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# proceedings:
# STORM-WATER MANAGEMENT WORKSHOP

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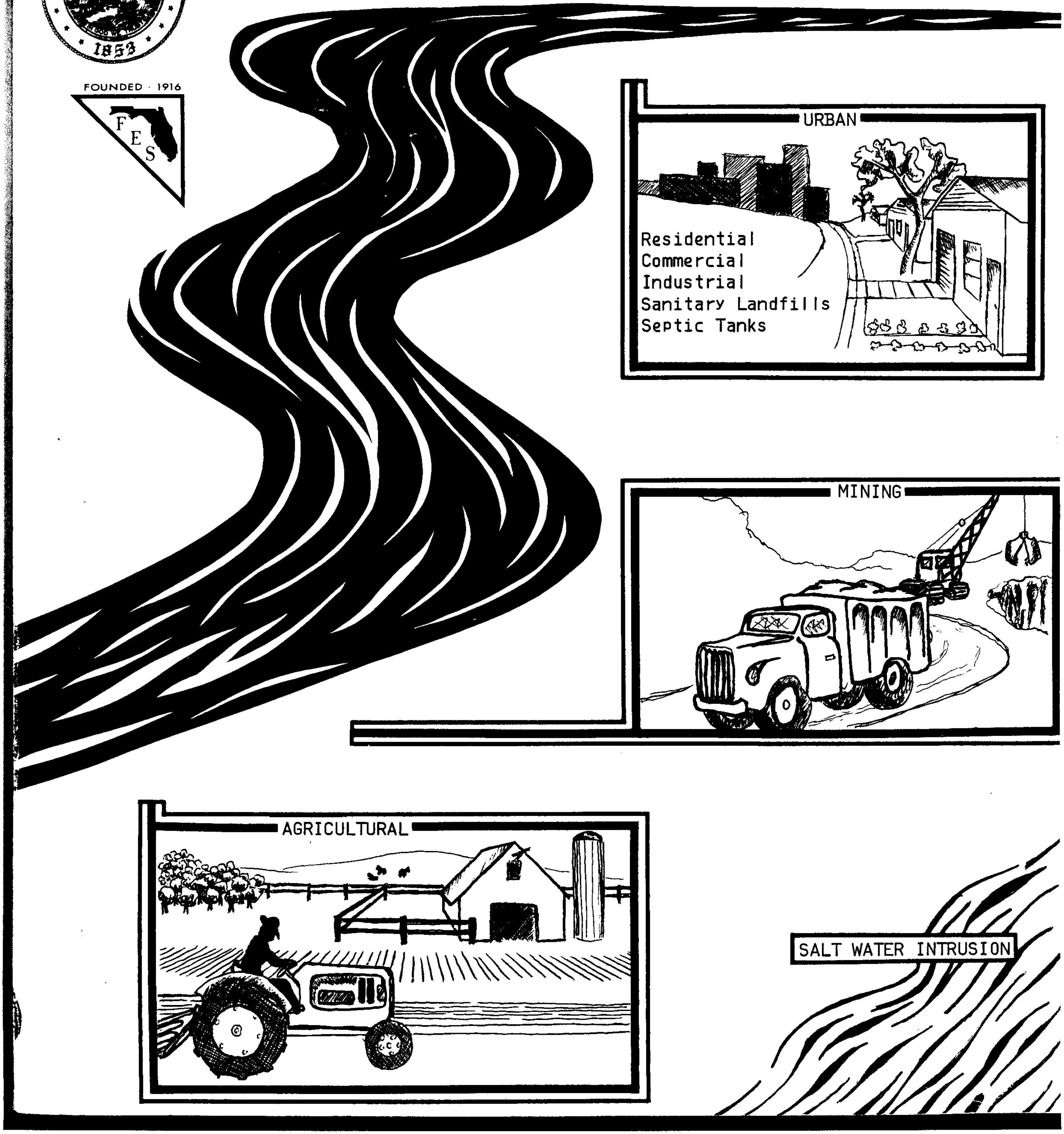

# PREFACE

Great challenges confronting those concerned with water quality are the identification of nonpoint source pollution and prevention of water quality degradation from nonpoint sources. The objective of this publication is to improve state-of-the-art knowledge in stormwater management and thus help establish methodologies for nonpoint source management. This publication is the result of a workshop held in Gainesville, Florida on February 26th and 27th, 1975. Most materials presented at the workshop are included. One additional paper was added to aid in establishing nonpoint sources problem areas in the State of Florida.

Five sections corresponding to the sessions of the workshop are included. The first session includes Federal and State regulations and guidelines with planning mechanisms. The second session presents the fundamentals for understanding complex stormwater management systems. This was followed by a session on water quality effects which helped establish the need for management. The fourth session was on the specific management aspects of abatement procedures. The near ultimate understanding results in quantification and model construction. Therefore, the last session was on model building. A commentary of all papers is presented last.

Many more problems of nonpoint source management, such as, sludge disposal, economical solutions, development of strict laws, and loading rates remain. Research and practical applications now underway will help provide additional data.

mpw
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## PROGRAM GOALS

Martin P. Wanielista, Ph.D., P.E.
Florida Technological University
College of Engineering
P. O. Box 25,000
Orlando, Florida 32816

Stormwater management is emerging in 1975 as one area requiring the utilization of engineering, scientific, and social-political disciplines. Why so many disciplines when stormwater is easily defined as the runoff waters resulting from the various forms of precipitation? The need for engineering is evident. The design of stormsewers, detention ponds, and other preventative, control, or treatment techniques is necessary. To design properly, a scientific understanding of the relationships among the water, land, and air environments is required. In addition, the person responsible for executing a plan must be aware of the political and social desires. It should be obvious that the definition of stormwater implies a stochastic somewhat uncontrolled problem. As additional knowledge and understanding of the problem are gained, more economical and efficient solutions are realized. The proceedings are designed to enhance knowledge and understanding of stormwater management with specific emphasis on:

1. State and Federal laws, regulations, and guidelines.
2. Basic Principles of hydrology, environmental quality and sediment transport.
3. Water quality effects from stormwater.
4. Design of abatement processes and
5. Use of existing mathematical models.

To immediately increase knowledge and understanding it must first be noted that stormwater management is considered a definite separate area, but also a part of larger studies on nonpoint source pollution. Nonpoint sources are land uses or locations at which pollutants are released to the natural environment at an uncontrolled rate. While point sources are locations or land uses at which pollutants are released at a controllable rate. An example of a point source is a wastewater treatment plant. It has a controlled discharge. Uncontrolled sources are stormsewers, agricultural feedlots, pastures, cultivated fields, salt water intrusion, precipitation, forests, (silviculture) and dry fallout. An illustration of nonpoint sources is found in Figure 1. Septic tanks can be classified as point and nonpoint sources depending on the control of the wastewaters from the drainfields. Sanitary landfills are similar and control or no control defines the type of pollution source.

Public law 92-500 section 305 requires a description of the nature and extent of nonpoint sources (stormwater included). The nature of the pollution character is measured by a set of water quality parameters and type of land use. The extent of the problem is the magnitude, degree,

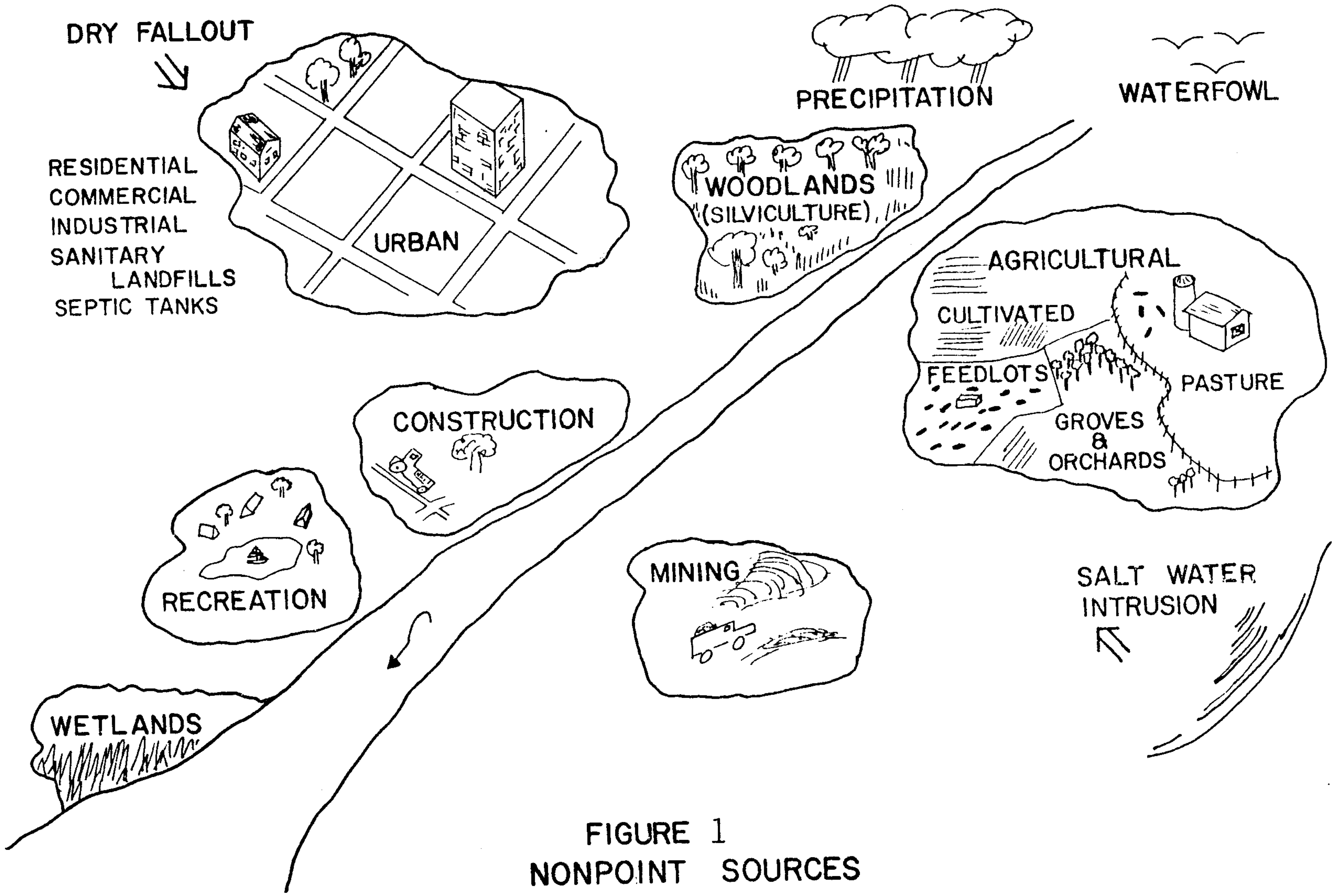

FIGURE 1
NONPOINT SOURCES

or limiting values of water quality resulting from nonpoint sources.

The workshop is arranged so that the parts of PL 92-500 related to stormwaters are presented first. Next, the State position for implementation of stormwater management plans with a program design to conduct nonpoint source studies (208 plans) are examined. Consistent with the plans and State and Federal Regulations, fundamentals of hydrology, environmental, and soil surveys are explained.

Nonpoint source pollution results in a decrease in water quality. In the third section, water quality effects from community development in South Florida, from various land use in Northern Florida, and documentation of contaminants in Urban runoff in Broward County are featured.

The abatement of pollution sources is the topic of the fourth section. The role of detention ponds, the various procedures used at Disney World, and an innovative approach at Miami International Airport are described.

The fifth and last section presents existing models for decision making and an analysis of and commentary on Stormwater Management. These papers bring together in a working package many of the concepts previously presented.

# THE EFFECTS OF LAND USE ON STORMWATER QUALITY AND NUTRIENT AND SUSPENDED SOLIDS EXPORTS FROM THREE NORTH FLORIDA WATERSHEDS.

Ralph R. Turner and Thomas M. Burton
Department of Oceanography
Tallahassee, Florida 32306

## INTRODUCTION

This paper quantitatively documents the effects of land use on hydrology and nutrient and suspended solids exports from three north Florida watersheds. These three watersheds represent a transition from a forested-agricultural watershed to a newly developing suburban watershed to an urban watershed. In addition, preliminary data are presented on nutrient and suspended solids loading from a regional shopping mall within the urban watershed.

Three general characteristic effects of urban development in a watershed are greater overland runoff, increased peak fluxes of water during storm events, and decreased water quality (13). However, urban watershed studies published to date have been very limited in the type of chemical parameters measured and are primarily descriptive treatments of the gross pollutional characteristics of stormwater runoff. Several recent review papers on urban sedimentation (9) and water quality (17, 19) have demonstrated extremely high variability in parameters such as biochemical oxygen demand, chemical oxygen demand, total phosphorus, and total coliform bacteria as a function of antecedent meteorological conditions, specific types of land use, and watershed hydrology. The composition of urban runoff can exceed the pollution potential of point sources such as wastewater treatment plants and industrial effluents and can accelerate cultural eutrophication (25).

The specific objectives of this study were 1) to quantitatively describe changes in concentration of nutrients and suspended solids for the complete hydrograph of observed storm events and to correlate observed changes with land use; 2) to calculate nutrient and suspended solids export from each watershed; 3) to develop a dynamic model of the ecological impact of urban development on a typical north Florida watershed; and 4) to provide adequate water quality data for the design of watershed management systems. This paper is a report on our progress in fulfilling these objectives.

## Description of the Study Area

Three watersheds of the Lake Jackson drainage area (11, 190 ha) were selected for intensive study. Lake Jackson (1960 ha) is located just north of Tallahassee, Leon County, Florida. Two of the three watersheds are similar in size (Ox Bottom Creek and Meginniss Arm Tributary) while the third (Ford's Arm Tributary)is less than one-half the size of the other two (Table 1) . All three watersheds have similar geomorphology and pedology with slopes of 4 to 5%. The soils are well drained, sandy loams over loamy subsoils.

The Ox Bottom Creek watershed enters the northern end of Lake Jackson and is part of a large, private estate with limited public access. More than 50% of the watershed is forested (Table 1) while the remainder is in agricultural use. Most of the forested portion (mixed pine-hardwoods) is located along the stream channel while the farmland is on the higher land towards the periphery of the basin. For purposes of identification, this watershed will be referred to in the remainder of the paper as forested or forested-agricultural.

The Meginniss Arm watershed, at the southern end of Lake Jackson, has undergone rapid development in the past 20 years and is now about 80% urban (Table 1). Most of this urban area is composed of single family residential areas, but several apartment complexes, office parks, commercial areas (including two large shopping malls) and two schools are included. Sanitary sewer facilities export wastes from this watershed to the watershed of an adjacent lake (Lake Munson). For purposes of identification, this watershed will hereafter be referred to as urban.

The Ford's Arm watershed is undergoing rapid development at present although about 84% of the watershed is still forested (Table 1). This watershed is being divided into subdivisions and already has more than 30 houses on it. Most of the agricultural land is associated with a riding stable. There is also an elementary school on this watershed. The houses all have septic tank drainage while the school is served by a package treatment plant. For purposes of identification, this watershed will be referred to as suburban for the remainder of this paper.

All three streams typically have low flow discharges of less than 0.02 cubic meters per second and occasionally become dry.

Rainfall varies widely over the study area but averages 146 cm per year. During the course of this study (July 1, 1973 to June 30, 1974) rainfall was 125 cm at our station on Meginniss Arm (lower than the officially reported rainfall at the Tallahassee Airport). Average annual temperature is 19.4° C with an average high of 27.2°C in July and an average low of 12°C in January (11).

TABLE 1.--Comparison of land use of the three watersheds.

| Land Use | Ox Bottom Creek (Forested-Agricultural) | Meginniss Arm Tributary (Urban) | Ford's Arm Tributary (Suburban) |
|---|---|---|---|
| Forest | 327 ha (52%) | 85 ha (12%) | 290 ha (84%) |
| Agricultural | 306 ha (48%) | 63 ha (9%) | 24 ha (7%) |
| Residential | 0 | 482 ha (67%) | 7 ha (2%) |
| Commercial | 0 | 91 ha (13%) | 0 |
| Interstate highway | 0 | 0 | 24 ha (7%) |
| Total | 633 ha | 721 ha | 345 ha |

## MATERIALS AND METHODS

Automatic samplers (Sigmamotor Model WM-4-24) were installed at each watershed. These samplers were either activated manually at the start of a storm or pre-set to activate automatically with a rise in the water level. Samples were taken over the entire hydroperiod at pre-set time intervals (20 or 30 minutes on the urban and 1 hour on the forested watershed). Turbidity and conductivity of each sample was determined, and samples were composited on the basis of these measurements.

Samples for dissolved silica and nutrient analyses were filtered through a prewashed 0.45 μ Millipore filter and preserved with $HgCl_2$. These samples were analyzed on a Technicon Auto-Analyzer II System using standard autoanalyzer techniques.

Suspended solids (non-filtrable residue) and dissolved solids (filtrable residue) were determined according to Standard Methods (1).

Discharge of the streams was determined from ratings and stage height recordings supplied by the U.S. Geological Survey. Rainfall was also recorded in each watershed by the U.S.G.S.; these data were supplemented by a network of "Tru-Chek" plastic rain gauges distributed throughout the watersheds. Instantaneous and integrated fluxes were calculated using stream discharges and constituent concentrations interpolated to 15 minute intervals.

More specific details of sampling, analytical techniques, and methods of calculation are available in a previous paper (22).

## RESULTS AND DISCUSSION

### Relationships Between Streamwater Concentration and Flow

The mean concentrations (± standard deviation) of streamwater constituents in the three watersheds are presented under low flow (baseflow) and high flow (stormflow) conditions in Table 2. The primary differences, under all flow conditions among the three watersheds, are in the concentrations of suspended solids (SS), dissolved solids (TDS), dissolved silicon (Si), and in the dissolved inorganic nitrogen species ($NO_3$-N, $NO_2$-N, $NH_3$-N).

Many of the mechanisms controlling constituent concentrations are illustrated by the suspended solids data. Suspended solids are lower in concentration in the urban and suburban system under low flow conditions than in the forested-agricultural watershed. Under low flow conditions,

TABLE 2.--Comparison of mean concentrations (mg/l) for stream water constituents in the three watersheds under stormflow and baseflow (low flow) conditions.

| Constituent | Forested | Suburban | Urban |
|---|---|---|---|
| | Stormflow | | |
| SS* | 34±25 | 176±324 | 299±378 |
| TDS* | 58±25 | 115±118 | 161±181 |
| Silicon | 3.57±0.48 | 2.56±0.49 | 1.72±0.74 |
| $NO_3$-N | 0.06±0.03 | 0.30±0.15 | 0.12±0.10 |
| $NO_2$-N | 0.002±0.002 | 0.04±0.05 | 0.014±0.02 |
| $NH_3$-N | 0.06±0.02 | 0.08±0.05 | 0.16±0.23 |
| $PO_4$-P | 0.10±0.06 | 0.05±0.04 | 0.12±0.13 |
| | Baseflow | | |
| SS* | 12±4 | 7±3 | 10±17 |
| TDS* | 43±8 | 53±9 | 86±30 |
| Silicon | 4.17±0.54 | 2.96±0.13 | 2.15±0.74 |
| $NO_3$-N | 0.05±0.03 | 0.18±0.05 | 0.10±0.06 |
| $NO_2$-N | 0.009±0.022 | 0.021±0.045 | 0.007±0.011 |
| $NH_3$-N | 0.04±0.01 | 0.05±0.02 | 0.06±0.12 |
| $PO_4$-P | 0.13±0.06 | 0.04±0.02 | 0.06±0.03 |

*SS = suspended solids; TDS = total dissolved solids.

the source of streamwater in all three watersheds is primarily ground water. In the forested-agricultural watershed, there are accumulations of leaf litter in the stream from the streamside forest. This accumulated leaf litter serves as a reservoir of organic detritus and leads to higher suspended solids concentration in this watershed than in the urban and suburban watersheds where much of the streamside forest has been removed. Under high flow conditions, there is a dramatic reversal with concentrations of suspended solids becoming several times greater in the urban and suburban watershed than in the forested-agricultural watershed. In the forested-agricultural watershed, there is very little overland flow even under high rainfall conditions as the water is intercepted by the vegetation and infiltrates and percolates through the extensive litter layer to the soil. Thus, even under high rainfall, very little inorganic material is eroded and the major fraction of suspended solids are litter and soil derived organic detritus.

In the urban watershed, much of the area is paved or denuded of vegetation for construction projects and leaf litter is not allowed to accumulate on lawns in the extensive residential area. As a result, much of the water flows overland washing off paved surfaces and eroding exposed soils. Peak stream discharge is much greater because of shorter residence time of the water in the soil so stream channels become underfit for the increased peak discharge and begin to erode, thus amplifying the problem. All of these factors result in the urban system having very high concentrations of suspended solids compared to the forested-agricultural system. This progression from low suspended solids in stormwater in the forested system to high suspended solids in the urban system is well illustrated in Table 2. Variability is also substantially increased because of the higher and more flashy stream discharge and because of a greater dependence on antecedent conditions in the urban system (length of time since accumulating surfaces were washed off by a preceding storm). Thus, urbanization of a watershed leads to much higher (as much as 30 times higher) and more variable concentrations of suspended solids.

The greater overland flow, higher peak discharge, and shorter residence time of water in soils in the urban system also explain many of the other observed differences among the watersheds (Table 2). For example, the dissolved silicon concentrations are much higher in the forested-agricultural system reflecting the longer and more intimate contact of water with soils.

Dissolved solids (TDS) follow the trend of higher and more variable concentrations as the watershed becomes progressively more urbanized (Table 2). Unlike the suspended solids data, TDS concentrations are higher in the urban and suburban systems under all flow conditions perhaps related to septic tank drainage and/or sewer leaks or to use of lawn fertilizers and to fecal inputs from dogs and cats. Loss of vegetation also contributes to nutrient losses as nutrients are no longer recycled by the vegetation resulting in increased nutrient losses (16). This could result in increased dissolved solids concentrations as observed here.

The concentration of nitrate and nitrite-nitrogen are higher under all flow conditions in the suburban watershed (Table 2). This difference is likely related to the fact that houses in this watershed have septic tanks and the effluent from a package treatment plant at a local school enters the stream. The urban watershed is intermediate between the suburban and forested-agricultural watersheds with respect to the inorganic nitrogen species because the sewage from the urban area is largely exported to another watershed. Occasional high nitrogen values in this watershed are correlated with observed breaks or failures of the sewer system.

The higher concentration of orthophosphate-phosphorus ($PO_4$-P) in the forested-agricultural system is in marked contrast to findings by others (see review by Ryden _et al_., 19). Some possible explanations for this discrepancy were suggested by Turner _et al_.(22) and include: 1) groundwater levels of $PO_4$-P are higher in the forested-agricultural watershed because of higher natural soil P levels or because of fertilization of the agricultural land; 2) algal primary productivity in the largely unshaded urban stream is high enough to significantly reduce $PO_4$-P levels in low flow runoff; and 3) the soil particles in suspension in the urban and suburban watersheds have a higher adsorptive capacity for P than does the organic detritus in the forested watershed. A fourth possible explanation is that the much longer and more intimate contact of the runoff with the soils in the forested-agricultural watershed leads to high values of dissolved P as appears to be the case for silica. We have not yet determined if any or all of the above explanations are operative.

Some typical responses of stream water constituents to discharge are illustrated in Figure 1. Suspended solids concentrations tend to be directly correlated with discharge in both the urban and forested watershed (note the tremendous difference in the horizontal and vertical scaling between the two watersheds in Figure 1). The dissolved constituents are typically inversely related to discharge as are illustrated by dissolved silicon and orthophosphate phosphorus (Figures 1c-1f). The peak in ortho-phosphate phosphorus concentration prior to stream discharge (Figure 1f) is a frequently occurring event in all three watersheds and may be related to initial flushing of accumulating surfaces. This same type of response has been reported elsewhere for dissolved organic nitrogen (8).

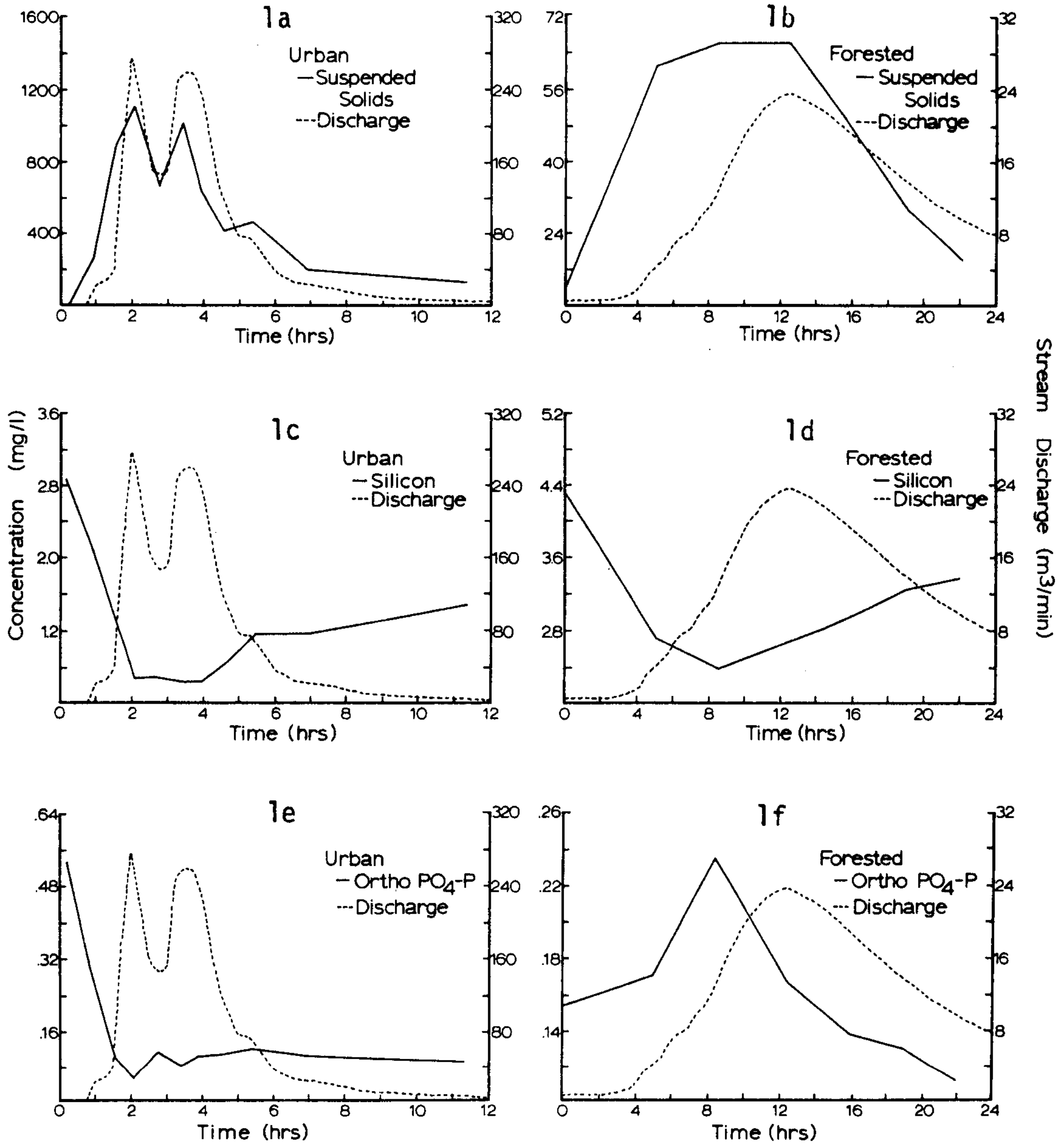

Figure 1: Comparison of stream discharge and concentrations of suspended solids, silicon, and ortho phosphate-phosphorus ($PO_4$-P) versus time in the two experimental watersheds for storm of November 21, 1973. Note variations in horizontal (time) and vertical (discharge and concentration) scales between watershed. Modified after Turner et al. (22).

## Relationships Between Stream and Constituent Discharge

A comparison of stream and constituent discharge for the same storm illustrated in Figure 1 is presented in Figure 2a through 2d. Discharge in these figures has been "normalized" by expressing quantities transported in 15 minute intervals as percentages of total storm load and plotting these percentages against time. This method facilitates comparison of stream and constituent discharge within and between watersheds.

Discharge is the primary factor in governing export of materials as is clearly demonstrated in Figures 2a through 2d. This relationship is especially remarkable for the dissolved constituents. Although concentrations of dissolved constituents are generally inversely related to stream discharge, export of materials is directly related to discharge. Other investigators (18, 21) have also found that variations in stream discharge are more important in determining export of nitrogen and phosphorus than is concentration.

Figures 2a through 2d also illustrate the striking contrast in the relative magnitude and temporal distribution of discharge between the two watersheds. The urban watershed has a much higher and more flashy peak stream and constituent discharge. Thus, the period of stormflow begins sooner and is considerably shorter in duration compared to the forested-agricultural watershed. The suburban watershed is intermediate in response between the other two watersheds.

In Figure 3, mean storm loads for the three watersheds are compared. Since these storm loads include storms of less than 0.25 cm to storms of over 5 cm representing a variety of antecedent conditions and rainfall intensities, the variability is expected to be large (indeed, standard deviation is often about equal to the mean). Nevertheless, several important differences among the watersheds are obvious. Export is greater for all constituents in the urban system. The most dramatic difference is in suspended solids with the urban system exporting 40 times more suspended solids per storm than does the forested-agricultural system. The suburban system also exports more suspended solids, dissolved solids, $NO_3$-N, and $NO_2$-N than does the forested system despite the fact that its discharge is only 40% of the discharge of the forested stream.

Since the mean discharge of the three streams is so different, calculations were made to "normalize" discharge of constituents in the urban and suburban systems to the forested-agricultural system (Table 3). The urban system discharges about 2.5 times more water per storm (in an 8 to 12 hour period) than does the forested-agricultural system (in a 24 to 48 hour period). The suburban watershed discharges only 40% (in a 16 hour period) of the discharge of the forested system; it is only one-half the size of the forested system. On a per volume of water basis,

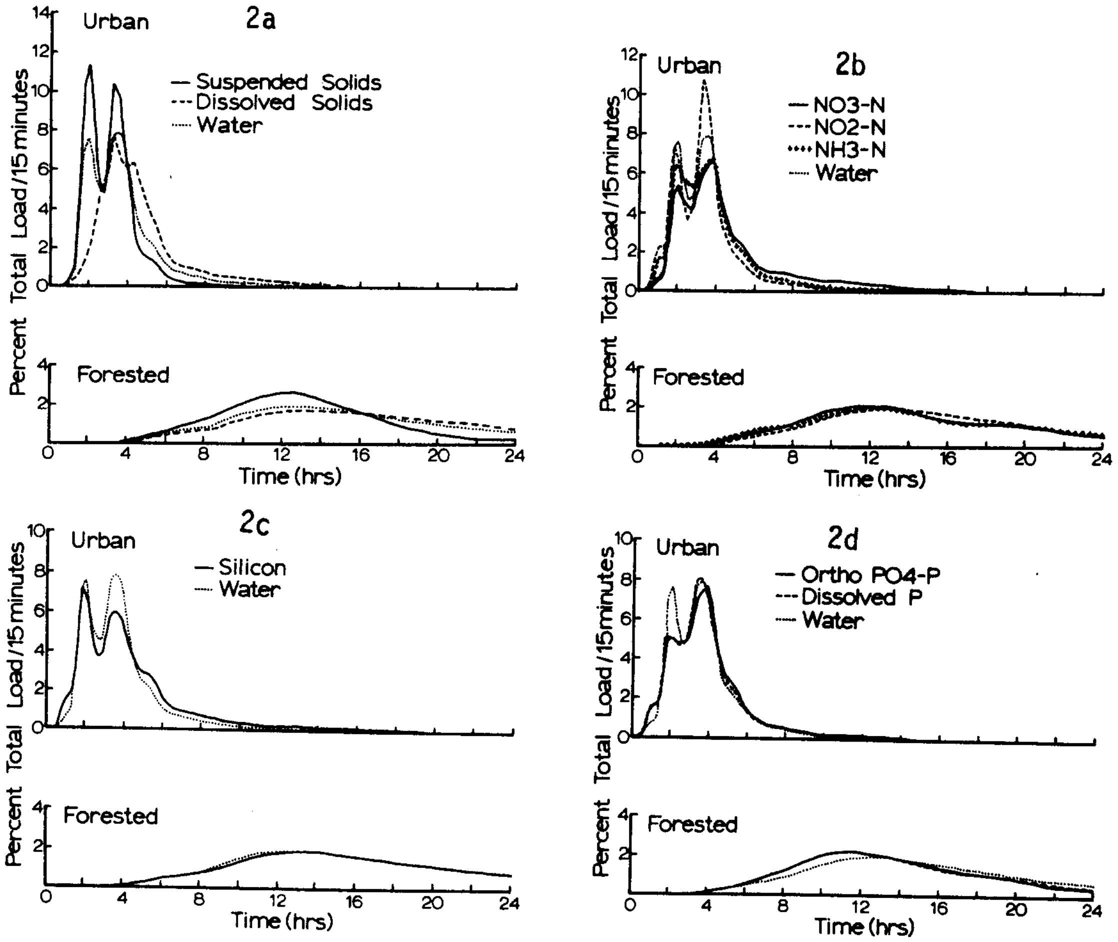

Figure 2: Comparison of the percent total loads of water, suspended and dissolved solids (2a), dissolved inorganic nitrogen species (2b), dissolved silicon (2c) and dissolved phosphorus (2d) transported in 15 minutes versus time for the two experimental watersheds for storm of November 21, 1973. Modified after Turner <u>et al</u>. (22).

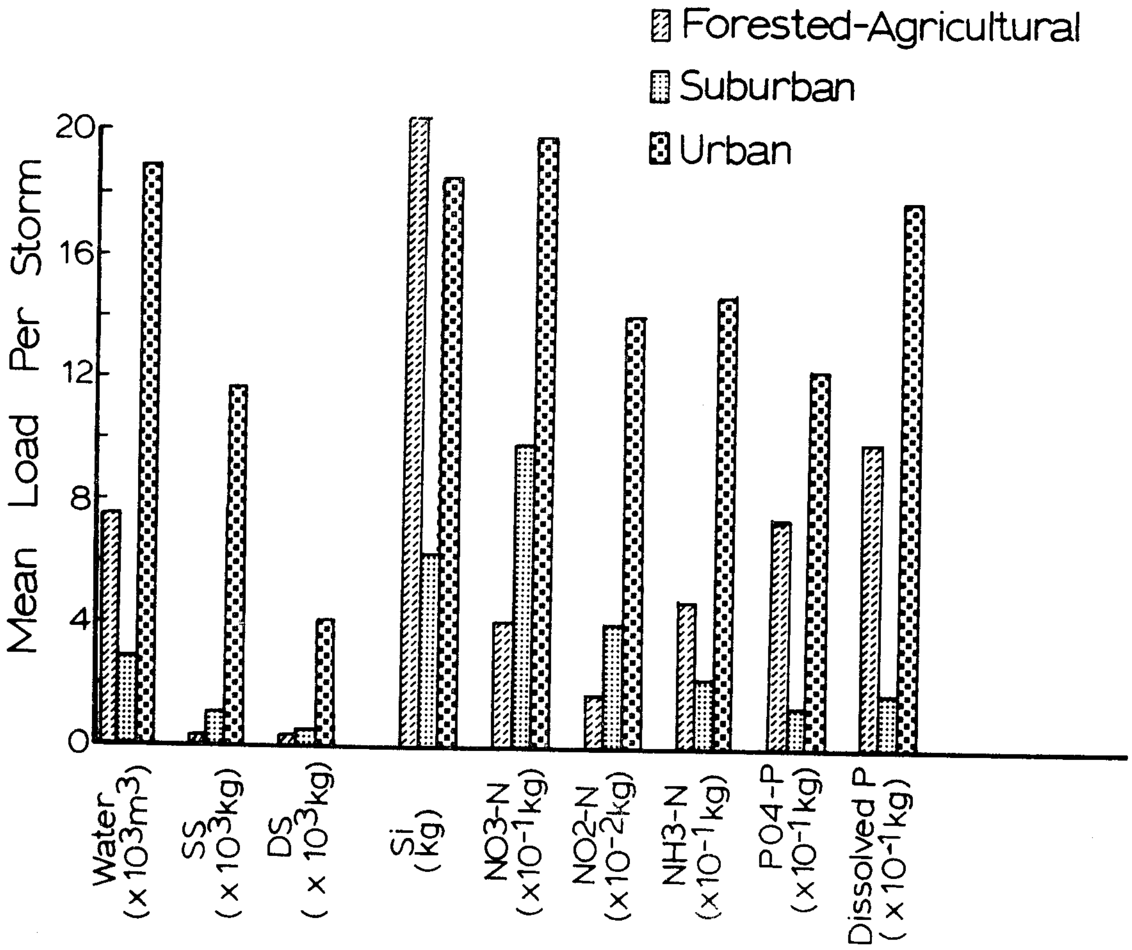

Figure 3: Comparison of mean load per storm for the three watersheds.

TABLE 3.--Ratio of mean load per volume of stormwater for urban and suburban watersheds compared to the forested watershed [(mean urban or suburban load/mean forested load)/(mean urban or suburban discharge/mean forested discharge)].

| Constituent | Urban Watershed | Suburban Watershed |
|---|---|---|
| Suspended solids | 16.06 | 9.21 |
| Dissolved solids | 5.16 | 4.08 |
| Silicon | 0.31 | 0.68 |
| $NO_3$-N | 1.92 | 5.00 |
| $NO_2$-N | 3.27 | 6.18 |
| $NH_3$-N | 1.23 | 1.24 |
| $PO_4$-P | 0.65 | 0.47 |
| Dissolved P | 0.72 | 0.47 |

there are still dramatic differences in export of suspended solids, dissolved solids, and all three inorganic nitrogen species. The most remarkable difference is in export of suspended solids where export is 16 times greater for the urban watershed and 9 times greater per volume of water for the suburban watershed. A significant portion of the suspended solids in the suburban watershed were contributed by construction of an interstate highway during the course of this study . Export of silicon and ortho and total dissolved phosphorus are lower per volume of water in both the urban and suburban watershed than in the forested watershed. This comparatively low export is linked to the much lower concentrations of silicon and dissolved phosphorus as discussed in the previous section.

## Significance of Stormwater Exports

Stormwater exports can be very significant in the annual export of materials from watersheds (3, 8, 10, 15). In order to assess the significance of stormflow relative to baseflow in our experimental watersheds, we computed the number of days required to export equivalent amounts of selected constituents from each watershed at baseflow as are transported by an average storm (Table 4). This table strongly suggests that urbanization has increased the importance of stormflow in annual export. This is especially true for suspended solids but is also true for nutrients. These findings could have important implications for management. It is possible that a large slug of nutrients are more detrimental than the same amount of nutrients trickled in over a long period of time. This question needs to be studied in more detail. It is also obvious that significant percentages of annual export can occur over short time spans during "wetter" months of the year again with important implications for receiving ecosystems.

## Quality of Storm Runoff from a Large Shopping Mall

The chemical quality of storm runoff from paved surfaces should be of considerable concern, especially when this runoff is discharged directly to a receiving stream or lake without benefit of treatment, natural or otherwise. The imperviousness of paved surfaces and their associated conduits assures that nearly all of the water falling on these surfaces will become surface runoff. Further, all of the pollutants which have accumulated on the surfaces since the last rainfall or cleaning will become a part of this runoff. Where paved surfaces comprise roofs, driveways, and residential streets, this surface runoff is often discharged to lawns and grassy swales with at least some chance of natural assimilation and treatment. The large roofed and paved surfaces of shopping malls usually necessitate disposal of storm runoff directly into the primary drainage system (often paved ditches) and thus there is little natural treatment. Shopping

TABLE 4.--Days required to transport equivalent amounts of material at baseflow as are transported by an average storm.

| Constituent | Urban Watershed | Suburban Watershed | Forested Watershed |
|---|---|---|---|
| Water | 19.3 | 3.3 | 6.2 |
| Suspended solids | 3859 (10.6 yrs) | 167 | 21 |
| Dissolved solids | 68.1 | 10.7 | 5.9 |
| Silicon | 7.8 | 2.43 | 5.6 |
| $NO_3$-N | 14.3 | 4.9 | 10.3 |
| $NO_2$-N | 10.8 | 2.2 | 4.7 |
| $NH_3$-N | 58.4 | 5.0 | 8.1 |
| Ortho $PO_4$-P | 21.8 | 3.6 | 5.8 |
| Dissolved P | 11.7 | 3.3 | 3.7 |

malls are often located in otherwise residential (suburban) areas and attract heavy human and vehicular traffic; therefore, they can have an impact on the quantity and quality of storm runoff which is quite disproportionate to their relative size in a watershed.

We have examined briefly the quantity and quality of storm runoff from a regional shopping mall in Tallahassee. The mall covers approximately 30 ha. (75 acres) and is adjacent to U.S. 27, near the interchange of this highway with I-10. Traffic studies by the Florida D.O.T. found vehicular usage of this mall to be approximately 8.6 million vehicles annually (7). The existing storm outfall (42" concrete pipe) for a reasonably well-defined section (10.8 ha) of the mall provided us with a convenient site for hydrochemical studies. We have collected water samples at this site on many occasions but only recently have we been able to obtain adequate hydrologic data simultaneously. Some of the typical characteristics of storm runoff from this mall can be illustrated by a storm event which we sampled on November 11, 1974. For this storm, runoff samples were collected manually at 2 - minute intervals on the rising limb of the hydrograph and at variable intervals ranging from 5 to 30 minutes on the falling limb. To quantify the atmospheric input of rainfall constituents for this storm, a 28 cm plastic funnel was used to collect rainwater sufficient for chemical analyses.

Table 5 summarizes concentrations of selected constituents of runoff for the entire runoff event (lasting 2.95 hrs) on November 11. Some notable features of this data set include 1) the very large variability in concentrations of nearly all the constituents, 2) the relatively high dissolved solids concentrations (as indicated by conductance and TDS) compared to the suspended solids concentrations, 3) the high proportions of volatile (i.e., organic) solids, dissolved organic carbon (DOC), and particulate organic carbon (POC) in the runoff, and 4) the high concentrations of phosphorus in the runoff considering the lack of a sanitary sewage source. Although the dissolved and suspended solids and DOC and POC concentrations are in reasonable agreement with levels reported from other urban watersheds (2, 5, 14, 20, 24) there is considerable departure from the literature values in levels of dissolved inorganic nitrogen species and phosphorus. In general other workers have found more dissolved inorganic nitrogen and considerably less phosphorus than reported here. The reasons for this are unclear but the fact that our values result from work on a single, rather small, storm with a long antecedent dry period and from an intensively used shopping mall are certainly contributing factors to the higher phosphorus levels. There is also a possibility that other studies have not adequately isolated the first flush of runoff by appropriate sampling. Relative to the higher dissolved nitrogen levels reported by others, we have noted a marked positive correlation between the occurrence of sanitary sewage leaks upstream and high dissolved nitrogen concentration downstream at our urban watershed sampling station. Such accidental

TABLE 5.--Summary statistics for concentrations of storm runoff constituents, Tallahassee Mall, November 11, 1974 (rainfall = 6.35 mm; runoff = 3.24 mm; antecedent dry period = 25 days).

| Constituent[1] | | Standard Deviation | Range | Number of Samples |
|---|---|---|---|---|
| Turbidity (JTUs) | 34 | 41 | 10-205 | 23 |
| Conductance (μmhos/cm) | 225 | 340 | 67-1530 | 23 |
| SS[2] | 57 | 63 | 6-195 | 23 |
| VSS[3] | 32 | 32 | 4-98 | 23 |
| TDS[4] | 202 | 339 | 41-1613 | 23 |
| VDS[5] | 67 | 143 | 4-708 | 23 |
| Cl | 10.2 | 16.6 | 2.1-75 | 23 |
| Si | 2.71 | 5.51 | 0.18-17 | 23 |
| $NO_3$-N | 0.184 | 0.083 | 0.051-0.352 | 23 |
| $NO_2$-N | 0.014 | 0.017 | 0.003-0.088 | 23 |
| $NH_3$-N | 0.076 | 0.044 | 0.035-0.214 | 23 |
| Ortho P | 1.47 | 3.09 | 0.028-12.0 | 23 |
| Diss. P | 1.62 | 3.23 | 0.086-12.5 | 23 |
| Tot. P | 2.69 | 4.50 | 0.281-15.1 | 23 |
| DOC | 131 | 197 | 12-648 | 10 |
| POC | 294 | 726 | 4-2220 | 9 |

[1] Concentrations in mg/l or as indicated.

[2] SS = suspended solids; [3] VSS = volatile suspended solids; [4] TDS = total dissolved solids; [5] VDS = volatile dissolved solids.

discharges of sanitary sewage in the watersheds of other studies could possibly have elevated average observed levels of dissolved nitrogen. To the best of our knowledge there were no sanitary sewage leaks within the shopping mall preceding the November 11 storm event.

Figures 4 and 5 illustrate respectively the temporal variations in flow rate and concentrations of several constituents and the cyclic variations in concentration as a function of flow rate. The trends shown by ortho phosphorus ($PO_4$-P) and specific conductance where concentrations are highest on the rising limb of the hydrograph, lowest at or near peak flow, and gradually increasing on the falling limb (Figure 5) are generally representative of other dissolved components of the mall runoff. The highest suspended solids (SS) concentration also occurred just prior to peak flow and varied almost directly with flow thereafter. Thus, relationships between flow and concentration noted earlier for the entire urban basin generally also held for runoff from the mall. The cyclic variations in concentration as a function of flow rate illustrated in Figure 5 are not often distinguishable in runoff from the urban basin but are very consistent with early flushing of the paved surface of the mall. These counterclockwise "hysteretic loops", as they are often called in hydrochemical parlance, clearly demonstrate higher concentrations of runoff constituents for a given flow rate on the rising stage of the hydrograph than for the same flow rate on the falling stage. The development of these loops depends on several factors including the length of the antecedent dry period and the intensity of rainfall. Clearly, they are more apt to occur with a gentle rainfall following a long antecedent dry period.

The temporal distribution of some runoff constituent exports over a storm hydroperiod in relationship to the temporal distribution of runoff has been illustrated (Figure 2) for the entire urban basin and indicates generally synchronous water and constituent export. The well-developed loops in concentrations of constituents as functions of flow rate in the shopping mall runoff suggest that exports of water and constituents may not have been very synchronous. Figure 6 demonstrates that for several constituents, this was indeed true. For instance, note that 50% of the total storm export of suspended solids (SS) was carried by the first 20% of the water export. Similarly note that 50% of the storm export of ortho phosphorus ($PO_4$-P) was carried by only the first 3% of the water export. Interestingly, exports of the dissolved inorganic nitrogen species and volatile dissolved solids (VDS) were more synchronous with water exports. One can infer from these trends that pollutionally significant portions of the mall runoff could be captured and treated, perhaps by disposal to shallow dry wells, in some cases by capturing only small fractions of the total runoff, i.e. the first flush. The 90% export bars in Figure 6 indicate that analogous to sanitary sewage treatment, if higher proportions of the total export of a pollutant are to be captured and treated the volume of water necessary to

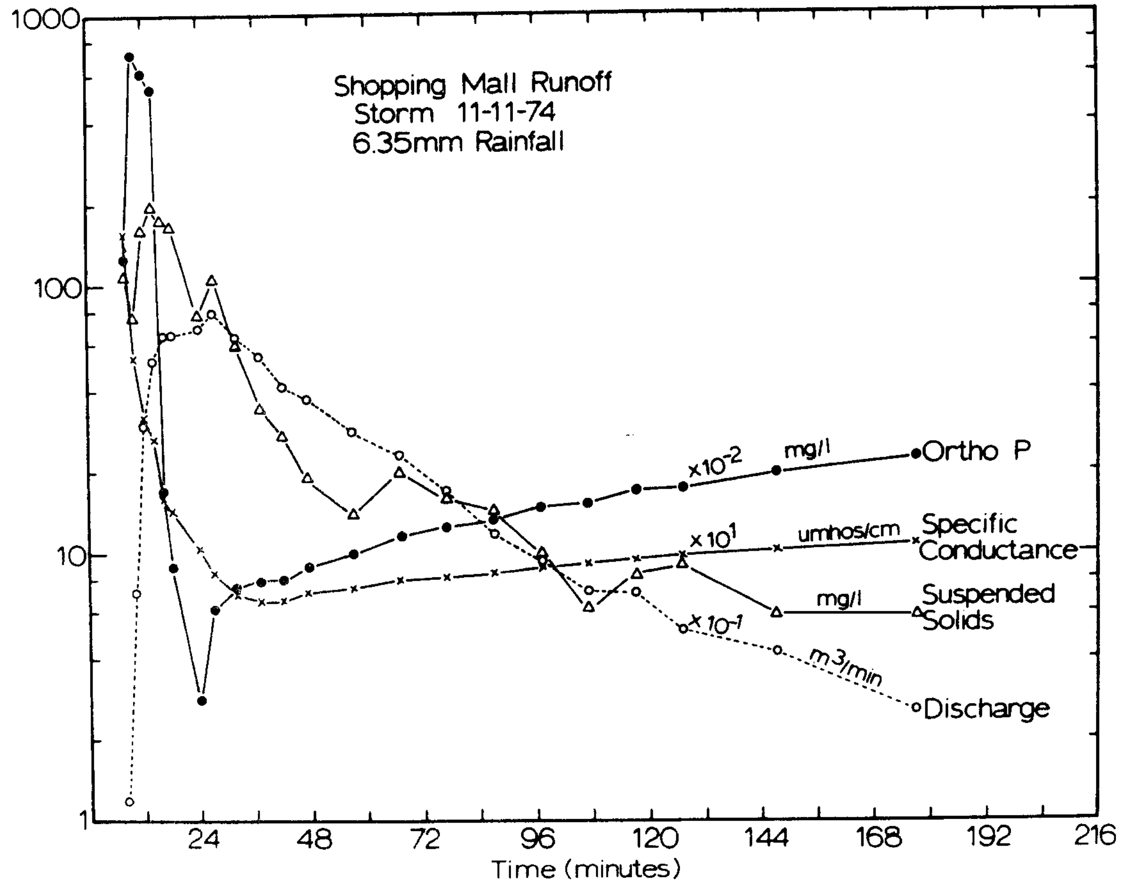

Figure 4: Comparison of discharge of water and concentrations of ortho phosphate-phosphorus, specific conductance, and suspended solids in shopping mall runoff at Tallahassee, Florida.

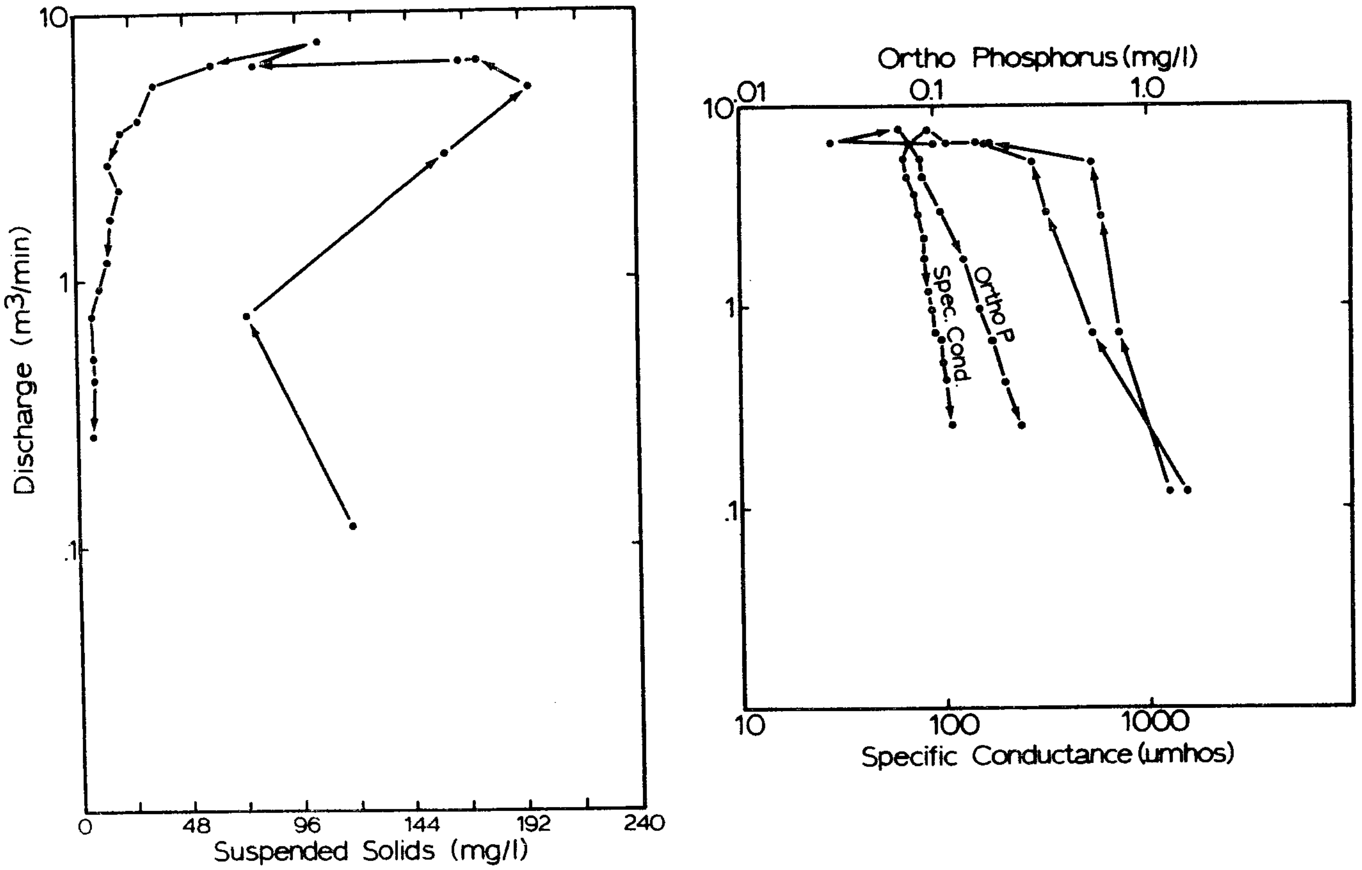

Figure 5: "Hysteretic loops" of concentration of suspended solids and specific conductance versus discharge of water for shopping mall runoff at Tallahassee, Florida. Arrows indicate time sequence of collection of samples.

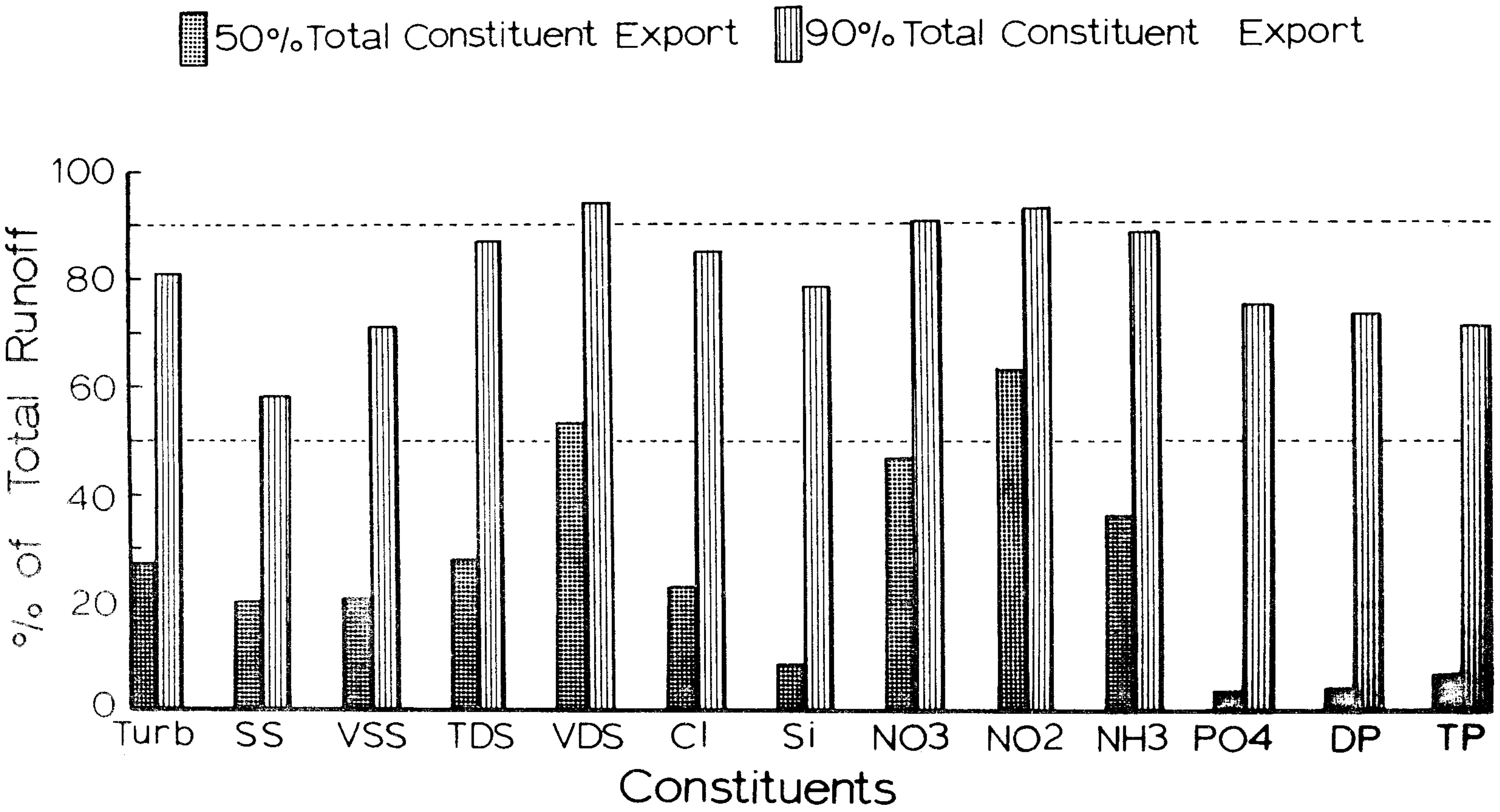

Figure 6: Amount of runoff necessary to transport 50% and 90% of constituent export.

obtain these proportions increase non-linearly. Thus, although only 3% of the water export carried 50% of the storm export of ortho phosphorus, 85% of the water carried 90% of the total export of ortho phosphorus. If the trends in the distribution of dissolved inorganic nitrogen exports observed for this storm are representative of similar storm events, it is evident that exports of these forms of nitrogen are relatively synchronous with export of water and thus efforts to capture pollutionally significant portions will have to include larger volumes of water than would be necessary for most of the other constituents. Although we have no data to support the suggestion, it seems probable that the export of particulate organic nitrogen was not synchronous with water export and behaved similarly to volatile suspended solids (VSS). Further, the synchrony between exports of volatile dissolved solids (VDS) and water suggested that exports of dissolved organic nitrogen and water were also synchronous.

Some simple mass balance calculations for the November 11 storm were quite revealing of the significance of rainfall by itself as a source of some runoff constituents (Table 6). Because of uncertainties in the completeness of flushing of mall surfaces of particulate matter, only dissolved substances could be included in the mass balance calculations. Further, since only 51.1% of the input rainfall appeared as runoff we had to make some assumptions about the chemistry of the water remaining in depression storage. Basically, we assumed that concentrations of constituents in depression storage were similar to those observed in final runoff. In any case the concentrations could not have been any less since some constituents were still increasing in concentration in the final runoff. Depression storage of the constituents given in Table 6 thus probably represents minimum values.

The most significant features of the mass balance were 1) the relatively large quantities of nearly all constituents remaining in depression storage and 2) the quantity of dissolved inorganic nitrogen contributed by rainfall. The large relative depression storage is consistent with a storm of this size (6.35 mm) since asphalt can store a minimum of 1.5 mm (6) and another 1 mm or more could have easily have been lost to ponding and evaporation. Furthermore, the low intensity and volume of rainfall was apparently insufficient to accomplish quantitative flushing of solids from the mall and soluble solid components remained to supply dissolved substances to late runoff and depression storage.

Rainfall concentrations and inputs of the runoff constituents in grams per hectare were quite comparable to inputs from similar storms which we have quantified for Tallahassee and to concentrations reported by others for the southeastern U.S. (4, 12, 22). The high percent rainfall contribution of the dissolved inorganic nitrogen species for this storm was somewhat surprising but consistent with findings by

TABLE 6.--Mass balances of some dissolved stormwater constituents for storm of 11/11/74, 10.8 ha section of shopping mall, Tallahassee, Florida. (Rainfall = 6.35 mm; runoff = 3.24 mm; antecedent dry period = 25 days).

| Constituent | Rainfall Input (g/ha) | Runoff Output (g/ha) | Depression Storage* (g/ha) | % Contribution from Rainfall |
|---|---|---|---|---|
| TDS** | -- | 3022 | 2356 | -- |
| VDS** | -- | 874 | 1519 | -- |
| Cl | 76 | 138 | 124 | 29.0 |
| Si | 0.63 | 16.7 | 16.4 | 1.9 |
| $NO_3$-N | 13.7 | 6.5 | 8.1 | 93.8 |
| $NO_2$-N | 0.32 | 0.33 | 0.43 | 42.1 |
| $NH_3$-N | 13.3 | 2.1 | 1.2 | (403) |
| Ortho P | 0.4 | 12.4 | 7.0 | 2.1 |
| Diss. P | 0.6 | 15.1 | 7.2 | 2.7 |
| DOC | --- | 868 | 735 | --- |

*Estimated from final sample concentrations and net storage volume.

**Total dissolved solids; volatile dissolved solids.

Kluesener and Lee (14) for an urban watershed in Madison, Wisconsin. They reported that 20 to 90% of NO3-N and nearly all NH3-N in stormwater runoff originated from rainfall. The apparent anomaly in the percent (403%) contribution of NH3-N, i.e. apparent massive retention or non-runoff loss, shown in Table 6 was also noted by Kluesener and Lee (14) and attributed to losses of early rainfall by evaporation. Alternately, considerable NH3-N could have been quickly adsorbed by particulate matter and never have appeared in the dissolved phase of the runoff. The small fraction of dissolved phosphorus contributed by rainfall (2.7%) observed by us is also consistent with findings by Kluesener and Lee (14) who reported that less than 10% of phosphorus were derived from rainfall.

## CONCLUSIONS

The effects of different land uses on stormwater quality and nutrient and suspended solids export are quite extensive. The progression from a forested-agricultural ecosystem to an urban system leads to: 1) increased overland flow and increased peak stream discharge; 2) increased total volume of discharge over a much shorter time span; 3) increased mean concentrations of dissolved solids (TDS), nitrate-nitrogen, and ammonia-nitrogen under all streamflow conditions in both the urban and suburban watersheds; 4) decreased mean concentrations of dissolved silicon and orthophosphate-phosphorus under all streamflow conditions in both the suburban and urban watersheds; 5) decreased mean concentrations of suspended solids under low streamflow conditions but dramatically increased mean concentrations of suspended solids under high streamflow conditions; 6) increased variability in the composition of streamwaters under all flow conditions; 7) increased export rates of all dissolved (except silicon) and suspended constituents during storm events and, therefore increased relative significance of storms as transport mechanisms.

Orthophosphate-phosphorus ($PO_4$-P) results differ from other published results as concentrations are much higher in the forested-agricultural watershed than in the suburban watershed and urban watershed. Even with lower concentrations, export of $PO_4$-P is still larger in the urban watershed because of the much greater runoff.

Results from this study have important implications for watershed management. Most of the observed changes are associated with anthropogenic sources of constituents within the watershed and with changes in hydrology. Methods have to be developed to control increased stream discharge, perhaps by greenbelt areas and holding ponds distributed throughout urban areas. The high loadings from the shopping mall suggest that, at least, the first flush of materials from paved surfaces needs to be treated. More data are needed on water quality and nutrient exports from other specific land uses in urban areas. Cleaning up our water resources will require treatment of stormwater from selected areas such as shopping malls, combined with control of runoff from urban areas by use of holding ponds, marshes, greenbelt areas or other such methods.

The variability of the stormwater runoff also has important implications for development of water quality criteria. Such criteria should be based on both loading rates and concentrations. Water quality monitoring stations in urban areas also have to include provisions for sampling complete storm hydrographs because of the increased importance of storm flow.

## ACKNOWLEDGMENTS

This project has been financed largely by grants from the Florida Department of Transportation and the Florida Game and Freshwater Fish Commission. Mr. John H. Phipps of Ayavalla Plantation owns the land which includes the forested experimental watershed and has been most cooperative in permitting access to his land for the conduct of this study. Ms. Judy Dietrich, Ms. Trina Billingsley and Mr. Tim Casey have provided essential technical assistance.

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# QUANTITY AND QUALITY OF RUNOFF FROM A RESEDENTIAL AREA NEAR POMPANO BEACH, FLORIDA

C. B. Sherwood and H. C. Mattraw
U.S. Geological Survey (WRD)
901 South Miami Ave.
Miami, Florida 33130

An event-oriented investigation of rainfall, runoff, and water quality in a residential area served by storm sewers in southeast Florida was begun in March 1974.

Instruments, developed by Smoot, 1974, include components designed to 1) monitor and record rainfall at several locations in the area and the resulting flow in the storm sewer, and 2) collect and preserve multiple samples of adequate volume for extended analyses from storms of appreciable size.

By the end of September, 1974, rainfall was recorded for 104 events, 19 of which were of sufficient magnitude to activate the sampling mechanism. Rainfall intensity was as high as 13 inches (330 millimeters) for 24 hours.

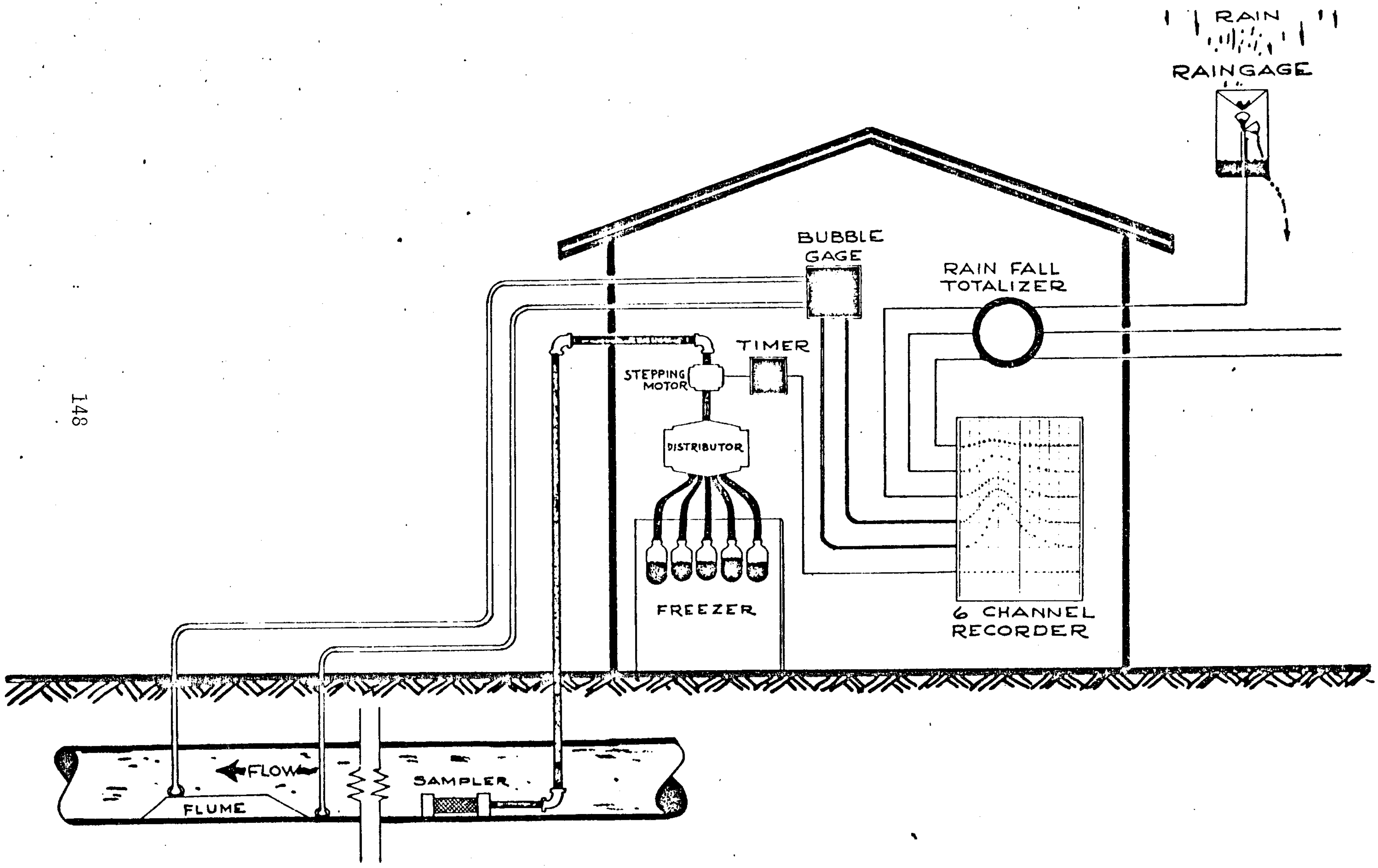
Samples were collected at 144-second intervals during the 19 storm events. In general the highest concentrations of most constituents occurred during rainfall events following long dry periods and the lowest concentrations occurred during periods of frequent rainfall. Peak concentrations, in milligrams per litre, ranged from 5.3 to 0.7 for nitrogen, 1.35 to 0.15 for phosphorus, and 290 to 15 for COD (chemical oxygen demand). A 1-inch (25 millimeters) storm of 30 minutes duration on June 16, 1974 resulted in a peak flow of 19 cubic feet per second (0.5 cubic meter per second) and loads of 1.4 pounds (0.6 kilogram) of nitrogen, 0.5 pound (0.2 kg) of phosphorus, and 15 pounds (6.8 kg) of COD.

Total coliform bacteria counts in some storms were as high as 1.8 million colonies per 100 milliliters of water.

The instrumentation and runoff and water quality data from selected rainfall events during April - September, 1974, are shown in the following illustrations and table.

## REFERENCE

Smoot, G. F. and others, 1974, Urban Storm -runoff-quality instrumentation, I.A.S.H. Publication No. 112.


RAIN
RAINGAGE
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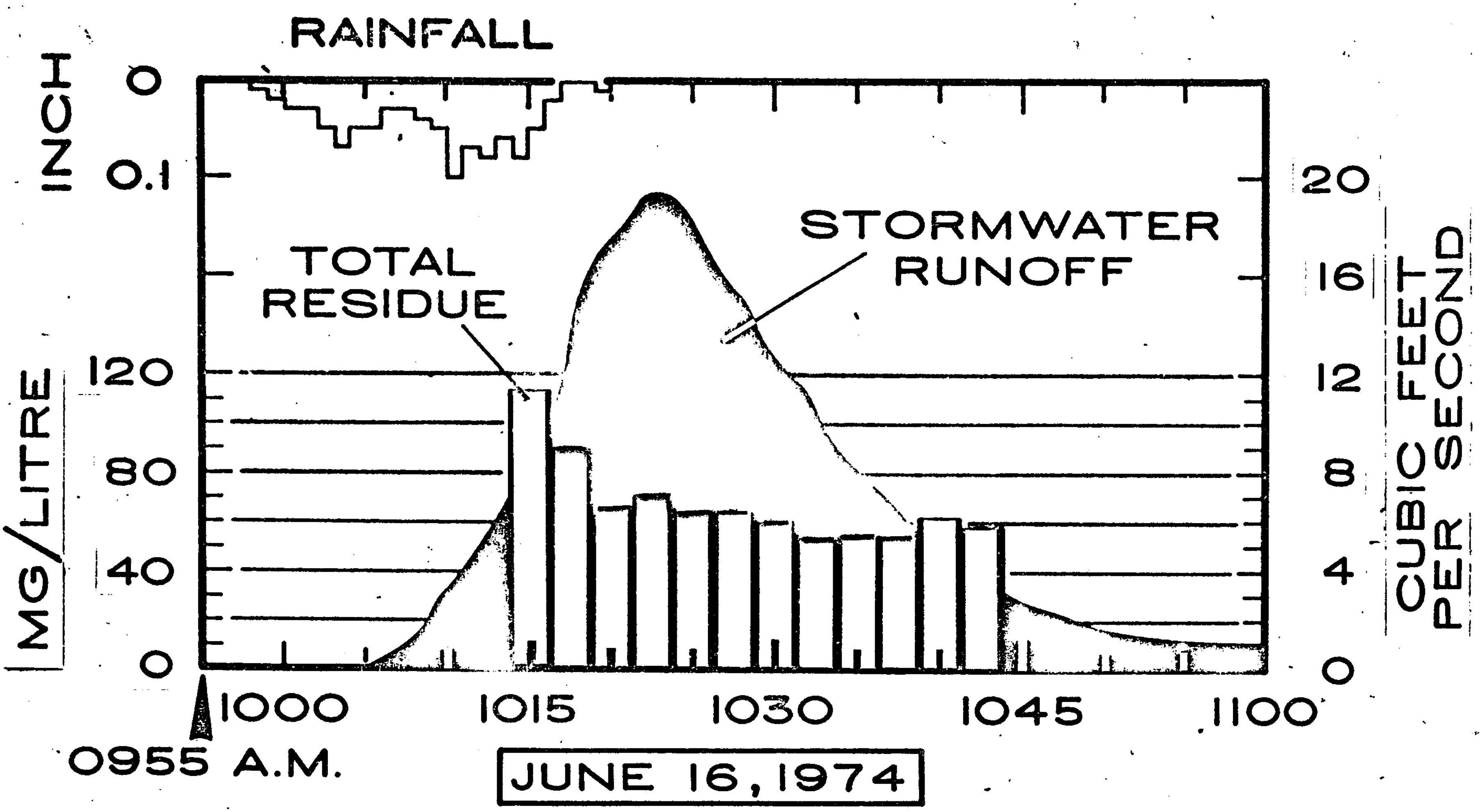
SAMPLER
FLUME



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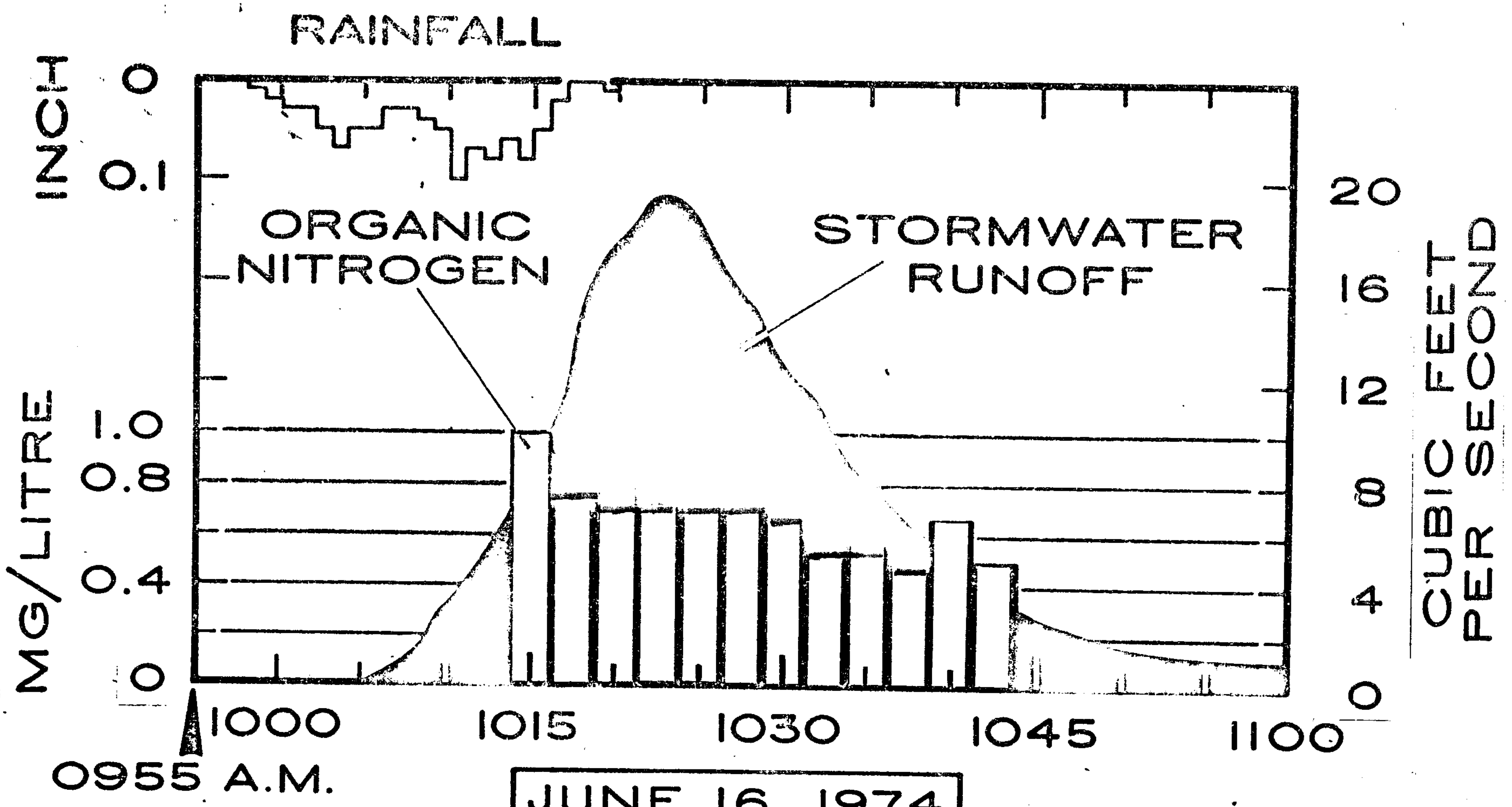

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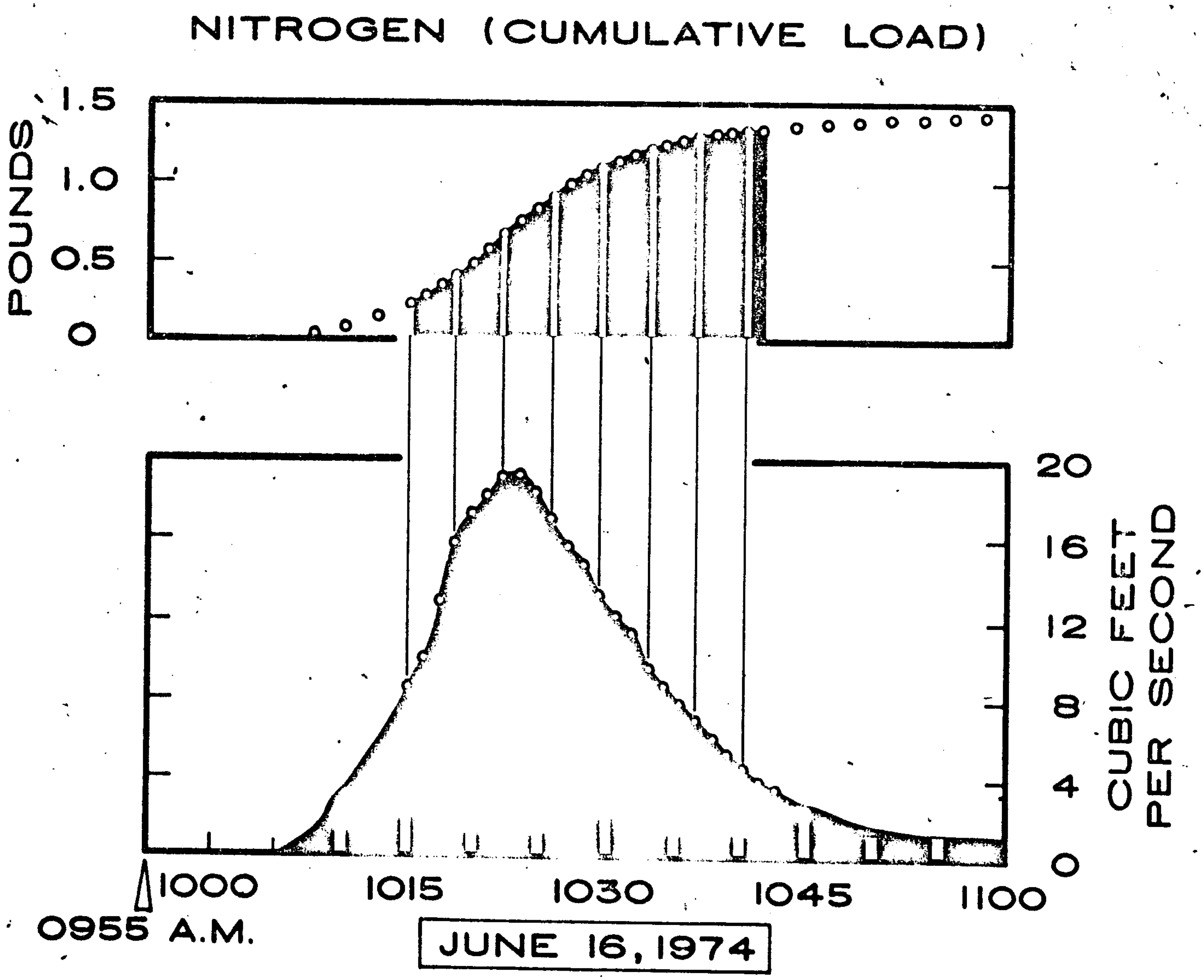

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## STORM WATER QUALITY
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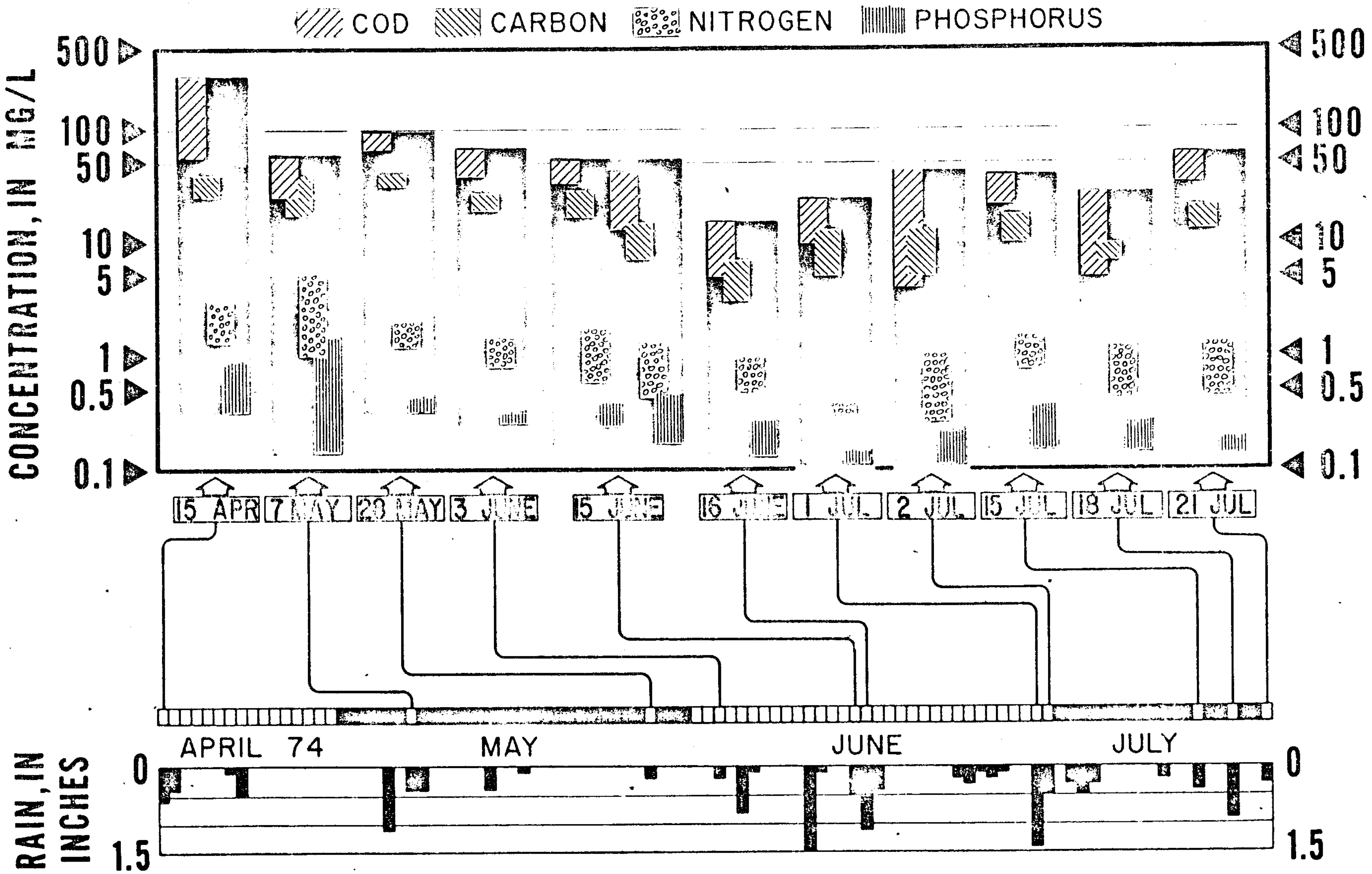

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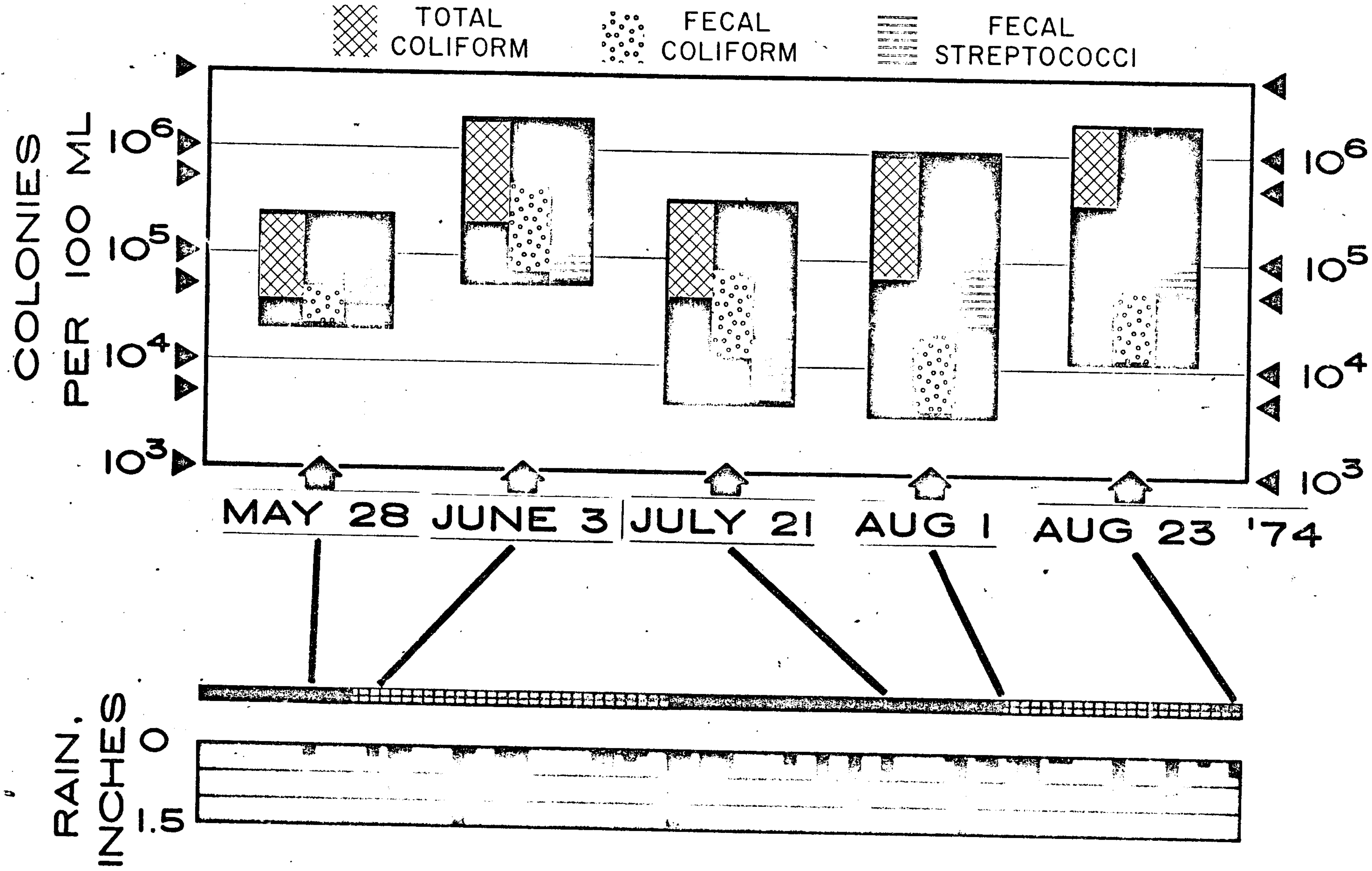

Table 1. -- Concentrations of selected constituents in runoff from a residential area near Pompano Beach, Florida - April - Sept. 1974.

| Date | | Total Rain (inch) | Max. Dis-charge (cfs) | Spe-cific Con-duct-ance (micro-mhos) | Organic Nitro-gen (N) (Mg/1) | Ammonia Nitro-gen (N) (Mg/1) | Total Nitrite (N) (Mg/1) | Total Nitrate (N) (Mg/1) | Total Phos-phorus (P) (Mg/1) | Bio-Chem-ical Oxygen Demand (Mg/1) | Chem-ical Oxygen Demand (High level) (Mg/1) | Total Resi-due (Mg/1) | Total Filt-rable Residue (Mg/1) | Total Carbon (C) (Mg/1) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Apr. 15 | Max. | 0.56 | 4.1 | | 3.1 | .14 | .06 | .80 | .88 | | 289 | | | 38 |
| | Min. | | | | 1.3 | .02 | .02 | .45 | .32 | | 57 | | | 25 |
| | Avg. | | | | 1.7 | .06 | .03 | .63 | .50 | | 151 | | | 32 |
| May 07 | Max. | 0.40 | 1.6 | 155 | 5.7 | .82 | .24 | 1.20 | 1.50 | 8.9 | 59 | 375 | 126 | 38 |
| | Min. | | | 155 | 1.0 | .50 | .04 | .46 | .14 | 8.9 | 23 | 116 | 102 | 17 |
| | Avg. | | | 155 | 2.4 | .59 | .10 | .76 | .44 | 8.9 | 39 | 189 | 114 | 27 |
| May 28 | Max. | 0.18 | 0.19 | 186 | 1.9 | 1.3 | .07 | .90 | .38 | | 87 | 164 | 138 | 39 |
| | Min. | | | 130 | | | | | | | | | | |
| | Avg. | | | 158 | | | | | | | | | | |
| June 03 | Max. | 0.16 | 0.32 | 140 | 1.20 | .40 | .06 | .88 | .29 | 10.0 | 67 | 118 | 111 | 28 |
| | Min. | | | 76 | .92 | .32 | .06 | .74 | .27 | 6.0 | 39 | 88 | 83 | 15 |
| | Avg. | | | 100 | 1.10 | .36 | .06 | .82 | .27 | 8.2 | 54 | 102 | 93 | 22 |
| June 15 | Max. | 0.39 | 1.8 | 79 | 1.90 | .26 | .03 | .61 | .47 | | 54 | 140 | 78 | 29 |
| | Min. | | | 59 | .38 | .06 | .02 | .38 | .17 | | 13 | 72 | 53 | 7 |
| | Avg. | | | 65 | .98 | .19 | .02 | .47 | .28 | | 33 | 100 | 63 | 14 |
| June 16 | Max. | 1.10 | 19 | 47 | 1.00 | .10 | .02 | .20 | .28 | | 15 | 114 | 51 | 7.0 |
| | Min. | | | 40 | .47 | .02 | .01 | .15 | .13 | | 5 | 54 | 26 | 3.0 |
| | Avg. | | | 44 | .67 | .06 | .01 | .17 | .20 | | 8 | 69 | 34 | 4.9 |
| July 01 | Max. | 1.35 | 21 | 120 | .39 | .01 | .01 | .29 | .15 | | 24 | 54 | 46 | 13 |
| | Min. | | | 105 | .31 | .01 | .01 | .21 | .11 | | 10 | 41 | 32 | 5 |
| | Avg. | | | 116 | .34 | .01 | .01 | .25 | .13 | | 16 | 47 | 38 | 11 |
| July 02 | Max. | 0.50 | 3.3 | 105 | 1.10 | .41 | .02 | .29 | .22 | | 42 | 112 | 74 | 13 |
| | Min. | | | 60 | .27 | .01 | .01 | .18 | .11 | | 4 | 40 | 34 | 4 |
| | Avg. | | | 85 | .44 | .07 | .01 | .23 | .13 | | 14 | 77 | 54 | 7 |
| July 15 | Max. | 0.39 | 2.3 | 81 | 1.60 | .25 | .02 | .83 | .38 | 15 | 39 | 142 | 92 | 18 |
| | Min. | | | 71 | .78 | .02 | .02 | .50 | .15 | 10 | 22 | 11 | 52 | 10 |
| | Avg. | | | 76 | 1.04 | .11 | .02 | .60 | .26 | 13 | 30 | 89 | 69 | 14 |
| July 18 | Max. | 0.94 | 5.7 | 61 | 1.30 | .11 | .03 | .34 | .27 | 7.2 | 27 | 108 | 48 | 10 |
| | Min. | | | 43 | .44 | .01 | .01 | .19 | .18 | 3.4 | 5 | 32 | 10 | 7 |
| | Avg. | | | 48 | .62 | .03 | .02 | .23 | .21 | 4.3 | 12 | 72 | 38 | 8 |
| July | Max. | 0.32 | 0.83 | 110 | 1.40 | .15 | .05 | .86 | .20 | 12.0 | 61 | 115 | 106 | 21 |
| | Min. | | | 74 | .45 | .02 | .03 | .38 | .14 | 6.5 | 34 | 9 | 50 | 13 |
| | | | | 88 | .78 | .07 | .04 | .58 | .17 | 9.4 | 45 | 82 | 82 | 17 |

Table 1.

Concentrations of selected constituents in runoff from a residential area near Pompano Beach, Florida - April - Sept. 1974.

| Date | | Total Rain (inch) | Max. Discharge (cfs) | Total Coliform (Col. per 100 ml) | Fecal Coliform (Col. per 100 ml) | Streptococci (Colonies per 100 ml) |
|---|---|---|---|---|---|---|
| Apr. 15 | Max. | 0.56 | 4.1 | | | |
| | Min. | | | | | |
| | Avg. | | | | | |
| May 07 | Max. | 0.40 | 1.6 | | | |
| | Min. | | | | | |
| | Avg. | | | | | |
| May 28 | Max. | 0.18 | 0.19 | 210,000 | 47,000 | 79,000 |
| | Min. | | | 35,000 | 22,000 | 31,000 |
| | Avg. | | | 87,000 | 32,410 | 56,000 |
| June 03 | Max. | 0.16 | 0.32 | 1,800,000 | 490,000 | 120,000 |
| | Min. | | | 210,000 | 72,000 | 60,000 |
| | Avg. | | | 510,000 | 280,000 | 97,000 |
| June 15 | Max. | 0.39 | 1.8 | | | |
| | Min. | | | | | |
| | Avg. | | | | | |
| June 16 | Max. | 1.10 | 19 | | | |
| | Min. | | | | | |
| | Avg. | | | | | |
| July 01 | Max. | 1.35 | 21 | | | |
| | Min. | | | | | |
| | Avg. | | | | | |
| July 02 | Max. | 0.50 | 3.3 | | | |
| | Min. | | | | | |
| | Avg. | | | | | |
| July 15 | Max. | 0.39 | 2.3 | | | |
| | Min. | | | | | |
| | Avg. | | | | | |
| July 18 | Max. | 0.94 | 5.7 | | | |
| | Min. | | | | | |
| | Avg. | | | | | |
| July 21 | Max. | 0.32 | 0.83 | 320,000 | 79,000 | 18,000 |
| | Min. | | | 42,000 | 10,000 | 5,000 |
| | Avg. | | | 170,000 | 34,000 | 10,000 |

Table 1.--(Cont'd) Concentrations of selected constituents in runoff from a residential area near Pompano Beach, Fla. - April - Sept. 1974.

| Date | | Total Rain (inch) | Max. Dis-charge (cfs) | Spe-cific Con-duct-ance (micro-mhos) | Organic Nitro-gen (N) (Mg/1) | Ammonia Nitro-gen (N) (Mg/1) | Total Nitrite (N) (Mg/1) | Total Nitrate (N) (Mg/1) | Total Phos-phorus (P) (Mg/1) | Bio-Chem-ical Oxygen Demand (Mg/1) | Chem-ical Oxygen Demand (High level) (Mg/1) | Total Resi-due (Mg/1) | Total Filt-rable Residue (Mg/1) | Total Carbon (C) (Mg/1) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Aug. 01 | Max. | | | 135 | .83 | .01 | .03 | .34 | .37 | 4.6 | 58 | 94 | 52 | 25.0 |
| | Min. | | | 75 | .33 | .01 | .01 | .17 | .10 | 12.0 | 22 | 32 | 27 | 9.0 |
| | Avg. | | | 93 | .50 | .01 | .02 | .28 | .23 | 7.4 | 36 | 49 | 36 | 15.7 |
| Aug. 17 | Max. | 0.69 | 4.4 | 86 | 1.20 | .01 | .020 | .68 | .58 | | 64 | 142 | 72 | 18 |
| | Min. | | | 5 | .56 | .01 | .Q10 | .38 | .24 | | 10 | 69 | 44 | 12 |
| | Avg. | | | 67 | .84 | .01 | .018 | .48 | .38 | | 28 | 88 | 59 | 15 |
| Aug. 23 | Max. | 0.27 | 2.33 | 85 | 2.10 | .06 | .03 | .26 | .60 | 8.7 | 31 | 173 | 83 | 17 |
| | Min. | | | 7 | .56 | .01 | .01 | .10 | .14 | 3.8 | 10 | 73 | 58 | 6 |
| | Avg. | | | 66 | .76 | .03 | .02 | .19 | .27 | 6.5 | 22 | 99 | 72 | 14 |
| Sept. 05 | Max. | 0.22 | 1.5 | 122 | 1.60 | .10 | .03 | .31 | .24 | 9.9 | 69 | 140 | 124 | 32 |
| | Min. | | | 68 | .77 | .02 | .01 | .12 | .13 | 3.6 | 26 | 82 | 68 | 16 |
| | Avg. | | | 106 | .99 | .05 | .02 | .24 | .18 | 7.6 | 52 | 113 | 99 | 22 |
| Sept. 06 | Max. | 0.22 | | 62 | 1.60 | .07 | .03 | .11 | .16 | 3.3 | 22 | 103 | 68 | |
| | Min. | | | 38 | .24 | .01 | .01 | .06 | .08 | 2.1 | 7 | 42 | 36 | 8 |
| | Avg. | | | 58 | .49 | .03 | .02 | .04 | .11 | 3.0 | 16 | 59 | 48 | 11 |
| Sept. 30 | Max. | 0.91 | 14 | 76 | .70 | .18 | .04 | .59 | .13 | 6.7 | 19 | 99 | 84 | 11 |
| | Min. | | | 42 | .23 | .08 | .01 | .21 | .08 | 2.2 | 7 | 25 | 20 | 5 |
| | Avg. | | | 56 | .44 | .12 | .02 | .35 | .09 | 4.8 | 13 | 50 | 34 | 7 |

Table 1.--(Cont'd)

Concentrations of selected constituents in runoff from a residential area near Pompano Beach, Fla. - April - Sept. 1974.

| Date | | Total Rain (inch) | Max. Discharge (cfs) | Total Coliform (Col. per 100 ml) | Fecal Coliform (Col. per 100 ml) | Streptococci (Colonies per 100 ml) |
|---|---|---|---|---|---|---|
| Aug. 01 | Max. | | | 950,000 | 23,000 | 100,000 |
| | Min. | | | 68,000 | 4,000 | 37,000 |
| | Avg. | | | 270,000 | 13,000 | 51,000 |
| Aug. 17 | Max. | 0.69 | 4.4 | | | |
| | Min. | | | | | |
| | Avg. | | | | | |
| Aug. 23 | Max. | 0.27 | 2.33 | 1,800,000 | 62,000 | 100,000 |
| | Min. | | | 340,000 | 12,500 | 49,000 |
| | Avg. | | | 980,000 | 37,400 | 7,500 |
| Sept. 05 | Max. | 0.22 | 1.5 | | | |
| | Min. | | | | | |
| | Avg. | | | | | |
| Sept. 06 | Max. | 0.22 | | | | |
| | Min. | | | | | |
| | Avg. | | | | | |
| Sept. 30 | Max. | 0.91 | 14 | | | |
| | Min. | | | | | |
| | Avg. | | | | | |