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The Effect of Storm Sewer Drainage on an Urban Lake

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THE EFFECT OF STORM SEWER DRAINAGE ON AN URBAN LAKE

by

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THE EFFECT OF STORM SEWER DRAINAGE ON AN URBAN LAKE

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The present study was undertaken to evaluate the impact from normal precipitation (rain, snow) into an urbanized lake during 1978-1980. Several stations were chosen, and various limnological parameters were investigated. Chemical analyses were used to estimate the annual load of nutrients input into the lake by the storm sewer and surface runoff. Excessive phosphorus and nitrogen loads from these sources were discharged into the lake.

Fecal coliform distribution in the lake before, during, and after several storm events was studied. In general, fecal coliform counts increased after storm events. Peak concentrations decreased markedly with distance of the station from the storm sewer outlet. When the storm ended, the fecal coliform cound usually decreased at each station. After a period of approximately 48 hours, the fecal coliform count returned to the levels which occurred before the storm event. In the swimming area the counts of fecal coliform during the testing period were considered to be within safe limits.

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INTRODUCTION

Limnologists have become increasingly concerned about the quality of water in lakes in urban areas. The result of this concern has been the promulgation of regulations, both state and federal, culminating in the Federal Water Pollution Control Act (FWPCA) as amended in 1971 and 1977 to maintain the biological integrity of the nation's waters.

The objective of the FWPCA is "to restore and maintain the chemical, physical, and biological integrity of the nation's waters". For that reason, it is expected that a large amount of public funds will be spent in the United States for the implementation of advanced waste-water treatment facilities. Many studies performed during the last two decades have shown that, in many cases, the concentration of pollutants in the water discharged by storm sewers was higher than their concentration in the effluent discharged by waste-water treatment plants (Rice, 1979). Because of this, the Environmental Protection Agency (EPA) is assisting in multiple research and development programs to identify, control, and correct the causes of known problems related to these storm events. These studies have provided valuable information that may help achieve the clean water goals following the construction of the advanced waste-water treatment plants.

The City of Kalamazoo, located in southwestern Michigan, situated about 56 km. from Lake Michigan on the Kalamazoo River, has two separate sewer systems: the sanitary and the storm sewer systems.

The former collects and transports domestic, commercial, and industrial waste-water to a treatment plant in which the water is "purified" before being discharged to the Kalamazoo River. The storm sewer system collects the natural precipitation which falls on the urban area and discharges it to a receiving body of water without previous treatment.

The purpose of this study was to evaluate the impact produced by urban runoff discharged into an urban lake. This was accomplished by estimating the annual input of phosphorus and nitrogen from urban runoff and by determination of the distribution of fecal coliform during wet and dry periods.

LITERATURE REVIEW

Stormwater runoff, according to Lager and Smith (1974), refers to "water pollution from combined sewer overflows, surface runoff either collected separately or occurring as nonsewered runoff, and overflows of infiltrated municipal sewage resulting from precipitation" (p. 64).

In the last five decades it has been recognized that stormwater runoff is heavily contaminated; the earliest attention to the problem was concerned with pollution from combined sewer overflows. In the last two decades a concern over urban runoff as a significant source of water pollution has begun to develop (Indian Nations Council of Governments, 1978).

Because the stormwater pollution problem is a very broad topic, this study was directed to the pollution problem produced by urban runoff into a receiving body of water. Urban runoff was defined by Tafury (1975) as "the releasing into the nearest collection channel (man-made or natural) of excess urban surface water caused by precipitation" (p. 3).

The literature review concerning urban runoff can be divided into three sections: emergence of an urban runoff problem, sources of pollution, and environmental effects of urban runoff discharges in the receiving body of water.

Emergence of an Urban Runoff Problem

The necessity of removing rainfall runoff in the cities was

recognized a long time ago. In ancient Rome, buildings, plazas, and streets of nonporous materials interfered with the natural percolation and runoff process. For that reason, the Romans constructed large underground drains that usually discharged into the nearest body of water. Human excretion and solid wastes were excluded by ordinance (Lager and Smith, 1974). This practice was later adopted by Europeans and Americans. As cities became larger, especially after the industrial revolution, the traditional method of using privies and "night soil" transport for the disposal of human waste was not efficient enough to keep backyards, slums, and living areas from filling with excrement and wastewater (Metcalf and Eddy, 1928).

At the beginning of the nineteenth century some disease epidemics were related to filthy living conditions. To effect a solution, in London in 1815, the law was changed to allow disposal of sanitary waste via the storm sewer; thus the first combined sewer was created. At the end of the nineteenth century it was realized that the wastewater problem was transferred from the land to the receiving water rather than providing a real solution (Lager and Smith, 1974). Many cities started to treat municipal sewage prior to discharge. The municipal sewage was captured by an interceptor sewage system to bring dry-weather flow to central locations for treatment. Because the capacity of combined sewer and treatment plants was designed to treat only an amount equivalent to dry-weather flow, relief points were constructed to divide the flow during storms. These combined sewers might be carrying five, fifty or more times the dry-weather flow (Lager and Smith, 1974). On the average up to

three times the dry-weather flow rate was intercepted with about half of this receiving some treatment, the rest was discharged to the receiving water without previous treatment. At that time it was thought that the amount of pollutants discharged during overflows was not very significant. Typically two to five percent of the total municipal sewage during a year was discharged, without treatment, by overflows (Weston, 1970; Odonaga Lake Study, 1971).

As cities expanded, combined sewer overflows discharged into a receiving body of water became very detrimental to the biological communities of the receiving water. During the wet season, when most overflows occurred, biochemical oxidation of the tremendous amount of organic material discharged into the body of water was able to deplete the amount of dissolved oxygen in the receiving waters. In the last 30 years most cities in the United States have required that all new building tracts be provided with separate sewer systems, one for sanitary wastes and one for urban runoff (Lager and Smith, 1974).

The wastes resulting from urban runoff were formerly discharged into the nearest body of water without previous purification because those wastes were considered relatively "clean". However, in the last two decades it has been recognized that the runoff from street surfaces is generally contaminated, and i, some cases it is similar to raw waste carried in the sanitary sewer. According to calculations done by Sartor et al. (1974), the urban runoff in a typical city, during the first hour of a moderate to a heavy storm may contribute considerably more pollutional load than the city's sanitary waste during the same period of time. Rice (1979) studied the effect of

storm runoff on the principal streams constituting the Dallas drainage area during the storm on February 11-13 of 1977. The urban runoff in Dallas during that period was found to contribute 99 percent of the Total Suspended Solids (TSS) load and 75 percent of the BOD_5 load. Only one percent of the TSS and 25 percent of the BOD_5 load was contributed by the waste-water treatment plant in Dallas. Simms (1979) studied the BOD_5 discharged into the Kalamazoo River from urban runoff and waste water treatment facilities from the city of Kalamazoo. He anticipated that the BOD_5 from urban runoff would exceed the amount discharged from sanitary waste water after the proposed secondary and advanced waste treatment facilities are completed.

Sources of Pollution

As precipitation occurs over metropolitan areas many of the pollutants found in the air adhere to water droplets or snowflakes before reaching the ground. The most common pollutants are carbon monoxide, volatile hydrocarbons, oxides of sulfur and nitrogen, particulate matter, and lead. Most of these pollutants are produced by internal combustion engines, factories, and power plants (Witters and Jones-Witters, 1976). However, it seems that the amount of air pollutants picked up by rain in the atmosphere is generally insignificant in comparison with the amount of particles that have settled to the city surface and are washed away during urban runoff (Lager and Smith, 1974). More studies are needed to evaluate the pollution load originating from the atmosphere.

As the rain reaches the city surface, it washes off contaminants

accumulated on impervious surfaces such as street surfaces, roofs of houses, sidewalks, driveways, and parking lots, and carries them away to the nearest water body via the sewer. The most important contaminants that are washed off are:

1. Air pollutant particles that have been settled to city surfaces (mentioned above).
2. Common sand and silt generally from erosion and construction sites. In the AVCO (1970) study, the average total suspended solid concentration was 2,242 mg./l. for storm runoff from one test area of the basin.
3. Deicing chemical compounds such as sodium chloride, and potassium chloride. A study done in the Kalamazoo River in Michigan by Nidy (1974) showed that "maximum salt concentrations in the Kalamazoo River were observed when rains or thawing temperatures followed periods of heavy snowfall or freezing rain. At such times large amounts of salt were washed from the streets of Kalamazoo. Salt concentrations in the river downstream from the city reached 65.1 ppm while upstream the salt concentration was only 41.2 ppm" (p. 27).
4. Residues from careless public and private waste collection operations.
5. Dog and bird feces. According to Feldman (1974), the dog population of New York is credited with depositing over 68,000 kg. of feces and 405,000 liters of urine on the

street daily, much of which is then washed by storm waters into the river.

Other pollutants that are added into the storm sewer come from the use of the storm sewer as a disposal site for crankcase oil used by cars, leaves and yard trimming (with possible high content of herbicides and fertilizers), and rinse water from home car washing (high content of soap, dirt, and grease). In some cases, material from sanitary sewers may infiltrate the storm sewer adding an extra load of pollutants, especially organic and bacterial contamination (Lager and Smith, 1974).

Environmental Effects of Urban Runoff Discharges

Although many different pollutants are discharged to the nearest water body, only a few are significant in producing water quality problems (Lee and Jones, 1980). According to Lee and Jones (1980) "water quality should never be defined by a list of concentrations of chemical components, the significance of the presence of a contaminant at a particular concentration must be judged by the impact that it has on organisms or some other beneficial use of the water" (p. 3). Generally the most significant pollutants that affect water quality are bacterial contamination and excessive fertilization (Lee and Jones, 1980). Organic matter, toxic elements, and others beyond the scope of this work, may also cause significant water quality problems.

The presence of large amounts of bacteria from bird and dog feces transported to the lake by storm sewers, may be pathogenic to humans. Warm-blooded animals have millions of intestinal micro-organisms, mostly

bacteria, that are discharged with their feces. Most of these fecal bacteria are harmless. However, feces from a warm-blooded animal infected with an enteric disease also contain large amounts of pathogenic bacteria. If these bacteria are carried by surface runoff into a waterbody there is a high risk of contamination if the water is used for recreational or consumption purposes (Holden, 1970).

In most sanitary or storm sewer discharges, the pathogenic bacteria are diverse and are present in low numbers when compared with harmless bacteria. Because of the necessity of rapid analyses of water samples, a routine for identifying pathogenic forms is almost impossible to devise. In searching for micro-biological indicators of pollution it is necessary that the indicator organism: a) be present whenever the pathogens are present, but in much greater numbers, b) be as resistant or more resistant to disinfectants and the aqueous environment than the pathogenic micro-organisms, and c) be easily detected by routine tests. Although micro-biological indicators signify the presence of fecal contamination, their absence does not guarantee the purity of the water (Lynch and Poole, 1979).

In the laboratory the most common indicator organisms used are the coliforms, the fecal streptococci and *Clostridium perfringens*. The term coliform, according to APHA (1975) refers to "all of the aerobic and facultative anaerobic gram-negative, non-spore forming, rod-shaped bacteria which ferment lactose with gas formation within 48 hours at 35^{o}C." (p. 678). Typical coliforms are bacteria of the genera *Escherichia*, *Citrobacter*, and *Klebsiella* (*Enterobacter*). Coliforms are widely used because it is generally believed that their natural

habitat is the intestine of warm-blooded animals. However, Duncan and Razzell (1972) found that Klebsiella pneumoniae and Enterobacter aerogenes can grow in non-animal environments. Bagley et al. (1978) presented evidence that Klebsiella strains may occur in high densities within the sapwood zones of the redwood. Only Escherichia coli is considered to be a truly intestinal bacteria and its ability to ferment lactose and produce gas at 44°C allows the separation of the fecal form from the total coliform (Lynch and Pool, 1979). Because of the ease of identifying fecal coliform, and their relatively high numbers in human and animal feces, fecal coliform counts have been chosen as an indicator of micro-biological contamination in this work.

The use of bacteria as indicators of water pollution has been discussed for a long time. According to Bonde (1977), bacterial indicators of pollution are inexpensive, rapid, and useful tools that cannot be replaced by chemical tests or by culturing for specific pathogens. Cooke et al. (1977) reported that the New Zealand Microbiological Society Committee on Coliform Bacteria has recommended continued use of coliform bacteria until more specific organisms are identified and internationally recognized as indicators of pollution. As a general conclusion, fecal coliforms are important test organisms to indicate the presence of pathogenic bacteria, but more effort should be made to apply a wide range of indicators to resolve specific concerns.

The excessive amount of nutrients (especially nitrogen and phosphorus) carried by urban runoff is a potential contribution to the eutrophication of urban lakes (Indian Nations Council of Governments,

1978). According to Lee and Jones (1980), this excessive fertilization is the most critical and often the only water problem that exists in urban lakes.

Eutrophication is a natural process of nutrient enrichment whereby lakes gradually become more productive. If this process is accelerated by human activities, the process is called "cultural eutrophication" (Moran et al., 1980). Nitrogen and phosphorus are particularly involved in the eutrophication process, since they are able to stimulate the growth of algae and aquatic vegetation. Such vegetation along the shoreline may interfere with recreational activities. Decomposition of dead algae may deplete the oxygen in the bottom areas and can result in large scale destruction of benthic organisms (Indian Nations Council of Governments, 1978).

Limnologists have recognized for many years that phosphorus may be the limiting nutrient for algae and aquatic vegetation in a vast majority of lake systems (Maciolek, 1954; Vollenweider, 1968; Wetzel, 1975; Lee et al., 1978). In order to control cultural eutrophication it is necessary to determine critical nutrient loading-rates above which eutrophication might be expected. Vollenweider (1968) analyzed the available nutrient budget and trophic condition for several lakes in Europe and in North America; he proposed an empirical relationship between phosphorus and nitrogen loadings, mean lake depth, and the trophic state of these lakes. For a given trophic level, deep lakes are shown to be capable of assimilating higher nutrient levels than shallow ones. Based on this analysis, he assigned certain values showing the permissible loading levels (loading which maintain an oligo-

trophic state) and dangerous loading levels (those which can cause a transition to a eutrophic state). For a lake with a mean depth of 5 m., the permissible loading of N, and P is 1.0 and 0.07 g./m.^{2} per year, respectively, and the dangerous loading is 2.0 for N and 0.13 for P g./m.^{2} per year. Many authors have reviewed Vollenweider's work. Shannon and Brezonik (1972) studied 55 Florida lakes; they found that the permissible and critical loading rates for N and P were 2.0 and 0.28 g./m.^{2} per year, and 3.4 and 0.49 g./m.^{2} per year. Although these values were somewhat larger than Vollenweider's permissible and critical rates, they concluded that they are in the same range. Florida lakes appear capable of assimilating somewhat greater quantities of nutrients before becoming mesotrophic or eutrophic than was suggested by Vollenweider's analysis. Dillon (1975) concluded that in many cases the nutrient loading of a lake combined with the mean depth is not always an adequate measure of the degree of eutrophy, particularly for lakes that have a high flushing rate.

In many instances a substantial part of the total phosphorus discharged into a water body is in a chemical form that cannot be used to support algal growth (Wetzel, 1975; Schaffner and Oglesby, 1978; Lee et al., 1978; Lee and Jones, 1980). The form that promotes algal growth is soluble orthophosphate, though some phytoplanktonic algae are known to utilize organic phosphate esters (Wetzel, 1975). According to Lee et al. (1978), the biologically available phosphorus is approximately equal to the soluble orthophosphate plus 0.2 times the difference between the total phosphorus and soluble orthophosphate

It appears that the water quality should be judged on the concen-

tration of nutrients which are biologically available rather than concentrations found in the water or in the sediments. By focusing only on chemical concentrations, large amounts of money could be expended for eutrophication control with little or no resulting improvement in water quality.

METHODS AND MATERIAL

The Study Area

Woods Lake is located in the north central part of Kalamazoo County, Michigan, four kilometers southwest of the center of the city of Kalamazoo. The city is located in southwestern Michigan about 56 km. east of Lake Michigan on the Kalamazoo River. The lake occupies a kettle or depression in glaciated material, 260 m. above sea level, and does not have any surface inlet or outlets. The city of Kalamazoo owns much of the south shore of the lake and leases the land as Oakwood Memorial Beach, which is a popular swimming place during the summer months (Baumhofer et al., 1980).

The drainage area and the area of the lake was determined by means of topographic and storm sewer maps and aerial photographs provided by the City of Kalamazoo, Department of Public Works. The total area under consideration is 92.3 hectares.

For the purposes of pollutant load analyses, the drainage area of the lake was separated into different sections (Simms, 1979). The classification used in this study was based on maps, aerial photographs and field observations. Residential areas within the catchment were classified according to lot sizes, house surfaces, and driveway surfaces. Within this scheme, three general classes were recognized (Table 1). The drainage area, including the lake, was subdivided into five sections according to the above scheme and degree of urbanization (Table 2 and Map 1). Descriptions of the five sections are

TABLE I. DESCRIPTION OF THE CLASSES OF RESIDENTIAL AREAS

Class	Lot Size Average	House Size Average	Driveway Size Average
1	1,200	130	80[a]
2	1,200	220	110[b]
3	1,200	300	160[b]

units are given in square meters
a) 85% of the total driveways are asphalted
b) 100% of the total driveways are asphalted

TABLE II. COMPOSITION OF WOODS LAKE DRAINAGE AREA ACCORDING TYPE OF RESIDENTIAL AREA AND DEGREE OF URBANIZATION

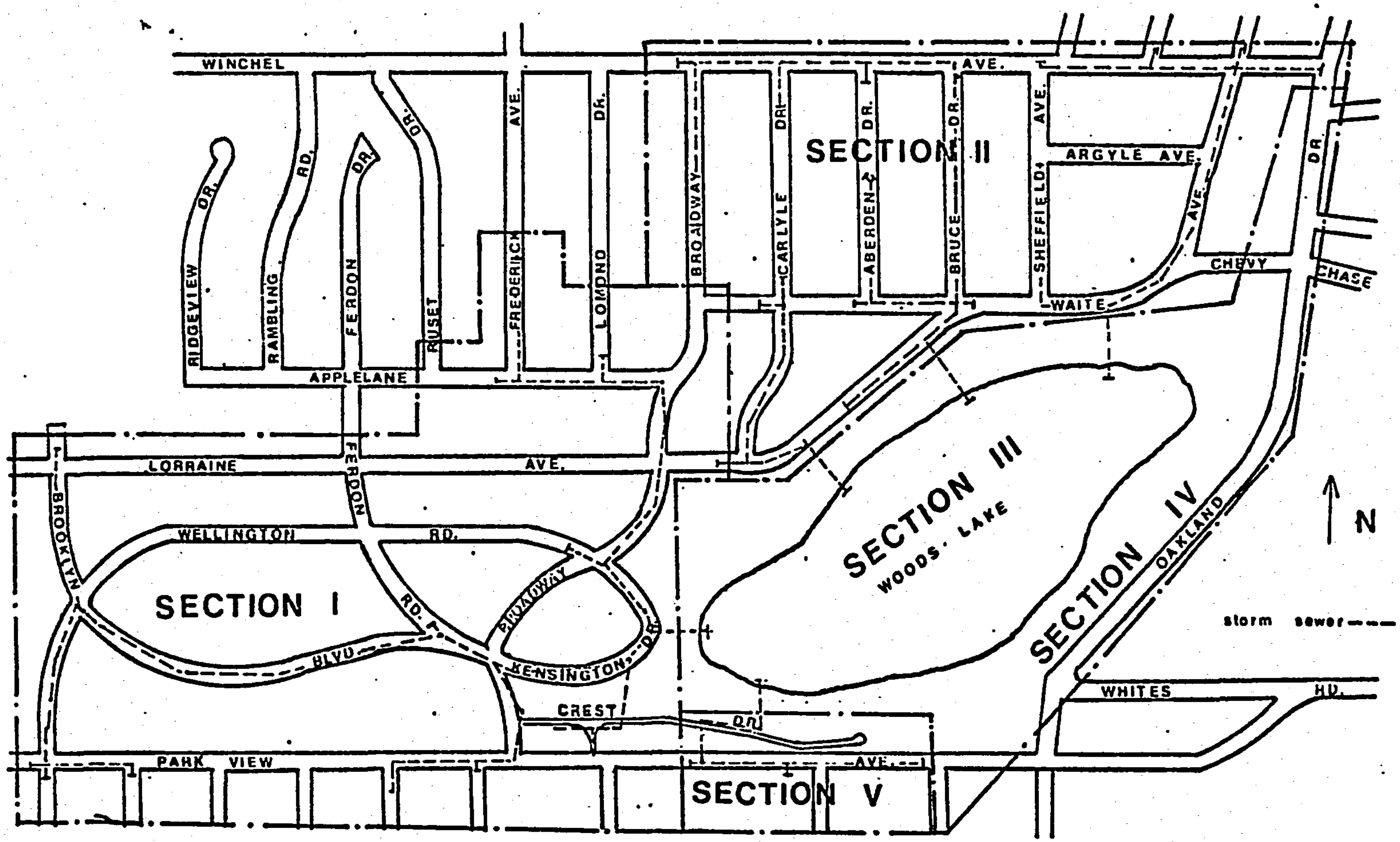
Location	Section I	Section II	Section IV	Section V
Area[a]	36.4	26.3	17.0	2.9
number of houses	223	115	34	14
% of total area urbanized	66	100	30	85
Average lot size[b]	1,200	1,200	1,200	1,200
Average house size[b]	130	220	300	130
Average driveway size[a]	80	110	160	80
Total area covered by roofs[a]	2.93	2.56	1.00	0.18
% $\frac{Ra}{Rt}$[c]	16	19	19	16

a) units are given in hectares
b) units are given in square meters
c) $\frac{Ra}{Rt} = \frac{\text{Roof cover discharging into paved surfaces}}{\text{Total roof cover}}$

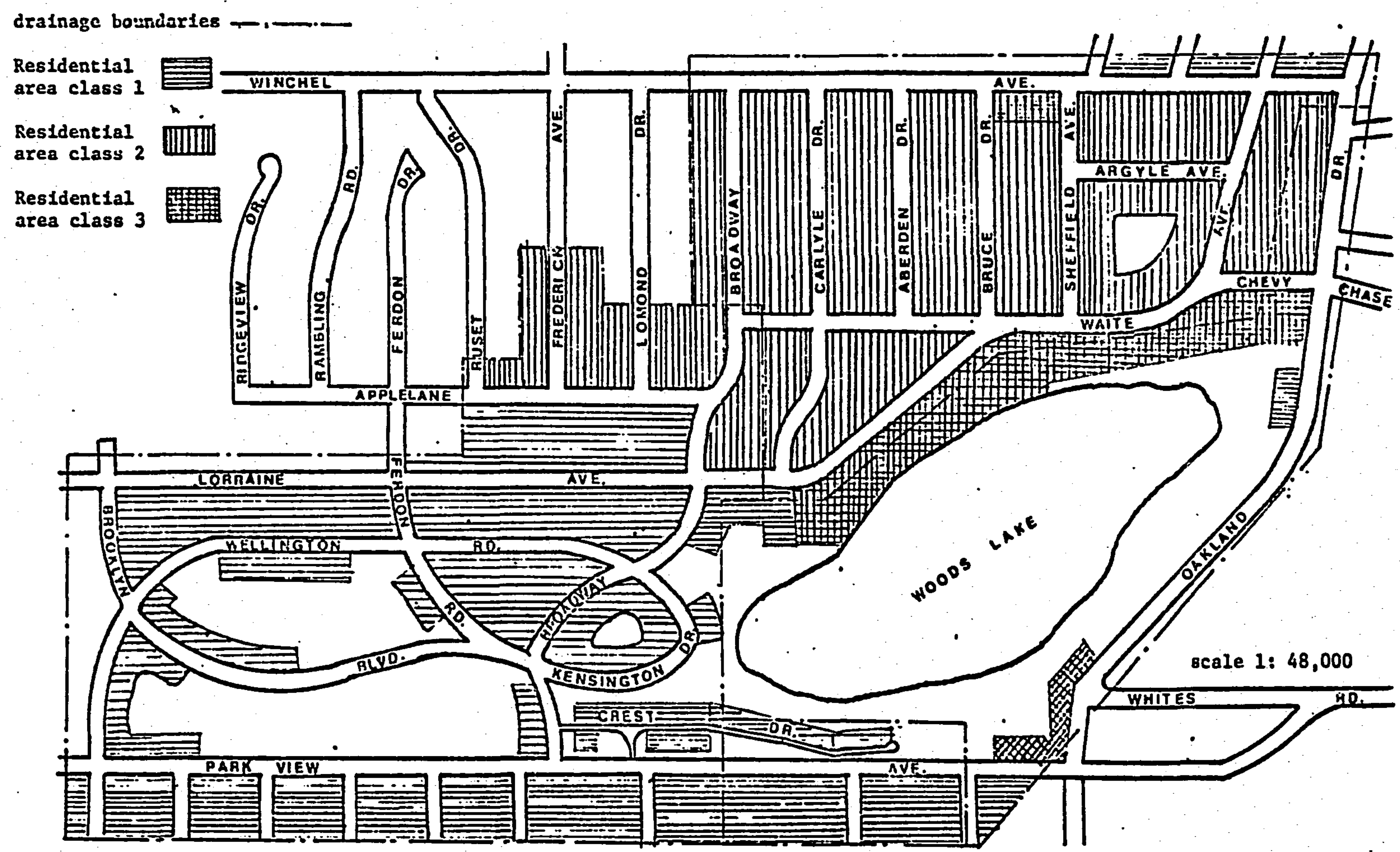
MAP 1. DRAINAGE AREA OF WOODS LAKE

drainage boundaries —·—·—

scale 1: 48,000



MAP 2. LAND USE CLASSIFICATION ACCORDING TO DIFFERENT TYPES OF RESIDENTIAL AREAS ON THE DRAINAGE AREA OF WOODS LAKE



given as follows:

Section I. Parkview Ave. - Lorraine Ave. (Map 2).

This area is located at the west side of the lake. The size of the drainage area is about 36.4 hectares. The area is 66% urbanized and most of the houses can be classified as residential area class 1. The rain is collected by a storm sewer network that discharges one meter below the surface at the west side of the lake.

Section II. Lorraine Ave. - Winchell Ave. (Map 2).

This 26.3 hectares section is situated at the north part of Woods Lake. The area is almost totally urbanized by houses that can be classified as residential area class 2. The rainwater is collected by three different storm sewer networks that discharge above the surface at three different places on the north shore of the lake.

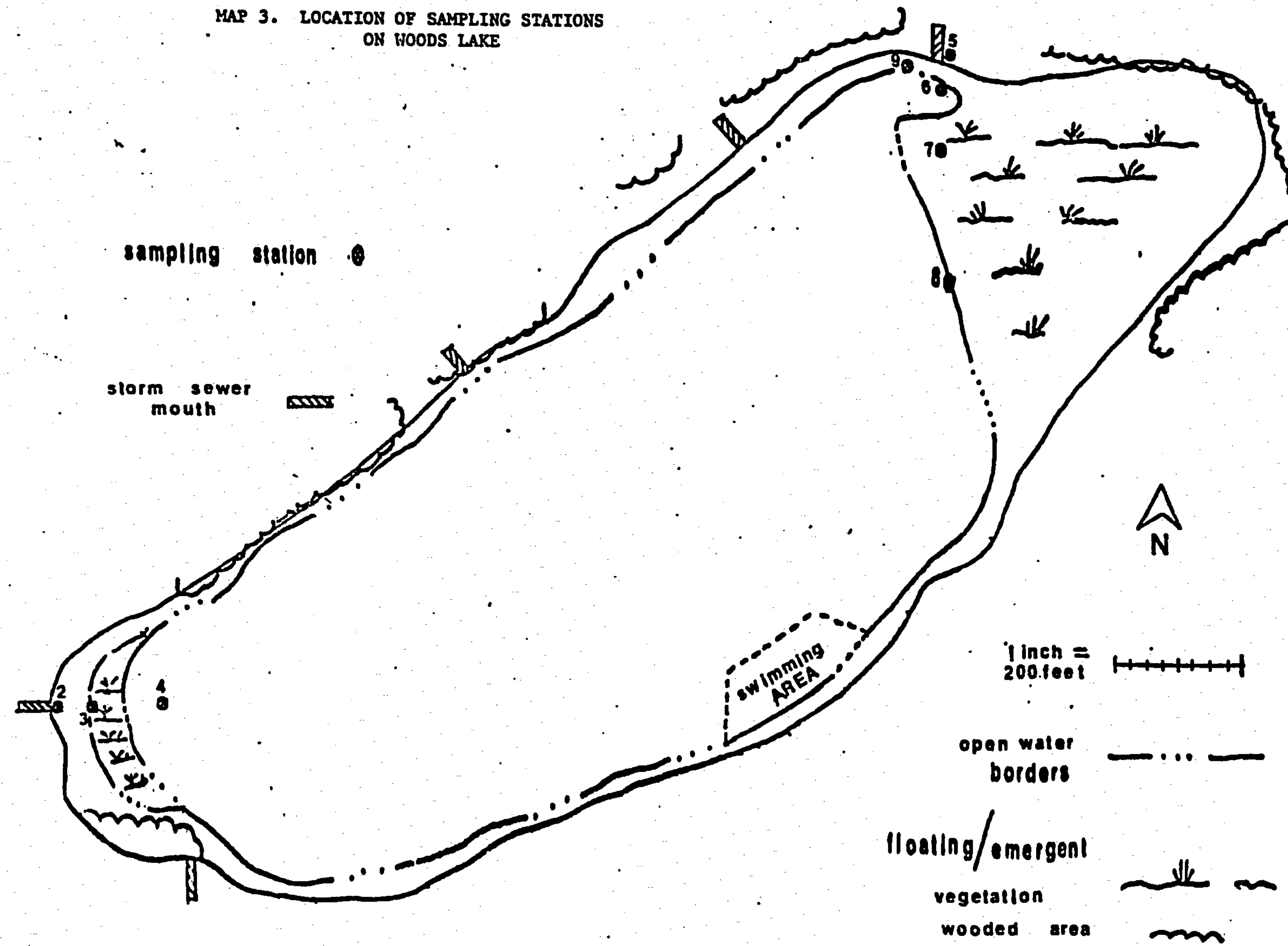
Section III. Woods Lake (Map 3).

The area occupied by the lake is about 9.7 hectares. The prevailing winds are from the west. Approximately in the middle of the lake the depth is about 10.2 meters (Baumhofer et al., 1980). In this study the maximum depth was estimated at 10.5 meters. Neumann (1959) examined the morphometry of a large number of lakes, and found that the average shape of most lake basins approximates an elliptic sinusoid, a geometric body whose base is an ellipse. From general morphometric estimates and the shape of the basin, it appears that Woods Lake conforms to this shape. Therefore the volume, V, and the mean depth, $\bar{Z}$, were calculated by the following formulas:

$V = 1.456 \times a \times b \times Zm$ (Wetzel, 1975)

a and b are half axes of the lake surface ellipse.

MAP 3. LOCATION OF SAMPLING STATIONS ON WOODS LAKE



Zm; maximum depth

$\bar{Z} = 0.464 \times Zm$

In Woods Lake, the values of a and b were respectively 320 and 114 meters. The volume of the lake is 557 x 10^6 liters and the mean depth is 4.87 meters.

The lake is covered by ice during three months of the average year. During spring and summer numerous aquatic plants, such as *Nymphaea tuberosa* (white water lily), *Pontederia cordata* (pickerelweed), *Lemna minor* (lesser duckweed), and *Najas flexilis* cover the northeast part of the lake. Also big masses of filamentous blue-green algae, *Anabaena* spp., and green algae, *Spirogyra* spp., were observed in the shallow parts of the lake.

Section IV. Lake surroundings (Map 2).

The lake is surrounded by an area that is urbanized only at the north side; the rainwater in this area discharges directly into the lake as surface runoff. The total drainage area is about 17 hectares. Most of the houses in this area can be classified as residential area class 3.

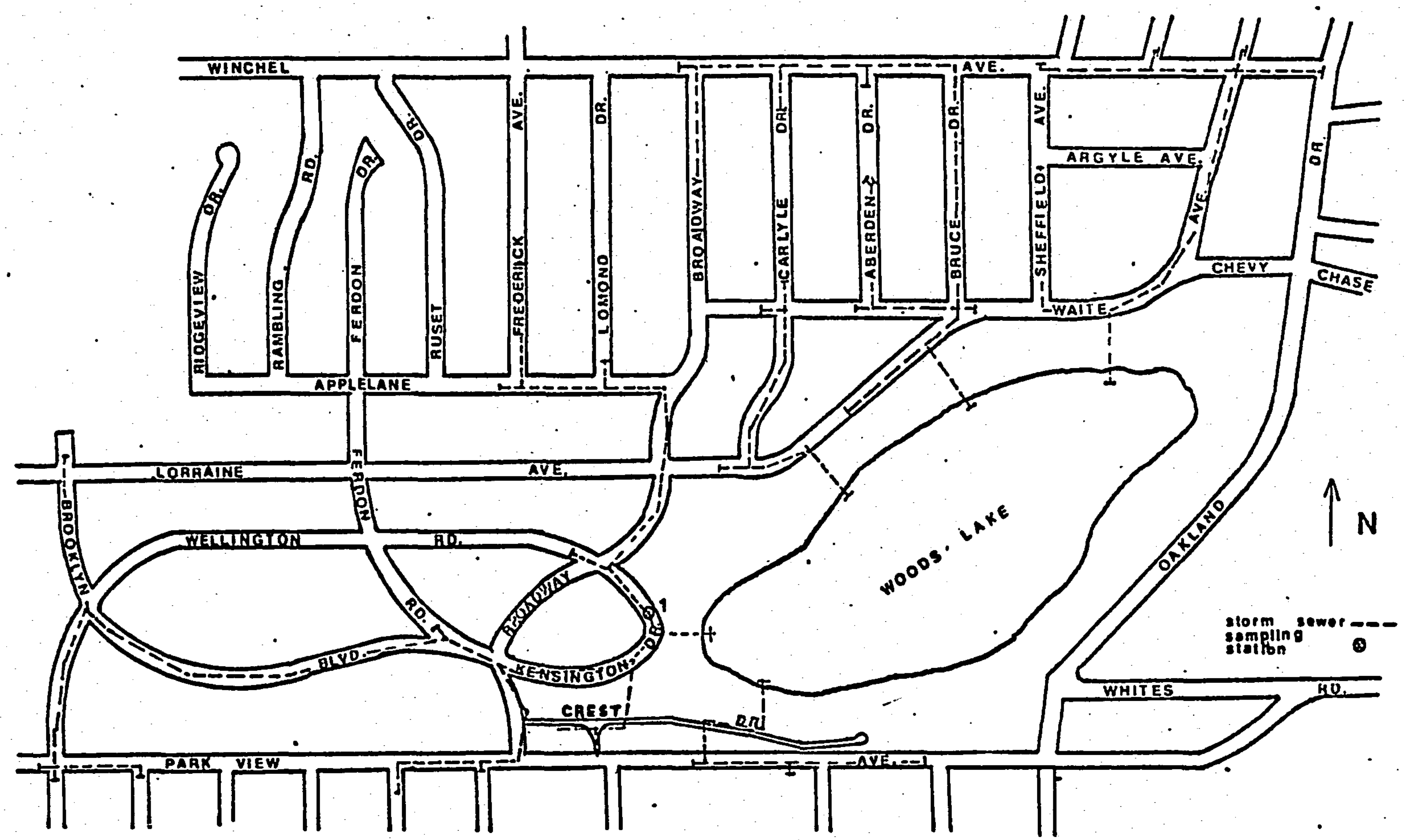
Section V. Crest Drive - Parkview Ave. (Map 2).

The drainage area of this section is about 2.9 hectares, and is located at the southwest side of the lake. The area is 80% urbanized and most of the houses can be classified as residential area class 1. The rain is collected by one storm sewer network that discharges one meter above the surface at the southwest side of the lake.

Description of the Test Sampling Stations

MAP 4. LOCATION OF SAMPLING STATIONS ON THE DRAINAGE AREA OF WOODS LAKE

scale 1: 48,000



One of the objectives of this study was to estimate the quantity of pollutants discharged into the lake and the impact produced. Therefore, it was necessary to select sites where the amount of urban runoff was large enough to produce a measurable impact in the lake. An additional consideration was the accessibility of the sampling sites. The stations selected are illustrated in Maps 3 and 4.

Station 1 was located in a manhole that collects the urban runoff from the north part of Section I. The station was located about 100 meters west from the storm sewer mouth that discharged at the west side of the lake (Map 4).

Stations 2, 3, and 4 were located 0, 12, and 50 meters offshore from the west end of the lake. A crescent-shaped barrier of bottom material, deposited from materials carried by urban runoff, was built at Station 2. The water depth at this station was about one and one-half meters.

Stations 5, 6, 7, and 8 were located at the northeastern side of the lake. Station 5 was located at the storm sewer outlet. Stations 6, 7, and 8 were located 6, 30, and 70 meters south of Station 5. A crescent-shaped barrier of bottom material was deposited at Station 6. The depth of the water at this station was one-half meter and the bottom material was composed of particles carried in by urban runoff. The area surrounding Station 6 was densely vegetated and as a result the circulation was greatly reduced during dry weather. During storm events, the urban runoff goes through this station before mixing with the rest of the lake.

Station 9 was located 20 meters west from the storm sewer at

Station 5, and 2 meters from the lake shore. Despite the proximity of Stations 5 and 9, they were separated by a thick barrier of vegetation that apparently prevented rapid mixing of water. At Station 9, where the water depth was less than one meter, much emergent vegetation was present. Bird activity was observed at this station.

Research Design

Because there were two objectives to this study, two independent designs were developed. One objective was to define the distribution and abundance of fecal coliform and phosphorus in the lake during the wet and dry periods.

The following protocol was developed to estimate the annual pollutional loading from urban runoff. The drainage area of the lake was divided into different sections for this purpose. The following formula (modified from Dunne and Leopold, 1978) was used to calculate the annual amount of urban runoff (Va) for each section.

$$Va = 10^7 \times A \times P \times r_a \qquad (1)$$

10^7 = factor to convert hectares-meters into liters

P = average annual precipitation in meters

A = area of the section in hectares

$r_a = (I + I' \times r_s) \times r_p$ = runoff coefficient of the section (2)

I = paved surface/total area

I' = nonpaved surface/total area

r_s = superficial runoff coefficient; variable according to land condition, slope, and type of soil.

r_p = street runoff coefficient; variable according to type of

pavement and slope.

The amount of runoff from impervious areas that drain into the lake for each section was determined by examination of aerial photographs and field inspection.

The total amount of a particular pollutant (Pi) was determined by the following formula:

$$Pi = 10^{-6} \times Va \times Ci \qquad (3)$$

10^{-6} = factor to convert mg. into kg.

Ci = annual average concentration of pollutant i in mg./l.

In order to estimate "Ci", a monitoring station at 1 was set up. The samples obtained from that site were analyzed for ammonia and phosphorus.

Stations 2 through 9 were selected to establish the abundance and distribution of fecal coliform in the storm sewer and the lake during wet and dry periods. A dry period was considered the time when the lake had not received precipitation for the last 48 hours, a wet period was the time during precipitation and up to 48 hours later.

Samples at Stations 6, 7, and 8 were monitored at intervals during two different storm events for twenty-four hours beginning with the onset of the storm.

Sampling Methods

Chemical sampling was conducted on a non-periodic basis at Station 1 from April of 1979 to March of 1980. Sixteen different samples were collected and analyzed for ammonia and phosphorus. One

sample for each storm was collected one hour or more after the beginning of the urban runoff.

Sampling was done at Stations 2 through 9 every two days from May 23 to July 3, 1980. Samples from Stations 6, 7, and 8 were collected at zero, one, and three hours from the beginning of a storm on May 29, 1980. At the same stations, samples were collected at zero, one, three, and 24 hour intervals after the storm of June 6, 1980. Samples from all these stations were analyzed for fecal coliform.

Grab samples were obtained from all the stations in one liter polyethylene bottles that had been acid-washed. With exception of fecal coliform, all the tests were done using standard methods (APHA, 1975). Fecal coliform number was determined using techniques outlined by the Millpore Corporation (1977).

RESULTS AND DISCUSSION

The concentrations of the various pollutants contained in the samples from Station 1 from April 1979 to March 1980 are presented in Table III. Also given in this table are the estimated annual average concentrations for each pollutant. These annual average values were calculated from monthly sample concentrations and corresponding monthly precipitation amounts (modified from Kluesener and Lee, 1974). Chemical determinations from other studies of urban runoff are given in Tables IV and V for comparison with the results of this study. Individual parameters are discussed separately.

Phosphorus

The maximum concentrations of phosphorus were registered during the storms of May 30 and November 8, 1979. In a study by Kluesener and Lee (1974), in Madison, the highest concentrations of phosphorus in the urban runoff were observed during similar times of the year (Table IV). These high phosphorus values during spring and fall coincide with the shedding of tree seeds and leaves. In the study area, seeds were observed in the streets and gutters in May. The accumulation of leaves was noted in November. An experiment by Kluesener and Lee (1974), involving seeds soaked in rain water, showed that the leachate from these seeds had a high concentration of phosphorus. From a similar study using oak leaves, Cowen and Lee (1973) concluded that "leaves may potentially fertilize many liters of runoff water

TABLE III. PHOSPHORUS AND AMMONIA CONCENTRATIONS IN URBAN RUNOFF FROM STATION 1; 4/1979 TO 3/1980

Date	Phosphorus (Total)	Ammonia
4/24/79	0.70	0.70
5/11/79	0.90	1.80
5/30/79	1.70	1.20
6/07/79	1.00	1.30
6/29/79	0.50	0.75
7/30/79	0.20	0.30
8/17/79	0.14	0.60
8/29/79	0.34	0.22
10/04/79	0.53	1.00
10/12/79	0.15	0.70
11/08/79	1.65	1.07
11/29/79	0.23	0.05
1/11/80	1.00	0.80
2/21/80	1.05	1.42
3/15/80	1.40	1.10
3/17/80	0.22	0.12
Annual Average	0.68	0.76

units are given in mg./l.

TABLE IV. CHEMICAL CHARACTERISTIC IN URBAN RUNOFF FROM MADISON STUDY: SEPTEMBER 1970 TO JULY 1971

Date	Average conc. Phosphorus Total	Average conc. Ammonia
9/02/70	0.9	0.35
9/03/70	0.9	0.26
9/23/70	0.5	0.24
9/24/70	0.5	0.30
11/09/70	3.0	0.32
2/19/71	0.5	0.40
3/14/71	1.3	0.75
4/16/71	1.3	1.05
5/04/71	0.7	0.80
5/18/71	3.5	0.85
5/23/71	1.3	0.20
5/24/71	0.8	0.24
6/20/71	0.9	0.22
6/22/71	0.6	0.25
6/24/71	0.4	0.46
7/08/71	1.4	0.50

units are given in mg./l.

TABLE V. COMPARISON OF AVERAGE ANNUAL CHEMICAL CONCENTRATIONS IN URBAN RUNOFF FROM DIFFERENT LOCATIONS

Location	Reference	Ammonia	Phosphorus (Total)
Ann arbor Michigan, 1965	Burm *et al.*, 1968	0.28	1.70
Durham N. Carolina, 1968	Bryan, 1971	--	0.19
Madison Wisconsin, 1971	Kluesener and Lee, 1974	0.45	0.98
Kalamazoo Michigan, 1980	This study, 1981	0.76	0.68

units are given in mg./l.

above the critical concentrations of phosphorus often cited as causing excessive growth of algae or aquatic plants in natural waters".

These experiments seem to indicate that areas having many trees may contribute large amounts of phosphorus to the storm water, depending on the season of the year and the maintainance of lawns within the basin. Another source of phosphorus income in the urban runoff has been attributed to lawn fertilization (Lager and Smith, 1974). Tague (1974) estimated that the total input from lawn fertilization into Gull Lake was a loading rate of 21.6 mg. per $m.^2$ of lake surface per year. One additional source of phosphorus could be emissions from automotive exhaust, since certain gasoline additives contain small amounts of phosphorus to control preignition and spark plug fouling. Some of the additives must be exhausted from the engine (Kluesener and Lee, 1974).

In general the estimated annual average concentration for phosphorus (Table V) found in this investigation is in the same range as was reported in the other studies. Some of the differences found may be due to differences in sampling techniques and types of residential areas in the urban drainage area. In the Madison study (Kluesener and Lee, 1974) the highest concentration of pollutants, except for ammonia, were found to occur in storm water during the first half-hour after the onset of the storm. The concentrations usually decreased after one hour or more and remained stable until the end of the runoff. In this study the average annual load for phosphorus was based on samples obtained one hour after the beginning of the urban runoff. Therefore, the load estimated for phosphorus

was very conservative.

Ammonia

The ammonia concentrations in the storm samples follow a similar pattern to that found for phosphorus. However, these values do not coincide with the trends reported in the Madison study (Kluesener and Lee, 1974). In addition the estimated annual average concentration in this study was higher than those reported in other studies.

One possible explanation for the high amounts of ammonia could be the presence of leaves, feces, and other organic material transported in the urban runoff. Ammonia is produced as the primary end product of the decomposition of organic matter by heterotrophic bacteria (Wetzel, 1974). Atmospheric contributions of both ammonia and nitrogen in urban runoff could result from the dry fallout accumulation during dry periods in the drainage basin. Wetzel (1974) pointed out that in the Great Lakes region, an atmospheric contribution occurs at a rate of approximately 1 $g./m.^2$ per year. He also noted that the nitrogen content of the snow is often higher than of the rain. Hutchinson (1944) discussed the reasonable evidence for combined nitrogen of the atmosphere being formed primarily from ammonia. In the Madison study, the authors suggested that most of the ammonia in urban runoff seems to originate from rain itself.

Estimates Annual Loading From Urban Runoff

In order to estimate the annual volume of runoff into Woods Lake, it was necessary to determine pervious and impervious surface areas of

the drainage basin. Table VI lists the percentages of impervious areas from streets, driveways, and roofs discharging into driveways, in each section. This Table also presents the impervious area compared to the total area for each section. The data in Table VI indicate that the principal contribution to the total imperviousness in each section is from streets, a contribution of more than 57 percent. The contribution of roofs to the total amount of imperviousness is small, less than 14 percent, due to the fact that most of the roof gutters discharge onto lawns or underground. Section I of the study area can be related to residences belonging to class 1, and Section II to residences belonging to class 2. Although the average impervious surface area for driveways and roofs is larger from residential areas in class 2 than those in class 1, the total number of residences is smaller, therefore similar percentage values of impervious area were obtained.

The estimation of the annual runoff for each section was calculated by the application of formulas 1 and 2. The results obtained for each section are given in Table VII.

The estimation of the annual loading for each pollutant from urban runoff for each section can be calculated by applying formula 3. In this study only the runoff from Section I was analyzed because the amount of imperviousness and type of vegetation is similar for Sections I, II, and V. During the storm of July 1, 1980, samples from different storm sewers from Sections I and II were analyzed. Because the values obtained were in the same range (Table VIII), the assumption that the composition of both urban runoff areas were

TABLE VI. IMPERVIOUSNESS DISTRIBUTION IN THE WOODS LAKE DRAINAGE AREA ACCORDING DIFFERENT SECTIONS

Location	Section I	Section II	Section IV	Section V
Area covered by streets & parking lots	4.60	3.60	1.46	0.57
Area covered by driveways	2.02	1.25	0.61	0.12
Area covered by roofs	0.61	0.73	0.24	0.04
Total paved area	7.24	5.58	2.27	0.73
% impervious street contribution	63.70	64.50	64.30	77.70
% impervious driveway contribution	28.20	22.50	25.00	16.70
% impervious roof contribution	7.10	13.00	10.70	5.60
% $\frac{Tp}{Ta}$[a]	19.90	21.20	13.50	23.00

units are given in hectares

a) $\frac{Tp}{Ta} = \frac{\text{Total paved area}}{\text{Total area}}$

TABLE VII. ESTIMATION OF ANNUAL RUNOFF DISCHARGED INTO WOODS LAKE FOR EACH SECTION

Location	Area[a]	r_s[b]	r_p[c]	r_a	P[d]	I	I'	Va[e]
Section I	36.4	.09	.75	.20	.857	.199	.801	62.4
Section II	26.3	.09	.75	.21	.857	.212	.788	47.3
Section IV	17.0	.09	---	.09	.857	.000	1.000	15.3
Section V	2.9	.09	.75	.22	.857	.230	.770	5.6

for meaning of symbols see pages 24 and 25
a) units are given in hectares
b) values obtained from Kalamazoo County; Geology and the Environment, 1978
c) values obtained from American Society of Civil Engineers, 1969; and Rantz, 1971
d) units are given in meters
e) units are given in megaliters = 10^6 liters

similar seems to be confirmed.

TABLE VIII. RESULTS OF URBAN RUNOFF ANALYSES AT STATIONS 1 AND 5

Location	Parameters Analyzed		
	Fecal Coliform (Number/100ml.)	Phosphorus (mg./l.)	pH
Station 1	13,500	0.430	5.3
Station 5	12,880	0.452	5.1

Summarized in Table IX are pollutant quantities from external sources discharged annually into Woods Lake. Data on urban runoff is given for Sections I, II, and V, and on surface runoff for Section IV, and on pollutants entering the lake from atmospheric sources. The estimated pollutant values for Section IV are based on the assumption that surface runoff is similar to urban runoff.

In Table IX the ammonia values have been converted to total nitrogen. The original ammonia values were multiplied by three. This factor was obtained using ratios suggested by the Kluesener and Lee (1974) and Brown and Green (1980) studies for ammonia/total nitrogen conversion.

The estimated annual loadings from atmospheric sources, direct precipitation and dry fallout, discharging onto the lake were not directly measured. The data were based on several assumptions.

Atmospheric contribution of phosphorus into a lake is highly variable, because the major sources of phosphorus-bearing materials are produced from erosion and air pollution. The proximity of a lake

TABLE IX. SUMMARY OF CALCULATED EXTERNAL NUTRIENT SOURCES FOR WOODS LAKE (KG./YEAR)

Source	Phosphorus	Nitrogen
Urban Runoff		
Section I	42.4	142.2
Section II	32.2	107.7
Section V	3.8	12.9
Total	78.4	262.8
Surface Runoff		
Section IV	10.4	34.8
Atmospheric		
Precip. & Dry Fallout	3.2	94.0

to urban-industrial complexes tends to be an important factor (Straw et al., 1978). In a 1974 study of the hydrologic and total phosphorus budget of Gull Lake, Kalamazoo County, Tague (1977) reported that the annual phosphorus loading from dry and wet fallout combined was 33.3 mg. per square meter of surface area. Similar values were estimated by Straw et al. (1978) for Austin Lake, Kalamazoo County. Therefore, based on these values, the total amount of phosphorus discharged onto the lake from direct precipitation and dry fallout was calculated to be 3.23 kg. per year. Compared with the amount of phosphorus discharged from urban runoff this amount is very small.

Atmospheric contribution of nitrogen to a lake is dependent on meteorological conditions and the location of the lake with respect to technological outputs (Wetzel, 1974). According to Wetzel (1974), in the Great Lakes region the atmospheric nitrogen contribution occurs at a rate of approximately 1 g. $m.^{-2}$ $yr.^{-1}$ Based on this value, the total amount of nitrogen discharged onto the lake from direct precipitation and dry fallout was calculated to be 94 kg. per year.

Data from Table IX indicate that more than 85 percent of the total phosphorus entering Woods Lake from external sources arises from urban runoff. It is estimated that 78.4 kg./year or 0.81 g./$m.^2$ per year of phosphorus is discharged from urban runoff into Woods Lake. With a mean depth of 4.68 m. for Woods Lake, this loading is more than one and one-half times the dangerous loading rate of Shannon and Brezonik (1972) and over six times the rate of Vollenweider (1968).

More than 68 percent of the total nitrogen influx from external sources arises from urban runoff. Atmospheric contributions amount to

about 25 percent. The 262.8 kg./year or 2.7 g./m.^{2} per year of nitrogen discharged from urban runoff is more than the dangerous loading rate proposed by Vollenweider (1968), and is a little below the value proposed by Shannon and Brezonik (1972).

The concentrations of phosphorus in samples obtained from different stations on the lake were very high, especially if the samples were obtained during or shortly after a storm event. These results are listed in Appendix 1. Big masses of filamentous blue-green and green algae were present in the lake, most likely due to excessive nutrient input. The findings of this study indicate that the levels of phosphorus and nitrogen from urban runoff discharging into Woods Lake are high and could be accelerating the eutrophication process.

Determination of Fecal Coliform Distribution During Dry and Wet Periods

In order to understand the contribution of fecal coliform to Woods Lake, it was necessary to investigate the various inputs. The known sources of pollutant input into the lake are urban runoff, surface runoff, direct precipitation to the lake, and dry fallout, and another possible source of pollutant input into the lake, ground water, was not investigated in this study.

The contribution of fecal coliform from rainwater directly into the lake was considered very low or lacking. Pitt and Bozeman (1980) estimated that the most-probable-number (MPN) of fecal coliform colonies in 100 ml. of rainwater is two or fewer. Coliform colonies were not detected in a rainwater sample analyzed from the storm on June 19, 1980. Therefore, fecal contribution from rainwater into the lake

does not seem important.

In general, ground water is almost free of fecal coliform because bacteria are filtered out as water percolates through the soil (Holden, 1970). Dry fallout originating from bird and other warm-blooded animal feces living in or near the lake, is a possible source of fecal coliform.

In this study, the volume of water from surface runoff was estimated to be about ten percent. Therefore the fecal coliform contribution from this source was judged to be minor compared with urban runoff.

The fecal contribution from urban runoff into the lake was studied for one year from June, 1979 to July, 1980, at Stations 1 and 5. The amount of fecal coliform in the storm sewers was very low during the winter months, and very high during summer and early fall (Table X). Weibel et al. (1964) and AVCO (1970) reported finding the same trend in the distribution of fecal coliform in the urban runoff with the highest values during summer and early fall and low levels during winter.

The principal source of fecal coliform in the urban runoff is from warm-blooded animal feces (AVCO, 1970). Weibel et al. (1964) found concentrations up to 47,000 fecal colonies per 100ml. in runoff samples obtained from gutters during early fall. Few fecal colonies were detected during the winter. Another possible source of fecal coliform in urban runoff is from sanitary sewer infiltrations into the storm sewers (Lager and Smith, 1974).

In order to determine the fecal distribution and abundance during

TABLE X. FECAL COLIFORM COUNTS AT STATIONS 1 AND 5 FROM JUNE, 1979 TO JULY, 1980.

Date	Station 1	Station 5
6/09/79	14,000	ns
1/11/80	667	ns
2/09/80	0	ns
5/29/80	ns	41,000
6/15/80	ns	15,330
7/01/80	13,580	12,880

Units are given in number/100ml.

ns; No sample.

dry and wet periods, samples at different stations were taken during the period between May and July, 1980. The results are given in Table XI. The following trends are apparent from the data in Table XI.

The amount of fecal coliform from samples at Stations 1, in the storm sewer, and Station 5, at storm sewer outlet, ranged from 11,000 to 40,000 colonies per 100ml. These values are in the same order of magnitude as values reported by Weibel et al. (1964).

In the samples obtained from Stations 1 and 5, on July 1, 1980, the number of fecal coliform colonies was similar. This fact could indicate that runoff in both sewers have similar bacterial composition.

Samples from Stations 2, 6, and 9 generally were found to have higher numbers of fecal coliform colonies than the other stations during dry periods. A period of 48 hours or longer without precipitation was defined as a dry period in this study. Stations 2, 6, and 9 were near the shore where many birds were observed. In general, the coliform counts obtained at the different stations during dry periods decreased in relation to the distance of the stations from the shore. This may be due to fewer birds offshore and/or dilution.

When comparing fecal coliform content in lake water samples during dry and wet periods, the counts were always higher during wet periods except at Station 9. At this station, the number of fecal coliform colonies detected did not vary in a consistent pattern. This station is about 20 meters west from the sewer outlet, but is separated by a thick barrier of emergent and submergent vegetation.

TABLE XI. FECAL COLIFORM COUNTS FROM SAMPLES AT DIFFERENT STATIONS FROM MAY TO AUGUST 1980

Date	Hour	Last[a] Storm Event	Station Identification Number								
			#1	#2	#3	#4	#5	#6	#7	#8	#9
5/23/80		+60h									
5/29/80	7:00am	0h					41,600	29,900	175	120	
5/29/80	8:00am	1h						TNT	2,840		
5/29/80	10:40am	3h							830		
6/04/80	12:00am	20h						1,900		55	
6/07/80	11:15am	0h					11,750	11,000	27[b]	25[b]	
6/07/80	0:30pm	1h					12,040	13,080	2,310	181	
6/07/80	3:45pm	3h						5,740	800	765	
6/08/80	5:25pm	27h						18,530	296	116	
6/11/80	11:30am	+60h						1,340	0	4	
6/13/80	11:30am	*38h						1,640	72	56	
6/15/80	1:30pm	0h					15,330	36,500	905	609	
6/17/80	3:30pm	48h						1,015	19	53	
6/20/80	11:00am	*20h						5,920		216	400
6/24/80	10:00am	+60h		165	40	4		12,750			120
6/26/80	0:30pm	+60h		79	37	0		2,200		40	155
6/30/80	11:30am	*35h		32				720		7	120
7/01/80	2:30pm	0h	13,580	21,190	14,000	29	12,880	16,200		71	93
7/03/80	8:00am	40h		23,000	1,980	76		16,000		32	42

+ more than; * aproximate
units are given in Number/100ml.
a) Elapse of time from the last storm event to the time when the sample was obtained
b). Sample collected before urban runoff reached the lake
TNT Too numerous to be counted

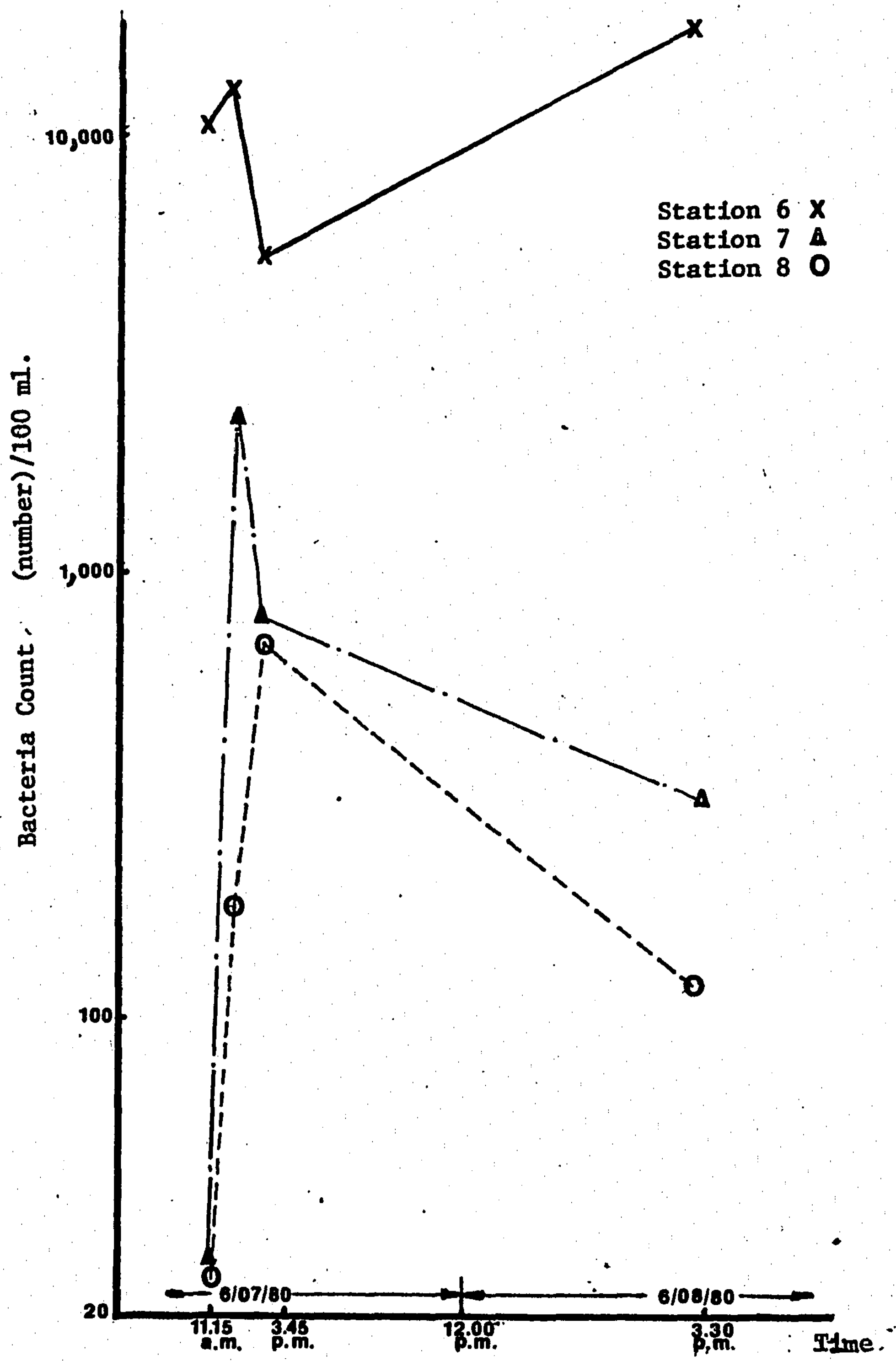
This apparently prevents mixing of urban runoff with the lake water at Station 9.

During the wet periods, the coliform counts were found to be inversely related to the distance of the stations from the storm sewer outlet. This decrease in counts with distance is most likely due to dilution as storm water is mixed with lake water.

At Station 7, during the storm of June 4, 1980, the number of fecal coliform colonies increased greatly during the first hour after the initial flush of urban runoff reached the lake; at Station 8, the fecal coliform count peaked in about two to three hours after the first runoff reached the lake since this station was farther from the storm sewer outlet. The highest counts at this station were lower than the counts in samples from stations located closer to a storm sewer outlet (Figure A). Eventually, the counts decreased to pre-storm levels. This decline in coliform counts is not due solely to dilution. Sedimentation, especially if the bacteria are attached to particles, starvation, sunlight, pH, and temperature have all been implicated in the disappearance of fecal coliform (Lynch and Poole, 1979). The death rate of fecal coliform is often considered to be a function of time modified by a marked temperature coefficient (Nemerow, 1974).

At Station 6, three hours after the onset of the storm of June 7, 1980, the fecal coliform counts decreased. However, 27 hours later, the coliform levels were higher than at the beginning of the storm (Figure A). At Stations 2 and 6, the highest count of fecal coliform were detected 40 hours after the storm of July 1, 1980.

FIGURE A. FECAL DISTRIBUTION AT STATIONS 6, 7, & 8 ON 6/07/80



The results obtained from Stations 2 and 6 differ from the other results. Because these stations are located very close to the storm sewer outlets much suspended material is deposited from urban runoff. It may be that the sediments play a role in the high counts of fecal coliform obtained after rainstorms. It is known that suspended materials are related to an increased surface area to which large amounts of bacteria can adhere (Cairns, 1974). It is possible that at the end of the storm, when no more mixing occurs, the bacteria on the sediments are released into the surrounding water. Because the water depth at Stations 2 and 6 is less than one meter and the water circulation is limited, the ratio of bacteria to volume of water is very high. After a period of time the coliform counts decreased to pre-storm levels. The disappearance of bacteria could be attributed to pH, sunlight, and water temperature (Lynch and Poole, 1979).

The Kalamazoo County Health Department analyzed water from the Woods Lake swimming area for fecal coliform. The data obtained are given in Table XII. They observed higher amounts of bacteria when the samples were taken a day after a storm event than if the samples were taken more than 48 hours later.

Maximum fecal coliform levels reached 90 counts in 100ml. According to the Environmental Protection Agency (EPA) criteria of 200 counts in 100ml. for contact recreation, the fecal coliform appears to present little health risk to swimmers.

TABLE XII: FECAL COLIFORM COUNTS AT THE WOODS LAKE'S SWIMMING AREA: JUNE - SEPTEMBER 1980

Date	Last[a] Storm Event	Count[b]
6/04/80	20h	40
6/18/80	+48h	40
7/02/80	-24h	90
7/30/80	-24h	30
8/13/80	nd	10
8/27/80	nd	20
9/10/80	nd	20

nd - no data available

a) elapse of time from the last storm event to the time when the sample was obtained; + more than; - less than

b) units are given in number/100ml. of sample

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. In class one and two residential areas approximately 21 percent of the area is impervious to the movement of rainfall into underground reservoirs.
2. Peak concentrations of pollutants were observed in urban runoff during the months of November and May.
3. More than 85 percent of the total phosphorus entering Woods Lake from external sources arises from urban runoff.
4. The estimated annual input of phosphorus from urban runoff into the lake exceeded the dangerous loading rate as proposed by Vollenweider (1968) and Shannon and Brezonik (1972).
5. More than 68 percent of the total influx from external sources arises from urban runoff. Atmospheric contributions amount to about 25 percent.
6. The estimated annual input of nitrogen from urban runoff exceeded the dangerous loading rate as proposed by Vollenweider (1968), and is a little below the value proposed by Shannon and Brezonik (1972).
7. During the summer months, high amounts of fecal coliform were detected in urban runoff; during the winter months the counts of fecal coliform were nearly negligible.
8. Fecal coliform counts were low at all stations in the lake

during dry periods.

9. In general fecal coliform counts increased after storm events. Peak concentrations decreased markedly with distance of the station from the storm sewer outlet. When the storm ended, the fecal coliform count usually decreased at each site. After a period of approximately 48 hours, the fecal coliform count returned to the levels which occurred before the storm event.

10. The observations indicated that the urban runoff is almost exclusively responsible for the increased counts of fecal coliform in the lake during wet periods.

Recommendations

Although there is an increase in the fecal coliform counts in Woods Lake both during and after storm events, increases are especially noticeable at the sites close to the storm sewer exits; it appears that those sites located at some distance from the storm sewers are less affected. During the testing period, the swimming area was little affected, with the highest count never exceeding 100 MPN/100ml. It can be concluded from these observations that the swimming area is safe for use both during and after storm events. More studies based on continuous monitoring during and after storm events should be done before this can be considered a reasonable conclusion. It is recommended that only the swimming area should be used for bathing during and after storm events.

The high concentrations of pollutants input from external sources, especially from urban runoff, are probably responsible for the accelerated eutrophication of the lake. The treatment of all urban runoff should be recommended if economically feasible. Other possible solutions include the direct addition of alum to the lake for pollutant precipitation or the dredging of deposited sediments near the storm sewer (Lee and Jones, 1980). Because all of these techniques have both advantages and disadvantages, more detailed studies must be done to find appropriate solutions.

A more detailed study of the hydrology of Woods Lake would give insight as to the input of nutrients from underground areas. This would allow for further delineation of pollutant sources.

APPENDIX 1. PHOSPHORUS DISTRIBUTION AT DIFFERENT STATIONS ON WOODS LAKE: SAMPLE DATA COLLECTED FROM MAY TO AUGUST 1980

Date	Hour	Last[a] Storm Event	Station Identification Number							
			#1	#2	#3	#4	#5	#6	#7	#8
5/23/80		+60h						1.130	nd	0.005
5/29/80	7:00am	0h					1.220	1.373	0.016	0.010
5/29/80	8:00am	1h						1.530	0.021	0.009
5/29/80	10:40am	3h						1.493	0.017	0.002
6/04/80	12:00am	20h						0.390	0.037	nd
6/07/80	11:15am	0h					0.283	0.665	0.029[b]	0.013[b]
6/07/80	0:30pm	1h					0.285	0.135	0.050	0.019
6/07/80	3:45pm	3h						0.088	0.024	0.023
6/08/80	5:25pm	27h						0.281	0.015	nd
6/11/80	11:30am	+60h						0.154	nd	nd
6/13/80	11:30am	*38h						0.171	0.021	nd
6/15/80	1:30pm	0h					0.054	0.088	0.012	0.016
6/17/80	3:30pm	48h						0.141	0.060	0.067
6/24/80	10:00am	+60h		0.030	0.028	0.016		0.202		
6/26/80	0:30pm	+60h		0.033	0.028	0.030		0.257		
6/30/80	11:30am	*35h		0.029				0.433		0.030
7/01/80	2:30pm	0h	0.430	0.590	0.392	0.038	0.452	0.700		0.027
7/03/80	8:00am	40h		0.109	0.075	0.062		0.705		0.067

+ more than; * aproximate
units are given in mg./l.
a) Elapse of time from the last storm event to the time when the sample was obtained
b) Sample collected before urban runoff reached the lake
nd non detectable

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