Detroit Water and Sewerage Department Model Extensions and Project Overview

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The Detroit Water & Sewerage Department (DWSD) collection system and WWTP serves the majority in Southeastern Michigan. This collection system has been modeled in detail since 1987. The primary model used for these evaluations has been the US EPA Stormwater Management Model (SWMM). While this model provides significant capability, the combined sewer evaluations performed for this area have required modifications both to the methods used to prepare the model and changes to the calculations performed by the model. This chapter highlights the changes that have been made to the model to provide an appropriate evaluation of the collection system performance.

Many of the new features added to the SWMM model have been driven by the need to evaluate different methods to control combined sewer overflows. Some changes were required by the sheer scope of the modeled area and by the complexity of the collection and treatment system.

The changes made include better methods to simulate flow routing; improved algorithms to simulate dry weather flow (DWF), rainfall dependent inflow/infiltration (RDI/I), and their seasonal variation; better methods to evaluate regulators, outfalls, and storage; and finally, better formats used to present the output to fairly evaluate the different options considered. Many of these updates to the model will be useful for other projects that may not have the large scope of this project.

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11.1 The Collection System

The Detroit Water & Sewerage Department serves almost three million people located in 76 communities in three counties in southeast Michigan. Because of the relatively flat topography, all of these communities are served by DWSD's single wastewater treatment plant (WWTP), which is located on the Detroit River. Average flows at the WWTP are approximately 2,440 million liters per day (650 mgd), with peak flows of 5,700 million liters per day (1,520 mgd). The WWTP will ultimately be expanded to achieve 6,370 million liters per day (1,700 mgd) of primary capacity, with secondary capacity of 3,190 million liters per day (850 mgd).

The DWSD service area covers over 2,280 square kilometers (880 square miles). Of this area combined sewers serve about 650 square kilometers (250 square miles). The system includes 126 overflow locations located on the Rouge River, the Detroit River, Lake St. Clair, and the Clinton River. Annual combined discharges from Detroit to these receiving waters are currently estimated to be 52 billion liters per year (14 billion gallons per year). Portions of these overflows receive some level of treatment.

Figure 11.1 shows the collection system and the different service areas. It should be noted that of the 76 communities, DWSD services fifteen first tier wholesale customers directly. These first tier customers provide service and billing arrangements for the remaining communities.

11.2 The Need to Model

There were a number of driving forces behind the development of the models used for the DWSD collection system. An initial model was developed in 1987 to understand the operation of the City of Detroit's collection system and provide more efficient operations. This model was used to gain a basic understanding of these conditions to formulate better operational strategies. The basic model was used for gaining operational insights. The model included only the major interceptors conveying flows to the WWTP; suburban inflows to the system were handled very simplistically.

As difficulties developed in drafting an NPDES discharge permit that incorporated control of combined sewer overflows, the U.S. Federal Court became involved. Based on comments by a technical committee formed by the U.S. Federal Court, it was noted that only fragmented analyses of portions of the DWSD collection system had been performed to date. The conclusion was reached that a system-wide model that included both the City of Detroit and the surrounding suburban communities and sanitary districts could provide better

Figure 11.1 Tributary area.

system-wide planning. As a result, a planning level model was developed between 1992 and 1994 that included interceptors, major collector trunk sewers, and detailed hydrology of the City of Detroit and the tributary suburban areas. This model was used to evaluate potential options for system-wide CSO control.

As the NPDES permit discussions developed, it was determined that a long-term combined sewer overflow (CSO) control plan must be developed for the City. At this point, it was understood that a more detailed model should be developed to properly evaluate the wide-range of potential CSO control options and recommend a final solution. As a result, the existing system-wide model was upgraded to serve the needs of the more detailed long-term planning process. This set of models, developed between 1995 and 1998, was used to address a number of issues including system capacity analysis, in-system storage analysis, review of alternatives, and evaluation of the annual performance of the recommended CSO control plan. This model continues to be used as the framework for more detailed design work.

11.3 How the Model Developed

The first model developed was referred to as the skeletal interceptor model. It only included the two major interceptors discharging to the WWTP. In fact, these interceptors were only included upstream to identifiable control points in the system such as pumping stations and control gates. The function of the model was to identify the hydraulic capacity from each different tributary areas of the collection system to the WWTP. The model was used to review the changes in capacity given the different control schemes that could be employed. These included operation of regulators, pumping stations, and control gates. Based on these interceptor capacities, estimates of annual overflow were developed using a simple HEC Storage Treatment Overflow Runoff Model (STORM).

The system-wide model included the interceptors as well as the major collector trunk sewers within the City of Detroit. Typically these included all trunk sewers three meters (10 feet) in diameter and greater, as well as trunks that convey suburban flows in the collection system. In addition, the model was extended upstream into suburban sanitary districts if they contained combined sewer overflow discharges. This provided a consistent analysis of the CSOs throughout the collection system.

Hydraulic models were developed using both the EXTRAN and TRANSPORT modules of SWMM. These models included the development of SWMM RUNOFF hydrologic models for all tributary areas, including the suburban districts. The hydrologic models included simple formulations for the wet weather flows generated in sanitary sewered areas.

Additional limitations were identified in the model as the alternative analysis was performed during the long-term CSO planning process. Additional refinements were then made to the model including further refinements to the RUNOFF hydrologic models. The limits and the updates made to SWMM are described in the following sections.

11.4 Limits of SWMM

A number of limitations were identified within SWMM through the analyses performed on the different phases of the project. Some of these limitations were related to the application of the SWMM model to the DWSD collection system and others were common to many similar analyses. The following limits were identified:

- Large subbasins – Because the scope of this model includes over 650 square kilometers (250 square miles) of combined sewer area, typical subbasin formulation was not adequate due to the larger than typical size of these subbasins. These large subbasins required

special flow routing to provide the peak flows and volumes under wide-ranging runoff conditions. The SWMM model framework does not directly support the needed changes. However, the desired hydrologic performance was provided using several components of the existing model framework.

- **Regulators** – Many system regulators are included in the model. The behavior of these regulators could not be adequately modeled using the existing SWMM formulation. The necessary modifications made to the model are described later in this chapter.
- **Outfalls** – The outfalls in the DWSD collection system are very complex structures. Significant effort was required to properly represent these structures so that upstream water surface profiles could be developed.
- **Dry Weather Flow** – Many of the simulations performed spanned significant periods of time. The continuous simulations in particular spanned several years. Since the DWF and performance of the system vary significantly throughout the year, the model framework needed updates to properly handle this variable.
- **Inflow / Infiltration** – The model framework did not directly support the wet weather contribution from sanitary sewered areas. While there are a variety of work-arounds, the project team made changes to the SWMM RUNOFF model to directly support this term. The changes incorporated into the model are detailed later in this chapter.
- **Seasonal variability** – Many of the performance parameters used in the model were observed to change throughout the year. In Detroit there are significant seasonal variations in several parameters. Since many of the modeling activities focused on continuous analysis, it was important to properly describe these changes. The seasonal variation of several parameters is described later in this chapter.
- **Storage operation** – Many of the alternatives evaluated included storage and treatment of CSOs. While SWMM TRANSPORT includes a storage element, use of this and other elements to properly model system performance significantly complicated the modeling process. As a result, an expanded storage element was devised to provide further operational flexibility as well as provide statistical information on performance. This greatly simplified model set-up and analysis. This element is described later in this chapter.
- **Statistics** – Providing the model output in a meaningful format was a challenge for the continuous modeling activities. The existing statistical formats were not useful for the large number of outputs to be tabulated. To address this, the SWMM STATS module was

modified to provide basic statistics for a large number of output locations, simplifying the preparation of performance statistics for the simulations performed. This is described later in this chapter.

11.5 Model Extensions

11.5.1 Large Subbasin Issues

Most subbasin areas included within the Greater Detroit Regional Sewer System (GDRSS) model are larger than 2.6 square kilometers (1 sq. mile). This is larger than what was intended when the SWMM model was developed. The SWMM user's manual, Huber and Dickinson (1988) recommends measuring the average overland paths and then calculating the subbasin width as the subbasin area divided by the flow length. An alternative was to calibrate the subbasin width based on the available flow data. These recommended methods resulted in very long flow lengths for the large subbasins.

It was noticed early in the modeling process that these long overland flow paths resulted in significantly more infiltration than was reasonable. The effect was that there was seldom any runoff from pervious areas in large subbasins. This was particularly evident during continuous simulations when many events had modest precipitation. In reviewing the literature, it was noticed that others have recommended that overland flow lengths over 15 to 30 meters (50 to 100 feet) not be used for urban systems (SCS, 1983). Beyond 15 to 30 meters, flows either take place in a collection system or are no longer being conveyed as sheet flow, but are part of concentrated flow where little infiltration takes place.

To adjust this, the GDRSS model was initially formulated using calculated widths that assumed 15 meters (50 feet) of overland flow. A new element, a routing channel, was developed to simulate the flow routing that takes place in the collection system within each subbasin or in the concentrated flow channel areas, as documented by Brink and TenBroek (1994). This routing channel was initially formulated as a single flat channel with dimensions tied to the subbasin area. These dimensions were generalized based on limited flow information.

During the long-term CSO planning process, it became more important to properly define the shape of the discharge hydrograph. This was because some of these alternatives reviewed source control options such as downspout disconnection, catch basin restrictions, and the addition of local storage. The effects of these options could only be evaluated if the effects on the flow hydrograph could be properly evaluated. Therefore, a complete analysis was performed of the flow routing effect in these large subbasins.

White et al. (1997) documented this work. Much of it depended on runoff relationships developed by Brater and Sherrill (1975). For this work, the performances of each of several test elements were reviewed. A complex routing

Figure 11.2 Model routing channel.

channel was selected for application within the GDRSS RUNOFF combined sewer areas. This representation simulated the peak rate and hydrograph shape well for a wide-range of storm events. A schematic of the complex element representation is presented in Figure 11.2. Key parameters for formulation include the circular pipe length and orifice area.

The routing channel element was formulated to provide good estimates of hydrograph shape for varying flow ranges. It was found that the pipe channel length could be set to route small storms such as the 12.7 mm (0.5-inch), 24-hour storm event with favorable results. Under this small event, peak flows through the complex element would not exceed the capacity of the downstream orifice storage element and would pass on into the TRANSPORT collection system. As flows increased, large events would be restricted to the capacity of the orifice storage element. The orifice element could be sized to deliver the expected peak flow rate for the 10-year, 1-hour design storm. For storm events greater than the 10-year, 1-hour, the peak would not be constrained by a maximum channel depth. In addition, the complex element can be easily modified to evaluate source control alternatives such as catch basin restriction by reducing the size of the orifice to produce a given peak reduction.

11.5 2 Regulator Issues

There are 127 overflows from the GDRSS collection system. At these discharge points there are many different types of regulation devices. These included weirs, inflatable dams, orifices, mechanical regulators, non-functioning mechanical devices, locally controlled gates, remotely controlled gates, and pipes. In many cases, these regulation devices could be simulated using orifice, weir, or pipe elements. In some cases, the regulators controlled to specific flow rates.

The standard version of SWMM TRANSPORT includes control elements that limit flows to specific flow rates. The standard SWMM EXTRAN does not have this capacity. To provide a similar function for these types of regulators, SWMM EXTRAN was modified to provide a flow-limiting element.

A second issue related to the way SWMM TRANSPORT controls flows at diversion locations. For this project, SWMM EXTRAN was used to review the hydraulic behavior at divergent points within the system under a variety of storm flow conditions. In most cases, the behavior at these locations could be characterized using what was termed a tabular flow split. A new tabular flow split element was added to SWMM TRANSPORT to support this work. The resulting SWMM TRANSPORT model mimicked the behavior observed with the more sophisticated SWMM EXTRAN model.

11.5.3 Outfall Issues

The collection system model contains many very complex outfall structures, including weirs, transition structures, multi-barrel outfalls, and backwater gates. Together, the head losses through these composite structures were very difficult to model properly.

The general approach was to represent each outfall system in the system-wide model using a two-step process. First, a HEC-2 backwater profile model was prepared for each outfall, as shown in Figure 11.3. This model was used to determine the stage-discharge relationship for each location. Next, the SWMM EXTRAN model was set-up to include hydraulically equivalent elements so that the same head losses as determined by the HEC-2 model were included. The

Figure 11.3 Outfall structure evaluation.

stage-discharge relationships obtained from both models were then compared to assess the accuracy of the representation in EXTRAN. The development of this methodology has been documented by Salim et al. (1997) using methods described by Bronner (1976 and 1987) and Burnham (1986).

The range of flow rates considered for these model comparisons were varied up to the peak flow expected during a 1-year, 1-hour design storm event. Because most rainfall events examined using this model are smaller than this design event, the resulting outfall representations have been judged to be appropriate during most important storm events. To assess the accuracy of the representation during larger events, flows generated using a 10-year, 1-hour design event were also reviewed. Figure 11.3 shows the different elements included in the analysis.

11.5.4 Seasonal Variability

Review of flow data from all the tributary areas showed that there was significant variability in some of the terms depending on the season of the year. This particularly affected the response of dry weather flow and inflow and infiltration. These are described in the sections below.

11.5.5 DWF Issues

The models used for analysis of annual performance require long-term simulations to provide the desired statistical results. A review of the dry weather flows observed at the DWSD WWTP showed that these dry weather flow rates vary throughout the year. Figure 11.4, below, shows the multiplication factors that are applied during different months during the year. High flows are typically recorded in the fall and spring. Lower flows are observed in the summer and

Figure 11.4 WWTP DWF factors.

winter periods. The factors shown are relative to a factor of 1.0 for the *driest* month (not the mean flow). The factors shown in this figure represent values developed from a two-year record of DWFs.

Initial review of these processes focused on the variability of flows at the WWTP. The observed pattern was shown to repeat with some consistency. To address this, the SWMM TRANSPORT model was modified to allow monthly changes in flow. This first approach required that all dry weather flows respond with the same changes in dry weather flow.

Subsequent data showed that different tributary areas of the collection system varied. An analysis of dry weather flows from suburban districts showed that, as expected, the variability was tied to the type of collection system and the age of the system. As a result, flow data from each of these suburban districts was evaluated and relationships were developed between the dry weather flows at the WWTP and these districts. Figure 11.5 shows the relationship between a single suburban district and flows observed at the WWTP. The data was developed from a flow meter collecting data from the suburban district that was compared to total flows measured at the WWTP. Monthly flow factors were developed for each suburban area where adequate flow data was available.

The SWMM EXTRAN and TRANSPORT models were modified to allow each subbasin to have its own monthly flow factors. This added capability provided the flexibility to allow each subbasin to accurately represent the dry weather flows that would be expected during different times of the year.

Figure 11.5 Suburban DWF relationship to WWTP.

11.5.6 I/I Issues

Review of the flow data from several sanitary tributary areas showed a variety of responses. It was noted that newer areas had significantly less wet weather response than older separately sewered areas. Because of limited flow data, initial efforts focused on developing this as a simple percentage of rainfall response. The SWMM RUNOFF model was modified to accept this formulation. This has been described by Miles et al (1996), Sherman et al. (1997), and Sherman et al. (1998).

Additional flow data showed that sanitary areas have an initial abstraction term (V_0), similar to depression storage in combined areas, where no wet weather flow is developed for small rainfall amounts. Once the initial abstraction amount is satisfied, the data generally showed a proportional response to rainfall (the RDI/I "C" slope term). The flow data also showed that each area has its own response shape depending on the size of the system and other factors. The flow data also showed that after the rainfall ended, the system recovered after a period of time so that the initial abstraction would affect the next storm. This response relationship is shown below in Figure 11.6.

Figure 11.6 I/I response formulation.

Because of the above information, SWMM RUNOFF was modified to allow the entry of an initial abstraction term, a rainfall response, and a series of shape terms. Together, these terms have been used to predict the wet weather inflows from all sanitary tributary areas.

The seasonal variability was evaluated for the initial abstraction and inflow/rainfall values. The SWMM RUNOFF model was updated to allow entry of these seasonally varying values by month. In general, the limits of the resolution for determining these values were based on a growing (summer time) and dormant

(late fall, winter, and early spring) conditions. The shape response terms were not varied, as a seasonal variation was not observed. This was as expected since the shape terms are related to the collection system configuration.

11.5.7 Storage Issues

Many of the alternatives that were evaluated included storage and treatment of combined sewer flows. The SWMM TRANSPORT model includes a storage element, as shown in Figure 11.7. To provide a simulation of the process it was used in conjunction with several splitter and manhole elements to properly define the operation of CSO basins. Because a large number of storage alternatives were evaluated, this model set-up and evaluation process was complicated and cumbersome.

Figure 11.7 Storage element formulation.

To address this, an expanded storage element was developed, also shown in Figure 11.7. This element provided for different operations such as decanting, shunting, and dewatering. The element also directly discharged to different manholes for proper categorization for dewatered, treated, untreated (using different criteria), decanted, and shunted flows. Together, this expanded storage greatly simplified model set-up and analysis.

11.5.8 Statistics

Providing the model output in a meaningful format was a challenge for the continuous modeling activities. The existing statistical formats were not useful for the large number of outputs that needed to be tabulated. To address this, the

SWMM STATS module was modified to provide basic statistics for a large number of output locations, simplifying the preparation of performance statistics for the simulations performed.

The annual parameters that were compiled were number of discharges, total discharge volume, maximum overflow event, average overflow duration, and maximum overflow duration. These statistics were compiled in a table for all manholes included in the interface file. This streamlined the evaluation process and reduced the amount of output that needed to be evaluated and compiled for simulation summaries.

11.5.9 Other Updates

Throughout this process, the project team and others that used the model reviewed the relative importance of different parameters. These reviews guided continuing development and data gathering activities as the model evolved. The items described above are changes made to the model to make it function better to reflect a better understanding of local processes.

Just as important as these model updates were the data collection activities that were undertaken to better understand the range of the parameters needed for the model. These included:

- Gathering of dry and wet weather flow data at the boundary of the suburban and City of Detroit collection system models. This allowed development of dry and wet weather flow relationships.
- Development of a project GIS to consistently assign hydrologic parameters.
- Collection of flow data in small areas to better refine hydrologic parameters.
- Development of software utilities to assist with summarizing data.

These activities and modeling tools allowed the correct data to be collected and incorporated into the model more efficiently. The project team consciously tried to keep the model simple wherever possible although the resulting model is quite complex. Elegant model formulations were sought that best reflected the observations made from the data that was collected.

11.6 Conclusions - Lessons Learned

The model development work described in this chapter took place over several years. The first simulations were rather simple and answered basic operational and capacity questions. Each of these simulations provided information that was used to define the important issues. These issues could either be operational in nature or focus on additional data gathering efforts in areas that were needed to refine the model parameters.

Throughout the modeling process, a technical committee composed of engineers from both the DWSD and the suburban communities have evaluated the data gathering, model building, and alternatives evaluation process. This process proved very valuable because it provided technical review as interim deliverables were prepared. These technical committee members understood the model formulation and underlying data as well as the project team. The added benefit was that the model became a much better representation of the entire system.

Another conclusion that the project team reached was that you should not be afraid to change the model. Many users of the SWMM model do not attempt to make changes to the model formulation or structure. While work-arounds are a way of life, it is often better to bring better formulations into SWMM so that other users can benefit. If the changes make sense, make them and document them so that other users can benefit from this knowledge.

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