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SIMULATION OF COMBINED SEWER OVERFLOWS: A CASE STUDY

by

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ABSTRACT

This paper deals with computer simulation of the combined sewer overflows from an urban catchment served by a combined sewer system. Discussions of results are based on long-term simulation of overflow volumes and the relationships between the volumes and the loads of pollutants discharged.

RÉSUMÉ

Ce rapport porte sur la simulation informatique de débordements d'égouts unitaires situés dans un bassin-versant desservi par l'égout unitaire. L'analyse des résultats est fondée sur la simulation à long terme du volume des débordements et sur les rapports entre ces volumes et la charge en polluants qui est déversée.

MANAGEMENT PERSPECTIVE

Computer simulation has become a useful tool for study of water resources for planning and control measures, in particular, where field data is limited.

This paper describes the application of a computer model to simulate the quantity and quality of combined sewer overflows for that part of the City of Hamilton which is served by combined sewers. The simulated overflow volumes and pollutants were evaluated for long-term rainfall data set.

PERSPECTIVE-GESTION

Les simulations informatiques sont devenues un instrument utile d'étude des ressources en eau axées sur la planification et les mesures de lutte contre la pollution, notamment lorsque les chercheurs ne disposent que de données limitées.

Cet article décrit l'application d'un modèle informatique à la simulation en quantité et en qualité des débordements des égouts unitaires qui desservent une partie de la municipalité d'Hamilton. Les volumes produits et la composition en contaminants ont été évalués à partir d'un ensemble de données relatives à des précipitations à long terme.

INTRODUCTION

Hamilton Harbour has been identified by the Great Lakes Water Quality Board (1987) of the International Joint Commission (IJC) as an area of concern. It is generally referred to as a water body with environmental degradation within the Canadian portion of the Great Lakes system.

The sources for such degradation included municipal and industrial discharges, combined sewer overflows and urban and agricultural land runoffs. Such contributors to the degradation of the Hamilton Harbour water quality has been discussed elsewhere (Rodgers et al., 1988).

Hamilton Harbour receives combined sewer overflows from the older part of the City of Hamilton. The report which follows describes a computer simulation study of the overflow volumes and loads of pollutants discharged from that area.

DESCRIPTION OF THE STUDY AREA

The location of the study area is shown in Figure 1. The area is served by a combined sewer system which collects stormwater and sanitary waste flows. The collected flows are conveyed by the trunk sewer interceptors to the Wastewater Treatment Plant (WWTP) for treatment. A retention tank (60,000m^3) has just been constructed but not yet been fully operational during the course of this study (Figure 2).

DESCRIPTION OF HAMILTON'S COMBINED SEWER SYSTEM

During the dry weather conditions, the sanitary discharges are conveyed through the deep trunk interceptors to the WWTP for treatment. During wet weather, the combined sewer flows exceed the capacity of the WWTP and it is necessary to divert the excess flows directly to the receiving water. The volumes of such overflows and their pollutants loads were determined in this study.

METHODOLOGY AND DATA LIMITATION

The STORM model (U.S. Corps of Engineers, 1977) was selected for the purpose of this study, because the model works on long term rainfall records, representing many months or years. The model is computationally less intensive and precise. Description of the STORM model has been reported elsewhere (U.S. Corps of Engineers, 1977; Whipple et al.,1983).

Ten years (1976-1985) of hourly precipitation, daily temperatures and daily rates of pan evaporation for each month were selected from station 2 (Figure 1), because of their availability and the least deviation of annual precipitation from Theissen distribution among the four nearest station. The hourly precipitation and evaporation rates were available from April to October. Therefore, for the remaining months it was necessary to divide the equal hourly values from available daily value and enter them into the time series data base. The missing daily evaporation rates from November to March were estimated.

PARTIAL CALIBRATION

Two separate data sets were available for volumetric calibration. The data set from Robinson and James (1982) contained four runoff events and a data set from Gore and Storrie (1977) included five runoff events which were used for calibration of subbasins B and C (Figure 2) respectively. The data sets for subbasins B and C are measured in catchment areas of 950 ha and 55 ha, respectively. The impervious surfaces for subbasins B and C were 29% and 41% respectively. There were no suitable data set for subbasin A. Consequently, the mean value of C_{imp} determined from subbasin C and the model's default value had to be used. The results of calibrations described by the ratios of simulated to observed data were 1.08, and 1.07, for subbasins B and C respectively.

Due to lack of measured water quality data in the study areas, calibration of water quality could only be performed by means of comparison of annual unit loads with results from earlier studies. The comparisons of the annual unit loads within an order of magnitude of reported values were considered to be adequate because the water quality characteristics in the combined sewer system vary greatly from one community to another (Hogland et al., 1984). The suspended solids (SS) and the biochemical oxygen demand (BOD) were selected for this study, because they were the primary concerns in urban runoff. Such concerns have been addressed elsewhere (Ellis, 1986). The results of calibrations for annual unit loads, including those reported by various workers, are shown in Table 1.

SIMULATION APPROACHES

The simulation proceeded with the current treatment rates and with a storage (60,000m^3) option. In order to reduce the computation time, subbasins, A, B, and C were aggregated into a single contributing catchment. The physiographic and hydrologic data for the aggregated catchment are presented in Table 2.

RESULTS AND DISCUSSIONS

The results of volumetric calibration appeared to be adequate as indicated by the results of earlier studies dealing with urban runoff volumes (Dillon, 1979). The comparisons of annual unit loads of SS and BOD (Table 1) showed variations from one study to another. This is conceivable, because each study area was characterized by different types of land use, and different size of catchment with various percentual imperviousness of land surfaces. Despite the numerous factors affecting the pollutant loads, the simulated annual unit loads of SS and BOD were within an order of magnitude of the earlier data. Such an accuracy is generally considered sufficient in planning studies (Whipple et al., 1983; Marsalek and Ng, 1987).

The application of continuous rainfall data in simulation of combined sewer overflows furnishes a time history of the response of the combined sewer system to all kinds of rainfall events. The time history of the rainfall events, described by such parameters as rainfall intensity and its duration, are important for estimation of overflow volumes (Figure 3) and loads, because they are the primary factors causing overflows. Figure 4 demonstrated the relationships between the rainfall amount and the overflow volumes and the effectiveness of an added storage capacity.

The STORM analysis of pollutants production from the study area and its overflows to the receiving water are presented in Table 3. It was not adequate for establishing the relationships between the overflow volumes and the loads discharged. However, it is interesting to note that the larger overflow volumes produced the lower concentrations of the pollutants. This is because the concentration of pollutants in stormwater runoff, in general, is lower than the concentration of pollutants in the sanitary flow (Water Resources Branch, 1979). Thus, when stormwater runoff entered the combined sewer system, a dilution of the sanitary flow took place. Further dilution would be expected if the volume of runoff was to increase.

Validation of the simulated overflow volumes was conducted based on the difference between simulated combined sewer flow volumes and the annual volume treated at the WWTP. The results of validation indicated a 5% overestimation for the simulation results.

SUMMARY

The long-term overflow volumes (June to September) accounted for about 65% and 38%, for the highest and lowest, respectively, of the yearly overflow volumes. There was no rigorous relationships between the overflow volumes and their pollutant loads. Instead, it was found that there was a dilution of pollutants in the overflow volumes.

In the overall estimation for the existing treatment capacity, about one-third of the annual wet weather flow, a mixture of stormwater and sewage, may be diverted in the form of combined sewer overflows to the receiving water. With an added storage capacity of 60,000 m^3, the simulated overflow volumes would be reduced to about one quarter of the annual overflow volume. Because of the uncertainties inherent to the simulation process and assumed spatially uniform rainfall input, the simulation results may be overestimated, since spatial rainfall distribution plays a significant role in the evaluation of runoff volumes (Mignosa and Paoletti, 1986).

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Table 1. Comparison of Pollutants in Combined Sewer Studied

Name	Year	Area Mean (ha)	Imp. %	Unit Loads (kg/ha/yr) SS	BOD
Maclaren	1978	491	51	431	36
Robinson & James	1982	12,060	39	1,713	46
Present Study	1989	6,169	38	243	37

Note: SS and BOD concentration from WWTP records (1981-85) were 425 mg/l and 200 mg/l respectively.

Treatment rates: Max. = $409 \times 10^3 m^3$/day,
Min. = $196 \times 10^3 m^3$/day.

Table 2. Physiographic and Hydrologic Data

Land Use:	Area (ha)	Impv. (%)
Residential	3,905	40
Institutional	284	15
Commercial	530	86
Industrial	568	42
Open	882	2

Table 3. Annual Precipitation and Simulated Annual Overflow Volumes and Pollutant Loads

				Pollutant Loads									
				SS					BOD				
				n/s			w/s		n/s			w/s	
Year	P (mm)	OV n/s	OV w/s	W	O	C	O	C	W	O	C	O	C
1976	888	35	9	1.3	1.0	29	.78	22	.20	.15	4.3	.11	3
1977	985	39	10	1.6	1.2	31	.93	24	.24	.18	4.6	.13	3
1978	839	33	8	1.5	1.1	33	.80	24	.22	.16	4.9	.11	3
1979	916	32	8	1.5	1.1	34	.78	24	.23	.16	5.0	.11	3
1980	787	31	8	1.4	1.2	39	.78	25	.22	.16	5.2	.11	4
1981	1028	46	12	1.5	1.2	26	.93	20	.23	.16	3.7	.13	3
1982	1095	44	11	1.6	1.2	27	.82	19	.24	.17	3.9	.11	3
1983	1037	42	11	1.6	1.2	29	.92	22	.24	.17	4.0	.13	3
1984	1008	44	11	1.5	1.2	27	.92	21	.23	.17	3.9	.13	3
1985	1007	34	11	1.5	1.2	35	.91	27	.23	.17	5.0	.12	4

Where: OV = overflow volumes in x $10^6 m^3$, P = Precipitation,
n/s = no storage, w/s = with a storage.
W = total washoff from watershed and dry weather flow in x 10^6kg,
O = pollutants in overflow to receiving water in x 10^6kg,
C = concentation of pollutants in overflow to receiving water in mg/l.

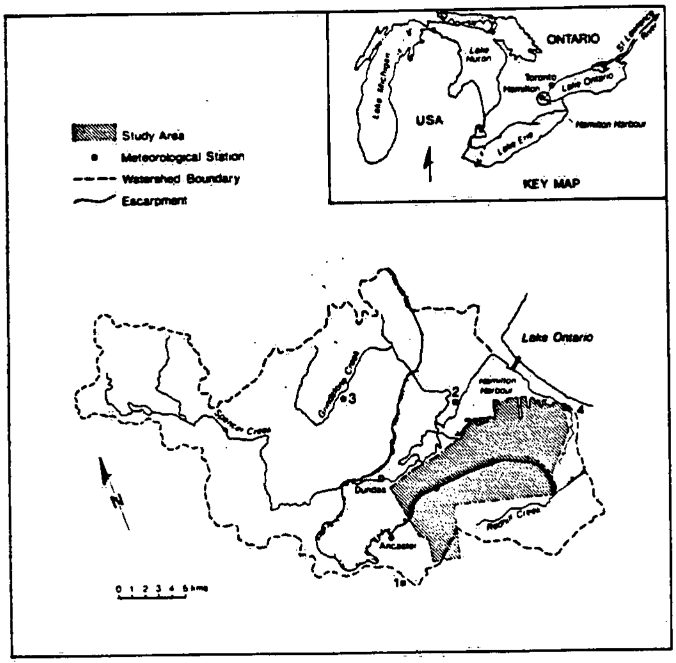

Figure 1 Location Map and Watershed of Hamilton Harbour

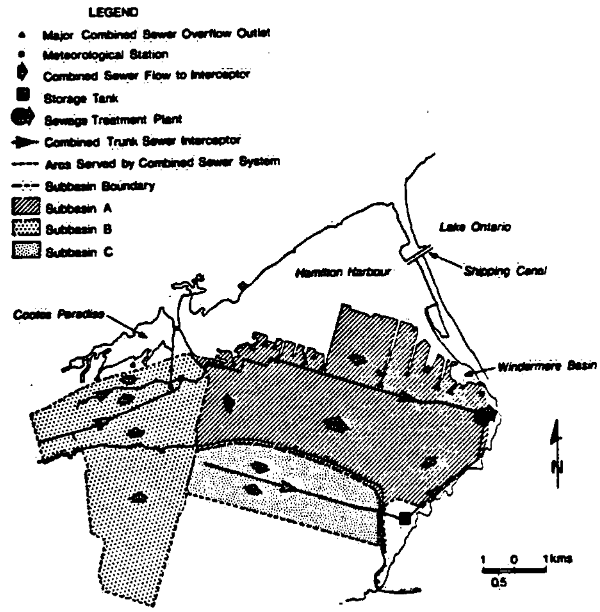

Figure 2 Study Area of Combined Sewer Overflows

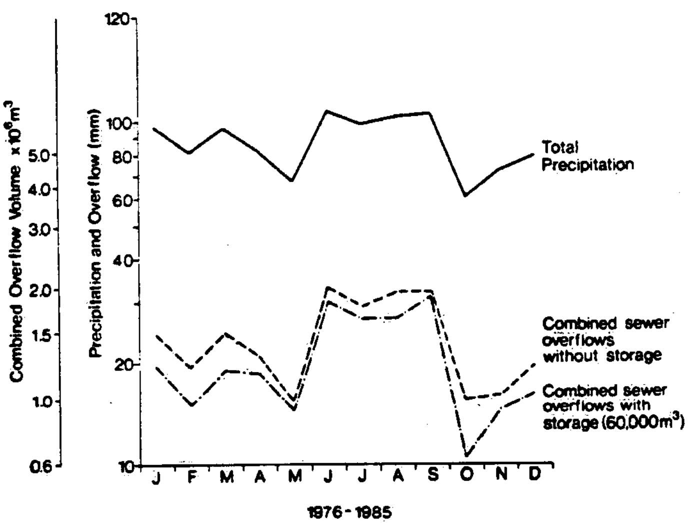

Figure 3. Mean Monthly Precipitation and Simulated Combined Sewer Overflow Volumes

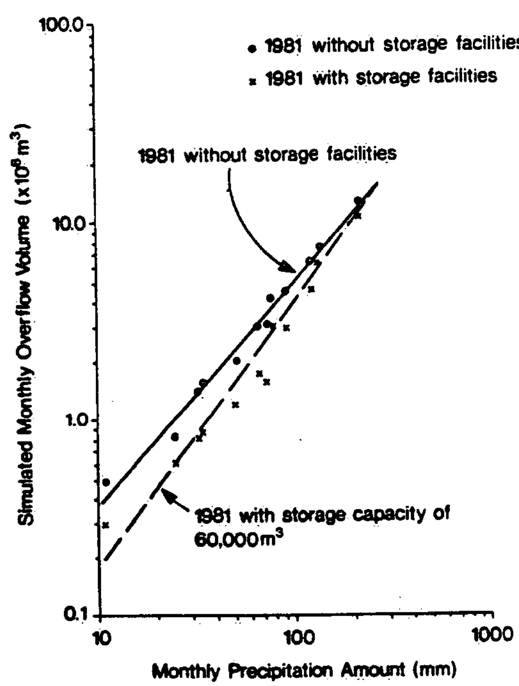

Figure 4. Effects of Precipitation Amount on Simulated Overflow Volumes.