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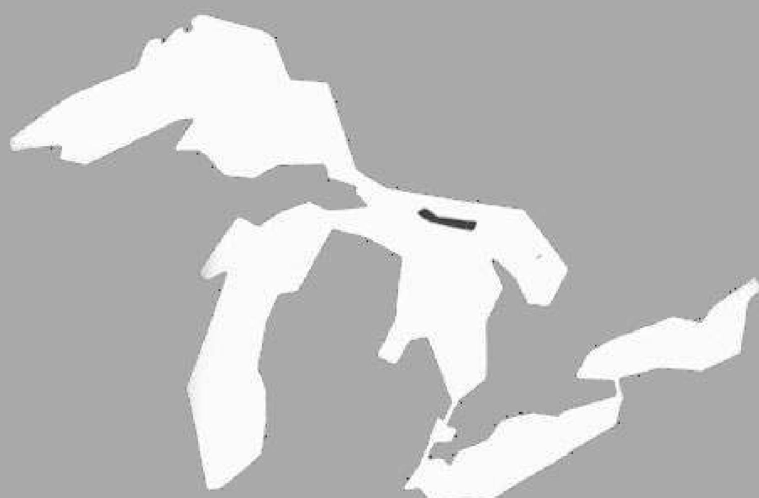
Municipal Pollutant Loadings to the Great Lakes from Ontario Communities

Research Report No. 94



Research Program for the Abatement of municipal Pollution under Provisions of the Canada-Ontario Agreement on Great Lakes Water Quality

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These RESEARCH REPORTS describe the results of investigations funded under the Research Program for the Abatement of Municipal Pollution within the provisions of the Canada-Ontario Agreement on Great Lakes Water Quality. They provide a central source of information on the studies carried out in this program through in-house projects by both Environment Canada and the Ontario Ministry of Environment, and contracts with municipalities, research institutions and industrial organizations.

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Wastewater Technology Centre
Canada Centre for Inland Waters
Environment Canada
P.O. Box 5050
Burlington, Ontario   L7R 4A6

Ontario Ministry of Environment
Pollution Control Branch
135 St. Clair Avenue West
Toronto, Ontario   M4V 1P5

MUNICIPAL POLLUTANT LOADINGS TO THE GREAT LAKES FROM ONTARIO COMMUNITIES

by

D.H. Waller and Z. Novak

RESEARCH PROGRAM FOR THE ABATEMENT
OF MUNICIPAL POLLUTION UNDER THE
PROVISIONS OF THE CANADA-ONTARIO
AGREEMENT ON GREAT LAKES WATER QUALITY

Project No. 75-8-33

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135 St. Clair Avenue West
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M4V 1P5

ABSTRACT

This report updates and extends previous estimates of total annual pollutant loads to the Great Lakes from Ontario communities. An improved method of estimating combined sewage loads is proposed and evaluated.

RESUME

Le présent rapport remet à jour les renseignements que nous possédons déjà sur les rejets estimatifs totaux annuels de polluants par les collectivités de l'Ontario. Il contient aussi des renseignements inédits. On y évalue de plus une méthode améliorée, proposée pour estimer les rejets dans les réseaux d'évacuation unitaire.

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1 INTRODUCTION

The Urban Drainage Subcommittee under the Canada-Ontario Agreement on Great Lakes Water Quality, in the problem definition phase of its program, supported an "Evaluation of the Magnitude and Significance of Pollution Loadings from Urban Stormwater Runoff in Ontario" [1]. That work, which was carried out by the American Public Works Association with the assistance of the University of Florida, is referred to herein as the APWA report. One role of the APWA work was to provide an information base and methodology for estimating pollutant loadings and costs of wet weather pollution control. It was planned that the estimates provided by the report would be updated as additional information and improved methods became available. This report is the first step in updating the pollutant loading estimates in the APWA report.

The principal objective in updating the loading estimates in the APWA report has been to produce estimates of total loads to the Great Lakes from wet and dry weather municipal sources in Ontario. The following modifications have been made to the information and procedures in the APWA report:

1) Surface runoff and sanitary sewage loading estimates are based on concentrations representative of values recorded in Ontario communities.

2) The method for calculating combined sewage loadings has been changed.

3) Total annual loads have been estimated; the APWA report estimated only per-acre values.

4) An attempt has been made to compare loadings from the municipal sources with total loads to the Great Lakes from all Ontario sources.

An attempt has been made to assess the sensitivity of the estimated loadings to the most important assumptions on which the estimates depend.

2. THE APWA REPORT

This section provides a summary of the data base and the methods used in the APWA report, and the unit loading values estimated in the report.

The APWA report presented information for the 56 cities in the Ontario portion of the Great lakes Basin with populations greater than 10,000. Detailed information for nine of these cities was used in the report as a basis for land use and other analyses.

2.1 Land Use

The developed fraction of the land area of each city was determined from an empirical relationship, derived from U.S. data, between the proportion of undeveloped land and the average population density for the total (developed and undeveloped) city area. Average distributions among major land uses in developed areas in the test cities were verified by comparison with U.S. data and were used to estimate land use distributions for each of the 56 cities [1].

2.2 Population Density and Total Population vs Sewerage System

Information about the nine test cities was used to derive a relationship between average population density in the developed area of any city and the percent of the urbanized area occupied by that density. This relationship, together with the percent of the developed area that was sewered in the test cities, was used to estimate the size of the sewered area in the remaining cities. The portion of sewered area served by combined sewers was known for 49 cities, and was estimated for the others [1].

2.3 Annual Runoff

Information about pervious areas and curb lengths in each land use was obtained for the nine test cities for comparison with U.S. data, and an expression relating imperviousness and population density in the developed portion of the urban area was adopted. Annual runoff was estimated from annual precipitation and imperviousness by a relationship based on the runoff coefficient used in STORM (U.S. Army Corps of Engineers' Storage, Treatment, Overflow, Runoff Model), modified by comparison with values calculated by STORM runs for four of the test cities. Using this relationship and annual rainfall equal to that for the nearest test city, annual runoff was calculated for the combined, storm and unsewered portions of each city [1].

The mean annual precipitation used for the 56 cities was 32.75 inches. Estimated values of runoff (inches) for areas served by each sewer type were:

Type	Range of Individual Values	Weighted Mean
Combined	13.3 to 20.1	16.2
Separate	10.4 to 17.2	12.8
Unsewered	8.1 to 10.9	9.5

2.4 Dry Weather Flow

Dry weather flow estimates were based on population estimates and an average flow of 90 Igpcd* [1].

2.5 Runoff Quality

Runoff quality estimates were based on recorded BOD concentrations or annual loadings from six U.S. and one Canadian community. Annual loadings were derived from concentrations by taking into account annual rainfalls and runoff coefficients. All of the loadings were for residential areas. Information from the seven areas with separate systems, and from three areas with combined systems, was used to establish a relationship between annual BOD loading and population density. The results of the analysis were summarized in an expression that related annual residential BOD load to population density and annual precipitation. Loading relationships for other land uses and other parameters, namely, suspended solids (SS), volatile suspended solids (VSS), total phosphate (T-PO_4) and total nitrogen (T-N), were obtained from information on dust and dirt composition and accumulation rates, assuming that the composition of dust and dirt was representative of the composition of runoff [1].

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* Imperial gallons per capita per day

2.6 Combined Sewage Quality

Residential combined sewage quality estimates were based on the average of BOD loadings measured in Washington, D.C., and loadings derived from mean BOD concentrations recorded in DesMoines and Milwaukee, by taking into account annual rainfalls and runoff coefficients. Combined sewage loadings were assumed to be a fixed multiple of the separate sewer loadings that would apply for the same combination of land use, precipitation, and population density. The multiplier was the ratio of the average residential BOD loading from the three combined areas to the mean loading from the seven separate areas referred to in Section 2.5.

2.7 Sanitary Sewage Quality

A dry-weather BOD load of 0.17 lb/cap/day was employed, and T-N and T-PO_4 loads were assumed to be 20 percent and 15 percent, respectively, of the BOD load [1].

2.8 Annual Loads

The population density and precipitation for each city, together with the average land use distribution, provided the basis for estimates of total wet and dry weather loads of BOD, T-N and T-PO_4 [1]. Weighted average estimated unit loads for the 56 cities are reproduced in Table 1, and are compared later in this report with unit loads estimated herein.

TABLE 1. Annual Loads Determined in APWA Report (lb/acre-year).

	- - - - - -BOD - - - -			- - - - -T-N - - - - -			- - -T-PO_4 (as PO_4) - - -		
	Comb.	Sep.	Unsew.	Comb.	Sep.	Unsew.	Comb.	Sep.	Unsew.
Dry Weather	1545	736	255	309	147	50.9	232	110	38.2
Wet Weather	137	25.7	21.3	20.8	3.9	3.2	5.3	1.0	0.8

The "dry weather" loadings in Table 1 represent total annual loads in untreated sanitary sewage, from areas served by combined sewers, storm sewers or no sewers, based on population density, per capita rates of sewage generation, and average sewage composition. "Wet weather" flows in Table 1 are estimated total annual loadings of combined sewage and surface runoff. No estimate was made of the proportions of combined sewage retained in the system by interceptor sewers or lost via combined sewer overflows.

3. SEWAGE AND SURFACE RUNOFF

Pollutant loading estimates in this report are based in part on information from the APWA report, and in part on data obtained by research studies and routine monitoring in Ontario communities. This section describes the sewage and surface runoff information that was used to derive estimates of municipal pollutant loads. This information is summarized in Table 8 at the end of this section.

3.1 Sewage

Raw sewage concentrations in Table 8 are flow-weighted mean values recorded in 1976 at the 14 primary and 81 secondary treatment plants operated by the Ontario Ministry of the Environment (MOE). Nitrogen concentrations were recorded in 1976 at only 10 of the primary and 44 of the secondary plants.

The mean per-capita sewage flow in Table 8 is based on 1976 data from 29 primary and 98 secondary plants in the Great Lakes basin. These plants include those operated by individual municipalities and, except for a number of smaller plants, those operated by the Ministry of the Environment.

Primary effluent BOD and suspended solids concentrations in Table 8 are flow-weighted mean values reported in 1976 for the 29 primary plants in the Great Lakes basin. These effluent concentrations are relatively low because they are derived from plants with lower-than-average influent concentrations, and they should not, therefore, be directly compared with influent concentrations in the table, which are mean values for all plants.

Secondary effluent BOD and suspended solids concentrations in Table 8 are based on flow-weighted mean values for all Ontario plants for which 1976 data was available.

Effluent nitrogen concentrations are flow-weighted values from 1976 MOE records. Effluent phosphorus concentrations were not based on recorded data, because phosphorus removal facilities at some plants, although they were operational by 1977, were not operational when 1976 data was obtained.

The Canada-U.S. International Joint Commission target value of 1 mg/L was, therefore, adopted for both primary and secondary effluents. This value may be low for some communities in the Upper Great Lakes, where the target value is the larger of 20% of influent phosphorus or 1 mg/L.

3.2 Surface Runoff

The APWA report provided estimates of the annual volume of surface runoff from areas served by each sewer type in each community in the Great Lakes basin. The weighted mean values from that report, cited in Section 2.3, which simplify calculations and do not affect total flow estimates have been adopted in Table 8.

Table 2 summarizes surface runoff composition recorded at nine locations in Ontario. All of these are predominantly, or entirely, residential. The data bases for these catchments vary in duration (some are very short) but the range of concentrations, except for suspended solids, is relatively narrow. The values listed at the bottom of Table 2 have been adopted herein as representative of surface runoff from residential areas in Ontario.

Information from the APWA report has been used to estimate the effect of land uses other than residential on surface runoff loads. The APWA report adopted a mean value of 0.799 lb/acre-in as the BOD load from residential areas in Ontario, based on data for one Canadian and six U.S. cities [1]. Values for other land uses and other constituents were based on relative rates of daily accumulation of dust and dirt, relative miles of curb per acre, and relative concentrations of each constituent in dust and dirt for each land use. The proportions used are summarized in Table 3.

For any constituent and land use, the loading used in the APWA report [1] can be found as the product of the BOD loading (0.779 lb/acre-in) and the appropriate three ratios shown in Table 3. If the ratios for residential areas are applied to the BOD concentration adopted for residential areas in Ontario in Table 8 (14 mg/L), the results are those shown in Table 4.

Considering that the values assumed in Table 2 are based on measured runoff concentrations in Ontario, and the ratios in Table 3 are based on the composition of dust and dirt in the United States, the agreement is as good as might be expected.

TABLE 2. Runoff Concentrations From Ontario Locations [a].

Location	Land use		Concentration (mg/L)			
			BOD	SS	TN	TP (as P)
Brucewood [b]	100% Residential		13.7	101	4.1	0.28
Broadview [c]	100% Residential (predominantly single family)		15.7	130	3.9	0.40
Guelph North [d]	Single	82.9	10.2	77	2.3	0.20
	Multiple	7.6				
	Commercial	6.2				
	Parks	3.3				
Guelph West [d]	Single	36.5	13.9	195	3.7	0.35
	Multiple	8.4				
	Institutional/ Commercial	3.1				
	Industrial	29.5				
	Open	22.5				
Malvern [e]	100% Residential 43 persons/ha		11.3	105	(4.1) [g]	0.46
Windsor A [f]	100% Residential 50 persons/ha		20.5	279	(1.3) [g]	0.14
Windsor B [f]	100% Residential 25 persons/ha		12.0	305	(1.5) [g]	0.32
Values adopted as representative of residential areas in Ontario			14	170	3.5	0.35

[a] All information in this table, except concentrations at Malvern and Guelph has been taken from [2].

[b] Arithmetic mean for 1974/75, excluding winter period.

[c] mean of flow-weighted mean values from individual storms, excluding winter period.

[d] Flow-weighted mean from [4], excluding winter period.

[e] Seasonally adjusted mean values from [3], as the sum of liquid and solid components.

[f] Annual arithmetic mean.

[g] Accounted for ammonia only, instead of TKN.

TABLE 3. Relative Values Used in APWA Report [1] to Adjust for Land Uses and Pollutants.

Land Use	Values Relative to Residential Land Use		Concentration in Dust and Dirt to Concentration of BOD in Dust and Dirt from Residential areas			
	Curb Miles per acre	Dust and Dirt per curb mile per day	BOD	SS	T-N	T-PO_4
Residential	1	1	1	20.4	0.165	0.042
Commercial	0.96	1.90	1.78	12.4	0.165	0.042
Industrial	0.47	3.65	0.73	17.4	0.165	0.042
Other	0.33	0.57	0.64	15.4	0.35	0.057

TABLE 4. Comparison of Relative Recorded and Estimated Residential Surface Runoff Concentrations (mg/L).

Category	Concentrations (mg/L)			
	BOD	SS	T-N	T-P
Recorded (Table 2, adopted values)	14	170	3.5	0.35
Based on Table 3:	14	286	2.3	0.19

The only Ontario study that has produced runoff quality information from other than mainly residential areas is based on the predominantly commercial and industrial Carling street catchment in London [5]. Table 5 indicates that concentrations derived from that study compare well, except for phosphorus loadings, with values based on the ratios of Table 3 and a mean residential BOD concentration of 14 mg/L.

TABLE 5. Comparison of Relative Recorded and Estimated Commercial and Industrial Surface Runoff Composition (mg/L).

		BOD	SS	T-P
Recorded[5]		18.3	191.5	0.55
Based on Table 3:	Commercial	24.9	173.0	0.19
	Industrial	10.2	244.0	0.19

Table 6 summarizes the results of two studies in the United States that considered land use effects on runoff composition. Results of one of these studies [6] indicated that BOD and nutrient loads in runoff from commercial and industrial areas were higher, and from recreational areas lower, than in runoff from residential areas. Results of the second study [7] indicated that industrial loadings were greater than residential, but commercial loadings for some constituents may be lower. The loadings in Table 6 are consistent with reference [6] in that industrial and commercial loadings are higher, and loads from other areas (recreational, educational centres) are lower, than loads from residential areas.

Table 3 has been used to further explore the effects of land use on runoff composition. The APWA report cited the following proportions of land uses in the developed portion of communities in the Ontario Great Lakes basin:

Residential	52.5%
Commercial	10.3%
Industrial	14.0%
Other	23.2%

Table 7 has been produced by the following procedure: for each parameter and land use, the total load per acre relative to the BOD load from a residential area was the product of the first two columns in Table 3 and the column in Table 3 for that parameter; for the mixed land use area in Table 7, each of these values was multiplied by the land use ratios cited above.

It can be seen from Table 7 that higher loadings from industrial and commercial areas are offset by lower values for the open areas and that, except for suspended solids, the weighted values do not differ significantly from those for residential areas. Considering all of the information presented above, there appears to be little justification for modifying the values assumed in Table 2 to take into account the effects of other land uses. The Table 2 values have, therefore, been adopted in Table 8 as representative of composite land uses in Ontario.

TABLE 6. Effects Of Land Use On Runoff Composition.

Land Use	Annual Loading lb/acre-year [6]		
	BOD	Kjeldahl-N	Ortho-P
Residential (mean 7 areas)	29	1.9	2.4
Residential/Commercial	35	1.7	2.9
Commercial (mean 2 areas)	38	3.5	3.1
Industrial/Residential	21	1.1	1.5
Light Industrial	25	1.2	1.7
Industrial (mean 2 areas)	37	2.8	5.7
Recreational	12	1.1	1.1

Land Use	Loading Intensity lb/curb mile [7]			
	BOD	Nitrate-N	Kjeldahl-N	Phosphate
Residential		0.06	2.04	1.07
- low/old single-family	8.6			
- low/old multi-family	20			
- med/new single-family	5.1			
- med/new multi-family	10			
Commercial		0.17	0.45	0.29
- central business district	2.4			
- suburban shopping centre	2.5			
Industrial		0.18	3.94	3.40
- light	39			
- medium	10			
- heavy	13			

TABLE 7. Relative Composition Of Runoff From A Wholly Residential And A Mixed Land Use Area.

	BOD	SS	T-N	T-P
Wholly Residential Area	1.00	20.4	0.165	0.042
Mixed Land Use Area				
- Relative contribution to weighted mean ratio:				
- Residential	0.53	10.8	0.087	0.022
- Commercial	0.32	2.3	0.030	0.007
- Industrial	0.17	4.2	0.035	0.008
- Other	0.03	0.7	0.016	0.003
Weighted mean ratio	1.05	18.0	0.168	0.040

TABLE 8. Assumed Composition Of Municipal Sewage And Surface Runoff From Ontario-great Lakes Communities.

MUNICIPAL SEWAGE

QUANTITY: 145 Igpcd

QUALITY: Annual mean concentrations (mg/L)

	Raw Sewage	Effluent Primary	Effluent Secondary
BOD	165.0	50.0	17.0
Suspended Solids	225.0	50.0	23.0
Total - N	30.0	22.0	18.0
Total - P	6.5	1.0	1.0

SURFACE RUNOFF

QUANTITY:	Combined Sewer Areas	16.2 in/yr
	Separate Sewer Areas	12.8 in/yr
	Unsewered Areas	9.5 in/yr
QUALITY:	Annual Mean Concentrations (mg/L)	
	BOD	14.0
	Suspended Solids	170.0
	Total Nitrogen	3.5
	Total Phosphorus	0.35

Similar values of runoff composition have been assumed to apply to combined sewered, separately sewered, and unsewered areas. There is no information on differences in land uses among these areas on which to base more refined estimates, and the fact that the average concentrations from mixed land uses are close to residential values argues that the effort required to obtain this information would not be justified.

The APWA report considered three factors other than land use that were believed to influence annual loading rates: population density, street sweeping frequency, and precipitation. Loadings in residential and "other" areas were assumed to decrease with decreasing population density. The information in Table 2, from Ontario cities, does not suggest that the effect of population density is significant and no allowance has been made herein for this effect. The APWA report acknowledged that street sweeping effectiveness would affect annual loads, but assumed that street sweeping intervals exceeded 20 days and that sweeping had no significant impact on pollutant loadings. Table 5 provides no information about street sweeping, but it is assumed that the values in the table reflect the effects of average street sweeping practices in Ontario. The APWA report considered annual loadings to vary directly with annual precipitation, and corrected loading rates for each city accordingly. The evidence in the report for an association between annual rainfall and annual loads is not strong, and the variation in annual rainfall among cities is not great. Therefore, in this report, the effect of rainfall has been ignored.

4. COMBINED SEWAGE

As indicated in Section 2.6, combined sewage loadings in the APWA report were based on average BOD values from three U.S. cities, and on the assumption that the composition of combined sewage bears a fixed relationship to the composition of surface runoff. This assumption ignores the probability that the composition of combined sewage will vary from one community to another according to relative amounts of sewage and surface runoff, and that the ratio of loadings in combined sewage and surface runoff will differ for each quality parameter because the relative values in sewage and surface runoff are not the same.

In addition, the loading value used in the APWA report for areas served by combined sewers was the total annual estimated combined sewage discharge. Effects of interceptor sewers in reducing amounts of combined sewage discharged annually in overflows were not taken into account.

This section describes a procedure for calculating loads discharged annually from a combined sewerage system that is intended to overcome these difficulties. The procedure has been tested by applying it to an Ontario catchment for which data was available.

4.1 Calculation Procedure

The procedure used to calculate combined sewage loads was included in a computer program that was used to calculate annual loads discharged from combined, separate and unsewered areas in Ontario Great Lakes communities. The calculation procedure is illustrated in Figure 1.

Calculation of annual loads from combined sewerage assumes that annual quantities and pollutant loadings in sanitary sewage and surface runoff are known.

Dry weather flow to the sewage treatment plant is the sewage flow in the fraction of the year when no runoff occurs. Pollutants in dry weather flow are assumed to be reduced by the fraction of the total annual sewage solids that are deposited in dry weather. Sewage flow in wet weather, together with storm water flow, constitutes combined sewage. Pollutant loadings in combined sewage are augmented by the solids, deposited in dry weather, that are assumed to be completely scoured in storm periods. The composition of materials deposited and scoured is assumed to be identical, in terms

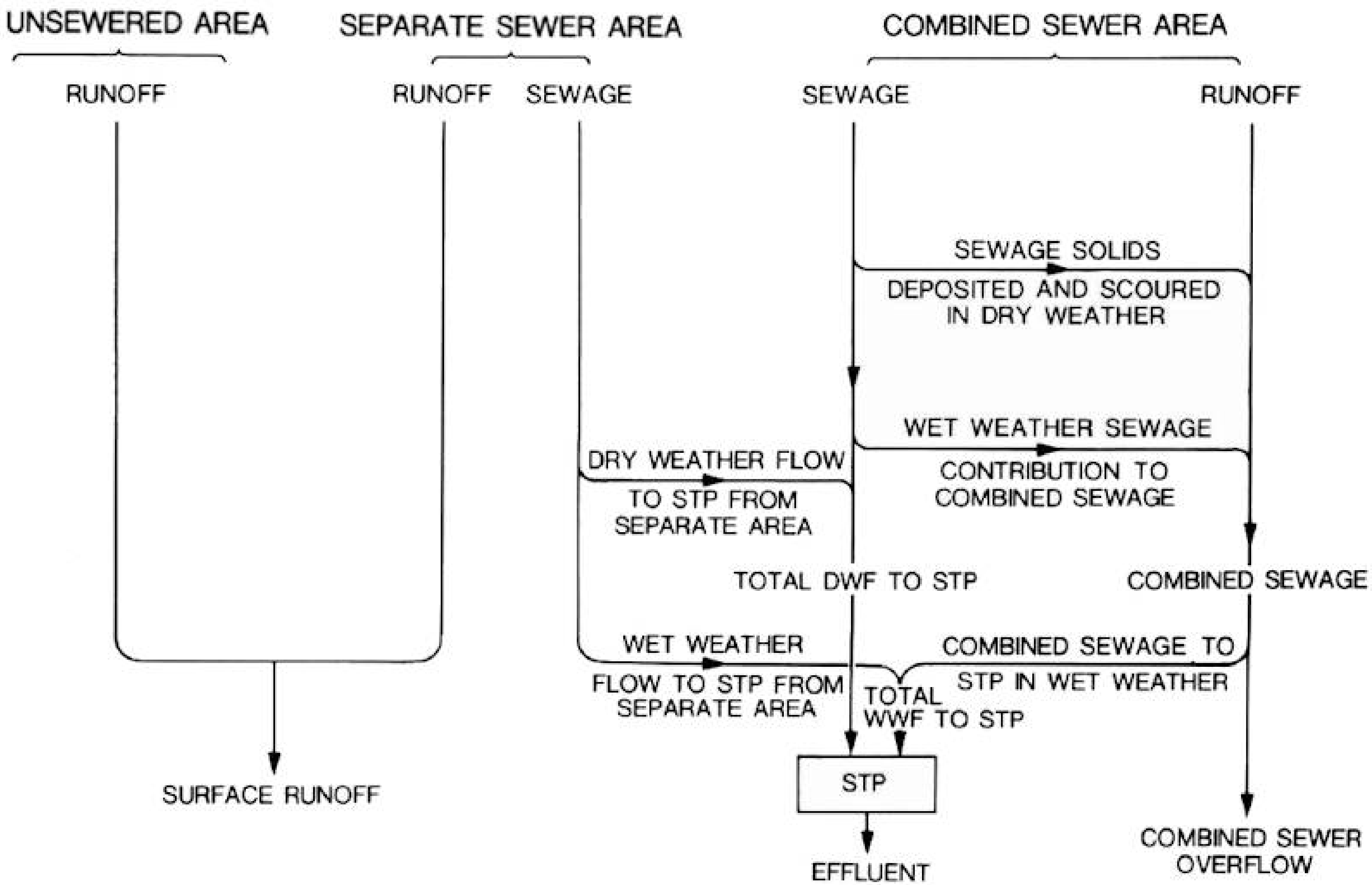

FIGURE 1: Basis Of Algorithm For Loading Calculations.

relative proportions of constituents, to raw sewage; this is probably untrue but no information is available on which to base a better assumption.

The magnitude and composition of combined sewage overflows (CSO) will depend on the size of the interceptor that conducts the combined sewage to the treatment plant. To obtain these values, repeated runs of the urban runoff model STORM [8] were made for a hypothetical city having the mean characteristics of the 25 cities in the Great Lakes Basin with combined sewers (Table 9). Precipitation and temperature data from the Malton-Toronto airport for the period 1970 to December 1976 were used in the STORM runs. All values in the rainfall record were multiplied by 0.96 to account for the difference between the mean rainfall of 34.06 inches recorded at Toronto and the basin-wide average of 32.7 inches used in the APWA report.

TABLE 9. Characteristics Of Hypothetical City Having Characteristics Of Combined Sewered Portion Of 25 Ontario Great Lakes Communities.

Population	-	70927 persons (based on total combined sewered population of 1,773,000 [1])
Area	-	2859 acres (based on a total combined sewered area of 71,477 acres [1])
Sewage Flow	-	145 Igpcd
Depression Storage	-	0.05 inch (a composite value, based on 0.02 in. for impervious areas and 0.08 in. for pervious areas)
Imperviousness	-	0.51 (based on [1])

The unit hydrograph option in the STORM model was used, which required the selection of a time of concentration. A value of one hour was selected rather arbitrarily. The chosen value corresponded to a mean velocity of about 5 fps across the hypothetical catchment. The results are not particularly sensitive to this parameter, but use of a relatively short time results in conservatively high estimates of overflow, which helps to offset the fact that many combined sewers subcatchments are smaller than the total area served by combined sewers in a community and, therefore, might be expected to yield more pronounced runoff peaks.

The results of the STORM runs are summarized in Table 10. The STORM runs assumed no diurnal variation in dry weather flow (DWF); therefore, the hours of overflow determined for an interceptor capacity of 1 DWF (943 hr/year) corresponded to the number of hours when storm runoff occurred.

TABLE 10. Results Of Storm Runs For Hypothetical City.

Interceptor Capacity as Multiple of DWF	Fraction of Annual Sewage in CSO	Fraction of Annual Runoff in CSO	Duration of Overflow	
			hr/yr	% of time
1	0.0542	0.850	943	10.8
2.5	0.0226	0.647	537	6.1
4.0	0.0116	0.490	334	3.9

* Annual rainfall 32.7 in.

The magnitudes and compositions of overflow in Table 10 are roughly comparable to those in Table 11, obtained from an analysis by MacKee [9] of rainfall data for Boston, even though the hours of runoff estimated by McKee were barely more than half those estimated in this analysis. The fractions of sewage in overflow in Table 11 have been taken directly from reference 9; fractions of runoff in overflow were calculated from information in that reference.

TABLE 11. Overflow Magnitude And Composition [9].

Interceptor Capacity as Multiple of DWF	Fraction of Annual Sewage In CSO	Fraction of Annual Runoff in CSO
1	0.041	0.89
2.5	0.023	0.74
4.0	0.015	0.62

* Annual rainfall 32.9 in. Calculated duration of storm runoff, 5.6% of total hours.

4.2 <u>Verification of Method</u>

Data from the combined severed Frankdale Catchment in East York [10, 11] were used to verify the procedure for estimating pollution loadings from combined sewer areas. Characteristics of the catchment are described in Table 12.

TABLE 12. Statistics On Frankdale Catchment [10, 11].

Area	383 acres	
Population Served	14,600 persons	
Annual Sewage Flow	542 IMG/yr	
Annual Direct Runoff	101.2 IMG/yr	
Duration of Direct Runoff	921 hr/yr	
	Annual Sewage Loadings (lb/yr)	Assumed Runoff Loadings. (lb/yr)
BOD	577,000	14,200
SS	555,000	172,000
Total N	146,000	3,540
Total P	25,000	354

* Based on direct runoff and Table 8.

The annual sewage flow in Table 12 is based on the recorded dry weather mean value. Sewage loadings are the product of this value and the means of measured dry weather concentrations.

The volume and duration of runoff in Table 12 are based on STORM simulations after calibration of the model with recorded rainfall and runoff data for the catchment. Recorded annual precipitation on the catchment was 29.73 inches.

Runoff composition was not recorded on this catchment. The runoff loadings in Table 12 are based on typical values for Ontario residential catchments, from Table 8, multiplied by the annual runoff from the Frankdale catchment.

Table 13 includes the results of application of the procedure described in Section 4.1 to estimate combined sewage loadings for the Frankdale catchment. The estimated loadings were produced from the equations illustrated in Figure 1.

The calculation requires, in addition to the information listed in Table 12, an estimate of the percentage of sewage solids that is deposited and scoured annually. Only two estimates appear to have been published. Waller [12] found that 10% of combined sewers in a generally steep area retained solids, and concluded that less than 3% of solids from the area were likely to be deposited and scoured. Pisano [13] estimated that 10% of solids in sewers in Dorchester and South Boston were deposited. In the Frankdale catchment the portion of sewer solids deposited and scoured was assumed to be 3% because sewers in the area are relatively steep. Slopes on most pipes are between 0.5% and 1.0%.

TABLE 13. Comparison Of Calculated, Storm Simulated, And Extended Measured Combined Sewer Loadings For The Frankdale Catchment Wet Weather Outflow.

	Calculated by Approach Proposed Here		Extended from Measured Values [14]		Simulated by Calibrated STORM [11]	
	Conc. (mg/L)	Load (lb/acre-yr)	Load (lb/acre-yr)	Conc. (mg/L)	Load (lb/acre-yr)	Load + 3% of DWF load (lb/acre-yr)
BOD	63	240	211	39.6	160	206
SS	170	645	694	130	527	571
Total N	15.9	60	53	10.9	44	56
Total P	2.6	9.7	8.4	1.9	7.5	9.5

Table 13 also shows two sets of values for combined sewage loadings and concentrations for the Frankdale catchment, derived from recorded flows and concentrations. Both sets of values represent total wet-weather discharges of combined sewage from this catchment. The values described as "Extended from Measured Values" were estimated by a simple extrapolation technique from measured values. The suspended solids value was over-estimated by this technique because the dry weather sewage concentrations used at the time the estimate was made were based on incomplete sampling results and proved to be higher when sampling was complete. The values described as "Simulated by Calibrated STORM" were based on the output of the STORM program after calibration with data for the Frankdale catchment. Because STORM does not take deposition and scour of sewage solids into account, Table 13 includes a column in which 3% of annual dry weather sewage loads have been added to the STORM results to represent this effect.

The loadings estimated by the method proposed herein agree reasonably well with values derived from measured data. The concentrations were higher than those derived by the STORM model because the model does not include deposit and scour of sewage solids. A complete comparison of the calculated values and those based on measured data is not possible because a) no information exists about surface runoff quality for the Frankdale catchment and, b) the methods used to derive estimates from the measured data are themselves subject to error. It is, therefore, not possible to determine whether discrepancies between the results arise from the method, from the data used in its application, or from inaccuracies in the "measured" values. Nevertheless, the results of the comparison in Table 13 suggest that the approach used here provides a simple and effective method of estimating annual loadings from a combined sewerage system. It will obviously be desirable to further test the approach when additional data become available.

5. LOADING CALCULATIONS

Annual loads of suspended solids, BOD, total nitrogen and total phosphorus, in sewage treatment plant effluent, surface runoff and combined sewage, were calculated for each of the 56 cities in the Great Lakes Basin, and totalled to provide an estimate for the basin as a whole. The computer program illustrated by Figure 1 was utilized to perform the calculations.

Loading calculations were repeated for the combined sewer communities, using different values for significant assumptions made in these calculations, to determine the sensitivity of the results to these assumptions.

Table 14 describes the characteristics of each of the 56 cities, based on data in the APWA report [1].

The program uses population density constants and the percentage of area served by combined sewers in each community, following the procedures used in the APWA report and summarized in Sections 2.1 and 2.2, to determine values for areas and populations in each community serviced by separate, combined or no sewers. Table 14 lists constants required to perform these calculations; some of these were not included in the final draft of the APWA report. The weighted mean percentage of sewered area occupied by combined sewers, in 18 cities for which the information is available, is 25%. This value was utilized for the remaining seven cities.

The program assigns concentrations for sewage treatment effluents, using values from Table 8, depending on whether a community is served by a primary or secondary treatment plant. Table 8 lists other assumptions, which are described in Section 3, about quantities and composition of sewage and runoff.

Sewage treatment loading estimates are based on sewered population multiplied by the effluent concentrations in Table 8. Surface runoff loadings from separately sewered areas are based on the size of area multiplied by unit loadings from Table 8.

Required input data for the program includes, in addition to demographic and runoff data, assumptions about the fraction of annual sewage solids that are deposited

TABLE 14. Data Describing Ontario Great Lakes Communities.

CITY	A	B	X	Z	AREA	FC	I	IE
Ajax	172.4	1.17	2.00	47.5	*2036*	0.	1	0
Aurora	64.7	1.17	2.00	75.6	6.86	0.	0	0
Barrie	152.2	1.17	2.00	51.8	7.16	0.	0	0
Belleville	101.9	0.86	2.00	36.6	5.94	34.	0	0
Brampton	53.9	0.58	2.00	29.9	5.81	2.	0	0
Brantford	51.2	0.58	2.00	31.8	9.48	0.	0	0
Burlington	108.0	0.86	2.855	37.1	13.81	0.	0	0
Chatham	49.2	0.58	2.00	33.3	5.46	37.	0	0
Chinguacousy	137.4	0.76	2.00	16.4	2.08	0.	0	0
Cobourg	153.7	1.17	2.00	51.5	2.89	0.	0	0
Dundas	195.2	1.17	2.00	43.0	3.47	0.	0	0
Etobicoke	119.4	0.76	2.00	20.8	30.62	0.	0	0
Galt	184.1	1.17	2.00	45.2	8.32	0.	0	0
Georgetown	218.0	1.17	2.00	39.0	3.08	0.	0	0
Guelph	228.0	1.17	3.00	42.7	11.30	0.	0	0
Hamilton	151.8	0.76	2.00	13.6	26.05	76.	0	0
Kingston	150.0	0.76	3.76	17.1	5.68	27.	0	1
Kitchener- Waterloo	84.6	0.76	1.70	32.0	22.07	0.	0	0
Leamington	204.5	1.17	2.00	41.4	2.01	0.	1	0
Lindsay	132.8	1.17	2.00	56.4	3.78	0.	0	0
London	136.8	0.92	2.00	32.2	33.17	0.	1	0
Markham	104.3	1.17	2.00	63.7	6.11	0.	1	0
Midland	127.3	1.17	2.00	57.7	3.40	90.	0	1
Mississauga	82.3	0.76	2.00	33.9	23.62	0.	0	0
Newmarket	82.7	1.17	2.00	70.0	9.02	0.	0	0
Niagara Falls	99.5	0.86	2.00	37.5	10.86	93.	0	1
North Bay	135.3	0.76	2.00	16.9	*2.26*	5.	0	0
0akville	94.3	0.66	2.00	39.4	9.99	0.	0	0
0rillia	187.2	1.17	2.00	48.5	5.66	0.	0	0
0shawa	51.1	0.58	2.00	31.9	13.61	0.	0	0
0wen Sound	120.4	1.17	2.00	59.5	6.04	50.	0	1
Peterborough	210.5	1.17	2.00	40.3	10.81	0.	0	0
Pickering	147.4	1.17	2.00	52.9	5.09	0.	0	0
Pt. Colborne	135.7	1.17	2.00	55.7	5.22	0.	0	0
Port Erie	229.4	1.17	2.00	37.1	2.00	0.	1	0
Preston	156.0	1.17	2.00	51.0	4.22	0.	0	0
Richmond Hill	101.4	1.17	2.00	64.6	10.20	0.	0	0
St. Catharines	50.0	0.58	2.00	32.8	16.33	46.	0	0
St Thomas	224.0	1.17	2.00	38.0	4.49	75.	0	0
Sarnia	157.3	0.76	2.00	12.7	4.69	26.	0	1
Sault Ste Marie	109.0	0.89	2.42	33.0	12.71	0.	0	1
Scarborough	134.1	0.76	2.00	17.2	31.94	20.	0	0
Simcoe	186.3	1.17	2.00	44.7	2.2B	0.	1	0
Stratford	192.2	1.17	2.00	43.6	5.02	0.	0	0
Sudbury	71.2	0.89	2.00	52.6	23.95	0.	0	0
Thunder Bay	86.4	0.74	*2.23*	31.0	14.10	0.	1	1
Toronto	585.0	0.82	4.87	.5	24.01	75.	0	0
Trenton	227.1	1.17	2.00	37.5	2.53	0.	0	1
Wallaceburg	181.0	1.17	2.00	49.9	2.58	37.	0	0
Welland	168.1	1.17	2.00	48.4	9.77	45.	0	0
Whitby	149.3	1.17	2.00	52.5	4.42	0.	0	0
Windsor	167.0	0.92	2.64	27.3	26.32	31.	0	1
Woodstock	170.6	1.17	2.00	47.9	6.04	0.	0	0
York	405.4	0.82	2.00	1.3	5.73	84.	0	0
York. East	314.7	0.82	2.00	3.4	5.25	63.	0	0
York, North	149.2	0.76	2.00	14.1	43.71	0.	0	0

A - constant in population density equation.
B - constant in population density equation.
X - calibration constant.
Z - undeveloped percentage of urban areas.
AREA - total city area,1000's of acres.
FC - percent of sewered area with combined sewers.
I - 1 = no value for FC available, 25% assumed.
IE - 0 denotes secondary treatment;1denotes primary treatment.

ASSUMPTIONS USED TO DETERMINE ANNUAL LOADINGS

1) Flow and concentrations from Table 8
2) Fraction of DWF solids deposited and scoured - 0.06
3) Fraction of hours with runoff - 0.108 (Table 10)
4) Interceptor capacity - 2.5
   - Fraction of annual sewage in overflow - 0.0226 (Table 10)
   - Fraction of annual runoff in overflow - 0.647 (Table 10)

and scoured, and the size of the interceptor serving each community. Assumptions made in estimating loadings to the Great lakes are described in the following paragraphs. The sensitivity of the estimated loadings to these assumptions is discussed in Sections 6 and 7.

In this analysis it was assumed that 6% of the annual solids load is deposited in dry weather and scoured during storms. This value is approximately mid-way between the two values cited in the discussion in Section 4.2.

An interceptor capacity of 2.5 times average dry weather flow is assumed to be representative of design practices in Ontario communities. Based on documented relationships between sewered populations and ratios of peak to average flow [15], this value might be expected in a system serving the population of the hypothetical Ontario city in Table 9.

9. ANALYTICAL RESULTS

Table 15 presents the results of the analysis of data for the 56 communities in the Ontario Great Lakes Basin. Annual loads of each constituent in this table are presented for; total wet and dry weather loads discharged from sewage treatment plants; wet weather loads discharged in combined sewer overflows; and wet weather loads discharged in storm runoff from separately sewered and unsewered areas.

The combined sewer loading estimates in Table 15 depend on assumptions about the percentage of sewage solids that are deposited and scoured, and about the capacity of combined sewer interceptors. Figure 2 summarizes the relative effects on combined sewer loadings of altering these assumptions. (It should be noted that the combined sewer overflow loading estimates for an interceptor capacity of 1 DWF are low because they do not include dry weather overflows that would occur because of normal sanitary sewage flow variations.)

TABLE 15. Estimated Municipal Loadings To The Great Lakes.

CITY	POP (1000S)	DEVELOPED AREA(1000AC) COMB	SEP	UNSEW	ANNUAL LOADS(1000LB/YR) BOD STP	CSO	RNOF	SS STP	CSO	RNOF	N STP	CSO	RNOF	P STP	CSO	RNOF
AJAX	12.52	.16	.49	.84	89.	20.	45.	123.	87.	552.	94.	4.1	11.	5.	.72	1.14
AURORA	11.27	0.00	.82	.86	77.	0.	59.	104.	0.	716.	81.	0.0	15.	5.	0.00	1.47
BARRIE	27.68	0.00	1.51	1.94	197.	0.	120.	266.	0.	1454.	208.	0.0	30.	12.	0.00	2.99
BELLEVILLE	34.74	.81	1.57	1.39	258.	80.	106.	365.	398.	1281.	274.	16.3	26.	15.	2.75	2.64
BRAMPTON	43.64	.08	3.99	0.00	392.	9.	162.	532.	41.	1967.	415.	1.8	41.	23.	.31	4.05
BRANTFORD	64.49	0.00	6.47	0.00	580.	0.	262.	785.	0.	3187.	614.	0.0	66.	34.	0.00	6.56
BURLINGTON	79.64	0.00	6.03	2.66	615.	0.	325.	832.	0.	3943.	651.	0.0	81.	36.	0.00	8.12
CHATHAM	35.69	1.35	2.29	0.00	317.	106.	93.	456.	627.	1131.	337.	22.3	23.	19.	3.52	2.33
CHINGUACOUSY	21.90	0.00	1.74	0.00	197.	0.	71.	267.	0.	857.	209.	0.0	18.	12.	0.00	1.76
COBOURG	11.28	0.00	.61	.79	80.	0.	49.	109.	0.	591.	85.	0.0	12.	5.	0.00	1.22
DUNDAS	17.20	0.00	.88	1.10	125.	0.	69.	169.	0.	835.	132.	0.0	17.	7.	0.00	1.72
ETOBICOKE	280.14	0.00	22.53	1.72	2445.	0.	966.	3308.	0.	11734.	2589.	0.0	242.	144.	0.00	24.16
GALT	38.90	0.00	2.01	2.55	281.	0.	158.	380.	0.	1924.	297.	0.0	40.	17.	0.00	3.96
GEORGETOWN	17.05	0.00	.84	1.04	125.	0.	65.	169.	0.	794.	132.	0.0	16.	7.	0.00	1.64
GUELPH	56.46	0.00	3.31	3.17	414.	0.	230.	559.	0.	2789.	438.	0.0	57.	24.	0.00	5.74
HAMILTON	303.00	17.11	5.40	0.00	2673.	1399.	219.	3958.	8036.	2662.	2842.	293.1	55.	157.	46.93	5.48
KINGSTON	58.42	1.27	3.44	0.00	1527.	129.	140.	1582.	632.	1694.	673.	26.4	35.	30.	4.49	3.49
KITCH-WATER	146.58	0.00	11.15	3.85	1164.	0.	569.	1575.	0.	6907.	1233.	0.0	142.	68.	0.00	14.22
LEAMINGTON	10.44	.13	.39	.65	75.	18.	36.	104.	71.	433.	79.	3.5	9.	4.	.64	.89
LINDSAY	12.75	0.00	.72	.92	90.	0.	57.	121.	0.	695.	95.	0.0	14.	5.	0.00	1.43
LONDON	220.32	3.45	10.35	8.69	1649.	408.	682.	2300.	1792.	8280.	1749.	81.9	170.	97.	14.41	17.05
MARKHAM	16.19	.25	.74	1.23	111.	23.	67.	155.	120.	815.	118.	4.7	17.	7.	.78	1.68
MIDLAND	10.99	.57	.06	.81	222.	44.	27.	247.	264.	326.	98.	9.3	7.	4.	1.47	.67
MISSISSAUGA	148.95	0.00	11.76	3.86	1185.	0.	593.	1603.	0.	7205.	1255.	0.0	148.	70.	0.00	14.83
NEWMARKET	18.95	0.00	1.26	1.45	130.	0.	95.	176.	0.	1149.	137.	0.0	24.	8.	0.00	2.37
NIAGRA FALLS	62.02	3.96	.30	2.53	1344.	286.	88.	1516.	1807.	1074.	595.	60.9	22.	27.	9.36	2.21
NORTH BAY	23.43	.09	1.78	0.00	210.	13.	72.	286.	51.	879.	222.	2.5	18.	12.	.45	1.81
OAKVILLE	54.07	0.00	3.73	2.33	402.	0.	221.	544.	0.	2688.	426.	0.0	55.	24.	0.00	5.53
ORILLIA	26.91	0.00	1.41	1.51	199.	0.	103.	269.	0.	1245.	210.	0.0	26.	12.	0.00	2.56
OSHAWA	92.40	0.00	9.27	0.00	831.	0.	376.	1125.	0.	4568.	880.	0.0	94.	49.	0.00	9.41
OWEN SOUND	18.47	.54	.54	1.37	373.	50.	63.	396.	262.	766.	165.	10.3	16.	7.	1.70	1.58
PETERBOROUGH	57.79	0.00	2.88	3.57	422.	0.	225.	571.	0.	2727.	447.	0.0	56.	25.	0.00	5.62
PICKERING	19.05	0.00	1.05	1.35	135.	0.	83.	183.	0.	1010.	143.	0.0	21.	8.	0.00	2.08
PT.COLBOURNE	17.99	0.00	1.01	1.30	127.	0.	80.	172.	0.	975.	134.	0.0	20.	7.	0.00	2.01
PORT ERIE	11.65	.14	.43	.69	84.	20.	38.	117.	79.	462.	90.	4.0	10.	5.	.73	.95
PRESTON	16.72	0.00	.91	1.16	119.	0.	72.	161.	0.	871.	126.	0.0	18.	7.	0.00	1.79
RICHMONDHILL	26.27	0.00	1.62	1.99	182.	0.	126.	246.	0.	1527.	192.	0.0	31.	11.	0.00	3.14
STCATHERINES	108.49	5.05	5.93	0.00	964.	381.	241.	1405.	2328.	2921.	1024.	80.7	60.	56.	12.58	6.01
ST THOMAS	25.54	.94	.31	1.53	183.	90.	59.	267.	459.	714.	195.	18.4	15.	11.	3.08	1.47
SARNIA	56.53	1.06	3.03	0.00	1474.	128.	123.	1520.	557.	1493.	649.	25.8	31.	29.	4.55	3.07
SLTSTEMARIE	70.21	0.00	4.73	3.78	1478.	0.	306.	1478.	0.	3716.	650.	0.0	77.	30.	0.00	7.65
SCARBOROUGH	328.19	5.29	21.16	0.00	2915.	637.	859.	4050.	2764.	10428.	3091.	127.8	215.	171.	22.56	21.47
SIMCOE	10.79	.14	.42	.70	77.	18.	38.	107.	74.	463.	81.	3.6	10.	5.	.64	.95
STRATFORD	24.50	0.00	1.25	1.58	178.	0.	98.	240.	0.	1195.	188.	0.0	25.	10.	0.00	2.46
SUDBURY	89.97	0.00	6.31	5.04	637.	0.	408.	862.	0.	4955.	675.	0.0	102.	37.	0.00	10.20
THUNDER BAY	97.43	2.05	6.16	1.52	2362.	199.	296.	2451.	1007.	3591.	1041.	40.8	74.	47.	6.85	7.39
TORONTO	750.02	17.92	5.97	0.00	6573.	2621.	242.	9251.	9993.	2944.	6973.	517.1	61.	386.	94.67	6.06
TRENTON	14.59	0.00	.71	.87	316.	0.	55.	316.	0.	669.	139.	0.0	14.	6.	0.00	1.38
WALLACEBURG	11.86	.23	.39	.67	86.	27.	36.	121.	120.	436.	91.	5.5	9.	5.	.96	.90
WELLAND	41.71	1.00	1.22	2.83	293.	106.	135.	416.	501.	1635.	311.	21.5	34.	17.	3.70	3.37
WHITBY	16.76	0.00	.92	1.18	119.	0.	73.	161.	0.	885.	126.	0.0	18.	7.	0.00	1.82
WINDSOR	200.37	4.15	9.23	5.76	4588.	449.	548.	4768.	2097.	6656.	2022.	91.0	137.	92.	15.70	13.70
WOODSTOCK	26.17	0.00	1.38	1.76	188.	0.	109.	254.	0.	1327.	199.	0.0	27.	11.	0.00	2.73
YORK	149.44	4.75	.90	0.00	1309.	589.	37.	1866.	2505.	446.	1390.	117.8	9.	77.	20.91	.92
YORK,EAST	106.29	3.20	1.88	0.00	934.	381.	76.	1327.	1664.	925.	991.	76.5	19.	55.	13.47	1.90
YORK,NORTH	499.70	0.00	37.55	0.00	4496.	0.	1524.	6083.	0.	18506.	4760.	0.0	381.	264.	0.00	38.10
TOTALS	4755.	76.	235.	85.	48614.	8228.	12075.	62774.	38335.	146624.	43065.	1668.	3019.	2325.	288.	302.
LOADS(LB/ACRE-YR)					157.	109.	38.	202.	507.	459.	139.	22.	9.	7.	4.	1.
CONCENTRATIONS(MG/L)					20.0	40.7	14.0	25.8	189.8	170.0	17.7	6.3	3.5	1.0	1.4	.35

TOTAL FLOW(IMG/YR) EFFLUENT: 243051. IN CSO: 20193. IN RUNOFF: 86249.

TABLE 15. Estimates Municipal Loadings To The Great Lakes (Cont'd)

THE FOREGOING RESULTS ARE BASED ON:

Fraction Of DWF Solids Deposited And Scoured=	0.06
Values Derived From Storm Analysis For Hypothetical Ontario City For Interceptor Capacity Of 2.5 Times DWF:	
Fraction Of Hours With Runoff=	0.108
Fraction Of Annual Sewage In Overflow=	0.023
Fraction Of Annual Runoff In Overflow:	0.65
Per Capita Sewage Flows	145.
- Comb Area=	16.2
- Separate Area=	12.8
- Unsewered Area=	9.5

Concentrations (mg/L)	BOD	SS	TN	TP
In Sewage:	165.00	225.00	30.00	6.50
In Primary Effluent:	50.00	50.00	22.00	1.00
In Secondary Effluent:	17.00	23.00	18.00	1.00
In Surface Runoff				
Sewered Area:	14.00	170.00	3.50	0.35
Unsewered Area:	14.00	170.00	3.50	0.35

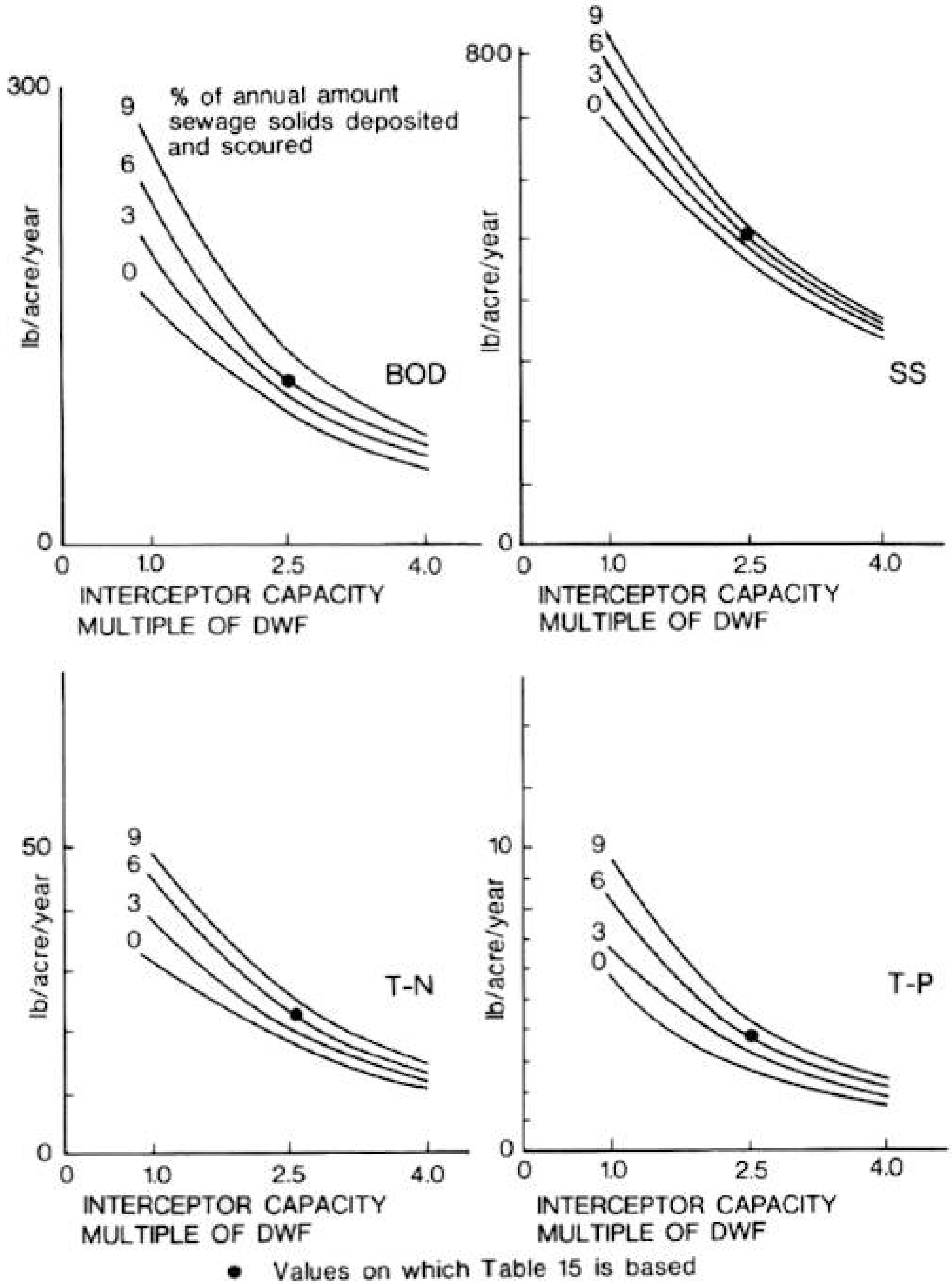

FIGURE 2: Effects on Combined Sewage Overflow Loadings of Altered Assumptions About Interceptor Capacity And Solids Deposition And Scour.

7. DISCUSSION

7.1 Reliability of Estimates

The estimated loadings in Table 15 depend on: i) demographic data and runoff estimates from the APWA report [1], and ii) assumptions made in calculations of combined sewer loadings. Doubts have been expressed about the reliability of some of the APWA data, particularly the estimated areas served by various sewer types, based on comparison with more recent data for specific communities [17]. However, in the course of the Grand River Basin Water Management Study, areas occupied by urban development and by various land uses in several cities agreed closely with values in the APWA report.

When the methodology and the information used to derive the estimates in the APWA report (which relied heavily on generalized relationships extrapolated from relatively few communities) are considered, discrepancies in estimates for individual communities are not unexpected. However, it might be expected that individual discrepancies would tend to cancel out in the calculation of total loadings for the basin. The APWA data is the best information available to describe all the communities in the Ontario Great Lakes Basin, and until the information on which Table 15 is based can be further confirmed or corrected, the loadings derived herein are the best estimates that appear possible at the present time.

The calculated combined sewage loads in Table 15, which were based on an estimated runoff from the APWA report of 16.2 inches, were recalculated using a runoff of 12.8 inches to illustrate the relative insensitivity of the loading estimates to runoff estimates. The results (in 1000 lb/yr) were as follows:

Annual runoff (inches)	BOD	SS	T-N	T-P
16.2	8228	38335	1668	288
12.8	7700	31924	1536	275

Surface runoff loading estimates will vary directly with runoff, since they are based on mean concentrations multiplied by runoff values.

The sensitivity of the estimated loads to assumptions about interceptor capacities, and deposited and scoured solids is indicated by Figure 2. As an example of the effects of these assumptions, it can be noted that the calculated phosphorus load would be increased by 50% if the interceptor capacity equalled 1.8 DWF instead of the value of 2.5 DWF used in the report, and that increasing the percentage of solids deposited and scoured from the assumed value of 6% to a value of 9% would increase the estimated phosphorus load by about 14%.

There are other factors, not recognized in the estimates of Table 15, that could increase, and might alter the relative magnitudes of municipal loadings: sediment and nutrients produced by erosion resulting from construction activity; illicit connections to storm sewers that permit the discharge of untreated sewage; and, bypasses and overflows from overloaded sanitary sewer systems and treatment plants. There is little available information on which to estimate the impact of the first two of these sources. A study by the Ontario Ministry of the Environment [18] determined that pollutant loads in sewage that bypassed three treatment plants serving sanitary sewerage systems equalled 0.9% to 12% of annual treatment plant effluent loads, and depended on the treatment plant and the pollutant being measured.

Combined sewer overflow discharges could exceed the values estimated in Table 15 if the effects of inflow and infiltration, which have been responsible for overloaded sewerage systems in many communities, are not recognized in derivation of the estimates. The sewage flows in Table 8 used to produce the estimates in Table 15 are believed to include infiltration and inflow. However, it is less certain that the assumed interceptor capacity allows for the effects of infiltration and inflow, i.e., for cases where the capacity of the interceptor, as a multiple of dry weather flow, is less than the design capacity. As Figure 2 indicates, pollutant loadings discharged in combined overflows could be doubled if the actual interceptor capacity is 1.3 DWF rather than the value of 2.5 DWF assumed in preparing Table 15.

In summary, for reasons described above, the estimates in Table 15 are conservative estimates of pollutant loads to the Great Lakes from Ontario municipal sources.

7.2 Relationship To APWA Results

Although this report adopted demographic and runoff data from the APWA report [1], sewage flows and wastewater compositions were not derived from that source. This section considers the relationship of unit loadings estimated in the APWA report to those derived herein. Total loadings cannot be compared because they were not derived in the APWA report.

Table 16 compares per-capita sewage loadings assumed in the APWA report with those used herein. Raw sewage BOD and nitrogen values from the APWA report are lower than those from Ontario communities summarized in Table 8; the phosphorus value is an order of magnitude higher, an apparent error. The APWA report does not provide an estimate of actual sewage loads to the Lakes because the effects of sewage treatment were not considered.

TABLE 16. Comparison Of Sanitary Sewage Loads In Apwa Report With Recorded Ontario Values (loads in lb/capita-day).

	APWA Report [1]	This Report (based on Table 8)		
		Raw Sewage	Primary Effluent	Secondary Effluent
BOD	0.17	0.24	0.073	0.024
T-N	0.034	0.044	0.032	0.026
T-P	0.0083	0.001	0.00015	0.00015

Table 17 lists surface runoff loadings and concentrations from the APWA report, and the Ontario values adopted herein. Comparisons should be based on concentrations shown in Table 17 because the Ontario data is expressed as concentrations and the Ontario loadings are based on annual runoff values from the APWA report. It may be seen from the table that the APWA values are substantially lower than those based on Ontario data.

Section 4 indicated why an improved procedure was adopted herein to calculate loadings from combined sewage systems. Table 18 compares the resultant loadings with those from the APWA report.

The two sets of values in Table 18 are not directly comparable. The APWA values do not represent actual loads to the Great Lakes because they are total wet weather

TABLE 17. Comparison Of Surface Runoff Quality From APWA Report With Values From This Report.

	Runoff [1] (in)	Surface Runoff Loadings (lb/acre-yr)						Surface Runoff Composition (mg/L)					
		BOD		T-N		T-P		BOD		T-N		T-P	
		APWA [a]	Herein [b]	APWA [a]	Herein [b]	APWA [a]	Herein [b]	APWA [c]	Herein [d]	APWA [c]	Herein [d]	APWA [c]	Herein [d]
Separate Sewer Areas	12.8	25.7		3.9		0.33		8.9		1.3		0.11	
Unsewered Areas	9.5	21.3		3.2		0.26		9.9		1.5		0.12	
Total [e]		24.1	38.0	3.7	9.0	0.31	1.0	9.3	14	1.37	3.5	0.11	0.35

a Table 1

b Table 15

c Table I loading divided by surface runoff

d Table 8

e APWA values are based on relative percentages of total land area on Ontario cities: separate sewer areas 35.8%, unsewered areas 19.5% [1].

combined sewage loadings, which do not consider flows intercepted and conveyed to treatment plants. The values from Table 15 are combined sewer overflow loadings only.

TABLE 18. Comparison Of Combined Sewage Loadings From The APWA Report With Values From This Report.

	Loading (lb/acre-yr)		
	BOD	T-N	T-P
APWA Report[1]	137	20.8	1.7
This Report (Table15)	110	22.0	4.0

7.3 Impact of Municipal Loadings

Figure 3 compares relative contributions to the Great Lakes from the three municipal sources for which estimated loadings are presented in Table 15. This figure indicates that 20% of the total load from municipal sources of phosphorus, the pollutant of greatest concern in terms of lake-wide effects, originates with storm-generated discharges of surface runoff and combined sewer overflow. Since municipal sources account for approximately one-third of the total phosphorus discharged to the Great Lakes from the province of Ontario [16], combined sewer overflows and surface runoff account for about 7% of the total phosphorus load contributed to the lakes from Ontario sources.

The effect of these two sources is somewhat greater if only loads reaching Lake Ontario are considered. Combined sewer overflows and surface runoff contribute 20% of the phosphorus from the 30 cities listed in Table 15 that are in the Lake Ontario basin. Since approximately 63% of the phosphorus entering this lake is from municipal sources [16], these sources furnish about 13% of the phosphorus reaching Lake Ontario from the province of Ontario.

Although on a lake-wide basis the contribution of combined sewage and surface runoff is not great, they do account for the largest portion of municipal wet weather loads to the lakes, and in some locations the impact of these loads is significant. Figure 4 illustrates that, in wet weather, these sources discharge BOD, nitrogen, and phosphorus loads that are more than twice, and suspended solids loads that are nearly five times, sewage treatment plant discharges in the same periods.

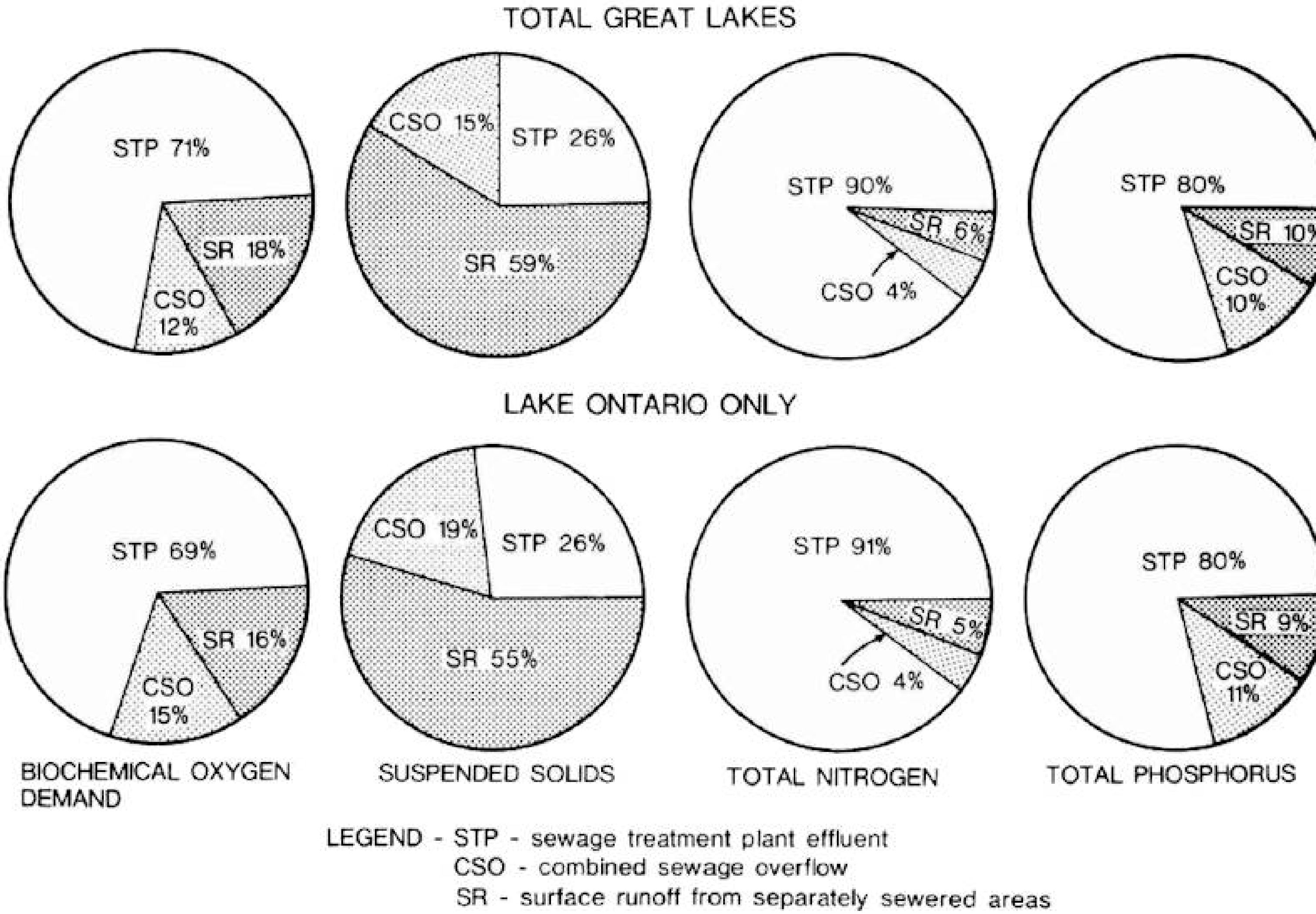

FIGURE 3: Relative Contributions To The Great Lakes From Municipal Sources In Ontario.

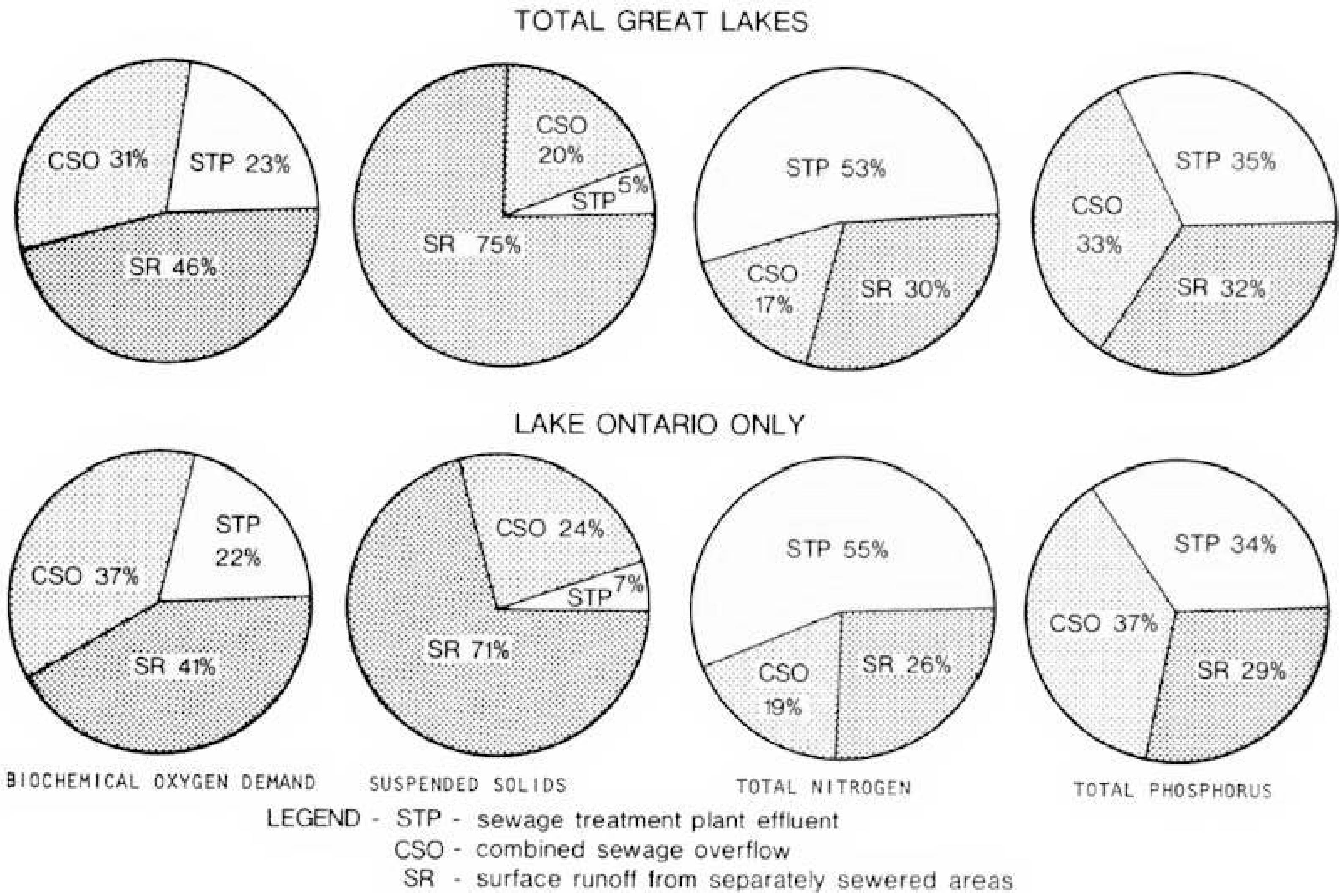

FIGURE 4: Relative Contributions to <u>Wet Weather</u> Loads to The Great Lakes From Municipal Sources in Ontario.

Table 15 indicates that surface runoff loads exceed those from combined sewer overflows. As it applies to BOD loads, this comparison may be misleading. A more complete appreciation of the effects of organic loadings on receiving waters would be obtained if the loads could be expressed in terms of TOD (total organic demand) instead of the five-day BOD (biochemical oxygen demand) values shown in Table 15 and Figures 3 and 4. TOD includes the sum of carbonaceous demands, represented by BOD values, and the nitrogenous demand exerted by unoxidized ammonia. Since raw sewage and combined sewage contain significant concentrations of ammonia, whereas values in surface runoff are generally negligible, the relative impacts of the former sources will be considerably greater than indicated by a comparison of BOD loads.

Bacterial loads have not been considered in this report, but it should be noted that both combined sewage and surface runoff contain significant concentrations of bacterial indicator organisms. Combined overflows have been blamed for high coliform counts at a number of locations on the Great Lakes, including Toronto, Hamilton, and Collingwood harbours.

8. CONCLUSIONS

1) Results of the analyses described herein indicate that in terms of phosphorus, the pollutant of greatest concern with respect to lake-wide effects, storm generated discharges of surface runoff and combined sewer overflow account for:

   a) 20% of loads discharged to the Great lakes from municipal sources in Ontario;
   b) approximately 7% of loads discharged to the Great Lakes from all Ontario sources; and
   c) approximately 13% of loads discharged to Lake Ontario from all Ontario sources.

2) The impact of combined sewer overflows and surface runoff may be very significant near populated areas in wet weather, when those sources discharge loads that are two to five times those discharged in treatment plant effluents.

3) Surface runoff and combined sewer overflows contribute almost equally to total BOD, nitrogen, and phosphorus loads reaching the Great Lakes; suspended solids in runoff are about three times those from combined sewer overflows.

4) The wet weather loading estimates above are conservative in that they do not fully consider effects of sediment, illicit discharges of sanitary sewage to storm sewers, treatment plant bypasses, or loss of design interceptor capacity due to infiltration and inflow.

5) The method described and used herein to estimate annual pollutant loads in combined sewage is simple and appears to be effective.

6) The demographic data used herein, derived from the APWA report [1], appear to be the best presently available, but should be verified and the results presented herein modified accordingly.

7) The results presented herein are not particularly sensitive to assumptions about amounts of annual runoff.

8) When unit loadings used in the APWA report [1] are compared with those derived herein on the basis on Ontario data:

a) APWA raw sewage loads are lower; effluent loads are not estimated.

b) APWA surface runoff concentrations are substantially lower.

c) Combined sewage loads are not comparable because wet weather interception and treatment of combined sewage were not considered in the APWA report.

ACKNOWLEDGEMENTS

When preparation of this report commenced, D.H. Waller* was serving as a member of the Technical Advisory Group to the Urban Drainage Subcommittee under the Canada Ontario Agreement on Great Lakes Water Quality, and Z. Novak** served as a member of the Working Group of the Subcommittee. The report has benefited substantially from comments and criticisms of J. Marsalek, F.A. Tonelli, D. Weatherbe, K. Shikaze and G. Zukovs. Special thanks are due to S.N. Singer.

* Department of Civil Engineering, Nova Scotia Technical College, P.O. Box 1000, Halifax.

** Water Resources Branch, Ontario Ministry of the Environment, 1 St. Clair Avenue West, Toronto.

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