NWRI CONTRIBUTION 85-11

Ng (21)

Study 83-334

# DIRECT CONTRIBUTION OF RAIN WATER TO LOADING OF URBAN STORM RUNOFF

by

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May 1985

## ABSTRACT

Rainwater and runoff samples were systematically collected and analyzed for 30 storm events in a light industrial urban catchment. Analysis of the water samples showed that rainwater supplied practically all the dissolved nitrogen compounds in the observed runoff. Rainwater also supplied significant amounts of nickel and copper and a portion of zinc, total phosphorus and total carbon. Rainwater is not an important source of major ions. The antecedent conditions of the preceding period had little linear relationship with rainwater and runoff quality.



## RÉSUMÉ

Des échantillons d'eau de pluie et de ruissellement ont été recueillis dans un bassin hydrographique d'une zone urbaine d'industrie légère pour 30 événements de tempête et ont été analysés systématiquement. L'analyse des échantillons d'eau a démontré que l'eau de pluie renfermait également une importante quantité de nickel et de cuivre ainsi que du zinc, du phosphore total et du zinc total. L'eau de pluie n'est pas une importante source d'ions majeurs. Les conditions qui avaient prévalu au cours de la période précédente avaient une bien faible relation linéaire avec la qualité de l'eau de pluie et de ruissellement.

## MANAGEMENT PERSPECTIVE

It is known that urban runoff can contain significant amounts of pollution loads. This report shows that a significant portion of certain pollutants is derived from the rainwater and not from the land. This information is useful for water quality modelling of urban runoff.

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## PERSPECTIVE - GESTION

L'on sait que les eaux de ruissellement urbain peuvent renfermer d'importantes charges polluantes. Ce rapport démontre qu'une bonne part de certains polluants provient de l'eau de pluie, et non pas de la terre. Ce renseignement est utile dans la modélisation de la qualité de l'eau du ruissellement urbain.

Le chef,

T. Milne Dick
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## TABLE OF CONTENTS

## 1.0 INTRODUCTION

This report is part of the Hydraulics Division study "Effect of Urban Land Use on Runoff Quantity and Quality". One of the goals of this study is to evaluate the contribution of rainwater to storm runoff quality. An earlier report by Ng (1982) presented some results of variations of rainwater chemistry and a subsequent report by Ng and Marsalek (1983) dealt with the effects of rainwater composition on urban runoff quality. Both reports found that rainwater contributed substantial portions of the pollutant loading in urban storm runoff, particularly the constituent of nitrogen compounds.

Although the studies dealing with pollutants and contamination sources are numerous, the contribution of pollutants from rainwater to urban storm runoff was studied in only a few cases. Black (1980) observed high concentration of ammonia nitrogen in surface runoff pollutants from a parking lot. He concluded that the source of ammonia nitrogen was apparently from rainfall. Wilber et al. (1975) found that lead and zinc loading in rainwater accounted for 89% of the total in a multiple land uses urban catchment of Lodi, New Jersey. They hypothesized that the lead and zinc originated from precipitation. Recently, Halverson, et al. (1984) studied the contaminant load in precipitation and urban runoff in a non-industrial urban area, and determined the direct contribution of material in the wet deposition. They found high ranking of nitrogen compounds in urban runoff which was input from precipitation.

It appears from various studies that rainwater contributes significant quantities of certain pollutants to the runoff loadings. Following such findings, it was interesting to evaluate the rainwater contribution to the runoff pollutant loadings in a systematical approach.

The report which follows deals primarily with the contribution of rainwater to the pollutants loading of urban storm runoff from field data collected during the 1982 and 1983 field seasons. An extensive field data set containing 19 dissolved chemical constituents were thoroughly evaluated in this study.

## 2.0 STUDY AREA

The study site is shown in Figure 1, which is referred to as the Blair Road Catchment. A brief description on the catchment follows. The land use in the area is classified as light industrial with a total contributing area of 10.3 ha. The catchment imperviousness is determined as 69%. The catchment is served by storm sewer. The sewer pipes are made of concrete and vary in diameter from .61 m to .69 m at the outfall. The sewer systems are a simple layout with one main pipe and one lateral. The catchment is well established. During the study period, there was no construction activity.

The types of industries located in the study area are: food processing, sheet metal, steel fabrication, engine oil refinery, woodworking, wholesale offices and warehouses. The catchment is fairly well maintained and clean.

## 3.0 METHODS AND OBSERVATIONS

### 3.1 Water Samples Collection

The Blair Road Catchment has been instrumented for collections of rainfall, runoff data including sampling street surface deposits and road runoff.

The data collection systems consisted of a rainfall monitoring station and a runoff monitoring station.

#### 3.1.1 Rainfall monitoring station

The rainfall monitoring station served to collect both rain-water samples and rainfall depths. For rainwater samples collection, a specially designed rainwater sampler was used (Ng, Boucher and Dolanjski, 1981). The rainwater sampler collected sequential rainwater samples, dry deposits and recorded the rainfall depths.

A brief description of the features of the sampler follows.

The sampler is equipped with a lid covering the rainwater collector (500 mm x 500 mm) funnel during dry periods. At the start of a rain event, the moisture sensing grids activated a control motor to drive the lid from the collector funnel and place it over the dry collector. Thus the rainwater samples collected in this manner are wet deposits from precipitation events. When the rain stops, the lid will move back to cover the rainwater collector by means of the electrically heated sensing grids sensor. The dry collector now opens to collect dry deposits.

A total of 23 sequential rainwater samples of 500 ml each can be collected during a rain event. The sequential rainwater samples are collected according to a preselected time interval.

### 3.1.2 Runoff Monitoring Station

The runoff monitoring station consisted of an automatic sampler and a flow meter. The sampler is a Sigmamotor Model 6201 Automatic Wastewater Sampler. The sampler collected up to 24 sequential samples of 500 ml each at a selected constant time interval. The constant time interval can be selected from 0 to 99 minutes. However, the time interval used in this study was in the range from 5 to 15 minutes. A calibrated weir was used in conjunction with a stilling well and a float-type water level recorder for flow measurements.

## 3.2 Rainwater and Runoff Samples Handling and Laboratory Analysis

A procedure was established to handle both rainwater and runoff samples after a storm event.

At the end of each precipitation event, rainwater and runoff samples were removed from the sampling devices. For rainwater sampling station, bottles with rainwater collected were removed and replaced with cleaned bottles for the next storm event. It should be noted in here that during a precipitation event certain sampling bottles may collect a full jar of rainwater and some bottles can be without sample in the sequence, because the uncertainties of precipitation nature and sampling technique. Details have been discussed by Ng (1982). For runoff sampling sation, all 24 samples were removed from the sampler and replaced with a cleaned set of bottles for the next runoff event. Again, it should be noted that runoff samples can always collect a full jar of sample up to 24 bottles during a runoff event, because the sampler is activated by a selected height of water level in a stilling well. As long as the level in the stilling well holds, the automatic sampler will continue to sample at selected constant time until the number of samples in the sequence are exhausted.

The samples were transported to the laboratory as soon as possible, usually within 12 hours after the event except when the storm period ended on a weekend or on a statutary holiday.

In the laboratory, the samples were transferred from field containers into laboratory bottles, splitted and preserved according to the amount of water required for analysis of a constituent. The procedures recommended by the Water Quality Branch, IWD, Ontario Region (1978) were used. The analytical methods for individual constituent are given in another reference by Water Quality Branch, IWD, Ottawa (1979 and 1981 update).

## 4.0 SELECTION OF CHEMICAL CONSTITUENTS AND ITS CONCENTRATION DETECTION LIMIT

Three groups of chemical constituents were selected for this study. These constituents are most commonly related to urban storm runoff and the atmospheric fallout pollution. A list of these substances and the detection limits for analyses are presented in Table 1.

## 5.0 DATA TREATMENT

### 5.1 Rainwater Sequential Data

As noted before, sequential rainwater samples collected during a precipitation event at constant time intervals were often insufficient (if less than 500 ml) for laboratory analysis of all the selected chemical constituents because of the nature of precipitation and sampling technique. The sampling technique used in this study was to collect sequential rainwater sample based on a fixed time interval during a rain event. Thus the volume of rainwater collected in this manner could be a full sample bottle or none, or in between. It depended on the rainfall intensity. The collecton of a full sample (500 ml) corresponded to the rainfall depth of 2 mm (Ng et al., 1981). If a sample collected is not sufficient for chemical analysis, several samples in the sequential order are composited to bring the amount of the sample to 500 ml. Similarly, if individual sample or a composited sample happen to be insufficient to meet the chemical analysis requirement, doubled distilled water is added to bring the sample to the required amount. Consequently, the analytical results of a constituent is corrected by a dilution factor. This dilution factor varied by the amount of distilled water being added. The dilution factor is calculated by the following expression:

$$DF = \frac{V_s}{(V_s - V_d)} \qquad (1)$$

where DF is the dilution factor
$V_s$ is the total volume of the sample
$V_d$ is the distilled water volume being added to the sample.

The dilution factor for correction of analytical results of rainwater samples are presented in Table 2. If DF = 1.000, indicated that no dilution was made for that sample.

## 5.2 Runoff Sequential Data

Sequential runoff samples collected during the runoff event were very often sufficient to meet the amount required for analysis of the selected constituent. The reason for this had been described in section 3.1.2. Thus correction on the analytical results is not needed.

## 5.3 Volume-Weighted Mean Concentration of Constituent

For the purpose of computing the loading of each of the selected constituents for a storm event, the mean concentration of each constituent is calculated from analytical results of sequential samples. The calculation is based on volume-weighted procedure which are applied to both rainwater and runoff constituents. The calculation is expressed as

$$\bar{c} = \frac{\sum C_i \; V_i}{\sum V_i} \qquad (2)$$

where $\bar{c}$ is the mean concentration of a constituent
$C_i$ is the concentration of a constituent at time t,
$V_i$ is the volume between time intervals during the event,
$\sum V_i$ is the sum of volume.

and $i$ is a subscript referred to sequential sample number.

## 5.4 Loading Rates

### 5.4.1 Rainwater

After the mean concentration of each constituent has been computed, the loading rates can be computed for rainwater. The unit area loading calculation is shown below:

$$L_p = A \times P \times \bar{C}_p \qquad (3)$$

where $L_p$ is the rainwater loading rate in mg/m$^2$ of a constituent

A is the conversion factor of Blair Road catchment area ($10^6 \ell$/mm/10.3 x $10^4 m^2$)

P is the "effective rainfall depth" in mm, and

$\bar{C}_p$ is the volume-weighted mean concentration in mg/l.

Note that "effective rainfall" defined in here is that portion of rainfall depth which produced the equivalent depth of measured runoff. Further detail will be given in the Discussion section regarding "effective rainfall". The measured rainfall and the measured runoff relationship is plotted in Figure 2. As seen from Figure 2, a 1 mm of rainfall yields an average of 0.55 mm of measured runoff in Blair Road Catchment. This average value is not used in the loading rate calculation since the interest for loading rate calculation is in individual event. Instead, the "effective rainfall depth" is used to calculate the loading rate. That is, P is numerically equal to the runoff depth R.

### 5.4.2 Runoff

The loading rate for runoff was calculated in the same manner as the rainwater. The unit area loading rate calculation is shown below:

$$L_R = A \times R \times \bar{C}_R \qquad (4)$$

where $L_R$ is the runoff loading rate in mg/m$^2$

A is given as above,

R is the runoff depth in mm, and

$\bar{C}_R$ is the volume-weighted mean concentration in mg/l.

It should be noted that during dry period, there is very little or no flow at the measuring gauge of the sewer. Therefore, the runoff volume measured during rain period is not subject to the base flow effect.

## 6.0 SUMMARY OF RESULTS

### 6.1 Selection of Events

Rainwater and runoff samples along with rainfall and runoff records were collected for 49 storm events in a light industrial urban catchment between June 1982 and December 1983. Among the 49 events some had incomplete data.

In this study, events with at least one complete set of either nutrients, or major ions, or total metals data were selected. The selected events along with rainfall and runoff depths, antecedent dry periods, and ratio of runoff to rainfall depths are listed in Table 3. Such selected events will enable a systematic computations on event loadings for both rainwater and runoff. So, after chemical analysis for each event, the volume-weighted mean concentration of each constituent for both rainwater and runoff was computed according to equations (1) and (2). Subsequently, the loading rate of each constituent of the sampled events were computed by equations (3) and (4) for rainwater and runoff respectively. In conjunction with the computation, it was noted that the concentration of some constituents was frequently below the detection limit. A summary of the occurrence of concentration above detection levels is presented in Table 4. In this case, if concentration of a constituent is found below detection level, it is assumed to equal to detection level. Thus the loading rate of an event can be computed. Results of loading rates computation are presented in Tables 5a, 5b and 5c. Accordingly, using the loading rates shown in Tables 5a, 5b and 5c, the ratio of rainwater load to runoff load is calculated. The results are presented in Tables 6a, 6b and 6c. Included in Tables 6a, 6b, and 6c, under Column A is the ratio of precipitation (by total depth of rain) loading to runoff loading.

## 6.2 Statistics of Constituent Concentration

Because of the tremendous variability in concentration, direct comparison of the same constituent between events may not be feasible. Subsequently, some basic statistics about the constituent concentration for all the events studied are determined, and are presented in Table 7. The basic statistics shown in Table 7 are minimum, maximum, and mean concentration along with the standard deviation from the mean for rainwater and runoff constituents.

## 6.3 Average Contaminant Loads of Rainwater and Runoff

By using Tables 5a, 5b and 5c and Tables 6a, 6b, and 6c, the average values and ratio of loading can be calculated. The results are presented in Table 8.

# 7.0 DISCUSSION

Effective Rainfall:

A very common method for calculating the loading of a constituent in a precipitation event is based on the product of precipitation volume and its concentration. If this precipitation load (calculated by total volume of rain of an event) is compared with the runoff load (calculated by measured runoff volume) of the same event, it could overestimate the contribution from the precipitation load. The runoff volume measured in a sewered urban catchment resulting from a rainfall event is only a portion of the rainfall volume. The other portion of the rainfall volume is lost in the forms as infiltration, surface detention, evaporation, wetting the ground surface, and a portion may be bypassed out of the sewer system. Therefore it seemed appropriate for the purpose of this study to use the effective rainfall volume to calculate the rainwater loading of a constituent for each rainfall event.

Rainwater Loads:

Results of rainwater loading for each constituent of each event are shown in Tables 5a, 5b and 5c. The level of contamination varies widely within the event and interevents. The average contaminant loads among all the events studied range from highest of sulphate to the lowest of Cadmium with the loading rates of 23.549 $mg/m^2$ to 0.025 $mg/m^2$ as shown in Table 8. Most of the loads vary over one and usually two, orders of magnitude. The level of variation of the nutrient group was in the order of same magnitude. The exception is phosphorus which was found in small amounts in the rainwater and the same result was reported by Halverson, et al. (1984). The nitrogen compounds appear to be quite consistent for 1982 and 1983 events and are relatively high. Similar result was reported by Randall et al. (1978).

Of the major ions loading, sulphate was found to be the highest in both years, and both sodium and potassium were found to be the lowest for both years of 1982 and 1983. A fact attributed to low loading rate in rainwater was believed that most storms were origined from inland regions or localized which carried rain with only minor concentrations of sodium as compared with that found in sea coast regions (Kennedy, et al. 1979). The major ions group in rainwater was extensively studied by Kennedy et al. (1979). However, very little information on rainwater loading rates has been found in literature.

Hence, it precludes comparison of the results of this study with other workers.

Among the trace metals studied, the loading of zinc, copper, nickel and lead were found to be predominently from rainwater. Cadmium, chromium and barium were usually found in considerably smaller quantities. This fact is also reflected by the percentage of samples with concentrations above the limit as presented in Table 4. The loading of zinc was found to be the highest of the trace metals group. The findings of the high zinc content in rainwater supports the observations by Wilber et al. (1975).

Regression analysis was carried out to determine the significant of linear relationship between precipitation quality and storm size and the length of the antecedent dry period for all the constituents. The results showed that no significant linear relationship between antecedent dry period or the storm size. The highest coefficient of determination between the antecedent dry period was .346 for total carbon and the lowest was -.378 for chromium. In fact, the coefficients of correlation for all the trace metals were negative. Similarly, there was no significant linear relationship between storm size and rainwater chemistry. It is apparent that the rainwater chemistry in an individual storm is not affected by either the antecedent dry period or the storm size. The poor relationship between rainwater chemistry and both of the antecedent dry period and storm size may suggest that rainwater chemistry in individual storm is the result of a rainout but not a washout processes in the air mass. These rainout and washout processes are beyond the scope of this study.

Runoff Loads:

Runoff loads also showed a wide variation of each contaminant in runoff water. The loads of sulphate and calcium were significantly higher than the other constituents. The nitrogen compounds were pronounced which were in the same order of magnitude as in rainwater.

Among all the constituents, the major ions group showed significantly higher loading rates, with the exception of potassium which is an order of magnitude less in the group. Sulphate and calcium loads were significantly dominant. Such finding supports the investigation in a non-industrial urban area reported by Halverson, et al. (1984).

The loading rate of zinc was significant among the trace metals. The loading rates of cadmium and chromium were only a small quantity, which were almost equal the same loading rates of precipitation.

The length of the antecedent dry period, was correlated with the runoff quality for all the constituents investigated. Regression analysis showed that there was no significant linear relationship between runoff quality and antecedent dry period. The highest and the lowest correlation coefficients were .622 and -.358 for ammonia and cadmium respectively. Model simulation of the urban storm runoff chemistry using accumulations and washoff equations (The Urban Drainage Committee, 1980. Alley and Smith, 1981, and Huber, et al., 1982) assumes that all pollutants are eroded from surface after a storm, and that the contribution of pollutants to runoff of the same event from rainwater is neglected. This assumption could not be confirmed here since the antecedent conditions tested had little linear relationship with runoff pollutants.

Ratio of Rainwater Load to Runoff Load:

The direct contribution of rainwater to pollutants of urban runoff may be viewed as the ratio between rainwater loads divided by runoff loads, since there are no standard appraoch and no rigorous method available to lead to a direct result. The ratio computed for each constituent of each event for both rainwater and runoff is shown in Tables 6a, 6b and 6c. The average ratio for each constituent and in different years of data is shown in Table 8, and plotted on bar charts as shown in Figures 3 and 4. Figures 3 and 4 give a better view for comparison between the constituent group both in magnitudes and in different years. Note that the average ratio is not identical to a ratio as calculated for average loads as shown in Table 8. The overall average of the ratio between rainwater loads and runoff loads shown a wide ranges of ratio from the lowest of .060 (calcium and the highest of 2.552 (ammonia). It is worthy to mention that the total wet and dry deposits from atmospheric input are important in runoff loading according to Miller and Mattraw, 1982, and the precipitation input alone is an important factor as well. But precipitation loads are not equally important for all constituents to urban runoff. From the results of this study, the nitrogen compounds in the runoff seemed to be entirely derived from rainwater but the major ions appeared to be contributed from surface sources, as indicated by the ratios shown in Table 8. Most of the nitrogen loading ratios are greater than 1. All the major ions loading ratio are less than 1. The major ions group with the highest ratio found is only .221 for sulphate and the lowest ratio found is calcium being .060.

In the trace metal group, copper and nickel had ratios greater than 1. It appears that these two substances in runoff were input from rainwater.

It is noted that the occurrence of detection level of copper and nickel in rainwater (Table 4) are higher than the occurrences of detection level in runoff. The ratios of the rest of the trace metal group are within 0.5 to .75. There are difficulties encountered in justifying the contributions of cadmium, chromium, lead and barium in rainwater because of the uncertainties of their occurrences in the detection limit, as shown in Table 4. Their highest occurrence above detection levels were slightly higher than 50% (rainwater). These substances were believed present in both rainwater and runoff although they were frequently below the detection limits. In addition, trace metals are non-degradable which may precipitate out of solutions under favourable pH conditons, be absorbed by clay particles or bound by the hydrous oxides by other metals such as iron, aluminum and manganese. The magnitude of percentage of occurrence above detection level of a substance in rainwater is not necessary to produce the same magnitude of the ratio of rainwater load to runoff load as shown in Table 4 and in Table 8. In the case of zinc, it had 100% occurrence of concentration above detection limit in both rain and runoff waters. But the ratios of the rainwater loading to runoff loading was accounted only about 61%.

Figure 3 reveals two interesting aspects. The first is that runoff loading rates of the major ions group were predominately higher than the rainwater loading rates. The second aspect is that both loading rates of rainwater and runoff contaminants had no substantial difference in both years. The only exception was that loading rate of sulphate had about 33% higher in 1983 as compared to 1982.

On Figure 4 the ratio of rainwater loading rate to the runoff loading rate showed nitrogen compounds (nitrate + nitrite, ammonia, and kjedahl), copper and nickel had the ratio greater than 1 in both years of 1982 and 1983. An exception was nitrate + nitrite which was slightly less than 1 (.947) in 1983.

Finally, the levels of direct contribution of rainwater to quality of runoff could be ranked according to the ratios of loading rates between rainwater and runoff presented in Table 8. The ranking is as follows:

| | | |
|---|---|---|
| Nitrogen compounds, copper and nickel | - | very significant |
| Lead and zinc | - | less significant |
| Total phosphorus | - | less significant |
| Total carbon | - | less significant |
| Major ions | - | least significant |
| Cadmium, chromium and barium | - | uncertain |

## 8.0 CONCLUSION

Investigation of constituents in individual rainfall - runoff events showed that rainwater contributed most of the nitrogen compounds observed in runoff. Rainwater also contributed signifcant amount of copper and nickel to runoff, and fair amount of zinc, lead, and certain amount of cadmium, chromium and barium. Rainwater contributed very little amount of major ions to runoff.

The length of antecedent dry periods and storm size showed little or no linear correlation with runoff quality as well as rainwater quality.

Models of urban runoff pollutants should consider the rainwater composition, and in particular, the atmospheric contributions of nitrogen compounds should be included.

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**TABLE 1. Constituents Studied and Detection Limits**

| Constituent | Detection Limit (mg/l) |
|---|---|
| Nitrate + Nitrite N | .005 |
| Ammonia N | .001 |
| Total Kjeldahl N | .010 |
| Dissolved Carbon | .200 |
| Total Phosphorus P | .001 |
| Calcium | .200 |
| Magnesium | .100 |
| Sodium | .100 |
| Potassium | .100 |
| Sulphate | 1.000 |
| Chloride | .100 |
| Barium | .100 |
| Cadmium | .010 |
| Chromium | .010 |
| Copper | .010 |
| Lead | .010 |
| Nickel | .010 |
| Zinc | .010 |

TABLE 2. The Dilution Factor for Correction of Analytical Results of Rain Samples

| Event No. | Storm Dates 1982 | Sequential Order of Sample 1 | 2 | 3 | 4 | 5 | 6 | 7 | Average |
|---|---|---|---|---|---|---|---|---|---|
| 8 | June 1 | 1.000 | 1.000 | 1.000 | 1.000 | | | | 1.000 |
| 14 | June 21 | 1.220 | 1.111 | 1.389 | | | | | 1.240 |
| 15 | June 23 | 1.000 | 1.000 | 1.000 | 1.515 | | | | 1.129 |
| 17 | June 29 | 1.000 | 1.389 | | | | | | 1.195 |
| 18 | June 30 | 1.000 | 1.000 | 1.000 | 1.000 | | | | 1.000 |
| 20 | July 17 | 1.000 | 1.000 | 1.000 | 1.000 | 1.220 | | | 1.044 |
| 21 | July 28 | 1.000 | 1.000 | 1.000 | 1.000 | | | | 1.000 |
| 23 | Aug. 2 | 1.000 | 1.000 | 1.000 | 1.000 | 1.316 | | | 1.063 |
| 25 | Aug. 8 | 1.000 | 1.000 | 1.000 | 1.000 | 1.282 | 1.000 | | 1.007 |
| 29 | Aug. 25 | 1.000 | 1.000 | 1.429 | 1.515 | 1.000 | 1.000 | 1.351 | 1.185 |
| 34 | Sept 18 | 1.429 | 1.136 | 1.351 | 1.000 | 1.471 | | | 1.189 |
| 41 | Sept 28 | 1.087 | 1.087 | 1.000 | 1.000 | 1.471 | | | 1.129 |
| 42 | Oct. 7 | 2.083 | 1.000 | 1.000 | 1.000 | | | | 1.271 |
| 43 | Oct. 7 | 1.000 | 1.111 | 1.000 | 1.000 | | | | 1.028 |
| 48 | Nov. 1-2 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | | | 1.000 |
| 49 | Nov. 2 | 1.087 | 1.000 | 1.351 | 1.000 | 1.000 | 1.000 | 1.000 | 1.050 |
| | 1983 | | | | | | | | |
| 9 | Apr. 15 | 1.075 | 1.087 | 1.000 | 1.000 | | | | 1.041 |
| 11 | Apr. 29 | 1.000 | 1.000 | 1.000 | 1.000 | | | | 1.000 |
| 17 | May 14 | 1.515 | 1.111 | 1.000 | 1.000 | | | | 1.157 |
| 18 | May 19 | 1.000 | 1.064 | 1.000 | | | | | 1.021 |
| 21 | May 30 | 1.000 | 1.429 | 1.000 | | | | | 1.143 |
| 25 | June 27 | 1.200 | 1.000 | 1.000 | 1.000 | | | | 1.050 |
| 27 | July 4 | 1.000 | 1.000 | 1.000 | 1.000 | | | | 1.000 |
| 34 | Aug. 11* | 1.000 | 1.000 | 1.000 | 1.220 | 1.000 | 1.000 | | 1.037 |
| 35 | Aug. 11* | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.400 | | 1.067 |
| 36 | Aug. 22 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | | 1.100 |
| 39 | Aug. 31 | 1.000 | 1.000 | 1.000 | | | | | 1.000 |
| 49 | Oct. 12 | 1.000 | 1.220 | 1.000 | 1.000 | 1.000 | 1.000 | | 1.104 |
| 51 | Oct. 24 | 1.000 | 1.000 | 1.312 | | | | | 1.000 |
| 58 | Nov. 24 | 1.000 | 1.000 | 1.000 | 1.000 | | | | 1.000 |
| 59 | Nov. 28 | 1.000 | 1.000 | 1.000 | | | | | |

* Same event with two sampling periods.

TABLE 3. Storm Dates, Rainfall and Runoff Depths and Antecedent Dry Period of Selected Storm Events

| Event I.D. | Storm Date | Rainfall Depth (mm) | Runoff Depth (mm) | Antecedent Dry Period (days) | Ratio of Runoff/Rainfall Depth |
|---|---|---|---|---|---|
| | 1982 | | | | |
| 8 | June 1 | 7.90 | 1.89 | 1 | .239 |
| 14 | June 21 | 6.10 | 1.44 | 6 | .236 |
| 15 | June 23 | 7.90 | 1.71 | 1 | .217 |
| 17 | June 29 | 7.90 | 1.86 | 1 | .235 |
| 18 | June 30 | 3.3 | 0.73 | 1 | .221 |
| 20 | July 17 | 18.00 | 3.65 | 12 | .203 |
| 21 | July 28 | 6.60 | 1.32 | 11 | .200 |
| 23 | Aug. 2 | 16.00 | 3.47 | 5 | .217 |
| 25 | Aug. 8 | 13.20 | 3.63 | 4 | .275 |
| 29 | Aug. 25 | 77.50 | 15.65 | 1 | .202 |
| 34 | Sept 18 | 12.20 | 2.79 | 2 | .229 |
| 41 | Sept 28 | 31.20 | 6.74 | 3 | .216 |
| 42 | Oct. 7 | 3.30 | 0.89 | 10 | .270 |
| 43 | Oct. 7 | 12.40 | 2.91 | 10 | .235 |
| 48 | Nov. 1-2 | 23.60 | 5.20 | 12 | .220 |
| 49 | Nov. 2 | 10.90 | 2.37 | 1 | .217 |
| | 1983 | | | | |
| 9 | Apr. 15 | 9.90 | 2.82 | 3 | .285 |
| 11 | Apr. 29 | 4.10 | 1.20 | 2 | .293 |
| 17 | May 14 | 4.60 | 0.97 | 7 | .211 |
| 18 | May 19 | 23.90 | 5.75 | 4 | .241 |
| 21 | May 30 | 14.70 | 3.36 | 4 | .229 |
| 25 | June 27 | 32.80 | 6.76 | 21 | .206 |
| 27 | July 4 | 18.00 | 3.64 | 1 | .202 |
| 34 | Aug. 11* | 42.90 | 8.97 | 2 | .209 |
| 35 | Aug. 11* | 42.90 | 8.97 | 2 | .209 |
| 36 | Aug. 22 | 10.20 | 2.09 | 11 | .205 |
| 39 | Aug. 31 | 18.00 | 4.85 | 1 | .269 |
| 49 | Oct. 12 | 17.30 | 4.71 | 1 | .272 |
| 51 | Oct. 24 | 21.60 | 4.71 | 10 | .218 |
| 58 | Nov. 24 | 5.60 | 1.14 | 3 | .204 |
| 59 | Nov. 28 | 18.30 | 3.96 | 14 | .216 |

* Same event with two sampling periods.

TABLE 4. Occurrence of Constituent Concentration Above Detection Limit in Rainwater and Runoff Samples

| Group | Constituent | Occurrence of Concentration above Detection Limit (%) | |
|---|---|---|---|
| | | Rainwater | Runoff |
| Nutrient | Nitrate + Nitrite | 100 | 100 |
| | Ammonia | 100 | 100 |
| | Kjedahlas N | 100 | 100 |
| | Total Carbon | 96.88 | 100 |
| | Total Phosphorus | 100 | 100 |
| Major Ions | Calcium | 98.94 | 100 |
| | Magnesium | 98.94 | 100 |
| | Sodium | 78.35 | 100 |
| | Potassium | 90.82 | 100 |
| | Sulphate | 100 | 100 |
| | Chloride | 92.86 | 100 |
| Trace Metals | Cadmium | 56.58 | 8.67 |
| | Copper | 90.00 | 82.14 |
| | Chromium | 38.16 | 44.90 |
| | Lead | 47.50 | 48.21 |
| | Nickel | 91.25 | 51.28 |
| | Zinc | 100 | 100 |
| | Barium | 3.80 | 12.57 |

TABLE 5a. Contaminant Load ($mg/m^2$) of Rainwater and Runoff Events by Catchment Surface

| Event No. | Date | Nitrate + Nitrite | | Ammonia | | Kjedahle N | | Total Carbon | | Total Phosphorus | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1982 | P | R | P | R | P | R | P | R | P | R |
| 8 | June 1 | 1.658 | 1.514 | 1.174 | .705 | 1.383 | 1.048 | 4.036 | 6.609 | .029 | .444 |
| 14 | June 21 | 1.979 | .412 | 1.341 | .080 | 1.709 | .262 | 3.347 | 2.332 | .067 | .044 |
| 15 | June 23 | .330 | 1.423 | .576 | .532 | .694 | 1.387 | .992 | 7.670 | .047 | .378 |
| 18 | June 30 | .138 | 1.059 | .217 | .550 | .315 | .805 | .696 | 5.827 | .006 | .273 |
| 20 | July 17 | 1.605 | 2.485 | 1.512 | .774 | 1.972 | 2.807 | 3.485 | 38.449 | .049 | .436 |
| 21 | July 28 | * | * | * | * | * | * | * | * | * | * |
| 23 | Aug. 2 | 2.546 | 2.350 | 1.990 | 1.023 | 2.566 | 2.430 | 5.789 | 16.917 | .040 | .292 |
| 25 | Aug. 8 | 1.954 | 1.667 | 1.417 | .551 | 4.785 | 2.162 | 4.797 | 18.186 | .039 | .303 |
| 34 | Sept 18 | 1.754 | 3.161 | .821 | .186 | 1.106 | .813 | 6.990 | 15.033 | .467 | .111 |
| 41 | Sept 28 | .993 | 1.848 | 2.067 | 1.214 | 2.863 | 2.504 | 9.571 | 14.373 | .048 | .453 |
| 42 | Oct. 7 | 1.519 | 3.004 | .847 | 1.618 | 1.039 | 2.992 | 2.385 | 13.542 | .035 | .337 |
| 43 | Oct. 7 | 1.147 | 2.834 | .890 | 1.197 | 1.234 | 2.471 | 4.085 | 13.229 | .003 | .655 |
| 48 | Nov.1-2 | 12.366 | 3.825 | 15.382 | 2.477 | 19.774 | 4.248 | 27.254 | 18.549 | .014 | .956 |
| 49 | Nov. 2 | .659 | 1.587 | .351 | .523 | .519 | 1.293 | 2.201 | 6.377 | .019 | .962 |
| | 1983 | | | | | | | | | | |
| 9 | Apr. 15 | 2.664 | 2.195 | 1.353 | .577 | 1.924 | 1.628 | 1.667 | 5.857 | .105 | .629 |
| 11 | Apr. 29 | 2.008 | .894 | 1.978 | .931 | 2.515 | 1.622 | 1.407 | 7.877 | .020 | .312 |
| 17 | May 14 | * | * | * | * | * | * | * | * | * | * |
| 18 | May 19 | 4.093 | 2.227 | 2.560 | 1.331 | 4.429 | 3.288 | 7.973 | 18.280 | .284 | .814 |
| 21 | May 30 | 2.790 | 2.731 | 1.791 | .858 | 4.282 | 1.868 | 14.941 | 9.750 | * | .632 |
| 25 | June 27 | 12.185 | 27.559 | 12.809 | 5.639 | 15.488 | 8.914 | 74.284 | 60.810 | 1.750 | .611 |
| 34 | Aug. 11 | 4.004 | 5.632 | 3.755 | 1.536 | 4.752 | 2.854 | 1.955 | 35.212 | .252 | .883 |
| 35 | Aug. 11 | 3.398 | 5.378 | 2.166 | 1.214 | 2.528 | 2.750 | 5.251 | 33.784 | .288 | .557 |
| 36 | Aug. 22 | 1.629 | 3.834 | .705 | .973 | .793 | 2.179 | 1.306 | 20.629 | .078 | .479 |
| 39 | Aug. 31 | 1.448 | 2.946 | .761 | .897 | 1.301 | 2.526 | 1.673 | 27.436 | .038 | .361 |
| 49 | Oct. 12 | 3.719 | 3.292 | 1.607 | .879 | 1.805 | 2.168 | 2.318 | 13.896 | .052 | .409 |
| 51 | Oct. 24 | 1.597 | 2.246 | .487 | .143 | .711 | .798 | 1.893 | 8.660 | .114 | .317 |
| 58 | Nov. 24 | .283 | .371 | .050 | .030 | .122 | .263 | .438 | 1.454 | .023 | .060 |
| 59 | Nov. 28 | 2.103 | 3.076 | 1.273 | .567 | 2.027 | 2.267 | 3.241 | 7.887 | .036 | .504 |

P = Rainwater  R = Runoff  * = No data

TABLE 5b. Contaminant Load ($mg/m^2$) of Rainwater and Runoff Events by Catchment Surface

| Event No. | Date | Calcium | | Magnesium | | Sodium | | Potassium | | Sulphate | | Chloride | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1982 | P | R | P | R | P | R | P | R | P | R | P | R |
| 8 | June 1 | 1.776 | 78.831 | .588 | 7.353 | .378 | 13.145 | .171 | 2.186 | 18.346 | 132.024 | .676 | 24.056 |
| 14 | June 21 | 2.805 | 41.912 | .588 | 7.736 | .439 | 7.165 | .380 | 1.601 | 9.411 | 34.680 | 1.008 | 7.200 |
| 15 | June 23 | 1.099 | 46.868 | .168 | 9.426 | .017 | 11.539 | .076 | 2.273 | 33.001 | 74.473 | 4.102 | 21.913 |
| 18 | June 30 | 9.542 | 46.297 | 1.723 | 5.748 | .186 | 5.483 | .969 | 2.088 | 9.765 | 67.384 | 1.188 | 9.301 |
| 20 | July 17 | 3.589 | 90.495 | 1.175 | 15.004 | .146 | 14.864 | .233 | .389 | 12.900 | 104.181 | .450 | 24.851 |
| 21 | July 28 | 1.518 | 26.956 | .211 | 3.928 | .185 | 2.909 | .238 | 1.350 | 1.188 | 30.526 | .264 | 3.298 |
| 23 | Aug. 2 | 6.087 | 73.634 | .736 | 8.459 | .199 | 8.659 | .505 | 2.381 | 16.839 | 107.747 | 1.095 | 14.201 |
| 25 | Aug. 8 | 4.251 | 106.228 | .855 | 11.436 | .246 | 9.177 | .489 | 3.400 | 28.690 | 97.768 | .932 | 8.812 |
| 34 | Sept 18 | 2.894 | 31.963 | 1.135 | 3.901 | .122 | 3.687 | .297 | 2.040 | 8.949 | 20.760 | .507 | 4.603 |
| 41 | Sept 28 | 2.046 | 96.780 | .216 | 14.464 | .244 | 17.670 | .434 | 4.548 | 17.835 | 90.220 | .793 | 18.284 |
| 42 | Oct. 7 | 1.911 | 48.591 | .532 | 4.438 | .532 | 4.028 | .141 | 2.139 | 10.260 | 44.608 | .713 | 6.145 |
| 43 | Oct. 7 | 1.208 | 91.910 | .320 | 9.532 | .320 | 7.517 | .093 | 3.739 | 15.031 | 85.049 | 1.015 | 10.425 |
| 48 | Nov.1-2 | 15.786 | 136.062 | 7.079 | 21.805 | 1.773 | 8.061 | 1.573 | 5.527 | 62.872 | 138.492 | 5.711 | 14.939 |
| 49 | Nov. 2 | .670 | 53.295 | .117 | 10.529 | .156 | 4.162 | .120 | 2.381 | 5.437 | 39.059 | .659 | 6.737 |
| | 1983 | | | | | | | | | | | | |
| 9 | Apr. 15 | 3.484 | 70.768 | .958 | 12.683 | 1.575 | 17.801 | .447 | 2.864 | 16.821 | 73.203 | 1.962 | 26.059 |
| 11 | Apr. 29 | 5.765 | 48.033 | 1.469 | 5.251 | .537 | 9.437 | .251 | 2.440 | 12.399 | 37.685 | 1.001 | 14.672 |
| 17 | May 14 | 1.920 | 21.617 | .618 | 2.999 | .453 | 2.961 | .126 | 1.087 | 4.898 | 16.619 | .403 | 4.249 |
| 18 | May 19 | 12.934 | 118.823 | 3.189 | 20.248 | 2.525 | 14.500 | 1.152 | 3.847 | 23.476 | 107.422 | 3.986 | 18.448 |
| 21 | May 30 | 10.010 | 89.547 | 2.832 | 12.896 | 1.807 | 8.480 | .911 | 2.670 | 20.893 | 112.615 | 1.761 | 11.647 |
| 25 | June 27 | 23.395 | 167.078 | 7.718 | 23.891 | 2.555 | 12.907 | 1.507 | 7.051 | 162.103 | 195.810 | 3.992 | 20.023 |
| 34 | Aug. 11 | 4.710 | 169.376 | 1.469 | 27.047 | .951 | 13.689 | .256 | 5.515 | 12.945 | 198.804 | 5.522 | 19.010 |
| 35 | Aug. 11 | 2.285 | 163.147 | .601 | 25.452 | .648 | 18.896 | .349 | 5.956 | 23.343 | 140.760 | 3.564 | 20.913 |
| 36 | Aug. 22 | 2.096 | 64.660 | .636 | 12.652 | .160 | 4.930 | .080 | 1.972 | 9.738 | 77.767 | .321 | 8.924 |
| 39 | Aug. 31 | 2.259 | 111.801 | .669 | 17.894 | 1.130 | 7.107 | .251 | 3.532 | 5.439 | 120.484 | 1.255 | 10.176 |
| 49 | Oct. 12 | 2.260 | 113.447 | .936 | 15.406 | 1.621 | 5.681 | .169 | 2.733 | 14.875 | 152.290 | 1.595 | 9.554 |
| 51 | Oct. 24 | 1.656 | 72.886 | .464 | 10.992 | 1.429 | 4.218 | .407 | 2.243 | 6.720 | 84.660 | 1.136 | 5.327 |
| 58 | Nov. 24 | .796 | 31.533 | .241 | 5.483 | .128 | 4.667 | .066 | 1.376 | 1.885 | 39.419 | .336 | 6.823 |
| 59 | Nov. 28 | 3.763 | 80.908 | 1.407 | 16.283 | .617 | 7.684 | .743 | 2.493 | 14.151 | 58.773 | 1.581 | 9.923 |

P = Rainwater R = Runoff * = No data

TABLE 5c. Contaminant Load ($mg/m^2$) of Rainwater and Runoff Events by Catchment Surface

| Event No. | Date | Cadmium | | Copper | | Chromium | | Lead | | Nickel | | Zinc | | Barium | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1982 | P | R | P | R | P | R | P | R | P | R | P | R | P | R |
| 8 | June 1 | .022 | .019 | .093 | .058 | .023 | .037 | .091 | .316 | .214 | .036 | .127 | .410 | .038 | .079 |
| 14 | June 21 | .014 | .010 | .103 | .010 | .014 | .010 | .068 | .047 | .066 | .010 | .111 | .037 | .029 | .017 |
| 15 | June 23 | .009 | .018 | .016 | .040 | .009 | .018 | .010 | .230 | .032 | .025 | .032 | .032 | .017 | .036 |
| 18 | June 30 | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 20 | July 17 | .018 | .023 | .183 | .061 | .048 | .052 | .183 | .234 | .206 | .047 | .308 | .267 | .183 | .234 |
| 21 | July 28 | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 23 | Aug. 2 | .020 | .018 | .079 | .067 | .038 | .038 | .140 | .263 | .139 | .065 | .067 | .309 | .130 | .182 |
| 25 | Aug. 8 | .038 | .023 | .438 | .074 | .041 | .078 | .278 | .248 | .261 | .144 | .165 | .202 | .146 | .322 |
| 29 | Aug. 25 | .505 | .096 | 1.711 | .306 | 1.273 | .218 | 4.067 | .699 | 3.783 | .297 | 1.588 | 1.319 | 3.969 | .962 |
| 34 | Sept 18 | .057 | .072 | .081 | .036 | .038 | .072 | .147 | .215 | .209 | .179 | .180 | .358 | .280 | .358 |
| 41 | Sept 28 | .103 | .095 | .240 | .119 | .089 | .100 | .337 | .433 | .277 | .302 | 1.413 | .782 | .674 | .524 |
| 42 | Oct. 7 | .012 | .011 | .097 | .102 | .014 | .046 | .124 | .558 | .079 | .057 | .207 | * | .089 | * |
| 43 | Oct. 7 | .010 | .035 | .093 | .195 | .010 | .052 | .083 | .832 | .062 | .209 | .145 | 1.617 | .104 | .358 |
| 48 | Nov. 1-2 | .014 | .067 | .068 | .259 | .014 | .088 | .108 | .648 | .079 | .244 | .350 | 5.802 | .143 | .679 |
| 49 | Nov. 2 | .025 | .028 | .084 | .140 | .023 | .032 | .129 | .242 | .095 | .097 | .324 | 1.888 | .225 | .282 |
| | 1983 | | | | | | | | | | | | | | |
| 9 | Apr. 15 | .043 | .033 | .946 | .181 | .022 | .036 | .151 | .248 | .323 | .073 | .559 | 1.129 | .215 | .362 |
| 11 | Apr. 29 | .004 | .015 | .056 | .124 | .004 | .015 | .020 | .201 | .016 | .015 | .092 | .602 | .040 | .155 |
| 17 | May 14 | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 18 | May 19 | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 21 | May 30 | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 25 | June 27 | .026 | .087 | .158 | .258 | .010 | .096 | .080 | .527 | .161 | .220 | .293 | 1.370 | .097 | .871 |
| 27 | July 4 | .223 | .043 | 1.517 | .148 | .159 | .072 | .881 | .337 | 1.081 | .085 | 4.295 | .642 | 1.591 | .427 |
| 34 | Aug. 11 | .050 | .100 | .515 | .140 | .048 | .100 | .243 | .583 | .137 | .202 | 1.207 | 1.029 | .476 | 1.003 |
| 35 | Aug. 11 | .019 | .107 | .457 | .111 | .028 | .107 | .093 | .542 | .253 | .242 | .558 | 1.372 | .187 | 1.067 |
| 36 | Aug. 22 | .013 | .027 | 2.070 | .075 | .012 | .027 | .063 | .238 | .107 | .054 | .288 | .569 | .117 | .269 |
| 39 | Aug. 31 | .042 | .062 | .126 | .105 | .042 | .062 | .209 | .318 | .167 | .127 | 1.088 | 1.149 | .418 | .623 |
| 49 | Oct. 12 | .021 | .061 | .042 | .129 | .209 | .061 | .152 | .323 | .152 | .127 | .802 | 1.366 | .209 | .605 |
| 51 | Oct. 24 | .010 | .048 | .076 | .048 | .010 | .048 | .047 | .253 | .076 | .109 | .237 | 1.966 | .095 | * |
| 58 | Nov. 24 | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 59 | Nov. 28 | * | * | * | * | * | * | * | * | * | * | * | * | * | * |

P = Rainwater R = Runoff * = No data

TABLE 6a. Ratio of Rainwater Load to Runoff Load

| Event No. | Date | Nitrate + Nitrite | | Ammonia | | Kjedahlas N | | Total Carbon | | Total Phosphorus | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1982 | A | B | A | B | A | B | A | B | A | B |
| 8 | June 1 | 4.583 | 1.095 | 6.966 | 1.665 | 5.523 | 1.320 | 2.555 | .611 | .277 | .066 |
| 14 | June 21 | 20.371 | 4.808 | 70.941 | 16.742 | 27.674 | 6.531 | 6.081 | 1.435 | 6.470 | 1.527 |
| 15 | June 23 | 1.068 | .232 | 4.993 | 1.083 | 2.305 | .500 | .596 | .123 | .569 | .124 |
| 18 | June 30 | .590 | .131 | 1.787 | .395 | 1.769 | .391 | .540 | .119 | .095 | .021 |
| 20 | July 17 | 3.181 | .646 | 9.629 | 1.955 | 3.460 | .702 | .447 | .091 | .556 | .113 |
| 23 | Aug. 2 | 4.994 | 1.084 | 8.967 | 1.946 | 4.865 | 1.056 | 1.577 | .342 | .629 | .136 |
| 25 | Aug. 8 | 4.217 | 1.160 | 9.345 | 2.570 | 8.047 | 2.213 | .959 | .264 | .473 | .130 |
| 34 | Sept 18 | 2.420 | .554 | 19.255 | 4.409 | 5.942 | 1.361 | 2.031 | .465 | 18.358 | 4.204 |
| 41 | Sept 28 | 2.488 | .537 | 7.885 | 1.703 | 5.294 | 1.144 | 3.089 | .667 | .494 | .107 |
| 42 | Oct. 7 | 1.872 | .506 | 1.939 | .524 | 1.286 | .347 | .652 | .176 | .390 | .105 |
| 43 | Oct. 7 | 1.722 | .405 | 3.164 | .744 | 2.125 | .499 | 1.314 | .309 | .022 | .005 |
| 48 | Nov.1-2 | 14.696 | 3.233 | 28.226 | 6.210 | 21.156 | 4.654 | 6.679 | 1.469 | .066 | .015 |
| 49 | Nov. 2 | 1.908 | .414 | 3.094 | .671 | 1.850 | .401 | 1.590 | .345 | .090 | .020 |
| | 1983 | | | | | | | | | | |
| 9 | Apr. 15 | 4.259 | 1.214 | 8.225 | 2.344 | 4.145 | 1.181 | .999 | .285 | .584 | .166 |
| 11 | Apr. 29 | 7.663 | 2.245 | 7.248 | 2.124 | 5.293 | 1.551 | .610 | .179 | .223 | .065 |
| 18 | May 19 | 7.626 | 1.838 | 7.979 | 1.923 | 5.590 | 1.347 | 1.180 | .436 | 1.447 | .349 |
| 21 | May 30 | 4.462 | 1.022 | 9.116 | 2.088 | 10.008 | 2.292 | 6.692 | 1.533 | * | * |
| 25 | June 27 | 2.146 | .442 | 11.027 | 2.272 | 8.434 | 1.737 | 5.930 | 1.222 | 13.098 | 2.865 |
| 34 | Aug. 11 | 3.402 | .711 | 11.696 | 2.444 | 7.967 | 1.665 | .266 | .056 | 1.366 | .285 |
| 35 | Aug. 11 | 3.023 | .632 | 8.533 | 1.783 | 4.397 | .919 | .744 | .155 | 2.474 | .517 |
| 36 | Aug. 22 | 2.073 | .425 | 3.533 | .724 | 1.776 | .364 | .309 | .063 | .799 | .164 |
| 39 | Aug. 31 | 1.827 | .491 | 3.157 | .849 | 1.915 | .515 | .227 | .061 | .387 | .104 |
| 49 | Oct. 12 | 4.154 | 1.130 | 6.737 | 1.833 | 3.061 | .833 | .613 | .167 | .463 | .126 |
| 51 | Oct. 24 | 3.259 | .710 | 15.648 | 3.411 | 4.084 | .890 | 1.003 | .219 | 1.652 | .360 |
| 58 | Nov. 24 | 3.744 | .764 | 8.302 | 1.694 | 2.275 | .464 | 1.476 | .301 | 1.914 | .391 |
| 59 | Nov. 28 | 3.165 | .684 | 10.386 | 2.243 | 4.140 | .894 | 1.903 | .411 | .334 | .072 |

A = Calculated by total rainfall depth; B = Calculated by effective rainfall depth
* = no data

TABLE 6b. Ratio of Rainwater Load to Runoff Load

| Event No. | Date | Calcium | | Magnesium | | Sodium | | Potassium | | Sulphate | | Chloride | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1982 | A | B | A | B | A | B | A | B | A | B | A | B |
| 8 | June 1 | .094 | .023 | .334 | .070 | .120 | .029 | .327 | .078 | .581 | .139 | .118 | .028 |
| 14 | June 21 | .284 | .067 | .322 | .076 | .260 | .061 | 1.000 | .236 | 1.150 | .271 | .593 | .140 |
| 15 | June 23 | .108 | .023 | .082 | .018 | .007 | .002 | .153 | .033 | 2.042 | .443 | .863 | .187 |
| 18 | June 30 | .877 | .206 | 1.275 | .300 | .144 | .034 | 1.975 | .464 | .617 | .145 | .544 | .128 |
| 20 | July 17 | .195 | .040 | .386 | .078 | .048 | .010 | 2.954 | .600 | .608 | .123 | .089 | .018 |
| 21 | July 28 | .282 | .056 | .269 | .054 | .318 | .064 | .880 | .176 | .195 | .039 | .400 | .080 |
| 23 | Aug. 2 | .381 | .083 | .401 | .087 | .106 | .023 | .977 | .212 | .720 | .156 | .355 | .077 |
| 25 | Aug. 8 | .146 | .040 | .272 | .075 | .097 | .027 | .524 | .144 | 1.067 | .294 | .385 | .106 |
| 34 | Sept 18 | .395 | .091 | 1.270 | .291 | .145 | .033 | .636 | .146 | 1.883 | .431 | .476 | .109 |
| 41 | Sept 28 | .098 | .021 | .069 | .015 | .064 | .014 | .442 | .095 | .915 | .198 | .201 | .043 |
| 42 | Oct. 7 | .146 | .039 | .444 | .120 | .489 | .132 | .243 | .066 | .852 | .230 | .430 | .116 |
| 43 | Oct. 7 | .056 | .013 | .143 | .034 | .181 | .043 | .106 | .025 | .770 | .181 | .415 | .098 |
| 48 | Nov.1-2 | .527 | .116 | 1.476 | .325 | 1.000 | .220 | 1.293 | .285 | 2.064 | .454 | 1.738 | .382 |
| 49 | Nov. 2 | .058 | .013 | .051 | .011 | .172 | .037 | .233 | .050 | .642 | .139 | .450 | .098 |
| | 1983 | | | | | | | | | | | | |
| 9 | Apr. 15 | .173 | .049 | .265 | .076 | .310 | .089 | .548 | .156 | .806 | .230 | .264 | .075 |
| 11 | Apr. 29 | .410 | .120 | .955 | .280 | .194 | .057 | .351 | .103 | 1.123 | .329 | .233 | .068 |
| 17 | May 14 | .421 | .089 | .976 | .206 | .724 | .153 | .547 | .115 | 1.397 | .295 | .450 | .095 |
| 18 | May 19 | .452 | .109 | .654 | .158 | .723 | .174 | 1.242 | .299 | .907 | .219 | .900 | .216 |
| 21 | May 30 | .488 | .112 | .959 | .220 | .931 | .213 | 1.491 | .341 | .810 | .186 | .660 | .151 |
| 25 | June 27 | .680 | .140 | 1.568 | .323 | .961 | .198 | 1.037 | .214 | 4.019 | .828 | .968 | .199 |
| 34 | Aug. 11 | .133 | .028 | .260 | .054 | .333 | .070 | .222 | .047 | .312 | .065 | 1.390 | .291 |
| 35 | Aug. 11 | .067 | .014 | .113 | .024 | .164 | .034 | .281 | .059 | .794 | .166 | .813 | .170 |
| 36 | Aug. 22 | .158 | .032 | .245 | .050 | .158 | .032 | .198 | .041 | .611 | .125 | .176 | .036 |
| 39 | Aug. 31 | .075 | .020 | .139 | .037 | .591 | .159 | .264 | .071 | .168 | .045 | .459 | .123 |
| 49 | Oct. 12 | .073 | .020 | .222 | .061 | 1.049 | .285 | .228 | .062 | .359 | .098 | .614 | .167 |
| 51 | Oct. 24 | .104 | .023 | .194 | .042 | 1.554 | .339 | .832 | .181 | .364 | .079 | .978 | .213 |
| 58 | Nov. 24 | .124 | .025 | .216 | .044 | .135 | .028 | .235 | .048 | .235 | .048 | .242 | .049 |
| 59 | Nov. 28 | .215 | .047 | .400 | .086 | .372 | .080 | 1.380 | .298 | 1.115 | .241 | .738 | .159 |

A = Calculated by total rainfall depth; B = Calculated by effective rainfall depth

TABLE 6c. Ratio of Rainwater Load to Runoff Load

| Event No. | Date | Cadmium | | Copper | | Chromium | | Lead | | Nickel | | Zinc | | Barium | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1982 | A | B | A | B | A | B | A | B | A | B | A | B | A | B |
| 8 | June 1 | 4.647 | 1.111 | 6.710 | 1.604 | 2.589 | .619 | 1.207 | .288 | 24.900 | 5.951 | 1.290 | .308 | 2.009 | .480 |
| 14 | June 21 | 6.016 | 1.420 | 43.012 | 10.151 | 6.016 | 1.420 | 6.212 | 1.466 | 27.446 | 6.477 | 12.671 | 2.990 | 7.264 | 1.714 |
| 15 | June 23 | 2.191 | .475 | 1.872 | .406 | 2.191 | .475 | .198 | .043 | 5.889 | 1.278 | .454 | .098 | 2.191 | .475 |
| 20 | July 17 | 3.839 | .779 | 14.785 | 3.001 | 4.618 | .937 | 3.839 | .779 | 21.678 | 4.401 | 5.683 | 1.154 | 3.839 | .779 |
| 23 | Aug. 2 | 4.989 | 1.083 | 5.403 | 1.173 | 4.613 | 1.001 | 2.444 | .530 | 9.898 | 2.148 | 1.007 | .219 | 3.299 | .716 |
| 25 | Aug. 8 | 5.979 | 1.644 | 21.469 | 5.904 | 1.902 | .52 | 4.076 | 1.121 | 6.586 | 1.811 | 2.972 | .817 | 1.646 | .453 |
| 29 | Aug. 25 | 5.251 | 1.061 | 5.588 | 1.129 | 5.847 | 1.181 | 5.822 | 1.176 | 12.720 | 2.569 | 1.204 | .243 | 4.128 | .834 |
| 34 | Sept 18 | 3.448 | .790 | 9.817 | 2.248 | 2.309 | .529 | 2.985 | .684 | 5.104 | 1.169 | 2.197 | .503 | 3.412 | .781 |
| 41 | Sept 28 | 5.049 | 1.091 | 9.387 | 2.028 | 4.137 | .894 | 3.602 | .778 | 4.252 | .918 | 8.365 | 1.807 | 5.960 | 1.288 |
| 42 | Oct. 7 | 3.793 | 1.024 | 3.495 | .944 | 1.172 | .316 | .824 | .223 | .513 | 1.386 | * | * | * | * |
| 43 | Oct. 7 | 1.258 | .296 | 2.027 | .476 | .841 | .198 | .424 | .100 | 1.265 | .297 | .381 | .090 | 1.230 | .289 |
| 48 | Nov.1-2 | .975 | .215 | 1.192 | .262 | .739 | .163 | .757 | .166 | 1.475 | .325 | .275 | .060 | 0.959 | .211 |
| 49 | Nov. 2 | 4.059 | .881 | 2.760 | .599 | 3.234 | .703 | 2.457 | .533 | 4.549 | .987 | .790 | .171 | 3.681 | .799 |
| | 1983 | | | | | | | | | | | | | | |
| 9 | Apr. 15 | 4.561 | 1.300 | 18.311 | 5.219 | 2.082 | .593 | 2.127 | .606 | 15.616 | 4.451 | 1.738 | .495 | 2.082 | .593 |
| 11 | Apr. 29 | .884 | .259 | 1.547 | .453 | .884 | .259 | .340 | .100 | 3.536 | 1.036 | .521 | .153 | .884 | .259 |
| 25 | June 27 | 1.435 | .296 | 2.963 | .611 | .488 | .101 | .740 | .153 | 3.544 | .730 | 1.037 | .214 | .539 | .111 |
| 27 | July 4 | 5.227 | 1.056 | 10.289 | 2.078 | 2.223 | .449 | 2.611 | .527 | 12.660 | 2.557 | 6.689 | 1.351 | 3.726 | .753 |
| 34 | Aug. 11 | 2.394 | .500 | 17.557 | 3.669 | 2.268 | .474 | 1.994 | .417 | 3.260 | .681 | 5.615 | 1.174 | 2.268 | .474 |
| 35 | Aug. 11 | .837 | .175 | 19.650 | 4.107 | 1.239 | .259 | .823 | .172 | 5.010 | 1.047 | 1.947 | .407 | .837 | .175 |
| 36 | Aug. 22 | 2.407 | .494 | 13.442 | 2.756 | 2.130 | .437 | 1.296 | .266 | 9.724 | 1.993 | 2.465 | .505 | 2.130 | .437 |
| 39 | Aug. 31 | 2.495 | .671 | 4.466 | 1.201 | 2.495 | .671 | 2.445 | .658 | 4.990 | 1.342 | 3.520 | .947 | 2.495 | .671 |
| 49 | Oct. 12 | 1.273 | .346 | 1.200 | .326 | 1.273 | .346 | 1.726 | .470 | 4.398 | 1.196 | 2.150 | .587 | 1.273 | .346 |
| 51 | Oct. 24 | .912 | .199 | 7.298 | 1.591 | .912 | .199 | .860 | .187 | 3.189 | .695 | .552 | .120 | * | * |

A = Calculated by total rainfall depth; B = Calculated by effective rainfall depth; * = No data

TABLE 7. Statistics of Constituent Concentration (mg/l) observed in Rainwater and Runoff for 1982 - 1983 Storm Events Studied

| | Minimum | | Maximum | | Mean | | Standard Deviation | |
|---|---|---|---|---|---|---|---|---|
| | Rainwater | Runoff | Rainwater | Runoff | Rainwater | Runoff | Rainwater | Runoff |
| Nitrate + Nitrite | .147 | .214 | 3.240 | 7.650 | .756 | .757 | .579 | .690 |
| Ammonia | .044 | .020 | 4.038 | 1.350 | .585 | .302 | .653 | .292 |
| Kjedahl as N | .107 | .132 | 5.180 | 2.790 | .827 | .572 | .820 | .489 |
| Total Carbon | <.200 | .991 | 19.000 | 11.900 | 1.753 | 3.824 | 2.255 | 2.580 |
| Total Phosphorus | .001 | .024 | 2.180 | 1.608 | .036 | .122 | .058 | .087 |
| Calcium | <.050 | 8.930 | 6.930 | 56.100 | 1.378 | 19.742 | 1.134 | 7.256 |
| Manganese | <.010 | 1.090 | 5.200 | 11.400 | .392 | 2.924 | .364 | .830 |
| Sodium | <.020 | .698 | .950 | 11.000 | .231 | 2.441 | .185 | 1.496 |
| Potassium | <.020 | .083 | 1.230 | 1.880 | .124 | .755 | .083 | .355 |
| Sulphate | 1.123 | 5.800 | 60.400 | 93.900 | 6.106 | 21.687 | 5.499 | 9.979 |
| Chloride | <.100 | <.100 | 7.700 | 21.900 | .505 | 3.627 | .451 | 2.645 |
| Cadmium | <.010 | <.010 | .040 | .020 | .011 | .010 | .004 | .002 |
| Copper | <.010 | <.010 | .090 | .090 | .068 | .029 | .077 | .023 |
| Chrominum | <.010 | <.010 | .040 | .050 | .014 | .013 | .021 | .007 |
| Lead | <.050 | <.050 | .160 | .490 | .105 | .095 | .298 | .101 |
| Nickel | <.030 | <.010 | .200 | .070 | .049 | .026 | .034 | .014 |
| Zinc | <.010 | <.010 | .590 | 1.789 | .229 | .140 | .216 | .224 |
| Barium | <.050 | <.050 | .100 | .200 | .052 | .031 | .032 | .031 |

TABLE 8. The Average Contaminant Load of Rainwater and Runoff and the Average Ratio of Rainwater to Runoff of the Studied Storm Events

| Group | Constituent | Average Loading (mg/m$^2$) | | | | Ratio of Rainwater to Runoff | | |
|---|---|---|---|---|---|---|---|---|
| | | 1982 | | 1983 | | | | |
| | | Rainwater | Runoff | Rainwater | Runoff | 1982 | 1983 | All Events |
| Nutrient | Nitrate + Nitrite | 2.202 | 2.013 | 3.225 | 4.799 | 1.139 | .947 | 1.043 |
| | Ammonia | 2.122 | .879 | 2.407 | 1.198 | 3.124 | 1.979 | 2.552 |
| | Kjedahl as N | 3.074 | 1.940 | 3.283 | 2.548 | 1.625 | 1.127 | 1.376 |
| | Total Carbon | 5.819 | 13.853 | 9.104 | 19.349 | .494 | .391 | .442 |
| | Total Phosphorus | .066 | .434 | .253 | .505 | .506 | .455 | .481 |
| Major Ions | Calcium | 3.942 | 69.273 | 5.524 | 80.259 | .059 | .059 | .060 |
| | Magnesium | 1.103 | 8.840 | 1.658 | 14.947 | .112 | .119 | .115 |
| | Sodium | .353 | 8.433 | 1.153 | 17.801 | .052 | .137 | .096 |
| | Potassium | .409 | 2.574 | .480 | 3.270 | .186 | .145 | .166 |
| | Sulphate | 17.895 | 76.097 | 23.549 | 101.16 | .232 | .211 | .221 |
| | Chloride | 1.365 | 12.485 | 2.030 | 12.558 | .115 | .144 | .129 |
| Trace Metal | Cadmium | .031 | .035 | .025 | .060 | .913 | .530 | .746 |
| | Copper | .131 | .097 | .287 | .130 | 2.302 | 2.201 | 2.258 |
| | Chromium | .030 | .052 | .043 | .061 | .749 | .379 | .554 |
| | Lead | .142 | .356 | .118 | .359 | .607 | .356 | .498 |
| | Nickel | .143 | .118 | .155 | .130 | 2.286 | 1.573 | 1.976 |
| | Zinc | .286 | 1.064 | .570 | 1.172 | .705 | .593 | .609 |
| | Barium | .172 | .279 | .206 | .619 | .735 | .424 | .602 |

Note that the average ratio is not identical to a ratio as calculated from average loads.

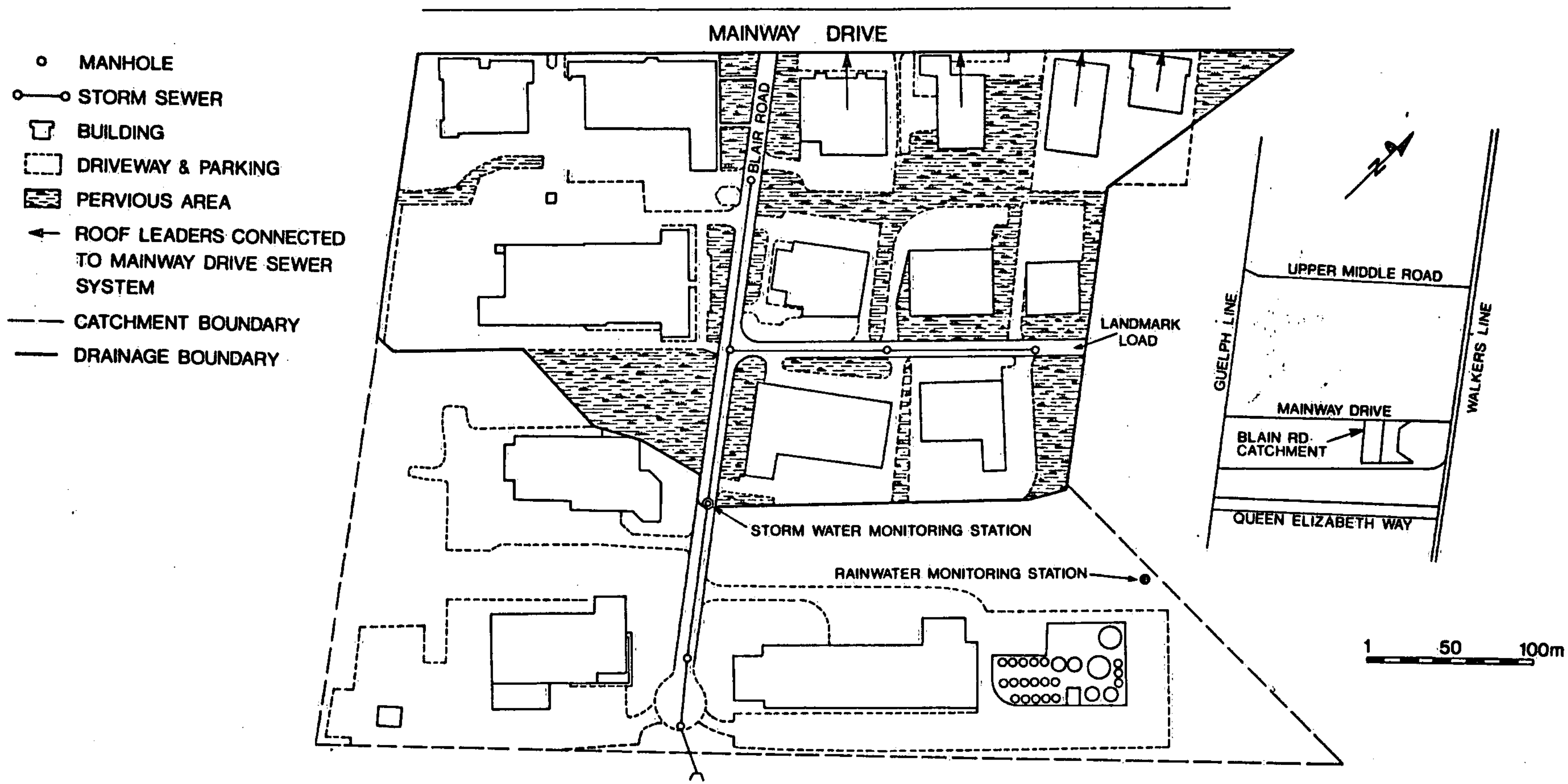


Figure 1 BLAIR ROAD CATCHMENT
BURLINGTON, ONTARIO

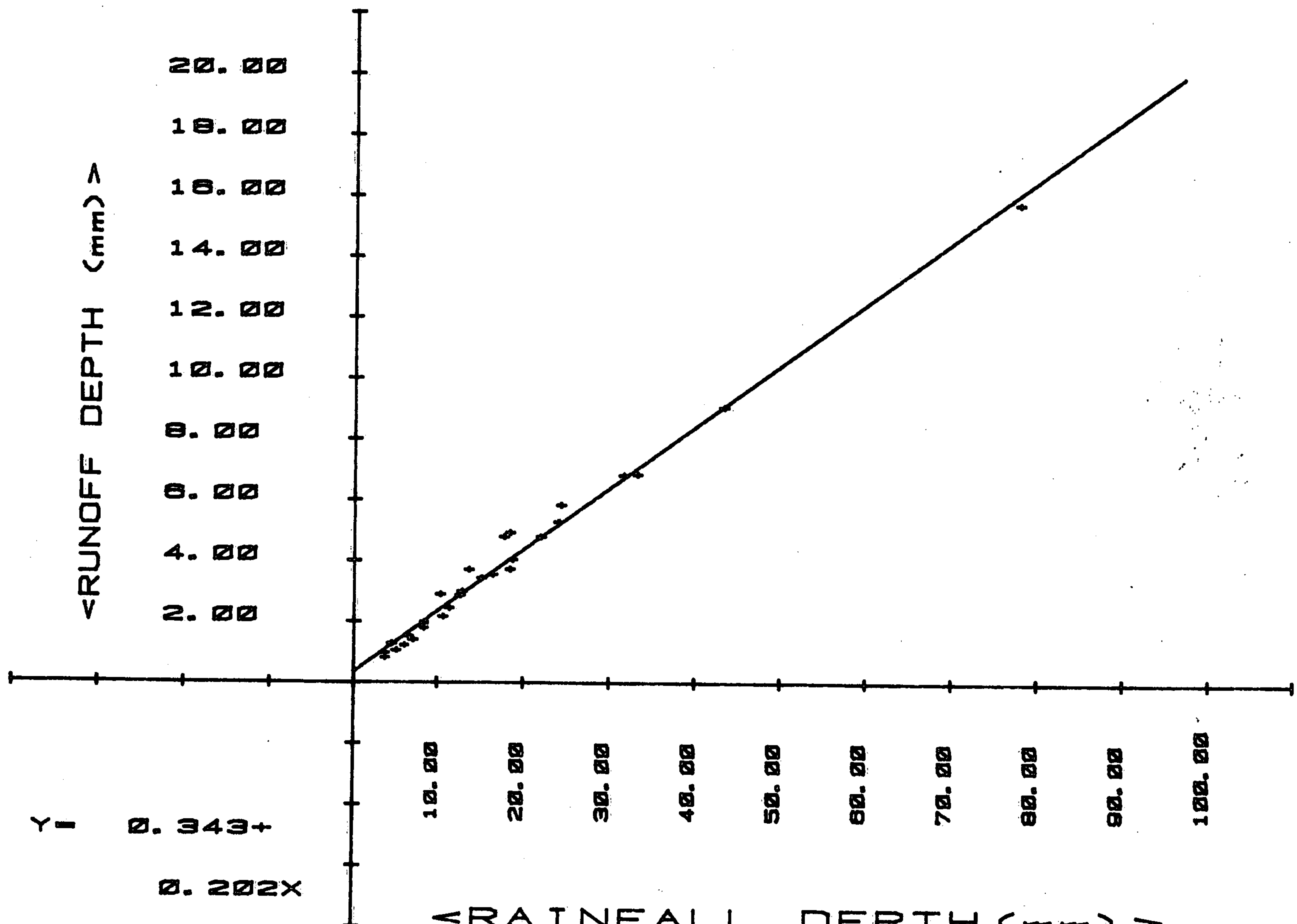


FIGURE 2. RAINFALL AND RUNOFF RELATIONSHIP

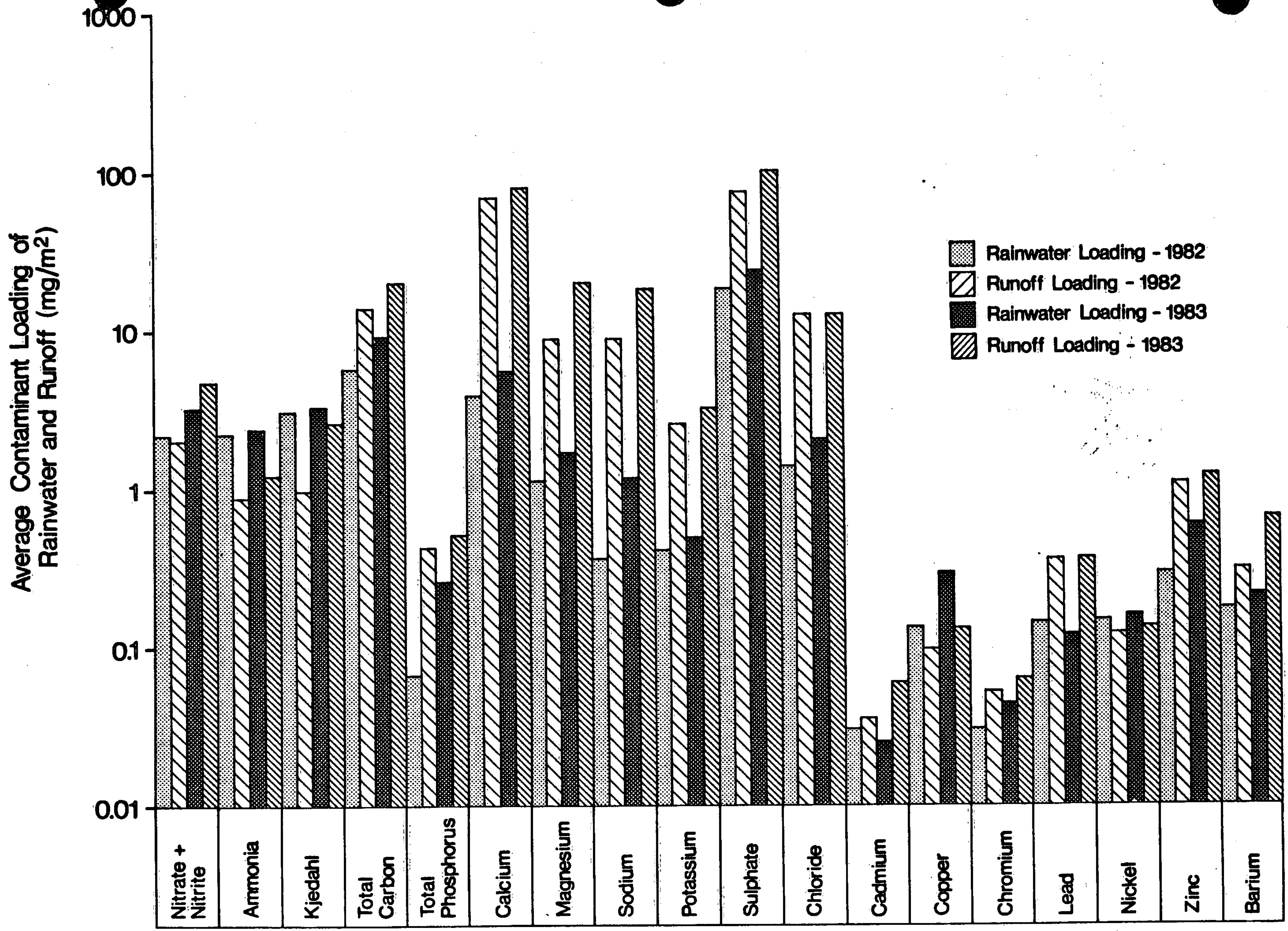


FIGURE 3. AVERAGE CONTAMINANT LOADINGS OF RAINWATER AND RUNOFF BLAIR ROAD CATCHMENT, BURLINGTON, ONTARIO.

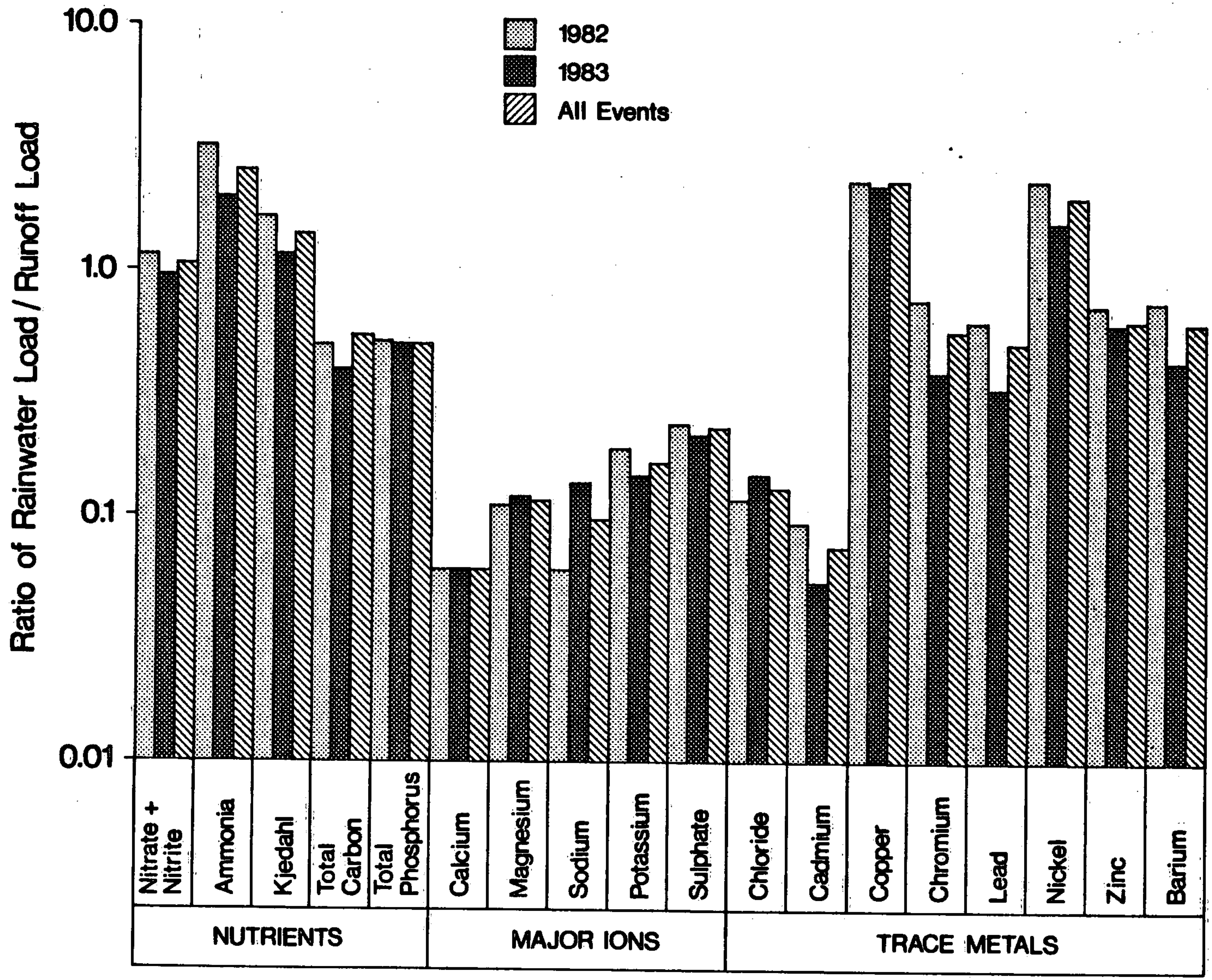


Figure 4 Ratio of rainwater load to runoff load.