PHOSPHATES IN PEORIA LAKE A QUANTITATIVE AND QUALITATIVE EVALUATION OF A NUTRIENT IN NATURAL WATERS

WILLIAM T. SULLIVAN and DAVID L. HULLINGER
Water Quality Section, Illinois State Water Survey, Peoria

ABSTRACT. — Peoria Lake, a 13-mile long expansion of the Illinois River, lies approximately midway between Chicago and the Mississippi River on the Illinois Waterway. Its waters are substantially augmented by a variety of soluble and suspended materials from municipal and industrial wastes and from agricultural runoff both directly and from tributary streams.

A study of the chemical and biological characteristics of Peoria Lake was conducted from March to October 1967. Samples were collected on 25 dates from 9 stations at a standard depth of 3 feet. Laboratory analysis of soluble and particulate fractions of ortho-, poly-, and organic phosphate forms has permitted an evaluation of the various phosphates found in these natural waters.

The phosphorus budget of Peoria Lake for the period of study showed the mean daily phosphate load for all fractions and forms entering the lake to be 77.2 $\times$ 10^3 pounds; total phosphate leaving the lake was 63.4 $\times$ 10^3 pounds. The net phosphate apparently retained in Peoria Lake was calculated to be a mean of 13.8 $\times$ 10^3 pounds per day, or 17% of that entering the lake. Possible mechanisms affecting this retention and the distribution of the various fractions and forms are discussed.

This report presents the results of a portion of a study conducted over a period of 30 weeks on Peoria Lake, a region of the Illinois River (Figure 1). The overall investigation dealt with a variety of physical, chemical, and biological parameters. This presentation will be concerned with 1) methods for determining phosphorus in natural waters and 2) the observed changes in the phosphorus fractions, dissolved and particulate, as well as in the forms, ortho-, poly-, and organic phosphate. The dynamics of phosphorus and the various phosphates are described in the context of a shallow, unstratified, eutrophic river-lake.

Peoria Lake has assumed greater importance in recent years, as has every readily accessible expanse of fresh water. The public water supply for the city of Peoria, Illinois, with a population of 133,000 is nominally of groundwater origin but is augmented by some pumpage of surface water. This is taken from an intake located at the Peoria Narrows on the downstream end of the lake. Recreational use of Peoria Lake for on-water sports has increased greatly with water skiing exhibitions and sailing regattas becoming frequent events during the summer months.

The Illinois River and its tributaries upstream of Peoria Lake receive domestic and industrial wastes from 11 cities with populations above 10,000, including the Chicago-Cook County area with approximately 8 million inhabitants.

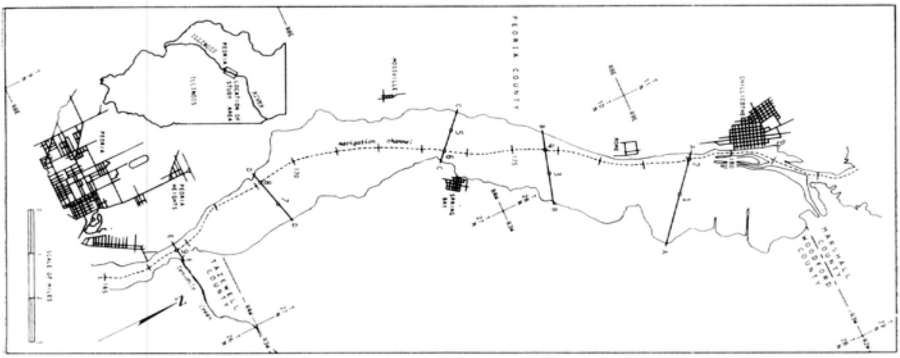

FIGURE 1. — Peoria Lake, transects and sampling stations.

On the basis of aquatic nutrients, the waters of Peoria Lake are as capable of supporting algal blooms today as in previous years when blooms occurred. Diatoms flourish, increasing turbidity and causing some coloration in the water. These organisms through photosynthesis also contribute dissolved oxygen.

Offensive organisms may still be detected by microscopic examination although their numbers are insufficient to impair water quality. A relationship between possible natural suppression of nuisance algae and concentrations of various phosphates is not known. A preliminary conclusion is suggested, in which the diminuation of certain algal populations is unlikely to be due to any paucity of phosphate.

THE ILLINOIS RIVER AND PEORIA LAKE

The Illinois River, of which Peoria Lake is a segment, is a stream of great age, flowing down an unusually flat gradient. As a subject for study the Illinois has long been favored, being referred to as ". . . the 'most studied' river in the world" (Mills *et al.*, 1966).

The Illinois Waterway extends across the state for a distance of 327.2 miles, of which 273 miles is the Illinois River. Beginning at the entrance of the Chicago River on Lake Michigan and flowing southward through the Chicago Sanitary and Ship Canal and a part of the Des Plaines River, the Waterway enters the Illinois River at its origin, the juncture of the Des Plaines and Kankakee Rivers.

Until 1938, four navigation dams divided the lower reach of the Illinois River into five pools, the last of which was at a common stage with the Mississippi River. At present six higher dams have increased the depth of the Illinois, aiding navigation and contributing to flood control. Peoria Lake is located in the third or Peoria Pool, 52.0 miles below Starved Rock Lock and Dam and 8.2 miles above Peoria Lock and Dam. Its present dimensions and other physical characteristics may be seen in Table 1.

Although it is formed by an expansion of the Illinois River, Peoria Lake (Figure 1) possesses features common to more orthodox lakes. The drainage basin of the Illinois River and its tributaries at Peoria Lake covers an area of 13,604 square miles. The lake bottom is covered with a thick layer of mud. A navigation channel 300 feet wide and from 9 to 21 feet deep runs the length of the lake. With a mean depth of less than 5 feet, Peoria Lake is unstratified throughout the year. Despite the general shallowness, very little emergent or floating rooted vegetation is to be found.

The whole pollutional load remaining after varying degrees of treatment that is borne by the upper reaches of the Illinois River is delivered to Peoria Lake. In recent years greater amounts of silt carried by the river have been attributed to erosional soil losses from

TABLE 1.—Physical Characteristics of Peoria Lake.

Length (Chillicothe to Peoria Narrows)	13.0 miles
Width	
Minimum	735 ft (0.139 miles)
Mean (area/length)	7,392 ft (1.400 miles)
Maximum	10,700 ft (2.027 miles)
Length-to-Width Ratio	9.3:1
Depth (at pool stage, 440.0 ft above mean sea level)	
Minimum	less than 1 foot
Mean (volume/area)	4.6 ft
Maximum (in navigation channel)	21 ft
Volume (at pool stage)	2.346×10^9 ft^3 (53.8×10^3 acre-feet)
During 3/13/67 - 10/3/67	
Minimum	2.3967×10^9 ft^3 (55.0×10^3 ac-ft)
Maximum	5.5401×10^9 ft^3 (127.4×10^3 ac-ft)
Area (at pool stage)	18.18 miles^2 (11,640 acres)
Retention time (estimated, 3/13/67 - 10/3/67)	
Minimum	1.60 days (38.4 hours)
Maximum	6.77 days (162.4 hours)

cultivated uplands. Increased barge traffic in recent years has also affected turbidity in the navigation channel and in adjacent shallower lake waters. Turbidity in certain areas of Peoria Lake is at times increased by phytoplankton, but suspended silt is the major constituent (Mills *et al.*, 1966).

Present water levels in Peoria Lake and throughout the Peoria Pool were established late in 1938 with the completion of the Peoria Lock and Dam. In the second year following stabilization of the pool at the present 440.0 feet above mean sea level, a marked increase in rooted aquatic plants appeared. Abundant growth continued for 10 years when it began to decline. Since the mid-1950's Peoria Lake has been virtually devoid of vascular aquatic plants. Turbidity has been suggested as a causative agent. However, in locations upstream where similar vegetative die-offs have occurred, decreased water turbidity has not produced a return of aquatic plants (Mills *et al.*, 1966). Whether this inhibition is in any way related to the relative absence of blue-green and other nuisance algae is not known. The increased silt load and absence of the phylogenetically higher plants have produced in Peoria Lake an extensive, shallow, turbid aquatic area unpunctuated by emergent vegetation.

LIMNOLOGICAL AND RIVER STUDIES

Background. Systematic chemical and biological examinations of Peoria Lake began with the work of Kofoid (1903). This led to his conclusion that the development of phytoplankton was limited by suspended silt that decreased light penetration of the water. He also believed that suspended decay bacteria propagated more in diminished light, consequently increasing the breakdown of suspended organic material.

Reoxygenation of the Illinois River after its passage through Peoria Lake was noted in a later study conducted by the Illinois State Water Survey (Greenfield, 1924). A further Survey investigation showed that decreased current velocity in Peoria Lake led to clarification of the water following sedimentation with an increase in algal growth in the clearer, slow flowing water (Boruff, 1930).

The U. S. Geological Survey found a decrease in suspended matter immediately below the Peoria Narrows and credited this to settling that had occurred in the lake (Collins, 1910).

Systematic sampling and analysis of water from the Illinois River at the water works intake near the Peoria Narrows was begun in October 1959 as part of the Water Quality Network of the U. S. Public Health Service. This has continued to the present in the Water Surveillance System of the Federal Water Pollution Control Administration. Analytical results for the seven years from 1959-1966 showed total phosphorus to range from 0.3 to 0.8 milligrams per liter phosphorus (mg/1 P) with summer and winter means of 0.42 and 0.59 mg/1 P respectively. Dissolved phosphorus values ran from 0.2 to 0.6 mg/1 P with a summer mean of 0.30 and a winter mean of 0.48 mg/1 P. The U. S. Public Health Service considered the results of these analyses on the Illinois River at Peoria to yield phosphorus values among the highest found anywhere in the nationwide system (U. S. Public Health Service, 1963).

A recent paper on waste treatment and the Illinois Waterway System described a lowering of phosphate loadings between stations at Lacon and Peoria, a distance of 22 river miles of which 13 miles consisted of Peoria Lake (Hurwitz *et al.*, 1965). Values for total phosphate as phosphorus showed decreases from 15.54 tons to 10.30 tons per day, for ortho-phosphate from 12.22 to 7.04 tons/day P, and in the case of organic phosphate a slight increase from 2.00 to 2.06 tons/day P. These changes were suggested as being attributable to algal uptake followed by the sedimentation of dead organisms. Other means of natural phosphate removal mentioned were the immediate settling of insoluble phosphates and adsorption of phosphate on suspended matter followed by settling. In terms of concentration, the June-September 1960 average for total phosphate at the Peoria station was found to be 0.40 mg/1 P representing a decrease of 0.19 mg/1 P from the average for the same period at Lacon (Hurwitz *et al.*, 1965).

1967 Study. An examination of Peoria Lake was begun by the Water Quality Section of the Illinois State Water Survey in March 1967. Samples were collected at nine stations (Figure 1) at a uniform depth of about 3 feet.

Five transects were established: "A" immediately below Chillicothe at mile point 179 + 480 feet, with a shore to short width of 9195 feet; "B" below Rome, at mile point 175 + 5085 feet, width 7575 feet; "C" immediately below Spring Bay at the Spring Bay Narrows, at mile point 173 + 2880 feet, width 5785 feet; "D" above Peoria Heights, at mile point 169 + 390 feet, width 6630 feet; and "E" in Peoria Narrows, at mile point 166 + 3950 feet, width 735 feet.

At each of the first four transects two water samples were taken, one in the lake proper and the other from the navigation channel. Water was collected by Kemmerer sampler and placed in ½

TABLE 2.—Chemical Characteristics of Peoria Lake, March 13 - October 3, 1967.
(Constituents in mg/1)

	Mean	Range
Temperature	19.5°C	5.0 - 27.3
Turbidity (Jtu)	115	28 - 296
pH	8.19	7.57 - 8.69
Dissolved oxygen	5.6	1.4 - 15.3
Alkalinity (as $CaCO_3$)	165	136 - 213
Total hardness (as $CaCO_3$)	268	215 - 324
Iron (total)	3.21	0.69 - 13.01
Ferrous	0.58	0.16 - 1.89
Ferric	2.63	0.52 - 11.12
Fluoride (total)	1.08	0.17 - 2.06
Silica (total)	6.10	1.96 - 14.80
Nitrogen (total-N)	8.85	3.88 - 14.98
Nitrate (NO_3-N)	4.33	1.65 - 11.12
Ammonia (NO_3-N)	1.15	0 - 5.45
Organic-N	3.37	0.64 - 9.84
Phosphorus (total)	1.13	0.47 - 3.02
Orthophosphate-P	0.84	0.25 - 2.30
Polyphosphate-P	0.15	0 - 0.67
Organic Phosphate-P	0.14	0 - 0.58

gallon polyethylene bottles. Sampling runs were begun up-lake and finished at transect "E" near the laboratory, minimizing the time between collection and preparation of the samples for analysis.

Analyses using wet chemical methods were conducted for total and ferrous iron, nitrate, ammonia, organic nitrogen, total and reactive silica, fluoride, alkalinity, hardness, pH, and turbidity, as well as for phosphorus. Measurements of dissolved oxygen were made with a galvanic cell oxygen probe. Water clarity estimations by Secchi disk plus water and air temperature measurements were made in the field. Summary results of these parameters are presented in Table 2. Biological analyses consisted of total plankton counts with differential determinations of green algae, blue-green algae, flagellates, and diatoms.

Sample collection was begun in March and repeated on a weekly and occasionally bi-weekly basis until October. In all, 225 samples were collected on 25 dates over a 30-week period at 9 stations on Peoria Lake.

Hydrologic records of water flow rates and river stages were obtained from the U. S. Army Corps of Engineers and the U. S. Geological Survey.

METHODS

Sample preparation. Raw water samples were delivered from Peoria Lake as quickly as possible, the maximum time being three hours and the minimum less than one hour. Well shaken, unfiltered samples were used for total phosphorus, total inorganic phosphate, and total orthophosphate analyses.

Samples for dissolved phosphorus, dissolved inorganic phosphate, and dissolved orthophosphate analyses were prepared by filtration through 0.45 μ membranes immediately upon receipt of the samples in the laboratory.

Phosphorus analysis. A review of current analytical methods for orthophosphate, total inorganic phosphate, and total phosphorus determinations was conducted before the Peoria Lake study was undertaken.

The customary procedure for phosphorus analysis involves the actual measurement of orthophosphate ($-PO_4^{-3}$). Any other forms of phosphate must be converted to orthophosphate for analysis.

Total phosphorus. In the analysis of total phosphorus in natural water it is necessary not only to hydrolyze all condensed phosphate but to oxidize organic phosphate. In surface waters, amounts of condensed and organic phosphates may be significant portions of the total phosphorus.

Probably the most widely tried method for total phosphorus is that presented in "Standard Methods for the Examination of Water and Wastewater" (American Public Health Association, 1965), though doubts have been expressed about the adequacy of its digestion technique. If this method were restricted to groundwater or to surface waters lacking significant amounts of organic matter it might be adequate.

Although the perchloric acid technique of oxidation does release all polyphosphate and organic phosphate, the hazards of its use on many surface water samples containing varying amounts of organic matter have made it undesirable (Jenkins, 1967; Sanning, 1967).

Potassium persulfate was suggested as an oxidizing agent by several authors. After a series of comparative trials, the digestion technique detailed by Gales *et al.* (1966) was selected. This was used in conjunction with the acidic molybdate solution of Robertson (1960) and the potassium antimonyl tartrate solution of Edwards *et al.* (1965). Ascorbic acid was used as the reducing agent for final color development (Menzel and Corwin, 1965).

Orthophosphate. Though several variations may be used, the determination of orthophosphate began with the addition of an acidic molybdate solution to an aliquot of sample. Free, dissolved PO_4 reacts with the molybdate giving 12-molybdophosphoric acid. A reducing agent was then added causing the formation of blue phosphomolybdic acid. The intensity of the resulting color is directly proportional to the amount of orthophosphate available for reaction (American Public Health Association, 1965). The color was measured photometrically at a wave length of 880 mμ in a Bausch and Lomb Spectronic 20 spectrophotometer-colorimeter.

The method selected for orthophosphate was that suggested by Edwards *et al.* (1965).

Aliquots of 10 ml diluted to 50 ml with double distilled water were used routinely on Peoria Lake water samples because of the high phosphorus concentration.

Total inorganic phosphate. In a number of different methods tested condensed polyphosphate were more or less completely hydrolyzed. Problems of accuracy and reproducibility made most of them unsuitable. The method of Robertson (1960) in which $Bi(NO_3)_3$ and nitric acid were used to hydrolyze polyphosphate provided the best procedure. Complete hydrolysis of known concentrations of various polyphosphates was found. The use of dry ascorbic acid as the reducing agent gave very good color development and consistent reproducibility of standard curves. A Lambert-Beer curve that lay in the same range as the previous orthophosphate curve was developed. Standards were run with each group of samples and recovery of known amounts of standard was found to be better than 99%.

All glassware including pipettes and reagent bottles were washed in a hot sulfuric acid-nitric acid mixture and rinsed only in distilled water. Polyethylene sample and storage bottles were washed in tap water then rinsed in dilute hydrochloric acid followed by rinsing in distilled water. No synthetic detergent washing compounds were used on any glassware employed in phosphorus analyses or in sample collections.

Total phosphorus, total inorganic phosphate, and orthophosphate were analyzed directly. The difference between total inorganic phosphate and orthophosphate was considered polyphosphate. Organic phosphate was regarded as the difference between total phosphorus and total inorganic phosphate. Total phosphorus and phosphate analyses were run on filtered and unfiltered samples. Dissolved fractions were the result of analyses on filtrate samples. Particulate fractions were the difference between total and dissolved values. Included in Table 3 is a summary of the procedures used to differentiate various fractions and forms of phosphorus in the course of the study.

Statistical evaluation. A two-way analysis of variance technique (ANOVA) was used to determine whether significant differences existed

TABLE 3.—Methods Used for Analyses of Phosphate-Phosphorus Fractions and Forms.

Fractions	Sample	Pretreatment	Color Reaction
TP Total phosphorus	unfiltered	Persulfate oxidation	Ascorbic acid reduction to molybdate blue
DP Total dissolved phosphorus	$0.45\ \mu$ membrane filtered	Persulfate oxidation	Ascorbic acid reduction to molybdate blue
PP Total particulate phosphorus	by difference (Total phosphorus — total dissolved phosphorus)		
Forms			
TO Total ortho-phosphate-P	unfiltered	none	Ascorbic acid reduction to molybdate blue
DO Dissolved ortho-phosphate-P	$0.45\ \mu$ membrane filtered	none	Ascorbic acid reduction to molybdate blue
PO Particulate ortho-phosphate-P	by difference (Total ortho-phosphate-P — dissolved ortho-phosphate-P)		
TPo Total poly-phosphate-P	unfiltered	$Bi(NO_3)_3$ hydrolysis	Ascorbic acid reduction to molybdate blue ———> total inorganic phosphate-P (TIP) TIP — total ortho-phosphate-P — TPo
DPo Dissolved poly-phosphate-P	$0.45\ \mu$ membrane filtered	$Bi(NO_3)_3$ hydrolysis	Ascorbic acid reduction to molybdate blue ———> dissolved inorganic phosphate-P (DIP) DIP — dissolved ortho-phosphate-P — DPo
PPo Particulate poly-phosphate-P	by difference (Total poly-phosphate-P — dissolved poly-phosphate-P)		
TOr Total organic phosphate-P	by difference (Total phosphorous — total inorganic phosphate-P)		
DOr Dissolved organic phosphate-P	by difference (Total dissolved phosphorus — total inorganic phosphate-P)		
POr Particulate organic phosphate-P	by difference (Total organic phosphate-P — dissolved organic phosphate-P)		

between the mean phosphorus concentrations for different sampling stations and sampling dates. The test showed whether the lake was homogeneous without isolating differences between means. The Student's t-test was used to indicate the station or stations responsible for any differences.

Linear product moment correlations were computed to: 1) relate concentrations of one fraction or form to another, and 2) relate phosphorus concentrations to turbidity and plankton.

A relationship between two variables may exist, although an extraneous factor may affect this relationship more than one variable affects another. To give numerical expression to the relationship between two variables, correlation coefficients were used. A significant correlation is shown by the degree of approximation to 1.0. Such a correlation indicates similar behavior and from this, one variable may be predicted from another. With this in mind all correlations were checked for significance using a specialized Student's t-test. Confidence intervals were used for predicting the range of each correlation when deemed appropriate (Natvella, 1963).

All statistical tests were computed for the 95% level of confidence.

PHOSPHATE-PHOSPHORUS CONCENTRATIONS

Comparisons based upon sampling stations. It was necessary to determine whether Peoria Lake was homogeneous through all nine sampling stations for each phosphate-phosphorus fraction and form before making comparisons between them. An analysis of variance showed only total and dissolved organic phosphate and dissolved polyphosphate to be homogeneous in concentrations throughout the lake.

The Student's t-test showed that concentrations of total and dissolved orthophosphate in the first six sampling stations were statistically similar at each two adjacent stations and also in the last three stations. This appeared to separate Peoria Lake into two segments: an upper segment including transects A, B, and C (stations 1-6), and a lower segment with transects D and E (stations 7-9).

Data for the entire 30-week study yielded mean values shown in Table 4 for each fraction and form at each sampling station. These means show the most abundant fraction to be dissolved phosphorus, comprising 64% of the total phosphorus. The major phosphate form was orthophosphate, which made up 75% of the total.

Changes in concentration with down-lake movement are depicted in Figure 2. As water moved from transect A to E there was a reduction in the phosphorus concentrations of most fractions and forms. This trend was gradual from transect A to C, with mean total phosphorus values decreasing from 1.26 to 1.17 mg/1 PO_4—P. There was an increased rate of change in concentration for most forms and fractions from transect C to D where the mean value for total phosphorus decreased from 1.17 to 0.93 mg/1. A virtually constant level was shown from transect D to E where a mean value of 0.94 mg/1 PO_4—P was found for total phosphorus.

When fractions and forms of total phosphorus were expressed in terms

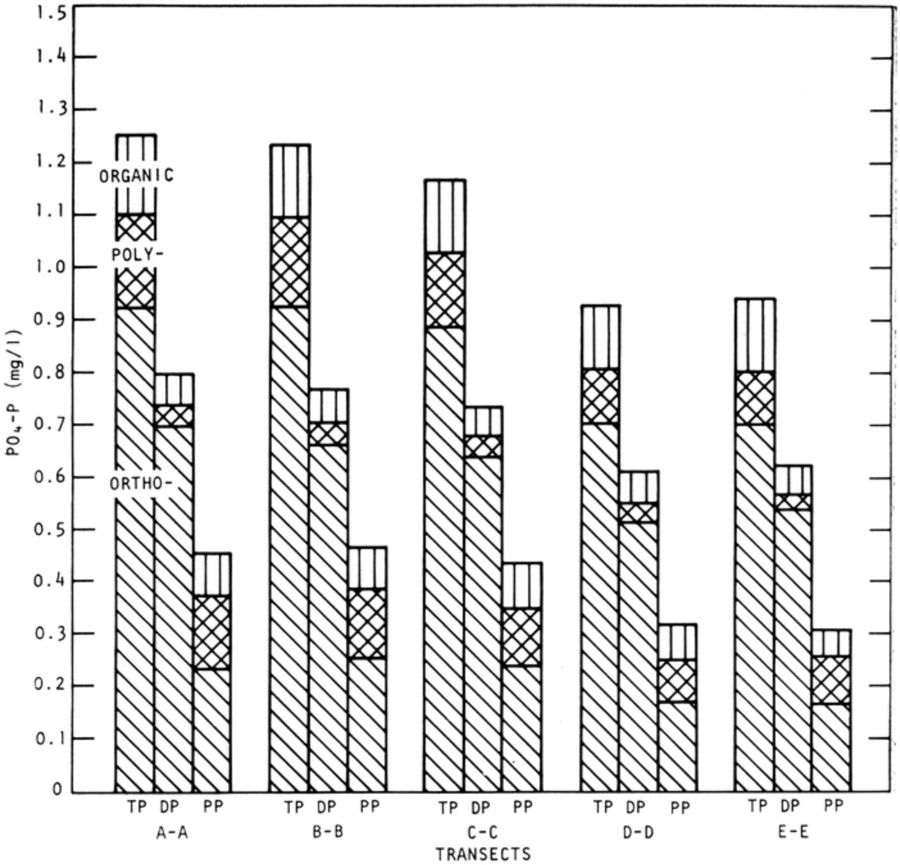

FIGURE 2. — Total, Dissolved, and Particulate Fraction Concentrations of Ortho-, Poly-, and Organic Phosphate at Each Transect.

of percent, a slight increase was found in dissolved phosphorus with a resultant reduction in the particulate phosphorus moving down-lake from transect A to E. This is shown in Table 5. It was also apparent that there was no appreciable change in the percentage of total ortho-, poly-, or organic phosphate forms from transects A through E. The distribution of forms on a mean percentage basis was observed to be 75, 13, and 12 percent for total orthophosphate, polyphosphate, and organic phosphate respectively.

As shown in Table 6, the percentage of dissolved and particulate orthophosphate remained nearly constant from transect A to E, with dissolved orthophosphate making up 74% of the total orthophosphate. An overall increase in dissolved polyphosphate and dissolved organic phosphate was found in moving down-lake. The mean for dissolved polyphosphate was 26% of the total

TABLE 4.—Means of All Forms and Fractions at Each Station on All Sampling Dates with Total Station Means and Standard Deviations (values in mg/1 P)

	Total P			Ortho-PO_4-P			Poly-PO_4-P			Organic-PO_4-P		
Station	Total	Diss.	Part.	Total	Diss.	Part.	Total	Diss.	Part.	Total	Diss.	Part.
1......	1.19	.70	.49	.86	.60	.26	.19	.04	.15	.15	.05	.10
2......	1.33	.89	.44	1.00	.78	.22	.18	.04	.14	.17	.07	.10
3......	1.14	.68	.46	.83	.58	.25	.17	.03	.14	.14	.06	.08
4......	1.34	.87	.47	1.03	.76	.27	.17	.04	.13	.14	.07	.07
5......	1.20	.73	.47	.89	.65	.24	.15	.03	.12	.15	.04	.11
6......	1.15	.74	.41	.89	.64	.25	.15	.04	.11	.12	.06	.06
7......	.87	.56	.31	.63	.48	.15	.13	.03	.10	.12	.05	.07
8......	.99	.66	.33	.77	.56	.21	.10	.04	.06	.13	.05	.08
9......	.94	.63	.31	.70	.53	.17	.12	.04	.08	.13	.06	.07
Mean....	1.13	.72	.41	.84	.62	.22	.15	.04	.11	.14	.06	.08
Standard Deviations...	±.41	±.31	±.20	±.36	±.30	±.13	±.09	±.04	±.09	±.09	±.04	±.07

polyphosphate, and dissolved organic phosphate was 41% of the total organic phosphate. Thus, it appeared that the percentage increases in dissolved polyphosphate and dissolved organic phosphate were responsible for the previously mentioned percentage increase in dissolved phosphorus.

The percentage distribution of ortho-, poly-, and organic phosphate in dissolved and particulate fractions is shown in Table 7. From this it appears that there was little percentage change in the dissolved forms of ortho-, poly-, and organic phosphate down-lake. There were, however, some changes in percentage in particulate forms with a general increase in particulate orthophosphate and a decrease in particulate polyphosphate. Particulate organic phosphate percentages did not change appreciably.

It can be concluded that as water moved down-lake there was little change in the percent distribution of the three forms of total phosphorus, i.e., ortho-, poly-, and organic. This was not true of the particulate forms

TABLE 5.—Down-Lake Changes in Percentage of Total Phosphorus.

Transect	% Diss.	% Part.	% Ortho-	% Poly-	% Organic
A..................	63	37	74	14	12
B..................	62	38	75	14	11
C..................	63	37	76	12	12
D..................	66	34	75	12	13
E..................	67	33	74	12	14
Mean..................	64	36	75	13	12

TABLE 6.—Down-Lake Changes in Fraction Percentage of Phosphate Forms.

Transect	Ortho-PO_4		Poly-PO_4		Organic PO_4	
	% Diss.	% Part.	% Diss.	% Part.	% Diss.	% Part.
A	74	26	22	78	39	61
B	72	28	21	79	44	56
C	72	28	23	77	35	65
D	74	26	30	70	41	59
E	76	24	33	67	45	55
Mean	74	26	26	74	41	59

of ortho- and polyphosphate however. Changes did occur as were reflected by a possible exchange between the particulate and dissolved phosphates. This was especially noticeable in poly- and organic phosphate fractions.

Interrelationships. Correlation coefficients between two variables were derived in order to determine which fractions and forms behaved similarly. Correlations with the greatest similarity were found between 1) TP:TO:DP:DO, 2) TPo:PPo, and 3) TOr:POr. All significant correlations are shown in Table 8.

Seasonal comparisons. Peoria Lake displayed an apparent alternation between river and lake characteristics with seasonal changes in flow.

An analysis of variance showed that a significant difference existed in the concentration of all phosphorus fractions and forms for all 25 sampling dates in the 1967 study. On the basis of changes in flow rates, retention times, and water temperatures it was found convenient to divide the study into three periods (Table 9).

Figure 3 shows the mean phosphorus concentration of all stations at each sampling date during the study. The mean concentrations (Table 10 and Figure 3) of total, dissolved, and particulate phosphorus and total, dissolved, and particulate

TABLE 7.—Down-Lake Changes in Form Percentage of Phosphorus Fractions.

Transect	Dissolved			Particulate		
	% Ortho-	% Poly-	% Organic	% Ortho-	% Poly-	% Organic
A	87	5	8	50	30	20
B	87	5	8	54	29	17
C	88	5	7	55	25	20
D	86	6	8	53	25	22
E	84	6	10	53	25	22
Mean	87	5	8	53	27	20

Table 8.—Similarities Between Fractions and Forms Expressed as Correlation Coefficients

	Correlation Coefficient	95% Confidence Interval
DP:DO	0.99	0.98 - 1.00
TP:TO	0.98	0.96 - 0.99
TO:DO	0.97	0.93 - 0.99
TO:DP	0.97	0.93 - 0.99
TP:DO	0.96	0.90 - 0.99
TP:DP	0.96	0.90 - 0.99
TPo:PPo	0.95	0.88 - 0.98
TOr:POr	0.87	0.72 - 0.94
TP:PP	0.72	0.44 - 0.86
PP:POr	0.68	0.39 - 0.84
PP:PO	0.56	0.21 - 0.77
DP:PP	0.48	0.10 - 0.73
TOr:DOr	0.47	0.08 - 0.72
DP:PO	0.34	0.04 - 0.64

orthophosphate increased notably from the first period to the second, and from the second period to the third. There was little change in means for total, dissolved, and particulate polyphosphate and organic phosphate, though on a date-to-date basis an analysis of variance showed significant changes. Within total phosphorus and total orthophosphate the particulate fraction remained more nearly constant than did the dissolved fraction (Figure 3). Maximum levels of total phosphorus and total orthophosphate were produced primarily by increases in dissolved orthophosphate. Within the total polyphosphate form, the dissolved fraction remained more nearly constant and changes appeared to be due mainly to variations in the particulate fraction. Within the total organic form, both the dissolved and particulate fractions increased and decreased

Table 9.—Physical Characteristics of Different Seasonal Periods.

Periods 1967	Flow (10^3 cfs)	Retention Time (days)	Water Temperature (°C)
(1) March 13 to May 29	26.2 (20.5 — 34.0)	1.86 (1.66 — 1.94)	11.6 (5.0 — 16.7)
(2) May 29 to August 14	10.9 (4.9 — 19.9)	3.21 (1.60 — 6.02)	24.1 (16.6 — 27.7)
(3) August 14 through October 3	5.4 (4.1 — 7.2)	5.55 (4.26 — 6.77)	20.6 (17.2 — 25.5)
Means for all periods	13.6	3.49	19.6

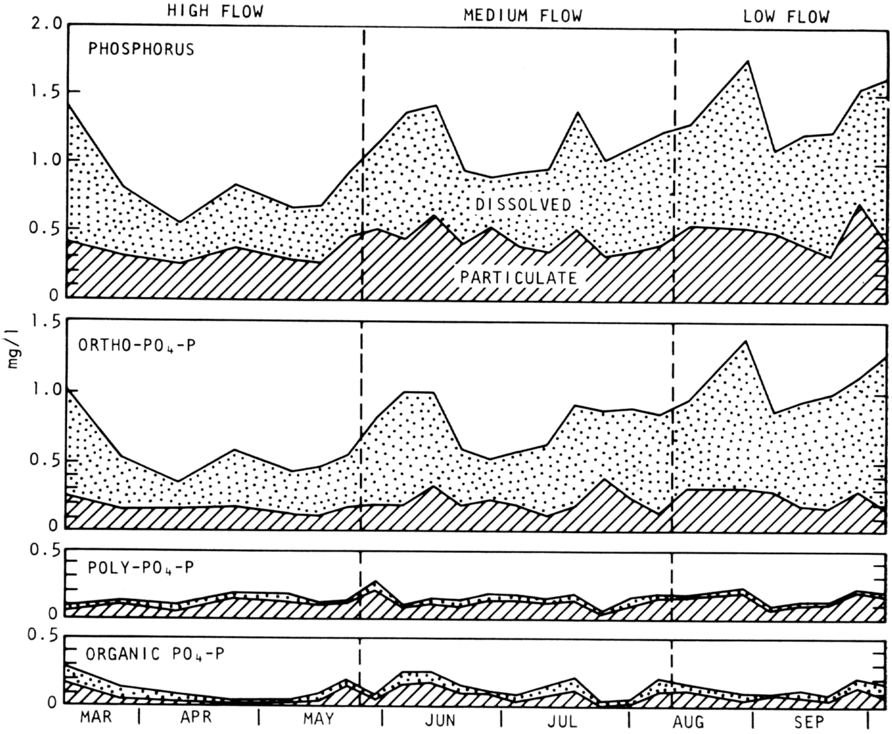

FIGURE 3. — Phosphate-Phosphorus Concentrations During Different Periods of Flow.

together. Therefore, major changes in total phosphorus were due to changes in dissolved orthophosphate, while the total poly- and organic phosphate fractions appeared somewhat interdependent.

From correlations of flow with phosphorus concentrations, it was found that only total and dissolved phosphorus and total and dissolved orthophosphate could be correlated with flow (Figure 4). The rate of concentration change was substantial from a flow of about 4,100 cfs to 10,000 cfs. During flows in excess of 10,000 cfs the rate of change was essentially constant. Flow appeared to have the greatest influence on dissolved orthophosphate as was thus reflected in the flow to total phosphate relationship.

Phosphorus, turbidity, and plankton. Concentrations of particulate phosphorus and particulate orthophosphate compared with turbidity showed moderately significant correlations. The correlation coefficient of mean particulate phosphorus to mean turbidity was 0.65 and mean particulate orthophosphate to mean turbidity was 0.64. The levels of phosphorus and turbidity were less in the lower lake segment than in the upper segment. These correlations suggest that phosphate, especially in the orthophosphate form, may be adsorbed on silt (Olsen, 1964; Muller and Tietz,

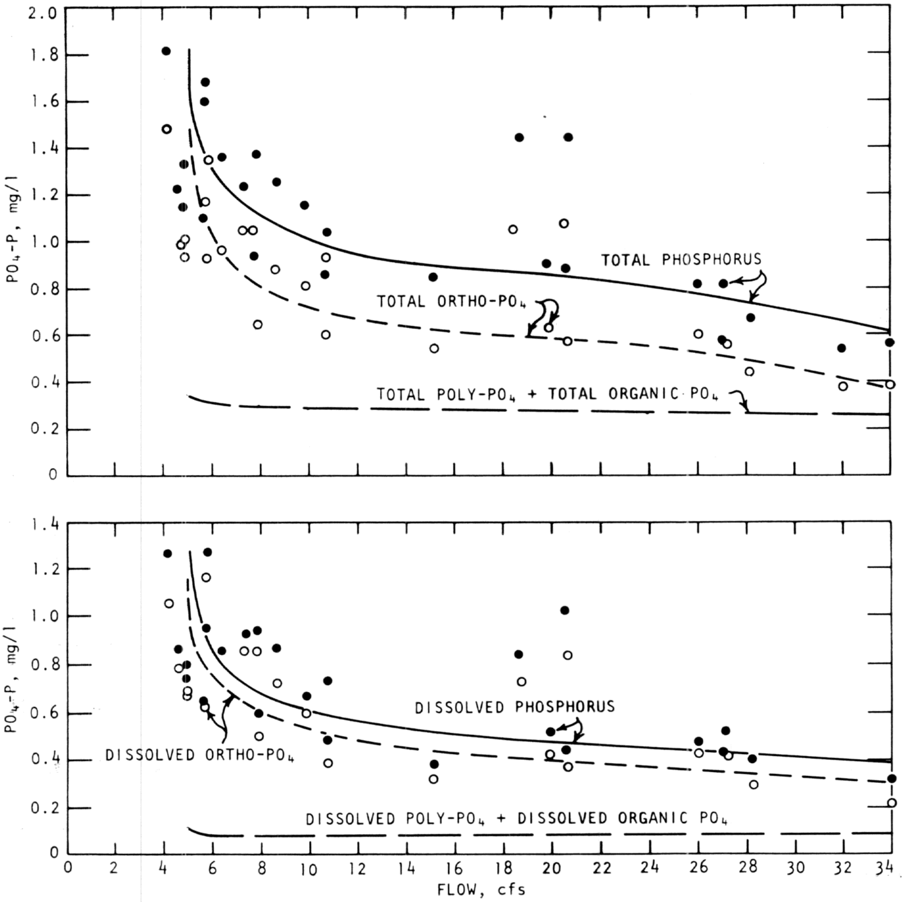

FIGURE 4.—Total and Dissolved Phosphate-Phosphorus Concentrations Expressed as Functions of Flow.

1966) and thus removed from the lake water by sedimentation.

Correlations of lower significance were found between mean total phosphorus and mean total plankton (correlation coefficient of 0.57) and between mean particulate phosphorus and mean total plankton (correlation coefficient of 0.40). It may be inferred that plankton had less of an influence on the phosphorus concentration than did some other factor. Plankton population increased two to three fold during the last 10 weeks of the study exceeding the level found in the first 20 weeks, while total phosphorus concentration increased only about 40%.

Phosphate loads. Flow rates, lake volumes, and phosphorus concentrations were used to calculate phosphate loads in terms of pounds per day. As Figure 5 shows, there was a decrease in phosphorus loadings in

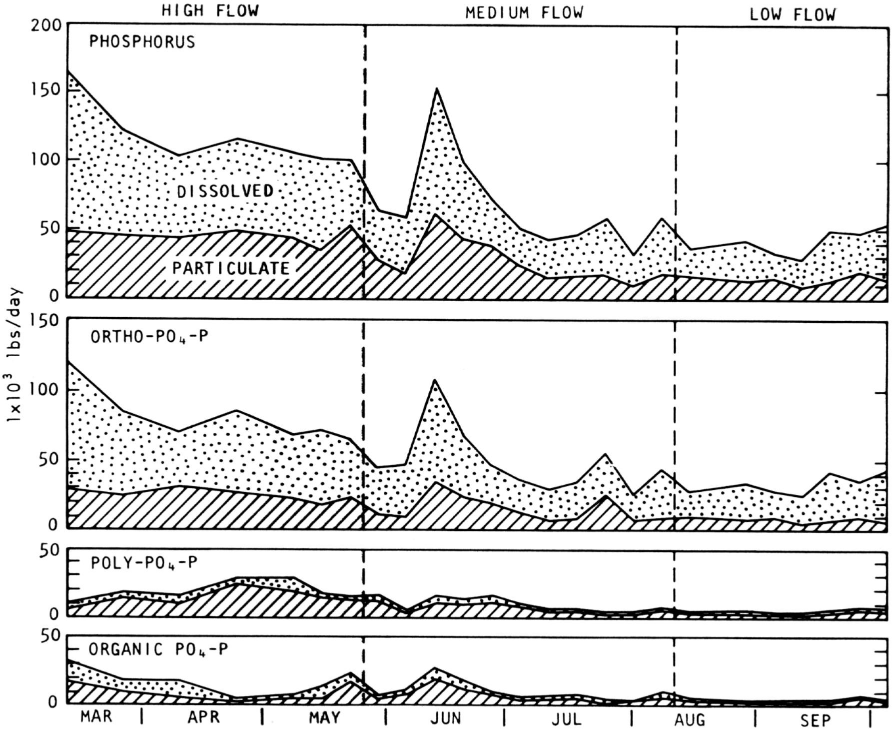

FIGURE 5. — Phosphate-Phosphorus Loads During Different Periods of Flow.

all fractions and forms from the first period to the second and from the second period to the third. This is accounted for by the fact that flow rate decreased much faster than phosphorus concentration increased. High flow rates are due principally to increases in surface runoff and to regulation by dams along the Illinois River.

Phosphorus budget. In calculating the phosphorus budget, mean phosphorus loads of the lower lake segment (stations 7-9) were subtracted from mean loads in the upper segment (stations 1-6). Since flow rate and retention time play a significant part in the phosphorus budget, these calculations were made for the third period of the study (from August to October 1967) when flow rate was lowest, retention time was highest, and Peoria Lake most resembled a true lake. Mean phosphorus loads retained and retention percentages were calculated for each phosphate form and fraction (Table 11). A comparison was made with means for the entire period of study.

During the third period the greatest retention, regardless of fraction, occurred in the orthophosphate form. Considerably less retention was found in polyphosphate, and even less in organic phosphate. This pattern was also seen in most of the mean values for the entire period of study.

TABLE 10.—PO_4-P Concentrations (mg/1) at Differing Periods.

	Period 1	Period 2	Period 3	Mean
Total P	.84	1.13	1.42	1.13
Total Ortho-PO_4-P	.58	.82	1.13	.84
Total Poly-PO_4-P	.13	.16	.16	.15
Total Organic PO_4-P	.13	.15	.13	.14
Dissolved P	.52	.69	.95	.72
Dissolved Ortho-PO_4-P	.42	.59	.88	.62
Dissolved Poly-PO_4-P	.03	.04	.03	.04
Dissolved Organic PO_4-P	.07	.06	.04	.06
Particulate P	.33	.43	.48	.41
Particulate Ortho-PO_4-P	.17	.23	.26	.22
Particulate Poly-PO_4-P	.10	.11	.13	.11
Particulate Organic PO_4-P	.06	.09	.09	.08

With few exceptions, a larger percentage of the phosphorus load was retained during the third period than was retained for the mean of all dates during the entire study. During the third period the form showing the highest percent retention was dissolved polyphosphate, though during the entire study particulate polyphosphate showed the highest percent retention. The means for the total 30 weeks showed a slight percentage gain for dissolved polyphosphate in water leaving Peoria Lake.

The mean daily load of total phosphorus entering Peoria Lake for the period of this study was 77,200 pounds, while that leaving the lake

TABLE 11.—Comparative Phosphorus Budgets for the Low Flow Period 3 and the Entire 30-Week Period of Study.

	Load retained (10^3 lbs/day)		Percent retained	
	Period 3	30-Week Mean	Period 3	30-Week Mean
Total P	11.4	13.8	25.9	17.9
Total Ortho-PO_4-P	9.1	9.5	25.4	17.3
Total Poly-PO_4-P	1.8	2.7	38.9	25.6
Total Organic PO_4-P	0.5	1.6	12.8	12.6
Dissolved P	6.6	5.8	22.2	12.7
Dissolved Ortho-PO_4-P	6.2	5.5	22.5	14.1
Dissolved Poly-PO_4-P	0.4	—0.1	40.0	—4.2
Dissolved Organic PO_4-P	0	0.4	0	8.9
Particulate P	4.8	8.0	31.8	25.7
Particulate Ortho-PO_4-P	2.9	4.0	34.2	24.2
Particulate Poly-PO_4-P	1.4	2.8	34.2	31.8
Particulate Organic PO_4-P	0.5	1.2	18.5	20.3

TABLE 12.—Comparative Date From Three Sources on Phosphate in Peoria Lake. (All values as mg/1 P)

	FWPCA 1959 - 1966	Hurwitz *et al.* June - Sept. 1960	1967 Study
Number of samples	350	25	225
Total phosphorus			
Mean		0.39	1.13 ± 0.41
Summer mean	0.42		
Winter mean	0.59		
Range	0.3 — 0.8		0.47 — 3.02
Dissolved phosphorus			
Mean			0.72 ± 0.31
Summer mean	0.30		
Winter mean	0.48		
Range	0.2 — 0.6		0.20 — 2.00
Total Orthophosphate mean		0.26	0.84 ± 0.36
Total Polyphosphate mean		0.05	0.15 ± 0.09
Total Organic Phosphate mean		0.08	0.14 ± 0.09

was 63,400 pounds. The net amount retained was 13,800 pounds per day or 17.9% of that entering the lake.

Comparison of 1967 data and previous data. Two major difficulties were found in placing current findings on phosphorus from the 1967 Peoria Lake study in historical perspective. First, only recently have phosphorus analyses been run on water samples from Peoria Lake. Previous sampling had generally been done only at the narrow outlet and in the area of station 9. Second, methods of filtration and analysis, especially for total inorganic phosphate and total phosphorus, have undergone many recent changes leading to higher total phosphorus values with a redefining of the phosphorus portion previously known as organic.

In a paper on phosphates in the Illinois Waterway System, Hurwitz *et al.* (1965) gave values shown in Table 12, here converted to phosphate-phosphorus. In addition, mean phosphorus concentrations for the period 1959-1966 based upon data published by the Water Pollution Surveillance System (U. S. Public Health Service, 1963) and the Federal Water Pollution Control Administration are presented for comparison with data from the 1967 Peoria Lake study.

Any lack of close comparability is suggested as being due as much to differences in methods of sampling, filtering, and analysis as to any real 2- to 4-fold increase in each phosphorus fraction and form in the lake.

Comparison with data from other bodies of fresh water. As the analytical data readily show, Peoria Lake is notably high in phosphorus content. A comparison of published concentrations of total phosphorus in a variety of lakes, parts of lakes, and reservoirs (Table 13) show Peoria

TABLE 13.—Comparative Levels of Total Phosphate in Fifteen Lakes and Reservoirs.

Lake	Year	Concentration, Means and/or Range (mg/1 P)	Reference
L. Santa Fe, Florida	1955	0.0016	Lackey & Putnam 1965
Fern L., Washington	1963	0.0043	Olsen et al. 1967
L. Dojran, Yugoslavia	1965	0.012	Petrovic 1965
L. Zoar, Connecticut	1955	(0.012—0.041)	Curry & Wilson 1955
L. Michigan, south basin	1954	0.013	Beeton 1960
L. Superior	1960	0.014	Beeton 1960
L. Huron, Saginaw Bay	1956	0.016	Beeton 1960
Slapy Reservoir, Czech	1959-60	(0.03—0.07)	Hrbacek 1966
Upper Klamath L., Oregon	1965-66	(0.03—2.0)	Miller & Tash 1967
Bantam L., Connecticut	1966	0.037	Frink 1967
L. Sebasticook, Maine	1965	(0.04—0.07)	Mackenthun et al. 1968
L. Erie, west end	1958	0.044	Beeton 1960
Sturgeon L., Ontario	1953-55	0.044	Neil 1958
Green L., Washington	1959	0.068	Sylvester & Anderson 1964
Peoria L., Illinois	1967	1.13 (0.47—3.02)	

Lake to have from 17 to 94 times the phosphorus concentration found in the other bodies of water. The first two examples cited, Lake Santa Fe, Florida, and Fern Lake, Washington, are oligotrophic and are included for comparison since their concentrations of total phosphorus are proportionally about as much below the other twelve lakes as Peoria Lake is above them.

Typical surface waters in Illinois in 1957 averaged 0.26 mg/1 P as total phosphate-phosphorus (Dietz and Harmeson, 1958). The Kaskaskia River, Illinois in 1960 showed concentrations to range from 0.08 to 0.30 mg/1 P (Englebrecht and Morgan, 1959). A recently published evaluation of the Ohio River gave as a 1966 maximum 0.39 mg/1 P (Ohio River Valley Sanitation Commission, 1967). All of these concentration levels were exceeded by the minimum total phosphorus concentration for Peoria Lake (Table 13).

With the exception of waters immediately adjacent to the outfalls of waste treatment facilities, Peoria Lake in 1967 showed some of the highest concentrations of total phosphorus yet reported.

This is also emphasized by a comparison of amounts of influent phosphorus from the drainage areas of three different lakes with that of Peoria Lake in 1967 (Table 14).

TABLE 14.—Phosphorus Input to Four Lakes. (Mean pounds/square mile of drainage area/year)

Lake	lb P
Lake Sebasticook, Maine	63.5
Lake Mendota, Wisconsin	188
Upper Klamath Lake, Oregon	263
Peoria Lake, Illinois	2,050

SUMMARY

1. Laboratory methods and techniques used permitted expressing

phosphorus concentration in natural water in terms of its various forms — ortho-, poly-, and organic — as well as in the fractions — dissolved and particulate.

2. The mean total phosphorus concentration observed in Peoria Lake was 1.13 mg/1 P with a range of 0.47 — 3.02 mg/1.
3. Orthophosphate represented 75% of the total phosphorus, and 64% of the total phosphorus was in a dissolved state.
4. Differences in total phosphorus concentration with down-lake water movement and in weekly fluctuations were principally reflected by changes in orthophosphate concentration.
5. Degrees of interchange were observed in the percentage distribution of dissolved and particulate fractions during down-lake water movement. The changes in total dissolved and total particulate phosphorus were reflected by corresponding changes in dissolved and particulate poly- and organic phosphate.
6. The only notable down-lake change in the distribution of the various forms of phosphate, i.e., ortho-, poly-, and organic, was in particulate ortho- and polyphosphate.
7. Dissolved orthophosphate was the only fraction of any form that could be shown to be related to flow or seasonal changes.
8. Despite a very low retention time, total phosphorus removal within the lake averaged 17.9%, or about 13,800 pounds per day.
9. Although observed nutrient conditions in Peoria Lake appeared sufficient to support plankton populations, such did not occur.

LITERATURE CITED

AMERICAN PUBLIC HEALTH ASSOCIATION. 1965. Standard methods for the examination of water and wastewater. 12th edition, New York.

BARROWS, HARLAN H. 1910. Geography of the middle Illinois valley. Illinois Geological Survey Bull. 15. 128 pp.

BEETON, ALFRED M. 1960. Great Lakes limnological investigations. Proceedings, Third Conference on Great Lakes Research, University of Michigan, Great Lakes Research Div., Publ. 4: 123-128.

BORUFF, C. S. 1930. Illinois River studies, 1929-1930. Industrial and Engineering Chemistry 22(1-8):1252-1259.

COLLINS, W. D. 1910. The quality of the surface waters of Illinois. U. S. Geological Survey Water Supply Paper 239. 94 pp.

CURRY, J. J. and S. L. WILSON. 1955. Effect of sewage-borne phosphorus on algae. Sewage and Industrial Wastes 27(11):1262-1266.

DIETZ, JESSE C. and ROBERT H. HARMESON. 1958. Phosphate compounds occurring in Illinois surface waters. Proceedings, Twelfth Industrial Waste Conference, Purdue University Extension Series 94.

EDWARDS, GAIL P., ALAN H. MOLOF and RICHARD W. SCHNEEMAN. 1965. Determination of orthophosphate in fresh and saline waters. J. Amer. Water Works Assoc. 57(7):917-925.

ENGLEBRECHT, RICHARD S. and JAMES J. MORGAN. 1959. Studies on the occurrence and degradation of condensed phosphate in surface water. J. Water Pollution Control Federation 31(4): 458-478.

FRINK, CHARLES R. 1967. Nutrient budget: Rational analysis of euthophication in a Connecticut lake. Environmental Sci. and Tech. 1(5):425-428.

GALES, M. E., E. C. JULIAN and R. C. KRONER. 1966. Method for quantitative determination of total phosphorus in water. J. Amer. Water Works Assoc. 58:1363-1368.

GREENFIELD, R. E. 1924. Comparison of chemical and bacteriological examinations made on the Illinois River during a season of low and a season of high water — 1923-1924. Illinois State Water Survey Bull. 20. 25 pp.

HRBACEK, JAROSLAV, LIDMILA PROCHAZKOVA, VERA STRASKRABOVA-PROKESKOVA and CHARLES O. JUNGE. 1966. The relationship between the chemical characteristics of the Vltava River and Slapy Reservoir with an appendix: Chemical budget for Slapy Reservoir. *In* Hydrobiological Studies 1, Acadamia Publishing House of the Czechoslovak Academy of Sciences, Prague, 41-84.

HURWITZ, E., R. BEAUDION and WILLIAM WALTERS. 1965. Phosphates and their "fate" in a sewage treatment plant — waterway system. Water and Sewage Works 112:84-89.

JEFFERSON, THOMAS. 1803. Notes on the State of Virginia. Wilson and Blackwell, Trenton, July 12, 1803.

JENKINS, DAVID. 1967. Analysis of estuarine waters. J. Water Pollution Control Federation 39(2):159-180.

KOFOID, C. A. 1903. The plankton of the Illinois river, 1894-1899; With introductory notes upon the hydrography of the Illinois River and its basin: Part 1, Quantitative investigations and general results. Bull. Illinois State Lab. Nat. Hist., VI, Art. II, November.

LACKEY, JAMES B. and HUGH D. PUTNAM. 1965. Ability of streams to assimilate wastes. Quart. J. Florida Acad. of Sci. 28(3):305-317.

MACKENTHUN, KENNETH M., LOWELL E. KEUP and R. KEITH STEWART. 1968. Nutrients in Lake Sebasticook, Maine. J. Water Pollution Control Federation 40(2) Part 2:R72-R81.

MENZEL, DAVID W. and NATHANIEL CORWIN. 1965. The measurement of total phosphorus in sea water based on the liberation of organically bound fractions by persulfate oxidation. Limnology and Oceanography 10(2):280-282.

MILLER, WILLIAM E. and JERRY C. TASH. 1967. Interim report—Upper Klamath Lake studies, Oregon. Fed. Water Pollution Control Admin., Publication WP-20 — 8 pp, September.

MILLS, HARLOW B., WILLIAM C. STARRETT and FRANK C. BELLROSE. 1966. Man's effect on the fish and wildlife of the Illinois River. Illinois Nat. Hist. Surv. Biol. Notes No. 57. 24 pp.

MÜLLER, GERMAN and GERD TIETZ. 1966. The phosphorus content of Lake Constance sediments, its admission to the deposited sediments from the free water of the lake. N. Jb. Miner. Abh. 105(1):41-62. (English summary)

NATVELLA, M. G. 1963. Experimental statistics. U.S. Department of Commerce, National Bureau of Standards Handbook 91, Government Printing Office, Washington, D. C.

NEIL, JOHN H. 1958. Problems and control of unnatural fertilization of lake waters. Proceedings, Twelfth Annual Industrial Waste Conference, Purdue University Engineering Extension Series 94, 12(3):301-316.

OHIO RIVER VALLEY SANITATION COMMISSION. 1967. (Orsanco-1967) Nineteenth yearbook, 1967. Commissioners of the Ohio River Valley Water Sanitation Commission, 414 Walnut Street, Cincinnati, Ohio 45202.

OLSEN, SIGURD. 1964. Phosphate equilibrium between reduced sediments and water — Laboratory experiments with radioactive phosphorus. Verh. Internat. Verein. Limnol. XV:333-341.

OLSEN, SIGURD, DIPTIMAN CHAKRAVARTI and PAUL R. OLSON. 1967. Water, bottom deposits and zooplankton of Fern Lake, Washington. Limnology and Oceanography 12(3):392-404.

PETROVIC, GROZDANA. 1965. Phosphorus in the water and mud of the eutrophic Lake Dojran. Arh. Biol. Nauka (Belgrade) 17(4):246-264. Translated from Chem. Abstracts 66(24):60, 108107s (1967).

ROBERTSON, REED S. 1960. Rapid method for estimation of total phosphate in water. J. Amer. Water Works Assoc. 52(4):483-491.

SANNING, D. E. 1967. Phosphorus determination — A method evaluation. Water and Sewage Works 114(4):131-133.

SYLVESTER, ROBERT O. and GEORGE C. ANDERSON. 1964. A lake's response to its environment. Proceedings ASCE, J. Sanitary Eng. Div. 90(SA1):1-24.

U. S. PUBLIC HEALTH SERVICE. 1963. Annual compilation of data October 1, 1962-September 30, 1963. Water Pollution Surveillance System, Div. of Water Supply and Pollution Control, Dep. of Health, Education and Welfare, Washington, D. C.

Manuscript received September 16, 1968.