other Stormwater Conveyances	Minimum of 10% of the total number of structures each year. All structures should be inspected at least once every 10 years.

All weirs, channel control structures, or other stormwater control structures should be inspected with a frequency that is the same as the associated stormwater structure or system. For example, a weir that controls flow in a canal should follow the inspection frequency listed in **Table 9-2** for canals; which is annually. A weir that controls flows in a grass swale should be inspected based on the frequencies shown in **Table 9-1**, based on the condition of the grass swale.

9.2 Review of Current NPDES Data Collection Practices For Annual Reporting

ADA met with the City staff and reviewed the current data collection process for developing the NPDES annual report. Information relating to the location, dimensions, installation dates, etc. of stormwater facilities within the City is currently stored in GIS Stormwater Infrastructure databases. However, maintenance activities and inspections of the facilities are recorded manually by field crews using paper records. A sample of the field inspection form currently being used is shown in **Figure 9-1**.

Storm Water NPDES Activity	1st Quarter			2nd Quarter			3rd Quarter			4th Quarter			TOTAL
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	
Exfiltration Trench / French Drains													
Exfiltration trench inspections (linear feet)													0
Exfiltration trench maintained (linear feet)													0
Swales													
Swales inspected (square feet)													0
Swales installed/restored (square feet)													0
Wet or Dry Ponds													
Wet or dry retention & detention ponds inspected													0
Wet or dry retention & detention ponds maintained													0
Wet or dry retention & detention ponds maintained -by contractors													0
Bags of litter manually removed													0
Storm Water Pump Stations													
Pump stations inspected													0
Pump stations maintained													0
Major outfalls (36" or greater diameter)													
Major outfalls inspected													0
Major outfalls maintained													0
Weirs, Valves or other Control Structures													
Weirs, Valves or other Control Structures inspected													0
Weirs, Valves or other Control Structures maintained													0
Stormwater Pipes & Culverts													
Pipes/culverts inspected (linear feet)													0
Pipes/culverts maintained (linear feet)													0
Inlets / Catch Basins / Grates / Manholes													
Inlets / Catch Basins / Grates / Manholes inspections													0
Inlets / Catch Basins / Grates / Manholes maintained													0
Inlets stenciled (placards)													0
Street / Parking Lot Sweeping													
Frequency of street sweeping (days)													0
Total weight of debris													0
Total cubic yards of debris collected													0
Total curb miles swept													0

NOTE: ALL MAINTENANCE ACTIVITIES COUNT AS INSPECTION ALSO.

Figure 9-1: Current field inspection and maintenance form for the City of Delray Beach.

The following data is collected throughout the year by the departments listed below in parentheses. The current procedure, which was implemented for completion of the Year 1 Annual Report (shown in **Appendix 9C**), involves gathering the separate data inputs listed below and then sending to Alan Wertepny, PE from Mock-Roos to compile, complete, and submit the Annual Report to DEP.

Part III.A.1 Structural Controls and Stormwater Collection Systems Operation

- Need to provide:
 - Number of Structures
 - Number of Inspections
 - Percent Inspected
 - Number of Maintenance Activities
 - Percent Maintained
- For the following classifications (responsible department shown in parentheses):
 - Dry retention systems (Stormwater Maintenance & Administration)
 - Underdrain filter systems (Stormwater Maintenance & Administration)

- Exfiltration trench/ French drains linear feet (lf) (Stormwater Maintenance & Administration)
- Grass treatment swales (miles) (Stormwater Maintenance & Administration)
- Dry detention systems (Stormwater Maintenance & Administration)
- Wet detention systems (Golf Course Maintenance)
- Pump stations (Stormwater Maintenance & Administration)
- Major outfalls (Stormwater Maintenance & Administration)
- Weirs or other control structures (Stormwater Maintenance & Administration)
- Pipes/ culverts (miles) (Stormwater Maintenance & Administration)
- Inlets/ catch basins/ grates (Stormwater Maintenance & Administration)

Part III.A.3 Roadways (responsible department shown in parentheses):

- Frequency and amount of litter collected (cy) (Parks and Recreation)
- Trash Pick-up Events miles cleaned and amount collected (cy) (Special Events Coordinator)
- Adopt-A-Road total miles cleaned and amount collected (cy) (Special Events Coordinator)
- Street sweeping frequency, total miles swept, and total material collected (cy) (Stormwater Maintenance & Administration)
- Total P and N loadings removed (lbs) (Stormwater Administrator – using FSA Calculator)
- Number of Inspections per equipment yard or maintenance shop (Fleet Superintendent)

PART III.A.4 Flood Control Projects (responsible department shown in parentheses):

- Number of flood control projects, non-stormwater treatment projects, planned stormwater retrofit projects, and completed stormwater retrofit projects (Engineering – recorded in CIP Database)

Part III.A.6 Pesticides, Herbicides, and Fertilizer Application (responsible entity shown in parentheses):

- Number of permittee personnel applicators and contracted commercial applicators of pesticides/herbicides (IFAS)
- Number of personnel with Green Industry BMP Program training (IFAS)
- Number of FDACS certified/licensed contractor applicators of fertilizers (IFAS)

Part III.A.7 Illicit Discharges and Improper Disposal (responsible entity shown in parentheses):

Part III.A.7.c – Investigation of Suspected Illicit Discharges and/or Improper Disposal

- Number of inspections for suspected illicit discharges, number of illicit discharges found, and number of citations issued (IPP)
- Number of reports of suspected illicit activity, and subsequent findings and charges issued
- Number of personnel/contractors trained in permit requirements/SWMP activity (Stormwater Administrator)

Part III.A.7.d – Spill Prevention and Response

- Number of hazardous material spills responded to
- Number of personnel/contractors trained in spill prevention and response (Stormwater Administrator)

Part III.A.7.e – Public Reporting

- Number of participants at public education and outreach events and number of visitors to stormwater-related pages (Program & Project Management)

Part III.A.7.g – Limitation of Sanitary Sewer Seepage

- Sanitary Sewer Overflows: # of incidents discovered, # resolved. Number of Infiltration and Inflow (I&I) incidents discovered, # resolved. (Public Works)

Part III.A.8 Industrial and High-Risk Runoff (responsible entity shown in parentheses):

- Number of facilities, inspections, and enforcement actions for:
 - Operating municipal landfills
 - Hazardous waste treatment, storage, disposal and recovery (HWTSDR) facilities (Public Works)
 - EPCRA Title III, Section 313 facilities (TRI)
 - Facilities determined as high risk by the permittee (Public Works)

Part III.A.9 Construction Site Runoff (responsible entity shown in parentheses):*Part III.A.9.a - Site planning and Non-Structural and Structural BMPs*

- Permittee: Number of construction site plans reviewed and approved. (Public Works/Engineering)
- Private: Number of construction site plans reviewed and approved. (Building Department)
- Number notified of ERP permit requirements, and number confirmed ERP coverage. (Building Department /Engineering)
- Number notified of CGP stormwater permit requirements, and number with confirmed CGP coverage (Building Department)

Part III.A.9.b - Inspection and Enforcement

- Permittee: Number of active construction sites, pre-, during, and post inspections of active construction sites for E&S and waste control BMPs, percentage of active construction sites inspected. (Public Works/Engineering)
- Private: Number of active construction sites, pre-, during, and post inspections of active construction sites for E&S and waste control BMPs, percentage of active construction sites inspected. (Public Works/Engineering)
- Enforcement Actions (Engineering & Code Enforcement)

Part III.A.9.c - Site Operator Training

- Number of construction site inspectors with DEP Certification and the number of training activities (Public Works and Engineering)

- Number of training activities for construction site plan reviewers and construction site operators (Public Works and Engineering)

9.3 Requirements for Future NPDES Reporting

Each year, the NPDES Annual Report Form must be completed in its entirety (see **Appendix 9A** for a blank copy of the report form). This includes a summary of the structural controls and stormwater collection systems operation, areas of new development and redevelopment, roadways and litter collection, flood control projects, municipal waste treatment and disposal, pesticides and fertilizer application, investigation of reported illicit discharges, inventory of high-risk runoff facilities, and construction site runoff. In addition, a status report of the TMDL's for Lake Ida should be included in Section IX of each Annual Report.

9.4 Year 2 Annual Report

Certain attachments to the report are required only during specific reporting years. The upcoming Year 2 Annual Report will include activities from the reporting period of October 1, 2017 through September 30, 2018. The report will be due to DEP by March 31, 2019. The following are required attachments for Year 2:

- A summary review of codes and regulations to reduce the stormwater impact from development.
- Florida-friendly ordinance for fertilizer use on urban landscapes

In June of 2018, FDEP held a Phase I MS4 Group Meeting and provided important information about the NPDES reporting process. The meeting focused on upcoming requirements for Year 2, and a summary of these is provided below.

9.4.1 New Development/Redevelopment Ordinances

In Year 2 it is required to conduct an inter-departmental review of local codes and land development regulations to identify potential changes that will reduce the stormwater impacts of new development and redevelopment. It is required that the City submit a summary report of the review activity, which includes:

- list of regulations reviewed;
- list of the current techniques aimed at reducing the stormwater impacts;
- list of techniques recommended/proposed for future incorporation into the regulations; and
- a plan for implementing changes.

To mitigate stormwater impacts from new developments, it is recommended that the City use practices to treat, store, and infiltrate runoff onsite before it reaches downstream water bodies. Site designs that reduce imperviousness and include low-impact development (LID) practices can be used to reduce flows and improve water quality.

Redevelopment of impervious surfaces, rather than development of new lands, can help reduce net increases in impervious surfaces and associated degradation to receiving

waters. Infrastructure upgrades during redevelopment can also be used to repair deteriorating pipes and upgrade undersized stormwater treatment systems.

A follow-up report should be submitted as part of the Year 4 Annual Report. This follow-up should summarize the implementation plan for changing the local codes to promote reducing stormwater impacts from new development and redevelopment.

9.4.2 Fertilizer Use

Each county and municipal government located within the watershed of a water body or water segment that is listed as impaired by nutrients shall, at a minimum, adopt the department's Model Ordinance for Florida-Friendly Fertilizer Use on Urban Landscapes. The City of Delray Beach includes Lake Ida, a nutrient-impaired water body, therefore the City must adopt the Model Ordinance, as part of the NPDES MS4 Permit.

The model ordinance, developed by DEP, is a comprehensive approach, which includes site plan design, landscape design, irrigation system design, and fertilizer application. **Appendix 9D** includes this model ordinance titled "*Florida-Friendly Landscape Guidance Models for Ordinances, Covenants, and Restrictions*." The approach provides guidelines for designing fertilizer free zones and low maintenance zones to prevent direct runoff to water bodies and provide a level of pre-treatment. In addition, fertilizer application practices, fertilizer content and application rates, and the timing of fertilizer application are covered in these guidelines.

This ordinance must be adopted within 2 years of the date of permit issuance and a copy of the adopted ordinance should be submitted with the Year 2 Annual Report.

9.5 Year 3 Annual Report

The Year 3 Annual Report will include activities from the reporting period of October 1, 2018 through September 30, 2019. This report will be due to DEP by March 31, 2020.

The following are required attachments for Year 3:

- A table of average annual pollutant loadings and Event Mean Concentrations (EMCs).

9.5.1 Monitoring Requirements

9.5.1.1 Assessment Program

As part of the Palm Beach County MS4 Permit, each municipality is required to submit an Assessment Program which includes a water quality monitoring plan, a report of pollutant loadings, an evaluation of trends in pollutant loading and water quality, and a plan for targeting areas using loading reduction measures.

The City of Delray Beach has developed and submitted an assessment program to the DEP on September 7, 2017 (see **Appendix 9E**).

Moving forward, the City should ensure that the Assessment Program provides the following:

- The receiving water/Water Body Identification and monitoring station that is needed for water quality data from the Joint Water Quality Monitoring Program. Include the number and location of Major Outfalls.
- While the joint report will include pollutant loading based on land use, each MS4 is responsible for reviewing their contributing areas, identifying their BMPs, and subtracting their reductions from the joint data based on those calculated reductions from BMPs within the MS4.
- An analysis of water quality data and load reductions with a summary of annual trends. Based on the analysis, the City should have a plan to target portions of their MS4 for possible pollutant control measures. This plan may include direct actions, identification of specific areas, and permit SWMP activities.

Lake Ida is listed as a receiving water body with Total Maximum Daily Load (TMDL) exceedances. Because a portion of the City drains to Lake Ida, a separate water quality monitoring plan for the lake must be submitted with the Assessment Plan. The City of Delray Beach, in conjunction with the City of Boynton Beach who also drains to the lake, has developed and submitted the Targeted Water Quality Monitoring Plan for WBID 3262A, Lake Ida to the DEP on August 23, 2017 (see **Appendix 9F**). The monitoring plan was reviewed and accepted by the DEP on January 19, 2018.

9.5.1.2 TMDL Status Update

While there are no specific requirements for Year 2, each Annual Report must include a status update of the TMDL process, including estimated pollutant load reductions during the reporting period and cumulatively since the SWMP was implemented.

9.5.1.3 Monitoring Summary

In Year 3 the City must submit a final report summarizing the monitoring program's results, including rainfall normalized annual stormwater pollutant loadings. This should include a table of average annual pollutant loadings and EMCs. The City must compare the current cycle's average annual pollutant loadings with those from the previous cycle's Year 3 Annual Report. The source of the data and methods or models used for calculations must be specified in the report. Based on the comparison of average annual pollutant loadings, the City should indicate whether pollutant loadings are increasing or decreasing for Lake Ida. The Monitoring Summary is due with the Year 3 Annual Report on March 31, 2020.

9.5.1.4 Supplemental SWMP

In Year 4, a Supplemental SWMP must be submitted to the DEP before March 31, 2021. The Supplemental SWMP should include Best Management Practices (BMPs) and other programs intended to reduce stormwater pollutant loads to Lake Ida. The plan should include:

- A table listing the BMPs and program activities to be implemented, a schedule for their implementation, and projected load reduction for each activity.
- A strategy for implementing periodic monitoring to document progress in pollutant load reductions to the TMDL waterbody, BMP effectiveness, as well as ambient water chemistry. This should allow the City to evaluate the effectiveness of their Supplemental SWMP in reducing TMDL pollutant loads.

9.5.1.5 Permit re-application information

If the total annual nutrient loading to Lake Ida has not decreased since the start of the permit (in 2017), the City must reevaluate its SWMP and identify and submit revisions that may help reduce nutrient loadings to Lake Ida. These revisions are to be submitted with the Year 4 Annual Report by March 31st, 2021.

In addition, the City must submit a copy of the assessment program as an attachment to the Year 4 Annual Report for DEP review and approval. The submission must identify any indication that the water quality in Lake Ida is improving (or that the nutrient loadings are decreasing). If the results are inconclusive, the submission must determine whether the assessment program is providing data that can be used to assess the effectiveness of the SWMP in reducing nutrient loading. If not, additional assessment elements should be identified.

9.6 Year 4 Annual Report

The Year 4 Annual Report will include activities from the reporting period of October 1st, 2019 through September 30th, 2020. This report will be due to DEP by March 31st, 2021. As mentioned in the above sections, the following are required attachments for Year 4:

- A follow-up report on plan implementation of changes to codes and regulations to reduce stormwater impacts from new development and redevelopment. See section 9.4.1.
- A TMDL Supplemental SWMP. See section 9.5.1.4.
- Permit re-application information relating to the monitoring results. See section 9.5.1.5.
- A report on the amendments used to strengthen the legal authority to conduct inspections and enforce compliance.

9.6.1 Illicit Discharges and Improper Disposal – Inspections, Ordinances, and Enforcement Measures

The City is encouraged to strengthen the legal authority to conduct inspections, conduct monitoring, and to control illicit discharges, illicit connections, illegal dumping and spills. It should also consider changing the legal authority for compliance with ordinances, permits, contracts, and orders, including the authority to take legal action and to eliminate illicit discharges or connections. Any amendments to the existing laws should be reported and submitted with the Year 4 Annual Report.

9.7 Recommendations for Streamlining Data Collection Procedures for Future Annual reporting

9.7.1 Reporting Issues

During the review of the SWMP Summary Table, it was found that some of the structural controls and stormwater collection systems were being inspected much more frequently than required as outlined in Table II.A.1.a of the State of Florida MS4 Permit FLS000018-004 (see **Appendix 9A**). For example, only 10% of all pipes and culverts should be inspected each year. However, of the 20.3 miles of total pipes and culverts, the City inspected 52 miles in the 2016-2017 reporting period. That is more than two inspections per pipe or culvert per year.

The same inspection rule applies for all inlets/ catch basins/ and grates. However, of the 2,630 reported facilities, there were 52 reported inspections, with a reported inspection percentage of 100%. The total number of inlets/ catch basins/ and grates that were inspected must be reported, even if a single inspection covers multiple structures. This type of anomalies was listed as a common deficiency in the 2018 Phase I MS4 Group Meeting and should be considered when completing the next annual report.

The Field Maintenance Tracking Log (**Figure 9-1**) that is used by the City was also reviewed by ADA. In the form, the swales are reported as square feet, but these should be reported as a measure of length (either linear feet or miles) to properly report this on the NPDES permit. In addition, wet and dry retention should be separated out, if possible.

9.8 GIS Database Refinements

ADA understands that the City has fully integrated their stormwater facilities database into GIS. However, it may be necessary to update the fields within the shapefiles to include data required for NPDES tracking and reporting. For example, the number of inspections or maintenance activities per stormwater facility for the reporting year.

Table 9-3 lists the GIS shapefiles that were created for the City and are currently maintained by the City's stormwater department. As an example, **Figure 9-2** shows the storm drain line file and the drainage manhole point file and the current fields associated with each. **Appendix 9G**, provides a full listing of the existing fields for the Storm Drain line shapefile, shown in **Figure G-1**.

Table 9-3: List of GIS shapefiles maintained by the City's stormwater department

Point Shapefile	Line Shapefile	Polygon Shapefile
Drainage headwall	GTG storm drain	Basins
Drainage inlets	Main GTG Test	Proposed Land Use
Drainage manholes	Pipes	Ponds
Drainage nodes	Storm Drains	Zoning District
Drainage outfalls	Swales	City Boundary
Major City Outfalls		

The screenshot displays two attribute tables and a map view. The top table, 'Selected Attributes of drain_manhole', lists fields such as FID, Shape, OBJE, id, sectio, manh, owner, fea, descri, date, time, longitude, latitude, northing, easting, label, editdate, editu, GlobalID, RimElev, InvertIn, AssetID, Invert, InvertIn, Invert, and Invert. The bottom table, 'Selected Attributes of Storm_Drain', lists fields including FID, Shape, OBJECTID, SHAPE_Leng, ID, Section_no, Drain_no, Owner, Feature_co, Descriptio, BuildDate, EditDate, Editor, Material, Size, Span, Rise, AssetID, InvertIn, InvertOut, Measured_L, Source, and Pipe Slope. The map view below shows an aerial photograph with several red lines representing storm drain features overlaid on a residential area.

Figure 9-2: Sample of GIS files and their current fields.

To properly document the inspection and maintenance activities as per the NPDES requirements, it is recommended that additional fields be included in these shapefiles to track facilities that have been inspected and/or maintained. This will help to streamline the data processing and reporting by allowing the number of inspection and maintenance activities to be automatically calculated using a simple query. For records that require the total length of inspection or maintenance, such as exfiltration trenches, swales, or pipes / culverts, the length of the shapefile features are already calculated in feet for each shapefile, so a query could easily sum the feature lengths that have been identified as inspected or maintained.

A sample of the proposed additional fields is shown in **Appendix 9G, Table G-2**.

Figure 9-3 shows a GIS screen capture of the storm drain line shapefile with additional columns listed for each quarter within each reporting year (i.e. 1Qtr_2018 is the first quarter of 2018). The columns use text fields for users to report either "I" for Inspected or "M" for Maintained. In this example, random inspection and maintenance activities were generated for the first three quarters of 2018. Since maintenance activities count as inspections, a query on this file for all inspections for the first quarter of 2018 is shown as "1Qtr_2018" = 'I' OR "1Qtr_2018" = 'M'. A report can then be generated for the length of these selected features in feet (SHAPE_Leng) to get the total length of inspected storm drains (633.3 ft for this example).

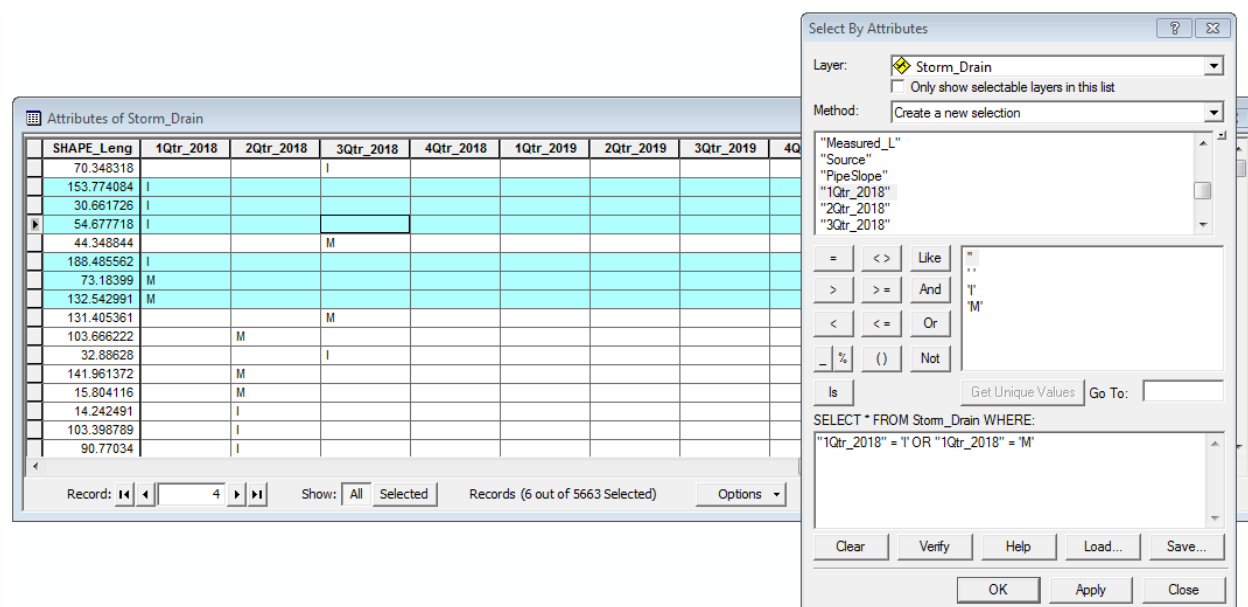


Figure 9-3: Sample of the proposed field additions to the linear shapefiles

To determine the total length of maintained features, the query would be shortened to "1Qtr_2018" = 'M' and the report generated as before.

For point features such as inlets and manholes, the same setup and queries can be performed as shown above; however, the total number of features would need to be counted rather than the sum of the lengths.

Having this data in the City's GIS database, maps can also be generated showing facilities that were maintained and/or inspected in a given year, in addition to facilities that need to be inspected in the upcoming reporting period. This approach adds a robust automated process to document and report inspection and maintenance activities.

9.9 GIS Training

GIS training for City staff can help with maintaining the stormwater databases and streamlining the data collection process for the NPDES MS4 Permit annual reporting. ADA recommends maintaining a GIS trained staff, including:

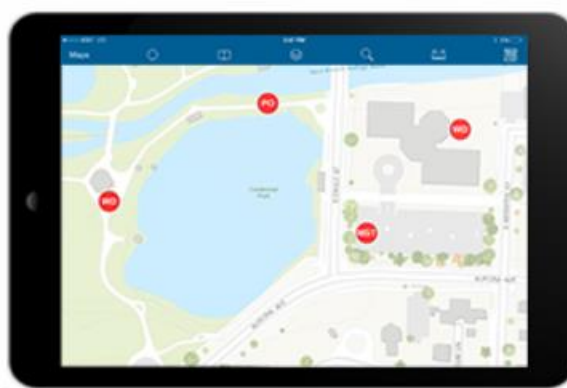
- Maintenance crews who want to know where their facilities are located and dates of previous inspections and/or maintenance activities.
- Utility supervisors who want to manage maintenance teams and monitor status of operations
- Engineering staff who need quick access to the utility database for modeling
- Managers who need specific metrics for annual planning and reporting

9.10 ArcGIS Online Tools

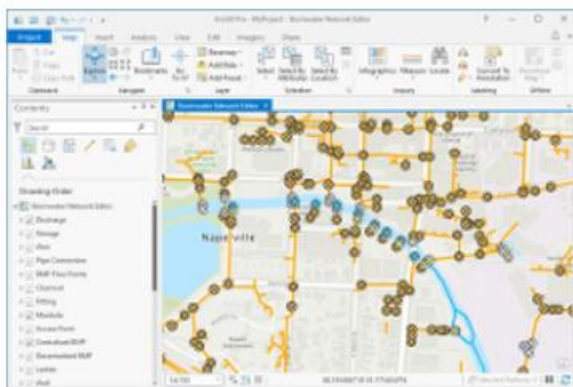
A more advanced solution is to utilize online, app-based mapping tools to allow field crews to generate data from a handheld device such as a smartphone or tablet. Applications such as ArcPad or ArcGIS for Windows Mobile have been used for field investigations for over a decade. ArcPad provides field-based personnel with the ability to capture, analyze, and display geographic information in the form of industry-standard vector and raster image files, in near real time. While ArcPad is directed more towards GIS-trained professionals, ArcGIS for Windows Mobile application is a task-driven GIS app for Windows tablet devices created for non-GIS trained professionals that typically perform simple data collection and field inspection projects. Collector for ArcGIS and Survey123 are free apps that can also extend the reach of your stormwater database into the field. Screen captures of these applications used for municipal work are shown in **Figure 9-4**.



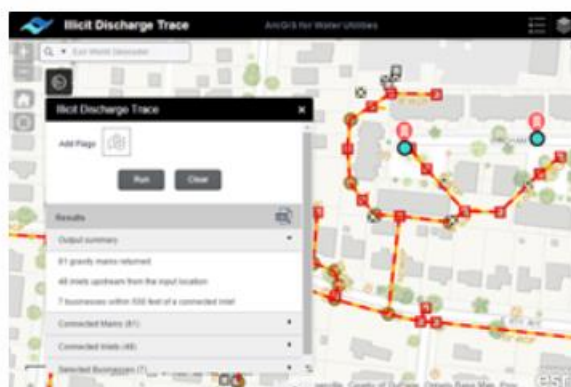
Manhole Inspection



Stormwater Construction Site Violation



Stormwater Utility Network Configuration



Illicit Discharge Trace

Figure 9-4: GIS-based software used for field inspection and reporting

These applications can be configured to match the City's field inspection and maintenance log forms. Staff can be trained to use the apps and build dashboards for data tracking in the field. Additionally, secure online GIS tools can be developed for

residents to use and report illicit discharges or improper disposal as required by Part III.A.7.c on the Stormwater Management Program Summary Table (see **Appendix 9B**).

9.11 Data Collection and/or Annual Report Preparation Outsourcing

An additional option is to outsource the database creation, GIS training, training for GIS online tools and even the NPDES data collection, annual reporting, and submittal process. It is estimated that database configuration for the stormwater structures and systems and training City staff would cost around \$20 to 40k, depending on the level of detail that is needed or wanted. Specialists in ESRI GIS training, such as Florida Technical Consultants located in Delray Beach, may provide the City staff with the required knowledge and understanding of the technology. However, there other firms with similar capabilities that could provide similar services