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A COMPREHENSIVE METHODOLOGY FOR PLANNING AND DESIGN OF URBAN RUNOFF CONTROL ALTERNATIVES

by

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A COMPREHENSIVE METHODOLOGY FOR PLANNING AND DESIGN OF URBAN RUNOFF CONTROL ALTERNATIVES

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ABSTRACT

A comprehensive methodology is proposed for various stages of urban-runoff modelling. The methodology consists of three stages, namely, the data preparation stage, the planning stage and the design/analysis stage.

For data preparation, a data analysis model was developed. The model serves as an interface between the existing climatological data banks and both the planning and design stage models.

In the planning stage, various alternatives of land use, drainage systems, and resulting pollutional loads are evaluated. Such an evaluation is done by means of a continuous urban runoff model (the STORM model of the U.S. Army) as well as by means of a simplified single-event model (Canadian version of the Storm Water Management Model of U.S. EPA).

In the design/analysis stage, the design of drainage and control alternatives is carried out as well as a detailed study of receiving waters. For this purpose, the use of a Canadian version of the SWMM model or of a new SWMM-WRE version including a dynamic wave flow routing scheme, can be made.

A case study and practical experience with the models discussed are described.

PROJET PHI 7 - REPERCUSSIONS DE L'URBANISATION ET DE L'INDUSTRIALISATION SUR LA PLANIFICATION ET LA GESTION DES EAUX A L'ECHELLE REGIONALE ET NATIONALE.

J. Marsalek

RESUME

L'article présente une méthodologie élaborée pour les diverses étapes de la modèlisation et de la gestion d l'écoulement urbain. La méthodologie comporte trois étapes à savoir celle de l'élaboration des données, de la planification et enfin celle de la conception et de l'analyse.

Pour ce qui est de l'élaboration des données, on a mis au point un modèle d'analyse des données. Celui-ci sert d'intermédiaire entre les banques de données existantes et les modèles des stades de la planification et de la conception.

Au stade de la planification, on évalue les diverses possibilités de l'utilisation des terres, des systèmes de drainage et des charges de pollution qui en résultent. Cette évaluation est faite au moyen d'un modèle qui stimule de façon continue l'écoulement urbain (le modèle STORM de l'armée américaine) ainsi qu'au moyen d'un modèle simplifié pour une seule circonstance (version canadienne du modèle STORM de l'E.P.A., relatif à la gestion des eaux).

Au stade de la conception et de l'analyse, on conçoit des moyens de drainage et de contrôle et on étudie de facon approfondie les eaux réceptrices. A cette fin, on peut utiliser une version canadienne du modèle SWMM ou une nouvelle version SWMM comprenant le schéma de cheminement dynamique de l'écoulement de l'onde.

On décrit certines études de cas et l'expérience pratique acquise avec les modèles.

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INTRODUCTION

The modelling of urban runoff has undergone a rapid development during the recent years. The first urban runoff models dealt with single events only and served for the sizing of storm drains. Current single-event and continuous simulation urban runoff models place equal emphasis on both runoff quantity and quality, and serve for the design of drainage systems as well as for environmental planning.

Combined features of the existing urban runoff models, many of which may be called urban runoff management models, can satisfy to various extent most of the needs and requirements of potential users [11]*. Under these circumstances, instead of developing new models which do not necessarily advance the state of the art of hydrological modelling, it appears to be more rational to adopt, interface and modify some of the existing urban runoff models to obtain the modelling tool required.

Such an approach based on the application, interfacing and modification of some existing urban runoff models is described in this paper. The overall objective of the study was to develop and test a methodology for urban runoff studies in Canada.

The proposed methodology consists of three stages - data preparation, planning and design/analysis. In the data preparation stage, the use is made of a newly developed Data Analysis Model. The planning stage is based on the STORM model of U.S. Corps of Engineers and partly on a lumped, modified version of the Storm Water Management Model (SWMM) of the U.S. Environmental Protection Agency. For the design/analysis stage, a modified SWMM model or the Water Resources Engineers version of the SWMM model are recommended. The methodology is schematically outlined in Figure 1. The

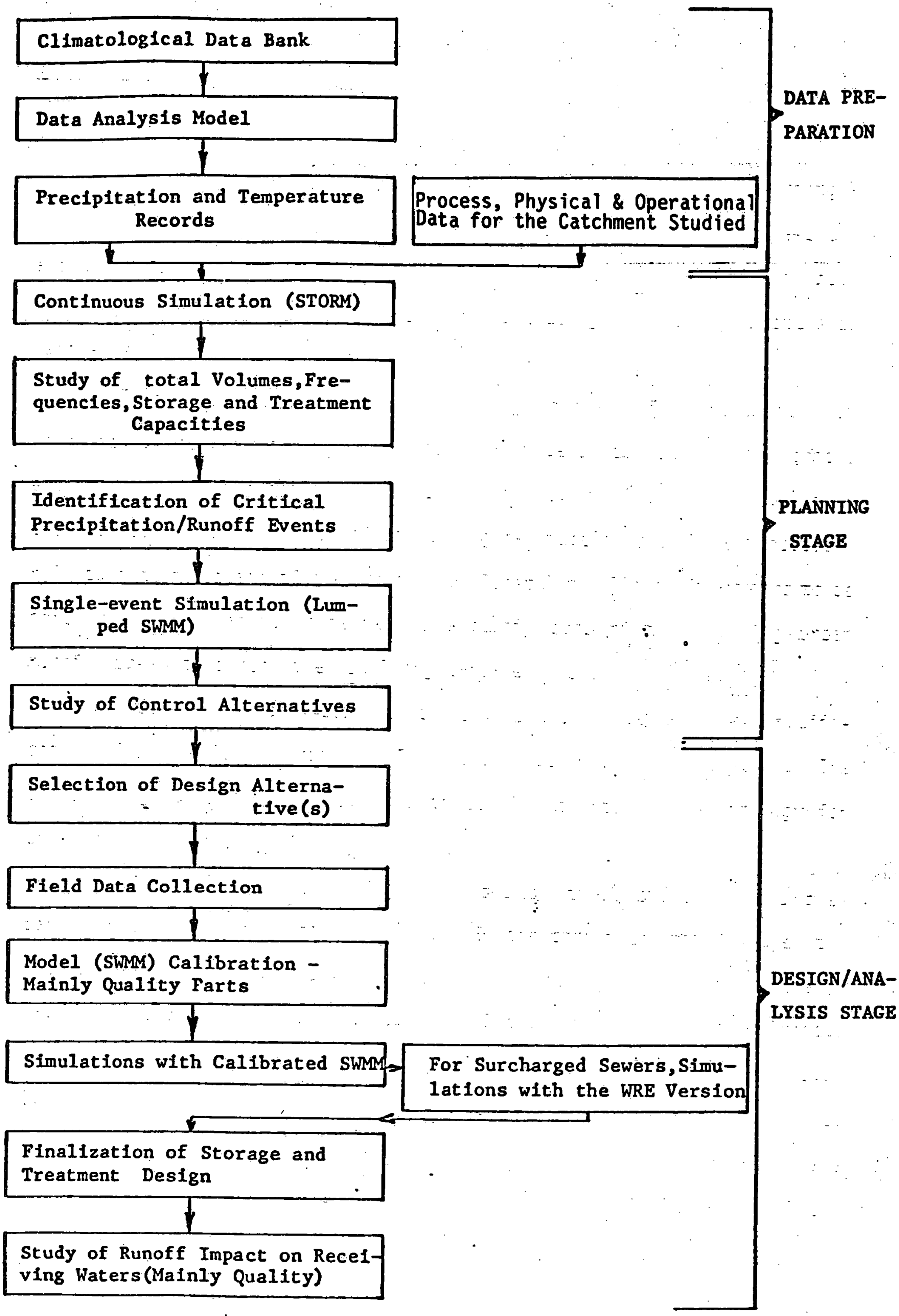


Figure 1. Interfacing of Computer Models in Urban Runoff Studies

description of individual components and of their testing follows.

DATA PREPARATION STAGE

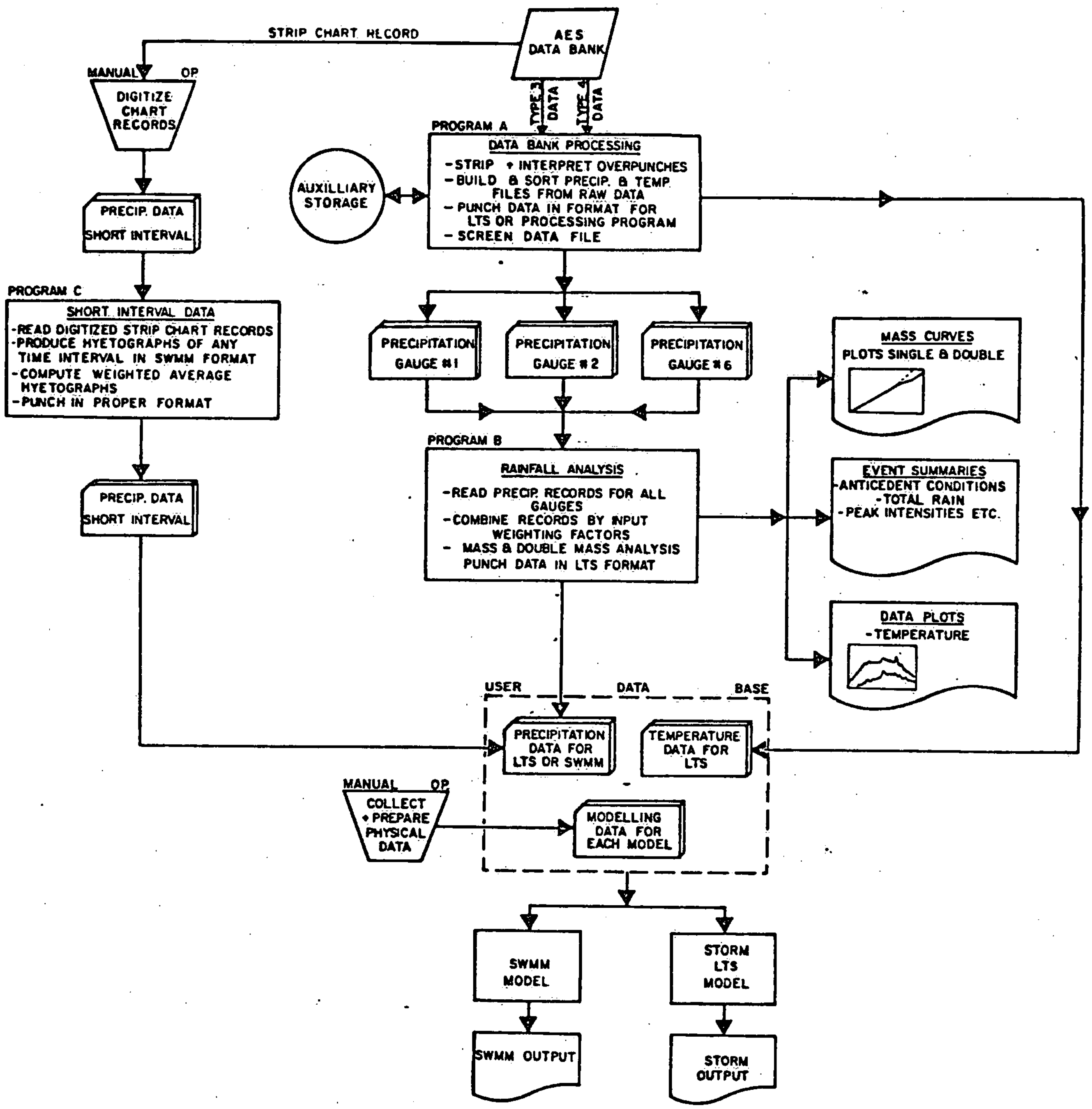
Applications of urban runoff models require large volumes of input data, the preparation of which amounts to a significant portion of the total project costs. It is therefore desirable to simplify and computerize this part of the runoff modelling to the maximum possible extent.

Generally, four types of input data are required: climatological, process, physical and operational data. The first type includes, in this study, precipitation and temperature data. The process data describe the hydrologic response of the catchment. Among examples of process data, one could name infiltration rates, surface storage capacity and overland flow parameters. Physical data describe the catchment geometry (area, slope) and properties of drainage elements (size, slope and roughness). The term operational data refers here to the demographic information for the area, municipal cleaning practices (street sweeping, sewer cleaning), application of de-icers, accumulation of dust and dirt, etc.

Climatological data are typically most voluminous and therefore their processing was computerized by means of the Data Analysis Model (DAM) [10] which serves as an interface between the existing data banks and both the planning and design stage models.

The flow chart of the DAM model is shown in Figure 2. For the planning stage modelling with the STORM model, referred to as a long-term simulation, hourly precipitation and temperature data are required. Such data are available on a magnetic tape from the Data Bank of the Canadian Atmospheric Environment Service, and consequently, the data processing and analysis can be fully computerized. The design/analysis modelling, also referred to as detailed modelling, typically requires short interval precipitation data (5-15 min) which are also available from the above source, but not yet in the digital form. Before using the DAM model, the user would have to digitize precipitation data in arbitrary time intervals. Once this has been done, the data processing is the same as in the former case.

Figure 2. Data Analysis Model - Flowchart



The DAM model reads precipitation data and combines them into a single record defined as a weighted average of all the gauge records. The data quality is checked by plotting single and double mass curves for individual gauges. A similar procedure is followed for the temperature data.

The output of the DAM model consists of the punched data cards for the STORM and SWMM models, mass curves plots, and of event summaries. These summaries list the times of start and end of each storm, its duration, the total depth of rainfall, the peak intensity and the antecedent dry period. The event summaries are useful for a fast review of precipitation data, and eventually, for the identification of critical rainfall/runoff events. An example of the DAM model event summary is shown in Table 1.

The remaining process, physical and operational input data for urban runoff models are prepared manually.

The preparation of these data should be guided by the results of the sensitivity analysis of the model used. Such an analysis indicates what detail and accuracy of input parameters is required. For some parameters, rough estimates may be acceptable without decreasing appreciably the accuracy of simulations. Other parameters have to be accurately determined.

Some information on the sensitivity analysis of the STORM and SWMM models is presented later.

PLANNING STAGE

In the planning stage, various alternatives of land use, drainage systems and the resulting pollutional impact on the receiving waters are evaluated. Typically, only limited information regarding the watershed is available, and consequently, a detailed runoff simulation is not feasible at this stage. At the same time, it is important to establish the

Table 1. DAM Model Event Summary

STORM EVENT SUMMARY FOR 1973,
SWMM - WEST-TORONTO STUDY AREA

(A STORM HAS BEEN DEFINED AS HAVING A TOTAL RAINFALL GREATER THAN 0.03 IN. (0.76-MM) AND HAVING LESS THAN 3 CONSECUTIVE DRY HOURS.)

STORM NUMBER 1

STARTED ON THE 4TH MONTH, 2ND DAY, 2ND HOUR
ANTECEDENT DRY DAYS UNKNOWN
ENDED ON THE 4TH MONTH, 3RD DAY, 10TH HOUR
TOTAL DURATION IN HOURS = 33
TOTAL RAINFALL IN HUNDREDTHS OF INCHES = 29 (7.3-MM)
MAXIMUM INTENSITY IN HUNDREDTHS OF INCHES PER HOUR = 2 (0.5-MM/HR.)

STORM NUMBER 2

STARTED ON THE 4TH MONTH, 4TH DAY, 16TH HOUR
ANTECEDENT DRY DAYS = 1.208
ENDED ON THE 4TH MONTH, 4TH DAY, 24TH HOUR
TOTAL DURATION IN HOURS = 9
TOTAL RAINFALL IN HUNDREDTHS OF INCHES = 14 (3.5-MM)
MAXIMUM INTENSITY IN HUNDREDTHS OF INCHES PER HOUR = 3 (0.8-MM/HR.)

STORM NUMBER 3

STARTED ON THE 4TH MONTH, 27TH DAY, 10TH HOUR
ANTECEDENT DRY DAYS = 22.375
ENDED ON THE 4TH MONTH, 28TH DAY, 4TH HOUR
TOTAL DURATION IN HOURS = 19
TOTAL RAINFALL IN HUNDREDTHS OF INCHES = 48 (12-MM)
MAXIMUM INTENSITY IN HUNDREDTHS OF INCHES PER HOUR = 8 (2.0-MM/HR.)

probability of occurrence of runoff events of various magnitude. This can be achieved by continuous simulation of urban runoff over a long period. Such a simulation is then referred to as long-term simulation.

The main objectives of the long-term simulation are the following:

a) to determine the total stormwater and overflow volumes, total pollutant emissions, and frequencies of occurrence;

b) to identify critical (quantity-wise and quality-wise) runoff events and their antecedent conditions on the basis of a precipitation record;

c) to determine the statistical effectiveness of such pollution abatement measures as runoff storage, treatment and environmentally oriented land use planning.

A literature search revealed that these objectives could be met by an existing long-term simulation model - the STORM model of U.S. Army, Corps of Engineers.

The STORM model is described in detail elsewhere [6]. Basically, it is a simple continuous simulation model which calculates runoff on an hourly basis as a function of rainfall and snowmelt, considering a composite runoff coefficient and precipitation reduced by the available surface depression storage.

For the calculation of runoff volumes, the catchment imperviousness related to the land use, appears to be the most important parameter.

Runoff quality is calculated for various land uses, and finally runoff treatment and storage capacities are considered.

To gain a better understanding of the STORM model and of its capabilities as well as limitations, the STORM model was applied on two test catchments for which some runoff measurements were available. The total runoff and overflow volumes as well as the number of events occurred and their duration are summarized in Table 2.

Table 2. STORM Testing on Toronto-West and Bannatyne Catchments (After ref. 10)

CATCHMENT	Total Overflow or Runoff Vol. (cm)		Number of Events		Total Event Duration (hrs.)	
	Meas.	Comp.	Meas.	Comp.	Meas.	Comp.
Toronto-West, A = 944 ha, combined sewer overflows simulated over 7 months	17.2	18.70	53	54	181	227
Bannatyne (Winnipeg), A = 220 ha, flows simulated over 4 months	5.51	4.88	24	24	92	66

The agreement between the measured and computed total volumes and overflow frequencies (Toronto-West only) is very good.

The STORM model was found very inexpensive to operate, the computer time for the STORM application on a 944 ha catchment over a 7-month period cost 4.00 dollars which is less than the cost of a single event simulation by detailed models.

The STORM model (1974 version) had several limitations, among these, the sanitary flow was not included in the model structure, and the simulation of limited storage/treatment options dealt only with flow rates without considering the flow quality. Also when comparing the observed and STORM-simulated peak flows, large discrepancies were found. Another urban runoff model, the Storm Water Management Model (SWMM) of U.S. EPA, was found free of the above limitations. It was realized that by applying the SWMM model for selected events in the planning stage, the quantity as well as quality aspects of various runoff control alternatives could be studied and a greater accuracy of flow simulations could be achieved.

The SWMM is, however, a single event model which requires the definition of antecedent conditions and yields no information regarding the frequency of occurrence of runoff events. These limitations can be removed by applying the SWMM in conjunction with the continuous model STORM. The STORM is used to identify critical precipitation/runoff events, their frequency of occurrence and their antecedent conditions. The simulations of these selected events are then repeated with the SWMM model to obtain a greater accuracy and detail of these simulations.

The SWMM model of U.S. EPA is described in detail elsewhere [8, 9]. The model consists of an executive block and four computational blocks - Runoff, Transport, Storage (and Treatment) and Receiving Waters. The model can be applied in a various degree of detail depending on the purpose of the study. The cost of SWMM simulations is directly related to the detail of these simulations (e.g. the number of elements considered).

The feasibility of using the SWMM, in a multi-event simulation mode, as a planning tool was investigated. The SWMM model was not, however, modified to operate in the continuous simulation mode, since this would require the addition of a water balance accounting.

For planning purposes, the SWMM simulations could be made cheaper by reducing the number of subcatchment and transport network elements to a minimum and increasing the time step. Even large catchments can be, in the planning stage, represented by a single overland flow element. Depending on the circumstances, few or no transport elements are used.

Parameters of the lumped overland flow element were defined as spatial averages. The element width, directly related to the length of overland flow, was defined as twice the total length of all main drainage pipes and gutters serving the area. For runoff transport, the volume of pipes in the simplified system was set approximately equal to the volume of the real system [10].

The simulations made with the lumped SWMM model closely appoximated those made with the discretized model, as demonstrated in Figure 3.

In a lumped drainage system, routing effects are grossly simplified, and the use of short time steps may not be necessary. As long as the continuity of outflow can be solved on the subcatchment, and the outflow computations are stable in time, longer time steps may be used in SWMM simulations. Using the lumped single catchment SWMM, time and rainfall steps of 15, 30 and 60 minutes were investigated, and the results are shown in Figure 4. Both runoff and transport elements were used in these simulations. As expected, the computed runoff volumes remained virtually constant and the peak flows decreased with the increasing time step. Even the reduced peak flows, obtained for the time step of 60 minutes, were found accurate enough for planning purposes.

One of the STORM features not available in the SWMM model is snowmelt. Since snowmelt may be a fairly important aspect of environmental planning in Canadian conditions, particularly from the quality point of view, a snowmelt quantity and quality model was developed and interfaced with the Runoff Block of SWMM.

Following a literature survey, the Anderson's snowmelt model [1] was selected to be built into the SWMM model as a user option [10]. This was one of the first attempts to simulate snowmelt in the urban environment, and, mostly because of lack of field data, numerous approximations had to be made.

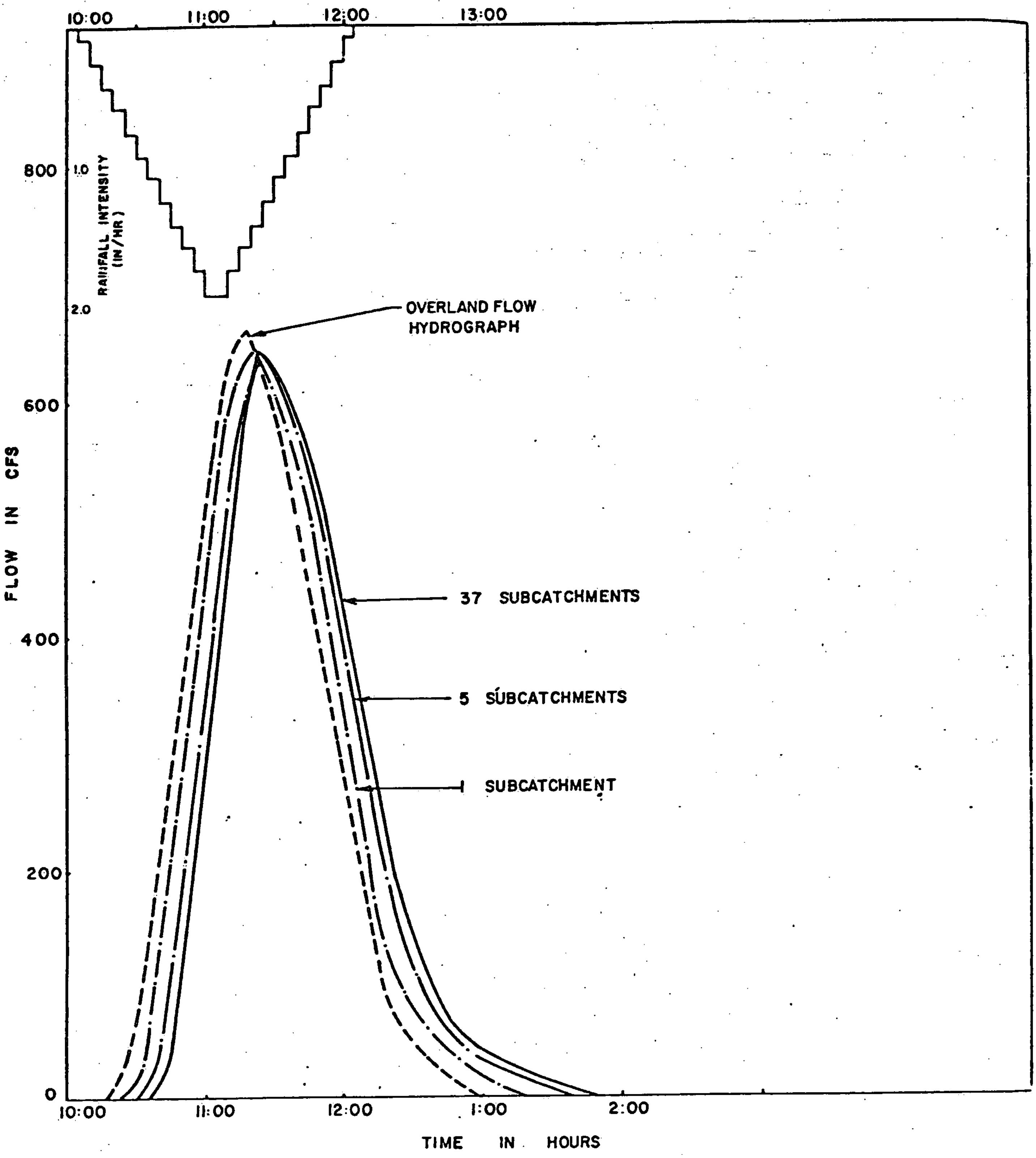


Figure 3. Effects of Catchment Discretization on Runoff Hydrographs

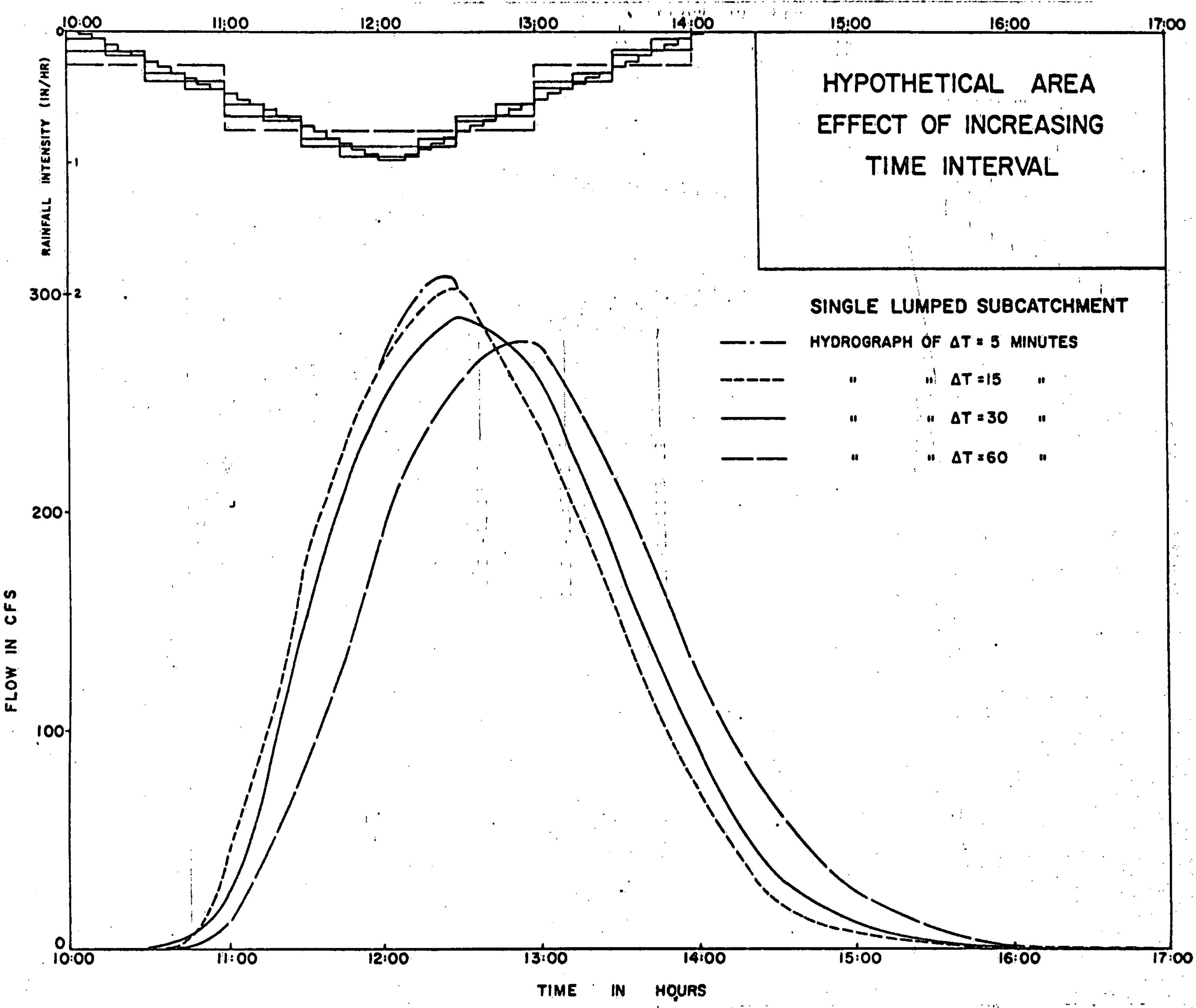


Figure 4. Effect of Increasing Time Interval on Simulated Hydrograph

The snowpack distribution and physical parameters were assumed to be known prior to the storm. The problem is then reduced to that of describing the physical changes in the snow cover during the snowmelt and/or rainfall periods and the resulting effects on runoff. The model requires hourly air temperature and wind speed data as climatological input data. The basic calculation is made in hourly intervals. If required by the runoff calculation, the computed hourly volumes are linearly interpolated for other time intervals.

Since hardly any field data were available to formulate a conceptual model of the quality of snowmelt water, the same approach as in the SWMM quality modelling was used. Pollutant accumulation on and washoff from the catchment surface were considered. The list of the SWMM water quality constituents was expanded for chlorides and lead. The input of chlorides onto the catchment surface was derived from typical application rates of de-icing salts, the accumulation of other constituents is considered in the same manner as in the SWMM model [10].

Limited attempts have been made to verify the snowmelt quantity and quality model on the Brucewood catchment for three events [3]. Though the model results indicated similar trends as observed data, more extensive testing will be required to reach conclusive results.

For runoff control, the SWMM model considers runoff storage and several levels of treatment [8]. The costs of implementing these control alternatives are also determined by means of the model. These costs were modified for Canadian conditions, the rest of the Storage Block of the SWMM model was adopted without any major changes.

In some applications, a preliminary analysis of the receiving waters would also be carried out in the planning stage using the Receiving Waters Block of the SWMM model or other models.

In the planning stage, the user obtains a good indication of the nature of runoff or overflow problems in the studied area and also learns the effectiveness of various runoff/overflow control measures. The information is obtained at a planning level, for which the relative effects and magnitudes are more important than absolute values required for design.

DESIGN/ANALYSIS STAGE

In this stage, the design of drainage system and control alternatives is carried out as well as a detailed study of receiving waters. Consequently, it is necessary to produce, for selected events, fairly accurate runoff hydrographs and pollutographs by a calibrated, detailed simulation model. At this level, the SWMM or a similar model, are recommended.

The older versions of the SWMM model (prior to May, 1976) have one limitation which may become apparent in the design/analysis stage -approximate simulation of sewer surcharging and backwater effects [8, 9, 10]. Note that this problem was not encountered in the planning stage, because sewers were either not considered at all (e.g. in the STORM model), or they were considered as an open channel network. Note also that the events which are important for the pollution abatement are not the low frequency storms used in the design and therefore the older SWMM versions are fully applicable to water quality studies.

Surcharging, however, becomes very important when analyzing flooding problems in an existing sewer system of insufficient capacity, or when evaluating the response of a drainage system to a storm of lower than design frequency. Under these circumstances, the older SWMM versions are not applicable and newer versions (after May, 1976) or other models have to be used. To simulate properly surcharging and backwater effects in a sewer system, it is necessary to use a model with the dynamic wave routing, such as, for example, the Water Resources Engineers version of the SWMM model (WRE-SWMM)[7], or the Dorsch HVM model [4].

In this study, the Dorsch HVM and WRE-SWMM were applied on the Bannatyne test catchment for two events [10]. In one of these events, the sewer system was surcharged. Both models performed well under such conditions and produced more realistic hydrographs than the original SWMM model (1975).

The WRE dynamic wave routing subroutine has been added to the latest nonproprietary SWMM version (May, 1976), thus making the SWMM fully applicable to the surcharged sewer problems.

The reliability of the SWMM simulations can be improved by calibration. This is particularly true for runoff quality, but the runoff quantity may also require calibration, if the input parameters contain large uncertainties. For instance, it is sometimes difficult to determine what portion of the total impervious area is directly connected to the sewers. An answer can be found through model calibration. While the model calibration is not necessary in the planning stage, and frequently not even possible because of lack of time and data, it is recommended that the design/analysis simulations are done with a calibrated model.

The model calibration requires some field data on runoff (overflow) quantity and quality, and their variation in time. The model simulations are then compared to the measurements and model parameters are adjusted to improve the agreement between the both sets of data. If no field data are available, a data collection program may have to be undertaken. The scope of such program is determined on the basis of the information obtained in the planning stage.

Model calibration, as well as the preparation of input data for detailed SWMM simulations, can be greatly aided by sensitivity analysis. Experimental sensitivity of the SWMM Runoff and Transport Blocks was performed by means of repeated simulations on test catchments [10] and the results are summarized below.

Sensitivity analysis - to assist users in the preparation of input data for detailed SWMM simulations, an experimental sensitivity analysis of the SWMM Runoff and Transport Blocks was performed by means of repeated simulations on a test catchment [10].

The parameters affecting the SWMM runoff quantity simulations (Runoff Block) can be listed in the order of decreasing importance as follows:

catchment imperviousness
catchment width (related to the length of overland flow)
infiltration capacity
gutter and catchment surface roughness
catchment slope.

In the Transport Block, the conduit length, number of conduits and conduit roughness were tested. The effects of the conduit length were negligible for pipes shorter than 1200 metres (4000 ft). For 3 km (2 miles) conduits, hydrograph attenuations of the order of 40% were found. Increasing conduit roughness attenuated proportionally the peak flow.

In a similar manner, the sensitivity of the runoff quality subroutine was studied considering the following parameters:

the washoff equation exponent b
options for the calculation of Suspended Solids
number of dry days
street cleaning, and
catchbasin loads.

The washoff exponent affects directly the rate of the pollutant removal, particularly in the initial period of runoff. The pollutants are washed off faster with the increasing value of the exponent b. Neither of the two options for the calculation of Suspended Solids proved to be applicable over a wide range of antecedent conditions. The number of dry days is perhaps the most important parameter affecting quasi-linearly the total runoff pollution load. The effect of street cleaning is very pronounced only for high cleaning efficiencies. Catchbasin loads contribute only little to the total pollution load.

In the Transport Block, the slope of combined sewers and the specific gravity of solids affect significantly the sediment deposition-scouring process, and consequently, the results of the quality simulations for combined sewers.

After calibration, the model is verified. Model verification consists of a rational analysis of both the computed output and any empirically derived parameters. If possible, the computed model output is compared with observed system output for other events than those used in model calibration.

The results of verifications of the SWMM model on eight urban test catchments were summarized in a recent paper [5]. While the SWMM quantity simulations were fully satisfacory for free flow in sewers, the quality simulations were in general much less satisfactory and an additional testing and/or refinement of the SWMM quality sub-routine was required. The results of these tests, described by the ratios of the observed to simulated hydrograph and pollutograph parameters, are given in Table 3 [5].

After new, calibrated hydrographs and pollutographs have been obtained, the design of sewer network, runoff storage and treatment, can be

	Runoff volumes Ratio $\mathrm{Vol.}_{obs.}/\mathrm{Vol.}_{sim.}$		
	average	standard deviation	% of simulations within ± 20% of observations
Bannatyne	1.40	0.34	24%
Brucewood	0.91	0.19	66%
Calvin Park	1.03	0.17	75%
Gray Haven	—	—	—
Halifax	1.01	0.14	85%
Oakdale	—	—	—
Malvern	1.01	0.12	89%
Toronto-West	0.87	0.26	50%

	Runoff peak flows Ratio $Qp_{obs.}/Qp_{sim.}$		
	average	standard deviation	% of simulations within ± 20% of observations
Bannatyne	1.12	0.09	81%
Brucewood	1.22	0.26	42%
Calvin Park	1.09	0.16	72%
Gray Haven	0.98	0.24	61%
Halifax	0.78	0.22	44%
Oakdale	1.04	0.19	70%
Malvern	1.05	0.16	77%
Toronto-West	1.12	0.14	70%

	Times to peak Ratio $Tp_{obs.}/Tp_{sim}$		
	average	standard deviation	% of simulations within ± 20% of observations
Bannatyne	0.98	0.12	90%
Brucewood	0.91	0.10	87%
Calvin Park	0.93	.09	92%
Gray Haven	1.02	0.05	100%
Halifax	1.11	0.21	60%
Oakdale	0.92	0.13	81%
Malvern	0.96	0.07	99%
Toronto-West	1.13	0.22	55%

	Bannatyne ISS=0	 ISS=1	Brucewood ISS=0	 ISS=1	Malvern ISS=0
(a)	average		average		
Total BOD obs. / Total BOD sim.	3.10	5.25	.66	.29	--
Total SS obs. / Total SS sim.	1.34	2.20	6.43	.46	4.12
Total COD obs. / Total COD sim.					.49
Total N obs. / Total N sim.					4.80
Total P obs. / Total P sim					2.45
(b)					
Peak BOD obs. / Peak BOD sim.	2.90	6.43	1.58	1.35	--
Peak SS obs. / Peak SS sim.	1.05	—	9.60	.43	5.48
Peak COD obs. / Peak COD sim.					.28
Peak N obs. / Peak N sim.					3.82
Peak P obs. / Peak P sim.					3.01

Table 3. SWMM Simulations on Selected Test Catchments [5].

```
PAGE    1                                                  THE BANNATYNE DISTRICT
                                                             QUANTITY ANALYSIS
TREATMENT RATE... 0.0000 IN/HR, ....0.0 CFS,_____0.0 ...MGD __________________________________________WEIGHTED AVERAGE VALUES________
STORAGE CAPACITY  0.0000 INCHES,    0.0 AC-FT,   0.000 MG                                                   BANNATYNE

EVENT ---D A T E--- HRS NO -R A I N F A L L- RUNOFF HRS TO --STORAGE-- ----O V E R F L O W---- ---TREATMENT---- --AGE OF STORAGE---
      YEAR MO DY HR STORAG DURTN  HRS QUANTY INCHES  EMPTY DURTN   MAX  NO  ST DUR WASTE INITL  HRS  QANTY AGE1 AGE2 AGE3 AGE4 AGE5
*****1 *********2 *3 ******4 *****5 ****6 *****7 ****7A *****8 ****9 ***10 *11 *12 *13 ***14 ***15 ***16 ***17 **18 **19 **20 **21 **22

    1   71  6  4 13    155     1    1   0.09   0.02      1     2  0.0    1   1   1  0.01  0.01    2  0.0   0.5  0.5  0.5  0.5  0.5
    2   71  6  5  3     12     2    2   0.23   0.09      1     3  0.0    2   1   2  0.09  0.09    3  0.0   0.5  1.5  1.5  1.0  1.0
    3   71  6  5 17     11     2    2   0.15   0.05      1     3  0.0    3   1   2  0.04  0.04    3  0.0   0.5  1.5  1.5  1.0  1.0
    4   71  6 10  5    105     3    3   0.15   0.06      1     4  0.0    4   1   3  0.05  0.05    4  0.0   0.5  2.5  2.5  1.5  1.5
    5   71  6 11 24     39     2    2   0.07   0.02      1     3  0.0    5   1   2  0.01  0.01    3  0.0   0.5  1.5  1.5  1.0  1.0
    6   71  6 19 11    176     4    4   0.45   0.18      1     5  0.0    6   1   4  0.18  0.17    5  0.0   0.5  3.5  3.5  2.0  2.0
    7   71  6 26  4    156     2    2   0.21   0.07      1     3  0.0    7   1   2  0.07  0.07    3  0.0   0.5  1.5  1.5  1.0  1.0
    8   71  6 27 19     36     2    2   0.07   0.01      1     3  0.0    8   1   2  0.01  0.01    3  0.0   0.5  1.5  1.5  1.0  1.0
    9   71  6 30 14     64     2    2   0.10   0.02      1     3  0.0    9   1   2  0.02  0.02    3  0.0   0.5  1.5  1.5  1.0  1.0
   10   71  7  3 19     74     1    1   0.16   0.05      1     2  0.0   10   1   1  0.04  0.04    2  0.0   0.5  0.5  0.5  0.5  0.5
   11   71  7  7  1     76     4    4   0.61   0.25      1     5  0.0   11   1   4  0.25  0.23    5  0.0   0.5  3.5  3.5  2.0  2.0
   12   71  7 10  3     69     4    4   0.30   0.12      1     5  0.0   12   1   4  0.11  0.10    5  0.0   0.5  3.5  3.5  2.0  2.0
   13   71  7 15 20    132     3    2   0.13   0.05      1     4  0.0   13   1   2  0.05  0.05    4  0.0   0.6  0.5  0.5  0.5  0.5
   14   71  7 17 21     45     6    5   0.31   0.11      1     7  0.0   14   1   5  0.11  0.08    7  0.0   0.7  2.5  2.5  1.3  1.3
   15   71  7 19  7     27     2    2   0.11   0.03      1     3  0.0   15   1   2  0.02  0.02    3  0.0   0.5  1.5  1.5  1.0  1.0
   16   71  7 22 13     75     2    2   0.14   0.04      1     3  0.0   16   1   2  0.04  0.04    3  0.0   0.5  1.5  1.5  1.0  1.0
   17   71  7 24  3     35     2    2   0.09   0.02      1     3  0.0   17   1   2  0.01  0.01    3  0.0   0.5  1.5  1.5  1.0  1.0
   18   71  7 25  6     24     2    2   0.23   0.09      1     3  0.0   18   1   2  0.09  0.09    3  0.0   0.5  1.5  1.5  1.0  1.0
   19   71  7 27 17     56     2    2   0.09   0.02      1     3  0.0   19   1   2  0.02  0.02    3  0.0   0.5  1.5  1.5  1.0  1.0
   20   71  7 28 20     72     4    3   0.25   0.09      1     5  0.0   20   1   3  0.09  0.09    5  0.0   0.7  1.5  1.5  0.8  0.8
   21   71  7 31  8      7     2    2   0.16   0.06      1     3  0.0   21   1   2  0.06  0.06    3  0.0   0.5  1.5  1.5  1.0  1.0
   22   71  8 16 21    344     4    4   0.34   0.13      1     5  0.0   22   1   4  0.13  0.11    5  0.0   1.0  2.5  2.5  1.0  1.1
   23   71  8 19  8     54     5    5   0.21   0.09      1     6  0.0   23   1   5  0.09  0.06    6  0.0   0.5  4.5  4.5  2.5  2.5
   24   71  9  5  5    399     3    3   0.57   0.24      1     4  0.0   24   1   3  0.23  0.23    4  0.0   0.5  2.5  2.5  1.5  1.5

AVE OF    24 EVENTS      0.0** 2.8  2.6   0.22   0.08    1.0   3.8  0.00     0.0*                    3.8  0.00  1.1  1.9  1.9  1.2  1.2
AVE OF    24 OVRFLW EVENTS     2.8  2.6   0.22   0.08    1.0   3.8  0.0 *    1.0 2.6  0.08  0.08    3.8  0.00  0.5  1.9  1.9  1.2  1.2

* NON-OVERFLOW EVENTS ONLY.
**EXCLUDING*** DRY PERIODS


          AVERAGE ANNUAL STATISTICS FOR  1 YEARS OF RECORD FOR THE PERIOD BEGINNING 710604 AND ENDING 710905
          ------------------------------------------------------------------------------------------------


          NUMBER OF EVENTS          24.0

          NUMBER OF OVERFLOWS       24.0

                                             INCHES
                                             ------

          TOTAL PRECIPITATION ON WATERSHED    5.47

          TOTAL RUNOFF FROM WATERSHED         1.92    FRACTION OF RAINFALL  0.35

          OVERFLOW TO RECEIVING WATER         1.92    FRACTION OF RAINFALL  0.35,  OF RUNOFF  1.00
```

Table 4. Case Study - STORM Model Output(After ref.10)

```
1PAGE    1                                                THE BANNATYNE DISTRICT
                                                              QUALITY ANALYSIS
 TREATMENT RATE    0.0000 IN/HR,     0.0 CFS,     0.0    MGD                                      WEIGHTED AVERAGE VALUES
 STORAGE CAPACITY  0.0000 INCHES,    0.0 AC-FT,   0.000 MG                                               BANNATYNE

 EVENT      DATE       RAIN ------S T O R M   R U N O F F------ ----S T O R A G E   O V E R F L O W---- ----FIRST 3 HOURS OVERFLOW----
        EVENT BEGAN   FALL  INCHS            TOTAL POUNDS              SEQ  INCHS          TOTAL POUNDS                INCH       TOTAL POUNDS
        YR MO DY HR  INCHS  QANTY    SUSP  SETL   BOD      N   PO4   NU  QANTY    SUSP  SETL   BOD      N   PO4     O   SUSP SETL  BOD    N  PO4
 ****1 *******2 *3 ****4 ****5 *****6 ****7 ****8 ****9 **10 *11 ***12 ****13 ***14 ***15 ***16 **17 **18 ***19 **20 **21 **22 **23

      1 71  6  4 13  0.09  0.02    418     2    74     23     2   1  0.01    418     2    74     23    2 0.01   418    2   74   23    2
      2 71  6  5  3  0.23  0.09   3278    14   439    170    17   2  0.09   3278    14   439    170   17 0.09  3278   14  439  170   17
      3 71  6  5 17  0.15  0.05   1227     6   158     63     6   3  0.04   1226     6   158     63    6 0.04  1226    6  158   63    6
      4 71  6 10  5  0.15  0.06   2578    13   346    134    14   4  0.05   2578    13   346    134   14 0.05  2578   13  346  134   14
      5 71  6 11 24  0.07  0.02    661     4    93     35     4   5  0.01    660     4    93     35    4 0.01   660    4   93   35    4
      6 71  6 19 11  0.45  0.18  19115    92  2231    975    99   6  0.18  19114    92  2231    975   99 0.17 18718   89 2105  955   97
      7 71  6 26  4  0.21  0.07   8478    44   989    432    44   7  0.07   8478    44   989    432   44 0.07  8478   44  989  432   44
      8 71  6 27 19  0.07  0.01    806     7   104     42     4   8  0.01    806     7   104     42    4 0.01   806    7  104   42    4
      9 71  6 30 14  0.10  0.02   1789    12   229     92     9   9  0.02   1788    12   229     92    9 0.02  1788   12  229   92    9
     10 71  7  3 19  0.16  0.05   7254    37   842    370    37  10  0.04   7253    37   842    370   37 0.04  7253   37  842  370   37
     11 71  7  7  1  0.61  0.25  47785   312  5062   2408   242  11  0.25  47784   312  5062   2408  242 0.23 46245  299 4900 2331  234
     12 71  7 10  3  0.30  0.12  11607    89  1253    590    59  12  0.11  11606    89  1253    590   59 0.10 10905   81 1169  550   55
     13 71  7 15 20  0.13  0.05   5239    40   613    267    27  13  0.05   5239    40   613    267   27 0.05  5239   40  613  267   27
     14 71  7 17 21  0.31  0.11  11886    92  1320    603    61  14  0.11  11885    92  1320    603   61 0.08  9388   69 1045  476   49
     15 71  7 19  7  0.11  0.03   2032    20   228    103    10  15  0.02   2031    20   228    103   10 0.02  2031   20  228  103   10
     16 71  7 22 13  0.14  0.04   4605    35   520    234    24  16  0.04   4605    35   520    234   24 0.04  4605   35  520  234   24
     17 71  7 24  3  0.09  0.02   1358    14   164     70     7  17  0.01   1358    14   164     70    7 0.01  1358   14  164   70    7
     18 71  7 25  6  0.23  0.09  12277    88  1334    621    62  18  0.09  12277    88  1334    621   62 0.09 12277   88 1334  621   62
     19 71  7 27 17  0.09  0.02   1975    19   227    101    10  19  0.02   1974    19   227    101   10 0.02  1974   19  227  101   10
     20 71  7 28 20  0.25  0.09  12432    92  1336    628    63  20  0.09  12431    92  1336    628   63 0.09 12431   92 1336  628   63
     21 71  7 31  6  0.16  0.06   8296    65   896    419    42  21  0.06   8295    65   896    419   42 0.06  8295   65  896  419   42
     22 71  8 16 21  0.34  0.13  29268   201  3367   1491   151  22  0.13  29267   201  3367   1491  151 0.11 27744  186 3169 1413  143
     23 71  8 19  8  0.21  0.09  11894   105  1339    604    61  23  0.09  11893   105  1339    604   61 0.06  9473   60 1070  481   49
     24 71  9  5  5  0.57  0.24  88547   716  9455   4468   449  24  0.23  88545   716  9454   4466  449 0.23 88545  716 9454 4468  449

  AVE OF   24 EVNTS  0.22  0.08  12287    88  1359    623    63
  AVE OF   24 OVRFLS 0.22  0.08  12287    88  1359    623    63      0.08  12286    88  1359    623   63 0.08 11905   85 1317  603   61


          AVERAGE ANNUAL STATISTICS FOR  1 YEARS OF RECORD FOR THE PERIOD BEGINNING 710604 AND ENDING 710905
          -----------------------------------------------------------------------------------------------


                                                                      SUSP     SETL     BOD        N      PO4
                                                                      ----     ----     ----     ----     ----

  TOTAL POUNDS WASHOFF FROM WATERSHED ----------------------------- 294883     2118    32616    14943     1506

  TOTAL POUNDS OVERFLOW TO RECEIVING WATER ------------------------ 294867     2119    32616    14943     1504

  CONCENTRATION OF POLLUTANTS IN OVERFLOW TO RECEIVING WATER MG/L - 1252.06    9.00   138.49    63.45     6.39

  FRACTION OF TOTAL WASHOFF OVERFLOWING TO RECEIVING WATER --------    1.00     1.00     1.00     1.00     1.00

  FRACTION OF TOTAL WASHOFF INITIALLY OVERFLOWING TO RECEIVING WATER   0.97     0.96     0.97     0.97     0.97
```

Table 4.(Continuation) STORM Model Output(After ref.10)

finalized and, lastly, the environmental impact of storm water or overflows on receiving waters evaluated.

DEMONSTRATION CASE STUDY

A demonstration case study was conducted on a test catchment for which four-months precipitation/runoff data were available. In the planning stage, the STORM model was applied and its abbreviated output is shown in Table 4. A visual inspection of the output indicated that two storms from the studied period might be of a particular interest -Storm No. 11 (July, 1971), from the quantity point of view, and Storm No. 24 (September 5, 1971), from the quality point of view. The latter storm not only produced significant runoff, but also was preceded by a long dry period - 16 days. This would allow high accumulation of pollutants on the catchment surface prior to the storm and their washoff during the storm.

Storm No. 24 was simulated with the calibrated SWMM model. The simulated runoff hydrograph and Suspended Solids pollutograph are shown, together with the observed hydrograph and pollutograph, in Figure 5. In the same Figure, the changes in the Suspended Solids pollutograph caused by the runoff control by storage, swirl concentrator, and a microstrainer (treatment level 4 of the SWMM model) are shown and the corresponding costs. Finally, it was assumed that the drainage system discharges into a lake and the simulation was carried out for such a receiving water body. Suspended Solids were simulated at a point near the drainage outlet and the results are shown in Figure 6. For an antecedent dry period of 16 days and no effluent treatment, the Suspended Solids concentrations were as high as 610 mg/litre. This value dropped down to 460 mg/litre for an eight-day dry period, and to 60 mg/litre for one dry day. For comparison, the level 4 treatment (the microstrainer) reduces the maximum Suspended Solids concentration to 210 mg/litre, if the 16-day dry period is considered. There are numerous other control alternatives and measures which could be studied with the previously described models.

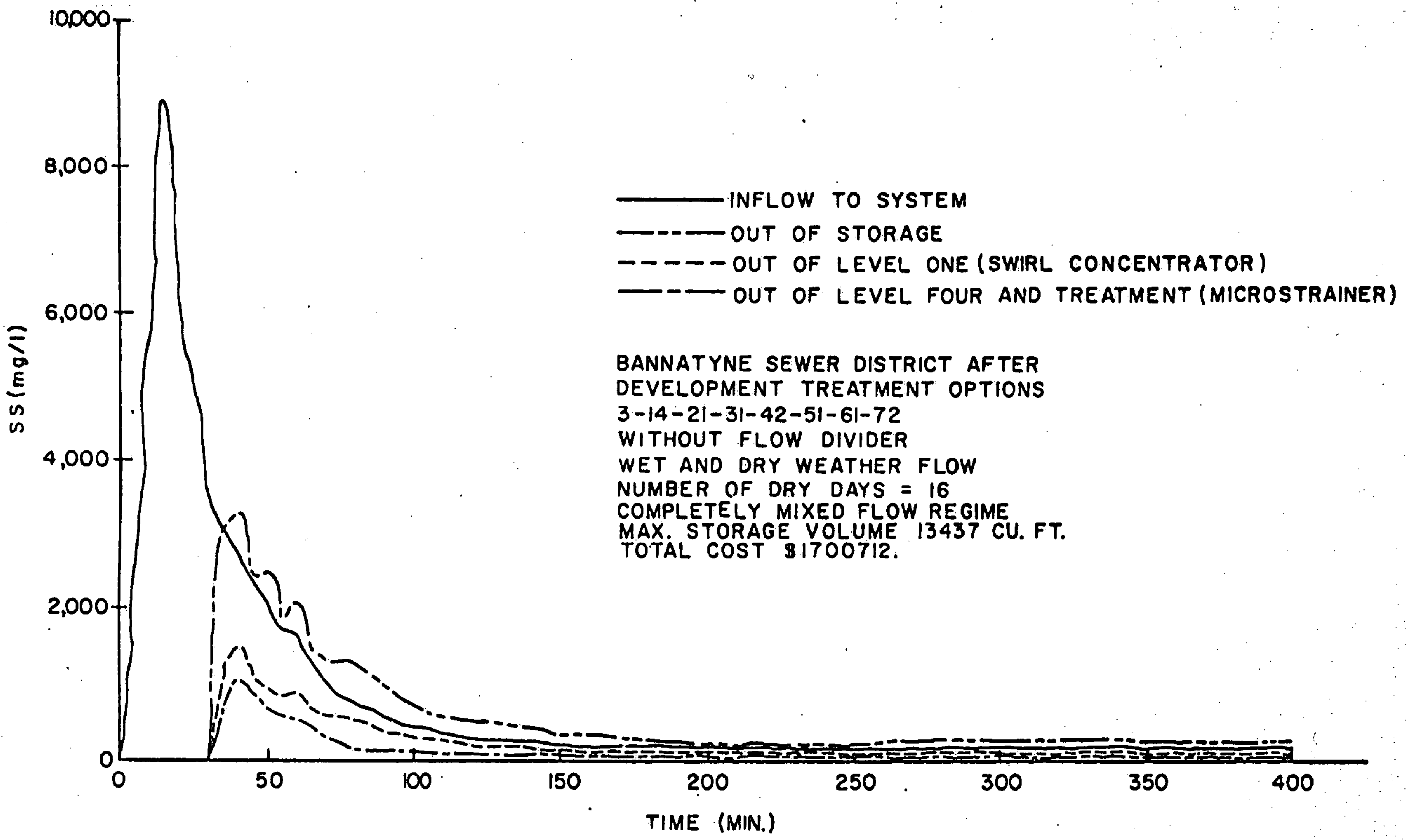


Figure 5. Suspended Solids Removal by Various Treatment Options [10].

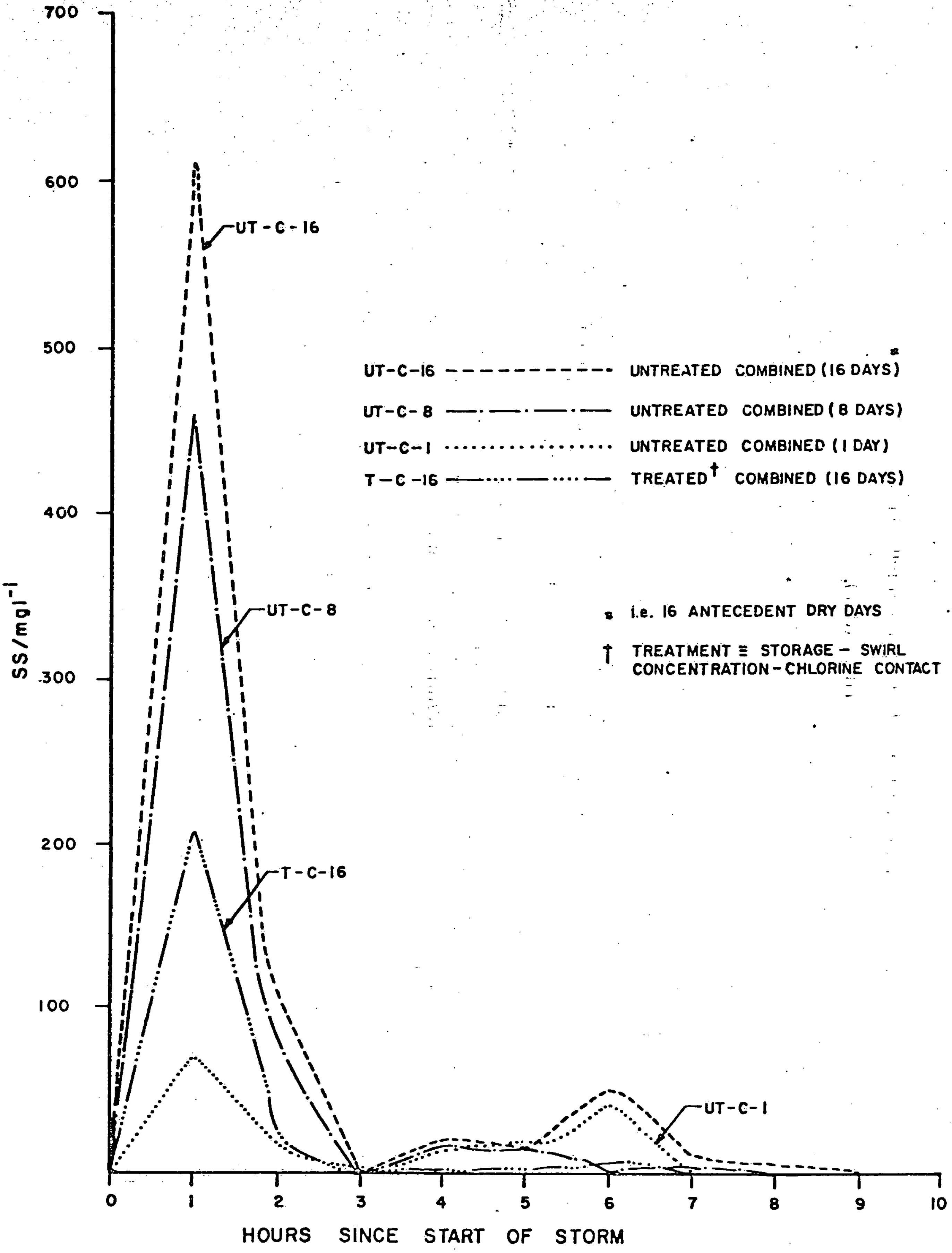


Figure 6. Suspended Solids Concentrations at Node (1)
(Receiving Water Body - Lake)

CONCLUSIONS

The existing urban runoff models can satisfy most of the users' needs for environmental studies of urban drainage. This may require the use of a combination of several models, which can be rather loosely interfaced, or some of their submodels modified, to obtain the desired modelling tool. Such an approach was demonstrated in this study aimed at developing and testing a methodology for urban runoff studies in Canada. Apart from data preparation, the methodology consists of two levels of modelling, the planning level and the design level. At the planning level, both the STORM and lumped SWMM models were used. The former model serves to determine the frequencies of runoff events and can also be used to identify the critical rainfall/runoff events to be modelled in a greater detail later. A lumped, uncalibrated SWMM model was also applied in the planning stage to study and compare various control alternatives.

In the design/analysis stage, a detailed calibrated model, such as e.g. the SWMM model, is used for the critical events identified in the preceding stage. The model calibration is particularly important for the runoff quality aspects. Should extensive sewer surcharging occur, it is necessary to use an urban runoff model with a complete dynamic wave flow routing.

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The Scientific Authorities for the study were J. Marsalek (technical aspects), G. H. Mills and Dr. R. W. Slater.

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