HYDRAULICS DIVISION
TECHNICAL NOTE

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TITLE: Environmental Impact of the Proposed Extension of the Quebec City Port. Simulation of Pollutant Loads in Urban Runoff.

REASONS FOR REPORT:

To respond to request from Quebec Region to assist in the assessment of an Environmental Impact Statement.

CORRESPONDENCE FILE NO:

5188

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1.0 SIMULATION OF POLLUTANT LOADS IN URBAN RUNOFF

One of the environmental impacts of the proposed extension of the Quebec City Port is the reduction of the flushing of the water body and muds between the proposed extension and the existing north shoreline. This newly confined water body, which extends over the ecologically sensitive mudflats, will be receiving the flow conveyed by the Beauport River as well as the surface runoff from adjacent areas. Because the Beauport River Basin is partly urbanized, the river flow carries significant pollution loads (4). Under the proposed arrangement, these loads and others from adjacent areas will no longer be expediently removed by the St. Lawrence River and may therefore affect adversely the water quality on the mudflats.

The evaluation of such pollution loads and of their impact on the receiving waters, confined by the proposed extension, was recommended earlier (3). To support this recommendation, a preliminary evaluation of the urban runoff pollution loads from the Beauport Community has been made and the results were given elsewhere (3).

The methodology used to evaluate urban runoff pollution loads was based on annual unit pollutant loads (2). The use of such procedure was governed by time constraints and the dearth of data readily available for such analysis.

Annual pollution loads are suitable for an expedient comparison of various pollution sources. On the other hand, a detailed analysis of water quality conditions in the receiving waters requires the knowledge of the distribution of pollution loads throughout the year. To provide such detailed information, continuous simulation of urban runoff quantity and quality has been undertaken for the urbanized part of the Beauport River basin. The continuous runoff simulation has been done for 11 years (1970-1980) using a time step of 1 hour. The results of this analysis confirm the annual pollution loads produced earlier (3) and describe the distribution of pollution loads in almost 1,100 rainfall/runoff events which occurred during the studied period. For selected events, hourly pollutant fluxes were also produced. As proposed by the regional DOE office, the information on runoff events could be used to select critical events which would be used in a physical model to model hydrodynamic and water quality processes in the studied area. Such a physical model would be used to evaluate the environmental impact of the proposed extension of the port.

A summary of simulation results follows. Additional analyses of the 11-year simulated runoff record can be performed upon request.

2. SIMULATION PROCEDURES

2.1 Simulation Model

The continuous simulation of urban runoff was performed by means of the STORM model, version 2.1, August, 1977. This model was described in detail elsewhere. A brief description of the STORM model is presented below. This description concentrates on the model features which were used in this work and it should serve for the understanding of the limitations of simulations results.

The STORM Model was developed jointly by the U.S. Corps of Engineers and Water Resources Engineers Inc. (5, 7). The model computes stormwater runoff from a single catchment in hourly time steps based on the record of a single raingauge. The rainfall depth in excess of the depression storage is transformed to direct runoff through the use of a specified runoff coefficient at each time step. Runoff from both pervious and impervious areas of the catchment is simulated.

The shape of the watershed is not considered by STORM, nor is the time of concentration taken into account. It is assumed that all runoff flows out of the catchment during the time step in which it is generated. For larger watersheds, with a concentration time greater than one hour, the computed hydrograph will generally occur earlier than the observed one. The reverse would be true for smaller watersheds with a concentration time less than one hour. This is not usually of great concern in many studies, however. The water balance between storms is determined via the recovery of depression storage based upon specified potential evapotranspiration rates.

The model performs no routing computations, and all direct runoff computed for each time step is assumed to drain from the catchment in that time step. Various combinations of storage and treatment capacities may be modelled and the effect of these on stormwater overflows investigated. Quality computations may be performed in each time step based upon the pollutant washoff equation.

Runoff Quantity

In STORM, runoff is computed hourly based upon the average watershed runoff coefficient, the rainfall within the hour and depression storage, according to the following formula:

$$R = C (P - f)$$

where R = urban area runoff in inches per hour
C = composite runoff coefficient dependent on urban land use
P = rainfall plus snowmelt in inches per hour over the urban area; and
f = available urban depression storage in inches per hour.

The runoff generated in each hour is assumed to drain from the watershed within that hour, and may be modified by any treatment or storage option specified.

Snowmelt is computed using the degree-day method, according to the formula:

$$MELT = COEF \times (T - T_T)$$

in which MELT = snowmelt in inches over the basin
COEF = degree-day coefficient, ranging from .05 to .15 inches per degree-day
T = average daily air temperature °F
T_T = temperature at which snow begins to melt.

Snowmelt is computed only for those days when the average daily temperature is above the temperature at which snow begins to melt, otherwise the precipitation is added to the snowpack. The computed snowmelt is distributed uniformly throughout the melting period, 9 a.m. to 5 p.m.

Runoff Quality

Runoff quality is also computed in hourly time steps. The rate of removal of a pollutant from the watershed within each time step is assumed to be exponentially related to the amount remaining after the preceding step. For each of five pollutants (Suspended Solids, Settleable Solids, BOD, Nitrogen, PO_4), the relationship is:

$$M_p = A\,P(t)\ \left(1 - e^{-E_u R_i \Delta t}\right)/\Delta t$$

where M_p is the amount of pollutant washed off in this time step, Δt

A is the availability coefficient

$P(t)$ is the amount of pollutant on the watershed at the start of this step

R_i is the runoff rate from impervious areas

E_u is the urban washoff decay coefficient

Δt is the time increment

For pollutants other than solids, additional pollutant quantities are derived as a fixed fraction of the suspended solids load.

The user may supply the various coefficients or rely on the default values in the program. Reference should be made to the User's Manual for a more detailed description of these (7). The amount of pollutant accumulation on the watershed is governed by the number of dry days, the total length of curb and gutter, the dust and dirt accumulation rate on the watershed, and cleaning practices. The various pollutants are expressed as fractions of the dust and dirt. The maximum permissible amount of pollutant is limited to that accumulated in 90 dry days.

In summary, the STORM model is an inexpensive versatile modelling tool recommended for preliminary planning of storage and treatment capacities required to control runoff from a single major catchment. Both the quantity and quality of surface runoff and combined sewer overflows are considered. Modelling options which were not used here include runoff storage and treatment, unit hydrograph analysis, and soil erosion computations.

2.2 STORM Calibration

The runoff quantity part is calibrated by varying the following parameters:

(a) Runoff coefficients for pervious and impervious areas
(b) Evapotranspiration rates
(c) Depression storage
(d) Rainfall reduction factor used to relate point precipitation to basin average rainfall.

Because the model considers the entire watershed as a single computational catchment, it is quite sensitive to each of these parameters and rapid calibration for period totals is generally possible.

The runoff quality part is generally calibrated by varying the following parameters:

(a) Daily dust and dirt accumulation rates for various land uses
(b) Composition of dust and dirt in terms of the five basic pollutants
(c) Street cleaning interval
(d) Street cleaning efficiency (0-100%)

2.3 Input Data for the Study

A brief description of input data used in runoff simulations follows. In most cases, these input data represent the best estimates made on the basis of limited background information.

2.3.1 Climatological data

Two types of climatological data were used - precipitation and air temperatures. Both types of data were taken from the station at the Quebec City Airport - the nearest station with appropriate records.

For runoff simulations, 11 years of climatological data (1970-1980) were used. Such a record length is more than adequate for this study.

Precipitation data were available in two forms - hourly rainfall data from April to November and daily precipitations for the remainder of the year. Daily precipitations were uniformly distributed over the 24-hour period. For runoff simulations, hourly precipitations were produced for the entire 11-year period and stored on magnetic tape.

Hourly air temperatures were available for the same station and these were used in snowmelt computations.

2.3.2 Catchment data

The information available for the Beauport River basin was rather limited (1) and, consequently, some catchment parameters had to be estimated on the basis of such incomplete information.

The size of the urbanized area contributing runoff to the Beauport River was taken as 2,770 ha (27.7 km^2). This area was further subdivided into segments with various land use, as shown in Table 1.

TABLE 1. LAND USE FOR THE URBANIZED PART OF THE BEAUPORT RIVER BASIN

Land Use	Percent of Total Area	Area (ha)	Imperviousness (%)
Residential - Single	46.5	1,288	15
Residential - Multiple	8.2	227	22
Commercial	4.9	136	80
Industrial	7.3	202	15
Open (Parks, etc.)	33.1	917	1

2.3.3 Hydrological parameters

For the purpose of runoff computations, the runoff coefficients were taken as follows:

Pervious areas $C = 0.10$

Impervious areas $C = 0.90$

The depression storage was $d = 2.5$ mm.

All the other hydrological parameters were specified by the model as built-in default values.

2.3.4 Parameters for runoff quality computations

The parameters which were used for quality computations were adopted from the literature (2, 6). Their listing is given in Tables 2 and 3.

TABLE 2. DUST AND DIRT ACCUMULATIONS

Land Use	Curb Length per ha (m/ha)	Street Cleaning Internal (days)	Daily Dust and Dirt Accumulation (kg/100 m curb)
Residential-Single	249	30	1.04
Residential-Multiple	286	30	3.42
Commercial	226	7	4.91
Industrial	226	90	6.85
Open	75	90	2.23

TABLE 3. COMPOSITION OF DUST AND DIRT (In kg/100 kg)

Land Use	Suspended Solids(SS)	BOD[2]	N[3]	P[4]
Residential-Single	12.1 - 35.0[1]	1.20	.048	.072
Residential-Multiple	8.8 - 23.3[1]	0.86	.061	.072
Commercial	18.7 - 53.7[1]	1.85	.041	.072
Industrial	7.4 - 21.2[1]	0.72	.043	.043
Open	12.2 - 35.1[1]	1.20	.048	.072

[1] Two sets of values used in calibration runs.

[2] Biochemical Oxygen Deman

[3] Nitrogen

[4] Phosphorus (as PO_4)

2.4 Model Calibration

Only the quality submodel of the STORM model was calibrated. Initial runs with default values of quality parameters produced mean SS, BOD, N, and P concentrations which were about two to three times lower than those reported in Ontario (6). Consequently, the STORM model was calibrated by adjusting the composition of dust and dirt to the values given in Table 3. After such calibration, the simulated mean annual loads became comparable to those calculated earlier from annual unit pollutant loads (3). This agreement was expected because the unit loads were derived from the same source of data (6) which was also used in this study for calibration.

Runoff quantity submodel has not been calibrated because of the lack of calibration data.

3.0 SIMULATION RESULTS

3.1 Runoff Quantity

Analysis of the 11-year simuałted runoff record yielded the statistics given in Table 4.

TABLE 4. RUNOFF QUANTITY RESULTS

Mean Annual Precipitation	1222 mm
Mean Annual Surface Runoff (mm)	217 mm
Mean Annual Surface Runoff (m^3/s)	0.19 m^3/s
Mean Number of Storms per Year	99/year
Watershed Runoff Coefficient	0.213
Mean Annual Maximum Runoff Event	12.7 mm

Discussion of Results

As it can be inferred from Table 4, almost 18% of the annual precipitation is converted into surface runoff. The corresponding mean annual surface runoff flow is 0.19 m^3/s (6.7 cfc). It should be emphasized that the simulation data discussed here were derived only for the urbanized part of the Beauport River basin.

The annual precipitation is on the average distributed in 99 events. The mean annual maximum runoff event contributes about 12.7 mm runoff which represents almost 6% of the annual runoff. By definition, the mean return period of this event is 2.33 years. It can be concluded that the distribution of the annual runoff into individual events is highly nonuniform.

The distribution of heavy storms in the 11-year record was further studied. For this purpose, 48 events with total runoff equal to or larger than 7.5 mm were studied. A frequency analysis was performed on this set of data and the results of this analysis appear in Figure 1*. The total event runoff varied from about 9 mm (the return period equal to 1 year) to about 18 mm (the return period of 10 years). The mean duration of these events was 20 hours.

It was also of interest to study the distribution of heavy storms during the year. Using the same set of data as above, the occurrences of these storms during various months were studied. The results of this analysis are given in Figure 2. The highest frequencies of occurrence were found from March to May and from August to October. Substantially lower frequencies were found in June, July, November and December. Finally, no occurrences were found for January and February.

3.2 Runoff Quality

The average annual statistics of simulated runoff quality data are given in Table 5.

* Figures are appended at the end of the report.

TABLE 5. RUNOFF QUALITY RESULTS

Characteristics	Constituent					
	Suspended Solids	Settleable Solids	BOD	N	P	Coliform
Total Annual Pollutant Load [tonnes]	1,001	87	73	19.6	4.0	4.75×10^{15}*
Mean Concentration [mg/L]	166.1	14.5	12.2	3.26	.67	$.8 \times 10^{5}$**
Mean Annual Event Load [tonnes]	97.5	8.7	7.3	1.90	.413	4.75×10^{14}*

*MPN

**MPN/100 ml

As mentioned earlier, the total loads in Table 5 agree fairly well with those derived earlier from annual unit loads. The loads of suspended solids appear to be particularly high. As discussed in the earlier report (3), suspended solids act as carriers for other pollutants, such as heavy metals and persistent toxic substances. The loads of such pollutants cannot be simulated by the STORM model. For some of these pollutants, the estimates of their annual loads were given in the earlier report (3).

It is of interest to examine the distribution of annual pollutant loads during the year. For this pupose, the events with annual maximum pollutant fluxes were identified and subject to frequency analysis. The results of such analysis for four basic constituents (SS, BOD, N and P) appear in Figure 3.

The mean annual event loads were determined from the frequency graph and presented in Table 5. The return period of such events was chosen as 2.33 years, which is consistent with the period used in the runoff quantity analysis. It is of interest to note that, although there are almost 100 events occuring each year, the average annual maximum event load represents about 10% of the total annual load. It was noticed that the events with annual maximum loads typically occur in the spring when there are large accumulations of dust and dirt on the catchment surface. For these events, the mean runoff duration was 20 hours and the mean runoff volume was 190,000 m^3 (6.86 mm).

Maximum hourly concentrations of pollutants in simulated urban runoff were also examined. For this purpose, 20 top-ranked events with large loads of suspended solids were examined in more detail. For these events, hourly pollutographs were obtained and the means of maximum hourly values calculated. The results of this analysis are given in Table 6.

TABLE 6. MEAN MAXIMUM HOURLY CONCENTRATIONS
(Based on 20 Events)

	Constituent					
	Suspended Solids	Settleable Solids	BOD	N	P	Coliform
Mean Maximum Hourly Concentration [mg/L)	612	39	76	12	4.4	$.8 \times 10^6$*

*MPN/100 ml

The concentrations reported in Table 6 appear to be realistic. No field data were available for further verifications.

4.0 SUMMARY AND CONCLUSIONS

Continuous simulation of runoff and snowmelt from the urbanized part of the Beauport River basin has been carried out using the STORM model and 11 years of precipitation and temperature data. No calibration data were available for the watershed studied. A limited calibration of runoff quality has been done by calibration data transposed from several Ontario test catchments.

Runoff quantity simulations indicate that the mean annual precipitation of 1,222 mm is distributed in 99 events, on the average. The mean annual runoff is 217 mm, or about 18% of the precipitation. The mean annual maximum event runoff is about 12.7 mm, or about 6% of the mean annual runoff. Intense storms with heavy runoff typically occur from March to May and from August to October.

Runoff quality simulations produced annual pollutant loads which were comparable to those derived earlier from annual pollutant unit loads. The annual pollutant loads were reported as follows: suspended solids - 1000 tonnes/year, BOD - 73 tonnes/year, N - 20 tonnes/year, and P - 4 tonnes/year. These loads were nonuniformly distributed in individual events. The mean annual maximum event load amounted to about 10% of the mean annual load. The events with annual maximum loads typically occurred in early spring. The mean duration of these events was 20 hours and the corresponding mean runoff volume was 190,000 m^3 (6.86 mm). These runoff characteristics may be used to construct a critical event which would be used in a physical model of the St. Lawrence River for further investigations of the impact of urban runoff on the receiving waters and the mudflats.

If required, additional information on various runoff characteristics can be obtained by further analysis of the simulated runoff record which was produced and retained by the Hydraulics Division.

Finally, it is believed that the modelling approach described in this report represents the highest level of sophistication which is justified for the limited catchment data available. Further improvements in the simulation results would be possible only through detailed surveys of the studied area and the collection of local calibration data.

5.0 REFERENCES

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6. Singer, S. N., 1977. "Preliminary Estimates of Urban Storm Water Unit Loadings for the Canadian Great Lakes Basin". Technical Memorandum, Water Resources Branch, Ministry of the Environment, Toronto.
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FIGURES

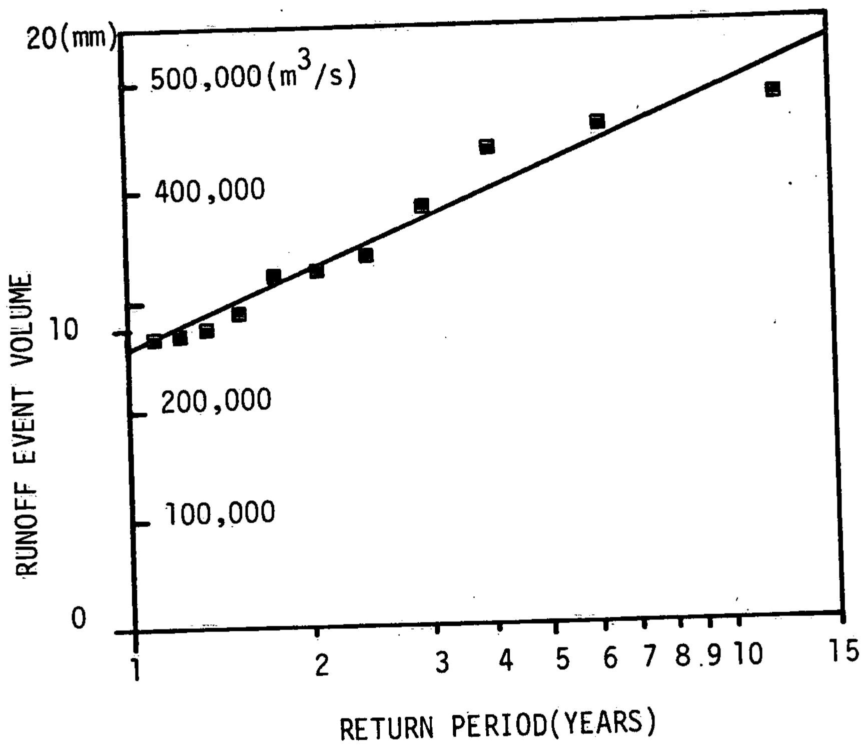

Fig.1. FREQUENCY CURVE OF SIMULATED RUNOFF EVENT VOLUMES

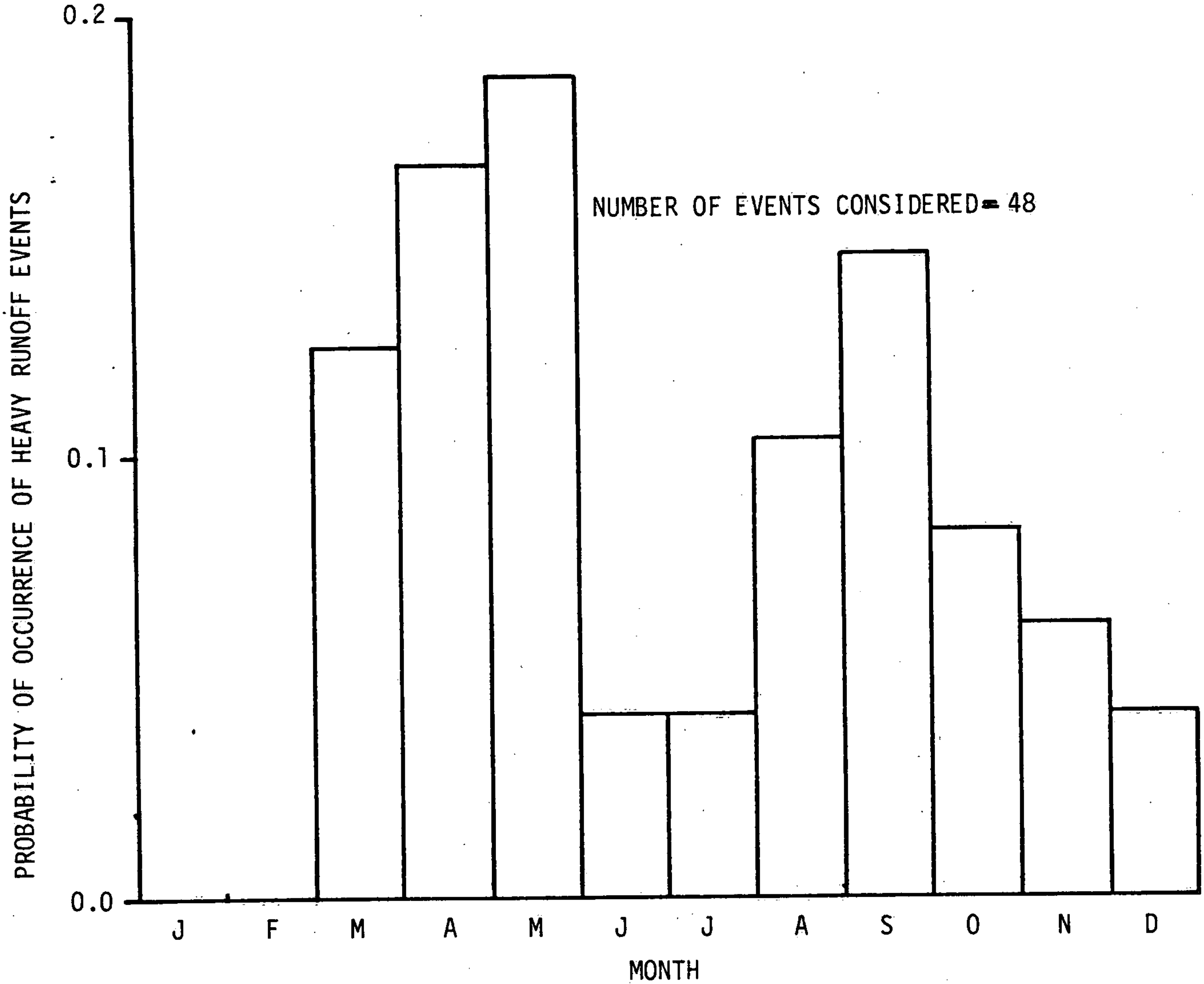

Fig.2. OCCURRENCE OF HEAVY RUNOFF EVENTS DURING THE YEAR

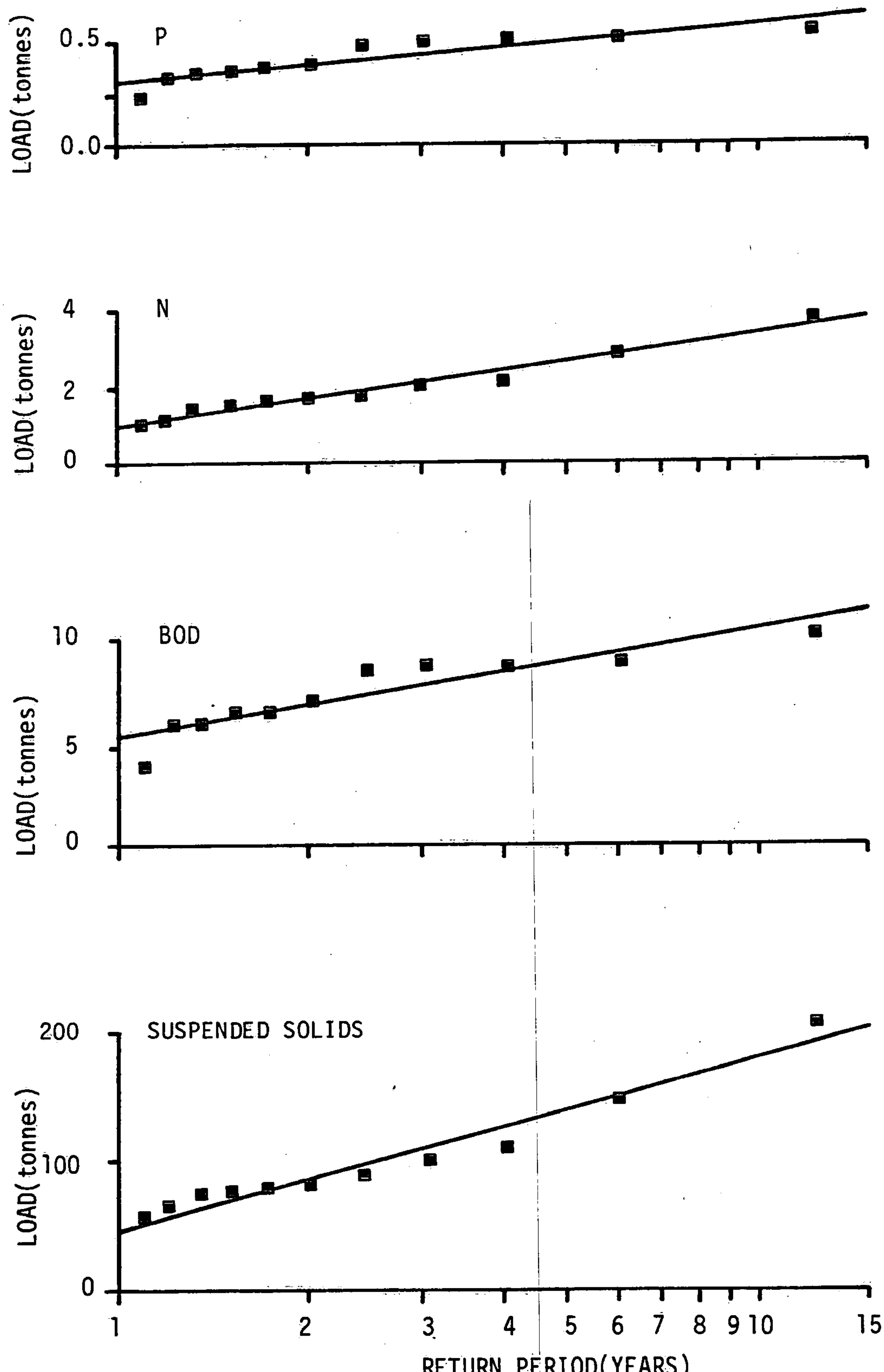

Fig.3. FREQUENCY CURVES OF SIMULATED RUNOFF EVENT LOADS FOR FOUR SELECTED POLLUTANTS