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EFFECTS OF RAINWATER COMPOSITION ON URBAN RUNOFF QUALITY

by

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MANAGEMENT PERSPECTIVE

This report provides a useful comparison between the concentration of pollutants in rain water and the subsequent surface runoff. Such data on runoff is not often correlated with the rainfall so that this report provides information on the sources of pollutants.

Notably, the concentration of dissolved nitrogen and a large part of the copper and zinc in runoff were derived from the incoming rain. Therefore, for example, some cleaning practices can not wholly eliminate zinc loadings.

T. Milne Dick
Chief, Hydraulics Division

PERSPECTIVE DE GESTION

Le présent rapport fournit une comparaison utile entre la concentration des polluants dans l'eau de pluie et le ruissellement qui s'ensuit. Les données sur le ruissellement ne sont pas souvent corrélées avec la hauteur de pluie, c'est pourquoi le rapport donne des renseignements concernant les sources de matières polluantes.

Il est à noter que la concentration d'azote dissous et une grande partie du cuivre et du zinc trouvés dans les eaux de ruissellement proviennent des pluies. Par conséquent, certaines pratiques de nettoyage, par exemple, ne permettent pas d'éliminer complètement les charges de zinc.

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LES EFFETS DE LA COMPOSITION DE L'EAU DE PLUIE SUR LA QUALITÉ DU RUISSELLEMENT URBAIN

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RÉSUMÉ

L'eau de pluie est l'une des principales sources de pollution du ruissellement urbain. Pour évaluer cette source de pollution par le ruissellement, les auteurs ont fait une étude sur le terrain de l'eau de pluie et de la composition du ruissellement. Les principaux objectifs de l'étude consistaient à déterminer les composés qui entrent dans le ruissellement urbain en passant par l'eau de pluie et à étudier les variations de ces apports. À cette fin, un captage urbain expérimental a été installé et pourvu d'appareils à Burlington (Ontario). L'appareillage du captage comprenait une station classique de contrôle du ruissellement ainsi qu'un pluviomètre de conception récente. Cet appareil a permis de contrôler l'intensité de la pluie au moyen d'un pluviographe à augets basculeurs, il a recueilli des précipitations sèches ainsi que des échantillons séquentiels d'eau de pluie. L'appareil a été construit à partir d'éléments disponibles sur le marché.

La composition de l'eau de pluie observée indique qu'elle est une source primaire d'azote dissous dans le ruissellement urbain. Parmi les autres apports importants, on peut mentionner le zinc et le cuivre. Pour ce qui est de matières en suspension, du phosphate, du carbone organique et du plomb, la contribution de l'eau de pluie à la pollution par le ruissellement s'est révélée négligeable.

Certaines concentrations de substances diverses dans l'eau de pluie au cours de tempêtes isolées ont varié suivant un facteur de dix. D'aussi grandes variations se sont évidemment répercutées dans les variations de la qualité du ruissellement en ce qui a trait aux composés acheminés surtout par l'eau de pluie.

Les auteurs en sont venus à la conclusion que l'eau de pluie fournit pratiquement tout l'azote dissous dans le ruissellement observé ainsi que certaines portions non négligeables de cuivre et de zinc. En ce qui concerne ces derniers éléments, la composition de l'eau de pluie devrait être considérée dans la simulation qualitative du ruissellement urbain.

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EFFECTS OF RAINWATER COMPOSITION ON URBAN RUNOFF QUALITY

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ABSTRACT

Rainwater is one of the major sources of pollution in urban runoff. To evaluate this source of runoff pollution, a field study of rainwater and urban runoff composition was undertaken. The main objectives of the study were to identify the constituents which are supplied to urban runoff by rainwater and to investigate variations in such contributions. Towards this end, an urban test catchment was established and instrumented in Burlington, Ontario. The catchment instrumentation comprised a conventional runoff monitoring station and a newly developed rainfall monitoring apparatus. This apparatus monitored the rainfall rate by means of a tipping bucket device, collected dry precipitation, and collected sequential samples of rainwater. The apparatus was constructed from commercially available components.

Observed rainwater compositions indicate that rainwater is a primary source of dissolved nitrogen in urban runoff. Other significant contributions included zinc and copper. For suspended solids, phosphorus, organic carbon and lead, the rainwater contributions to runoff pollution were insignificant.

Concentrations of various substances in rainwater during individual storms varied by a factor of ten. Such large variations were then reflected in runoff quality variations for those constituents which were primarily supplied by the rainwater.

It was concluded that the rainwater supplied practically all the dissolved nitrogen in the observed runoff and significant portions of copper and zinc. For these constituents, the rainwater composition should be considered in the modelling of urban runoff quality.

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EFFECTS OF RAINWATER COMPOSITION ON URBAN RUNOFF QUALITY

INTRODUCTION

Urban runoff has been identified as major source of pollutants including suspended solids, nitrogen, phosphorus, and some heavy metals. The severity of runoff impact on the receiving waters quality is further increased by the fact that runoff pollution loads may be concentrated in a small number of events of a relatively short duration. Such concentrated discharges then create shock loadings in the receiving waters.

The early exploratory studies of urban runoff quality demonstrated the pollutional character of runoff and the large variability in runoff composition from one event to another as well as during individual events. Under such circumstances, the best source of runoff quality data were local field studies. High costs of such studies, however, led to attempts to model runoff quality using both statistical as well as physically based approaches.

The current physically based approaches to runoff quality modelling are based on the concept of pollutant accumulation on the catchment surface during dry weather periods and the subsequent washoff during the periods of runoff (Huber et al., 1982). Although various pollutants may accumulate at different rates, the basic mechanisms for accumulation, washoff, and routing are the same.

In recent studies, increased attention has been paid to the sources of pollutants in urban runoff. By identifying the sources of individual pollutants, it would be possible to select the most appropriate conceptual model for individual pollutants. The basic sources of pollution in urban runoff include wet fallout (washout by rainwater), dry fallout, surface deposition from land use activities, and the scouring of sewer deposits. The last source, the scouring of sewer deposits, is usually negligible in storm sewers with fair gradients. The other three sources have been investigated in field studies of urban runoff in Burlington, Ontario and some preliminary results of these studies are described in this paper.

This paper deals primarily with the contribution of rainwater to the pollutant loadings in urban runoff from the Blair Road catchment in Burlington. So far, only a limited amount of rainfall/runoff data have been processed fully and this limits the scope of findings presented here. As more data are processed, the analysis will be further extended.

PREVIOUS RESEARCH

Although the studies dealing with the composition of rainwater are fairly numerous, the compositions of both rainwater and runoff were studied in only a few cases. Extensive studies of bulk precipitation chemistry were reported by Shiomi and Kuntz (1973) for Lake Ontario Basin. They concluded that bulk precipitation may be a significant source of nitrogen and phosphorus entering the lake. The monthly pollutant deposition rates were higher from April to November than the average over the whole year. Samples collected in urban areas exhibited higher mean concentrations of inorganic nitrogen.

James and Shivalingaiah (1983) used the existing monthly data on atmospheric dry fallout and distributed the fallout loading over an industrial area. Such distributions were correlated with the wind velocity and direction and served for quantification of surface deposits in runoff quality simulations.

Goettle and Krauth (1980) produced the annual loadings of various pollutants in rainwater and urban runoff. After adding the wet and dry fallout contributions and comparing their sum to the runoff loading, the pollutants were divided into three distinct groups - (1) Pollutants with comparable concentrations in wet fallout and runoff (e.g. nitrate, ammonia, copper, cadmium and lead), (2) Pollutants with greater concentrations in runoff than in wet and dry fallout (suspended solids, chemical oxygen demand), and (3) Pollutants with much higher concentrations in runoff than in wet and dry fallout (total phosphorus).

Randall et al.(1978) collected composite samples of wet and dry fallout and correlated the observed pollutant loadings with those in runoff. They concluded that wet fallout contributes significantly to the pollutant loadings carried by surface runoff in large metropolitan areas. The washout of pollutants by rain, which was fairly uniform throughout the whole metropolitan area, occurred early during storms regardless of the magnitude or intensity of the storm. The deposition of atmospheric pollutants by dustfall was considerably smaller than wet fallout.

Malmquist (1978) studied atmospheric dry fallout and its contribution to urban runoff pollution. The dry fallout contribution to runoff pollution was found to be considerably smaller than that in the wet fallout. The highest wet fallout contributions to runoff pollution were found for total nitrogen (70%) and some heavy metals (up to 40%).

It appears from various studies that wet fallout (rain washout) may contribute significant quantities of certain pollutants to the runoff loadings. The wet fallout loadings exceed those in dry fallout for all the pollutants reported with the exception of suspended solids. Following such findings, it was of interest to evaluate the rainwater contribution to the runoff pollutant loadings and to investigate the effect of variations in the rainwater composition on runoff quality.

STUDY AREA

A map of the study area, which is referred to as the Blair Road catchment, is shown in Fig.1. The land use in the area can be classified as light industrial. The total contributing catchment area is 10.3 ha and it can be further broken down as follows:

Rooftop areas	2.09 ha
Parking lots	4.52 ha
Streets	0.48 ha
Lawns	3.21 ha.

The catchment imperviousness was determined as 69%. The catchment is served by storm sewers, which vary in diameter from 0.61 m to 0.69 m at the outfall. All sewers are made of concrete pipes. The overall drainage density of the area can be expressed as 0.035 km of sewers per one hectare of the serviced area. This represents a very low drainage density and should lead to a fairly slow hydrological response of the catchment.

The types of industries located in the study area include food processing, sheet metal and steel fabrication, and wholesale offices and warehouses. In the overall evaluation, the area is fairly clean and well maintained.

FIELD OBSERVATIONS

The Blair Road catchment has been instrumented for observations of rainfall/runoff processes. The data collection system consisted of a runoff monitoring station and a rainfall monitoring station. Additional data were obtained in later phases of the study by sampling street surface deposits and road runoff.

Runoff monitoring station

The station serving for monitoring of runoff consisted of a flowmeter and an automatic sampler. For flow measurements, a calibrated weir was used in conjunction with a stilling well and a float-type water level recorder.

Runoff quality was monitored by collecting and analyzing runoff samples. For this purpose, a Sigmamotor automatic wastewater sampler was used. The sampler collected up to 24 sequential samples, 500 ml each. The constant sampling interval was selected in the range from 5 to 15 minutes.

Rainfall monitoring station

For the monitoring of rainfall, a new sequential sampler was developed. The instrument recorded rainfall rates, collected sequential samples of rainwater, and also collected composite samples of dry fallout. The instrument was assembled from commercially available components. A brief description follows (Ng, Boucher and Dolanjski, 1981).

The sequential rainwater sampler combines a modified Sangamo precipitation sampler, a modified Manning S-4040 automatic wastewater sampler, and a tipping bucket assembly in a fabricated stainless steel body, as shown in Fig.2. At the start of rainfall, moisture sensing grids activate a control motor which then removes the lid from the rainwater collector (500 x 500 mm) and places it over the dry fallout collector. The collected rainwater passes through a tipping bucket assembly which serves for recording rainfall rates and then is directed into an automatic sampler. The sampler collects up to 23 sequential samples in 500 ml bottles, at constant time intervals. The volume of individual samples depends on the rainfall intensity and the sampling interval. The collection of a full sample of 500 ml correspond to the rainfall depth of 2 mm.

At the end of rainfall, the electrically heated sensor grids dry out and the lid swings into the closed position - covering the rainwater collector and opening the dry fallout collector.

The operation of the tipping bucket is recorded by a Sodeco impulse printer which prints out times of individual bucket tips.

WATER QUALITY PARAMETERS

The selection of parameters studied was limited to those which are of interest in runoff studies and which could be reliably analyzed in both rainfall and runoff samples. Low concentrations of suspended solids in rainwater prevented their analysis and further consideration in this study.

Sources of nutrients in urban runoff are numerous and include organic pollution, fertilizers, air scavenging, and automobile exhausts. Nutrient loadings carried by urban runoff then contribute to the eutrophication of lakes and impoundments and to the increased productivity of rivers. Consequently, the following four types of nutrients were studied - nitrate/nitrite, ammonia, the Total Kjeldahl Nitrogen (TKN), and total phosphorus. As an indicator of organics, dissolved organic carbon was used.

Urban runoff is known to transport significant quantities of trace elements. Many of these elements are known for their toxicity and the resulting adverse impact on the receiving waters. These elements generally originate from combustion and industrial sources and can be transported in both wet and dry fallout. The selection of trace elements was limited to copper, lead, and zinc, which are most widespread in urban runoff.

Additional runoff quality data were available from two other urban catchments in Burlington (Marsalek, 1984).

The laboratory analysis of all samples was done by the Analytical Laboratory of the Water Quality Branch, Inland Waters Directorate, Burlington. For details of analytical methods, reference is made to the laboratory manual (Water Quality Branch, 1979).

RESULTS AND DISCUSSION

The results presented below deal with pollutant concentrations observed in rainwater and runoff, variations in concentrations during individual events, and comparisons of loadings contributed by rainwater and runoff.

Pollutant concentrations

Two types of concentrations were considered in the analysis - observed(instantaneous) concentrations and volume-weighted mean concentrations.The observed concentrations are summarized in Table 1. Comparisons of concentrations observed in rainwater and runoff are done for various characteristics of both data sets.

Table 1. Pollutant concentrations observed in rainwater and runoff

	Concentrations (mg/L)					
Parameter	Range Rain-water	Range Runoff	Mean Rain-water	Mean Runoff	St.Deviation Rain-water	St.Deviation Runoff
NO_2/NO_3	.22 - 1.50	.27 - 1.51	.581	.724	.384	.293
NH_4	.13 - 0.92	.02 - 0.49	.464	.254	.208	.017
TKN	.18 - 1.07	.17 - 0.85	.505	.418	.258	.189
DOC	.40 - 2.00	1.2 - 6.40	.968	2.52	.417	1.12
TP	.003- .043	.015- .358	.013	.128	.010	.079
Cu	.010-.067	.010- .057	.023	.022	.013	.011
Pb	.065	.012 - .43	---	.113	---	.092
Zn	.014-.840	.018 - .53	.040	.155	.024	.120

When comparing ranges, it appears that they are fully comparable for concentrations of all forms of nitrogen, copper and zinc in both rainwater and runoff. For dissolved organic carbon, the maximum concentrations in runoff exceed those in rainwater several times and, finally, for total phosphorus and lead, the maximum concentrations in runoff were an order of magnitude higher than those in rainwater.

The next comparison was made for means of observed concentrations. At 95% level of confidence, the differences between mean concentrations of NO_2/NO_3, TKN, and copper in rainwater and runoff were insignificant. For the remaining five parameters, the differences in means were statistically significant. In the case of ammonia, the rainwater mean concentration exceeded that in runoff and the opposite was true for dissolved organic carbon, total phosphorus, lead, and zinc.

The volume-weighted concentrations of various parameters were also calculated and presented in Table 2 below. For 95% level of confidence, the differences between these mean concentrations of ammonia, TKN and copper in rainwater and runoff were insignificant. Such results are similar to those noted above for arithmetic mean concentrations.

Table 2. Volume-weighted mean concentrations in rainwater and runoff

	Mean Concentrations (mg/L)	
Parameter	Rainwater	Runoff
NO_2/NO_3	.571	.802
NH_4	.383	.258
TKN	.419	.430
DOC	.885	2.71
TP	.011	.141
Cu	.022	.020
Pb	--	.092
Zn	.041	.132

It follows from comparisons of volume-weighted mean concentrations that the loadings of various forms of nitrogen and copper in runoff are primarily contributed by rainwater. On the other hand, rainwater contributed barely any phosphorus and lead, but some considerations may be given to the contributions of organic carbon and zinc.

Besides comparisons of event loadings, it was of interest to examine the variations in runoff quality resulting from variations in rainwater composition. For this purpose, the earlier described rainwater and runoff quality data were used. In this regard, sequential rainwater quality data are relatively unique, because in most studies only composite samples of rainwater are collected.

Variations in rainwater compositions in the Blair Road catchment were investigated and reported earlier by Ng (1982). Some of his results are summarized in Table 3 and Fig.3.

It can be inferred from Table 3 that the composition of rainwater may vary significantly between events as well as during individual events. It appears from Fig.3 that although there are large random variations in the rainwater composition, there is a persistent trend of gradually decreasing concentrations for practically all parameters.

Table 3. Rainwater composition in Blair Road catchment

	Concentrations (mg/L)			
Parameter	Mean	St.deviation	Range of observed concentrations	Range of mean event concentrations
NO_2/NO_3	.620	.370	.02 - 1.67	.17 - 1.64
NH_4	.470	.300	.01 - 1.45	.10 - 1.09
TKN	.530	.297	.12 - 1.35	.16 - 1.07
DOC	1.15	.379	.40 - 2.70	.90 - 2.20
TP	.018	.009	.003-.059	.01 - .038
Cu	.025	.014	.010 - .13	.01 - .051
Zn	.054	.036	.010 - .26	.019- .128

To investigate the relationship between variations in rainwater and runoff compositions, correlations between both sets of data were investigated for the limited data available (4 events). In this analysis, a lag time of 10 minutes was assumed for the runoff record. The average values of the linear correlation coefficient varied from 0.35 to 0.79. The highest values were found for ammonia and TKN, the lowest values for organic carbon and copper. Although the results for ammonia and TKN support the earlier inferences based on concentrations, the correlation analysis results are inconclusive because of the limited data and the analysis should be extended further as more data becomes available.

The analysis of rainwater and runoff composition indicates certain tendencies which should be further explored for a larger data base. One of the study objectives was to examine the levels of pollutants in runoff from a catchment with industrial land use. For this purpose, some data on runoff quality in three Burlington test catchments are compared in Table 4.

The data in Table 4 show hardly any effects of land use on runoff composition. Concentrations observed in the Blair Road catchment are comparable to those observed in commercial and residential areas with one exception - nitrates and nitrites. Concentrations of nitrates and nitrites in the residential area seem to exceed those observed in the other two catchments.

The rainwater composition data were compared with the bulk precipitation data reported for Lake Ontario Basin (Shiomi and Kuntz, 1973).

Table 4. Runoff composition in catchments with various land use

Parameter	Mean observed concentrations(mg/L)		
	Blair Rd catchment (industrial)	Aldershot Plaza (commercial)	Malvern catchment residential)
NO_2/NO_3	.724	.674	1.573
TP	.128	.252	.159
Cu	.022	.022	.013
Pb	.113	.098	.044
Zn	.155	.127	.160

For inorganic nitrogen, the concentrations observed in the Blair Road catchment amounted to about 60% of the values reported for bulk precipitation. Similarly, the concentrations of total phosphorus and zinc reported here were lower than the bulk precipitation data. Only in the case of copper did the Blair Road exceed the bulk precipitation data.

CONCLUSIONS

A number of conclusions can be drawn from the analysis of rainwater and runoff composition in the present study in regard to effects of rainwater composition on urban runoff quality:

1. Rainwater is the main source of supply of nitrogen to the runoff.
2. Besides nitrogen, rainwater also supplied relatively high proportions of copper, zinc, and dissolved organic carbon.
3. The sources of total phosphorus and lead in urban runoff are primarily landuse activities and dry fallout with practically no contribution from rainwater.
4. There are large random variations in the rainwater composition. Such variations are reflected in urban runoff composition both in time and in magnitude. The relationship was indicated by correlation analysis, but more data are required to reach firm conclusions.
5. Continued monitoring of rainwater and runoff composition should help to establish more accurately the effects of rainwater composition on urban runoff quality. The monitoring of rainwater and runoff composition should extend to include both commercial and residential land uses.
6. Concurrent analysis of rainwater and runoff composition loading should provide considerable information about the impacts of rainwater composition on urban runoff quality.
7. Rainwater composition, particularly dissolved nitrogen, copper and zinc should be considered in the modelling of urban runoff quality.

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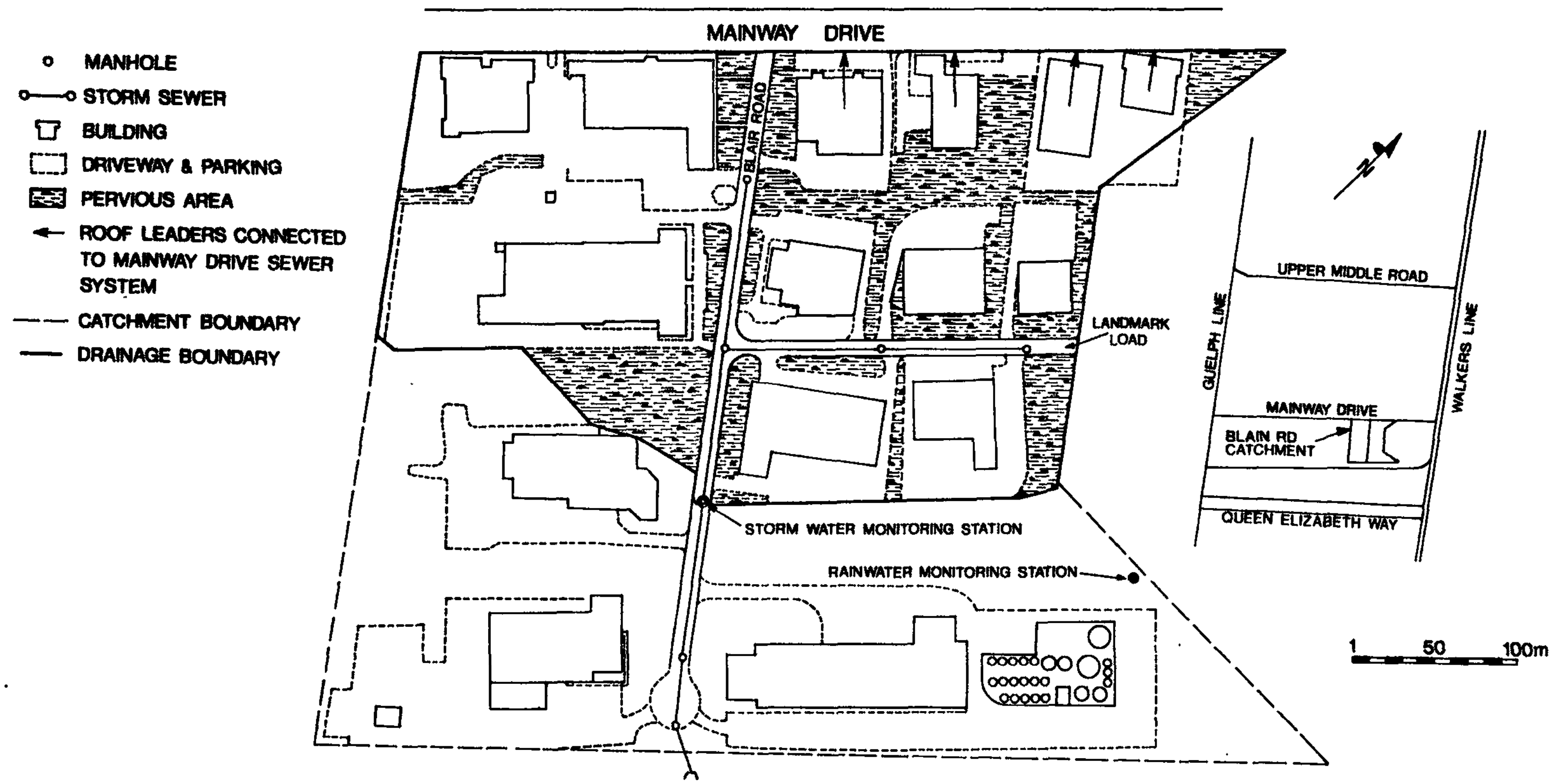

Figure 1 BLAIR ROAD CATCHMENT
BURLINGTON, ONTARIO

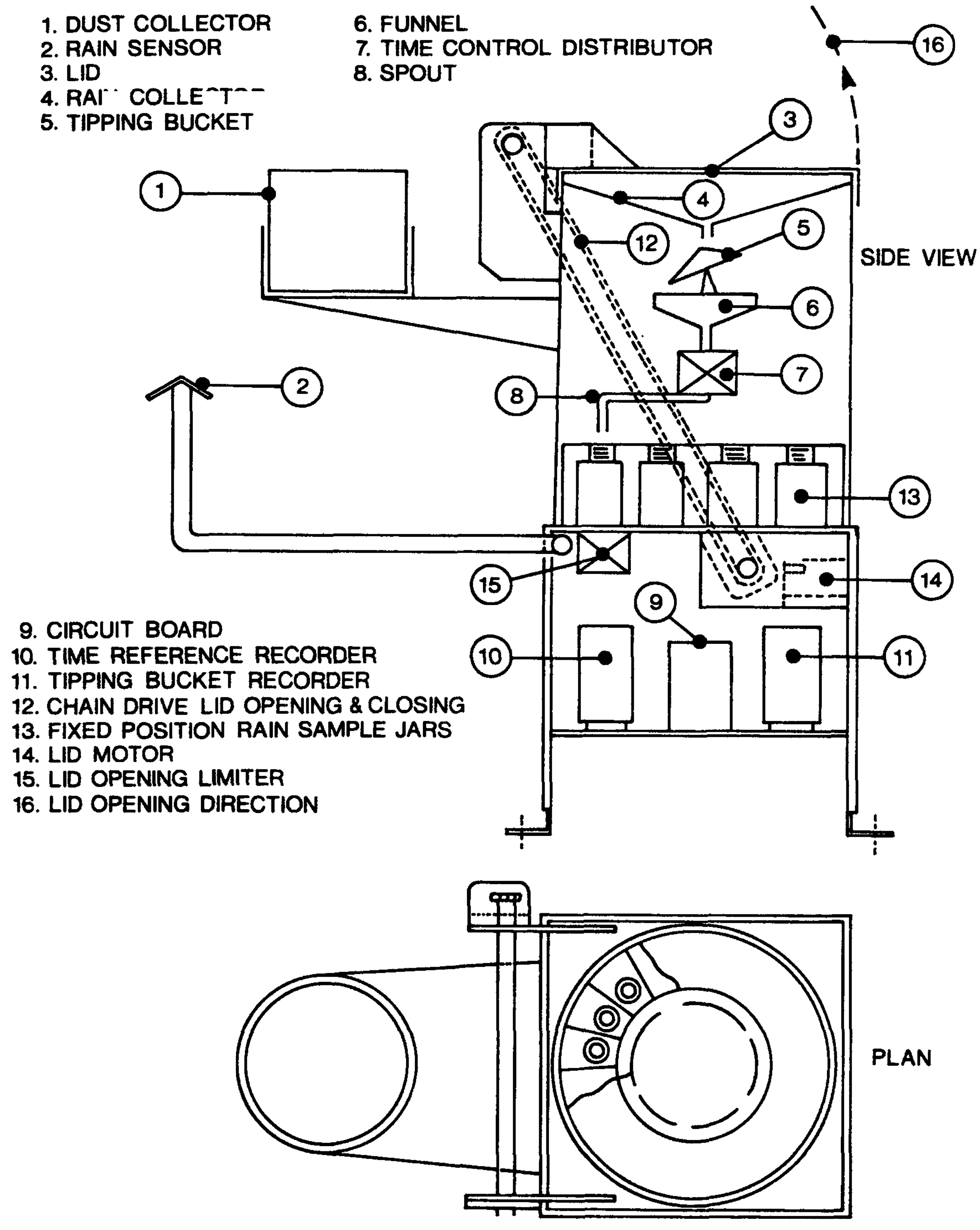

Figure 2. SEQUENTIAL RAINWATER SAMPLER

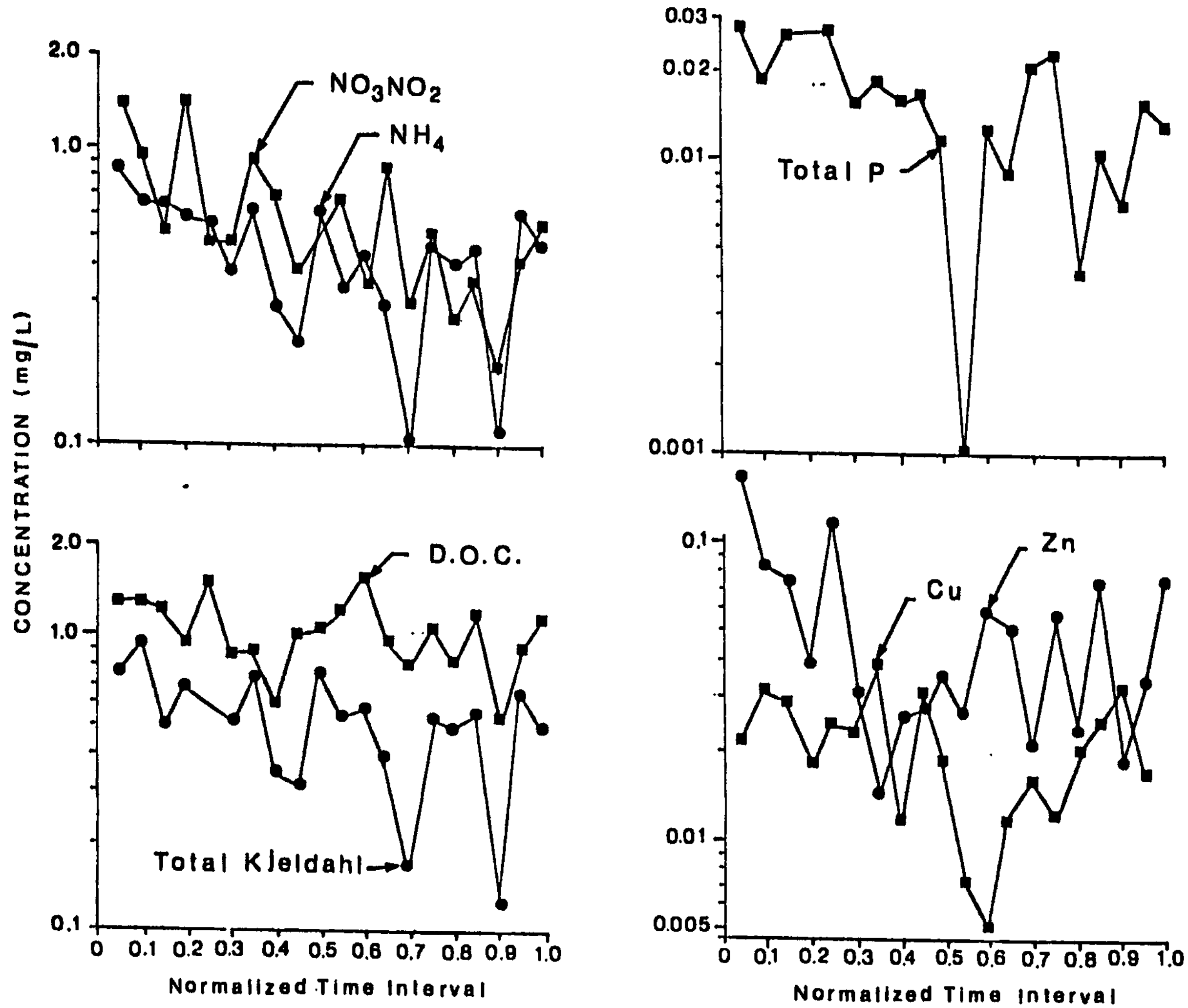

Figure 3. VARIATION TREND OF MEAN CONCENTRATION OF RAIN COMPOSITION.