Modeling Methodology for Determining Pollutant Concentrations and Loadings for Combined Sewer Overflows: A Simplified CSO Model

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The Detroit Metropolitan area occupies much of the basin of the Detroit River - the basin as a whole is home to about four million people. The Detroit River provides important habitat for fish and birds. Atmospheric transport and deposition of chemical contaminants over the entire basin, leakage from sites contaminated according to Michigan's Act 307, and industrial effluents to the system provide sources for a variety of toxic chemicals to the Detroit River through the combined sewer overflow (CSO) process (Arimoto, 1989; Michigan Department of Natural Resources, 1993; Michigan Department of Natural Resources and Ontario Ministry of Environment, 1995). The Detroit River receives treated and untreated waste water from the City of Detroit and suburban districts, industries, runoff from urban and agricultural lands, and effluent from combined sewer overflows (Lin, 1994; Roginski, 1981; USEPA and EC, 1988; Rhee, 1995). The city is entirely served by combined sewers. As might be expected, CSOs have been demonstrated to be a major source of conventional and toxic contamination to the Detroit River, for example by the 1979-1980 major monitoring and modeling work on the section 201 Final Facilities Plan

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conducted by the Joint Venture (Giffels et al., 1980), to characterize the Detroit River CSO loadings and the Detroit River Remedial Action Plans (Stage I & II) (Michigan Department of Natural Resources and the Ontario Ministry of the Environment, 1991; Michigan Department of Natural Resources and Ontario Ministry of Environment, 1995).

A simplified CSO model has been developed as a rapid and inexpensive way to estimate and assess potential environmental hazards, as opposed to standard cause-and-effect modeling which typically costs \$2,000,000 to \$15,000,000 per study for Detroit. This model is a large-scale multiple-input multiple-output (MIMO) system. The modeling task can be eased by applying the decomposition-coordination strategy of the large-scale system theory (Huang and Fan, 1993). The goal of the present work is to use the field data generated by the current Southeast Michigan Council of Governments, U. S. Geological Survey, and Detroit Water and Sewerage Department (SEMCOG/USGS/DWSD CSO; Perry, 1996) study, and other resources to build a simplified CSO model capable of correlating and predicting the CSO concentrations and loadings to the Detroit River. Three groups of input variables to the model have been considered: the runoff concentrations of pollutants by land use; the runoff and CSO volumes; and the dry weather flow rates and concentrations of pollutants. This study focuses on three constituents, cadmium, copper, and lead.

The *first* input data, the runoff concentrations of cadmium, copper, and lead as a function of land use, were obtained from the stormwater pollutant loading factors presented in the Rouge River National Wet Weather Demonstration Project Report (Cave, et al., 1994). These runoff concentrations by land use already incorporate whatever leakage from Michigan's Act 307 contaminated sites and atmospheric deposition occur through runoff during the antecedent period. The *second* input data, the runoff and CSO volumes, were obtained from SEMCOG's database system (daily precipitation) and the CDM report (Camp Dresser and McKee, 1993). The *third* input data, the dry weather flow rates and concentrations of cadmium, copper, and lead, have been obtained from the DWSD Industrial Waste Control (IWC) database (1993-1994) and residential sources (Salley and Kummler, 1986; Garakani et al., 1991).

Because actual case studies involved complicated geometry and source functions, the modeling was performed in two model scenarios. First, daily average based estimation of CSOs concentrations was conducted using 1980 cadmium data from the City of Detroit's Section 201 Final Facilities Plan report for whole Detroit River basin (Kummler, 1983; Salley and Kummler, 1987). Second, a storm event based estimation of CSO concentrations was performed for two sampling sites (Conner Creek and Fischer sites). Four CSOs discharging to the Detroit River were monitored in 1994-1995 to characterize storm-related water quantity and quality to calculate their respective pollutant loads.

17.1 Theoretical Modeling Background

A simplified CSO model is presented as a rapid and inexpensive way to predict the CSO loadings and concentrations of contaminants. Figure 17.1 shows a simplified sewerage/CSO system.

Figure 17.1 Simplified sewerage/CSO system.

The system has $(n+1)$ inputs and $(n+1)$ outputs. Each input represents a sewer line. Variables Q_{S_i} and C_{S_i} ($i=1,2,\dots,n$) are designated, respectively, the volumetric flow rate of the i -th stream and the concentration of a pollutant in it. These variables are further divided into variables $Q_{S_i}^r$ and $C_{S_i}^r$ for the runoff, and $Q_{S_i}^d$ and $C_{S_i}^d$ for the dry weather flow of conservative contaminants.

$$Q_{S_i} = Q_{S_i}^r + Q_{S_i}^d \quad (17.1)$$

$$C_{S_i} = \frac{Q_{S_i}^r}{Q_{S_i}} C_{S_i}^r + \frac{Q_{S_i}^d}{Q_{S_i}} C_{S_i}^d \quad (17.2)$$

Q_0 and C_0 characterize a wastewater stream from all other sources that connect directly to the main sewer interceptor without being part of CSOs. Corresponding to each sewer line, there is a CSO outfall to the river. Variables Q_{C_i} and C_{C_i} ($i=1,2,\dots,n$) are designated, respectively, the volumetric flow rate of the CSO stream and the concentration of the pollutant in it. The other output is the main stream going to the Detroit Wastewater Treatment Plant (DWWTP). This main stream is characterized by variables Q_{t_i} and C_{t_i} representing the volumetric flow rate of the stream and the concentration of the pollutant in it. Variables Q_T and C_T are designated, respectively, the total volumetric flow rate and concentration to the DWWTP.

17.1.1 Sub-system Model for a Daily-Average-Based Estimation

The structure of each of the n sub-systems is illustrated in Figure 17.2 for a detailed analysis. Here we neglect hydraulic interactions between adjacent sub-systems. Each sub-system is still modeled as a mixer-splitter, with the following assumptions:

1. As a mixer, the flow rate is the sum of the flow rates of all input streams. In the mixer, perfect mixing is assumed. Hence, the concentration of a pollutant is the ratio of the total input of the pollutant to the total volume flow into the sub-system.
2. As a splitter, the concentration of the pollutant in each split branch is the same as that before splitting; the sum of the flow rates in all branches is the same as the flow rate before splitting.
3. Any wastewater leakage from the mixer-splitter is negligible.

In each sub-system i , there exist two inputs, a dry weather flow and a runoff. Each input is characterized by the flow rate of a stream and the concentration of a pollutant in the stream. The two inputs are well mixed in the mixer. The mixed stream is characterized by the flow rate, Q'_{s_i} , and the concentration of a pollutant, C'_{s_i} . The mixed stream is then split into two branches. One branch as a CSO goes directly to the Detroit River. The flow rate of this stream, Q_{C_i} , is a portion of the runoff into the same sub-system. This portion is characterized by the factor, f'_i . Thus:

$$Q_{C_i} = f'_i Q'_{s_i} \quad (17.3)$$

According to the CDM report (Camp, Dresser, and McKee, 1993), this factor averages 0.51 for the entire DWSD system; this value is used throughout this study, but can be changed if site-specific information is available. The concentration of the CSO, C_{C_i} , is the same as that of the mixed stream, C'_{s_i} , as the splitting only affects the flow rate.

Figure 17.2 Structure of a sub-system.

The other branch joins other down-flow streams from the sub-systems ahead of it and eventually goes to the DWWTP. The flow rate of this branch, Q_{t_i} , is:

$$Q_{t_i} = Q'_{s_i} - f'_i Q_{s_i}^r \quad (17.4)$$

From Figures 17.1 and 17.2, we can find that each of the n sub-systems is independent in estimating the concentration and flow rate of the CSO to the Detroit River. In other words, the concentration and the loading of any pollutant of the CSO are solely determined by the runoff and dry weather base flow into the same sub-system (neglecting infiltration and inflow). The concentration of a particular pollutant in the CSO in the sub-system i is:

$$\begin{aligned} C_{C_i} &= C'_{s_i} \\ &= \frac{Q_{s_i}^r C_{s_i}^r + Q_{s_i}^d C_{s_i}^d}{Q_{s_i}^r + Q_{s_i}^d} \end{aligned} \quad (17.5)$$

The loading of the pollutant in the CSO, L_i , is:

$$L_i = Q_{C_i} C_{C_i} = f'_i Q_{R_i} \frac{Q_{s_i}^r C_{s_i}^r + Q_{s_i}^d C_{s_i}^d}{Q_{s_i}^r + Q_{s_i}^d} \quad (17.6)$$

The values of $Q_{s_i}^r$, $C_{s_i}^r$, $Q_{s_i}^d$, $C_{s_i}^d$, and f'_i can be obtained or estimated from the CDM report, the Technical Memorandum No. 34 of the Rouge River national wet weather demonstration project report, and the DWSD Industrial Waste Control (IWC) database.

Note that the selection of the number of sub-systems is determined by the data availability, the requirement of prediction precision, etc. The index i for differentiating sub-systems can be individual CSOs (45 CSO locations along the Detroit River in the U.S. side) or can be aggregated CSOs for comparison to Treatment Plant or globally averaged CSO statistics.

17.1.2 Sub-system Model for an Event-Based Estimation

The model given in Equations 17.5 and 17.6 is a steady-state model and thus can not be directly used for an event-based estimation. However, this model can be easily modified as a pseudo-dynamic model with an acceptable prediction error, if the following assumptions hold:

1. The dry weather flow data inputs are constant. This implies that $Q_{s_i}^d$ and $C_{s_i}^d$ do not change during wet weather events.
2. The runoff concentration, $C_{s_i}^r$, is independent of time during the event. The runoff concentration, $C_{s_i}^r$, can be obtained from the stormwater pollutant loading factors presented in the Rouge River National Wet Weather Demonstration Project Report (Cave et al., 1994).

The SWMM RUNOFF model calculates the amount and timing of overland discharge $Q_{s_i}^r$ from defined combined sewered areas for specific rainfall events. This SWMM model can simulate the runoff response with a variety of different rainfall hyetographs imposed on different portions of the system.

With the above two assumptions, we can derive a pseudo-dynamic model based on the steady-state model in Equations 17.5 and 17.6. The concentration of a pollutant in the CSO at the time t , i.e. $C_{C_i}(t)$, can be evaluated:

$$C_{C_i}(t) = \frac{Q_{s_i}^r(t) C_{s_i}^r + Q_{s_i}^d C_{s_i}^d}{Q_{s_i}^r(t) + Q_{s_i}^d} \quad (17.7)$$

The loading of the pollutant in the CSO to the Detroit River at time t , i.e. $L_i(t)$, is:

$$\begin{aligned}
 L_i(t) &= Q_{C_i}(t)C_{C_i} \\
 &= f_i Q_{s_i}^r(t) \frac{Q_{s_i}^r(t)C_{s_i}^r + Q_{s_i}^d C_{s_i}^d}{Q_{s_i}^r(t) + Q_{s_i}^d}
 \end{aligned} \tag{17.8}$$

17.2 Modeling Methodology

A simplified CSO model has been developed for the prediction of CSO loadings and concentrations to the Detroit River. We have considered three groups of input variables to the model: the runoff loadings and concentrations of pollutants by land use; the runoff and CSO volumes; and the dry weather loadings and concentrations of pollutants. In this study we focused on three constituents, cadmium, copper, and lead.

The first input data, the runoff concentrations by land use of cadmium, copper, and lead were obtained from the stormwater pollutant loading factors presented in the Rouge River National Wet Weather Demonstration Project Report (Cave et al., 1994). These runoff concentrations, which are a function of locally derived land use empirical values, automatically incorporate the average leakage from Michigan's Act 307 contaminated sites and atmospheric deposition through runoff.

The second input data, the runoff and CSO volumes, were obtained from SEMCOG's database system (daily precipitation) and the CDM report (Camp Dresser and McKee, 1993). CDM developed a complete hydraulic model of the major sewer interceptors to estimate response to rainfall events and assess potential combined sewer overflow control measures within the region tributary to the DWWTP in 1993. They selected the period of record of precipitation for January 1, 1982 through December 31, 1992 and calculated the annual average rainfall to be 34.25 inches (870 mm). However we require the precipitation record for the specific year. The Michigan Department of Agriculture (MDA) manages the SEMCOG rain gage network data; they supplied the daily average precipitation summary of the 72 stations in the SEMCOG Network for the years 1982 through 1994 in a digital format (the MDA/Climatology and MSU/Agricultural Weather Service Program's jointly operated Bulletin Board System). We selected ten rain gage stations over the Detroit River basin and calculated the arithmetic (equivalent to area averaged) average of gaged quantities for any specific year.

The third input data, the dry weather flow rates and concentrations of cadmium, copper, and lead, were obtained from the DWSD IWC database (1993-1994) and residential sources (Garakani et al., 1991; Kuplicki, 1995).

The schematic diagram of simplified CSO modeling is shown in Figure 17.3. Because actual case studies involved complicated geometry and source functions, the modeling was performed in two model scenarios. First, daily-average-based estimation of CSOs concentrations was conducted using the cadmium data in 1980 from Section 201 Final Facilities Plan report for the whole Detroit River basin. Second, storm-event-based estimation of CSOs concentrations was performed for two sampling sites (Conner Creek and Fischer sites).

The U.S. Geological Survey (USGS) monitored four CSOs discharging (Conner Creek, Fischer, Schroeder, and Rosa Parks sites) to the Detroit River in 1994-1995 to characterize storm-related water quantity and quality and to calculate their respective pollutant loads. Flow measuring stations are located as near as practicable to the outlet of each CSO. Water-level, velocity, discharge, and precipitation were measured continuously. Samples at all sites were collected at discrete times during each storm event. Thus estimates of variability of pollutant concentrations during a single event can be made (these could be stochastically distributed in a next version).

Figure 17.3 Schematic diagram of simplified CSO model.

17.2.1 Daily-Average-Based Estimation: Model Scenario I

In daily-average-based estimation we used the flow rates and concentrations data of cadmium in 1980 from Section 201 Final Facilities Plan Report (Giffels et al., 1980). The dry weather quality and industrial waste loadings were available for the Detroit Water and Sewerage Department's service area at various locations.

17.2.2 Data Input for Model Scenario I

Three input variables are used for this Model Scenario 1: the average daily runoff concentrations by land use, the average daily runoff and CSO volumes, and the average daily dry weather flow rates and concentrations of cadmium.

Average Daily Runoff Concentrations by Land Use for Cadmium

We used the recommended concentrations by land use category (Table 17.1) presented in the Rouge River National Wet Weather Demonstration Project report (Cave et al., 1994).

Table 17.1 Average daily runoff concentrations by land use category for four constituents.

Land use Category	Percent Imperv.	Cd (µg/l)	Cu (µg/l)	Pb (µg/l)
Forest/Rural Open	2.0 %	0	0	0
Urban Open	11.0 %	1	0	14
Agricultural/Pasture	2.0 %	0	0	0
Low Density Residential	19.0 %	4	26	57
Medium Density Residential	38.0 %	4	26	57
High Density Residential	51.0 %	3	33	41
Commercial	56.0 %	3	37	49
Industrial	76.0 %	5	58	72
Highways	53.0 %	3	37	49
Water/Wetlands	51.0 %	1	7	11

Average Daily Runoff and CSO volumes

We decomposed the Metro-Detroit basin into four sub-systems and obtained the runoff and CSO volumes (Table 17.2) following the CDM report (Camp Dresser and McKee, 1993).

These concentrations are typically total recoverable metals, and are used because the dissolved fraction is not available. Sedimentation and resuspension values are unknown and in this work that level of detail is not desired.

Table 17.2 Runoff and CSO volumes for sub-systems.

	District	Runoff (MGD)	CSO (MGD)
Sub-system 1	Fox Creek	5.8	3.0
Sub-system 2	East Side	8.6	4.1
Sub-system 3	Central City, S.E. Oakland, Evergreen-Farmington	86.6	46.2
Sub-system 4	West Side, Western Wayne County	40.1	18.6

Dry Weather Flow and Concentrations

The dry weather flow and concentrations of cadmium in 1980 were obtained from Section 201 Final Facilities Plan report (Giffels et al., 1980).

17.2.3 Storm Event-Based-Estimation: Model Scenario 2

In storm-event-based estimation we used the flow rates and concentrations data of cadmium, copper, and lead in 1993 from the DWSD Industrial Waste Control (IWC) database.

Monitoring Sites

Conner Creek District. Conner Creek district drains primarily into the Conner Creek Sewer, which flows in a general north-south direction and discharges through the Conner Creek regulator into the Detroit River Interceptor (DRI) or through the Conner Creek outfall to the Detroit River. The Conner Creek Sewer also transports suburban flow from the City of Centerline.

Fischer District. Fischer district is a small overflow draining area from primarily residential areas in the vicinity of Indian Village. Flow transported in the Fischer Sewer is either pumped into the DRI by the Fischer Pump Station or overflowed to the Detroit River through a triple box outfall.

Data Input for Model Scenario 2

Three input variables are used for storm-event-based estimation (Model Scenario 2): the average runoff concentrations by land use, the average CSO volumes by unit time, and the average dry weather flow rates by unit time and concentrations of cadmium, copper, and lead.

Average Runoff Concentrations by Land Use for Three Constituents. We used the recommended concentrations by land use category (Table 17.1) presented in the Rouge River National Wet Weather Demonstration Project report (Cave, et al., 1994).

Average CSO Volumes per Unit Time. The Storm Water Management Model (SWMM) Runoff block calculates the amount and timing of overland discharge from defined combined sewer areas for specific rainfall events. This model can simulate the runoff response by a variety of different rainfall hyetographs imposed on different portions of the system. This makes the model ideally suited for computing runoff from a number of tributary areas based on a spatially varied rainfall input. Since the objective of this work is to create a simplified model not dependent on SWMM, we arbitrarily used a hypothetical Gaussian storm model.

Dry Weather Flow by Unit Time and Concentrations. The average dry weather flow rates per unit time and concentrations of cadmium, copper, and lead, have been obtained from the DWSD IWC database (1993-1994) and residential sources.

17.3 Modeling Results and Discussion

Two model scenarios were evaluated using a simplified CSO model. First, daily-average-based estimation of CSOs concentrations was conducted using the cadmium data in 1980 from Section 201 Final Facilities Plan report for the whole Detroit River basin. Second, storm-event-based estimation of CSOs concentrations was performed for two sampling sites (Conner Creek and Fischer sites).

17.3.1 Daily-Average-Based Estimation: Model Scenario 1

The estimated average daily CSO concentration of cadmium for overall system in 1980 is 27.2 $\mu\text{g/l}$, which is 15% lower than the CSO monitoring data (32.0 $\mu\text{g/l}$ in 1979 from Section 201 Final Facilities Plan Report (Giffels et al., 1980). The computed average daily concentration of DWWTP inflow (30.6 $\mu\text{g/l}$) in 1980 is 11% higher than the estimated average daily CSO concentration (27.2 $\mu\text{g/l}$). The computed results are illustrated in Figure 17.4.

17.3.2 Storm-Event-Based Estimation: Model Scenario 2

Quantification of Combined Sewer Overflow

We used the hypothetical time-series CSO volume for each district (Table 17.3).

Dry Weather Flow Rates and Concentrations

The Industrial Waste Control (IWC) database includes information only for Significant Industrial Users (SIU) that are required to participate in the Industrial Pretreatment Program. Hence we treated the concentration of the flow contributed

Figure 17.4 Average daily flow rates, concentrations, and loadings of cadmium for DWWTW inflow, CSO runoff, and dry weather flow in 1980.

Table 17.3 Time-series CSO volume (MGH) distribution for typical storm event.

	Conner Creek	Fischer
Time + 1 hr	16.12	0.21
2 hr	37.36	0.50
3 hr	24.75	0.33
4hr	12.00	0.16
5 hr	6.00	0.08
6 hr	2.81	0.04
7 hr	1.35	0.02
8 hr	0.68	0.01
9 hr	0.34	0.005
10 hr	0.15	0.002

from remaining Industrial Users as the same as that of residential flows. The concentrations of residential flow for cadmium, copper, and lead, were obtained from the dry weather flow analysis of domestic/commercial discharges in the DWSD Industrial Waste Control Program Report (McNamee et al., 1995). Table 17.4 summarizes the dry weather flow concentrations for three parameters.

Table 17.4 Dry weather flow concentrations for industrial and residential flows.

	Industrial Effluent ($\mu\text{g/l}$)	Residential Effluent ($\mu\text{g/l}$)
Cadmium	13.8	0.8
Copper	209.7	25.3
Lead	111.3	6.2

Predicted Time-series CSO Concentrations

The computed time-series CSO concentrations of three constituents at two sampling sites (Conner Creek and Fischer) are illustrated in Figures 17.5 through 17.7. The averages of computed CSO concentrations for each parameter were compared with the averages of pollutant qualities (Table 17.5) that were sampled and analyzed during 1994-1995 by USGS and DWSD.

As shown in Figure 17.5 for CSO concentration of cadmium for the 10 hour duration, the concentration follows the runoff flow so that the CSO concentration profiles illustrate a decreasing trend after the peak flow (2nd hour) of CSO. This decreasing trend occurs in both Conner Creek district and Fischer district. Figure

17.6 represents the CSO concentration of copper at two sites. The concentration of copper in the Conner Creek district shows dilution by runoff flow that is opposite to the Fischer site. For the Conner Creek district, the industrial effluents from many plants are diluted with runoff flow. For the Fischer district, the CSO volume consists primarily of residential effluents and is concentrated with runoff flow during the storm event. Figure 17.7 illustrates how the lead concentration for two CSO sampling sites increases during the 10 hour period.

Figure 17.5 Storm-event-based computation of time-series CSO concentration of cadmium in 1993 for two sampling sites.

The USGS has measured the CSO event concentrations at four CSO locations. We can compare the theoretical predictions with the USGS field data if we adjust the USGS data sets for samples with values below the detection limit. We assumed that the concentrations which are recorded as below detection limit (BDL) are equal to 50% of the detection limit.

Based upon the results (Table 17.5) for the storm-event-based estimation for the Conner Creek site, the average of computed CSO concentrations of cadmium during a 10 hr period deviates by 60% from the measured value, copper (Cu) 18%, lead (Pb) 28%. For the Fischer site, the average of computed CSO concentrations of cadmium (Cd) differs by 49%, from the monitored value, copper 58%, lead

Figure 17.6 Storm-event-based computation of time-series CSO concentration of copper in 1993 for two sampling sites.

Figure 17.7 Storm-event-based computation of time-series CSO concentration of lead in 1993 for two sampling sites.

44%. Values for Conner Creek are believed to be more accurate because Fischer flow rates are much lower and concentrations are therefore subject to a greater representativeness problem.

Table 17.5 Comparison of averages of computed and monitored concentrations (µg/l).

	Conner Creek					Fischer				
	Computed		Monitored*		Diffe- rence (%)	Computed		Monitored*		Diffe- rence (%)
	Conc.	Std. Dev.	Conc.	Std. Dev.		Conc.	Std. Dev.	Conc.	Std. Dev.	
Cd	2.21	0.10	5.50	4.63	-60	2.46	0.90	4.84	5.26	-49
Cu	31.2	6.6	39.8	38.2	-18	27.6	1.3	65.0	68.1	-58
Pb	26.8	6.0	37.1	52.9	-28	33.0	14.5	59.1	71.0	-44

* From USGS/DWSD monitored data during 1994-1995 (Conner Creek: 24 samplings, Fischer: 36 samplings).
Assumed that concentrations which are recorded as BDL are equal to 50% of the detection limit.

17.4 Conclusion

Representing a design in which sewage and surface runoff combine and exceed retention and treatment system capacity, CSOs are identifiable as a troubling source of contamination for water bodies that are cumulative recipients of overflows. CSOs collect and transmit contaminants from a variety of other sources. Since 1989, the DWSD has been engaged in discussions with the Michigan Department of Environmental Quality (MDEQ), the National Wildlife Federation (NWF) and the Greater Detroit Chamber of Commerce (CofC) on the activities to be undertaken to minimize PCB and mercury inputs to the sewer system (Detroit Water and Sewerage Department, 1995). Because of the City of Detroit’s Industrial Pretreatment Program, the general decline of industrial activity in the area, the conscientious efforts of industries to reduce discharges through pollution prevention, and other factors, the CSO concentrations and loadings of pollutants were substantially reduced during the last decade.

This study is a planning level approach to the CSO concentration prediction at CSO outfalls using a simplified CSO model. The average runoff concentrations of pollutants by land use, the average runoff and CSO volumes, and the average dry weather flow rates and concentrations of pollutants were used as inputs to the model. The modeling was performed for two model scenarios: a daily-average-based estimation and a storm-event-based estimation.

The results for the daily-average-based estimation indicated that the computed average daily CSO concentration of cadmium for the overall system in 1980 (27.2 $\mu\text{g/l}$) is close to the monitored data (32.0 $\mu\text{g/l}$) in 1979. The results for the storm-event-based estimation revealed that the average of computed CSO concentrations of cadmium in the Conner Creek site during a 10 hr period deviates by 60% from the measured value, copper 18%, lead 28%. For the Fischer site, the average of computed CSO concentrations of cadmium differ by 49% from the monitored value, copper 58%, lead 44%.

According to the computed CSO concentration of cadmium for the 10 hour duration, the concentration occurs by the runoff flow so that the CSO concentration follows a decreasing trend after the peak flow (2nd hour) of CSO. This decreasing trend occurs in both the Conner Creek district and the Fischer district. The CSO concentration of copper in the Conner Creek shows dilution by runoff flow that is opposite to the Fischer site. For the Conner Creek district, the industrial effluents from many plants are diluted with runoff flow. For the Fischer district, the CSO volume consists primarily of residential effluents and is concentrated with runoff flow during the storm event. For the CSO concentration of lead in two sampling sites, the runoff flow increases the CSO concentrations during a 10 hour period.

The shape of the hyetograph can have a major effect on the runoff characteristics in relatively small, urbanized basins. In order to estimate the more accurate time-series CSO volumes for sampling sites, the SWMM model is a useful tool for the evaluation.

Consequently, the simplified CSO model offers a good procedure to estimate the CSO concentrations for pollutants to assist in remediation decision-making. This model is applicable to any Area of Concern, for example, Rouge River, although the Rouge studies can afford predictive, continuous modeling.

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