SOURCES AND YIELDS OF NUTRIENT AND ORGANIC LOADINGS IN THE ROANOKE RIVER BASIN ABOVE SMITH MOUNTAIN LAKE, VIRGINIA

by

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I. INTRODUCTION

The deterioration of water quality in many of our nation's natural lakes and artificial impoundments has caused increasing concern over the causes and consequences of the process of eutrophication. This is as it should be, for our surface waters are one of the nation's most valuable resources and they must be carefully protected to maintain the level of quality necessary to render them suitable for a myriad of uses. The American Public must insist upon the formulation of sensible and workable objectives for water quality management. These objectives, in turn, must be implemented by legislation strong enough to accomplish the desired end. Regulations must be tempered to accept the premise that all streams and lakes can not be returned to the same quality, but standards should be established whereby all waters are reclaimed for some rationally selected "intended use."

The end result of the subjection of impounded waters to organic and nutrient loadings is the natural process of maturation known as eutrophication, whereby the lake progresses through stages of biological productivity. While eutrophication is a natural process, it is enhanced by the presence of man and his activities. As the drainage basin above an impoundment is altered by agricultural development, industrial expansion or the growth of urban areas, there is an increase in the quantity and types of materials being introduced into the watercourse and the reservoir begins to undergo change. Such change usually connotes an acceleration in the eutrophication process.

A thorough understanding of the effect of activity in a watershed on the temporal and spatial distribution and transport of organic and nutrient loadings to the impoundment is necessary in order to arrive at a complete description of the lake fertilization process. Since the eutrophication rate of impounded waters is, to a degree, a function of the characteristics of the tributary watershed, the engineer responsible for reservoir planning and water quality management should not overlook this aspect in the study of any proposed impoundment. The character of the tributary drainage basin of any proposed impoundment should be well documented prior to the implementation of any water quality project. The study should include both qualitative and quantitative information on probable loadings of degradable organic materials that might cause oxygen depletions and of nutrients that might stimulate the growth of nuisance aquatic flora.

Many reservoir sites that have previously seemed only marginal or completely unsuited for development for conventional hydroelectric power generation are now becoming more attractive in light of the special economics of pumped storage operation. These hydrogeneration facilities do not require the tremendous flows necessary for the operation of conventional hydroelectric power generation projects. The characterization of the watershed tributary to proposed pumped storage projects should be an integral part of the reservoir water quality planning.

This study was conducted on the Roanoke River watershed above Smith Mountain Lake. The 40-year average discharge for the Roanoke River at the Altavista gaging station, which is located several miles below the present Smith Mountain - Leesville complex, is only 1814 cfs (1).

This flow was not sufficient for development of a favorable conventional hydro power project. However, the American Electric and Power Company found the Smith Mountain dam site suitable for a pumped storage operation. When completed in 1965, the project was put into operation as a run-of-the-river pumped storage impoundment, one of the nation's first. Although the need for peaking power made the development economically feasible, project implementation created new water quality problems in the watershed.

The Smith Mountain impoundment is located below the Roanoke, Virginia metropolitan area. The two major sources of inflow to the impoundment are the Roanoke River, draining 511 square miles at Niagra, Virginia, and the Blackwater River, draining 208 square miles at Union Hall [1]. The principal branch of the reservoir is the Roanoke River arm, which is approximately 40 miles long. This part of the impoundment receives the runoff, treated domestic sewage, and industrial waste discharges from the Roanoke, Virginia metropolitan area. The river flow below the city is a rich source of both nutrients and organic material. Prior to filling the impoundment, the river was a shallow, rapidly flowing stream of little economic importance which passed through a sparsely populated rural area. The reservoir now provides a very popular recreation site for western Virginia. This use of the impoundment appears to be threatened because the nutrient rich inflow seems to becausing the Roanoke River arm of the reservoir to undergo a rapid rate of eutrophication. It has been indicated by some state officials that the implementation of more advanced wastewater treatment practices at the Roanoke, Virginia wastewater treatment plant would effectively halt the aging of the lake and would, within a couple of years, allow the water quality of the late to "clear up."

Little information has been available on the sources of nutrients in the watershed, or on the percentage of the total nutrient loadings actually attributable to the Roanoke Wastewater Treatment Plant. The purpose of this study was to document data on water quality in the Upper Roanoke River Basin above Smith Mountain Lake, and to investigate the sources and yields of organic and nutrient materials contributing to the eutrophication of the impoundment.

II. LITERATURE REVIEW

An increase in nutrient loadings to an impounded body of water has a very important effect on the productivity level. As in the case of agricultural land where fertilization is used to enhance crop yield, the aquatic environment will similarly exhibit an increase in standing crop as a result of an increase in nutrient input. Fruh [2] has described standing crop in a body of water as including the algae, shoreline vegetation, zooplankton, fish, benthic animals, and bacteria. The stimulation of algal growth and the growth of other nuisance aquatic flora, according to Martin and Weinberger [3], has at least three readily apparent deleterious effects in terms of water quality.

1. Exertion of a demand on the oxygen resources of a lake during absence of sunlight and following death of the organism.
2. Return of inorganic nutrients to the aquatic system following death and degradation of the plant cells.
3. Cause an upset in the food chain, thereby affecting the life cycles of higher species.

In addition, some species of algae may release substances toxic to other aquatic life.

The supply of nutrients entering our lakes, both natural and man-made, is of some immediate concern in terms of water quality management. Fruh [2] has described a nutrient as any substance required for the stimulation of growth, metabolism, or as the source of energy for an organism. The nutrients, as thus defined and required in relatively large quantities by any organism (macronutrients) are carbon, hydrogen oxygen, sulfur, calcium, magnesium, potassium, nitrogen, and phosphorus.

Historically, phosphorus has been considered to be the so-called limiting factor in the fertilization of lakes. The limiting factor being the required chemical constituent for algal metabolism present in the smallest amount in accordance with Von Liebig's Law of the Minimum (4). Phosphorus, being relatively rare in natural waters because of the insolubility of its inorganic compounds, seems to be the required nutrient most consistent with Von Liebig's definition. Recent research by Weiss (5) has indicated that nitrogen may play a more dominant role than phosphorus in algal growth stimulation, and Kuentzel (6) has proposed carbon as playing the more decisive role. Other researchers, Eyster (7) and Provasoli (8), have noted the importance of the trace metals, calcium, magnesium, sodium, and potassium in productivity. It is most probable that limiting conditions in any real situation arise from some synergistic relationship of essential nutrients, and, perhaps, other chemical, physical, and biological factors that have not been considered. In order to assess the role of nutrients in the eutrophication of impounded waters, data on qualitative and quantitative yields for the tributary watershed are essential.

Any attempt to assess the environmental impact of nutrient yields from the drainage basin tributary to an impounded body of water must be correlated with some estimate of the quantities of nutrients required to produce an increased rate of productivity in the impoundment.

Kerr, Paris, and Brockway (9) concluded that CO_2 produced by aerobic bacterial respiration in the decomposition of organic materials provided a carbon source for the stimulation of algal growth. Thus it was proposed that a relationship exists between the loading of degradable organic material to a lake and the potential for excessive growth of nuisance aquatic plants.

Sawyer (10) states that nuisance growth conditions within a lake can be expected when the inorganic phosphorus and nitrogen concentrations reach 0.01 mg/1 and 0.30 mg/1, respectively. Sylvester (11) reported limiting conditions of 0.01 mg/1 and 0.20 mg/1 for the respective parameters at Green Lake near Seattle, Washington. Many, if not most, natural and artificial lakes approach or exceed these hypothetical limitations during much of each year.

The role of trace metals in regulating the growth of aquatic flora is now being investigated more fully. Eyster (7) has indicated that the algae Chlorella sp. requires the metal calcium in optimal concentrations of 0.15 mg/1 and 0.30 mg/1 for the cellular functions of digestion and nitrogen fixation respectively. An optimal concentration of sodium of 2.00 mg/1 was also noted with the explanation that the precise cellular functions of sodium are as yet unknown. Provasoli (8) noted that for waters from some European lakes and the Great Lakes, increases in the concentrations of sodium and potassium have resulted in the stimulation of blue-green algae.

Several writers have suggested that a complete analysis of sources of nutrients entering the aquatic environment should include consideration of the following. (2) (12)

1. Atmosphere, including precipitation.
2. Groundwater.
3. Lake sediment and stream bed storage.

4. Agricultural land runoff.
5. Forest land runoff.
6. Urban drainage.
7. Industrial and domestic wastewater effluents.

The role of the atmosphere in contributing plant nutrients to a watershed appears to be relatively minor even in areas of heavy rainfall. Weibull, Anderson and Woodward (13) reported inorganic nitrogen in Cincinatti rainfall as varying from 0.02 to 1.4 mg/l as N. Another consideration which could have a profound effect on the concentration of nitrogen in precipitation is the possible use of ammonia stripping towers to remove the element from sewage treatment plant effluents. The introduction of ammonia into the atmosphere through the use of stripping towers will achieve removals of about 92 percent, but the gas will become immediately available to aquatic flora when returned to the earth in precipitation (3). This possibility takes on greater importance for treatment facilities located near large bodies of water. The action of lightning in thunderstorms can also result in the oxidation of elemental nitrogen gas to NO_3-N. Finally, there exist algae and bacteria that are capable of fixing atmospheric nitrogen to satisfy their nitrogen requirements. While little data are available on the phosphorus content of precipitation (2), it is not thought that this is a significant source of phosphorus.

Groundwater seepage as a source of nutrient supply to impounded waters has not been widely reported. Sylvester and Anderson (14), in a study of Green Lake, Washington, estimated that one-third of the total flow received by the impoundment was due to groundwater supply.

They assumed the mean total phosphorus content of the subsurface water to be 0.3 mg/1. Other researchers (2) have reported a wide variety of nitrate concentrations in groundwaters, varying from 0 to several hundred mg/1, depending on the geographical lication. In areas where groundwater flow to impoundments is significant, the nitrate content of this potential nutrient source may be of some concern.

Storage of nutrients in stream beds and bottom sediments of lakes has become of interest in light of recent trends to alter the rate of lake eutrophication by removing certain sources of nutrients from inflows, notably wastewater discharges. Jaworski, Villa, and Hetling (12) estimated that about 38 percent of all phosphorus entering the upper Potomac River in 1966 was lost to stream bed storage. Middleton (15) reported values as high as 5.8 mg/g and 6.1 mg/g for organic nitrogen and total phosphorus, respectively in Smith Mountain Lake bottom sediments. Recent research, (16), (17), (18), has indicated that nutrients can become available from bottom storage in response to a change in inflow nutrient concentration. Such a change may cause a shift in the equilibrium between sediment and water, causing release of nutrients back into solution.

Historically, the economy of the United States has tended to progress from the rural-agricultural to the urban-industrial. This shift in the basis of the national economy has been accompanied by a concurrent population shift. Concentration of people in urban rather than rural areas has had a marked effect upon the nutrient balances in our watercourses. Nichols (19) has described the agrarian society as approaching the closed system ideal with respect to the economy of the two prime nutrients, nitrogen and phosphorus. In such a situation, the food chain acts as the vehicle by which the nutrient balance is maintained, with very minor losses, between the soil and living things. Sawyer [20] presented the following data to illustrate the relative rapidity of nutrient return to the soil from the position of man at the top of the food chain. The data are based on a 65 year lifetime.

Element	Wt. consumed lb.	Wt. retained lb.	% Excreted
Nitrogen	840	4.0	99.5
Phosphorus	80	1.5	98.1
Potassium	175	0.6	99.7

Additionally the organic detritus from decayed crops and animal wastes acted to replenish the soil nutrient supply rather rapidly.

A schematic diagram of the nitrogen and phosphorus nutrient budget in a rural-agrarian economy is shown in Figure 1 (21).

The closed system which characterized the agrarian society was upset as the nation's cities began to develop. With the aggregation of the nation's population into metropolitan areas, nutrients were no longer returned to the soil, but were exported to the developing cities in the form of farm produce and livestock. Faced with increasing nutrient depletion and demands for greater production the farmer was forced to turn to artificial fertilizers to maintain his land in a productive state. Application of these additives restored soil productivity, but according to Sawyer [20], it also increased nutrient loadings to the aquatic environment due to greater runoff losses caused by inefficient

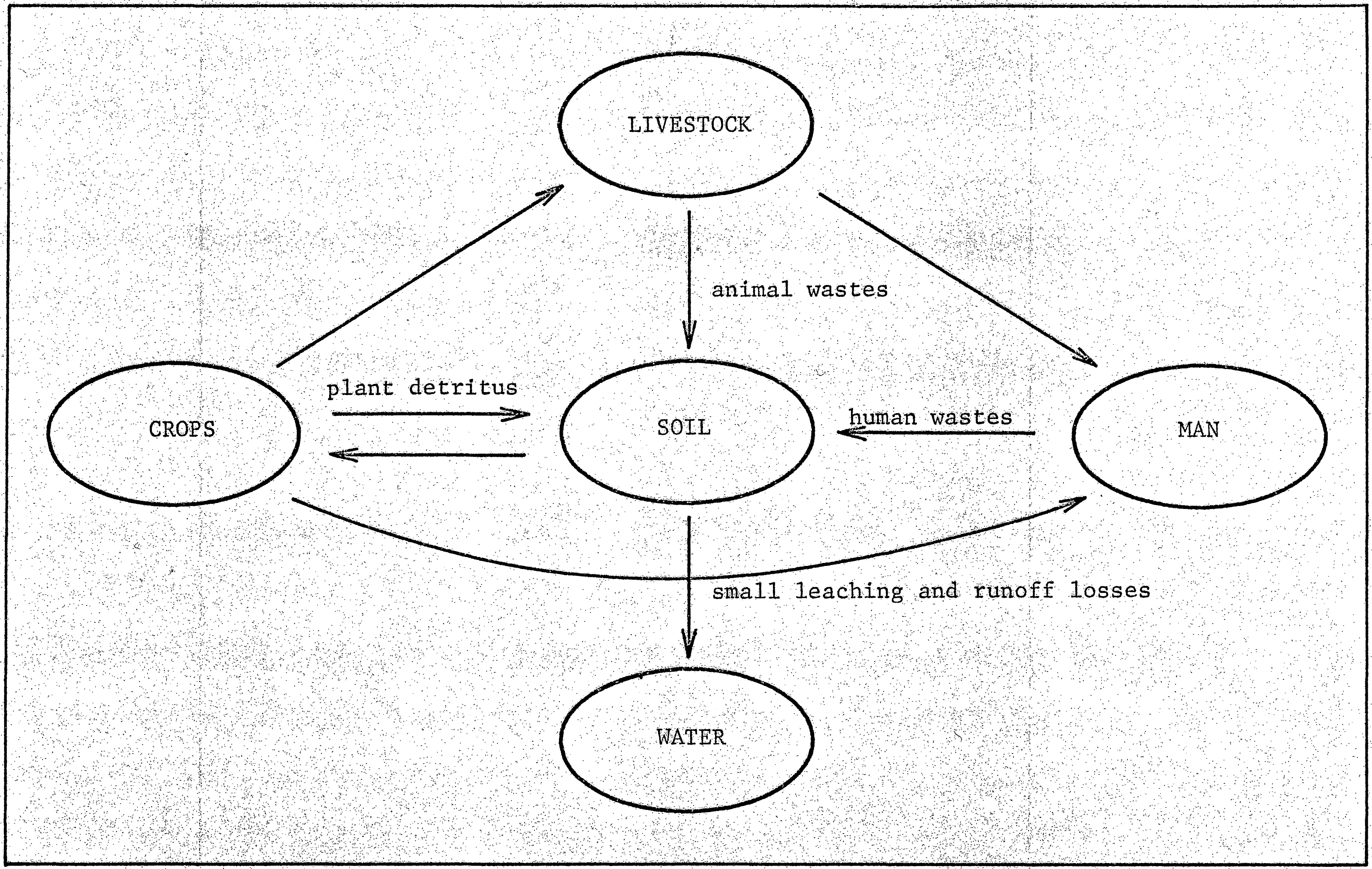

Figure 1: Nutrient Budget in a Rural - Agrarian Economy

application and poor land management procedures.

In the post-World War II years the requirement for commercial fertilizers to replenish depleted croplands has increased at a fantastic rate as shown in Figure 2 (22). The difference in the increase in the use of nitrogen and phosphorus in fertilizers since 1945 is shown in Figure 2. Sawyer [21] ascribes this difference to continued one crop farming rather than periodic rotation. Wadleigh [13] supports this in stating that in excess of one million tons of elemental phosphorus are being applied to American croplands annually. He further states that the actual mechanism by which fertilizer phosphorus is lost to the watercourses is soil erosion rather than runoff as commonly supposed. This is due to the capacity of clay particles, in particular, to adsorb phosphorus. The bound phosphorus is not readily released to solution, but is washed to the watercourse through soil erosion.

Not all agriculture losses of fertilizer nutrients to the aquatic environment are due to runoff from croplands. Nutrients exported from agricultural lands by incorporation into the food chain are also finding their way into the watercourses via the water carriage sewage disposal systems in use throughout the country. The majority of sewage treatment facilities in use today have not been designed to accomplish nutrient removal, and this only small removals are achieved in conventional wastewater treatment (3). The net effect is the operation of an open system where nutrients are continuously exported from agricultural lands to our urban areas, and thence to the surface water of the Country.

Figure 3 (21) is a schematic diagram of the agricultural nutrient

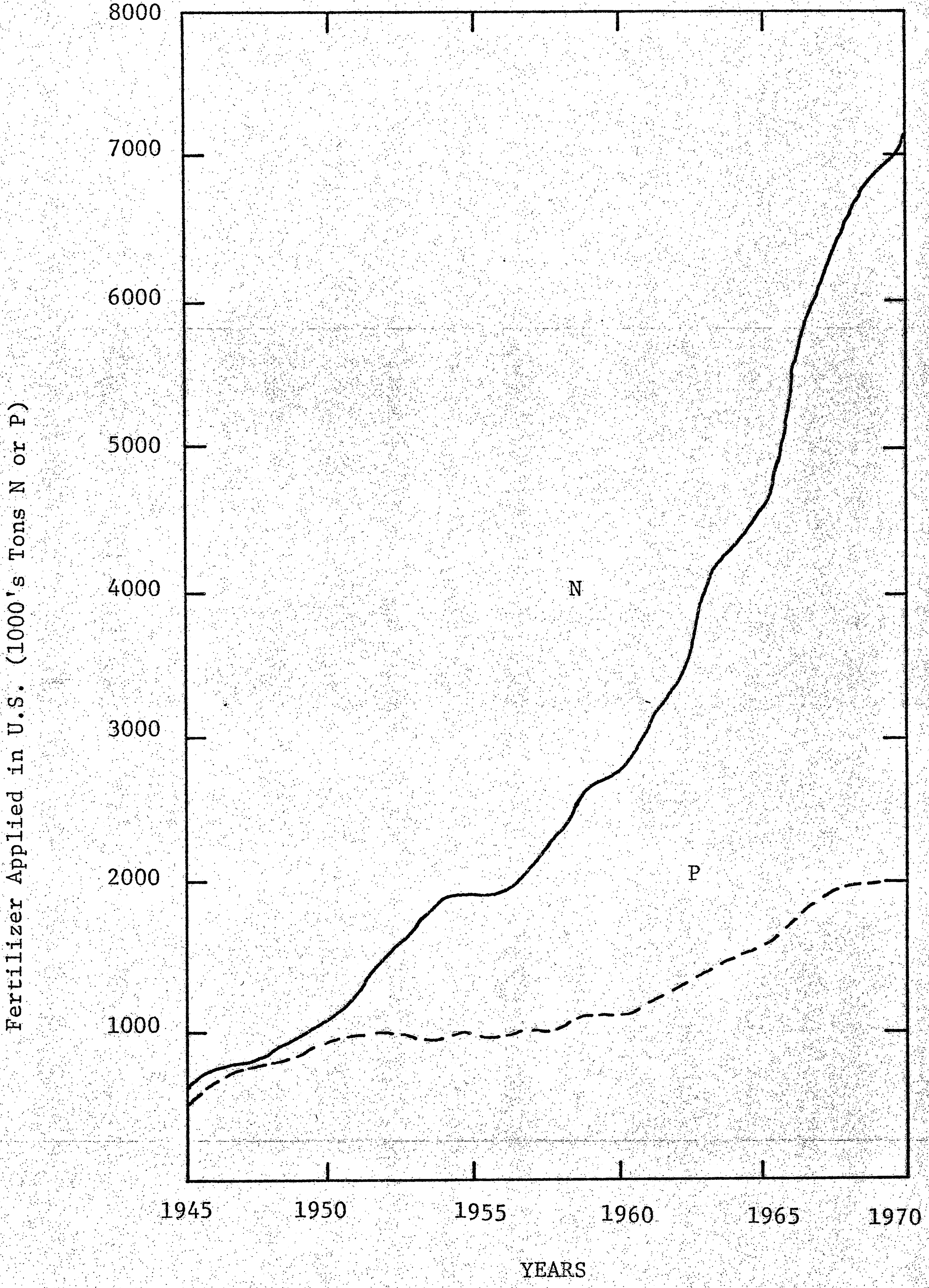

Figure 2: Farm Fertilizer Utilization in the United States.

balance, in terms of nitrogen and phosphorus, such as exists in an open system, as found in an urban-industrial society. Data reported by several researchers in regard to phosphorus and nitrogen yields from various types of land drainage are presented in Table I.

Phosphorus yields from agricultural lands have been observed to range between 0.80 and 1.92 lb/day/mi.^{2} as total phosphate [24] [12] [10]. Jaworski et al., (12), reported yields of 0.65 and 5.30 lb/day/mi.^{2} for total Kjehldal Nitrogen and NO_3-N, respectively in agricultural subwatersheds during an investigation of the Potomac River Basin.

Very little attention has been focused upon forested lands as sources of nutrients that eventually enter the watercourses. Sylvester (11) reported yields of total phosphate in three forested watersheds in the western United States ranging from 1.73 to 4.18 lb/day/mi.^{2}. Jaworski et al., (12) observed a total phosphate yield of 0.50 lb/day/mi.^{2} in agricultural subwatersheds of the Potomac River Basin.

Nitrogen yields in forest drainage have been observed by Sylvester (11) to range from 2.27 to 5.17 lb/day/mi.^{2} as NO_3-N. Jaworski et al., (12), in reporting on the Potomac River Study, noted forest drainage yields of 2.02 lb/day/mi.^{2} NO_3-N, and 0.41 lb/day/mi.^{2} TKN.

Weibel et al., (13), from a study in a Cincinnati, Ohio, found urban land drainage to be a significant source of nutrients entering the Ohio River. Observations from this study indicated total phosphate yields of 4.38 lb/day/mi.^{2}. Owen and Johnson (24), in the Lake Ontario Study reported total phosphate yields of 8.23 lb/day/mi.^{2}. Jaworski et al., (12) reported total phosphate yields of 1.10 lb/day/mi.^{2} in

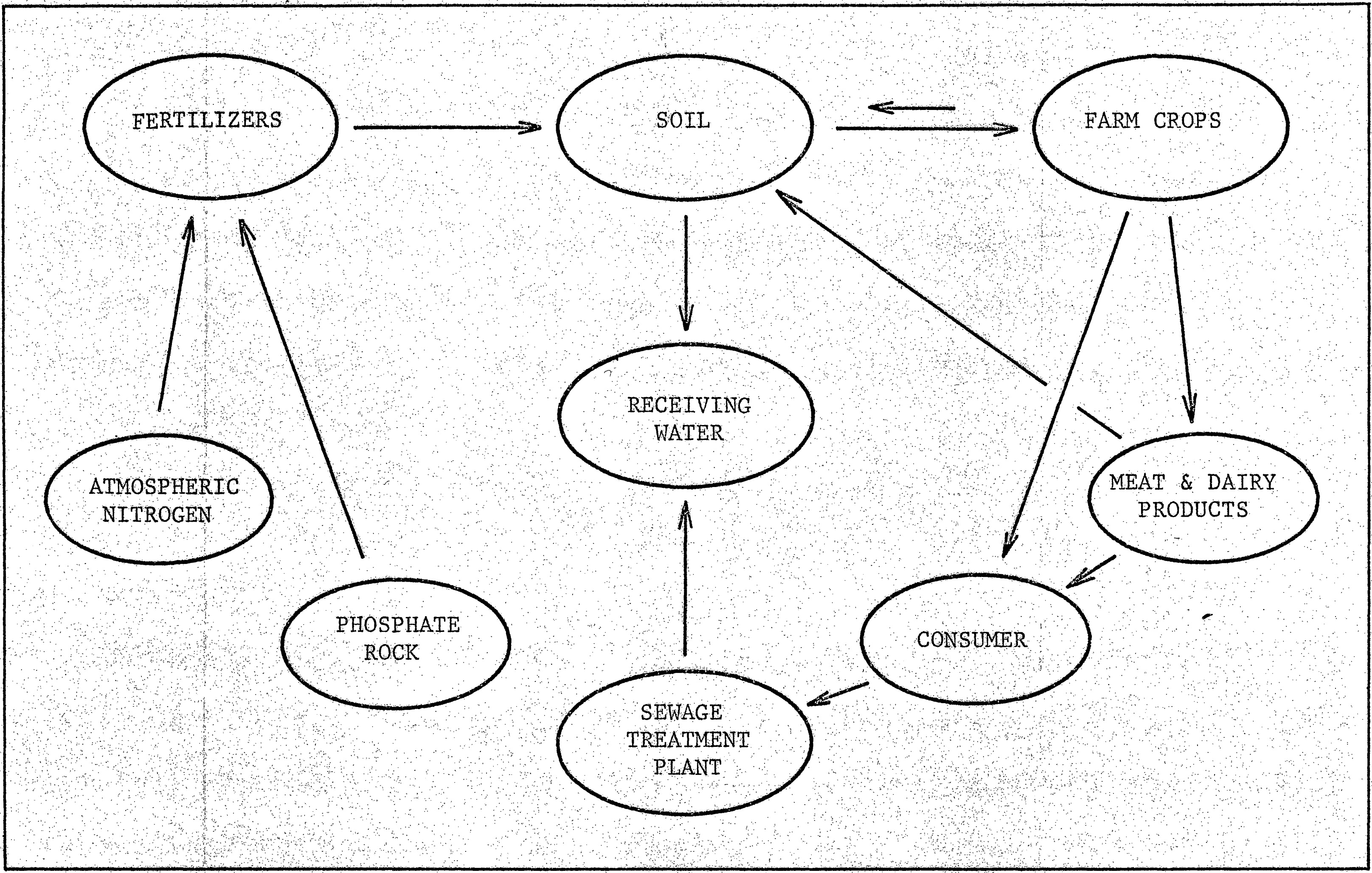

Figure 3: Nitrogen - Phosphorus Budget in an Urban Economy

Table I

Nutrients Yields From Various Watershed Types

Researcher	Study Area	Land Use								
		Agriculture #/day/mi^2			Forest #/day/mi^2			Urban #/day/mi^2		
		TOT PO_4	NO_3-N	TKN	TOT PO_4	NO_3-N	TKN	TOT PO_4	NO_3-N	TKN
Jaworski, et al [12]	Potomac River	1.25	5.30	0.65	0.50	2.02	0.41	1.10	2.70	0.67
Owen & Johnson [24]	Ontario	0.80	-	-	-	-	-	8.23	-	-
	Ontario	1.65	-	-	-	-	-	-	-	-
Sawyer [10]	Madison	1.92	-	-	-	-	-	-	-	-
Sylvester [11]	Western U.S.	-	-	-	3.99	5.17	-	-	-	-
	Western U.S.	-	-	-	4.18	2.27	-	-	-	-
	Western U.S.	-	-	-	1.73	-	-	-	-	-
Weibel, *et al*. [13]	Cincinatti	-	-	-	-	-	-	4.38	2.19	-

urban land drainage from the Potomac River Basin.

Nitrogen yields from urban watersheds observed in the Potomac River Basin by Jaworski et al., (12) were 2.70 and 0.67 lb/day/mi.^{2} as NO_3-N and TKN, respectively. Weibel et al., (13) reported NO_3-N yields of 2.19 lb/day/mi.^{2} in the Cincinatti study.

It is very difficult to quantify the contribution of industrial wastewater effluents to the enrichment of surface waters, since these wastes are peculiar to the individual processes that spawn them. However, some general characterizations may be made about the basic nature of wastewaters from different industrial classifications (25). Food and drug processing industries characteristically produce waste streams containing high concentrations of organic material, including proteins, fats and vitamins. Chemical production results in the release of a wide variety of by-products in the process waste including acids, bases, organic and inorganic solids, and nutrient materials such as phosphorus and nitrogen. The production of consumer materials may again give rise to a wide variety of constituents in the waste stream. Some materials industries wastewaters may exhibit only trace amounts of the nutrients of prime concern in stream and lake fertilization. Pulp and paper wastes, for example, are so nutrient-poor that conditioning by phosphorus and nitrogen addition is necessary before such wastes may be sucessfully treated by biological means.

The average concentrations of phosphorus and nitrogen in domestic sewage are about 12 mg/l and 40 mg/l, respectively (2). The enrichment of surface waters via the yields of nitrogen and phosphorus from domestic wastewaters is somewhat less difficult to quantify since the composition of domestic sewage does not vary greatly throughout the country.

Actual nutrient loadings to the aquatic environment from domestic wastewater effluents is dependent upon the efficiency of the treatment process in use. Martin and Weinbarger (3) have reported phosphate reductions as high as 77 percent in secondary sewage treatment plants, but note that the average removal is only about 10 percent. Total nitrogen reductions in conventional wastewater treatment processes are also very low.

According to Sawyer (20), the phosphorus content of domestic sewage has been increased by a factor ranging from two to four by the relatively recent advent of synthetic detergents. The household detergents currently on the market are approximately 50 percent by weight inorganic phosphates (24). This increased phosphate loading from detergent use has shifted the phosphorus balance in domestic sewage such that greater than 70 percent is traceable to synthetic detergents (20)

Nitrogen in fresh domestic wastewaters occurs almost entirely in the organic or ammonia state. In addition to ultimately serving as a nutrient source for nuisance aquatic growths, nitrogen in these forms exerts a demand on the oxygen resources of the receiving water as it is biologically oxidized to nitrate. Very little nitrification occurs in most conventional sewage treatment processes, leaving the nitrogenous oxygen demand (NOD) to be satisfied by the receiving stream.

A sampling program designed to evaluate the nutrient yields in a watershed should take into account both diurnal and seasonal fluctuations in the quantities of materials being introduced into the waterways.

Owen and Johnson [24] found that about 77 percent of the total phosphorus yield from a Lake Ontario watershed occurred during the period from February to April, while only eleven percent occurred from April to September. Jaworski et al., [12] state that sampling only during summer low flow conditions can cause misleading conclusions about nutrient contributions.

Diurnal fluctuations in nutrient yields are particularly important in the cases of domestic sewage discharges where the quantities may vary with the efficiency of treatment.

Figure 4 is a generalized graph, adapted from the data reported by two researchers [12] [24], showing the fluctuations of nutrient yields that may be expected in a watershed on an annual basis.

A search of the literature on nutrient yields in watersheds above impoundments indicates that no generalization can be made about the relative magnitude of contributions from various sources. Any attempt to quantify the nutrient yields from the various sources in a drainage basin must be accomplished by a comprehensive study of the particular situation, realizing that each watershed is unique and that previous studies of other watersheds can serve only as guides in the conduct of a particular analysis.

Historically, the BOD test has been the principal parameter for measuring the carbonaceous content of a wastewater. Recent studies have shown the organic carbon content of a water to be of extreme importance in regulating productivity lenitic aquatic environments (9). In spite of this, regulatory and policy-making agencies have shown

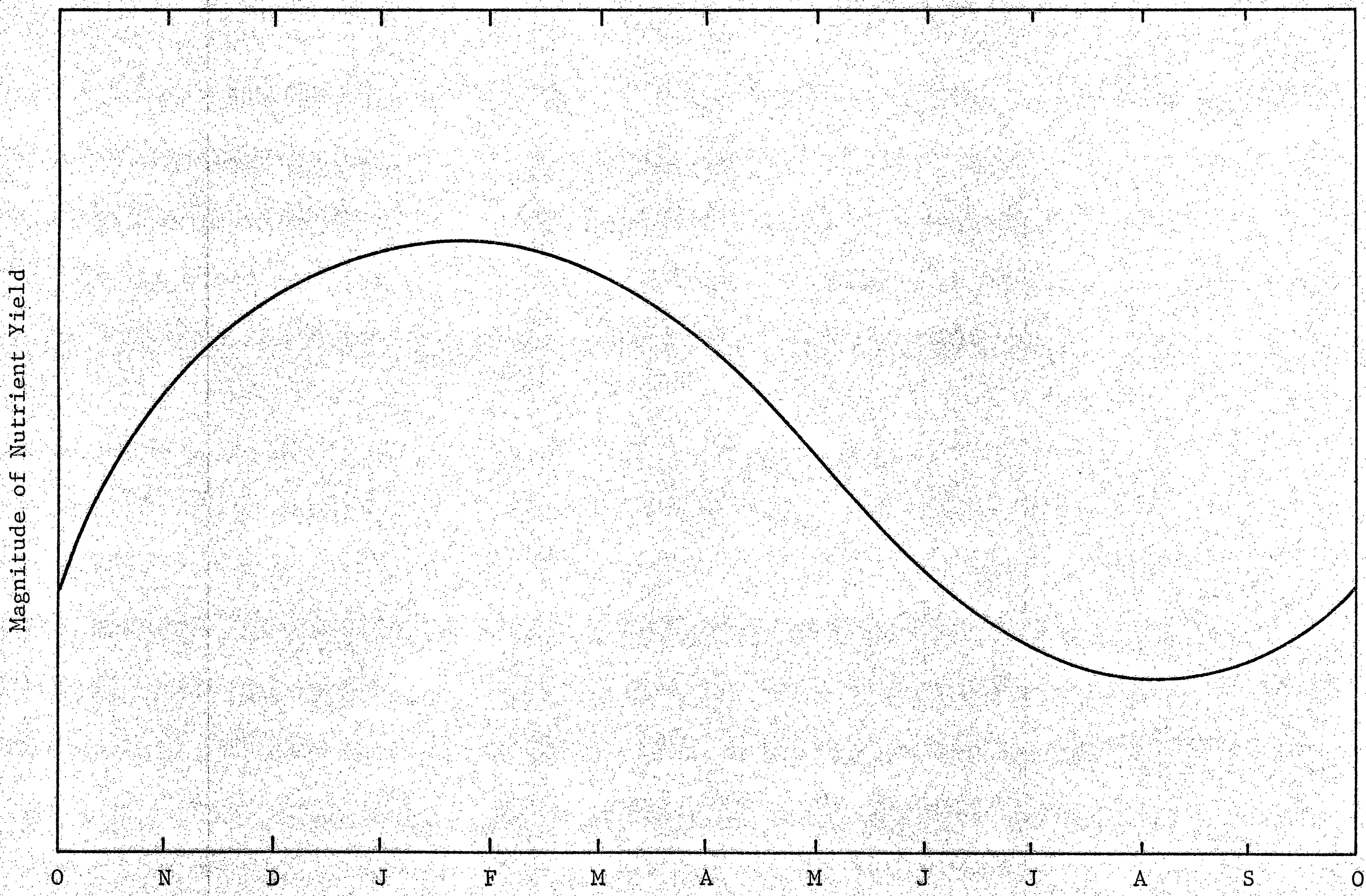

Figure 4: Typical Seasonal Variations in Nutrient Yields from Watershed Runoff

little interest in establishing organic carbon criteria for treated wastewaters. It has been shown that the BOD test does not define the organic carbon content of a waste (26).

It is very difficult to quantify the yields of organic carbon to an impoundment from its tributary drainage basin. This is primarily because a dynamic situation exists within streams with respect to the concentration of organic carbon. Biological activity, mainly respiration, continually changes the concentration of organic carbon as it is taken up and eventually incorporated into CO_2. Consequently, little data are currently available on the organic carbon yields within a watershed.

III. MATERIALS AND METHODS

This investigation of the Upper Roanoke River Basin above Smith Mountain Lake was conducted during the period from 19 June 1971 through 30 July 1971. A map of the basin is shown in Figure 5. Table II presents physical data on the drainage areas of the Roanoke River and its major tributaries in the upper basin. Sixteen sampling sites were selected at various locations in the basin in order to determine the location of principal sources of nutrient and organic loadings, and to document changes in water quality on the main stem of the river above Smith Mountain Reservoir. The location of the sampling stations are shown in Figure 5 and are described in Table III. Table IV lists the dates and times on which each station was sampled.

In designing a sampling program to make use of automatic collection equipment, it is imperative to assure that the limitations imposed by the employment of such equipment do not compromise the integrity of the sampling procedures. The size and weight of this type of equipment may impose restrictions on its placement in relatively inaccessible sampling locations. In some cases, a minor compromise in sampling site selection was necessary to facilitate equipment placement during the study. However, in all instances the sampling sites utilized in this study were deemed to be satisfactory.

Sampling sites were selected prior to initiation of the program with a view to establishing a series of collection points that would enable the author to adequately monitor all the major sources of nutrient and organic loadings in the basin. It is the opinion of the

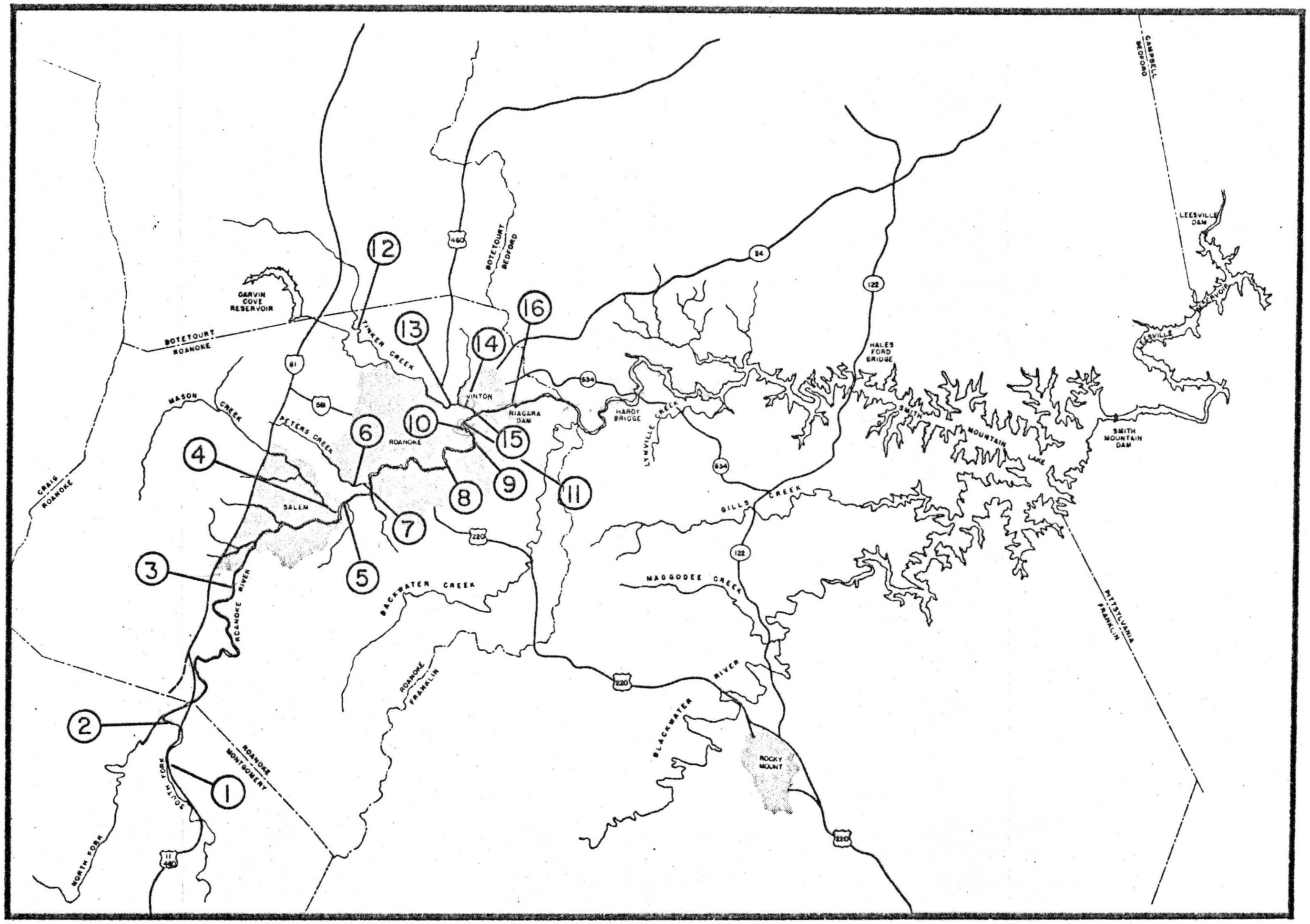

Figure 5: Map of the Upper Roanoke River Basin Showing Sampling Stations

TABLE II

Drainage Areas of Roanoke River and Tributaries in the Study Area

Description	Drainage Area sq. miles
1. South Fork of Roanoke River near Shawsville, Virginia	109
2. Roanoke River at Lafayette, Virginia	257
3. Mason Creek	30
4. Peters Creek	9
5. Roanoke River at Walnut St. Bridge in Roanoke, Virginia	388
6. Tinker Creek	104
7. Roanoke River at Niagra Dam	511

TABLE III

Sampling Station Descriptions

Station	Location
1	Roanoke River adjacent to U.S. 460 one mile above Green Hill Sausage Co.
2	Roanoke River adjacent to Va. 673 one mile below Green Hill Sausage Co.
3	Roanoke River above City of Salem 500 yards below bridge
4	Mason Creek 500 yards above confluence with Roanoke River
5	Roanoke River 1,000 yards below mouth of Mason Creek
6	Peters Creek at water intake of Roanoke Electric Steel Corp.
7	Peters Creek 500 yards below outfall of Roanoke Electric Steel Corp.
8	Roanoke River 0.5 mile above Roanoke Industrial Park
9	Roanoke River 1,000 yards above outfall of Roanoke Sewage Treatment Plant
10	Secondary effluent of Roanoke Sewage Treatment Plant
11	Roanoke River 500 yards below outfall of Roanoke Sewage Treatment Plant
12	Tinker Creek at bridge on U.S. Rt. 11
13	Tinker Creek above Roanoke Sanitary Landfill at U.S. Rt. 24 bridge
14	Secondary effluent of Vinton Sewage Treatment Plant
15	Tinker Creek 500 yards above confluence with Roanoke River
16	Roanoke River at Niagra Dam

TABLE IV

Sampling Dates and Times of Each Station

Station Number	Sampling Time and Date	
1	1200-2400	28 June 1971
	0100-1100	29 June 1971
2	1300-2400	28 June 1971
	0100-1200	29 June 1971
3	1600-2400	8 July 1971
	0100-1500	9 July 1971
4	1000-2400	27 July 1971
	0100-0900	28 July 1971
5	1700-2400	8 July 1971
	0100-1600	9 July 1971
6	0800-2400	16 July 1971
	0100-0700	17 July 1971
7	0800-2400	16 July 1971
	0100-0700	17 July 1971
8	1600-2400	6 July 1971
	0100-1500	7 July 1971
9	1000-2400	19 June 1971
	0100-0900	20 June 1971
	1600-2400	6 July 1971
	0100-1500	7 July 1971
	2000-2400	21 July 1971
	0100-1900	22 July 1971
10	0900-2400	19 June 1971
	0100-0800	20 June 1971
	2000-2400	21 July 1971
	0100-1900	22 July 1971
11	1300-2400	29 June 1971
	0100-1200	30 June 1971
12	2300-2400	22 July 1971
	0100-2200	23 July 1971
13	1700-2400	15 July 1971
	0100-1600	16 July 1971
14	1700-2400	15 July 1971
	0100-1600	16 July 1971

TABLE IV (Continued)

Sampling Dates and Times of Each Station

Station Number	Sampling Time and Date	
15	1300-2400	29 June 1971
	0100-1200	30 June 1971
	2200-2400	22 July 1971
	0100-2100	23 July 1971
16	1100-2400	29 July 1971
	0100-1000	30 July 1971

author, that in designing this sampling program, this objective was met.

The objectives of the sampling program, as implemented in this study, were to obtain samples over a 24-hour period at each station from one to three times during the period of investigation, and to analyze the collected samples for diurnal variations in several chemical parameters.

All water samples were collected by an Instrument Specialities Company Model 718 Automatic Sampler. The use of two such devices made it possible to monitor both the contributing source and the Roanoke River above or below the source. Each machine was programmed to pump a 500 ml sample at hourly intervals for a period of 24 hours. The sampling probe of each machine was placed in the stream flow at the desired location and held in position by the use of an anchored float. Between uses the probe and 20 foot suction line were cleansed thoroughly with a no-phosphate detergent and continuously rinsed with clean water for a period of 15 minutes. Each machine was equipped with an insulated sample bottle container with provisions for 24-500 ml bottles and a space to pack the bottles with ice. Prior to the first sampling run and between each subsequent run, the polypropylene bottles were washed and rinsed with a solution of 50 percent nitric acid. Packing each sample bottle container with cubed ice prior to a sampling run made it possible to cool samples as they were collected and prevented sample temperatures from rising above 15 C. prior to retrieval. This is higher than the maximum allowable sample temperature of 10 C. recommended by Nemerow [25], but since it was experienced for a relatively short time span and does represent a maximum, no appreciable change in the various chemical parameters was experienced. Following retrieval of the automatic samplers, the water samples were transported immediately to the Sanitary Engineering Laboratory of the Virginia Polytechnic Institute and State University where they were refrigerated until all chemical analyses could be completed.

The five day Biochemical Oxygen Demand (BOD_5) was determined according to procedures in Standard Methods for the Examination of Water and Wastewater. [27]. Samples of sewage effluents were dechlorinated according to Standard Methods prior to determination of BOD_5. Chemical Oxygen Demand (COD) was determined according to Standard Methods. Analysis for Total Organic Carbon (TOC) was conducted with a Beckman Model 915 Total Carbon Analyzer. Total Kjeldahl Nitrogen (organic-N + NH_3-N) was determined with a Technicon Auto Analyzer equipped with a 50 mm flow cell and operated according to Technicon Industrial Method 30-69A-sodium nitroprusside modification. Concentration of nitrates (NO_3-N) was measured according to the phenoldisulfonic acid method as presented in Standard Methods. Orthophosphate determinations were made according to the Stannous Chloride procedure in Standard Methods. Total phosphate was similarly measured following sample digestion by the persulfate method as given in Standard Methods. All colorimetric measurements were made with a Klett-Summerson Colorimeter. Samples for the determination of monovalent and divalent cations were prepared according to Standard Methods and analyzed with the aid of a Jarrell-Ash Dial-Atom Atomic Absorption Spectrophotometer. Concentrations of sodium and potassium were measured by flame emission spectrophotometry, while magnesium and calcium were measured by atomic absorption spectrophotometry.

Data on streamflows on the main stem of the Roanoke River were obtained from the United States Geological Survey (28), and the Virginia Department of Conservation and Economic Development (29). Flows in tributaries and in the Roanoke River at each sampling station were estimated by developing a flow factor at each site based on the ratio of its drainage area to the total drainage area of the Roanoke River at the closest gaging station. The drainage areas at each sampling station were determined from United Coast and Geodetic Survey 7.5 minute Quadrangle Maps of the area.

Domestic wastewater discharges were obtained from the Cities of Roanoke and Vinton for their respective sewage treatment plants.

III. RESULTS

In order to more accurately define the daily yields of the parameters included in this study, automatic sampling equipment was used for the collection of all water samples. By monitoring diurnal variations in the concentration of the various parameters, it was possible to minimize errors that might have been introduced by using grab sampling techniques. The automatic sampling equipment was programmed to operate on an hourly basis. The hourly samples collected were, in turn, composited on a two-hour basis for analysis. The results showing diurnal variations are presented in Figures 7 through 66 in Appendices A through D.

Observed diurnal variations in COD, BOD_5, and TOC at Stations 1 through 16 for the dates sampled are shown in Figures 7 through 26 in Appendix A. A wide variation was observed in the ratios of $TOC:COD:BOD_5$ for all stations monitored except the sewage effluent. This is in agreement with the findings of Jones and Jennelle (26) that the BOD_5 test is not an adequate measure of the organic carbon content of a wastewater sample. It is also known that the COD analysis does not detect some organic carbon compounds that are amenable to the TOC analysis (27). Diurnal variation in BOD_5 was much less than the variation in either COD or TOC. This not only reflects the relative sensitivity of the three parameters, but may also indicate that a considerable portion of the organic material present is not amenable to biological degradation.

The only significant diurnal variations in organic loadings were observed at the two municipal sewage treatment plants. Figures 18, 19, and 23 show the observed diurnal fluctuations in the organic parameters at the Roanoke and Vinton treatment plants, respectively. Changes in effluent quality correspond to fluctuations in hydraulic loading to the plant. Organic removal efficiency was observed to be poorest when the plants were reported to be operating at daily peak flow (31).

The observed diurnal variations in the concentrations of NO_3-N and TKN at Stations 1 through 16 are shown in Figures 27 through 46 which are located in Appendix B. The wide variation in TKN observed at Station 2, as shown in Figure 28, may be due to the presence of a meat processing plant located approximately one mile upstream. Waste discharges from this source were observed to be intermittent. A wide variation in TKN concentration was also observed at Station 9 as shown in Figures 35 and 36. These variations appear to be random and are probably due to waste discharges from the industrial park located upstream from Station 9. A sampling run conducted at Station 9 during wet weather flow exhibited no detectable TKN, as shown in Figure 36. This was probably due to dilution with storm water runoff. The concentrations of NO_3-N exhibit little change along the river course above the urban area. The actual observed concentrations fluctuate widely, but these variations appear to be random in nature.

Data showing the daily variation in TKN and NO_3-N concentrations in the municipal wastewater discharges monitored are presented in Figures 38, 39, and 43. The nitrogen concentrations in the plant effluents were observed to reach maxima at periods of peak flow. Most of the nitrogen was in the TKN form. Nitrification was not being accomplished at either of the two municipal wastewater treatment plants.

The observed diurnal variation in the concentration of total-PO_4 and ortho-PO_4 at Stations 1 through 16 for the dates sampled are shown in Figures 47 through 66 which are located in Appendix C. The wide range in the concentration of total-PO_4 observed at Station 2, as shown in Figure 48, may be due to the presence of the previously cited meat packing operation located upstream from the sampling point. This hypothesis is reinforced by the lack of any detectable ortho-PO_4 at Station 2; all detectable phosphorus being in the non-ortho-PO_4 form.

Good correlation in the diurnal variation in the concentration of ortho-PO_4 and total-PO_4 was observed for most of the sampling stations located above the urban area. Most of the phosphorus observed at stations above the urban area was in the ortho-PO_4 form. The close agreement between the ortho-PO_4 and total-PO_4 curves for the sampling points above the urban area may indicate that the additional phosphate recovered by acid hydrolysis in the total-PO_4 test was not organic or condensed polyphosphates, but inorganic phosphates adsorbed onto stream-carried sediment and not detected by the ortho-PO_4 test.

Poor correlation in the diurnal variation of total and ortho-PO_4 concentrations was observed for sampling stations located within the urban area. The non-ortho-PO_4 concentration observed in urban runoff are thought to be primarily organic phosphate. The variation of phosphate concentration in the domestic wastewater effluents monitored are shown in Figures 58, 59, and 63. The phosphorus concentrations in the effluents reach a maximum during the peak flow period as was observed for the carbonaceous material and nitrogen loadings.

Figure 64 shows the diurnal variation in phosphorus concentrations at Station 15 on 29 and 30 June, 1971. Station 15 is located at the mouth of Tinker Creek below the Roanoke Sanitary Landfill. This area has been denuded of vegetation and the runoff is increased both in volume and sediment load. The sampling run conducted on 29 and 30 June, 1971 was during a period of rainfall and subsequent high runoff from the landfill area. The shape of the curve and distribution of the phosphate forms detected indicates that the predominant yields of phosphate were the inorganic forms found in eroded material, and the variation in yield of phosphorus from the landfill was related to the period of direct runoff.

The diurnal variation in the concentration of mono- and divalent cations (sodium, potassium, calcium, and magnesium) at Stations 1 through 16 are shown in Tables XIV through XXIX. The most dramatic deviations in cation concentration occurred in the sewage treatment plant effluents, but even these exhibited minimal diurnal variation.

The data collected from the sampling program were analyzed on the basis of source and yields of organic and nutrient materials. The Upper Roanoke River Basin was divided into urban and rural subwatersheds for presenting unit area drainage yields. The drainage basin above Niagra Dam consists of about 100 square miles of urban area and about 412 square miles of rural area. About 25 percent of the rural area is classified as agricultural and most of which is devoted to pastureland rather than crop production (30). The drainage basin above the Roanoke-Salem metropolitan area is entirely rural, as are the upper reaches of the three principal tributaries; Mason, Peters, and Tinker Creeks. All three major tributaries and the main stem of the Roanoke River pass through the metropolitan area. Table IV shows the drainage area at each sampling station and the flow on the date sampled. The domestic wastewater discharges in the basin consist of the Roanoke and Vinton municipal plants, which are a 30 MGD activated sludge facility (31) and a 0.8 MGD trickling filter, respectively (32). Flow from industrial wastewater discharges is approximately 50,000 gpd (32).

The daily mean concentration of each parameter monitored at Stations 1 through 16 is shown in Table VI.

The flow in the main stem of the Roanoke River above the industrial park located between Stations 8 and 9 was observed to exhibit extremely high TOC values in relation to the observed COD and BOD_5 values as shown for Stations 3, 5, and 8 in Table VI. The TOC:COD was observed to be the highest, 3.5, at Station 3, which is located at a point where the tributary drainage basin is entirely rural. The TOC:BOD_5 ratio was observed to decrease as the stream entered the urban area. Only on one occasion, during a period of heavy rainfall, was the TOC:COD ratio at Station 9 observed to exceed unity. This was probably due to an increased sediment load in the stream due to higher runoff yields during the rainfall. The high TOC:BOD_5 ratios observed above the urban area indicate that most of the organic material present was refractory. This

TABLE V

Drainage Areas at Each Station and Flows on Date Sampled

Station	Drainage Areas (Mi.^{2})	Flow (CFS)
1	133	86.0
2	138	89.0
3	318	130.0
4	29	13.0
5	373	137.0
6	8	5.4
7	8	5.5
8	391	191.0
9	397	*431.0
9	397	219.0
9	397	114.0
10	-	42.1
10	-	42.1
11	399	276.0
12	54	24.0
13	99	65.0
14	-	1.0
15	102	74.0
15	102	47.0
16	512	331.0

* wet flow

TABLE VI

Average Concentrations of all Parameters Monitored at Stations 1 Through 16

	Station	Parameter (mg/1)										
		COD	TOC	BOD_5	TKN	NO_3-N	T-PO_4	O-PO_4	Na	K	Ca	Mg
	1	11.80	-	3.60	0.06	0.30	0.56	0.04	2.61	1.42	43.60	20.46
	2	14.78	-	7.64	0.12	0.33	2.86	-	2.98	1.42	44.64	20.80
	3	8.70	30.10	4.90	*	0.28	0.17	0.12	1.29	3.85	47.80	17.95
	4	16.20	11.90	2.40	*	0.93	0.17	0.09	4.24	1.58	45.60	12.50
	5	15.70	28.20	4.60	*	0.31	0.20	0.14	1.73	4.78	47.17	16.04
	6	15.25	7.77	4.49	*	0.73	1.39	0.83	1.25	2.18	45.75	20.83
	7	16.75	10.11	4.25	*	0.72	1.39	0.64	2.26	2.17	45.40	19.83
	8	11.80	24.17	6.90	*	0.40	1.07	0.29	0.93	4.08	23.36	12.27
above	9	33.02	11.96	6.95	0.80	0.28	0.82	0.22	3.47	2.04	41.06	20.24
outfall	10	111.25	48.79	42.00	17.14	0.16	27.98	12.46	110.5	5.30	22.10	13.89
below	11	20.23	17.35	7.86	0.27	0.77	0.98	0.26	14.70	3.38	44.75	22.71
	12	14.84	10.38	3.05	0.00	0.55	0.54	0.23	4.69	2.01	49.00	21.18
	13	18.80	14.10	5.13	0.48	0.52	5.66	1.01	10.94	2.74	46.09	16.32
	14	189.70	89.10	63.20	8.95	0.39	23.04	13.04	45.09	9.97	1.42	2.36
	15	30.98	20.92	5.98	1.92	0.50	3.88	2.72	26.65	3.60	29.31	20.75
DAM	16	32.79	15.08	11.73	2.01	0.18	5.58	1.01	24.54	4.01	46.17	17.45

---

*Not detectable

would be expected since no source of readily degradable carbonaceous material exists in the rural area.

Concentrations of NO_3-N exhibit little change along the river course above the urban area. The daily mean concentration remains at about 0.3 mg/1 as N at Stations 1, 2, 3, and 5 as shown in Table VI. TKN concentrations in the river flow above the urban area and in Mason Creek and Peters Creek were below the detection limits of the analysis used as shown for Stations 3 through 8 in Table VI. The TKN concentration observed at Station 2 was due to waste discharges from the meat processing industry located upstream. At Station 9, located downstream from the Roanoke Industrial Park, TKN concentrations were observed to average 0.8 mg/1 as N.

TKN concentrations were observed to be 17.14 and 8.95 mg/1 in the Roanoke and Vinton domestic wastewater discharges, respectively.

The TKN concentrations at Station 16, which is at Niagra Dam, were much greater than those observed at other portions of the basin as shown in Table VI. Nitrifying activity above this point was found to be minimal as evidenced by the low NO_3-N concentration.

The NO_3-N level at Station 16 was lower than that observed at Station 11 below the Roanoke Sewage Treatment Plant. This may be attributed to biological uptake in the watercourse. It has been suggested that the levels of biological activity in the Niagra impoundment are such that it acts as a huge waste stabilization pond treating the entire flow of the Roanoke River prior to its introduction into Smith Mountain Lake (32).

Phosphorus concentrations in the surface waters of the upper basin averaged about 0.20 mg/1 as PO_4 as shown in Table VI. The higher concentration observed at Station 2 was due to the effects of the upstream waste discharges from the meat packing plant. Phosphorus concentrations at Stations located in the urban area rose sharply as seen for Stations 6, 7, 8, and 9 in Table VI. The concentrations of phosphorus in the domestic wastewater effluents were approximately 25 mg/1 as PO_4 as shown for Stations 10 and 14. The high concentrations of phosphate compounds in the sewage discharges are reflected in the increased levels observed at Niagra Dam (Station 16).

The mean daily concentrations of the mono- and divalent cations (sodium, potassium, calcium, and magnesium) were observed to vary little throughout the surface waters of the basin as shown in Table VI. The only significant deviations from the norms occurred in the wastewater effluents. These flows were observed to contain higher levels of sodium and lower levels of calcium and magnesium than the surface waters of the basin.

Table VII shows the calculated daily load of each parameter monitored at Stations 1 through 16. The daily yield of TKN from sources in the rural portion of the basin was negligible, except for an industrial discharge upstream of Station 2. The secondary effluent of the Roanoke Sewage Treatment Plant observed to be the greatest single contributor of TKN to the surface waters of the basin. Likewise, the organic and phosphorus loadings from this facility were observed to be the greatest single sources in the basin. The data in Table VII were used to compute

TABLE VII

Average Daily Yields of all Parameters Monitored at Stations 1 Through 16

lbs

Parameter (#/day)

Station	COD	TOC	BOD_5	TKN	NO_3-N	T-PO_4	O-PO_4	Na	K	Ca	Mg
1	5457	-	1686	58	140	259	20	1209	658	20196	9477
2	7104	4900	3672	279	160	1375	-	1432	633	21476	9998
3	6086	21058	3428	*	198	120	88	902	2693	33440	12557
4	1143	840	169	*	66	12	7	299	111	3217	882
5	11795	21186	3456	*	232	151	105	1300	3591	35439	12051
6	447	228	132	*	21	41	24	37	64	1340	610
7	498	301	126	*	21	41	19	67	64	1350	589
8	12164	24916	7113	*	412	1103	299	959	4206	24081	12649
9	29649	10739	6240	718	251	736	198	3116	1832	36868	18174
10	25234	11067	9526	3888	36	6346	2826	25064	1202	5013	3150
11	45763	39248	17780	611	1742	2217	588	33253	7646	101230	51373
12	1920	1343	395	0	71	70	30	607	260	6339	2740
13	6551	4913	1788	167	181	1972	352	3812	955	16061	5687
14	950	446	317	45	2	115	65	226	50	12	7
15	10116	6831	1953	627	163	1267	888	8702	1176	9571	6776
16	58456	26884	20912	3583	321	9948	1801	43749	7149	82310	31109

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*Not detectable

average yields of all parameters studied from wastewater effluents and unit area yields from land drainage sources.

Wastewater loadings of nutrient and organic materials to the upper basin are shown in Table VIII. Total organic carbon is the only organic parameter taken to be of significance in stimulating algal production, hence BOD_5 and COD data are not presented in Table VIII. Nitrate nitrogen (NO_3-N) yields were not tabulated for the wastewater discharge, since nitrification was not occurring in the sewage treatment facilities. With the exception of the monovalent cation potassium, all wastewater yields of the parameters monitored were found to originate primarily from the Roanoke Sewage Treatment Plant. Industrial waste discharges accounted for approximately 30 percent of the total potassium yield from all wastewater sources. Wastewater discharges account for 6517, 3045, and 25,560 #/day of total-PO_4, TKN, and TOC, respectively.

Table IX shows the calculated daily yields of selected parameters from the rural and urban portions of the watershed. The total-PO_4 yield of 34 #/day/mi^2 for the urban area was considerably higher than the values reported in the literature and presented in Table I. The high total phosphorus levels observed at stations 13 and 15 are thought to be caused by heavy suspended loads associated with direct runoff. The elimination of this source of phosphate would reduce the yield to 10 #/day/mi^2 of total PO_4. While this value is still high, it is more reasonable when compared to the high value reported in the literature of 4.38 #/day/mi^2. The yields of 3.0 and 1.7 #/day/mi^2, as NO_3-N and TKN, respectively, agree well with the average values of 2.45 and

TABLE VIII

Calculated Wastewater Loadings to Basin

Parameter	Roanoke Municipal Plant	Industrial Discharges	Vinton Municipal Plant	Total
Population Served	220,000	---	6,000	226,000
Total PO_4				
#/day	6300	102	115	6,517
#/capita/day	0.0285	---	0.019	
TKN as N				
#/day	2800	200	45	3,045
#/capita/day	0.013	---	0.0075	
TOC				
#/day	25,200	---	450	25,650
#/capita/day	0.114	---	0.075	
Sodium				
#/day	25,000	2540	225	27,765
#/capita/day	0.114	----	0.038	
Potassium				
#/day	2300	1000	50	3,350
#/capita/day	0.014	----	0.008	
Calcium				
#/day	5000	150	*	5,150
#/capita/day	0.023	---	*	
Magnesium				
#/day	3100	650	*	3,750
#/capita/day	0.014	---	*	

---

* negligible

TABLE IX

Calculated Loadings from Land Runoff Sources

Parameter	Urban Runoff	Rural Runoff	Total
Area	112 mi^2	400 mi^2	512 mi^2
Total PO_4			
#/day	2,970	710	3,680
#/day/mi^2	34.0	1.77	
NO_3-N as N			
#/day	336	456	792
#/day/mi^2	3.0	1.14	
TKN as N			
#/day	191	176	367
#/day/mi^2	1.7	0.44	
TOC			
#/day	8,740	13,000	21,740
#/day/mi^2	78.0	32.5	
Sodium			
#/day	5,940	3,850	9,790
#/day/mi^2	53.1	9.62	
Potassium			
#/day	3,350	1,960	5,310
#/day/mi^2	30.0	4.91	
Calcium			
#/day	24,150	56,700	80,850
#/day/mi^2	216.2	140.9	
Magnesium			
#/day	6,550	26,200	32,750
#/day/mi^2	65.5	65.4	

0.67 #/day/mi^2 reported for urban drainage in the literature and presented in Table I.

No information was found in the literature on land drainage yields of organic carbon. The yields of mono- and divalent cations from forest drainage have been recorded by Bormann and Likens (33). They found cation yields to be directly dependent upon vegetative covers, increasing markedly as forest lands in their study area were denuded.

The rural drainage yields observed in the upper basin were a combination of the contributions from forested and agricultural lands. This study was conducted during the summer of 1971 and it is not thought that nutrient yields due to spring crop fertilization are reflected in the data. Nutrient yields during the summer are expected to be lower than those experienced during the fall and winter since plant uptake is at a maximum during the summer growing season and less material is lost by leaching. Additionally, stream bank erosion and ground water yield are at a minimum during summer low flow conditions, resulting in less nutrient transfer to the watercourses via these mechanisms.

The yield of total-PO_4 from the rural area was 1.77 #/day/mi^2. This value agrees very well with the range of values reported from the literature in Table I. Likewise, the rural drainage yields of TKN and NO_3-N compare very favorably with the typical values reported in Table I. The NO_3-N yield observed in the study was found to be lower than the values reported in the literature primarily because most of the tributary watershed is pasture and forest lands.

Urban drainage was observed to be the principal source of nutrients with the exception of the divalent cations, calcium and magnesium and total organic carbon. The yields of these materials from rural drainage were calculated to be, respectively, 32.5, 140.9, and 65.4 #/day/mi^2. While the unit area yields for each of these materials from the urban area were found to be greater than the above values, the rural portion of the watershed was found to be the principal source of these substances.

Table X presents a comparison of the total and percentage yield of the various parameters monitored from the two types of land drainage and from all wastewater effluents. Wastewater effluents accounted for 54 percent of the organic material entering the basin. The remainder being distributed between urban runoff and rural runoff, at 19 and 27 percent respectively.

Wastewater discharges also contribute 64 percent of the total phosphorus and 73 percent of the total nitrogen entering the watershed. Nitrate nitrogen yields were divided between urban and rural drainage which contributed, respectively, 42 percent and 58 percent of the daily total of 792 pounds. Organic and ammonia nitrogen yields, as recorded by the TKN analysis, were confined almost entirely to domestic and industrial wastewater discharges.

TABLE X

Comparison of Loadings From All Sources

Parameter lb/day	All Wastewater Discharges lb/day	Rural Runoff lb/day	Urban Runoff lb/day	Total lb/day
Total PO_4 as PO_4	6,517	710	2,970	10,197
% of Total	64%	7%	29%	100%
Nitrate Nitrogen as N	-----	456	336	792
% of Total	0%	58%	42%	100%
Total Kjehldal Nitrogen as N	3,045	176	191	3,412
% of Total	89%	5%	6%	100%
Total Organic Carbon	25,650	13,000	8,740	47,390
% of Total	54%	27%	19%	100%
Sodium	27,765	3,850	5,940	37,555
% of Total	74%	10%	16%	100%
Potassium	3,350	1,960	3,350	8,660
% of Total	39%	22%	39%	100%
Calcium	5,150	56,700	24,150	86,000
% of Total	6%	66%	28%	100%
Magnesium	3,750	26,200	6,550	36,500
% of Total	10%	72%	18%	100%

IV. DISCUSSION

One measure of the validity of computed daily yields of the parameters monitored during the course of this study is the relationship of the summation of the computed yields for the various sources in the basin to the yields computed from the data obtained at Station 16. A comparison of these data is presented in Table XI.

The difference between the computed total phosphate yields and the observed yield at Station 16 was only 2.5 percent. The higher calculated yield may indicate some loss of phosphate to stream bed storage.

The difference in the calculated daily yield of TKN from the yield observed at Station 16 was also insignificant, being only 5.2 percent. The reason for the significantly higher calculated yield of nitrate nitrogen is not known. One would expect the observed nitrate value to be greater because of nitrification in the stream. However, the data indicates that denitrification may be occurring in Niagra Reservoir.

A large difference is seen to exist between the observed yields of organic carbon and the yields calculated from the sampling program data. This is interpreted to be the result of biological activity within the surface waters of the basin. Both aerobic and anaerobic activity results in a continued degradation of organic carbon to satisfy metabolic needs. Thus the calculated yield of organic carbon should be greater than the observed yield at Station 16.

The calculated yields of cations all demonstrate positive deviations from the observed total daily yields with the exception of sodium, which exhibits a negative deviation of about 14 percent. This may be an

TABLE XI

Comparison of Computed Total Loadings to Observed Loadings Entering Impoundment

Parameter	Computed Total (lb/day)	Observed Total (lb/day)	Excess (+) or Deficit (-) (lb/day)	% Error (+) or (-)
Total PO_4 as PO_4	10,197	9,948	249	+2.5
Total Kjehldal Nitrogen as N	3,412	3,600	-188	-5.2
Nitrate Nitrogen as N	792	321	471	+147
Total Nitrogen as N	4,204	3,921	283	+7.2
Total Organic Carbon	47,390	26,890	20,500	+76
Sodium	37,555	43,750	-6,195	-14.1
Potassium	8,660	7,150	1,510	+21.1
Calcium	86,000	82,310	3,690	+4.5
Magnesium	36,500	31,110	5,390	+17.4

indication that interchange with the stream bed is affecting the concentration of cations in the surface water. In ion exchange phenomena, the cations calcium, magnesium, and potassium will be preferentially selected on risen sites previously occupied by sodium. Such an ion exchange mechanism could be presumed to account for the noted discrepancies in cation yields.

A major concern of the governmental unit of the Roanoke Valley has been the effect of municipal sewage treatment plant discharges on the rate of enrichment of Smith Mountain Lake. This concern has been prompted by pressure from regulatory agencies to adopt the regional planning concept for wastewater treatment and to initiate construction programs aimed at achieving higher quality effluents from municipal plants. Of particular interest has been the question of removal of plant nutrients from waste streams. A major thrust of this research was to develop a comparison of the relative magnitude of nutrient and organic yields from the various sources in the basin, in light of their ability to stimulate the growth of nuisance aquatic flora in the Smith Mountain Impoundment.

The inflow to Smith Mountain Lake was observed to contain concentrations of plant nutrients far in excess of the so-called "limiting" values in terms of producing algal blooms that have been reported in the literature and shown in Table XII. The concentration of total phosphate in the lake inflow of 5.60 mg/l as PO_4 far exceeds the accepted limiting value of 0.031 mg/l. The comparison of nitrogen levels was made on the basis of total nitrogen since both the ammonia and nitrate forms are

TABLE XII

Comparison of Concentrations Entering Impoundment to Accepted Limiting Concentrations

Parameter	Observed Concentration (mg/1)	Limiting Concentration (mg/1)	Reference
Total PO_4 as PO_4	5.60	0.031	(10)
Nitrate Nitrogen at N	0.20		
Total Kjehldal Nitrogen as N	2.01		
Total Nitrogen as N	2.21	0.20-0.30	(10) (11)
Total Organic Carbon	15.10		
Sodium	24.50	2.0	(7)
Potassium	4.01		
Calcium	46.20	0.30	(7)
Magnesium	17.45		

available for microbial use. The total nitrogen concentration at the headwaters of the impoundment was observed to be 2.21 mg/l as N, exceeding the limiting concentration range of 0.2-0.3 mg/l.

Data are not currently available on the levels of organic carbon required to allow bacterial respiration to proceed to a point at which the CO_2 produced will stimulate algal growth. This is a very complex synergistic relationship and is at best only partially understood at this time. The observed organic carbon concentration of 15.1 mg/l in the lake inflow is probably adequate to support considerable heterotrophic activity.

The only data found in the literature on the role of cations in limiting algal growth was reported by Eyster (7) for sodium and potassium. The reported growth limiting concentrations of 2.0 and 0.30mg/l for the respective cations are far exceeded by the prevailing levels in the Roanoke River at Niagra.

The data collected from direct sampling of wastewater discharge during the course of this study made it possible to evaluate the projected yields of nutrient materials to the impoundment if the wastewater sources were eliminated. A comparison of projected inflow nutrient concentrations at the headwaters of the impoundment in the absence of wastewater discharges to the accepted limiting concentrations as generally reported in the literature are presented in Table XIII. Although it is recognized that organic carbon may be a limiting constituent in algal productivity, it has not been included in Table XIII. This is because no relationship exists for relating productivity protential to organic carbon. Many organic compounds are very resistant to biological degradation and are not suitable substrates for bacterial growth even though they contribute to the observed carbon level in the TOC analysis.

The calculated total phosphate concentration predicted to enter the impoundment in the absence of wastewater contributions is 2.06 mg/1 as shown in Table XIII. This exceeds the published limiting value by a factor of 66.4, which would seem to indicate that phosphorus contributions from wastewater discharges in the Upper Roanoke River Basin are not significant in the stimulation of algal production in Smith Mountain Lake.

Likewise, the predicted nitrogen concentration of 0.64 mg/1 exceeds the published limiting values by a factor ranging from 2.1 to 3.2. Although the nitrogen levels approach limiting conditions much more closely than phosphorus, it is not expected that a nitrogen-limiting condition could be attained due to the capability of blue-green algae to fix atmospheric N to satisfy their metabolic requirements.

The two cations, sodium and calcium, for which data on limiting concentrations is available, would not approach growth limiting levels if the wastewater yields of these elements were eliminated. The predicted concentrations for sodium and calcium exceed the published limiting values by factors of 2.7 and 151, respectively. Furthermore, there is no reason to expect that demineralization processes will be required for wastewater treatment.

This study was conducted during low flow conditions in the summer of 1971. There is a potential for increase in yields of nutrient materials from land drainage sources during periods of higher flow.

TABLE XIII

Comparison of Limiting Concentrations to Concentrations Calculated to Enter Impoundment if Tertiary Treatment of all Wastewater Discharges is Required

Parameter	Calculated Concentrations	Limiting Concentration	Calculated/Limiting
Total PO_4 as PO_4	2.06	0.031	66.4
Nitrate Nitrogen as N	0.44	-----	----
Total Kjehldal Nitrogen as N	0.20	-----	----
Total Nitrogen as N	0.64	0.20-0.30	2.1-3.2
Sodium	5.49	2.0	2.7
Potassium	2.97	---	---
Calcium	45.3	0.30	151
Magnesium	18.37	----	---

Data available from the literature (12) record increases by a factor of 1,000 in daily phosphorus yields and 200 in daily nitrogen yields from land drainage between summer and spring flow conditions. As previously noted, Figure 4 presents a qualitative relationship between runoff nutrient yields and season. Figure 6 shows recorded flows at the four gauging stations on the main stem of the Roanoke River for the 1970 water year. Judging from the recorded correlation between river discharge and nutrient yield in Figure 6, it would not be unreasonable to expect land drainage yields of nutrients above Smith Mountain Lake to increase dramatically above the levels observed in this study during the spring and fall seasons. This would even further decrease the relative importance of nutrient yields from wastewater sources.

Additional studies are needed to more adequately define the relative importance of the various parameters in the enrichment of Smith Mountain Lake. The upgrading of wastewater treatment will be a significant step toward improving water quality in both the river and the lake. However, the results of this study indicate that no dramatic improvements in water quality at Smith Mountain Lake are to be expected because of the other sources of organic carbon, nitrogen and phosphorus in the tributary watershed.

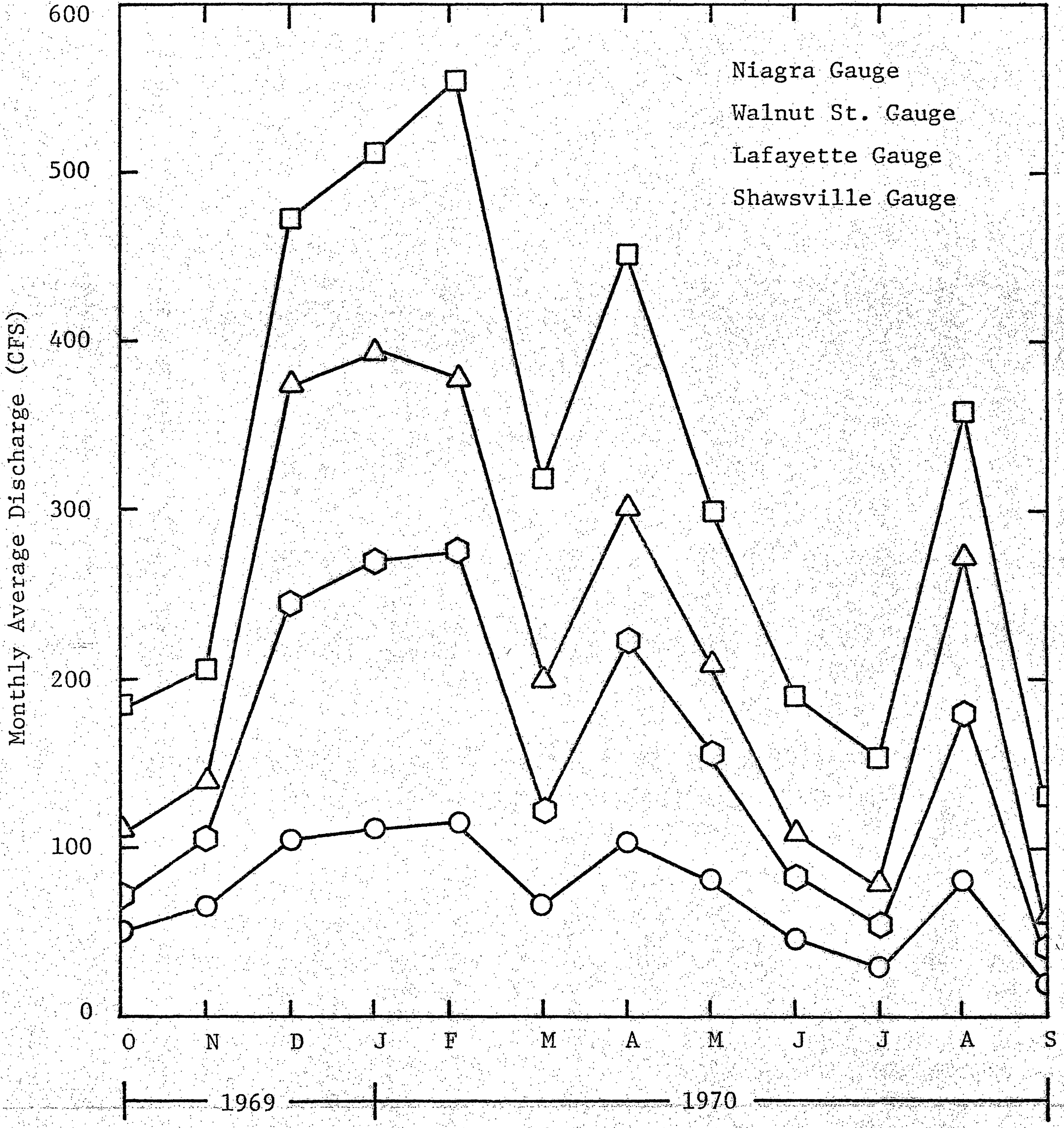

Figure 6: Monthly Average Discharges at Selected Gauges on the Main Stem of the Roanoke River.

V. CONCLUSIONS

1. Organic and nutrient yields in the Upper Roanoke River Basin are sufficiently high to support levels of autotrophic production in Smith Mountain Lake that would prove deleterious to the continued beneficial recreation use of the impoundment.

2. Wastewater discharges contribute 54 percent, 64 percent, and 73 percent, respectively of the organic carbon, total phosphate, and total nitrogen entering the surface waters of the upper basin.

3. Urban drainage contributes 19 percent, 29 percent, and 12 percent of the organic carbon, total phosphate, and total nitrogen, respectively, entering the surface waters of the upper basin.

4. Rural drainage contributes, respectively, 27 percent, 7 percent, and 15 percent of the organic carbon, total phosphate, and total nitrogen entering the surface waters of the upper basin.

5. Diversion of all wastewater discharges from the basin would not lower influent concentrations to the Smith Mountain Impoundment to levels that would approach limiting conditions for any nutrients for which the growth-limiting levels are presently known.

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APPENDIX A

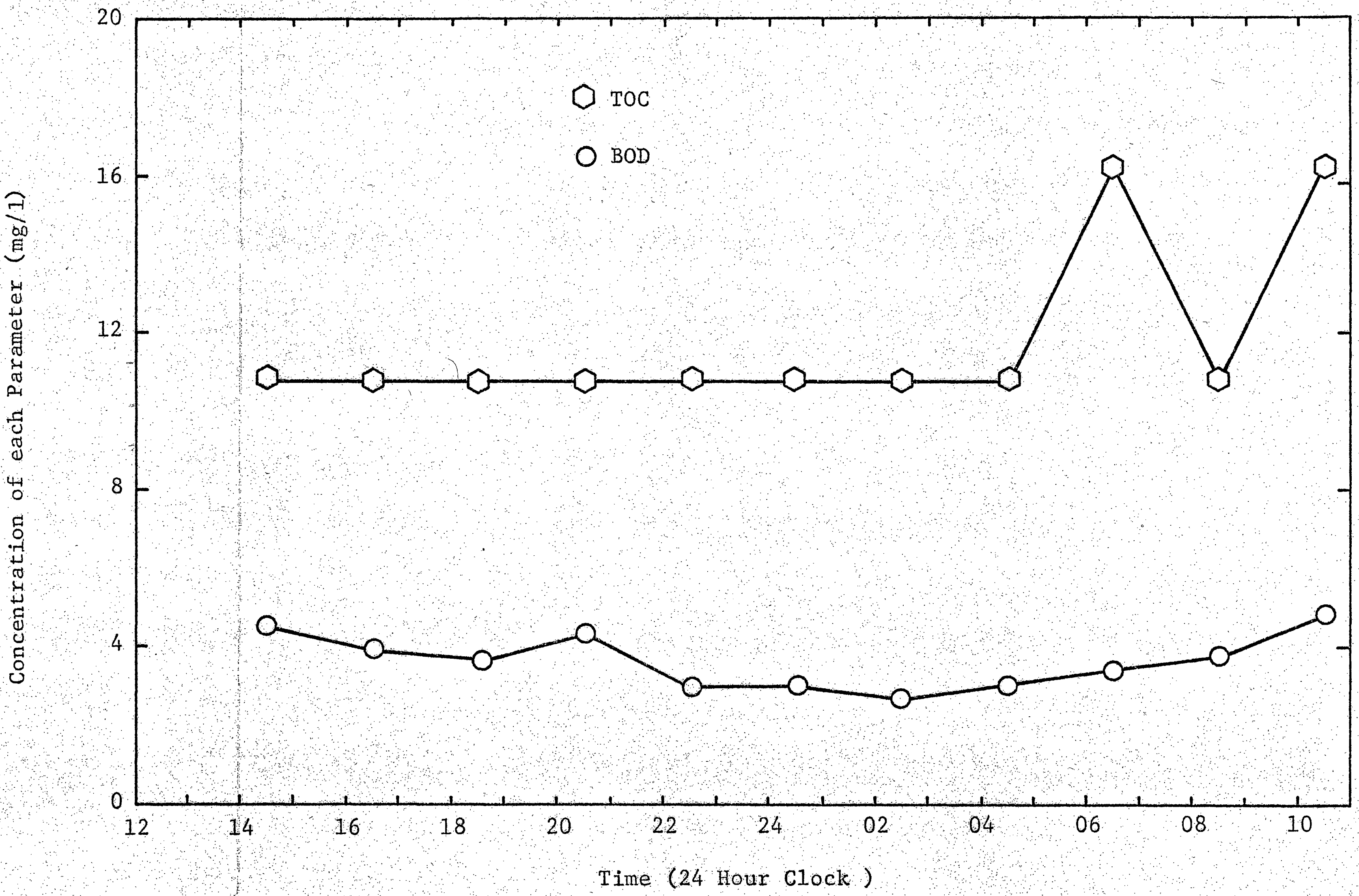


Figure 7: Diurnal Fluctuations in Organic Loadings at Station 1 on 28 and 29 June, 1971

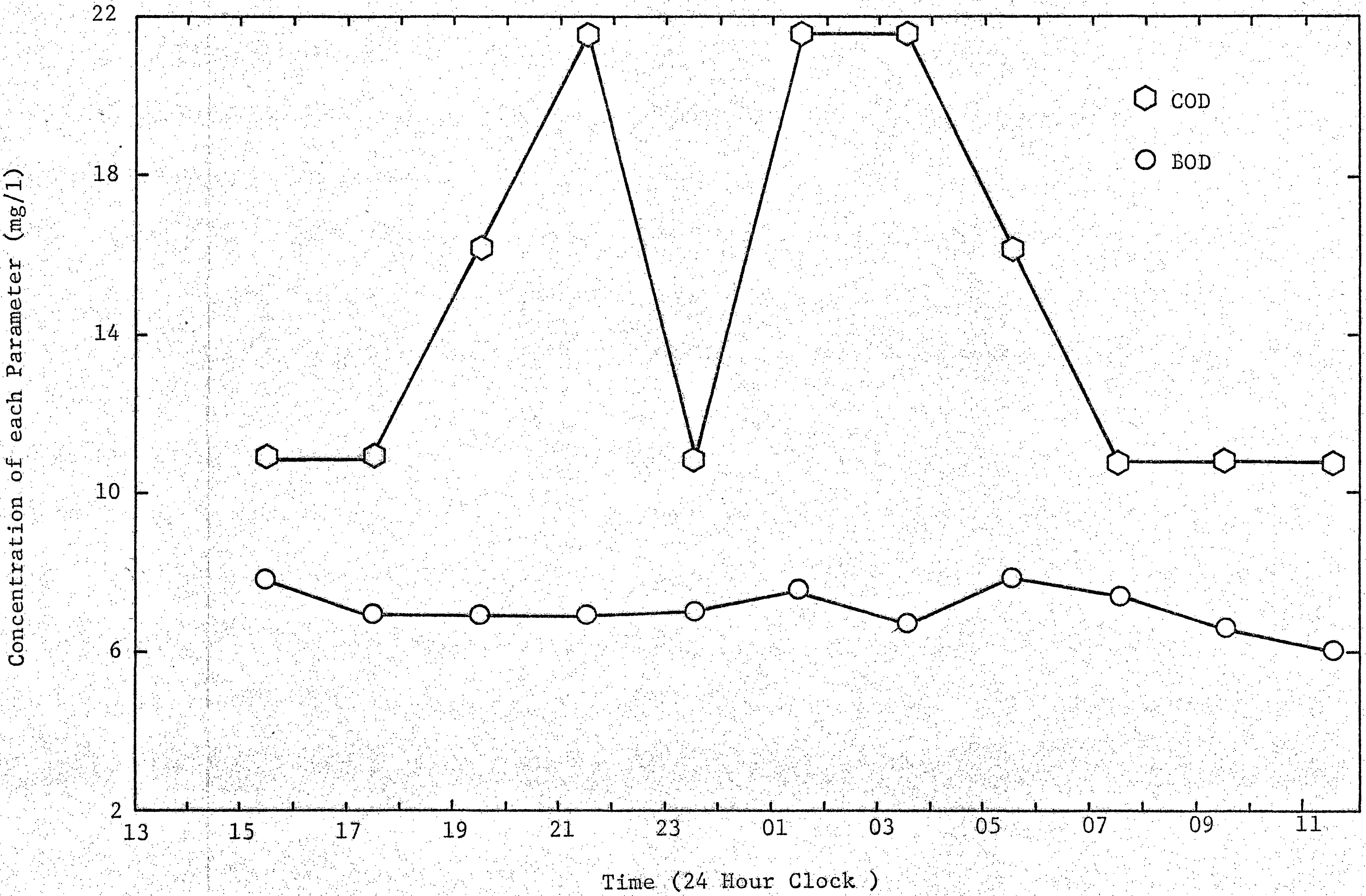


Figure 8: Diurnal Fluctuations in Organic Loadings at Station 2 on 28 and 29 June, 197]

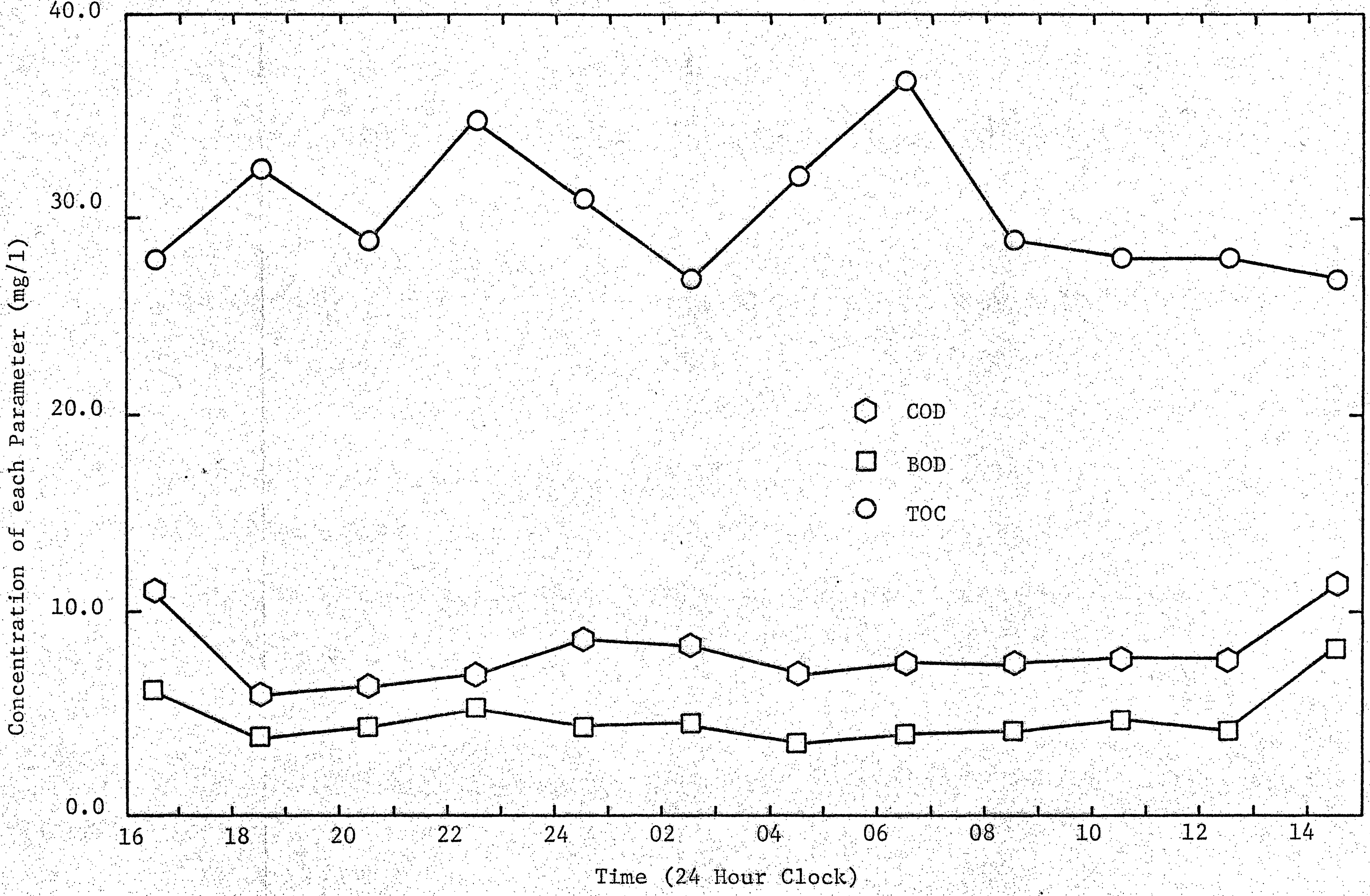


Figure 9: Diurnal Fluctuations in Organic Loadings at Station 3 on 8 and 9 July, 1971

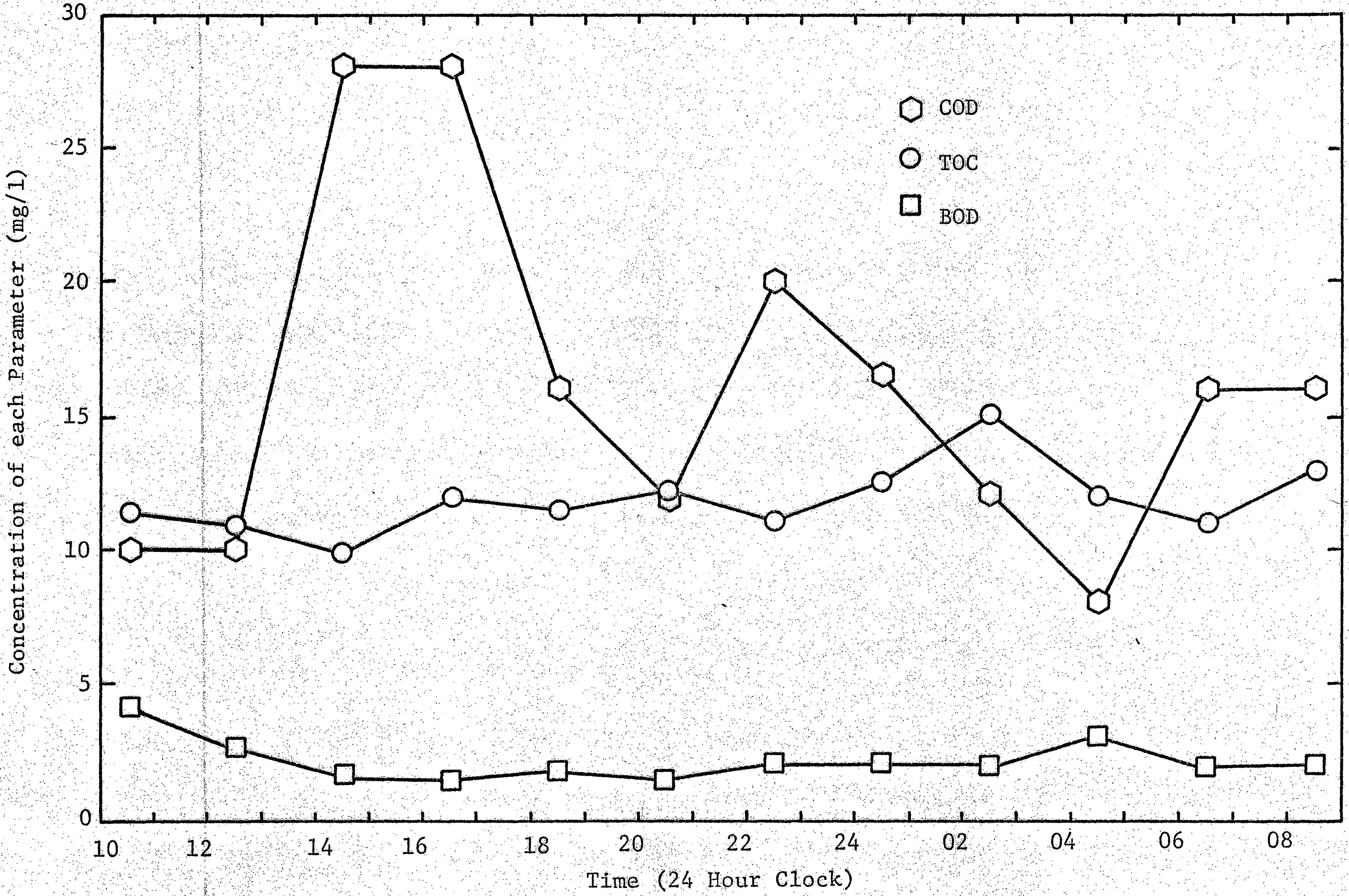


Figure 10: Diurnal Fluctuations in Organic Loadings at Station 4 on 27 and 28 July, 1971

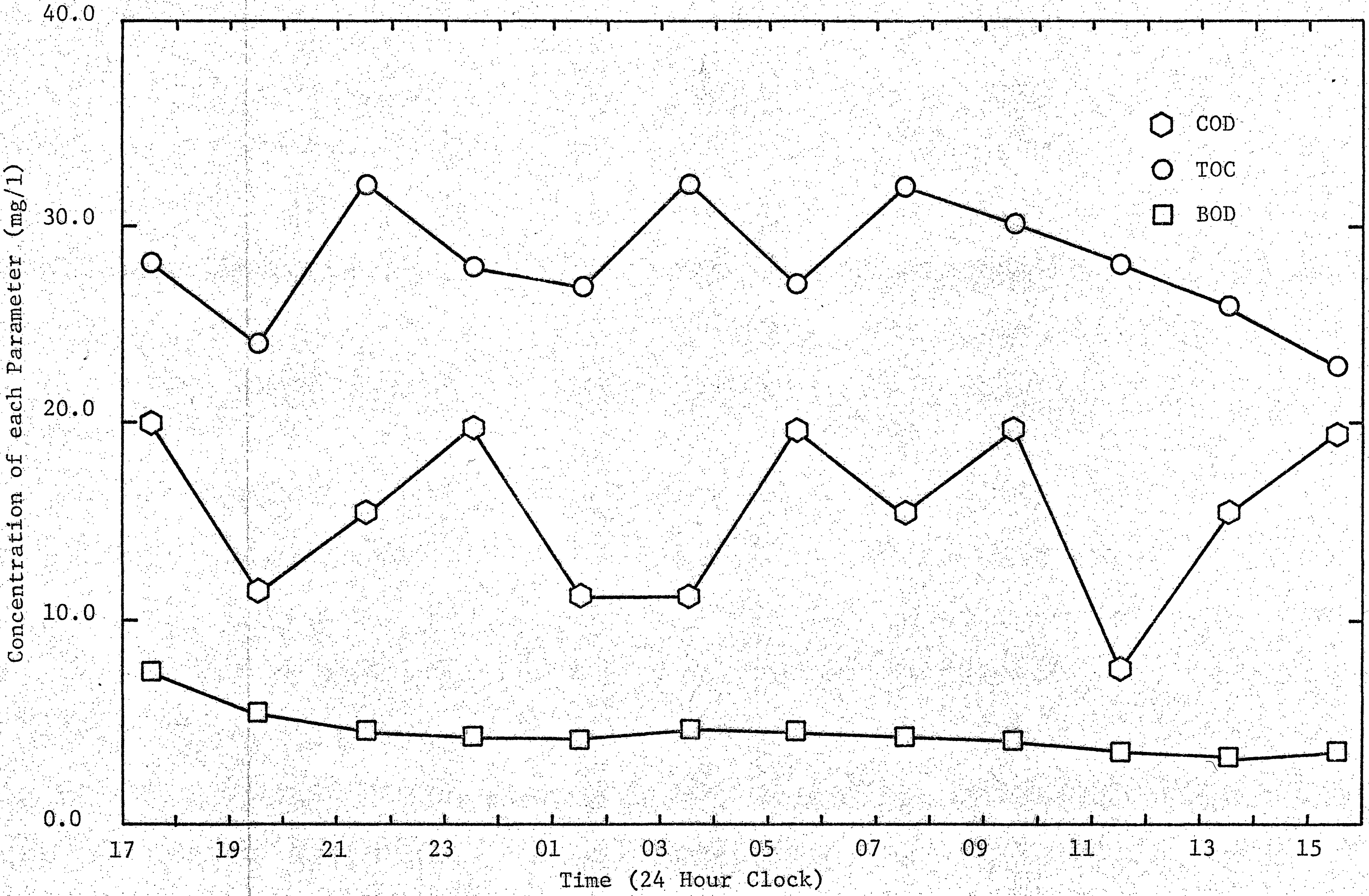


Figure 11: Diurnal Fluctuations in Organic Loadings at Station 5 on 8 and 9 July, 1971

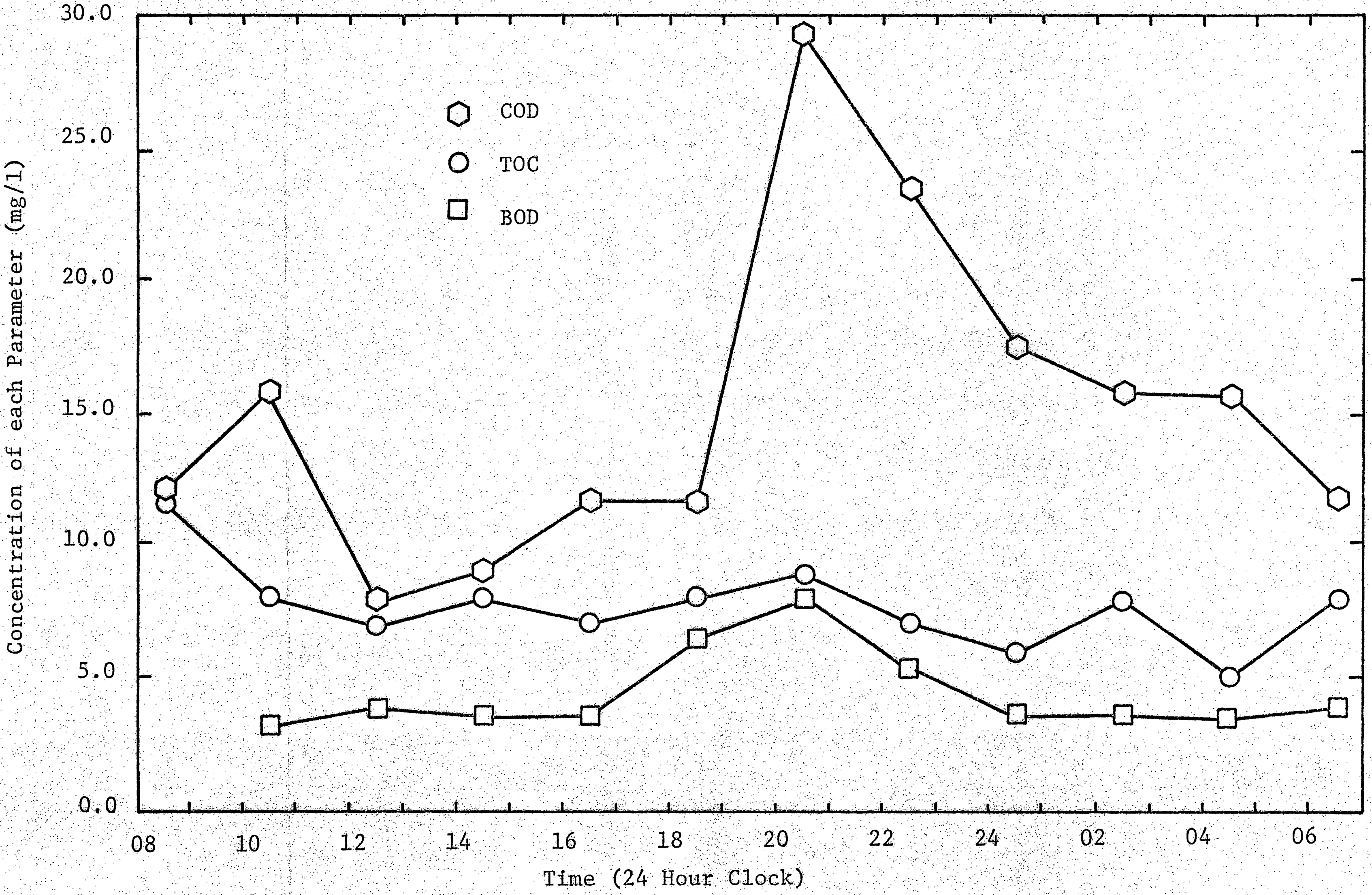


Figure 12: Diurnal Fluctuations in Organic Loadings at Station 6 on 16 and 17 July, 1971

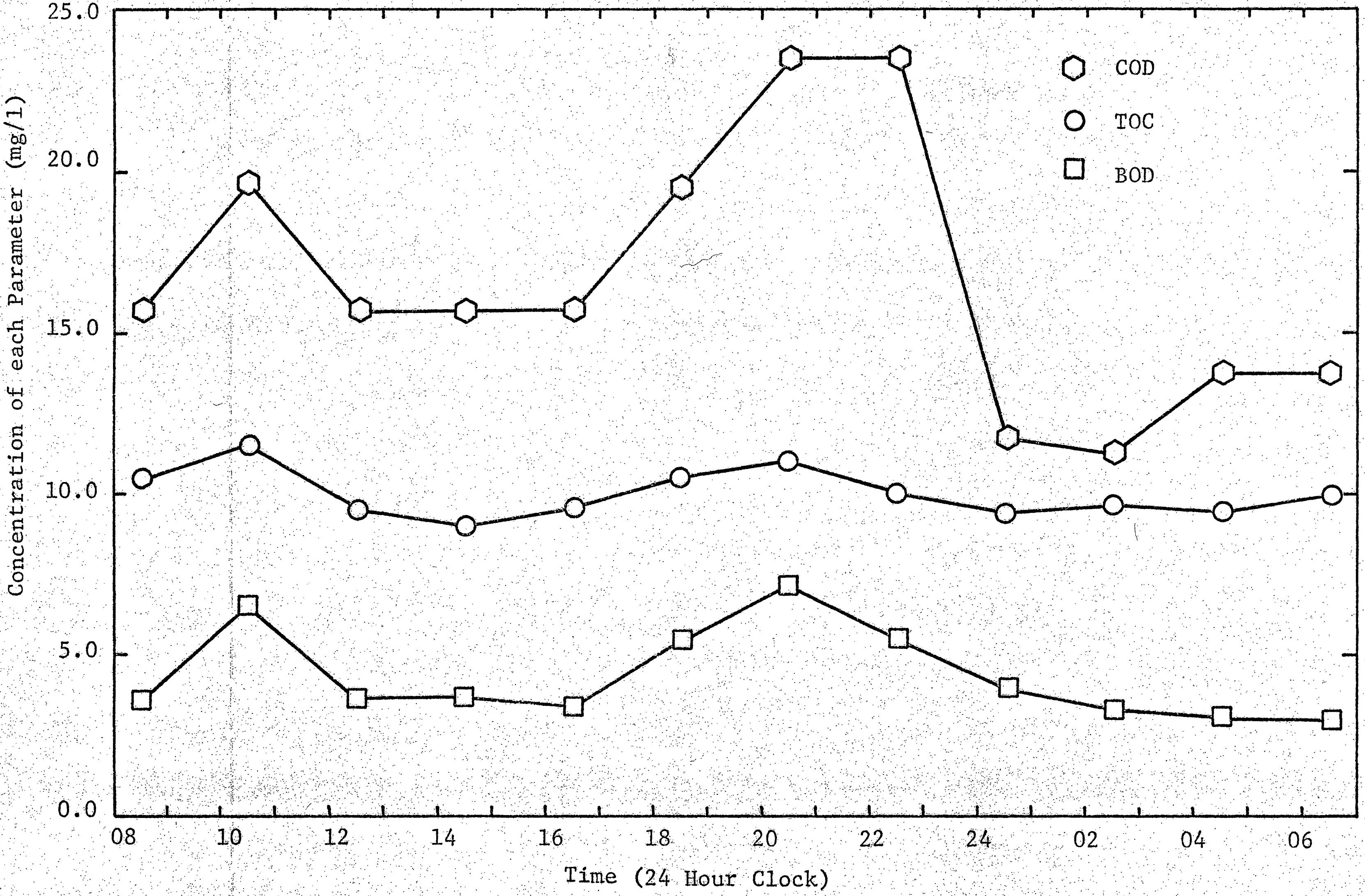


Figure 13: Diurnal Fluctuations in Organic Loadings at Station 7 on 16 and 17 July, 1971

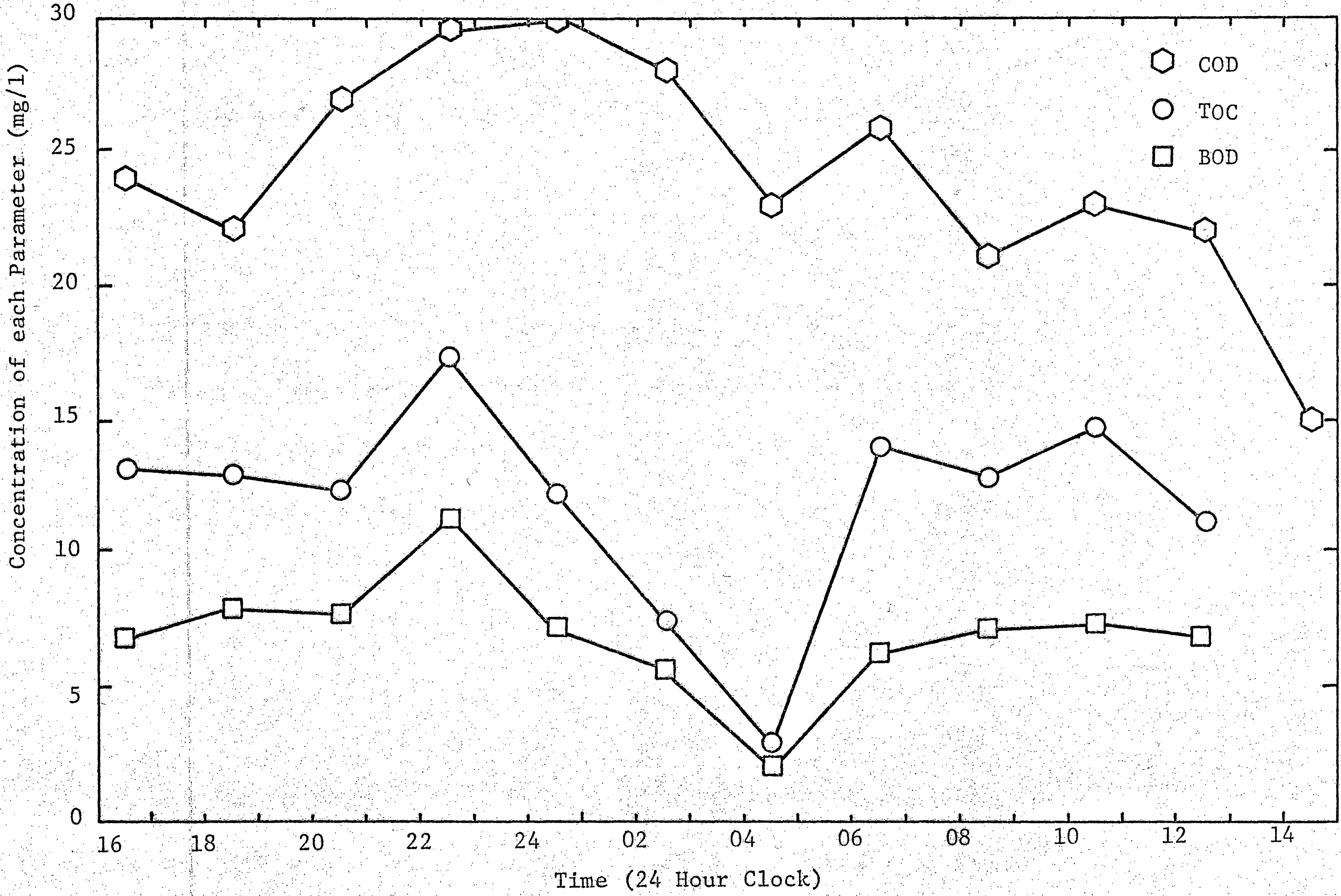


Figure 14: Diurnal Fluctuations in Organic Loadings at Station 8 on 6 and 7 July, 1971

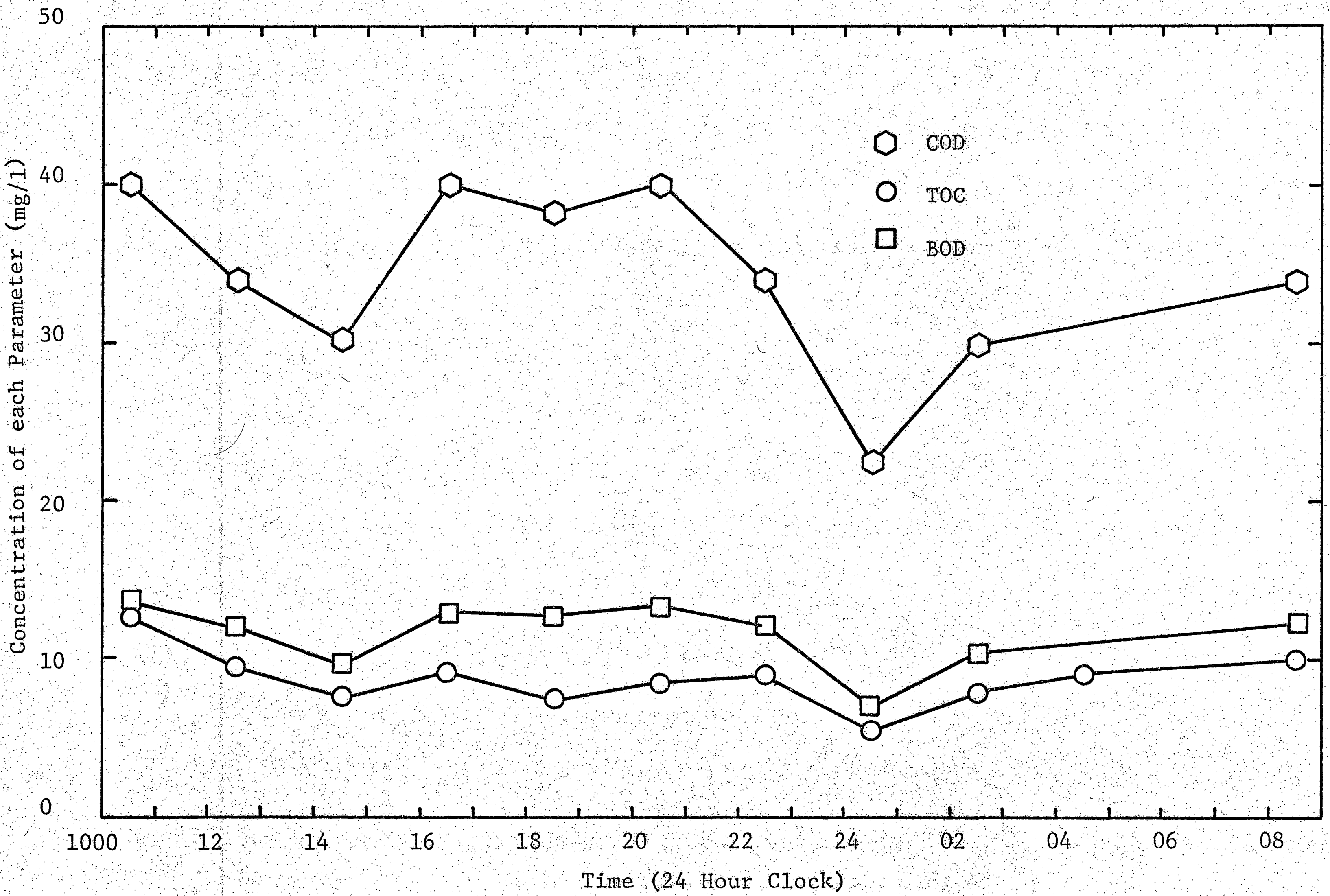


Figure 15: Diurnal Fluctuations in Organic Loadings at Station 9 on 19 and 20 June, 1971

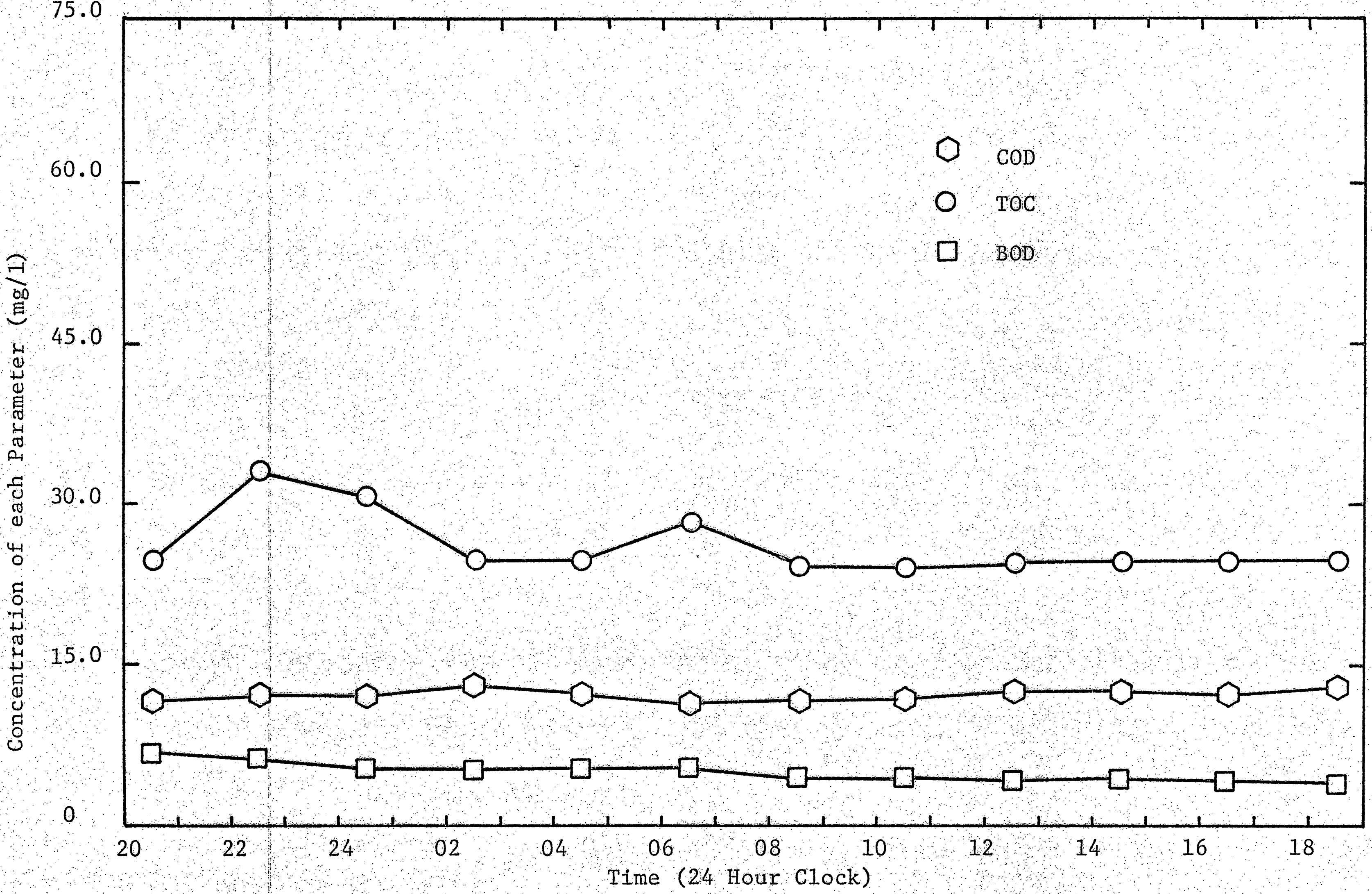


Figure 16: Diurnal Fluctuations in Organic Loadings at Station 9 on 21 and 22 June, 1971

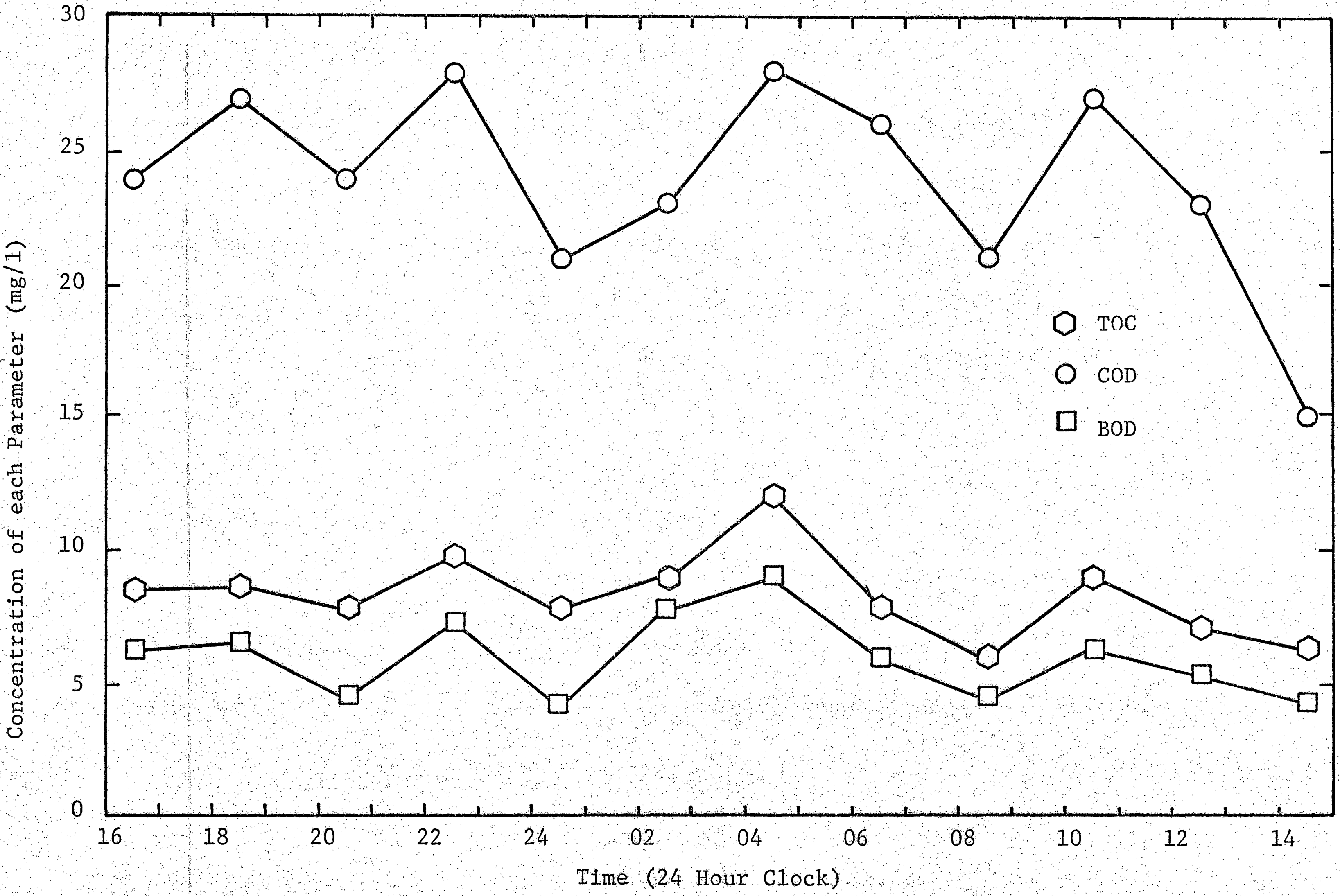


Figure 17: Diurnal Fluctuations in Organic Loadings at Station 9 on 6 and 7 July, 1971

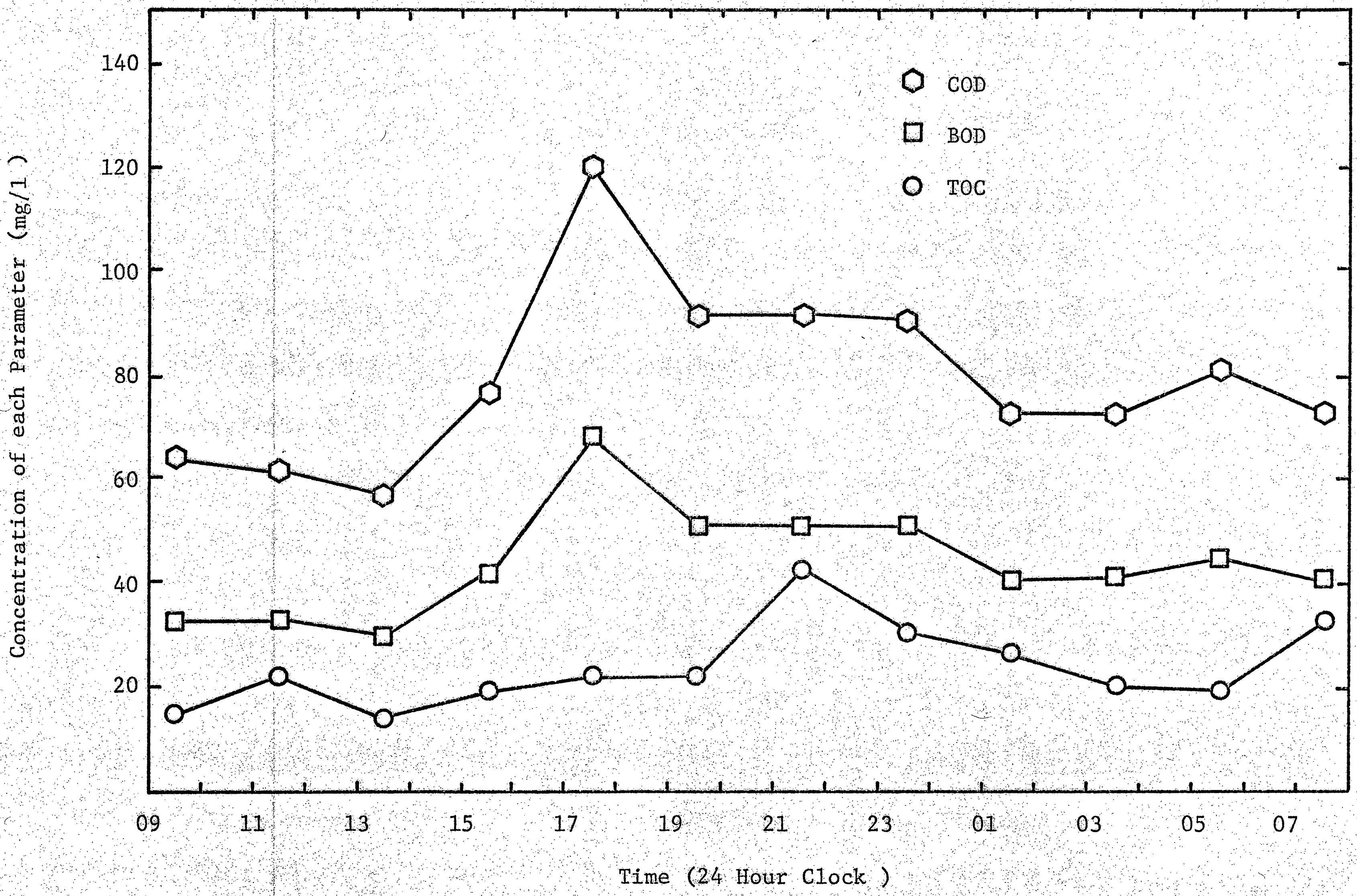


Figure 18: Diurnal Fluctuations in Organic Loadings at Station 10 on 19 and 20 June, 1971

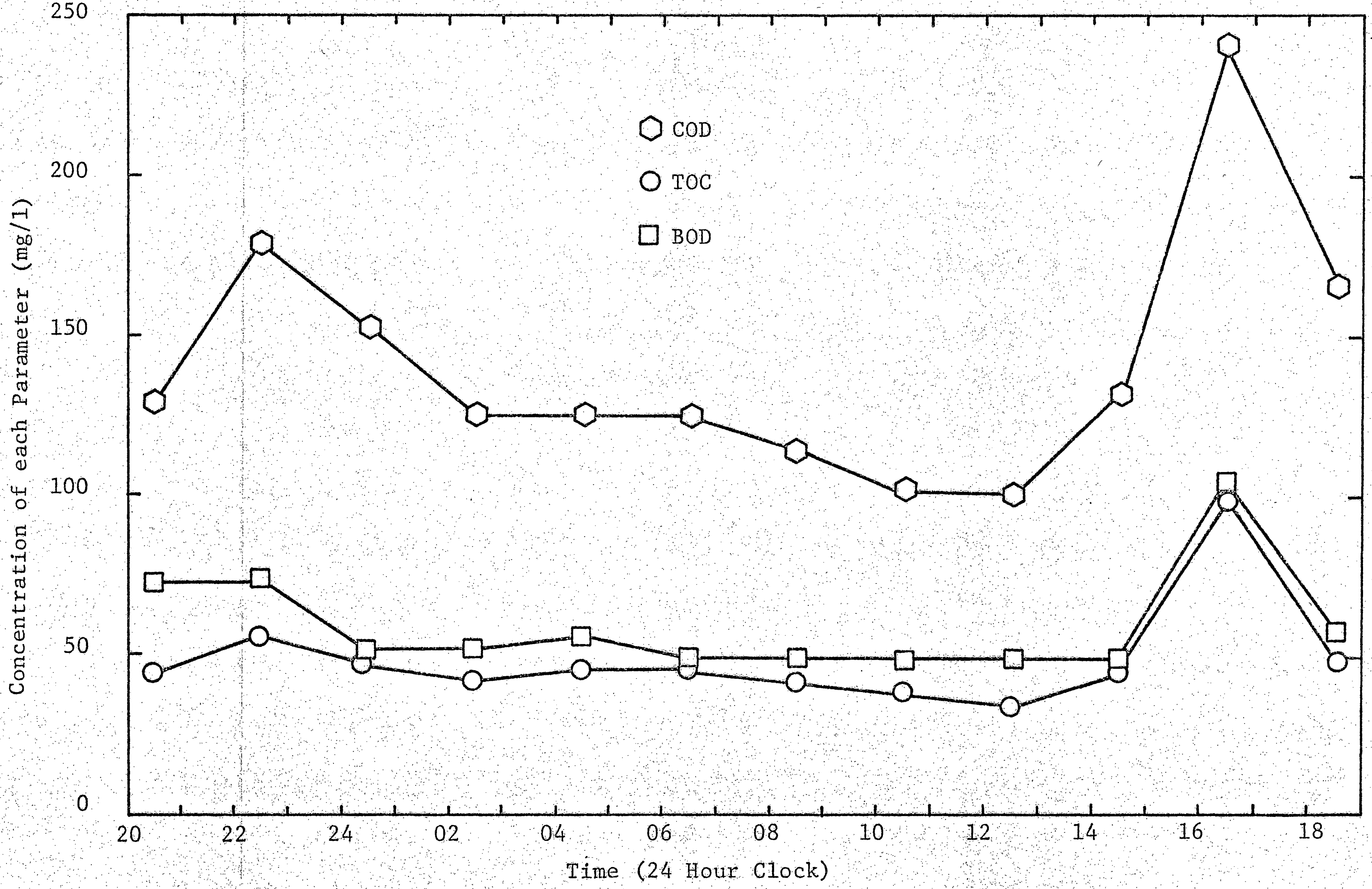


Figure 19: Diurnal Fluctuations in Organic Loadings at Station 10 on 21 and 22 July, 1971

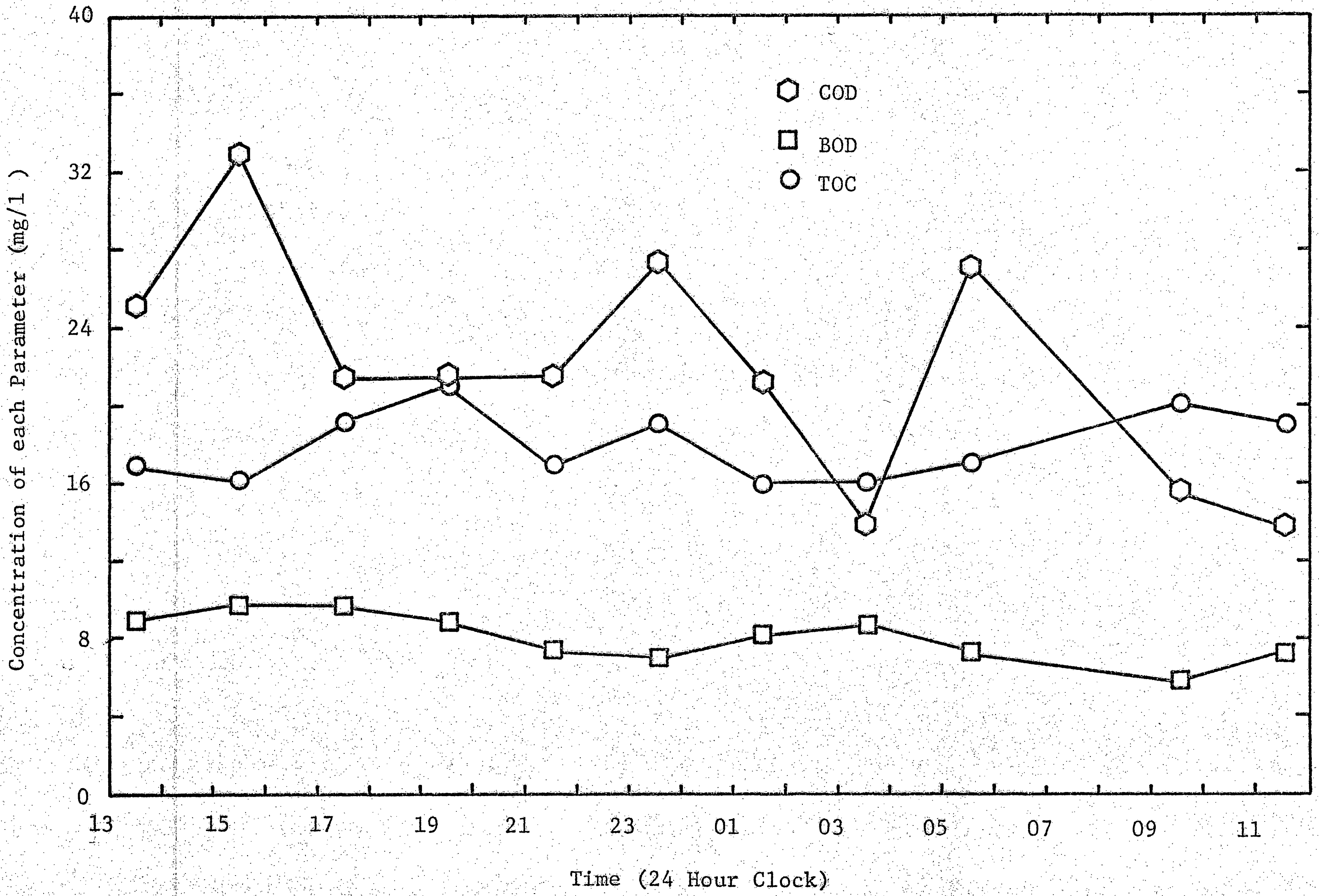


Figure 20: Diurnal Fluctuations in Organic Loadings at Station 11 on 29 and 30 June, 1971

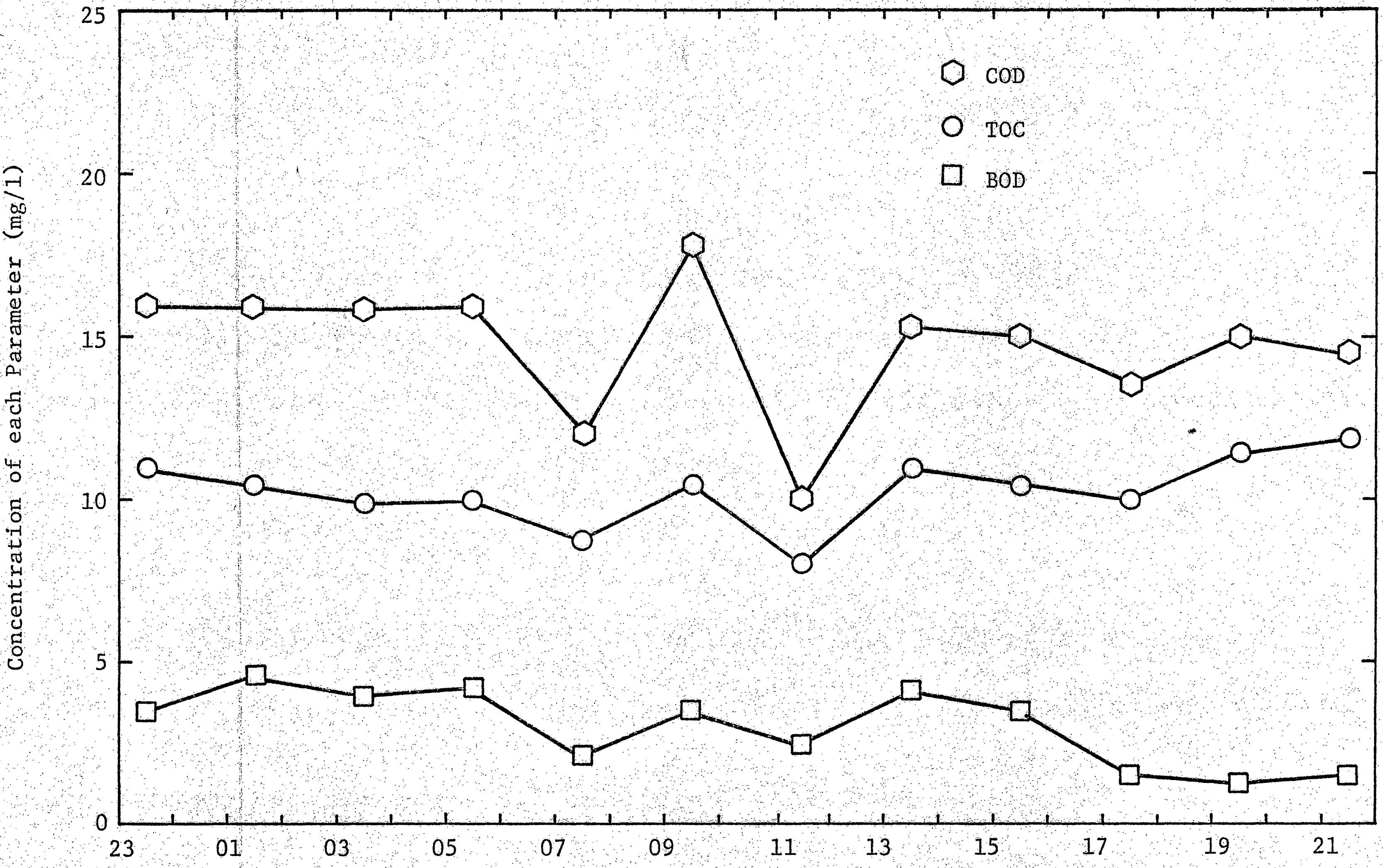


Figure:21: Diurnal Fluctuations in Organic Loadings at Station 12 on 22 and 23 July, 1971

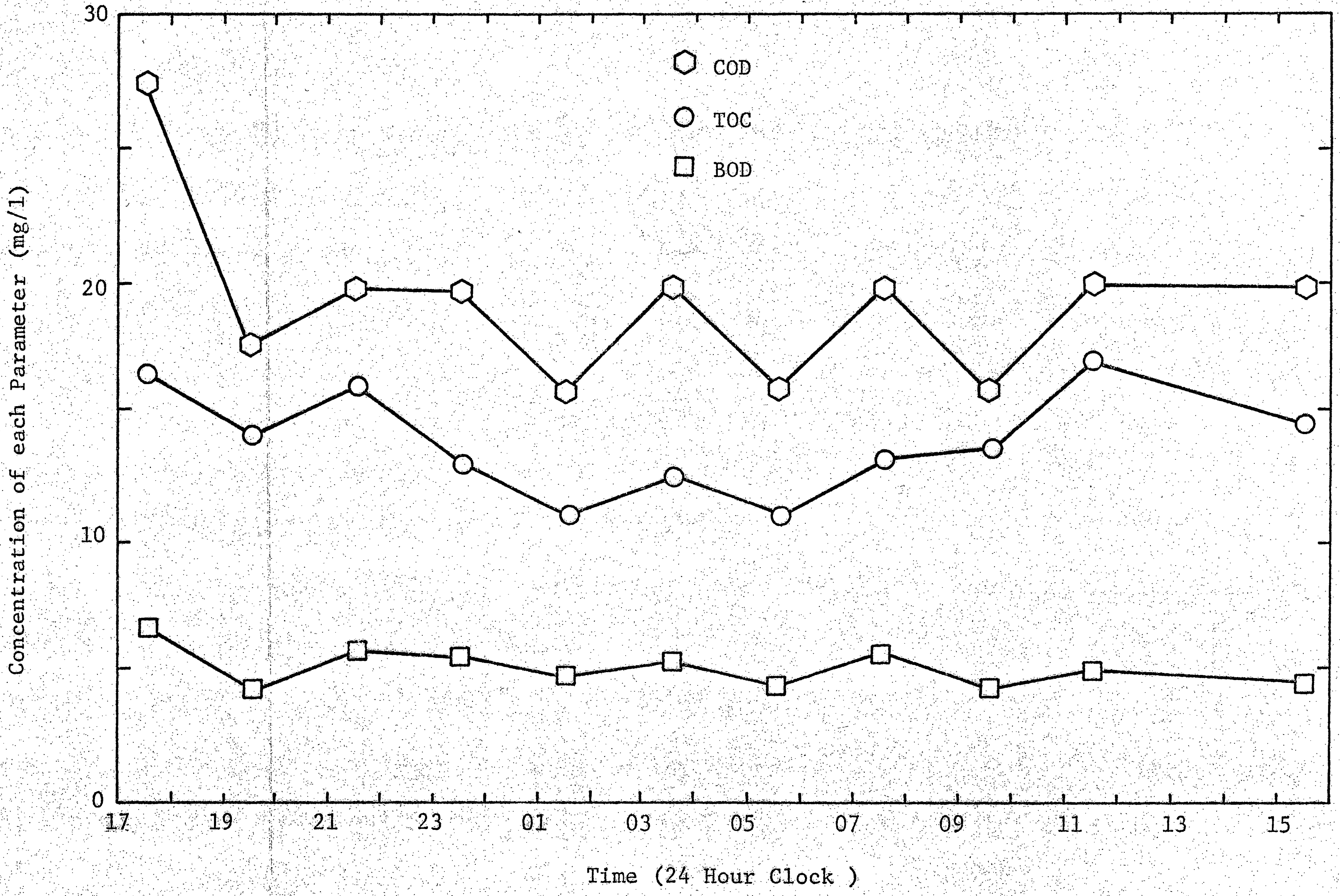


Figure 22: Diurnal Fluctuations in Organic Loadings at Station 13 on 15 and 16 July, 1971

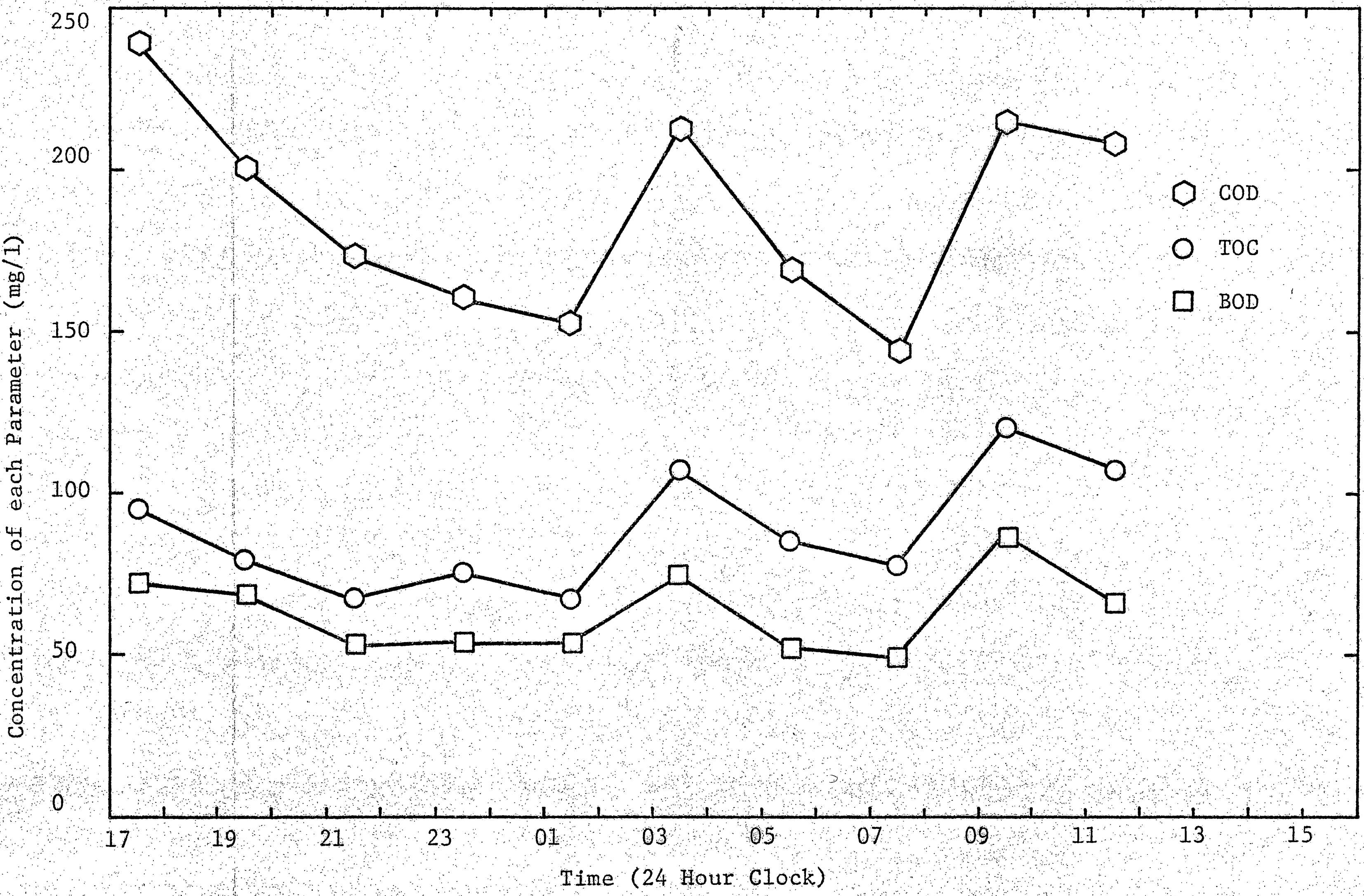


Figure 23: Diurnal Fluctuations in Organic Loadings at Station 14 on 15 and 16 July 1971

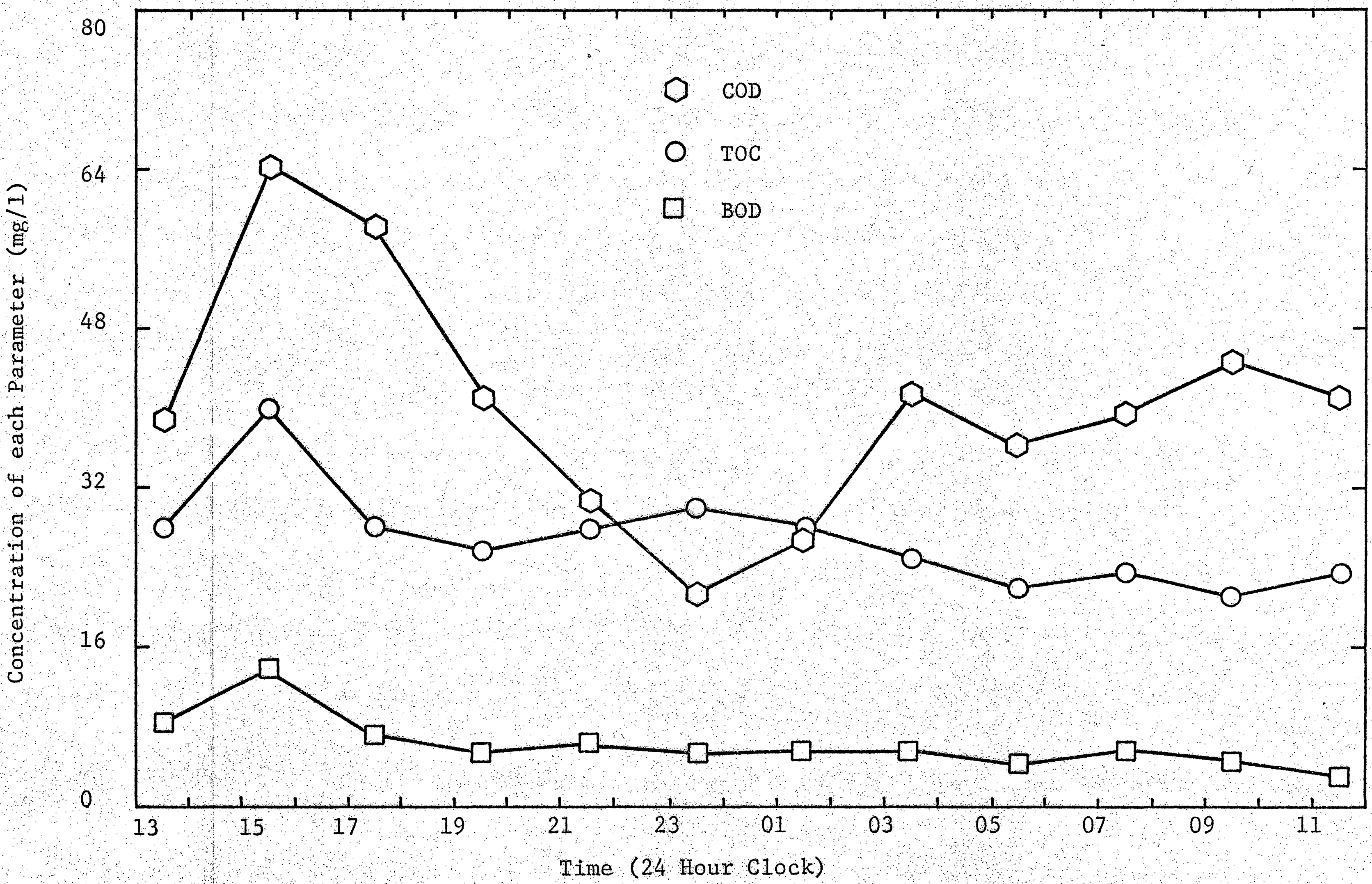


Figure 24: Diurnal Fluctuations in Organic Loadings at Station 15 on 29 and 30 June 1971

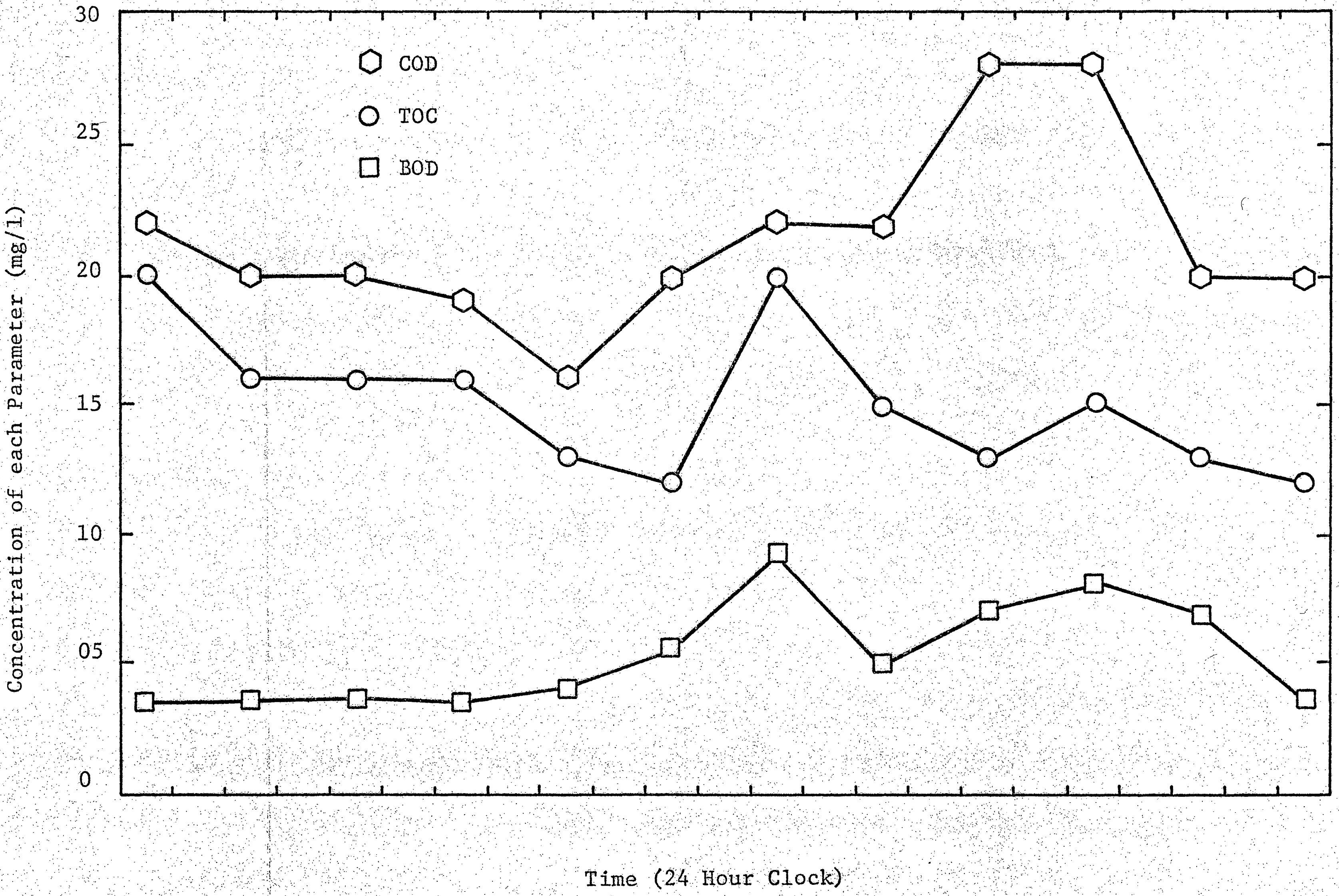


Figure 25: Diurnal Fluctuations in Organic Loadings at Station 15 on 22 and 23 July 1971

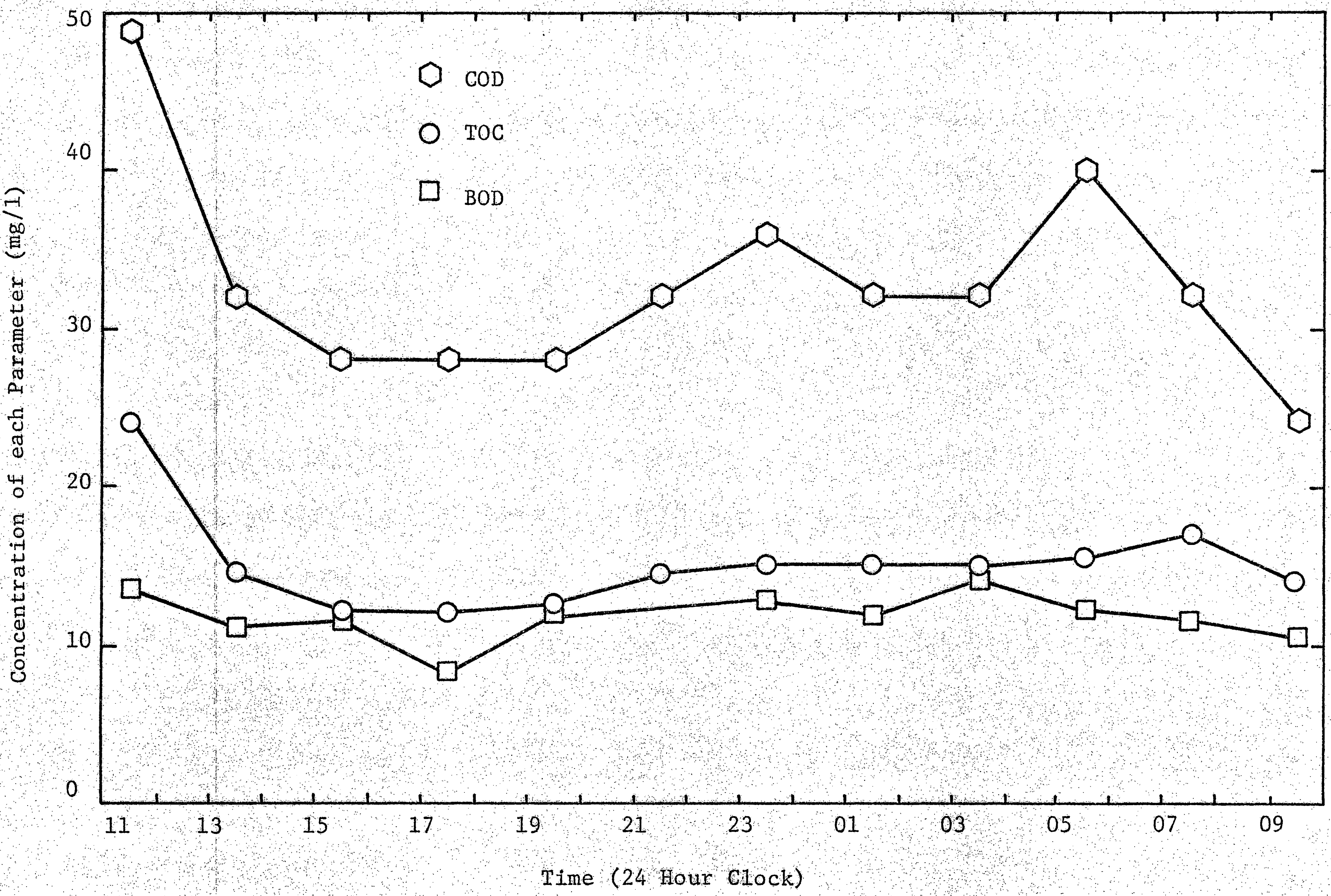


Figure 26: Diurnal Fluctuations in Organic Loadings at Station 16 on 29 and 30 July 1971

APPENDIX B

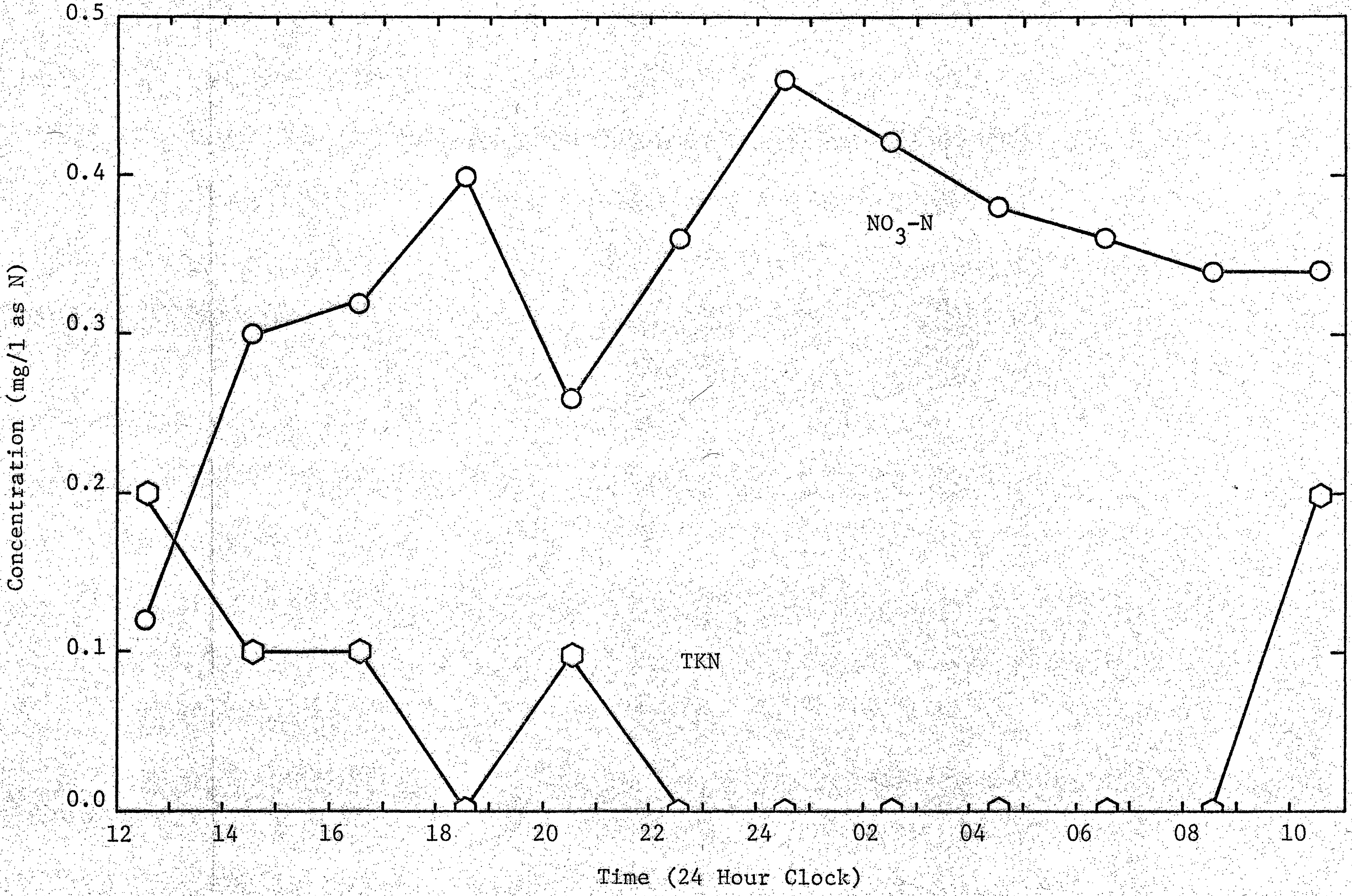


Figure 27: Diurnal Fluctuations in Nitrogen Loadings at Station 1 on 28 and 29 June, 1971

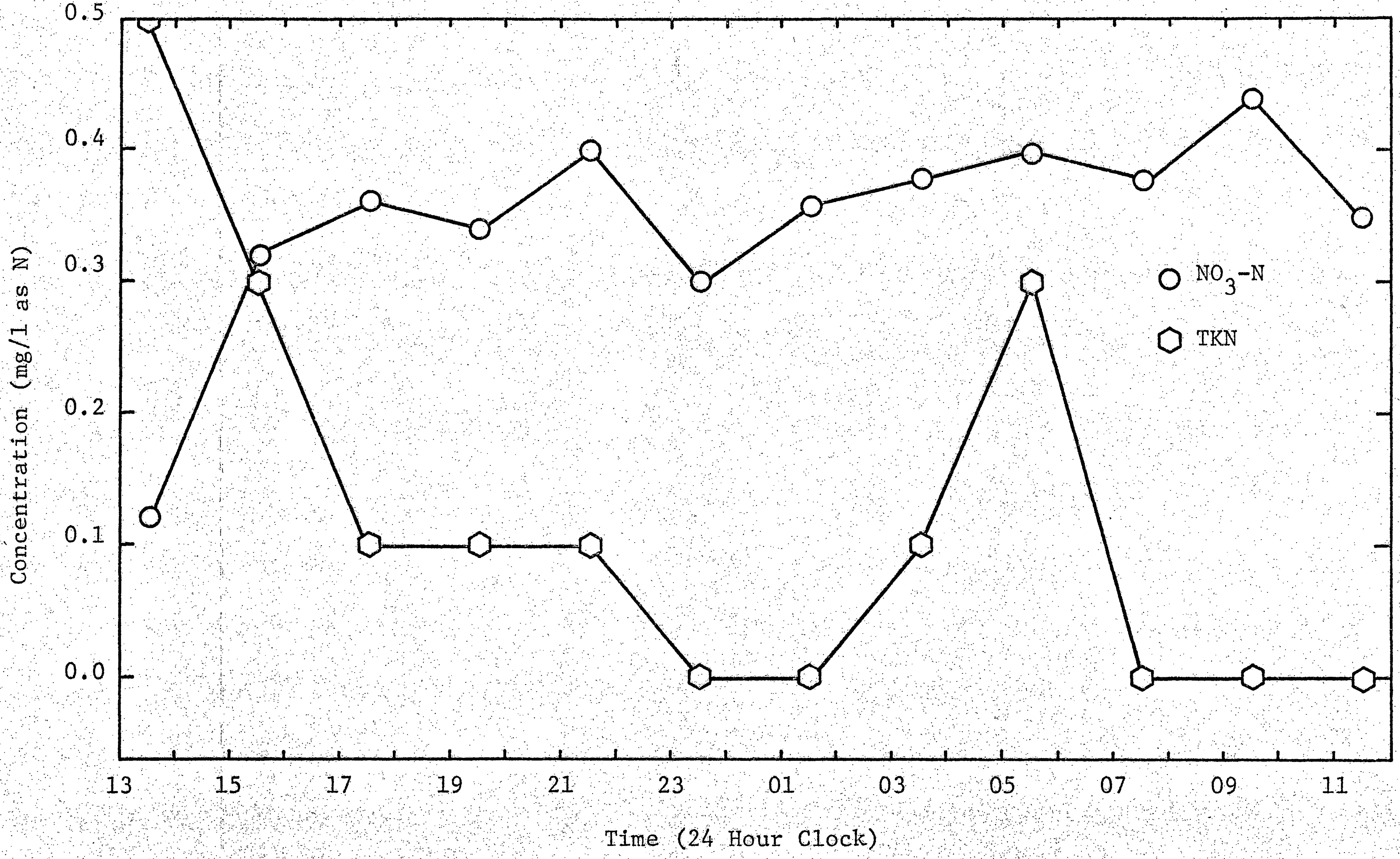


Figure 28: Diurnal Fluctuations in Nitrogen Loadings at Station 2 on 28 and 29 June, 1971

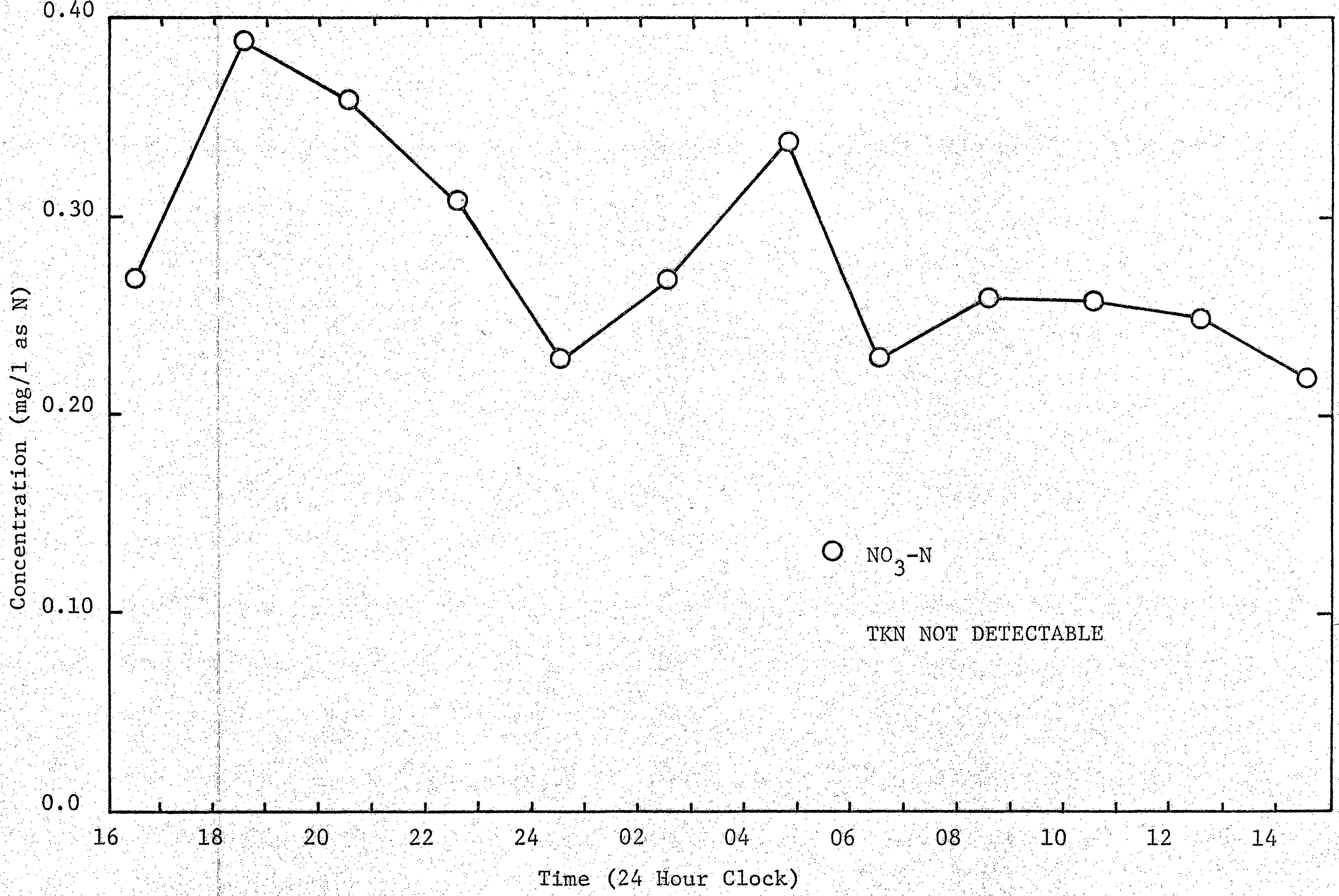


Figure 29: Diurnal Fluctuations in Nitrogen Loadings at Station 3 on 8 and 9 July, 1971

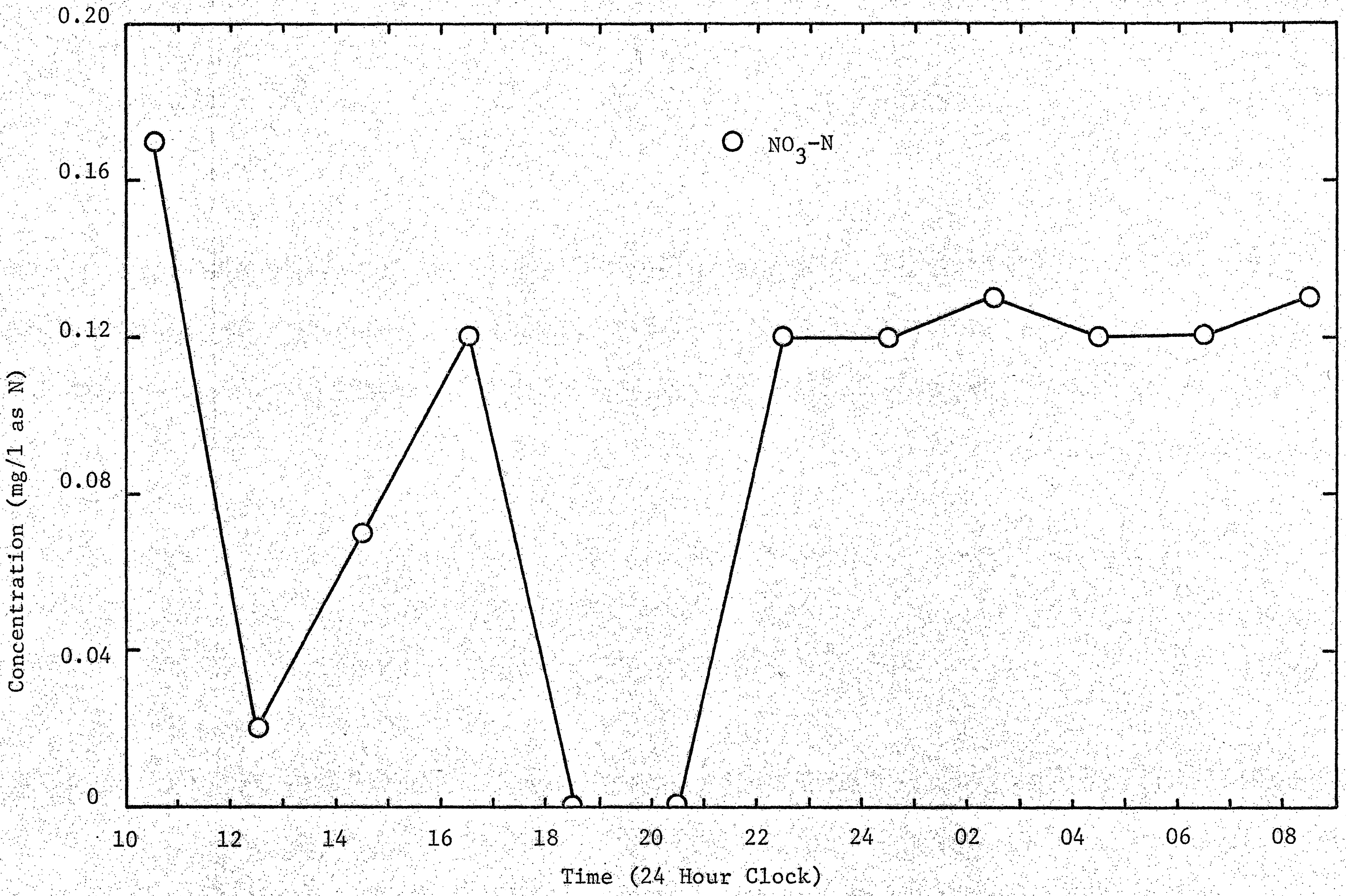


Figure 30: Diurnal Fluctuations in Nitrogen Loadings at Station 4 on 27 and 28 July, 1971

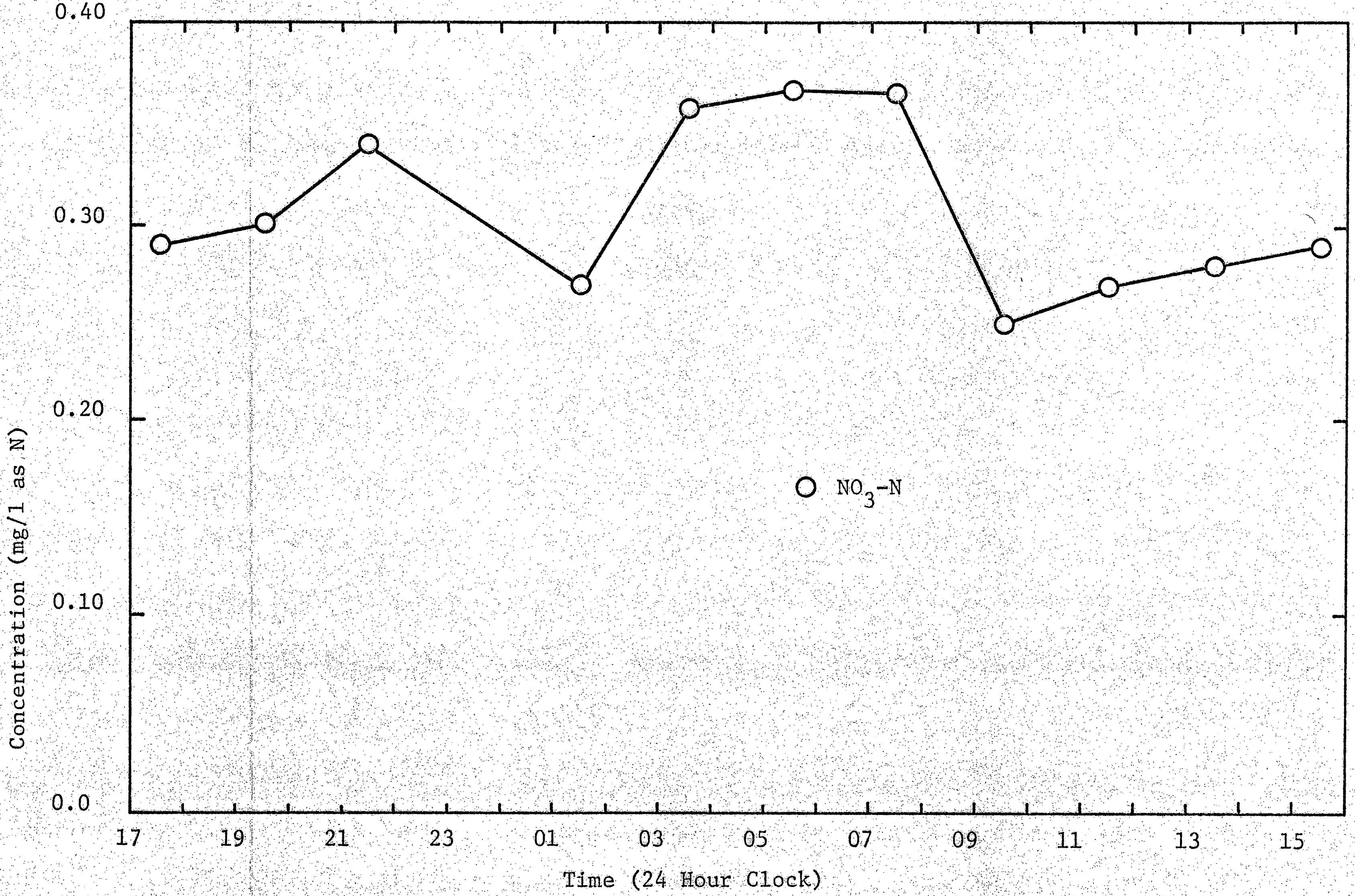


Figure 31: Diurnal Fluctuations in Nitrogen Loadings at Station 5 on 8 and 9 July, 1971

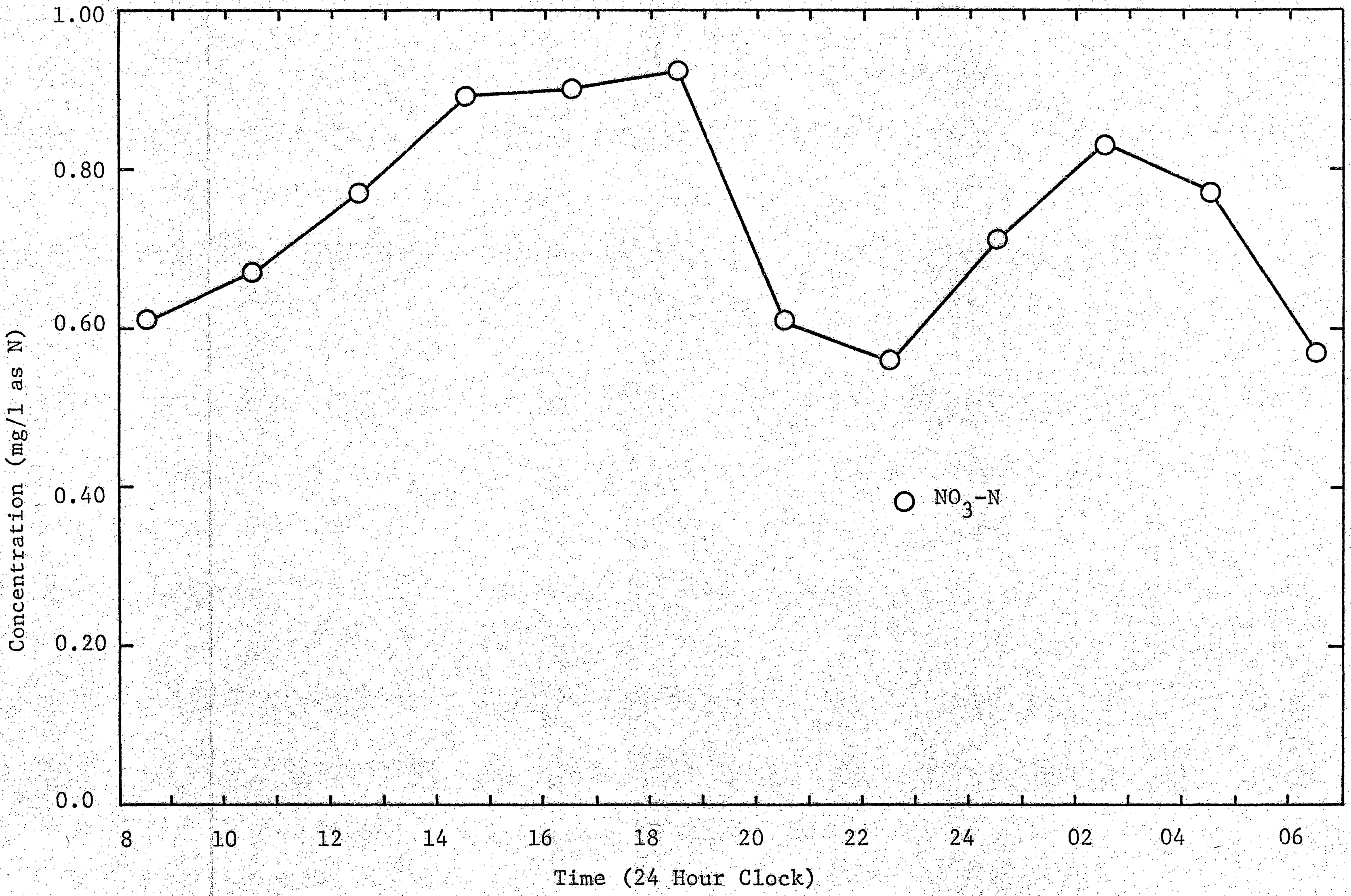


Figure 32: Diurnal Fluctuations in Nitrogen Loadings at Station 6 on 16 and 17 July, 1971

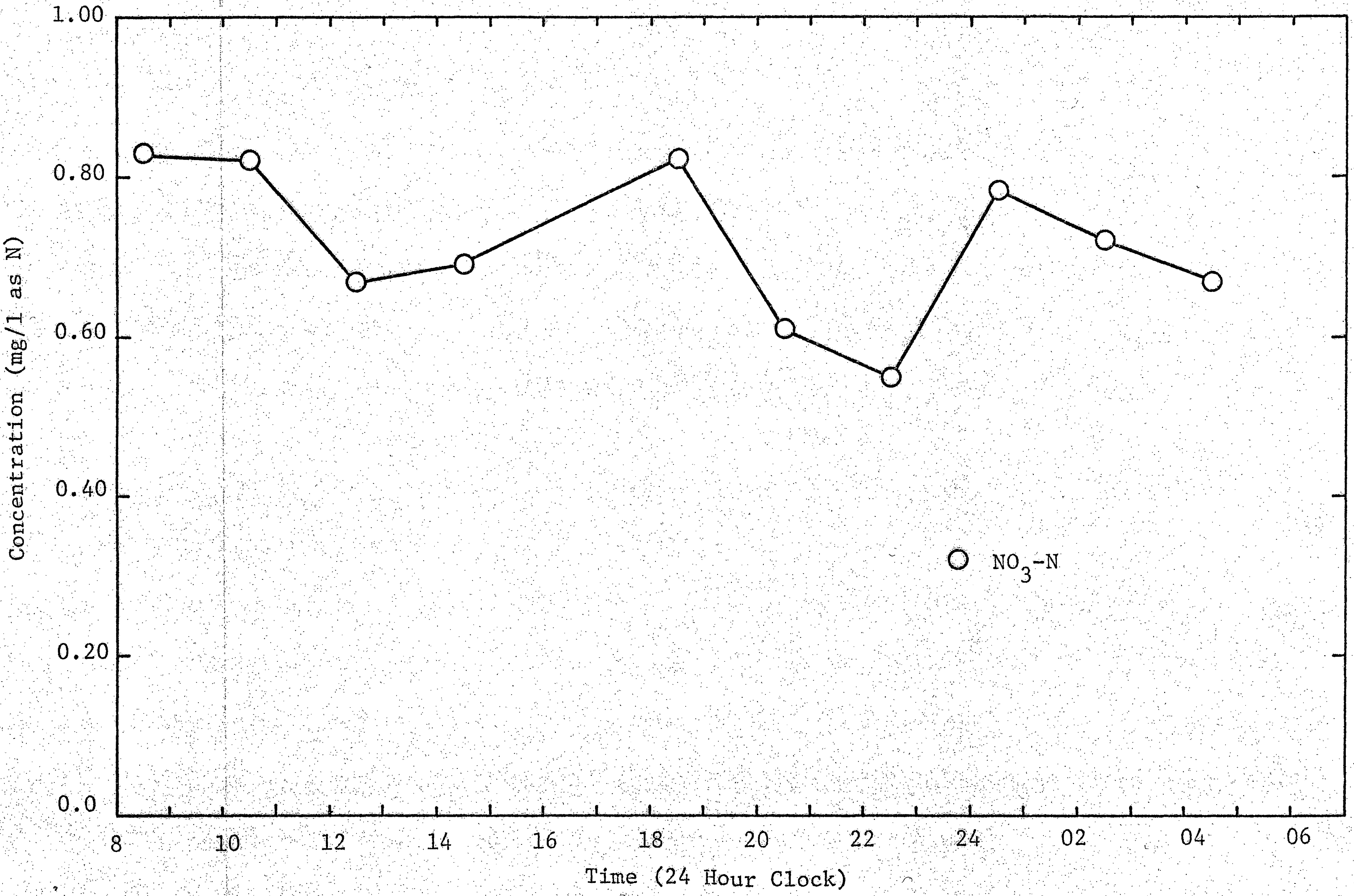


Figure 33: Diurnal Fluctuations in Nitrogen Loadings at Station 7 on 16 and 17 July, 1971

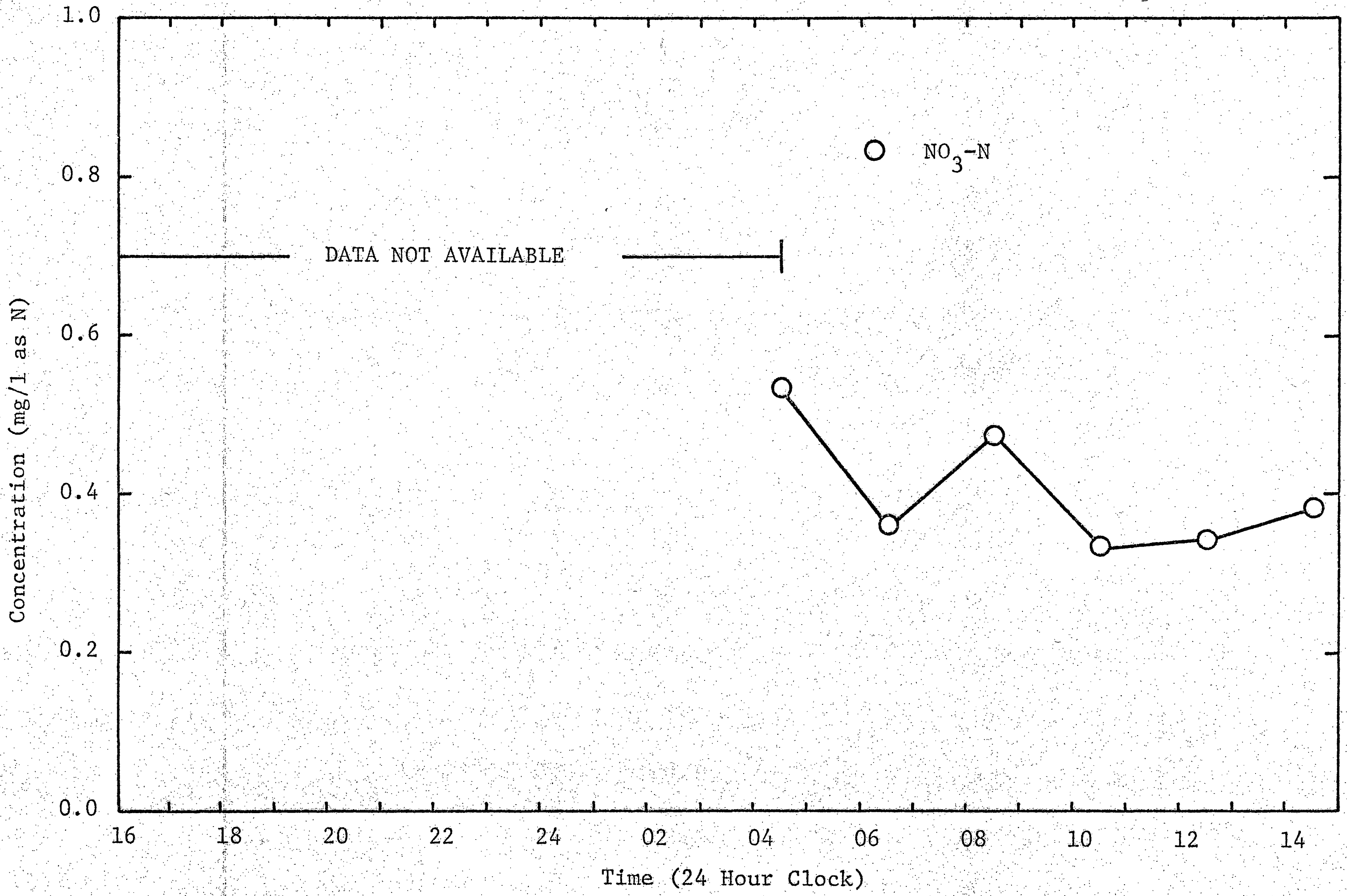


Figure 34: Diurnal Fluctuations in Nitrogen Loadings at Station 8 on 6 and 7 July, 1971

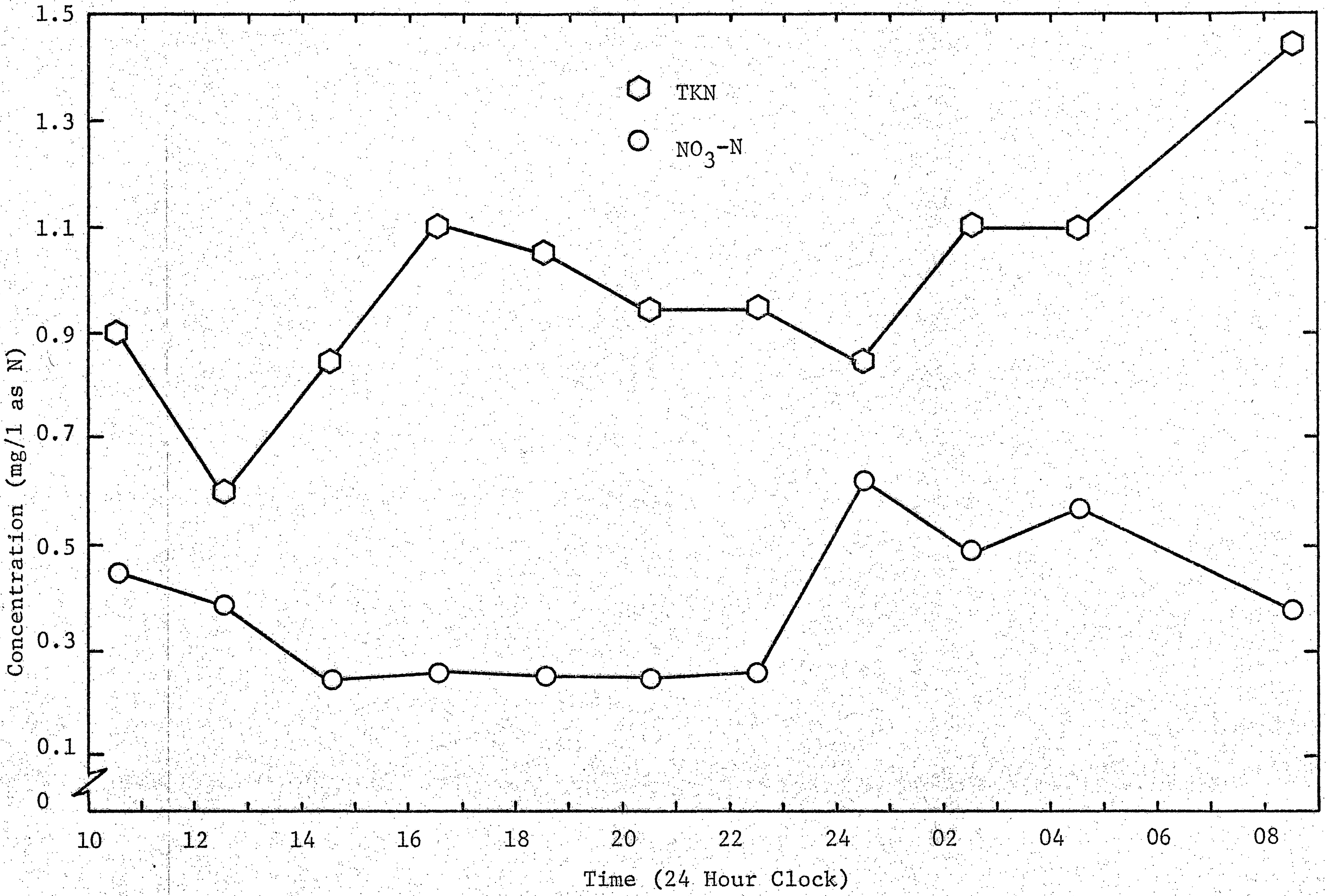
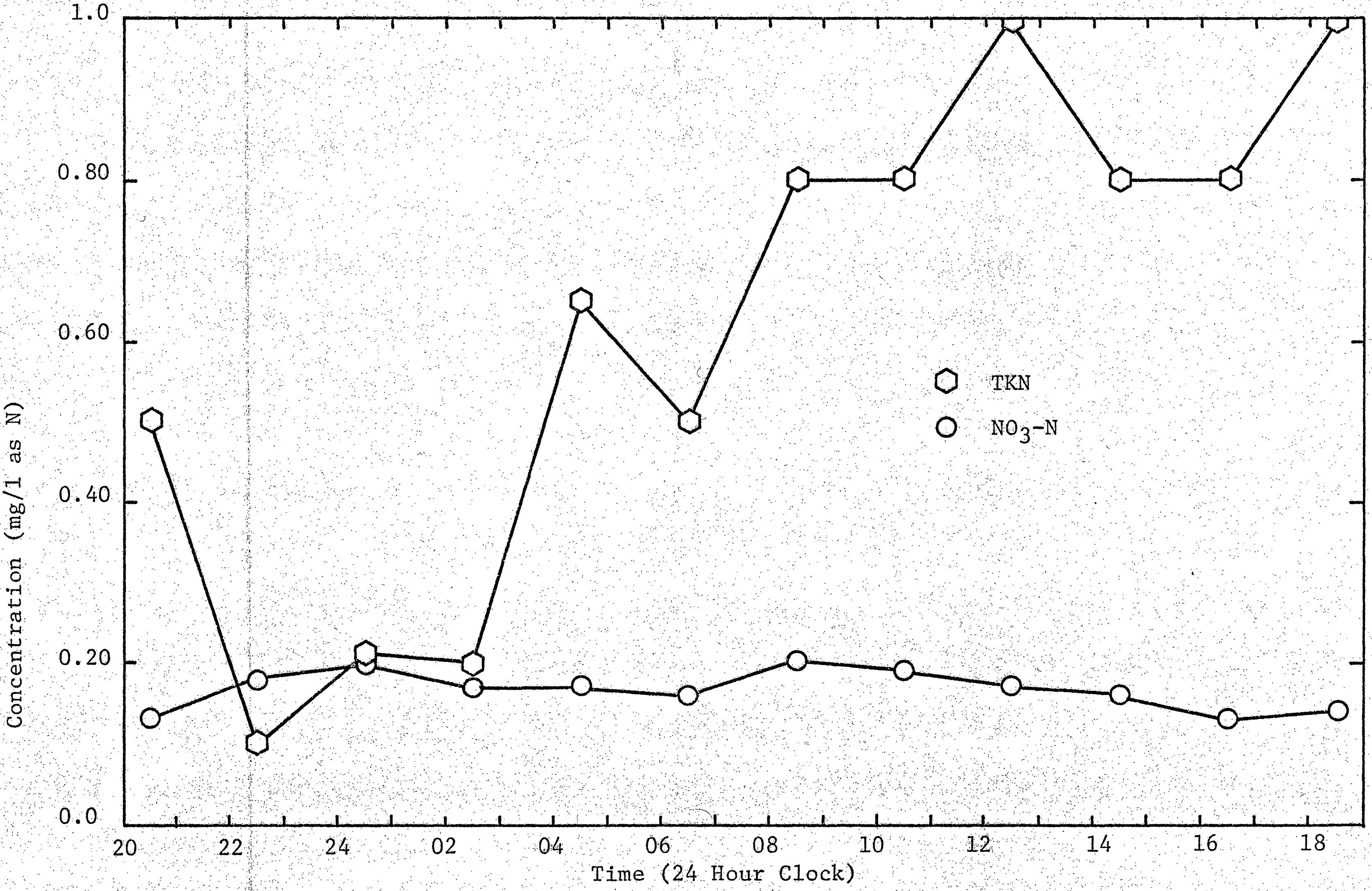


Figure 35: Diurnal Fluctuations in Nitrogen Loadings at Station 9 on 19 and 20 June, 1971



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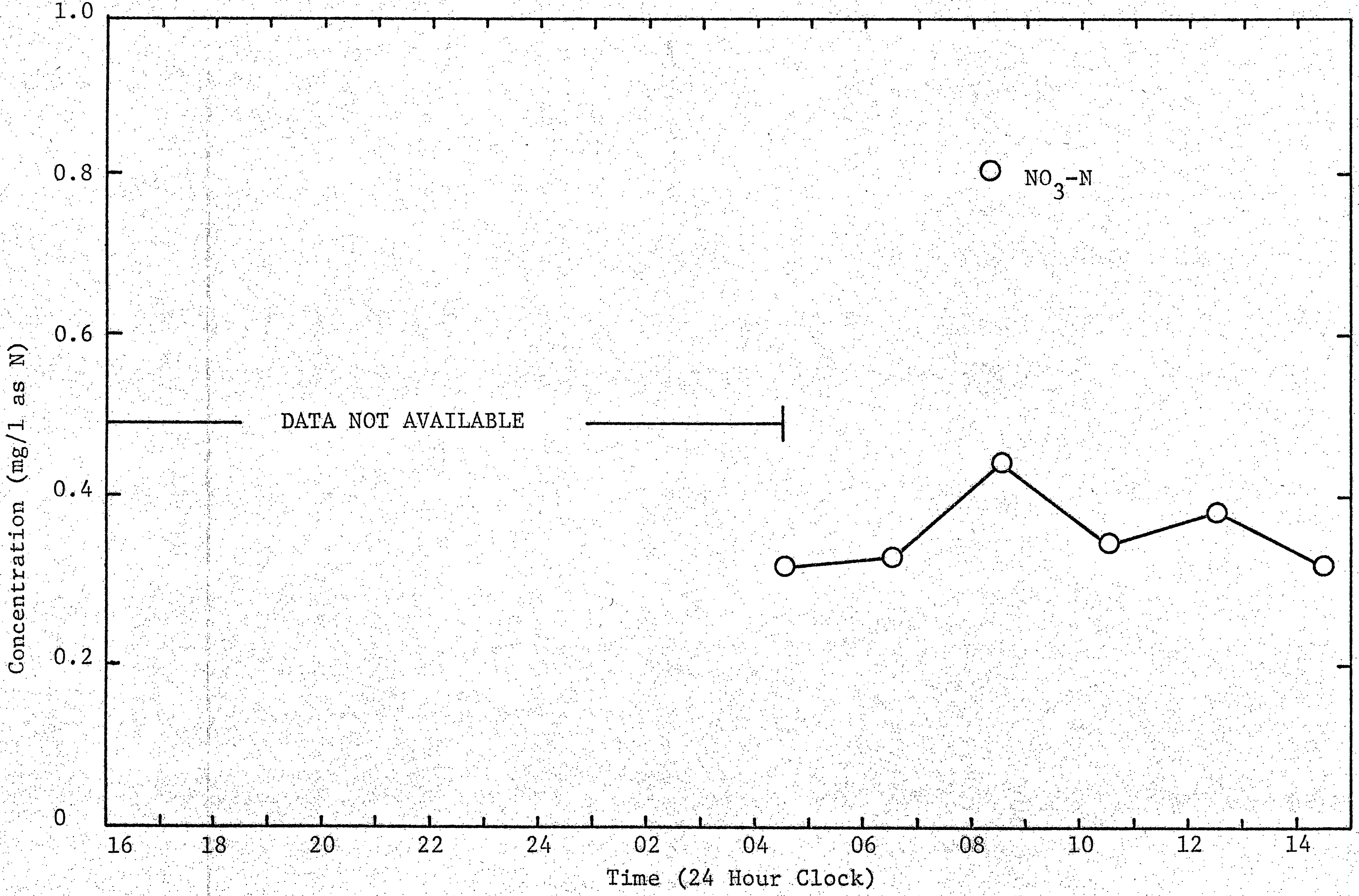

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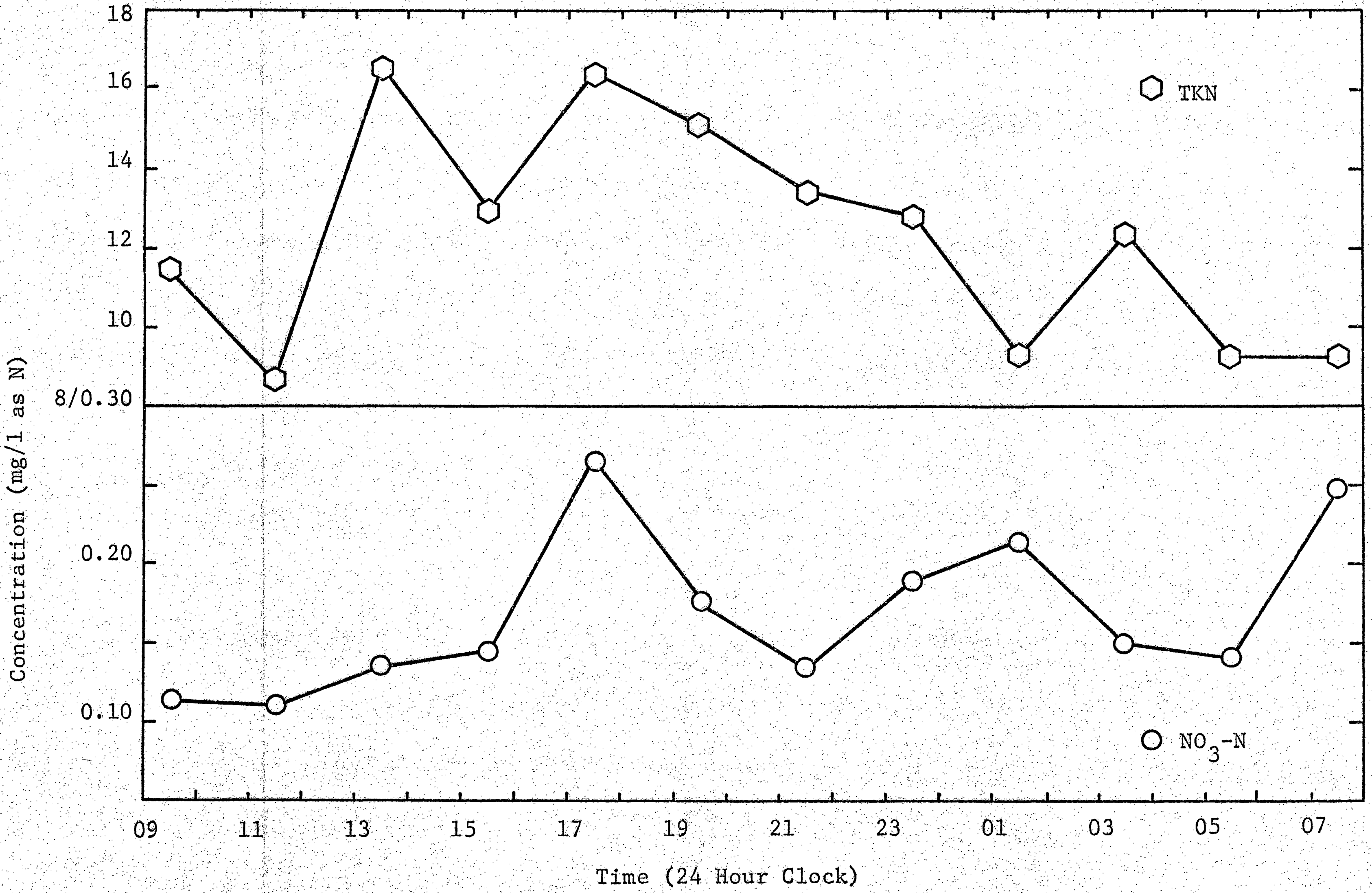

Figure 38: Diurnal Fluctuations in Nitrogen Loadings at Station 10 on 19 and 20 June 1971

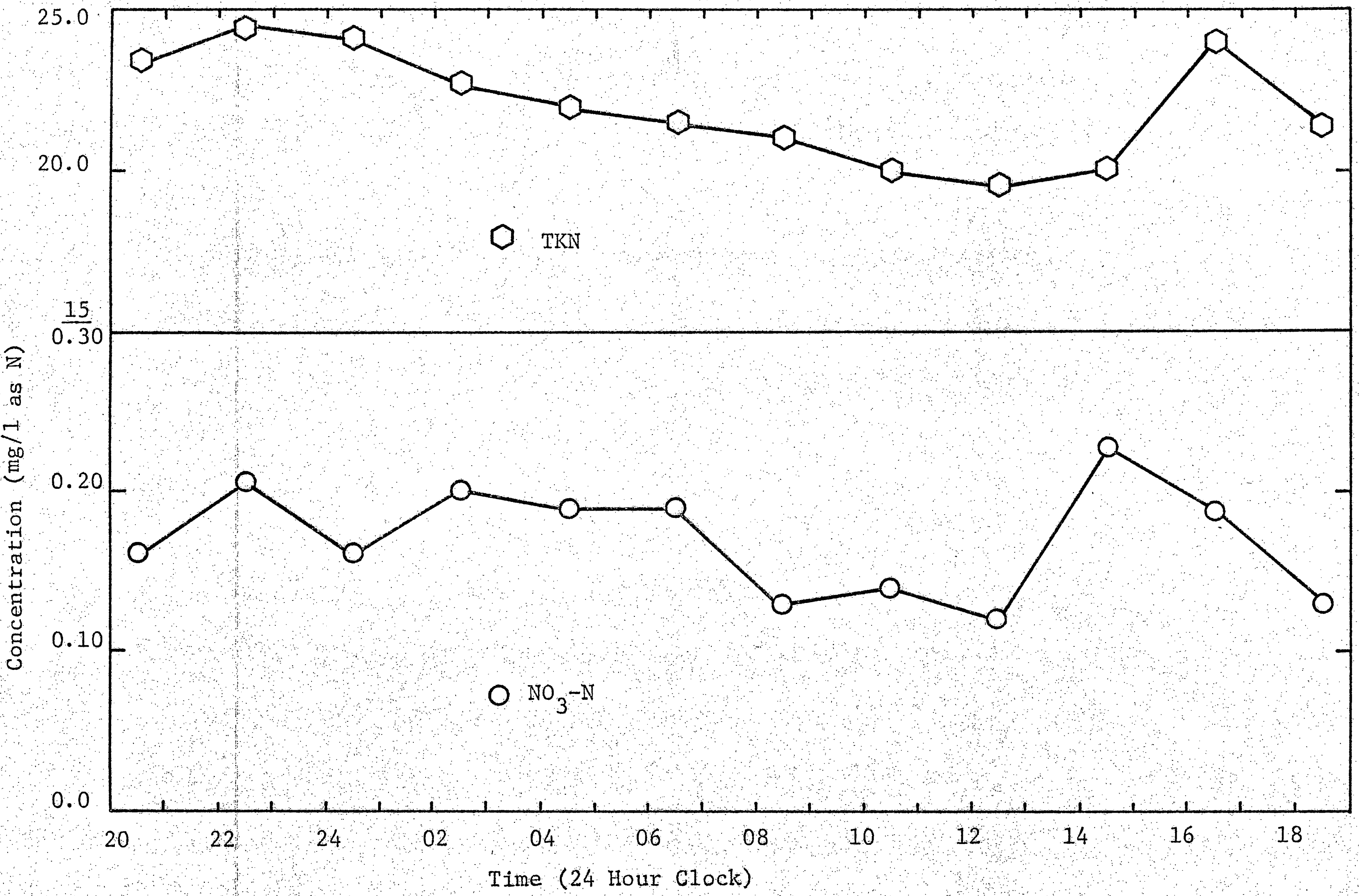

Figure 39: Diurnal Fluctuations in Nitrogen Loadings at Station 10 on 21 and 22 July 1971

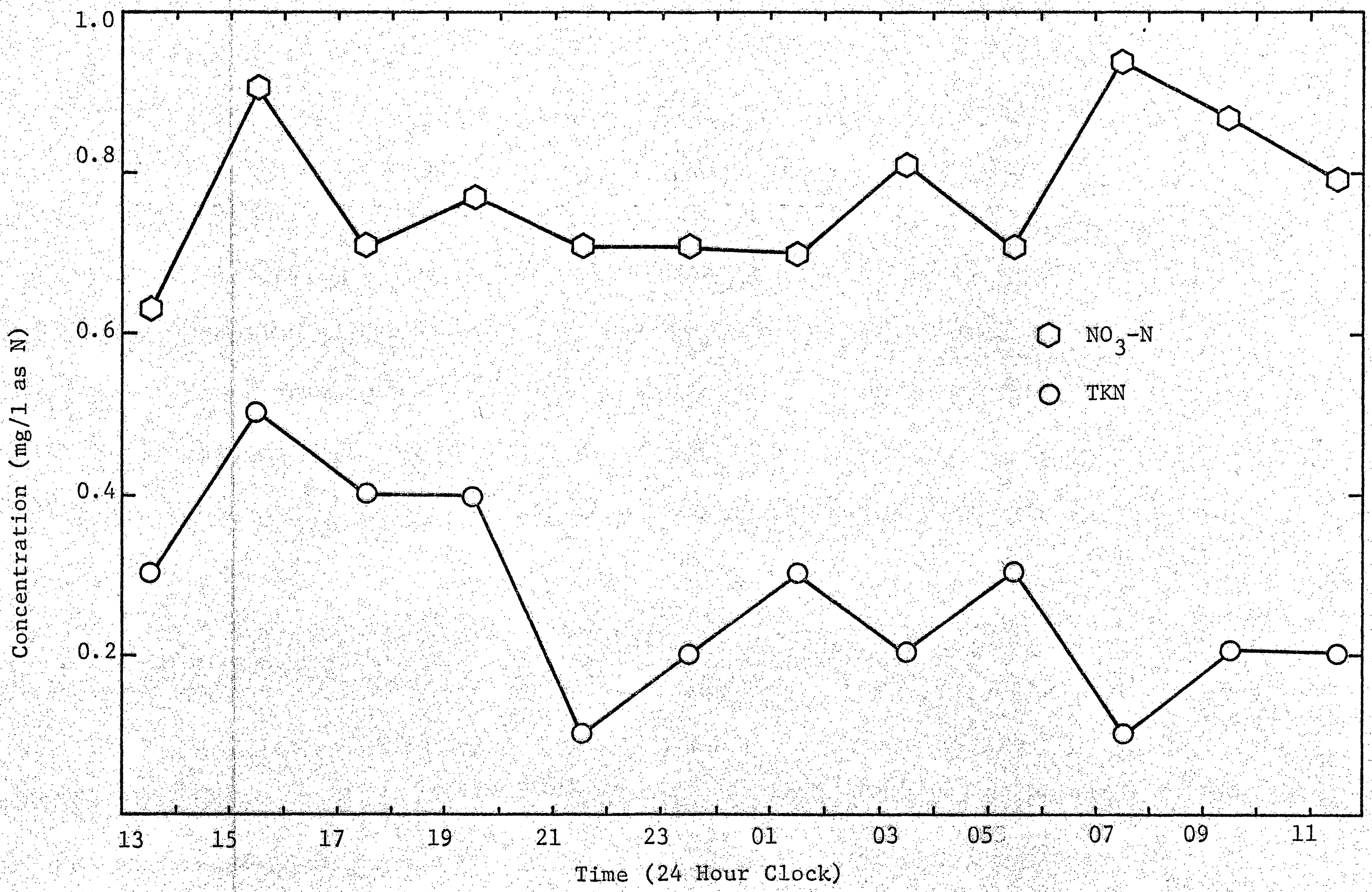

Figure 40: Diurnal Fluctuations in Nitrogen Loadings at Station 11 on 29 and 30 June 1971

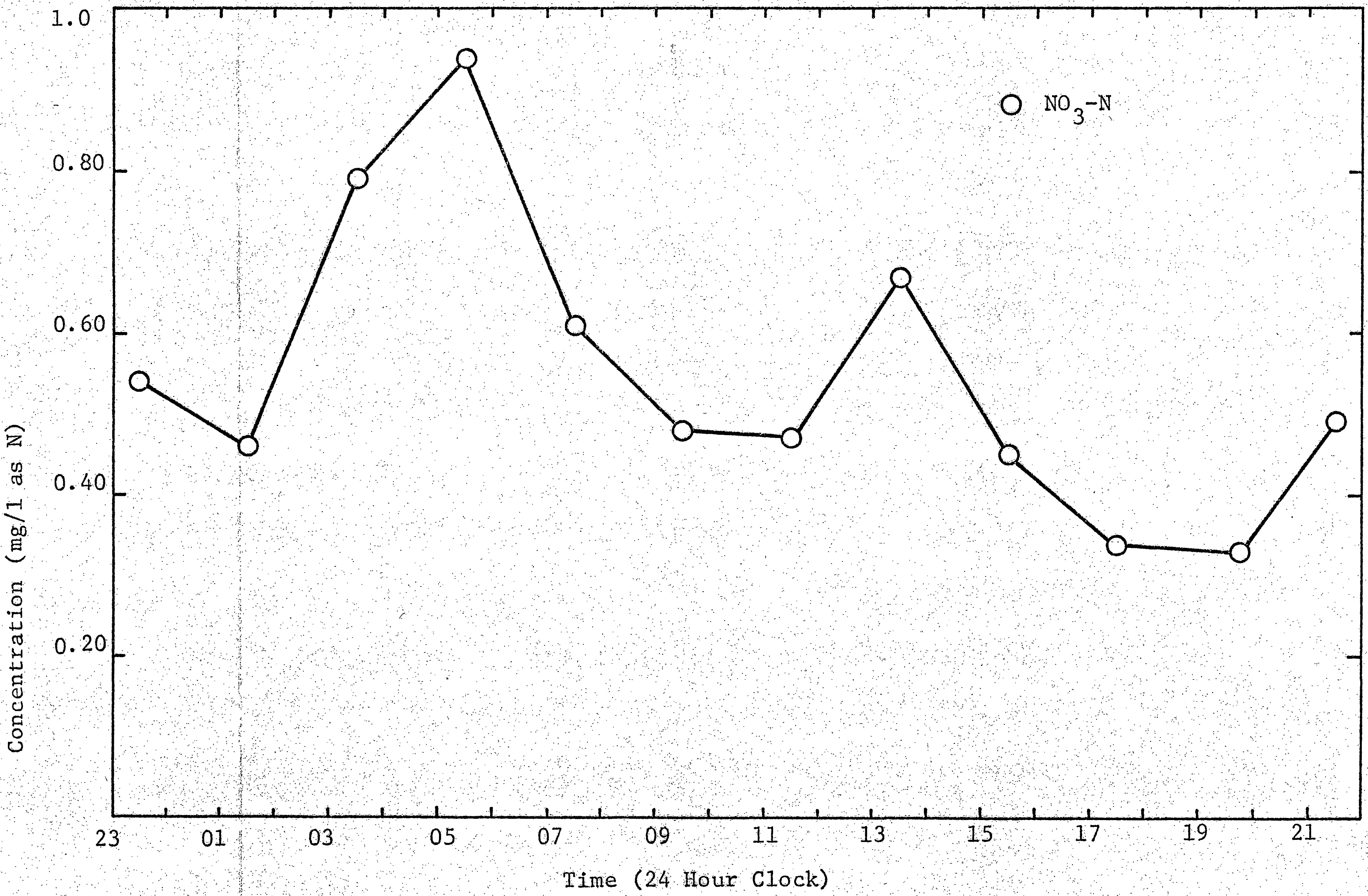

Figure 41: Diurnal Fluctuations in Nitrogen Loadings at Station 12 on 22 and 23 July 1971

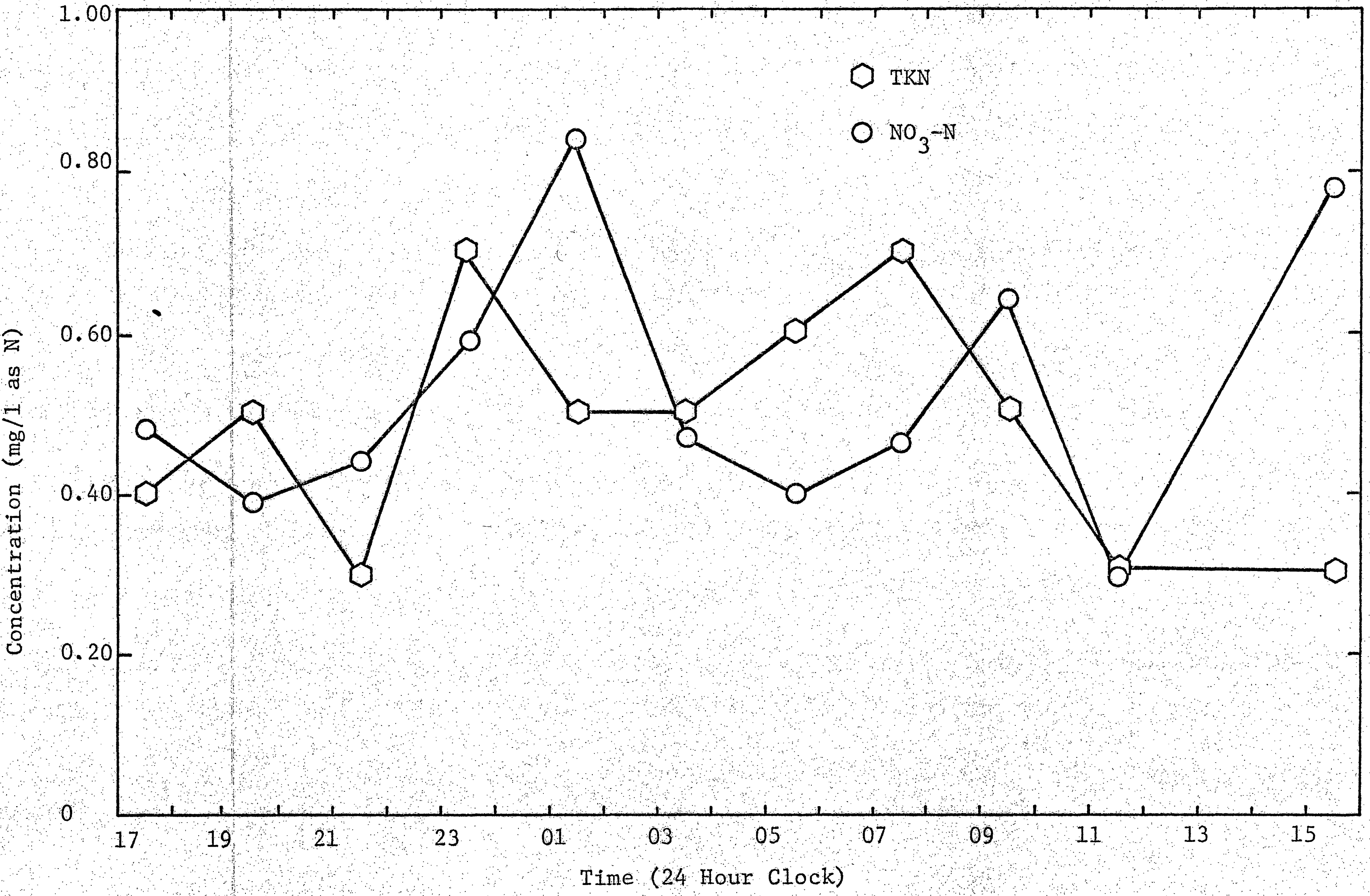

Figure 42: Diurnal Fluctuations in Nitrogen Loadings at Station 13 on 15 and 16 July 1971

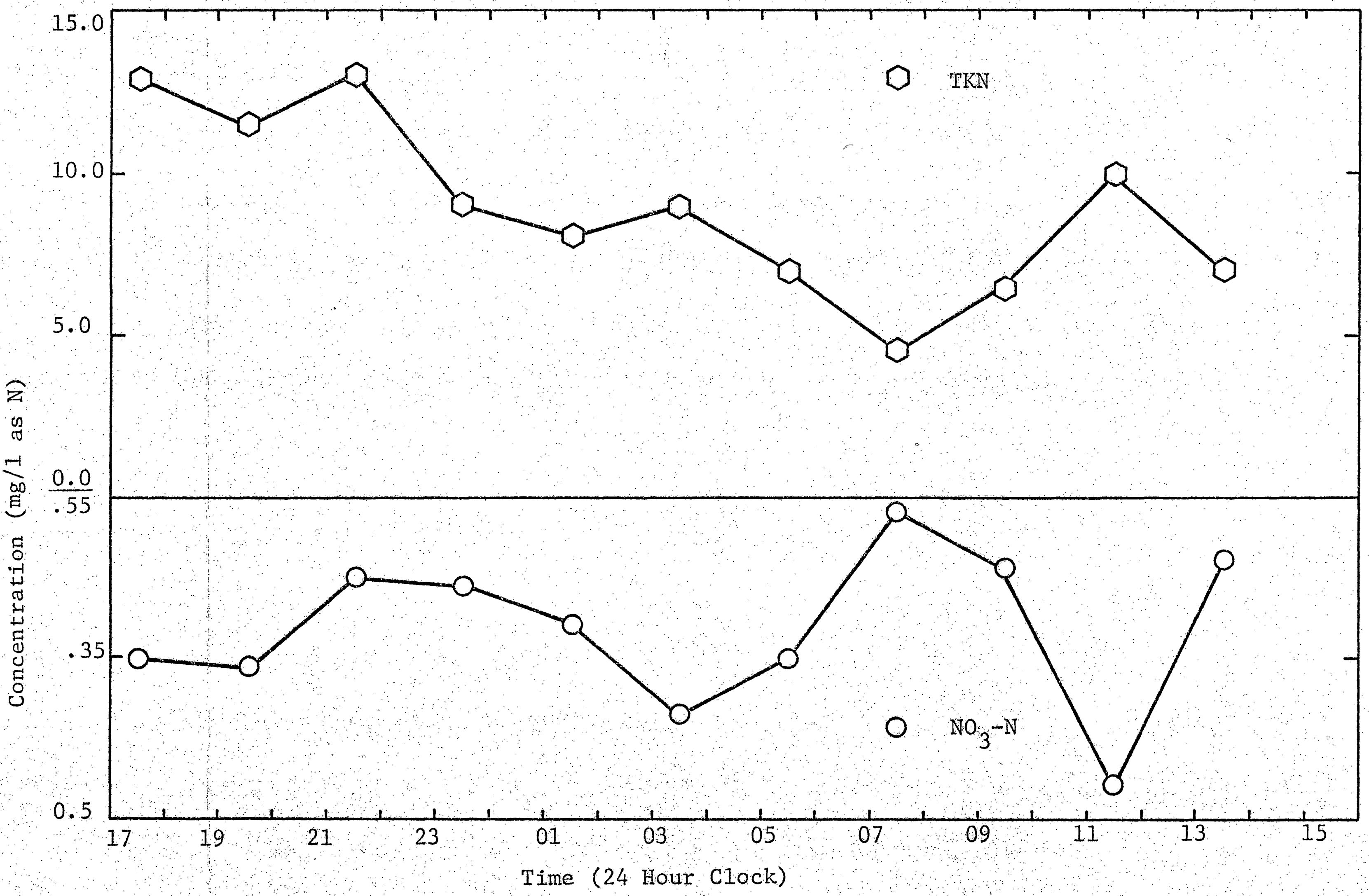

Figure 43: Diurnal Fluctuations in Nitrogen Loadings at Station 14 on 15 and 16 July 1971

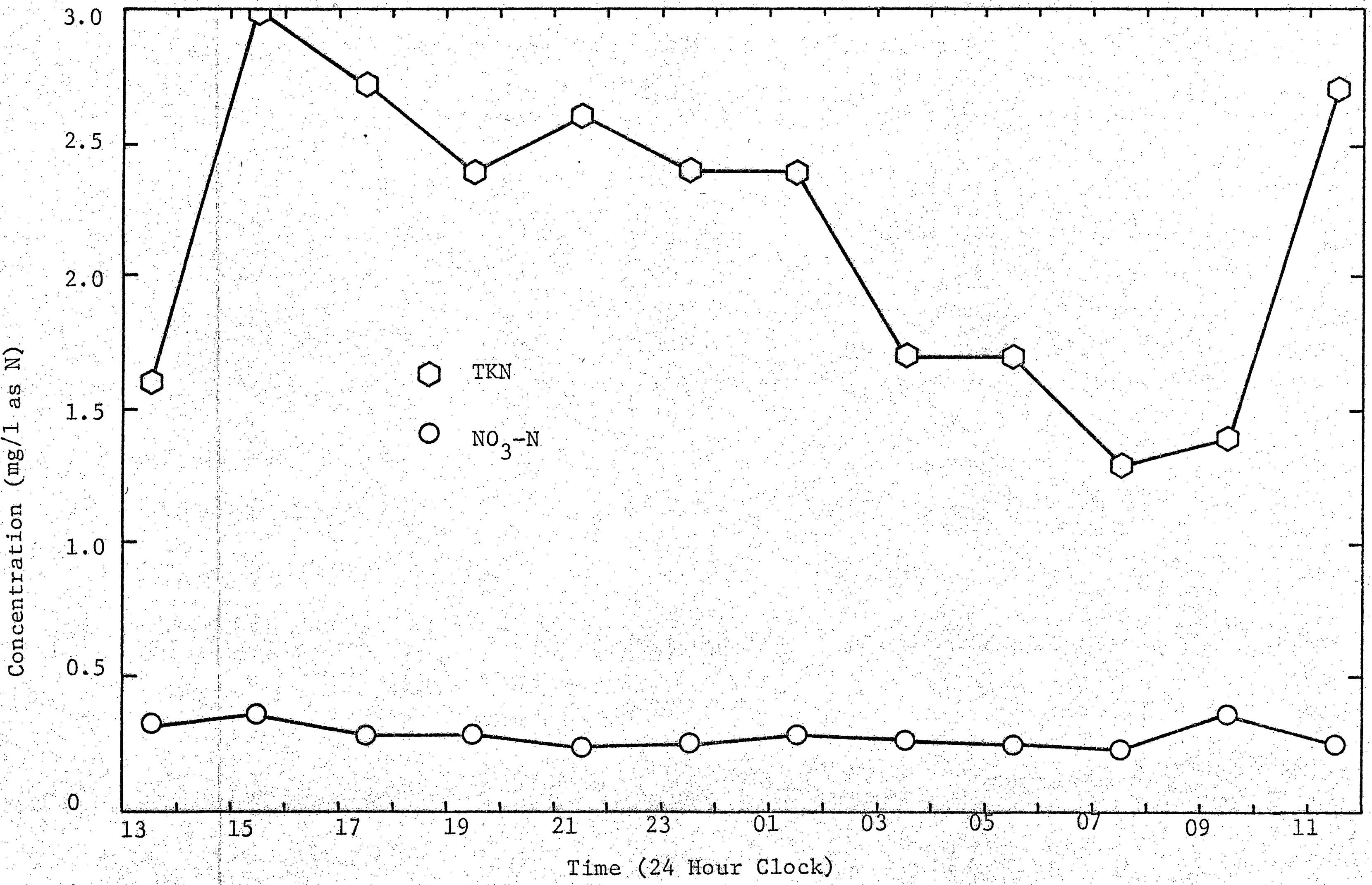

Figure 44: Diurnal Fluctuations in Nitrogen Loadings at Station 15 on 22 and 23 July 1971

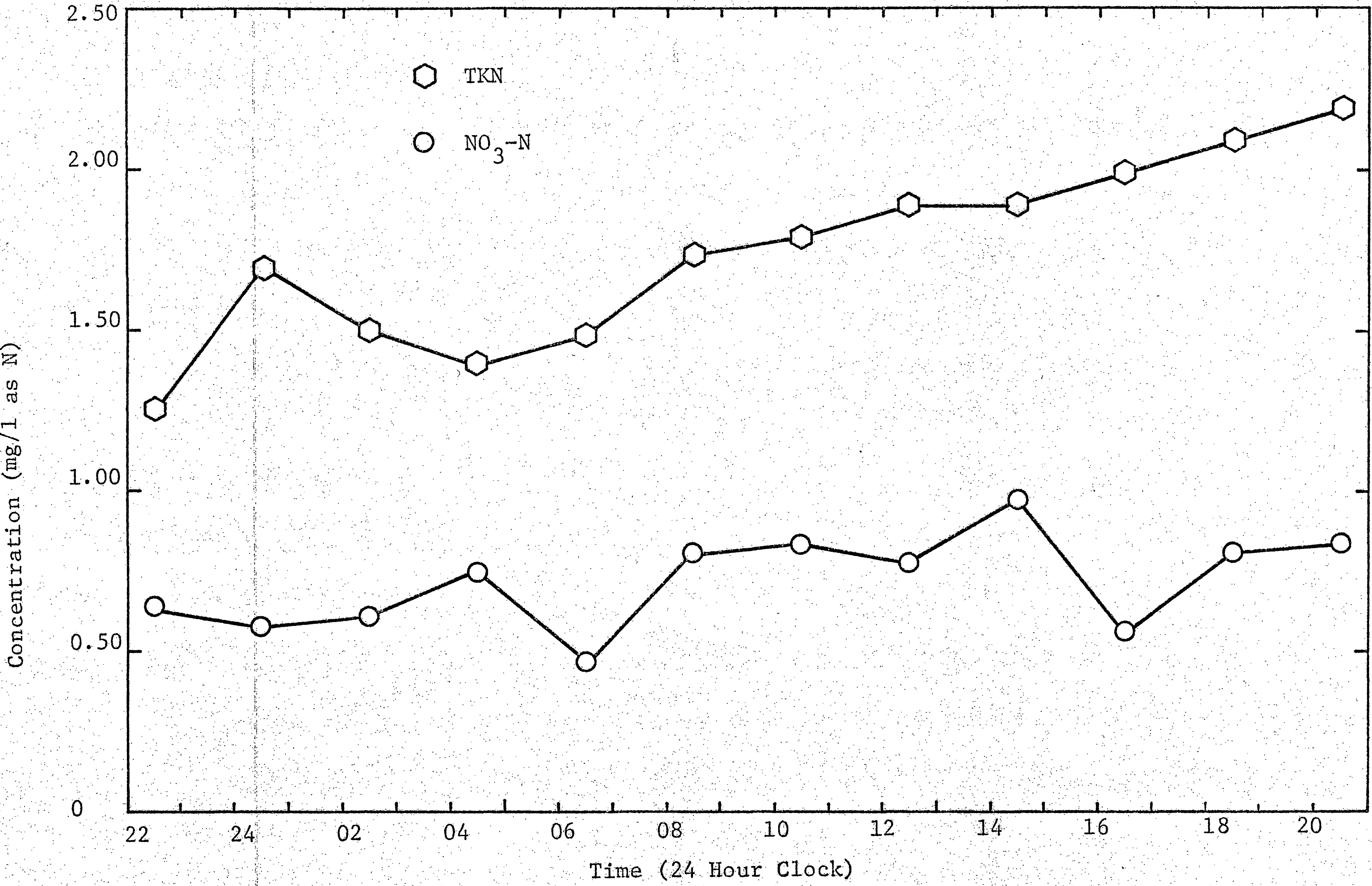

Figure 45: Diurnal Fluctuations in Nitrogen Loadings at Station 15 on 29 and 30 June 1971

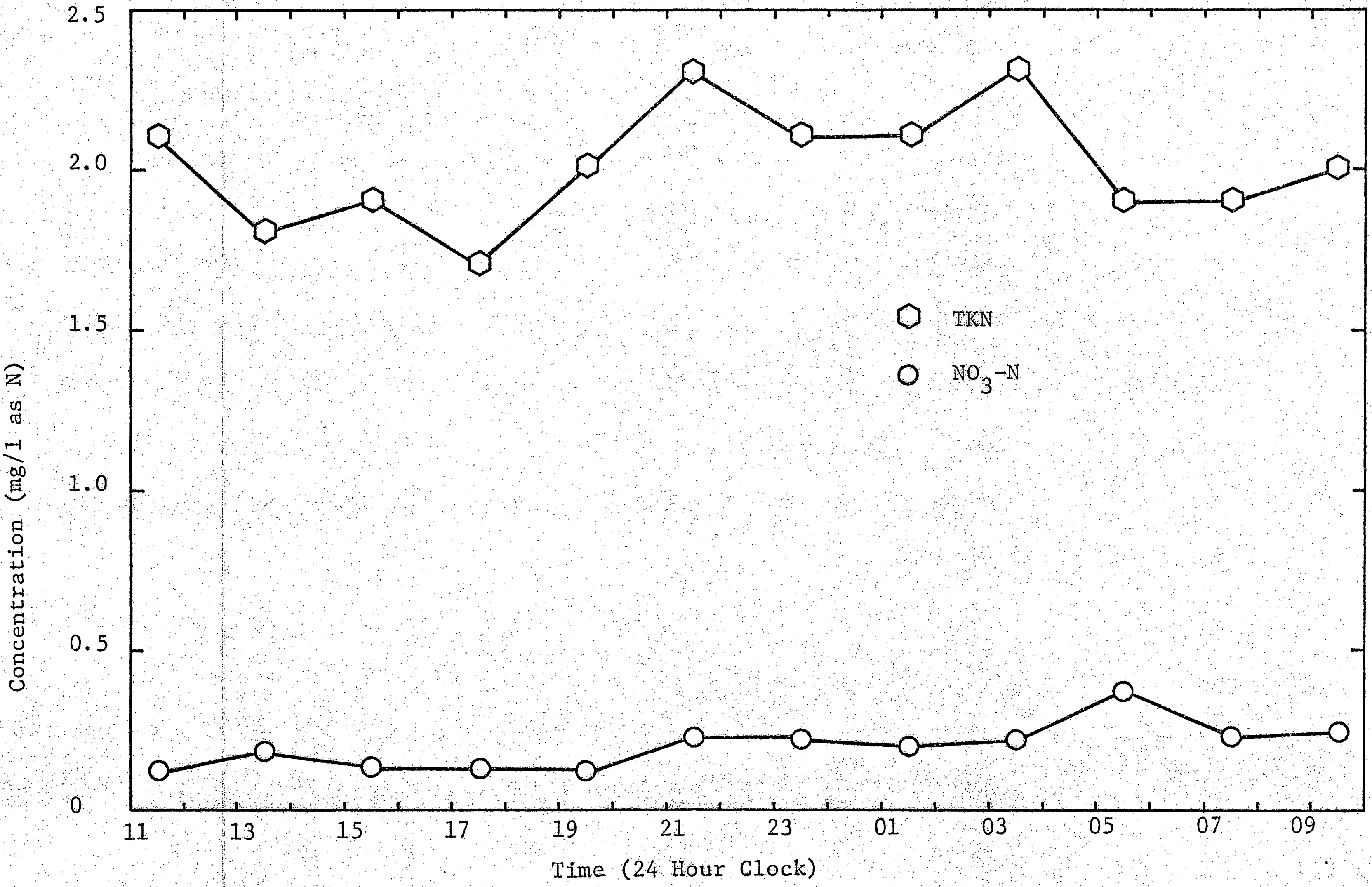

Figure 46: Diurnal Fluctuations in Nitrogen Loadings at Station 16 on 29 and 30 July 1971

APPENDIX C

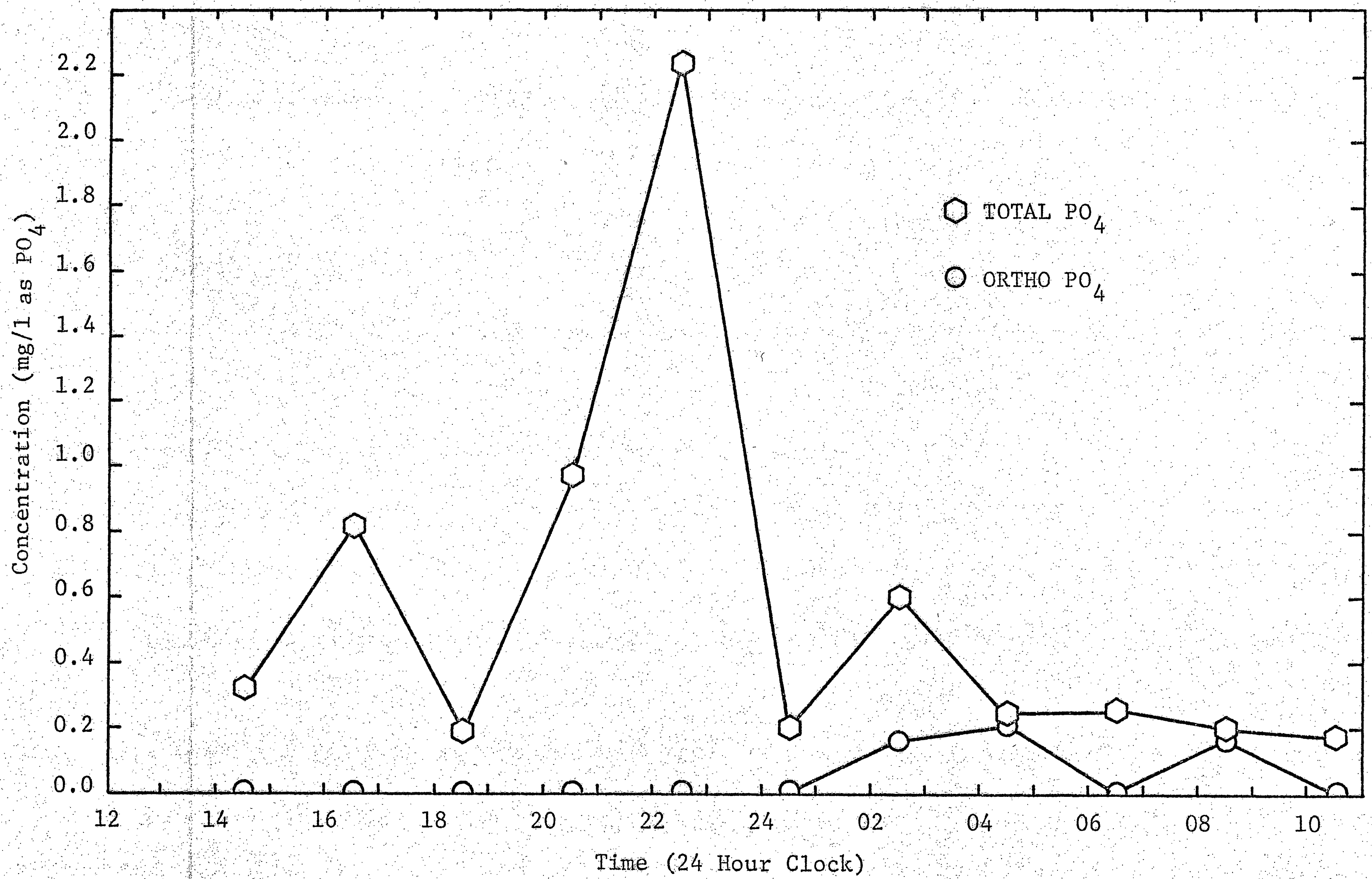

Figure 47: Diurnal Fluctuations in Phosphorus Loadings at Station 1 on 28 and 29 June, 1971

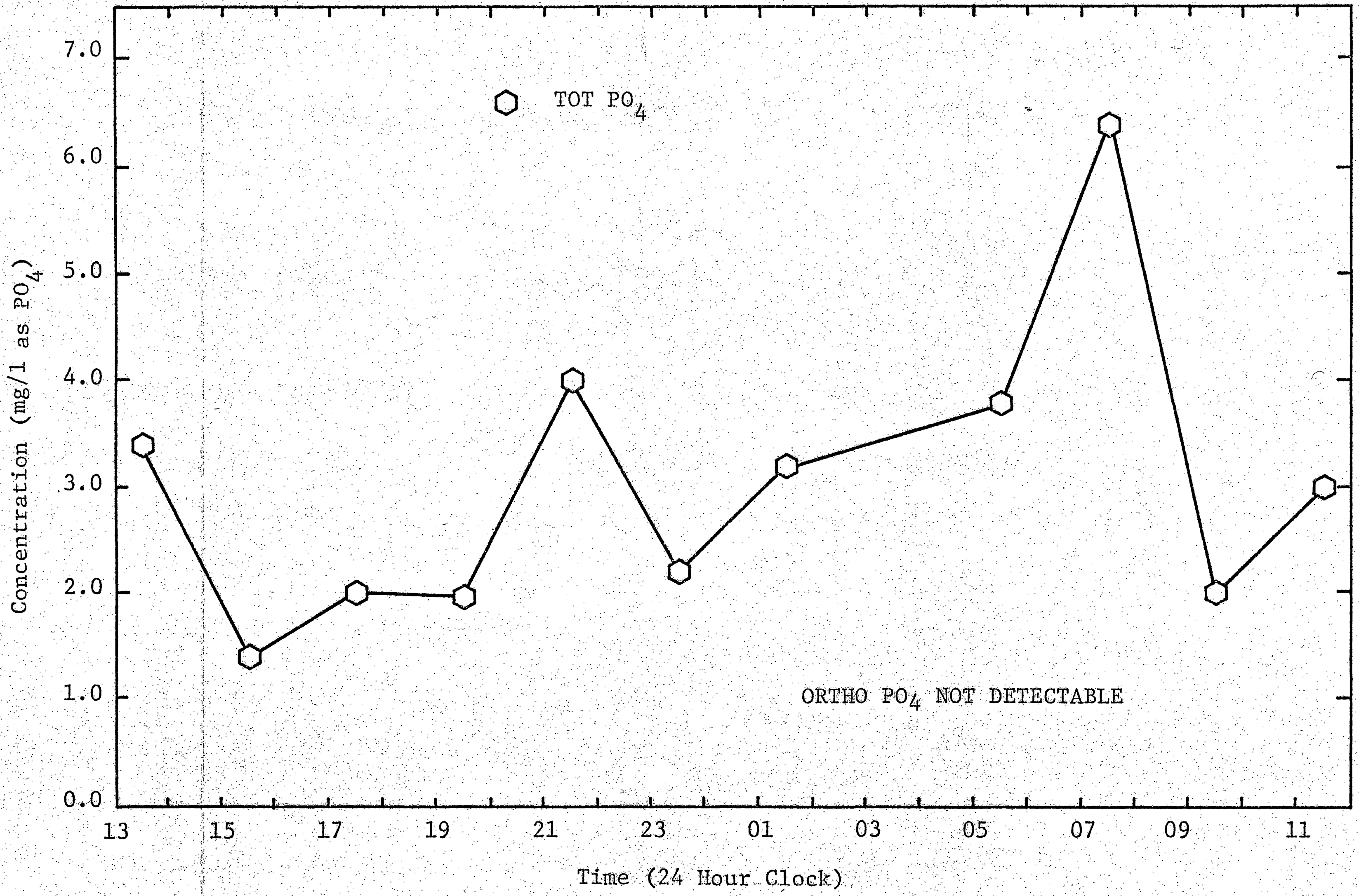

Figure 48: Diurnal Fluctuations in Phosphorus Loadings at Station 2 on 28 and 29 June, 1971

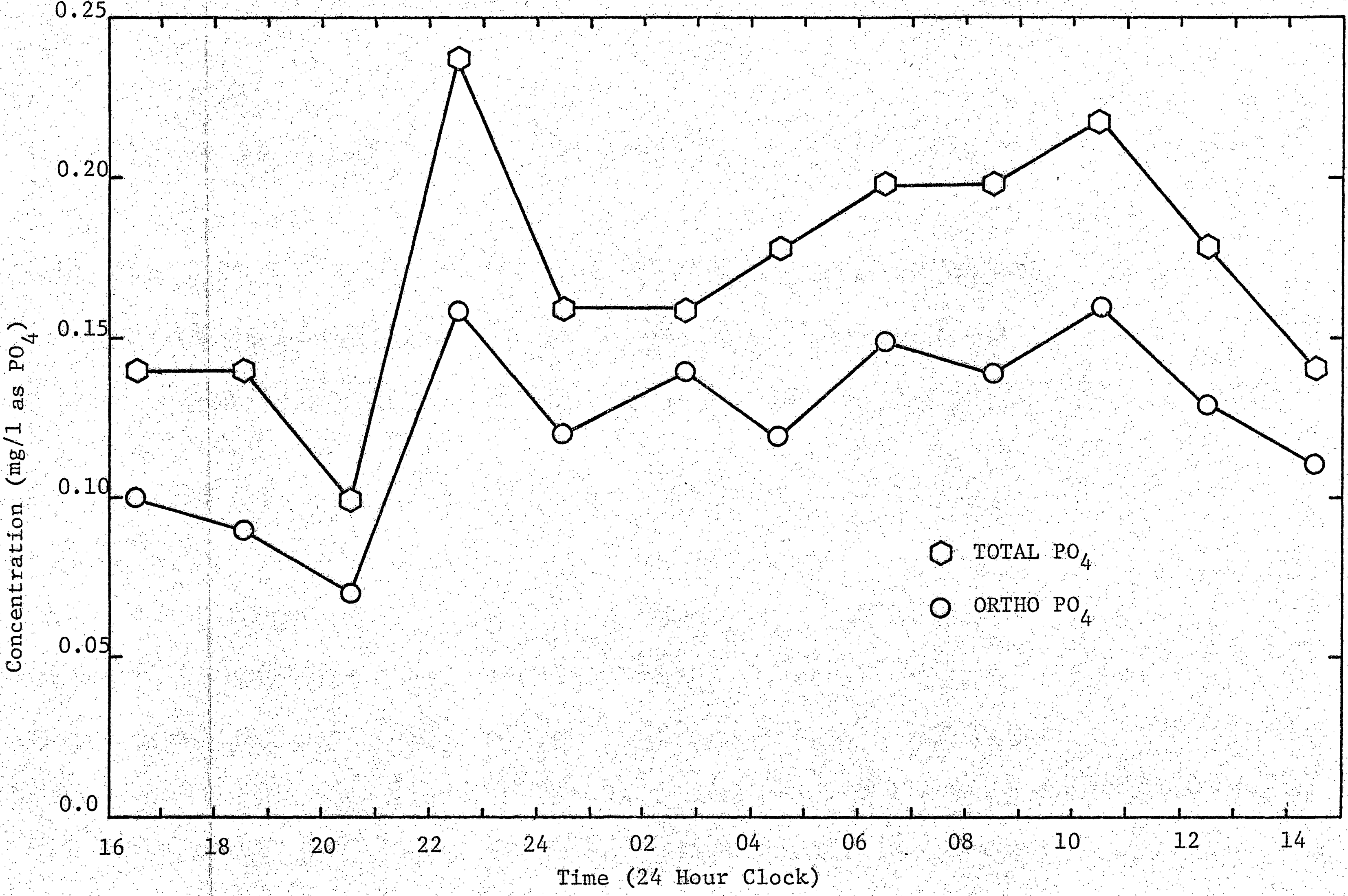

Figure 49: Diurnal Fluctuations in Phosphorus Loadings at Station 3 on 8 and 9 July, 1971

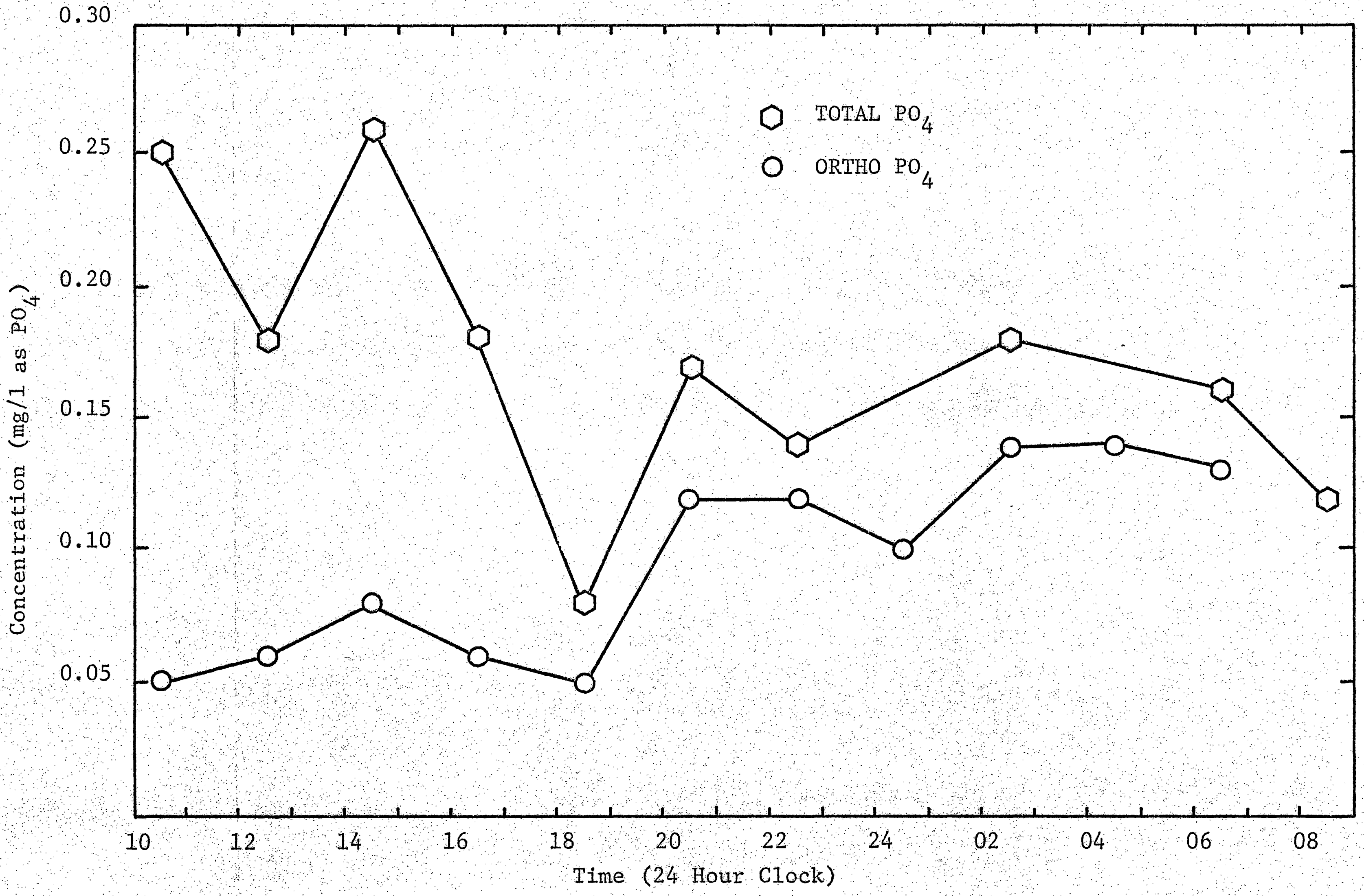

Figure 50: Diurnal Fluctuations in Phosphorus Loadings at Station 4 on 27 and 28 July, 1971

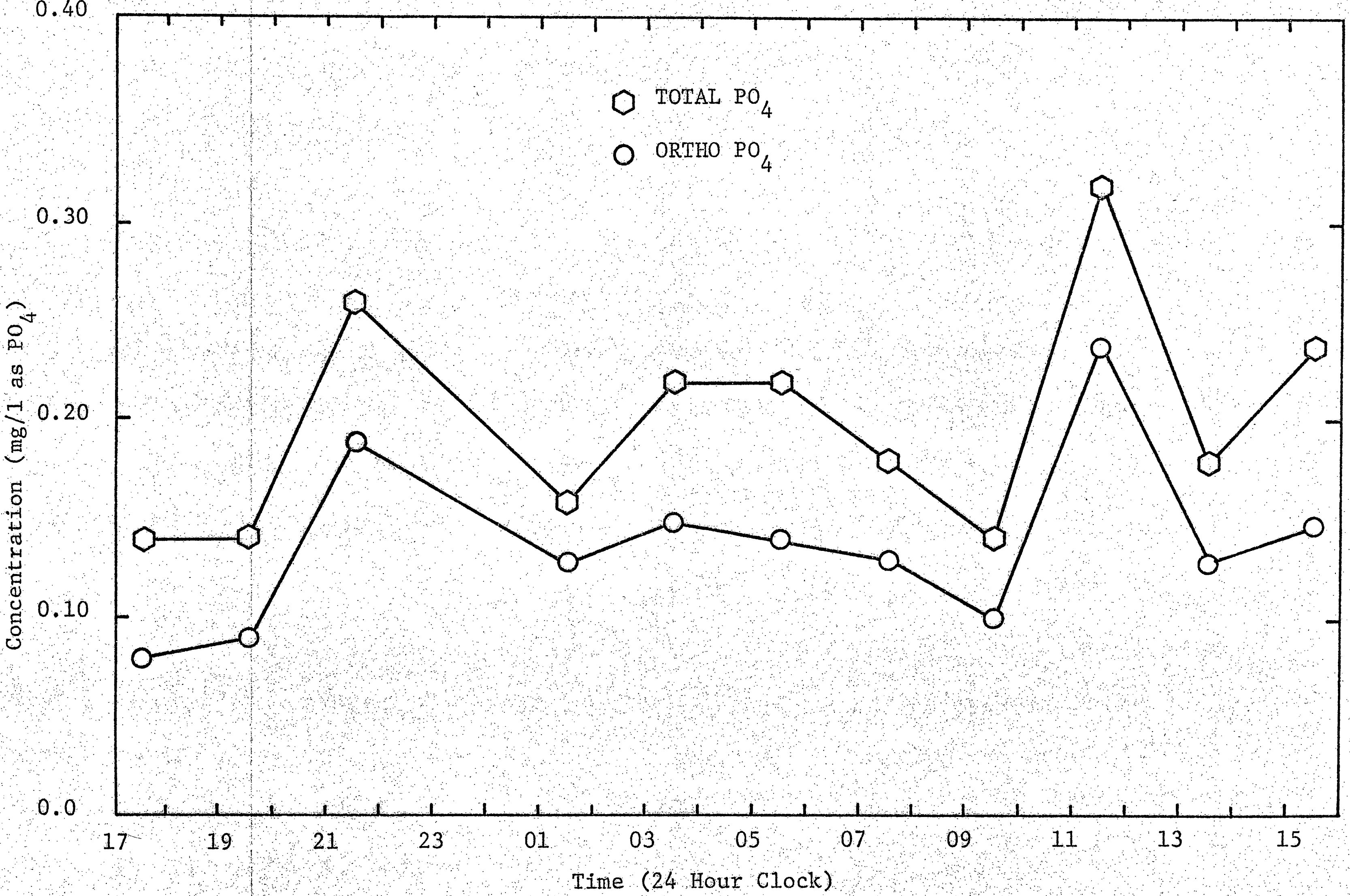

Figure 51: Diurnal Fluctuations in Phosphorus Loadings at Station 5 on 8 and 9 July, 1971

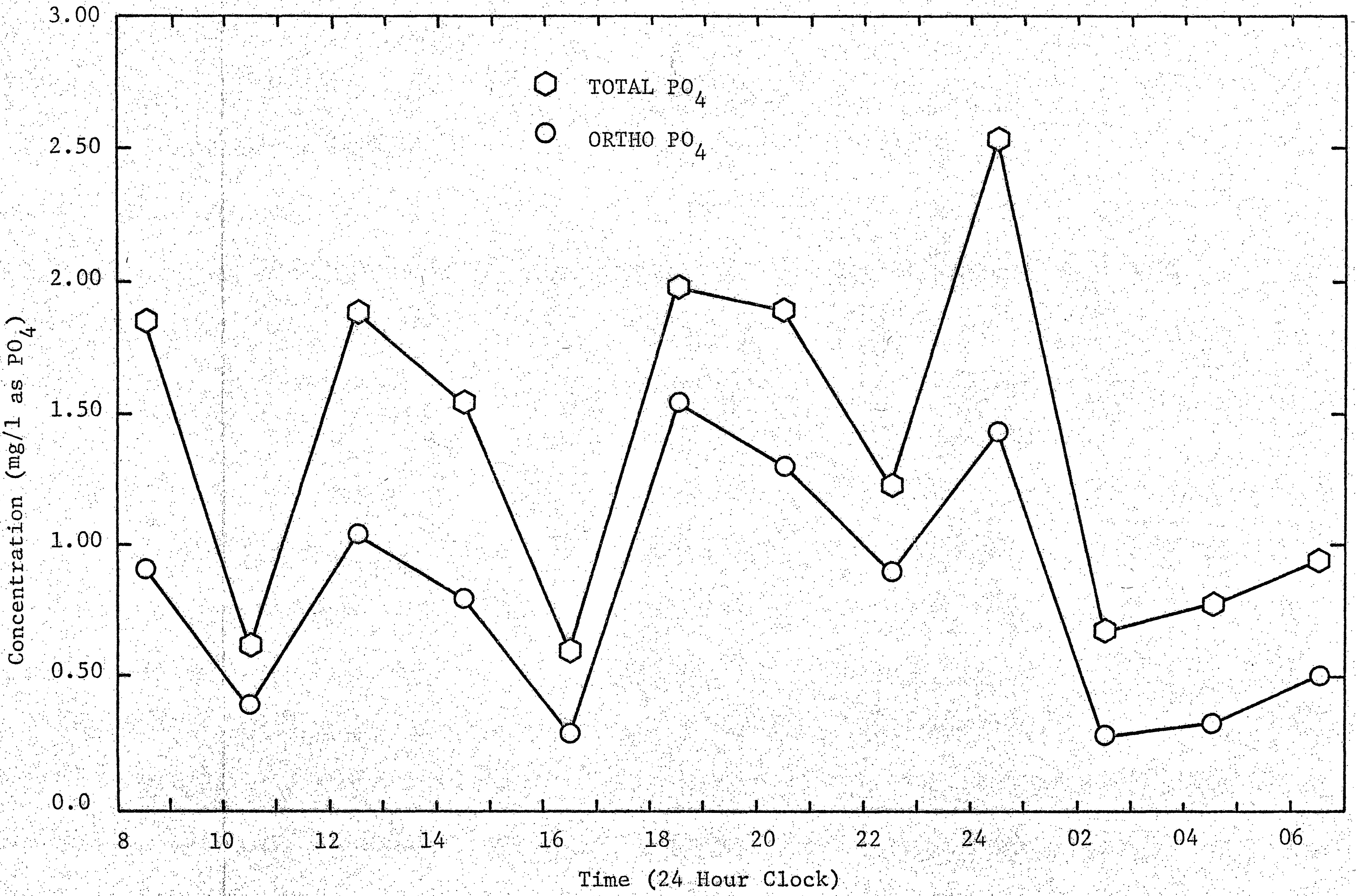

Figure 52: Diurnal Fluctuations in Phosphorus Loadings at Station 6 on 16 and 17 July, 1971

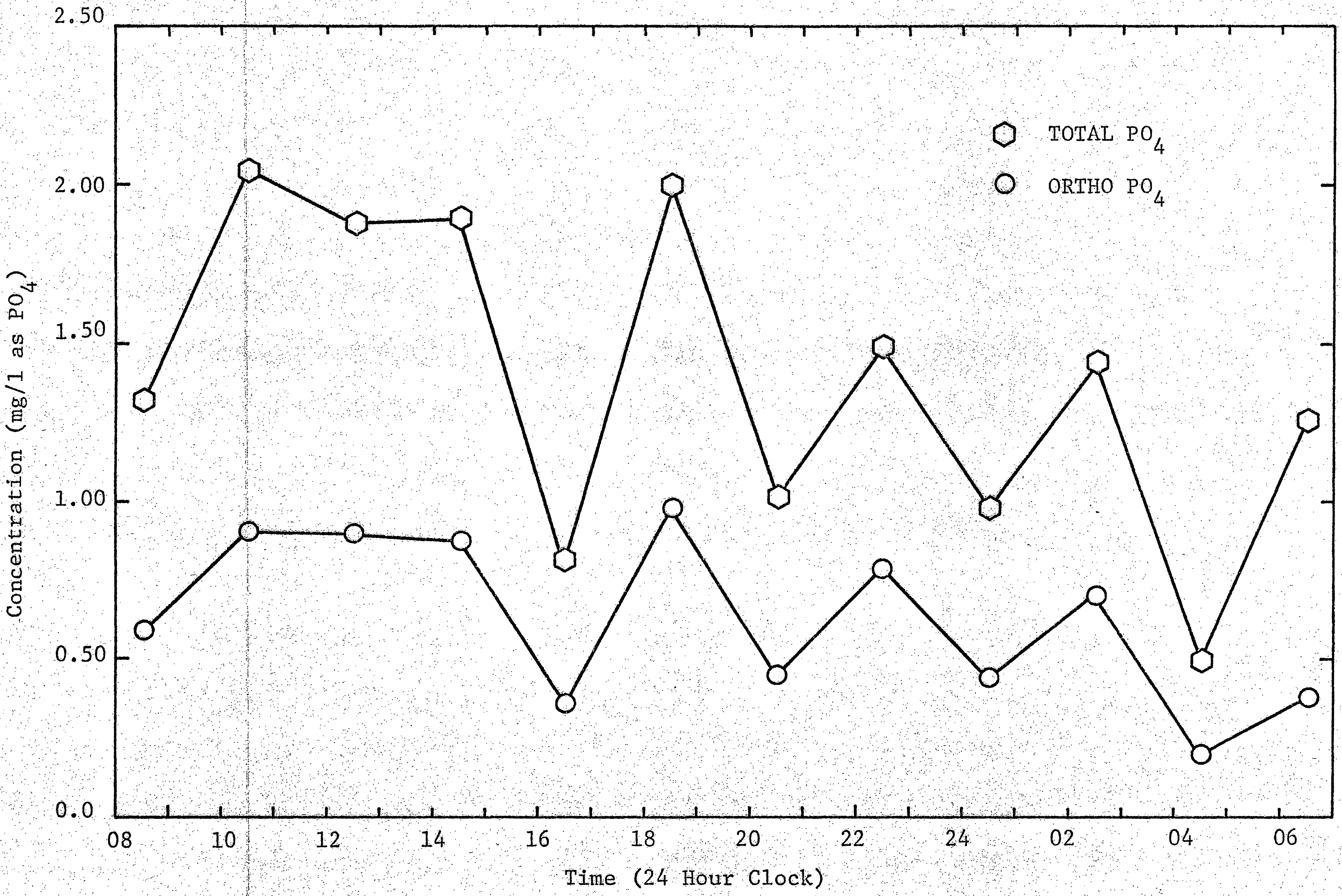

Figure 53: Diurnal Fluctuations in Phosphorus Loadings at Station 7 on 16 and 17 July, 1971

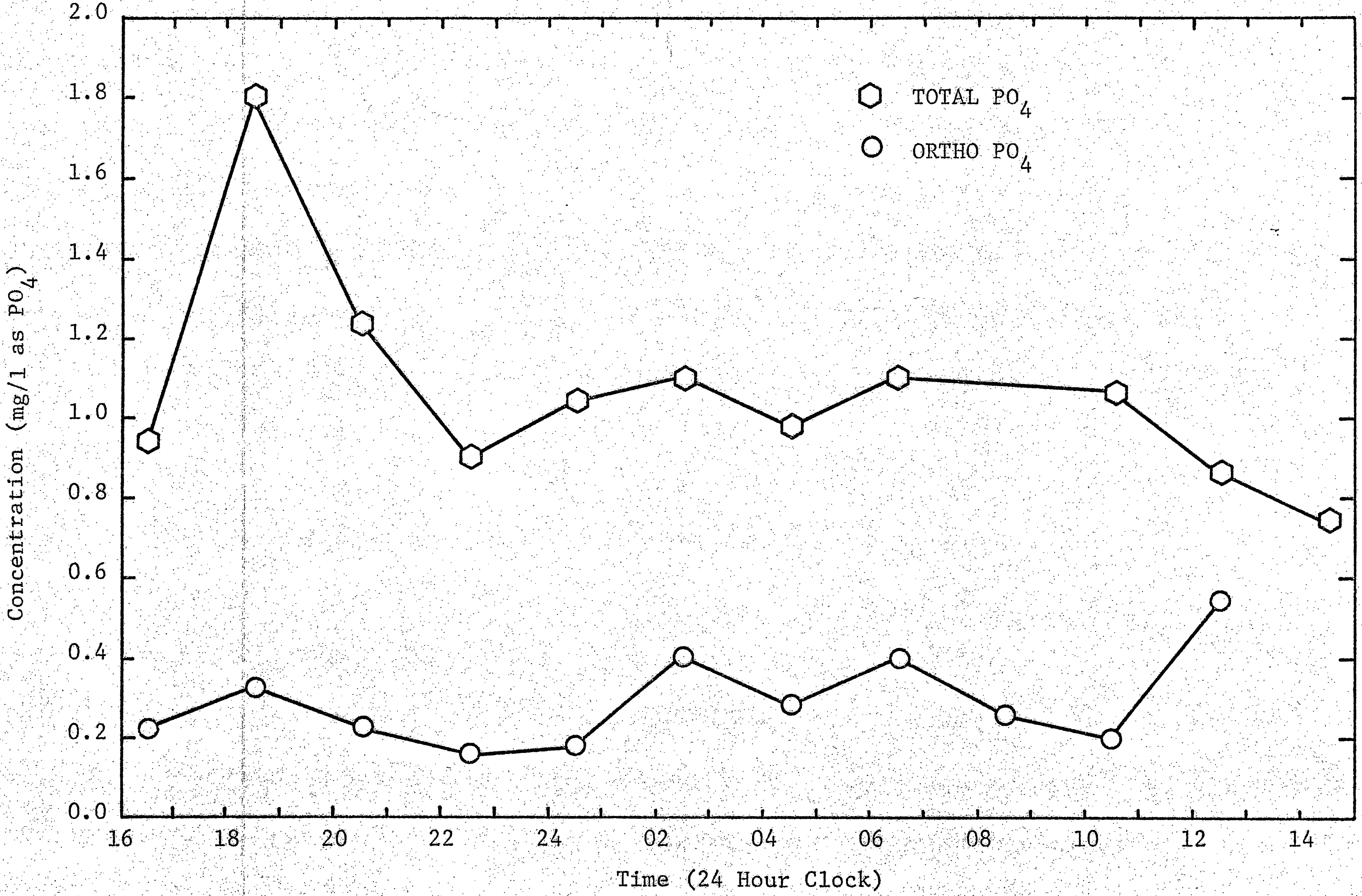

Figure 54: Diurnal Fluctuations in Phosphorus Loadings at Station 8 on 6 and 7 July, 1971

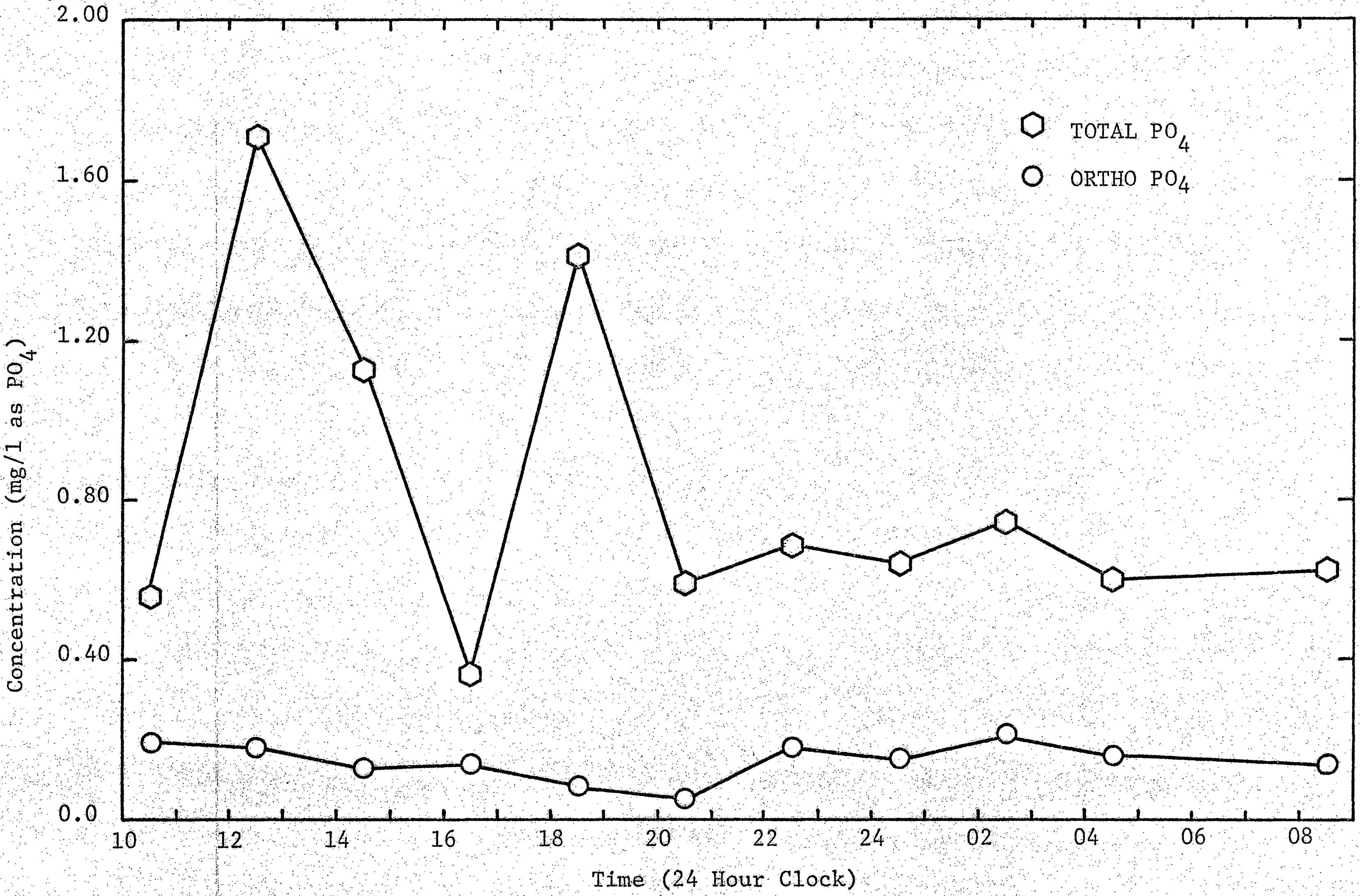

Figure 55: Diurnal Fluctuations in Phosphorus Loadings at Station 9 on 19 and 20 June, 1971

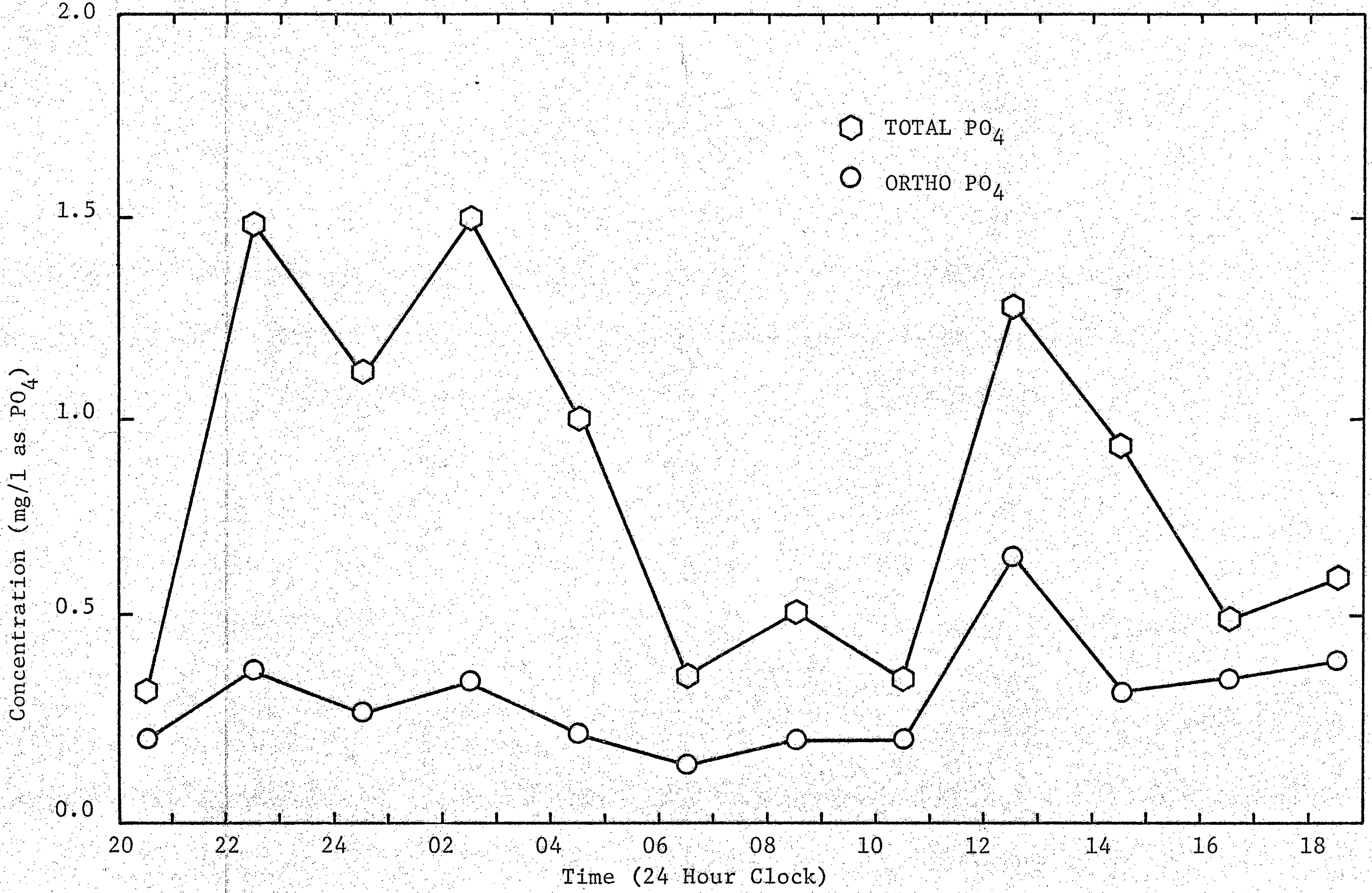

Figure 56: Diurnal Fluctuations in Phosphorus Loadings at Station 9 on 21 and 22 June, 1971

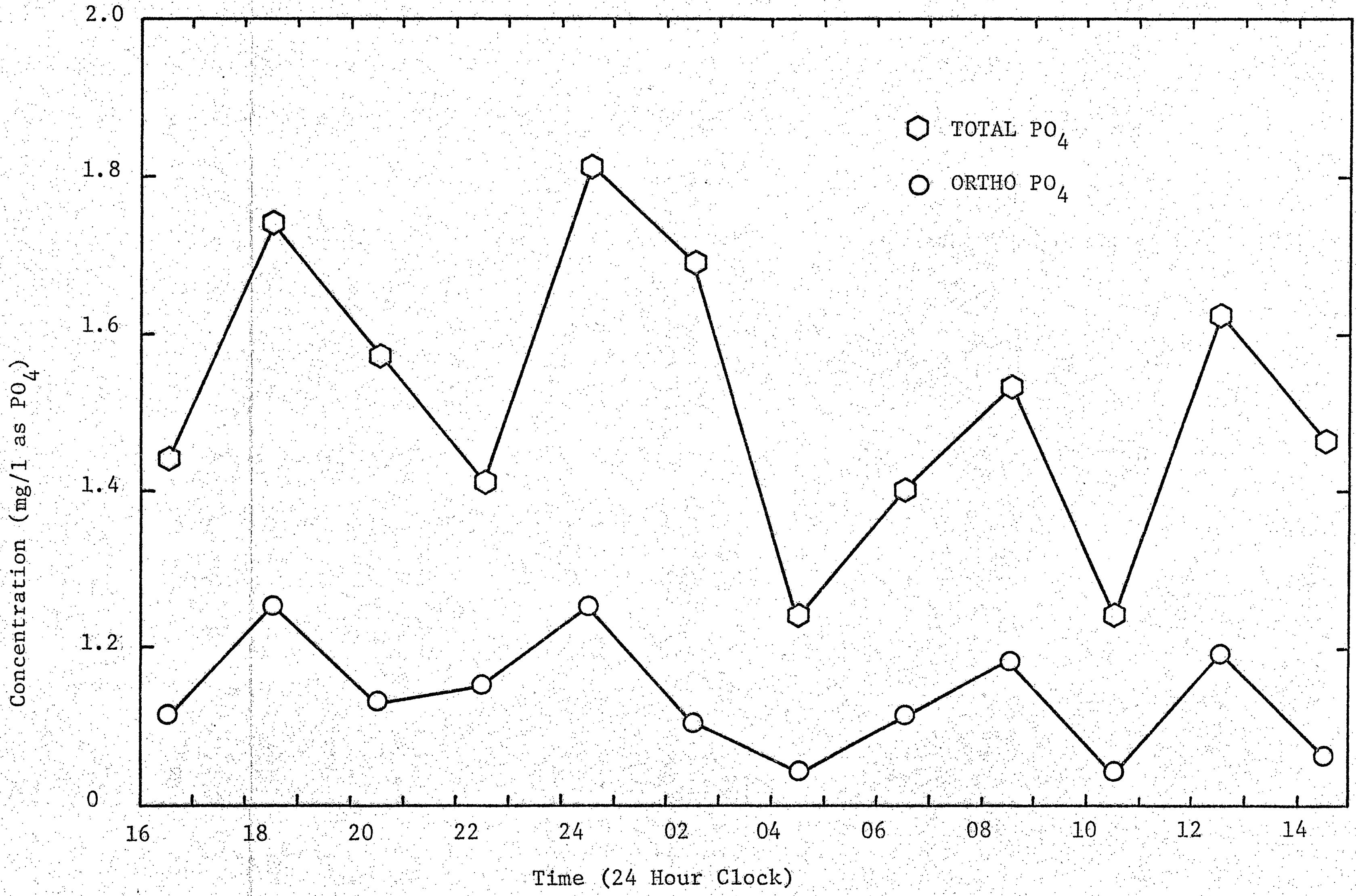

Figure 57: Diurnal Fluctuations in Phosphorus Loadings at Station 9 on 6 and 7 July, 1971

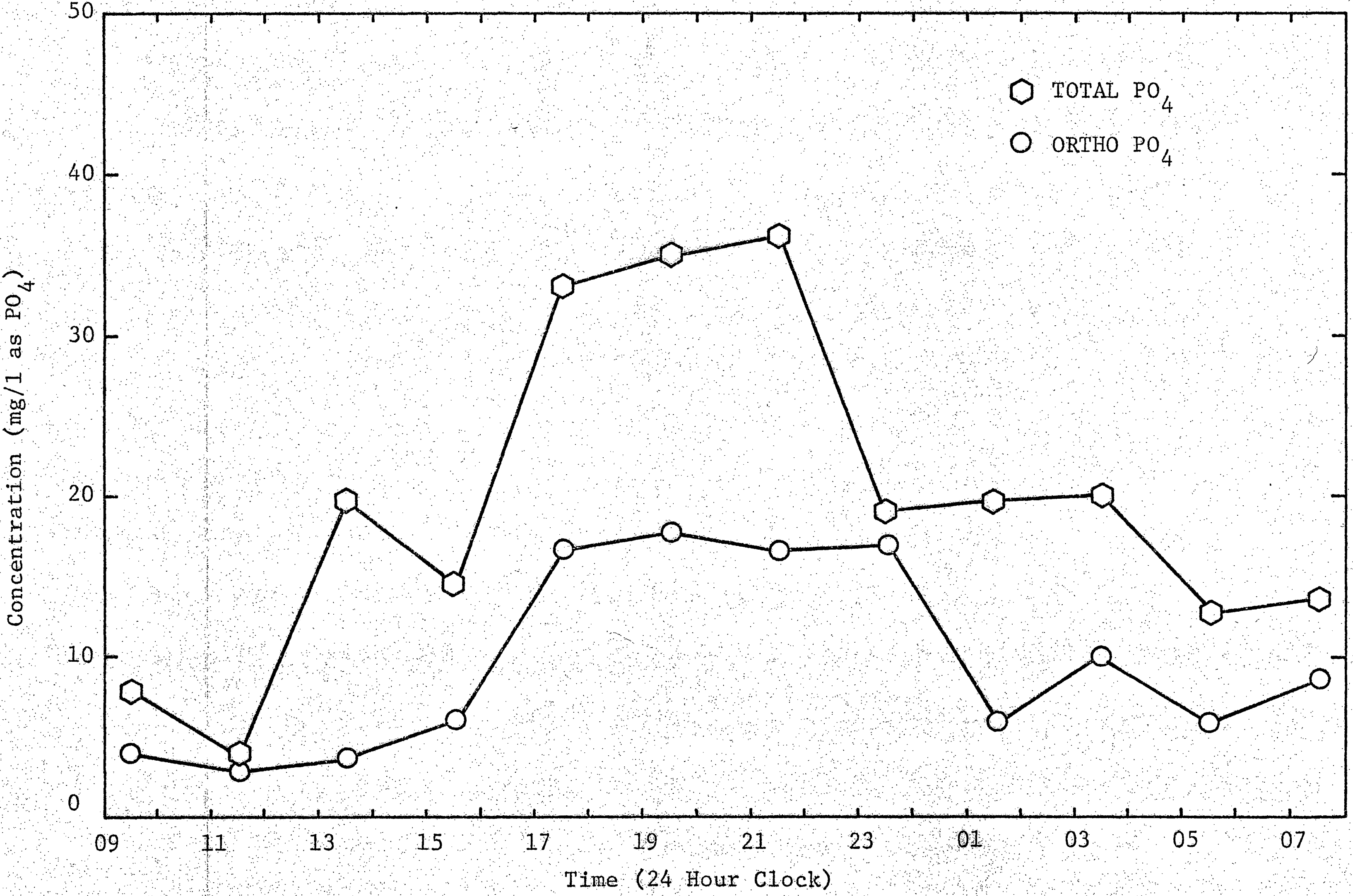

Figure 58: Diurnal Fluctuations in Phosphorus Loadings at Station 10 on 19 and 20 June 1971

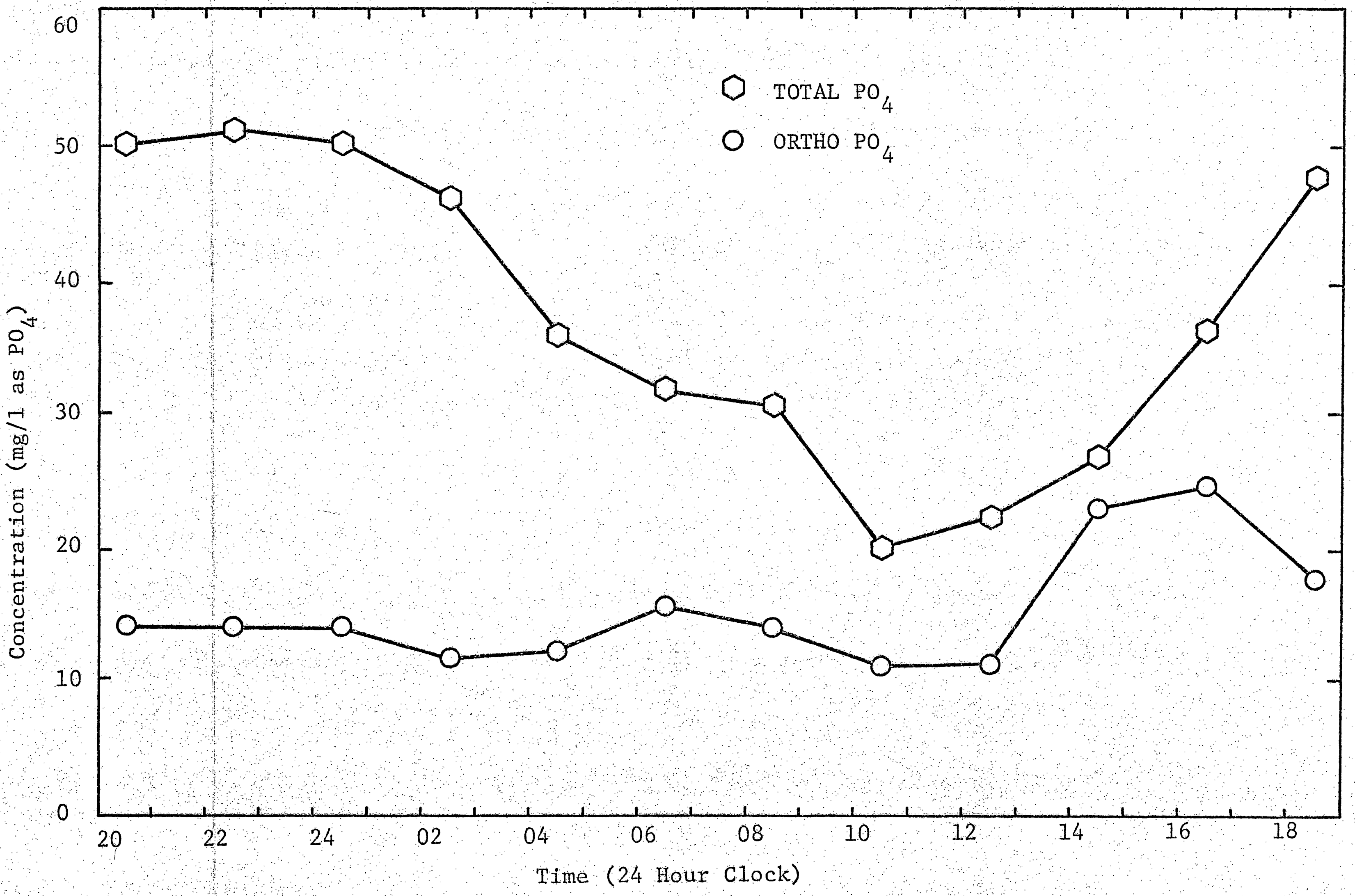

Figure 59: Diurnal Fluctuations in Phosphorus Loadings at Station 10 on 21 and 22 July 1971

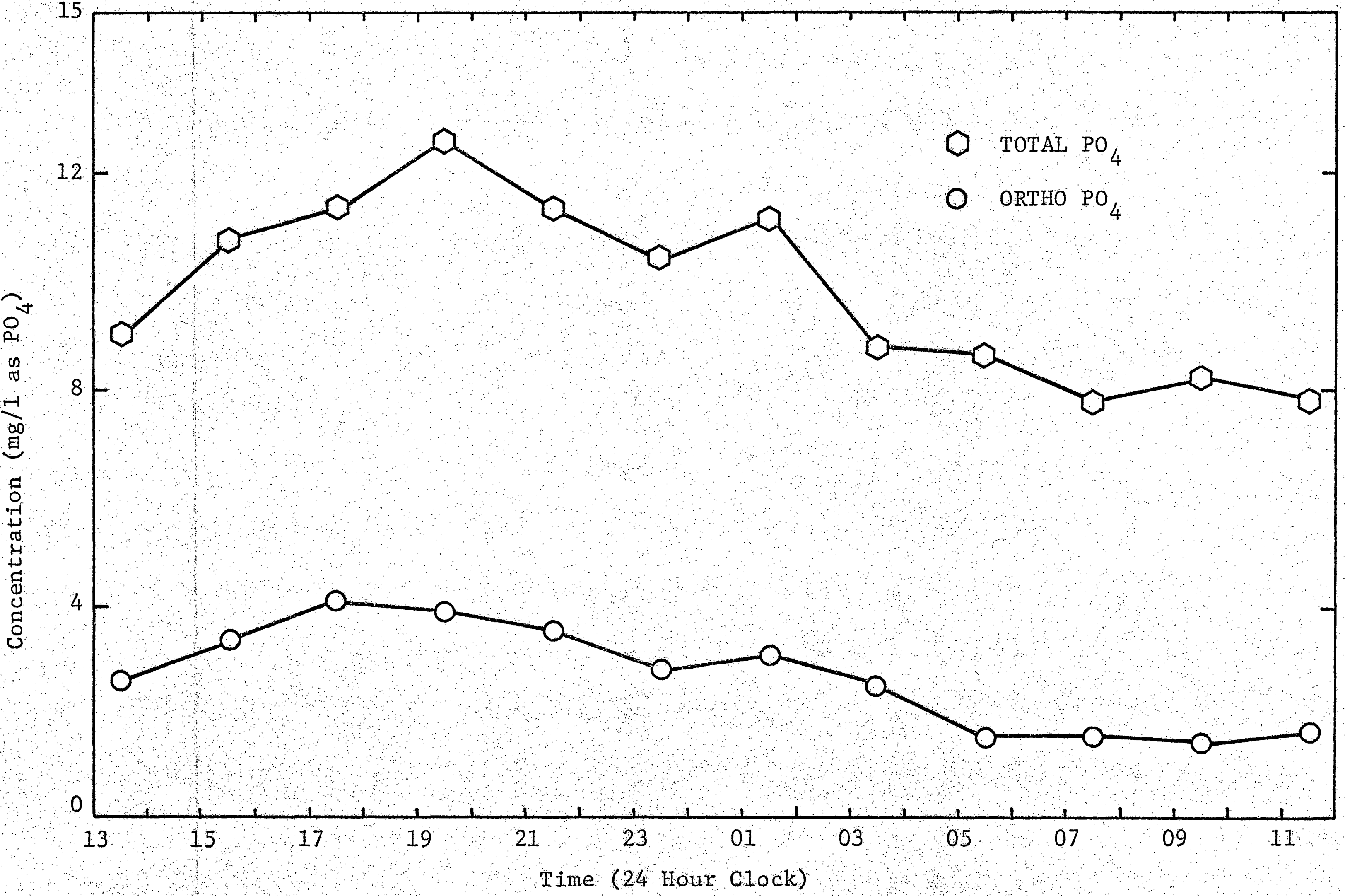

Figure 60: Diurnal Fluctuations in Phosphorus Loadings at Station 11 on 29 and 30 June 1971

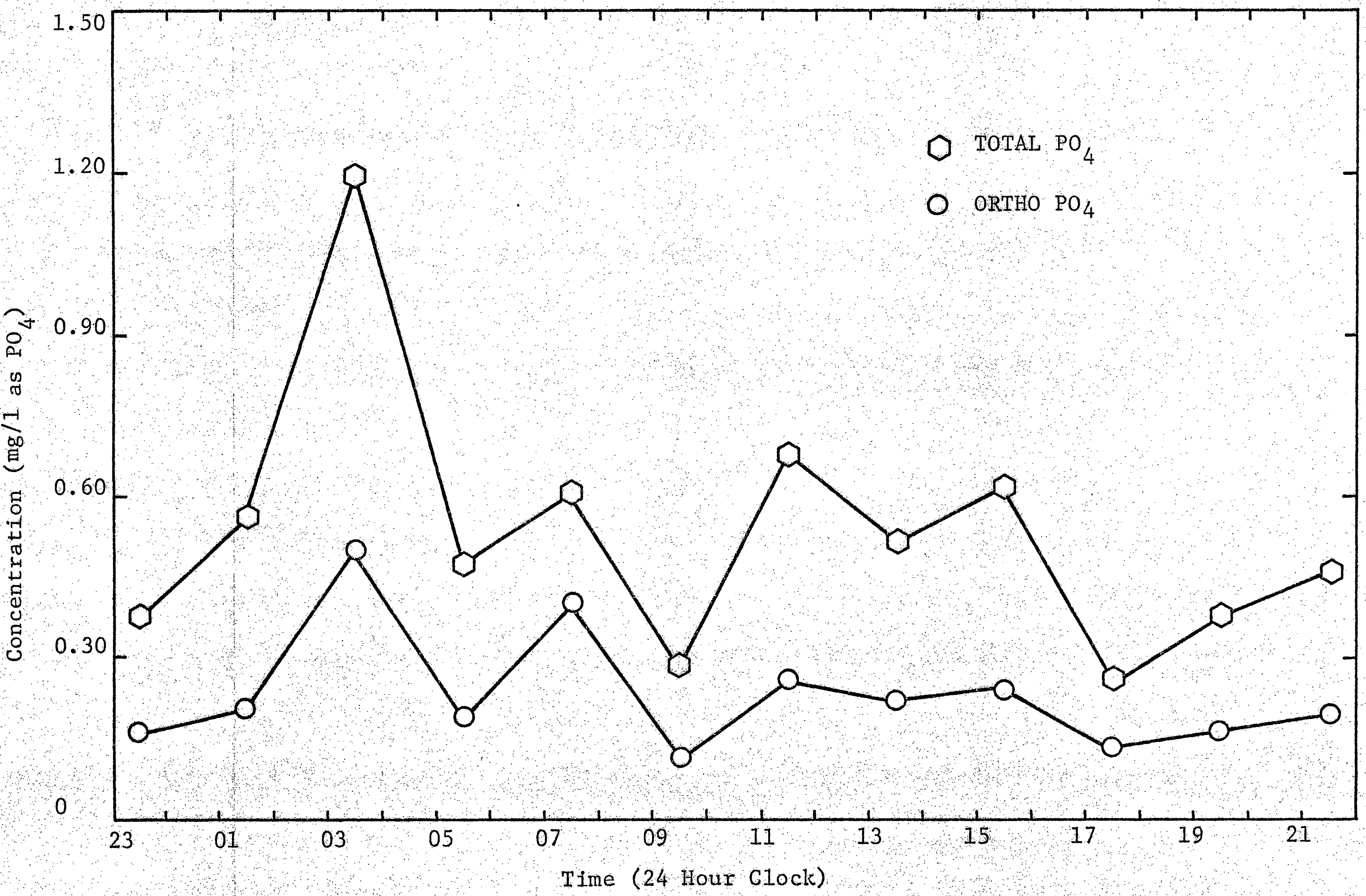

Figure 61: Diurnal Fluctuations in Phosphorus Loadings at Station 12 on 22 and 23 July 1971

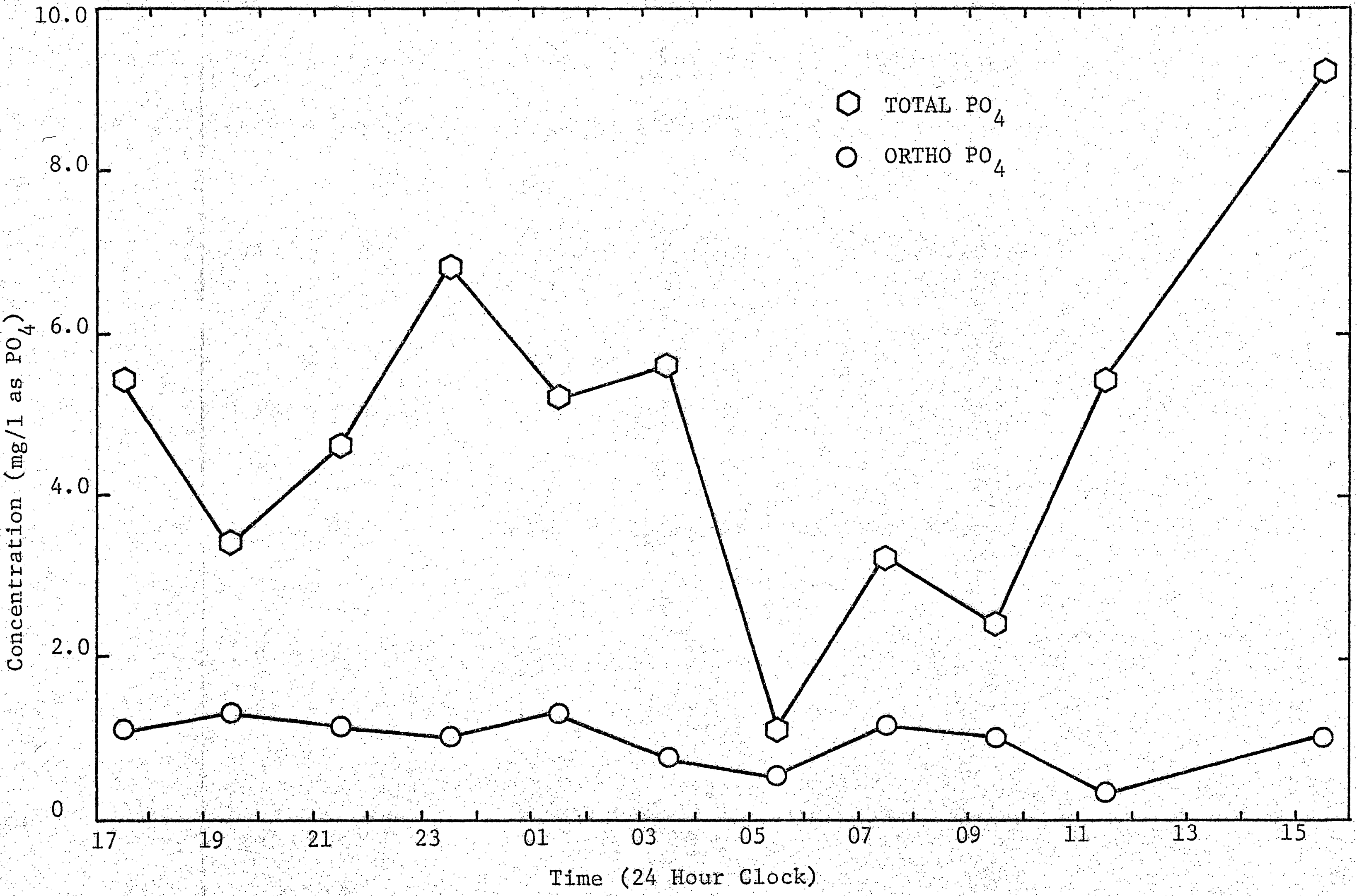

Figure 62: Diurnal Fluctuations in Phosphorus Loadings at Station 13 on 15 and 16 July 1971

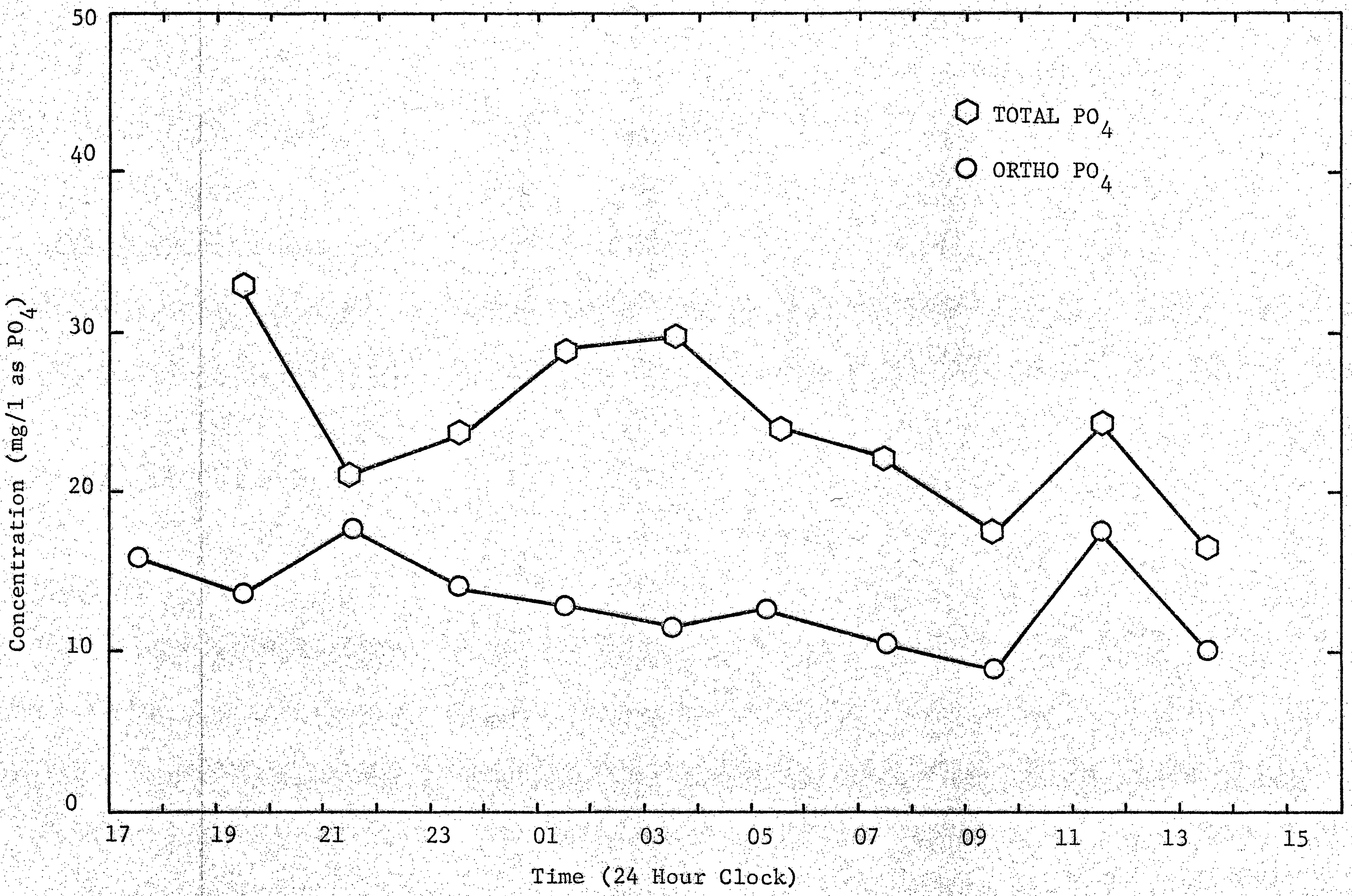

Figure 63: Diurnal Fluctuations in Phosphorus Loadings at Station 14 on 15 and 16 July 1971

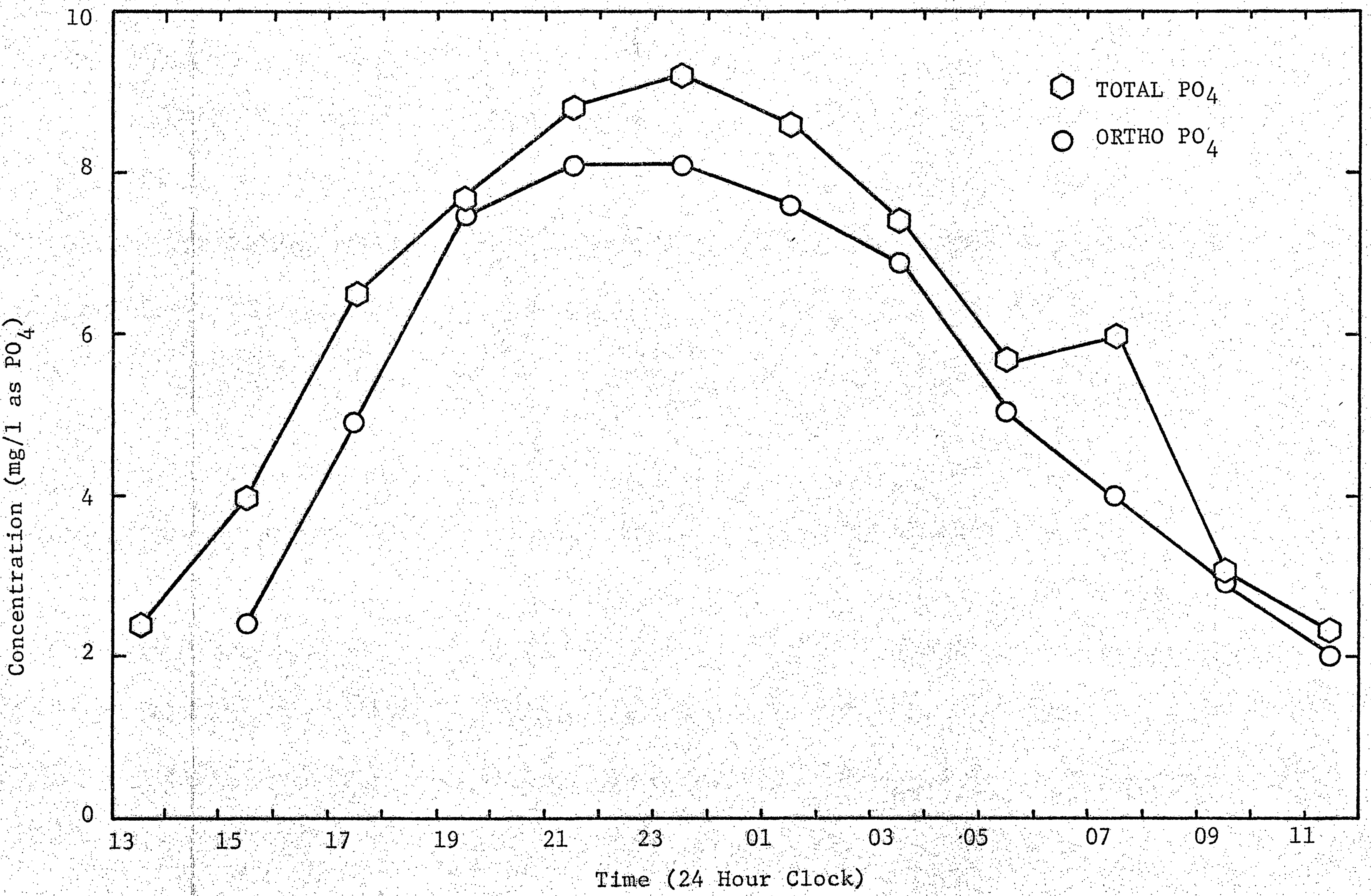

Figure 64: Diurnal Fluctuations in Phosphorus Loadings at Station 15 on 29 and 30 June 1971

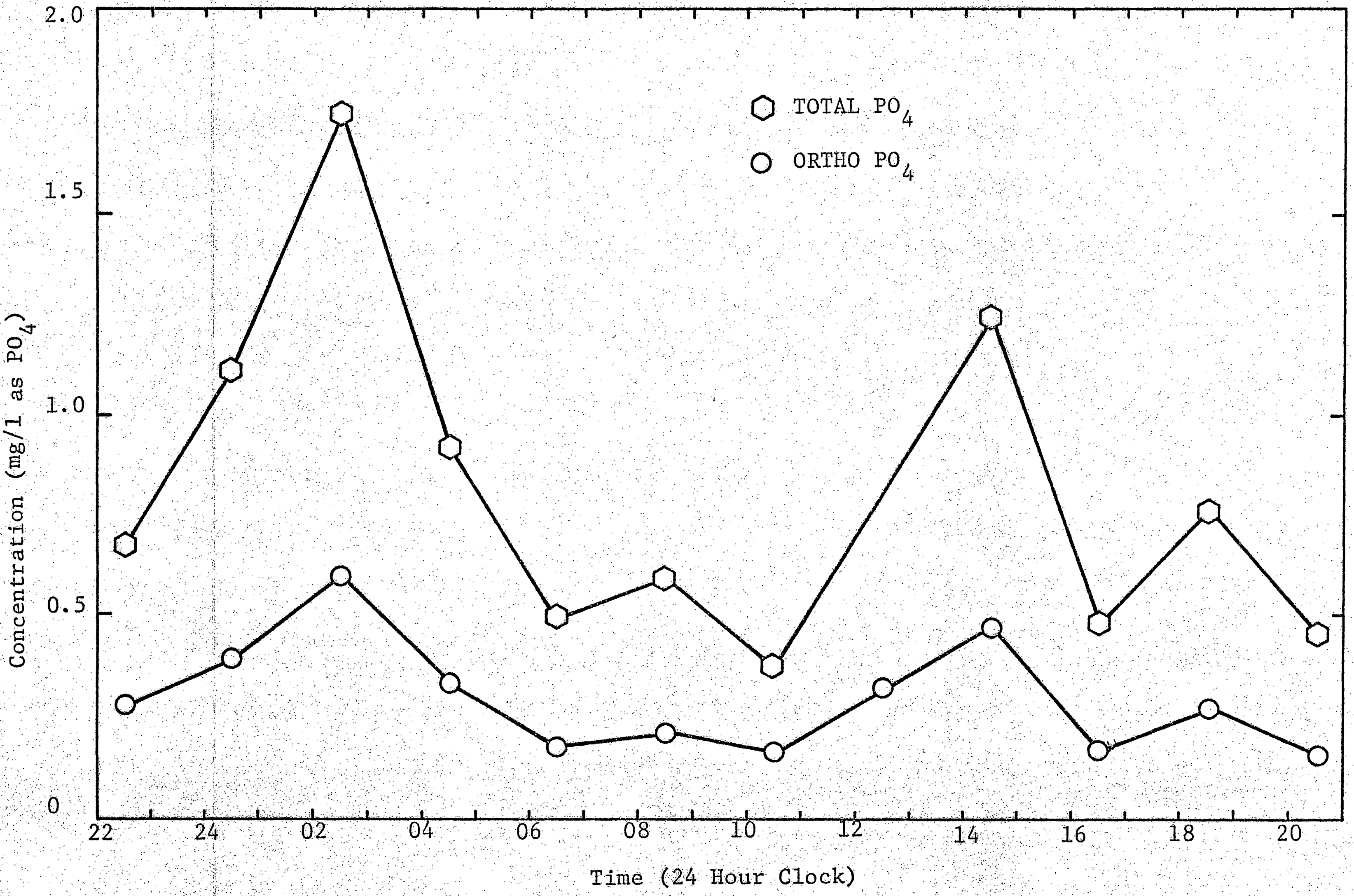

Figure 65: Diurnal Fluctuations in Phosphorus Loadings at Station 15 on 22 and 23 July 1971

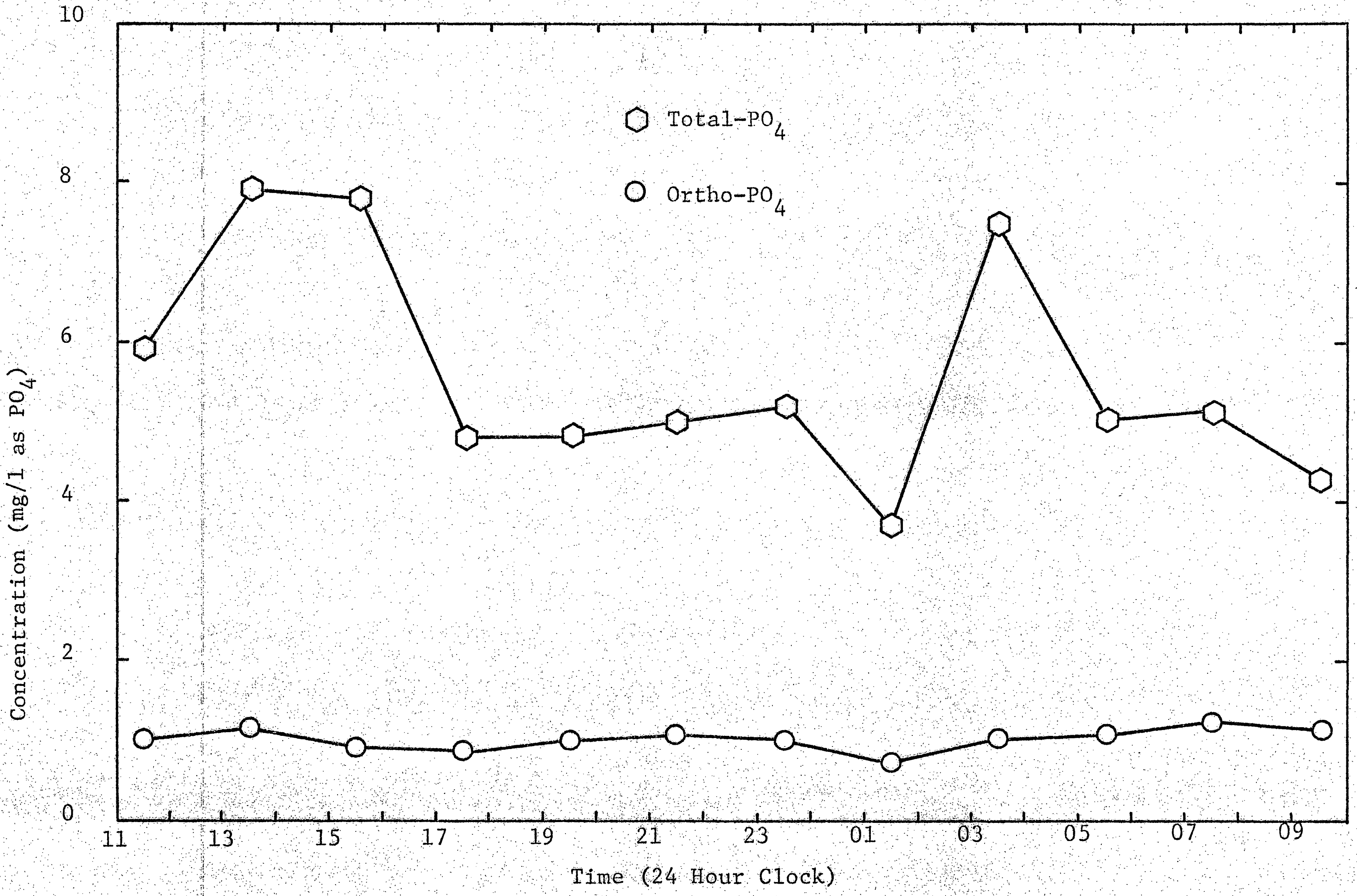

Figure 66: Diurnal Fluctuations in Phosphorus Loadings at Station 16 on 29 and 30 July, 1971

APPENDIX D

TABLE XIV

Observed Concentrations of Sodium, Potassium, Calcium, and Magnesium in mg/ℓ At Station 1

Date	Time Interval	Na	K	Ca	Mg
06-28-71	1200-1300	-	1.5	38.0	19.5
	1400-1500	2.60	1.5	38.0	20.5
	1600-1700	2.55	1.4	45.0	20.0
	1800-1900	2.40	1.4	44.1	19.5
	2000-2100	2.40	1.4	45.0	21.5
	2200-2300	2.55	1.5	45.0	20.0
06-29-71	2400-0100	2.40	0.9	46.0	21.0
	0200-0300	2.90	1.3	45.0	21.0
	0400-0500	2.75	1.2	44.6	21.0
	0600-0700	2.75	1.2	42.5	21.5
	0800-0900	2.75	1.1	45.0	20.5
	1000-1100	2.75	1.2	45.0	19.5

TABLE XV

Observed Concentrations of Sodium, Potassium, Calcium, and Magnesium in mg/ℓ At Station 2

Date	Time Interval	Na	K	Ca	Mg
06-28-71	1300-1400	-	1.5	36.6	19.0
	1500-1600	2.9	1.4	45.6	21.0
	1700-1800	2.32	1.4	43.6	20.0
	1900-2000	2.25	1.4	44.6	20.5
	2100-2200	2.75	1.5	45.6	21.0
	2300-2400	2.90	1.5	46.6	21.5
06-29-71	0100-0200	2.90	1.3	47.0	21.0
	0300-0400	2.90	1.3	45.0	22.0
	0500-0600	3.04	1.2	45.6	21.5
	0700-0800	3.04	1.5	44.0	20.5
	0900-1000	4.50	1.5	45.0	20.5
	1100-1100	3.25	1.5	44.6	21.5

TABLE XVI

Observed Concentrations of Sodium,
Potassium, Calcium, and Magnesium in mg/ℓ
At Station 3

Date	Time Interval	Na	K	Ca	Mg
07-08-71	1600-1700	2.25	4.1	48.0	19.0
	1800-1900	1.80	4.1	48.0	17.5
	2000-2100	1.0	4.1	48.0	18.0
	2200-2300	1.0	4.1	48.0	17.0
07-09-71	2400-0100	1.4	3.8	49.0	18.0
	0200-0300	1.4	4.4	48.0	19.0
	0400-0500	1.0	3.8	46.0	16.0
	0600-0700	1.8	3.8	47.0	17.0
	0800-0900	1.0	4.4	48.0	18.0
	1000-1100	0.8	4.1	46.0	19.0
	1200-1300	1.0	4.1	48.0	18.0
	1400-1500	1.0	4.4	49.0	19.0

TABLE XVII

Observed Concentrations of Sodium,
Potassium, Calcium, and Magnesium in mg/ℓ
At Station 4

Date	Time Interval	Na	K	Ca	Mg
07-27-71	1000-1100	4.3	1.8	45.5	14.0
	1200-1300	4.3	1.6	46.0	14.0
	1400-1500	3.8	1.6	45.5	13.5
	1600-1700	3.8	1.4	45.0	12.8
	1800-1900	3.8	1.4	45.0	12.0
	2000-2100	4.0	1.6	44.5	11.5
	2200-2300	4.3	1.4	45.0	11.2
07-28-71	2400-0100	4.3	1.6	45.5	12.0
	0200-0300	4.6	1.6	46.0	12.0
	0400-0500	4.9	1.6	46.0	12.0
	0600-0700	6.0	1.8	46.0	12.5
	0800-0900	5.8	1.6	47.0	13.0

TABLE XVIII

Observed Concentrations of Sodium, Potassium, Calcium, and Magnesium in mg/ℓ At Station 5

Date	Time Interval	Na	K	Ca	Mg
07-08-71	1700-1800	1.8	4.9	48.0	18.0
	1900-2000	1.8	4.9	48.0	17.0
	2100-2200	1.8	5.1	47.0	16.5
	2300-2400	1.8	4.7	48.0	17.0
07-09-71	0100-0200	1.8	4.7	47.0	16.0
	0300-0400	1.8	4.7	47.0	17.0
	0500-0600	1.4	4.1	46.0	10.0
	0700-0800	1.8	4.6	46.0	14.0
	0900-1000	1.8	4.9	48.0	18.0
	1100-1200	1.4	4.9	48.0	18.0
	1300-1400	1.8	4.9	47.0	14.0
	1500-1600	1.8	4.9	46.0	17.0

TABLE XIX

Observed Concentrations of Sodium, Potassium, Calcium, and Magnesium in mg/ℓ At Station 6

Date	Time Interval	Na	K	Ca	Mg
07-16-71	0800-0900	1.0	2.1	45.0	20.0
	1000-1100	1.4	2.2	45.0	20.0
	1200-1300	1.4	2.1	45.0	21.0
	1400-1500	1.4	2.2	45.0	21.0
	1600-1700	1.4	2.2	46.0	20.0
	1800-1900	1.4	2.1	46.0	20.0
	2000-2100	1.4	2.2	46.0	20.0
	2200-2300	1.4	2.2	46.0	20.0
07-17-71	2400-0100	1.4	2.2	47.0	22.0
	0200-0300	1.0	2.2	46.0	22.0
	0400-0500	0.7	2.2	46.0	22.0
	0600-0700	1.1	2.2	46.0	22.0

TABLE XX

Observed Concentrations of Sodium, Potassium, Calcium, and Magnesium in mg/ℓ At Station 7

Date	Time Interval	Na	K	Ca	Mg
07-16-71	0800-0900	2.3	2.2	46.0	18.5
	1000-1100	2.3	2.2	45.0	18.0
	1200-1300	1.8	2.2	45.0	19.5
	1400-1500	2.3	2.1	45.0	20.0
	1600-1700	3.2	2.1	45.0	19.5
	1800-1900	2.3	2.2	46.0	19.5
	2000-2100	1.4	2.2	45.0	21.0
	2200-2300	2.8	2.2	45.0	21.0
07-17-71	2400-0100	2.3	2.2	45.0	21.0
	0200-0300	2.3	2.1	46.0	21.0
	0400-0500	1.8	2.2	46.0	20.0
	0600-0700	2.3	2.1	46.0	19.0

TABLE XXI

Observed Concentrations of Sodium, Potassium, Calcium, and Magnesium in mg/ℓ At Station 8

Date	Time Interval	Na	K	Ca	Mg
07-06-71	1600-1700	0.7	3.8	40.0	14.0
	1800-1900	0.5	3.9	21.0	13.0
	2000-2100	1.0	3.9	19.0	11.5
	2200-2300	1.0	4.9	20.0	15.0
07-07-71	2400-0100	1.0	5.1	9.0	11.0
	0200-0300	–	–	–	–
	0400-0500	1.0	4.1	17.0	11.5
	0600-0700	1.0	4.1	20.0	10.0
	0800-0900	1.0	3.9	20.0	10.0
	1000-1100	1.0	3.9	23.0	12.5
	1200-1300	1.0	3.9	27.0	12.0
	1400-1500	1.0	3.4	41.0	14.5

TABLE XXII

Observed Concentrations of Sodium, Potassium, Calcium, and Magnesium in mg/ℓ At Station 9

Date	Time Interval	Na	K	Ca	Mg
06-19-71	1000-1100	2.75	2.22	40.5	20.0
	1200-1300	3.15	2.15	40.0	19.5
	1400-1500	3.15	2.35	38.5	20.2
	1600-1700	3.15	2.20	40.0	20.0
	1800-1900	3.15	2.10	38.2	19.5
	2000-2100	3.15	2.05	40.0	18.2
	2200-2300	3.15	1.95	38.5	20.0
06-20-71	2400-0100	3.15	1.95	38.5	20.0
	0200-0300	3.15	2.05	40.5	19.5
	0400-0500	2.75	1.72	41.0	18.5
	0600-0700	-	-	-	-
	0800-0900	3.15	2.22	37.7	19.0
*07-06-71	1600-1700	0.7	6.0	18.0	11.0
	1800-1900	1.0	4.3	12.0	12.0
	2000-2100	1.0	4.9	10.0	12.0
	2200-2300	1.0	3.8	22.0	14.5
07-07-71	2400-0100	1.0	4.9	23.0	12.0
	0200-0300	1.0	5.2	10.0	12.0
	0400-0500	1.0	7.8	9.0	10.0
	0600-0700	1.0	4.5	19.0	10.0
	0800-0900	1.0	3.8	18.0	10.0
	1000-1100	1.4	3.8	20.0	10.5
	1200-1300	0.7	3.8	25.0	12.0
	1400-1500	0.7	4.4	29.0	13.0

*Data taken on 07-06-71 and 07-07-71 during wet weather flow.

TABLE IIXX (Continued)

Observed Concentrations of Sodium, Potassium, Calcium, and Magnesium in mg/ℓ At Station 9

Date	Time Interval	Na	K	Ca	Mg
07-21-71	2000-2100	4.9	1.9	42.5	20.5
		5.4	2.1	44.0	20.5
07-22-71	2400-0100	4.9	1.8	44.5	21.0
	0200-0300	3.8	2.1	44.0	21.5
	0400-0500	5.4	2.4	42.5	22.0
	0600-0700	3.8	1.9	44.0	22.0
	0800-0900	4.3	2.1	44.0	20.8
	1000-1100	3.8	1.9	44.0	20.8
	1200-1300	5.4	1.8	40.5	19.0
	1400-1500	4.9	1.8	42.5	21.0
	1600-1700	4.9	2.1	42.5	22.0
	1800-1900	4.9	2.1	42.0	22.2

TABLE XXIII

Observed Concentrations of Sodium,
Potassium, Calcium, and Magnesium in mg/ℓ
At Station 10

Date	Time Interval	Na	K	Ca	Mg
06-19-71	0900-1000	75.0	6.3	31.2	19.5
	1100-1200	81.0	6.7	30.2	20.0
	1300-1400	87.0	6.6	34.2	18.5
	1500-1600	85.0	6.1	37.0	20.0
	1700-1800	94.0	6.8	35.0	21.2
	1900-2000	85.0	7.7	33.0	19.7
	2100-2200	86.0	8.0	30.5	19.2
06-20-71	2300-2400	96.0	8.1	28.5	18.7
	0100-0200	97.0	7.9	29.2	19.0
	0300-0400	95.0	7.5	31.5	19.2
	0500-0600	95.0	6.1	33.7	20.2
	0700-0800	85.5	5.8	30.5	19.7
07-21-71	2000-2100	130.0	15.2	3.5	7.0
	2200-2300	134.0	15.5	2.5	6.5
07-22-71	2400-0100	144.0	15.0	5.0	7.0
	0200-0300	144.0	14.5	10.0	7.8
	0400-0500	134.0	14.0	12.0	8.8
	0600-0700	130.0	13.5	13.5	9.0
	0800-0900	130.0	12.5	15.5	8.8
	1000-1100	130.0	11.2	19.0	9.0
	1200-1300	140.0	11.0	19.0	8.5
	1400-1500	134.0	11.5	17.0	9.5
	1600-1700	124.0	14.0	14.0	8.5
	1800-1900	116.0	14.8	15.0	8.0

TABLE XXIV

Observed Concentrations of Sodium, Potassium, Calcium, and Magnesium in mg/ℓ At Station 11

Date	Time Interval	Na	K	Ca	Mg
06-29-71	1300-1400	14.9	3.4	40.5	21.0
	1500-1600	14.6	3.3	41.5	21.0
	1700-1800	15.2	3.6	42.5	21.0
	1900-2000	16.0	3.7	42.5	22.0
	2100-2200	15.2	3.4	43.0	23.0
	2300-2400	15.2	3.1	44.5	23.0
06-30-71	0100-0200	14.5	3.5	47.0	21.5
	0300-0400	17.0	3.4	45.5	23.0
	0500-0600	13.0	3.3	48.0	24.0
	0700-0800	14.0	3.4	47.0	24.5
	0900-1000	14.0	3.1	47.5	24.0
	1100-1200	13.6	3.3	47.5	24.5

TABLE XXV

Observed Concentrations of Sodium, Potassium, Calcium, and Magnesium in mg/ℓ At Station 12

Date	Time Interval	Na	K	Ca	Mg
07-22-71	2300-2400	4.3	2.1	49.0	22.0
07-23-71	0100-0200	3.8	2.1	49.5	21.8
	0300-0400	3.8	1.9	49.5	21.2
	0500-0600	3.8	1.8	50.0	21.0
	0700-0800	3.8	1.9	49.5	21.2
	0900-1000	4.9	2.1	49.0	21.5
	1100-1200	4.9	2.1	48.5	21.5
	1300-1400	4.9	1.9	49.0	21.5
	1500-1600	4.9	2.1	48.0	20.0
	1700-1800	7.5	2.1	48.5	20.0
	1900-2000	5.4	1.9	48.5	20.5
	2100-2200	4.3	2.1	49.0	22.0

TABLE XXVI

Observed Concentrations of Sodium,
Potassium, Calcium, and Magnesium in mg/ℓ
At Station 13

Date	Time Interval	Na	K	Ca	Mg
07-15-71	1700-1800	-	2.9	-	-
	1900-2000	14.0	2.9	44.0	15.0
	2100-2200	9.4	2.9	47.0	17.5
	2300-2400	11.5	2.4	47.0	15.5
07-16-71	0100-0200	10.0	2.4	45.0	16.5
	0300-0400	8.6	2.4	48.0	16.5
	0500-0600	8.0	2.7	45.0	15.5
	0700-0800	11.5	2.9	48.0	16.5
	0900-1000	11.0	2.9	47.0	17.0
	1100-1200	14.0	2.9	44.0	17.5
	1300-1400	13.0	2.9	48.0	16.0
	1500-1600	9.3	2.7	44.0	16.0

TABLE XXVII

Observed Concentrations of Sodium, Potassium, Calcium, and Magnesium in mg/ℓ At Station 14

Date	Time Interval	Na	K	Ca	Mg
07-15-71	1700-1800	58.0	11.5	-	2.0
	1900-2000	52.0	10.5	-	2.0
	2100-2200	14.0	2.9	1.0	1.5
	2300-2400	47.0	11.0	0.5	1.0
07-16-71	0100-0200	45.0	10.8	1.0	3.0
	0300-0400	63.0	20.5	-	2.0
	0500-0600	39.0	10.2	1.0	2.0
	0700-0800	39.0	9.4	2.0	3.0
	0900-1000	64.0	9.0	-	4.0
	1100-1200	60.0	11.0	-	2.5
	1300-1400	15.0	2.9	2.0	3.0
	1500-1600	-	-	-	-

TABLE XXVIII

Observed Concentrations of Sodium,
Potassium, Calcium, and Magnesium in mg/ℓ
At Station 15

Date	Time Interval	Na	K	Ca	Mg
06-29-71	1300-1400	46.0	4.0	30.0	21.0
	1500-1600	43.0	4.1	31.0	21.0
	1700-1800	44.0	4.4	31.5	20.5
	1900-2000	44.0	4.2	31.5	20.0
	2100-2200	46.0	4.6	31.0	19.5
	2300-2400	46.0	4.5	31.5	21.0
06-30-71	0100-0200	49.0	4.3	32.0	19.0
	0300-0400	41.0	4.0	32.0	20.0
	0500-0600	32.0	3.5	33.0	22.0
	0700-0800	31.0	3.4	33.5	21.0
	0900-1000	44.0	3.7	34.0	21.5
	1100-1200	55.0	3.2	35.0	21.0
07-22-71	2200-2300	10.8	3.0	45.0	20.0
07-23-71	2400-0100	8.0	2.8	45.0	19.0
	0200-0300	8.0	2.8	46.5	21.0
	0400-0500	8.0	3.0	46.5	21.5
	0600-0700	8.8	3.2	46.5	21.8
	0800-0900	8.0	3.2	47.0	22.0
	1000-1100	9.0	3.0	47.0	21.5
	1200-1300	10.8	3.1	47.0	21.2
	1400-1500	10.0	3.2	47.0	21.0
	1600-1700	12.2	3.1	46.0	21.0
	1800-1900	13.0	3.0	47.0	20.5
	2000-2100	12.0	3.2	47.0	20.0

TABLE XXIX

Observed Concentrations of Sodium, Potassium, Calcium, and Magnesium in mg/ℓ At Station 16

Date	Time Interval	Na	K	Ca	Mg
07-29-71	1100-1200	41.0	-	26.0	10.0
	1300-1400	20.0	3.6	45.0	16.5
	1500-1600	8.0	1.1	43.0	9.0
	1700-1800	15.5	3.0	46.5	16.0
	1900-2000	21.5	4.5	49.0	20.0
	2100-2200	23.5	4.7	49.5	20.0
	2300-2400	25.0	4.7	49.5	20.0
07-30-71	0100-0200	28.0	4.5	49.5	20.0
	0300-0400	28.0	4.5	49.0	19.5
	0500-0600	28.0	4.3	49.0	19.5
	0700-0800	28.0	4.5	49.0	19.8
	0900-1000	28.0	4.7	49.0	19.2

SOURCES AND YIELDS OF NUTRIENT AND ORGANIC LOADINGS IN THE ROANOKE RIVER BASIN ABOVE SMITH MOUNTAIN LAKE, VIRGINIA

by

Thomas J. Grizzard, Jr.

(ABSTRACT)

Sources and yields of nutrient and organic loadings in the Upper Roanoke River Basin were investigated during the summer low flow period of 1971. Parameters monitored at sampling stations in the basin included biochemical oxygen demand, chemical oxygen demand, total organic carbon, total phosphate, orthophosphate, Total Kjeldahl Nitrogen, nitrate nitrogen, sodium, potassium, calcium, and magnesium. These data were used in conjunction with flow and drainage area data to determine the relative magnitude and daily yields of nutrient and organic yields from various sources.

Sources of nutrient and organic materials entering the basin included rural and urban land drainage, and domestic and industrial wastewater effluents. The yields of materials from the various sources were computed in order to determine the magnitude of each in contributing to the fertilization of Smith Mountain Lake.

The domestic wastewater effluents were found to be the prime contributors of organic carbon, nitrogen, and phosphorus in the upper basin.

Urban land drainage was found to be the major runoff source of phosphorus, while rural land found to be the greatest drainage source of nitrogen.

It was found that diversion of all wastewater effluents in the tributary watershed would not reduce the concentration of macronutrients in the Roanoke River flow to the levels generally promulgated as being adequate to support excessive productivity in lenitic aquatic environments.