Volume 1

City of Key West
2012 Stormwater Master Plan

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Prepared for:

City of Key West

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Executive Summary

Background

The 2012 Stormwater Master Plan updates the previous 1994, 2001, and 2006 studies. This effort involved the following activities:

- Collecting existing stormwater drainage reports, record drawings of stormwater infrastructure, and other available data
- Supplementing these existing data with a field inventory of stormwater infrastructure using global positioning system (GPS) technology to confirm existing information and to augment the dataset where no records exist
- Updating the City of Key West's (the City's) existing stormwater drainage model with this newly compiled data

This 2012 Stormwater Master Plan mapped locations within the City that flood from heavy rainfall, and developed and prioritized future stormwater flooding mitigation projects that the City could use to update its Long Range Stormwater Utility Capital Project Plan. While the scope called for CH2M HILL to develop up to 20 projects, 37 projects were recommended from the 58 projects that were evaluated. Not all of these conceptual projects provided flooding relief, especially gravity wells located at low elevations, but all locations evaluated are documented for the City's future reference. A master plan needs to be regularly updated (every 5 to 12 years) to account for changes in regulations and/or the City infrastructure and priorities. While many projects were identified in this plan, there may be others identified in the future by the City as a result of issues found during detail design or for operation and maintenance needs. Some of the projects evaluated herein are conceptual in nature and need further development to determine feasibility or additional details.

The recent availability of new landscape (elevation) data and other geographic information system (GIS) data gives the City a cost-effective way of updating its stormwater program using the latest technologies. A major effort in this update to the City's stormwater plan was the inventory of facilities in the field utilizing GPS equipment (conducted in the spring 2011). This field data collection program focused on building a geo-referenced City stormwater facilities inventory, and included the sanitary system where the two were collocated. The City purchased the GPS unit and OMI[1] will continue to use it to collect data for the GIS database in the future. These inventory data, construction drawings from recent projects, OMI local knowledge, input from the residents through public meetings, and previous studies were used to develop a current computer simulation model of the City system. In addition, a detailed evaluation of the stormwater runoff on North Stock Island was conducted for the first time.

[1] OMI is the contracted operator of City's collection system.

Key West has some unique characteristics that affect the way stormwater projects are prioritized. For example, low elevations near the coast require that traditional "pipe" projects have larger pipes because of low hydraulic pressures generated from standing water on the flat landscape. The highly developed island does not normally have sufficient area for large pipes, especially considering the other utilities. Also, the City's policy is to reduce stormwater pollutant discharge into the nearshore coastal waters to help protect the natural resources, including beaches, so new outfalls are not encouraged. South Florida residents are accustomed to standing water immediately after a larger rainfall, as long as the runoff percolates or drain relatively quickly. Consequently, improvements to drainage are measured in sub-foot improvements and the ability to drain after the peak of the storm passes.

Methodology

To develop the list of projects, a three-step process was used:

1. Identify areas with larger flooding issues (that is, rank the sub-basins where flooding occurs)
2. Evaluate projects for these areas to determine their effectiveness
3. Assess the feasibility of the potential projects and provide a recommendation for implementation

A computer model of the City's stormwater system was updated and used to develop the maps of existing flood concerns. A scoring and ranking of sub-basins with a higher severity of flooding was conducted. However, projects were subsequently developed for nearly all areas that had high peak stormwater stages and not just the highest ranked sub-basins. The projects were selected based on visual inspection of maps showing peak stormwater stages during design storms, areas of known problems, and potential space and suitability for siting a project. Many of these projects are conceptual, and more work is required to determine if there is sufficient space (rights-of-way) and to collect site-specific data (for example, soils, permeability, etc.).

Two sets of projects were evaluated (Alternatives 1 and 2). Alternative 1 projects were primarily gravity recharge wells with some other miscellaneous projects. For example, the George Street pump-assisted well project (located at Catherine and Ashby Streets) was in Alternative 1 because it is in design and will likely be constructed soon. North Stock Island requires some clearing of its drainage ways, which was considered an operational cost and not a capital project, so this activity is not listed as a ranked project. Alternative 2 projects included one more location with pump-assisted recharge wells and a pump-assisted outfall located at areas that have chronic problems, primarily because of the low elevations at this location. Alternative 2 also included addressing areas that have localized flooding issues that require some minor activity to address.

In many locations with low elevations, the gravity recharge wells did not help reduce the peak stages much, as expected. In some of these locations, it is recommended that projects include evaluating other infiltration controls, like exfiltration trenches and open pavers, to reduce the duration of standing water. No gravity recharge wells at some study locations are recommended because they are just not effective because of the low elevation of the landscape. In a few locations where chronic flooding occurs, the effectiveness of new outfalls was examined in the Alternative 2 projects. These outfalls could be effective in lowering flood stages in some areas, but access to the waterfront would be difficult because of existing development.

Of the 43 Alternative 1 projects, 26 were considered to have moderate to high effectiveness in lowering the peak elevation of standing water during a 10-year storm (approximately 7 inches of rain in a 24-hour period). Many of the Alternative 2 projects did not yield significant changes in peak elevation results in the computer modeling, but are still recommended to address areas where localized flooding has been reported.

Conceptual Cost Estimates for Potential Projects

Opinions of capital costs were estimated based on recent Key West bid packages on similar projects. The construction costs were escalated to include non-capital costs to generate the total project cost opinion to the City. Costs were reported as a range (low to high). The total capital costs of all 26 recommended Alternative 1 projects ranged from $12.9 million to $18.0 million. The average reduction in the 10-year stormwater flood levels at these 25 locations is 0.74 feet. The estimated cost opinion of the additional 12 recommended Alternative 2 projects ranged from $8.5 million to $12.8 million. The average reduction in flood levels at these Alternative 2 locations is not a valid comparison, as many of these projects are to address inlet capacity and isolated locations with reported long-term standing water, not from the modeling results. One project was recommended but because of access to waterfront restrictions, its feasibility is questionable. The total cost opinions, determined by adding all (recommended or not) of the low and high ranges, are $28.8 million to $42.5 million, respectively. However, only approximately $21.4 million to $30.8 million (low to high range) of the projects are recommended in this Master Plan. Exhibit ES-1 lists these projects. These costs included allowances for curb and gutter modifications to address disability access and utility conflicts at intersections in most projects.

In addition to reducing flooding, the proposed projects add water quality benefits by directing more stormwater into the ground. The City’s existing stormwater system directs approximately 45 percent of the runoff from the sub-basins included in the computer simulation into the ground, while the proposed projects increase this to approximately 51 percent. These estimates were for the larger design storms only, and only for the City’s portion of the islands so this captured runoff volume is not all-inclusive. Regardless of the actual removal rate, however, both the existing and proposed increase in the reduction of stormwater to surface nearshore waters is significant.

The projects were prioritized based on general groupings on how effective they were relative to other projects and an overall opinion of importance to a neighborhood. These qualitative priority groups will allow the City to look for opportunities to implement projects depending on available funding or urgency. Note that some projects may indicate some moderate flood reductions, but they were included to see if they help reduce levels further downhill; if not, then they were not recommended.

EXHIBIT ES-1
Conceptual Projects Planning-level Cost Estimates and 10-Year Flood Reductions
City of Key West 2012 Stormwater Master Plan

Intersections/Locations with Projects	Model Node/ Sub-Basin	Proposed Project	Project No.	Cost (low)	Cost (high)	Recommended for Implementation (Y/N)	10-yr Storm Stage Reduction (ft)
Patricia and Ashby neighborhood piping from Rose and Thompson to PS	N100 (130)	Approx. 1,500 LF of 18" pipe and 16 Inlets, 800 LF of exfiltration trench along Bertha Ave	A1	$785,242	$1,478,334	Y	NA
20th Ter and Donald St	N4147	1 Gravity Recharge Well	B1	$264,649	$384,773	Y	0.21
20th St and Eagle Ave	N3930	1 Gravity Recharge Well	B2	$264,649	$384,773	N	0.10
Duck Ave and 19th St	N4145	1 Additional Gravity Recharge Wells, 1 intersection	B3	$355,894	$515,123	Y	1.53
Donald St and 19th Ter	N4147	1 Additional Gravity Recharge Well	B4	$264,649	$384,773	Y	0.21
Harris and 10th Ave	N6000	1 Gravity Recharge Well; 120 LF 18" pipe; 8 inlets; WQ Box	C1	$353,017	$547,509	Y	0.66
Fogarty and 11th St	N3730	1 Gravity Recharge Well	C2	$264,649	$384,773	N	0.04
Fogarty and 12th St	N3720	1 Gravity Recharge Well	C3	$264,649	$384,773	N	0.09
Patterson and 12th St	N3710	1 Gravity Recharge Well	C4	$264,649	$384,773	N	0.09
Washington St and Leon St	N2840	1 Additional Gravity Recharge Well	D1	$264,649	$384,773	N	0.04
Seminary St and Leon St	N2830	2 Gravity Recharge Wells	D2	$355,894	$515,123	N	0.10
Whalton and Von Phister St	N240	1 Additional Gravity Recharge Well	D3	$264,649	$384,773	N	0.11
United St and Packer St	N2883	1 Additional Gravity Recharge Well	D4	$264,649	$384,773	N	0.50
United St and Georgia St	N2865	1 Gravity Recharge Well	D5	$264,649	$384,773	Y	2.64
On Washington St at Washington and Georgia St intersection	N3050	1 Additional Gravity Recharge Well	D6	$264,649	$384,773	Y	0.24
Southard and Grinnell St	N2550	1 Gravity Recharge Well	E1	$264,649	$384,773	Y	0.22
Greene St and Duval St	N2120	1 Gravity Recharge Well	E2	$264,649	$384,773	N	0.19
Caroline and Duval	N2130	1 Gravity Recharge Well	E3	$264,649	$384,773	Y	0.24
Eaton St and Whitehead St	N1190	1 Additional Gravity Recharge Well	E4	$264,649	$384,773	Y	0.47

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Eaton and Duval, Fleming and Duval area	N1120	2 Gravity Recharge Wells, 2 locations	E5	$355,894	$515,123	Y	1.28
On Whitehead mid-block, South of Greene	N2010	1 Gravity Recharge Well	E6	$264,649	$384,773	Y	0.50
Simonton Beach Pump Station	N2110	Additional Investigations at existing pressurized recharge well system. Allowance for new recharge well and piping	E7	$250,000	$350,000	Y	NA
On Simonton St mid-block between Caroline and Eaton St	N2140	1 Additional Gravity Recharge Well	E8	$264,649	$384,773	Y	0.80
Donald St and 17th St	N4110	1 Additional Gravity Recharge Wells	F1	$355,894	$515,123	Y	0.22
Donald St and 17th Ter	N4120	1 Additional Gravity Recharge Wells	F2	$355,894	$515,123	Y	0.22
17th St and south of Roosevelt	N4175	1 Additional Gravity Recharge Well	F3	$264,649	$384,773	Y	0.24
Fort and Olivia	N635	1 Additional Gravity Recharge Well	G1	$264,649	$384,773	N	0.10
Amelia and Emma St	N605	1 Gravity Recharge Well	G2	$264,649	$384,773	N	0.07
Mid-block on Whitehead St between United St and South St	N5000	1 Gravity Recharge Well, in mid-block	G3	$264,649	$384,773	N	0.01
Catherine and Ashby St Pump Station (a.k.a. George St Pump Station)	N3020	2 Pressurized Recharge Wells and 2 Pipes, see design	H1	$4,651,670	$5,582,004	Y	1.55
Angela and Simonton, and on Angela mid-block of Duval and Simonton St	N1160	2 Gravity Recharge Wells	I1	$355,894	$515,123	Y	2.88
Olivia St and Pohalski Ave, Olivia and Frances	N755	2 Gravity Recharge Wells, 2 intersections	J1	$355,894	$515,123	Y	1.60

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White and Petronia	N720	1 Additional Gravity Recharge Well	J2	$264,649	$384,773	Y	1.57
Grinnell and Virginia	N2887	1 Gravity Recharge Well	J3	$264,649	$384,773	Y	0.98
Florida and Olivia	N900	1 Additional Gravity Recharge Well	J4	$264,649	$384,773	Y	0.33
Fleming St and Grinnell St	N2540	1 Gravity Recharge Well	J5	$264,649	$384,773	Y	1.03
Petronia St and Georgia St	N920	1 Additional Gravity Recharge Well	J6	$264,649	$384,773	N	0.25
Riviera Dr and Riviera St	N3800	1 Additional Gravity Recharge Well	K1	$264,649	$384,773	N	0.01
Near Kennedy Dr (13 St) and Northside St	N3760	1 Gravity Recharge Well	K2	$264,649	$384,773	N	0.12
Northside Dr and 14th St	N3770	1 Gravity Recharge Well	K3	$264,649	$384,773	N	0.16
Along 14th St, near Stadium Apts	N3790	3 Gravity Recharge Wells	K4	$793,947	$1,154,319	Y	0.17
Along 14th St, near Stadium Mobile Home Park	N3780	1 Additional Gravity Recharge Well	K5	$264,649	$384,773	Y	0.11
Venetian Dr and Trinidad Dr	N4200	1 Gravity Recharge Well	L1	$264,649	$384,773	N	0.03
Alternative 2 Projects							
Patricia and Ashby Pressure Well Addition	N100 (130)	Add 1 Recharge Well to existing pressurized system (include pipes, valves, etc.)	A2	$91,245	$130,350	Y	0.09
Mid-block on Dennis St between Venetia St and Balance St	N3340	1 Pump, 150 LF 24” pipe to tie into County High School outfall	A4	$460,763	$674,025	Y	0.66
Eagle and 20th St	N3930	Equivalent 42” pipe	B5	$930,146	$1,656,227	N	0.09
Cindy St and 19th St	N4145	Equivalent 36” pipe	B6	$1,482,875	$2,743,390	Y-Q	1.53
Harris and 10th Ave Expanded Neighborhood Project	N6000	4,500 LF 18" pipe; 12 intersections; 4 WQ Boxes	C1	$2,594,374	$4,313,171	Y	0.66

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On Packer St, at intersection of Olivia St. and Packer St	N2570	1 Additional Gravity Recharge Well/or alternative exfil.	D7	$264,649	$384,773	Y	0.11
Near Casa Marina Ct and Reynolds	N300	250 LF of exfiltration trench and 4 inlets	D8	$109,119	$167,042	Y	NA
James St and Grinnell St	N2530	Equivalent 24" pipe	E9	$400,887	$687,490	N	0.09
Eisenhower Dr between Angela and Albury Sts	N2705	Equivalent two 24" pipes	J7	$304,383	$532,577	Y	1.44
Eagle between 16th and 17th Sts	N3810	650 LF of exfiltration trench and 8 inlets	K6	$272,224	$394,709	Y	NA
14th St north of Flagler Ave	N3820	550 LF of exfiltration trench and 8 inlets	K7	$236,233	$354,292	Y	0.07
Fogarty and 3rd St	N3220 (3225)	2 new pressurized recharge wells; 18" pipe install 300 LF(new)+360 LF(replacing 10")+275 LF(replacing 12") = 1,235 LF of pipe; about 12 inlets	M1	$3,127,658	$3,961,008	Y	2.06
Staples Ave between 6th and 7th Sts	N3410	450 LF of exfiltration trench and 8 inlets, 850 LF 18" pipe to a new outfall	M2	$344,742	$619,875	Y	NA
4th St near Flagler Ave	N3310	1 Gravity Recharge Well/or alternative exfil.	M3	$264,649	$384,773	Y	0.11
3th St near Flagler Ave	N3320	1 Gravity Recharge Well/or alternative exfil.	M4	$264,649	$384,773	Y	0.08
N. Duval St Inlets		30 inlets to be repaired /replaced	E10	$143,550	$495,000	Y	NA

Note:
Conceptual planning level costs are in 2011 dollars. Recommendations within this report, Yes/No/Y-Q = Yes but feasibility is questionable. NA=not applicable, typically because these projects are based more on professional judgment and citizen reports than model quantification.

SECTION 1

Introduction

The City of Key West's (the "City's") stormwater system consists of approximately 63 permitted outfalls and associated stormwater collection systems,[1] 54 vertical exfiltration drains, 5 pressurized wells (at 3 locations), approximately 121 stormwater gravity recharge wells, and associated collection and treatment systems. There are other small facilities that include open-bottom catch basins and swales that assist in allowing ponded water to infiltrate into the porous soils on the island. The City occupies the island of Key West, some nearby small islands, plus the northern half of North Stock Island (north of U.S. Highway 1). Both Fleming Key and Sigsbee Park are part of Naval Air Station Key West and are inaccessible to the public; the Navy operates other properties on the island as well. Sunset Key (near Mallory Square) is residential and is part of the City, but is physically isolated except for sanitary sewer service. The City is responsible to operate only its own stormwater systems (not the Navy's or Florida Department of Transportation's [FDOT's]) and this report focuses only on the City's facilities. Key West operates its municipal separate storm sewer system (MS4) under a federal permit, called an MS4 National Pollution Discharge Elimination System (NPDES) permit. This operation is funded by a stormwater management utility (SMU).

1.1 History of Stormwater Management in Key West

Much of the City's stormwater infrastructure was built on an as-needed basis. Over the years, the City realized the need to develop planning documents to assist in the prioritization of stormwater mitigation projects. A drainage investigation report was prepared in 1989,[2] and a stormwater runoff study was prepared in 1994.[3] In 2001, the City developed its Long Range Stormwater Utility Plan, which is currently being implemented. As part of its regular operations, the City has identified a need to update its Long Range Stormwater Utility Plan to continue to move its stormwater capital program forward in a more efficient manner. As part of this project, the City wanted to take advantage of recently obtained aerial mapping and topographic data to update its inventory of stormwater infrastructure and to develop a Stormwater Master Plan. This task is the start of the City modernizing its utility database into a geographic information system (GIS).

The City drainage systems are a combination of infrastructure designed to standards at the time they were constructed, but some older systems were nonstandard (that is, too small) when constructed. Many of these nonstandard systems appear to have been built by developers. Other nonstandard systems appear to have been built by City staff with whatever pipe and materials were on hand at the time of construction. These older (prior to 2000) outfall collection systems were not designed with pollution control as required by

[1] There are other private property outfalls and approximately 40 Navy outfalls for which the City does not have direct responsibility.

[2] CH2M HILL. 1989. *Part 1 Drainage Investigation for the City of Key West*. Prepared for the City of Key West. July 1989.

[3] Kisinger, Campo, and Associates, Inc. (KCA). 1994. *Stormwater Runoff Study*. Prepared for the City of Key West. September 1994.

today's standards. There are a number of artificial and natural drainage systems that also serve the City.

Prior to the 1980s, stormwater gravity recharge wells were not as prevalent as they are today. The oldest operational City well located on Margaret Street between Virginia and Catherine Streets was constructed prior to the 1970s. The history of this well is unclear. A total of 12 wells were built as part of City development of Mallory Square, Key West Bight parking lots, police and fire facility parking lot, and the Southernmost Point.

In 1989, the City initiated its comprehensive planning efforts. CH2M HILL was tasked to begin the process of identifying drainage structures through field investigation because plans did not exist in City records for much of the drainage system. The Drainage Investigation Report was completed in 1989.

As required by the City's Comprehensive Plan, Kisinger, Campo and Associates (KCA) performed a 1994 Stormwater Runoff Study that identified and mapped flood problems (KCA, 1994). The report included aerial mapping using surveyed ground controls. Some surveying of stormwater facilities was included in the scope of work. Eight flood areas (several blocks large in some cases) were identified and ranked by severity. The number of structures and cost to address these problems was estimated. This report highlighted the state of stormwater system and noted many deficiencies, such as clogged inlets, too few and poorly placed inlets, collapsed outfalls, and other similar problems common with an aged system. The 1994 KCA study recommended future work to include modeling and design as funds became available. A total of 20 wells were built by the City Engineering Department in the flood zones identified in the 1994 KCA report. The City also created the stormwater program in the Utilities Department in part resulting from the recommendations of this report.

The Utilities Department began a long process of developing an inventory of its system (both sanitary and stormwater) and cleaning and repairing its sewers. In general, sanitary repairs were implemented at a higher priority because of health concerns. However, progress was also made in improving the storm sewer system. In June 2001, the City created a Long Range Stormwater Utility Plan that identified seven additional flood zones for a total of 15 flood zones which were principally located in low areas.[4] The plan further documented existing systems and identified capital projects and funding requirements. The City stormwater plan incorporated policies set out in a City-generated Water Quality Improvement white paper that was the basis for the policy related to diverting water from outfalls primarily by shallow recharge wells[5]. One well was built in a flood zone identified in the 2001 Long Range Plan but funding limitations kept the ambitious plan from being implemented.

Based on changes to state law and rules, the City implemented a stormwater utility to fund their stormwater program in 2003. This utility has allowed the City to implement many more projects than was previously possible. The City's Utilities Department led the installation of additional wells to address standing water problems not identified in the KCA Report or the Long Range Plan. In 2006, Perez Engineering & Development, Inc. (Perez) and Parsons prepared a Draft Design Memorandum for the City that updated the

[4]City of Key West. 2001. *Key West Long Range Stormwater Utility Plan*. Prepared by the City Engineering Services. June 2001.

[5]City of Key West. 2000. *Water Quality Improvement Program*. A white paper prepared by the City. Undated, circa 2000.

mapping and the City computer simulation model of the drainage system.[6] This report helped identify additional locations where recharge wells may be located. This 2006 work provided the City with Adobe and AutoCAD maps of their stormwater system. Many of their existing inlets were surveyed to obtain elevations, and the main island was simulated in the Interconnected Pond Routing (ICPR) computer model. This 2006 ICPR model is referred to as the City's stormwater system model in this report.

A total of 49 stormwater gravity recharge wells have been installed by the City's Engineering Department (not including the original Margaret Street well). The Utilities Department has constructed approximately 66 additional stormwater gravity wells and 5 stormwater pump-assisted wells (2 at Simonton/Front Street, 2 at White/Casa Marina Court, and 1 at Patricia/Ashby). In addition, the Utilities Department restored hydraulic conveyance capacity to seven critical drainage flow ways (canals/ditches) and provided for the associated environmental mitigation. These flow ways directly serve more than 14 essential stormwater collection system outfalls.

1.2 Purpose

This Stormwater Master Plan updates the previous 1994, 2001, and 2006 studies. This effort involves the following:

- Collecting existing stormwater drainage reports, record drawings of stormwater infrastructure, and other available data
- Supplementing these existing data with a field inventory of stormwater infrastructure using global positioning system (GPS) technology to confirm existing information and to augment the dataset where no records exist
- Updating the City's existing stormwater drainage model with this newly compiled data
- Preparing a stormwater master plan report

This 2012 Stormwater Master Plan mapped locations within the City that flood from heavy rainfall, and developed and prioritized future stormwater flooding mitigation projects to update the Long Range Stormwater Utility Capital Project Plan.

1.3 Master Plan Report

This document serves as a basis for alternative analysis of potential stormwater mitigation projects. CH2M HILL's scope called for up to 20 new projects to be recommended and prioritized. More than 20 were identified, and 56 potential conceptual projects were evaluated in this study. However, this list of projects is not all-encompassing. From time to time, new projects may be identified by the City to meet a deficiency not previously identified. An area may include some stormwater upgrades while a street or neighborhood may be addressing a different issue, such as repaving or sewer repairs. Often new issues arise during the detailed design phase of the project that may lead to alterations, which is why projects listed here should be considered conceptual. The availability of funding may also affect which projects are implemented. Smaller projects may be handled under the

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[6]Perez and Parsons. 2006. *City Of Key West Stormwater Drainage Improvements, Phase II: Draft Design Memorandum*. Prepared for the City of Key West, Florida. October 2006.

operations maintenance budget, while others will need additional capital improvement financing. Finally, master plans are not meant to be static documents and need regular updates to address new priorities and regulations. Cities normally update stormwater master plans every 5 to 12 years, depending on the level of activity.

Projects identified in the 2012 Stormwater Master Plan were placed into groups that are more effective or less effective, and some conceptual projects were determined to be not effective. This grouping allows the City to address projects under changing funding and project opportunities. To this end, this document includes the following:

- Description of the data collection effort and methodology
- Summary of data collected
- Description of the modeling approach and set-up
- Summary of the modeling results
- Estimate of stormwater quality loadings
- Development of projects in areas of known flooding problems

Attachments to this 2012 Stormwater Master Plan are as follows:

- Attachment A: North Stock Island Stormwater Analysis
- Attachment B: Selected Stormwater BMPs Fact Sheets
- Attachment C: Cost Estimates
- Attachment D: Selected Exhibits, Large-Scale Maps

SECTION 2

Data Collection

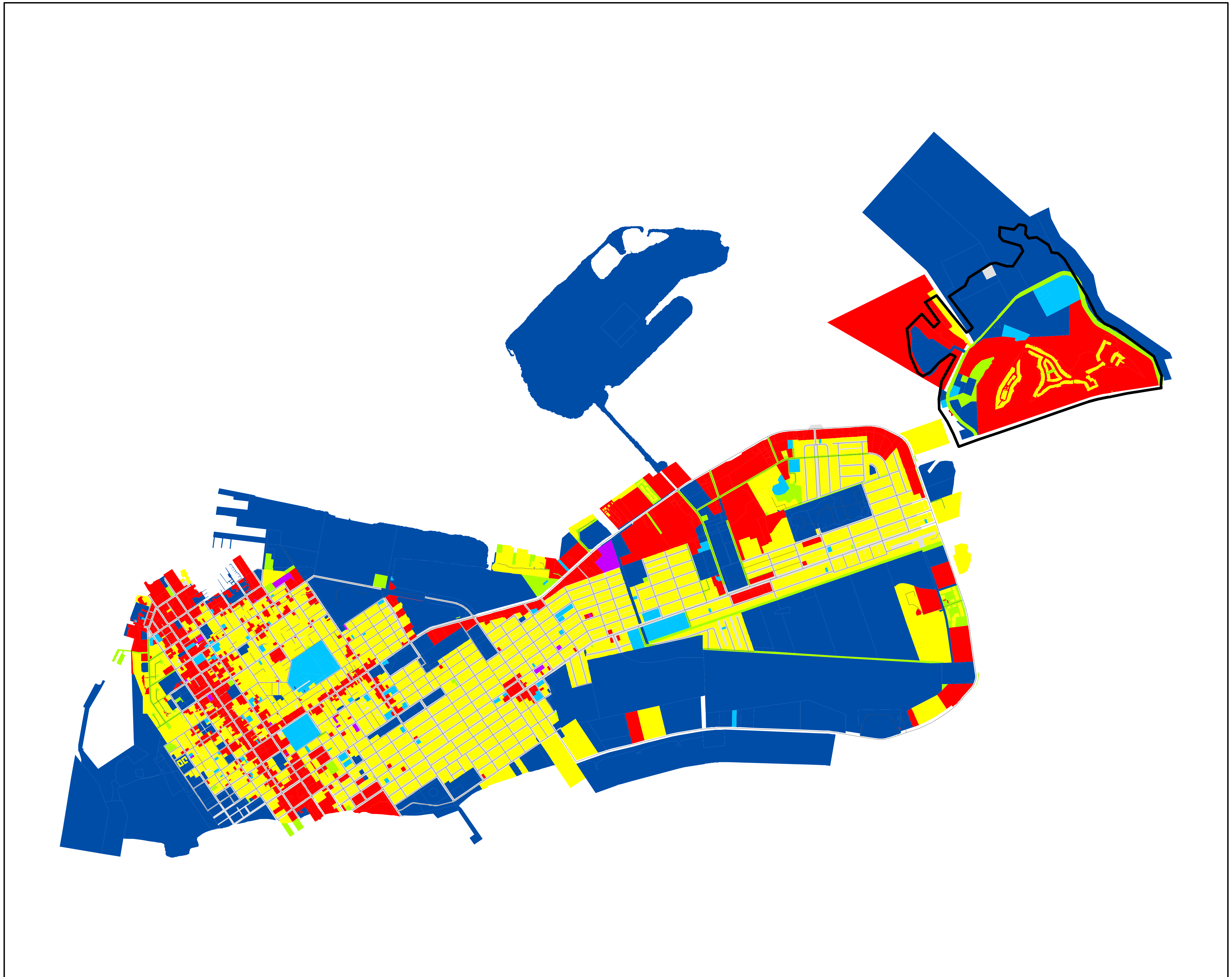
The data collection effort involved reviewing existing stormwater drainage reports, record drawings of stormwater infrastructure, and other data. Literature was supplemented by using GPS technology to inventory stormwater facilities in the field. The GPS data collection effort was conducted from January 28 to May 20, 2011. This section describes the data used related to the Stormwater Master Plan.

2.1 General Conditions

The island of Key West is located approximately 130 miles southwest of Miami at the end of U.S. Highway 1 (Overseas Highway, US 1). The City of Key West consists of the main island, some surrounding smaller islands/keys, and the northern section of Stock Island located to the east of the main island. The entire Florida Keys, including Key West, are inside Florida Keys National Marine Sanctuary boundary. The City consists of approximately 5.9 square miles of land, but the Navy occupies a large portion of the area. The main island is approximately 3.5 miles long and 1 mile wide. Key West is the county seat of Monroe County. The county airport also occupies approximately 250 acres of land created primarily on fill in a salt marsh on the southeast side of the island. North Stock Island is delineated by U.S. 1 on the southern boundary. Exhibit 2-1 shows the general land use on the island. City and county offices, and Navy and county lands are shown as government use; schools, hospital, fire stations, and similar are shown as institutional use. These uses were derived from the Monroe County property appraiser database. The main island of Key West is primarily residential and commercial. North Stock Island contains the Florida Keys Community College, a closed landfill, hospital, elementary school, golf course with residences, botanical gardens, miscellaneous smaller businesses, and a county jail.

The City was initially developed on the higher land on the western portion of the main island, and this area (generally west of 1st Street) is known as Old Town. The elevations are higher just east of Duval Street at nearly elevation 15 (all elevations are expressed in North American Vertical Datum of 1988 [NAVD 88]; see datum discussion in Section 2.1.3). Old Town's landscape slopes down toward the Gulf of Mexico to the north and the Atlantic Ocean to the south. East of 1st Street is generally called New Town and is relatively flat. In 2008, the Florida Division of Emergency Management conducted a mapping update project that collected high-resolution aerial photographs and topographic (elevation) data. Exhibit 2-2 shows the general topography based on these new data (a larger map is included in Attachment D).

Key West is generally a low island consisting of a layer of sandy or marly soil, typically 3 to 5 feet deep on top of an oolitic limestone base. The limestone is characterized by having large cavities or cracks that is very porous. Freshwater seeping into the ground forms a thin layer of less-dense water and mixes with saltier groundwater over tidal cycles. Because of this porous characteristic and because there are no potable groundwater sources in the City, shallow reuse wells are used for stormwater control.



LEGEND

Streets

Property Use Type

- Un-assigned
- Commercial
- Government
- Industrial
- Institutional
- Miscellaneous
- Residential

North Stock Island

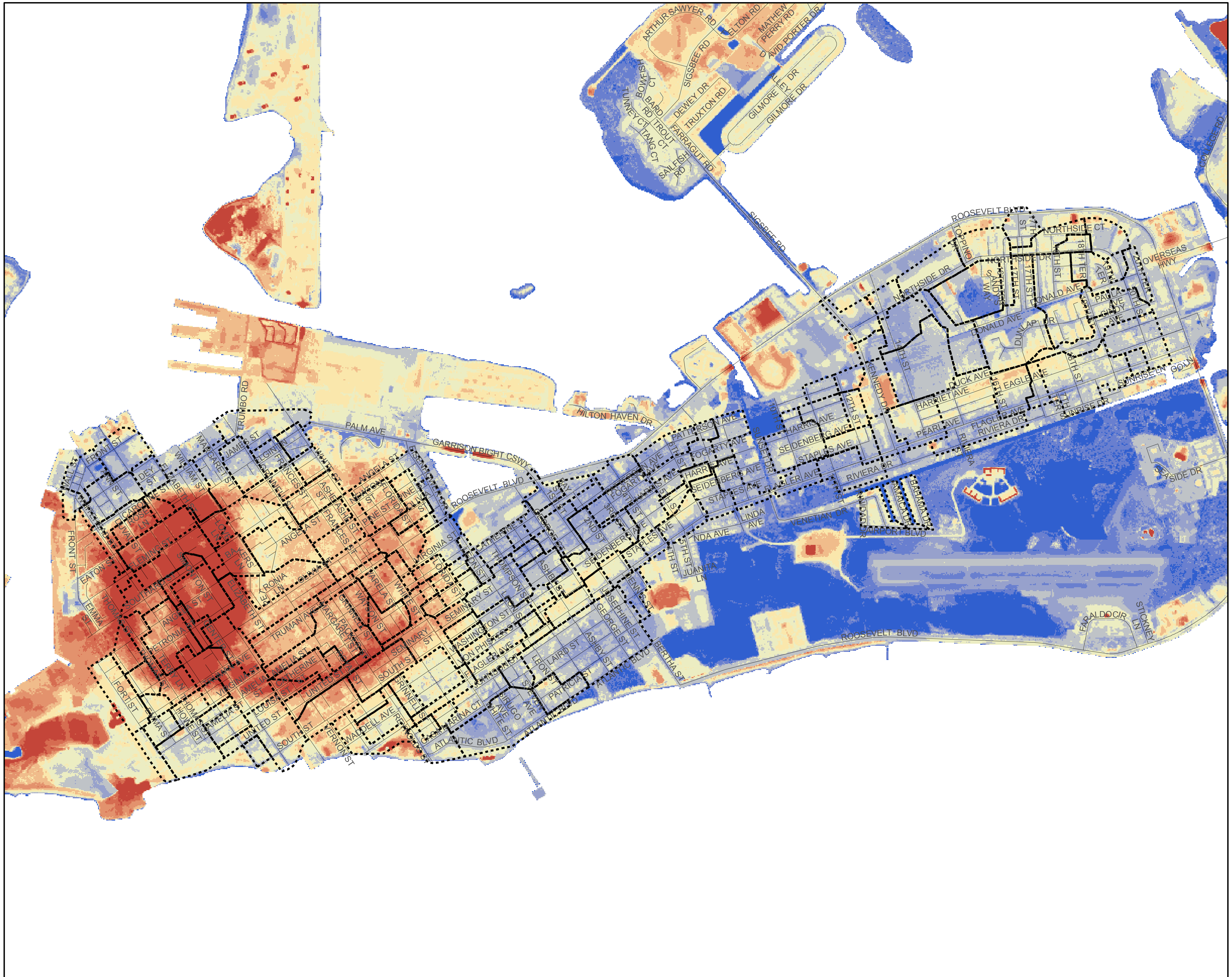
Notes:
Property uses are a generalized interpretation of the property appraiser's parcel data property use descriptions.

N

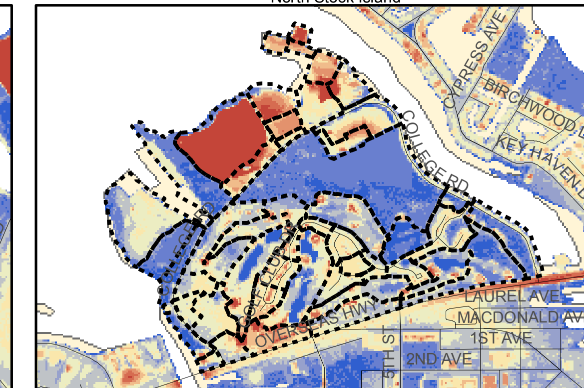
0 0.25 0.5
Miles

Exhibit 2-1
Land Use

Key West Stormwater Master Plan
Key West, Florida



North Stock Island



LEGEND

Roads

Sub-Basin

Digital Elevation Model
Elevation in Feet

- <0
- -0.1- 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4- 5
- 5 - 6
- 6- 7
- 7 - 8
- >8

Only City sub-basins contributing runoff to City-maintained outfalls are shown. City areas draining directly to Gulf, Ocean, or canals are not modeled, but are still managed for potential water quality effects.

N

0 0.25 0.5
Miles

Exhibit 2-2
Topography

Key West Stormwater Master Plan
Key West, Florida

\\GAINESVILLE\PROJ\KEYWESTFLCITYOF\414274KEYWESTSWMP\GIS\MAPFILES\FINAL\TOPOGRAPHY_20110808.MXD HHARDEST 8/10/2011 16:01:36

CH2MHILL

Exhibit 2-3 shows the U.S. Department of Agriculture's (USDA) Soil Survey for the island. Most of the island is listed as urban, which is a general term the USDA uses for developed land and no published soil data exist. Most soil data are available from soil borings conducted during construction projects, or City staff's general knowledge.

Experience has shown that the depth to rock varies greatly from one location to another. The groundwater table fluctuates with the tides because of the porosity of the rock. The elevation of the groundwater table is normally approximately 0.5 to 1.5 feet above the tide levels depending on proximity to the coast.

2.1.1 Climate

Because of the proximity of the Gulf Stream to the Straits of Florida (approximately 12 miles) and the tempering effects of the Gulf of Mexico to the west and north, Key West has a notably mild, tropical-maritime climate where the average temperatures during the winter are only approximately 14 degrees Fahrenheit lower than in summer. Humidity remains relatively high during the entire year. There is no known record of frost, ice, sleet, or snow in Key West. Precipitation is characterized by dry and wet seasons. The period of December through April receives slightly less than 25 percent of the annual rainfall. This rainfall usually occurs in advance of cold fronts in a few heavy showers, or occasionally five to eight light showers per month. June through October is normally the wet season, receiving approximately 53 percent of the yearly rainfall total, in the form of numerous showers and thunderstorms. Early morning is the most likely time for precipitation. Direct hurricane strikes are not common, but the City has experience several severe wind storm flooding events (Tropical Storm Fay and Hurricane Wilma are two notable recent wind storms).[1]

Exhibit 2-4 includes a summary of monthly totals for precipitation and temperature. Included in this summary are the number of storms with precipitation totals between 0.1 and 1.0 inches. The 0.1-inch threshold is important because this value is often used to distinguish storms that may cause enough runoff to have a measurable effect, approximately 62 storms per year at the City. The larger storms are much fewer, approximately 10 storms per year. Of note in this National Oceanic and Atmospheric Administration (NOAA) dataset is the highest daily storm of 22.75 inches that occurred in November 1980. Daily precipitation data sometimes masks storm events that have duration longer than a calendar day (over midnight), but as shown in Exhibit 2-4 storms with rainfall totals in excess of 5 inches can occur almost any time of the year.

An important rainfall data input is the storm characteristics used to assess and design infrastructure. *Design storms* are expressed in terms of a return period, which is an expression of probability. For example, a 10-year storm means that there is a 1 in 10 chance that a storm at least as large as that one would occur in any given year. The Federal Emergency Management Agency (FEMA) often uses the 100-year storm (1 percent chance of occurrence per year) as a threshold for determining flooding potential. However, extensive flooding can occur with much smaller storms, including the 2-year storm (50 percent chance of occurrence). The design storms used in the evaluation are shown in Exhibit 2-5. These volumes are based on standard literature values available from either the South Florida Water Management District (SFWMD) or FDOT. The SFWMD guidance was used to establish the time distribution of rainfall intensities (hyetographs).

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[1]See http://www.hurricanecity.com/city/keywest.htm for more information on hurricanes.

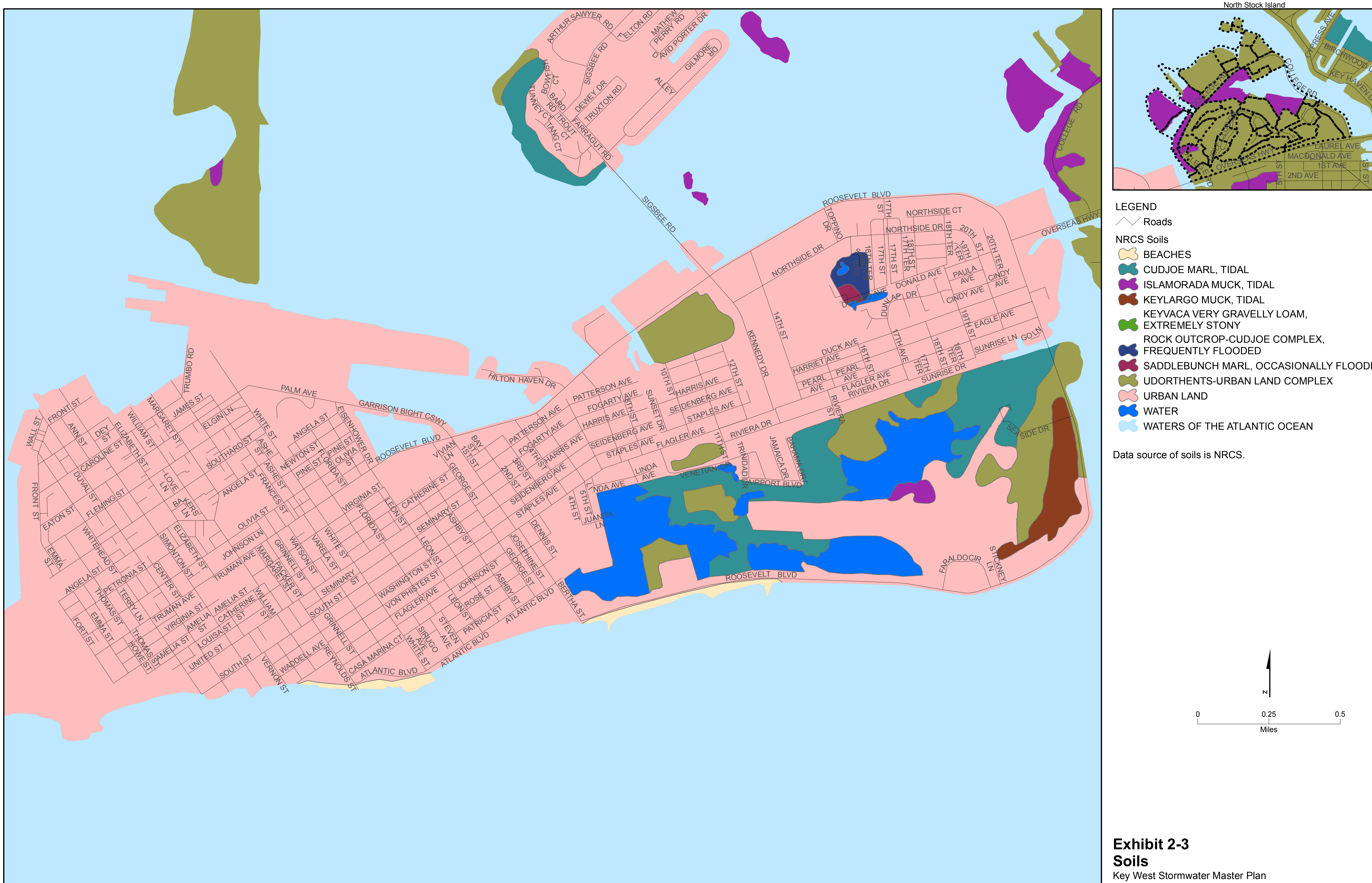

Exhibit 2-3
Soils
Key West Stormwater Master Plan
Key West, Florida

EXHIBIT 2-4
Summary of Long-Term Climate Data for Key West, Florida
City of Key West 2012 Stormwater Master Plan

	Temperature			Precipitation				
Month[1]	Daily Max	Daily Min	Mean	Mean	Median	Highest Daily[2]	Mean No. of Days[3] ≥0.1 inch	Mean No. of Days[3] ≥1 inch
Jan	75.3	65.2	70.3	2.22	1.12	6.42	3.6	0.5
Feb	75.9	65.7	70.8	1.51	1.36	2.54	3	0.4
Mar	78.8	68.8	73.8	1.86	1.46	5.26	3	0.4
Apr	81.9	72.1	77	2.06	1.6	6.19	2.9	0.6
May	85.4	75.9	80.7	3.48	2.65	7.2	4.4	1.1
Jun	88.1	78.7	83.4	4.57	3.54	5.14	6.6	1.3
Jul	89.4	79.6	84.5	3.27	3.24	3.05	6.5	0.8
Aug	89.5	79.2	84.4	5.4	4.17	3.29	9	1.6
Sep	88.2	78.5	83.4	5.45	5.43	6.06	9.7	1.3
Oct	84.7	75.7	80.2	4.34	3.08	6.49	6.4	1
Nov	80.6	71.9	76.3	2.64	1.26	22.75	3.5	0.6
Dec	76.7	67.3	72	2.14	1.64	6.66	3.2	0.6
Annual	82.9	73.2	78.1	38.94	38.26	22.75	61.8	10.2

Notes:

Key West International Airport, Source: NOAA Coop Station 084570 summary report.

[1]Monthly summary of temperature and mean/median precipitation from 1971 to 2000
[2]Derived from 1948 to 2001 data
[3]Derived from 1971 to 2000 daily data

EXHIBIT 2-5
Design Storms for the City of Key West
City of Key West 2012 Stormwater Master Plan

Return Period (years)	Duration (hr)	Distribution	Volume (in)
2	24	FLMOD	5
5	24	FLMOD	6
10	24	FLMOD	7
10	72	SFWMD72	10.5
25	24	FLMOD	9
25	72	SFWMD72	12
100	24	FLMOD	12
100	72	SFWMD72	17

Notes:

Used Interconnected Pond Routing (ICPR) distributions as identified above: Florida-modified Type II storm (FLMOD) or the SFWMD 72-hour distribution (SFWMD72).

2.1.2 Previous Reports

There were two reports that summarize most of the data utilized from historical studies. The first report is a historical summary of the City's stormwater program compiled by the City in 2010.[2] The report details the development of the City's program and includes several design guidelines that the City is currently using. The second reference is the 2006 Perez and Parsons design memorandum that provides the updated City ICPR model and a brief update on the then recent projects.[3] Additional infrastructure that was built since the 2006 report was based on plans provided by the City.

2.1.3 New Data Sources

Elevations on a landscape are set relative to long-term elevations of the ocean and a network of fixed benchmarks. The U.S. National Geodetic Survey (NGS) maintains this network and has updated the historic standard established in 1929 with a new standard referred to as the 1988 datum. In practical terms, the landscape has not moved, but the yardstick used to measure the elevation has been shifted. The SFWMD and most municipalities have traditionally required the National Geodetic Vertical Datum of 1929 (NGVD29) for surveying and expressing elevations. However, the SFWMD and other municipalities are in the process of switching to the North American Vertical Datum of 1988 (NAVD88). This is clearly a time of transition so available literature is presented in one or the other reference datum. Except for the most recent work (post-2010 or so), elevations are typically expressed in NGVD29. The conversion between NAVD88 from NGVD29 in Key West is to subtract 1.345 feet (ft), so the reported NAVD88 elevation would be lower for the same location. This conversion may vary slightly from one side of the City to the other, but this difference would be slight and of little consequence to normal public work facilities. The conversion was computed using the NGS VERTCON2 program at latitude 24°33′26″ N and longitude 81°47′14″W.[4]

As discussed previously, a new topographic map (that is, elevations) is available for the City. The Light Detection and Ranging (LiDAR) topographic dataset is an aerial survey conducted for the Florida Division of Emergency Management LiDAR Project. These data were produced in Monroe County by a team led by CH2M HILL under the guidance of a professional mapper/surveyor, and are available to the public through the SFWMD. The bare-earth surface contains voids (blank data) in areas that were densely vegetated, covered by bridges, buildings, water, fresh asphalt, sand, and so forth. The LiDAR raw data point cloud was flown at a density sufficient to support a maximum final post-processing spacing of 4 feet for unobscured areas. 3001 Inc. flew the survey January 12, 2008, through February 8, 2008. CH2M HILL was the prime contractor and was responsible for quality control and data deliverables, as well as the overall task execution. The data used for the Stormwater Master Plan were the same data available to the public and were obtained formally through the SFWMD.

LiDAR survey data was obtained to support the creation of updated FEMA Flood Insurance Rate Maps (FIRM) in coastal areas that is being conducted by the Division of Emergency

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[2] City of Key West. Stormwater Program. Internal Utility Report. June 2010.

[3] Perez and Parsons. City Of Key West Stormwater Drainage Improvements, Phase II: Draft Design Memorandum. Prepared for the City of Key West, Florida. October 2006.

[4] http://www.ngs.noaa.gov/cgi-bin/VERTCON/vert_con.prl

Management. A key difference in these elevation data and previous work is that all elevations are now expressed in NAVD88. The output of the LiDAR project is 1-foot contours, but the accuracy is technically at a 2-foot contour interval, with the 1-foot contours interpolated. Data accuracy of elevations obtained by remote sensing is an important consideration.

The LiDAR Project generally followed the same specifications that the Southwest Florida Water Management District (SWFWMD) uses. LiDAR point cloud data contains reflections from all surfaces, including the top of trees and buildings. These data need filtering to obtain bare land surface elevations. Post-processing included comparing ground truth checkpoints with LiDAR points from a subset of data points within 3 feet horizontally from the ground truth points. The points that fell above the ground surface on vegetation canopies, buildings, or other obstructions were removed from the data set. Comparisons were also made between the survey points and the LiDARderived terrain surface. These comparisons provide an additional verification of the LiDAR data against the survey data. The following paragraph is an excerpt of the accuracy report that is associated with the specific LiDAR data collected from the City and nearby islands (this report is extracted from the metadata file):

> *Ground truth data were collected for each of the following land cover categories: 1. Bare-earth and low grass 2. Brush lands and low trees 3. Forested areas fully covered by trees 4. Urban areas. The Fundamental Vertical Accuracy is calculated using the bare-earth and low grass land class. A comparison of these values indicated a Vertical Root Mean Square Error (RMSEz) of 0.19 feet, which equates to a Vertical Accuracy of 0.37 feet at the 95 percent confidence level. The Supplemental Vertical Accuracies are calculated using each of the land cover classes, except for the bare-earth and low grass land class. The remaining land cover classes that are used for comparisons are brush lands and low trees, forested areas fully covered by trees, and urban areas. The RMSEz values and Vertical Accuracies are shown with each respective land class, along with histograms of vertical error distribution. Brushland and low trees set includes only those points that were collected in areas of brush lands and low trees. The resulting RMSEz is 0.27 feet, which equates to a Vertical Accuracy of 0.53 feet at the 95 percent confidence level. Forested set includes only those points that were collected in forested areas fully covered by trees. The resulting RMSEz is 0.13 feet, which equates to a Vertical Accuracy of 0.25 feet at the 95 percent confidence level. Urban Land Cover only those points that were collected in areas of urban land cover. The resulting RMSEz is 0.15 feet, which equates to a Vertical Accuracy of 0.29 feet at the 95 percent confidence level. The Consolidated Vertical Accuracy is calculated using all land cover classes. The result of these comparisons of these values indicated a Vertical Root Mean Square Error (RMSEz) of 0.17 feet, which equates to Vertical Accuracy of 0.33 feet at the 95 percent confidence level.*

In general, though the raw LiDAR results here are highly accurate for aerial survey methods, the reduction of the point cloud of reflections through filtering software, coupled with geo-positioning of the aircraft and control points, yields accuracies of approximately 4+ inches for well-defined surfaces like bare ground, and approximately 7+ inches for brushy and low treed areas. Despite this relatively good accuracy for a large scale survey, the National Map Accuracy Standards would not allow these data to be listed as more accurate than ±1 foot (that is, 90 percent of the data must lie within one-half the contour interval) and the maps are considered accurate to a 2-ft contour interval.

The LiDAR project collected high-resolution aerial photographs during the same time period. All topographic data were georectified (edge matched and assigned real-world coordinates) and delivered in a GIS database (ArcMap-compatible). Many geographic data sets are now publically available in GIS format. Additional data layers obtained from the County GIS office included roads, parcels, and political boundaries. Soils data and other geopolitical information were obtained from the Florida Geographic Digital Library.

2.1.4 Tidal Datum and Levels

A main consequence of the datum conversion is a restatement of the sea level elevations surrounding Key West. The main NOAA tide gauge at Key West (ID: 8724580) is located in the boat basin on the west side of the main island. The updated tide levels are presented in Exhibit 2-6 and are based on NOAA tide data from 1983 through 2001. As shown in Exhibit 2-6, mean sea level used to be near -0.2 in the NGVD29 reference datum, but is now expressed close to -1.5 under the new NAVD88 datum. Similarly, stormwater evaluations are most often conducted under mean high water (MHW) conditions that used to be near elevation 1.1 NGVD29, but are now close to -0.2 NAVD88.

For purposes of this study, the boundary condition at the ocean is being set at elevation 0 NAVD88, which is closer to the mean higher-high water (MHHW) and represents a seasonally high high-tide level. This higher level is consistent with current City design policy.[5]

EXHIBIT 2-6
Tide Levels at the Key West NOAA Gauge in Different Vertical Datum
City of Key West 2012 Stormwater Master Plan

Description	Acronym	Elevation NAVD88	Elevation NGVD29
Mean Higher-High Water	MHHW	0.05	1.40
Mean High Water	MHW	-0.24	1.11
Mean Tide Level	MTL	-0.88	0.47
Mean Sea Level	MSL	-1.52	-0.18
Mean Lower-Low Water	MLLW	-1.76	-0.42
Mean Range of Tide	MN	1.28	1.28
Highest Water Level	MAX	1.98	3.33
	MAX DATE	9/8/1965	

Notes:
All elevations are in feet.
Based on NOAA Gauge 8724580 for Key West, accessed 9/1/2009

2.1.5 Sea Level Rise

The change in vertical datum is only a shift in the values that elevations are expressed. There is no physical landscape change associated with the conversion. However, there is a documented rise in sea level over time resulting from an increase in volume (melting glaciers), regardless of the actual cause. The long-term sea level rise at Key West has

[5]City of Key West (City). 2010. *2010 City of Key West Stormwater Program*. Internal document prepared by the City. June 2010.

historically been at approximately 2.2 millimeters per year (mm/yr).[6] The U.S. Army Corps of Engineers (USACE) recently analyzed the rate of change and has made extrapolations in the future (EC 1165-2-211). This USACE analysis must be considered for all USACE Civil Works projects. The long term estimates for sea level rise varies between 0.5 to 1.5 feet over the next fifty years.[7]

If the historical trend continues (2.2 mm/yr), then the rise in a 50-year period would total approximately 0.4 feet. The USACE guidance listed projections are much higher. They group the likelihood of occurrence in three categories: low, intermediate, and high. The sea level rise associated with these three categories is 0.8, 1.6, and 2.3 feet, respectively, during a 50-year period (Year 2061). The USACE guidance states that observed data should be used as the low estimate if there is a long-term record, which Key West has.[8] Assuming then that the USACE results are approximately double the observed records at Key West, the range of potential sea level rise around the City is approximately 0.5 to 1.0 ft in 50 years for the low to moderate projections.

2.2 Reported Flooding Problem Areas

The City conducted three workshops to solicit input from the community. During the workshops, upcoming projects were discussed and the public was invited to mark up maps showing problem areas. City and CH2M HILL staff discussed the problem areas with the citizens to determine the nature and severity of the problem. Additional information was obtained from FEMA.

FEMA insurance claims include historical events that were not likely a result of stormwater flooding (that is, hurricane and tropical storm claims were included). However, FEMA categorizes the claims into repetitive and severe repetitive categories, and the City results are as follows:

- Severe Repetitive Loss Properties (as of 10/31/2010): 8
- Repetitive Loss Properties (as of 5/31/2010): 216

These FEMA claims are confidential data subject to the federal Privacy Act so no specific data about the affected parcels are available publicly. The City allowed CH2M HILL to observe a large scale map with many dots. Note that a FEMA claim may not always be an accurate conclusion of severity of flooding, just that the owners have made repeated claims.

From this visual review, a general mapping of areas with known repetitive claims was developed for informational purposes. The public comments and FEMA reported losses were combined on a single map, as shown in Exhibit 2-7. Additional observations were made during the large seasonal storms that occurred mid- and late-October 2011. Regardless of the source, the reported flooding problem areas generally correspond to those low spots that experience flooding already identified in previous studies and by the City through public complaints.

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[6](http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8724580 Key West, FL)

[7]Shugar, K. and J. Obeysekera. 2010. Climate Change and Sea Level Rise Planning and Adaptation Strategies. Presentation to Governing Board Joint Workshop with the Water Resources Advisory Council. South Florida Water Management District. West Palm Beach, Florida. February 10, 2010.

[8]Key West data go back 94 years, see Ref. 6

LEGEND

- Approximate Locations of FEMA Claims for Severe, Repetitive Property Loss
- Approximate Locations of FEMA Claims for Repetitive Property Loss
- Public Reports of Standing Water

Sources:
Residents of Key West- Public Meeting Responses (April 26 & March 21, 2011)
FEMA claims are approximate locations as provided by the City.
No major FEMA claims reported on Stock Island.

N

0 0.25 0.5
Miles

Exhibit 2-7
Reported Drainage Issues

Key West Stormwater Master Plan
Key West, Florida

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CH2MHILL

2.3 GPS Field Data Collection

The City has been working to improve its stormwater infrastructure since the 1990s and over time has had its consultants collect inventory data. Each time this occurs, new information is developed. However, much of these data were scattered on CAD files developed with various style conventions. Also, OMI operates both the sanitary system and storm sewers under contract for the City. The operators have a long tenure and, like many Public Works departments, have staff who know how the pipes are connected better than most reports can express. Because most new data are being managed in GIS format, the City included a task to create a detailed stormwater system inventory utilizing the latest GPS technology to consolidate information into a common platform. Because of the timing of the project and the funding sources, this field data collection program focused on building a complete City stormwater facilities inventory and then included the sanitary system where the two were collocated. The City purchased the GPS unit, and OMI will continue to use it to collect data for the GIS database in the future. This section of the report describes the GPS field data collection program conducted under this project.

2.3.1 Coordinate System, Datum, and Units

The data collected is presented in the horizontal projected coordinate system of North American Datum of 1983 (NAD83), State Plane Florida East (feet), and using a vertical datum of NAVD88 (feet). However, the data was collected using the WGS 84 geographic coordinate system. During data post-processing and exporting procedures described later in this document, the data were adjusted to a geographic coordinate system using the NAD83 horizontal datum. This procedure was based on the Trimble Corporation guidance (GPS equipment provider).

2.3.2 Equipment and Accuracy

To obtain the best possible accuracy, a Trimble model GeoXH GeoExplorer 2008 series GPS data logger unit with an 85320 Tornado Antenna mounted on a backpack was utilized. The GeoXH handheld delivers real-time sub-foot accuracy with the internal antenna (using H-star technology), and has the potential to achieve decimeter accuracy with the optional Tornado™ external antenna. Terrasync software was loaded on the mobile device, and Pathfinder Office software was loaded on a laptop for office use to create a data dictionary, transfer files, post-process data, and export data to GIS data files.

2.3.3 Feature Types and Attribution

A data dictionary was created prior to field data collection to identify which types of features will be collected, what attributes and attribute values would be associated with each feature, and how they would be symbolized on the GPS data logger screen. Data dictionaries help increase data collection efficiency and improve the integrity of the data by standardizing the attribute information collection with the use of dropdown menus pre-populated with defined attributes. The following features were captured to model and map the City's stormwater system as follows:

- Catch Basins
- Manholes
- Wells (shallow vertical French drains [VFD] and the deeper gravity/pumped wells)
- Outfalls

2.3.4 Field Collection Methodology

Prior to field collection, the GPS device was configured with the appropriate settings for the project. All data files, background files (street centerlines), and data dictionary files were transferred to the device, which was tested to make sure it was working properly and that the batteries were fully charged prior to deployment.

A hard-copy street map was used for reference. To ensure that the field team covered all ground and avoided missing features, the field team started at the farthest southwest corner of the island and traveled each street, starting southwest and heading northwest and then checking each side street. As each street was traveled, that street was marked on the hard-copy street map as ground already covered. Only features along City-maintained roads were required to be collected. However, sometimes additional features along County- and FDOT-maintained roads were also collected because of their importance for characterizing the stormwater system or their ownership was unsure by the field team.

The data collection team used bicycles to conduct the survey. There were several benefits of using bicycles as transportation. The field crew did not have the burden of having to deal with the often difficult parking, narrow streets, or one-way streets, especially in Old Town. In addition, and more importantly, using a bicycle enabled the GPS receiver to have a clear exposure to the sky most of the time, reducing physical interference and avoided the need to reset GPS receiver (which would have been necessary if the data collection was done by vehicle and the device was constantly being taken in and out of the vehicle). As such, the GPS receiver was able to collect good "between-intersection" data as well as increasing the accuracy of the feature positions as a result of a longer-maintained carrier signal lock.

2.3.4.1 Horizontal and Vertical Positional Data Collection

As the field team came across a stormwater feature (manhole, catch basin, well, or outfall), the location of the feature was collected using GPS. Each feature was assigned a unique field identification (ID) number.

A position was not logged until a carrier lock with a minimum of four satellites was maintained (typically five were available) and all parameters that were configured in the GPS settings were entered. To ensure that the required accuracy was being met in the field, Accuracy Based Logging was used. This allows the user to specify the required accuracy, and the GPS device does not log the position of a feature until the estimated required accuracy is met. The Accuracy Value for Display/Logging field was set to "Vertical" and "Post-Processed", which uses the predicted estimated vertical accuracy of the current GPS position (the estimated vertical accuracy that is likely to be achieved after the field data have been post-processed). The Post-processing Base Distance Field was set to less than 3 kilometers (km), as there are several base stations on the island within 3 km. The "Required Accuracy" was set to 1 ft. A carrier lock was able to be maintained for long periods of time unless it was disrupted by things such as tree canopy or tall buildings. In this case, a new carrier lock needed to be established and maintained. In some portions of town, like northern Duval Street, tall buildings did obstruct signals, which reduced the accuracy of the readings (especially the vertical readings).

2.3.4.2 Attribute Data Collection

While the location of the feature was being logged, the attribute information of the feature was also being populated in the data dictionary on the GPS device. Most of the attribute information required some type of measurement. For taking surficial measurements such as catch basin grate sizes, a standard measuring tape was used. For measuring the bottom of structures, depths to pipes, and pipe diameters, a 12-foot-long PVC measuring rod, marked in 0.1-foot increments, with an “L” extension piece was utilized. The rod was inserted into the structure. The “L” extension was used to feel the sides of the structure for the presence of pipes because many pipes were submerged in water and not visible from the surface. Pipe diameters were calculated by subtracting the depth to the top of the pipe from the depth to the bottom of the pipe.

Surficial attribute information, such as catch basin type, grate material, length, and width, were recorded while capturing the positional location of a feature. Sub-surface measurements, such as the bottom of structure, pipe inverts, pipe diameter, and material, were obtained with the assistance of OMI.

Initially all attribute information, including the sub-surface measurements, were entered into the data dictionary at the same time the location of the feature was being logged. However, at times, the field team was unable to get the sub-surface measurements. This was a result of several factors, such as a drain being too full of debris, or a jammed manhole lid. For these reasons, some features were re-visited and the data were obtained with the assistance of OMI. The data dictionary was modified at that point to include a feature attribute called “need OMI” with value options of “YES” or “NO.” The features that had “YES” value were re-visited and the attributes collected at a later date than the positional location. From a database management perspective, it became more efficient to collect only the surficial attribute information while collecting the location of the feature and re-visiting the site with OMI to get the belowground measurements for all data. This new method required the field team to modify the data dictionary again, removing the numeric fields for the pipe inverts, diameter, material, and so forth, only keeping the surficial attributes. This new method also required the field team to keep detailed sketches of the street intersections and mid-streets that contained stormwater features, with the features numbered using the unique field ID number that was assigned to each feature in the field and logged in the GPS device while getting its positional location. This allowed the features to be easily updated with the belowground measurement data at a later date using the field ID. Each field sheet was given a number (for example, FS-1, FS-2, FS-3, etc.). Polygon shapefiles were digitized to spatially represent the location of each field sheet for ease of reference within the GIS.

After each week of data collection, the stormwater engineer re-visited the previous week’s field coverage with OMI to collect missing sub-surface measurements. After recording these measurements on the field sketches, the measurement values were transferred to spreadsheet tables by feature ID number, and the tables were joined to the spatial data that was collected with the GPS unit, using the unique feature ID number as the field with which the join would be based.

2.3.5 Data Processing and Quality Control

To obtain the best accuracy possible, the data was post-processed using the differential correction wizard in Pathfinder Office software. Automatic carrier and code processing was performed using a single base provider. The closest CORS Key West base station with the highest integrity index was used. A process defined by Trimble was used to obtain the best possible height data.

Stormwater pipelines were digitized and attributed in the office using GIS software, based on the field sketches that were marked up by the stormwater engineer and OMI, who provided support in reconciling pipeline connection and material questions. After all data had been collected, a map book was created for second review by OMI personnel. A page was generated for each intersection and mid-block containing stormwater features (approximately 325 pages). The features were labeled with their field identity number, elevation, and inverts. Pipes were labeled by diameter. OMI marked these pages with any corrections or notes.

In locations where as-built design drawings were available, facility elevations were based on the land surveyed data. All GPS data were mapped and checked against available aerial photographs to ensure that data measured in the field generally corresponded to the aerial photographs (no obvious large differences).

There were a total of 1,449 pipeline segments in the initial database. After the initial data collection, 247 line segments/pipes did not have a field-measured diameter because of access issues. A total of 28 of those line segments without a diameter are not actually a pipe but a line segment, which was digitized anyway to show connectivity that was assumed. An example of this type of connection would be the connection between a catch basin, manhole, and well that all make up one triple-chamber baffle box. These maps were provided to OMI. OMI reviewed the questionable data and filled in missing locations, or corrected assumed connections that were not present. These corrections were made to the GIS before final delivery to the City.

2.3.6 Summary of Field Data Collection Results

Exhibits 2-8 and 2-9 list the total facilities inventoried in the GIS for drainage features and pipelines, respectively. Not all outfalls were field-located, as they were inaccessible by land and were estimated from maps or the nearest manhole. The 189 wells include both the shallow recharge wells (117 gravity, plus 5 pressurized) and vertical French drains (67). The vertical French drains are basically open-bottom inlets with deeper rock base, used to reduce standing water.

The GIS data inventory focused on City facilities and some state and private infrastructure was not inventoried. When as-built drawings were available, they were utilized to fill in some GIS data.

EXHIBIT 2-8
Final List of Stormwater Features in the GIS Database

Feature	Count
Catch Basins	1,162
Storm Manholes	515
Wells	189
Outfall	41
Mains (pipes)	1,579
Sanitary Manholes	348

Note:
Wells included gravity wells, vertical French drains, and pump-assisted wells

EXHIBIT 2-9
Final Inventory of Pipelines in the GIS Database

Diameter	# of Pipes	Total Length (feet)
NULL	218	6,804
4	1	20
6	27	832
8	76	3,588
10	67	3,649
12	234	14,355
15	232	13,526
18	392	19,487
24	179	16,160
30	30	4,010
36	60	10,297
42	35	3,863
48	18	2,768
54	5	650
60	5	1,682
Total	**1,579**	**101,691**

Notes:

NULL means that no diameter is recorded in the database, but these are typically small pipe lengths that connect inlets to the main drainage system.

Lengths are based on GIS map distances.

Elliptical pipes are recorded to their approximate vertical depth.

SECTION 3

Hydrologic and Hydraulic Modeling of Existing Conditions

This 2012 Stormwater Master Plan updates the cumulative studies conducted previously by others over the last 20 years. Each time a new study builds on previous evaluations, updating for new conditions, information, data, and regulatory criteria. The City had Perez and Parsons build a computer model for the main island stormwater system.[1] The 2005 City model was used as the starting point for this 2012 study. Data collected during the field inventory described in Section 2 was used to update the City's model. In addition to field data, as-built drawings of recent projects were used to be sure that the revised City model was accurate. The old City model had drainage wells and some pipes and inlets in roads owned and operated by FDOT or the County and not all of these were inventoried by the City. In these cases (mostly along Flagler, Truman, and Roosevelt, both north and south drives), the former City model data were used as is.

The computer modeling of the stormwater system on North Stock Island was conducted separately from the main island. Previous studies of the stormwater system included only the main island because there were no flooding complaints on North Stock Island. The City's stormwater utility recently conducted a standalone analysis of North Stock Island and this is incorporated into the City's Stormwater Master Plan as Attachment A. The separate analysis conducted in late 2010 was reviewed and updated after the field data collection to ensure it is current. The methods used for North Stock Island are consistent with those used for the main island, except that the North Stock Island analysis had no previous City model to start from. This section describes how the City's 2005 computer model was updated and provides the results of the simulated existing conditions for the main island.

3.1 Overview of ICPR Program

The ICPR computer program was used to simulate the design storms in the 2005 City model and was retained for the 2012 update.[2] This computer program is popular in Florida and is often used in designing stormwater facilities. It is a typical stormwater node-link model where excess stormwater is estimated to predict runoff hydrographs (flow versus time) into nodes, and links are hydraulic elements such as pipes, channels, or street overflow. A node can be a pond, manhole, or a placeholder used to connect links.

For simulating large storm events, hydrologic modeling entails predicting the stormwater runoff hydrograph from the sub-basins. The program was used to compute runoff using standard Soil Conservation Service (SCS) methods for the design storms described in Section 2. These SCS methods are standard practice and are accepted by the SFWMD. Unit hydrographs and rainfall distributions are defined by SFWMD criteria. Hydraulic modeling entails predicting flow rates in links and water depths at nodes in a process that is generically called *routing* the storm. Routing is accomplished by iterative numerical

[1] Perez and Parsons. City of Key West Stormwater Drainage Improvements, Phase II: Draft Design Memorandum. Prepared for the City of Key West, Florida. October 2006.

[2] ICPR Version 3.10, Service Pack 6; 2002 by Streamline Technologies, Inc.

solutions to equations of physics (termed *dynamic routing*) that account for water staging up and backwater effects from downstream nodes. By utilizing dynamic routing, the stormwater model can accurately compute the flows and water elevations in the entire drainage system. The capacity of street inlets is assumed to be non-limiting in the computer model, which is a common assumption used in stormwater master plans. Sometimes this assumption is inaccurate, especially in older neighborhoods. Therefore, the 2012 Stormwater Master Plan is primarily evaluating the capacity of the pipes and not the inlets. This assumption requires that inlet capacity be considered independently of the modeling results.

3.2 Sub-Basin Delineation

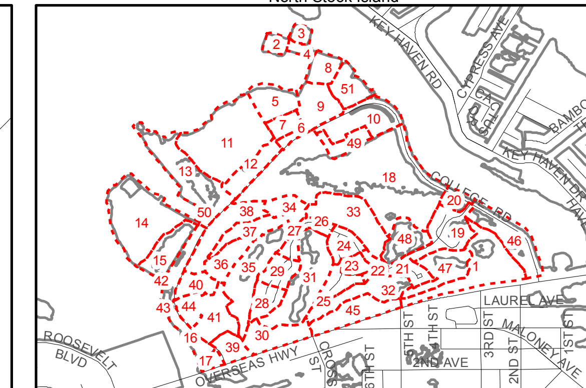
Sub-basins are used in the hydrologic model to estimate runoff, and each sub-basin is usually associated with a node. The 2005 City model was used as a starting point for the sub-basin delineation. Although the topography has been updated with more detailed mapping, the sub-basins in the City are typically defined by the pipe networks and street elevations. The blocks between major streets often form the sub-basin divides, and the previous work often used the sanitary sewer as-built manhole elevations near the middle of intersections as input data. The 2005 CAD file was not as accurate in its world coordinate location as the recent GIS data are. The 2005 maps of the system sub-basins were re-georeferenced using the new GPS-collected data and road intersections as control points to align the 2005 files as best possible. Georeferencing in this manner causes 'warping' and 'stretching' in some areas. Some of the boundaries where the warping was the most obvious were adjusted. These sub-basins were then double-checked by an engineer for accuracy and modified as needed to accurately represent the stormwater system. Exhibit 3-1 illustrates the revised sub-basins for the updated City ICPR model.

3.3 Model Set-up

The City's 2005 model was not available electronically for this project. This model was re-entered using the input files in the report. This 2005 model contained 206 nodes and 449 links. After entry, the results from the reconstituted model were compared to the 2005 report's results for the 10-year design storm, which is a reasonable sized storm for expecting moderate performance in the system. The median difference in estimated peak stages was 0.035 ft (less than 0.5 inches). However, there were several nodes (approximately 28) where the former model predicted much higher peak stages than the new model (greater than 0.5 ft). These areas also correspond to locations with high predicted peak flow rates, which is indicative of some instability in the numerical solution at these locations. The input data for these areas were rechecked and additional work was done to see if alternative routing parameters would alter the results (they did not). Furthermore, the peak stages predicted in the new model appeared consistent with surrounding node elevations. Without the original electronic files to compare detailed results and because the program code has been updated since 2005, the reconstituted ICPR model was deemed acceptable and was used as the basis for updates.

The initial change to the City's model was to change all of the input data into NAVD88. This was done by subtracting 1.345 feet from every elevation data point in the model. To develop a current (2011) computer model of existing conditions, it was necessary to enter projects implemented since 2005, including the White Street pump-assisted wells and approximately 31 new intersections with gravity wells. Because the George Street pump-assisted well system is still being designed, it was not included in the existing conditions model.

North Stock Island



LEGEND

- Roads
- Shoreline
- Sub-Basins

Only City sub-basins contributing runoff to City maintained outfalls are shown. City areas draining direct to Gulf, Ocean or canals are not mapped, but are still included for potential water quality effects.

0 0.25 0.5
Miles

Exhibit 3-1
Drainage Map
Key West Stormwater Master Plan
Key West, Florida

CH2MHILL

Another decision was made to construct one model for the entire main island. The 2005 model was similarly constructed. Sub-basins were assigned to "groups" in ICPR that generally corresponded to outfalls. Portions of the City can be simulated by turning groups on and off; however, the interconnections between sub-basins through street connections need to be considered when operating the program. Also, the same node and pipe naming scheme from the 2005 City model was used in the new model.

The following steps were also completed to develop an accurate update to the City's stormwater model:

- Pipe sizes and pipe connectivity were checked against the GPS field data. If a difference in pipe sizes existed between the field data and former City model, the pipe size and connectivity provided in the field data was used.
- Gravity recharge wells were already in the former City model, and it included proposed wells that were turned off (no flow). However, some of the new projects were in other locations and some of the proposed wells were not constructed. The locations of the existing gravity recharge wells were identified from field data and entered in the model as a node with rating curve associated with it. A typical rating curve was used for all the gravity wells (discussed further below).
- The GIS topographic data was used for calculating elevation- area for each basin. The Digital Elevation Model (DEM) based on the LiDAR data was used to intersect the sub-basin boundary to produce the stage-area table for each sub-basins and then entered into the model. The drainage sub-basin contributing areas were also updated in the model based on the new GIS work.
- Three new sub-basins were added to include areas of reported flooding problems or to better route stormwater to the seawall where it currently drains. The Patricia and Ashby area was modified to remove a wetland south of Atlantic Boulevard because it does not drain north of the street.

Additional details about the input data are described further below.

3.3.1 Hydrologic Characteristics

The SCS methods referred to previously included using the Curve Number Method to estimate excess runoff volume and a unit hydrograph to predict the timing of runoff. The peaking factor used for the unit hydrograph was 256, which is commonly used by the SFWMD for near-flat landscapes. The City is mostly built-out and there have been no major land use changes on the main island since 2005, so the same curve numbers from the 2005 City model were utilized. Exhibit 3-2 lists those used previously. It is noted that these curve numbers by land use are fairly high (more runoff volume), but the City has fairly high impervious area because of the relatively high density on the main island and the runoff potential is greater because of high groundwater levels relative to the ground surface. The time of concentrations for the unit hydrographs were adopted from the City's model that was based on the SCS TR-55 method.

EXHIBIT 3-2
Curve Numbers Applied in the City of Key West
City of Key West 2012 Stormwater Master Plan

Land Use	Percent Impervious	Curve Number
Residential High Density	60	91
Open Land	0	80
Retail Sales and Services	84	95
Residential Medium Density	45	88
Commercial and Services	79	94
Recreational	14	83
Institutional	73	93
Industrial	80	94
Mobile Home Units	65	92

3.3.2 Hydraulic Characteristics

The hydraulic elements refer to those physical facilities that are designed to move stormwater, and also include the overland flow that may occur when the pipes are too small to convey the runoff flow rates. Stormwater runoff reaches a node and then can build up if the capacity of the inlets (also called the catchbasin) is insufficient to allow the water to enter the pipes. If the pipe capacity is overwhelmed, then runoff can also stage up over the inlets in the streets until water starts to flow to lower elevations, very often through the streets. As noted in the beginning of this section, inlets are normally sized to exceed the capacity of connecting pipes so it is assumed that all stormwater can get into the pipes. This may not be the case if the inlets are blocked with debris or, as is likely in many parts of the City, if the inlets are relatively small. It is assumed in the City's model, as is typically done, that inlets are not limiting flow into the system.

In coastal regions, there are two methods commonly applied to analyze stormwater systems: by sub-basin or by interconnected sub-basins. The sub-basin approach allows water to stage up only within the sub-basin until the pipes or other infrastructure can drain the stormwater. This approach is applicable when sizing elements to manage runoff from a limited area. The disadvantage of the sub-basin approach for a regional plan is that different sub-basins will stage up to different heights, and flood mapping will be discontinuous. For this Master Plan, the sub-basins were modeled interconnected by the streets or other low areas, which was the approach used in past studies, too. The streets were simulated in the model as typical two-lane streets with weirs of irregular shape. Weir equations were used to prevent from double accounting the storage volume of the node and street channel flow.

Storage to hold the excess runoff while it is being routed through the pipes or streets was determined by using the updated LiDAR topographic data. Elevation-area was exported from the GIS and entered into ICPR for the nodes.

Pipes included in the model mostly represented the main conveyances toward each outfall, or recharge well. The invert elevations were typically the same used in the existing conditions model adjusted to NAVD88, unless there were new as-built data for the new construction. Pipe diameters in the 2005 model were checked against the GPS inventory.

The boundary elevation at the outfalls used in the master plan was the same elevations obtained from the Key West tidal gauge for the MHHW, a constant 0 NAVD88. Again, studies can assume different boundary conditions, either constant or varying tides. In varying the tides, an assumed sinusoidal curve is used to represent boundary elevations. To be conservative, the timing of the curve would be such that the peak would cause the highest flooding on land. Alternatively, by assuming a constant elevation, the timing of the tides is not an issue. However, the constant boundary condition assumption in the model will simulate long duration flooding, which is overly conservative. However, both approaches should provide similar peak flood elevations.

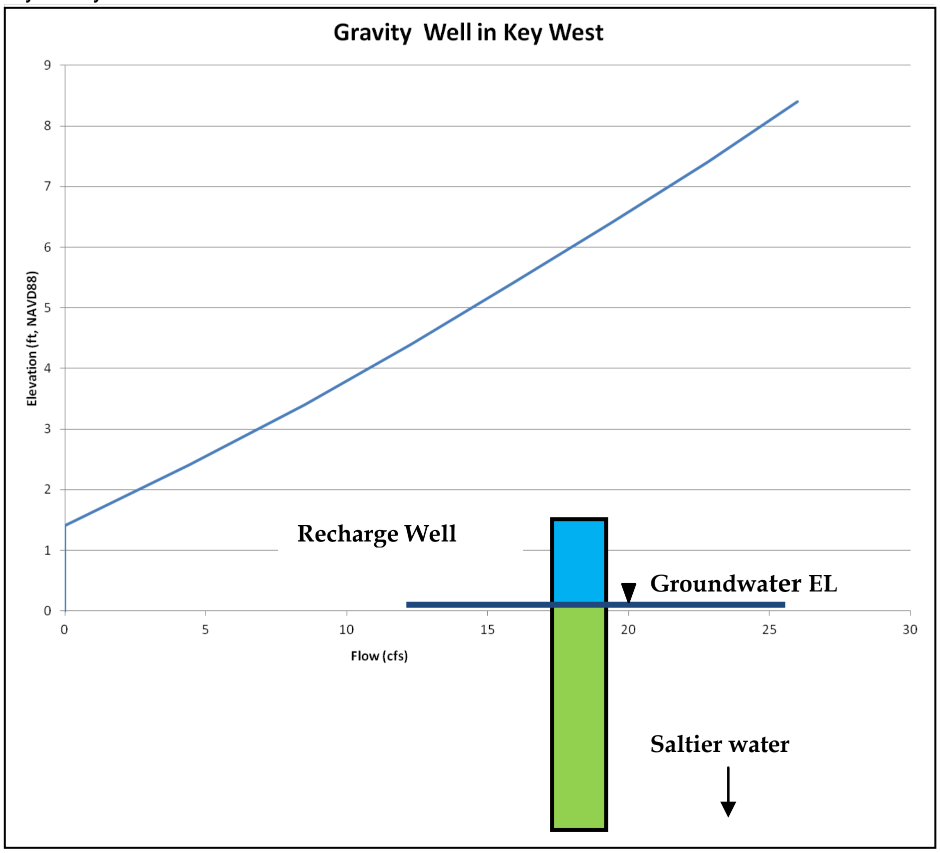
3.3.3 Recharge Wells

There are two types of recharge wells used in Key West to manage stormwater, those flowing by gravity or by pump assistance. In general, when the landscape is less than approximately elevation 2.7 NAVD88, the capacity of the gravity-driven wells is diminished by the high groundwater conditions and limited depth of staged stormwater over the top of the well. Stormwater (freshwater) must build up to overcome the density difference of the saltier groundwater so flow down a well does not begin until water in the casing reaches 1.4 ft deep. Friction losses will require another 0.2 ft of water, so flow does not begin until stormwater stages to approximately 1.6 ft NAVD88. Because the groundwater table normally fluctuates with the tide, a conservative estimate is to assume that the elevation of the groundwater in the well is approximately high tide (elevation 0 NAVD88, MHHW) and would stay at high tide during the entire storm. These wells are typically 24 inches in diameter, cased to approximately 60 ft deep, with the open hole extending 90 to 120 ft below land surface. These wells are also sometimes referred to as shallow wells, as opposed to the deep injection wells used at the wastewater plant, or as drainage wells. However, City operations staff also sometimes label the vertical French drains as shallow wells, but these are mostly just open-bottom inlets to reduce ponded water between storms. These vertical drains are not included in the model as they are not expected to relieve high peak runoff rates.

The flow down the recharge well will also depend on the ability of the rock formation to allow flow to move. In general, the limestone under the City is highly transmissive, so much so that it is sometimes hard to take physical measurements of the capacity. In 2002, CH2M HILL prepared a white paper about recharge well capacities where data from recent wells were reviewed and the rating curve in Exhibit 3-3, adjusted for NAVD88, was recommended.[3] This rating curve has been used to represent all gravity wells in the City since that time. This rating curve was relatively conservative (that is, low flow) compared to the data, but recharge well performance will reduce over time, as they require maintenance to keep the pores clean. There are also some instances where the limestone was not as porous as typical, but in general the standard rating curve will be used unless new data indicate otherwise.

[3] CH2M HILL. *Estimation of Drainage Well Capacities for the City of Key West*. Prepared for the City of Key West. April 2002.

EXHIBIT 3-3
Gravity Recharge Well Rating Curve Used in the ICPR Model
City of Key West 2012 Stormwater Master Plan



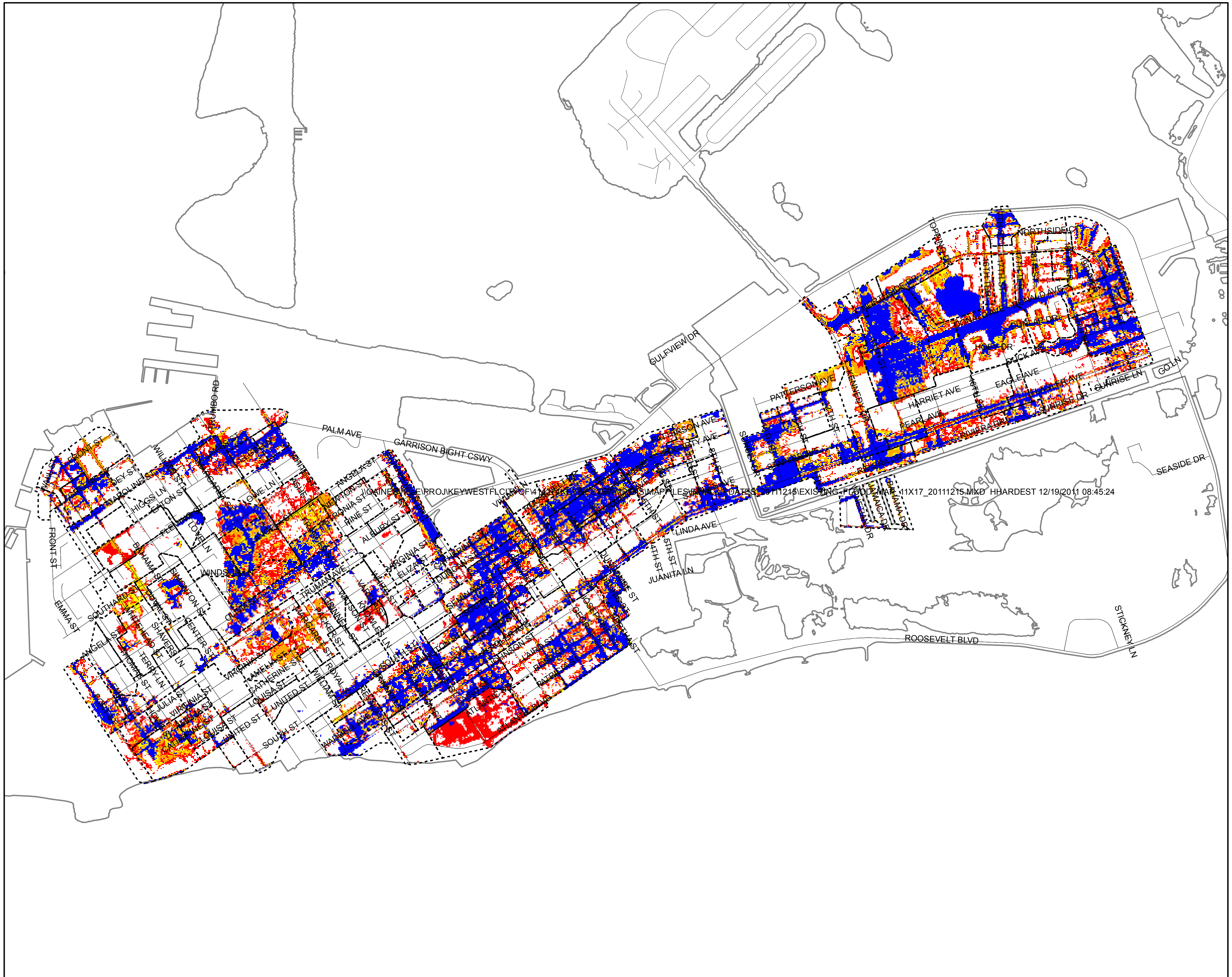
There are three pressure-assisted wells systems in the City: Patricia and Ashby, Simonton Beach, and White Street. Simonton Beach and White Street have two wells, while Patricia and Ashby has one. Stormwater is treated in vortex separator units and then pumped to the recharge wells. These sites are sometimes also called pressure wells and they operate at low landscape elevations because the pumps provide the extra force to push the freshwater down the well. The pressure wells themselves are the same size as the gravity wells, but the pumps and wells are matched such that the capacity of the pump station matches the well capacity. Each pump/well combination was rated at approximately 8,300 gallons per minute (gpm), or 18 ft^3/sec. While the rate will vary some between sites and as the water levels change, the pumping rate was assumed constant for this evaluation. From Exhibit 3-3, one can infer that the net pressure at the pressure-assisted wellhead is approximately 6.2 ft, but that can vary slightly between sites depending on many factors (for example, number of elbows and splits in the piping, valving, actual factory impeller rating, and actual groundwater elevations at the well). In fact, the actual operation of the Simonton Beach pressure-assisted system has been at a higher pressure than expected, likely from the poor permeability of the limestone at that location. Because of this, it was assumed that the actual capacity of the existing system was only approximately half (equivalent to one well) for simulating existing conditions.

3.3.4 Design Storms

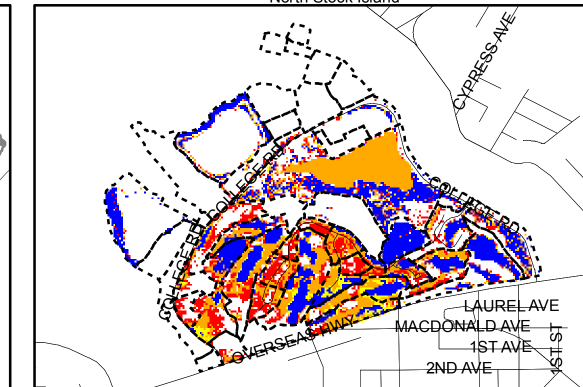
The design storms sizes were listed in Section 2. The ICPR model has the SFWMD time distributions of rainfall intensities included as standard options. The global storms option was used to simulate the five storms: 5-, 10-, 25-, and 100-year return period storms. By SFWMD convention, storms smaller than 25 years were of 24-hour duration and the two larger storms (25- and 100-year) had a 72-hour duration. Using SFWMD's guidance, the longer duration storms have constant rainfall for 48 hours then the intense 24-hour storm occurs. This approach is used in Florida so that stormwater facilities have a factor of safety in their capacity to manage the flood volume from large storms.

3.4 Existing Conditions Modeling Results

The stormwater model estimates the staging of stormwater at nodes in the model. The elevations of the peak staged levels of stormwater runoff were plotted on the topographic map for the four design storms, as is shown in Exhibit 3-4. A larger version of this map with the nodes and elevations is available in Attachment D included with the report. The runoff stages primarily in the lower landscape areas, as has been documented previously. These results were used as a basis for evaluating new projects later in this report. Exhibit 3-5 provides the predicted peak stages for each node.



North Stock Island



LEGEND

- Roads
- Shoreline
- Flooding at the 5yr, 24 hr Storm Stage
- Flooding at the 10yr, 24 hr Storm Stage
- Flooding at the 25yr, 100 hr Storm Stage
- Flooding at the 100yr, 72 hr Storm Stage
- Sub-Basin

Only City sub-basins contributing runoff to City-maintained outfalls are shown. City areas draining directly to Gulf, Ocean, or canals are not modeled, but are still managed for potential water quality effects.

N

0 0.25 0.5
Miles

Exhibit 3-4
Existing Flooding Map
Key West Stormwater Master Plan
Key West, Florida

EXHIBIT 3-5
Simulated Peak Stage Results from the Existing Conditions Model of the City's Stormwater System
City of Key West 2012 Stormwater Master Plan

Model Node	Road N-S Reference	Road E-W Reference	5-Yr, 24-Hr	10-Yr, 24-Hr	25-Yr, 72-Hr	100-Yr, 72-Hr
N100	Between Thompson and Leon	South of Atlantic Blvd	1.78	1.88	2.07	2.34
N1000	7th	North of Patterson	0.65	0.70	0.86	0.96
N1005	7th	Patterson Ave	1.91	2.07	2.64	2.72
N1010	6th	North of Patterson	0.82	0.86	1.02	1.16
N1015	6th	Patterson Ave	1.92	2.00	2.15	2.38
N1020	6th	Fogarty Ave	1.93	2.01	2.16	2.39
N1025	6th	Harris Ave	2.77	2.78	2.81	2.85
N1030	7th	Fogarty Ave	1.96	2.02	2.17	2.39
N110	Between George and Ashby	South of Atlantic Blvd	1.78	1.88	2.07	2.34
N1120	Duval	Eaton	5.63	6.25	6.98	7.79
N1130	Duval	Fleming	6.88	7.51	7.82	8.06
N1140	Duval	Angela	7.09	7.74	7.97	8.25
N1150	Whitehead	Angela	4.74	5.31	5.59	5.98
N1160	Simonton	Angela	7.12	7.27	7.56	8.03
N1170	Duval	Petronia	8.60	8.75	8.88	9.00
N1180	Duval	Southard	7.04	7.70	7.92	8.16
N1190	Whitehead	Caroline	2.86	2.91	2.97	3.03
N200	White	Between Atlantic Blvd and Casa Marina Ct	0.66	0.66	0.66	2.29
N2000	Whitehead	Front	1.88	1.94	2.06	2.20
N2010	Whitehead	Greene	2.32	2.36	2.45	2.57
N210	White	Laird	2.55	2.62	2.77	3.05
N2100	Duval	Front	1.21	1.32	1.46	1.67
N2110	Ann	Front	0.00	0.00	1.40	1.67
N2120	Duval	Between Greene and Front	1.89	2.02	2.20	2.40
N2130	Duval	Caroline	2.92	3.03	3.18	3.30
N2135	Duval	Between Caroline and Eaton	3.71	3.80	3.90	4.27
N2140	Simonton	Caroline	2.93	3.13	3.57	3.93
N215	Whalton	Johnson	2.88	3.15	3.28	3.45
N220	Florida	Laird	2.55	2.62	2.78	3.06
N2200	Elizabeth	Greene	0.77	0.88	1.02	1.22
N230	White	Von Phister	3.68	3.70	3.76	3.90
N2300	William	Caroline	1.82	1.89	2.03	2.20
N235	White	Von Phister	4.26	4.28	4.33	4.39
N240	Whalton	Von Phister	3.50	3.62	3.83	4.09
N2400	Margaret	Caroline	1.78	1.86	1.98	2.13
N245	Grinnell	Von Phister	3.51	3.63	3.83	4.08
N250	Grinnell	Johnson	2.73	2.82	3.01	3.25
N2500	Grinnell	Boundary, North of Trumbo Rd	1.96	2.13	2.33	2.69
N2510	White	Eaton	2.06	2.18	2.38	2.73
N2520	Frances	Eaton	2.06	2.17	2.37	2.72
N2530	Grinnell	Eaton	2.21	2.22	2.39	2.72
N2540	Grinnell	Fleming	3.92	4.14	4.36	4.47
N2550	Southard	Margaret	4.46	4.55	4.74	5.00

EXHIBIT 3-5
Simulated Peak Stage Results from the Existing Conditions Model of the City's Stormwater System
City of Key West 2012 Stormwater Master Plan

Model Node	Road N-S Reference	Road E-W Reference	5-Yr, 24-Hr	10-Yr, 24-Hr	25-Yr, 72-Hr	100-Yr, 72-Hr
N2555	Williams	Fleming	8.87	8.89	8.91	8.94
N2560	Margaret	Carey Ln	4.32	4.55	4.94	5.34
N2563	Passover	Windsor Ln	4.63	4.78	4.97	5.34
N2567	William	Windsor Ln	4.78	4.93	5.13	5.31
N2570	Passover Ln	Olivia	5.31	5.38	5.50	5.72
N2600	Whitehead	Truman	7.34	7.46	7.56	7.62
N2610	Center	Truman Ave	6.23	6.30	6.45	6.67
N2700	Between Florida and Pearl	Truman Ave	1.81	1.89	2.06	2.33
N2705	Jose Marti Dr/Eisenhower Dr	Truman Ave	1.81	1.86	2.06	2.32
N2710	Georgia	Truman Ave	3.20	3.34	3.92	4.88
N2730	Varela	Truman Ave	3.20	3.30	3.45	3.66
N2740	Grinnell	Truman	3.95	4.08	4.34	4.74
N2750	Passover Ln	Truman Ave	5.35	5.46	5.64	5.87
N2800	Pearl	Between Eliza and Virginia	2.04	2.11	2.21	2.42
N2802	Jose Marti Dr	Between Virginia and Truman	1.68	1.85	2.07	2.34
N2807	White	Catherine	1.70	1.86	2.07	2.34
N2810	Leon	Catherine	1.87	1.91	1.99	2.41
N2820	Thompson	Catherine	1.87	2.02	2.22	2.49
N2830	Thompson	Seminary	2.22	2.30	2.46	2.66
N2832	Thompson	Washington	3.07	3.13	3.21	3.43
N2834	Thompson	Von Phister	3.44	3.46	3.49	3.62
N2836	Leon	Von Phister	3.20	3.30	3.44	3.65
N2838	Tropical	Von Phister	3.20	3.30	3.44	3.65
N2840	Leon	South	3.20	3.29	3.44	3.65
N2842	Tropical	Washington	3.20	3.30	3.44	3.65
N2844	Tropical	South	2.18	2.32	2.97	3.63
N2846	Tropical	Seminary	3.01	3.29	3.42	3.64
N2847	Pearl	Catherine	2.81	2.84	2.89	2.93
N2850	Florida	Catherine	4.17	4.20	4.23	4.28
N2852	Pearl	United	2.94	3.00	3.10	3.20
N2855	Florida	United	4.17	4.19	4.22	4.27
N2860	Georgia	Catherine	4.46	4.55	4.74	5.00
N2865	Georgia	United	4.82	4.83	4.87	4.94
N2870	White	Catherine	3.22	3.59	4.46	5.31
N2880	Varela	Catherine	3.56	3.94	4.72	5.68
N2883	Packer	Catherine	2.62	2.86	3.41	4.33
N2887	Grinnell	Virginia	5.84	5.87	5.94	6.03
N2890	Margaret	Catherine	3.85	4.35	5.31	5.63
N2892	Royal	Catherine	2.63	2.87	3.56	5.12
N2895	William	Catherine	4.64	5.32	6.34	6.47
N2900	Eisenhower Dr	Newton	1.97	2.02	2.09	2.27
N300	Reynolds	Atlantic Blvd	0.64	0.81	1.19	1.44
N3000	George	Catherine	1.63	1.80	2.09	2.38

EXHIBIT 3-5
Simulated Peak Stage Results from the Existing Conditions Model of the City's Stormwater System
City of Key West 2012 Stormwater Master Plan

Model Node	Road N-S Reference	Road E-W Reference	5-Yr, 24-Hr	10-Yr, 24-Hr	25-Yr, 72-Hr	100-Yr, 72-Hr
N3010	George	United	1.69	1.91	2.17	2.45
N3020	Ashby	Catherine	1.98	2.05	2.22	2.48
N3030	Ashby	United	2.05	2.12	2.26	2.51
N3040	Ashby	Seminary	2.06	2.14	2.29	2.53
N3050	George	South	2.43	2.62	2.76	2.91
N3060	Ashby	Washington	1.77	1.91	2.25	2.72
N310	Reynolds	Von Phister	3.68	3.76	3.87	4.08
N3100	1st	N. Roosevelt Blvd	0.74	0.79	0.90	1.02
N3110	1st	Roosevelt Dr	1.51	1.63	1.91	2.20
N3115	1st	Patterson Ave	1.84	1.95	2.13	2.34
N3120	1st	Seidenberg Ave	1.86	1.97	2.19	2.59
N320	Reynolds	South	5.01	5.05	5.12	5.22
N3200	4th	Patterson Ave	1.85	1.94	2.11	2.33
N3210	3rd	Patterson Ave	1.85	1.95	2.13	2.34
N3220	4th	Fogarty Ave	1.99	2.06	2.20	2.41
N3225	3rd	Fogarty Ave	1.87	1.96	2.14	2.35
N3230	5th	Fogarty Ave	1.99	2.06	2.21	2.41
N3235	5th	Seidenberg Ave	2.71	2.74	2.79	2.87
N3240	4th	Harris Ave	2.06	2.11	2.23	2.43
N3250	3rd	Harris Ave	1.87	1.96	2.14	2.35
N3260	2nd	Fogarty Ave	1.88	1.97	2.14	2.35
N3300	Between 5th and 6th	Flagler Ave	1.22	1.41	1.63	1.96
N3310	4th	Flagler Ave	1.95	2.08	2.21	2.39
N3320	3rd	Flagler Ave	2.30	2.39	2.51	2.71
N3330	2nd	Flagler Ave	2.63	2.68	2.79	2.97
N3340	Dennis	Venetia	1.77	1.90	2.15	2.51
N3345	1st	Flagler Ave	2.95	3.03	3.13	3.29
N3350	George	Flagler Ave	3.15	3.24	3.36	3.52
N3360	Thompson	Flagler Ave	3.25	3.36	3.50	3.66
N3370	Between Lean and Tropical	Flagler Ave	3.30	3.41	3.56	3.73
N3375	Between White and Tropical	Flagler Ave	3.45	3.51	3.71	3.90
N3400	8th	Flagler Ave	1.75	1.81	1.93	2.10
N3410	7th	Flagler Ave	1.96	2.02	2.12	2.26
N3500	West of the 9th St. Canal	Patterson Ave	1.42	1.45	1.50	1.59
N3600	11th	Flagler Ave	1.31	1.52	1.76	2.00
N3605	West of 11th	Flagler Ave	1.38	1.58	1.84	2.06
N3610	Between 10th and 11th	Flagler Ave	1.53	1.71	2.03	2.23
N3615	10th St.	Flagler Ave	2.24	2.40	2.74	2.94
N3620	12th	Flagler Ave	2.40	2.49	2.61	2.70
N3700	11th	North of Patterson	0.80	1.02	1.48	1.85
N3710	12th	North of Patterson	1.22	1.50	2.06	2.34
N3720	12th	Fogarty Ave	2.01	2.12	2.30	2.48
N3730	11th	Fogarty Ave	2.16	2.20	2.29	2.42

EXHIBIT 3-5
Simulated Peak Stage Results from the Existing Conditions Model of the City's Stormwater System
City of Key West 2012 Stormwater Master Plan

Model Node	Road N-S Reference	Road E-W Reference	5-Yr, 24-Hr	10-Yr, 24-Hr	25-Yr, 72-Hr	100-Yr, 72-Hr
N3740	13th	About Patterson Ave	1.42	1.71	2.28	2.57
N3750	13th	North of Patterson	1.81	2.02	2.36	2.61
N3760	13th	Northside	2.25	2.37	2.60	2.87
N3765	Between 13th and 14th	Northside	2.30	2.42	2.64	2.92
N3770	14th	Northside	2.30	2.42	2.64	2.92
N3780	14th	Nr. Stadium MH Park	2.05	2.17	2.40	2.84
N3790	14th	Nr. Stadium Apts.	2.33	2.43	2.64	2.91
N3800	Rivera St (15th)	Flagler Ave	1.45	1.60	1.89	2.33
N3810	16th	Flagler Ave	1.87	2.04	2.26	2.51
N3820	14th	Flagler Ave	2.05	2.25	2.47	2.65
N3830	Between 13th and 14th	Flagler Ave	2.10	2.28	2.50	2.68
N3835	13th	Flagler Ave	2.21	2.30	2.50	2.68
N3837	13th	Riviera	2.22	2.31	2.50	2.68
N3900	18th	Flagler Ave	1.80	1.95	2.21	2.56
N3902	West of 18th	Flagler Ave	1.83	1.97	2.22	2.56
N3910	17th	Flagler Ave	2.26	2.31	2.43	2.59
N3912	17th	Riviera	2.17	2.31	2.43	2.59
N3915	18th	Eagle	1.86	2.00	2.27	2.61
N3920	Between 19th and 20th	Flagler Ave	2.27	2.43	2.71	3.03
N3930	20th	Duck to Eagle Ave	2.60	2.70	2.87	3.12
N400	Alberta	Seminole Ave	3.49	3.52	3.58	3.72
N4000	Whitehead	Between Fleming and Southard	5.75	6.67	7.00	7.31
N4010	Whitehead	Fleming	2.45	2.67	3.18	4.02
N410	William	Washington	3.38	3.69	3.88	4.06
N4100	15th-ish	Northside	2.20	2.38	2.72	3.05
N4102	Donald Canal	Northside	2.33	2.53	2.90	3.27
N4105	16th-ish	West of Donald	2.36	2.56	2.92	3.28
N4110	17th St	Donald area	2.38	2.58	2.94	3.29
N4115	16th St	North of Donald	2.38	2.58	2.94	3.29
N4120	18th	Donald	2.38	2.58	2.94	3.29
N4125	20th St	Northside	2.28	2.40	2.62	2.95
N4130	20th	Donald	2.38	2.52	2.82	3.21
N4140	19th	Donald	2.46	2.64	2.94	3.29
N4143	19th	Donald	2.38	2.58	2.94	3.29
N4145	19th	Cindy	2.83	2.87	2.95	3.25
N4147	18th	Pearlman	2.58	2.74	2.97	3.28
N4150	20th	Cindy	2.39	2.52	2.82	3.21
N4160	18th Ter	Northside	2.45	2.63	2.84	3.00
N4170	18th St	Northside	2.52	2.74	3.02	3.22
N4175	17th	Northside Ct	2.79	2.92	3.05	3.18
N4180	Trinity	Northside	2.38	2.57	2.94	3.29
N4200	Venetian	Venetian	2.21	2.23	2.29	2.37
N4210	Jamaica	Venetian	1.43	1.81	1.92	1.99

EXHIBIT 3-5
Simulated Peak Stage Results from the Existing Conditions Model of the City's Stormwater System
City of Key West 2012 Stormwater Master Plan

Model Node	Road N-S Reference	Road E-W Reference	5-Yr, 24-Hr	10-Yr, 24-Hr	25-Yr, 72-Hr	100-Yr, 72-Hr
N4220	Bahama	Venetian	1.63	1.89	2.00	2.07
N500	Duval	Bound past South	1.15	1.40	1.69	2.07
N5000	Whitehead	South St	1.56	1.67	1.88	2.16
N510	Simonton	South	4.12	4.14	4.18	4.24
N520	Simonton	United	4.34	4.44	4.54	4.73
N530	Simonton	Louisa	3.87	4.38	5.50	5.76
N540	Duval	Catherine	3.38	3.45	3.57	3.71
N600	Fort	Amelia	1.80	2.08	2.71	3.25
N6000	10th St	Harris Ave	2.28	2.43	2.76	2.97
N605	Emma	Amelia	2.59	2.81	3.09	3.41
N610	Emma	Virginia	2.85	2.96	3.17	3.45
N615	Howe	Amelia	2.72	2.85	3.08	3.40
N620	Howe	Virginia	2.96	3.05	3.20	3.45
N625	Whitehead	Catherine	2.74	2.85	3.07	3.39
N627	Whitehead	Amelia	2.98	3.04	3.16	3.41
N628	Whitehead	Virginia	3.81	3.82	3.85	3.95
N630	Whitehead	United	2.71	2.80	2.97	3.25
N635	Fort	Truman	3.64	3.76	3.93	4.13
N640	Emma	Truman	3.69	3.78	3.92	4.09
N641	Thomas	Truman	4.80	4.85	4.96	5.12
N642	Emma	Olivia	3.99	4.06	4.19	4.36
N643	Emma	Petronia	4.50	4.51	4.53	4.60
N645	Thomas	Petronia	3.99	4.27	4.86	5.98
N700	White	Fleming	2.56	2.61	2.70	2.93
N705	Frances	Fleming	3.18	3.21	3.24	3.32
N710	White	Southard	3.20	3.52	4.28	4.79
N720	White	Angela	3.91	4.43	5.16	5.32
N730	Ashe	Angela	4.21	4.72	4.99	5.21
N750	Frances	Petronia	5.00	5.14	5.36	5.57
N755	Frances	Olivia	5.45	5.50	5.60	5.73
N800	Florida	Eliza	3.82	3.84	3.89	3.96
N810	White	Eliza	5.02	5.09	5.15	5.21
N820	White	Virginia	2.66	2.91	3.52	4.53
N830	Varela	Virginia	5.09	5.12	5.19	5.30
N900	Pearl	Alberta	2.39	2.56	2.91	3.83
N905	Pearl	Petronia	3.10	3.31	3.69	4.06
N920	Florida	Newton	3.10	3.31	3.69	4.06

Note:
See Attachment A for North Stock Island Results.

SECTION 4

Water Quality Considerations

The Florida Keys represent a unique habitat and ecosystem. The City's tourist business depends on the beaches and nearshore natural resources. Key West, both the main island and North Stock Island, is surrounded by sensitive coastal waters. The Florida Keys National Marine Sanctuary (FKNMS) near the islands is considered an Outstanding Florida Water (OFW), which requires extra protection under state environmental rules. Because of its popularity, the City has been the subject of significant regional, state, and Federal scrutiny and regulatory oversight, with most aspects of growth and development reviewed at all levels of government.

In previous sections of this 2012 Stormwater Master Plan the discussion has focused on street and building flooding. However, in many ways the water quality effects that stormwater has on nearshore waters have shaped the City's stormwater program as much as the physical flooding issues. This section discusses the City's programs related to water quality and provides an estimate on reductions of pollutants that may occur given different Best Management Practices (BMPs).

4.1 Impaired Waters

The Clean Water Act (CWA) is the Federal program mandating the regulation of water quality. In broad terms, the CWA requires that states establish water quality goals, called *designated uses*; standards that may contain specific quantitative numeric criteria and subjective criteria; an antidegradation criteria (no 'back-sliding' allowed); and a regulatory system to implement their program. If a state does not do these activities, then the U.S. Environmental Protection Agency (EPA) will implement the CWA in that state. However, most states have implemented programs and have received authority to manage the Federal program under EPA oversight. The CWA includes a permitting program to regulate point sources, which is called the NPDES program. This program is well known for the regulation of wastewater plants and industrial facilities, but the CWA always included urban stormwater as well. EPA did not develop the NPDES program for stormwater until the early 1990s, and then only for medium and large municipalities. In 2000, Florida received delegated authority from EPA to manage the stormwater program. As the NPDES stormwater permitting authority, the Florida Department of Environmental Protection (FDEP) is responsible for promulgating rules and issuing permits, managing and reviewing permit applications, and performing compliance and enforcement activities.

Note that the NPDES program is a Federal program and it is separate from the state of Florida stormwater rules and program. Additional permitting requirements are needed to comply with state rules (Section 62-25, Florida Administrative Code [FAC]), normally regulated under the state's Environmental Resource Permit (ERP) system under delegated authority from FDEP to the SFWMD for Key West. In addition, while dredge and/or fill activities in surface waters falls under permitting requirements of the CWA and state rules (included in the ERP), the NPDES permit is separate from the Section 404 permit which is regulated by the U.S. Corps of Engineers.

Local agencies (City or County) can also have additional requirements as part of their development rules. Coastal beach water samples are collected by the county health departments (by OMI in Key West) and analyzed for enterococci and fecal coliform bacteria, then reported to FDEP. High concentrations of these bacteria may indicate the presence of microorganisms that could cause disease, infections, or rashes. County health departments will issue health advisories or warnings when these high bacteria conditions are confirmed, and often these conditions are associated with high rainfall and stormwater runoff.[1]

Although this may already seem like a lot of regulatory programs that could affect urban stormwater, there is another CWA provision that overarches and integrates with the NPDES program, called the Total Maximum Daily Load (TMDL). States must identify receiving waters where required pollution controls are not sufficient to attain or maintain applicable water quality standards (known as the Section 303(d) list). TMDLs establish the maximum amount of a pollutant that a water body can assimilate without causing exceedances of water quality standards. The federal regulations at Chapter 40, Section 130.7 of the Code of Federal Regulations (40 CFR 130.7) directs the states to:

- Identify the waters that require TMDLs
- Rank, or prioritize, those waters taking into consideration the water uses and severity of the pollution problem
- Identify the pollutant(s) causing or expected to cause violations of the applicable water quality standards
- Identify the waters targeted for TMDL development in the next 2 years.

Section 305(b) of the Federal CWA requires each state to also deliver a water quality characterization or water quality assessment of state waters, known as the 305(b) report, and the states are required to submit an integrated report (303(d) and 305(b)) report every other year.

Florida has implemented the TMDL program in its rule called the *Impaired Waters Rule* (Section 62-303, FAC). Water bodies that do not meet water quality standards are "listed" on the 303(d) list, identified as "impaired" for the particular pollutants of concern. Nutrients and bacteria are of note for the Keys as well as mercury, which is considered a statewide issue. TMDLs must be developed, adopted, and implemented to reduce the level of anthropogenic (man-made) pollutants in the water body so it can be removed from the 303(d) list, or "de-listed." TMDLs address both wastewater and municipal stormwater as point sources, and non-point sources from other areas for the TMDLs to form a comprehensive management program to implement the CWA goals of attaining water quality standards. Florida rules implements the TMDLs by developing Basin Management Action Plans (BMAPs).

In 1998, FDEP listed the water bodies surrounding the City as impaired for nutrients, primarily total phosphorus (TP) and total nitrogen (TN). The water quality of the nearshore waters on the Gulf side of the islands are dominated by the distant sources from the natural and regulated discharges of the main land (from the Everglades to the Mississippi River). However, anthropogenic sources from the Southern Keys, or Lower Keys, also contribute to

[1] Current beach water sampling results can be found at http://esetappsdoh.doh.state.fl.us/irm00beachwater/beachresults.aspx?county=Monroe

the nearshore water quality. Local sources include wastewater and stormwater originating in the City, U.S. Navy facilities in and adjacent to the City, FDOT in Key West and unincorporated areas of Monroe County in the southern portion of Stock Island. In addition, low dissolved oxygen levels are problematic in the canals surrounding the Keys because of stagnant flows.

As part of the TMDL process (see Section 64-303.600, FAC), FDEP evaluates whether existing or proposed pollution control mechanisms will effectively address the impairment before placing a water body on the state's verified list. If FDEP can document there is reasonable assurance that the impairment will be effectively addressed by the control measure(s), then the water will not be listed on the final verified list. FDEP has issued a Reasonable Assurance Report (RAR) for the Lower Keys stating that this is the case for the City, provided that the City follows through with its plans to implement pollutant reduction from both its wastewater and stormwater system.[2] To avoid another regulatory burden, the City committed to FDEP to implement stormwater controls to improve water quality. FDEP adopted the RAR for the Florida Keys, including the controls listed in it, in February 2012.

It should be noted that the state is currently developing new numeric criteria for nutrients in estuarine and coastal waters. It will be approximately 1 year before these new criteria are completed. As long as the RAR is approved by EPA, there should be no immediate impact of the new nutrient criteria to the City stormwater program. However, long-term impacts are uncertain.

4.1.1 Reasonable Assurance for Water Quality Compliance

As part of the development of the RAR, the City contributed in formulating the elements that it would implement to bring the waters into compliance. Many of the improvements that reduce pollutants to the nearshore are related to the sanitary system, but stormwater controls are also included, as follows:

- Eliminate stormwater outfalls using sediment and debris traps, also known as baffle boxes, in conjunction with gravity stormwater wells to eliminate direct nutrient discharges from City stormwater outfalls to nearshore waters at the rate of approximately two outfalls per year into the foreseeable future
- Retrofit stormwater outfalls to BMP standards using baffle boxes to reduce the nutrient loading associated with direct discharge to nearshore waters
- Install pump-assisted stormwater recharge wells at five locations within the City to reduce localized flooding and avoid nearshore contamination by the pollutants currently being directly discharged to receiving waters
- Operate a strategic street sweeping program to collect trash, debris, sediments, and similar materials before they reach the City's storm sewer systems
- Implement a stormwater utility to provide dedicated funding for ongoing stormwater management activities

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[2]CDM and URS. 2008. *Southern Keys Area Reasonable Assurance Documentation*. http://www.dep.state.fl.us/water/watersheds/bmap.htm Prepared for the Florida Department of Environmental Protection, Tallahassee, FL. December 2008.

Most of these elements have been implemented, although the rate of implementation of capital projects has been sporadic depending on funding availability. For example, only three of the pump-assisted wells have been constructed, as they are costly projects to implement. Furthermore, it should be clarified that the City is not planning to eliminate any outfall pipes but will look into adding water quality improvements to reduce discharge volume and pollutant loads.

4.1.2 Natural Habitats

While this topic is not related to impaired waters *per se*, it is part of the regulatory framework that affects the stormwater program and is therefore included here. Mangroves are tropical plants that are adapted to loose, wet soils, salt water, and being periodically submerged by saltwater tides. Mangroves perform special natural functions along Florida's coastline, including:

- Trap and cycle various organic materials, chemical elements, and important nutrients in the coastal ecosystem.
- Provide one of the basic food chain resources for marine organisms.
- Provide physical habitat and nursery grounds for a wide variety of marine organisms, many of which have important recreational or commercial value. While mangroves are not considered endangered, some threatened and endangered species may habitat these trees.
- Serve as storm buffers by reducing wind and wave action in shallow shoreline areas.

Mangroves form dense root systems and propagate easily in shallow waters. Left unmanaged, these wetland trees can form dense vegetation approximately 20 feet high with tall, arching roots that intermingle. Over time, mangroves also can obstruct the drainage ways, including the canals and outfalls in nearshore waters.

Because of the historic rapid destruction of coastline wetland habitat, the state, through FDEP, now regulates the alteration and trimming of mangroves.[3] Three species of mangroves that grow along the shoreline of many estuaries in Florida are the red mangrove, the white mangrove, and the black mangrove. Mangrove trimming and alteration may be done by property owners under certain exemptions, as specified in Section 403.9326 of the Florida Statutes. Other trimming requires the services of a professional mangrove trimmer and may require a permit.

The City has had to obtain permission to conduct widespread removal of mangroves in some drainage ways, including Riviera Canal and the pond adjacent to Donald Street in the City's New Town area. As part of their permit conditions, they must maintain and protect mangroves in other parts of the City, including the salt marshes around the airport and in the middle of North Stock Island. North Stock Island has several outfalls that have mangroves in the swales leading up to them and between the end of the pipe and open water (on the Gulf side of the outfall). While these outfall pipes are open and functioning, the pathways between the end of the pipes and water are obstructed. Permits will be required to remove these mangroves.

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[3] The trimming and alteration of mangroves is governed by Sections 403.9321-403.9333 of the Florida Statutes, *Mangrove Trimming and Preservation Act*.

4.2 City of Key West Programs

In 1989 the City began evaluating its drainage system in support of its Comprehensive Planning efforts as part of Florida's Growth Management Act requirements. Between 1989 and 2001, the City commissioned studies and started to more diligently operate its stormwater system as an infrastructure investment. In 1995, the stormwater operation and maintenance was contracted to a third party contractor. Many recommended improvements were made and regular updates to its program were implemented primarily through the public works department under the Comprehensive Planning regulations of the state. The nature of stormwater management has changed dramatically since the early 1990s.

Traditionally, sporadic funding for drainage projects in many Florida communities prevents them from developing a comprehensive, cohesive, and coordinated stormwater management program. The City recognized that stormwater maintenance and operations needed to be upgraded, drainage master planning efforts authorized and adopted, major capital improvements built, and water quality programs developed. These activities required increased annual funding to accomplish these objectives, and capital outlays will be required for equipment, land acquisition, and construction projects. In 2001, the City's Long Range Stormwater Utility Plan recommended establishing a dedicated stormwater utility, which was established in 2003. Fees generated from the stormwater utility fund the activities related to stormwater management.

4.2.1 Federal Stormwater Requirements

The NPDES stormwater permitting program was implemented by EPA in two phases. Phase I, promulgated in 1990, addressed the following stormwater sources:

- "Large" and "medium" MS4s located in incorporated places and counties with populations of 100,000 or more
- Eleven categories of industrial activity, one of which is large construction activity that disturbs 5 acres or more of land

Phase II, promulgated in 1999, addressed additional sources, including MS4s not regulated under Phase I, and small construction activity disturbing between 1 and 5 acres. The population threshold for automatic inclusion in the Phase II program is 50,000 (Key West's population is closer to 24,500). One provision of the rules allow states to designate municipalities to be included if there is reasonable justification, such as proximity to other regulated communities or sensitive water bodies.

In 1992, when Congress reauthorized the National Marine Sanctuaries Act, it required all national marine sanctuaries to review their management plans every 5 years. During the early 2000s, the regulatory agencies updated the management plan to protect the FKNMS and, through many stakeholder workshops and discussions, recommended that Key West be included in the MS4 program. Because of the general importance of maintaining the regional water quality in Key West, in addition to the multiple regulatory initiatives, the City applied for and entered the NPDES MS4 program as a Phase II community in 2005.

4.2.2 Key West Stormwater Pollution Prevention Plan

The Phase II permit is a general permit that requires the City to develop a Stormwater Pollution Prevention Plan that includes certain minimum elements. The City must report to

FDEP the progress of implementing the Plan each year. The MS4 Stormwater Pollution Prevention Plan pertains to the entire City and contains parts that are not capital improvements and these are applied City-wide. Some of these management elements include such non-structural activities as:

- Public information booths at community events
- Website education campaign
- Public service announcements and interviews on the radio
- News articles or public service announcements on stormwater education issues in local weekly or daily newspaper
- Public meetings and focus groups to obtain input regarding water quality, utility work, grant programs, flood plain management
- Storm drain stenciling
- Support a "Clean Key West Task Force" with a mission to organize public and private groups in developing an adopt and area program, City-wide clean-up initiatives and recommending code enforcement initiatives, code modifications, and City procedures.
- Adopt-an-Area Program for trash clean up and inlet monitoring
- A stormwater hotline to give citizens 1) a method of reporting polluters; 2) a method of providing input for the stormwater program; and 3) a venue for consultation (a number is published in the paper, stormwater brochures, and on the City website)
- Modify storm system map, as needed
- Track reports of illicit discharges
- Conduct illicit discharge screening in inlets and outfalls; reduce infiltration and inflow and cross connections to sewer system
- Public, employee, and business education on illicit discharges/hazardous waste
- Develop and implement community group and school presentations
- City ordinance requiring conformance with FDEP and SFWMD rules

All of the above activities are conducted by the City to comply with CWA requirements. In addition to these non-structural programs, the City funds structural capital projects and regular operation and maintenance of the stormwater infrastructure under its utility.

4.3 Water Quality BMPs

Drainage improvements often entail increasing the conveyance capacity with larger pipes and ditches. However, larger conveyance that reduces flooding often conflicts with water quality goals. The Stormwater Master Plan approach is favored by FDEP and SFWMD so regional controls, like a wet pond serving many acres, could be identified. In Key West, the City is built-out and there are no unimproved lands available for regional controls. Because of this, and because of the flat landscape of the islands, stormwater BMPs at Key West typically serve smaller areas. One exception may be the runoff that originates from the higher land in Old Town and drains through streets and pipes to the low-lying land near the coastline along Caroline, Eisenhower, and Catherine Streets (not an inclusive list).

As described in Section 2, the City has traditionally implemented gravity recharge wells as its predominant stormwater control. A drainage recharge well will divert water that may stage up in streets and eventually drain to City outfalls into the ground. While some of this drainage may still seep to nearshore waters, the slower movement, filtration, and adsorption in the ground reduces pollutant levels. At lower elevations, the recharge wells do not work consistently unless pumped. The pollutant levels at some outfalls can be reduced somewhat by including in-line settling basins. The City currently prefers triple-chamber baffle boxes with screening to capture trash. Finally, the City is also investing in catchbasin inserts that include filtering of stormwater entering that specific inlet. These inserts are used primarily for isolated locations (North Stock Island) or where there is not enough room for new boxes.

Low Impact Development (LID) is currently a popular topic in stormwater management. LID management principals are based on localized treatment and volume reduction. LID BMP examples include:

- Minimize impervious area
- Porous pavement (not gravel parking areas)
- Bioswales
- Rain gardens
- Individual inlet protection
- Vegetated swales
- Infiltration basins
- Rainwater harvesting
- Landscape restoration
- Green roofs

This list is neither comprehensive nor static. However, many of these principles are based on reducing the volume of runoff through local capture and either infiltration or reuse in individual properties, and are not necessarily amenable to stormwater projects in City rights-of-way. The recharge wells also divert stormwater into the ground and away from the outfalls like LIDs. Gravel parking lots are not considered LID when they have compacted subgrade soil. Similarly, pervious pavement is engineered to remove the infiltrated stormwater to attain LID status. According to the FDEP RAR,[4] stormwater BMPs that have been proven to work well in the Florida Keys include:

- Baffle boxes
- Buffers zones using natural vegetation
- Deep stormwater disposal wells
- Rain barrels
- Reduction of impervious areas
- Source controls (street sweeping falls under this category)

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[4]CDM and URS. 2008. *Southern Keys Area Reasonable Assurance Documentation*. http://www.dep.state.fl.us/water/watersheds/bmap.htm Prepared for the Florida Department of Environmental Protection, Tallahassee, FL. December 2008.

- Xeriscape (landscape restoration)

This list includes some of the LID technologies. More details about BMPs are provided in Section 5.

4.4 Stormwater Loading

Stormwater quality is usually expressed in terms of loading (pounds per day or year). In general, this is estimated using average values of annual runoff and pollutant concentrations. It is difficult to monitor stormwater quality. The concentrations can vary tremendously between storm events. Concentrations depend on season, type of pollutant (solid, dissolved, organic, volatile, etc.), time between storm events, size of the storm event (did the runoff flush debris from roads?), and sampling methods. Of course, annual precipitation also varies significantly. It is common to estimate loading utilizing the equation often referred to as the EPA Simple Method, which is basically volume of runoff times concentration and some conversion factors. The concentrations are expressed as an event mean concentration (EMC), which is based on a volume-weighted average from several observed storms. These values are presented below.

The computational method recommended by EPA (1992)[5] was used to estimate annual loading:

$$\begin{aligned} L &= Q \times EMC \\ &= \left\lfloor P \times P_j \times R_v / 12 \right\rfloor \times EMC \times A \times 2.72 \end{aligned}$$

where:

L = Annual pollutant load (lb/y)

$Q = \left\lfloor P \times P_j \times R_v / 12 \right\rfloor \times A$

= Annual runoff volume (acre-feet [ac-ft])

and where:

P = Annual rainfall depth (in/y)

P_j = Factor that corrects for storms that produce no runoff

R_v = Runoff Coefficient

EMC = Event mean concentration (milligrams per liter [mg/L])

A = Drainage area (acres)

12 and 2.72 are conversion factors.

The runoff coefficient can be estimated from the fraction of imperviousness, and it is not the same as used for estimating the runoff curve number. The equation typically used in the EPA method for average annual runoff is:

$$R_v = 0.05 + 0.9 \times Imp$$

where:

Imp = Fraction of imperviousness

In the RAR, the runoff coefficient was computed as:

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5 U. S. EPA. *Guidance Manual for the Preparation of Part 2 of the NPDES Permit Application for Discharges from Municipal Separate Storm Sewers Systems.* Office of Water. Washington, D.C. EPA 833-B-92-002. November 1992.

$$R_v = 0.95 \times DCIA + 0.10 \times (1\text{-}DCIA)$$

where:

DCIA = Fraction of directly connected imperviousness area

The area and imperviousness is determined for each sub-basin and then summed for an approximate estimate of pollutant loading for each constituent. The runoff coefficient was estimated using the relationship derived from the RAR. By comparing the RAR method of estimating runoff to the imperviousness used to estimate curve numbers listed in Exhibit 3-2, the following regression equation was developed to relate R_v to the range of curve numbers used in the City:

$$R_v = 0.0485 \times CN - 3.789$$

where:

CN is the curve number

This equation assumed that most impervious land reaches the City system. Because many of the parking areas in front of parcels are paved or compacted, this is a reasonable assumption.

4.4.1 EMC Selection

It is difficult to monitor stormwater because of the logistics of being ready to collect when it rains, compositing grab samples, false starts, and lab holding times. Some data are available and through the various stormwater programs in Florida there is a literature base that is commonly used. For the City, two EMCs are applicable: those used in the RAR and those proposed for the draft Statewide Stormwater Rule (SSR). The SSR is proposed legislation that refers to a guidance document to determine loadings.[6] Both the RAR and SSR only provide EMCs for TN and TP. Each of the EMCs that these references have is provided in Exhibits 4-1 and 4-2 for the RAR and SSR, respectively.

The EMCs for both sources listed above were derived from data provided by ERD.[7] This reference provides a summary table of the data monitored for various pollutants and land uses. Exhibits 4-1 and 4-2 show that there is not total agreement in EMCs for a given land use; in fact, the descriptions are broad. For example, institutional is typically used for schools and they may or may not have a lot of open land associated with a given location. Also there is a fair amount of deviation in the data, and it is not uncommon for monitored concentrations to have 30 to 60 percent deviation from the mean. By looking at these data and using judgment, the EMCs used to estimate loading for the Key West SWMP is listed in Exhibit 4-3. These values were rounded up to a reasonable significant digit, depending on the parameter.

[6] Florida Department of Environmental Protection. Environmental Resource Permit Stormwater Quality Applicant's Handbook: Design Requirements For Stormwater Treatment Systems In Florida. March 2010 Draft. http://www.dep.state.fl.us/water/wetlands/erp/rules/stormwater/index.htm

[7] Environmental Research and Design (ERD). Evaluation of Current Stormwater Design Criteria with the State of Florida. Prepared for the Florida Department of Environmental Protection. Tallahassee, FL. June 2007.

EXHIBIT 4-1
Nutrient EMCs Listed in the FDEP Reasonable Assurance Report for the Keys
City of Key West 2012 Stormwater Master Plan

Land Use Description	DCIA	CI	CP	TN (mg/L)	TP (mg/L)
Agriculture, Golf Course	0.5%	0.95	0.10	2.32	0.34
Commercial	90%	0.95	0.10	1.82	0.21
High Density Residential	50%	0.95	0.10	1.64	0.27
Roadways	90%	0.95	0.10	1.85	0.40
Industrial	70%	0.95	0.10	1.87	0.28
Public Facilities	70%	0.95	0.10	2.29	0.20
Low Density Residential	10%	0.95	0.10	1.97	0.35
Medium Density Residential	30%	0.95	0.10	2.01	0.30
Urban Open	0.5%	0.95	0.10	1.58	0.13
Forest, Open, Park	0.5%	0.95	0.10	1.24	0.22
Waterbodies & Watercourses	25%	0.95	0.10	0.98	0.16

Notes:

Table 16 in Appendix D of the Reasonable Assurance Report Technical Appendix.
DCIA=Directly Connected Impervious Area
CI=Runoff coefficient for imperviousness;
CP=Runoff coefficient for pervious

EXHIBIT 4-2
Nutrient EMCs Listed in the Draft Statewide Stormwater Design Guidance
City of Key West 2012 Stormwater Master Plan

	Event Mean Concentration (mg/L)	
Land Use Category	TN	TP
Low-Density Residential	1.50	0.18
Single-Family	1.85	0.31
Multi-Family	1.91	0.48
Low-Intensity Commercial	0.93	0.16
High-Intensity Commercial	2.48	0.23
Light Industrial	1.14	0.23
Highway	1.37	0.17

Note:
Table 3.4 in Draft Guidance Document, March 2010

EXHIBIT 4-3
Event Mean Concentrations of Selected Pollutants Applied in the Master Plan
City of Key West 2012 Stormwater Master Plan

Land Use	TN	TP	BOD_5	TSS
Residential High Density	2.3	0.52	11	78
Open Land	1.2	0.06	1	8
Retail Sales and Services	2.4	0.35	11	70
Residential Medium Density	2.1	0.33	8	38
Commercial and Services	1.2	0.18	8	58
Recreational	1.2	0.06	1	8
Institutional	2.9	0.20	8	20
Industrial	1.2	0.26	11	60
Mobile Home Units	2.3	0.52	11	78

Notes:
BOD_5=5-day biochemical oxygen demand
TSS=total suspended solids.

4.4.2 Loading Estimates

Using the procedures noted above, the pollutant loadings were estimated for each sub-basin for TN, TP, BOD, and TSS in pounds per year (lb/yr). These results are shown in Exhibit 4-4. This estimate is only for the delineated sub-basins in the City model (Exhibit 3-1). There are areas directly contributing into the nearshore waters and Navy, FDOT, and county properties not included in the City stormwater model.

4.4.3 Credit for Diverting Stormwater Controls

The RAR assessment assigned a default nutrient reduction value of 10 percent removal for baffle boxes and drainage wells. Assuming both technologies are present together, a gravity drainage well would reduce pollutants by approximately 20 percent. However, the volume of stormwater entering the groundwater nodes in the model can be tracked for the design storm events. Generally, there are a larger number of small storms where a large fraction of the runoff enters the groundwater. Although some nutrients or dissolved pollutants may travel to nearshore waters, their effect is delayed and localized concentrations are highly diluted. For all practical purposes and by standard practice, stormwater discharged into the stormwater recharge wells should be assumed to have 100 percent removal. The amount of rainfall being recharged during the design storms is listed in Exhibit 4-5. The cumulative frequency of rainfall event sizes is shown in Exhibit 4-6. A total of 50 percent of the annual rainfall volume occurs in storms with less than 1 inch of rain, specifically at approximately 0.7 inches; and the 5-year design storm of 6 inches would include approximately 93 percent of the cumulative event volume. This means that on average approximately 93 percent of the rainfall comes from storms less than or equal to 6 inches. As shown in Exhibit 4-5, 45 percent of the stormwater volume is directed into the groundwater during the 5-year event and does not vary much for larger storms. While the capture of smaller storms may be a little higher percentage than for the large design storms, these estimates should provide a good approximation of the effectiveness of the overall current volume reduction. A planning level estimate of approximately 30 to 40 percent removal from City stormwater, rounding down some to account for the directly connected area to nearshore waters, is recommended for the current stormwater system. This estimate does not include the Navy lands, except for some smaller residential areas on the mainland. Only the Navy, FDOT, and county facilities in the sub-basins included in the City model are included in the pollutant load and volume reduction estimates.

EXHIBIT 4-4
Estimated Pollutant Loads from Sub-Basins in the Stormwater Model
City of Key West 2012 Stormwater Master Plan

Sub-Basin	Road N-S Reference	Road E-W Reference	TN (lb/y)	TP (lb/y)	BOD (lb/y)	TSS (lb/y)
100	Between Thompson and Leon	South of Atlantic Blvd	64.1	10.3	236.5	1493.8
130	Between George and Ashby	South of Atlantic Blvd	356.3	56.4	1309.7	8151.3
200	White	Between Atlantic Blvd and Casa Marina Ct	189.0	27.2	668.6	3909.5
210	White	Laird	80.6	12.0	282.0	1706.8
215	Whalton	Johnson	17.1	2.5	60.2	347.1
220	Florida	Laird	40.5	6.8	152.1	999.0
230	White	Von Phister	43.6	6.5	151.0	948.6
235	White	Von Phister	122.9	14.4	393.1	2020.9
240	Whalton	Von Phister	99.0	16.4	378.6	2317.5
245	Grinnell	Von Phister	39.3	6.0	141.4	855.7
250	Grinnell	Johnson	16.7	2.6	60.6	372.7
300	Reynolds	Atlantic Blvd	105.7	10.2	326.4	1393.2
310	Reynolds	Von Phister	96.4	15.0	381.8	2500.4
320	Reynolds	South	125.5	16.6	429.4	2317.6
400	Alberta	Seminole Ave	109.7	17.2	451.5	2999.5
410	William	Washington	33.7	5.5	131.1	869.0
500	Duval	Bound past South	196.5	29.8	854.9	5634.6
510	Simonton	South	129.7	19.7	562.8	3692.0
520	Simonton	United	80.1	13.3	329.7	2239.1
530	Simonton	Louisa	38.8	6.4	177.5	1267.5
540	Duval	Catherine	122.2	18.1	470.3	2880.3
600	Fort	Amelia	10.1	1.1	23.3	173.1
605	Emma	Amelia	79.6	12.0	263.2	1906.6
610	Emma	Virginia	43.2	8.6	193.4	1364.2
620	Howe	Virginia	44.0	7.2	164.3	1064.8
625	Whitehead	Catherine	48.5	7.7	183.2	1154.5
627	Whitehead	Amelia	23.4	3.6	88.0	532.3
628	Whitehead	Virginia	32.6	5.0	123.1	773.4
630	Whitehead	United	18.0	2.7	61.0	420.9
635	Fort	Truman	74.8	13.3	308.4	2198.2
640	Emma	Truman	30.9	5.5	122.1	818.7
641	Thomas	Truman	56.3	7.8	201.8	1132.9
642	Emma	Olivia	42.0	7.1	164.4	1060.1
643	Emma	Petronia	50.9	9.5	211.1	1413.8
645	Thomas	Petronia	49.5	8.1	197.0	1312.9
700	White	Fleming	42.6	6.6	163.5	1032.9
705	Frances	Fleming	42.0	6.5	155.5	930.4

EXHIBIT 4-4
Estimated Pollutant Loads from Sub-Basins in the Stormwater Model
City of Key West 2012 Stormwater Master Plan

Sub-Basin	Road N-S Reference	Road E-W Reference	TN (lb/y)	TP (lb/y)	BOD (lb/y)	TSS (lb/y)
710	White	Southard	83.5	13.7	319.9	2022.2
720	White	Angela	32.8	5.2	123.9	824.0
730	Ashe	Angela	34.1	5.2	118.1	731.6
750	Frances	Petronia	36.6	5.5	133.5	846.2
755	Frances	Olivia	59.2	10.0	229.5	1488.8
800	Florida	Eliza	27.9	4.2	100.1	583.6
810	White	Eliza	16.7	2.2	63.1	355.7
820	White	Virginia	27.9	3.4	95.6	489.9
830	Varela	Virginia	85.1	14.3	338.2	2190.4
900	Pearl	Alberta	35.3	5.8	130.7	852.6
905	Pearl	Petronia	35.9	5.8	134.1	811.2
920	Florida	Newton	74.9	12.0	278.0	1691.9
1005	7th	Patterson Ave	21.1	3.4	79.7	508.8
1015	6th	Patterson Ave	75.7	12.6	294.7	1875.6
1020	6th	Fogarty Ave	41.2	4.8	129.7	649.6
1025	6th	Harris Ave	24.0	4.0	92.3	613.8
1030	7th	Fogarty Ave	30.7	5.0	113.2	716.4
1120	Duval	Eaton	150.9	21.8	593.6	3675.9
1130	Duval	Fleming	140.9	22.7	587.0	3838.5
1140	Duval	Angela	13.7	2.2	54.5	376.8
1150	Whitehead	Angela	142.0	25.1	607.5	4027.7
1160	Simonton	Angela	139.2	22.9	601.8	3904.7
1170	Duval	Petronia	30.6	4.9	125.3	838.9
1180	Duval	Southard	51.1	8.4	211.0	1466.8
1190	Whitehead	Caroline	31.2	5.1	138.5	959.5
2000	Whitehead	Front	45.7	6.7	195.2	1279.8
2010	Whitehead	Greene	13.1	1.8	44.0	260.2
2100	Duval	Front	110.7	16.7	471.6	3105.3
2110	Ann	Front	142.1	23.1	619.3	4153.8
2120	Duval	Between Greene and Front	138.3	22.5	596.8	3996.7
2130	Duval	Caroline	49.8	8.1	204.1	1357.5
2135	Duval	Between Caroline and Eaton	77.4	11.5	343.0	2157.2
2140	Simonton	Caroline	26.4	4.0	115.4	757.3
2200	Elizabeth	Greene	52.5	9.1	211.3	1433.3
2300	William	Caroline	121.0	19.6	483.7	3074.2
2400	Margaret	Caroline	102.5	16.3	409.9	2641.9
2500	Grinnell	Boundary, North of Trumbo Rd	154.6	26.6	758.4	4998.9
2510	White	Eaton	49.8	8.1	206.0	1357.0
2520	Frances	Eaton	52.7	8.2	211.6	1333.1
2530	Grinnell	Eaton	87.2	15.0	364.7	2421.2
2540	Grinnell	Fleming	31.0	5.0	114.9	736.8
2550	Southard	Margaret	106.6	17.4	419.1	2656.6
2555	Williams	Fleming	104.8	16.9	406.4	2633.8

EXHIBIT 4-4
Estimated Pollutant Loads from Sub-Basins in the Stormwater Model
City of Key West 2012 Stormwater Master Plan

Sub-Basin	Road N-S Reference	Road E-W Reference	TN (lb/y)	TP (lb/y)	BOD (lb/y)	TSS (lb/y)
2563	Passover	Windsor Ln	54.6	8.6	195.5	1193.4
2567	William	Windsor Ln	68.2	11.1	256.1	1597.3
2570	Passover Ln	Olivia	193.1	32.0	791.4	5067.6
2600	Whitehead	Truman	99.8	15.4	403.4	2591.9
2610	Center	Truman Ave	122.7	19.9	509.2	3318.1
2700	Between Florida and Pearl	Truman Ave	13.5	2.2	50.1	320.6
2705	Jose Marti Dr/Eisenhower Dr	Truman Ave	40.6	6.4	158.7	1079.7
2710	Georgia	Truman Ave	70.3	10.2	252.0	1521.4
2730	Varela	Truman Ave	28.9	4.7	117.0	808.3
2740	Grinnell	Truman	33.5	5.5	141.1	980.8
2750	Passover Ln	Truman Ave	190.0	21.7	650.8	3239.4
2800	Pearl	Between Eliza and Virginia	16.4	1.3	46.3	156.3
2802	Jose Marti Dr	Between Virginia and Truman	47.7	6.4	151.2	952.4
2810	Leon	Catherine	28.8	3.9	97.9	536.5
2820	Thompson	Catherine	45.0	6.3	157.1	850.6
2830	Thompson	Seminary	123.7	16.8	434.2	2388.5
2832	Thompson	Washington	19.2	3.0	69.8	418.1
2834	Thompson	Von Phister	12.3	1.9	42.9	274.6
2836	Leon	Von Phister	17.1	2.7	63.2	382.5
2838	Tropical	Von Phister	57.2	9.0	208.3	1258.0
2840	Leon	South	57.2	8.9	206.8	1227.5
2842	Tropical	Washington	23.0	3.7	85.7	536.1
2844	Tropical	South	24.5	4.0	91.1	581.0
2846	Tropical	Seminary	49.1	4.6	145.4	600.9
2847	Pearl	Catherine	13.7	2.2	51.2	305.1
2850	Florida	Catherine	20.6	3.6	80.9	528.2
2852	Pearl	United	19.0	3.0	68.5	444.6
2855	Florida	United	27.1	4.3	99.5	638.3
2860	Georgia	Catherine	15.8	2.1	54.0	301.2
2865	Georgia	United	26.4	3.5	93.9	548.8
2870	White	Catherine	33.7	4.8	132.7	819.9
2880	Varela	Catherine	67.1	11.8	264.3	1718.0
2883	Packer	Catherine	34.6	5.6	137.8	929.8
2887	Grinnell	Virginia	44.6	7.3	171.7	1112.3
2890	Margaret	Catherine	190.7	27.5	716.7	4066.1
2892	Royal	Catherine	17.6	3.0	68.5	436.2
2895	William	Catherine	61.0	10.9	252.9	1728.9
2900	Eisenhower Dr	Newton	69.4	10.7	264.1	1728.7
3000	George	Catherine	24.8	4.0	93.3	561.6
3010	George	United	17.9	3.0	67.5	437.1
3020	Ashby	Catherine	24.0	3.6	85.1	494.5
3030	Ashby	United	25.3	4.0	93.0	561.7
3040	Ashby	Seminary	53.5	8.2	191.3	1139.1

EXHIBIT 4-4
Estimated Pollutant Loads from Sub-Basins in the Stormwater Model
City of Key West 2012 Stormwater Master Plan

Sub-Basin	Road N-S Reference	Road E-W Reference	TN (lb/y)	TP (lb/y)	BOD (lb/y)	TSS (lb/y)
3050	George	South	31.7	5.1	117.1	744.8
3060	Ashby	Washington	8.1	1.2	28.4	184.2
3100	1st	N. Roosevelt Blvd	50.6	9.4	224.8	1573.6
3110	1st	Roosevelt Dr	47.5	8.7	209.3	1474.8
3115	1st	Patterson Ave	73.4	14.0	304.3	2124.4
3120	1st	Seidenberg Ave	30.8	5.1	121.0	803.2
3200	4th	Patterson Ave	75.5	11.4	310.3	1994.8
3210	3rd	Patterson Ave	32.8	5.8	129.0	900.3
3220	4th	Fogarty Ave	73.7	11.6	268.9	1603.0
3230	5th	Fogarty Ave	36.3	5.7	133.9	844.6
3235	5th	Seidenberg Ave	25.6	4.0	93.3	583.9
3240	4th	Harris Ave	61.6	9.7	230.4	1433.5
3250	3rd	Harris Ave	25.9	3.9	90.5	568.2
3260	2nd	Fogarty Ave	93.7	15.4	351.7	2231.2
3300	Between 5th and 6th	Flagler Ave	75.0	12.1	277.1	1851.4
3310	4th	Flagler Ave	33.7	4.6	112.5	680.5
3320	3rd	Flagler Ave	30.0	4.1	119.2	779.5
3330	2nd	Flagler Ave	36.9	5.4	134.2	884.4
3340	Dennis	Venetia	53.3	7.3	206.9	1250.7
3345	1st	Flagler Ave	44.3	6.8	188.4	1264.5
3350	George	Flagler Ave	58.3	9.0	211.9	1291.0
3360	Thompson	Flagler Ave	18.3	2.8	63.7	415.0
3370	Between Lean and Tropical	Flagler Ave	45.4	7.6	172.1	1081.3
3400	8th	Flagler Ave	75.8	12.0	280.7	1788.5
3410	7th	Flagler Ave	69.7	11.2	263.8	1723.8
3500	West of the 9th St Canal	Patterson Ave	58.8	9.4	218.0	1397.8
3600	11th	Flagler Ave	89.6	13.2	329.6	1826.1
3610	Between 10th and 11th	Flagler Ave	67.8	7.1	204.9	962.6
3620	12th	Flagler Ave	57.9	9.2	228.6	1364.1
3700	11th	North of Patterson	34.4	5.4	133.3	818.9
3710	12th	North of Patterson	38.3	5.3	189.9	1202.6
3720	12th	Fogarty Ave	43.6	9.2	208.9	1430.1
3730	11th	Fogarty Ave	65.6	10.1	236.8	1365.6
3740	13th	About Patterson Ave	130.2	14.3	467.0	1983.2
3750	13th	North of Patterson	38.4	3.5	141.4	584.5
3760	13th	Northside	37.8	6.0	239.8	1531.1
3770	14th	Northside	62.1	9.6	332.0	2112.4
3780	14th	Nr. Stadium MH Park	101.7	20.6	470.4	3161.9
3790	14th	Nr. Stadium Apts.	266.4	48.5	1155.5	7136.8
3800	Rivera St (15th)	Flagler Ave	235.3	37.0	893.0	5568.1
3810	16th	Flagler Ave	87.5	13.6	347.3	2272.6
3820	14th	Flagler Ave	74.9	11.4	299.4	1898.2
3830	Between 13th and 14th	Flagler Ave	62.3	9.2	270.2	1703.9

EXHIBIT 4-4
Estimated Pollutant Loads from Sub-Basins in the Stormwater Model
City of Key West 2012 Stormwater Master Plan

Sub-Basin	Road N-S Reference	Road E-W Reference	TN (lb/y)	TP (lb/y)	BOD (lb/y)	TSS (lb/y)
3837	13th	Riviera	64.6	9.6	267.0	1656.5
3900	18th	Flagler Ave	198.9	30.0	702.9	4272.8
3910	17th	Flagler Ave	40.1	5.7	136.4	852.1
3912	17th	Riviera	29.3	4.4	104.9	615.7
3920	Between 19th and 20th	Flagler Ave	19.1	2.9	67.4	402.7
3930	20th	Duck to Eagle Ave	112.4	17.5	404.7	2492.3
4000	Whitehead	Between Fleming and Southard	85.5	11.5	347.4	2026.8
4010	Whitehead	Fleming	20.5	2.2	70.6	360.5
4100	15th-ish	Northside	169.6	26.6	823.0	5229.2
4105	16th-ish	West of Donald	112.4	24.2	520.4	3537.9
4110	17th St	Donald	226.9	44.5	967.3	6559.1
4115	16th St	North of Donald	123.4	20.3	533.2	3228.3
4120	18th	Donald	203.5	39.0	858.3	5654.0
4125	20th St	Northside	112.2	16.9	507.7	3248.9
4130	20th	Donald	20.0	3.2	77.6	452.1
4140	19th	Donald	35.2	6.0	136.5	862.6
4145	19th	Cindy	67.7	12.0	267.0	1796.8
4147	18th	Pearlman	105.3	16.1	382.2	2244.6
4150	20th	Cindy	45.0	6.8	161.2	929.2
4160	18th Ter	Northside	24.0	4.0	112.4	635.5
4170	18th St	Northside	61.0	9.5	260.5	1533.6
4175	17th	Northside Ct.	66.6	9.5	279.7	1825.5
4180	Trinity	Northside	127.0	19.0	587.3	3429.3
4200	Venetian	Venetian	46.5	7.2	190.1	1068.0
4210	Jamaica	Venetian	32.7	4.9	124.9	677.4
4220	Bahama	Venetian	34.3	5.2	124.4	686.6
5000	Whitehead	South St	27.4	5.0	129.6	901.2
6000	10th St	Harris Ave	116.8	18.1	422.2	2520.0
Subtotal Loads (lb/yr)	Main Island		13,016	2,044	51,330	321,378
North Stock Island						
6	Parking Lot in Front of Elementary School		14.5	1.4	59.4	231.1
7	Adams Elementary School area		47.0	3.2	129.7	324.3
10	Front of Hospital (swales with mangroves)		117.8	12.1	501.3	2188.2
11	Closed Landfill (Ponds at higher elev.)		36.8	3.2	66.6	502.5
12	Closed Landfill Buildings		9.3	1.2	43.1	241.4
14	County Detention Center		259.9	22.5	935.5	4109.4
18	Salt Marsh		302.7	36.1	1523.4	9147.5
19	Residential Area (east)		65.7	10.0	387.7	2621.1
20	Residential Area (entrance)		16.3	2.8	122.0	781.9
21	Residential Area (east)		26.7	4.1	149.5	988.6
22	Residential Area (central)		14.1	2.2	71.7	445.3
23	Residential Area (central)		15.2	2.3	83.5	550.6

EXHIBIT 4-4
Estimated Pollutant Loads from Sub-Basins in the Stormwater Model
City of Key West 2012 Stormwater Master Plan

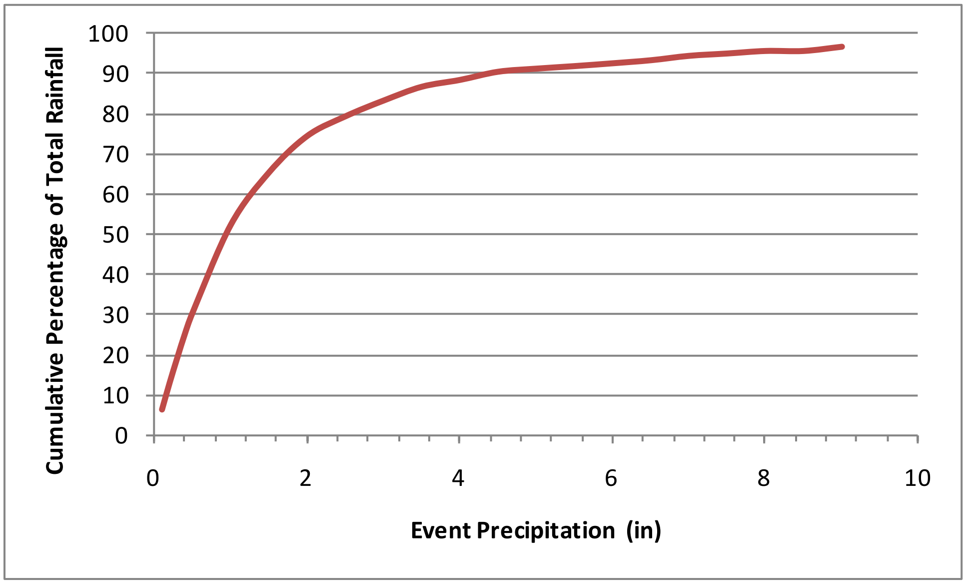
Sub-Basin	Road N-S Reference	Road E-W Reference	TN (lb/y)	TP (lb/y)	BOD (lb/y)	TSS (lb/y)
24	Residential Area (central)		28.6	4.4	145.1	902.4
25	Residential Area (central)		29.5	4.5	164.1	1081.3
26	Residential Area (central)		13.3	2.0	72.4	471.8
27	Residential Area (west)		15.0	2.3	86.9	587.3
28	Residential Area (west)		29.0	4.5	150.2	945.6
29	Residential Area (west)		30.1	4.6	159.0	1014.7
30	Golf Course Fairway (south, nr. 14th Tee)		62.5	9.1	342.3	2491.6
31	Golf Course Pond (middle, nr. 16th Green)		127.0	19.0	845.4	6125.6
32	Golf Course Pond (south, nr. 2nd Tee)		64.5	9.7	430.0	3117.7
33	Golf Course nr. 1st Fairway		86.8	12.8	561.7	4050.8
34	Clubhouse Area		46.3	5.0	214.5	1240.0
35	Golf Course Pond (west, nr. 12th Tee)		108.9	16.3	725.6	5259.4
36	Wetland behind FKAA Storage Facility		69.6	10.5	353.9	2250.2
37	Golf Course nr. 10th Fairway		43.2	6.5	283.5	2047.2
38	Golf Course nr. 11th Fairway		67.1	10.4	454.1	3214.9
39	Southwest corner, so. of Botanical Garden		33.5	5.6	178.8	1258.0
40	FKAA Storage Facility		36.6	5.4	202.4	1016.1
41	Southwest, nr. Botanical Garden		87.4	15.8	443.4	2996.1
44	West, just north of Botanical Garden		38.7	4.4	151.7	735.3
45	Golf Course Fairway (south, nr. 2nd Tee)		72.8	10.6	381.5	2779.8
46	Golf Course on East, nr. Mangrove Swales		70.5	12.1	522.7	3389.8
47	Golf Course Ponds (middle, nr. 4th Green)		63.6	9.5	423.5	3069.6
48	Golf Course Wetland (east, nr. 8th Green)		51.5	7.7	342.0	2476.0
49	Wetlands and back of Hospital		49.8	3.8	155.0	539.0
NSI Subtotal			**2,371**	**316**	**12,611**	**80,612**
Main Island Subtotal	**(From Above)**		**13,016**	**2,044**	**51,330**	**321,378**
Grand Total			**15,387**	**2,360**	**63,941**	**401,990**

EXHIBIT 4-5
Estimated Volume of Stormwater Directed to Recharge Wells during Design Events
City of Key West 2012 Stormwater Master Plan

Design Storm Return Period	Volume of Runoff (ac-ft)	Percent Directed to Groundwater during Event
5-yr, 24-hr	634.8	45.0%
10-yr, 24 hr	743.2	43.6%
25-yr, 72 hr	1,425.5	47.2%
100-yr, 72 hr	1,990.2	44.4%

Note:
Simulation results for 24-hour storms hydraulically routed for 30 hours and 72-hour storms were routed for 80 hours.

EXHIBIT 4-6
Cumulative Distribution of Rainfall Events in Key West
City of Key West 2012 Stormwater Master Plan



Source: Environmental Research & Design, Inc. (ERD). 2007. Evaluation of Current Stormwater Design Criteria within the State of Florida. Prepared for the Florida Department of Environmental Protection, Tallahassee, FL. June 2007.

SECTION 5

Conceptual Proposed Projects Cost Data

This section provides a brief overview of the BMPs and controls used in the Stormwater Master Plan. This section is divided into two parts, a brief overview of the flooding and water quality controls used in Key West, and a section on cost information. Together with the model results, these components are applied to form recommended projects that are discussed in section.

5.1 Stormwater Controls

As noted in Section 4, there is a limited amount of stormwater practices utilized in Key West. Some of these practices are for flooding controls; others are for water quality improvements. Most projects may contain some of both types of controls, while others are primarily water quality projects. As part of a broader commitment to reducing stormwater pollutant discharges from the nearshore waters, the City primarily utilizes recharge wells and infiltration controls. The City also has installed water quality baffle boxes (moderately large concrete boxes with screens and walls to trap trash and sediment) on some outfalls where the low elevations will not allow good infiltration. A broad overview of typical practices used in Key West is included in Attachment B, and includes a short description of the following:

- Stormwater recharge wells
- Infiltration controls
- Grass swale or channel
- Water quality baffle boxes
- Water quality inlets (a.k.a. individual inlet protection or inlet filters)
- Vortex and swirl separators
- Catchbasin cleaning
- Pavement sweeping
- Rooftop runoff management
- Zoning and development controls
- Litter and household hazardous waste controls
- Removal of illicit connections (for example, altered sewer cleanouts)

Stormwater recharge wells can be either gravity or pressurized. Infiltration controls include exfiltration trenches (also called French drains) and pervious pavement. This section contains more specific information about these items. Most of the general BMPS applied for the MS4 permit (like public education, illicit connection, litter control, and so forth) will not be discussed further as they are typical operations of the stormwater utility.

The City currently has guidelines that they use to select drainage projects with recharge wells and exfiltration trenches. MHW, MHHW, and the ground surface elevation above sea level must be considered because fresh water floats on top of saltwater (salinity differential). It takes 1.6 ft of standing water above the saltwater in the casing to overcome friction loss and salinity differential to force the stormwater down the well (driving force). The discharge rating curves for recharge wells were discussed in Section 3. Based on the documented sea level rise and the projections of increasing levels, as well as the discharge rating curve, the City will not install gravity recharge wells at elevations below 4 ft mean sea level (NGVD29), which is approximately elevation 2.7 ft NAVD88. Trench drains, French drains, pressurized wells, and gravity collection systems (outfalls) will be used for drainage sub-basins with lower elevations. However, most of New Town (eastern half of the City) are at low elevations that would preclude highly productive gravity wells, though some are installed there at low elevations. Gravity wells installed at low elevations (approximately elevation 3 NAVD88 or less) may still function at low tide or at very low flow rates. However, the cost-effectiveness of a gravity recharge well with low capacity must be carefully considered when compared to other options.

Exfiltration trenches are often utilized in South Florida where the soil is permeable. Because of the disturbed nature of most of the City soils, site-specific data collection is required to determine the permeability. Permeable soils with a hydraulic conductivity exceeding 1×10^{-5} cubic foot per second per square foot (cfs/ft^2) per foot of head is the normal design criteria.[1] Locations with nearby trees (less than approximately 20 ft) may also affect the siting of a trench. The SFWMD allows exfiltration trenches to extend down into the groundwater table, while some communities do not. In Key West, nearly all such trenches will be in the groundwater, which is considered acceptable especially because there is no potable groundwater in the City. The typical FDOT detail for these trenches is to make the rock trench at least 2 ft deeper than the invert of the pipe. FDOT also requires a minimum of 18-inch-diameter perforated pipe. CH2M HILL normally specifies a larger-diameter perforated high-density polyethylene (HDPE) pipe, 24 inches, and the rock trench 8 to 12 ft deep (total) with the top of the pipe set approximately 3 ft below the street. The pipe can be set deeper to accommodate a lower grade line. Perez recently designed a trench approximately 4 ft by 4 ft of rock with an 18-inch-diameter pipe with only approximately 1 ft of rock cover over the pipe and 2 ft total cover from the street. This would be a minimum amount of soil and rock cover for an exfiltration trench.

Based on discussions with other engineers in South Florida and CH2M HILL's experience, small pipe and trenches tend to fill with silt and fail faster (6 to 10 years) than larger trenches and pipes. FDOT used to state that the life of exfiltration trenches is approximately 10 to 15 years, but currently refrains from such estimates because of the variability of factors affecting service life. When failure occurs, the exfiltration trench rock and pipes need replacement. CH2M HILL designs exfiltration trenches with larger pipes when possible because they appear to function longer. The biggest challenge is often the space availability for deeper trenching. An 8- to 10-ft-deep trench, approximately 4-ft-wide at the location of the pipe, with at least 2 ft of cover over the pipe to the street is recommended, but a shallower trench may be used as long as there is approximately 4 ft by 4 ft square of rock. The trench is normally wrapped in woven geotextile with high permeability to improve its life span. Baffling in the attached catchbasins with a snout or other similar type of protection is also recommended. The baffle must be removable for pipe cleaning. Using the geotextile fabric, pre-treatment, and regular maintenance are considered keys to extending the life of exfiltration trenches. A schematic of exfiltration trench cross section is shown in Attachment B under Infiltration Controls.

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[1] FDOT. Drainage Handbook, Exfiltration Systems. Tallahassee, FL. January 2007. www.dot.state.fl.us/rddesign/dr/files/EXFILTRATION-HB-2007.pdf

In Miami-Dade County, it is common to install an inlet with 50 ft of exfiltration trench on either side to address isolated standing water. In other applications, the exfiltration trench is used instead of just hard pipe to promote as much infiltration of stormwater as possible for treatment credit. The trench pipe lengths between inlets should be limited to allow for jet cleaning. Assuming access from both ends and an effective hose length of 100 ft, the inlet spacing should be approximately 200 ft; FDOT recommends 300 ft or less. If the pipe connects to an outfall, a concrete box with a baffle set at the high water table elevation is required to keep the trench from dewatering and to induce more infiltration.

While the City does not prefer to install new outfalls, there are some low areas where an outfall may need to be constructed primarily because of low elevations and chronic flooding. These cases will be examined carefully before proceeding. If a new outfall is deemed necessary, steps will be taken to reduce as much runoff volume as practical and water quality practices will be implemented to reduce pollutant loads.

Water quality improvements can be included with a water quality baffle box to reduce sediment, associated pollutants, and trash from being discharged. In some areas with limited space for boxes, such as on North Stock Island, water quality can be improved with inserts that filter the initial runoff rate before discharge. Water quality projects are recommended but are not necessarily included in the modeling, as they are not hydraulic improvements to reduce flooding.

5.2 Cost Methodology

Construction costs of proposed projects were developed using cost data from recently bid projects, cost estimates[2] of similar projects, vendor quotes, and engineering judgment. These projects' components and construction cost data were evaluated and grouped into larger, more general project components that can easily be assigned to proposed projects. A cost range based on bid elements was then estimated for each project component grouping. This methodology will provide order-of-magnitude project costs, which is adequate for planning purposes. The project component groups for the 2012 Stormwater Master Plan are as follows:

- Trench excavation, backfill, and pipe
- Catch basins, inlets, and manholes
- Triple chamber baffle box with injection well
- Pavement/curb
- Outfall/seawall reconstruction
- Outfall check valve
- Pump station, including pumps, vortex unit, and other appurtenances
- Generator and platform
- Exfiltration trench

Many of the proposed projects in the 2012 Stormwater Master Plan are similar to the gravity injection well projects already constructed by the City. Because these projects' improvements are centered about the intersection near which the work was performed, this easily lends itself to the evaluation of the construction costs of these proposed projects on a per-intersection basis. Other project components will be evaluated on a unit-cost basis.

[2] Definitive Level or Class 1 estimate as defined by the American Association of Cost Engineering (AACE). It is considered accurate from -5 percent to +15 percent.

The project component groups, units, and cost ranges are shown in Exhibit 5-1.

EXHIBIT 5-1
Project Component Groups and Cost Opinions
City of Key West 2012 Stormwater Master Plan

Element	Unit	Low	High
Trench Excavation, Backfill, and Pipe			
Storm Pipe	intersection	$39,234	$45,339
Force Main	LF	$105	$213
Catch Basins, Inlets, and Manholes	intersection	$19,372	$33,970
Triple Chamber Baffle Box with Gravity Injection Well	ea	$70,300	$114,000
Pavement/Curb			
Includes ADA improvements	intersection	$31,487	$39,887
Does not include ADA improvements	LF	$32	$108
Outfall/Seawall Reconstruction	ea	$12,000	$24,000
Outfall Check Valve	ea	$10,700	$13,200
Pump Station (pumps, vortex, appurtenances)		$1,575,000	$1,798,011
Generator and Platform	ea	$266,300	$295,000
Exfiltration Trench	LF	$218	$245

Note:
LF=linear foot

After construction cost opinions have been developed, the following factors[3] are applied to achieve a total project cost:

- General conditions, taxes, overhead, profit, mobilization and demobilization, and bonds: 15 percent
- Contingency: 10 percent (because of the conceptual nature of projection)
- Key West location factor: 20 percent (shipping, high density, and high travel costs)
- Project design fees: 10 percent
- Engineering services during construction and construction management: 10 percent

Given the planning-level scope of these cost estimates, escalation is not expected to significantly affect the construction costs, and therefore has not been taken into account.

5.3 ADA Requirements

The proposed projects often involve the demolition and restoration of sidewalk and streets. The American with Disabilities Act (ADA) requires that these projects meet the 2010 ADA Standards for Accessible Design. These standards establish minimum clear width and slopes for sidewalks and ramps.

According to 28 CFR 35.151, the ADA requirements for new construction and alterations, curb ramps are required for:

[3]Percentages are applied to construction costs.

- Newly constructed or altered streets, roads, and highways must contain curb ramps or other sloped areas at any intersection having curbs or other barriers to entry from a street level pedestrian walkway.
- Newly constructed or altered street level pedestrian walkways must contain curb ramps or other sloped areas at intersections to streets, roads, or highways.

The additional costs associated with the implementation of ADA standards will be accounted for in the cost estimates.

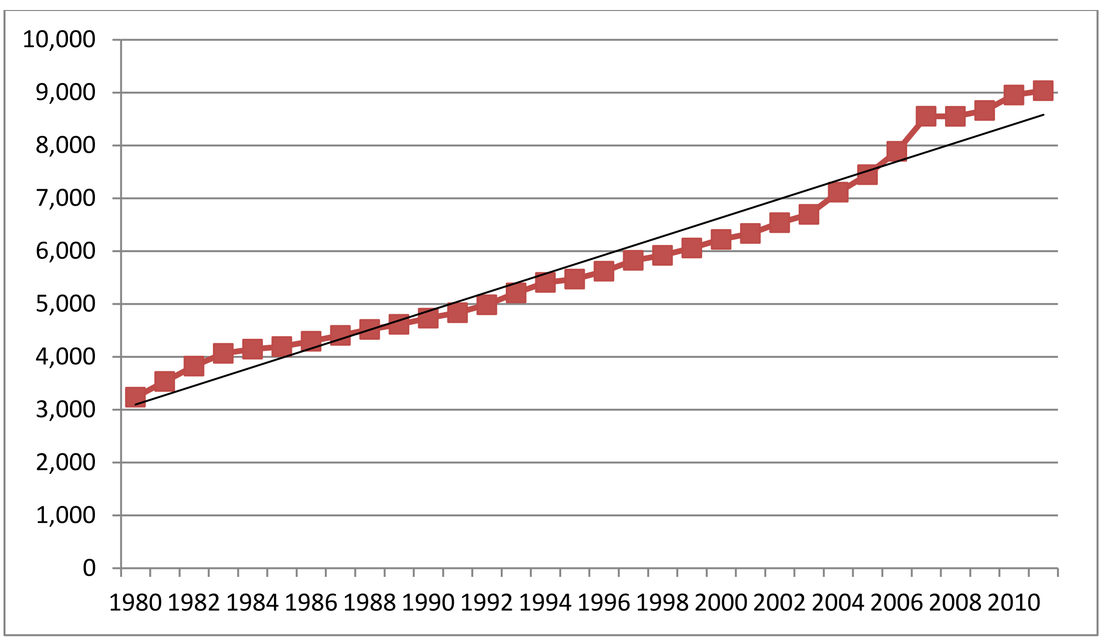
5.4 Construction Cost Trends

The *Engineering News-Record* (ENR) publishes a construction cost index (CCI) on a monthly basis that includes both a labor component and a materials component. ENR tracks prices from 20 U.S. cities. The same suppliers provide price quotes each month. ENR also takes local union wage rates into consideration.

The CCI measures the costs against base year costs (1913).[4] The May 2011 index is 9,034.67. In comparison to the May 2010 CCI of 8,761.47, there has been an increase of construction costs of approximately 3.1 percent between May 2010 and May 2011.

Because the timing of proposed projects is unknown at this time, CCI has not been applied to the cost estimates. However, the CCI can be applied to the cost estimates when the timing of the projects is known. Exhibit 5-2 shows the CCI trend from the years 1980 through May 2011, which can be extended for projects to be completed within the next couple of years. The long-term average trend in the CCI for the last 30 years is approximately 3 percent increase per year.

EXHIBIT 5-2
Construction Cost Index, 1980–2011
City of Key West 2012 Stormwater Master Plan



[4]Base year index is 100.

SECTION 6

Assessment and Project Definition

This section describes how the information and data provided in the previous sections were applied to develop and evaluate specific projects. The existing flooding conditions were presented in Section 3; Section 4 provided water quality loadings and issues that need to be considered; and Section 5 listed project types and cost data to be used. To develop the projects, a three-step process was used:

1. Identify areas with larger flooding issues (that is, rank the sub-basins where excessive flooding occurs)
2. Evaluate projects for these areas to determine their effectiveness
3. Assess the potential projects to provide a priority for implementation

These steps are described in each subsection below. Key West has some unique characteristics that affect the way stormwater projects are prioritized. For example, the low elevations near the coast make traditional "pipe" projects less effective unless very large pipes are used. The highly developed island does not normally have sufficient area for large pipes, especially considering the other utilities. Also the City wants to reduce stormwater pollutant discharge into the nearshore coastal waters to help protect the natural resources, including beaches, and larger conveyances alone will not achieve this water quality goal. Residents are accustomed to standing water immediately after a larger rainfall, as long as the runoff percolates or drain relatively quickly. Consequently, improvements to drainage are measured in sub-foot improvements and the ability to drain after the peak of the storm passes.

When defining and prioritizing projects, applying a strict benefit-cost comparison often tends to skew projects toward high-value neighborhoods that may cause some social justice concerns. A methodological ranking procedure that considers flooding issues equally regardless of the area is preferred. However, Federal FEMA funding often requires a positive benefit-cost ratio to justify grant money. Some master plans use a ranking procedure to include water quality values. This procedure tends to highlight highly developed sub-basins as higher pollutant sources because of high runoff volumes; however, because the entire island is mostly built-out in moderate to high density, this criteria is not necessary. The City's preferred technologies to reduce flooding include the recharge wells and infiltration BMPs, so water quality benefits will be included in the projects. New or larger outfalls will be considered only when other options to reduce flooding are limited.

6.1 Identification of Areas with Significant Flooding

Exhibits 3-4 and 3-5 provided the estimated flood levels for the existing stormwater system. These data were used to identify which sub-basins have more problems than others under existing conditions. This initial assessment and sub-basin ranking is useful for discussion purposes but does not in itself identify priority projects.

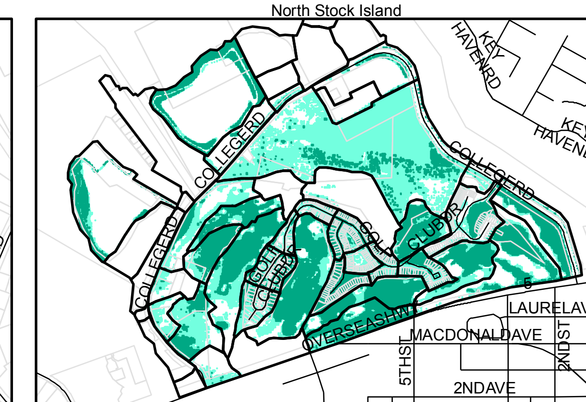
Level of service (LOS) is a common term often used in drainage studies to define performance. For example, the SFWMD requires that local roads and parking lots drain at least a 5-year design storm, so a typical local road design would provide at least a 5-year LOS for flooding. Some stormwater plans use a scoring system to rank areas. Typical scoring criteria may address the following issues:

- Emergency structures operational during a 100-year flood
- Number of buildings or parcels with high water levels
  - Structures (residential and commercial) should be damage free during the 100-year flood
- Length of major roads under target depths of standing water
  - Major evacuation routes should be passable during the 100-year flood
  - Major streets should be passable in the 10-year flood
  - Residential streets should be passable during the 5-year storm
- Length of canals or ditches flooded out of bank
- Pounds per year of pollutant loads

Based on CH2M HILL's experience in defining and conducting these types of assessments in coastal areas, two criteria tend to differentiate projects: number of buildings or structures flooded during the 100-year flood and length of major streets flooded in the 10-year flood. Consequently, only these two criteria are used herein.

To determine what constitutes damage to structures during the 100-year flood, the first floor elevations of each structure would need to be known and that information is not often generally available. Some buildings would be damaged in lower floods, while other buildings are elevated. This assessment assumed that flooding more than 1 ft deep over the general landscape elevation (from LiDAR data) would potentially damage a structure. The Monroe County property assessor parcel database was used to identify lots. To be slightly more conservative, the assessment counted the parcels where there was some 100-year flooding greater than 1 ft deep, even if only a small part of the lot was that deep. Exhibit 6-1 shows the 100-year flood and the zones deeper than 1 ft (darker red). Note that North Stock Island residences (in the golf course development) were permitted with first floor elevations set more than 1 ft above the ground so North Stock Island was not included in the sub-basin ranking (no known problems).

The second criterion, length of streets not passable during the 10-year flood, was assessed to all roads in the sub-basins regardless of whether they are considered major. The Monroe County street GIS database was used to identify roads. The LiDAR data was used to determine areas deeper than 6 inches during the 10-year flood. While some studies may apply a higher value, the 6-inch threshold was selected as a reasonable depth that may last for a short time during a large rain event given the wide variety of roads on the island. The length of road was determined using GIS to intersect the road centerlines with the flood polygons. Exhibit 6-2 shows the roads where flooding occurs in excess of 6 inches. As with Exhibit 6-1, the darker shading shows the deeper staged stormwater.



LEGEND

- Roads
- Property Boundary
- Existing 100 Year Flood Stage
- Existing 100 Year Flood Stage Exceeding Ground Surface by 1 Ft. or More
- Sub-Basin

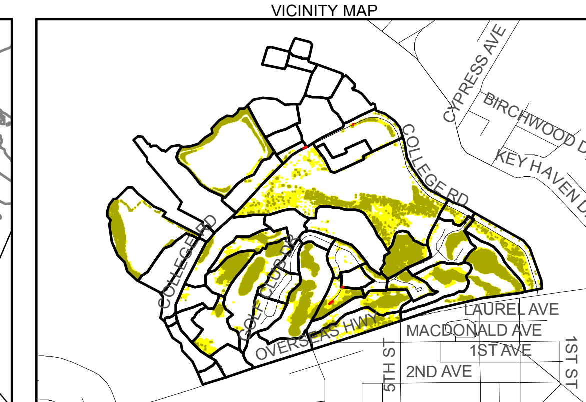
Only City sub-basins contributing runoff to City-maintained outfalls are shown. City areas draining directly to Gulf, Ocean, or canals are not modeled, but are still managed for potential water quality effects.

N

0 0.25 0.5
Miles

Exhibit 6-1
Parcels With 100 Year Flood Stage Exceeding Ground Surface by 1 Ft. or More
Key West Stormwater Master Plan
Key West, Florida

CH2MHILL



LEGEND

- Shoreline
- Roads
- Roads where 10 Yr. Flood Stage Exceeds Ground Surface by 0.5 Ft. or More
- Existing 10 Yr Flood Stage
- Existing 10 Yr. Flood Stage Exceeding Ground Surface by 0.5 Ft. or More
- Sub-Basin

Only City sub-basins contributing runoff to City-maintained outfalls are shown. City areas draining directly to Gulf, Ocean, or canals are not modeled, but are still managed for potential water quality effects.

N

0 0.25 0.5
Miles

Exhibit 6-2
Roads Where 10 Yr. Flood Stage Exceeds Ground Surface Elevation by 0.5 Ft. or More
Key West Stormwater Master Plan
Key West, Florida

To rank the severity of flooding in sub-basins, a simple process was used. The number of parcels per sub-basin with 100-year floods was identified and sorted from most to least and then assigned a criterion sub-rank 1 through 147 (out of 209 sub-basins on the main island). No ties were assigned, and the ranking was based on the standard sorting routine in Excel. Similarly, the length of street per sub-basin were identified and sorted from most to least and then assigned a criterion sub-rank 1 through 117 (out of 209 sub-basins on the main island, only 118 sub-basins had flooding in this category, plus three very small lengths on North Stock Island). Sub-basins without flooding were assigned a ranking value of 200 in both criterion sub-rankings.

After the individual sub-rankings for each criterion was completed, the initial ranking scores were added without weighting. For example, Sub-basin 130 contained the greatest number of parcels affected by the 100-year flood (sub-ranked 1) and the longest length of streets affected by the 10-year storm (sub-ranked 1). Sub-basin 130 had a combined score of 2, which was the lowest score and was, therefore, ranked the highest in severity of flooding. Sub-basin 130 probably scored somewhat higher than others because of its relative size (the entire Patricia and Ashby neighborhood where extensive stormwater infrastructure already exists because of the low elevations and known problems). The final sub-basin ranking was then based on the combined score and in this step ties were assigned the same rank. Exhibit 6-3 provides the sub-basin flood severity rankings, from 1 to 162.

EXHIBIT 6-3
Sub-Basin Rankings to Identify Areas with Greater Flooding
City of Key West 2012 Stormwater Master Plan

Sub-Basin	Road N-S Reference	Road E-W Reference	Rank of Length of Flooding in Streets at Least 0.5-ft During 10-yr Storm	Rank of No. of Parcels with at Least 1-ft Flooding During 100-yr Storm	Sum of Scores	Final Sub-Basin Ranking
130	Between George and Ashby	South of Atlantic Blvd	1	1	2	1
4147	18th	Pearlman	4	4	8	2
2840	Leon	South	3	6	9	3
6000	10th St	Harris Ave	2	9	11	4
3930	20th	Duck Ave to Eagle Ave	6	11	17	5
2550	Southard	Margaret	16	4	20	6
3220	4th St	Fogarty Ave	9	12	21	7
1015	6th St	Patterson Ave	7	18	25	8
4110	17th St	Donald Ave area	5	29	34	9
2830	Thompson	Seminary	22	13	35	10
240	Whalton	Von Phister	28	8	36	11
210	White	Laird	10	27	37	12
3340	Dennis	Venetia	15	22	37	12
2510	White	Eaton	23	17	40	14
4120	18th	Donald	16	25	41	15
3260	2nd	Fogarty Ave	24	22	46	16
4150	20th	Cindy	30	16	46	16
2120	Duval	Between Greene and Front	13	36	49	18
3030	Ashby	United	21	29	50	19

EXHIBIT 6-3
Sub-Basin Rankings to Identify Areas with Greater Flooding
City of Key West 2012 Stormwater Master Plan

Sub-Basin	Road N-S Reference	Road E-W Reference	Rank of Length of Flooding in Streets at Least 0.5-ft During 10-yr Storm	Rank of No. of Parcels with at Least 1-ft Flooding During 100-yr Storm	Sum of Scores	Final Sub-Basin Ranking
2500	Grinnell	Boundary, North of Trumbo Rd	34	18	52	20
3020	Ashby	Catherine	20	32	52	20
3837	13th	Riviera Dr	12	40	52	20
2520	Frances	Eaton	32	24	56	23
220	Florida	Laird	26	34	60	24
3600	11th	Flagler Ave to Riviera Dr	39	21	60	24
3610	Between 10th and 11th	Flagler Ave	14	46	60	24
3200	4th	Patterson Ave	18	46	64	27
2838	Tropical	Von Phister	29	36	65	28
3800	Rivera St (15th)	Flagler Ave to Riviera Dr	61	6	67	29
2530	Grinnell	Eaton	43	26	69	30
635	Fort	Truman	8	64	72	31
2563	Passover	Windsor Ln	60	14	74	32
2820	Thompson	Catherine	36	40	76	33
3115	1st	Patterson Ave	30	46	76	33
3620	12th	Flagler Ave	41	40	81	35
3370	Between Lean and Tropical	Flagler Ave	69	14	83	36
4145	19th	Cindy	57	27	84	37
605	Emma	Amelia	25	62	87	38
3830	Between 13th and 14th	Flagler Ave	44	46	90	39
2100	Duval	Front	27	64	91	40
755	Frances	Olivia	65	29	94	41
1160	Simonton	Angela	48	46	94	41
3912	18th	Riviera Dr	40	55	95	43
1020	6th	Fogarty Ave	53	44	97	44
2400	Margaret	Caroline	18	80	98	45
3210	3rd	Patterson Ave	52	46	98	45
3400	8th	Flagler Ave	50	52	102	47
2705	Jose Marti Dr/ Eisenhower Dr	Truman Ave	46	60	106	48
3000	George	Catherine	56	52	108	49
310	Reynolds	Von Phister	37	73	110	50
2555	Williams	Fleming	33	80	113	51
3410	7th	Flagler Ave	58	55	113	51
3900	18th	Flagler Ave	78	36	114	53
3760	13th	Northside	35	87	122	54
3810	16th	Flagler Ave	73	52	125	55
4130	20th	Donald	81	44	125	55
245	Grinnell	Von Phister	63	64	127	57

EXHIBIT 6-3
Sub-Basin Rankings to Identify Areas with Greater Flooding
City of Key West 2012 Stormwater Master Plan

Sub-Basin	Road N-S Reference	Road E-W Reference	Rank of Length of Flooding in Streets at Least 0.5-ft During 10-yr Storm	Rank of No. of Parcels with at Least 1-ft Flooding During 100-yr Storm	Sum of Scores	Final Sub-Basin Ranking
2567	William	Windsor Ln	62	71	133	58
2802	Jose Marti Dr	Between Virginia and Truman	47	87	134	59
400	Alberta	Seminole Ave	51	87	138	60
3300	Between 5th and 6th	Flagler Ave	83	55	138	60
2130	Duval	Caroline	37	103	140	62
730	Ashe	Angela	105	36	141	63
700	White	Fleming	59	84	143	64
3240	4th	Harris Ave	42	103	145	65
3040	Ashby	Seminary	88	60	148	66
3010	George	United	95	55	150	67
3770	14th	Northside	54	96	150	67
1030	7th	Fogarty Ave	64	87	151	69
2600	Whitehead	Truman	49	103	152	70
625	Whitehead	Catherine	90	64	154	71
3790	14th	Nr. Stadium Apts.	67	87	154	71
235	White	Von Phister	84	73	157	73
4000	Whitehead	Between Fleming and Southard	93	64	157	73
3820	14th	Flagler Ave	74	84	158	75
230	White	Von Phister	72	87	159	76
2836	Leon	Von Phister	79	80	159	76
750	Frances	Petronia	100	62	162	78
3910	17th	Flagler Ave	68	96	164	79
640	Emma	Truman	71	96	167	80
620	Howe	Virginia	65	103	168	81
3310	4th	Flagler Ave	87	84	171	82
830	Varela	Virginia	99	73	172	83
2300	William	Caroline	70	103	173	84
3730	11th	Fogarty Ave	45	137	182	85
2832	Thompson	Washington	116	73	189	86
3350	George	Flagler Ave	109	80	189	87
905	Pearl	Petronia	103	87	190	88
320	Reynolds	South	98	96	194	89
3330	2nd	Flagler Ave	75	120	195	90
2847	Pearl	Catherine	75	127	202	91
4140	19th	Donald	82	120	202	91
627	Whitehead	Amelia	89	114	203	93
4105	16th-ish	West of Donald	200	3	203	93
630	Whitehead	United	80	127	207	95
3500	West of the 9th St Canal	Patterson Ave	112	96	208	96

EXHIBIT 6-3
Sub-Basin Rankings to Identify Areas with Greater Flooding
City of Key West 2012 Stormwater Master Plan

Sub-Basin	Road N-S Reference	Road E-W Reference	Rank of Length of Flooding in Streets at Least 0.5-ft During 10-yr Storm	Rank of No. of Parcels with at Least 1-ft Flooding During 100-yr Storm	Sum of Scores	Final Sub-Basin Ranking
2570	Passover Ln	Olivia	200	9	209	97
3230	5th	Fogarty Ave	107	103	210	98
4100	15th-ish	Northside	114	96	210	98
642	Emma	Olivia	92	120	212	100
610	Emma	Virginia	117	96	213	101
2900	Eisenhower Dr	Newton	86	127	213	101
4175	17th	Northside Ct.	77	137	214	103
3320	3rd	Flagler Ave	95	120	215	104
4125	20th St	Northside	103	114	217	105
2890	Margaret	Catherine	200	18	218	106
2800	Pearl	Between Eliza and Virginia	100	120	220	107
3720	12th	Fogarty Ave	94	127	221	108
705	Frances	Fleming	90	137	227	109
4115	16th St	North of Donald	200	32	232	110
1150	Whitehead	Angela	200	34	234	111
2810	Leon	Catherine	102	137	239	112
4180	Trinity	Northside	200	40	240	113
641	Thomas	Truman	112	137	249	114
3345	1st	Flagler Ave	114	137	251	115
800	Florida	Eliza	107	147	254	116
3250	3rd	Harris Ave	54	200	254	117
200	White	Between Atlantic Blvd and Casa Marina Ct	200	55	255	118
2110	Ann	Front	200	64	264	119
2880	Varela	Catherine	200	64	264	119
4210	Jamaica	Venetian	200	71	271	121
710	White	Southard	200	73	273	122
3920	Between 19th and 20th	Flagler Ave	200	73	273	122
4200	Venetian	Venetian	200	73	273	122
1190	Whitehead	Caroline	85	200	285	125
1005	7th	Patterson Ave	200	87	287	126
3780	14th	Nr. Stadium MH Park	200	87	287	126
2000	Whitehead	Front	97	200	297	128
1120	Duval	Eaton	200	103	303	129
1130	Duval	Fleming	200	103	303	129
2610	Center	Truman Ave	200	103	303	129
2842	Tropical	Washington	200	103	303	129
3710	12th	North of Patterson	200	103	303	129
2010	Whitehead	Greene	105	200	305	134
1025	6th	Harris Ave	109	200	309	135

EXHIBIT 6-3
Sub-Basin Rankings to Identify Areas with Greater Flooding
City of Key West 2012 Stormwater Master Plan

Sub-Basin	Road N-S Reference	Road E-W Reference	Rank of Length of Flooding in Streets at Least 0.5-ft During 10-yr Storm	Rank of No. of Parcels with at Least 1-ft Flooding During 100-yr Storm	Sum of Scores	Final Sub-Basin Ranking
1170	Duval	Petronia	109	200	309	135
2895	William	Catherine	200	114	314	137
3050	George	South	200	114	314	137
3750	13th	North of Patterson	200	114	314	137
4170	18th St	Northside	200	114	314	137
2750	Passover Ln	Truman Ave	200	120	320	141
4220	Bahama	Venetian	200	120	320	141
100	Between Thompson and Leon	South of Atlantic Blvd	200	127	327	143
500	Duval	Bound past South	200	127	327	143
720	White	Angela	200	127	327	143
2887	Grinnell	Virginia	200	127	327	143
3740	13th	About Patterson Ave	200	127	327	143
4160	18th Ter	Northside	200	127	327	143
300	Reynolds	Atlantic Blvd	200	137	337	149
600	Fort	Amelia	200	137	337	149
645	Thomas	Petronia	200	137	337	149
2855	Florida	United	200	137	337	149
215	Whalton	Johnson	200	147	347	153
628	Whitehead	Virginia	200	147	347	153
900	Pearl	Alberta	200	147	347	153
1180	Duval	Southard	200	147	347	153
2834	Thompson	Von Phister	200	147	347	153
2844	Tropical	South	200	147	347	153
3110	1st	Roosevelt Dr	200	147	347	153
3235	5th	Seidenberg Ave	200	147	347	153
3700	11th	North of Patterson	200	147	347	153
250	Grinnell	Johnson	200	200	400	162
410	William	Washington	200	200	400	162
510	Simonton	South	200	200	400	162
520	Simonton	United	200	200	400	162
530	Simonton	Louisa	200	200	400	162
540	Duval	Catherine	200	200	400	162
643	Emma	Petronia	200	200	400	162
810	White	Eliza	200	200	400	162
820	White	Virginia	200	200	400	162
920	Florida	Newton	200	200	400	162
1140	Duval	Angela	200	200	400	162
2135	Duval	Between Caroline and Eaton	200	200	400	162
2140	Simonton	Caroline	200	200	400	162

EXHIBIT 6-3
Sub-Basin Rankings to Identify Areas with Greater Flooding
City of Key West 2012 Stormwater Master Plan

Sub-Basin	Road N-S Reference	Road E-W Reference	Rank of Length of Flooding in Streets at Least 0.5-ft During 10-yr Storm	Rank of No. of Parcels with at Least 1-ft Flooding During 100-yr Storm	Sum of Scores	Final Sub-Basin Ranking
2200	Elizabeth	Greene	200	200	400	162
2540	Grinnell	Fleming	200	200	400	162
2700	Between Florida and Pearl	Truman Ave	200	200	400	162
2710	Georgia	Truman Ave	200	200	400	162
2730	Varela	Truman Ave	200	200	400	162
2740	Grinnell	Truman	200	200	400	162
2846	Tropical	Seminary	200	200	400	162
2850	Florida	Catherine	200	200	400	162
2852	Pearl	United	200	200	400	162
2860	Georgia	Catherine	200	200	400	162
2865	Georgia	United	200	200	400	162
2870	White	Catherine	200	200	400	162
2883	Packer	Catherine	200	200	400	162
2892	Royal	Catherine	200	200	400	162
3060	Ashby	Washington	200	200	400	162
3100	1st	N. Roosevelt Blvd	200	200	400	162
3120	1st	Seidenberg Ave	200	200	400	162
3360	Thompson	Flagler Ave	200	200	400	162
4010	Whitehead	Fleming	200	200	400	162
5000	Whitehead	South St	200	200	400	162

North Stock Island is not included here because there were no areas with significant flooding identified (see results in Attachment A).

6.2 Identification of Potential Projects

A total of 43 projects were initially identified based on visual inspection of peak stormwater stages during design storms (Exhibit 3-4), areas of known problems (Exhibit 2-7), and potential space and suitability for siting a project. (Availability of space and rights-of-way was approximate and may affect the feasibility and final design of any given project.) These initial projects were primarily gravity recharge wells, and only one project was a new pressure well system, the George Street Pressure-Assisted Well project that is currently in design. Another project near Harris Avenue and Sunset Drive included a gravity recharge well and a new outfall, as the elevation is too low for a gravity well alone to provide significant relief, and the discharge is to a pond already being managed as a stormwater basin. Patricia and Ashby is a high problem area because of its low elevation and because the residential neighborhood collects runoff like a bowl. An existing pump station with a single pressure well is located here, as well as 12 gravity recharge wells scattered throughout the neighborhood. However, the drainage piping in the neighborhood is nearly non-existent or too small to be effective. One project includes installing piping in this neighborhood to better connect intersections to the pump station; however, improvements from this change will not show up in the computer model because this neighborhood is modeled as a single composite unit. The Simonton Beach pressure well system has not performed as expected. The modeling indicates that it should work, so a project to investigate, restore, or perhaps add another well to that system is being proposed. These projects are discussed in more detail later in this section.

Some of the initial project locations were selected based on the City's ongoing stormwater program to intercept runoff higher on the landscape prior to reaching the lower elevations. Several recharge wells were located near the northern end of retail-oriented Duval Street, so any project there will likely be on a side road because of the high level of traffic and retail businesses on Duval. Some additional projects were located in New Town in areas that are too low for significant relief by gravity recharge wells. These were included initially to be part of the general assessment and to demonstrate that more gravity recharge wells would not be effective. These 43 projects were grouped in what is called Alternative 1. This alternative is considered the most passive plan.

A second alternative (Alternative 2) was developed that eliminated ineffective wells from Alternative 1 (kept 27 projects). Additional capacity was attained in one neighborhood using a new pressurized well system, and new outfalls were investigated at four sub-basins. The proposed new pressure system was near Fogarty Avenue and 4th Street (east of the proposed Catherine and Ashby pump station). Alternative 2 also included the addition of a second pressure well at the existing Patricia and Ashby pump station. The Patricia and Ashby well project would be cost-effective because there is already sufficient capacity in the pump station to serve two recharge wells and the second well would add reliability to the existing system. There are four areas where exfiltration trenches and associated inlets are added to reduce the duration of standing water, plus three more gravity wells at high elevations, at locations OMI reported as areas with extended standing water.

Although new outfalls are not a preferred choice for the City, there are some areas that will not improve substantially unless there is more positive drainage provided. The landscape is just too low for gravity recharge wells to be effective and there is limited room for new pressure-assisted pump station. These areas included the sub-basins along: Cindy Avenue and 19th Streets (east end of island); Duck and Eagle Avenues and 20th Street; James Street and Grinnell Street; and along Eisenhower Drive and Olivia Street. These additional proposed outfalls are speculative at this point because there are no good routes to get large new pipes to the waterfront. These are included here so the City can consider what level of improvement is necessary to serve these sub-basins.

Exhibit 6-4 provides an initial listing of the projects and the relative sub-basin rankings associated with them, and Exhibit 6-5 shows a map of the locations of these projects. These projects were simulated for further assessment. Some of the highly ranked sub-basins with stormwater issues are either addressed projects in other sub-basins, or may be deferred. This is discussed further in Section 6.2.2.

The North Stock Island recommendations were for maintenance clearing of drainage ways partially obstructed by mangroves, and include water quality inlets to treat the road runoff. These activities are not listed below, but will be included as projects to implement in the final recommendations. Other smaller projects will be conducted on an *ad hoc* basis to address standing water and water quality improvements.

EXHIBIT 6-4
Initial List of Potential Capital Projects for Stormwater Improvements
City of Key West 2012 Stormwater Master Plan

Intersections/Locations	Model Node/Sub-Basin	Proposed Project	Sub-Basin Ranking	Comments
Alternative 1 Projects				
Patricia and Ashby neighborhood piping from Rose and Thompson to PS	130	Approx. 1,500 LF of 18" pipe and 16 Inlets, 800 LF of exfiltration trench along Bertha Ave	1	Improve connectivity to existing pump station (PS), neighborhood levels remain mostly unchanged
20th Ter and Donald St	4147	1 Gravity Recharge Well	2	Low elevation, project needs careful consideration
Washington St and Leon St	2840	1 Additional Gravity Recharge Well	3	One of few intersections in area without gravity well
Harris and 10th Ave	6000	1 Gravity Recharge Well; 120 LF 18" pipe; 8 inlets; WQ Box	4	Recharge well for water quality improvement, includes an outfall
20th St and Eagle Ave	3930	1 Gravity Recharge Well	5	Low elevation, project needs careful consideration, adds a well to an area with another one
Southard and Grinnell St	2550	1 Gravity Recharge Well	6	
Donald St and 17th St	4110	1 Additional Gravity Recharge Wells	9	Locate on the streets at higher elevations in mid-block
Seminary St and Leon St	2830	2 Gravity Recharge Wells	10	
Whalton and Von Phister St	240	1 Additional Gravity Recharge Well	11	
Donald St and 17th Ter	4120	1 Additional Gravity Recharge Wells	15	
Greene St and Duval St	2120	1 Gravity Recharge Well	18	Need to locate off Duval, low elevations
Catherine and Ashby St Pump Station (a.k.a. George St Pump Station)	3020	2 Pressurized Recharge Wells and 2 Pipes, see design	20	Project in design, not constructed
Riviera Dr and Riviera St	3800	1 Additional Gravity Recharge Well	29	
Fort and Olivia	635	1 Additional Gravity Recharge Well	31	
Duck Ave and 19th St	4145	1 Gravity Recharge Wells, 1 intersection	37	
Amelia and Emma St	605	1 Gravity Recharge Well	38	
Angela and Simonton, and on Angela mid-block of Duval and Simonton	1160	2 Gravity Recharge Wells	41	
Olivia St and Pohalski Ave, Olivia and Frances St	755	2 Gravity Recharge Wells, 2 intersections	41	These are more like alleys off Olivia, may reduce runoff downhill

EXHIBIT 6-4
Initial List of Potential Capital Projects for Stormwater Improvements
City of Key West 2012 Stormwater Master Plan

Intersections/Locations	Model Node/Sub-Basin	Proposed Project	Sub-Basin Ranking	Comments
Near Kennedy Dr (13th St) and Northside St	3760	1 Gravity Recharge Well	54	
Caroline and Duval	2130	1 Gravity Recharge Well	62	Need to locate off Duval, low elevations
Northside Dr and 14th St	3770	1 Gravity Recharge Well	67	
Along 14th St, near Stadium Apts	3790	3 Gravity Recharge Wells	71	
Fogarty and 11th St	3730	1 Gravity Recharge Well	85	
Donald St and 19th Ter	4147	1 Additional Gravity Recharge Well	91	Low elevation, project needs careful consideration
17th St and south of Roosevelt	4175	1 Additional Gravity Recharge Well	103	
Fogarty and 12th St	3720	1 Gravity Recharge Well	108	
Venetian Dr and Trinidad Dr	4200	1 Gravity Recharge Well	122	
Eaton St and Whitehead St	1190	1 Additional Gravity Recharge Well	125	
Along 14th St, near Stadium Mobile Home Park	3780	1 Additional Gravity Recharge Well	126	
Eaton and Duval, Fleming and Duval area	1120	2 Gravity Recharge Wells, 2 locations	129	Need to locate off Duval, limited available land
Patterson and 12th St	3710	1 Gravity Recharge Well	129	
On Whitehead mid-block , South of Greene	2010	1 Gravity Recharge Well	134	
White and Petronia	720	1 Additional Gravity Recharge Well	143	Also may provide reductions downhill
Grinnell and Virginia	2887	1 Gravity Recharge Well	143	Also may provide reductions downhill
Florida and Olivia	900	1 Additional Gravity Recharge Well	153	
Fleming St and Grinnell St	2540	1 Gravity Recharge Well	162	
Petronia St and Georgia St	920	1 Additional Gravity Recharge Well	162	
Mid-block on Whitehead St, between United St. and South St	5000	1 Gravity Recharge Well, in mid-block	162	Near Southernmost Point
Simonton Beach Pump Station	2110	Additional Investigations at existing pressurized recharge well system. allowance for new well and piping	162	Existing wells not as effective as others. Consider another well located away from others.

EXHIBIT 6-4
Initial List of Potential Capital Projects for Stormwater Improvements
City of Key West 2012 Stormwater Master Plan

Intersections/Locations	Model Node/Sub-Basin	Proposed Project	Sub-Basin Ranking	Comments
On Simonton St mid-block between Caroline and Eaton St	2140	1 Additional Gravity Recharge Well	162	May provide reductions downhill
United St and Packer St	2883	1 Additional Gravity Recharge Well	162	May provide reductions downhill
United St and Georgia St	2865	1 Gravity Recharge Well	162	Add another well in vicinity
On Washington St at Washington and Georgia Intersection	3050	1 Additional Gravity Recharge Well	162	
Alternative 2 Projects				
Alternative 1 Projects but Eliminate ineffective Recharge Wells from Alternative 1	See Comments		--	Eliminate gravity wells at nodes: 240, 2830, 2840, 2883, 4145, 3710, 3760, 3730, 3720, 3800, 4200, 5000, 605, 635, 6000 (well only), and 3930
Harris and 10th Ave	6000	Expand into a neighborhood redevelopment project	4	Remove Alt. 1 gravity wells and provide positive drainage for neighborhood at Sub-basin 6000
Patricia and Ashby Pressurized Recharge Well Addition	100 (130)	Add 1 well to existing pressurized system (include pipes, valves, etc.)	1	
Eagle and 20th St	3930	Equivalent 42" pipe	5	Try to route south, across Flagler Ave to Riviera Canal.
Fogarty and 3rd St	3225	2 new pressurized recharge wells; 18" pipe install 300 LF(new)+360 LF(replacing 10")+275 LF(replacing 12") = 1,235 LF of pipe; about 12 inlets	7	Can be part of a larger neighborhood project to improve more than drainage
James St and Grinnell St	2530	Equivalent 24" pipe	30	Could be part of Caroline St project
Cindy St and 19th St	4145	Equivalent 36" pipe	37	Try to route east. May tie into Duck Ave in an area project if access to waterfront is found
Eisenhower Dr between Angela and Albury Sts	2705	Equivalent two 24" pipes	48	Put in two outfalls to serve long, low street
Staples Ave between 6th and 7th Sts	3410	450 LF of exfiltration trench and 8 inlets, 18" pipe tie to existing outfall	51	Neighborhood project to reduce standing water duration
Eagle between 16th and 17th Sts	3810	650 LF of exfiltration trench and 8 inlets	55	Neighborhood project to reduce standing water duration

EXHIBIT 6-4
Initial List of Potential Capital Projects for Stormwater Improvements
City of Key West 2012 Stormwater Master Plan

Intersections/Locations	Model Node/Sub-Basin	Proposed Project	Sub-Basin Ranking	Comments
14th St north of Flagler Ave	3820	550 LF of exfiltration trench and 8 inlets	75	Neighborhood project to reduce standing water duration
4th St near Flagler Ave	3310	1 Gravity Recharge Well	82	Reduce duration of standing water
At intersection of Olivia St. and Packer St, on Packer St	2570	1 additional Gravity Recharge Well	97	Reduce duration of standing water
3rd St near Flagler Ave	3320	1 Gravity Recharge Well	104	Reduce duration of standing water
Near Casa Marina Ct and Reynolds	300	250 LF of exfiltration trench and 4 inlets	149	Neighborhood project to reduce standing water duration
Mid-block on Dennis St, between Venetia St and Blanche St	3340	1 Pump, 150 LF 24” pipe	12	Combined project with the City to add the pump and discharge to the existing outfall to reduce the duration of standing water near Key West High School,
N. Duval Street Inlets		30 inlets to be repaired/replaced		

6.2.1 Project Assessment for Effectiveness

The proposed projects were evaluated using a computer stormwater simulation model. Two models were constructed, one for each of the two alternatives. Alternative 2 was considered an add-on to the gravity projects and, except for the recharge wells eliminated, the Alternative 2 projects were added to the Alternative 1 model. The results from these two models were compared to the existing conditions model to determine the effectiveness of the projects in reducing the peak flood levels. In addition to the intersections (model nodes) where these projects are being built, a selected group of low elevation nodes were also examined. These comparisons were made by subtracting the peak elevations of the Alternative 1 results from the existing model results, and are shown in Exhibit 6-5 as flood reductions. Only the 10-year and 100-year peak flood elevation reductions are shown as these are applicable to the flood severity ranking criteria.

As shown in Exhibit 6-6, many of these projects do not reduce flooding significantly. This is partly because many of the gravity recharge well projects are in low elevation areas where they do not have much effect. However, there are some projects with much better reductions. The projects were assigned a category High (reductions 0.5 ft or more), Medium (reductions of 0.2 to 0.5 ft), Low (reductions between 0.2 to 0.1 ft reduction), and Negligible (less than 0.1 ft). Using this relative assessment method for the Alternative 1 projects, 12 projects were in the High category, 9 in the Medium, 10 in the Low, and 12 were Negligible. The projects in the Negligible category were eliminated, as were four in the Low category because they were either not needed or became part of an Alternative 2 project instead.

North Stock Island

LEGEND

Proposed Projects

- Alternative 1 - Effective Projects
- Alternative 1 - Not Effective Projects
- Alternative 2 - Additional Projects
- Roads
- Sub-Basins

Only City sub-basins contributing runoff to City-maintained outfalls are shown. City areas draining directly to Gulf, Ocean, or canals are not modeled, but are still managed for potential water quality effects.

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Miles

Exhibit 6-5
Proposed Projects

Key West Stormwater Master Plan
Key West, Florida

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EXHIBIT 6-6
Effectiveness of Alternative 1 Projects to Reduce Peak Flood Elevations
City of Key West 2012 Stormwater Master Plan

Intersections/Locations with Alternative 1 Projects	Model Node (Sub-Basin)	Proposed Project	Location Group ID	10-yr Storm Stage Reduction	100-yr Storm Stage Reduction	10-yr Effects (H/M/L/N)
Patricia and Ashby neighborhood piping from Rose and Thompson to PS	N100 (130)	Approx. 1,500 LF of 18" pipe and 16 Inlets, 800 LF of exfiltration trench along Bertha Ave	A1	0	0	N
20th Ter and Donald St	N4147	1 Gravity Recharge Well	B1	0.21	0.19	M
20th St and Eagle Ave	N3930	1 Gravity Recharge Well	B2	0.10	0.13	L
Duck Ave and 19th St	N4145	1 Additional Gravity Recharge Wells, 1 intersection	B3	1.53	0.67	H
Donald St and 19th Ter	N4147	1 Additional Gravity Recharge Well	B4	0.21	0.19	M
Harris and 10th Ave	N6000	1 Gravity Recharge Well; 120 LF 18" pipe; 8 inlets; WQ Box	C1	0.66	0.82	H
Fogarty and 11th St	N3730	1 Gravity Recharge Well	C2	0.04	0.05	N
Fogarty and 12th St	N3720	1 Gravity Recharge Well	C3	0.09	0.07	N
Patterson and 12th St	N3710	1 Gravity Recharge Well	C4	0.09	0.07	N
Washington St and Leon St	N2840	1 Additional Gravity Recharge Well	D1	0.04	0.06	N
Seminary St and Leon St	N2830	2 Gravity Recharge Wells	D2	0.10	0.1	N
Whalton and Von Phister St	N240	1 Additional Gravity Recharge Well	D3	0.11	0.07	L
United St and Packer St	N2883	1 Additional Gravity Recharge Well	D4	0.5	1.03	H
United St and Georgia St	N2865	1 Gravity Recharge Well	D5	2.64	1.98	H
On Washington St at Washington and Georgia St intersection	N3050	1 Additional Gravity Recharge Well	D6	0.24	0.55	M
Southard and Grinnell St	N2550	1 Additional Gravity Recharge Well	E1	0.22	0.22	M
Greene St and Duval St	N2120	1 Gravity Recharge Well	E2	0.19	0.12	L
Caroline and Duval	N2130	1 Gravity Recharge Well	E3	0.24	0.08	M
Eaton St and Whitehead St	N1190	1 Additional Gravity Recharge Well	E4	0.47	0.02	M
Eaton and Duval, Fleming and Duval area	N1120	2 Gravity Recharge Wells, 2 locations	E5	1.28	0.83	H
On Whitehead mid-block, South of Greene	N2010	1 Gravity Recharge Well	E6	0.5	0.24	H
Simonton Beach Pump Station	N2110	Additional Investigations at existing pressurized recharge well system. Allowance for new recharge well and piping	E7	0	0.08	N
On Simonton St mid-block between Caroline and Eaton St	N2140	1 Additional Gravity Recharge Well	E8	0.80	0.88	H
Donald St and 17th St	N4110	1 Additional Gravity Recharge Wells	F1	0.22	0.19	M
Donald St and 17th Ter	N4120	1 Additional Gravity Recharge Wells	F2	0.22	0.19	M

EXHIBIT 6-6
Effectiveness of Alternative 1 Projects to Reduce Peak Flood Elevations
City of Key West 2012 Stormwater Master Plan

Intersections/Locations with Alternative 1 Projects	Model Node (Sub-Basin)	Proposed Project	Location Group ID	10-yr Storm Stage Reduction	100-yr Storm Stage Reduction	10-yr Effects (H/M/L/N)
17th and south of Roosevelt	N4175	1 Additional Gravity Recharge Well	F3	0.24	0.04	M
Fort and Olivia	N635	1 Additional Gravity Recharge Well	G1	0.10	0.05	N
Amelia and Emma St	N605	1 Gravity Recharge Well	G2	0.07	0.04	N
Mid-Block on Whitehead St between United St and South St	N5000	1 Gravity Recharge Well, in mid-block	G3	0.01	0.03	N
Catherine and Ashby St Pump Station (a.k.a. George St Pump Station)	N3020	2 Pressurized Recharge Wells and 2 Pipes, see design	H1	1.55	1.19	H
Angela and Simonton, Angela & mid-block of Duval and Simonton St	N1160	2 Gravity Recharge Wells	I1	2.88	1.07	H
Olivia St and Pohalski Ave, Olivia and Frances	N755	2 Gravity Recharge Wells, 2 intersections	J1	1.6	0.59	H
White and Petronia	N720	1 Additional Gravity Recharge Well	J2	1.57	0.97	H
Grinnell and Virginia	N2887	1 Gravity Recharge Well	J3	0.98	0.25	H
Florida and Olivia	N900	1 Additional Gravity Recharge Well	J4	0.33	0.78	M
Fleming St and Grinnell St	N2540	1 Gravity Recharge Well	J5	1.03	0.29	H
Petronia St and Georgia St	N920	1 Additional Gravity Recharge Well	J6	0.25	0.16	M
Riviera Dr and Riviera St	N3800	1 Additional Gravity Recharge Well	K1	0.01	0.03	N
Near Kennedy Dr (13 St) and Northside St	N3760	1 Gravity Recharge Well	K2	0.12	0.14	L
Northside Dr and 14th St	N3770	1 Gravity Recharge Well	K3	0.16	0.19	L
Along 14th St, near Stadium Apts	N3790	3 Gravity Recharge Wells	K4	0.17	0.24	L
Along 14th St, near Stadium MH	N3780	1 Additional Gravity Recharge Well	K5	0.11	0.27	L
Venetian Dr and Trinidad Dr	N4200	1 Gravity Recharge Well	L1	0.03	0.03	N
Selected Low Areas Cumulative Effects		**Comment**				
Eisenhower	N2705	Chronic flooding in low area	J	1.44	0.33	H
Eisenhower	N2900	Chronic flooding in low area	J	0.00	0.07	N
Near Caroline and Key West Bight	N2520	Currently called Caroline St. Corridor Project Area	J	0.07	0.07	N
Washington and Leon	N2840	Low area between other projects	D	0.00	0.00	N

Notes:
(H/M/L/N) means High, Medium, Low, or Negligible effect (see text for thresholds)
Sub-basin in parentheses when it varied in name from the model node (Nxxx)

A similar list is presented in Exhibit 6-7 for Alternative 2 projects. Maps were prepared to show the results of implementing the projects in formats such as those provided for existing conditions; however, only the Alternative 2 results were mapped because the change in flooding was small for Alternative 1 alone in most areas and they would be shown on Alternative 2 anyway. Exhibits 6-8a and 6-8b provide a general flood extent map for Alternative 1 and 2 conditions, respectively. Exhibits 6-9a and 6-9b provide maps showing parcels and the 100-year flood extents, including areas with depths of 1 ft or more, for each alternative result. Exhibits 6-10a and b provide map showing the roads inundated by 0.5-ft or more during the 10-year storm for each alternative. As shown on the maps, any improvements are small because of the flat landscape at low elevations. Most improvements only reduce the peak elevations by a small amount, as listed in Exhibits 6-6 and 6-7.

One caveat in creating more linkage directly to the groundwater in the streets that are at a low elevation, either through wells, exfiltration trenches, or other swale projects is that seasonally high tides may allow more standing water in some low spots (that is, groundwater seeping up). Furthermore, as with all exfiltration trench projects, the permeability of the subsoils should be tested to determine how well percolation may occur in proposed project areas.

To facilitate discussion and assessment, the projects were grouped geographically because some projects addressed similar problem areas and can benefit a location away from the specific project location. The order of the grouping was based on the order of listing in Exhibit 6-4 and do not correlate to any other study. The subsections that follow provide discussion on these groups.

6.2.1.1 Group A: Patricia and Ashby to White Street

This area is very low lying and is generally bounded by Flagler Avenue on the north, Bertha Street on the east, White Street on the west, and Atlantic Boulevard to the south. The City has two pressurized recharge well locations there, with three wells, plus many gravity recharge wells. Despite this infrastructure, the area near Patricia and Ashby still has the highest flooding severity in the City. There are three projects evaluated in this modeling for this group, but in addition to the projects listed previously there are other projects that should be investigated, as follows:

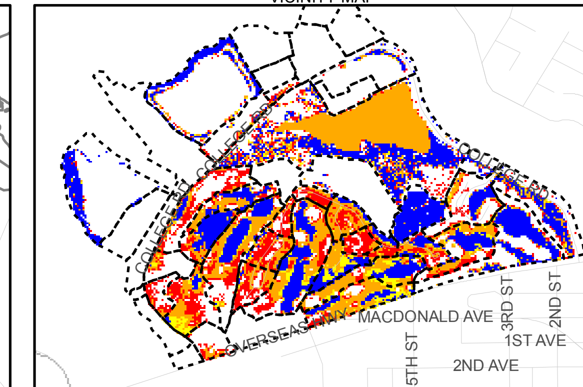
ID	Project	Model Node	Brief Description
A1	Patricia and Ashby neighborhood piping from Rose and Thompson to PS	N100	Approx. 1,500 LF of 18" pipe and 16 Inlets in the neighborhood
A2	Patricia and Ashby Pressure Well Addition (Alt. 2)	N100	Add 1 well to existing pressurized system (include pipes, valves, etc.)
A3	Swale Reclamation	B130	Open pavers or trench in currently paved swales. Some areas could use trenches if no room in swales (e.g. Johnson, Laird, and Rose).
A4	Mid-block on Dennis St between Venetia St and Balance St	N3340	Add 1 pump and approx. 150 LF of 24” pipe. Tie to existing 24” outfall pipe owned by the City at High School.

EXHIBIT 6-7
Effectiveness of Alternative 2 Projects to Reduce Peak Flood Elevations
City of Key West 2012 Stormwater Master Plan

Intersections/Locations with Alternative 2 Projects	Model Node (Sub-Basin)	Proposed Project	Location Group ID	10-yr Storm Stage Reduction	100-yr Storm Stage Reduction	10-yr Effects (H/M/L/N)
Patricia and Ashby Pressure Well Addition	N100 (130)	Add 1 Recharge Well to existing pressurized system (include pipes, valves, etc.)	A2	0.09	0.13	N
Mid-block on Dennis St between Venetia St and Balance St	3340	1 Pump, 150 LF 24” pipe	A4	0.66	0.92	H
Eagle and 20th St	N3930	Equivalent 42” pipe	B5	0.09	0.13	N
Cindy St and 19th St	N4145	Equivalent 36” pipe	B6	1.53	0.67	H
On Packer St, at intersection of Olivia St. and Packer St	N2570	1 Additional Gravity Recharge Well	D7	0.11	0.07	L
Near Casa Marina Ct and Reynolds	N300	250 LF of exfiltration trench and 4 inlets	D8	0	0	N
James St and Grinnell St	N2530	Equivalent 24” pipe	E9	0.09	0.13	N
Eisenhower Dr between Angela and Albury Sts	N2705	Equivalent two 24” pipes	J7	1.44	0.33	H
Eagle between 16th and 17th Sts	N3810	650 LF of exfiltration trench and 8 inlets	K6	0.0	0.11	N
14th St north of Flagler Ave	N3820	550 LF of exfiltration trench and 8 inlets	K7	0.07	0.01	N
Fogarty and 3rd St	N3220 (3225)	2 new pressurized recharge wells; 18" pipe install 300 LF(new)+360 LF(replacing 10")+275 LF(replacing 12") = 1,235 LF of pipe; about 12 inlets	M1	2.06	0.68	H
Staples Ave between 6th and 7th Sts	N3410	450 LF of exfiltration trench and 8 inlets, 18” pipe tie to existing outfall	M2	0	0	N
4th St near Flagler Ave	N3310	1 Gravity Recharge Well	M3	0.11	0.08	L
3th St near Flagler Ave	N3320	1 Gravity Recharge Well	M4	0.08	0.07	N
Selected Low Areas Cumulative Effects		**Comment**				
Eisenhower	N2705	Chronic flooding in low area	J	1.44	0.33	H
Eisenhower	N2900	Chronic flooding in low area	J	0.00	0.07	N
Near Caroline and Key West Bight	N2520	Currently called Caroline St. Corridor Project Area	J	0.08	0.13	N
Washington and Leon	N2840		D	0.00	0.00	N

Notes:
(H/M/L/N) means High, Medium, Low, or Negligible effect (see text for thresholds)
Sub-basin in parentheses when it varied in name from the model node (Nxxx)

VICINITY MAP



LEGEND

- Streets
- Shoreline
- Flooding at the 5yr, 24 hr Storm Stage
- Flooding at the 10yr, 24 hr Storm Stage
- Flooding at the 25yr, 100 hr Storm Stage
- Flooding at the 100yr, 72 hr Storm Stage
- Sub-Basin

Only City sub-basins contributing runoff to City-maintained outfalls are shown. City areas draining directly to Gulf, Ocean, or canals are not modeled, but are still managed for potential water quality effects.

N

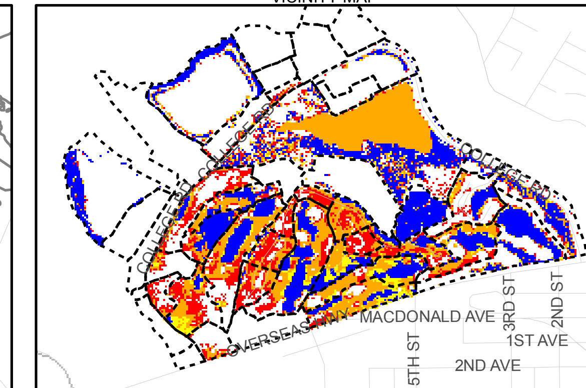
0 0.25 0.5
Miles

Exhibit 6-8a
Flood Conditions with Proposed Projects Alternative 1
Key West Stormwater Master Plan
Key West, Florida

\\GAINESVILLE\PROJ\KEYWESTFLCITYOF\414274KEYWESTSWMP\GIS\MAPFILES\FINAL\UPDATES_20111215\PROPOSED_FLOOD_MAP_ALT1_11X17_20120116.MXD HHARDEST 1/17/2012 08:27:18

CH2MHILL

VICINITY MAP

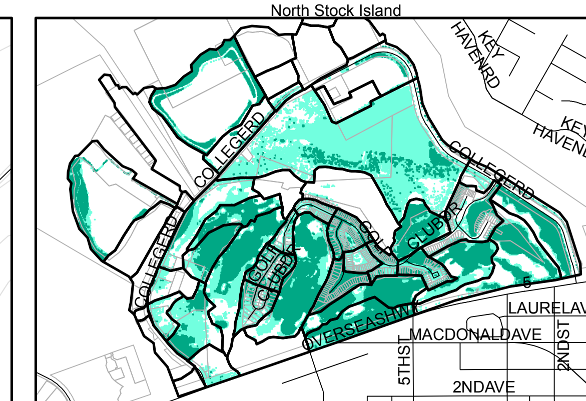


LEGEND

- Streets
- Shoreline
- Flooding at the 5yr, 24 hr Storm Stage
- Flooding at the 10yr, 24 hr Storm Stage
- Flooding at the 25yr, 100 hr Storm Stage
- Flooding at the 100yr, 72 hr Storm Stage
- Sub-Basin

Only City sub-basins contributing runoff to City-maintained outfalls are shown. City areas draining directly to Gulf, Ocean, or canals are not modeled, but are still managed for potential water quality effects.

Exhibit 6-8b
Flood Conditions with
Proposed Projects Alternative 2
Key West Stormwater Master Plan
Key West, Florida



LEGEND

- Roads
- Property Boundary
- Proposed 100 Year Flood Stage
- Proposed 100 Year Flood Stage Exceeding Ground Surface by 1 Ft. or More
- Sub-Basin

Only City sub-basins contributing runoff to City-maintained outfalls are shown. City areas draining directly to Gulf, Ocean, or canals are not modeled, but are still managed for potential water quality effects.

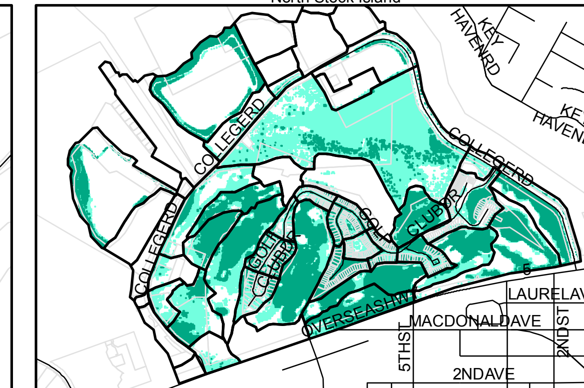
N

0 0.25 0.5
Miles

Exhibit 6-9a
Parcels With 100 Year Flood Stage Exceeding Ground Surface by 1 Ft. or More (Proposed Conditions - Alternative 1)
Key West Stormwater Master Plan
Key West, Florida

\\GAINESVILLE\PROJ\KEYWESTFLCITYOF\414274KEYWESTSWMP\GIS\MAPFILES\FINAL\UPDATES_20111215\ALT1PARCELS100YRSTORM_EXCEEDSURFACE1FT_11X17_20120117.MXD HHARDEST 1/18/2012 17:26:20

CH2MHILL



LEGEND

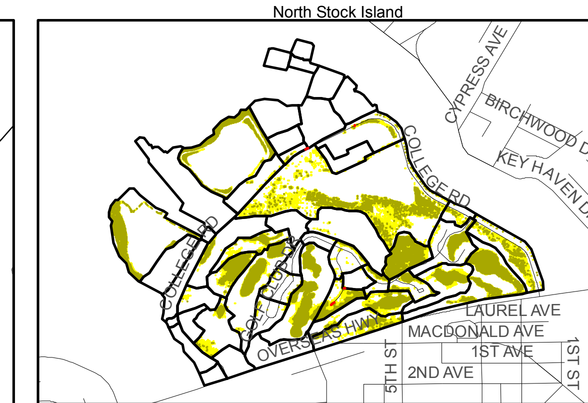
- Roads
- Property Boundary
- Proposed 100 Year Flood Stage
- Proposed 100 Year Flood Stage Exceeding Ground Surface by 1 Ft. or More
- Sub-Basin

Only City sub-basins contributing runoff to City-maintained outfalls are shown. City areas draining directly to Gulf, Ocean, or canals are not modeled, but are still managed for potential water quality effects.

N

0 0.25 0.5
Miles

Exhibit 6-9b
Parcels With 100 Year Flood Stage Exceeding Ground Surface by 1 Ft. or More (Proposed Conditions - Alternative 2)
Key West Stormwater Master Plan
Key West, Florida



LEGEND

- Shoreline
- Roads
- Roads where 10 Yr. Flood Stage Exceeds Ground Surface by 0.5 Ft. or More
- Proposed 10 Yr Flood Stage
- Proposed 10 Yr. Flood Stage Exceeding Ground Surface by 0.5 Ft. or More
- Sub-Basin

Only City sub-basins contributing runoff to City-maintained outfalls are shown. City areas draining directly to Gulf, Ocean, or canals are not modeled, but are still managed for potential water quality effects.

N

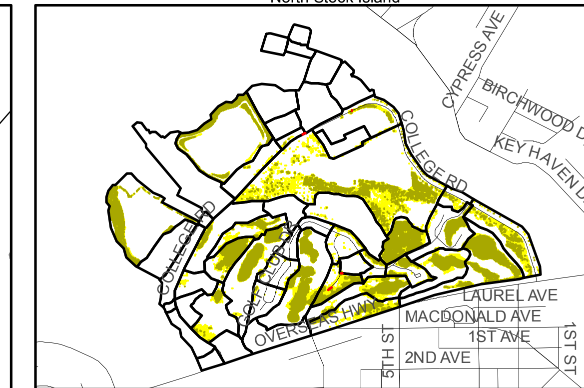
0 0.25 0.5
Miles

Exhibit 6-10a
Exceeds Ground Surface Elevation by 0.5 Ft. or More
(Proposed Conditions - Alternative 1)
Key West Stormwater Master Plan
Key West, Florida

\\GAINESVILLE\PROJ\KEYWESTFLCITYOF\414274KEYWESTSWMP\GIS\MAPFILES\FINAL\UPDATES_20111215\ALT1_ROADS10FTSTORM_EXCEEDGROUNDSURFACE05_11X17_20120117.MXD HHARDEST 1/18/2012 16:52:18

CH2MHILL

North Stock Island



LEGEND

- Shoreline
- Roads
- Roads where 10 Yr. Flood Stage Exceeds Ground Surface by 0.5 Ft. or More
- Proposed 10 Yr Flood Stage
- Proposed 10 Yr. Flood Stage Exceeding Ground Surface by 0.5 Ft. or More
- Sub-Basin

Only City sub-basins contributing runoff to City-maintained outfalls are shown. City areas draining directly to Gulf, Ocean, or canals are not modeled, but are still managed for potential water quality effects.

N

0 0.25 0.5
Miles

Exhibit 6-10b
Exceeds Ground Surface Elevation by 0.5 Ft. or More
(Proposed Conditions - Alternative 2)
Key West Stormwater Master Plan
Key West, Florida

\\GAINESVILLE\PROJ\KEYWESTFLCITYOF\414274KEYWESTSWMP\GIS\MAPFILES\FINAL\UPDATES_20111215\ALT2_ROADS10FTSTORM_EXCEEDGROUNDSURFACE05_11X17_20120117.MXD HHARDEST 1/18/2012 16:35:27

CH2MHILL

The overall effectiveness at reducing peak flood levels of additional projects in this group was estimated to be low. There is likely a diminishing effect of additional projects because the area already has existing infrastructure. However, these projects are considered important to the City and are recommended because they will improve the overall drainage and reduce the duration of flooding. Swale reclamation will be considered an operations cost to the City and is not included here as a project cost, but it could be part of a broader neighborhood project. There is an existing gravity well at Dennis St (A4) that is too low to be effective. A small pump station would be needed to lift water to a positive outfall, and the only location near here is an existing one utilized for the high school. A project to combine the drainage here to the City outfall should be investigated.

6.2.1.2 Group B: Eastern End Near Donald Street and Duck Avenue

There is a low area along the eastern end of Duck Avenue and some of the streets just northeast of the intersection of 20th Street/Northside Drive (behind the hotels) that stage up during large storms. Four projects include gravity recharge wells, while an Alternative 2 project would replace two of these projects with an outfall system.

ID	Project	Model Node	Brief Description
B1	20th Ter and Donald St	N4147	1 Gravity Well
B2	20th St and Eagle Ave	N3930	1 Gravity Well
B3	Duck Ave and 19th St	N4145	1Gravity Wells, 1 intersection
B4	Donald St and 19th Ter	N4147	1 Additional Gravity Well
B5	20th St and Eagle Ave	N3930	Equivalent 42” pipe existing 42” outfall pipe on 18th St
B6	Cindy St and 19th St	N4145	New outfall, equivalent 36” pipe routed eastward to waterfront

Because of the low elevations here, the gravity recharge wells are not highly effective in reducing peak flood stages. However, instead of the gravity wells, more exfiltration trenches could be installed provided sufficient percolation exists. The gravity wells at N4147 (B1) and N4145 (B3) are recommended, but an exfiltration project may also be possible in these areas and they are highly ranked problem areas for flooding. The gravity well at N3930 (B2) is not recommended because of low performance (0.1 ft 10-year flood reduction). The gravity well near Donald Street and 19th Terrace is recommended as it performed moderately (N4143, B4) but this sub-basin was not as highly ranked as a flooding problem as others in the grouping.

In Alternative 2, two more outfalls could be installed to achieve higher flood reduction results. Both of these outfalls were arbitrarily routed to the ocean (or Riviera Canal) but there are not any available right-of-ways for these outfalls. One of these outfalls would replace a moderately performing well project at N4145 (B3). The B3 project reduced the 10-year flooding by approximately 0.2 ft, but an outfall would be more effective. This sub-basin was ranked 37th so given that a new outfall here would be difficult, the gravity well project would be considered more feasible. More piping in these neighborhoods to connect intersections may be investigated during the design of this project (if initiated). The B5 project was routed to an existing outfall along 18th Street at Riviera Canal, but the long route and existing runoff did not allow this project to be effective and it is not recommended.

6.2.1.3 Group C: New Town Near Fogarty Avenue and 11th Street

This area is just east and south of a salt pond that connects to Rivera Canal and drains mostly north to the Gulf, but the neighborhood mostly drains to the pond. This is an area where citizens reported excessive standing water after storms. The elevations are low here, especially near the pond. Four projects were evaluated for this area:

ID	Project	Model Node	Brief Description
C1	Harris and 10th Ave	N6000	1 Gravity Well; 120 LF 18" pipe; 8 inlets; WC Box
C2	Fogarty and 11th St	N3730	1 Gravity Well
C3	Fogarty and 12th St	N3720	1 Gravity Well
C4	Patterson and 12th St	N3710	1 Gravity Well

Harris Avenue is very low between 10th Street and Sunset Drive and is in an area with parcels being affected by the 100-year flood. This location is recommended for a new outfall into the salt pond. To reduce pollutants, a gravity well or water quality box would be placed in the system approximately one block away from the pond where the ground is a little higher. A control box with a weir will be placed near the outfall to induce more flow into the recharge well. The positive outfall makes a large impact on the predicted flooding in the area. However, the gravity well was ineffective, so only a water quality control box is recommended to be implemented.

The other three projects (C2, C3, and C4) were located to the northeast of Harris. None of these gravity well projects are recommended because of low to negligible effectiveness. If Project C1 goes to design, the pipe network and water quality treatment opportunities for the whole neighborhood needs to be evaluated as a larger project that addresses all of this group's area (more pipes and inlets and other street improvements). A cost estimate for this neighborhood redevelopment (street and drainage only) is included in the Alternative 2 list of projects.

6.2.1.4 Group D: Old Town South, North of Flagler and West of White St.

There is a slight ridge of higher landscape that stretches from United Street and Simonton Street, then eastward to near White Street. Stormwater runoff collects in the roads along Washington and Von Phister Streets, especially at lower intersections. This area already has a lot of gravity recharge wells, and some more were evaluated at project locations D1 through D5 in the following group summary:

ID	Project	Model Node	Brief Description
D1	Washington St and Leon St	N2840	1 Additional Gravity Well
D2	Seminary St and Leon St	N2830	2 Gravity Wells
D3	Whalton and Von Phister St	N240	1 Additional Gravity Well

ID	Project	Model Node	Brief Description
D4	United St and Packer St	N2883	1 Additional Gravity Well
D5	United and Georgia St	N2865	1 Gravity Well
D6	On Washington St at Washington and Georgia intersection	N3050	1 Additional Gravity Well
D7	At intersection of Olivia St and Packer St, on Packer St	N2570	1 Additional Gravity Well
D8	Nr Casa Marina Ct and Reynolds	N300	250 LF of exfiltration trench and 4 inlets

Of these gravity recharge wells, D1, D2, and D3 have negligible effect and are not recommended. At D4, the well was placed at relatively high elevation and is effective, but it does not help downstream and there is no real flooding issue here so it is not recommended either. Also, there is a diminishing effect of additional projects in this neighborhood since the area already has infrastructure. D5 is effective at reducing street flooding in this sub-basin, but it is not highly ranked as a flooding problem. The last three projects were added not because of predicted flooding, but because of reported issues by OMI or the public. These are fairly isolated and changes could be relatively as simple as new inlets connected to minor exfiltration trench or gravity wells.

6.2.1.5 Group E: Old Town North, Duval, and Front Street Area

This area is near the highest use retail district on the island, making projects here more complicated to locate and build. The Simonton Beach Pressure-Assisted Well project helped to reduce flooding in the immediate area, but the wells at this project do not appear to have as much capacity as others constructed on the island, though the computer simulations indicate good performance here. The original project at Simonton always assumed that the City would implement more gravity recharge wells at the higher elevations to reduce the volume of stormwater reaching the intersection anyway. Recent projects have installed more gravity wells that improve the severity score of this area. However, more diagnostic and probably more capital investment is needed for the Simonton Beach pressure well system (E7 below).

This group of projects addresses the same neighborhood, on both sides of Duval Street, in areas where runoff staging is still predicted. There were nine projects evaluated here:

ID	Project	Model Node	Brief Description
E1	Southard and Grinnell St	N2550	1 Additional Gravity Well
E2	Greene St and Duval St	N2120	1 Gravity Well
E3	Caroline and Duval (East of Duval)	N2130	1 Gravity Well
E4	Eaton St and Whitehead	N1190	1 Gravity Well
E5	Eaton and Duval, Fleming and Duval	N1120	2 Gravity Wells, 2 intersection
E6	On Whitehead, mid-block South of Greene	N2010	1 Gravity Well

ID	Project	Model Node	Brief Description
E7	Simonton Beach Pump Station	N2110	Needs more piping, assume1 Pressure Well addition to existing system
E8	On Simonton mid-block between Caroline and Eaton St	N2140	1 Additional Gravity Well
E9	James St and Grinnell St	N2530	New outfall, equivalent 24" pipe
E10	N. Duval St inlet		Repair or replacement of inlets with small openings. Should help near East Front St.

The sub-basin around the northern end of Duval Street was ranked 6th in the list of flood severity. Some of these projects had high or medium effectiveness at reducing the severity of flooding, although the projects at Caroline Street or north were low or negligible because of the low elevations. In general, recharge wells at the lower elevations provided low improvements and those at higher elevations (located more southerly) provided moderate to high improvements. The gravity recharge well project (Project E2) with negligible improvements is not recommended. The recommended projects were as follows: the moderately performing wells were at Southard and Grinnell (E1), Caroline and Duval (E3), and Whitehead near Eaton (E4); and those with higher improvements on higher lands near Eaton (E5), Whitehead south of Greene (E6, another location with marginal elevation, but potentially good flood reductions) and on Simonton near Eaton (E8). Most projects listed near the intersection of Duval Street should be located off of Duval on the side street. Given the difficulty in finding locations for projects in the highly developed area, all of these projects should be considered for implementation as the opportunity arises. The repair of inlets is in addition to the additional gravity recharge wells. Adding another 24-inch outfall near the Key West Bight add negligible effect (E9, an Alternative 2 project) and is not recommended. The City is looking at this area of town in detail, and additional projects may be identified in the future.

Duval Street has major stormwater collector pipes down the middle of most of the street. The pipe draining the northern end of Duval Street stretches from Petronia Street northward. The pipe to the north end is large, 54 inches in diameter by the time it gets to the waterfront at the north end. However, the topography is such that south of Southard Street runoff moves east and south. The inlets along Duval Street are old and small. Many of them have been repaired over the years, and the openings into the pipes (inlet tops) were reconstructed smaller than current standards. The City's stormwater computer simulation model does not account for small inlets explicitly, so the restrictive effect of these inlets is not typically quantified in the modeling.

One of the reasons that the modeling and real-world observations along Front Street do not match well could be because of the stormwater from Duval Street is just not getting through the inlets and flowing down the streets until it stages in the low East Front Street area. Upgrading the inlets along Duval Street to more modern standards (using FDOT Types 5 or 6) is highly recommended. Current standards would have an open throat lower than the gutter flow line in the curb. Types 5 and 6 do not have manhole access, which is probably more suited for the limited sidewalk space on Duval, but other types of inlets can be considered. Most mid-block inlets would have double throats (that is, extends in both directions). The City should start at the upstream end, starting at Southard Street because of the topography, and work north prioritizing mid-block locations because of probable easier construction. If this project is done in phases, then the effectiveness of new inlets on reducing overland runoff to the north can be evaluated before working in the heavy pedestrian and retail business concentrated at the north end of Duval Street. This project assumes that the inlet boxes below street level can be reused and only the tops and curbs around the inlets need to be replaced for the low-end estimate. Full box replacement was used for the high-end estimate. The cost of new tops was assumed to be approximately half of the costs of the full inlets recently bid on the gravity well projects. Between Southard and Wall Street (near the waterfront), there are 14 inlets at intersections on Duval, plus 6 inlets on adjoining streets on Wall and Front Streets, and 16 inlets mid-block between intersections. For costing purposes in the SWMP, it is assumed that 30 inlets will be replaced.

6.2.1.6 Group F: New Town North, 17th Street, and Donald Street Area

The City recently added a gravity recharge well at 17th Street and Northside Court, and there are three gravity recharge wells along Donald Street, near the ditch/canal there. The neighborhood is higher to the north and drains south to the ditch, which collects runoff and drains to a pipe that goes under the Publix Shopping Center. The landscape near the ditch, where the three existing wells are, is low and the gravity wells there do not have a high capacity. This neighborhood could use additional wells, provided the wells are located at higher elevations. The following gravity recharge wells were evaluated:

ID	Project	Model Node	Brief Description
F1	Donald St and 17th St	N4110	1 Additional Gravity Wells
F2	Donald St and 17th Ter	N4120	1 Additional Gravity Wells
F3	17th St and South of Roosevelt	N4175	1 Additional Gravity Well

The effectiveness of these gravity recharge wells at reducing peak elevations was moderate, but they must be located at high enough ground to work effectively. Most of the flooding is in the roads and along Donald Street because of the low landscape, and the existing ditch cannot contain all runoff reaching it. The housing development to the south side of the ditch (mostly in N4110, west end of housing) is more affected by the 100-year flood than the residences to the north, and the elevations in the parking lot there is marginal at best for new gravity wells. There is one well in N4175 already, and another one was simulated here to intercept some runoff flowing down toward the Donald Street ditch. Some water quality improvements may be possible through exfiltration trenches or landscaping around the large median area along 17th Street. However, the low ground elevations along Donald Street are problematic for infiltration technologies.

6.2.1.7 Group G: Old Town Southwest, West of Whitehead, and Before the Fort

There are low streets in this area that collect runoff. There are many older homes in this neighborhood and the streets are narrow. The flood severity ranking for these nodes were 31 or lower. The following gravity recharge wells were evaluated at locations where flooding occurs and there may be room for projects:

ID	Project	Model Node	Brief Description
G1	Fort and Olivia	N635	1 Additional Gravity Well
G2	Amelia and Emma St	N605	1 Gravity Well
G3	Whitehead and South St area	N5000	1 Gravity Well, in mid-block

The overall effectiveness of these gravity projects was negligible because of the relatively low elevation. The G3 project was to address staging near the Southernmost Point where a gravity recharge well already exists, but it was not effective and is not deemed necessary. None of these Group G projects are recommended.

6.2.1.8 Group H: New Town, Catherine, and Ashby Streets (George Street Pump Station)

This single project is the proposed pressurized well project recommended for the neighborhood just south of the HOB School. This neighborhood ranked 20th in the flood severity scores, but is a known problem area. This project (H1) is under design and will be recommended. The pump-assisted recharge well has relatively high reduction in flood levels for the area served (N3020 in model).

6.2.1.9 Group I: Old Town, Central, Public Facilities Office Area

This is also a single project (I1) that involves installing two gravity recharge wells near the parking lot next to the City offices near Angela and Simonton Streets (N1160 in model). This area is a localized low spot and runoff collects and stages up here until it can overtop a ridge and flow down a side street. This neighborhood ranked 41st in the flood severity score. The two gravity recharge wells here performed high in terms of reducing peak flood elevations.

6.2.1.10 Group J: Old Town Northeast, Areas Contributing to the Eisenhower Drive and Key West Bight Areas

The landscape along Eisenhower Drive is low and it collects runoff from the higher ground in central Old Town. The same is true for the streets around Key West Bight, along Caroline and Frances Streets. The City has installed multiple gravity recharge wells near here along Pearl and westward and along Caroline, and these projects do not reduce staging to levels that eliminate flooding. However, improvements have been made and the basins along here rank approximately 45th or lower in the flood severity ranking. The projects listed below are opportunities for additional projects in this area:

ID	Project	Model Node	Brief Description
J1	Olivia St and Pohalski Ave, Olivia and Frances	N755	2 Gravity Wells, 2 intersections
J2	White and Petronia	N720	1 Additional Gravity Well
J3	Grinnell and Virginia	N2887	1 Gravity Well
J4	Florida and Olivia	N900	1 Additional Gravity Well
J5	Fleming St and Grinnell St	N2540	1 Gravity Well
J6	Petronia St and Georgia St.	N920	1 Additional Gravity Well

ID	Project	Model Node	Brief Description
J7	Truman and Eisenhower Dr	N2705	New outfalls, equivalent of two 24" pipes

Nearly all of these gravity recharge well projects had high to medium effect on reducing flood levels at their nodes because they are at higher elevations. The well at Petronia and Georgia Streets, a lower intersection (J6, N920 in model), was not effective and is not recommended. However, the peak staging along Eisenhower Drive and Caroline Street did not reduce significantly with the additional gravity wells (Alternative 1). If these projects are installed, then the volume of stormwater flowing downhill will be reduced, resulting in shorter duration of ponding. As such, Projects J1 through J5 are recommended.

Because of the low land around these areas, significant reductions will only come from new outfalls. The waterfront is congested in this area, but there are some locations where a smaller pipe (24-inch assumed) could be worked in between buildings if the City could obtain right-of-ways to the waterfront. Two outfalls were simulated toward the lower end of Eisenhower Drive and these were highly effective for the smaller 10-year storm, but only moderately effective for the 100-year storm.

6.2.1.11 Group K: New Town Areas Surrounding Kennedy Drive and the Ball Fields

The area between the northern end of Kennedy Drive and 14th Street, mostly along Northside Drive, has relatively high peak stormwater levels. These levels are also high going south down 14th Street where there are some high-density residences, mobile homes, and apartments. The apartments are on raised ground so most of the problems would be north of this location. The roads around the ball fields are not too flooded, except near 14th Street and Northside Drive intersection. The landscape is somewhat lower as Kennedy Drive goes south, until it is very low just south of Flagler Avenue, near Riviera Street. This location is only served by a 10-inch outfall, and the inlets and interconnection of pipes here is poor. Two additional sites near here were added in Alternative 2 as exfiltration trenches to address complaints identified by OMI or the public. Otherwise, these projects are mostly gravity recharge wells:

ID	Project	Model Node	Brief Description
K1	Patterson and 12th St	N3710	1 Gravity Well
K2	Near Kennedy Dr and Northside St	N3760	1 Gravity Well
K3	Northside Dr and 14th St	N3770	1 Gravity Well
K4	Along 14th St, near Stadium Apts	N3790	3 Gravity Wells
K5	Along 14th St, near Stadium mobile home park	N3780	1 Additional Gravity Well
K6	Eagle St between 16th and 17th Sts	N3810	650 LF of exfiltration trench and 8 inlets
K7	14th St north of Flagler Ave	N3820	550 LF of exfiltration trench and 8 inlets

The only projects in this group that were recommended were Projects K4 and K5, which is where some of the street flooding is reported, but the modeling did not estimate effective reductions to the 10-year peak flood stages. These two locations were not very highly ranked (71st and 126th, respectively) so these would be considered low priority. Projects K1 through K3 are not recommended because of low flood reductions and no reported problems. The other exfiltration trenches projects (K6 and K7, reported flooding) could be implemented if the soils conditions were permeable enough to support the infiltration.

6.2.1.12 Group L: New Town, Venetian Drive

This is one project (L1) to address street flooding along Venetian Drive. This road is the only entrance and exit from a small neighborhood. The basin has a relatively low flood severity ranking (122nd) and most of the problem was because of only slight encroachment of the 100-year flood from the streets to the parcels. A gravity recharge well in this area has negligible effect because of the low elevation, and no project is recommended here.

6.2.1.13 Group M, New Town Near Patterson Avenue and 3rd Street

One Alternative 2 project (M1) is a pressure well system located near the intersection of Patterson or Fogarty Avenues near 3rd Street. This sub-basin was ranked 7th in the flood severity score. The landscape in this area is too low for gravity wells to flow with enough capacity to make an impact so only a pressure well was evaluated here. This project would serve the general neighborhood and was highly effective at reducing the elevations near the project. Three other projects were added to Alternative 2 in the vicinity of this project to address issues identified by OMI or the public. Gravity recharge wells were included because the landscape is a little higher there, but none of these additional projects provided significant relief in the computer model results and are added as small projects to address known isolated issues. Because of the proximity of Project B2 to Riviera Canal, a small outfall could be installed to reduce the duration of standing water at this intersection. The model did not predict reductions but this project is still recommended as an isolated project to address reported problems. The following table lists all of Group M projects:

ID	Project	Model Node	Brief Description
M1	Fogarty and 3rd St	N3220	2 new pressurized recharge wells; 18" pipe install 300 LF(new)+360 LF(replacing 10")+275 LF(replacing 12") = 1,235 LF of pipe; about 12 inlets
M2	Staples Ave between 6th and 7th Sts	N3410	450 LF of exfiltration trench and 8 inlets, 18" pipe tie to existing outfall
M3	4th St near Flagler Ave	N3310	1 Gravity Recharge Well
M4	3rd St near Flagler Ave	N3320	1 Gravity Recharge Well

6.2.2 Summary of Highest Ranked Sub-basins

The scope of work for the 2012 Stormwater Master Plan included the evaluation of 20 projects for the City. Part of this reasoning for limiting the number of projects is that there is only so much funding available and a list of up to 20 projects would take the City a while to implement. As noted previously, more than 20 projects were looked at (57) and 37 are recommended to be evaluated for further implementation. It would be logical to develop 20 projects in the top twenty sub-basins according to the severity of flooding ranking. However, the ranking process was only one tool used to identify problem areas and there were reasons why a particular sub-basin may not have a specific project. The top 20 ranked sub-basins are listed in Exhibit 6-11 along with a brief explanation why some sub-basins did not have a project listed or recommended. In a few sub-basins, the most feasible project would be a pressurized recharge well but since these are very expensive, it is recommended to defer some of these projects until some of the less expensive projects are implemented.

EXHIBIT 6-11
Top 20 Highest Ranked Sub-basins
City of Key West 2012 Stormwater Master Plan

Sub-basin	Final Sub-Basin Ranking	Project ID	Location Where No Project Is Located	Recommendation for Implementation or Comment
130	1	A1		Yes
4147	2	B1		Yes
2840	3	D1		No, not enough flood reduction
6000	4	C1		Yes, could be part of a larger neighborhood project (see Alt. 2)
3930	5	B2		No, too low
2550	6	E1		Yes
3220	7	M1		Yes, In Alt. 2
1015	8	None	6th and Patterson	Low and not near an outfall. Could be part of a larger neighborhood project to put in a system to either an outfall or pump station. Not in an area with a lot of reported flooding issues.
4110	9	F1		Yes
2830	10	D2		No, too low
240	11	D3		No, too low
210	12	None	Johnson St and Whalton	Close to White St. Pump Station, no reported problems. Could add pipes to White St pump station in future.
3340	12	A4		Yes, In Alt 2, but requires coordination with school board.
2510	14	None	Eaton and White	Low landscape makes pressure system only option. Congested and high traffic area, but not an area of reported flooding issues. Defer project here.
4120	15	F2		Yes
3260	16	None	2nd and Fogarty	This area could be addressed as part of N3220 project.
4150	16	None	Cindy St. and 20th St.	Could be addressed as part of N4145 project
2120	18	E2		No, too low
3030	19	None		Will be addressed as part of N3020 project
2500	20	None	Grinnell and NE of Trumbo	Most of this is on Navy land
3020	20	H1		Yes, in design now
3837	20	K1		Yes, need a project here but gravity recharge wells are not effective here. Investigate more inlets or pipes.

6.3 Conceptual Cost Estimates for Potential Projects

Using the methodology presented in Section 5.2 and the project component construction costs in Exhibit 5-1, an approximate capital cost for each proposed project was developed by selecting the elements specific to each project. The proposed project costs are shown in Exhibit 6-12, with a more detailed breakdown of the estimate presented in Attachment C. Project costs should be considered approximate, planning-level estimates; more accurate cost estimates can be conducted during the design of each project. A range is provided to illustrate the uncertainty in the estimates. For planning purposes, the higher number could be used to be conservative. The total capital costs of all of the Alternative 1 projects range from $17.5 million to $24.6 million. The estimated cost opinion of the Alternative 2 projects range between $11.3 million to $17.9 million. The total cost opinions, determined by adding all of the low and high ranges, respectively, are $28.8 million to $42.5 million. However, out of these projects, only approximately $21.4 million to $30.8 million (low to high range) of the projects are recommended. The two outfall projects at the east end of the island are questionable because they would have to cross U.S. highways and discharge into areas that are already highly developed. These two outfalls are not in the recommended total costs shown in Exhibit 6-12.

This conceptual cost estimate should be considered in 2011 dollars (ENR CCI = 9,035). Note that these capital costs have included provisions for ADA and utility relocation based on the bid costs of recent projects in Key West. The North Stock Island water quality projects are considered to be included in the normal City operational budget and are not included here. Also, if lower costs alternatives were developed utilizing infiltration technologies (like exfiltration trenches, open pavers, etc.) or grant funding continues to be available, then the City's total capital cost may be lower. Any reductions are assumed to be within the range of estimates provided for the purposes of this Stormwater Master Plan.

In addition to reducing flooding, the proposed projects add water quality benefits by directing more stormwater into the ground. The City's existing stormwater system directs about 45 percent of the runoff from the sub-basins included in the computer simulation into the ground, while the Stormwater Master Plan recommended projects increases this to approximately 51 percent. Because not all of the City area was included in the hydraulic model, the overall pollutant reduction from the island is lower than those percentages listed. Regardless of the actual removal rate, both alternatives increase the reduction of stormwater to surface nearshore waters significantly.

EXHIBIT 6-12
Conceptual Projects Planning-level Cost Estimates
City of Key West 2012 Stormwater Master Plan

Intersections/Locations with Alternative 1 Projects	Model Node/ Sub-Basin	Proposed Project	Project No.	Cost (low)	Cost (high)	Recommended (Y/N)
Patricia and Ashby neighborhood piping from Rose and Thompson to PS	N100 (130)	Approx. 1,500 LF of 18" pipe and 16 Inlets, 800 LF of exfiltration trench along Bertha Ave	A1	$785,242	$1,478,334	Y
20th Ter and Donald St	N4147	1 Gravity Recharge Well	B1	$264,649	$384,773	Y
20th St and Eagle Ave	N3930	1 Gravity Recharge Well	B2	$264,649	$384,773	N
Duck Ave and 19th St	N4145	1 Additional Gravity Recharge Wells, 1 intersection	B3	$355,894	$515,123	Y
Donald St and 19th Ter	N4147	1 Additional Gravity Recharge Well	B4	$264,649	$384,773	Y
Harris and 10th Ave	N6000	1 Gravity Recharge Well; 120 LF 18" pipe; 8 inlets; WQ Box	C1	$353,017	$547,509	Y
Fogarty and 11th St	N3730	1 Gravity Recharge Well	C2	$264,649	$384,773	N
Fogarty and 12th St	N3720	1 Gravity Recharge Well	C3	$264,649	$384,773	N
Patterson and 12th St	N3710	1 Gravity Recharge Well	C4	$264,649	$384,773	N
Washington St and Leon St	N2840	1 Additional Gravity Recharge Well	D1	$264,649	$384,773	N
Seminary St and Leon St	N2830	2 Gravity Recharge Wells	D2	$355,894	$515,123	N
Whalton and Von Phister St	N240	1 Additional Gravity Recharge Well	D3	$264,649	$384,773	N
United St and Packer St	N2883	1 Additional Gravity Recharge Well	D4	$264,649	$384,773	N
United St and Georgia St	N2865	1 Gravity Recharge Well	D5	$264,649	$384,773	Y
On Washington St at Washington and Georgia St intersection	N3050	1 Additional Gravity Recharge Well	D6	$264,649	$384,773	Y
Southard and Grinnell St	N2550	1 Gravity Recharge Well	E1	$264,649	$384,773	Y
Greene St and Duval St	N2120	1 Gravity Recharge Well	E2	$264,649	$384,773	N
Caroline and Duval	N2130	1 Gravity Recharge Well	E3	$264,649	$384,773	N
Eaton St and Whitehead St	N1190	1 Additional Gravity Recharge Well	E4	$264,649	$384,773	Y
Eaton and Duval, Fleming and Duval area	N1120	2 Gravity Recharge Wells, 2 locations	E5	$355,894	$515,123	Y
On Whitehead mid-block, South of Greene	N2010	1 Gravity Recharge Well	E6	$264,649	$384,773	Y
Simonton Beach Pump Station	N2110	Additional Investigations at existing pressurized recharge well system. Allowance for new recharge well and piping	E7	$250,000	$350,000	Y
On Simonton St mid-block between Caroline and Eaton St	N2140	1 Additional Gravity Recharge Well	E8	$264,649	$384,773	Y

EXHIBIT 6-12
Conceptual Projects Planning-level Cost Estimates
City of Key West 2012 Stormwater Master Plan

Intersections/Locations with Alternative 1 Projects	Model Node/ Sub-Basin	Proposed Project	Project No.	Cost (low)	Cost (high)	Recommended (Y/N)
Donald St and 17th St	N4110	1 Additional Gravity Recharge Wells	F1	$355,894	$515,123	Y
Donald St and 17th Ter	N4120	1 Additional Gravity Recharge Wells	F2	$355,894	$515,123	Y
17th St and south of Roosevelt	N4175	1 Additional Gravity Recharge Well	F3	$264,649	$384,773	Y
Fort and Olivia	N635	1 Additional Gravity Recharge Well	G1	$264,649	$384,773	N
Amelia and Emma St	N605	1 Gravity Recharge Well	G2	$264,649	$384,773	N
Mid-Block on Whitehead St between United St and South St	N5000	1 Gravity Recharge Well, in mid-block	G3	$264,649	$384,773	N
Catherine and Ashby St Pump Station (a.k.a. George St Pump Station)	N3020	2 Pressurized Recharge Wells and 2 Pipes, see design	H1	$4,651,670	$5,582,004	Y
Angela and Simonton, Angela & mid-block of Duval and Simonton St	N1160	2 Gravity Recharge Wells	I1	$355,894	$515,123	Y
Olivia St and Pohalski Ave, Olivia and Frances	N755	2 Gravity Recharge Wells, 2 intersections	J1	$355,894	$515,123	Y
White and Petronia	N720	1 Additional Gravity Recharge Well	J2	$264,649	$384,773	Y
Grinnell and Virginia	N2887	1 Gravity Recharge Well	J3	$264,649	$384,773	Y
Florida and Olivia	N900	1 Additional Gravity Recharge Well	J4	$264,649	$384,773	Y
Fleming St and Grinnell St	N2540	1 Gravity Recharge Well	J5	$264,649	$384,773	Y
Petronia St and Georgia St	N920	1 Additional Gravity Recharge Well	J6	$264,649	$384,773	N
Riviera Dr and Riviera St	N3800	1 Additional Gravity Recharge Well	K1	$264,649	$384,773	N
Near Kennedy Dr (13 St) and Northside St	N3760	1 Gravity Recharge Well	K2	$264,649	$384,773	N
Northside Dr and 14th St	N3770	1 Gravity Recharge Well	K3	$264,649	$384,773	N
Along 14th St, near Stadium Apts	N3790	3 Gravity Recharge Wells	K4	$793,947	$1,154,319	Y
Along 14th St, near Stadium MH	N3780	1 Additional Gravity Recharge Well	K5	$264,649	$384,773	Y
Venetian Dr and Trinidad Dr	N4200	1 Gravity Recharge Well	L1	$264,649	$384,773	N
Subtotal				$17,529,250	$24,645,986	

EXHIBIT 6-12
Conceptual Projects Planning-level Cost Estimates
City of Key West 2012 Stormwater Master Plan

Intersections/Locations with Alternative 1 Projects	Model Node/ Sub-Basin	Proposed Project	Project No.	Cost (low)	Cost (high)	Recommended (Y/N)
Alternative 2 Projects						
Patricia and Ashby Pressure Well Addition	N100 (130)	Add 1 Recharge Well to existing pressurized system (include pipes, valves, etc.)	A2	$91,245	$130,350	Y
Mid-block on Dennis St between Venetia St and Balance St	N3340	1 Pump, 150 LF 24" pipe	A4	$460,763	$674,025	Y
Eagle and 20th St	N3930	Equivalent 42" pipe	B5	$930,146	$1,656,227	Y-Q
Cindy St and 19th St	N4145	Equivalent 36" pipe	B6	$1,482,875	$2,743,390	Y-Q
Harris and 10th Ave Expanded Neighborhood Project	N6000	4,500 LF 18" pipe; 12 intersections; 4 WQ Boxes	C1	$2,594,374	$4,313,171	Y
On Packer St, at intersection of Olivia St. and Packer St	N2570	1 Additional Gravity Recharge Well/or alternative exfil.	D7	$264,649	$384,773	Y
Near Casa Marina Ct and Reynolds	N300	250 LF of exfiltration trench and 4 inlets	D8	$109,119	$167,042	Y
James St and Grinnell St	N2530	Equivalent 24" pipe	E9	$400,887	$687,490	N
Eisenhower Dr between Angela and Albury Sts	N2705	Equivalent two 24" pipes	J7	$304,383	$532,577	Y
Eagle between 16th and 17th Sts	N3810	650 LF of exfiltration trench and 8 inlets	K6	$272,224	$394,709	Y
14th St north of Flagler Ave	N3820	550 LF of exfiltration trench and 8 inlets	K7	$236,233	$354,292	Y
Fogarty and 3rd St	N3220 (3225)	2 new pressurized recharge wells; 18" pipe install 300 LF(new)+360 LF(replacing 10")+275 LF(replacing 12") = 1,235 LF of pipe; about 12 inlets	M1	$3,127,658	$3,961,008	Y
Staples Ave between 6th and 7th Sts	N3410	450 LF of exfiltration trench and 8 inlets, 850 LF 18" pipe	M2	$344,742	$619,875	Y
4th St near Flagler Ave	N3310	1 Gravity Recharge Well/or alternative exfil.	M3	$264,649	$384,773	Y
3th St near Flagler Ave	N3320	1 Gravity Recharge Well/or alternative exfil.	M4	$264,649	$384,773	Y
Duval St Inlets		30 inlets to be repaired/replaced		$143,550	$495,000	Y
Subtotal				$11,292,143	$17,883,475	
Total Recommended Projects				**$20,226,099**	**$28,826,294**	

Note:
Conceptual planning level costs are in 2011 dollars. Recommendations within this report, Yes/No/Y-Q = Yes but feasibility is questionable.

Attachment A
North Stock Island Stormwater Analysis

North Stock Island Stormwater Drainage Assessment

PREPARED FOR: City of Key West

PREPARED BY: CH2M HILL

DATE: July 11, 2011

Contents

Summary

North Stock Island (NSI) was annexed into the City of Key West in the mid-1990s. Stock Island is physically separated from other portions of the City and NSI is surrounded by the Gulf of Mexico on three sides and the Florida Department of Transportation (FDOT) U.S. Highway 1 (US 1) on the south. This study reviewed the available data for NSI and conducted a detailed computer study of the drainage patterns. NSI can be divided into two general parts: those properties located inside the College Road loop and those located outside the loop. Most property inside the loop road drains to a large salt pond which, in turn, drains through City culverts to the Gulf. Some of the interior property drains to roadside swales (shallow ditches) which are also drained by City culverts to the Gulf. Properties located on the outside of the loop road drain to the Gulf.

The computer simulations were conducted using standard South Florida Water Management District (SFWMD) approaches to simulate large rainfall events. These storms

are selected by engineering convention and are often used to assess developments during permitting. NSI was divided into 51 drainage basins based on recent topographic information obtained from the state, permits, and existing infrastructure. An existing conditions simulation was conducted assuming all pipes are open and clear. These simulation results indicate little flooding problems up to the 100-year design storm. While the golf course would experience standing water on fairways, even in moderate storms, this would not be a priority area for the City because it is not affecting homes or roads. The Key West Golf Course property is owned by the City and it is leased to the operators on a long-term basis. The golf and drainage facilities on the golf course are privately owned.

Based on an August 2010 field review and City operations, some of the City outfalls were blocked by mangroves that somewhat impeded stormwater from reaching the pipes. Since then all outfalls on the eastern side have been unblocked (completed December 2010). A hypothetical simulation was conducted assuming each City outfall pipe end located in mangroves was blocked by 80 percent of its depth. Under these conditions, stormwater may stage up to a point to overflow College Road, especially in the west; but not to a point to cause widespread residential flooding. Consequently, the results of this evaluation validates that the City should pursue the proper permits to clear mangroves from the exit of the pipes to keep the flow pathway clear to open water. This effort may include installing new headwalls and aprons to allow for easier maintenance in the future. Furthermore, under the auspices of their federal National Pollutant Discharge Elimination System (NPDES) permit requirements, the City plans to retrofit the street inlets (City-operated) along College Road with water quality inserts that will help reduce and prevent the discharge of pollutants that may be entering the outfalls from the street.

Introduction

The City of Key West encompasses both the main island known as Key West, some small nearby islands, and a portion of the island to the east called Stock Island. Specifically, the portion of Stock Island that is part of the City is north of US 1 and is commonly referred to as North Stock Island (NSI). The City has conducted stormwater planning for the main island of Key West, but has not conducted a study for NSI previously. NSI was annexed to the City in the mid-1990s and there are no known serious flooding problems located here. This study was commissioned to evaluate the potential flooding problems on the island and to address current stormwater management issues.

NSI has several distinct and important features. The closed City landfill is most prominent on the landscape as it reaches an elevation of about 90 feet. NSI contains a number of important commercial and institutional properties, including the Lower Keys Medical Center (hospital), Florida Keys Community College (FKCC), Gerald Adams Elementary School, Monroe County Main Detention Facility (jail), Key West Tropical Forest and Botanical Gardens (gardens, a private park), a Florida Keys Aqueduct Authority (FKAA) water storage facility (ground storage tanks and pumps), and the Key West Country Club (golf course) with associated residential units located in the middle of the golf course. While this list does not include all properties on NSI, it includes most of them.

NSI can be characterized further by using College Road which makes a horseshoe loop with both ends intersecting US 1. The City maintains the loop road culverts; the FDOT maintains

US 1. Inside the loop, most stormwater drains to a large salt pond surrounded by mangroves wetlands and the City owns this salt pond (i.e., the land). Also inside the College Road loop are the following major properties: the golf course with associated residential areas, hospital, gardens and the FKAA storage facility. There are only a couple small parcels not included in this list of property owners. Drainage from inside the loop travels through a series of City outfalls (**Figure 1**). These outfalls were already constructed when the City annexed NSI in the mid-1990s. The remaining properties are on the outside of the loop road and drain to the surrounding Gulf of Mexico waters except for some area in the front of the elementary school and landfill entrance.

Some of the properties on NSI have state stormwater permits from the SFWMD and all properties are covered under the City's NPDES Municipal Separate Storm Sewer System (MS4) permit. The City operates its stormwater system under the auspices of a Stormwater Management Utility created in 2001, but implemented in 2003. The NPDES MS4 program is part of the Clean Water Act with delegated management authority to the Florida Department of Environmental Protection (FDEP). City coverage under the NPDES MS4 permit was included under the NPDES stormwater permitting program because of the sensitivity of the surrounding receiving waters (Gulf and Ocean). The City first came under NPDES MS4 coverage in 2005. The NPDES program requires water quality improvements as opposed to flooding reduction.

In general there have been little complaints of flooding or water quality issues on City property in NSI. The golf course has been observed using pumps to lower standing water on the course after moderate to large storms. Portable pumps discharge to the wetlands which drain into the salt pond. The manager of the botanical gardens acknowledges that their property ponds water from time to time because it is a low spot in the southwestern interior corner. They have enlarged their water features to provide more stormwater storage. Otherwise, most of the other commercial properties on the outside of the loop road drain directly to the Gulf and do not interact with City outfalls that drain the central portion of the island.

The City is aware of potential blockage of the some of the outfalls on pipes terminating in the mangroves. The contract operator of the City sewer system, OMI, cleaned the culvert pipes in 2009 so the pipes are not blocked internally. These pipes were re-cleaned in December 2010 and the pipe openings are unobstructed. However, the mangroves send root networks out in front of the pipes and sand and silt builds up and eventually restricts the flow path in front of the pipes. Mangroves themselves are not currently considered an endangered species but they are known to provide habitat to many threatened and endangered species in Florida, so they are afforded special regulatory protection. In 1996, FDEP implemented the Mangrove Trimming and Preservation Act (http://www.dep.state.fl.us/water/wetlands/mangroves/). This Act regulates the trimming and alteration of mangroves while also banning the use of herbicides and other chemicals used to defoliate mangroves. Mangroves cannot be removed, excessively trimmed, or otherwise significantly disturbed without a permit from the FDEP. Consequently, outfalls that are currently blocked by mangroves have not been cleared because of the restriction.

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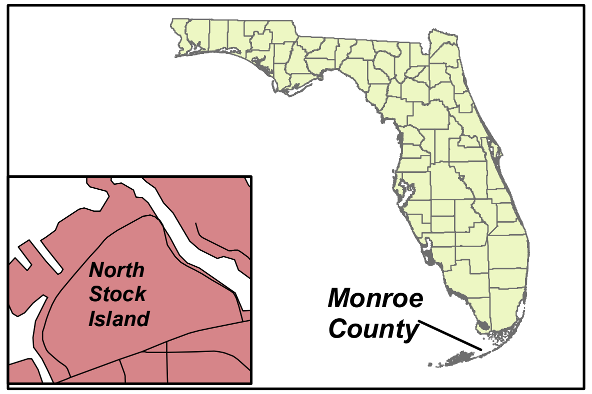


LEGEND
Outfalls

N
0 500 1,000
Feet

Source:
Aerial: LABINS, 2009
-City Owned Outfalls

FIGURE 1
North Stock Island and Stormwater Outfalls
North Stock Island Stormwater Assessment

CH2MHILL

Project Objective

The objective of this evaluation was to determine the potential flooding issues on NSI using detailed computer simulation of stormwater runoff, storage, and flood routing. Storm surge from hurricanes is not included in this assessment.

Elevations and Reference Datum

Elevations on a landscape are set relative to long-term elevations of the ocean and a network of fixed benchmarks. The U.S. National Geodetic Survey (NGS) maintains this network and has updated the historic standard established in 1929 with a new standard referred to as the 1988 datum. In practical terms, the landscape has not moved, but the yardstick used to measure the elevation has been shifted. The SFWMD and most municipalities has traditionally required the National Geodetic Vertical Datum of 1929 (NGVD29) for surveying and expressing elevations. However, the SFWMD and other municipalities are in the process of switching to the North American Vertical Datum of 1988 (NAVD88). This is clearly a time of transition so available literature is presented in one or the other reference datum. Except for the most recent aerial mapping by the state, elevations are typically expressed in NGVD29. The conversion between NAVD88 from NGVD29 in Key West is to subtract 1.345 feet (ft), so the NAVD88 elevation would be a smaller value for the same location. This conversion may vary slightly from one side of the City to the other, but this difference would be slight and of little consequence to normal public work facilities. The conversion was computed using the NGS VERTCON2 program at latitude 24° 33′ 26″ N and longitude 81° 47′ 14″ W (http://www.ngs.noaa.gov/cgi-bin/VERTCON/vert_con.prl).

A main consequence of this datum conversion is a restatement of the sea level elevations surrounding Key West. The main National Oceanic and Atmospheric Administration (NOAA) tide gauge at Key West (ID: 8724580) is located in the boat basin on the west side of the main island. The updated tide levels are presented in **Table 1** and are based on NOAA tide data from 1983 through 2001. From the updated NOAA data, one can see that while mean sea level used to be near -0.2 in the NGVD29 reference datum, it is now expressed close to -1.5 under the new NAVD88 datum. Similarly, stormwater evaluations are most often conducted under mean high water (MHW) conditions which used to be near elevation 1.1 NGVD29, but are now close to -0.2 NAVD88.

For purposes of this study, the boundary condition at the ocean is being set at elevation 0 NAVD88, which is closer to the mean higher-high water (MHHW) which will represent a seasonally high high-tide level.

TABLE 1
Tide Levels at the Key West NOAA Gauge in Different Vertical Datum
North Stock Island Stormwater Assessment

Description	Acronym	Elevation NAVD88	Elevation NGVD29
Mean Higher-High Water	MHHW	0.05	1.40
Mean High Water	MHW	-0.24	1.11
Mean Tide Level	MTL	-0.88	0.47
Mean Sea Level	MSL	-1.52	-0.18
Mean Lower-Low Water	MLLW	-1.76	-0.42
Mean Range of Tide	MN	1.28	1.28
Highest Water Level	MAX	1.98	3.33
	MAX DATE	9/8/1965	

All elevations are in feet.
Based on NOAA Gauge 8724580 for Key West, accessed 9/1/2009

Data Sources

Data was collected from available sources from literature and the City. On August 18, 2010, a CH2M HILL engineer and OMI representative conducted a field review. The City-operated outfalls were inspected. During this inspection, the first culvert on the east (City Outfall 60) was found because it was not too far from the road and the mangroves had been partially trimmed. This 18-inch pipe was nearly blocked in front of the pipe, both ends; but evidence of flow was present because of trash gathered near the end located in the swale (inside the loop). There were extensive mangroves in front of both pipe ends. A similar situation was found at City Outfall 61 located just north of 60. Most of the remaining outfalls were not found as their ends were deep within the mangroves growing in the swales and along the coastline. On December 7, 2010, CH2M HILL inspected these same pipes after OMI re-cleaned them and found all pipe ends and they were unblocked. However, the flow path between the end of some of the pipes and the open water were still covered by mangroves.

There are 7 main pipes that drain the salt pond at its east end, and these were observed to be flowing freely during the review. These are large (36-inch by 48-inch elliptical) corrugated pipes, and through probing with a shovel it was determined that there was little sand deposition in these pipes. These pipes are not covered by mangroves and there is a strong tidal current flowing through these pipes. The pipe located near the north end was starting to have some mangroves encroach on it, so this needs to be monitored.

OMI provided the approximate location, type and size of the outfalls that they had cleaned. However, OMI did not have invert elevations. The City had survey data for only four of the outfalls located on the east side, Outfalls 60, 62, 61, and 63 (the pipe draining the swale in front of the hospital). The invert elevations from the survey were nearly the same on each end with the pipe being a little higher at the catch basin inlet in the street. The invert elevations at the catch basin inlets for these were about 0.8, -0.7, -0.7, and -3.8 for Outfall 60, 61, 62, and 63, respectively. These elevations are believed to be expressed in NGVD29 elevations. In April 2011, the City relocated these outfalls during a GPS field inventory. The figures reflect these locations, except for a pipe in front of the elementary school that was hard to find because grass had grown over it and the City does not maintain it.

Several of the properties on NSI have stormwater permits from the SFWMD. The SFWMD permit database was queried for properties located on Stock Island and permits were found for the Key West Country Club (golf course and residential), FKCC, and jail. The as-built drawings from the landfill closure were available to CH2M HILL as well as some drawings from the layout of the FKAA storage facility (no stormwater pipes are at FKAA). The City also provided permit documents for the residential area located inside the golf course.

The original golf course was developed at about the same time of the advent of Florida's modern stormwater permitting system. In 1981 the club obtained conceptual approval for constructing Phase I of their ponds and outfalls to the salt marsh from the SFWMD (surface water management permit number 44-00003-S). At that time there was a plan to develop residential units in the middle of their property. The general drainage plan was to drain the streets to the golf course ponds. The SFWMD staff report listed the minimum first floor elevations to be 11 ft NGVD29 and minimum road crown elevations to be 4.5 ft NGVD29. The staff report lists the design basis as the 10-year, 3-day storm. The golf course drains to surrounding wetlands and mangrove marshes through three outfall structures located in ponds on the course. These outfalls have water control boxes with orifice holes. In 1995 the permit was modified for the actual construction of the residential units (application no. 44-00003-S-02). Special conditions included minimum first floor building elevations to be 9 ft NGVD29 and minimum road crown elevations of 4.5 ft NGVD29. The design drawings used for this 1995 permit was used to determine the elevations of the golf course outfall structures because they are as-built conditions and were more legible than the 1981 archive copy of the permit. However, the elevations of the downstream pipe inverts in the wetlands (i.e., the outlets of the golf course outfalls) were not listed on these drawings. This invert data is not important as the pipes are fully submerged under normal conditions.

The state obtained LiDAR (Light Detection and Ranging) survey for Monroe County in late 2007 and created 1-ft contour maps. Although the contours are expressed in 1-ft intervals (NAVD88), the actual national map standard vertical accuracy is ±1 ft because the maps were prepared at 2-ft contour intervals and interpolated. These topographic data and concurrent aerial photography was obtained from the state through the Monroe County Geographic Information System (GIS) Department. In addition, parcel and road data layers were obtained in GIS ArcMap format from the county. These data were used as the basis for GIS-based mapping. The resulting map of the topography is included as **Attachment A**.

Computer Modeling Approach and Setup

The Interconnected Pond Routing (ICPR®) computer model was used to simulate the design storms (Version 3.10, Service Pack 6; © 2002 by Streamline Technologies, Inc.). The program was used to compute runoff using standard Soil Conservation Service (SCS) methods. Routing is accomplished using dynamic routing that accounts for ponding and backwater effects. This model can accurately compute the flows and elevations in the entire NSI drainage system. In this case the model results of primary interest are the staging of stormwater that occurs inside the loop and on College Road.

Basin Delineation

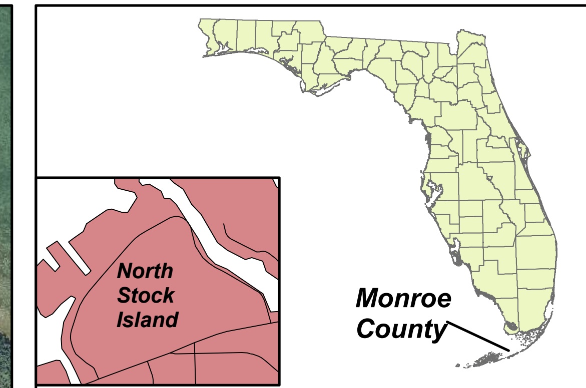
NSI was divided into 51 sub-basins based on the variety of data obtained from the permitting files and the topography (**Figure 2**). Nineteen of these sub-basins were located outside of College Road so they were routed directly to the Gulf. Some of these sub-basins, like the landfill, jail, and community college have permitted facilities that were represented in the model. In some instances, like for the jail, there was not detailed information for the site's entire infrastructure, so all of the ponds were modeled as one pond with multiple weirs based on definitions in the permit. The landfill ponds are located at a higher elevation so the peak stormwater elevations for this sub-basin (Sub-basin 11) are noticeably higher than the others. Sub-basin 18 is the large salt marsh inside College Road.

Computer Simulation Setup

ICPR is a classic link-node hydrologic computer model. Nodes are often used to represent storage on the land, either through ponds or street ponding. Nodes are also used to represent the constant boundary conditions in the Gulf; held at a constant elevation of 0. This boundary condition is conservative as the tide fluctuations would allow standing water to drain more quickly than assuming a constant elevation. The links are conveyance elements that are usually pipes, drop structures, or weirs at NSI. Because of the flatness of the island, no open channels were included as water would just cascade by overland flow into the next drainage basin or outfall in most cases without pipes. **Figure 3** provides the ICPR model schematic for NSI.

Runoff was estimated for every sub-basin and directed to a node in the hydraulic model. In some instances, sub-basins were combined to drain into one node in the model, like near the FKAA storage facility. Runoff from Sub-basins 40, 37, and 36 can collect behind the storage tanks in wetlands that are represented as one node. This node can then overflow when stormwater stages to a certain elevation into Sub-basin 35 which has a pond that, in turn, is connected by pipe to the pond in Sub-basin 31 that has an outfall to the salt marsh. Runoff from the property to the south of the botanical gardens (Sub-basin 39) can flow into the pond in the gardens (Sub-basin 44) based on the topography of the area. Overland flow connections in the model were simulated as broad crested weirs, like the wetlands behind FKAA and the gardens pond which can both overflow into Sub-basin 35 on the golf course.

Runoff was computed using the Curve Number Method. A sub-basin curve number was computed based on impervious are and then entered directly into the model without entering an imperviousness fraction as part of the input. The unit hydrograph used in the computations was based on a peaking factor of 256 which is standard for the flat conditions in South Florida. The time of concentration for each sub-basin was estimated based on Soil Conservation Service Technical Report 55 methodology. Model input data are included in **Attachment B**.



LEGEND

Subbasins

N

0 500 1,000

Feet

Source:
Aerial: LABINS, 2009
Subbasin: CH2M HILL, 2010

FIGURE 2
North Stock Island Drainage
Basins Delineation for Assessment
North Stock Island Stormwater Assessment

CH2MHILL

Nodes
A Stage/Area
V Stage/Volume
T Time/Stage
M Manhole

Basins
O Overland Flow
U SCS Unit CN
S SBUH CN
Y SCS Unit GA
Z SBUH GA

Links
P Pipe
W Weir
C Channel
D Drop Structure
B Bridge
R Rating Curve
H Breach
E Percolation
F Filter
X Exfil Trench

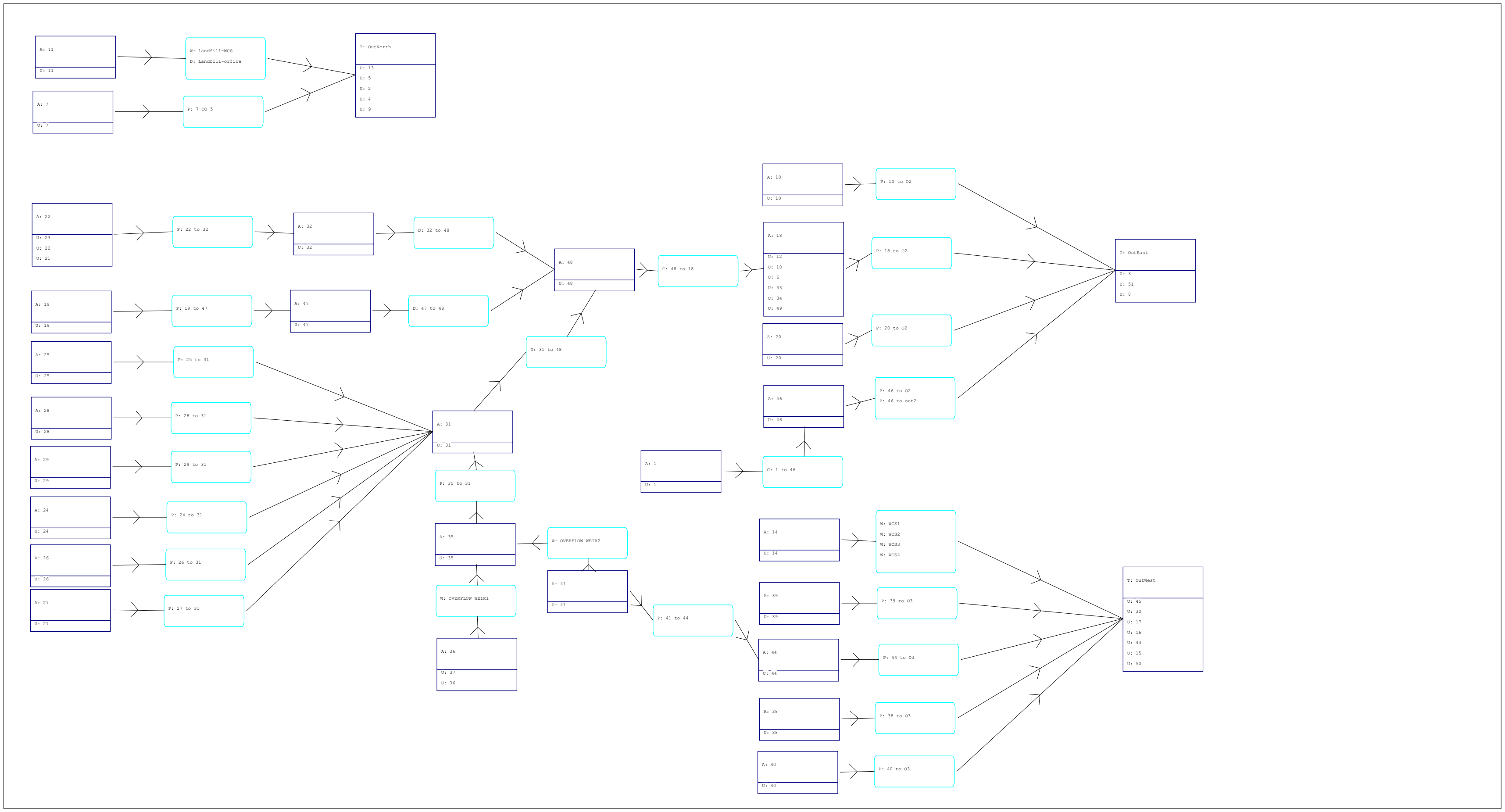


Figure 3
Schematic Diagram of the Computer Simulation
North Stock Island Stormwater Assessment

All pipe invert data were reviewed and adjusted to the NAVD88. Storage in the ponds and fairways and overland flow paths were established using the LiDAR data (NAVD88). Street flooding was allowed in the private roads in the country club residential area and was allowed to stage up only within the sub-basin with no overland flow leaving the roads. As discussed below, this road storage did not seem to cause flooding results in the neighborhood. Some of the City outfalls did not have elevation data. The street inlet elevations at unknown locations were approximated from the LiDAR data and the outlets set at about 0 NVGD29, then shifted to -1.345 NAVD88. Since these pipes are normally submerged, the elevations of the outlets were not critical to the computations. The pipe and weir invert data are provided as part of the input data in **Attachment B**.

Not every pipe and inlet in private systems was included in this evaluation. Runoff was generally routed to one node that acted like the outfall for that sub-basin. For example, the residential areas inside the country club have multiple catchbasins and pipes that serve the roads and swales in the development. One pipe connects each sub-basin to a golf course pond and it was included in the model for this neighborhood. Street ponding was added at elevation 3 NAVD88, typically which is about the average roadway low elevation in the development. One foot of storage in the streets was added by taking the roadway length times a 24-ft average road width. In a few sub-basins, the area of isolated wetlands was added to the storage (e.g., Sub-basin 19). This approach is expected to conservatively estimate high stormwater staging in these sub-basins, but the private country club residential area was already evaluated during permitting and since it is a relatively modern system, it was expected to function as designed.

Design Storms

The design storms used in the evaluation are shown in **Table 2**. These volumes are based on standard literature values available from either the SFWMD or FDOT. The SFWMD guidance was used to establish the time distribution of rainfall intensities (hyetographs).

TABLE 2
Design Storms for the City of Key West
North Stock Island Stormwater Assessment

Return Period (years)	Duration (hr)	Distribution	Volume (in)
2	24	FLMOD	5
5	24	FLMOD	6
10	24	FLMOD	7
25	72	SFWMD72	12
100	72	SFWMD72	17

Used ICPR distributions as identified above: Florida-modified Type II storm or the SFWMD 72-hour distribution.

Existing Drainage and Conditions Simulations

By convention, stormwater master planning is conducted under fully functional pipes and outfalls even if there is sediment or other known issues about the storm sewer system because most of the time these known problems could be fixed as maintenance activities. This assumption of minor effort is not always accurate as some maintenance activities may require substantial funds. NSI is known to have potential issues with the mangrove wetlands blocking flow paths to the City's outfalls and the state does not allow alteration of mangroves without special permitting.

The City is in the process of purchasing and installing water quality inserts for the inlets along the City rights-of-way on College Road. These inserts are to help reduce pollutant discharges to the Gulf from the MS4 system. The MS4 Stormwater Pollution Prevention Plan pertains to the entire City and contains parts that are not capital improvements and these are applied city-wide. Some of these management elements include non-structural activities like:

- Public information booths at community events
- Website education campaign
- Public service announcements and interviews on the radio
- News articles or public service announcements on stormwater education issues in local weekly or daily newspaper
- Public meetings and focus groups to obtain input regarding water quality, utility work, grant programs, flood plain management
- Storm drain stenciling
- Support a "Clean Key West Task Force" with a mission to organize public and private groups in developing an adopt and area program, city-wide clean-up initiatives and recommending code enforcement initiatives, code modifications and city procedures.
- Adopt-an-Area Program for trash cleanup and inlet monitoring
- A Stormwater Hotline to allow citizens 1) a method of reporting polluters; 2) a method of providing input for the stormwater program; and 3) a venue for consultation (a number is published in the paper, stormwater brochures, and on the City website)
- Modify storm system map, as needed
- Track reports of illicit discharges
- Conduct illicit discharge screening in inlets and outfalls; reduce infiltration and inflow and cross connections to sewer system
- Public, employee, and business education on illicit discharges/hazardous waste
- Develop and implement community group and school presentations

- City ordinance requiring conformance with FDEP and SFWMD rules

All of the above activities are conducted by the City to comply with Clean Water Act requirements. These operations are managed under the City's Stormwater Management Utility utilizing its utility fees. Additional capital project funding often comes from grants that require co-funding that is also derived from utility fees. To date, the City has a backlog of capital projects that are being implemented as funding becomes available. There is no capital project identified for NSI prior to this study other than the water quality inlet inserts. Note that the installation of these inserts will cause an incremental increase in maintenance costs for the NSI area.

Assuming Fully Functional Outfalls

The baseline scenario was conducted assuming all outfalls were fully functional. The results are expressed as the peak stormwater levels in the sub-basins containing storage areas (i.e., significant low spots, wetlands, or ponds) for each of the 4 design storms. **Table 3** lists these flood elevations.

The adopted level-of-service for drainage is included in a City's Comprehensive Plan. The severity of the flooding problem depends on which storm is causing the flooding. For example, most roads in residential neighborhoods should not have flooding deeper than 6-inches during a 10-year design storm. Key West's adopted drainage level of service is to prevent post-development discharge rates to exceed pre-development discharge rates during a 25-year, 24-hour storm, the same as SFWMD's requirements.

Whenever the water level exceeds about elevation 3 in the middle of NSI, there is a potential for street flooding. In general, College Road elevations are at about 3 NAVD88 or higher. Since the staged stormwater levels are below elevation 3 NAVD88 around most of the loop road under existing conditions there are no current problems identified on this road except for in front of the Botanical Garden for the largest storms. Note that loop road does increase in elevation to near elevation 6 around US 1 so higher staged water levels in Sub-basin 41 may not be overtopping the road. However, there appears to be a potential for minor street flooding (0.66-ft deep for a 25-year storm). A couple of the sub-basins in the residential area are estimated to have standing water in the streets, especially for the larger 25- and 100-year storms, but since the model did not account for water spilling out onto the neighboring golf course, these staged depths are overstated and are still below household first floor levels (first floors are at about elevation 8.6 NAVD88 per the SFWMD permit). For the system fully-functional scenario, there were no areas identified with substantial flooding for any of the four design storms.

The golf course has portions of several fairways below elevation 3 NAVD88 so there will be standing water on the course that may affect playability, especially on the holes with ponds in the fairway. However, the standing water on the course results from the size of the golf course's outfall pipes, the high tailwater conditions used in the assessment, and the generally low elevation of the course's landscape.

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TABLE 3
Summary of Modeling Results for Existing Facilities without Blockage by Mangroves Compared to Conditions with Blocked City Outfalls
North Stock Island Stormwater Assessment

Description of Location	Modeled Basin Name	Dedicated Outfall?	Simulated Design Storm	Existing Max. Elevation	Blocked 80% Max. Elevation	Difference	**Comments on Blocked Outfalls Scenario**
Southeast Golf Course, Near Green at 6th Hole	1		2-yr, 24-hr	0.69	0.69	0.00	
	1		5-yr, 24-hr	0.92	0.92	0.00	
	1		10-yr, 24-hr	1.10	1.10	0.00	
	1		25-yr, 72-hr	1.41	1.78	0.37	
	1		100-yr, 72-hr	1.65	2.57	0.92	
Front of Hospital (swales with mangroves)	10	Yes	2-yr, 24-hr	0.18	1.45	1.27	Blocked both ends
	10		5-yr, 24-hr	0.26	1.78	1.52	
	10		10-yr, 24-hr	0.36	2.10	1.74	
	10		25-yr, 72-hr	0.63	2.85	2.22	
	10		100-yr, 72-hr	1.07	4.01	2.94	Potential minor street flooding when blocked
Closed Landfill (Ponds at higher elev.)	11	Yes	2-yr, 24-hr	9.15	9.15	0.00	Not Blocked
	11		5-yr, 24-hr	9.43	9.43	0.00	
	11		10-yr, 24-hr	9.70	9.70	0.00	
	11		25-yr, 72-hr	10.93	10.93	0.00	
	11		100-yr, 72-hr	11.52	11.52	0.00	
County Detention Center	14	Yes	2-yr, 24-hr	1.51	1.51	0.00	Not Blocked
	14		5-yr, 24-hr	1.59	1.59	0.00	
	14		10-yr, 24-hr	1.66	1.66	0.00	
	14		25-yr, 72-hr	1.80	1.80	0.00	
	14		100-yr, 72-hr	1.99	1.99	0.00	
Salt Marsh	18	Yes	2-yr, 24-hr	0.07	0.07	0.00	Not Blocked
	18		5-yr, 24-hr	0.09	0.09	0.00	
	18		10-yr, 24-hr	0.13	0.13	0.00	
	18		25-yr, 72-hr	0.27	0.27	0.00	
	18		100-yr, 72-hr	0.45	0.45	0.00	
Residential Area (east)	19		2-yr, 24-hr	1.32	1.32	0.00	
	19		5-yr, 24-hr	1.58	1.58	0.00	
	19		10-yr, 24-hr	1.84	1.84	0.00	
	19		25-yr, 72-hr	2.82	2.82	0.00	
	19		100-yr, 72-hr	3.49	3.49	0.00	
Residential Area (entrance)	20	Yes	2-yr, 24-hr	0.01	0.34	0.33	Blocked both ends
	20		5-yr, 24-hr	0.03	0.51	0.48	
	20		10-yr, 24-hr	0.04	0.68	0.64	
	20		25-yr, 72-hr	0.10	1.30	1.20	
	20		100-yr, 72-hr	0.22	2.03	1.81	
Residential Area (central)	22		2-yr, 24-hr	2.94	2.94	0.00	
	22		5-yr, 24-hr	3.08	3.08	0.00	
	22		10-yr, 24-hr	3.24	3.24	0.00	
	22		25-yr, 72-hr	3.78	3.78	0.00	
	22		100-yr, 72-hr	4.48	4.48	0.00	
Residential Area (central)	24		2-yr, 24-hr	2.92	2.92	0.00	
	24		5-yr, 24-hr	3.09	3.09	0.00	
	24		10-yr, 24-hr	3.30	3.30	0.00	
	24		25-yr, 72-hr	4.11	4.11	0.00	
	24		100-yr, 72-hr	5.03	5.03	0.00	

TABLE 3 (CONT.)
Summary of Modeling Results for Existing Facilities without Blockage by Mangroves Compared to Conditions with Blocked City Outfalls
North Stock Island Stormwater Assessment

Description of Location	Modeled Basin Name	Dedicated Outfall?	Simulated Design Storm	Existing Max. Elevation	Blocked 80% Max. Elevation	Difference	**Comments on Blocked Outfalls Scenario**
Residential Area (central)	25		2-yr, 24-hr	3.09	3.09	0.00	
	25		5-yr, 24-hr	3.53	3.53	0.00	
	25		10-yr, 24-hr	3.94	3.94	0.00	Road min. EL is 3.2 at end of cul-de-sac, minor LOS reduction +- 150 LF.
	25		25-yr, 72-hr	5.04	5.04	0.00	
	25		100-yr, 72-hr	6.21	6.21	0.00	
Residential Area (central)	26		2-yr, 24-hr	1.80	1.80	0.00	
	26		5-yr, 24-hr	2.23	2.23	0.00	
	26		10-yr, 24-hr	2.64	2.64	0.00	
	26		25-yr, 72-hr	3.80	3.80	0.00	
	26		100-yr, 72-hr	4.59	4.59	0.00	
Residential Area (west)	27		2-yr, 24-hr	1.80	1.80	0.00	
	27		5-yr, 24-hr	2.23	2.23	0.00	
	27		10-yr, 24-hr	2.64	2.64	0.00	
	27		25-yr, 72-hr	3.81	3.81	0.00	
	27		100-yr, 72-hr	4.59	4.59	0.00	
Residential Area (west)	28		2-yr, 24-hr	2.85	2.85	0.00	
	28		5-yr, 24-hr	3.05	3.05	0.00	
	28		10-yr, 24-hr	3.29	3.29	0.00	
	28		25-yr, 72-hr	4.20	4.20	0.00	
	28		100-yr, 72-hr	5.17	5.17	0.00	
Residential Area (west)	29		2-yr, 24-hr	2.89	2.89	0.00	
	29		5-yr, 24-hr	3.06	3.06	0.00	
	29		10-yr, 24-hr	3.29	3.29	0.00	
	29		25-yr, 72-hr	4.18	4.18	0.00	
	29		100-yr, 72-hr	5.24	5.24	0.00	
Golf Course Pond (middle, nr. 16th Green)	31	Yes	2-yr, 24-hr	1.73	1.73	0.00	Not Blocked
	31	Private	5-yr, 24-hr	2.12	2.12	0.00	
	31		10-yr, 24-hr	2.51	2.51	0.00	
	31		25-yr, 72-hr	3.61	3.64	0.03	
	31		100-yr, 72-hr	4.39	4.42	0.03	
Golf Course Pond (south, nr. 2nd Tee)	32	Yes	2-yr, 24-hr	1.86	1.86	0.00	Not Blocked
	32	Private	5-yr, 24-hr	2.38	2.38	0.00	
	32		10-yr, 24-hr	2.81	2.81	0.00	
	32		25-yr, 72-hr	3.62	3.62	0.00	
	32		100-yr, 72-hr	4.38	4.38	0.00	
Golf Course Pond (west, nr. 12th Tee)	35		2-yr, 24-hr	1.74	1.74	0.00	
	35		5-yr, 24-hr	2.13	2.13	0.00	
	35		10-yr, 24-hr	2.53	2.53	0.00	
	35		25-yr, 72-hr	3.60	3.63	0.03	
	35		100-yr, 72-hr	4.25	4.40	0.15	
Wetland behind FKAA Storage Facility	36		2-yr, 24-hr	2.74	2.74	0.00	
	36		5-yr, 24-hr	2.99	2.99	0.00	
	36		10-yr, 24-hr	3.04	3.04	0.00	
	36		25-yr, 72-hr	3.85	3.85	0.00	
	36		100-yr, 72-hr	4.63	4.63	0.00	
Golf Course nr. 11th Fairway	38		2-yr, 24-hr	0.78	1.76	0.98	Blocked one end
	38		5-yr, 24-hr	1.13	2.15	1.02	
	38		10-yr, 24-hr	1.45	2.45	1.00	
	38		25-yr, 72-hr	2.26	3.17	0.91	
	38		100-yr, 72-hr	2.90	3.82	0.92	

TABLE 3 (CONT.)
Summary of Modeling Results for Existing Facilities without Blockage by Mangroves Compared to Conditions with Blocked City Outfalls
North Stock Island Stormwater Assessment

Description of Location	Modeled Basin Name	Dedicated Outfall?	Simulated Design Storm	Existing Max. Elevation	Blocked 80% Max. Elevation	Difference	**Comments on Blocked Outfalls Scenario**
Southwest corner, nr. Botanical Garden	39	Yes	2-yr, 24-hr	0.50	2.30	1.80	Blocked one end
	39		5-yr, 24-hr	0.92	2.50	1.58	
	39		10-yr, 24-hr	1.49	2.67	1.18	
	39		25-yr, 72-hr	2.31	3.08	0.77	
	39		100-yr, 72-hr	2.75	3.47	0.72	Potential minor street flooding when blocked
FKAA Storage Facility	40		2-yr, 24-hr	1.29	2.59	1.30	Blocked one end
	40		5-yr, 24-hr	1.61	2.75	1.14	
	40		10-yr, 24-hr	1.87	2.89	1.02	
	40		25-yr, 72-hr	2.23	3.12	0.89	
	40		100-yr, 72-hr	2.67	3.50	0.83	
Southwest corner, nr. Botanical Garden	41		2-yr, 24-hr	1.77	2.60	0.83	
	41		5-yr, 24-hr	2.39	3.15	0.76	
	41		10-yr, 24-hr	2.87	3.54	0.67	Potential minor street flooding when blocked
	41		25-yr, 72-hr	3.66	3.73	0.07	Potential street flooding
	41		100-yr, 72-hr	4.24	4.40	0.16	Potential street flooding
West, just north of Botanical Garden	44	Yes	2-yr, 24-hr	1.19	2.34	1.15	Blocked one end
	44		5-yr, 24-hr	1.62	2.83	1.21	
	44		10-yr, 24-hr	1.99	3.16	1.17	
	44		25-yr, 72-hr	2.92	3.70	0.78	Potential minor street flooding when blocked
	44		100-yr, 72-hr	3.54	4.08	0.54	Potential street flooding
Golf Course on East, nr. Mangrove Swales	46	Yes	2-yr, 24-hr	0.12	0.45	0.33	Blocked both ends
	46		5-yr, 24-hr	0.19	0.62	0.43	
	46		10-yr, 24-hr	0.26	0.78	0.52	
	46		25-yr, 72-hr	0.72	1.78	1.06	
	46		100-yr, 72-hr	1.61	2.57	0.96	
Golf Course Ponds (middle, nr. 4th Green)	47	Yes	2-yr, 24-hr	1.31	1.31	0.00	Not Blocked
	47	Private	5-yr, 24-hr	1.57	1.57	0.00	
	47		10-yr, 24-hr	1.83	1.83	0.00	
	47		25-yr, 72-hr	2.80	2.80	0.00	
	47		100-yr, 72-hr	3.45	3.45	0.00	
Golf Course wetland (east, nr. 8th Green)	48		2-yr, 24-hr	1.14	1.14	0.00	
	48		5-yr, 24-hr	1.18	1.18	0.00	
	48		10-yr, 24-hr	1.21	1.21	0.00	
	48		25-yr, 72-hr	1.32	1.32	0.00	
	48		100-yr, 72-hr	1.39	1.39	0.00	

TABLE 3 (CONT.)
Summary of Modeling Results for Existing Facilities without Blockage by Mangroves Compared to Conditions with Blocked City Outfalls
North Stock Island Stormwater Assessment

Description of Location	Modeled Basin Name	Dedicated Outfall?	Simulated Design Storm	Existing Max. Elevation	Blocked 80% Max. Elevation	Difference	**Comments on Blocked Outfalls Scenario**
Adams Elementary School area	7		2-yr, 24-hr	0.36	0.36	0.00	
	7		5-yr, 24-hr	0.48	0.48	0.00	
	7		10-yr, 24-hr	0.62	0.62	0.00	
	7		25-yr, 72-hr	0.91	0.91	0.00	
	7		100-yr, 72-hr	1.49	1.49	0.00	
Approximate Mean Higher-High Water	Gulf outfalls		2-yr, 24-hr	0.00	0.00	NA	
	Gulf outfalls		5-yr, 24-hr	0.00	0.00	NA	
	Gulf outfalls		10-yr, 24-hr	0.00	0.00	NA	
	Gulf outfalls		25-yr, 72-hr	0.00	0.00	NA	
	Gulf outfalls		100-yr, 72-hr	0.00	0.00	NA	

Elevations are expressed in NAVD88.
Blocked 80% Condition assumes that a pipe with an end in a mangrove area has its area blocked 80% of its diameter. Except for the salt marsh which has no mangroves around its pipe ends.
Residential areas in Golf Course are permitted to have street crown elevations above 4.5 ft NGVD (about 3.2 ft NAVD88) and first floor elevations above 9 ft NGVD (about 7.65 ft NAVD88). Street flooding in private areas not noted.

NA = not applicable

Assuming City Outfalls are Blocked 80 Percent of Depth

To evaluate how partial blockage of the City's outfalls may affect the staging of stormwater on NSI, one scenario was conducted with the City-operated pipe ends located in the mangrove wetlands blocked by 80-percent of the pipe's diameter. This is accomplished in the computer simulation by specifying the depth of blockage. So for 18-, 24-, and 36-inch diameters, the blockage was 14-, 19- and 29-inches, respectively. For some outfalls, the pipes inside College Road are located in inlet boxes, so their ends were not blocked. These are located primarily on the western side of NSI. On the eastern side, both ends of the outfalls are typically in mangroves so both ends were assumed blocked in the simulation. The exception is the 7 main culverts under College Road for the salt pond that are not currently blocked and it is assumed that they would be maintained to flow freely because of their importance and the strong flow currents through these pipes discourage mangrove growth. Also, the golf course outfalls were not blocked in the simulation although they empty into mangrove-dominated wetlands. If the fairway ponds already stage water, then blocking them more would just cause deeper standing water. Since these golf course drainage facilities are private systems, no further evaluation was conducted. Similarly, the properties around the outside of College Road have private facilities that would need to be maintained by their owners so no changes were implemented to the model for these sub-basins.

The results are presented in **Table 3** alongside the previous baseline results to compare the increase in staged water in certain sub-basins. Obviously, the sub-basins with the assumed blocked outfalls would experience the greatest affect. There was some increase in staging on several of the golf course sub-basins along the southern side of the property since they drain through the swales leading to City outfalls on the southeast side of College Road assumed partially blocked. No increase in flood elevations from the assumed blockage affected the first floor of residences in the country club.

The assumed blockages could impede flow enough from the southwestern corner of the interior of the loop to cause overtopping of College Road (near the gardens). This overflow could be problematic for the larger 100-year storm; however, eastern College Road remains un-flooded so access to the hospital and community college would be maintained through the eastern side of the loop road. The swale area in front of the hospital was estimated to have the 100-year storm staged high enough to be problematic if the outfall was blocked. Again, stormwater would likely overtop the curb and flow into the Gulf or salt marsh prior to reaching depths as high as those predicted in front of the hospital.

Climate Change Effects

Key West is potentially one of the most vulnerable cities to the effects of climate change and sea level rise. The Keys are at low elevations with much of the developed landscape on NSI at elevation 4 to 6 NAVD88. The long term estimates for sea level rise varies between 0.5 to 1.5 feet over the next fifty years[1]. As the sea level rises, drainage by gravity will be more difficult. On NSI, the golf course appears to be most vulnerable because of large areas with elevations at 3 NAVD88 or less. Even with diking and pumping stations, the porous ground

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[1] Shugar, K. and J. Obeysekera. 2010. Climate Change and Sea Level Rise Planning and Adaptation Strategies. Presentation to Governing Board Joint Workshop with the Water Resources Advisory Council. South Florida Water Management District. West Palm Beach, Florida. February 10, 2010.

will allow the ocean to keep groundwater levels high, backing stormwater into the onsite ponds. Gravity drainage wells will likely act as a conduit introducing high tides into the low areas as the sea levels rise. The residential properties at the golf course are much less vulnerable because their minimum first floor elevations are at 9 ft NGVD29 (about 7.7 NAVD88). The road crowns are at 4.5 NGVD29, or higher, but the lower shoulders are closer to 3 ft NAVD88 based on the LiDAR topography. As the sea level rises, NSI will experience increased street flooding during seasonal higher-high tides, like many other low lying places in Key West already experience.

Recommendation

From the assessment of blocked City outfalls, it is apparent that any current and future blockage needs to be removed and kept open. This is a challenge in the Keys because mangroves are prolific. Seed sprouts and root propagation makes all of the shallow waters around the island potential mangrove habitat unless they are maintained aggressively.

While the state allows for trimming of limbs for “necessary purposes,” the removal of saplings and roots is considered alteration and is not allowed without a permit. The pathway between the end of the storm pipes to open water needs to be cleared and deepened to prevent the seedlings from blocking drainage from NSI. Consequently, the City should pursue obtaining the necessary permit(s) and treat NSI as one large project area. It may be feasible to include NSI as part of other mitigation programs that the City has in place. In addition to using mechanical removal, it would help if the state would allow the headwalls to the outfalls to be replaced with concrete walls with a concrete apron. The aprons do not have to be large (4-ft by 3-ft, typical) and will reduce future mangrove and siltation immediately in front of the pipe entrances.

Some of the outfalls may be too deep to have headwalls easily constructed (like near the hospital), but several pipe ends in the swales inside the loop road may be amenable to change. There are eight outfalls that could use these headwalls, and four of these pipes would have new headwalls located at both ends. One of the greater challenges will be installing the headwalls while minimizing the impacts, especially the deeper outfalls. All work would be expected to be installed in wet conditions requiring dewatering and potential sheet piling to reduce impact area during construction. However, these impact areas would be temporary and once installed, the pipes will likely function as designed with much less future maintenance.

The wetlands may impede some of the runoff flow paths in the future even with these changes, but this would occur further from the pipe inlet/outlet and stormwater could flow through a wider perimeter of mangrove roots to reach the pipe. Having a permit in place to perform routine maintenance would be the main benefit.

The only location that may benefit from some additional drainage is in front of the Botanical Gardens. While the ponded water levels are estimated to potentially overtop the road for the design storms, the depths are not so great as to cause immediate concern. An inlet with a tie-in to a nearby existing inlet to the north would be sufficient to reduce the water levels here.

Attachment A

Topographic Map Insert

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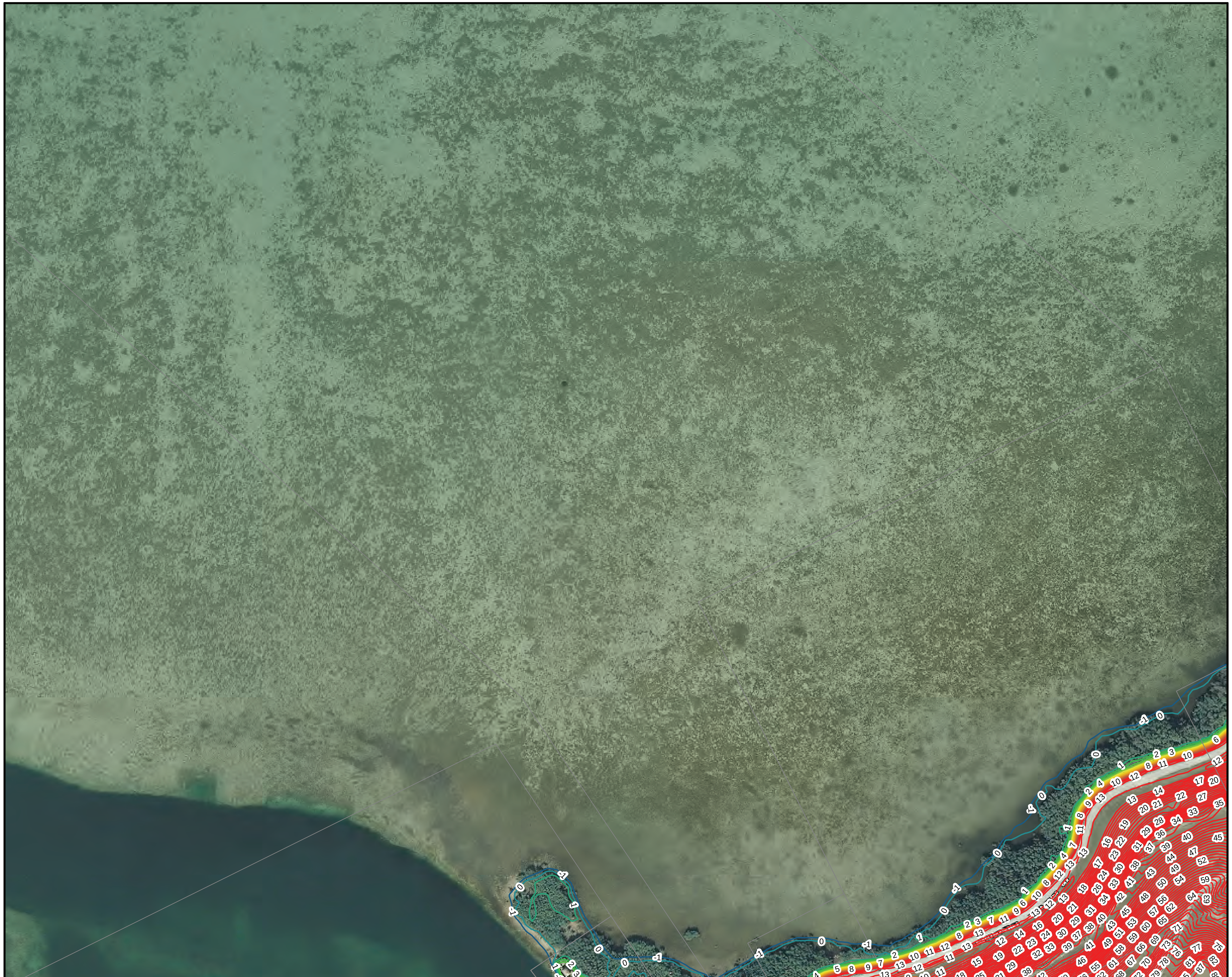

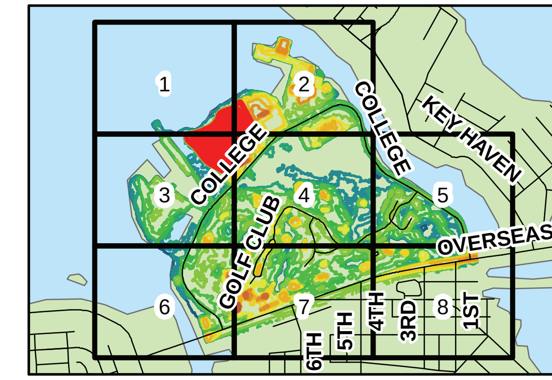

LEGEND

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*Contours meet National Map Accuracy Standards of –2-ft.

Sources
High Res. Imagery: LABINS, 2009
Parcel Boundary, Road: Monroe County GIS Database, 2009
LIDAR: CH2MHILL for Florida Division of Emergency Management, 2008

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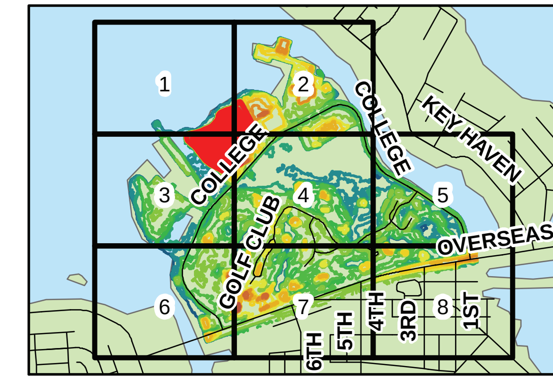
Stock Island Topographic Map

Stock Island, Florida

CH2MHILL



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Stock Island Topographic Map

Stock Island, Florida

Stock Island Topographic Map

Stock Island, Florida

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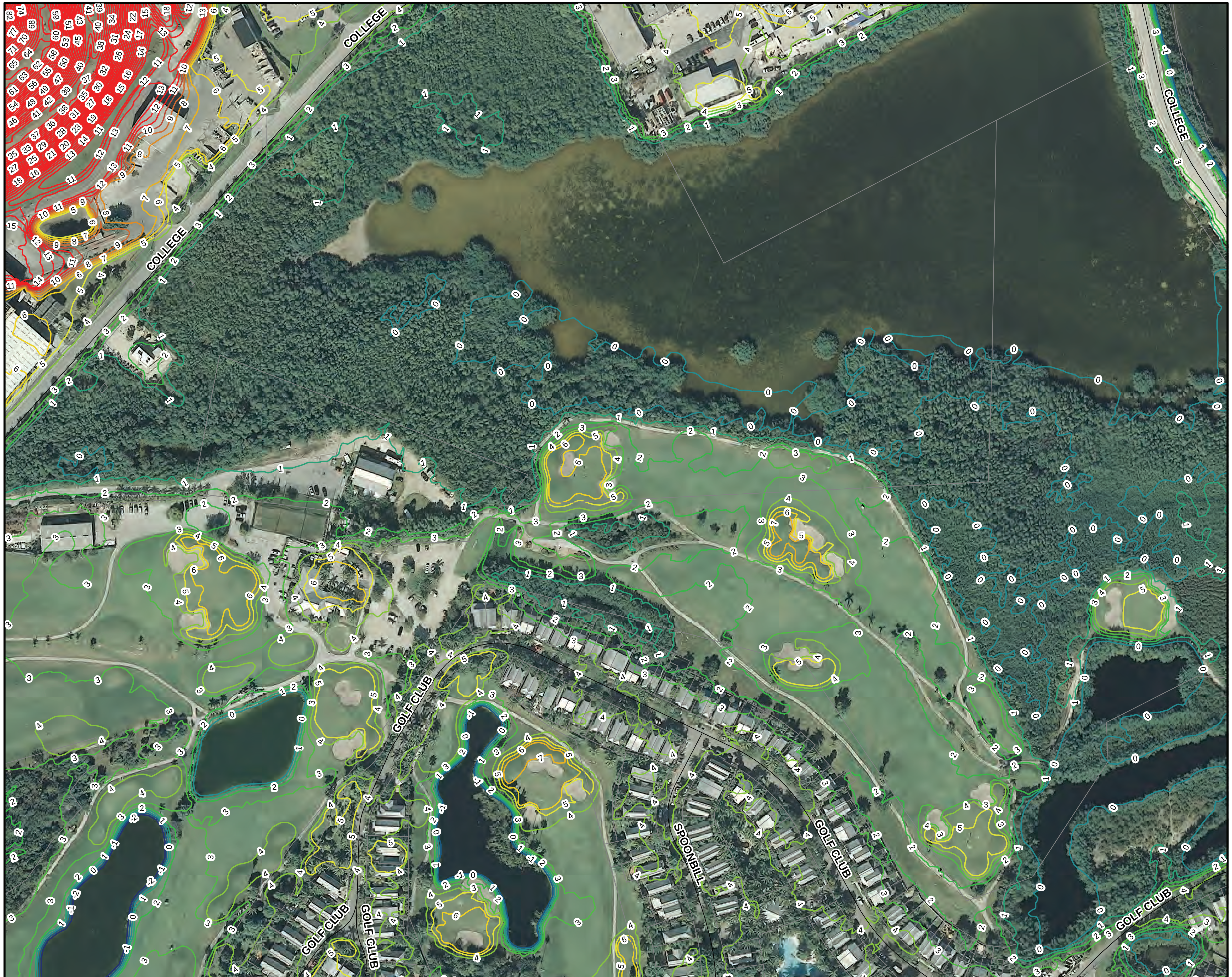

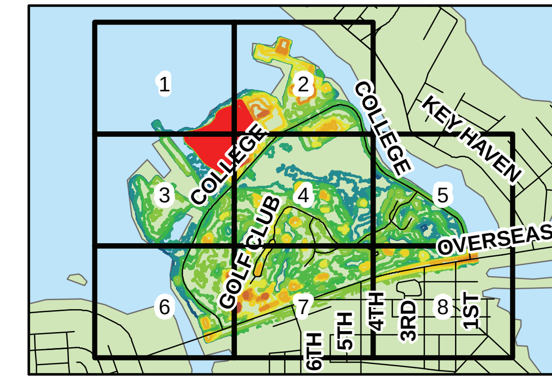

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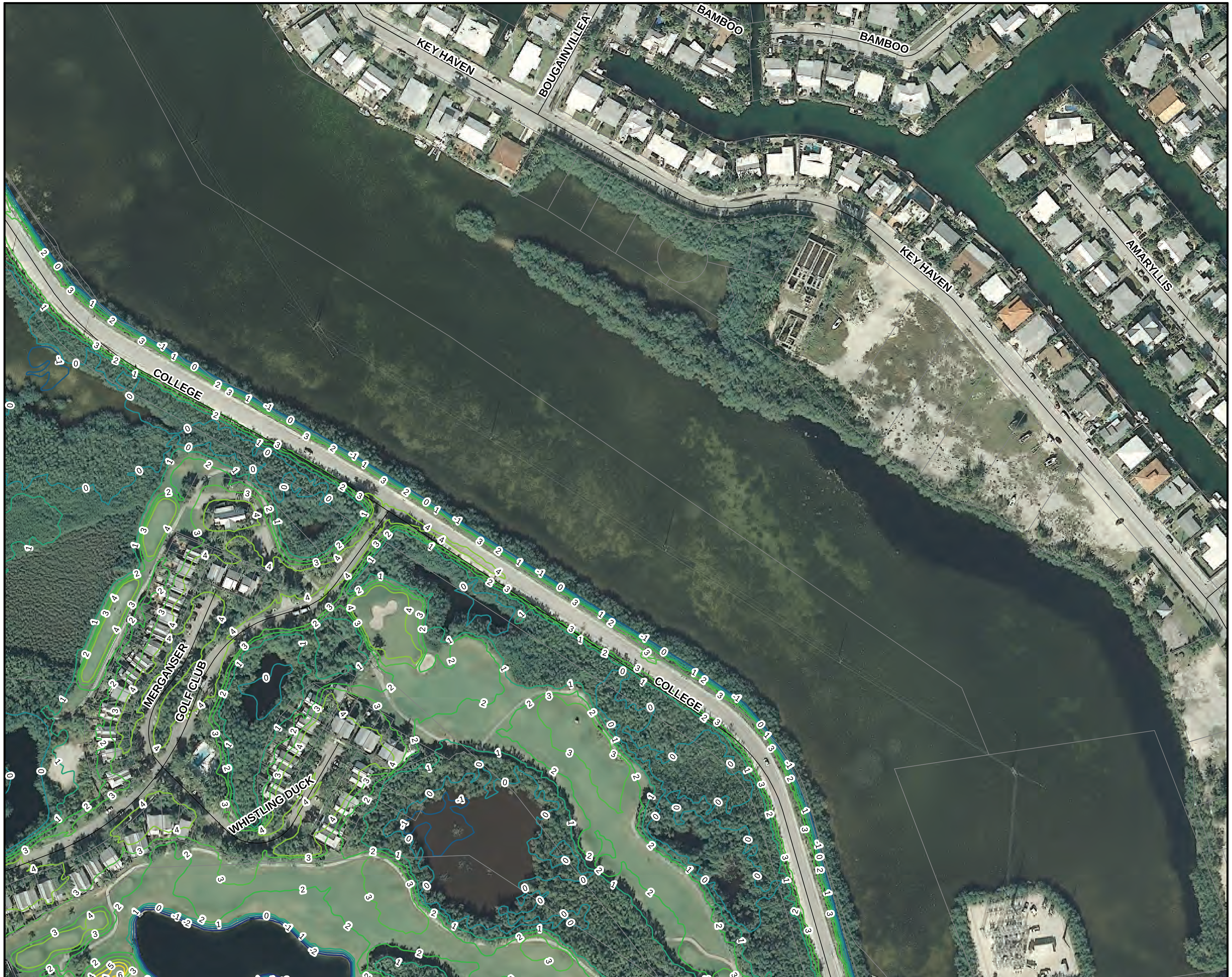
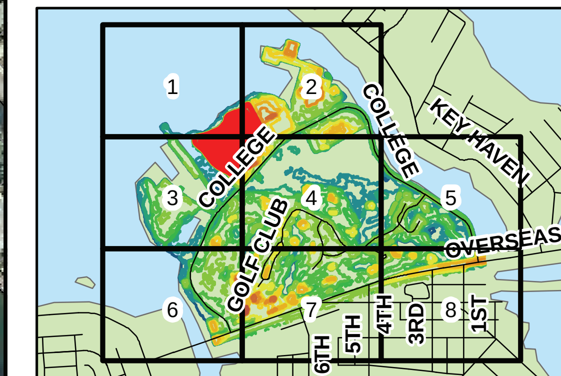
CH2MHILL





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Stock Island, Florida

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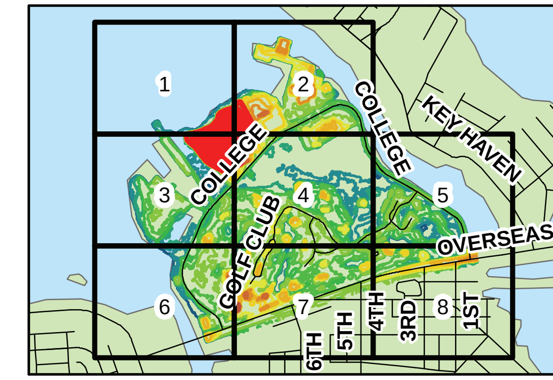

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Stock Island Topographic Map

Stock Island, Florida

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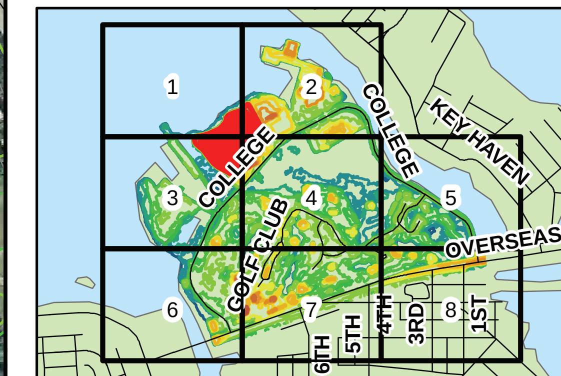

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Stock Island, Florida

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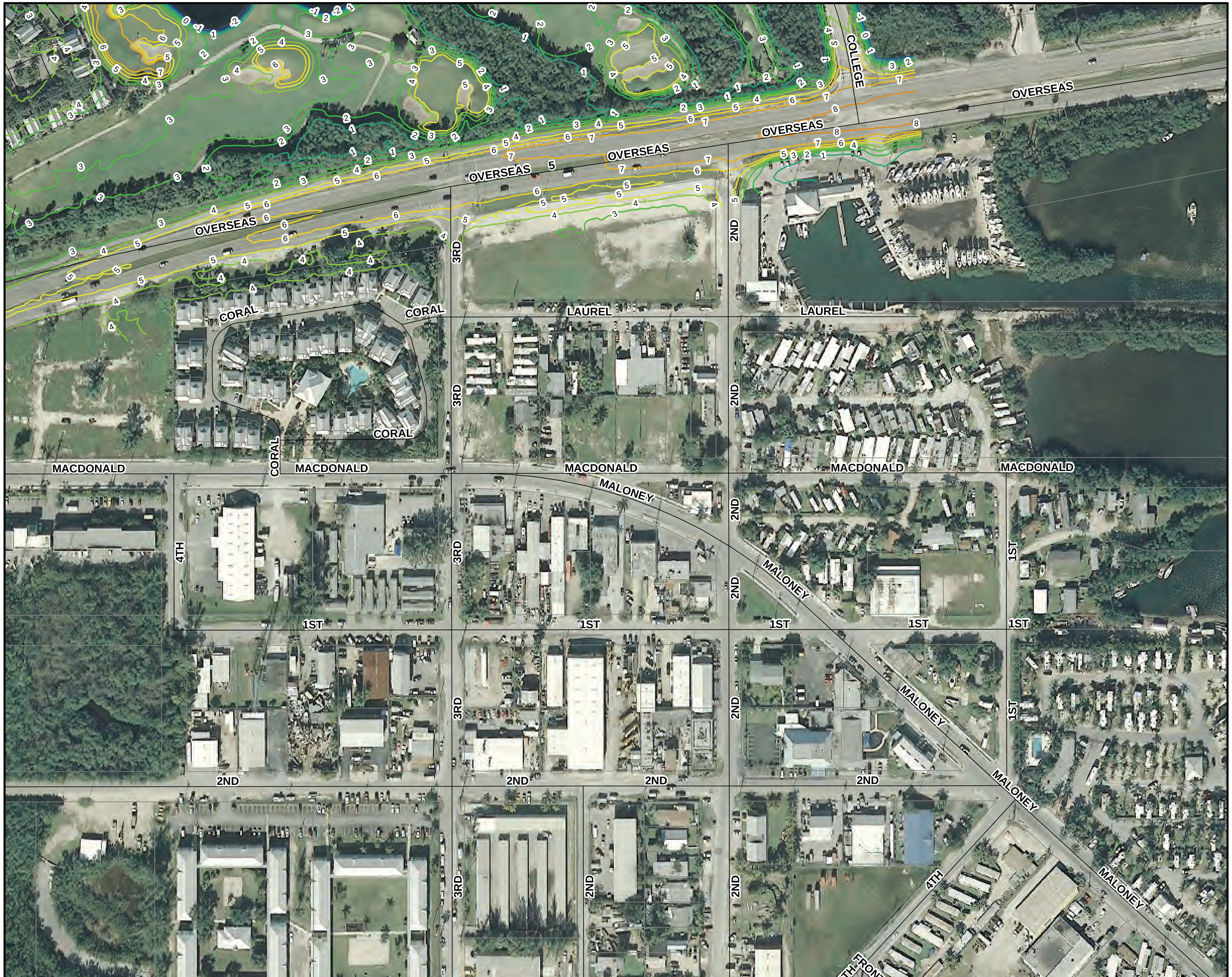

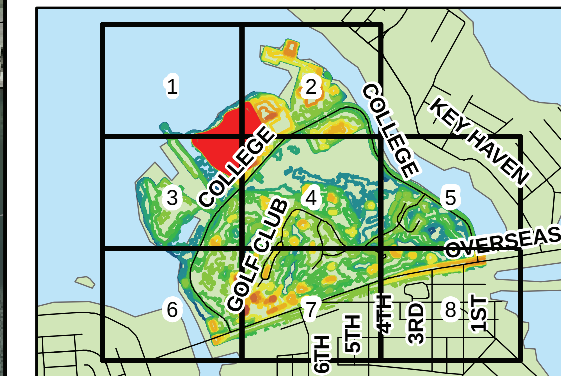

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Stock Island Topographic Map

Stock Island, Florida

CH2MHILL

Attachment B

Computer Simulation Input Data

ICPR Input and Output moved to Model Output Volume

Attachment B
Selected Stormwater BMPs Fact Sheets

ATTACHMENT B

Selected Stormwater BMPs Fact Sheet

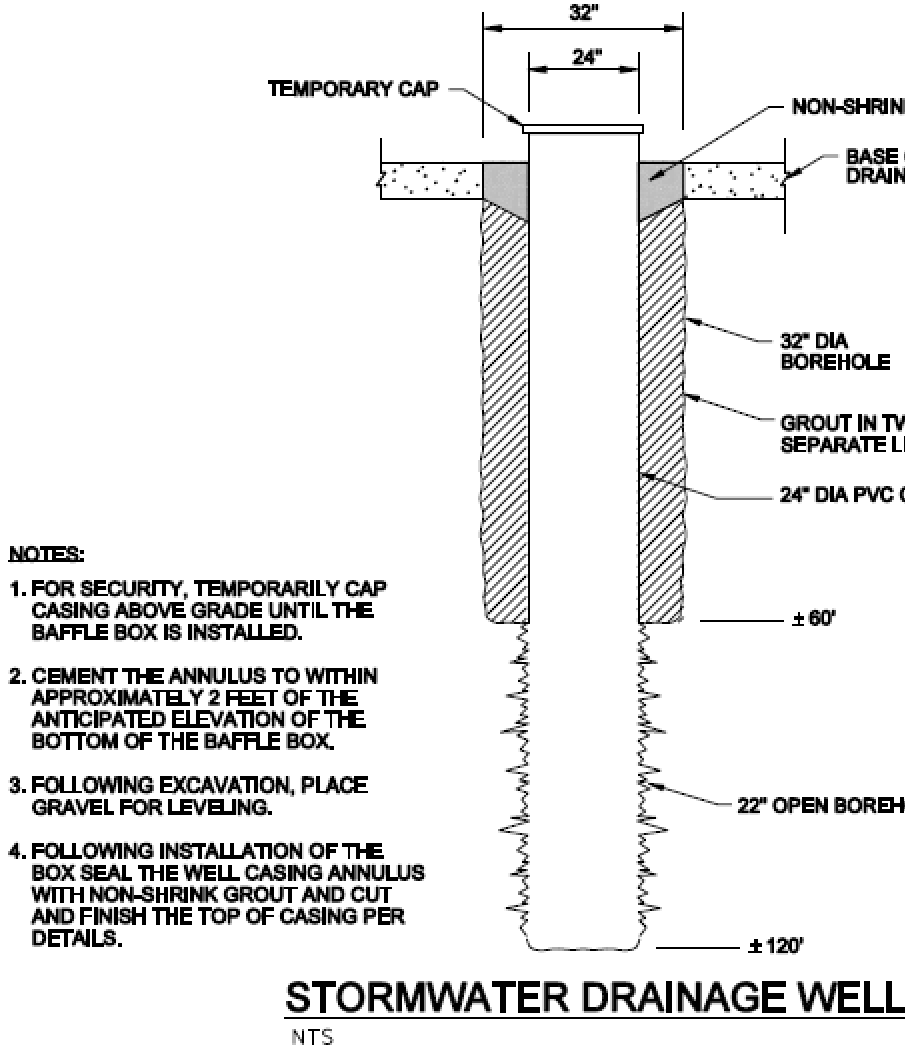
Stormwater Recharge Wells

Description:

Wells that can be used to inject, either by gravity or pressure, stormwater deeper into the ground than surface infiltration facilities will allow. The flow rates can be relatively high.

Purpose

Recharge wells' primary purpose is to remove water from the surface to lower, permeable zones underground. Because of the cost of construction, these are used normally in highly developed urban areas with limited space for other technologies. These recharge wells are also a way of reaching a highly transmissive zone of groundwater that can allow water to flow quicker than through the surficial soils.



Source: CH2M HILL Gravity Well VI Design Drawing Detail

Application:

These can only be used in certain areas with non-potable groundwater, and these wells can be relatively shallow (less than 200 feet deep). Gravity wells need to have enough elevation (about 1.4 to 1.6 ft above the water table) to overcome the weight of denser saltwater and friction before flow begins. Pressurized wells can be used to increase flow rates in low areas. Stormwater wells are generally not permissible in areas where users may utilize groundwater for water supply, so the groundwater needs to be very brackish or salty. This limits applications to coastal zones.

Advantages:

- Removes stormwater from outfalls or low areas with excessive standing water
- Gravity wells have small footprints
- Gravity wells are relatively cheap for highly urban areas
- Not very visible after construction because they are underground (only manhole shows).
- Can have relatively high recharge rates if the subsurface soil and rocks are permeable

Disadvantages:

- Requires regular cleaning to maintain the well's capacity high
- Even with cleaning, well capacity tends to reduce over time
- Pressurized wells are extremely expensive, and normally include underground construction in areas with high ground water.
- Must include pre-treatment to reduce sediment buildup in well
- Permitting can be difficult, especially with pressurized systems
- Well capacity can vary a lot over short distances and depths, and cannot be guaranteed *a priori*

Design Criteria:

A test well is often used to estimate the capacity of the well and location of permeable zones. A typical stormwater drainage well in South Florida is about 100 to 150 feet deep, cased to a depth of about 60 feet. The open hole must span one or more permeable layers.

Casing can be either steel or PVC, but must be grouted into place so the stormwater from a pressurized system would not seep up the outer sides. The grouting is required regardless of whether it is a pressure or gravity well.

Pre-treatment is a must with fine static screens and grit and coarse sand removal. The casing of the well is finished on top with a plate cover (skimmer) to prevent large objects from entering the well. In South Florida, the pre-treatment and gravity well is sometimes placed in one combined structure.

Pollutant Removal Effectiveness:

Stormwater redirected into the ground is normally considered 100 percent removed for all pollutants. However, it is likely that some dissolved pollutants could migrate to nearshore waters, but it would nearly impossible to determine this loading as the dilution would be too great to measure.

Cost:

Cost can vary with the well diameter. Typical well diameters are 24-inches for intersections. The well is about $40,000 to $60,000 for a 100 feet deep well, but there are additional costs for piping and pre-treatment. Smaller diameter wells are often used for roof or air conditioner drainage.

O&M Considerations:

Recharge wells in South Florida may have very high initial capacity that reduces over time as solids or bacteria builds up inside the open well. The capacity can be restored somewhat through flushing with an air-lift, mechanically (brush), or by chemicals (acid). Pre-treatment normally eliminates only larger particles and fines can still enter the wells. Screening is needed to keep floatables, like leaves or trash, out of the well.

Regular cleaning is recommended. For pressure wells, the need for cleaning can be monitored by well pressures during pump operation. For gravity wells, it is less apparent. Routine inspection (video) and cleaning should be schedule every one or two years. The large coastal storm surge from hurricanes has caused sand to enter the wells which may necessitate additional cleaning. Screening must be inspected and cleaned at a greater frequency, about quarterly.

Works Cited:

CH2M HILL design and operation experience in South Florida.

Infiltration Controls

Description:

Below is a list of several management control measures that can be used to reduce the adverse impacts of stormwater on watersheds:

- Exfiltration Trenches
- Permeable Paving System
- Dry Detention Pond
- Bioretention Basin

Purpose:

The purpose of the measures described here is to reduce peak flows while minimizing adverse impacts to stream hydrology and water quality. These trenches can be placed underground and concealed. Flow is captured by the available storage and then infiltrated into the ground.

Source: Pennsylvania Stormwater Best Management Practices, 2006

Application:

Exfiltration Trenches

Exfiltration trenches are excavated stone-filled trenches in which stormwater runoff is collected and percolated to the surrounding soil. Infiltration basins are impoundments where incoming stormwater runoff is stored until it gradually exfiltrates through the porous soil. In some parts of the county these are called infiltration trenches.

Permeable Paving System

Permeable paving systems are an alternative to conventional pavement whereby runoff is diverted through a porous asphalt layer or open blocks and into an underground stone layer. The stored runoff then gradually infiltrates into the subsoil. There are several types available, and are generally in a class of BMPs included with low impact development.

Porous pavement is most applicable in low volume applications, like in parking areas, and requires high maintenance to keep from clogging. Open pavers are also used to allow stormwater to percolate. Again, a combination of rock subgrade is included to provide some storage. Some communities are using extra deep beds (several feet) to provide more storage.

Dry Retention Pond

A dry retention pond is a permanent stormwater management facility that temporarily stores incoming stormwater. The pond typically is dry between storm events. These are generally not applicable in the City because of high groundwater conditions.

Bioretention Basin

Two general types of bioretention facilities exist: off-line and on-line. Off-line bioretention basins consist of sand and soil mixtures planted with native plants that receive runoff from overland flow or a traditional drainage system. On-line bioretention basins have the same composition, but are located in grass swales or other conveyance systems that enhance pollutant removal by quiescent settling and biofiltration. These are generally not applicable to the City because of the sandy natural soils and high groundwater levels. These could be used in areas of unsuitable soil conditions, although an exfiltration trench is more likely to be utilized.

Advantages:

- No chemical addition
- Sequesters runoff that would otherwise enter the sewer system

Disadvantages:

- Groundwater table encroachment may reduce peak infiltration rates.
- Prone to clogging with time
- Operation dependent on soil infiltration rates

Design Criteria:

Infiltration controls must be properly designed to intercept runoff, retain it, and allow its eventual infiltration into the subsoil.

Pollutant removal Effectiveness:

The pollutants removed are directly proportional to the volume removed. This, in turn, is determined by the size of available storage and infiltration rates.

Costs:

Varies greatly by different technology.

O&M Considerations:

Monthly and annual inspections should be performed, during which time accumulated sediment should be removed and clogged outlets cleared.

Works Cited:

Schueler. *A Current Assessment of Urban Best Management Practices*. 1992.

Schueler. *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMP's*. 1987.

EPA. *National Menu of Stormwater Best Management Practices.* *http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=min_measure&min_measure_id=5*

Grass Swale or Channel

Description:

A grass swale or channel is a shallow and wide open-channel drainage way. Grass swales or channels are often used as alternatives to, or enhancements of, conventional storm sewers.

Purpose:

Swales or channels vegetated with grass or other suitable vegetation is useful as both runoff conveyance facilities and pollutant filtering devices.

Source: http://www.lakesuperiorstreams.org/stormwater/toolkit/examples/swaleExamples.html

Application:

Grass swales or channels filter pollutants as stormwater runoff moves through the drainage system. Where possible, natural drainage ways should be maintained and used as part of the swale drainage system. The main mechanism for removing dissolved pollutants is infiltration during small events. Removal rates are reduced substantially if the swale vegetation is not maintained or if the sediment load buries the vegetation and is readily resuspended during subsequent events.

Grass swales or channels provide ancillary benefits of reducing runoff peak rates and increasing opportunities for infiltration. By reducing flow velocities and increasing the time of concentration, grass swales or channels reduce runoff peaks.

Advantages:

- Inexpensive compared to alternative BMPs

Disadvantages:

- Creation of nuisance conditions (e.g. mosquitoes)
- Traffic hazards
- Excess sediment must be removed

Design Criteria:

The effectiveness of a swale or channel in reducing runoff volume and removing pollutants is a function of the drainage area, level of perviousness, slope and cross section of the channel, soil permeability, and density and type of vegetation in the swale. Broad swales on flat slopes, with dense vegetation, are the most effective.

The design velocity for a swale or channel should be less than 1.5 feet per second to reasonably remove pollutants. However, lower velocities are required to achieve suitable sediment trap efficiencies.

Soil with a high infiltration rate is most appropriate for grass swale best management practices. Topsoil should be suitable for healthy turf growth. Where the existing soil is unsuitable for growth (such as clayey or rocky soil), applying about 12 inches of loamy or sandy soil is beneficial. Using native plant species is preferable, and using invasive plants such as common reed should be avoided. Reductions in total suspended solids (TSS), total phosphorus (TP), and total nitrogen (TN) are achieved through vegetative filtration and stabilization. Therefore, a healthy stand of vegetation is essential for water-quality functions.

Swales or channels are most suitable for large-lot residential sites (that is, ½-acre or ¼-acre lots, with the swales established in common areas) and campus-like developments. A swale or channel serving a tributary area less than 1-2 acres will enhance water quality significantly. Parking should be restricted in swales.

Pollutant Removal Effectiveness:

Grass swales remove pollutants by the filter action of grass, settling, and, in some instances infiltration into the subsoil.

The expected removal efficiency of a well designed, well maintained conventional swale or channel is projected to be 70 percent for TSS, 30 percent for TP, 25 percent for TN, and 50 to 90 percent for various trace metals. Swales appear to be more effective at removing metals than nutrients.

Cost:

Typically, grassed swales cost less to construct than curbs, gutters, and underground pipe. Costs may run from $5 to $15 per linear foot, depending on swale dimensions.

Regular maintenance costs for conventional swales are minimal. Cleanout of sediments and spot vegetation repair may be required. Grassed swales also require general lawn maintenance, such as mowing, watering, and chemical application. In residential subdivisions, adjacent homeowners will manage this responsibility.

O&M Considerations:

Maintenance of grass swales is limited to maintaining the vegetation and occasionally removing trash. If native vegetation is used instead of groomed turf, vegetation need only be mowed seasonally to retard the woody growth vegetation. The frequency of trash removal depends on the location and "attractiveness" of the swale as a disposal site.

Routine mowing is required if turf grasses are used. However, homeowners and groundkeepers can maintain the swales as part of their normal mowing. Periodic watering and fertilizing may be needed to maintain a dense growth.

Excessive sediment should not accumulate if erosion is controlled adequately upstream. However, if excessive siltation occurs, the excess sediment must be removed.

Works Cited:

Vegetative Best Management Practices. February 1997.

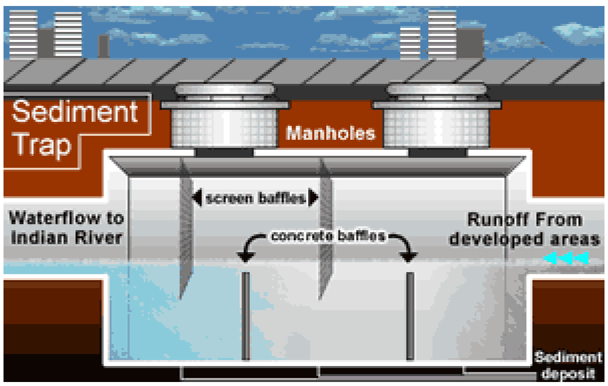
Water Quality Baffle Boxes

Description:

A baffle box is sometimes called a water quality box, is typically a pre-cast box with extra walls included to promote the settling of solids. Key West currently uses a three-stage patented system designed to remove trash with screening, heavy particulates, and absorbed hydrocarbons from stormwater runoff. Baffle boxes can be specified and constructed without using a proprietary system.

Purpose:

Baffle boxes remove heavy particulates and absorbed pollutants from stormwater runoff.



Source: Brevard County Stormwater web page: http://countygovt.brevard.fl.us/project_type_baffleboxes.cfm

Application:

Baffle boxes can be included in many suburban and urban areas, and is generally considered a conventional urban best management practices. The purpose of these boxes is to collect solids and pollutants closer to the source or to serve an area where a regional facility may not fit, so they are often used for smaller sites.

Advantages:

- Small land use requirement
- Can be specified and delivered as a cost-effective precast unit
- Passive technology, although some designs are more elaborate and are patented
- Pollutants are removed when inlet is cleaned

Disadvantages:

- Need to consider elevations of the baffles to allow hydraulic grade line to function without backing up (may be hard in low coastal applications)
- A simple box will provide limited removal, typically just larger particles and trash, because of the short retention times.

Design Criteria:

Baffle box designs must not restrict flow. Screens should be included, but need to have by-pass provisions. Need to consider ballast requirements.

Pollutant Removal Effectiveness:

Gravitational settling within the first two chambers achieves partial removal of grit and sediments. Pollutants are actually removed when trapped residuals are cleaned out of the inlet.

Cost:

Water quality inlet cost ranges from $15,000 to $35,000 per inlet, although large custom designs could be much more. Retrofitting into older neighborhoods can be costly for utility relocations.

O&M Considerations:

Boxes require at least quarterly clean out. In some areas, monthly cleanout may be required.

Works Cited:

Stormwater Technology Fact Sheet: Baffle Boxes. U.S. EPA. 2001. EPA 832-F-01-004.

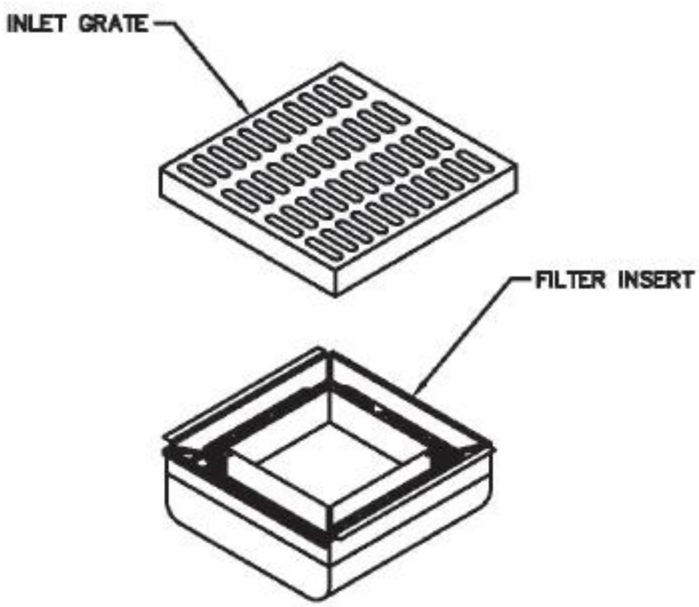
Water Quality Inlets

Description:

A water quality inlet, also known as an oil/grit separator, is typically designed to remove heavy particulates and absorbed hydrocarbons from stormwater runoff. Some swirl concentrator type of devices is available for inlets too. Most all of these devices are patented technology from commercial suppliers. Baffling over the pipes ends leaving the inlet can be included in this category.

Purpose:

Water-quality inlets remove heavy particulates and absorbed hydrocarbons from stormwater runoff.



Source: Pennsylvania Stormwater Best Management Practices Manual, 2006

Application:

Water quality inlets can be applied in most small development situations, such as parking lots, gas stations, and convenience stores, and along some roadways.

Water quality inlets are frequently applied in ultra-urban areas, where space or storage is not available for other more effective urban best management practices.

Advantages:

- Small land use requirement
- Pollutants are removed when inlet is cleaned

Disadvantages:

- Most systems are applied to contributing watershed areas of two acres or less
- Widespread application will require more maintenance at many locations
- In some regions, it may be difficult to find environmentally acceptable disposal methods

Design Criteria:

Water quality inlet design must not restrict flow. Also, swirl-type inlets require some driving energy (i.e., elevation relief) to function properly.

An inverted pipe elbow or other type of baffle (e.g., snout) can help to remove floatables (trash) and keeps the less dense oil near the surface, where it binds with sediments and ultimately settles.

Pollutant Removal Effectiveness:

Most of these inlet products include absorbents in a tray and/or screens. Gravitational settling within the inlet box may achieve partial removal of grit and sediments (see water quality baffle boxes fact sheet). Pollutants are actually removed when trapped residuals are cleaned out of the inlet.

Cost:

Water quality inlet cost ranges from $5,000 to $15,000 per inlet, and average $7,000 to $8,000. This translates to a cost of $10 to $40 per cubic foot of stormwater treated.

O&M Considerations:

Inlets require at least quarterly clean out, but may be monthly at some locations. The absorbant type of material normally must be disposed of in a landfill and replaced.

Works Cited:

A Current Assessment of Urban Best Management Practices, Schueler et al, March 1992 for MWCOG

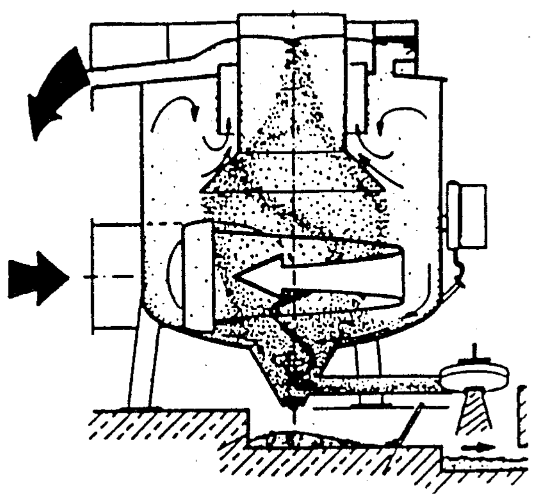
Vortex and Swirl Separators

Classification:

Treatment Systems

Description:

These devices direct water to flow in a circle, then solids collect in the relatively slower water speeds in the middle of the circle and settle. Vortex separators are similar in design and operational theory to swirl concentrators. The major differences between the vortex separator and the swirl concentrator are in the design details and the flow outlet alignment. Both of these treatment systems separate flow into a large volume of clear overflow and a low volume of concentrated waste that is intercepted for collection (settled solids).



Vortex Separator

Source: ED& P INC

Purpose:

The purpose of vortex separators/concentrators is to regulate the quantity and quality of stormwater at the point of overflow.

Application:

Vortex separators are applicable to areas requiring a treatment system within a storm sewer system. They are most applicable at sites with sufficient hydraulic head to operate the concentrator without auxiliary pumping. The City has some of these as pretreatment prior to its pressurized wells systems.

Advantages:

- High flow rate primary treatment for solids removal
- No moving parts

- Accept a wide range of flow rates
- Relatively small land requirements

Disadvantages:

- Influent pumping may be required
- Limited capacity of most commercial equipment
- Limited suppliers of equipment
- Sludge handling may be required (clean out)

Design Criteria:

Typically vortex separators are designed for peak hydraulic loading rates of 20,000 to 120,000 gallons per day per square foot (gpd/ft^2).

Pollutant Removal Effectiveness:

Pollutant removal efficiencies for vortex separators for loading rates between 20,000 and 120,000 gpd/ft^2 are listed below:

Total suspended solids:	10-70 percent
BOD:	5-35 percent
Total phosphorus:	2-10 percent
Total nitrogen:	3-20 percent
Lead:	10-70 percent

Pollutant removal efficiencies have been found to be higher, given equivalent hydraulic loading rates for vortex separators compared with swirl concentrators.

Cost:

The construction cost of vortex separators ranges from $5,000 to $8,000 per million gallons per day of treated flow.

O&M Considerations:

Periodic inspections are required. In some situations, washdown of the facility after each wet-weather event may also be required.

Works Cited:

http://www.enviro.nfes.navy.mil. October 1999

Columbus Water Works. *Advance Demonstration Facility for Wet Weather Treatment Technologies*. 1999.

Catchbasin Cleaning

Classification:

Source Controls

Description:

Catchbasins with sumps are installed in storm sewer systems to trap solids before they enter the sewer system. Catchbasin cleaning involves the removal of accumulated deposits which may be removed manually, or by eductor, bucket, or vacuum.

Purpose:

The purpose of catchbasin cleaning is to reduce the heavy "first flush" effect of deposited solids from stormwater flows and to help reduce sediment buildup in sewers. Catchbasin cleaning maintains system efficiency and reduces the accumulation of sediment and associated pollutants by small runoff events.

Catchbasin before installation.

Source: Concast Pipe

Application:

Catchbasin cleaning is applicable to all catchbasins and inlets. Baffling is sometimes included over the pipe inlets to improve performance (snouts, see http://bmpinc.com/products/sort/snout for a commercial product or one could be made out of aluminum to specifications, also see water quality inlet fact sheet).

Advantages:

- Maintains system efficiency
- Reduces sediment accumulation in the sewers generated by small runoff events

Disadvantages:

- Vacuum and eductors are noisy
- Cleaning schedules must work around traffic loads and seasonal disruptions
- Overall pollutant removals are low
- Must be placed at numerous locations
- Will only reduce "first flush" effects and larger particles, some trash
- Required cleaning frequency is difficult to predict without conducting long term, site specific, catchbasin debris accumulation studies

Design Criteria:

Not applicable.

Pollutant Removal Effectiveness:

The maximum pollutant removal efficiencies for catchbasin cleaning are listed below.

Total suspended solids:	<50 percent
BOD:	<25 percent
Fecal Coliform:	<10 percent
Total phosphorus:	<25 percent
Total nitrogen:	<35 percent
Lead:	<50 percent

These removal rates apply to the portion of the total pollutant load available to catchbasins and can be achieved only if the catchbasin is cleaned often enough to maintain sediment trap efficiency. If the catchbasin fills and is not cleaned, the pollutant removal efficiency approaches zero.

Cost:

Total unit cost of catchbasin cleaning ranges from $10 to $19 per ton of sediment removed.

O&M Considerations:

Optimum cleaning frequency can be predicted with long-term, site-specific, catchbasin debris accumulation studies.

Works Cited:

EPA 403/9--75-021, *Handbook for Sewer System Evaluation and Rehabilitation*. EPA. December 1975.

Pavement Sweeping

Classification:

Source Controls

Description:

Pavement sweeping is the periodic removal of surface accumulation of litter, debris, dust, and dirt from pavement. Methods of pavement sweeping include manual sweeping, mechanical broom sweepers, and vacuum sweepers.

Source: Elgin Sweeper Company

Purpose:

Although the major objective of pavement sweeping is to enhance appearance, it also reduces transport of pollutants into the storm sewer system during rain events.

Application:

For an effective program, public notification of the days and times of sweeping is essential to clean parking areas.

Advantages:

- Improvement of air quality, aesthetic conditions, and public health
- Florida plans to give pollution credit to sweeping and catch basin cleaning (TMDLs)
- No new construction required

Disadvantages:

- Streets must have curbs for reasonable effectiveness
- Pavement type and quality influences effectiveness
- Overall pollutant reduction drops off substantially with lower frequency
- Areawide pollutant removal is low because it is limited to streets and parking lots

Design Criteria:

Pavement sweeping equipment should be selected based on the type of pavements that will be swept, the type of debris to be collected, and the desired efficiency.

Pollutant Removal Effectiveness:

Pollutant removal efficiencies for pavement sweeping are estimated as follows:

Total suspended solid:	<30 percent
BOD:	<15 percent
Fecal Coliform:	<5 percent
Total phosphorus:	<15 percent
Total nitrogen:	<20 percent
Lead:	<30 percent

These efficiencies apply to the fraction of the total pollutant load available to the street sweeper.

Cost:

Pavement sweeping costs range from $94 to $270 per curb mile.

O&M Considerations:

Regular maintenance of the street sweeping equipment should be performed.

Works Cited:

Moffa, P. Control and Treatment of Combined Sewer Overflows. 1990.

Rooftop Runoff Management

Description:

Modifications to conventional building design that retard runoff originating from roofs. The modifications include vegetated roof covers, roof gardens, vegetated building facades, and roof ponding areas. Rain barrels could be included in this category too. These types of BMPs are also included in a class called low impact development.

Purpose:

Roofs are an important source of concentrated runoff from developed sites. If runoff is retarded at the source, the size of other BMPs throughout the site can be significantly reduced in size. Rooftop runoff management effectively slows down the runoff rate of runoff derived from roofs, and by delaying runoff peaks it lowers runoff discharge rates. In highly urbanized areas, rooftop measures may be the only practical alternative for relieving pressure on overtaxed storm sewer systems.

Vegetated roof cover for a conventional flat roofed commercial building
(Courtesy of OPTIMA; Wilhelm Harzmann Modern Bausysteme)

Application:

Managing rooftop runoff is of the greatest benefit in highly urbanized settings where space for other BMPs is limited. In addition to achieving specific stormwater runoff management objectives, rooftop runoff management is also aesthetically and socially beneficial. Rooftop runoff management measures are suitable for flat or gently sloping roofs. Furthermore, rooftop runoff management techniques can be retrofitted to conventionally constructed buildings.

Advantages:

- Reduces energy consumption for heating and cooling
- Reduces radiated heat from roofs and walls, helping moderate urban microclimates
- Aesthetically pleasing

Disadvantages:

- Additional building maintenance
- Less effective in storms greater in magnitude than a 2-year return frequency storm

Design Criteria:

Rooftop measures are primarily runoff peak attenuation measures. The methods for evaluating the peak attenuation properties of these measures are based on approaches used for other runoff peak attenuation BMPs . Downspout disconnection further reduces the pollutant load to the sewer.

Pollutant Removal Effectiveness:

Rooftop runoff management is primarily intended to increase the time of concentration of runoff derived from roofs; however, this measure will trap some airborne particles.

Cost:

The savings in energy costs and the extended life of the roof will frequently offset the additional capital costs of vegetative roof cover.

O & M Considerations:

All rooftop runoff management measures must be inspected and maintained periodically. Furthermore, the vegetative measures require the same normal care and maintenance that a planted area does. The maintenance includes attending to plant nutritional needs, irrigating as required during dry periods, and occasionally weeding. The cost of maintenance can be significantly reduced by judiciously selecting hardy plants that will outcompete weeds. In general, fertilizers must be applied periodically. Fertilizing usually is not a problem on flat or gently sloping roofs where access is unimpeded and fertilizers can be uniformly broadcast. Properly designed vegetated roof covers should not be damaged by treading on the cover system. Maintenance contracts for the routine care of the vegetative cover frequently can be negotiated with the installer.

- When retrofitting existing roofs, preserve easy access to gutters, drains, spouts, and other components of the roof drainage system. It is good practice to thoroughly inspect the roof drainage system quarterly. Foreign matter, including leaves and litter, should be removed.

Works Cited:

Aron, G., et al. *Field Manual of the Pennsylvania Department of Transportation, Storm Intensity-Duration-Frequency Charts*. Pennsylvania State University. 1986.

Lieseche, H., *et al*. *Fundamentals of Roof-Greening* (*Grundlagen der Dachbegrunung*). Platzer Verlag, Berlin, Germany. 1989 (Available in German language only).

Tourbier, J. T. and R. Westmacott. *Water Resources Protection Technology – A Handbook to Protect Water Resources in Urban Development*. Washington, D.C. The Urban Land Institute. 1981.

Tourbier, J. T. and R. Westmacott. *Water Resources Protection Measures in Land Development*. Final Report prepared for the U.S. Department of the Interior, Water Resources Center, University of Delaware. 1974.

U.S. Department of Agriculture. Urban Hydrology for Small Watersheds. Technical Release Number 55 (TR-55). National Technical Information Service. 1986.

Zoning and Development Controls

Description:

Development of green spaces without consideration for stormwater management can adversely impact the hydrology and water quality of the streams in the watershed. Below is a list of several zoning and development control measures that can be used to reduce adverse impacts:

- Cluster Zoning
- Development Density Restrictions
- Lot Size Restrictions
- Impervious Surface Limits
- Property Tax Incentives
- Zoning Incentives
- Tree Cover Ordinance
- Lot Disturbance Limits
- Open Space Conservation
- Mandated Best Management Practices (BMPs)
- Agricultural Preservation Zoning

Purpose:

The purpose of the measures described herein is to reduce the adverse impacts to stream hydrology and water quality as a result of development.

Application:

Each of these measures is aimed at reducing the amount of impervious surface area. Impervious area increases stormwater runoff compared to undeveloped green spaces.

Cluster Zoning

Cluster zoning locates developments in groups or clusters to reduce the impacts of sprawling developments.

Development Density Restrictions and Lot Size Restrictions

The goal of development density restrictions and lot size restrictions is to increase the size of lots and thus reduce the number of developments per acre.

Impervious Surface Limits

Impervious surface limits are used to increase the amount of green space or other pervious ground coverings. Pervious ground coverings encourage infiltration of rainfall and reduce the amount of runoff entering storm sewers or water bodies.

Property Tax and Zoning Incentives

Property tax and zoning incentives can be used to reduce the amount of impervious land surface by encouraging larger lots, green spaces, cluster zoning, or density restrictions.

Tree Cover Ordinance

Tree cover ordinances encourage the planting and maintaining of trees within the watershed.

Lot Disturbance Limits

The goal of lot disturbance limits is to reduce erosion caused by the removal of trees and grass.

Open Space Conservation

Open space conservation aims to maintain green space and discourage conversion to impervious surfaces.

Mandated Best Management Practices (BMPs)

Mandated BMPs require developers, governments, and other entities to incorporate measures to manage stormwater. BMPs include such items as detention ponds, silt fences, and other measures to control or treat stormwater pollution.

Agricultural Preservation Zoning

Agricultural preservation zoning discourages the development of agricultural lands. Development of these lands reduces the amount of pervious surface and increases runoff.

Advantages:

- Reduces the volume of runoff entering the sewer systems
- Reduces nonpoint pollution

Disadvantages:

- Limited effects in established areas

Design Criteria:

See related BMP fact sheets.

Pollutant Removal Effectiveness:

Dependent on ability to retrofit established areas, which is typically low. Zoning and development controls would be more effective in newly developed areas.

Costs:

Developers would incur any costs associated with implementation of zoning and development requirements.

O&M Considerations:

See related BMP fact sheets.

Works Cited:

Task force on CSO Pollutant Abatement. *Combined Sewer Overflow Pollution Abatement*. 1989.

Litter and Household Hazardous Waste Controls

Description:

Litter and household hazardous waste controls include those actions that reduce or eliminate improper disposal of litter and household hazardous wastes (such as paints, oils, and solvents). Below is a list of several litter and household hazardous waste control measures:

- Anti-litter bylaws
- Adopt-a-street programs
- Pet waste clean-up bylaws
- Recycling programs
- Household hazardous waste disposal sites
- Storm drain stenciling

Purpose:

Litter and household hazardous wastes, when improperly disposed of, can get into storm sewers and then to local streams. Litter in streams ruins the aesthetic nature of the streams and may be hazardous (as is the case of broken glass or old razors). Household hazardous wastes (such as oil slicks) entering streams also reduce aesthetics and may be toxic to aquatic organisms. The purpose of these measures is to encourage proper disposal of litter and household hazardous wastes.

Application:

Anti-Litter and Pet Waste Cleanup Bylaws

Anti-litter and pet waste cleanup bylaws are generally local ordinances that make it illegal to litter or leave pet wastes (such as feces) on public or private property. Litter and pet wastes that are not picked up are generally washed into streams during storms. Under these bylaws, someone caught littering or not cleaning up after their pets is assessed a fine.

Adopt-a-Street Program

The adopt-a-street program encourages individuals or groups to take over the cleanup of local streets. Similar to the adopt-a-stream program, this program is one in which the adopting group cleans up their street several times per year. Local trash collection is usually pre-arranged. This type of program removes trash from streets before it is washed into streams.

Recycling Programs

Many communities already have mandatory recycling ordinances. Recycling reduces litter by encouraging people to properly dispose of their trash. Recycling programs can provide curb-side pickup or drop-off centers.

Household Hazardous Waste Disposal Sites

Similar to recycling programs, household hazardous waste disposal sites can be provided to encourage proper disposal of these wastes. The types of household wastes that require special disposal methods include used motor oil, paints, paint thinners, and cleaning solutions.

Storm Drain Stenciling

Storm drain stenciling is a program in which storm drains are labeled with warnings that anything entering the storm drain will end up in a local river or stream. Stenciling has been successfully used in conjunction with household hazardous waste disposal sites to reduce the amount of household hazardous wastes that are dumped down storm drains.

Advantages:

- Acts as pre-treatment (trash removal)

Disadvantages:

- Inconsistent trash removal

Design Criteria:

Not applicable.

Pollutant Removal Effectiveness:

There is no way to quantify the volume of trash collected.

Cost:

Not applicable.

O&M Considerations:

Litter-reduction programs are most successful when supplemented by public education programs

Works Cited:

http://www.saveourstreams.org

http://doh.dot.state.nc.us

URL: recycle.uteledo.edu

Removal of Illicit Connections

Description:

Removal of illicit connections involves the location and removal of illicit connections from the stormwater conveyance system.

Purpose:

Illicit connections to the stormwater conveyance system often contain pollutants that are carried to receiving waters. Locating and removing illicit connections will reduce the amount of contaminants entering receiving waters.

Application:

Through water quality analysis, field investigations, and evaluations, stormwater managers are continuously searching for and removing illicit connections to the stormwater conveyance system.

Advantages:

- Total removal of pollutants
- Public participation in identification of illicit sources

Disadvantages:

- The task of locating and removing illicit connections can be very expensive and time-consuming

Design Criteria:

Not applicable.

Pollutant Removal Effectiveness:

A well planned and implemented illicit connection removal program is very effective in reducing the amount of unanticipated and unallowed pollutants entering receiving waters.

Cost:

The cost of a successful illicit connection program depends upon the size of the stormwater conveyance system to be monitored and the urban density of the watershed.

O&M Considerations:

To be successful, an illicit connection removal program must be adequately funded each budget year.

Works Cited:

Moffa, P. *Control and Treatment of combined Sewer Overflows*. 1990.

Attachment C
Cost Estimates

PROPOSED PROJECTS COST ESTIMATES

Alternative 1

Gravity Well Project (1 well, 1 intersection)		Low	High
Gravity Well Project		$160,393	$233,196
GC/Tax/OH/Profit/Mob/Demob/Bond	15%	$24,059	$34,979
Contingency	10%	$16,039	$23,320
Key West Factor	20%	$32,079	$46,639
Design & Services During Construction	20%	$32,079	$46,639
Total Project Cost		$264,649	$384,773

Gravity Well Project (2 wells, 1 intersection)		Low	High
Gravity Well Project		$160,393	$233,196
Additional Injection Well		$55,300	$79,000
GC/Tax/OH/Profit/Mob/Demob/Bond	15%	$32,354	$46,829
Contingency	10%	$21,569	$31,220
Key West Factor	20%	$43,139	$62,439
Design & Services During Construction	20%	$43,139	$62,439
Total Project Cost		$355,894	$515,123

Gravity Well Project (3 wells, 1 intersection)		Low	High
Gravity Well Project		$160,393	$233,196
Additional Injection Wells - 2		$110,600	$158,000
GC/Tax/OH/Profit/Mob/Demob/Bond	15%	$40,649	$58,679
Contingency	10%	$27,099	$39,120
Key West Factor	20%	$54,199	$78,239
Design & Services During Construction	20%	$54,199	$78,239
Total Project Cost		$447,139	$645,473

Gravity Well Project (2 wells, 2 intersections)		Low	High
Gravity Well Projects - 2		$320,787	$466,391
GC/Tax/OH/Profit/Mob/Demob/Bond	15%	$48,118	$69,959
Contingency	10%	$32,079	$46,639
Key West Factor	20%	$64,157	$93,278
Design & Services During Construction	20%	$64,157	$93,278
Total Project Cost		$529,298	$769,546

Harris and 10th Avenue		Low	High
Gravity Well Project		$0	$0
18-inch HDPE Storm Pipe - 120 LF		$20,400	$43,200
Intersections 2, assume pavement within ranges		$62,975	$79,774
Inlets - 8		$23,200	$80,000
Control Box (Weir) - 48" x 48"		$107,375	$128,850
GC/Tax/OH/Profit/Mob/Demob/Bond	15%	$32,092	$49,774
Contingency	10%	$21,395	$33,182
Key West Factor	20%	$42,790	$66,365
Design & Services During Construction	20%	$42,790	$66,365
Total Project Cost		$353,017	$547,509

Harris and 10th Avenue Neighborhood		Low	High
Above Harris Construction Costs + 8 intersections		$0	$0
Intersections 12, assume pavement within ranges		$377,848	$478,643
18-inch HDPE Storm Pipe - 4,500 LF		$765,000	$1,620,000
Inlets - in intersections		$0	$0
Control Box (Weir) - 48" x 48" -- Assume 4		$429,500	$515,400
GC/Tax/OH/Profit/Mob/Demob/Bond	15%	$235,852	$392,106
Contingency	10%	$157,235	$261,404
Key West Factor	20%	$314,470	$522,809
Design & Services During Construction	20%	$314,470	$522,809
Total Project Cost		$2,594,374	$4,313,171

Catherine and Ashby St. Pump Station		Low	High
Catherine and Ashby St. Pump Station		$2,819,194	$3,383,033
GC/Tax/OH/Profit/Mob/Demob/Bond	15%	$422,879	$507,455
Contingency	10%	$281,919	$338,303
Key West Factor	20%	$563,839	$676,607
Design & Services During Construction	20%	$563,839	$676,607
Total Project Cost		$4,651,670	$5,582,004

Patricia and Ashby Neighborhood Piping		Low	High
18-inch HDPE Storm Pipe - 650 LF		$255,000	$540,000
Inlets - 16		$46,400	$160,000
Exfiltration trench - 800LF		$174,504	$195,960
GC/Tax/OH/Profit/Mob/Demob/Bond	15%	$71,386	$134,394
Contingency	10%	$47,590	$89,596
Key West Factor	20%	$95,181	$179,192
Design & Services During Construction	20%	$95,181	$179,192
Total Project Cost		$785,242	$1,478,334

Alternative 2

Eagle and 20th Outall		Low	High
Pipeline (42") between 500 LF to 1,300 LF depending on route			
Assume 1,000 LF and ROW costs included		$288,750	$600,000
Intersections - 2		$62,975	$79,774
State HWY Coordination Allowance, opinion		$200,000	$300,000
Sea Wall Reconstruction		$12,000	$24,000
GC/Tax/OH/Profit/Mob/Demob/Bond	15%	$84,559	$150,566
Contingency	10%	$56,372	$100,377
Key West Factor	20%	$112,745	$200,755
Design & Services During Construction	20%	$112,745	$200,755
Total Project Cost		$930,146	$1,656,227

Cindy and 19th Outall		Low	High
Pipeline (36") between 2,000 LF to 2,300 LF depending on route			
Assume 2,300 LF and ROW costs included		$592,250	$1,219,000
Intersections - 3		$94,462	$119,661
State HWY Coordination Allowance, opinion		$200,000	$300,000
Sea Wall Reconstruction		$12,000	$24,000
GC/Tax/OH/Profit/Mob/Demob/Bond	15%	$134,807	$249,399
Contingency	10%	$89,871	$166,266
Key West Factor	20%	$179,742	$332,532
Design & Services During Construction	20%	$179,742	$332,532
Total Project Cost		$1,482,875	$2,743,390

Fogarty and 3rd St.		Low	High
Pump Station (pumps, vortex, appurtenances)		$1,575,000	$1,798,011
Injection Wells - 2		$110,600	$158,000
18-inch HDPE Storm Pipe - 1,235 LF		$209,950	$444,600
GC/Tax/OH/Profit/Mob/Demob/Bond	15%	$284,333	$360,092
Contingency	10%	$189,555	$240,061
Key West Factor	20%	$379,110	$480,122
Design & Services During Construction	20%	$379,110	$480,122
Total Project Cost		$3,127,658	$3,961,008

Patricia and Ashby Pressure Well Addition		Low	High
Injection Well		$55,300	$79,000
GC/Tax/OH/Profit/Mob/Demob/Bond	15%	$8,295	$11,850
Contingency	10%	$5,530	$7,900
Key West Factor	20%	$11,060	$15,800
Design & Services During Construction	20%	$11,060	$15,800
Total Project Cost		$91,245	$130,350

James St and Grinnell Outall		Low	High
Pipeline (24") between 650 LF to 700 LF depending on route			
Assume 700 LF and ROW costs included		$136,500	$273,000
Intersections - 3		$94,462	$119,661
State HWY Coordination Allowance, opinion		$0	$0
Sea Wall Reconstruction		$12,000	$24,000
GC/Tax/OH/Profit/Mob/Demob/Bond	15%	$36,444	$62,499
Contingency	10%	$24,296	$41,666
Key West Factor	20%	$48,592	$83,332
Design & Services During Construction	20%	$48,592	$83,332
Total Project Cost		$400,887	$687,490

Eisenhower Dr Outfalls		Low	High
Pipeline (24") between 200 LF to 250 LF depending on route			
Assume 500 LF (2 pipes) and ROW costs included		$97,500	$195,000
Intersections - 2		$62,975	$79,774
State HWY Coordination Allowance, opinion		$0	$0
Sea Wall Reconstruction - 2		$24,000	$48,000
GC/Tax/OH/Profit/Mob/Demob/Bond	15%	$27,671	$48,416
Contingency	10%	$18,447	$32,277
Key West Factor	20%	$36,895	$64,555
Design & Services During Construction	20%	$36,895	$64,555
Total Project Cost		$304,383	$532,577

Exfiltration Projects (250 LF, 4 inlets)		Low	High
Exfiltration (250 LF)		$54,533	$61,238
Inlets - 4		$11,600	$40,000
GC/Tax/OH/Profit/Mob/Demob/Bond	15%	$9,920	$15,186
Contingency	10%	$6,613	$10,124
Key West Factor	20%	$13,227	$20,248
Design & Services During Construction	20%	$13,227	$20,248
Total Project Cost		$109,119	$167,042

Exfiltration Projects (650 LF, 8 inlets)		Low	High
Exfiltration (650 LF)		$141,785	$159,218
Inlets - 8		$23,200	$80,000
GC/Tax/OH/Profit/Mob/Demob/Bond	15%	$24,748	$35,883
Contingency	10%	$16,498	$23,922
Key West Factor	20%	$32,997	$47,844
Design & Services During Construction	20%	$32,997	$47,844
Total Project Cost		$272,224	$394,709

Exfiltration Projects (550 LF, 8 inlets)		Low	High
Exfiltration (550 LF)		$119,972	$134,723
Inlets - 8		$23,200	$80,000
GC/Tax/OH/Profit/Mob/Demob/Bond	15%	$21,476	$32,208
Contingency	10%	$14,317	$21,472
Key West Factor	20%	$28,634	$42,945
Design & Services During Construction	20%	$28,634	$42,945
Total Project Cost		$236,233	$354,292

Exfiltration Projects (450 LF, 8 inlets)		Low	High
Exfiltration (450 LF)		$98,159	$110,228
Inlets - 8		$23,200	$80,000
GC/Tax/OH/Profit/Mob/Demob/Bond	15%	$18,204	$28,534
Contingency	10%	$12,136	$19,023
Key West Factor	20%	$24,272	$38,046
Design & Services During Construction	20%	$24,272	$38,046
Total Project Cost		$200,242	$313,875

PROJECT COMPONENT GROUPINGS

	Unit	Low	High
Gravity Well Project	intersection	$160,393	$233,196
Trench Excavation, Backfill, and Pipe			
Storm Pipe	intersection	$39,234	$45,339
Storm Pipe - 18"	LF	$170	$360
Storm Pipe - 24"	LF	$195	$390
Storm Pipe - 36"***	LF	$258	$530
Storm Pipe - 42"***	LF	$289	$600
Force Main	LF	$105	$213
Catch Basins, Inlets, and Manholes	intersection	$19,372	$33,970
Inlet	ea	$2,900	$10,000
Triple Chamber Baffle Box with Injection Well	ea	$70,300	$114,000
Triple Chamber Baffle Box	ea	$15,000	$35,000
Injection Well	ea	$55,300	$79,000
Well Abandonment	ea	$10,000	$20,000
Control Box (Weir)	ea	$107,375	$128,850
Pavement/Curb			
Includes ADA improvements	intersection	$31,487	$39,887
Does not include ADA improvements	LF	$32	$108
Outfall/Seawall Reconstruction	ea	$12,000	$24,000
Outfall Check Valve**	ea	$10,700	$13,200
Pump Station (pumps, vortex, appurtenances)		$1,575,000	$1,798,011
Generator and Platform	ea	$266,300	$295,000
Exfiltration Trench*	LF	$218	$245

GC/Tax/OH/Profit/Mob/Demob/Bond	15%
Contingency	10%
Key West Factor	20%
Design & Services During Construction	20%

* GW5 Schedule of Values
**Vendor quote for 24-inch check valve ($5,700), plus excavation, dewatering, and restoration costs ($5,000-$7,500 assumed)
***Costs adjusted from vendor quote, no extras for crossing state highways included here.

Attachment D
Selected Exhibits, Large-Scale Maps

LEGEND

- Nodes
- Sub-Basin
- Streets
- Shoreline
- Flooding at the 5yr, 24 hr Storm Stage
- Flooding at the 10yr, 24 hr Storm Stage
- Flooding at the 25yr, 100 hr Storm Stage
- Flooding at the 100yr, 72 hr Storm Stage

Only City sub-basins contributing runoff to City-maintained outfalls are shown. City areas draining directly to Gulf, Ocean, or canals are not modeled, but are still managed for potential water quality effects.

N

0 0.125 0.25

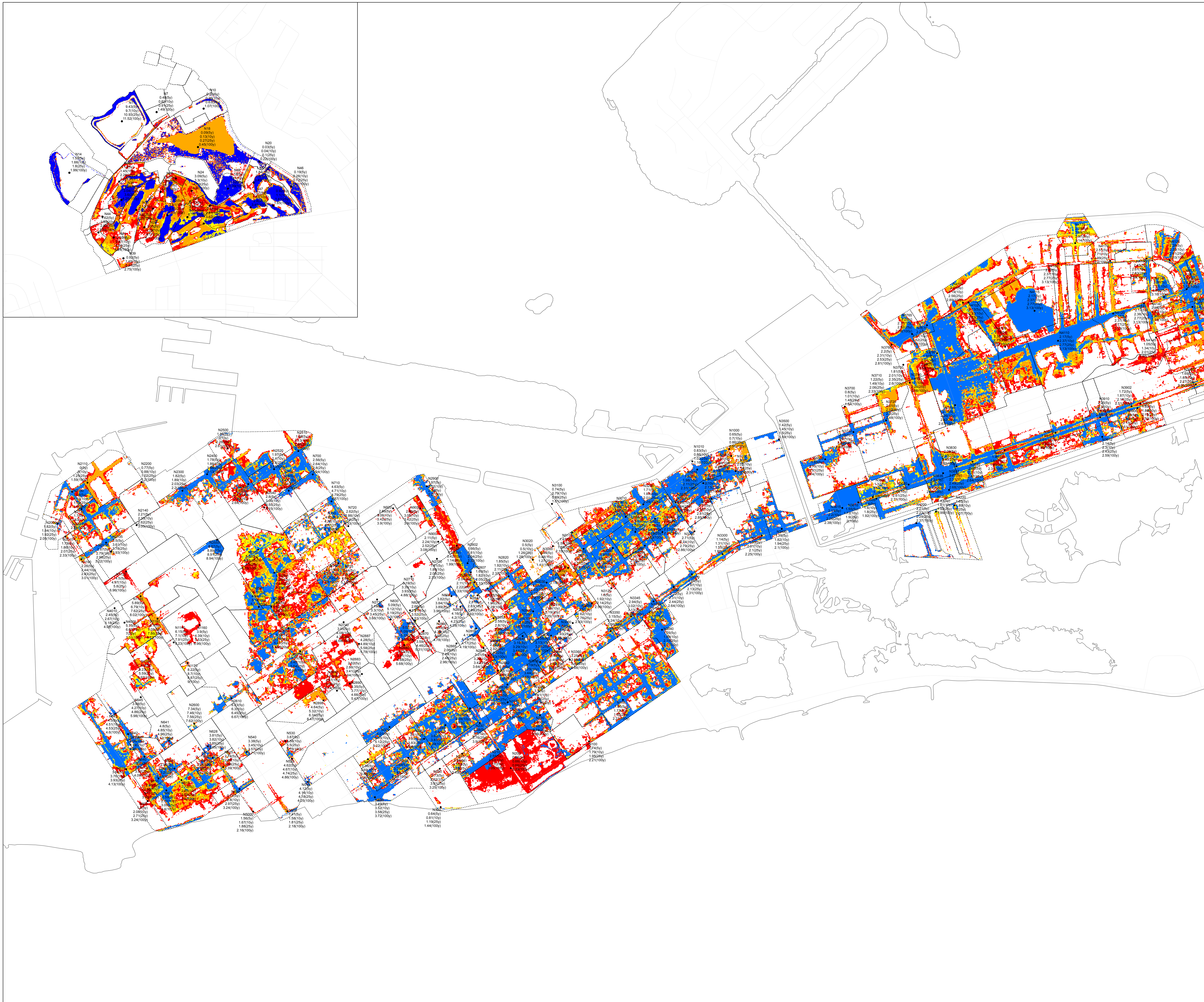
Miles

Flood Conditions with Proposed Pojects
Alternative 1

Key West Stormwater Master Plan

Key West, Florida

CH2MHILL



LEGEND

- Nodes
- Sub-Basin
- Streets
- Shoreline
- Flooding at the 5yr, 24 hr Storm Stage
- Flooding at the 10yr, 24 hr Storm Stage
- Flooding at the 25yr, 100 hr Storm Stage
- Flooding at the 100yr, 72 hr Storm Stage

Only City sub-basins contributing runoff to City-maintained outfalls are shown. City areas draining directly to Gulf, Ocean, or canals are not modeled, but are still managed for potential water quality effects.

N

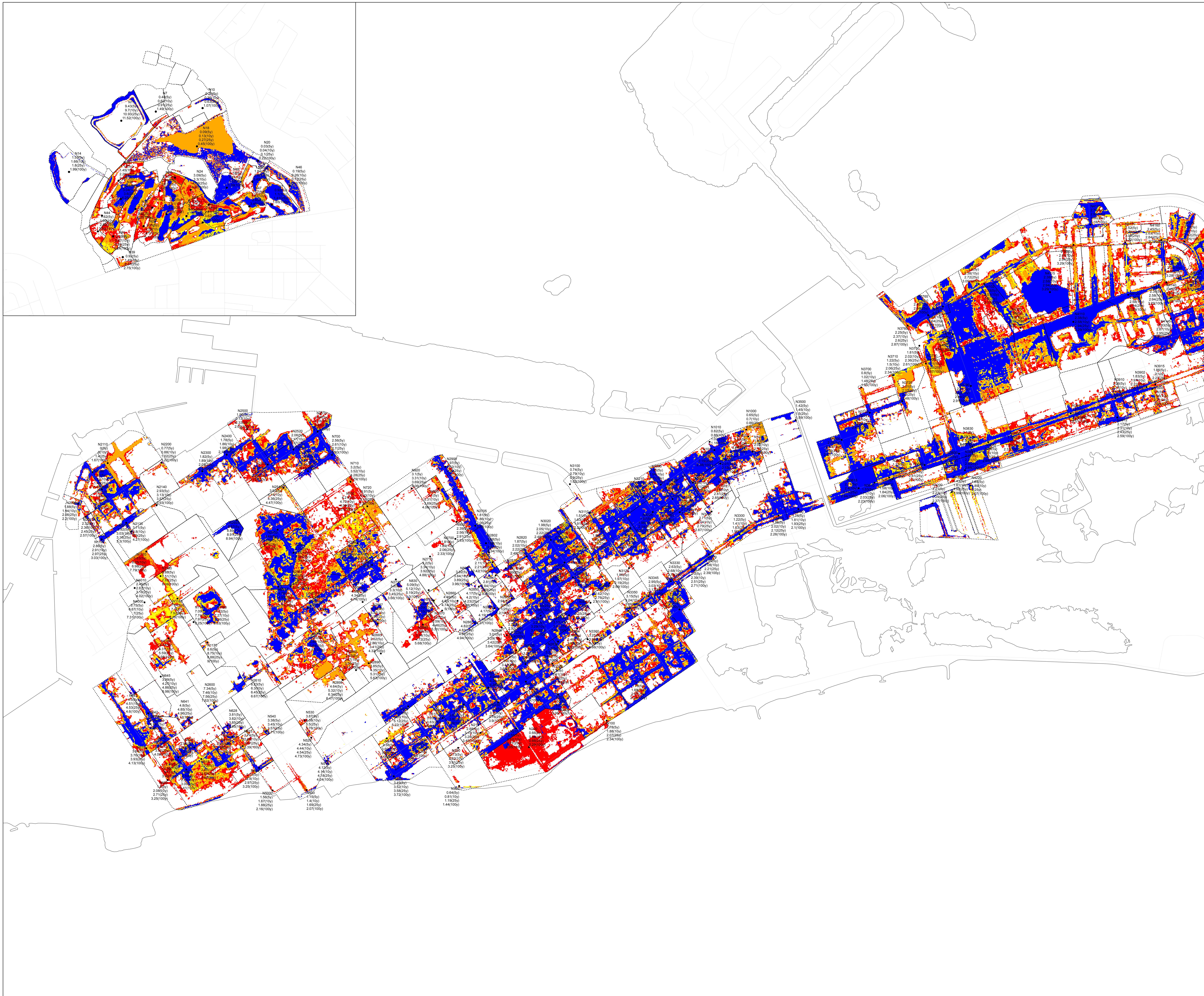
0 0.125 0.25
Miles

Flood Conditions with Proposed Pojects
Alternative 2

Key West Stormwater Master Plan

Key West, Florida

CH2MHILL



LEGEND

- Nodes
- Sub-Basin
- Streets
- Shoreline
- Flooding at the 5yr, 24 hr Storm Stage
- Flooding at the 10yr, 24 hr Storm Stage
- Flooding at the 25yr, 100 hr Storm Stage
- Flooding at the 100yr, 72 hr Storm Stage

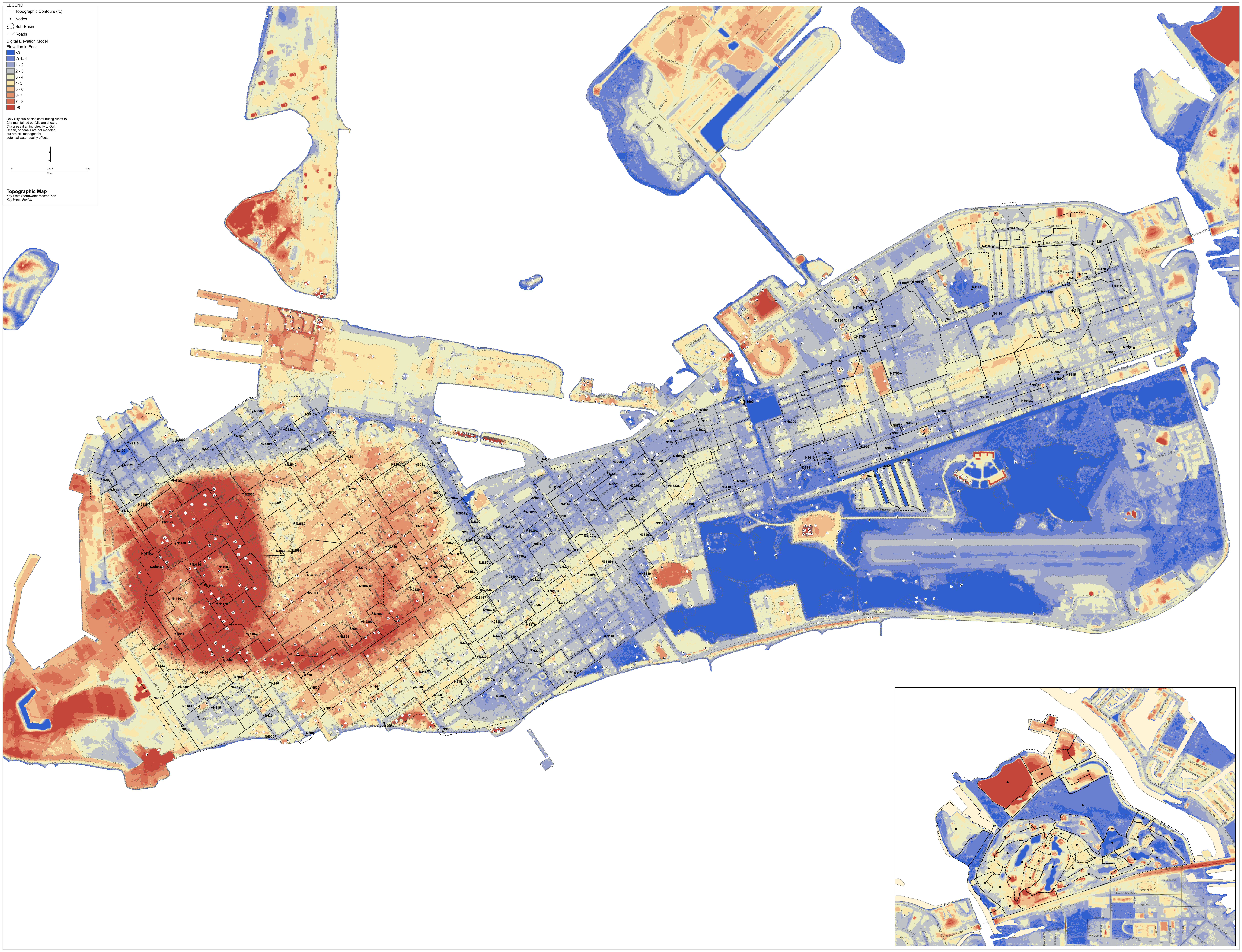
Only City sub-basins contributing runoff to City-maintained outfalls are shown. City areas draining directly to Gulf, Ocean, or canals are not modeled, but are still managed for potential water quality effects.

N

0 0.125 0.25
Miles

Existing Flood Map
Key West Stormwater Master Plan
Key West, Florida

CH2MHILL



LEGEND
Topographic Contours (ft.)
Nodes
Sub-Basin
Roads
Digital Elevation Model
Elevation in Feet
<0
-0.1- 1
1 - 2
2 - 3
3 - 4
4- 5
5 - 6
6- 7
7 - 8
>8
Only City sub-basins contributing runoff to
City-maintained outfalls are shown.
City areas draining directly to Gulf,
Ocean, or canals are not modeled,
but are still managed for
potential water quality effects.
N
0
0.125
0.25
Miles
Topographic Map
Key West Stormwater Master Plan
Key West, Florida
CH2MHILL