1982

A Preliminary Assessment of Nutrient Loading Into Narragansett Bay Due to Urban Runoff

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A PRELIMINARY ASSESSMENT OF NUTRIENT LOADING INTO NARRAGANSETT BAY DUE TO URBAN RUNOFF

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In partial fulfillment of the Master of Marine Affairs degree

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INTRODUCTION

In 1907, Weber introduced into scientific jargon a series of words meant to describe the general nutrient condition of the water contained in German bogs (Hutchinson, 1970). One of his series, eutrophic, originally meant well-nourished. Today this term is used not only in its strict sense of increase in nutrient supply but also to mean the effects of this increased supply. This second part of the use of the word, the effects, are often thought of in man-centered ways. If the results of eutrophication are undesirable to man, then eutrophication is thought of as a type of pollution. Not all eutrophication is pollution. Eutrophication is generally considered a natural stage in the succession of standing bodies of water (lakes) and usually leads to extinction. When this natural process is accelerated by man's activities it is thought of as cultural eutrophication (Likens 1972).

This study is a component of a more comprehensive investigation at the Marine Ecosystems Research Laboratory, (MERL), University of Rhode Island, that was undertaken in order to assess the potential for eutrophication in both its meanings as a natural and man-induced process occuring in the upper portions of Narragansett Bay and its watershed. This assessment required identification and quantification of the various inputs in order to establish the annual loading and eventual effects of the four important nutrients; ammonia, nitrate-nitrite, silicate and phosphate. The loading from rivers, sewage treatment plants, runoff and combined sewer overflows (CSO) were judged the most critical for this preliminary assessment. This portion of the overall study involved sampling runoff and CSO effluents. The runoff and CSO stations that were sampled were divided among five land use types: residential, streets and highways, commercial, industrial and combined sewer overflow.

The comprehensive MERL study was designed to arrive at an overall dissolved inorganic nutrient budget for the bay (Table VII). The runoff study was designed to achieve not only the total loading of dissolved inorganic nutrients by way of run-off to the Bay but also to identify the land use types/activities in such a way as to allow rating of inputs in order of relative importance. With the establishment of the importance of each nutrient input in a total budget picture, it is then possible to implement a reasonable scientific approach to limiting the largest inputs. This ability to choose the area that would most benefit from input controls is based on the availability of scientific information which then leads to good management decisions. This study took place from November 1979 to November 1980. The stations that were sampled were all in the upper bay watershed and the locations of each is shown in Figure 1.

PARAMETERS MEASURED

Nitrogen and phosphorus have long been known as critical elements in plant growth. In the case of some marine algae silicate is also an important element. The three nutrients nitrogen, phosphorus and silicate were the elements that were measured in this study to identify the potential for eutrophication resulting from urban runoff to upper Narragansett Bay.

Nitrogen

Of the three nutrients considered the most vital to algae growth; nitrogen, phosphorus and silicon, nitrogen is considered the most complex. Nitrogen can be found in many forms in the environment including dissolved inorganic forms such as ammonia (NH_3)and oxidized forms as nitrite (NO_2^-) and nitrate (NO_3^-), in dissolved organic form (DON) and in particulate organic and inorganic forms. Nitrogen can also occur in dissolved gas form as nitrogen gas (N_2) and nitrous oxide (N_2O) (Jolly 1964).

The major inorganic forms, nitrate (NO_3), nitrite (NO_2) and ammonia (NH_3) can all be used as nitrogen (N) sources by the majority of algal species (Raymont

1980). For this reason, these are the forms of most concern in assessing eutrophication potential and are the forms that were measured in this study. In terms of immediate usefulness, NH_3 has an advantage in that it can be used directly in the production of amino acids without any expenditure of energy to change its form (Raymont 1980).

NH_3 is a major component of the dissolved N found in sewage effluent and is also present in rain. The major source of NO_2 is municipal effluents. NO_3 is found in runoff from land and in rainwater (MacKenthun 1965). According to Raymont (1980, p. 337) "nitrogen is generally the most important element in relation to nutrient limitation of productivity in marine environments".

Phosphorus

The major form of phosphorus in seawater (and the one measured in this study) is as the inorganic orthophosphate ion generally referred to as phosphate (P). Orthophosphate (PO_4^{3-}), is the final breakdown product in the phosphorus cycle and the form most readily available for biological utilization (Griffith 1973). In certain instances of higher productivity, organic compounds of phosphorus, produced by biological processes, can form a significant part of the total dissolved phosphorus (P). There has not, however, been much progress in the attempt to characterize these organic compounds. It would be expected that these compounds would include several substances that include the orthophosphate grouping such as phospholipids and sugar esters.

Phosphorus can also occur in the particulate form. In many recent coastal and estuarine studies particulate phosphorus measurements have been made. However, these measurements have not lead to information of an interpretive nature since the availability of the element (P) to organisms is dependent on the nature of the association with particulate material and the types of associations between P and the particulate materials have not been adequately characterized (Raymont 1980.

Silicon

Silicon is the simplest of the three nutrients investigated. The major cycle of silicon involves only inorganic forms. This cycle can be described in two steps. Step one is the production of opaline silica by the utilization of dissolved silicon by phytoplankton (diatoms). Step two is the dissolution of this opaline silica following the death of the organisms (Raymont 1980).

Silicon as studied here is not actually measured to assess eutrophication potential. It is studied here as a necessary element in the maintenance of a typical estuarine phytoplankton community.

Silicate is required by diatoms for skeletal formation. If the amount of silicate available to the phytoplankton is low compared with the amount of nitrogen and phosphorus then a shift in the phytoplankton community can take place. The shift in the phytoplankton community would be in the direction of non-silicate requiring algae. A shift in the phytoplankton community from the diatoms (algae that require silicate) can have a profound effect on the following trophic levels. Zooplankton grazers are known to be selective as to size and shape of phytoplankton grazed. A shift in the phytoplankton community could lead to the inefficient grazing of zooplankton resulting in a lower total biomass. It has been speculated by O'Connors et al. (1978) that there are two pathways for the transfer of biomass through marine webs. One pathway leads from large phytoplankton by way of a 1 to 3 step food chain to fish that are harvestable by man. The other leads through approximately 5 trophic levels to various gelatinous predators (jellyfish). Therefore, the amount of silicon that is available in the environment can have very important effects on the type of phytoplankton produced. A more indepth discussion and study of the effects of silicon in the environment is being undertaken by the Marine Ecosystem Research Laboratory (MERL) at present in a year long study of the effects of nutrient additions to estuaries.

SOURCES OF NUTRIENT INPUTS

Point Sources

Point sources are effluents that are reported and can be traced to specific sources. For example, treated sewage that is found in a body of water can easily be traced back to the effluent pipe coming from a sewage treatment plant. That treated sewage could have originated from only one point source, a sewage treatment plant (STP) or any one of a number of STP's if more than one is located in the area.

Combined sewer overflows (CSO) are considered point sources in terms of sewage outfall. They can also be considered non-point sources since they also carry urban runoff.

Non-point Sources

Urban runoff is a non-point source of pollution, not easily evaluated or controlled. Non-point sources of pollution are really many unrecorded point sources of pollution. Rain falls onto roofs, streets, parking lots, gardens and yards. Some water is absorbed but much of the area in urban regions is impervious allowing the rain to flow into gutters and find its way into drains and waterways. In its movement, the rain has collected dust particles from the air that may have come from a municipal incinerator carrying PCBs and other toxic chemical vapors. It can collect animal refuse from streets with its bacterial load, organic debris and nutrients, larger forms of litter, heavy metals and petroleum byproducts from industrial sites and roadways. The air and land always feel and look refreshed and clean after a rainfall but in reality the pollutants have only been collected and moved from many areas to some body of water. This water body may be someone's drinking water, recreational area or favorite shellfishing or fishing ground.

METHODS

Storm generated discharges occur when enough rain has fallen to wet the ground and allow the excess to runoff. In order to sample this runoff either automatic samplers or personnel must be ready at all times since the nature of rain is very variable and unpredictable. Automatic samplers were not available, however, with the help of the Channel 10 weathermen and the National Weather Service, we were able to be at the chosen station before a rain event took place in order to sample the "first flush". The year November 1979 - November 1980 was the sampling period.

Sample Site Selection

The sites chosen to be sampled in the upper portion of Narragansett Bay were determined by selecting those sites that fulfilled the highest number of preconditions listed below. The conditions were established to help insure the greatest number of successful sampling trips as possible, prior to an actual rain event. The criterion for site selection are listed below.

1. For storm drains there were no sanitary inputs; for CSO there were; into the drainage system being studied.
2. The study area being drained is > 95% one land use type.
3. The drain system under consideration is representative of that land use type in Rhode Island.
4. Maps exist of areas under consideration to allow total acreage calculation.
5. The drain outfall is not usually underwater at high tide or high water.
6. The outfall must be approachable (w/o long or dangerous hikes in the rain) and should be able to be sampled with reasonable safety.

7. With the chip and timing method, a catch basin or manhole near the outfall for the deposition of chips for velocity measurements is a necessity. With a flow meter this is not necessary.
8. Sampling must be able to take place any time of the day or night, the outfall cannot be blocked by fences or gates and is on public property.
9. A parking place shoud be reasonably close to the outfall.
10. The natives are friendly.

A series of storm drains in Providence and Warwick were investigated as possible sample sites for this study. Six stations were chosen as those available that best met the criteria listed above. These station locations are shown in Figure 1 and are listed and classified below.

Station 1 - I-95 - Street and Highway (Figure 1, No. 1)

This station is located on the northward bound side of I-95 in Warwick between Jefferson Blvd. and Rt. 10 exits. It drains 135.5 acres, 1½ miles of Rt. I-95 and one mile of Rt. 10 interchange. There is some groundwater intrusion. The drainage pipe is 120" in diameter and can be sampled by standing on top of the pipe and dropping a bucket down. The round pipe empties into an open channel that is 13.08 ft. wide. The channel leads directly to the Pawtuxet River. There are 8,561 acres in the upper bay watershed that are described as streets and highways, which this station is used to represent.

Station 2 - Westminster - Industrial (Figure 1, No. 2)

The industrial park is located in East Providence just across the Runnins River from Seekonk. The drainage system is completely underground until it reaches the Runnins River as an outfall. The sampling required the raising of a manhole cover since the outfall is covered by the river during times of even low

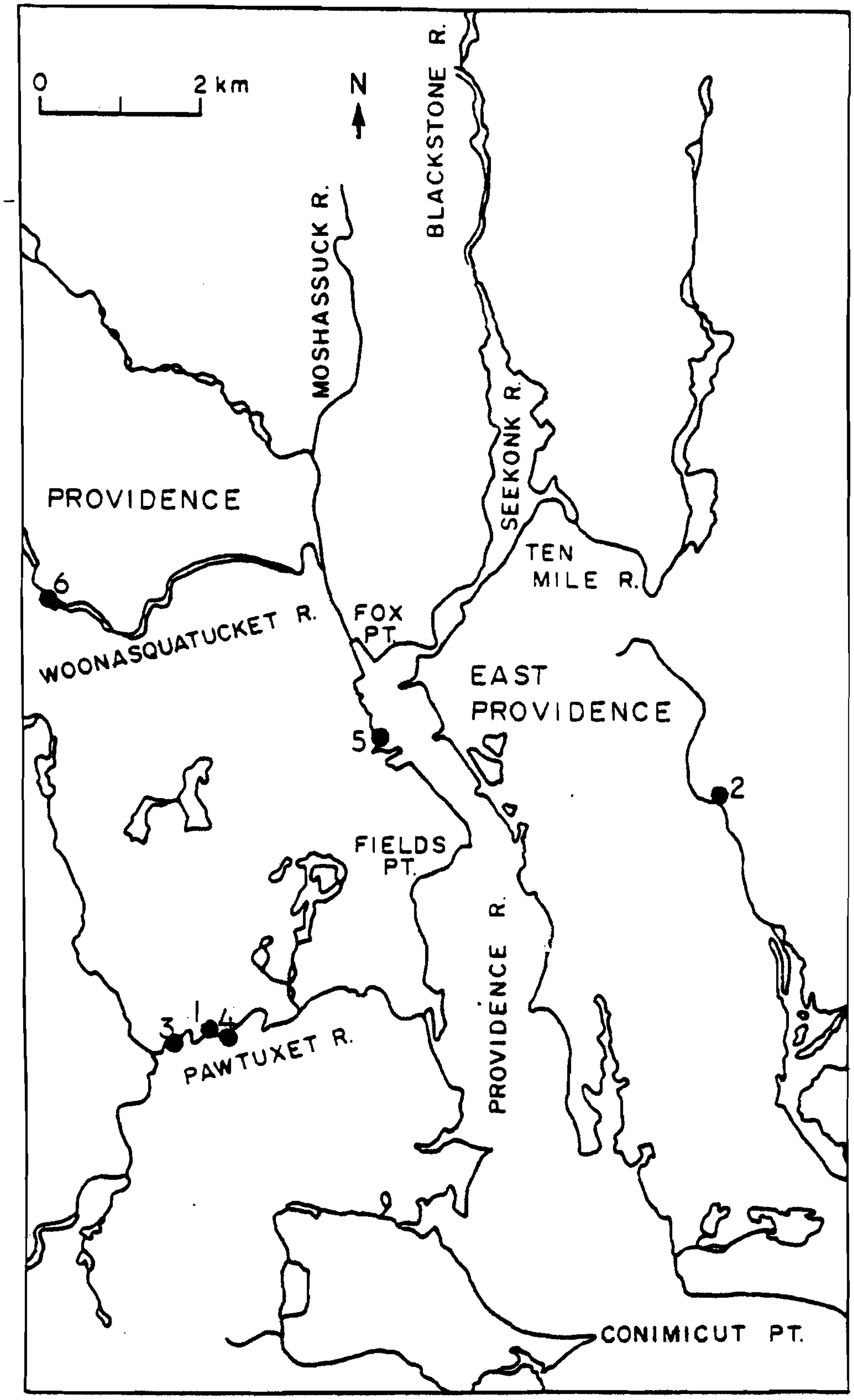


Figure 1.
1. I-95 Street and Highway
2. Westminster - Original Industrial
3. Shopping Mall - Commercial
4. Manolla Ave. - Residential
5. Thurbers Ave. - Industrial
6. Sheridan St. - CSO

rainfall. The pipe is 14" in diameter and was located on Catamore Blvd. between Jordan St. and Highlands Ave. This drainage area consisted of 38.6 acres. The number of acres in the upper watershed area considered industrial is 4,142. This industrial park is not really representative of the rest of the area in R.I. classified as industrial. The park is too new, clean, and does not have any of the heavy industry common to other areas. This area was abandoned after one storm and replaced with the Thrubers Ave. station as more representative.

Station 3 - Shopping Mall - Commercial (Figure 1, No. 3)

This area consists of approximately one half of a widely used shopping mall parking lot in Warwick. The parking lot is heavily traveled and completely paved with an asphalt-sand mix. It is gently sloped toward the catch basins. The drain travels underground from the parking lot to the outfall which is at the Pawtuxet River. The outfall, which is a 58"x36" elliptical corrugated pipe, has one other small pipe outfall to its side. Only once during the sampling did the river rise enough to cover the outfall so as to prevent sampling. This outfall carries the runoff from 30.92 acres and represents the total commercial acreage in the upper bay watershed which is 5,709 acres.

Station 4 - Manolla Ave. - Residential (Figure 1, No. 4)

A 36" concrete storm drain pipe, is located at the foot of a hill at the end of Manolla Ave., Warwick, a middle-class residential neighborhood consisting of single family homes on ¼ to ½ acre lots. The drain opens to a 100 yd. long culvert that leads to the Pawtuxet River through a wooded area. The drainage area here is 137.9 acres. There are 43,656 acres of residential area in the upper bay watershed.

Station 5 - Thurbers Ave. - Industrial (Figure 1, No. 5)

This station is located at the traffic light at the foot of the Thurbers Ave. exit off of I-95 northbound, at the intersection of Allens Ave. and Thrubers Ave. This is a very old area of town with a long history of industrial activity. This storm drain, for a few acres, is also a combined sewer overflow system. The outfall pipe is 72" in diameter and opens into a channel a short distance from the bay. It is tidally influenced and therefore can only be sampled at certain time intervals. This station is a better representation of a typical R.I. industrial area than the previously sampled Westminster Industrial Park. This drain covers 3.6 acres for sanitary use and 217.8 acres total drainage. There are 4,142 acres in the upper bay watershed zoned industrial.

Station 6 - Sheridan St. - CSO (Figure 1, No. 10)

Located at the end of Sheridan St. in Providence is a 54" pipe which discharges to the Woonasquatucket River. This is a combined sewer overflow system carrying rain water and sanitary sewer discharge to the river. This system serves 37.1 acres of combined residential and commercial land use. There is a housing complex adjacent to the drainage area and some smaller stores and halls. There are 9,648 acres in the city of Providence on CSO drainage systems.

Sampling Procedure and Analysis

A discrete sampling regime was used. Discrete samples characterize water quality for short periods of time. Sampling was undertaken at regular, usually one hour, intervals except during a flush when sampling was done every 15 or 20 mintues for the duration of the flush. (Data points on Figures 2-13 vary according to the duration and intensity of rainfall). The greatest concentration of material often occurs during the early period of the storm. As the runoff flow increases in the sewers, the accumulation of the dry weather solids are flushed from the sewers, or collected from the contributing land areas. The initial flows containing high concentrations of contaminants are often referred to as the "first flush". It was postulated that the relative height of a "first flush" peak could be influenced by the time interval between rainfall events. However, according to Whipple (1977), "there does not appear to be any discernible tendency for storm loadings to vary with the number of days since the preceding rainfall", (p. 2245). The preliminary nature of this study necessitated the exclusion of the determination of this question with regard to Narragansett Bay.

Discrete sampling allows a total picture of water quality throughout the storm event. Each point on the graphs in Figures 2-13 represent a single sample. The analysis of each sample allows the determination of the concentration of each nutrient at every time interval. The extrapolation of concentration vs. flow volume allows an accurate assessment of flux. (Flux = flow x concentration which equals the amount of nutrient flowing into the Bay per storm to be calculated). Pooled sampling is another possible method that could be employed here but is not recommended since it would not allow the storm profile of flux to be determined. Discrete sampling with flux determination is very dependent on accurate monitoring of stream flow variabilities. Monitoring can be accomplished by in stream flow meters or the chip and timing method.

At the time of this research the chip and timing method including a marked dipstick was employed. Since then a flow meter intercalibration has indicated an 8% difference in flow velocity by the two methods. The chip method giving 8% lower velocities. No correction of initial velocity measurements were considered necessary.

Sample collection was made at the outfall of each storm drain. Where high water prohibited collection was made through a manhole. All samples were collected with a clean polyethylene beaker suspended on a monofilament line. Water was drawn with a syringe and put through a 0.45 μm millipore filter into 60 ml plastic bottles that had been cured with deionized water and stored on ice.

The nutrients were analyzed using a Technicon-Autoanalyzer, based on the procedures recommended by Friedrich and Whitledge (1972). Each sample was run in duplicate, interspersed with a synthetic seawater wash. Standards were run each day prior to samples; internal standards were added at least once every 40 samples. Peaks were recorded on two 2-channel Hewlett-Packard recorders. The average concentration of duplicate samples is reported. Corrections for baseline drift were made when necessary by changes in transmission of internal standards or by stopping the analyzer at intervals with the sample probe in synthetic seawater (baseline water). Precision is estimated at: c.v. of ±0.98% at 5 μm ammonia, c.v. of ±1.8% at 5 μm nitrite plus nitrate; c.v. of ±1.05% at 5 μm phosphate and c.v. of 1.16% at 5 μm silicate.

Storm Sampling

The sampling period, November 1979 - November 1980, was included in a time period of the worst recorded drought in many years in Rhode Island. Due to this drought the number of storm events successfully measured during their entirety was limited to 12. The twelve storms with dates, locations, land use types, drain type and total rainfall can be found in Table 1, and are described below.

Highway - Station 1 (Figure 1, No. 1)

The flow vs. time graphs(Figs. 2,3, and 4-A)are descriptive of the type of storm sampled. Samples were taken every hour except during periods of heavy rainfall called peakes or flushes.

Julian date 79330 - This storm consisted of low, fairly steady rainfall for five hours (300 min.) before a heavy downfall occurred. There was one small peak at three hours (180 min.) (Figure 2A).

Table I

Storm Sampling Dates and Locations

Station - Dates	Julian Date	Land Use Type	Storm Drain/CSO	Rainfall/cm (rounded)
1 - Interstate 95		highway	SD	
11-26-79	79330			1.10
4-28-80	80119			0.65
10-25-80	80299			3.70
2 - Westminster Park		industrial	SD	
12-06-79	79340			1.10
3 - Shopping Mall		commercial	SD	
12-13-79	79347			0.50
4-09-80	80100			5.75
4 - Manolla Ave.		residential	SD	
3-21-80	80081			1.10
10-18-80	80292			0.50
5 - Thurbers Ave.		industrial	SD	
5-21-80	80142			1.20
7-29-80	80211			3.20
6 - Sheridan St.		residential/ commercial	CSO	
7-29-80	80211			3.20
10-28-80	80302			0.60

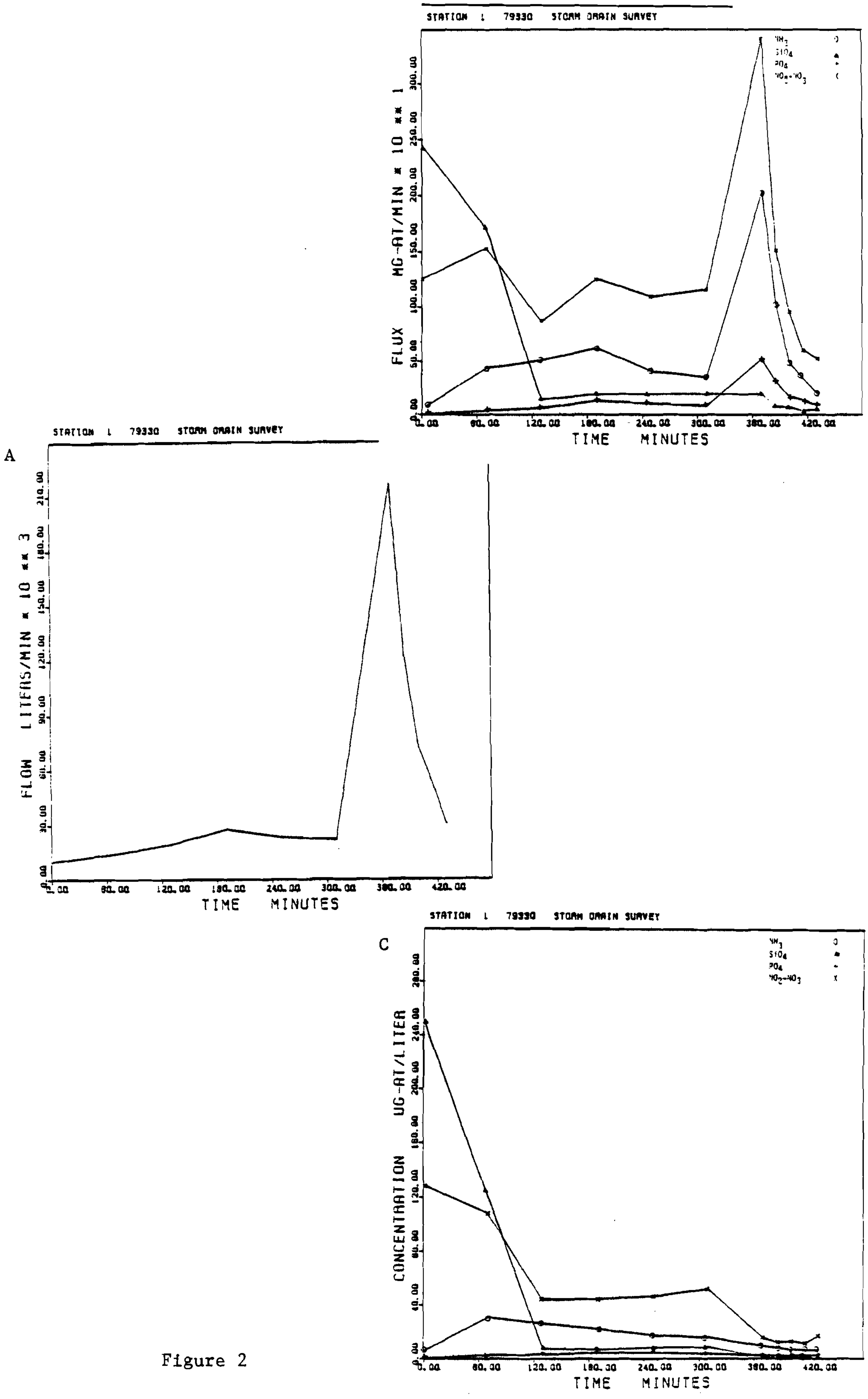
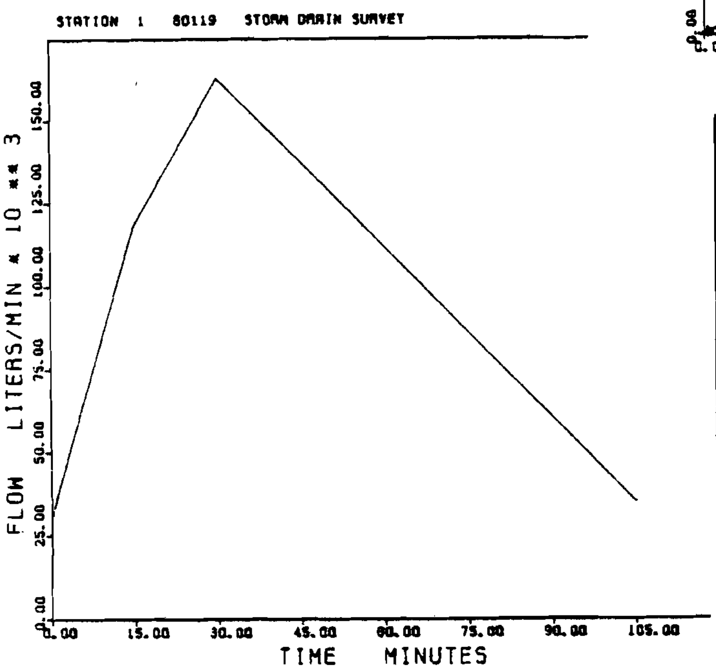
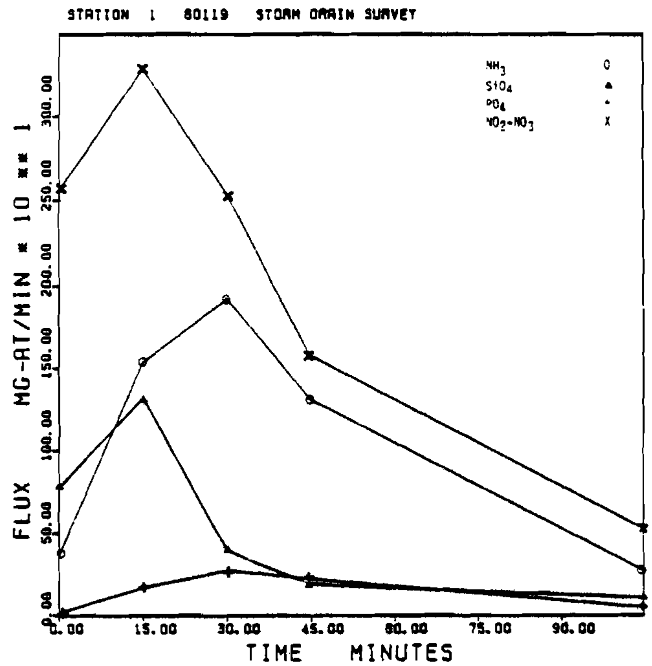

A
STATION 1 79330 STORM DRAIN SURVEY
FLOW LITERS/MIN * 10 ** 3
0.00
30.00
60.00
90.00
120.00
150.00
180.00
210.00
0.00
60.00
120.00
180.00
240.00
300.00
360.00
420.00
TIME MINUTES
B
STATION 1 79330 STORM DRAIN SURVEY
FLUX MG-AT/MIN * 10 ** 1
0.00
50.00
100.00
150.00
200.00
250.00
300.00
NH_3
SiO_4
PO_4
NO_2+NO_3
TIME MINUTES
C
STATION 1 79330 STORM DRAIN SURVEY
CONCENTRATION UG-AT/LITER
0.00
40.00
80.00
120.00
160.00
200.00
240.00
280.00
NH_3
SiO_4
PO_4
NO_2+NO_3
TIME MINUTES

Figure 2

A


STATION 1 80119 STORM DRAIN SURVEY
FLOW LITERS/MIN * 10 ** 3
0.00
25.00
50.00
75.00
100.00
125.00
150.00
0.00 15.00 30.00 45.00 60.00 75.00 90.00 105.00
TIME MINUTES

B


STATION 1 80119 STORM DRAIN SURVEY
NH3 O
SiO4 ▲
PO4 +
NO2-NO3 X
FLUX MG-AT/MIN * 10 ** 1
0.00
50.00
100.00
150.00
200.00
250.00
300.00
0.00 15.00 30.00 45.00 60.00 75.00 90.00
TIME MINUTES

C

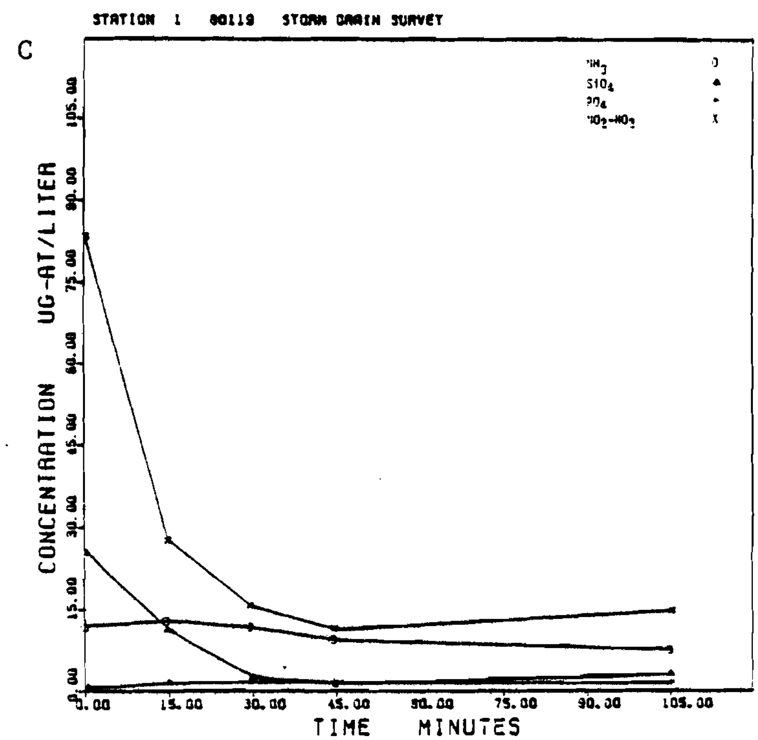
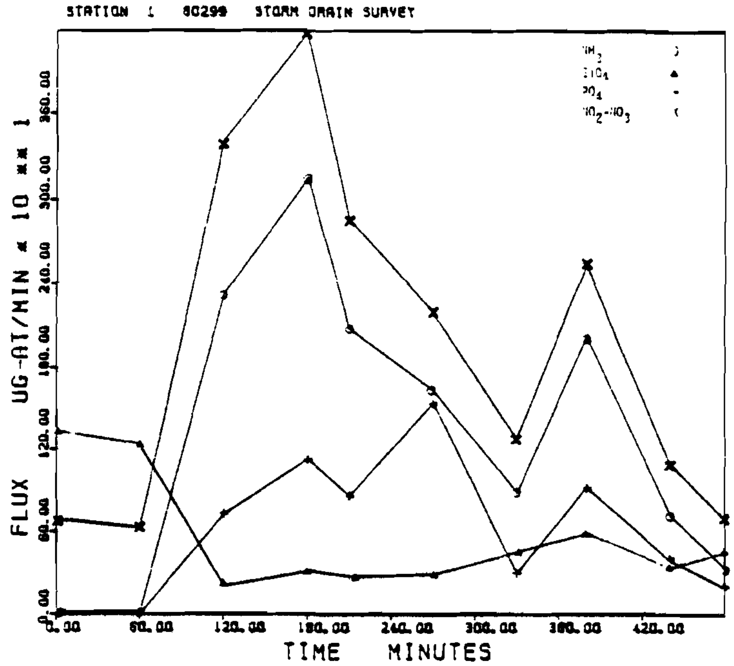
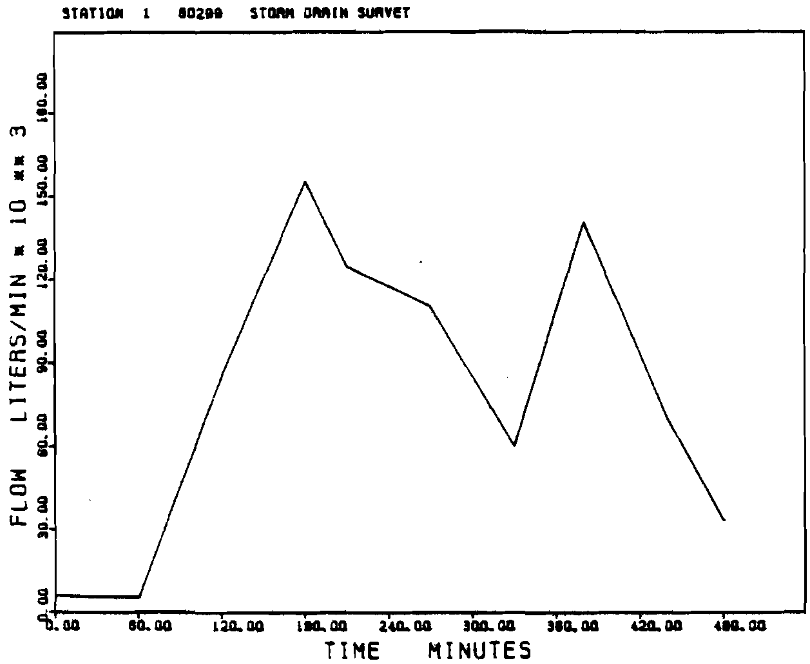

STATION 1 80119 STORM DRAIN SURVEY
NH3 O
SiO4 ▲
PO4 +
NO2-NO3 X
CONCENTRATION UG-AT/LITER
0.00
15.00
30.00
45.00
60.00
75.00
90.00
105.00
0.00 15.00 30.00 45.00 60.00 75.00 90.00 105.00
TIME MINUTES

Figure 3


STATION 1 80299 STORM DRAIN SURVEY
FLUX UG-AT/MIN * 10 ** 1
0.00
60.00
120.00
180.00
240.00
300.00
360.00
TIME MINUTES
0.00 60.00 120.00 180.00 240.00 300.00 360.00 420.00

B

A


STATION 1 80299 STORM DRAIN SURVEY
FLOW LITERS/MIN * 10 ** 3
0.00
30.00
60.00
90.00
120.00
150.00
180.00
TIME MINUTES
0.00 60.00 120.00 180.00 240.00 300.00 360.00 420.00 480.00

C

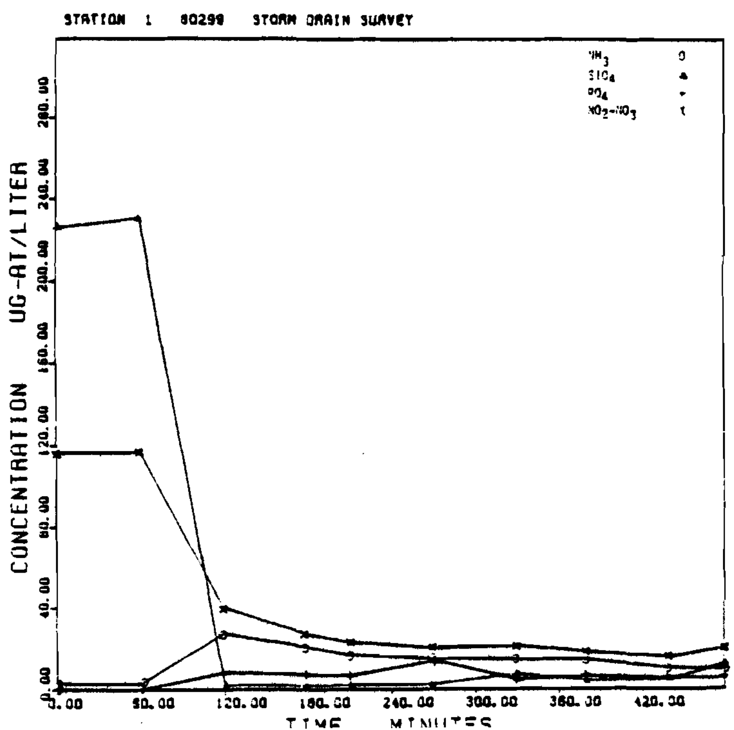

STATION 1 80299 STORM DRAIN SURVEY
CONCENTRATION UG-AT/LITER
0.00
40.00
80.00
120.00
160.00
200.00
240.00
280.00
TIME MINUTES
0.00 60.00 120.00 180.00 240.00 300.00 360.00 420.00

Figure 4

Julian date 80119 - A fairly heavy, steady downpour made up the storm profile for this storm. The peak occurred at 30 minutes but the flow responded to only a gradual lessening of rain (Fig. 3A).

Julian date 80299 - Two very obvious and one smaller peak occurred during this storm profile. The three peaks occurred at three hours (180 mins.), four hours and 30 minutes (270 mins.) and six hours and 15 minutes (375 mins.) (Fig. 4A).

Comparison between the flux graphs (Figs. 2, 3 and 4B) (flux = concentration times flow) v. time and the flow v. time for each respective storm show certain similarities. The flux of NO_2-NO_3 and NH_3 closely follows the amount of flow. The PO_4 peaks seem to lag slightly behind the peaks in flow. The SiO_4 peaks are not very responsive at all.

It is interesting to note that in the concentration graphs (Figs. 2, 3 and 4C) the SiO_4 and the NO_2-NO_3 peaks start consistently high. Since sampling is begun at low flow or standing water conditions these high concentrations may indicate a fairly high accumulation or dissolution rate of the SiO_4 and NO_2-NO_3. It is known that the silicate dissolution rate is slow which could explain the drop in silicate concentration when the water velocity increases and the obvious non-correlation with flux graphs.

Station #1 (Fig. 1, #1) is the only one with sufficient data to allow the derivation of correlation coefficients between total rainfall and the total loading of the individual nutrients. These are listed in Table II.

Table II.

Nutrients	Correlation Coefficient
Ammonia (NH_3)	.9950
Phosphate (PO_4)	.9997
Nitrite-Nitrate (NO_2-NO_3)	.9277
Silicate (SiO_4)	.6268

The correlation coefficients for all but the silicate are near 1.0 and indicate that loading factors can be calculated by rainfall measurements alone. However, this is not recommended until more data is accumulated to establish the accuracy of these initial calculations.

Industrial - Station 2 (Fig. 1, #2, Fig. 5A, B and C).

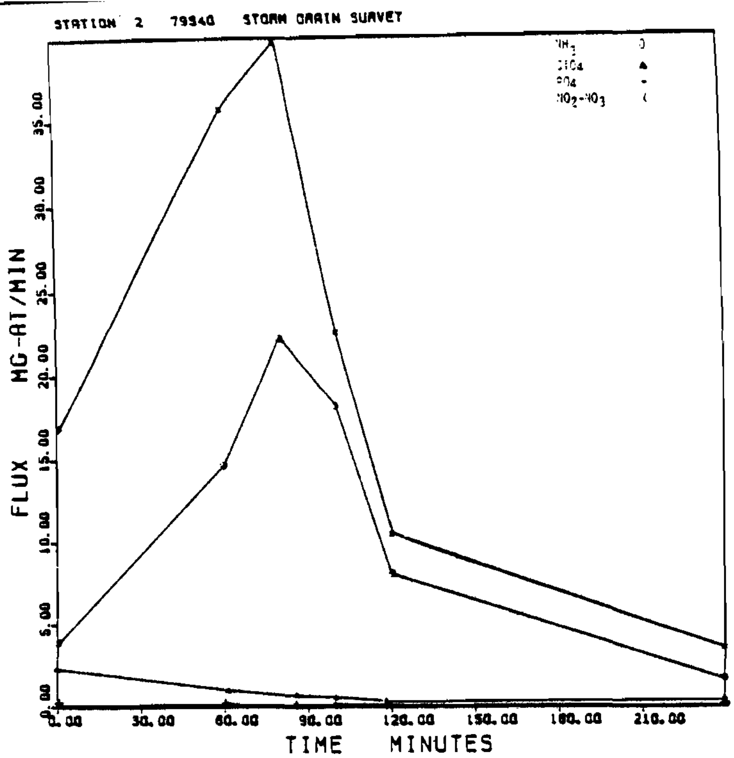
The one storm sampled at the Westminster Park Industrial station consisted of one peak at one hour and 20 minutes (80 mins.) (Fig. 5A). This storm showed the NH_3 and NO_2-NO_3 peaks in flux (Fig. 5B) following closely the storm profile but with no real reaction in PO_4 or SiO_4. In general levels of all of the nutrients were relatively low and considered as non-representative of most of the industrial areas of Rhode Island. This station was not studied further.

Commercial - Station 3 (Fig. 1 #3).

The commercial station was sampled twice (Figs. 6 and 7) for nutrients. The two storms represent opposite ends of a spectrum in terms of rainfall and intensity.

Julian date 79347 (Fig. 6A) - This entire storm profile would look like a straight line if the axis of flow were not greatly expanded compared to all the other flow graphs. Drizzle or very light rain would be the adjectives used to describe this precipitation. The flow over the entire six hours barely changed. Even so, flux (Fig. 6B) of NH_3 and NO_2-NO_3 still followed the storm profile very closely. The concentrations of all of the nutrients (Fig. 6C) changed imperceptibly until the rain stopped completely.

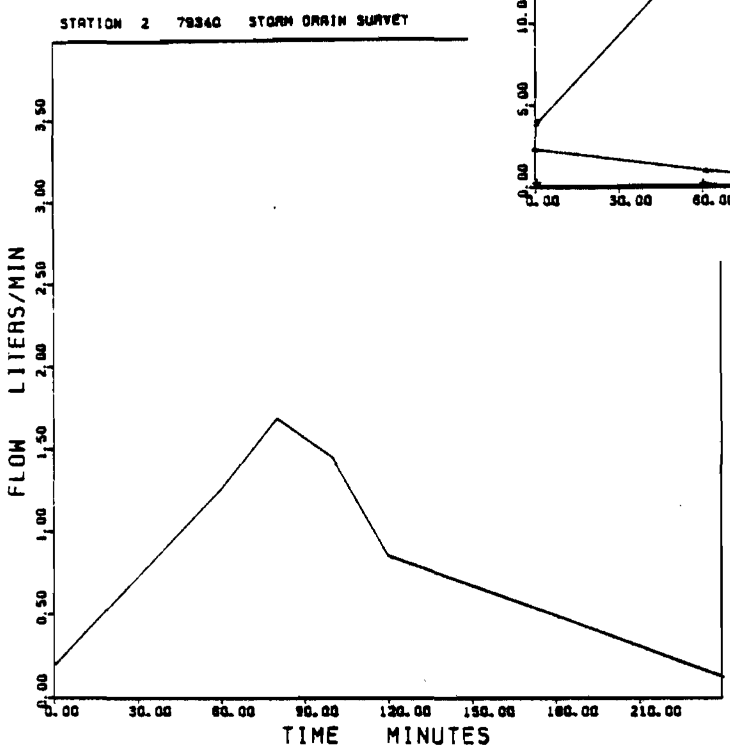
Julian date 80100 - The second storm (Fig. 7) sampled at the commercial location had the largest percipitation of any storm sampled over the entire sampling period. The storm persisted for a period of over ten hours. The greatest bulk of the rain came between six and one half and eight hours (Fig. 7A). Here, however, an unusual peak of SiO_4 occurred with the peak in the flow. The PO_4 responded but with a very



STATION 2 79340 STORM DRAIN SURVEY
FLUX MG-AT/MIN
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
0.00 30.00 60.00 90.00 120.00 150.00 180.00 210.00
TIME MINUTES

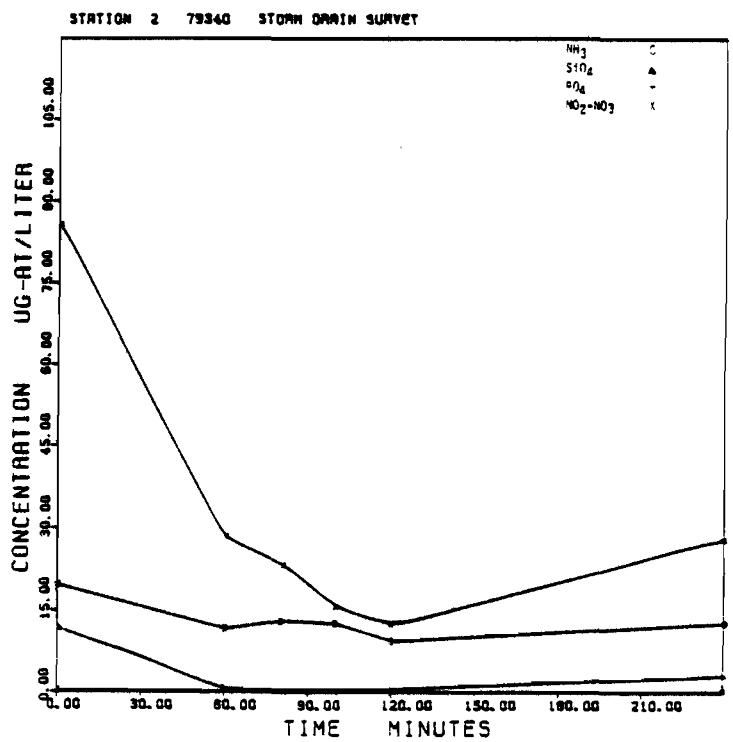
B

A



STATION 2 79340 STORM DRAIN SURVEY
FLOW LITERS/MIN
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
0.00 30.00 60.00 90.00 120.00 150.00 180.00 210.00
TIME MINUTES

C



STATION 2 79340 STORM DRAIN SURVEY
NH_3
SiO_4
PO_4
NO_2-NO_3
CONCENTRATION UG-AT/LITER
0.00
15.00
30.00
45.00
60.00
75.00
90.00
105.00
0.00 30.00 60.00 90.00 120.00 150.00 180.00 210.00
TIME MINUTES

Figure 5

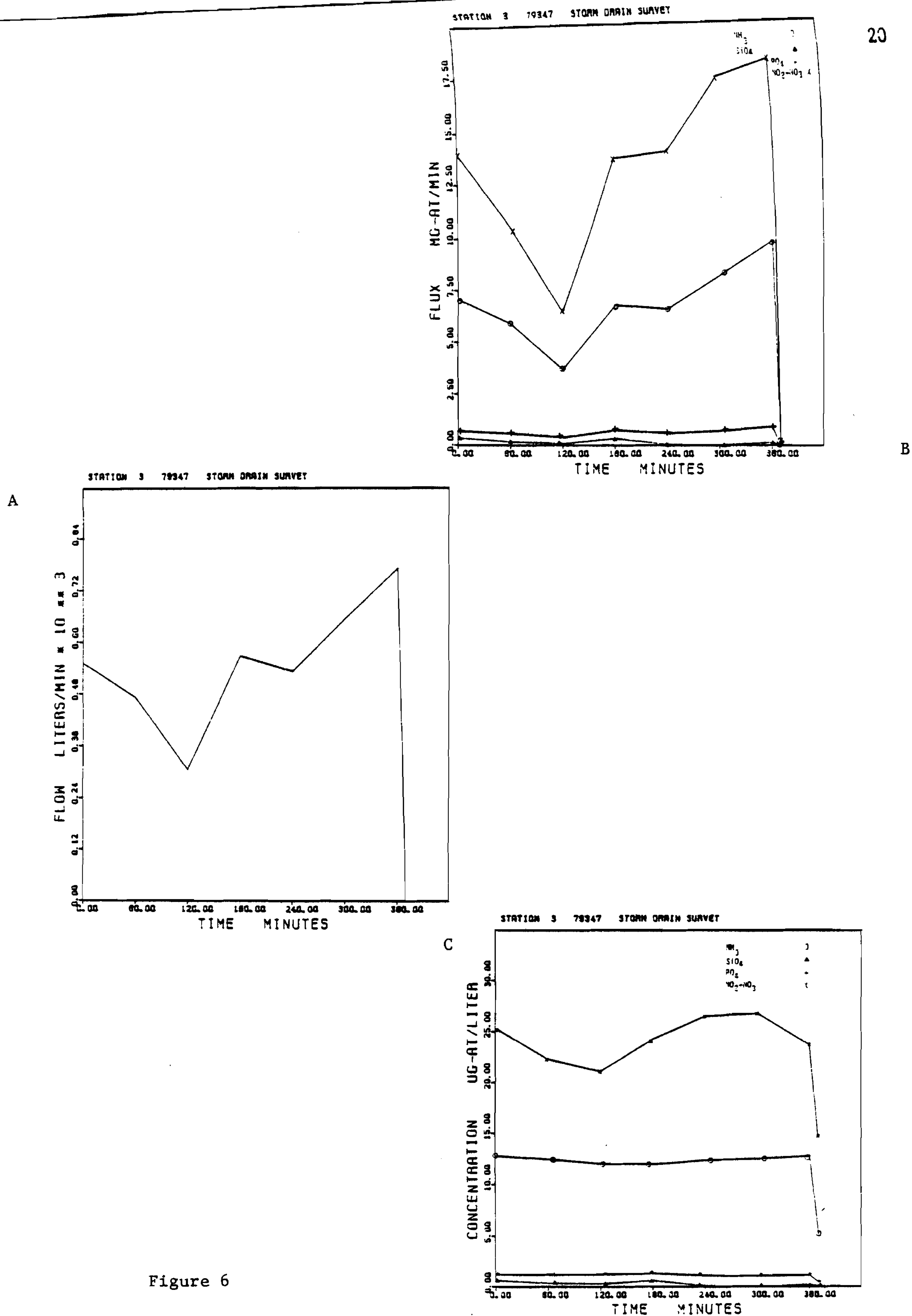
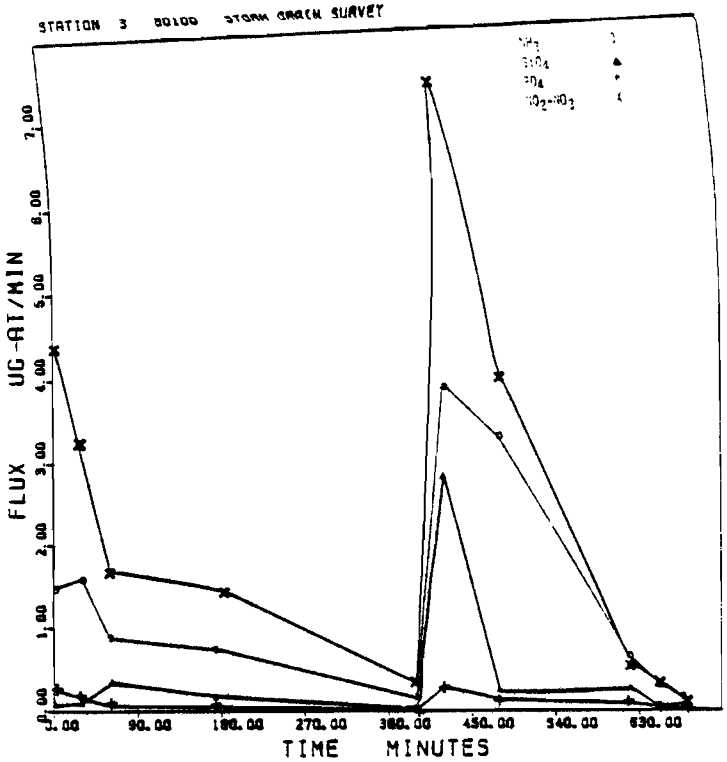
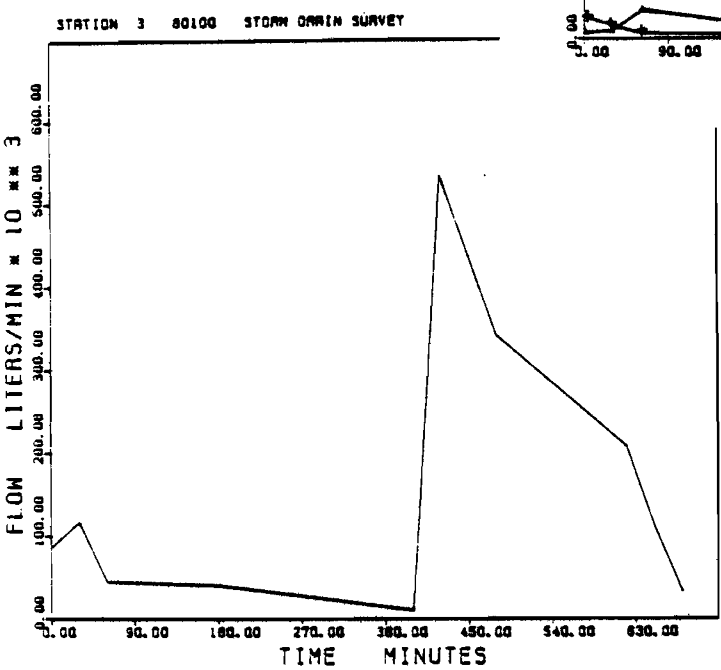

STATION 3 79347 STORM DRAIN SURVEY
NH3
SIO4
PO4
NO2+NO3
FLUX MG-AT/MIN
0.00 2.50 5.00 7.50 10.00 12.50 15.00 17.50
0.00 60.00 120.00 180.00 240.00 300.00 360.00
TIME MINUTES
B
STATION 3 79347 STORM DRAIN SURVEY
A
FLOW LITERS/MIN * 10 ** 3
0.00 0.12 0.24 0.36 0.48 0.60 0.72 0.84
0.00 60.00 120.00 180.00 240.00 300.00 360.00
TIME MINUTES
STATION 3 79347 STORM DRAIN SURVEY
C
NH3
SIO4
PO4
NO2+NO3
CONCENTRATION UG-AT/LITER
0.00 5.00 10.00 15.00 20.00 25.00 30.00
0.00 60.00 120.00 180.00 240.00 300.00 360.00
TIME MINUTES

Figure 6


STATION 3 80100 STORM DRAIN SURVEY
NH_3
SiO_4
PO_4
NO_2-NO_3
FLUX UG-AT/MIN
TIME MINUTES

B

A


STATION 3 80100 STORM DRAIN SURVEY
FLOW LITERS/MIN * 10 ** 3
TIME MINUTES

C

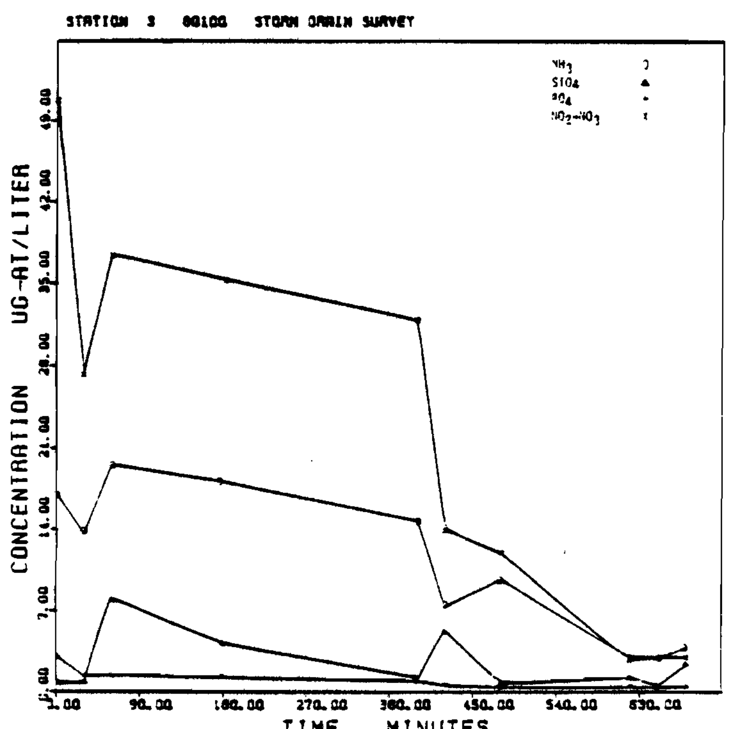

STATION 3 80100 STORM DRAIN SURVEY
NH_3
SiO_4
PO_4
NO_2-NO_3
CONCENTRATION UG-AT/LITER

Figure 7

low amplitude. It would appear that commercial areas contribute relatively small amounts of phosphate by way of runoff to the environment (Fig. 7C).

Residential - Station 4 (Fig. 1, #4).

Two storms were sampled at the residential station (Figs. 8 and 9). They both were slow to peak but the storm occurring earlier in the year did not peak while it was being sampled.

Julian date 80081 (Fig. 8) - This storm had a few minor peaks but continuted at some strength for a period of two to three days (Fig. 8A). The fluxes of NH_3 and NO_2-NO_3 (Fig. 8B) followed the flow profile but with quite a separation of values. The NH_3 flux was low relative to the NO_2-NO_3 flux (Fig. 8B).

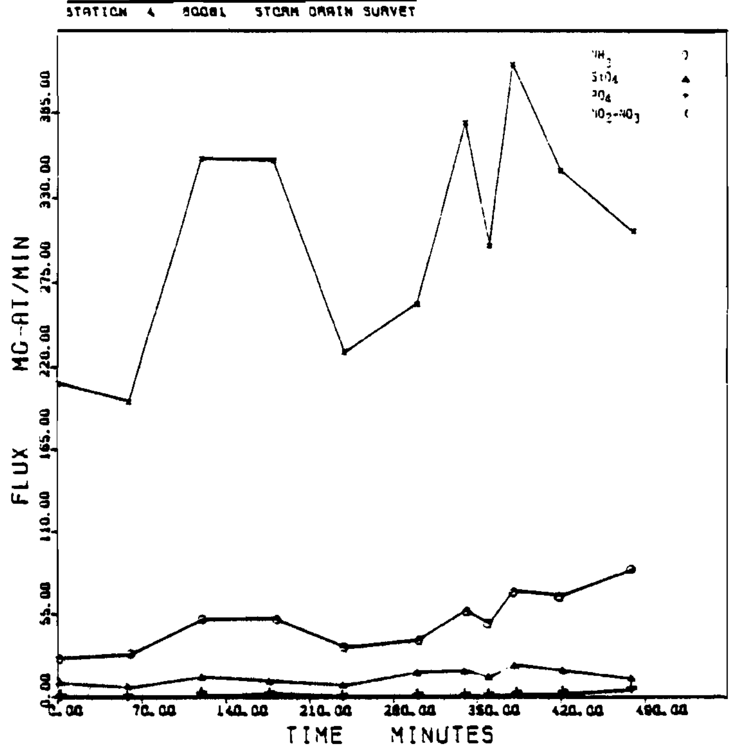
The concentrations of all nutrients (Fig. 8C) showed a fairly straight line until the flow increased dramatically. This increase in flow showed a decrease in concentration of all the nutrients especially NO_2-NO_3.

Julian date 80292 - This storm (Fig. 9) was similar to the one previously sampled; it started slowly with one peak after at least six hours (Fig. 9A). The major difference is that this peak was short lived and the storm was sampled to the end of the rainfall. It is interesting to note that the pattern of concentration (Fig. 9C) drop at the rain peak was again displayed. As the rain rate decreased, though, concentration showed an increase, most pronounced in NO_2-NO_3 measurements (Fig. 9C). There seems to be an inverse relationship at this station between rainfall intensity and NO_2-NO_3 concentration.

Industrial - Station 5 (Fig. 1, #5).

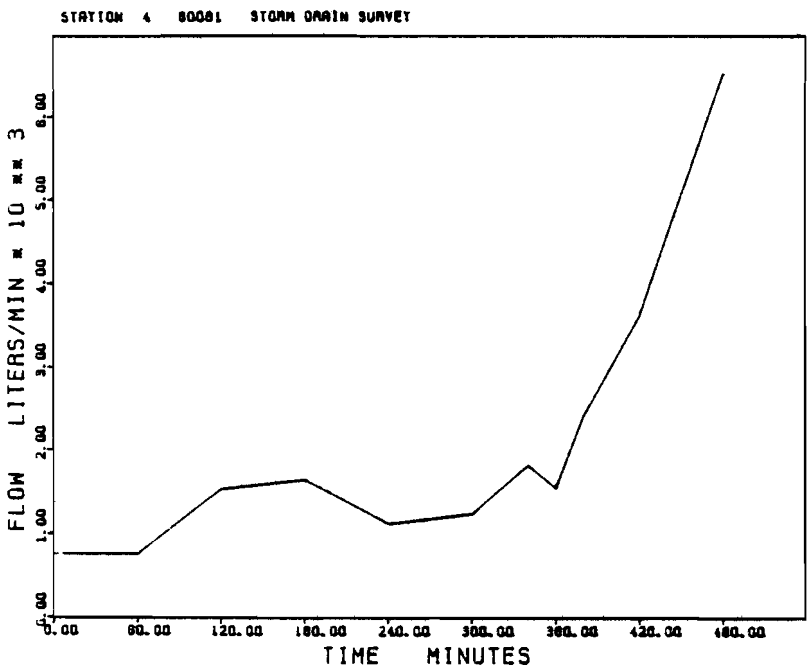
The two storms that were sampled here have very different storm profiles (Figs. 10 and 11).

Julian date 80142 (Fig. 10) - A storm consisting of one broad peak with the crest at four hours (240 mins.) (Fig. 10A). The four nutrients measured all in-


STATION 4 80081 STORM DRAIN SURVEY
NH_3
SiO_4
PO_4
NO_2-NO_3
FLUX MG-AT/MIN
0.00
55.00
110.00
165.00
220.00
275.00
330.00
385.00
0.00 70.00 140.00 210.00 280.00 350.00 420.00 490.00
TIME MINUTES

B

A


STATION 4 80081 STORM DRAIN SURVEY
FLOW LITERS/MIN * 10 ** 3
0.00
1.00
2.00
3.00
4.00
5.00
6.00
0.00 60.00 120.00 180.00 240.00 300.00 360.00 420.00 480.00
TIME MINUTES

C

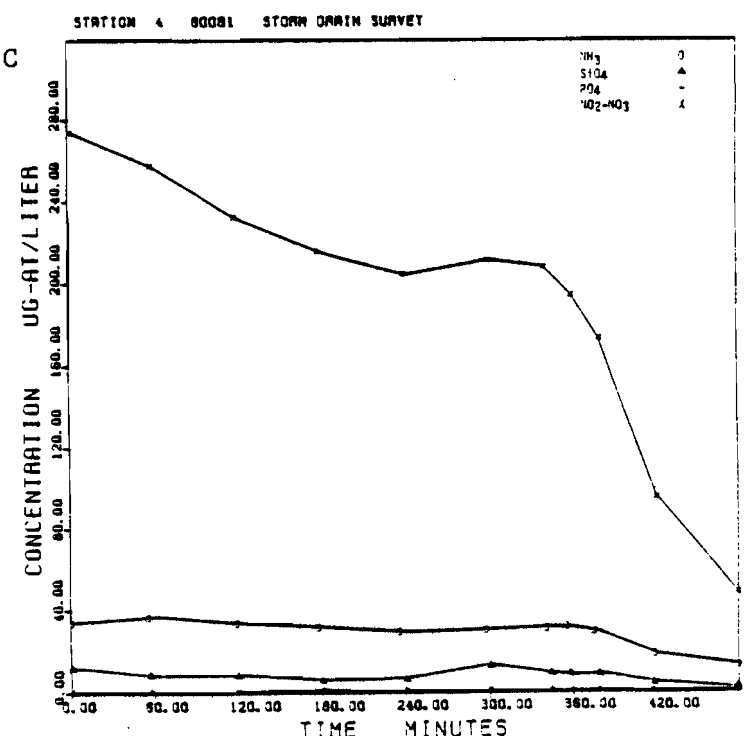
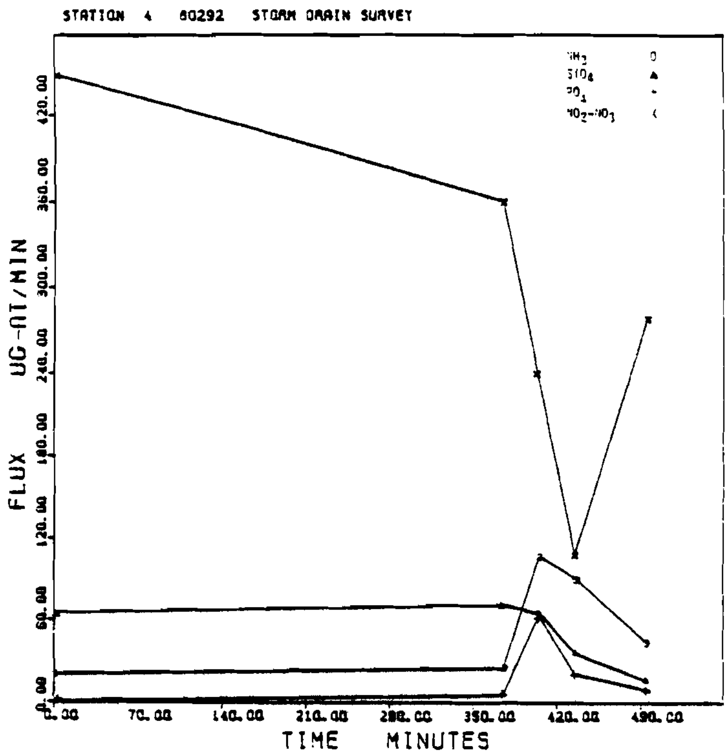
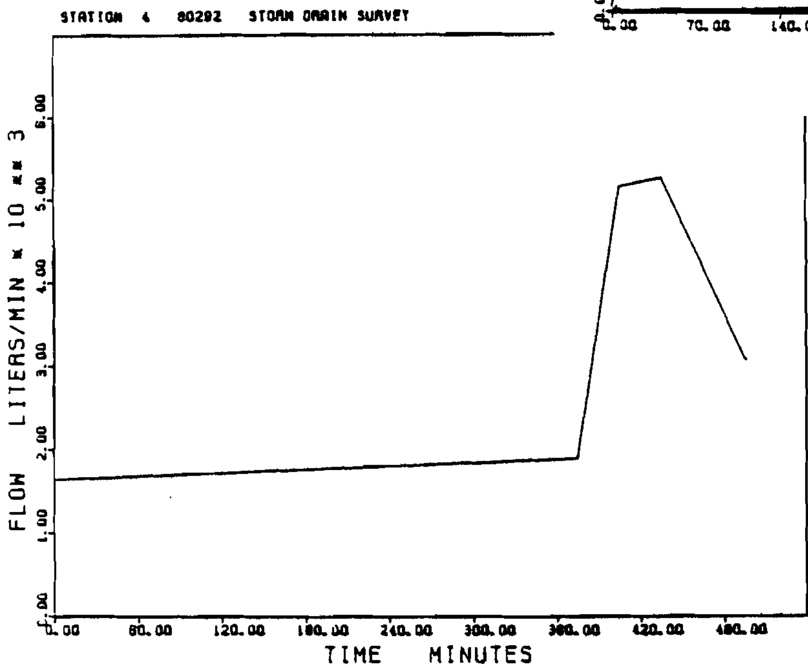

STATION 4 80081 STORM DRAIN SURVEY
NH_3
SiO_4
PO_4
NO_2-NO_3
CONCENTRATION UG-AT/LITER
0.00
40.00
80.00
120.00
160.00
200.00
240.00
280.00
0.00 60.00 120.00 180.00 240.00 300.00 360.00 420.00
TIME MINUTES

Figure 8

B


STATION 4 80292 STORM DRAIN SURVEY
NH3
SIO4
PO4
NO2-NO3
FLUX UG-AT/MIN
0.00
60.00
120.00
180.00
240.00
300.00
360.00
420.00
0.00
70.00
140.00
210.00
280.00
350.00
420.00
490.00
TIME MINUTES

A


STATION 4 80292 STORM DRAIN SURVEY
FLOW LITERS/MIN * 10 ** 3
0.00
1.00
2.00
3.00
4.00
5.00
6.00
0.00
60.00
120.00
180.00
240.00
300.00
360.00
420.00
480.00
TIME MINUTES

C

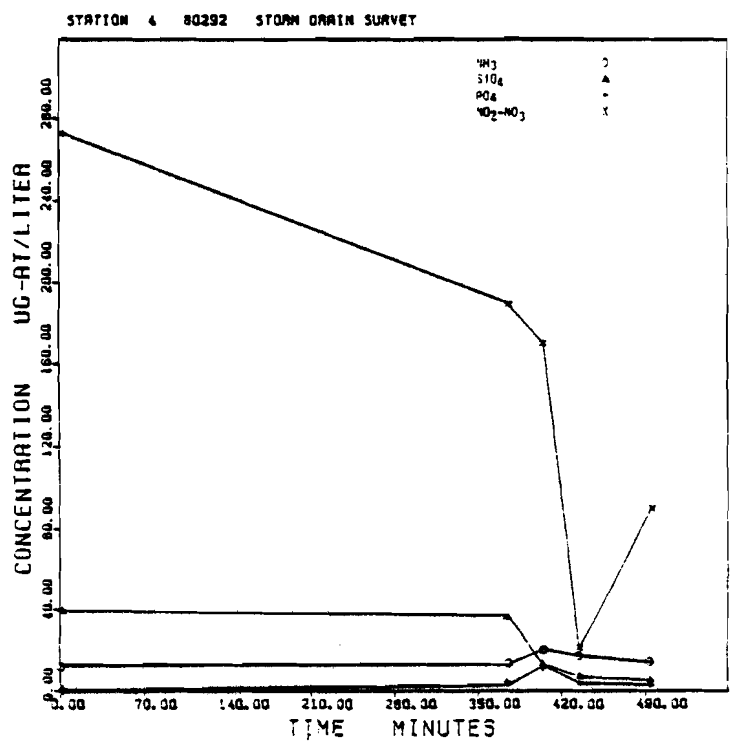
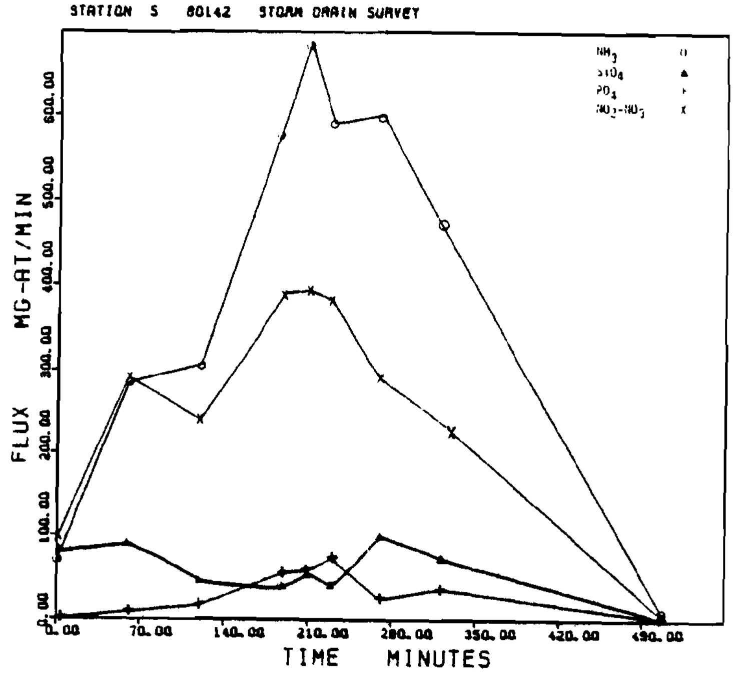
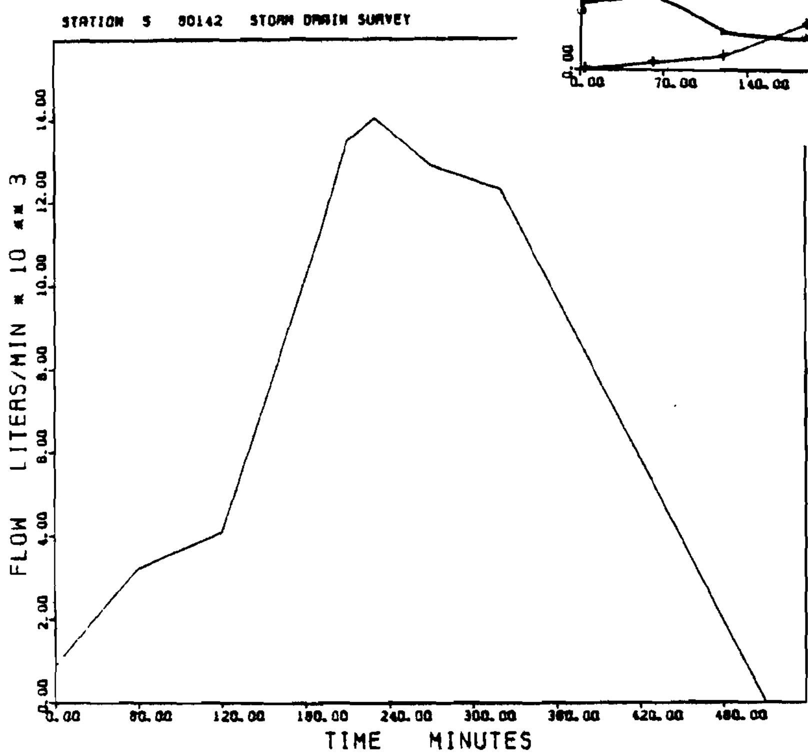

STATION 4 80292 STORM DRAIN SURVEY
NH3
SIO4
PO4
NO2-NO3
CONCENTRATION UG-AT/LITER
0.00
40.00
80.00
120.00
160.00
200.00
240.00
280.00
0.00
70.00
140.00
210.00
280.00
350.00
420.00
490.00
TIME MINUTES

Figure 9

B



A



C

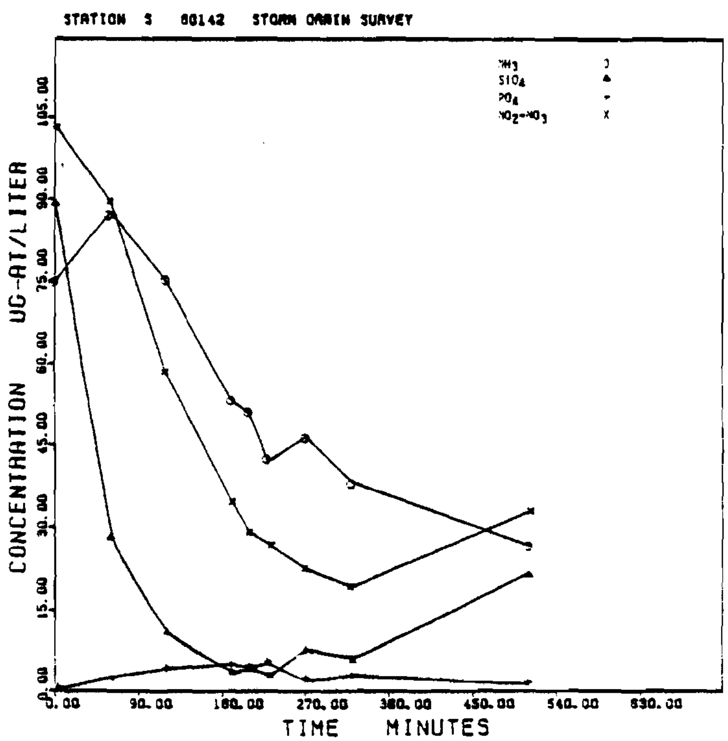


Figure 10

dicate some variation with the flow resulting in a certain amount of variable flux (Fig. 10B). It is interesting to note that all of the nutrients except phosphate start high with a fairly steady decrease that is not changed to an indication of increase until the flow changes to a decrease (Fig. 10C). The inverse relationship between flow and concentration again.

Julian date 80211 (Fig. 11) - This storm had two obvious peaks but may have had one more prior to the start of sampling (Fig. 11A). It is interesting that the fluxes of all four nutrients follow each other very closely (Fig. 11B). All four nutrients have fairly stable concentrations for the first two hours (120 mins.) (Fig. 11 C). Following that NO_2-NO_3 and SiO_4 increase in response to an increase in flow until a peak is reached and the concentrations crash. The PO_4 and NH_3 decrease and all of the nutrients except SiO_4 increase as the flow decreases.

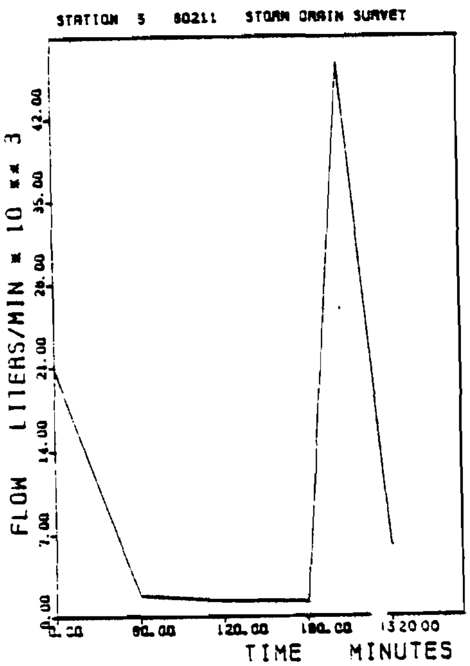
Combined sewer overflow (CSO) - Station 6 (Fig. 1 #6).

This is the only station whose effluent contains human feces as well as nutrient additions due to urban runoff. Two storms were sampled here (Figs. 12 and 13).

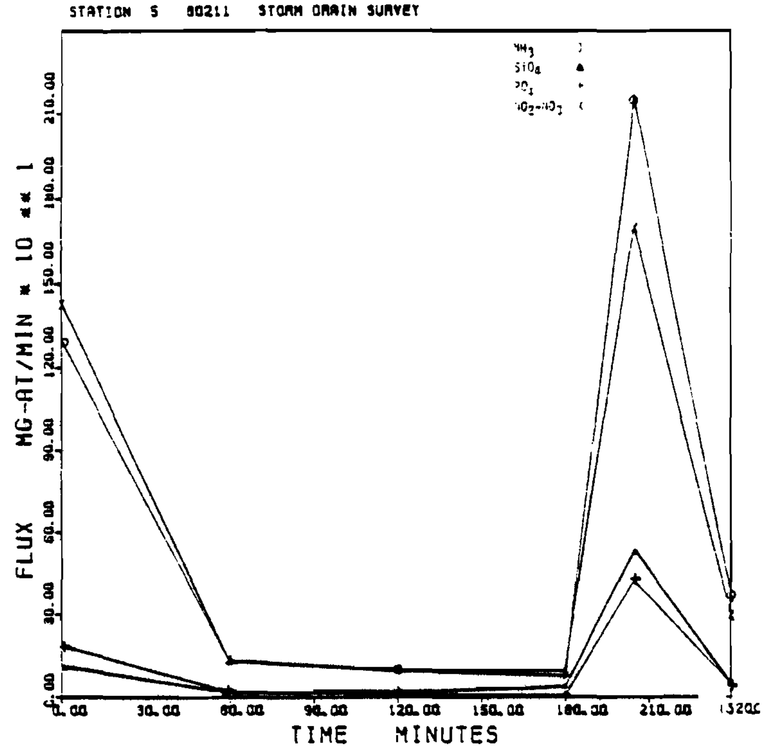
Julian date - 80211 (Fig. 12) - Two stations were sampled during this storm, stations 5 and 6. This storm had three obvious peaks (Fig. 12A). The flux (Fig. 12B). of all but the SiO_4 followed fairly well the storm profile. The concentration graphs (Fig. 12C) showed an overall decrease in all the nutrients except SiO_4 until the flow decreased and resulted in concentration increases.

Julian date - 80302 (Fig. 13) - The overall intensity and total rainfall of this storm was very low (Fig. 13A). The fluxes of (Fig. 13B) all the nutrients followed closely with the storm profile. In general, concentrations decreased with flow (Fig. 13C).

A



B



C

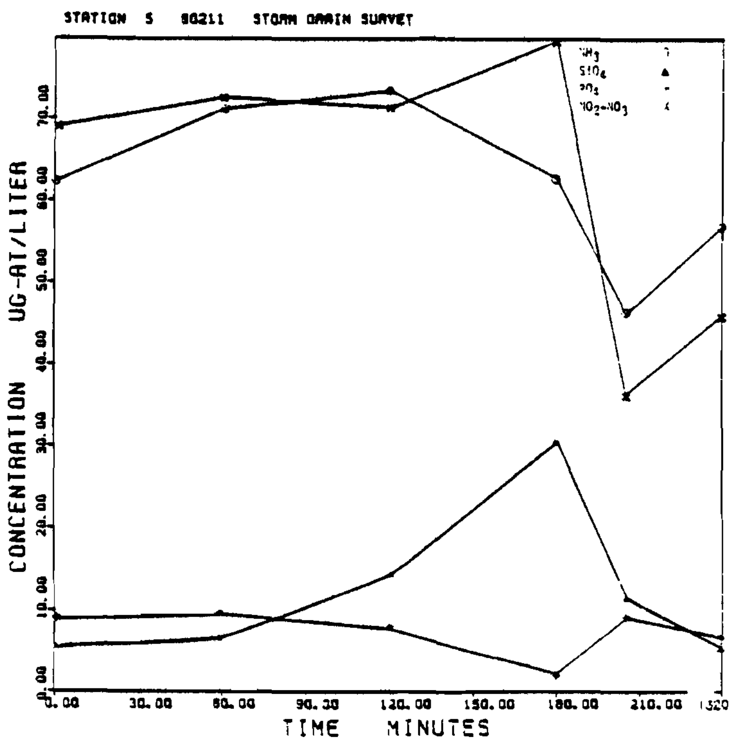
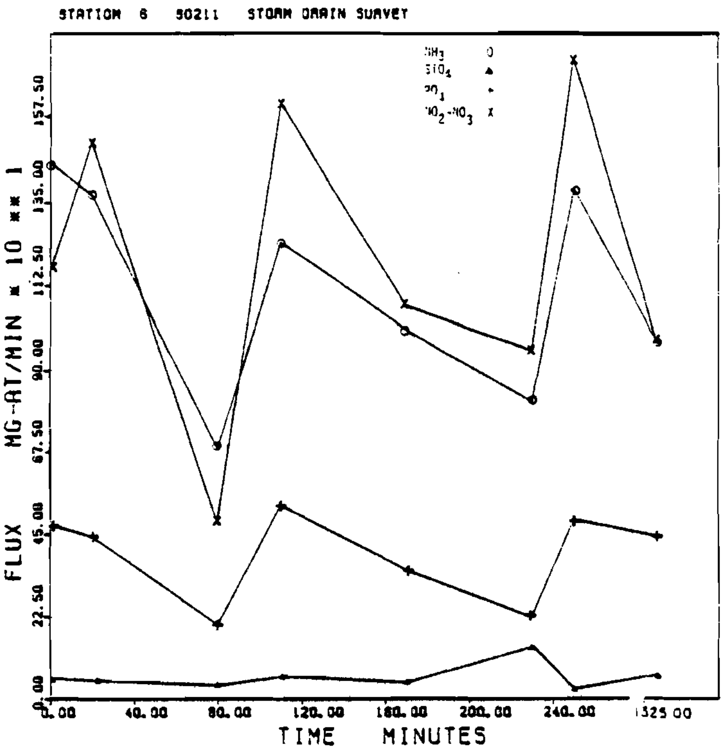
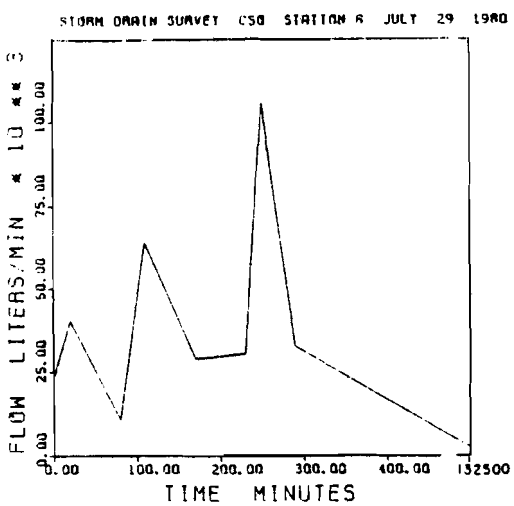


Figure 11



B

A



C

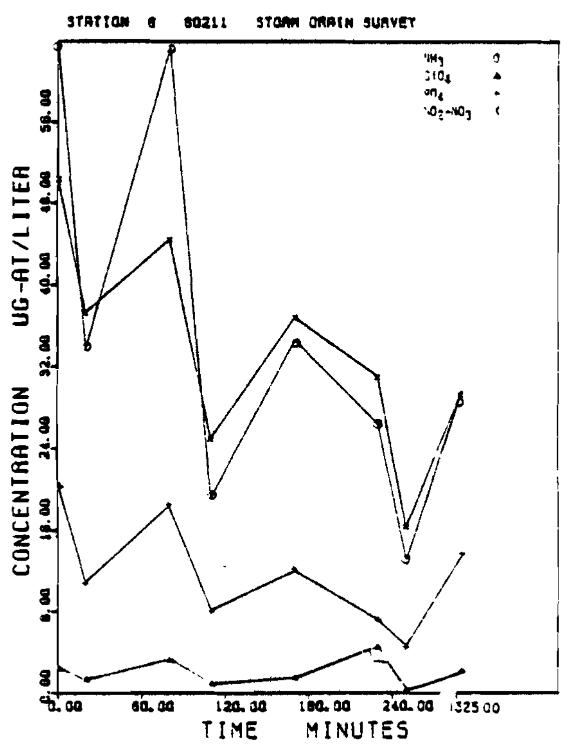
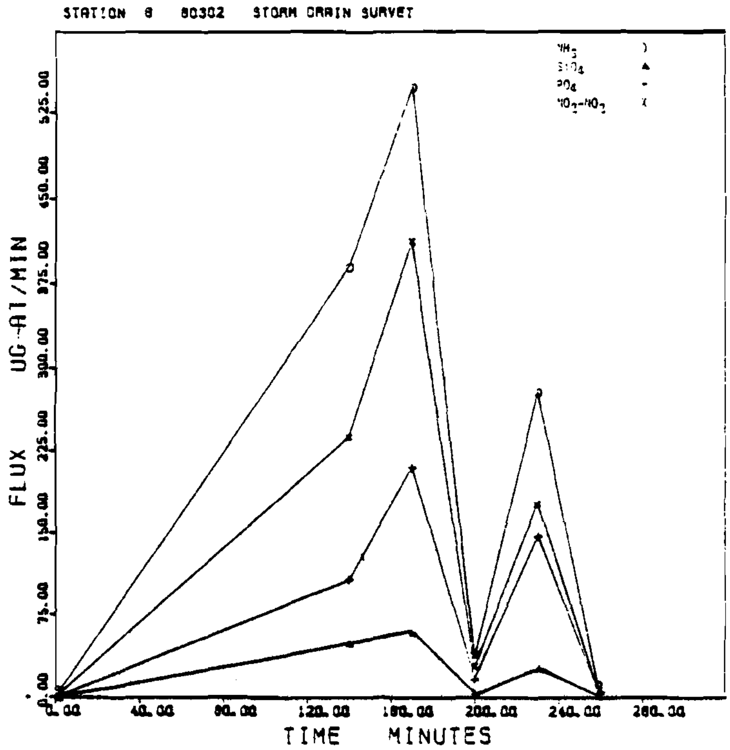
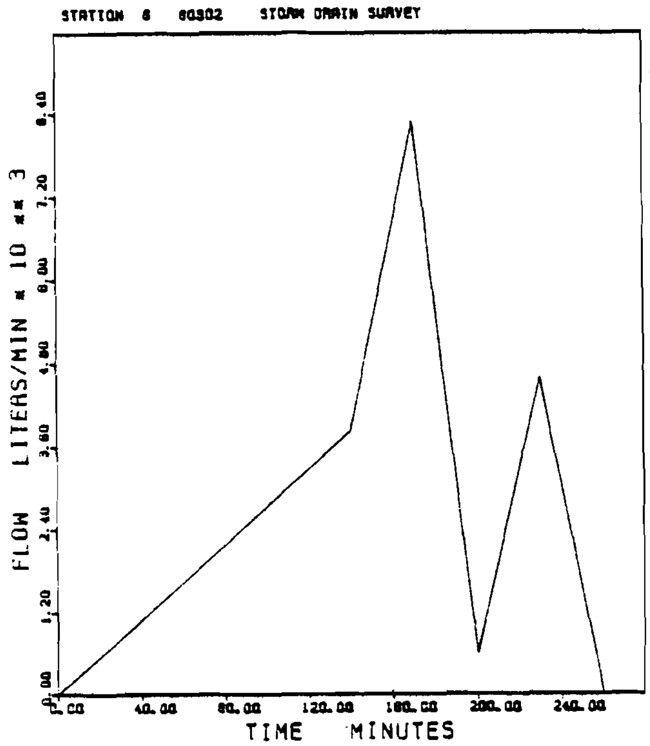


Figure 12



B

A



C

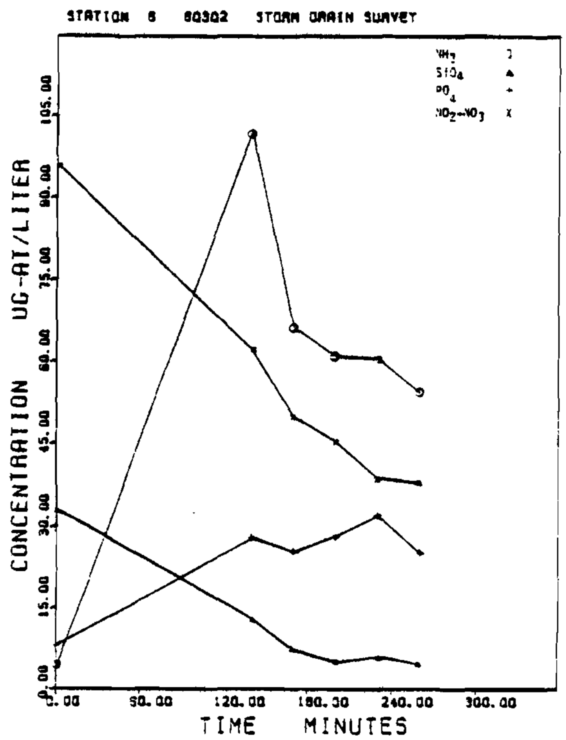


Figure 13

RESULTS

From the analysis of the individual storms sampled a series of tables can be derived. The first of which is Table III Nutrient Loading. Table III is the average loading of the measured dissolved inorganic nutrients per unit of land use type per rainfall. The comparison of nutrient loadings for different land use types can be important in the determination of which land use types are the largest donors of nutrients by runoff to any water body. English and metric units are used here to allow easy comparison with other data.

Table III

Nutrient Loading

	Nitrogen		Phosphorus		Silica	
	a	b	a	b	a	b
Highway	4.11	101.56	0.40	37.06	0.90	21.98
Commercial	0.26	6.37	0.01	0.23	0.002	0.04
Residential	2.38	58.90	0.04	0.89	0.28	6.98
Industrial	0.99	24.48	0.05	1.24	0.15	3.62
CSO	10.03	247.76	1.86	46.08	0.68	16.69

a. moles/cm rain - acre
b. ug-at/mm rain - m^2

These data indicate that the CSO stations contribute the largest amount of nitrogen and phosphorus per land use unit with the second closest in both nutrients being the highway. The highway is also the number one contributor of silica. These per land use area ratings are not however the total picture. They only indicate the greatest concentration per unit area not necessarily the greatest contribution to the total budget.

In order to assess the over all budget contribution an analysis of Land Use Data from the entire upper bay watershed needs to be considered. Table IV shows the breakdown of the sixteen communities in the upper Narragansett Bay watershed into their respective land use types and area.

Table IV

Summary of land use data in acres by city and town in upper Narragansett Bay drainage basin.

	Resid.	Ind.	Comm.	Inst.	Comm. and Util.	Rec. and Cult.	Agric. and Ext.	Streets and Hwy.	Vacant	Water-bodies	Total acres	Pop. (1970)	Pop./Acre
Providence[a]	3,929	560	781	1,199	767	998	5	3,097	768	24	12,101	179,116	14.8
Warwick[b]	8,323	315	1,134	2,153	432	1,174	-	-*	7,765	-	21,296	83,694	3.9
Pawtucket[c]	2,083	529	414	594.5	187	295.5	-	1,136	414	64	5,717	76,984	13.5
Cranston[d]	5,116	357	387	1,063	166	743	604	1,531	7,341	-	17,308	74,287	4.3
E.Providence[e]	2,402	376	498	256	960	1,337	175	1,193	1,253	317	8,766	48,207	5.5
Attleboro[f]	2,177	491	202	1,062	--	687	477	1,581	8,844	2,251	17,772	32,907	1.8
Cumberland[g]	3,181	193	220	367	269	138	1,368	-	11,110	1,332	18,176	26,605	1.5
W.Warwick[g]	2,037	241	215	192	92	170	310	-	1,783	217	5,257	24,323	4.6
N.Providence[g]	1,903	70	176	158	27	131	59	-	1,038	119	3,681	24,337	6.6
Johnston[g]	2,600	113	263	97	256	67	698	-	10,395	1,067	15,556	22,037	1.4
Central Falls[h]	426	102	98	53	4	16	4	23	38	74	838	18,716	22.4
Bristol[g]	1,624	165	119	110	70	511	774	-	3,002	351	6,726	17,860	2.6
Barrington[g]	3,085	22	66	206	64	418	151	-	1,179	500	5,691	17,554	3.1
Lincoln[g]	1,877	348	116	254	386	-	421	-	7,372	493	11,267	16,182	1.4
Seekonk[i]	1,900	180	897	-	-	496	1,791	350†	6,234	425	11,923	12,500	1.0
Warren[g]	993	81	119	74	34	74	821	-	1,171	445	3,812	10,523	2.8
Total	43,656	4,144	5,695	7,838	3,712	7,256	7,658	8,561	69,684	7,679	165,890	685,832	4.1
Percent	26.38	2.50	3.45	4.15	3.54	4.38	4.63	5.17	41.42	4.38			

*included in residential;

†also included in other acreages.

References for Land Use Statistics

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b. City of Warwick, Department of City Planning, "Warwick, 1990" 1972.

c. City of Pawtucket, City Planning Department, "Land Use Inventory and Commentary," (Edward M. Hennigan, City Planning Director) Sept. 1977.

d. City of Cranston, City Planning Commission, "Land Use Analysis," January 1974.

e. City of East Providence, Department of Planning and Urban Development "Land Use Analysis: 1973" (Joseph L. Savick, Director) December 1974.

f. Town of Attleboro, Dept. of Planning, Personal communication, 1979.

g. 208 Land Use Summaries, U.S. Dept. of Housing and Urban Development.

h. Howe, Spencer, Principal Planner, Dept. of Community Affairs, State of Rhode Island, personal communication, December 1979.

i. Town of Seekonk Planning Board, "A Master Plan for the Town of Seekonk," May 1979.

Table V is the compilation of the data contained in each of the stations sampled. It is interesting to note that the majority of land use in the upper bay is residential (43,656 acres).

Table V CALCULATION

Station/ Land Use Type	Number of Acres Per Station	Total Acres in Watershed	Factor X
Highway	136	8,561	63
Commercial	31	5,708	185
Residential	138	43,656	317
Industrial	218	4,142	19
CSO	37	9,648	260

Loading Per Storm = Concentration x Flow Volume Measured

Average Input = Average of all Inputs Per Location Normalized to One Centimeter of Rain

Annual Loading = Average Input x Annual Rainfall x Factor

The combination of the information in Tables III and V allows the development of the Total Loading of Inorganic Nutrients to the Providence River by Urban Runoff, Table VI. Table VI indicatesthat even though the concentration of nitrogen being released from residential areas (Table III) is only about 1/5 of that being released from CSO the fact that the majority of land use is residential in the upper bay makes the contribution overall quite significant (9.6×10^6 moles/yr) in fact the highest. The greatest amount of phosphorus, on the other hand, still comes from CSO with the highway contribution following. The residential area also leads in terms of silica contribution. The total loading for the sample year is also included.

Table VI

Total Loading of Inorganic Nutrients to the Providence River by Urban Runoff

	NITROGEN	PHOSPHORUS	SILICA
Highway	3.26	0.31	0.71
Commercial	0.14	0.004	0.001
Residential	9.60	0.16	1.15
Thurbers - Industrial	0.38	0.02	0.06
Sheridan - CSO	8.89	1.66	0.61
Total Loading Per Sample Year (Dec. '79 - Nov. '80)	22.3	2.2	2.5

Rainfall December '79 - November '80 = 92.329 cm = 36.35 in.

(Units 10^6 moles)

Table VII

Summary of Known Inputs of Inorganic Nutrients to the Providence River

SOURCES	NITROGEN	PHOSPHORUS	SILICA
Rivers	110.0	7.9	38.8
Sewage Effluent	34.6	5.2	8.1
CSO 002	3.4	0.4	1.0
Run-off	24.0	2.3	2.7

Total for rainfall of 1 meter = 100 cm

(Units 10^6 moles)

To demonstrate the relative importance of the total loading of inorganic nutrients by way of runoff a Summary of Known Inputs of Inorganic Nutrients to the Providence River (Table VII) developed by MERL during the previously mentioned study has been included. There are two differences however, in that the MERL Summary is for an average yearly rainfall as compared to an actual yearly rainfall shown in Table VI and the MERL pollution gradient experiment was conducted from September 1979 - September 1980. A comparison of the values of inputs due to various sources indicated that at least for Nitrogen runoff accounts for nearly 20% of the input as compared with rivers and nearly 70% of that of sewage effluents.

Discussion

The making of good management decisions depends upon the availability of scientific information. In the assessment of nutrient loading to the Providence River it is important to know the relative importance of the major budget catagories. The combination of this study with the MERL pollution gradient survey has allowed an overall ranking of the level of importance of the four major sources of inorganic nutrients to the Providence River.

The results indicate that the order of overall importance is: first, rivers; second, sewage effluent and thirdly, runoff. In terms of nitrogen contribution runoff accounts for nearly 20% as much as rivers and approximately 70% of that of sewage effluent (Table VII).

The runoff catagory can also now be broken into land use types and their subsequent nutrient loading factors. For contribution of nitrogen to the Providence River the residential land use catagory ranks highest with the CSO value closely behind (Table VI). Since nitrogen is the most important limiting factor for marine algae in terms of eutrophication control the residential and CSO drains would then be the most effective for application of nutrient input control measures.

Special Notes

1. This study was conducted through a grant from the Environmental Protection Agency Region I to the Marine Ecosystems Research Laboratory.

2. It must be noted that the conducting of this experiment was a truly difficult task. The locations that allowed access were usually not in the nicest parts of town and rainfall has no concept of timeliness. The samples were collected when it rained regardless of whether that occurred in the middle of the night, all hours of a weekend or any holiday. The difficulty of knowing when it will rain is something that was not actually considered prior to the start of this experiment.

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