

THE ATMOSPHERIC CONTRIBUTION OF PHOSPHORUS  
TO AN AQUATIC SYSTEM

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## CHAPTER I

### INTRODUCTION

As many cities are becoming increasingly aware of the scarcity of adequate and desirable water resources, they must have a greater concern for the preservation of existing supplies. Because pure water is a threatened resource, knowledge of pollutant levels and identification of both point and non-point pollutant sources are a necessity.

Water resources can be affected by a multitude of pollutants in our environment. Pollutants may give a direct effect such as toxic chemicals or an indirect effect such as one with a high BOD. Some elements or compounds are pollutants only when present in excessive amounts. Nitrogen and phosphorus, elements essential to all living things, are only required in such small amounts that they are of concern to water quality control. Phosphorus, according to Sawyer (1), has a critical level of approximately 10 ppb. More recent investigations show critical levels of phosphorus can result in tremendous algal blooms and other forms of noxious growth that can lead to rapid water quality deterioration. Most water resources are either phosphorus or nitrogen limited, meaning that the concentration of phosphorus or nitrogen must increase in order for growth to occur in excess of that currently taking place. Gakslatter (3) in his study of 623 lakes found 417 (67%) to be phosphorus limited, while 187 (30%) were nitrogen limited. The lakes dealt with in his study received

municipal secondary sewage treatment plant effluents, otherwise, the percent of those phosphorus limited would have greatly increased.

Not all forms of phosphorus are immediately available for algal growth. Organic and inorganic phosphorus must be subjected to microbial attack and hydrolysis before they may be utilized by algae (4). Orthophosphate is the form most readily available to algae and can cause immediate algal blooms possibly leading to a deterioration in water quality.

It is because of the small concentration required that phosphorus control as a limiting nutrient becomes increasingly difficult. There are four major avenues for input of phosphorus to aquatic systems: watershed, tributaries, direct discharge and atmosphere. All have been examined extensively, with the atmosphere as a possible exception. Therefore, it is the purpose of this paper to examine the atmosphere as a source of phosphorus to Lake Carl Blackwell and to conclude as to its significance as a non-point source of phosphorus to this aquatic system.



## CHAPTER II

### LITERATURE REVIEW

The literature regarding atmospheric contributions of phosphorus indicates great variability in the methods utilized in individual studies. Several forms and atmospheric phases of phosphorus were studied using a multitude of techniques. Accordingly, results, conclusions and opinions regarding phosphorus are sometimes quite conflicting. An attempt is made in this review to assemble the various methods of studying atmospheric phosphorus, as well as, the results and conclusions established.

#### Definitions

Since many different forms of phosphorus in many different atmospheric phases have been collected and studied, it is important that they be defined in order to facilitate an understanding of techniques and results to follow:

Ortho-phosphate (Phosphate). The soluble reactive form of phosphorus existing as free phosphate ions that is most readily utilized by plant life. From 35% to 50% of total phosphorus.

Total Phosphorus. All forms of phosphorus present in a sample regardless of its chemical nature.

Dry Fallout (Particulate or aerosol). An atmospheric phase of phosphorus added to the ecosystem during the absence of rain, snow or

other forms of precipitation. Occurs either by gravity settling of aerosols or direct impaction.

Precipitation. A phase of phosphorus dissolved or suspended in rain, snow or other forms of precipitation.

Bulk Precipitation. A mixture of the precipitation and dry fallout phases of phosphorus.

### Atmospheric Phosphorus

Phosphorus in the atmosphere exists as a dry, suspended or dissolved solid. It never exists in a gaseous phase. Phosphorus remains in the atmosphere until it settles out due to gravity or is removed with precipitation. The time a particle remains suspended is largely a function of its size. In a study by Lee (5), the mass mean diameter of a particle containing phosphorus was 3.7 to 3.9 microns, which indicated a reasonably long atmospheric residence time. He further pointed out that particle size can grow through condensation and coagulation, thus having a large effect on residence time. Support of this was given by Peterson (6) who stated that possible changes in forms of chemicals can take place in the atmosphere through coagulation with particles of different origins. Fifty percent of all suspended substances are water soluble, and modifications due to homogenous or heterogenous gas or particle reactions can take place. Residence time can further be influenced by climate and general atmospheric circulation and geographical location, as related by Sievering (7). Climate and breeze cell circulation around large bodies of water can serve to suspend and to concentrate pollutants on a mesoscale. Breeze cell circulation was found to result in high

concentrations of pollutants (7).

Atmospheric phosphorus is the result of direct emissions or entrainment by winds, but few researchers have elaborated on possible phosphorus sources. Of those investigators reviewed only one had prepared tables of emission inventories. Of the possible sources of atmospheric phosphorus, Murphy (8) considered fertilized manufacturing to be the major source. Twenty five percent of the emissions from this industry were phosphorus, and he calculated the annual phosphorus input to the atmosphere to be 41,700 metric tons per year. In order of decreasing significance, Murphy stated phosphorus sources to be forest fires, agricultural burning, wind blown soil, chemical manufacturing and phosphate rock mining. Sittig (9) listed pesticide manufacturing and industrial emissions as primary sources and the use of crude oil and coal in boilers and furnaces as secondary sources.

Sources considered by other researchers included agricultural activities, sewage treatment activities, and industrial emissions (5) (10). Approximately 40% of all atmospheric phosphorus was of natural origin (8). Natural sources included pollens, seeds, bird droppings, microorganisms and natural phosphates such as phosphorites and apatites (5) (11).

As previously stated, there were four basic avenues for phosphorus input to a body of water: direct discharge, tributaries, atmosphere and watershed. Atmospheric input results from fallout, precipitation or both. According to Schrauphagel (12) only 1.2% of the phosphorus found in Wisconsin waters was contributed by precipitation. Stewart (13) also agreed that precipitation was an insignificant source of phosphorus when compared to that contributed by soil

and man's activities. With respect to agricultural and lake management, nitrogen studies were considered to be of more importance than studies concerning the contribution of phosphorus via bulk precipitation. Other sources of phosphorus are considered to be of greater importance than bulk precipitation (10). However, Rich (14) cited the Dillon-Rigler model as predicting that more than one third of the total phosphorus in a heavily urbanized area came from the atmosphere. In a Great Lakes study, 5.5% to 13.9% of the total phosphorus loading came from the atmosphere via bulk precipitation (15). Sievering (7) also agreed that air borne pollutants contributed to a significant degree to large water-body pollution. Murphy (8) stated that one fifth to one third of all phosphorus going into Lake Michigan was scavenged from the atmosphere. Fish (16) commented that 5% of all reactive phosphorus came from the rain. In a study of the nutrients supplied to the northern lakes by the atmosphere, 63% was found to be in the reactive form and 73% was reported as total soluble phosphorus (17). Of that phosphorus added to a body of water, from 50% to 90% has been found to remain (4).

Of the many different forms of phosphorus studied by Whitehead (18), bulk precipitation was found to be the most geochemically significant in the contribution of mineral salts to surface and groundwater and in the nourishment of plants. He also found it to be the most significant form in the study of atmospheric contributions of minerals to aquatic systems.

#### Sampling Methods

Researchers showed continued variability in the sampling methods

used for phosphorus collection, and the variability to some extent was dependent on the form or phase of phosphorus collected. A V-shaped plate glass trough exposed only during rainfall was utilized by Fish (16). Whitehead (18) used a four foot square polyethylene sheet that drained into a jar for the collection of bulk precipitation. Murphy (8) simply used open plastic or glass containers for the collection of precipitation and collected particulate matter separately with a high volume sampler. However, he chose to omit particulate matter from his results after stating that it was only representative of the area immediately surrounding the sampler; but he did go on to state that the larger the particle, the greater the chance of local origin. Fish (16) also omitted fallout from his results.

Of the sampling methods used, most researchers chose the use of polyethylene funnels connected to polyethylene collection bottles (15) (19) (20) (21) (22). This choice was also supported by Galloway (19) who researched various sampling systems and methods employed for the collections of direct fallout by gravity. Results showed that the collectors with the best efficiency were plastic funnels connected to plastic collection bottles by plastic tubing. The tubing acted as a vapor trap and slowed evaporative losses (19). Galloway pointed out that the use of glass can severely contaminate samples and therefore recommended the use of plastic for the collection of inorganic compounds. Wide mouth cylinders were recommended for snow collection. Gore (20) and Shiomi (15) equipped their funnels with gauze or glass wool to filter out insects and other possible contaminants. Some researchers also provided bird prongs

around funnels to eliminate possible contaminants from birds (15) (21).

Shiomi (15) and Allen (21) protected their collection bottles from exposure to light in order to inhibit growth of algae, thus eliminating uptake of ortho-phosphate. However, this provided no significant protection of the sample from bacterial action. Heron (23) suggested the use of iodine impregnated bottles to prevent interference from microorganisms. This method was also used by Allen (21). Other possible interferences with sampling included adsorption of phosphorus onto sides of polyethylene containers (15) dust and smoke (20) and location of samplers.

Location of samplers on a microscale included keeping the funnel next to the ground (20), keeping it above the splash level (21), placement on roof tops (16) (18) and placement of at least one meter above roof tops (8). On a mesoscale, Shiomi (15) showed a positive relationship between atmospheric loading and the degree of urbanization; but, pointed out that there was little apparent relationship between sampler location and phosphorus concentration. This indicated that industrial areas were not large sources of phosphorus in bulk precipitation since his samplers were located in a highly industrialized area. Allen (21) also concluded that nutrient quantities were not affected by distance from influencing sources. However, the increase in nutrient loading from a watershed was proportional to the increase in percent of land in agricultural usage (24). Since the fraction of emissions deposited increased with particle sizes (25) and a major fraction of phosphorus was lost from cultivated fields in association with particulate matter (26), the

location of samplers with respect to land usage and influencing sources becomes increasingly important. This was supported in the results of research by Swank (24). Phosphorus was shown to vary as much as 0.36 kg/ha/yr depending on sampler location.

Frequency of sample collection also varied among researchers. Murphy (8), Galloway (19), and Fish (16) placed samplers immediately prior to a precipitation event and collected them as soon as possible afterwards. Allen (21) collected samples weekly and compiled them into monthly samples. Gore (20) did not collect samples from the field until 1000 ml had accumulated. For storage prior to analysis, Murphy (8) and Allen (21) froze their samples.

#### Phosphorus Analysis

Many different analytical methods were used in determination of phosphorus in samples. Gales' (27) persulfate oxidation method for conversion of organic phosphorus to ortho-phosphate was most widely utilized (5) (13) (15) (26). Other versions of digestion were employed by Murphy (8), Galloway (19) and Allen (21). Total phosphorus was determined by Fish (16) after oxidation of the sample by mercury-lamp irradiation. Barcia (17) oxidized his samples using the Armstrong and Tibitts (28) method of photochemical combustion. Prior to digestion, Lee (5) fractionated samples using an Anderson cascade impactor.

For analysis of ortho-phosphate, the Murphy-Riley (29) method was used by Barcia (17), Murphy (8) and Fish (16). Some researchers determined ortho-phosphate on filtered and/or unfiltered samples (8) (20). Other methods used included autoanalyzers (15) (19) and

modifications of the stannous chloride method outlined in Standard Methods (30) that produced detectable limits to  $3 \times 10^{-4}$ mg/l phosphate.

### Results

The results of those researchers reviewed were by no means consistent, with the possible exception that all atmospheric phosphorus concentrations and quantities were low. However, as previously stated, phosphorus needed only to be present in small quantities to have an impact on aquatic systems. The variability in results was due to one or a combination of many factors such as sampler location, chemical and/or atmospheric phase of phosphorus collected, period of sampling, volume of sample collected, time of year, analytical methods, etc.

Regarding atmospheric phases of phosphorus collected, inconsistency prevailed again with researchers collecting precipitation only, bulk precipitation only, fallout or any combination of the three. Analysis included ortho-phosphate, total phosphate, or combinations and variations of these forms, such as soluble ortho- or total phosphate. According to Gatz (25) the annual wet and dry deposition were approximately equal. Whitehead (18) commented that bulk precipitation was 4 to 10 times more concentrated than rainfall. In a study by Galloway (19) concerning the influence of bulk on wet precipitation, it was found that dry deposition contributed significantly to the composition of the bulk sample year round. He attributed this to collector design. His results showed poor comparison of phosphorus concentrations found in bulk to that in wet precipitation during the period from August to November, while using a funnel collector for precipitation and a cylinder for fallout. Good comparison was found



between December and March, while using cylinders for both precipitation and fallout. Also, he concluded that dry deposition can severely affect the chemical composition of rain and snow, regardless of the collection method used.

Kluesener (11) claimed that the phosphorus value from dustfall was three times that of rainfall. However, in a study on Great Lakes precipitation chemistry, Shiomi (15) pointed out that even though a substantial part of the atmospheric contribution of phosphorus may be in the particulate phase, the overall impact on a lake or body of water will be dependent on the solubility and reactivity of the phosphorus. Of the total atmospheric phosphorus collected in their studies, Shiomi (15) and Murphy (8) claimed that approximately 50% was soluble and reactive. This was conflicting with a study regarding nutrient input into a New Zealand lake by Fish (16) which claimed that of the total reactive phosphorus added to the lake he studied, the atmosphere accounted for only 5%. This obvious implication of more important phosphorus sources was somewhat supported by Stewart (13). His results agree that phosphorus from precipitation was insignificant when compared to that contributed by soil and human influence. He did, however, comment that if the total phosphorus striking the watershed did reach the lakes studied, it would have contributed approximately 43% of the phosphorus budget. He goes on to relate the unlikelihood of this occurring due to the uptake of nutrients by vegetation and soil.

A study of contributions made from a record snowfall in comparison with two days of rainfall, during the month of December in Ohio, showed that snowfall contributes 49.9% of the discharge from the

watershed and 8% of the phosphorus, while, the rainfall contributed 28% of the discharge and 6% of the phosphorus. The study therefore concluded that less nutrients come from the watershed from snow melt than were added through snowfall. Also, more phosphorus was contained in runoff of rainfall than was added (31). All in all, it was established that little phosphorus was stripped from runoff over impermeable surfaces or by unimpeded flows.

According to Jones (26) most phosphorus input comes with spring runoff and periods of high rainfall. He calculated the annual contribution of total phosphorus in rainfall to be 0.32 kg/ha over the area he studied. In a study regarding sources of nutrients in a Canadian lake, Hetling (32) commented that only 2% of the total phosphorus contributions came from rainfall and dustfall. He presented figures from 118 to 350 lb/sq.mi/yr. These figures allow for a contribution of 100 kg of phosphorus per year into the lake itself.

Variations of phosphorus with time and distance from influencing sources were recognized by Allen (21). He cited that phosphorus inputs vary from 0.2 to 1.0 kg/ha/yr. In reported data from Armstrong (33), total dissolved phosphorus concentrations were 0.018 mg/l and 0.0095 mg/l, for rain and snow respectively. At a Mays Point, New York (30) bulk precipitation sampling station, total phosphorus concentrations from 0.003 mg/l to 0.087 mg/l were reported, with a mean of 0.022 mg/l; whereas, 100 mg/l and 130 mg/l concentrations were reported in Sweden and France, respectively. For precipitation collected by Murphy (8), phosphorus input yielded an average concentration of total phosphorus of 0.034 mg/l and the average annual contribution for 74 cm of precipitation was 0.25 kg/ha. He also reported a phosphorus

concentration from an average of snowfall samples to be 0.034 mg/l. Fish (16) presented 0.057 g/ha-mm as the ortho-phosphate contribution from precipitation in New Zealand for 341 mm of rainfall over a 20-month period. This is equivalent to an annual contribution of 0.0117 kg/ha/yr. He also pointed out that the ortho-phosphate fraction was 78.4% of the total phosphorus collected.

In a study of nitrogen and phosphorus contributions from the atmosphere, Chapin (10) cites that high concentrations vary with location and time of year. Delaware had high concentrations in the summer, whereas, England had high concentrations in December, March and June. Table I contains total phosphorus levels at several different geographical locations (10). Shiomi (15) recorded the mean concentration, in a study on Lake Ontario, to be 0.058 mg/l from January to December, but shows an April to November mean of 0.068 mg/l over the same time period (1970-1971). This supports the previously stated seasonal variation in concentrations of total phosphorus. Probably one of the more widely known studies of bulk contributions of total phosphorus is that of a Moore House, England, by Gore (20). In this six-year study, total phosphorus ranged from 0.34 to 1.85 kg/ha/yr with an average contribution over this time being 0.85 kg/ha/yr. Gore also presented 0.27 kg/ha/yr as the average combined value obtained at Old Sun Level and Cottage Hill, 1964-1966.

Another reported variation in the amount of atmospheric phosphorus collected is in the quantity of phosphorus versus the quantity of precipitation. Chapin (10) showed no close consistent relationship of phosphorus with quantities of rain. Allen (21) agrees with Chapin except for occasional extremely high and low rainfall quantities,

TABLE I

## ATMOSPHERIC CONTRIBUTIONS OF PHOSPHORUS (10)

Study	Rainfall cm	P Contribution kg/ha/yr	
		Inorganic	Total
North America			
New Haven, Conn.			0.10
Delaware	100		0.56
Cincinnati, Ohio			0.80
Kent, Ohio			0.14
Northwest Ontario	snow		0.27-0.40
Green Bay, Wisc.			0.08
Madison, Wisc.		0.18-0.33	0.23-1.02
Other			
Australia, Melbourne			0.30
Czechoslovakia			0.07-0.16
England			0.12-1.09
France			0.40
Gambia			0.17
Germany			0.13
Ghana			3.30
India, Kerala			4.75
Italy			1.60-2.00
Nigeria			0.40-2.60
Russia, Voronezh			0.30
Scandinavia	100		0.15-1.00
South Africa, Natal			8.00

which exhibited greater and lesser quantities, respectively. On the contrary, Shlomi (15) stated that high concentrations of phosphorus were associated with small quantities of precipitation. Fish (16) agreed by reporting that the heavier the rainfall the lower the nutrient concentration.

## CHAPTER III

### MATERIALS AND METHODS

#### Lake Description

Lake Carl Blackwell, located approximately 12 kilometers west of Stillwater, Oklahoma, was constructed in 1938. The original project purpose was to provide recreational facilities, but it now serves in addition as a municipal water supply for the City of Stillwater. The lake has a maximum surface area of approximately 1400 ha and a storage capacity of  $67.80 \times 10^6 \text{ m}^3$ . The average depth is 4.84 m.

The area surrounding the lake is primarily used for cattle grazing, agricultural crops and recreation. There are no industrial point source discharges into the lake. Nutrient enrichment is provided through septic systems, agricultural runoff and atmospheric contributions. The lake is in a eutrophic state.

#### Sampler Location

As previously stated, some researchers feel there is great need for concern with the location of samplers in relation to influencing sources. Care was taken to place samplers in strategic locations so as to provide an accurate representation of phosphorus contributions to the lake. The three sites were positioned where it was felt that they would best depict actual contributions to the lake surface. The

site locations are shown in Figure 1.

Site Number 1 was located within the confines of the Camp Redlands Water Research Station on the north side of the lake. Access to the site was by unpaved road. The sampling platform, mounted in an eastward direction, was located eight feet from the ground on a telephone pole (Figure 2). The sampler was positioned four feet from the pole. This site allowed for minimal interference from wind breaks for northern winds. The presence of unpaved roads was not considered an interference because the lake is surrounded by such roads and they all have a possible impact on the lake. Land use surrounding the site was primarily cattle grazing.

Site Number 2 was located approximately four feet from the ground, on the top of a fence post, at the west end of the lake, in a low lying area. The site was also located approximately fifteen feet from a highway. Surrounding this site were agricultural crops and cattle grazing.

Site Number 3 was positioned on a telephone pole, in the same manner as Site Number 1 (Figure 2), on the south side of the lake. This site allowed for minimal interference from wind breaks for south winds. The surrounding area contained recreational facilities and a natural wildlife habitat consisting of grasses and trees. Roads in the area were both paved and unpaved.

#### Sampling Method

Bulk precipitation was collected in a sampler of similar design to that preferred by previously mentioned researchers. It consisted of a 150 mm polyethylene powder funnel placed in the mouth of a

Figure 1. Location of Sites on Carl Blackwell Lake



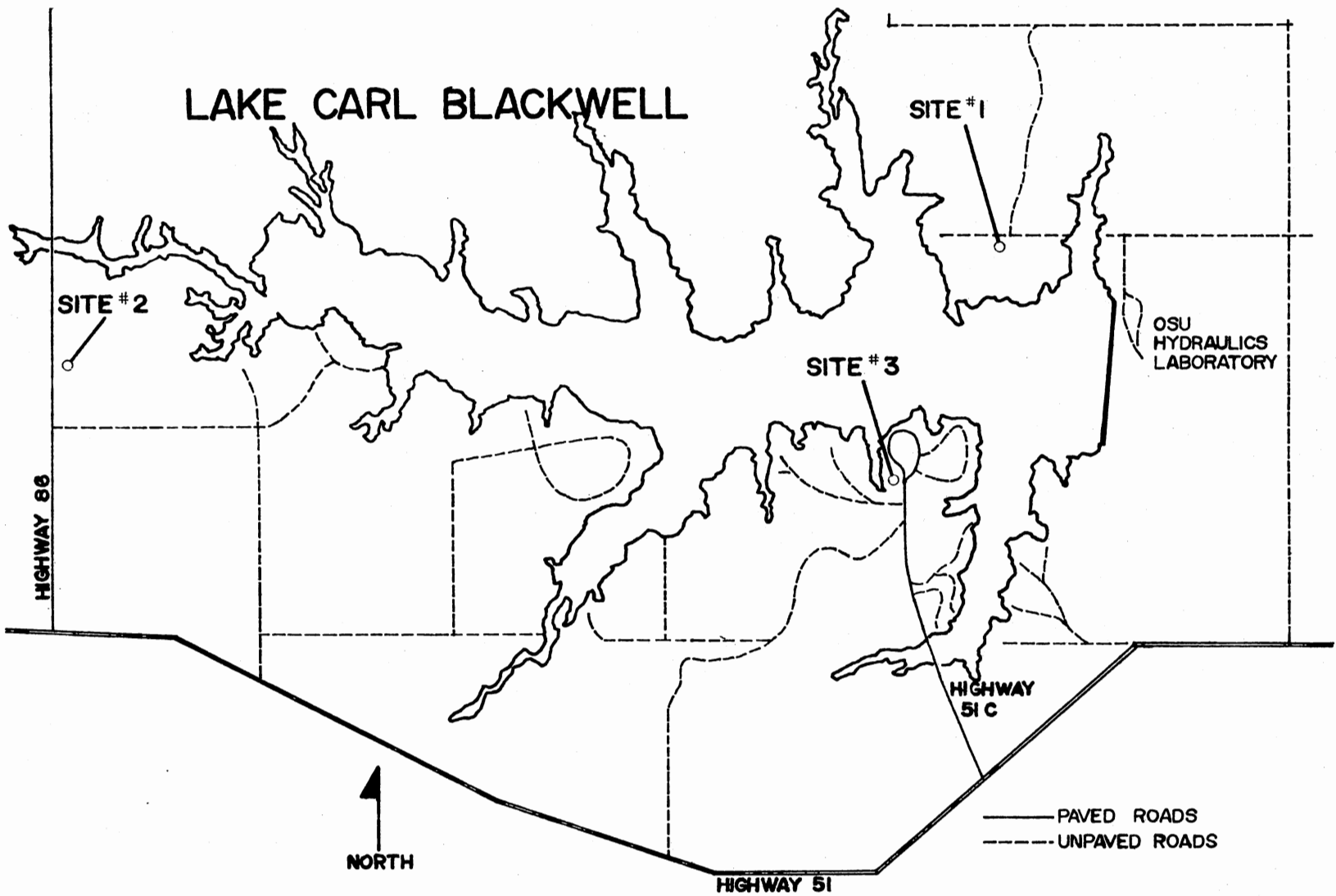
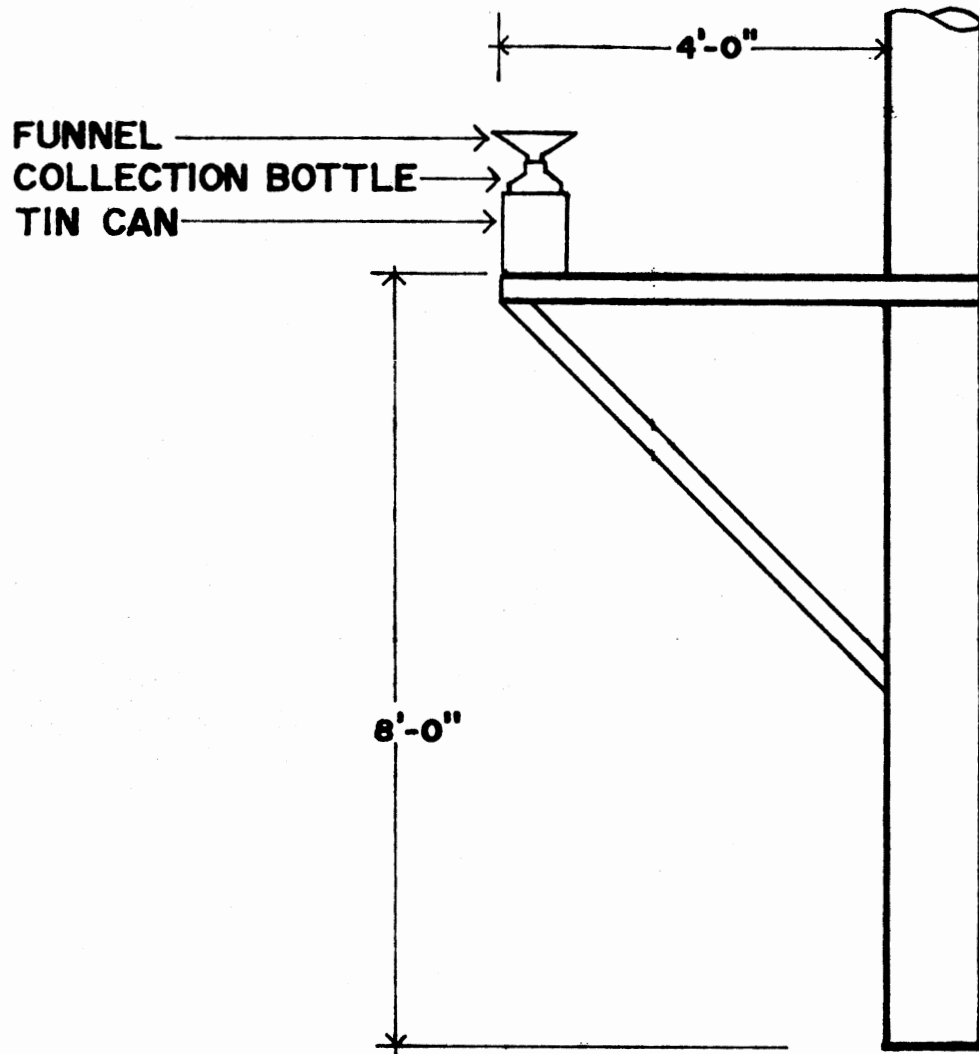


Figure 2. Positioning of Samplers on Telephone Poles



narrow neck one liter polyethylene bottle. It was believed that since evaporative losses could not affect the quantity of phosphorus collected and that its presence could only serve as a possible means of interference, the use of plastic tubing to connect the funnel to the collection bottle, as preferred by other researchers, was eliminated. Evaporative losses, if any, were minimal due to immediate collection. Volumes of precipitation collected were measured with a graduated cylinder. A number 18 wire screen was placed in the neck of the funnel to eliminate contamination from large insects, leaves and other matter. Polyethylene cylinders were used for snow and sleet collection.

Frequency of sample collection was somewhat dependent on precipitation occurrence, at which time they were exchanged for clean acid washed collection bottles. Funnels were rarely acid washed. A monthly collection schedule was maintained by washing the funnel with distilled water, if a precipitation event had not occurred at the end of each month. Only 25 ml to 75 ml of distilled water were used for the funnel wash down in order to eliminate the possibility of diluting the phosphorus sample too much for analytical procedures.

#### Analytical Procedures

Total phosphorus analyses were performed on unfiltered samples from each site as soon as possible after collection. Each sample was digested prior to phosphate analysis using the persulfate digestion technique described in Standard Methods (30). This method converted all forms of phosphorus to ortho-phosphate, which was then determined using the Stannous Chloride Method (30). A Bausch and Lomb

Spectrophotometer was used in the above mentioned procedure. Frequent standard curves were determined in order to insure quality control of all reagents, as well as, to refine techniques. If insufficient volumes of precipitation for individual analysis were collected at each site, all sites were combined. Duplicate samples were run when adequate sample volumes were collected. Quantities of phosphorus, as total phosphorus, were calculated from concentrations of phosphate and volumes of samples collected. Calculations for contributions in kilograms per hectare were determined from the average quantity of phosphorus collected and the known surface area of the collectors.

## CHAPTER IV

### RESULTS AND DISCUSSION

Total phosphorus contributed to Lake Carl Blackwell varied considerably over the year sampled. As previously mentioned individual sampling periods were dependent on precipitation events, with the possible exception of the last sampling period of the month. Results of each sampling period are shown in Figure 3. Plotted points are located in the middle of each sampling period. Milligrams of phosphorus represent either the average of the milligrams collected at each site during each sampling period or a combination of the individual sites divided by the number of the sites combined. The largest phosphorus contribution was 0.466 mg occurring in May. The smallest contribution occurred during June when 0.00025 mg were collected over a three day period. The monthly average contribution of phosphorus to Lake Carl Blackwell was 0.0504 kg/ha; and the annual contribution was 0.6049 kg/ha. This annual amount falls into the lower one half of those values presented in Table I (10).

Monthly total phosphorus contributions were plotted at roughly the middle of each month as kg/ha in Figure 4. Peaks in Figures 3 and 4 can be seen in October, January and May. The peaks in October and May, preceeded by the increasing phosphorus contributions, are somewhat indicative of seasonal variations. Since the area surrounding the samplers is primarily agricultural, one possible explanation for these

Figure 3. P as  $PO_4$  Collected During Each Sampling Period  
Plotted Versus the Mid-Point of the Sampling  
Period.

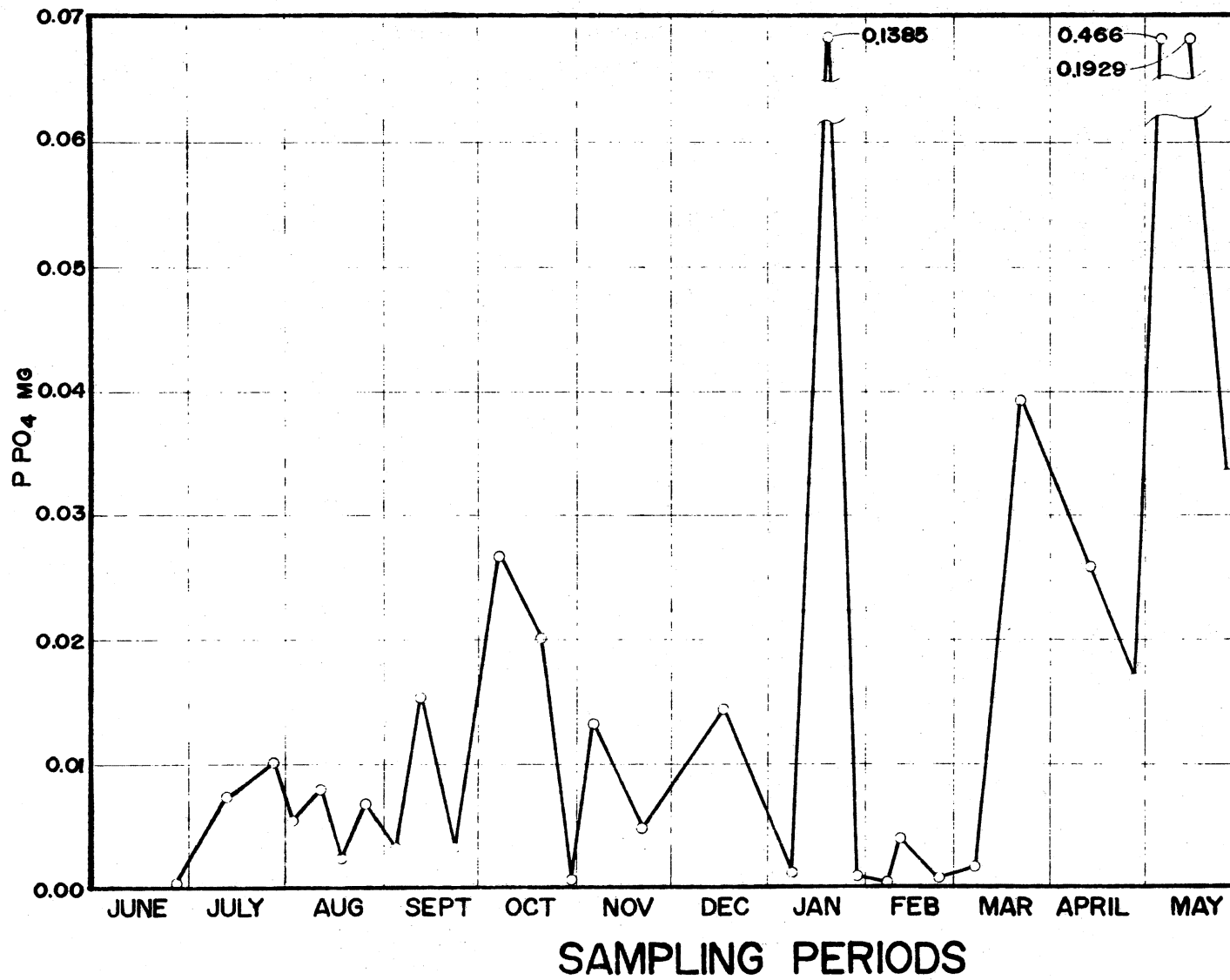
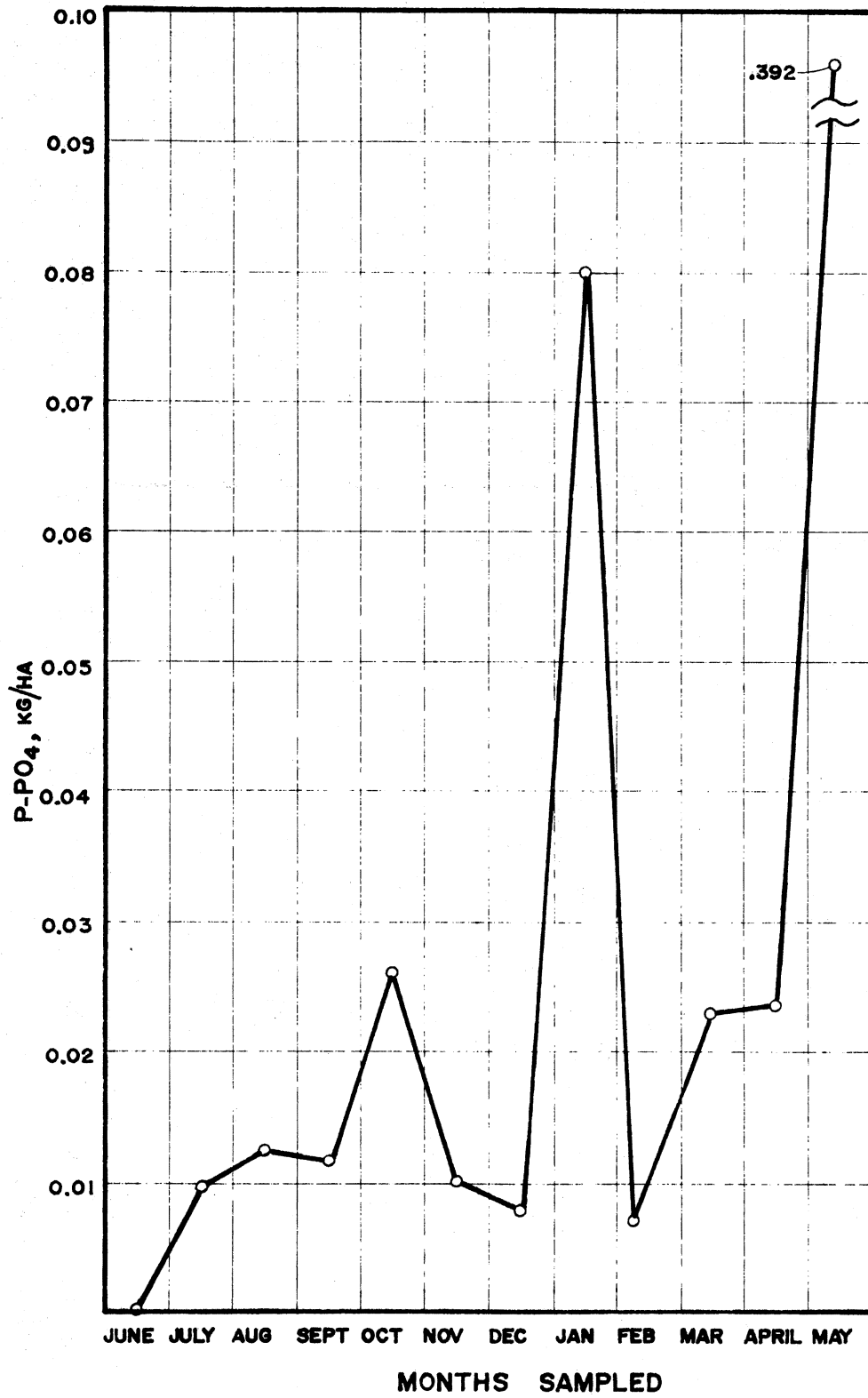




Figure 4. The Total Monthly Average Phosphorus Contribution From All Sites Plotted Versus the Mid-Point of the Month.

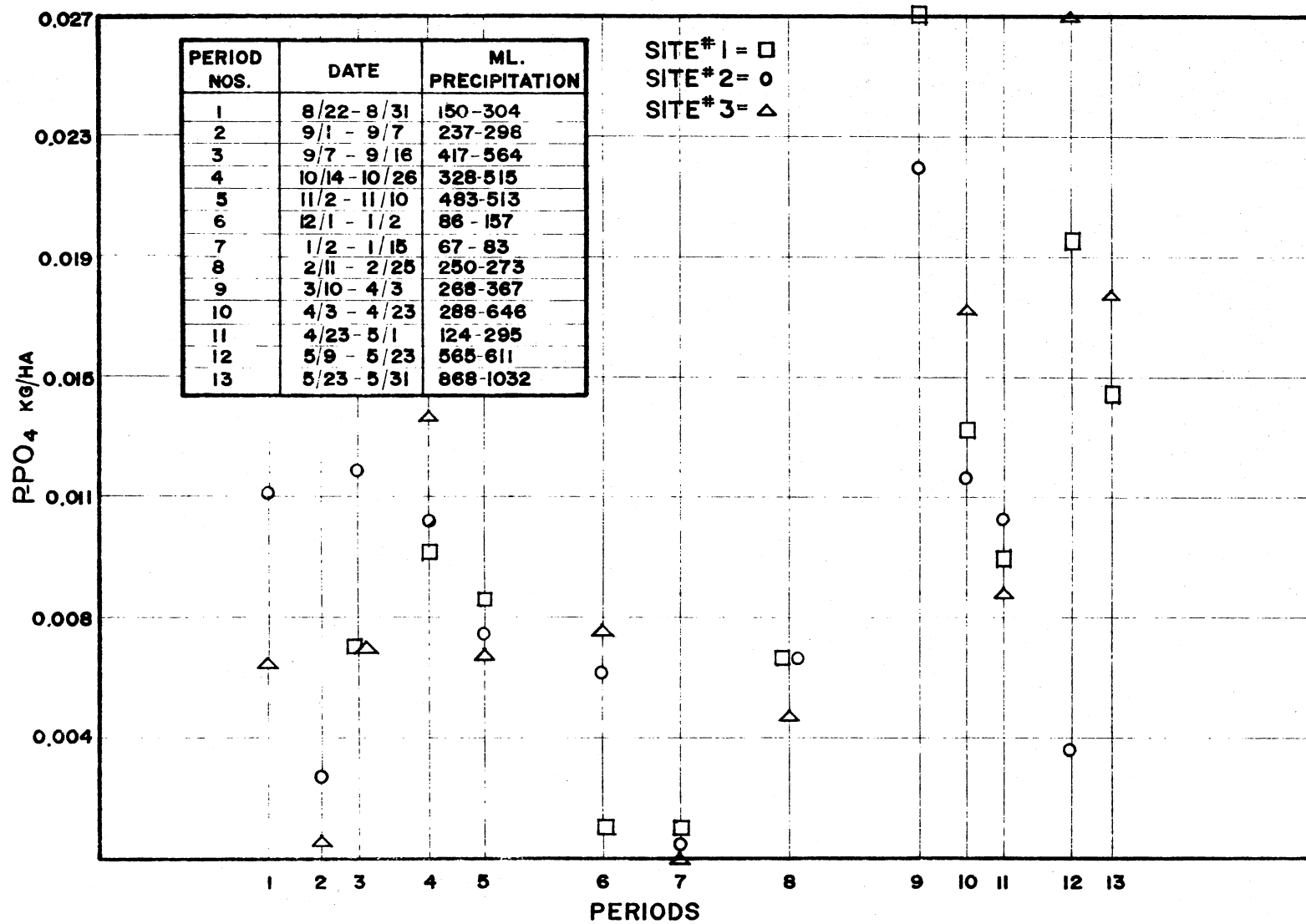


peaks or trends is increased phosphorus contributions from soil conditioning and planting. Natural contributions, such as pollen, seeds, etc., in addition to agricultural activity and increased winds, were possibly responsible for the observed March, April and May increased in total atmospheric phosphorus contributions. Similar peaks are observed by Allen (21). Chapin (10) also supports seasonal variations in phosphorus contributions. Kluesener (11), in his work, attributed the peak that he had observed in May to birds, pollen and seeds.

The peak in January is somewhat more difficult to explain. During the winter months, croplands are generally fertilized, in addition to the usual spring fertilization. This fertilization is a possible source of phosphorus, however, nitrogen was probably the major element added. A more plausible explanation would be the scavenging action of snowfall. The January sampling period in which the peak is located also marks the first snowfall of the winter. An appreciable amount of snowfall was collected, thus lending the possibility that a large amount of various elements, including phosphorus, could have been collected.

Variations in phosphorus contributions, as well as, quantities of precipitation collected occurred at each site. Figure 5 shows phosphorus collected at each site for those sampling periods when samples were not combined. Quantities of phosphorus collected, for each sampling period, were found to vary among the sites. The degree of variation could not be correlated with amounts of precipitation, season of the year or location of the site. Murphy (8) also found the mean for total phosphorus samples collected at different sites to show great variability.

Figure 5. Comparison of Quantities of Phosphorus Collected at Individual Sites for Sampling Periods When Samples Were Not Combined.



Variation of phosphorus concentrations and quantities in relation to precipitation are shown on Figures 6 and 7, respectively. No positive correlation could be made between phosphorus concentration and the amount of precipitation collected, with the possible exception that several high concentrations were achieved with low precipitation. As previously stated, Allen (21) observed high concentrations with extremely low precipitation and the converse with high precipitation events. Quantities of phosphorus collected were found, as a general trend, to increase with increasing amounts of precipitation (Figure 7) with the possible exception of a few points depicting high quantities with little precipitation. As previously stated, other researchers achieved similar results.

To consider the impact of atmospheric phosphorus on the aquatic environment, current lake levels were obtained from the Oklahoma State University Hydraulics Laboratory located below the dam at Lake Carl Blackwell. From these elevations monthly surface areas and volumes of the lake were calculated. When considering the monthly contribution of phosphorus to the lake (based on the monthly average of samples as previously presented and assuming no appreciable outflow of phosphorus) a concentration of 1.30 ppb could be achieved. The total phosphorus concentration, based on the annual atmospheric contribution could reach as high as 15.0 ppb. However, it should be pointed out that 65% of the total annual contribution occurred during the month of May. Since only approximately 50% of the phosphorus added to a body of water stays there and only 50% of total phosphorus is immediately available for algal usage, the effects of the monthly and annual contribution would not be immediately realized. Also, that

Figure 6. Plot of Phosphorus Concentration Versus the Volume of Precipitation Collected.

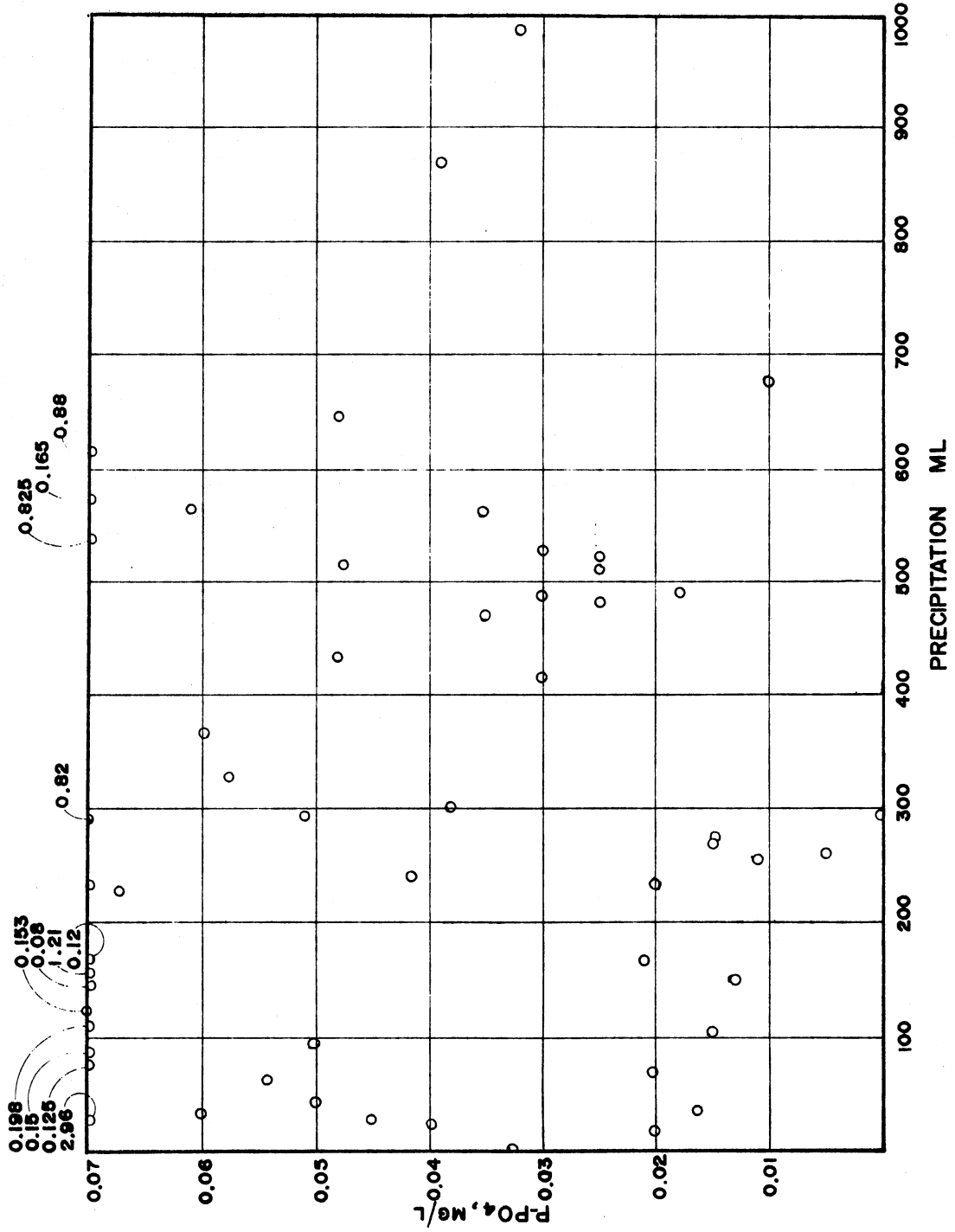
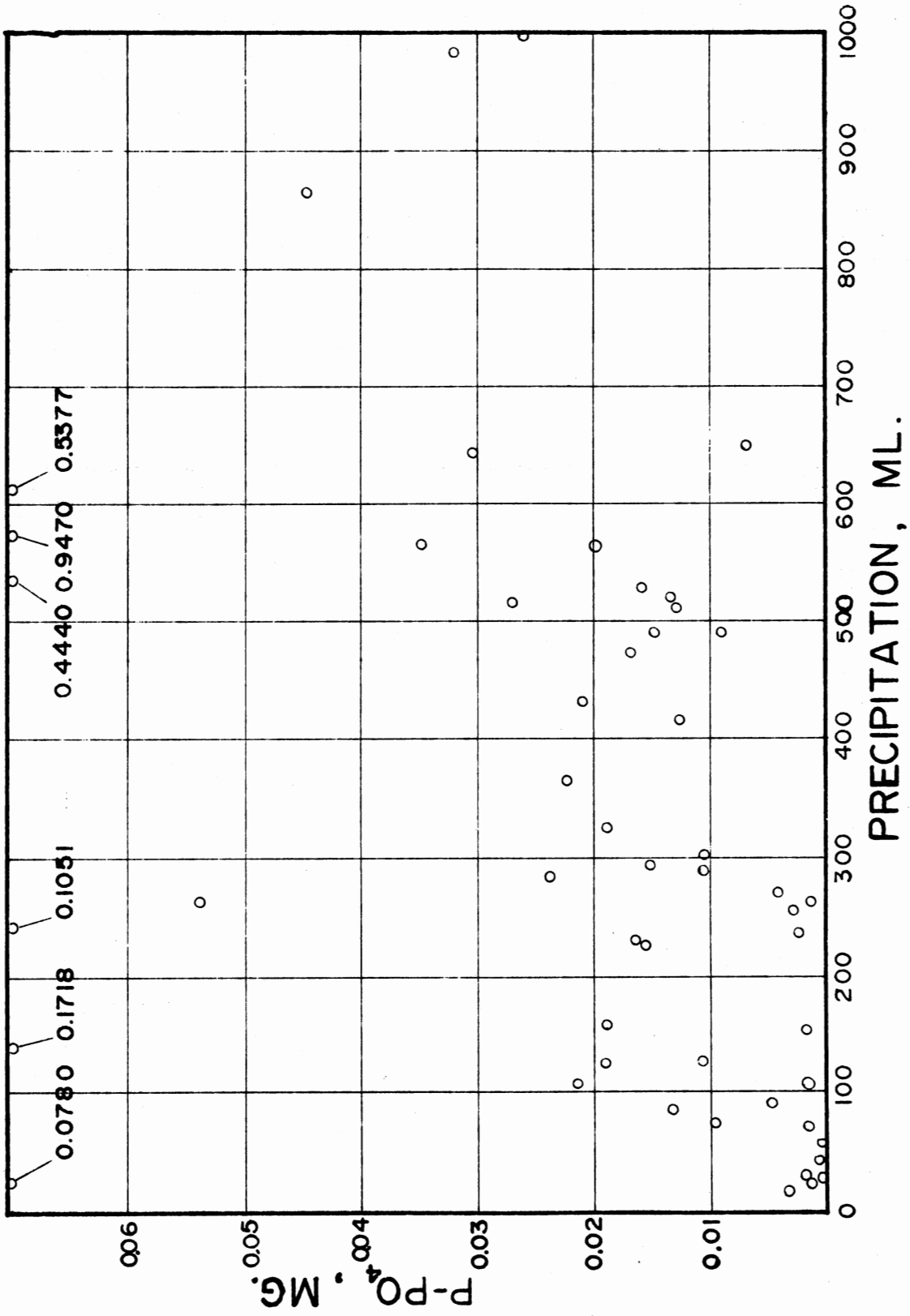




Figure 7. Plot of Phosphorus Quantities Versus the Volume of Precipitation Collected.



phosphorus not immediately available to algae may undergo dissolution and hydrolysis thus making it available. Therefore, it is apparent that the concentration of phosphorus, resulting from atmospheric contributions, within Lake Carl Blackwell could reach critical levels within a few years. In addition the atmosphere, even though it might not be the major contributor of phosphorus to a body of water, can be considered a potentially significant non-point source of phosphorus.

## CHAPTER V

### CONCLUSIONS

From the previously discussed experimental findings, observations and calculations, the following conclusions may be drawn:

1. The atmosphere is a definite source of phosphorus to Lake Carl Blackwell.
2. As a general trend, phosphorus quantities increased as the volume of precipitation increased.
3. Atmospheric phosphorus contributions vary with sampler location.
4. The atmosphere can become a significant non-point source of phosphorus to Lake Carl Blackwell.

## CHAPTER VI

### RECOMMENDATIONS FOR FUTURE STUDY

Based on the literature reviewed and the data collected in this study, the following recommendations for future study can be made:

1. Examine phosphorus inputs from the watershed, tributaries and direct discharge into the lake, as well as, from the atmosphere to obtain a better understanding of the impact of land use patterns on water quality.
2. Obtain particulate, precipitation, as well as, bulk precipitation samples to aid in the possible determination of sources contributing to atmospheric phosphorus thus having an impact on water quality.
3. Research concerning dispersion characteristics of phosphorus from sources.

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VITA 2

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