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# Memorandum

*To:* *Tom Simmons, MMSD*

*From:* *Dan Lau, CDM Smith; Pat Chiang, OTIE*

*QA/QC:* *Eric Loucks, CDM Smith*

*Date:* *January 20, 2014*

*Subject:* *Ad Hoc 110 Edgewood Drainage Study TM1*

## Introduction

The Village of Shorewood (Village) has experienced basement backups and surface flooding for many years, particularly during the July 15, 2010 and July 22, 2010 storm events. The events prompted the Village to conduct investigations to find the causes and solutions to improve the sewer system performance. However, the alternative recommended by the Village's consultant has been considered too costly for acceptance by the Village. The Milwaukee Metropolitan Sewerage District (District) has initiated Ad Hoc Modeling Question 110 with the objective of identifying a more cost effective solution that incorporates Green Infrastructure (GI) practices that does not increase flows to the District's facilities.

To identify a feasible solution to mitigate the flooding problems, a hydraulic model (Baseline model) has been prepared to first evaluate the combined sewer system capacity and restrictions. This technical memorandum (Ad Hoc 110, TM1) documents the preparation of the Baseline model, including the review of the data and the model information provided, as well as the assumptions of the model boundary condition setup to replicate the operation of the District's system.

## XP-SWMM Model Review

The Village has developed a hydraulic model to support planning efforts over the years. The model was constructed using the XP-SWMM hydraulic simulation software program developed by XP Solutions. The "Combined 2015 north projects 13" model was obtained from the Village's consulting engineer. The model includes sewer pipes with diameters of 6 inches or larger in the combined sewer watershed. The total tributary area in the model is 717.4 acres which covers the southeast portion of the Village (approximately 579.7 acres) and a portion of the City of Milwaukee (City) (approximately 137.7 acres), that includes part of the University of Wisconsin at Milwaukee (UWM) campus. Figure 1 provides a map of the area represented in the model and shows the pipe

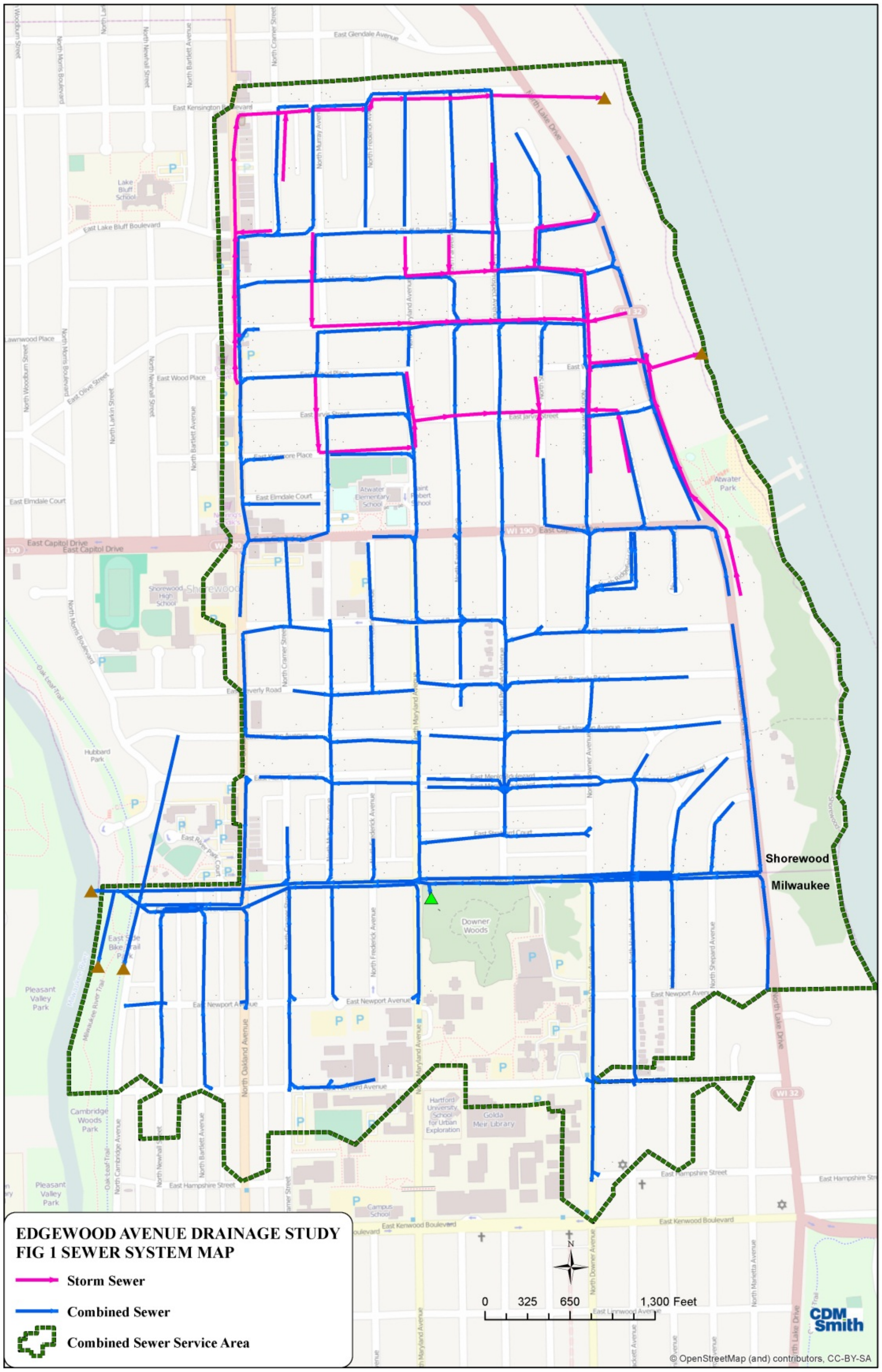


**Figure 1. Sewer System Map**

segments included in the model. The model represents the Village's current sewer system and planned improvements up to year 2015. However, the Village's existing GI practices and the UWM campus's stormwater improvements are not included in the existing model. Furthermore, some of the structure layout and operation of the District's system which serves the combined system at the downstream end near Edgewood Avenue are not explicitly represented.

# Baseline Model Preparation

The Baseline model for the Edgewood Drainage Study was prepared by modifying the Village's XP-SWMM model. These modifications are described in the following paragraphs.

### *Design Rainfall Distributions*

The Southeastern Wisconsin Regional Planning Commission's (SEWRPC) 2000 rainfall distribution was used to replace the Huff first quartile rainfall distribution in the Village's model to be consistent with other stormwater management studies undertaken by the District. The SEWRPC rainfall distribution is widely used in local stormwater management applications, and is accepted by the District for use in projects regulated under the MMSD Chapter 13 Rule, "Surface Water and Storm Water." The peak rainfall intensity occurs in the $2^{nd}$ quartile of a storm, that is, between 15 minutes and 30 minutes of a one-hour storm. The distribution allows soil to be dampened in the first 15 minutes and leads to more conservative estimates of storm runoff.

### *Village Existing GI Practices – Downspout Disconnection*

According to Village's 2009 Wet Weather Flow Volume and Peak Management Project study report, 1,988 downspouts were disconnected or were found to be already disconnected; representing about one third of the structures in the Village's combined sewer service area (CSSA). However, due to the complexity and variability of the downspout disconnection implementation across the combined sewer watershed (for example, partial disconnection at some of the properties), the existing downspout disconnection implementation is not simulated in the Baseline model. The exclusion of downspout disconnections in the model builds some small degree of conservatism into the design flows, but the impact is minimal for major rain events.

### *UWM Stormwater Improvements*

The Baseline model was updated with the following UWM stormwater green infrastructure projects and stormwater management enhancements that have taken place since 2004. The year 2004 was selected as the time the District funded Shorewood Study, "Wet Weather Flow Volume and Peak Management Project" was conducted. It was assumed the UWM stormwater improvement projects prior to 2004 were addressed in that study and reflected in the current XP-SWMM model obtained from the Village. The planned capital projects within the UWM Northwest Quadrant do not involve building and parking lot expansion, but rather transforming the existing St. Mary Hospital space into higher education space. No increase in impervious area within the Quadrant will occur. The following changes were incorporated into the Baseline model:

- Sandburg Commons Green Roofs – 33,000 square feet of green roof.

- Pavilion Gateway Demonstration Project – One feature of the pavilion project is to mitigate runoff from 1.48 acres of impervious surface, out of the entire 4 acres in the full project area. The implementation will reduce a and a fifty-percent probability peak flow event into the storm sewer by 97%, a ten-percent probability peak flow event by 79%, and a one-percent probability peak flow event by 48%.

- UWM Children's Center Underground Storage Facility– The facility will provide 1,540 cubic yards (0.31 MG) of underground stormwater storage within the UWM Northwest Quadrant which is designed to provide as much storage capacity as practicable to serve the long term runoff volume reduction goals of UWM and the State of Wisconsin. Currently, only runoff from the Children's Center rooftop (approximately 1 acre) is discharged to the facility. The stored water drains back to the sewer system through a 6-inch perforated pipe. Since no detailed outlet structure design was provided at this time. In this study, it was assumed the drain time for the facility is long and the impact of the facility outflow on the local sewer system is minimum.

Details of the proposed UWM stormwater improvements were requested, but were not received for incorporation into the model. However, the qualitative information described above allowed us to incorporate the proposed underground storage and to reduce the impervious area within the UWM subbasins to account for the proposed green roof area and other green infrastructure.

### *District Combined Sewer Overflow System near Edgewood Avenue*

The outfall of the combined sewer system which serves the Village and the City consists of several separate and complementary facilities, which are under the jurisdiction of the District (Figure 2). Two District Intercepting Structures (IS) receive flows from the local combined systems. IS-73 receives flows from the Village's 78-inch trunk sewer along East Edgewood Avenue. The dry weather flow is directed to a 39-inch special section Metropolitan Intercepting Sewer (MIS) to the south and wet weather flow is routed to the west through a 72-inch near surface collector (NSC). IS-74A receives flows from the City's 60-inch trunk sewer along East Providence Avenue. The dry weather flow is directed to the same 39-inch special section MIS and wet weather flow is routed to the west through a 60-inch NSC. A 96-inch NSC combines flows from the 72-inch NSC and 60-inch NSC. The 96-inch NSC routes flows to the Inline Storage System (ISS) via the North Shore 4 (NS04) tunnel drop shaft or overflows to a 72-inch combined sewer overflow (CSO) to the Milwaukee River when the NS04 gate is closed.

The hydraulic features of these structures were modified in the model with the following data obtained from the District:

- Plans of 72-inch NSC Plans of 39-inch special section MIS

- Plans of IS-73 at North Oakland Avenue and East Edgewood Avenue

- Plans of IS-74A at East Providence Avenue and North Bartlett Avenue

- Plans of Junction Chamber C09101which combines the 72-inch NSC flow from the Village and the 60-inch NSC flow from the City and diverts to drop shaft NS04 through a 96-inch NSC
- Plans of drop shaft NS04
- Plans of 72-inch CSO to the Milwaukee River (CSO091)
- Milwaukee County Flood Insurance Study dated in 2008
- District Conveyance System Model (CSM) 2011

Specific changes made to the Village's model included the following to produce a better representation of the hydraulics in the Baseline model:

- Added a segment of 96-inch NSC upstream of the ISS connection.
- Adjusted two control weir heights at the Village's and the City's MIS and NCS connections based on the District's record drawings. The weir heights were raised by 1.32 feet at the Village's connection and 0.83 feet at the City's connection.
- Adjusted the invert of the 60-inch MIS going south where the 39-inch MIS connects based on the District's record drawings. The invert was lowered by 3 feet.
- Changed the boundary condition at the downstream end of the 60-inch MIS from a free outfall condition to a fixed tailwater elevation.

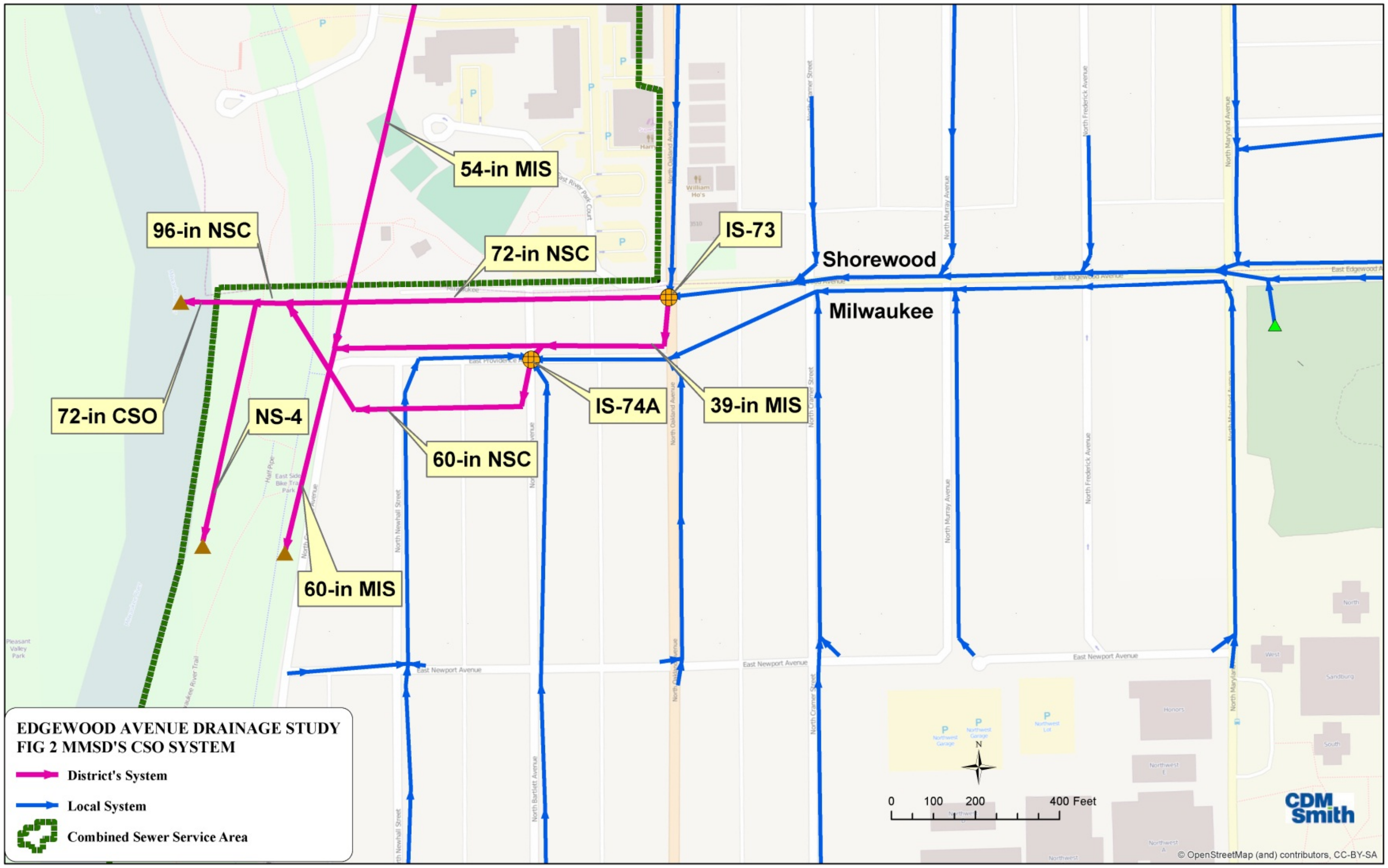


**Figure 2. District's Combined Sewer Overflow System**

### *Model District System Boundary Condition Assumptions*

During rainfall events, flows exceeding the capacity of the MIS are routed to the ISS through NS-04. For extreme rain events, the NS-04 gate is closed and the excess storm runoff will discharge to the Milwaukee River through the 72-inch CSO. The actual operation of NS-04 is rather complicated and requires a comprehensive analysis of the District conveyance and storage system using the District's CSM. Evaluation of the historical operation records in regards to storm events did not find a strong correlation between the two. That is, a major localized rainfall event in Shorewood did not necessarily see a closure of the NS-04 gate to the ISS. After communication with the District modeling team, the decision was made to model the system with two boundary condition scenarios (flow routed to ISS or flow discharges to the Milwaukee River) for each design storm.

To set up the upstream (inflows) and downstream boundary conditions for the 54-inch/60-inch dry weather MIS, it was originally planned to use District's meter data for the major storm events from 1997 to 2005. After reviewing the rainfall records of these events, it was concluded none of the events are short enough to represent the 1-hour design storms. Hence, the Shorewood-developed inflow hydrograph to the 54-inch MIS (with a magnitude about two times of the CSM2011 flows) and a fixed water level about 2 feet above the pipe crown of the 60-inch MIS were used as the boundary conditions.

### *Milwaukee River Level Impact to the Local Systems*

To determine the impact of Milwaukee River stages on the local system performances, the Baseline models with the NS-04 gate closed scenario were tested with the different river stages as the downstream boundary conditions of the 72-inch CSO to the river. Three river stages were selected: river stage at the "normal" water elevation (a non-wet weather elevation that is lower than the downstream invert elevation of the 72-in CSO, 13.58 feet, MMSD and Village Datum); river stage at 20 feet; and river stage at 23 feet. The river stage at 20 feet boundary condition was selected as it matches the approximate pipe crown elevation of the 72-inch CSO and the Flood Insurance Study (FIS) 10 percent (10-year) annual chance flood elevation. The one percent (100-year) annual chance flood elevation (23 feet) was also evaluated to determine the river stage impact to the local system during an extreme event.

## Baseline Model Results

The Baseline model results are presented and include a number of parameters: peak flows at the key manholes where the local systems connect to the MIS, the total volume of runoff at these key structures, the number of manholes that do not meet the established surcharging criterion, and an average hydraulic grade line (HGL) elevation. Two District Intercepting Structures IS-73 and IS-74A were selected as the key locations.

### *Milwaukee River Impacts*

The Baseline model results are presented in the following tables and demonstrate the impacts of the Milwaukee River stages and the NS-04 operation on the local system performances. Table 1 provides the "NS-04 gate closed" scenario model results with the different Milwaukee River stages as the boundary conditions of the 72-inch CSO. The results show the river stages have no or little impact on the local system performance, since the river stages (23 feet and lower) are significantly lower than the lowest element in the Village's sewer system (elevation 32.24 feet). Table 1 also presents the two major local combined sewer components that discharge to the District's facilities. The 78-inch sewer draining to IS-73 primarily drains Shorewood and some drainage area from Milwaukee. The 60-inch sewer draining to IS-74A conveys flow from the City of Milwaukee. These sewers are also not impacted by high stages on the river.

The next column in Table 1 presents the number of manholes that show a hydraulic grade line (HGL) less than six feet below grade. The design criterion adopted for the Shorewood project to determine whether basement backup damages occur is six feet below grade; that is, if the HGL is kept at or below this six-foot depth, basement backups/damages are assumed to be minimal. Along with the last columns in the table, the average maximum HGL over the entire system, these two measures serve as indicators of the overall performance of the current system or any proposed improvements. The analysis shows 5 manholes out of 481 total manholes in the system are not able to meet the six feet below grade criterion even during smaller storm events such as the 20 percent (5-year) design event. It should be noted that across the Edgewood Area drainage system, there are 14 manholes (13 in Shorewood and one in Milwaukee) where the crown of the connecting pipe is less than 6 feet below grade. For these so-called shallow manholes, the performance criterion was modified such that the performance was considered acceptable if the HGL was below the highest pipe crown.

**Table 1. Milwaukee River Impacts to the Local System Performances with NS-04 Closed**

| Design Storm | Milwaukee River Stage (Village Datum, ft) | Peak Flow at IS-73 (cfs) | Total Volume at IS-73 (MG) | Peak Flow at IS-74A (cfs) | Total Volume at IS-74A (MG) | No. of Problem Manholes* | Average Maximum HGL (ft) |
|---|---|---|---|---|---|---|---|
| 20 percent (5-year) 1-hour | Normal Water Elev. | 405 | 12.4 | 65 | 2.5 | 5 | 83.8 |
| | 20 | 405 | 12.4 | 65 | 2.5 | 5 | 83.8 |
| | 23 | 405 | 12.4 | 65 | 2.5 | 5 | 83.8 |
| 2-inch 1-hour | Normal Water Elev. | 495 | 16.3 | 90 | 3.3 | 74 | 85.3 |
| | 20 | 495 | 16.3 | 90 | 3.3 | 74 | 85.3 |
| | 23 | 485 | 16.3 | 90 | 3.3 | 74 | 85.4 |
| 3-inch 1-hour | Normal Water Elev. | 520 | 26.5 | 165 | 5.5 | 239 | 89.1 |
| | 20 | 520 | 26.5 | 165 | 5.5 | 239 | 89.1 |
| | 23 | 510 | 26.5 | 165 | 5.5 | 239 | 89.1 |

* HGL less than 6 feet below grade or HGL higher than pipe crown for shallow manholes

### *Baseline Results at Key Downstream Locations*

Table 2 provides the model results with two different NS-04 operations scenarios: "Flow routed to ISS", and "NS-04 gate closed" with the river at "normal" river elevation (not wet weather). The results show the NS-04 operations have no impacts on the Milwaukee system (IS-74A), as flows for both NS-04 operating conditions are identical. NS-04 opening has a minor impact on flows leaving the Shorewood system (IS-73). The closed gate condition results in decreased flows by 15 cfs or 3 percent for the 2-inch event, and decreased flows by 30 cfs or just under 6 percent for the 3-inch storm event. However, although there is a slight difference in flows and system capacity for the different NS-04 operating conditions, the number of manholes that do not meet the six-foot HGL criterion does not change, indicating no significant impact to the Shorewood or Milwaukee systems in terms of HGL or basement flooding (there is no appreciable change in the average HGL elevation). The results in Table 2 demonstrate that District's outlet has sufficient capacity to convey the 20 percent recurrence interval flow (5-year event flow). There is a slight reduction in overall capacity when the ISS gates close because apparently, the ISS drop shaft has more capacity than the 72-inch CSO. However, the capacity of either outlet exceeds the capacity needed to discharge the 20 percent recurrence interval combined flow.

Figure 3 provides a system performance map during a 3-inch design storm. The combined sewer manholes that do not meet the 6-foot below grade criteria are highlighted in yellow, representing approximately sixty percent of the combined sewer manholes. Extensive basement backups are observed in the Village of Shorewood, south of East Capitol Drive where no partial storm sewer separation has been constructed. These results indicate a local system capacity of between a 20 and 10 percent probability (5- and 10-year) recurrence interval event. The level of service is likely closest to the 20 percent chance event as minimal surcharging is observed for the 20 percent probability (5-year) event, but there is widespread surcharging during the 2 inch per hour event.

**Table 2. Baseline Model Results at Key Locations in the System**

| Design Storm | NS04 Operation | Peak Flow at IS-73 (cfs) | Total Volume at IS-73 (MG) | Peak Flow at IS-74A (cfs) | Total Volume at IS-74A (MG) | No. of Problem Manholes* | Average Maximum HGL (ft) |
|---|---|---|---|---|---|---|---|
| 20 percent (5-year) 1-hour | Flows routed to ISS | 405 | 12.4 | 65 | 2.5 | 5 | 83.7 |
| | NS-04 gate closed overflow to river | 405 | 12.4 | 65 | 2.5 | 5 | 83.8 |
| 2-inch 1-hour | Flows routed to ISS | 510 | 16.3 | 90 | 3.3 | 73 | 85.2 |
| | NS-04 gate closed overflow to river | 495 | 16.3 | 90 | 3.3 | 74 | 85.3 |
| 3-inch 1-hour | Flows routed to ISS | 540 | 26.5 | 165 | 5.5 | 238 | 89.0 |
| | NS-04 gate closed overflow to river | 520 | 26.5 | 165 | 5.5 | 239 | 89.1 |

* HGL less than 6 feet below grade or HGL higher than pipe crown for shallow manholes

### *Baseline Model – Village Model Comparison*

As discussed previously, several modifications were made to the Village's model. Table 3 compares peak flows and total volumes for both models at the two key locations where the local systems connect to the MIS. The Village's model considered a free outfall condition for the 72-inch CSO outfall at the Milwaukee River. Therefore, the same boundary condition was assumed in the Baseline model.

Peak flows generated from the Baseline model (using the SEWRPC 2000 rainfall distribution) are slightly different than the flows generated from the Village's model (using the Huff first quartile rainfall distribution) depending on the magnitude of the storms. For the 20 percent (5-year), 1-hour and the 2-inch 1-hour rain events at IS-73, flows are about 20 percent and 9 percent higher, respectively for the Baseline model. At IS-74A, flows are about 20 percent higher for both rain events. This difference is primarily attributed to the use of the SEWRPC rainfall distribution used in the Baseline model which achieves higher runoff by allowing some of the initial rainfall volume to partially saturate the soil prior to the most intense rainfall period. The result is more runoff intensity and volume in the Baseline model than the Village's model. At IS-74A for the 3-inch rain event, Baseline model flows are a little more than 20 percent higher. However, for the 3-inch rainfall event at IS-73, the Baseline model predicts slightly lower peak flows by about 2 percent. This difference is attributed to a more explicit representation of the District's NS-04 related facilities, especially in the flow diversions at the intercepting structures. The Baseline model has higher wet weather overflow weir heights, a higher tail water elevation at the 60-inch MIS than the Village's model, which produces a lower receiving flow at IS-73, and increases the backwater on the Village's system. The total volumes received at the intercepting structures are generally similar between the two models, since both models used the same total rainfall depth in each of the design storm runs. The Baseline increases in flow and HGL (as they compare to the Village's model) also increase the number of manholes that do not meet the six foot criterion for basement backups, producing more conservative model results.

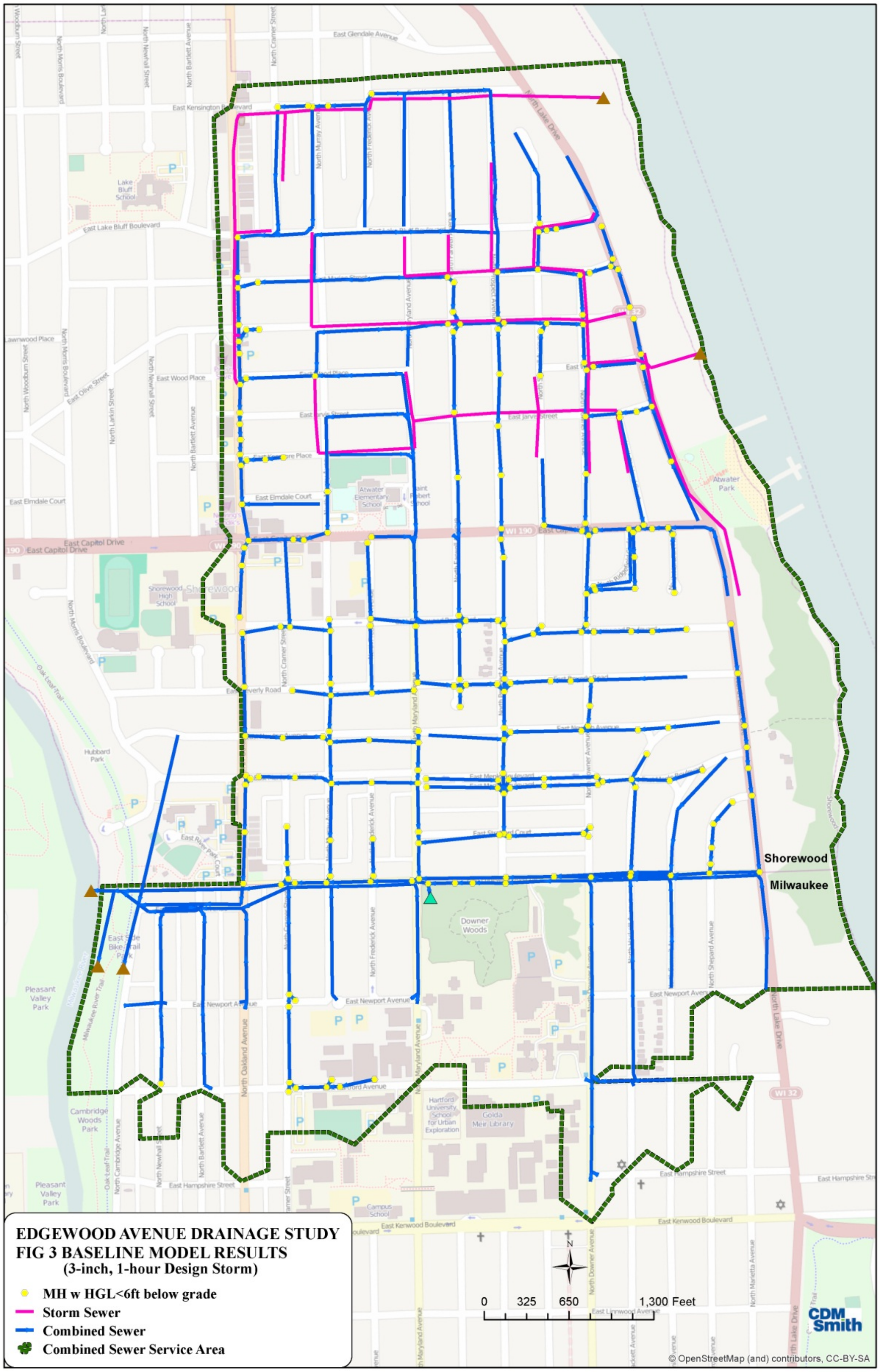


**Figure 3. System Performance Map**

**Table 3. Model Comparisons between Baseline Model and Village's Model at Key Locations in the System (free outfall to the Milwaukee River; "normal" water level)**

| Design Storm | Model | Peak Flow at IS-73 (cfs) | Total Volume at IS-73 (MG) | Peak Flow at IS-74A (cfs) | Total Volume at IS-74A (MG) | No. of Problem Manholes* | Average Maximum HGL (ft) |
|---|---|---|---|---|---|---|---|
| 20 percent (5-year) 1-hour | Shorewood | 335 | 12.3 | 55 | 2.5 | 0 | 83.6 |
| | Baseline | 405 | 12.4 | 65 | 2.5 | 5 | 83.8 |
| 2-inch 1-hour | Shorewood | 455 | 16.2 | 75 | 3.3 | 25 | 84.4 |
| | Baseline | 495 | 16.3 | 90 | 3.3 | 74 | 85.3 |
| 3-inch 1-hour | Shorewood | 530 | 25.5 | 135 | 5.4 | 163 | 87.7 |
| | Baseline | 520 | 26.5 | 165 | 5.5 | 239 | 89.1 |

* HGL less than 6 feet below grade or HGL higher than pipe crown for shallow manholes

## District's System Level of Service

To assess whether the District's receiving and outfall system to CSO091 provides a 20 percent (5-year) level of service to the local sewersheds, it was agreed in discussions with the District to compare the Baseline model flows to the hydraulic capacity of the District's system components. The District determined that flows generated by its flow model (FFS) and simulated in the CSM2011 model were representative of system-wide flows but did not produce representative flows from small, short time-of-concentration combined sewer service area sewersheds such as those in the Edgewood area. Therefore, flows generated in the Baseline model were compared to hydraulic capacities for the pipes flowing full. Table 4 presents the Baseline model 20 percent (5-year) 1-hour peak flow rate and hydraulic capacity of the District's system.

**Table 4. Comparisons between Baseline 20 percent (5-year) Peak Flows and Hydraulic Capacity of District's Facilities**

| Shorewood Peak Flows | | Milwaukee Peak Flows | | | Combined Flows | | |
|---|---|---|---|---|---|---|---|
| Baseline 20 percent (5-yr) 1-hr Peak Flow IS-73 (cfs) | 72-inch NSC (cfs) | Baseline 20 percent (5-yr) 1-hr Peak Flow IS-74A (cfs) | 60-inch NSC (cfs) | Baseline 20 percent (5-yr) 1-hr Peak Flow 96-inch NSC (cfs) | 96-inch NSC (cfs) | Baseline 20 percent (5-yr) 1-hr Peak Flow 72-inch CSO (cfs) | 72-inch CSO (cfs) |
| 405 | 465 | 65 | 265 | 440 | 1,350 | 440 | 980 |

The results in Table 4 show that the 20 percent (5-yr), 1-hr design flows produced by the Baseline model are less than the capacities of the NSC pipes that drain outflows from the local system at IS-73 and IS-74A. In addition, the combined flows from both pipes that include the flows from both north and south of Edgewood are less than the capacities of the 96-inch NSC which drains to the ISS and CSO091. The capacities of the pipe segments do not change substantially for any of the various Milwaukee River stage conditions and are adequate to pass the 20 percent design event.

It is difficult to establish exactly what level of service beyond the 20 percent recurrence interval is provided from the District's facilities, since the local sewer system lacks the capacity to convey higher flows fully to the District's system. However, similar to the Village's system, the District's system would be likely to surcharge in a 2-inch or 3-inch storm.

## Summary and Conclusions:

To evaluate the Edgewood combined sewer system capacity and restrictions, a Baseline model was prepared by modifying the Village's XP-SWMM model with the addition of the UWM's stormwater improvements and the revision of the District's combined sewer overflow system near Edgewood Avenue. The SEWRPC 2000 rainfall distribution was used to replace the Huff first quartile rainfall distribution in the Village's model to be consistent with the District's other projects and also provide a more conservative estimate of runoff. For each design storm, the system was modeled with two boundary condition scenarios, flow routed to the ISS or flow discharged to the Milwaukee River (the NS-04 gate closed). Under the flow discharged to the Milwaukee River scenario, the model was tested further to determine the impact of Milwaukee River stages on the local system performances. Three different river stages as the downstream boundary conditions of the 72-inch CSO to the river were selected: river stage at the normal water elevation (free outfall condition), river stage at 20 feet (approximate to the downstream pipe crown of the 72-inch CSO and to the FIS 10 percent annual chance flood elevation), and river stage at 23 feet (the FIS one percent annual chance flood elevation).

A set of measures was established to reveal the system performance under the different scenarios. The measures include the peak flows and total volumes at two District Intercepting Structures IS-73 and IS-74A, and the basement backup conditions in the system. The basement backup conditions were represented by number of manholes with maximum HGLs that do not meet the 6-foot below grade criteria and the average maximum HGL over the system.

- The Baseline model results were compared among the different NS-04 operations, among the different Milwaukee river stages, with the Shorewood model results, and with the hydraulic capacity of the District's system. The comparisons reveal:

- NS-04 operating conditions have no significant impact on flows leaving the Shorewood system and have no impacts on the Milwaukee system.

  The District's interceptor system provides at least a 20 percent probability (5-year) level of service.

- Milwaukee River stages have no significant impact on the 20 percent design event capacity of the District's system components associated with NS-04

- The local sewer system has a current level of service corresponding to approximately a 20-percent probability rainfall.