Is Your Wastewater Collection System Model Stressed—In a Good Way?

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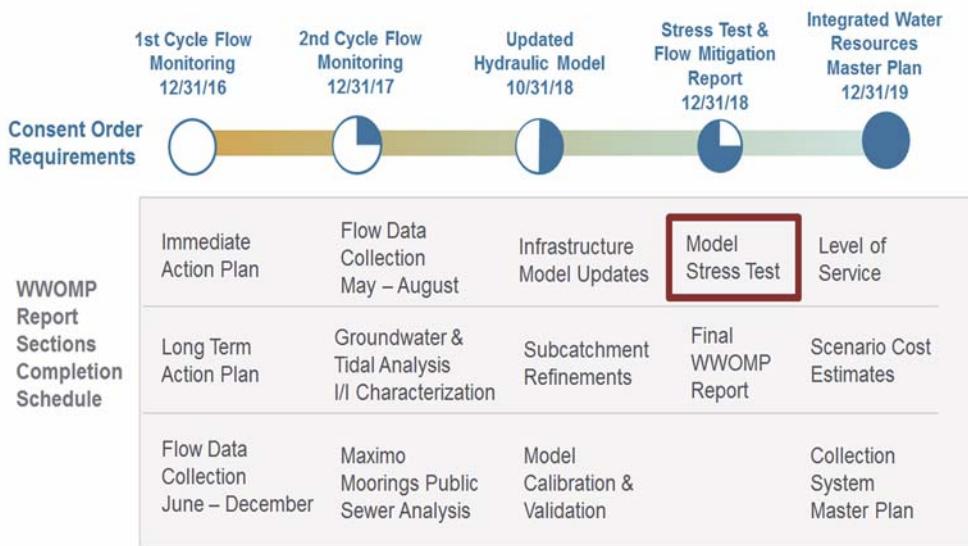
Figure 1. City's Consent Order Mandates Related to Wastewater Collection System Hydraulic Model

Figure 2. Eight-Step Stress Test Methodology

In 2015 and 2016 the City of St. Petersburg (city) experienced extreme rain events that resulted in unauthorized discharges due to capacity limitations in the sewer collection system, water reclamation facility effluent filters, injection wells, and impacts from inflow and infiltration (I/I). Because of the 2015 wet weather overflow events, the city engaged a team of professional engineers to perform an evaluation of its wastewater collection system and water reclamation facilities to identify the most cost-effective solution to mitigate potential similar overflows during future storm events. The city advanced a two-phase approach for development of a Wet Weather Overflow Mitigation Program (WWOMP).

During Phase 1 of WWOMP, the team performed an assessment of the city's wastewater collection system hydraulic model. Phase 1 determined that the city's model was up to date relative to software and collection system components; however, the model needed to be modified to respond to rainfall inputs and recalibrated so that it could be a more useful tool in assessing I/I and capacity issues within the system. In addition to the recommendations related to the model, the near-term recommendations from Phase 1 included:

- Construct additional injection well capacity
- Perform I/I field reconnaissance during wet weather
- Expand implementation of manhole inserts and plugs
- Perform public outreach to target private sources of I/I
- Facilitate local plumbing workshops to discuss practices that impact I/I

As Phase 1 was completed, the city entered into a consent order to mitigate overflows and develop a long-term strategy for improving its wastewater collection system.

During Phase 2, the team conducted an engineering study geared toward collecting data and improving evaluation tools to more cost-effectively target and mitigate the primary sources of I/I. The data were collected to update the model calibration and validation, characterize I/I sources, and develop stress test scenarios under wet weather simulations to identify areas vulnerable to potential system surcharging and/or overflows. The
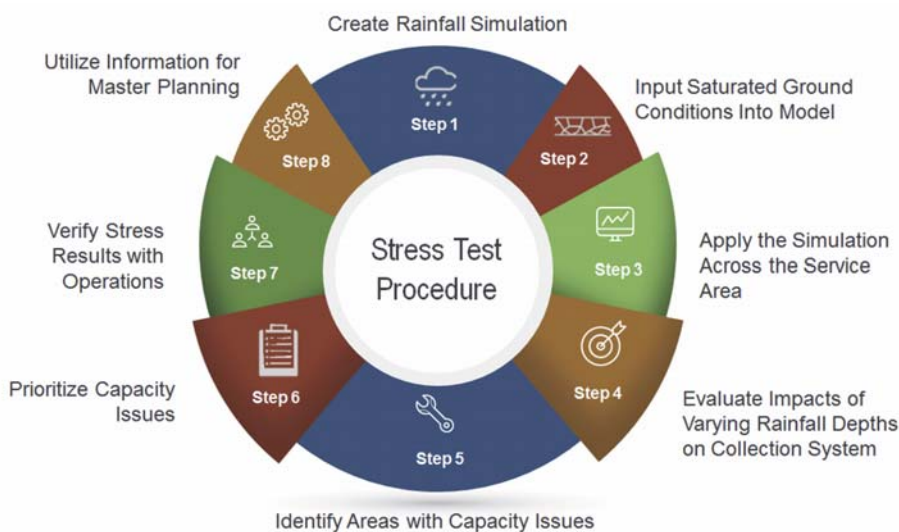
Phase 2 components are shown with their corresponding consent order mandates in Figure 1.

This article presents a step-by-step process to successfully evaluate rainfall impacts on a coastal community's wastewater collection system. Under this process, the collection system response to a variety of wet weather conditions was evaluated to identify where the collection system is vulnerable to capacity issues, under what conditions those issues may occur, and the cost to mitigate the most-extreme wet weather conditions. The results of this work will be incorporated into the city's Integrated Water Resources Master Plan (IWRMP).

Approach

With the completion of the calibration and validation of the collection system model, the city had a tool with which to analyze the collection system for its response to a variety of rainfall events and to perform conceptual planning of system improvements. To understand where the collection system experiences capacity issues, such as surcharging sewers, bottlenecks, and/or overflowing manholes, a stress test was performed for the collection system using the updated model. A stress test is a model simulation exercise intended to use a set of hypothetical conditions and assumptions that create challenging conditions across the entire collection system. In addition to evaluating the system response to current conditions, the stress test was also used to evaluate the effect of future conditions, including future population projections and the stressor of climate-adjusted rainfall.

Methodology

The stress test was performed using the following general methodology:
- Define the existing and future conditions model scenarios for which the stress test is to be run. Model scenarios include definition of the rainfall amount, distribution, and planning horizon.
- Gather data and perform analyses to support development of the identified model scenarios.
- Build and run the stress test model scenarios and report the results.
- Use the results of the stress test, along with data and the results of previous WWOMP analyses (as appropriate) to provide a ranking of the capacity issues within the collection system.

The eight-step process used for performing a stress test of the city's wastewater collection system is presented in Figure 2.

Step 1: Create Rainfall Simulation
A synthetic rainfall event was developed using data and information collected during the 2016 Tropical Storm Hermine. The storm's total
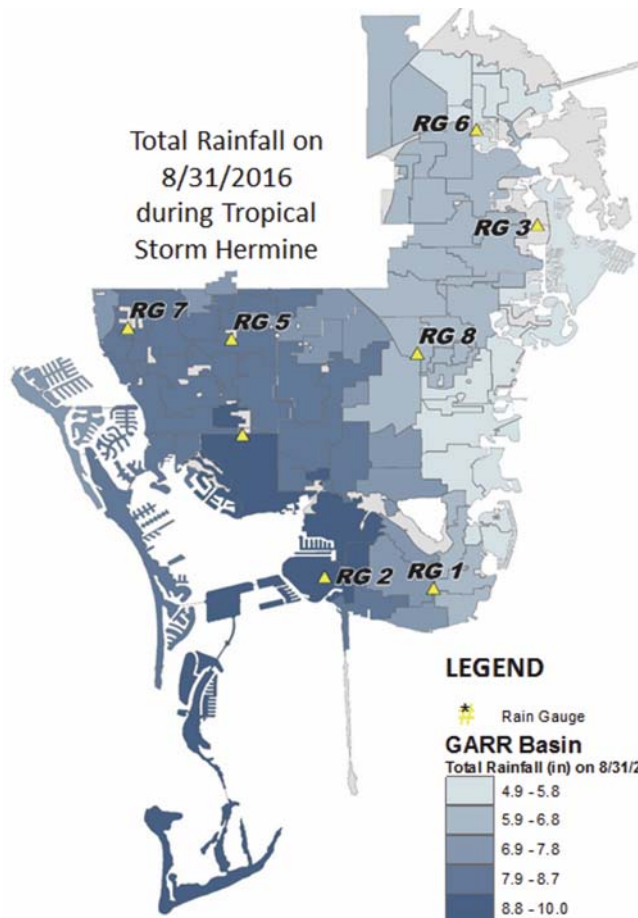

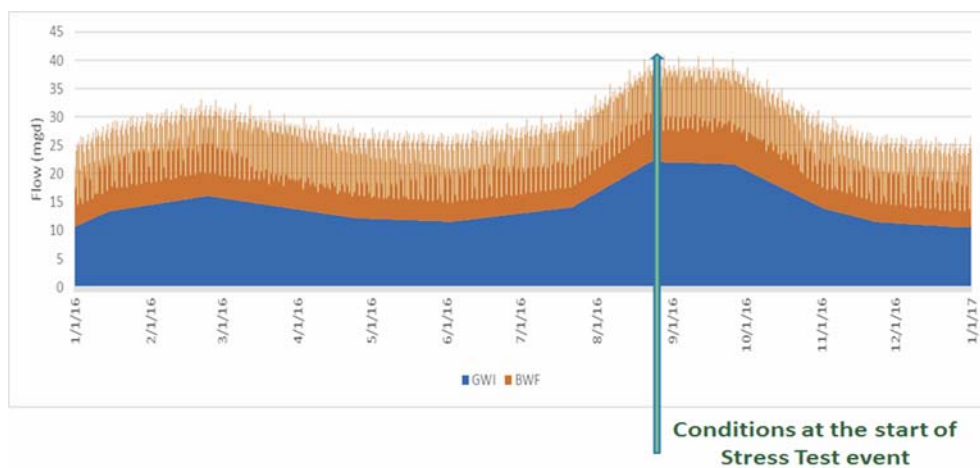Figure 3. Rainfall Measurements

Figure 4. Impact of Saturated Ground Conditions

rainfall varied significantly across the sewershed (as shown in Figure 3); therefore, using the actual rainfall would result in an uneven stress application across the collection system. Rainfall always varies spatially event by event, and there is no established pattern for what areas of the system get more rainfall than others.

To address this situation, a synthetic rainfall event was developed using the storm and rain gauge RG 2 as a basis to stress the system evenly. As shown in Figure 3, RG 2 received the most rainfall during the storm's most intense 24 hours on Aug. 31, 2016, and therefore represents the most extreme condition for rainfall. The rainfall time series at RG 2 for this 24-hour period was used to establish the stress test rainfall distribution. The distribution was then scaled to various

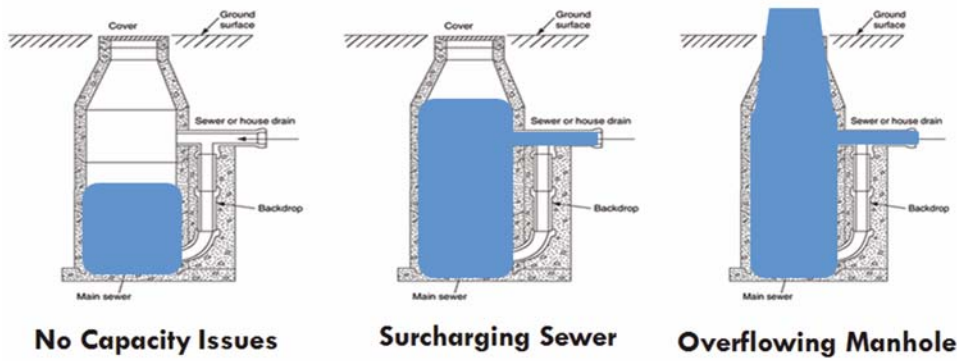Figure 5. Definition of System Capacity Issues

No Capacity Issues   Surcharging Sewer   Overflowing Manhole
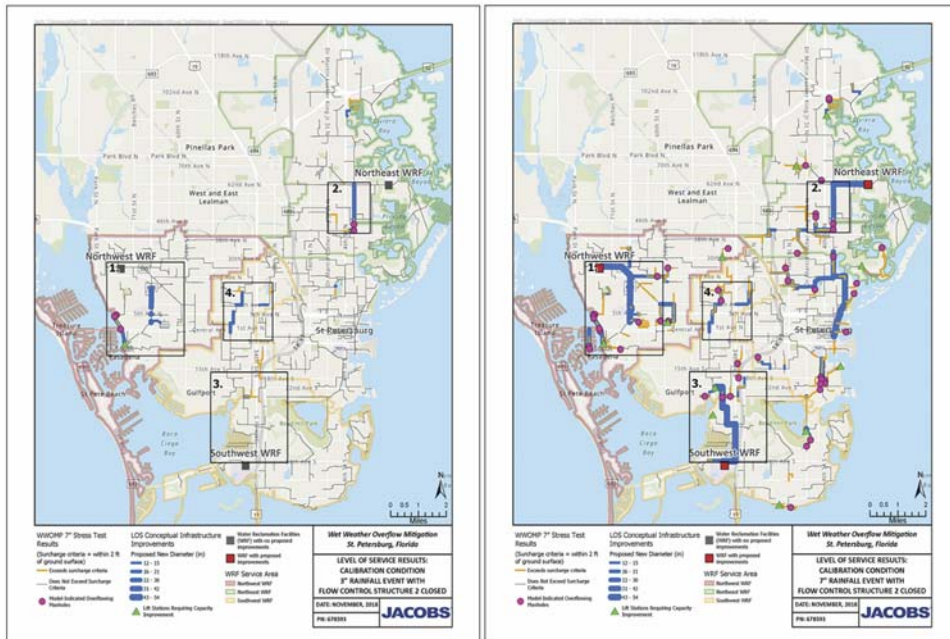

Figure 6. Comparison of Surcharged and Overflow Conditions for 3-in. and 7-in. Rainfall Events

Table 1. Overview of Model Capacity Issues for 3-in. Rainfall Event

BASIN	MODELED CAPACITY ISSUES	CONCEPTUAL INFRASTRUCTURE TO ADDRESS CAPACITY ISSUES	OPINION OF COST
NEWRF	Two overflowing MHs, 1.8 mi surcharging sewer	1.63 mi of sewer replacement to upsize downstream sewer and sections of trunk sewer to WRF.	Construction Cost: $9.5M Capital Cost: $15.6M
NWWRF	Three overflowing MHs, 0.8 mi surcharging sewer	1.79 mi of sewer replacement to upsize downstream sewer and sections of trunk sewer to WRF. Improvement to one downstream lift station.	Construction Cost: $12.3M Capital Cost: $20.1M
SWWRF	0 overflowing MHs, 2.2 mi surcharging sewer	1.44 mi of sewer replacement to upsize downstream sewer and sections of trunk sewer to WRF.	Construction Cost: $8.7M Capital Cost: $14.2M
TOTAL	Five overflowing MHs, 4.8 mi surcharging sewer	4.86 mi of sewer replacement. One lift station improvement.	Construction Cost: $30.4M Capital Cost: $49.9M

total rainfall amounts to evaluate the collection system response to a range of rainfall amounts.

Step 2: Input Saturated Ground Conditions Into Model

There are essentially two seasons in Florida: the dry season (December-June) and the wet season (July-November). During the dry season, soils are significantly less saturated than during the wet season. It takes a lot of rainfall to get a response in the collection system, so it was important to run the stress test with saturated ground conditions. This was important because starting the stress test with the ground conditions experienced in May would have resulted in much of the applied rainfall remaining in the ground, and thereby not affecting the collection system. This would not represent a "stressed" condition for the collection system. This difference is illustrated in Figure 4.

In Figure 4, the orange upper portion of the chart represents base wastewater flow (BWF), which is the flow discharged by users into the sanitary sewer system. As shown in the figure, the BWF tends to be consistent. The blue lower portion of the figure represents groundwater infiltration (GWI), which represents the flow of groundwater that enters the collection system through leaking pipes, pipe joints, and manhole walls.

Running the stress test with wet ground conditions, following several days of rain, caused the voids in the soil to already be filled with water. This situation impacts the collection system as the rain is seeking a place—whether inside the collection system or flooding above ground. This step ensured that the more conservative approach was taken with the model simulation. The stress test rainfall events were evenly applied across the collection system with completely saturated ground conditions.

Step 3: Apply Simulation Across the Service Area

The third step was comprised of completing the modeling exercise using the inputs established from Steps 1 and 2. Rainfall depth was the only assumption that was varied with the stress test. The results of the model run were evaluated under Step 4.

Step 4: Evaluate Impacts of Varying Rainfall Depths on Collection System

Varying rainfall depths were selected with which to evaluate the system response. The team desired to incrementally stress the collection system to develop a knee-of-the-curve analysis for assessing the collection system's response to rainfall depth. The following incremental rainfall depths were evaluated:

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- 7-in. rainfall depth was the average depth that fell across the system during the most intense 24 hours of Tropical Storm Hermine.
- 5-in. and 3-in. rainfall depths were selected to compare smaller events with the 7-in. event.
- 2-in. and 4-in. rainfall depths were selected to determine incremental stress.

Step 5: Identify Areas With Capacity Issues

Sanitary sewers are designed to flow less than full. The stress test determined areas where capacity issues were most likely to occur in the system. The capacity issues identified from the model simulation were the starting points for further investigation. The two primary capacity issues noted from the stress test were: 1) surcharging sewers that receive more flow than the pipes can carry but not so much flow as to spurt out of manholes, and 2) locations where the system is overwhelmed to the degree that manholes are overflowing.

The criteria for defining surcharging sewers was flow within 2 ft of ground surface (refer to Figure 5). It's noted that there were several other sewers surcharged with the flow level above the crown of the pipe. It was determined that those conditions were not sufficiently surcharged to meet the stress test criteria.

While the metersheds that contain the model-predicted flooding manholes help to direct the city to areas of interest, the cause of the capacity issue(s) resulting in the flooding manholes may not be contained within these metersheds. The metersheds downstream of the flooding manholes may contain bottlenecks, such as an undersized sewer or lift station, that cause backup in the upstream system. Conversely, an upstream metershed may contribute significant I/I to the collection system, resulting in a flooding manhole in a downstream metershed. Each area containing flooding manholes must be evaluated and the cause of the flooding manhole diagnosed before action can be taken to mitigate the capacity issue.

Figure 6 visually compares the results of the 3-in. and 7-in. rainfall events. The red dots shown in the figure indicate overflowing manholes and the blue lines represent highly surcharged sewers. Additional information is presented in Tables 1 and 2 for these rainfall events for comparison purposes at the city's Northeast Water Reclamation Facility (NEWRF), Northwest WRF (NWWRF), and Southwest WRF (SWWRF).

The results of the model stress test indicated that the total number of overflowing manholes and mi of surcharging sewer nearly doubles for each rainfall variation (3-in., 4-in., 5-in., and 7-in.). A summary of the systemwide impacts for each rainfall event is presented in Table 3.

Step 6: Prioritize Capacity Issues

As the city's IWRMP is developed, each area of the collection system exhibiting manhole overflows and excessive sewer surcharge in response to wet weather was evaluated to determine the most cost-effective combination of I/I reduction and capacity improvements. Given the level of needed capacity improvements, combined with other utility infrastructure improvements, the city needed a strategy to prioritize the collection system issues.

Early in the WWOMP, the collection system metersheds were initially ranked by the I/I characterization performed on the metered flow data. Under the I/I characterization, observed flow data were disaggregated into individual components: GWI, base sanitary flow, and rainfall-derived I/I (RDII). At the conclusion of this effort, the basins were ranked by their maximum GWI and/or RDII. While this approach was useful in identifying the leakiest areas within the sewer system, flow analysis alone cannot account for the system capacity limitations and secondary flow paths. The stress test performed using the calibrated and validated collection system model incorporates both the calibrated I/I parameters, and the hydraulic pathways and restrictions in the system, into each scenario model run. To comply with the requirements of the city's consent order, a ranking of basins was developed from the results of the stress test.

While surcharging in sewers can result in increased maintenance costs, the most immediate concern related to capacity issues is the potential impact to human and environmental health caused by unpermitted discharges from the sanitary system; therefore, the areas for improvement within the collection system were ranked by the number of model-predicted flooding manholes. Table 4 provides an overview of the ranking

Table 2. Overview of Model Capacity Issues for 7-in. Rainfall Event

BASIN	MODELED CAPACITY ISSUES	CONCEPTUAL INFRASTRUCTURE TO ADDRESS CAPACITY ISSUES	OPINION OF COST
NEWRF	10 overflowing MHs, 9 mi surcharging sewer	5.88 mi of sewer replacement to upsize downstream and trunk sewer to WRF. Improvement to three downstream lift stations. One new injection well for peak flows. 5-MG equalization storage, 5-mgd PS.	Construction Cost: $53.9M Capital Cost: $88.5M
NWWRF	14 overflowing MHs, 9.5 mi surcharging sewer	9.09 mi of sewer replacement to upsize downstream and trunk sewer to WRF. Improvement to three downstream lift stations. One new injection well for peak flows. 5-MG equalization storage, 5-mgd PS.	Construction Cost: $70M Capital Cost: $114.9M
SWWRF	24 overflowing MHs, 17.5 mi surcharging sewer	15.56 mi of sewer replacement to upsize downstream and WRF trunk sewer. Improvement to four downstream lift stations. 5-MG equalization storage, 5-mgd PS. 15-mgd influent pump station.	Construction Cost: $119.5M Capital Cost: $195.9M
TOTAL	48 overflowing MHs, 36 mi surcharging sewer	30.53 mi sewer replacement 10 lift station improvements. Two new injection wells. 15-MG equalization storage.	Construction Cost: $243.5M Capital Cost: $399.3M

Table 3. Overview of Model Capacity Issues for Rainfall Events

RAINFALL	NUMBER OF OVERFLOWING MANHOLES	MILES OF SURCHARGING SEWERS	OPINION OF CAPITAL COST
3-in.	5	4.8	$49.9M
4-in.	9	8.8	$95.1M
5-in.	16	20.1	$207.1M
7-in.	48	36	$399.3 M

of the metersheds exhibiting modeled flooding manholes from all the calibration condition rainfall stress test model runs, sorted first by the number of overflowing manholes in response to the 2-in. rainfall event. Metersheds that contained no modeled overflowing manholes for that rainfall event were sorted by overflowing manholes in response to the 3-in. rainfall event, and so on. This methodology places higher priority on the overflowing manholes that occur during more frequent events.

This ranking points to the critical vulnerabilities within the city's collection system; however, the improvements necessary to resolve these vulnerabilities may occur within these metersheds—downstream to resolve system bottlenecks and/or upstream to remove significant sources of I/I.

Step 7: Verify Stress Test Results

After the priorities were determined, it was important to verify the stress test results with the city's operations staff, and the step was essentially a form of ground truthing the model-predicated results. Even though the results were based upon a synthetic simulation, staff can verify if the priority locations tend to experience problems during wet weather.

Each area exhibiting model-predicted manhole overflows and excessive surcharge in response to wet weather was evaluated with the city's operations staff, and the team reviewed the locations of potential capacity issues with the staff. This step included updating lift station operational strategies. In general, the locations the model simulation predicted as problematic matched the field conditions observed by city staff.

Step 8: Utilize Information to Select Level of Service

The stress test revealed several model-indi-cated capacity issues throughout the collection system in each of the water reclamation facility basins. Issues were often increasing in severity in response to an increase in rainfall. These capacity issues included: 1) surcharging sewers due to sewers under capacity relative to flows, 2) surcharging sewers due to downstream bottlenecks, and 3) flooding manholes. These model-indicated capacity issues will require system improvements to achieve the level of service chosen as part of the IWRMP.

Results

The first action after the stress test was completed was for the city to select a level of service for master planning purposes. Jacobs then determined the most cost-effective combination of improvements to achieve the selected level of service. Conceptual cost estimates were developed for infrastructure improvements to mitigate the capacity issues for various rainfall depth scenarios.

Table 4. Prioritized Metershed Based on Overflowing Manholes

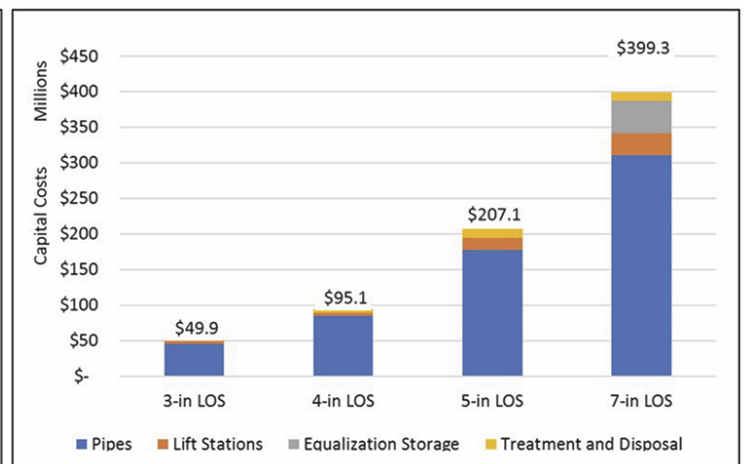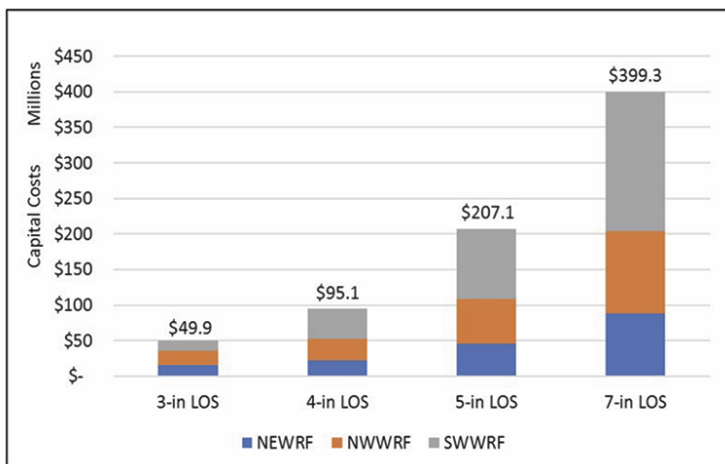| Rank	Metershed	Basin	Number of Model-Indicated Overflowing Manholes				
			2-inch Rainfall	3-inch Rainfall	4-inch Rainfall	5-inch Rainfall	7-inch Rainfall
1	31	NW	1	2	3	3	4
2	17	SW	0	0	1	2	3
3	22	NE	0	0	1	1	1
4	10	SW	0	0	0	4	6
5	70	SW	0	0	0	1	3
6	12	SW	0	0	0	1	2
7	37	SW	0	0	0	1	2
8	67	SW	0	0	0	1	2
9	SWWRF	SW	0	0	0	1	2
10	8	SW	0	0	0	1	1
11	20	NE	0	0	0	1	1
12	19	NE	0	0	0	0	2
13	68	NW	0	0	0	0	2
14	1	SW	0	0	0	0	1
15	7	SW	0	0	0	0	1

Figure 7. Comparing the Level of Service Scenarios

The results and associated costs were presented to the city council to facilitate its selection of an appropriate level of service for capital planning. It's interesting to compare the results of all four scenarios to see how they vary across basins and improvement strategy (Figure 7).

Figure 8 summarizes the incremental benefits the city would realize if it decided to use a planning level of service less than the 7-in. rainfall event.

- If the city elected to construct no improvements, the model simulation resulted in 48 overflowing manholes and 35.9 mi of surcharging sewers.
- Investing $50 million to mitigate the impacts from the 3-in. rainfall event lowered the results to 44 overflowing manholes and 35.1 mi of surcharging sewers.
- Investing $95 million to mitigate the 4-in. rainfall event lowered the impacts to 35 overflowing manholes and 34.5 mi of surcharging sewers.
- More-appreciable improvement was observed with mitigating the 5-in. rainfall event. A $207 million investment would reduce conditions to 10 overflowing manholes and 18.5 mi of surcharging sewers.

The city ultimately decided, for planning purposes, to select the 7-in. rainfall event to determine all capital investments necessary to eliminate overflowing manholes and sewers surcharging within 2 ft of the ground surface. Without the stress test results, it would have been very difficult to select a level of service for the IWRMP.

References

- "Wet Weather Overflow Mitigation Program – Phase II." CH2M Hill Engineers. August 2018.
- "Collection System Level of Service Technical Memorandum." Jacobs Engineering. October 2018.

Figure 8. Incremental Benefits Across Level of Service Scenarios