A Matrix Approach to Prioritizing a Sewer Collection System Capital Improvement Plan

Amanda Savage, Tara Kivett, Steven Cook, Eric Harold, and Ifetayo Venner

The City of Clearwater (City) collection system service area includes 2 million ft (379 miles) of gravity sewers, 185,000 ft (35 mi) of force main, approximately 10,000 manholes, and 80 lift stations (not including privately maintained stations). The majority of the system is comprised of vitrified clay pipe (VCP) installed over 50 years ago. The City owns and operates three water reclamation facilities (WRFs), with a combined capacity of 220 million gallons per day (mgd): Marshall Street, Northeast, and East. The City's wastewater collection system encompasses approximately 26 sq mi and serves approximately 111,000 permanent residents.

In the late 1990s, the City performed a sanitary sewer evaluation study (SSES) to assist with a management, operation, and maintenance (MOM) program. The program included investigations of the collection system, such as manhole inspections, line inspections, smoke testing, and sediment surveys. In addition, lift station drawdown testing and flow monitoring were performed, along with the development and calibration of a model of the collection system. The model included the results of the SSES and the MOM program, identifying the existing collection system conditions and the need for annual programs to correct the deficiencies.

As a result, the City created a tiered system to prioritize the remedial actions and incorporated them into the City's capital improvement plan (CIP). The majority of the inflow and infiltration remediation projects were completed between 2002 and 2005. Then, in 2005, as a result of significant redevelopment, the City expanded and recalibrated the model to aid in decisions involving development and annexation impacts to the system. The City completed most of the remaining tier one and tier two projects related to the remedial actions between 2005 and 2009.

In 2010, the City decided to perform another evaluation of its collection system and revisit the remaining remedial actions incorporated in the CIP. The ultimate goal was to determine which projects were urgently needed, and whether the City could reallocate funds slated for the collection system improvements to competing treatment plant rehabilitation projects.

Industry Best Practices, Model Updates, and Verification

Under contract to the City, Malcolm Pirnie, the water division of ARCADIS (Pirnie/ARCADIS) updated the City's existing model to reflect collection system improvements implemented since the last model update and recalibration in 2005. The model was also reviewed to verify the conformance of its configuration with industry best practices.

Model-predicted flows were compared to historic WRF influent flow data in order to assess the ability of the model to accurately predict the collection system response to dry and wet weather events. The model was evaluated with best industry practices based on three categories: physical network, dry weather flows, wet weather flows.

Physical Network

The physical parameters, such as ground elevation, invert elevation, and diameter, were in line with best practices for the nodes. However, most of the gravity manholes were modeled to allow flow to be "stored" if the hydraulic grade line exceeded the manhole rim, which is not within best practices. The manhole lid settings were adjusted to allow flow to be lost out of the top of the manhole.

The links were modeled within best practices for location and diameters, but were loaded with 10 percent sediment, even though the City regularly cleans the gravity sewers. To conform with best practices, a hand full of gravity sewers were surveyed to verify the lack of sediment, and then the sediment was removed from the model.

Most of the pumps in the numerous lift stations were modeled within best practices. However, a number of the pumps were modeled with one design point or with a set discharge head. Best practices would include providing multi-point pump curves for each pump.

Dry Weather Flows

The model did not separate the base sanitary flows from groundwater infiltration

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(GWI). The per capita usage was modified for each flow meter basin to account for the GWI. A diurnal pattern was applied to the combined dry weather flows. However, this pattern would likely have been modified (dampened) to account for the relatively constant diurnal GWI flow entering each flow meter basin. The GWI is generally constant throughout the day, but varies from day to day and season to season. Separating these dry weather flow components, in line with industry best practices, would allow the City to better estimate the influence of groundwater and potentially identify areas with leaks.

Wet Weather Flows

The wet weather flows in the model occur as a direct result of rainfall that enters the system. There are several methods (hydrologic models) available to calculate the wet weather flow within the software. This particular model uses a combination of the "Fixed" volume method with the "Wallingford" routing method, which has been successfully applied on several other sanitary sewer modeling projects and is considered to meet industry best practices. There were four elements on how this model was applied that are not within typical best practices for sanitary sewer system modeling.

- **Single Response**

  The wet weather response in sanitary sewer systems is typically thought of as the summation of three individual responses: fast, medium, and slow. The fast response represents direct inflow into the system through defects such as open cleanouts or defective manhole lids. The medium response represents a more delayed sewer system response that is typical of flow entering from cracks or other defects in pipes and manholes. The slow response occurs over a longer duration and results from elevated groundwater levels that can persist (often for days or weeks) after a storm event has ended.

Each of these responses would have specific parameters for the volume and routing model used. The summation of these three responses can match the metered response better than if only a single response was used.

The model currently uses only a single response to generate the wet weather response, which does not conform with industry best practices for model calibration. It would also not likely predict the response of the system to wet weather flows as accurately as if the model considered the wet weather response as the summation of three individual responses. When the model is next calibrated, the City will consider using the wet weather response to more accurately predict the response to wet weather events.

- **Storm Specific Wet Weather Flow Parameters**

A review of the last recalibration report detailed a process where parameters used to generate the wet weather flow in the model were developed for three separate storms. This resulted in sets of parameters (such as the "Fixed runoff coefficient" and the "Wallingford routing coefficient") unique to each storm. Best practices for modeling recommend a single set of wet weather flow parameters that can be applied to each calibration storm event. This allows for greater model applicability to a variety of storms.

After calibration, the wet weather parameters were further adjusted for the future planning phase of the model use. The January 2007 report detailed a process where the runoff and routing coefficients were adjusted for a storm event of higher intensity than any observed during the monitoring period. This adjustment was accomplished by graphing the runoff volume coefficient against the storm event depths. A best-fit curve was developed and extrapolated to the design storm event (a 10-year, 24-hour storm). The routing coefficient used for the design storm was adjusted by selecting the most common value used for the calibration events, or the value used in the event that most closely matched the design storm. This process appears to be a proprietary process developed by the model developers and has not been verified or adopted as an industry best practice.

Ideally, the hydrologic portion of the model should be updated to use a single set of wet weather flow parameters for each storm in the monitoring period. The same set of wet weather flow parameters could then be used for various storm event sizes, including a storm of greater intensity (e.g., a design storm).

- **Wetting Event**

For capital improvement planning in 2005, a one-year, six-hour wetting storm was simulated just prior to the 10-year design storm event. This storm had a total depth of 1.47 in. and served to make the soil conditions ahead of the design storm saturated, increasing the wet weather response from the design storm.

If the intent of the wetting event was to establish saturated ground conditions, other methods are available in the modeling soft-

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ware that would generate those conditions without generating flow in the system. The use of a wetting event in the collection system prior to the design storm essentially uses up available conveyance capacity and would therefore exacerbate any model-predicted capacity issues.

Further, the addition of the one-year, six-hour storm immediately preceding the design storm 10-year storm event essentially increases the design storm event to an equivalent much greater than the 10-year storm. Without studying the probability of a one-year event immediately preceding a 10-year storm, there is no way of knowing how large the resultant event is. This practice is not commonly used for wet weather analysis.

- **Design Storm Selection**

According to the January 2007 recalibration report, the 10-year, 24-hour event was selected as the design event for the capital improvement plan development. This was based on a conservative interpretation of the Florida Administrative Code 62-604, Collection Systems and Transmissions Facilities (Section 62-604.400, Design/Performance Considerations), which requires that lift stations "remain fully operational and accessible during the 25-year flood, and that lesser flood levels may be designed for, dependent on local conditions, but in no case shall less than a 10-year flood be used." The conditions described are for flood conditions, not for wastewater design flow conditions. Typically, lift stations should remain operational and accessible during floods 10 years and longer, but they should not necessarily be required to convey the flows resulting from a 10-year or 25-year rainfall event.

The rainfall distribution for the design storm was developed using the United States Soil Conservation Service (USSCS) distribution, rather than using actual rainfall data. When this distribution has been applied on other collection system modeling projects across the United States, it has typically resulted in collection system flows that exceed a five-year storm event resulting from an actual rainfall distribution. Although the use of this distribution is in line with acceptable modeling practices, it should be noted that it will likely result in higher (more conservative) peak flows in the system. When coupled with the one-year wetting event storm, it is likely that the design storm event used was overly conservative in determining the required capital improvements.

Model Updates for Best Practice Conformance

Based on the review of the model, it was suggested that the City implement the recommendations listed for future model recalibrations in order to develop a model that more accurately predicts the response of the collection system to dry and wet weather flow events.

- A wetting storm event should not be used prior to the design storm event. As the model was calibrated to conditions where the ground conditions were saturated, introducing a wetting storm event will be overly conservative.
- The model should be updated with pump curves for each lift station, where possible, so that the downstream hydraulic conditions will more accurately reflect the station's capacity.
- The manhole representation in the model should be updated to allow for flooding.
- The model should be updated to assume that all pipes in the collection system are sediment-free, unless specific data is available to conclude otherwise. The best modeling practice for sediment deposits is to place sediment in the model at the actual locations of the deposit, and not as a uniform layer in all of the pipes.
- Model subcatchments should be reviewed in detail and modified to reflect a parcel boundary tributary to each model load point.
- Dry weather flows should be separated into two components: the base sanitary flow and the GWI.
- Separate weekday and weekend diurnal patterns should be developed for each flow meter basin.
- A single set of wet weather flow generation parameters should be developed that matches all of the storms in the monitoring period.
- The wet weather response should be comprised of three separate responses: fast, medium, and slow.
- An additional dry weather flow input should be added to account for GWI and the varying groundwater conditions that are typical in Florida. This groundwater infiltration module will account for the seasonal variations in the dry weather flow condition observed in the system.
- The calibration process should include a verification process where the model's performance is measured against one or more historical storms and suitable comparative information is available (e.g., wastewater treatment plant (WWTP) flows, in-system flow data, customer complaints, etc.). This verification will ensure that the model can be used on a variety of storm events.

Table 2. Prioritization Matrix

Criteria	Subset	Weighting (%)	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Criteria Total
Model Flooding & Surcharging			Surcharging between 3ft and 1ft	Surcharging between 1ft and rim of MH	Flood Volume Small	Flood Volume Medium	Flood Volume Large	
	-	50						
Critical Areas/Public Impact/Visibility			Little Risk (1,000 ft to waterway)		Moderate Risk (500 ft to waterway)		High Risk (200 ft to waterway)	
	Environment Risk	15						
			Low Density	Medium Density (Minimal Visibility)	High Density (Minimal Visibility)	Medium Density (High Visibility)	High Density (High Visibility)	
	Community Impact	20						
Other Projects Dependant Upon Project			No Subordinates	1 Subordinates	2 Subordinates	3 Subordinates	More than 3 Subordinates	
	-	15						
							Total	

Due to schedule and budget constraints, the model was not recalibrated. The first four recommendations were updated in the model and the model verification proceeded.

Model Verification

To verify the acceptable use of the model for planning purposes, the updated model was analyzed to evaluate its ability to reasonably simulate the response of the collection system to dry and wet weather events using information from recent storms. Model-predicted WRF influent flow results were compared to hourly WRF influent flow records for the period of June 23 through July 3, 2009. This verification period was selected because it included three separate storm events, with dry weather flow periods occurring before each storm.

The verification showed that the model closely predicts wet weather flows when the ground is saturated and the groundwater levels are elevated, which is considered to be a worst-case scenario for the collection system wet weather response. Since capital improvement planning projects will be determined largely from the peak wet weather flows that the collection system must convey, the use of this model as a wet weather planning tool, including this CIP reprioritization project, is acceptable.

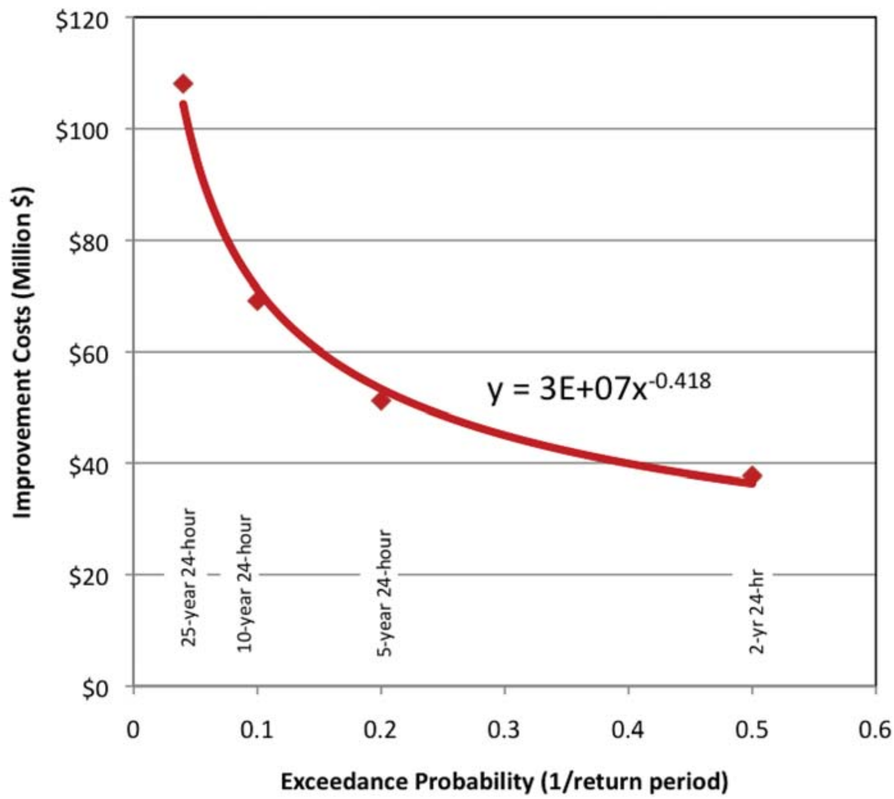

Figure 1

Collection System Assessment and Improvements

The updated model was used to assess the collection system response during the two-year, five-year, 10-year, and 25-year return period storms, each with a duration of 24 hours based on the Type II Florida-modified rainfall distribution pattern (hyetograph) as recommended by the National Resources Conservation Service (NRCS; formerly the U.S. Soil Conservation Service) and the Southwest Florida Water Management District's Environmental Resource Management (ERM) permit information manual. Collection system improvements were simulated in the model for each design storm. From the model results, improvements or "projects" were recommended to remedy modeled deficiencies. Budgetary costs for each recommended improvement were determined from recent projects and manufacturer information, and were assigned to each project.

Control Storm Selection

All of the improvements for the various design storm events were summarized and analyzed to determine the point where the City would receive the largest return on capital invested. A variation of a knee-of-the-curve technique (the cost of the improvements and the potential level of control to meet the correlation between the collection system design criteria during the design storm event return period) was used to help the City choose the most cost-effective level of control (design storm). The recommended improvements and associated costs increase significantly with increasing design storm intensity due to inflow and infiltration. The point where the marginal increase in improvement costs exceeds the marginal benefit is where the tangent line to the curve is 45 degrees (see Table 1).

Although the City selected a lower-intensity design storm than previously as its control storm for wet weather planning, this storm is still more conservative than two neighboring cities (City of St. Petersburg and City of Largo) that have established the two-year, 24-hour design storm as their control storm. Further, as the level of service (LOS) that the City has chosen to use was increased from requiring no freeboard below the manhole rim to requiring 3 ft of freeboard, the City's wet weather planning will now be more conservative than previous efforts, despite the reduction in the intensity of the control storm. A spatial analysis was performed showing the locations requiring project improvements to reduce flooding and surcharging using the LOS and control storm from previous wet weather planning efforts (surcharging to the rim and a 10-year, 24-hour control storm with wetting storm) and the updated LOS and control storm (surcharging to within 3 ft of the manhole rim and a five-year control storm). The analysis indicated that the new LOS and control storm selection is more conservative, requiring additional improvements to reduce flooding and surcharging to the established LOS.

The City accepted the most cost-effective scenario, the five-year, 24-hour design storm event, with a level of service (LOS) that maintained a 3 ft freeboard in the manholes and wet wells for subsequent capital improvement planning development and reprioritization.

Capital Improvement Plan Prioritization

Sixty-eight capital improvement projects were identified for implementation to enable the collection system to convey the base sanitary flow and the inflow and infiltration from the five-year, 24-hour control storm, while maintaining the recommended LOS to the three WRFs. A decision matrix was implemented to help organize and prioritize the

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large number of improvements identified, and the prioritization matrix is shown in Table 1. Every project was assigned a grade for each of the three criteria summarized in the sections. As some of the criteria were of greater importance to the City than others, the grades for each criterion were weighted according to their importance. An overall criteria total was developed for each project and they were then ranked, based on this overall total. The projects with the highest criteria total were given the highest priority for implementation.

Prioritization Criteria Definitions

Historic Sanitary Sewer Overflows

During the collection system assessment, a relatively intense storm in August 2010 occurred and caused four sanitary sewer overflows (SSOs). Even though the storm did not register as a five-year storm per the NCRS guidelines, it was one of the more forceful storms the City had experienced in the last few years. This prompted the City to request a comparison of the August 2012 SSO locations and the model-predicted results for the control storm. Figure 2 illustrates the results of the comparison and shows that the model predicted significantly more SSOs during the control storm than occurred during the August 2010 storm. This was an expected result because the five-year, 24-hour storm was more intense than the August 2010 storm.

Since these four locations have flooded in the recent past, it was assumed that they would have a higher likelihood of flooding during other storm events and would flood before the SSO locations unrelated to historic overflows. It was important for the City to invest capital funds to first address flow constraints at the historic SSO locations. To be able to assign a higher priority to locations with known capacity restrictions during storm events occurring within the last decade, the projects that address model-predicted flooding and surcharging in locations with documented historical SSOs were automatically ranked higher than projects addressing model-predicted flooding and surcharging without historically recorded SSOs in the area. Each set was ranked using the prioritization matrix.

Thus, the improvements were classified into two sets:

- Improvements related to historic SSOs.
- All other improvements (model-predicted surcharging within the sanitary sewer system or flooding).

The City has still included all of the improvements in its future CIP, even though there are two classifications.

Flooding and Surcharging

Projects were graded according to the amount of model-predicted flooding or surcharging expected, should the project not be implemented. The accepted LOS for the system allows for surcharging within the manholes and wet wells to within 3 ft of the rim. Projects to increase the freeboard to within 3 ft of the rim, but which were not associated with flooding, were considered to be a lower priority and received a lower grade than projects to reduce large volumes of SSOs. The City's top priority is the health of its residents and the environment; hence, this criterion was heavily weighted. The City is also required to report SSOs in excess of 1,000 gal of flood volume to the Florida Department of Environmental Protection (FDEP), and SSOs may results in fines and potentially consent orders for the City.

Critical Areas/Public Impact/Visibility

Since the City's top priority is the health of its residents and the environment, this criterion subset prioritizes the impacts to both the residents and the environment.

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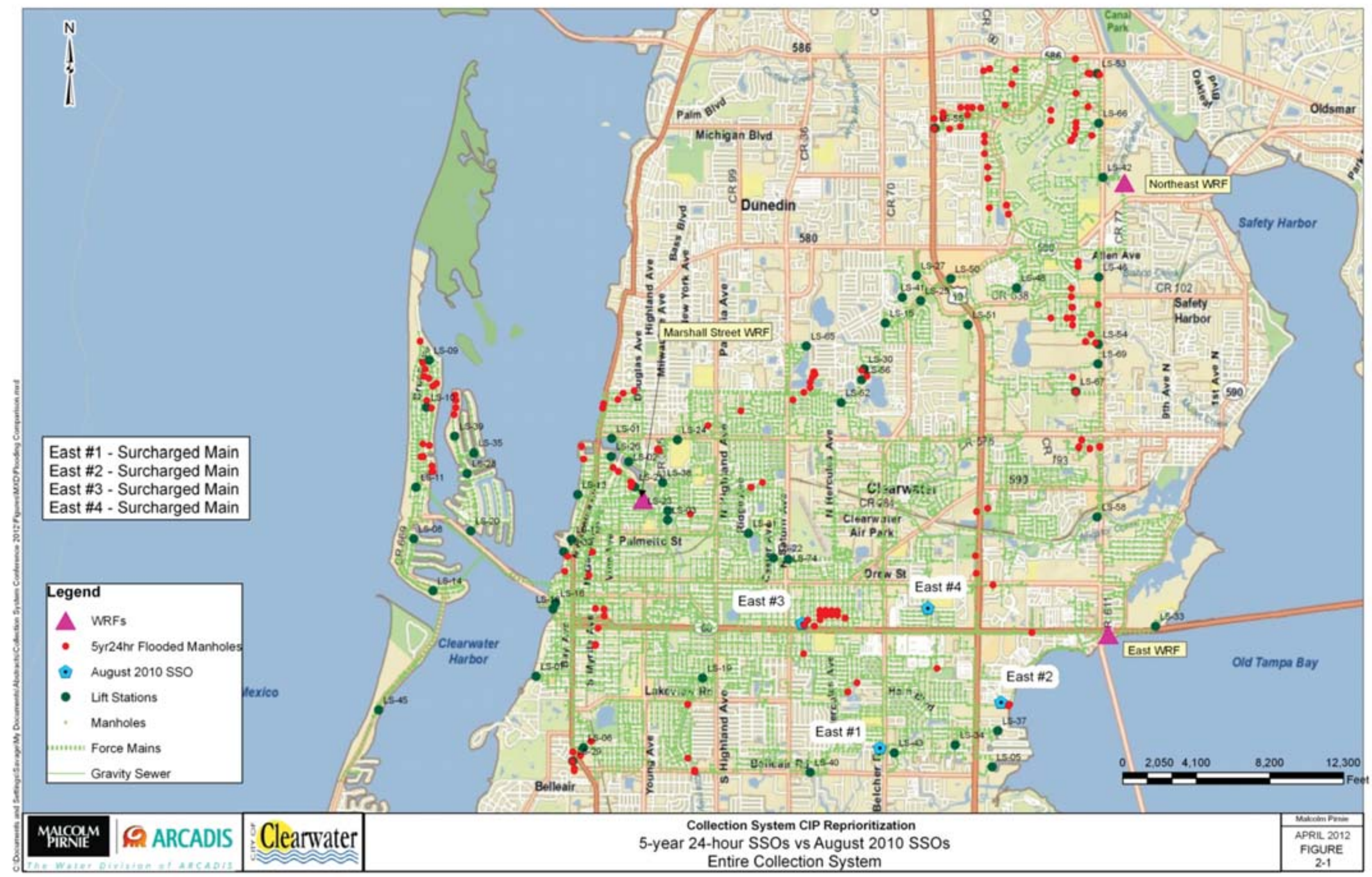

Figure 2: August 2010 Sanitary Sewer Overflow Comparison

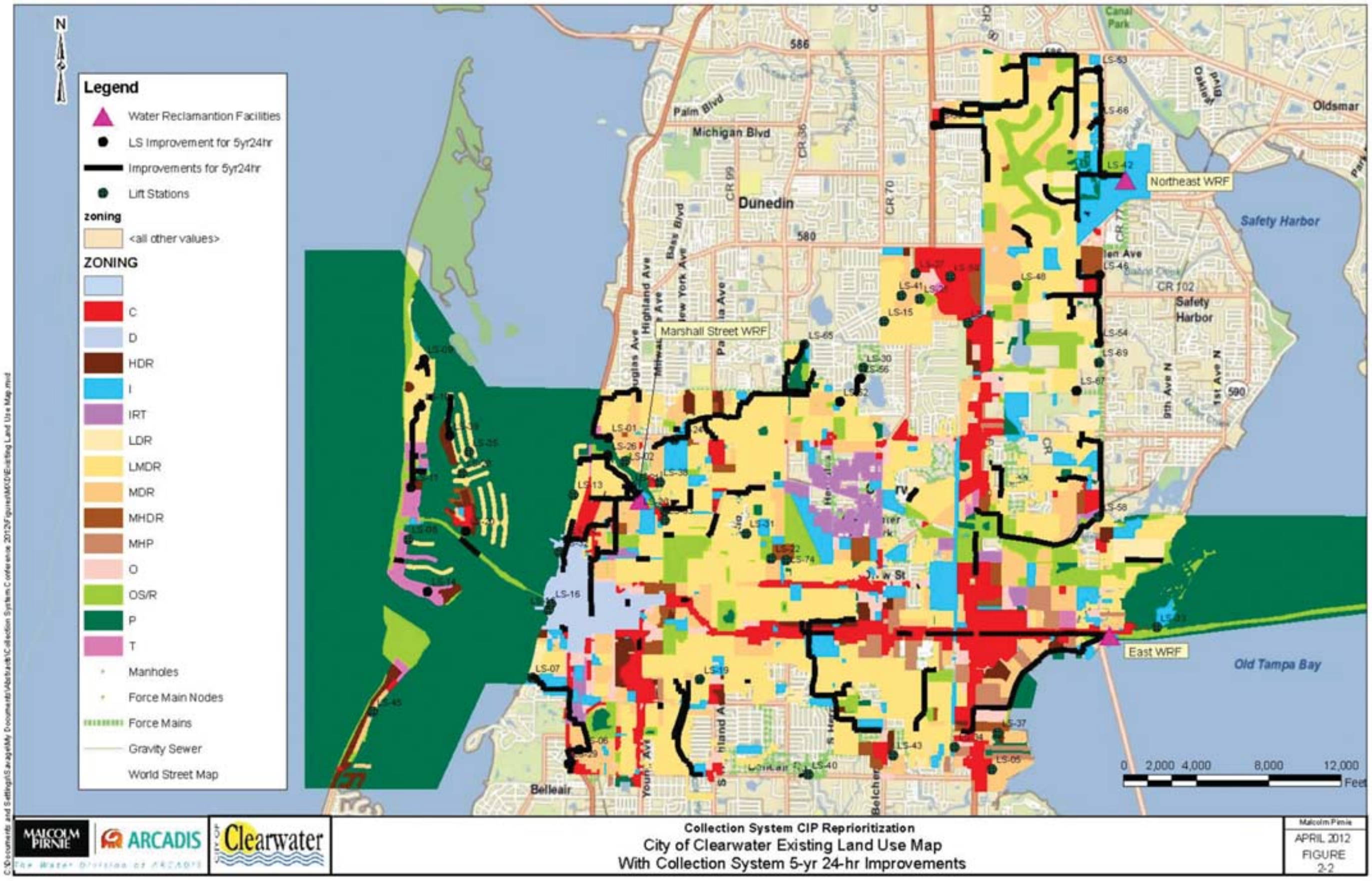

Figure 3: City of Clearwater's Existing Land Use Map

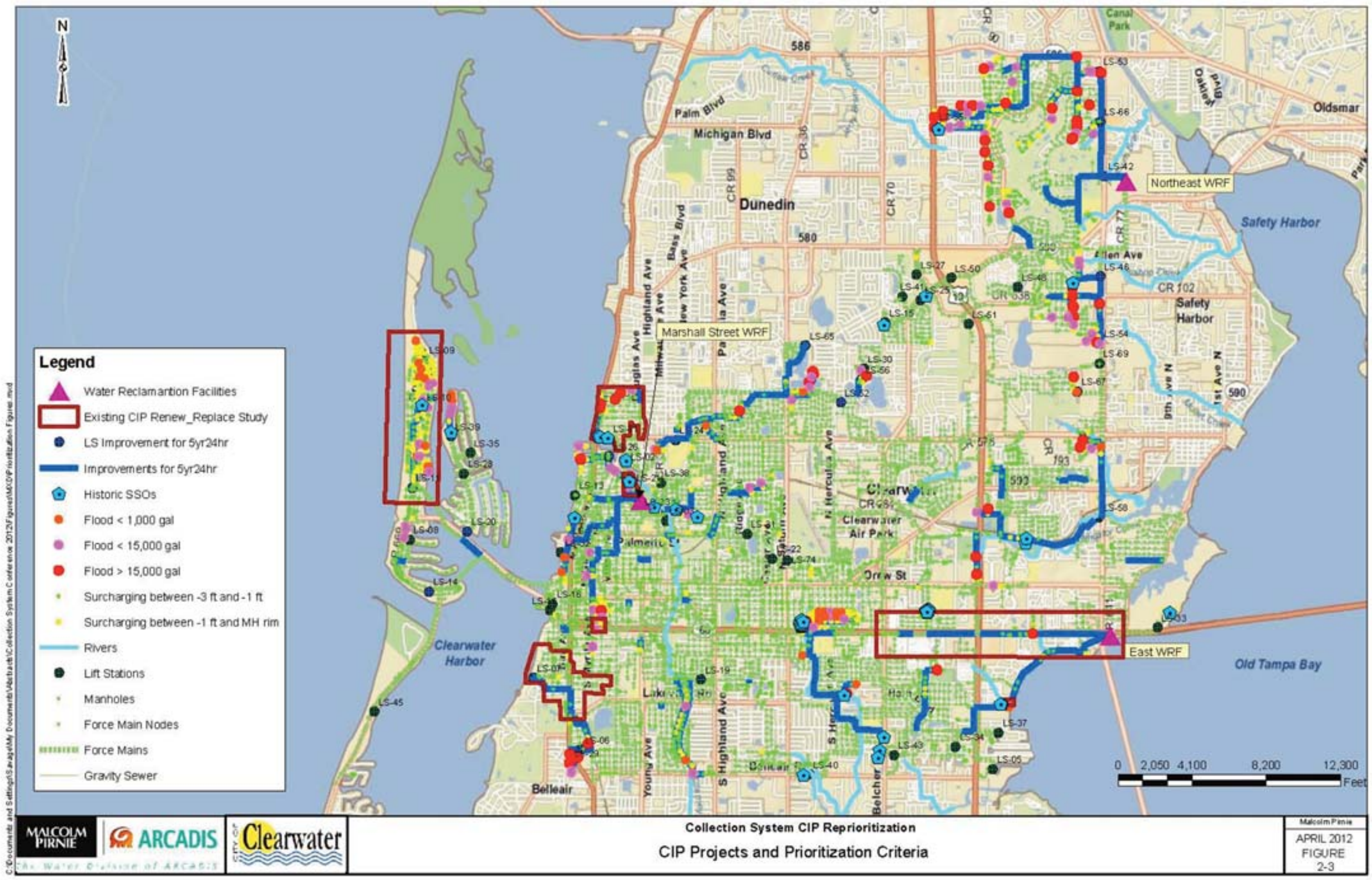

Figure 4: Capital Improvement Plan Projects and Prioritization Criteria

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Environmental Risk

Projects were graded according to the distance from the site of a potential SSO to a natural water body, including streams, creeks, rivers, Tampa Bay, and the Gulf of Mexico. Projects within 200 ft of a water body were considered to pose a higher environmental risk, and therefore, were a higher priority and received a higher grade than projects greater than 1,000 ft from a water body.

Community Impact

Projects were graded according to the level of exposure to residents and visitors to a potential SSO. Projects in a low-density, low-visibility location were considered to be a lower priority and received a lower grade than projects in a high-density, high-visibility location, such as Clearwater Beach. Population densities were estimated using the City's existing land use map (ELUM), shown in 3. High-visibility areas were considered to be commercial areas and areas explicitly identified by City staff during project meetings, such as properties on the beaches, along Clearwater Harbor, along Old Tampa Bay, and around the Countryside Golf Course.

Quantity of Upstream Projects

Projects were graded according to a number of associated upstream projects. Projects that influence other projects (there were several subordinate projects) were considered to be a higher priority and received a higher grade than projects that were independent of other projects. This allows downstream projects, which would have a higher impact on the system and SSOs than an upstream project, to have a higher importance. For example, a large interceptor that collects flows from a number of gravity sewer branches would be given a higher priority for improvement than a gravity sewer branch improvement that flows into the interceptor. This allows the interceptor to be upgraded or constructed prior to the gravity sewer and avoid potential downstream capacity constraints from increased flow occurring as a result of the gravity sewer improvement.

Prioritization Results

The project rankings ranged from 480 points to 120 points. Twenty-seven projects were categorized as being related to historic SSOs, and the remaining 41 projects were automatically ranked lower than the projects relating to historic SSOs. Figure 4 shows the results of the prioritization matrix for the most critical improvement project. The City was provided a sheet similar to Figure 5 for each project, as well as a table listing the projects in the prioritized order.

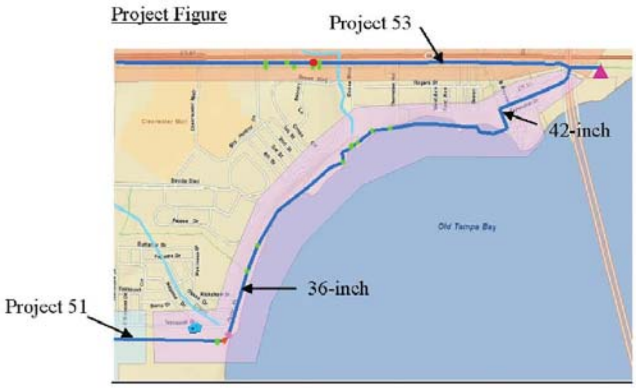
Conclusion

The City of Clearwater was able to create and use an effective decision matrix to prioritize the 84 improvement projects identified during the collection system modeling and assessment. The City's existing hydraulic model was updated, with improvements completed since the last update and calibration. The model was reviewed and evaluated against a recent storm event and industry best practices. It was found to have been set up and calibrated with atypical techniques not in line with industry best practices, but the model could accurately predict the total flows to the WRFs during wet weather scenarios with saturated soils and elevated groundwater levels. Knowledge of the system and historic SSOs enabled the team to select prioritization criteria and weightings that allowed the projects to be easily prioritized.

The project was completed in January 2011 and was used as guidance in the development of the City's 2012 CIP, which was recently published. As a result of the application of this method, the City was able to allocate scarce resources to the projects that will provide the most benefit to its customers. The prioritization project enabled the City to develop a six-year CIP (2012 through 2017) that addresses sanitary collection system and lift station deficiencies and contains accurate project cost estimates, resulting in an enhanced level of confidence. The prioritization process allowed for improved fund allocation, thereby releasing funds for competing treatment plant rehabilitation projects.

Project No. 52 – South Interceptor

Project Figure



Project Description

The project involves increasing the diameter of the main interceptor to the East WRF as indicated on the project figure to reduce capacity constraints locally and reduce upstream flooding and surcharging for Project Nos. 47, 48, 50 and 51.

Estimated CIP Budget

Lift Station	$0
Force Main	$0
Gravity Sewer	$2,400,000
Total	**$2,400,000**

Prioritization Criteria Table

Criteria	Subset	Weighting (%)	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Criteria Total
Model Flooding & Surcharging			Surcharging between 3ft and 1ft	Surcharging between 1ft and rim of MH	Flood Volume Small	Flood Volume Medium	Flood Volume Large	250
	-	50					**5**	
Critical Areas/Public Impact/Visibility			Little Risk (1,000 ft to waterway)		Moderate Risk (500 ft to waterway)		High Risk (200 ft to waterway)	155
	Environment Risk	15					**5**	
			Low Density	Medium Density (Minimal Visibility)	High Density (Minimal Visibility)	Medium Density (High Visibility)	High Density (High Visibility)	
	Community Impact	20				**4**		
Other Projects Dependant Upon Project			No Subordinates	1 Subordinates	2 Subordinates	3 Subordinates	More than 3 Subordinates	75
	-	15					**5**	
							Total	**480**

Figure 5: Improvement Project Results Page