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STORMWATER DISCHARGES TO HAMILTON HARBOUR

by

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ABSTRACT

Long-term mean monthly discharges of stormwater plus dry weather flow and combined sewer overflows have been studied in the City of Hamilton by means of computer simulations. Using a 10 year hourly input data base, a partially calibrated STORM model was applied to the Upper Hamilton, Central Hamilton and West Hamilton districts. For various treatment rates and storage options, monthly and seasonal distributions of stormwater plus dry weather flow and combined sewer overflows were produced for each of the contributing subareas as well as the whole area. Without storage, about one third of the average annual stormwater plus dry weather flow volumes from the entire basin may be diverted in the form of combined sewer overflow to the harbour. This overflow volume may be somewhat overestimated, because of assumed spatially uniform rainfall distribution necessitated by limitations of rainfall data. Further verifications of the simulation results against field data are recommended.

RÉSUMÉ

On a étudié, pour la ville de Hamilton, au moyen de simulations d'ordinateur, les relevés mensuels moyens à long terme du débit d'eau de pluie, du débit de temps sec ainsi que du trop-plein d'égouts unitaires. Avec une base de données horaires d'entrée couvrant une période de 10 ans, on a appliqué un modèle STORM partiellement étalonné dans les districts de Upper Hamilton, Central Hamilton et West Hamilton. Une distribution saisonnière et mensuelle du volume d'eau de pluie et du débit de temps sec ainsi que du trop-plein d'égouts unitaires a été obtenue pour diverses vitesses de traitement et options de stockage dans chacune des sous-régions contribuantes ainsi que pour la région globalement. Sans stockage, environ un tiers des volumes annuels d'eau de pluie ajoutés aux débits de temps sec du bassin total pourrait se déverser dans le port sous la forme de trop-plein d'égoûts unitaires. Il se peut que le trop-plein soit quelque peu surestimé, l'hypothèse d'une hauteur de pluie uniformément répartie dans l'espace étant rendue nécessaire par les limites de l'information sur les chutes de pluie. On recommande d'effectuer des comparaisons supplémentaires des résultats de simulation avec les données recueillies sur le terrain.

MANAGEMENT PERSPECTIVE

Hamilton Harbour has been identified by the Water Quality Board of the International Joint Commission (IJC) as one of the areas of concern with recurring water pollution problems. Such problems are mostly caused by industrial chemicals, metals and nutrients originating from a number of sources. In order to develop an effective remedial strategy for control of such sources, their strength and significance need to be assessed. The report that follows evaluated one of the diffuse sources in the Hamilton Harbour Remedial Study area, combined sewers overflows in the City of Hamilton. The monthly and seasonal distributions of combined sewers overflow volumes were produced.

PERSPECTIVE - GESTION

Le Conseil de la qualité de l'eau de la Commission mixte internationale (CMI) a classé le port de Hamilton parmi les secteurs préoccupants affligés de problèmes de pollution chroniques. Ces problèmes sont causés dans la majorité des cas par des produits chimiques industriels, des métaux et des éléments nutritifs libérés dans l'environnement depuis un certain nombre de sources. Afin de mettre au point une stratégie corrective visant à limiter ces sources, il faut d'abord déterminer leur intensité et leur portée. Ce rapport évalue l'une des sources non ponctuelles relevées dans la région de l'étude de dépollution du port de Hamilton, soit le trop-plein des égoûts unitaires dans la ville de Hamilton. On a obtenu la distribution mensuelle et saisonnière des volumes de trop-plein d'égoûts unitaires.

INTRODUCTION

Hamilton Harbour, including Cootes Paradise and the Windermere basin, has been identified by the Water Quality Board (1987) of the International Joint Commission (IJC) as an area of concern. It is generally considered to be a water body with environmental degradation within the Canadian portion of the Great Lakes system.

The causes for such impairment were identified and included such sources as municipal and industrial discharges, combined sewer overflows, and urban and agricultural land runoffs.

In the Hamilton area, certain point sources of contaminants, such as municipal and industrial discharges, have been treated with efficiencies over 90 percent, during the past decade. Yet, there are some other diffuse sources, such as urban and agricultural runoff, may convey various contaminants and discharge them into the harbour. Without controls, the diffuse sources may continue to limit the rate of recovery of the harbour's water body.

Among the diffuse sources, urban runoff has been identified by the IJC as one of the contributing sources to the degradation of the Hamilton Harbour. Urban runoff enters the harbour either in the form of stormwater, from separate storm sewer systems, or combined sewer overflows from combined sewer systems.

The Hamilton Harbour receives urban stormwater from the following municipal areas: Waterdown, Dundas, Ancaster, City of Hamilton, and a portion of West Burlington (Aldershot, Tyandaga and Maple Community).

In the report that follows, a study of combined sewer overflows from the City of Hamilton to Hamilton Harbour is described.

DESCRIPTION OF THE HAMILTON HARBOUR WATERSHED

Watershed Area

The Hamilton Harbour Watershed is shown in Figure 1. The total drainage area is 49,400 ha (Snodgrass, 1981). The surface area of the harbour is 2,150 ha (Rodgers et al., 1988), giving a drainage area to harbour surface area ratio of 23. Major sub-catchments of the watershed include Redhill Creek, Spencer Creek, Grindstone Creek and the Burlington Hager/Rambo (including Indian Creek) diversion. The contributing areas of sub-catchments compiled from reports by Snodgrass (1981), Robinson and James (1982) and Water Survey of Canada (1985) are shown in Table 1.

Urban Area within the Watershed

For the purpose of this study, the urban area within the Hamilton Harbour Watershed needed to be defined. The total area was measured from a topographic map of scale 1:25,000 and further distributed into three major land use types by means of a regression method developed by the Ontario Community Planning Branch (1970). This method uses the population as input data. The populations were obtained from the city clerk's office of the regional municipality and verified against the Statistics Canada 1981 Census Report (Statistics Canada, 1981). The results of land use types calculated by the regression method were checked against the municipality's land use plan within the urban area. The distribution of the three major land use types in the urban area is presented in Table 2. The industrial area within the waterfront of the Hamilton Harbour was measured from a map, because the waterfront area is completely industrial.

ANNUAL HYDRAULIC INPUTS TO HAMILTON HARBOUR

The average annual combined volume of the sub-catchments surface runoff and wastewater treatment plants (WWTP) discharges is 298.3×10^6 m^3 (Table 3). The annual volume was calculated from hydrometric records for Redhill Creek, Spencer Creek, and Grindstone Creek, and the flow records for the WWTPs. Runoff from ungauged basins such as those of Rambo-Hager Diversion, Falcon Creek, Aldershot Creek, and some small creeks draining to Cootes Paradise, was estimated by means of the product of the drainage area multiplied by the mean annual surface runoff depth. The mean annual surface runoff depth for these areas, obtained from a report by Moin and Shaw (1986), equalled 350 mm. The streamflow records of Red Hill Creek, Spencer Creek, Grindstone Creek and the WWTP discharge records were obtained from Water Survey of Canada and the sewage treatment plants, respectively. The industrial plants discharges were not considered in the calculation of hydraulic loads, because their water supply is drawn from the harbour. Table 3 summarizes the annual average discharges for all of the above sources.

The combined sewer overflows from the City of Hamilton were excluded in Table 3. During dry weather, the sanitary sewage and infiltration are conveyed to the WWTP. During wet weather, the stormwater combined with sanitary sewage exceeding the treatment plant's capacity is diverted to the harbour. This flow carries a mixture of stormwater and the untreated sanitary sewage directly to the harbour. The exact amount of sewage overflows and their duration are unknown, because they are not routinely measured except for a few special studies. From the practical point of view, it is impossible to monitor all the overflow points and runoff events. Consequently, the amount of overflows from combined sewer systems has to be estimated by other means than measurements, and this was the main objective of this study.

REASONS FOR STUDY

It can be inferred from Table 2 that the urban land uses of the City of Hamilton represent about 73% (6945/9486) of all urban land within the Hamilton Harbour watershed, and, therefore, produces the largest stormwater contribution to the Harbour. The city also exhibits a diversity of land use types characterized by intense industrial activities along the harbour shoreline, high density commercial activities in the central business district and low-density residential land use above the escarpment.

About 75% of the city area is served by a complex combined sewer network. During periods of dry weather, the sanitary discharges are conveyed cross-town to deep trunk collector sewers and delivered to the Woodward Avenue Wastewater Treatment Plant. During wet weather, the combined sewer flows exceed the capacity of the treatment plant and it is necessary to divert the excess combined sewer flows directly to receiving streams and the harbour water body.

Several related stormwater and combined sewer flow studies for the City of Hamilton were conducted earlier (Gore and Storrie, 1977; Henry, 1982; MacLaren, 1978; Robinson and James, 1982; Ontario Water Resources Commission, 1968 and Snodgrass, 1981). Robinson and James (1982) conducted a comprehensive study which included the whole area of the City of Hamilton.

A sewer separation program has been taking place, and will likely continue in conjunction with the redevelopment or replacement of old sewers. Recently, a storage tank (60,000 m^3, unconfirmed) for combined sewer flows was built adjacent to Greenhill Avenue, just east of Rosseau Road. This facility will serve to reduce the pollution due to wet weather overflows from the upper escarpment of the Fennel area discharging directly into Redhill Creek. When writing this report, the storage facility was not yet fully operational. The effects of this facility on the combined sewer overflows were also evaluated.

SCOPE OF THE STUDY

The scopes of this study can be summarized as follows:

(i) To establish monthly and seasonal time distributions of the stormwater plus dry weather flow (DWF) and the combined sewer overflow (CSO) volumes to the receiving waters.

(ii) To examine the feasibility of partial calibration of the STORM model by using limited field measured data.

METHODOLOGY

As most of Hamilton's storm sewers are not gauged, except for some specific studies, it is necessary to estimate the quantity of water drained from the contributing areas. Determination of runoff and overflow volumes by means of field measurements of the very complicated sewer systems for the City of Hamilton is impractical. There are more than 20 major combined sewer outfalls in the Hamilton sewer system. To overcome such shortcomings, various rainfall-runoff simulation models can be used. These models were developed specifically for urban catchments to estimate runoff produced from contributing areas. These models range from event models suitable for sewer sizing such as ILLUDAS (Terstriep et al., 1974), to comprehensive models, such as SWMM (Huber et al., 1982) simulating most processes in the urban drainage system, including both quantity and quality of stormwater calculated at specified locations and in very short time intervals. Event models are suitable for predictions of peak rate of flood flow, but not for estimating daily flows. A continuous simulation model such as STORM (U.S. Corps of Engineers, 1976), is computationally less intensive and precise, but it is useful for estimating average flows over extended time periods from hourly data inputs. This method has been adopted for this study. A brief description of the STORM model follows. A schematic of the major processes of stormwater in combined sewer system is shown in Figure 2.

DESCRIPTION OF STORM MODEL (U.S. Corps of Engineers, 1976)

The STORM (Storage, Treatment, Overflow, Runoff Model) considers the interaction of seven stormwater elements:

precipitation (rainfall/snowmelt)
surface runoff
dry weather flow
pollutant accumulation and washoff
land surface erosion
treatment rates, and
detention reservoir storage.

Basically, the model operates with time series of hourly precipitation and temperature data which may extend over a large number of years. The catchment area is described in terms of land use types and imperviousness. Pollutant accumulation rates are associated with the land use type. The precipitation in excess of available depression storage is transformed to runoff at the outlet of the catchment. Flow and quality routing is not considered and the pollutograph is directly related to the runoff rate in any hour of flow. A treatment rate for this runoff may be specified. Flows in excess of this rate may be stored or considered as overflows discharged directly into the receiving waters. The stormwater plus DWF and CSO volumes were the subject of this investigation.

Quantity and Quality Estimation

Three major steps are involved in estimating stormwater quantity and quality.

(i) Computation of runoff quantity

The hourly runoff depths are calculated according to the following expression:

$$R = C (p - d) \qquad (1)$$

where R = runoff in mm

C = composite runoff coefficient

p = precipitation over the catchment area (mm)

d = available depression storage in mm

Average annuall runoff coefficients for the pervious and impervious areas need to be specified in order to obtain a single composite runoff coefficient according to the equation given below

$$C = C_p + (C_I - C_p) \sum_{i=1}^{L} X_i F_i \qquad (2)$$

where C_p = runoff coefficient for pervious surfaces

X_i = area in land use i as a fraction of total urban catchment area

F_i = fraction of land use i that is impervious

L = total number of land uses

The above composite runoff coefficient is applied to all events in the precipitation record regardless of their characteristics.

(ii) Computation of the Quality of Runoff

The STORM can simulate several basic pollutants in the urban runoff. These pollutants include suspended and settleable solids, chemical and biochemical oxygen demands, nitrogen, phosphorus and coliform bacteria. The computational procedures are based on pollutant accumulation and washoff within the study area. The quality of runoff was not reported here, because of a lack of field data to validate the results.

(iii) Computation of Storage, Treatment and Overflow

Computations of treatment, storage and overflows, conducted in the STORM model, are performed on an hourly basis throughout the study period. Every hour, in which runoff occurs, the treatment facilities are utilized to treat as much runoff as possible. When the runoff rate exceeds the treatment rate, the excess runoff is by-passed to storage. When the runoff rate is lower than the treatment rate, the excess treatment rate is utilized to deplete the stored volume. If the storage capacity is exceeded, all the excess runoff is considered as an overflow. This overflow is lost from the system and cannot be treated later. The quantity of the system overflows are computed by

$$Q_{OV} = Q_{RD} - Q_T - Q_S \tag{3}$$

where Q_{OV} = basin mm of combined sewer overflow

Q_{RD} = basin mm of runoff and dry weather flow routed

Q_T = basin mm of minimum treated of $(Q_{RD} + Q_{S_{t-1}}, T)$

Q_S = basin mm of minimum of runoff stored at $(Q_{RD} - Q_T, S)$

$Q_{S_{t-1}}$ = basin mm of storage remaining in previous hour

T = treatment in basin mm/hour

S = storage capacity in basin mm

DATA ACQUISITION

Meteorological Data

Meterological input data for the STORM model include time series of hourly precipitation, daily evaporation rates and daily temperatures. Ten years (1976-1985) of hourly precipitation, daily evaporation rates and daily temperature records were selected from the Royal Botanical Garden (RBG) climatic station. There are some limitations on the data. In particular, the hourly precipitation and daily evaporation rates data are available only from April to October. Therefore, for the remaining months, it was required to divide the available daily precipitation values into 24 equal hourly values and enter into the time series data base. The missing daily evaporation rates from November to March were estimated. The choice of RBG climatic station is based on the following reasons. There are four rain gauges in the harbour watershed, but only two of these, the RBG and Airport stations, collect hourly rain data. In order to select a representative gauge station record, a Thiessen network was constructed to determine the weighted average distribution for each station. A comparison of the Thiessen polygon results with the annual precipitation of each station is shown in Table 4. Among the four gauge stations, Millgrove Station appears to be the closest to the Thiessen network values. Since the Millgrove Station did not record hourly values, the Royal Botanical Garden record, which was the second closest to the Thiessen value and representative for the urban areas around the harbour, had to be used. To this end, uniform rainfall distribution over the study area had to be assumed, and the variations of storm movement were not considered.

Physiographic Data

The physiographic input data to the STORM model include the catchment area, the distribution of land use within the catchment and the imperviousness of the individual land use types. The catchment area and the distribution of land use within the study area are readily available from Robinson and James (1982). Dimensions of major combined sewer trunks within the city limits of Hamilton were obtained from the Hamilton sewers plan, Department of Engineering, the Regional Municipality of Hamilton-Wentworth. All major combined sewer and trunk interceptors were identified and shown schematically in Figure 3. The drainage network shown in Figure 3 for the combined sewer system of the City of Hamilton may be divided into three major subareas shown in Figure 4 and designated as follows:

(a) Central Hamilton (CH) - lower escarpment from Queen Street in the west to the Redhill Creek in the east, below escarpment and north of Greenhill Avenue.

(b) Upper Hamilton (UH) - starting from sewer flow dividing line near West 5th Street toward the Mountain Brow Boulevard in the east.

(c) West Hamilton (WH) - comprises Westdale, McMaster below the escarpment and west of West 5th Street on upper escarpment.

These three major drainage basins, served by combined sewers, and their contributing areas are indicated in Figure 5 and listed below:

Central Hamilton, A = 2741 ha

Upper Hamilton, A = 1228 ha

West Hamilton, A = 2200 ha

Total area is 6169 ha.

The land use data within the study sub-areas were adopted from Robinson and James (1982). The hydrologic and catchment input data are arranged according to the major interceptor layout. The compiled input data are presented in Table 5. The interceptors shown in Figure 4 are designated as trunks A to H. The trunk E is a separate storm sewer. By this trunk sewer, stormwater is collected and drained to Redhill Creek at Upper Ottawa Street between Limeridge Road and Stone Church Road, where the sanitary sewage is collected by a sanitary sewer and delivered via a 1.52 m diameter pipe to the trunk sewer F (Figure 4). The sizes and connectivities of the eight trunk sewers are listed in Appendix A. The STORM model does not require pipe sizes and their connectivity as an input.

DESCRIPTION OF THE HAMILTON SEWAGE TREATMENT PLANT OPERATIONS

The Hamilton Sewage Treatment plant is located on Woodward Avenue (Figure 3). During the dry weather, sanitary sewage is conveyed to the treatment plant by 3 major trunk sewers from cross-town (H), upper Hamilton (F) and east Hamilton (G) for treatment (Figure 4).

The average daily treatment rate is 196,000 m^3/day (plant records from 1980 to 1985), or 2.3 m^3/s, and the maximum treatment rate is 409,000 m^3/day or 4.7 m^3/s.

During the wet weather when the combined sewer flows exceed plant capacity (4.7 m^3/s), the storm sewage is partially or totally diverted to Cootes Paradise, Hamilton Harbour, and Redhill Creek at outfall points. Most of the diversions are activated by remotely controlled gates, but a few, such as the James Street overflow, are controlled by manual adjustment of overflow gates. The remotely controlled gates are activated from the plant. The locations of these remotely controlled and fixed gates are listed in Appendix B. Consequently, the exact amount of sewage overflow and the duration of overflow are not known, because such phenomena are not routinely measured. The gates may be closed for several hours after the actual storm runoff has ceased. In addition, the plant itself may become occasionally overloaded, when some gates are out of service, causing partial by-passing at the plant. The total duration of such by-passing is recorded, but the volume of sewage by-passed is unknown.

Partial Calibration of the STORM Model

Before the STORM model can be used in simulation, certain model parameters should be calibrated against the observed values.

Runoff Quantity Calibration

Recognizing the complexity of the sewer system for the study area with numerous overflow control devices and the interconnected combined sewerage system, it is impractical to measure flow at all outfalls. Consequently, such flows need to be simulated by a calibrated model. Limited data collected in several past studies were used for partial model calibration.

The runoff quantity can be computed by using one of the three methods offered by the STORM model. These three methods are the coefficient method, the U.S. Soil Conservation Curve Number Technique, or a combination of the two. Among the three methods, the coefficient method is recommended for watersheds with relatively high percentage of imperviousness, because the losses due to infiltration are relatively small. The most important parameters required adjustments are the average annual runoff coefficients for impervious and pervious areas along with depression storage of the watershed as given in equations (1) and (2).

The objective of this calibration is to establish the runoff coefficients for each of the three subbasins. The runoff coefficients are used by the STORM model to produce a composite coefficient applied to all precipitation events which occurred on the catchment.

Before proceeding with the calibration, goodness of fit and accuracy criteria need to be established. Such criteria have been described by Fleming (1975). Since STORM model does not simulate peak flow rates and the flow times to peak, the only criteria needed to be established is for runoff volumetric calibration. It is the aim to achieve the agreement between simulated and observed values within 10%. Such accuracy is considered to be adequate as indicated by the earlier studies dealing with urban runoff volumes (Dillon, 1979; Proctor and Redfern, and Maclaren, 1976).

A set of four independent runoff events measured at Hydro-sub-station Gauge of Chedoke Creek in West Hamilton was chosen from a report by Robinson and James (1982) for runoff volumetric calibration for West Hamilton sub-area. Another series of five runoff events measured by Gore and Storrie (1977) was used for runoff volumetric calibration for Upper Hamilton. The Hydro-sub-station gauge has a drainage area of 950 ha with an average impervious surface area of 29%. The Gore and Storrie test catchment bounded by Kenilworth and Fennel area has a catchment area of 55 ha with an average impervious surface area of 41%. Only the measured runoff events for which rainfall was recorded at the Royal Botanical Garden were considered.

There was no suitable data set for calibrating runoff volumes for Central Hamilton area (see Figure 5). To this end, the calibrated parameter C_{imp} from the Upper Hamilton area and the model default values were used for Central Hamilton. The mean value of C_{imp} derived from the two calibration data sets is 0.85. In view of the intense commercial and industrial land uses in this area, with an average of 53% (Robinson and James, 1982) imperviousness, the application of such value is justified.

The volumetric calibration results of STORM model are listed in Table 6. The ratios of simulated runoff volume to measured runoff volume are 1.08 and 1.07 for the West Hamilton and the Upper Hamilton areas, respectively.

Simulation of Stormwater Plus DWF and Combined Sewer Overflows

The partially calibrated STORM model was used to conduct a long-term continuous simulation of stormwater plus DWF and CSO volumes.

The input data record consisted of 10 years (1976-1985 inclusive) of hourly precipitation and daily mean temperature data.

The study area was discretized into 20 subareas, each of which corresponded to one outfall. The hydrologic and sub-area input data are listed in Table 5 and the corresponding outfalls are shown in Figures 3 and 4. As shown in Figure 4, the trunk sewer BC has no outfall assigned, because it discharges into the trunk sewer H. Subsequently, the contributing area corresponding to the trunk sewer BC is distributed among the subareas contributing to the trunk sewer H. This is done by evenly distributing the BC contributing area among all the subareas with outfall numbers 5 to 19. The final adjusted contributing subareas, numbers 5 to 19, are presented in Table 7 together with the estimated daily dry weather flows including infiltration. The dry weather flow and infiltration data were estimated from six years (1980-1985) of flow records obtained from the WWTP on

Woodward Avenue. The total DWF for the study area was 196,000 m^3/day. This flow was then distributed among the sub-areas according to their areas of proportionality to the entire area (see Table 7).

In order to reduce the computation times, the 20 sub-areas in the study area were further aggregated into 3 subbasins, with three outfalls, according to the sewer trunks interception pattern, using a technique referred to as "lumping" (Marsalek, 1973; Perks, 1976). The lumping was arranged in such a manner that the three areas with the outfalls Nos. 1 to 4, 5 to 19, and 20 were designated as West Hamilton sub-basin, Central Hamilton sub-basin, and Upper Hamilton sub-basin, respectively. The aggregated physiographic and hydrologic data for the lumped sub-basins are shown in Table 8. The outfalls are shown schematically in Figure 6.

Figure 6 shows that Cootes Paradise, Hamilton Harbour and Windermere Basin receive stormwater plus DWF and CSO from West Hamilton, Central Hamilton and Upper Hamilton sub-basins, respectively.

SIMULATION APPROACHES

For the purpose of determining the quantity of the stormwater plus DWF and the CSO, the STORM simulations have to consider the treatment rate and storage volumes for various operational options. The following operational options were considered:

Option 1: The existing maximum treatment rate of 409,000 m^3/day, without storage facilities.

Option 2: The existing maximum treatment rate of 409,000 m^3/day, with a storage capacity of 60,000 m^3.

Option 3: The projected maximum treatment rate of 683,000 m^3/day, with a storage capacity of 60,000 m^3.

The performance of the above control options was simulated for 10 years of hourly precipitation and daily mean temperature data from January 1, 1976 to December 31, 1985.

Simulation Results

The results of simulation are presented in the form of average monthly data for the simulation period of 10 years and each of the 3 subbasins analysed. It should be noted that results for individual event values are not reported here because it would be impractical. For this reason, the event values occurred in a calendar month are averaged for the month and the mean daily values may be derived from the monthly results. Furthermore, the monthly precipitation data from the Royal Botanical Gardens and the frequency of monthly precipitation are listed in Appendices C and D, respectively. The surface areas and volumes of the three receiving waters, Hamilton Harbour, Cootes Paradise and Windermere Basin, are listed in Appendix E.

The simulation results are divided into stormwater plus DWF and CSO volumes for each calendar month of the year, for the three studied subbasins, and three operational conditions.

The simulated average stormwater plus DWF treated and CSO volumes occurred in a calendar month for each sub-basin for given treatment rate and storage options are plotted in Figure 7. The same results of the stormwater plus DWF and CSO volumes for all three sub-basins combined are plotted in Figure 8.

DISCUSSION OF RESULTS

Partial Calibration of STORM Model

Calibration implies the comparison of model simulation results to field measurements to ensure that the model is producing accurate information. Ideally, the model should be calibrated against a data set, and then verified against another set of data which has not been used in calibration. Such an approach could not be taken in this study, which was conducted without a field program. Consequently, the STORM model was partially calibrated by using the data collected earlier. Such data were not available for the entire year. For this reason, the calibration conducted for the STORM model can satisfy only some of the criteria set out in the STORM calibration guidelines. The calibration has been accomplished by using Robinson and James (1982) and Gore and Storrie (1977) field data.

Distribution of Monthly Stormwater plus DWF and Combined Sewer Overflow Volumes

The simulated long term daily stormwater plus DWF and CSO volumes, plotted in Figures 7 and 8 for each sub-basin, as well as the entire basin, respectively, show an interesting contrast of the variation of distributions of stormwater plus DWF and CSO volumes during the year. For sub-basins (Figure 7) and the entire basin (Figure 8), the variations of stormwater plus DWF and CSO volumes indicate low, high and low during the year. These variations correspond approximately to the periods from January to May, June to September and October to December, respectively. For discussion purposes, these periods are defined as period 1, period 2 and period 3 which correspond to January to May, June to September, and October to December, respectively. There are two obvious trends depicted in Figures 7 and 8. The first trend suggests that high runoff usually occurred during the summer months. The other trend shows that the Central Hamilton sub-basin (Figure 6) produced the highest stormwater runoff and overflow volumes, the Upper Hamilton and West Hamilton areas were second and third, respectively. The second trend simply reflects the size of the contributing area.

For the purpose of comparison of the operational options described earlier, the simulated average daily stormwater plus DWF and the CSO volumes for the entire basin and sub-basins were grouped into three periods. The distribution of periodical averages is listed in Tables 9 and 10.

Comparisons of Overflow Volumes for Various Operational Options

The STORM model can simulate stormwater plus DWF and CSO volumes from a combined sewer system. Therefore, it is possible to estimate the overflow volume reductions for various operational options if both stormwater plus DWF and CSO volumes are calculated. The estimated CSO volume reduction of Options 2 and 3 were related to the CSO volume of Option 1 (existing treatment operation). Volume reductions, in relation to the volume for Option 1, for Options 2 and 3 were divided by the Option 1 volume and expressed as percentages.

Results of estimation of overflow volume reductions for various options are presented in Tables 11 and 12 for the entire basin and subbasins respectively.

It may be noted here that the sum of the stormwater plus DWF treated and CSO volumes under various options (Tables 9 and 10) is not identical. This is particularly true because the STORM model is equipped with storage option of computation. As noted earlier in the section of Computation of Storage, Treatment and Overflows, the stormwater plus DWF rate in any hour of flow in excess of the treatment rate may be stored or considered as CSO. Thus, it can be seen from Tables 9 and 10 that the stormwater plus DWF volumes treated under options 2 and 3 are higher than option 1 (on the other hand, CSO volume is lower) because the excess stormwater plus DWF is stored and treated later when the stormwater plus DWF rate is lower than the treatment rate. It is interesting to note that period 2 (June to

September) in Table 9 shows the highest CSO volume among the three periods. It accounts for about 40% of the total annual CSO volume, under existing treatment capacities.

Annual Mass Balance Estimation

As mentioned earlier, this study was conducted without field data. To this end, verification of the simulated results by the STORM model may be necessary. The verification is conducted by means of the annual mass balance. The annual mass balance is based on the difference between the simulated annual stormwater plus DWF volume and the recorded annual stormwater plus DWF minimum volume treated at the Hamilton Wastewater Treatment Plant. The difference is then compared for agreement with the simulated CSO volume by the STORM model. To do this, equation (3) applied by the STORM model is repeated here for convenience.

$$Q_{OV} = Q_{RD} - Q_T - Q_S \qquad (4)$$

where Q_{OV}, Q_{RD}, Q_T, and Q_S have been defined before, except the unit used in here is m^3/year.

The annual mass balance estimation is valided only for option 1, because options 2 and 3 are projected operations by the STORM model. Therefore, there is no measured data existence including Q_S. For this reason, the term of Q_S in equation (4) may be dropped. And equation (4) is rewritten for the purpose of annual mass balance estimation for option 1.

$$Q_{OV} = Q_{RD} - Q_T \tag{5}$$

where Q_{OV} = simulated average annual (1976-1985) volume of combined sewer overflow in m^3/year

Q_T = recorded average annual (1980-1985) minimum volume treated at the Hamilton Wastewater Treatment Plant in m^3/year, and

Q_{RD} = simulated average annual (1976-1985) volume of stormwater plus DWF in m^3/year

Computations of Q_{OV}, Q_{RD} and Q_T

The simulated results of the daily rates of CSO for the entire basin (Table 9, option 1) were used to calculate the average annual CSO volume. The calculation is

$$Q_{OV} = \left(\frac{106 + 153 + 84}{3}\right) \times 10^3 \times 365 = 42 \times 10^6 \ m^3/year$$

Similarly, the simulated results of the daily rates of stormwater plus DWF for the entire basin (Table 9, option 1) were used to calculate the average annual stormwater plus DWF volume. The calculation is

$$Q_{RD} = (\frac{320 + 350 + 253}{3}) \times 10^3 \times 365 = 112 \times 10^6 \ m^3/year$$

The average daily minimum treatment rate records (1980-1985) from the Hamilton Wastewater Treatment Plant is 196,000 m^3/day (Table 7). The average annual minimum treated stormwater plus DWF volume is calculated by

$$Q_T = 196 \times 10^3 \times 365 = 72 \times 10^6 \ m^3/year$$

By substituting Q_{OV}, Q_{RD} and Q_T values into equation (5), the result of the average annual mass balance is 2×10^6 m^3/year (or 5%) overestimated for the simulated CSO volume than the difference of volumes between the simulated stormwater plus DWF volume and the recorded stormwater plus DWF of minimum treated volume.

The discrepancy of the average annual mass balance estimation is primarily due to the limitation of accuracy of the model calibration and the different lengths of the data records being used. Another factor, such as volume of stormwater plus DWF by-passing, which may contribute to the error is not included in the estimation. The different lengths of data records are an important factor for estimation of CSO volume, because the CSO volume may vary from one year to another due to the precipitation nature. In particular, the storm intensity and duration, which are the primary factors to cause the combined sewer system overflow. A storm with high intensity combined with long duration may produce larger overflow volume than a combination of several overflow volumes produced by a number of moderate storms. The length of data records applied for the simulated average annual volumes is 10 years, and the length of data records used for the average annual minimum volume treated is 6 years. Nevertheless, the 5% overestimation on the average annual mass balance suggested that the partially volumetric calibrated STORM model is adequate for the studied basin.

CONCLUSIONS

Stormwater discharges, dry weather flows and combined sewer overflows were simulated for that part of the City of Hamilton which is served by combined sewers. The results indicate that, for the entire basin and the existing treatment capacity, about one third of the annual wet-weather flow, representing a mixture of stormwater and municipal sewage, may be diverted in the form of combined sewer overflows to the Hamilton Harbour. With an added storage capacity of 60,000 m^3, the simulated overflow volume would be reduced to about one quarter of the annual volume. Finally, the proposed increase in the treatment rate to 683,000 m^3/day combined with the addition of a storage facility with the capacity of 60,000 m^3 would further reduce the simulated overflow volume to about one seventh of the annual wet-weather flow. Because of uncertainties inherent to the simulation process, the simulation results are more useful for comparison of control alternatives rather than for establishing exact magnitudes of overflow volumes. The main sources of simulation uncertainties include uncertainties in the physiographic input data and limitations of the precipitation data which necessitate the assumption of uniform spatial distribution. This assumption generally leads to overestimation of simulated overflows.

The simulation results were based on the existing catchment conditions and treatment capacities (1988). Changes in land use and the continuing redevelopment of the sewer network will alter the sewer flows as well as the combined sewer overflows. Under such circumstances, the results presented in this report will no longer apply and should be updated in future work.

ACKNOWLEDGEMENTS

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FIGURES

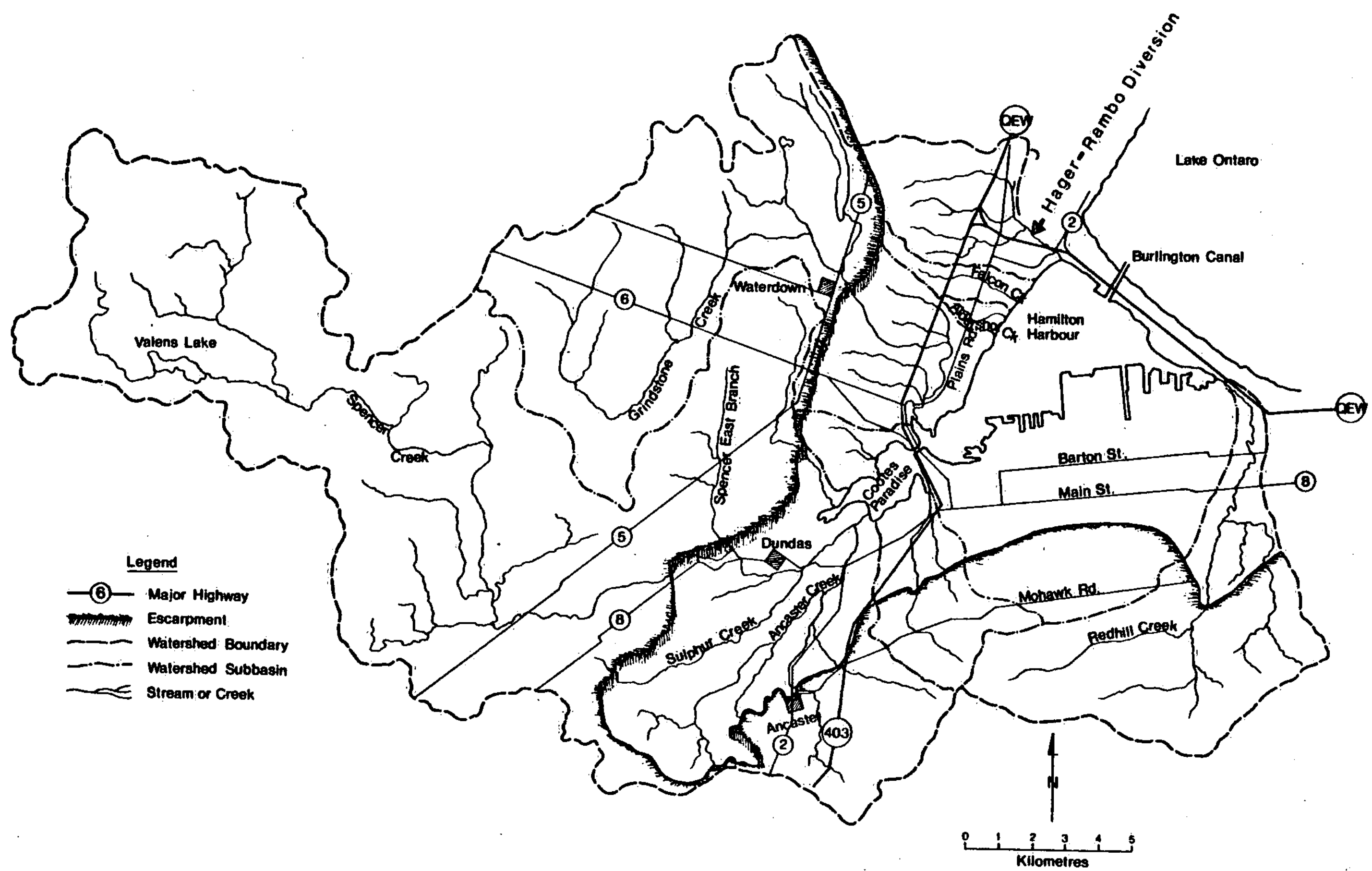


Figure 1. Hamilton Harbour Watershed

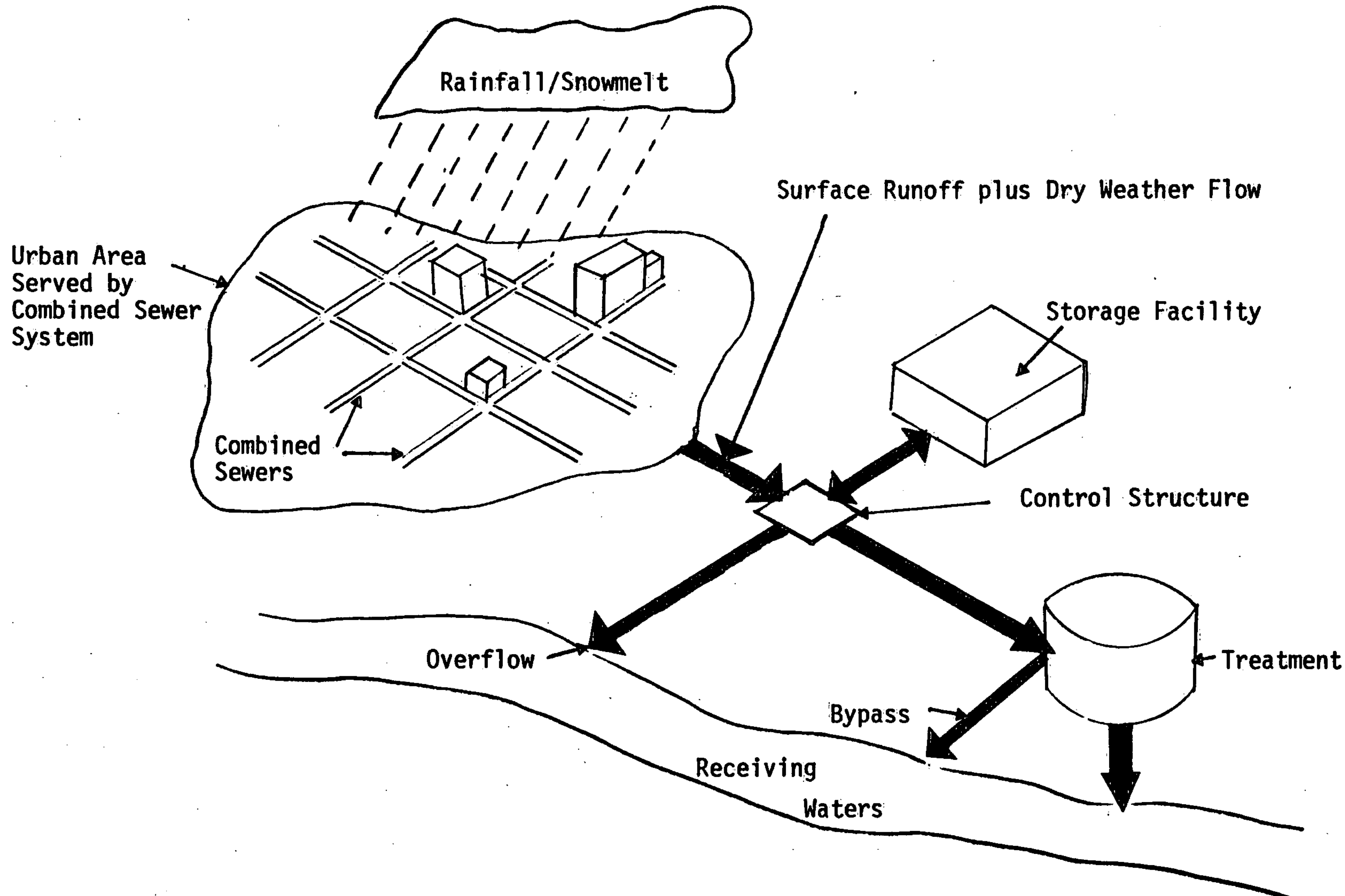


Figure 2. Schematic of Major processes of Urban Runoff in Combined Sewer System

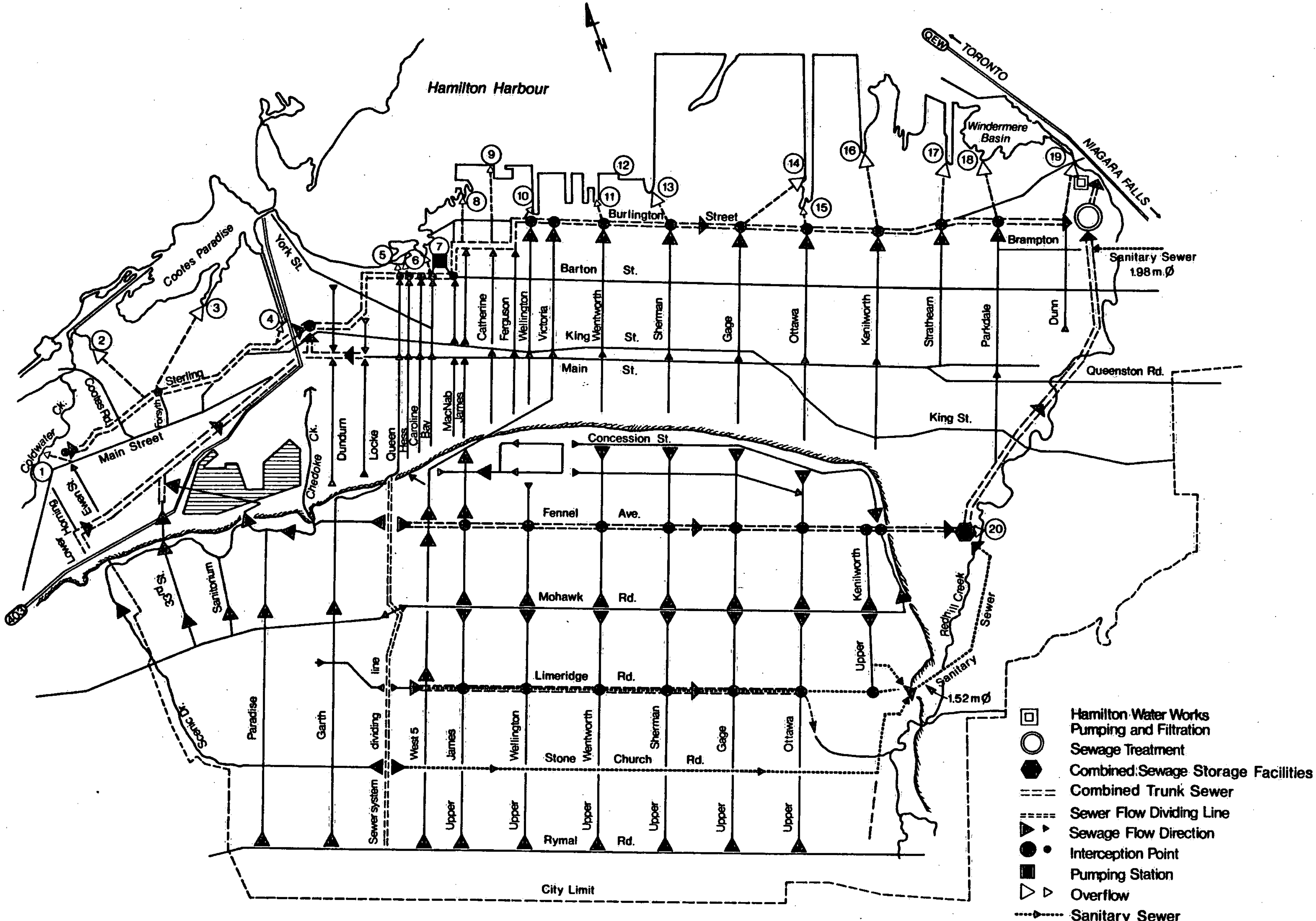


FIGURE 3. SCHEMATIC DRAINAGE NETWORK OF COMBINED SEWERS AND INTERCEPTORS

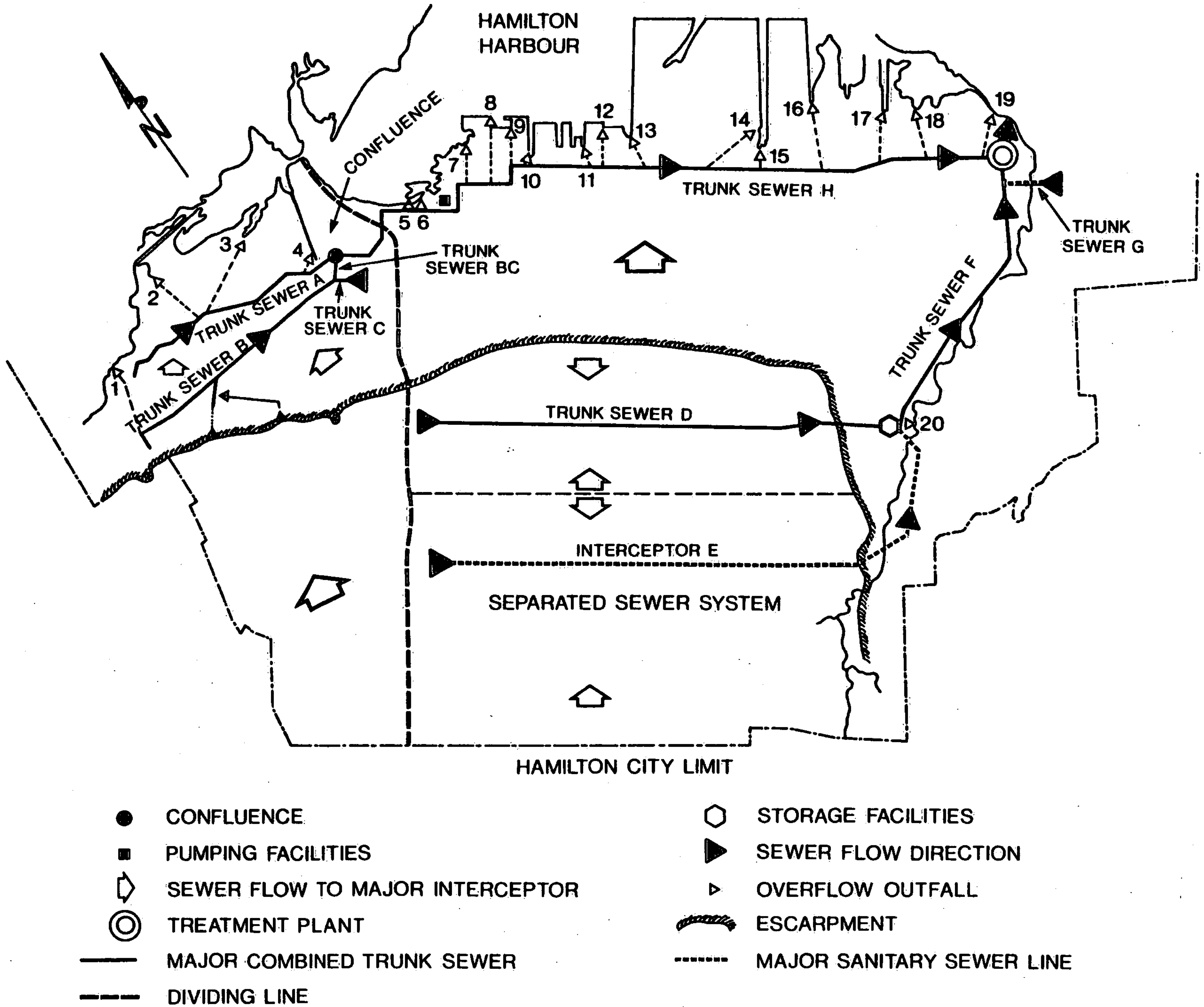


FIGURE 4. DESIGNATED COMBINED TRUNK SEWER WITH OVERFLOW AT VARIOUS OUTFALLS

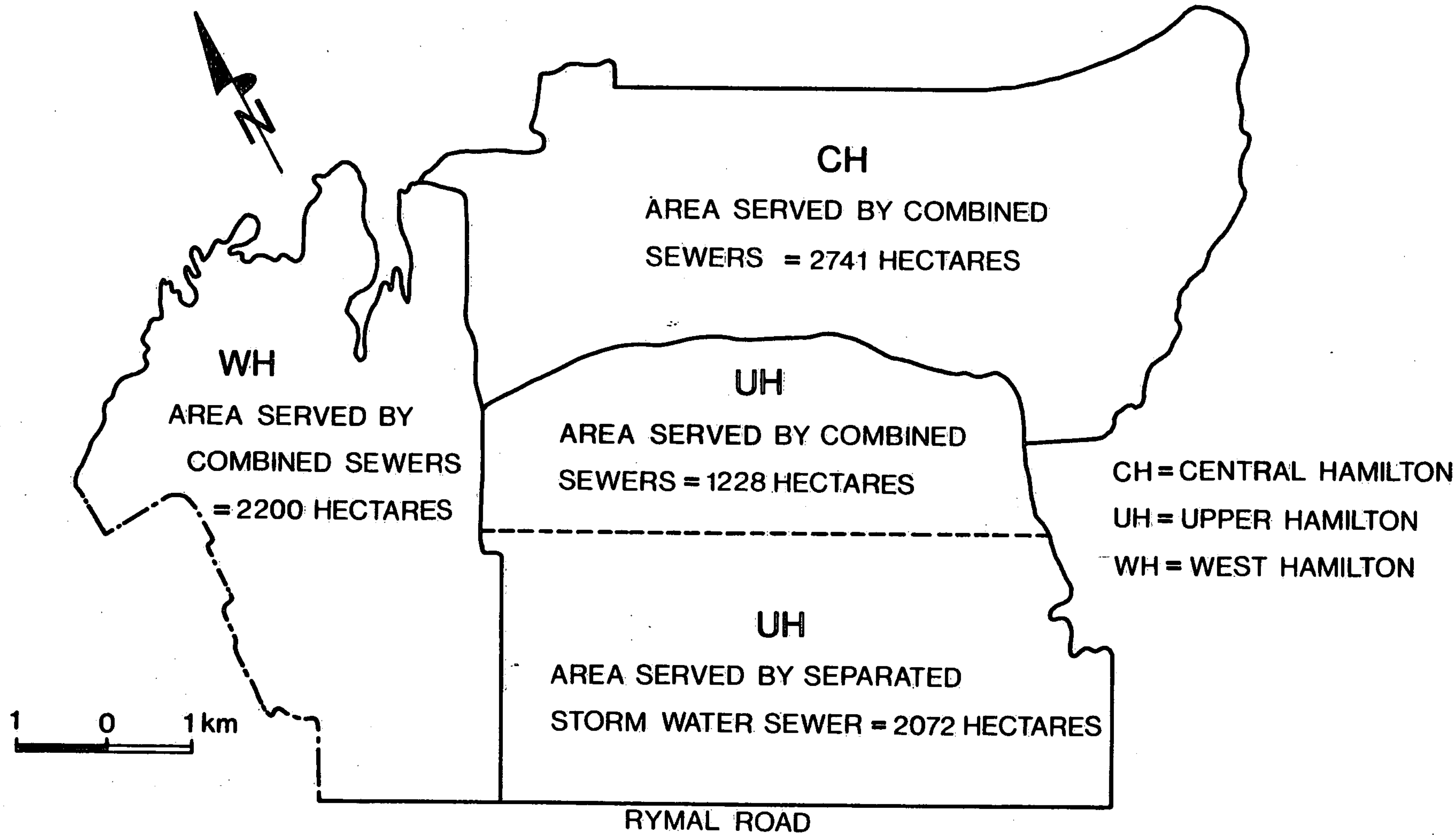


FIGURE 5. DESIGNATED DRAINAGE BASIN SERVED BY COMBINED SEWERS

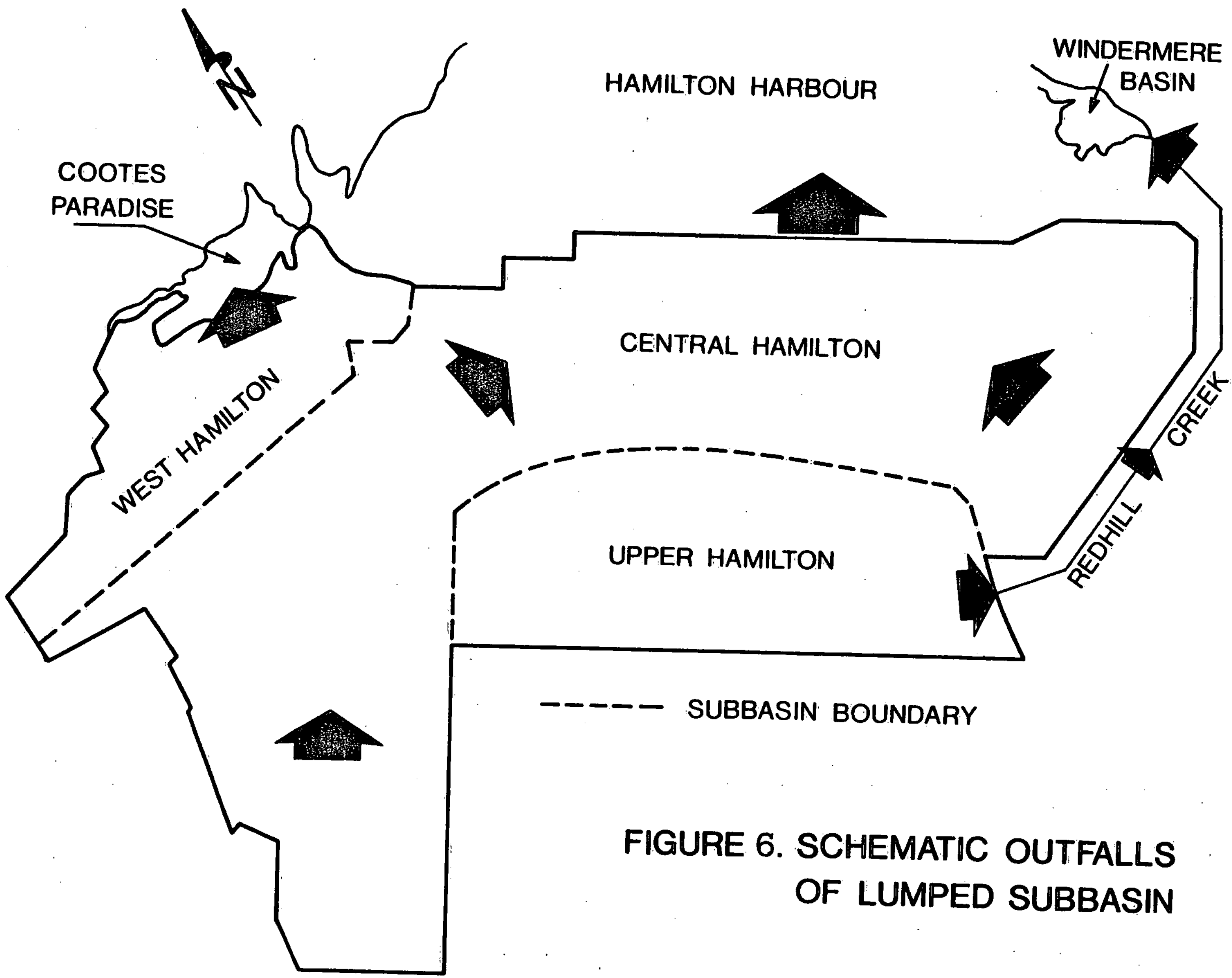


FIGURE 6. SCHEMATIC OUTFALLS OF LUMPED SUBBASIN

Figure 7. Simulated Long Term Monthly Stormwater Plus DWF and Combined Sewer Overflow Volumes for Upper Hamilton, Central Hamilton and West Hamilton

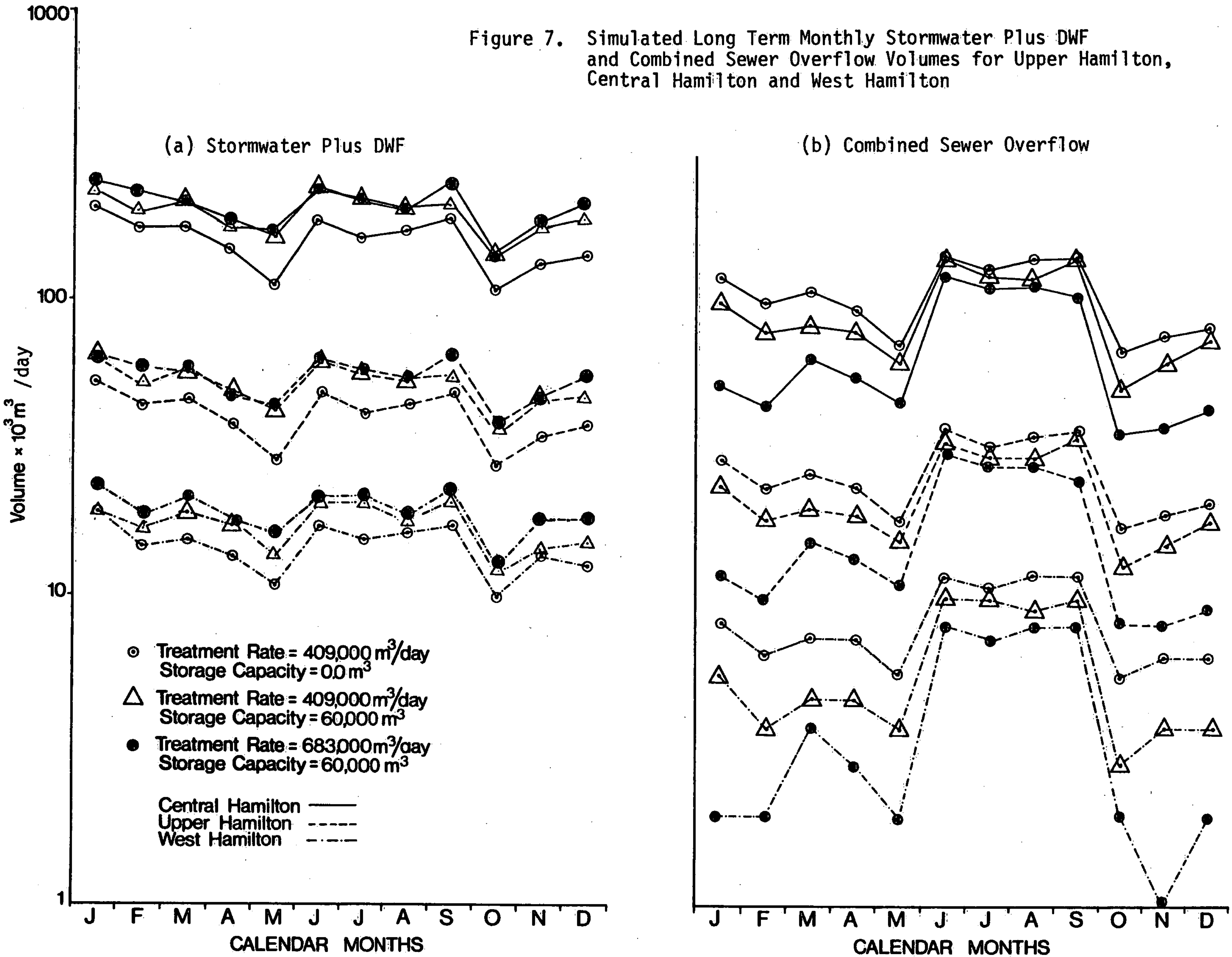
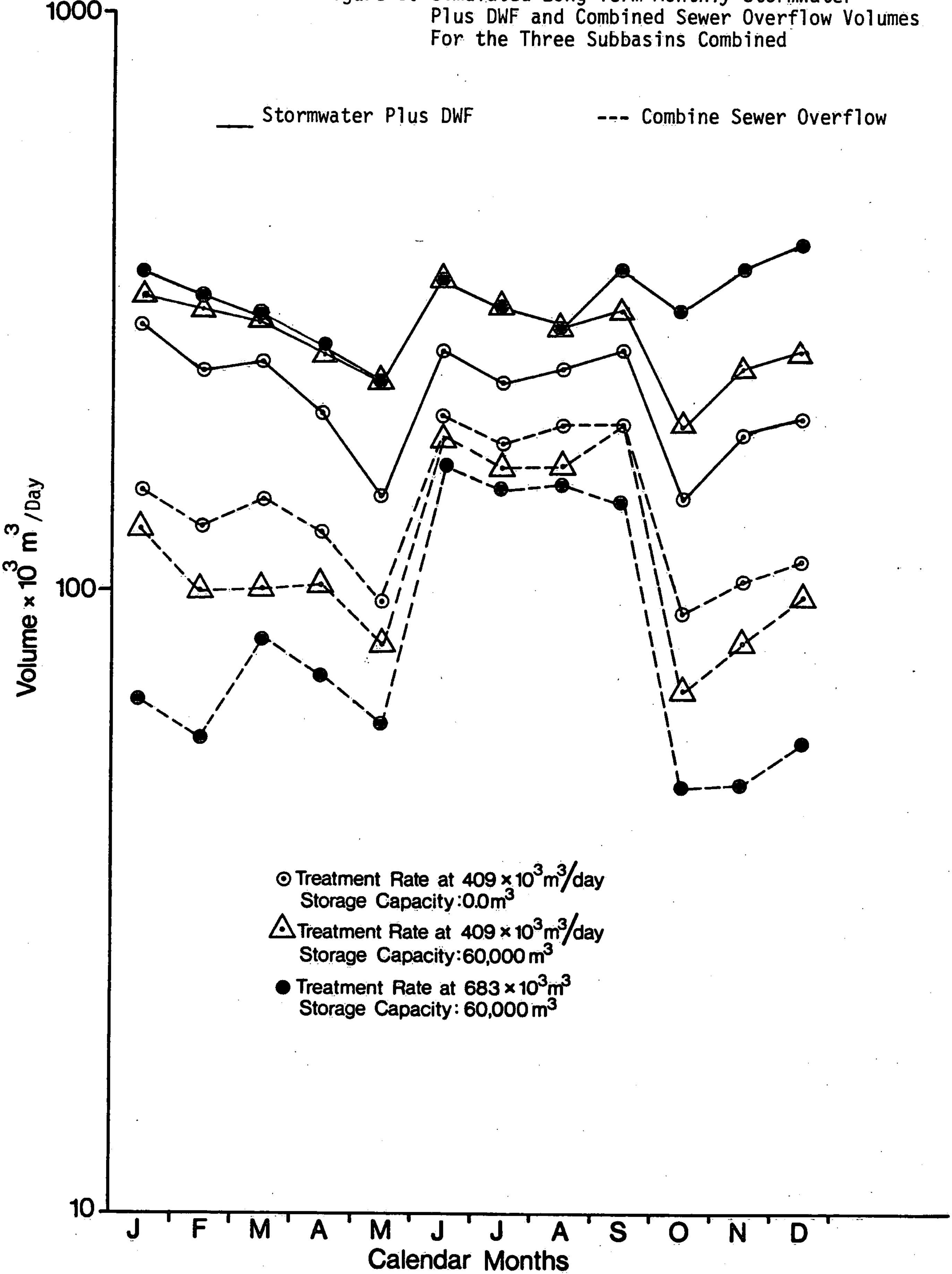


Figure 8. Simulated Long Term Monthly Stormwater Plus DWF and Combined Sewer Overflow Volumes For the Three Subbasins Combined



TABLES

Table 1. Contributing Area of Hamilton Harbour Watersheds

Watershed	Area (Ha)
Redhill Creek	6,631
Central District Area	2,746
Chedoke Creek	2,694
Spencer Creek*	16,640
Grindstone Creek	8,260
Burlington Rambo-Hager Diversion	2,262
Aldershot Creek	1,274
Falcon Creek	416
Undefined Watersheds (ungauged)	
Ancaster Creek	
Hickory Creek	
Hopkins Creek	
Long Valley Creek	
Sulphur Creek	
Vine Brook Creek	8,477
Westdale Brook	
Total	49,400
Hamilton Harbour Surface Area	2,150
Grand Total	51,550

*above gauge station

Table 2. Urban Land Uses within the Hamilton Harbour Watersheds (ha).

Watershed	Population	Residential	Commercial	Industrial	Open
1. Redhill Creek	36,700	2,170	217	116	4,128
2. Central Business District and Chedoke Creek	307,700	3,091	437	914	998
3. Spencer Creek includes Dundas, and Ancaster	34,020	588	140	170	15,742
4. Grindstone Creek, Waterdown & Flamborough	26,870	622	59	196	7,383
5. Burlington includes Aldershot/ Plains Road Falcon & Rambo/Hager	25,000	545	52	169	3,186
Total	430,290	7,016*	905*	1,565*	31,437

____ sum = 6945 ha
* sum = 9486 ha

Table 3. Summary of Annual Hydraulics Inputs to Hamilton Harbour.

Description	Year	Annual Volume $x10^6 m^3$		Remarks
		WWTP*	Surface & Streams	Data Source
Spencer Creek	1976-1985		65.6	WSC**
Grindstone Creek	1976-1985		30.1	WSC**
Ungauged Creeks	17 years		29.8 (e)	
Redhill Creek	1978-1985		22.8	
Burlington Areas (include: Falcon Creek Rambo-Hager Aldershot Creek and area)	17 years		13.8 (e)	
Hamilton WWTP*	1980-1985	87.2		
Burlington WWTP	1980-1986	26.7		
Dundas WWTP	1980-1985	2.1		
Waterdown WWTP	1980-1986	0.6		
Harbour Surface Received from precipitation	1976-1985		19.6	
Total		116.6	181.7	

The Grand Total is $298.3 \times 10^6 m^3$

* WWTP: Wastewater Treatment Plant
** WSC: Water Survey of Canada
(e) Estimated from mean annual runoff (Moin and Shaw, 1986)

Table 4. Comparison of Thiessen Network Weighting to Individual Gauge Station

Year	Precipitation (mm)					Deviation (Thiessen-Gauge Station)/ Gauge Station (%)			
	Thiessen Network	Hamilton Airport	Millgrove	Royal Botanical Garden	Hamilton Treatment Plant	Hamilton Airport	Millgrove	Royal Botanical Garden	Hamilton Treatment Plant
1976	924	909	962	870	867	1.7	-4.0	6.2	6.6
1977	1003	985	990	1072	945	1.8	1.3	-6.4	6.1
1978	877	839	893	908	780	4.5	-1.8	-3.4	12.4
1979	858	918	850	865	811	-6.5	0.9	-0.8	5.8
1980	732	800	708	770	687	-8.5	3.4	-4.9	6.6
1981	907	1045	871	893	928	-13.2	4.1	1.6	-2.3
1982	1055	1096	1081	1015	960	-3.7	-2.4	3.9	9.9
1983	943	1075	940	923	839	-12.3	0.3	2.2	12.4
1984	1022	1013	1022	1008	1070	0.9	0	1.4	-4.5
1985	887	1067	930	793	826	-16.9	-4.6	11.9	7.4
Mean	921	975	925	912	871	-5.2	-0.3	1.2	3.2

Table 5. Hydrologic and Catchment Input Data.

Outfalls No.	Name	Contributing area ha	Hydrologic Parameters: Impervious ha (%)	Pervious ha	Combined Surface Dep. mm	Land Use Data: Residential ha (%)	Institutional ha (%)	Commercial ha (%)	Industial ha (%)	Open Land ha (%)
1	Ewen Rd.	86	26 (30)	60	1.91	50 (58)	6 (7)	2.5 (3)	2.5 (3)	25 (29)
2	McMaster	103	32 (31)	71	1.91	60 (58)	7 (7)	3 (3)	3 (3)	30 (29)
3	Forsyther	147	40 (27)	107	1.91	86 (58)	10 (7)	4 (3)	4 (3)	43 (29)
4	Chedoke	213	55 (26)	158	1.91	124 (58)	15 (7)	6 (3)	6 (3)	62 (29)
	Subtotal	549	153	396	1.91	320 (58)	38 (7)	15.5 (3)	15.5 (3)	160 (29)
BC	Trunk Sewer BC	1651	352 (23)	1299	1.91	957 (58)	115 (7)	50 (3)	50 (3)	479 (29)
5	Queen	67	32 (48)	35	1.91	37 (55)	1.3 (2)	8.7 (13)	15.4 (23)	4.7 (7)
6	Hess	66	40 (60)	26	1.91	36 (55)	1.3 (2)	8.6 (13)	15.2 (23)	4.6 (7)
7	James	41	18 (44)	23	1.91	23 (55)	.8 (2)	5.3 (13)	9.4 (23)	2.9 (7)
8	Catherine	74	34 (46)	40	1.91	41 (55)	1.5 (2)	9.6 (13)	17.0 (23)	5.2 (7)
9	Ferguson	24	13 (56)	11	1.91	13 (55)	.5 (2)	3.1 (13)	5.5 (23)	1.7 (7)
10	Wellington	400	232 (58)	168	1.91	220 (55)	8.0 (2)	52 (13)	92.0 (23)	28.0 (7)
11	Wentworth	340	122 (36)	218	1.91	187 (55)	6.8 (2)	44.2 (13)	78.2 (23)	23.8 (7)
12	Hillyard	30	17 (55)	13	1.91	17 (55)	.6 (2)	3.9 (13)	6.9 (23)	2.1 (7)
13	Birch	109	45 (41)	64	1.91	60 (55)	2.2 (2)	14.2 (13)	25.1 (23)	7.6 (7)
14	Gage/	638	376 (59)	262	1.91	351 (55)	12.8 (2)	82.9 (13)	146.8 (23)	44.7 (7)
	Plymouth	98	75 (77)	23	1.91	54 (55)	2.0 (2)	12.7 (13)	22.5 (23)	6.9 (7)
15	Ottawa	268	155 (58)	113	1.91	147 (55)	5.4 (2)	34.8 (13)	61.6 (23)	18.8 (7)
16	Kenilworth	295	168 (57)	127	1.91	162 (55)	5.9 (2)	38.4 (13)	67.9 (23)	20.7 (7)
17	Parkdale	182	104 (57)	78	1.91	100 (55)	3.6 (2)	23.7 (13)	41.9 (23)	12.7 (7)
19	Dunn	109	32 (29)	77	1.91	60 (55)	2.2 (2)	14.2 (13)	25.1 (23)	7.6 (7)
	Subtotal	2741	1463	1278		1507	55	356	631	192
20	Combined Fennel	1228	454 (37	774	2.0	958	61 (5)	86 (7)	49 (4)	74 (6)
20	Sanitary Limeridge	2072	767 (37)	1305	2.0	1326	104 (5)	145 (7)	83 (4)	414 (20)
	Subtotal	3300	1221	2079		2112	165	231	132	660
	Grand Total	8241	5052	5052		4896	373	653	828	828

Value in bracket is in percentage of the contributing area

Table 6. Volumetric Calibration of STORM Model

Data Sources	Event Date	RBG* Rainfall (mm)	Measured Runoff (mm)	Simulated Runoff (mm)	Simulated Runoff/ Measured Runoff
West Hamilton (Robinson & James, 1982)					
CPERV = 0.10	22 July 80	3.7	1.26	1.30	1.03
CIMP = 0.75	14 Aug 80	4.0	0.57	0.65	1.14
DEPRS = 1.5 mm	22 Aug 80	11.2	2.15	2.40	1.11
	13 Sept 80	8.1	1.95	2.00	1.02
	Average	6.8	1.48	1.59	1.08
Upper Hamilton (Gore & Storrie, 1977)					
CPERV = 0.10	19 July 77	4.6	0.99	1.10	1.11
CIMP = 0.80	1 Aug 77	4.6	0.91	1.00	1.09
DEPRS = 1.5 mm	3-4 Aug 77	6.6	1.84	2.10	1.14
	10 Aug 77	11.7	3.91	4.10	1.05
	11 Aug 77	7.6	2.67	2.60	0.97
	Average	6.5	1.78	1.93	1.07

* Royal Botanical Gardens

Table 7. Adjusted Subbasin Areas with Dry Weather Flows and Infiltration

Outfall Number	Subbasin	Area (ha)	Percentage of Total Area %	Estimated Dry Weather Flow & Infil. 10^3 m^3/day
1	Ewen Rd.	86	1.40	2.75
2	McMaster	103	1.70	3.33
3	Forsyth	147	2.40	4.70
4	Chedoke	213	3.50	6.85
5	Queen	177	2.88	5.65
6	Hess	176	2.88	5.65
7	James	151	2.48	4.80
8	Catherine	184	2.98	5.85
9	Ferguson	135	2.18	4.27
10	Wellington	510	8.28	16.22
11	Wentworth	450	7.28	14.27
12	Hillyard	140	2.28	4.47
13	Birch	219	3.58	7.01
14	Plymouth	748	11.98	23.48
15	Ottawa	208	3.38	6.62
16	Kenilworth	378	6.08	11.91
17	Strathearn	405	6.58	12.90
18	Parkdale	292	4.78	9.37
19	Dunn	219	3.58	7.01
20	Fennell	1228	19.80	38.81
	Total	6169	100.00	195.92

Table 8. Lumped Physiographic Data

	West Hamilton	Central Hamilton	Upper Hamilton
<u>Catchment Land Use Data</u>			
Total area (ha)	549	4392	1228
Residential (%)	58	57	78
Institute (%)	7	5	5
Commercial (%)	3	8	7
Industrial (%)	3	5	4
Open (%)	29	19	6
<u>Hydrologic Data</u>			
Runoff Coefficient:			
(a) Impervious areas	0.75	0.85*	0.80
(b) Pervious area	0.10	0.10	0.10
Surface depression storage (mm)	2.0	1.5	1.5
Daily dry weather flow plus infiltration (m^3/day)	17,443	139,542	39,016
Distributed Treatment Rate (m^3/day)	36,400	291,200	81,400

* Average of Upper Hamilton and STORM default values contributing area

Table 9. Mean Seasonal Stormwater plus DWF and Combined Sewer Overflow Distribution During the Three Periods Defined Below

Entire Basin	Operational Option	Period 1 Jan-May (x10 m^3/day)	Period 2 Jun-Sept (x10 m^3/day)	Period 3 Oct-Dec (x10 m^3/day)
Stormwater plus DWF	1	320	350	253
CSO	1	106	153	84
Stormwater plus DWF	2	393	434	328
CSO	2	86	141	68
Stormwater plus DWF	3	421	468	366
CSO	3	51	110	36

Note: stormwater plus DWF includes CSO value

Table 10. Mean Seasonal Stormwater plus DWF Treated and Combined Sewer Overflow Volumes Distribution

Subbasin	Option	(x 10^3 m^3/day)					
		Period 1 Jan - May		Period 2 June - Sept		Period 3 Oct - Dec	
		ST	OV	ST	OV	ST	OV
Central Hamilton	1	238	80	257	114	187	63
	2	289	66	321	107	245	52
	3	313	43	341	86	267	30
Upper Hamilton	1	61	20	69	29	49	16
	2	77	16	84	26	63	13
	3	80	7	91	20	72	5
West Hamilton	1	21	6	24	10	17	5
	2	27	4	29	8	20	3
	3	28	1	36	4	27	1

ST = stormwater plus DWF treated
OV = Combined sewer overflow

Note: stormwater plus DWF includes combined sewer overflow value

Table 11. Comparisons of Combined Sewer Overflow Volume Reduction (%) for Various Operational Options for Entire Basin.

Basin	Option	Period 1	Period 2	Period 3
Entire Basin	1	0	0	0
	2	19	8	19
	3	52	28	57

Table 12. Comparisons of Combined Sewer Overflow Volume Reduction (%) for Various Operational Options for Three Sub-Basins.

Basin	Option	Period 1	Period 2	Period 3
Central Hamilton	1	0	0	0
	2	18	6	17
	3	46	25	52
Upper Hamilton	1	0	0	0
	2	20	10	19
	3	65	31	69
West Hamilton	1	0	0	0
	2	33	20	40
	3	83	60	80

APPENDICES

Appendix A. Listing of Trunk Sewer Size Dimensions and Connectivities.

Appendix B. List of Remotely and Fixed Controlled Gates and Overflow Facilities.

Appendix C. Monthly Precipitation Data from Royal Botanical Gardens.

Appendix D. Number of Monthly Precipitation Events Recorded from Royal Botanical Gardens.

Appendix E. Water Bodies of Hamilton Harbour.

APPENDIX A
Listing of Trunk Sewer Size Dimensions and Connectivities

Connectivity	Dia (m)	Box (mxm)	Slope	Remarks
Interceptor A				
West Park Ave.	0.457		0.004	starting
Sanders Blvd.	1.016		0.0015	
McMaster Campus	1.016		0.0015	
Overflow at McMaster	1.524		0.0016	overflow #2
Mac to Sterling St.		1.22x1.22	0.001	
Forsyth Ave.		1.372x1.524	0.002	
Sterling St.		2.134x1.677	0.001	overflow #3
King St. W.		1.677x1.906	0.0018	
Glen Rd.		1.220x1.372	0.010	overflow #4
Cross Hwy 403	0.76			sanitary sewer interceptors A, BC
Interceptor H				
Hunt St.	1.524		0.001	
Head St.	1.524		0.001	
Victoria Park	1.524		0.001	diagonal crossing
Locke St.	1.524		0.001	
Barton St.	1.524		0.001	
Queen St.	1.524		0.001	intercepts
Overflow at Queen	1.220		0.020	overflow #5
Hess/Caroline	1.677		0.001	intercepts
Overflow at Hess	1.677		0.001	overflow #6 connection to pumping station
MacNab St. N.	1.676		0.001	
Ferrie St.	1.677		0.001	
James St. N.	1.677		0.001	intercepts overflow #7
Catherine St.	1.677		0.001	intercepts overflow #8
Ferguson St. N.		1.524x1.575	0.0068	intercepts, overflow #9
Burlington St.		1.524x1.575	0.0068	
Wellington St. N.		1.220x1.334	0.0017	intercepts, overflow #10
Wentworth St. N.		1.220x1.334	0.0007	intercepts, overflow #11
Hillyard		1.220x1.334	0.0007	intercepts, overflow #12
Birch		1.524x1.575	0.0007	intercepts, overflow #13
Plymouth/Gage		1.524x1.651	0.00075	intercepts, overflow #14

Listing of Trunk Sewer Size Dimensions and Connectivities
Continued

Connectivity	Dia (m)	Box (mxm)	Slope	Remarks
Interceptor H				
Ottawa	2.287		0.001	intercepts, overflow #15
Kenilworth	2.287		0.001	intercepts, overflow #16
Strathearn	2.287		0.001	intercepts, overflow #17
Parkdale	2.592		0.001	intercepts, overflow #18
Glow St.	2.592		0.001	
Dunn	2.592		0.001	intercepts, overflow #19
Treatment Plant	2.592			
Interceptor B				
Lower Horning	1.829		0.010	inlet chamber
Iona Ave.		2.134x1.434	0.008	confluence
Lower Horning	1.067		0.002	
Ofield		1.524x1.296	0.002	
Ewen		1.524x1.296	0.002	overflow #1
Iona		2.134x2.134	0.009	
Riffle Range		2.134x2.134		
Emmerson,				
Broadway				
Bowman				
Wilmont		2.896x2.363	0.002	intercepts
Royal Ave.				overflow to channel
Royal Ave.	0.915		0.002	sanitary
Longwood				intercepts
Merge to C				merge with interceptor C
Combined Interceptors B&C	1.982		unkown	interceptor BC
Confluence	1.524		0.001	merge with interceptor A at Hunter St. Beginning of interceptor H
Interceptor C				
Beckett Dr.	0.381 0.533			two inlet chambers from upper Hamilton
Locke St.		0.915x1.372	0.0216	
Bold St.		0.915x1.169	0.0119	merge
Dundurn St.	1.982		unknown	intercepts

Listing of Trunk Sewer Size Dimensions and Connectivities
Continued

Connectivity	Dia (m)	Box (mxm)	Slope	Remarks
<u>Interceptor D</u> - Fennel Ave.				
Columbia Dr.	1.270		0.0011	beginning
West 5th St.		1.524x1.524	0.0048	intercepts
Upper James		1.677x1.829	0.0048	intercepts
Upper Wellington		2.134x2.134	0.0025	intercepts
Upper Wentworth		2.439x2.592	0.0035	intercepts
Upper Sherman		2.744x2.896	0.005	intercepts
Upper Gage		3.049x3.201	0.005	intercepts
Upper Ottawa		3.506x3.201	0.005	intercepts
Mountain Brow		3.506x3.201	0.005	intercepts
Greenhill Avenue		3.049x3.049	0.075	drop from escarpment to Greenhill storage facilities with overflow to Redhill Creek overflow #20
Storage facilities				
<u>Interceptor E - Limeridge Rd. (Separate Storm Sewer Only)</u>				
(Storm Sewer)				
Upper James	0.686		0.007	
Upper Wellington	0.762		0.0075	intercepts
Upper Wentworth	1.982		0.0035	to creek outlet
Upper Sherman	0.686		0.005	outlet to creek
Upper Gage	1.067		0.005	
Upper Ottawa	1.372		0.005	outlet to Redhill Creek
Upper Kenilworth	1.067		0.005	outlet to Mountain Brow escarpment
(Sanitary Sewer)				
Yeoville Ct.	0.254		0.006	begin (between Hawkridge Ave and Yeoville Ct
Upper James	0.254		0.007	intercepts
Upper Wellington	0.254		0.005	intercepts
Upper Wentworth	0.534		0.005	to Russet sewer line
Upper Sherman	0.254		0.007	to Legget Cres. sewer line
Upper Gage	0.381		0.005	to trunk sewer
Upper Ottawa	1.524		0.003	sanitary trunk sewer to WWTP begins

Listing of Trunk Sewer Size Dimensions and Connectivities
Continued

Connectivity	Dia (m)	Box (mxm)	Slope	Remarks
Kenilworth	1.524		0.005	trunk sewer
Albion Falls Blvd.	1.524		0.005	to trunk sewer
Trunk Sewer	1.524		0.004	to WWTP through Greenhill storage facilities
<u>Interceptor F</u>				
Greenhill Storage Facilities	1.676		0.004	begins
Dundonald Ave.	1.676		0.001	intercepts sanitary only
Hansford St.	1.676		0.003	intercepts sanitary only
Lawrence	1.676		0.008	intercepts combined
Biard Ct.	1.676		0.005	intercepts sanitary only
Railway Crossing	1.981		0.0018	increased dia.
Rennie St.	1.981		0.0018	intercept sanitary only
Brampton St.	2.592		0.0013	interceptor G from east
WWTP	2.592			treatment plant
<u>Interceptor G</u>				
G Not included in this study	1.982		0.001	trunk sewer from east Hamilton

APPENDIX B
List of Remotely and Fixed Controlled Gates of Overflow Facilities

Remotely Controlled Gate Location

1. Lawrence and Red Hill Creek
2. Royal and Delbrook Court
3. Ferguson and Ferrie
4. Queen and Barton
5. Rosemary and Wentworth
6. Brampton and Strathearn
7. Ferguson and Burlington
8. Glen Road and Macklin
9. Greenhill - will be disconnected once the storage facility is operational

Fixed Controlled Gates Location

10. Hess and Barton
11. Caroline and Barton
12. Park and Barton
13. McNab and Stuart
14. James and Guise
15. Gage and Barton
16. Gage and Cannon
17. Gage and Dunsmere
18. Ottawa and Burlington
19. Kenilworth and Merchison
20. Kenilworth and Barton
21. Strathearn and Burlington

APPENDIX C. Monthly Precipitation Data from Royal Botanical Garden

	Measured Monthly Precipitation in (mm)											
Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1976	88.9	42.9	152.7	92.2	102.9	78.2	52.1	35.3	115.8	52.3	18.3	38.1
1977	52.6	33.6	91.4	83.5	35.1	100.4	88.8	87.0	227.6	48.2	88.0	136.2
1978	111.3	32.6	59.7	65.8	74.2	29.6	63.6	76.8	188.8	68.4	60.4	76.4
1979	93.2	26.8	74.6	117.8	85.6	38.4	32.4	62.6	53.6	76.0	98.1	107.8
1980	40.5	30.8	103.6	110.2	56.0	71.0	77.0	47.6	64.6	77.8	42.0	49.1
1981	14.8	73.6	24.4	75.7	56.0	61.6	81.0	179.8	135.0	88.0	49.7	53.0
1982	109.6	34.4	87.9	57.6	73.9	109.4	50.8	138.2	121.6	27.0	109.6	95.2
1983	32.2	55.8	90.6	87.8	113.2	53.0	78.6	87.4	53.4	77.4	93.6	100.2
1984	42.9	95.0	79.0	82.0	125.2	122.5	70.3	81.2	123.0	20.5	67.5	98.6
1985	42.8	42.4	80.8	36.6	43.5	53.3	58.6	99.6	44.5	68.4	207.5	15.2
Sum	628.8	467.9	844.7	809.2	765.6	717.4	653.2	895.5	1127.9	604.0	834.7	769.8
Mean	62.9	46.8	84.5	80.9	76.6	71.7	65.3	89.6	112.8	60.4	83.5	77.0

APPENDIX D. Number of Monthly Precipitation Events Recorded from Royal Botanical Garden

	Number of Events											
Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1976	1	15	11	7	10	6	11	7	7	9	3	2
1977	0	9	10	10	5	8	10	8	14	4	10	15
1978	1	0	10	11	14	5	5	7	12	10	4	7
1979	4	5	17	10	8	5	6	8	4	14	14	9
1980	3	3	8	10	9	9	6	7	9	8	7	6
1981	1	9	8	12	9	6	7	12	11	13	7	4
1982	2	7	17	10	9	13	3	10	15	4	13	14
1983	2	5	8	15	15	5	7	9	6	8	14	7
1984	4	9	13	13	12	12	4	4	8	3	10	10
1985	1	7	10	5	11	7	8	7	7	14	12	4
Total Event No.	19	69	112	103	102	76	67	79	93	87	94	78
Mean	1.9	6.9	11.2	10.3	10.2	7.6	6.7	7.9	9.3	8.7	9.4	7.8

APPENDIX E
Water Bodies of Hamilton Harbour

	Area (10^6 m^2)	Volume (10^6 m^3)
Harbour[a]	21.5	287.0
Cootes Paradise[b]	1.6	0.74
Windermere Basin[c]	0.5	0.16

Data Sources

[a] Snodgrass, 1981

[b] Semkin, 1976

[c] Navigation Chart, Canadian Hydrographic Services, April 15, 1988