CONSIDERATIONS ON THE PHOSPHATE ION MOVEMENT IN A MODEL TERTIARY SEWAGE TREATMENT SYSTEM

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ABSTRACT

CONSIDERATIONS ON THE PHOSPHATE ION MOVEMENT IN A MODEL TERTIARY SEWAGE TREATMENT SYSTEM

By Charles E. Day, III

Research was conducted on a new system designed to clean domestic sewage. The system appeared to represent a concentration of the natural aquatic ecosystem with the variables of water flow, light, and oxygen content controllable. Since phosphates are one of the major waste products in domestic sewage, the research was concerned with the movement of phosphates in the experimental system. The object was to determine whether or not most of the phosphates simply passed through the system. The alternate possibility was that the phosphates entered into a dynamic cycle between the water and the organisms in the water. This alternate possibility had already been demonstrated in the natural aquatic ecosystems where the phosphates are low in concentration compared to domestic sewage concentrations.

Radioactive P-32 in the inorganic phosphate form was introduced into the system, and its location in the system and its progress through the system were studied. Measurements and evaluations were made by geiger counter

monitoring on site, and by liquid scintillation techniques in the laboratory. The water and various solid samples were analyzed for P-32 activity. The results were compared with the literature in the field, and with the relevant data known for the system.

The findings indicated that over 99.9% of the phosphates enter into the dynamic cycle between the water and the organisms and materials in the water. The amount of phosphates passing through the system unaffected was extremely low or non-existent. The time required for the bulk of the P-32 to pass through the system was over sixteen times the mean retention time of the water in the system. The most basic conclusion was that with respect to phosphates the system does behave in the same manner as a natural aquatic ecosystem. This finding should assist in making possible the application of known biological phenomena to interpret, understand, control, and modify this new type of sewage treatment system more easily.

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By

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

The problem of clean water in this country is rapidly gaining wide attention. Unclean waters are a health menace to the population as well as to the ecosystem (Storer, 1953). Disease and destruction of food chains, recreational areas, industrial sites, and transportation systems are direct results of unclean water (Hanlon, 1964, Storer, 1953). Industrial contamination and domestic pollution are the two main factors involved in the widespread destruction of our freshwater systems.

The water demand increases with population and technological development. This demand is affected by a reduction in time and treatment space available for cleaning used water. The relative amounts of unused water for dilution compared with the increasing amounts of used water which must be diluted is another limiting factor. Thus the necessity for obtaining better methods of water treatment is becoming paramount.

One possible technique for cleaning domestic waste water is currently under investigation at Michigan State University. In April 1964, Dr. Karl L. Schulze (1966b ms) began a project on tertiary waste water treatment. This

tertiary system consists of a highly concentrated biological community in an aquarium which is fed by the final effluent from the East Lansing sewage treatment plant in East Lansing, Michigan. The sewage entering the plant is cleaned by the Activated Sludge Process which is the most complete treatment process presently in use (Schulze, 1966b ms).

This particular study on the phosphate ion movement in the tertiary sewage treatment system utilized carrier free P-32 in the inorganic phosphate form. The P-32 was introduced as a tracer to provide further information about the "behavior" of the tertiary sewage treatment system. The purpose was to find out whether or not the movement of phosphate in this model system is similar to the movement in the aquatic ecosystem. If so, then one of the major phenomena in an aquatic community can be related to the biological approach to sewage treatment. Information from this study supports the idea that such systems are similar to natural ecologic processes. The possibility of utilizing data from the disciplines of biology and sanitary engineering on this problem, therefore, becomes more tenable. Such a combination of data can lead to a large saving of time in experimental duplication, and can enhance the understanding of both fields of study.

CHAPTER II

LITERATURE REVIEW

With the widespread introduction of commercial fertilizers for agricultural purposes, the role of phosphorus in the aquatic ecosystem became a matter of great interest. Hayes and Coffin (1951) noted that excess phosphates introduced to a pond or lake disappeared in a very short time, even when in excess by a factor of 100 or more over the normal amount of phosphorus in the water.

When radioactive phosphorus became readily available, the ability to study phosphate movement in aquatic ecosystems was enhanced. Hutchinson and Bowen (1947a) demonstrated that within one week after introducing radioactive phosphorus as the inorganic phosphate into a small lake the Potamogeton contained 1000 times the amount of radioactive phosphorus found in the water.

Hayes and Coffin (1951) found that P-32 in water was reduced to 33% of the introduced amount after three days when investigating under similar conditions. Equilibrium was reached a few hours later. At equilibrium the total phosphorus enhancement to the lake was only 0.25%. They assumed that there was a phosphorus exchange between the water, mud, and life forms.

Hayes, McCarter et al. (1952) reported that a plateau of radioactive phosphorus was reached in the water at about 10% of the quantity of the radioactive phosphate introduced, but that the curve for removal was not logarithmic. This indicated that the removal, or loss, from the water was not a simple one-way process which might occur with diffusion out of the water to solids. Less than one-sixth of all of the introduced phosphorus remained in the water at equilibrium. The half-life for phosphorus in water was 3.73 days, and for all solids combined the value was 27 days. Equilibrium was reached most rapidly under growing eutrophic conditions. As a result of this work, Hayes et al. postulated an active exchange between water phosphorus and solids phosphorus which together formed a single system.

That there is a return of phosphorus from organic material to the water was established by Cooper (1935) when he studied the phosphorus return to water from dead zooplankton.

Hutchinson and Bowen (1950b) and Whittaker (1953a) have shown that plankton is primarily responsible for P-32 removal in the inorganic phosphate form. Studies by Whittaker (1961b) in aquarium microcosms support this observation. In these studies more than 50% of the introduced radioactive phosphorus had been taken up by the plankton and returned to the water in five hours. The uptake of P-32 by plankton may be as great as one-half the equilibrium value in the first hour. The algae uptake

range varies from 1-5% per hour. Uptake by microcrustaceans is rapid also, but phosphorus is taken up more slowly by higher animals. In general the larger the organism, the slower the uptake per unit mass, and the slower the decline from the maximum concentration.

The study of the bacterial fractions of plankton contributed more knowledge about phosphate movement. Waksman et al. (1937) and Renn (1937) showed that when natural waters were stored there was a large increase in the bacterial population and a loss of dissolved phosphate, but little attention was given to this. The multiplication of bacteria was generally considered to be peculiar to stored water. However, Birge and Juday (1934) and Bere (1933) found populations of bacteria in lake water to be 10^4 to 10^6 cells per ml of water.

Rigler (1956a) found that multiplication of bacteria was not unique to stored water, and that the turnover of inorganic phosphates could be measured in minutes instead of days. Bacteria were largely responsible. These studies showed that after 1.5 hours over 97% of the introduced phosphates was taken up by the plankton. At six hours when 95% remained in the plankton, 68.4% of the total radioactive phosphates was in the bacterial fraction of the plankton. Further work indicated that the equilibrium was reached in twenty minutes with 93% of the phosphate in the plankton. Nearly 70% was in the bacterial fraction. From this the phosphate turnover time for bacteria was found to be 3.6

minutes and 5.4 minutes in two separate trials. Comparison with two other lakes yielded similar results.

In general the phenomenon observed is an initial rapid departure of inorganic phosphate from the water, followed by a slowing of the rate later on as equilibrium is reached with the various community fractions. There is no simple logarithmic relationship. Whittaker (1961b) has pointed out three facts common to lakes and aquaria: (1) an initial rapid movement of phosphate to the plankton, an intermediate phase when the phosphate is in the community fractions, and a final phase when the phosphate goes to the sediment, surface films, and mud; (2) the rates of movement are very fast at first; and (3) the removal and concentration is biological and dependent on the activities of the organisms although adsorption is significant. Whittaker also noted that turnover rates are less dependent on phosphate levels and more dependent on organism characteristics and relative community fractions.

However, Ball and Hooper (1963) have indicated that the rate of removal and the total amount of removal of P-32 from a trout stream may be highly dependent on the distribution of P-32 between the soluble and particulate phases after it has been added to the experimental system.

Welch (1952) and Odum (1959) emphasize that much remains to be understood concerning the movement of phosphorus in the aquatic environment. However, it is clearly understood that phosphorus is not a passive element in any

form and that its behavior is greatly influenced by any organic material with which the water may have contact.

Inasmuch as the phosphate content of domestic sewage is high, an efficient method of removal is desirable. There is a possibility that phosphates in sewage are not involved in the biological cycles as a whole; so much phosphate is available that it is no longer a limiting factor in community fraction growth. Phosphates may be in excess to the degree that much of it does not enter into the biological cycles at all. On the other hand there is a possibility that the cycles are so dynamic that they will handle almost all of the phosphates in any quantity. The research in this study indicates that the latter possibility is the more correct one.

CHAPTER III

THE TERTIARY SYSTEM

The tertiary system used in this research was developed by Dr. Karl L. Schulze, Department of Civil and Sanitary Engineering at Michigan State University, East Lansing, Michigan. A series of aquariums receive final effluent from one of the final clarifiers of the East Lansing sewage treatment plant. The pretreated waste water is administered to the aquariums from a small constant level tank by a variable speed Sigmamotor pump (Schulze, 1966b ms). While there are four aquariums, or tanks, the first one is the major functional unit. This first tank is equipped with a thermometer, a dissolved oxygen metering electrode, three air diffusers, three fluorescent lamps, and 18 pieces of fiberglass window screen (Schulze, 1966b ms). The screens are placed like the plates in a car battery. The total surface area of the screens is 772 cm^2 per liter of water (Schulze, 1966b ms).

The final effluent enters one end of the tank as a continuous flow, passing through a burette used to measure rate of inflow. Water leaves by a surface outflow at the opposite end of the tank. The total capacity of the tank

is 48.4 liters. Figure 1 shows a diagram of the tertiary system. Figures 2 and 3 are photographs of the first tank in the system.

Figure 1 is a flow diagram of the tertiary system taken from the report by Schulze (1966b ms). Figures 2 and 3 on pages 11-13 are of tank #1. Tank #1 was the only portion of the system used for the research concerning the movement of phosphate ions described in this paper. Figure 3 provides a coordinate reference system for the surface monitoring described in Chapter IV. Coordinates A,B,C,D-1 delineate the area covered entirely by Lemna minor throughout the research period.

In tank #1 the screens trap suspended solids in the water, forming a substrate. Bacterial colonies develop on this substrate along with sessile protozoans, especially Epistylis sp. A whole web of life arises from this base, feeding on it and the soluble and insoluble materials in the water. The detritus is sluffed off to the bottom of the tank. The aeration bubblers provide oxygen to be used for respiration and reduction of the biological oxygen demand. In addition they set up a circular current which is perpendicular to the direction of water flow. This is observed by the surface ripple distribution and by the tendency for Lemna minor to grow in the calmer waters on the opposite side of the tank. The light is utilized for photosynthetic and photochemical reactions. A timer

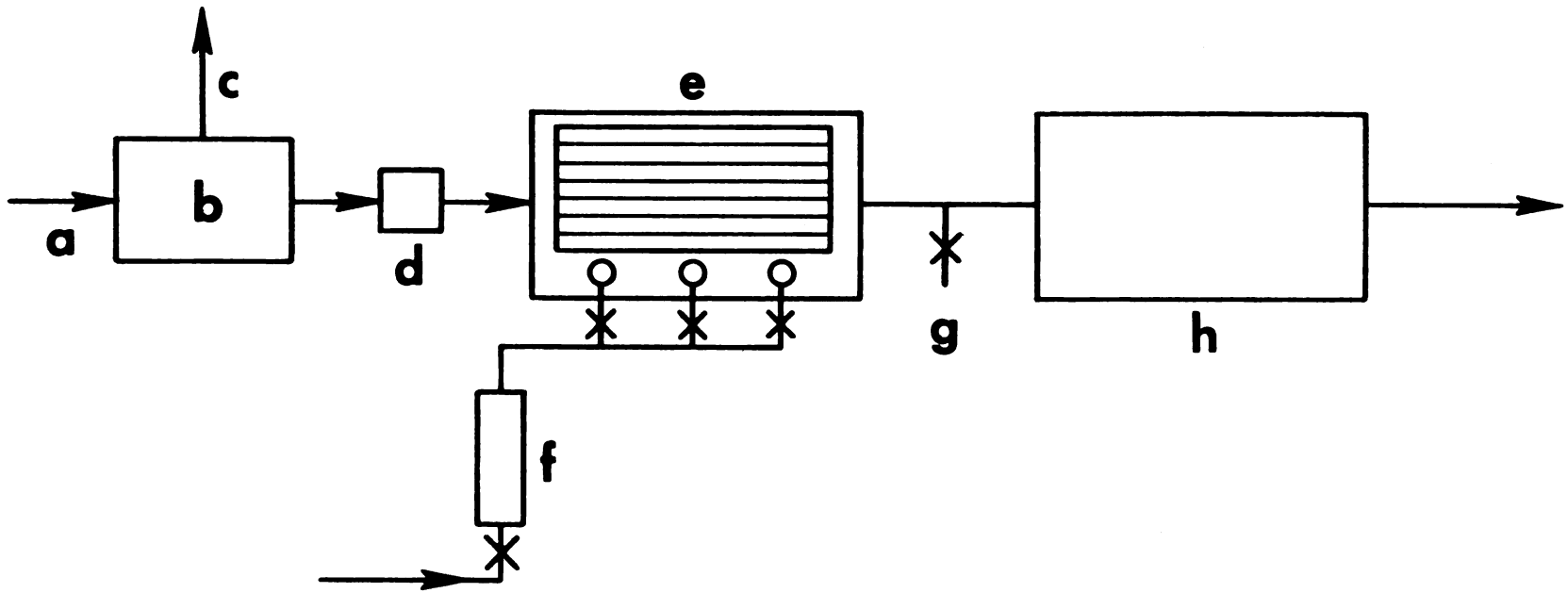


Figure 1. Flow diagram of tertiary treatment experiment:
a. incoming flow
b. constant level tank
c. excess flow
d. variable feed pump
e. tank I with fiberglass screen unit
f. air flow meter
g. sampling valve
h. tank II containing plants and fish

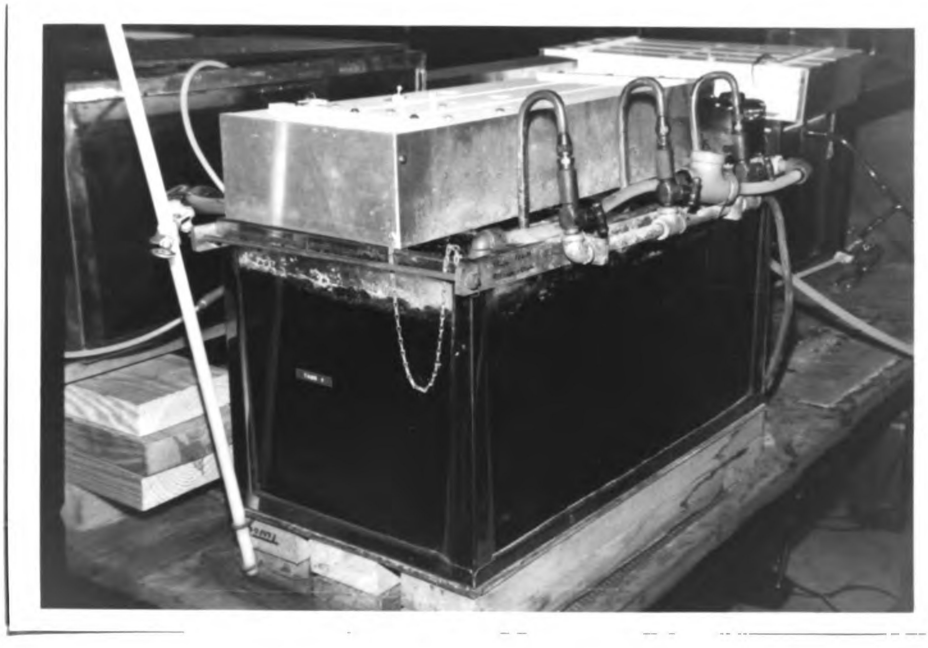


FIGURE 2.--Tank #1 of the model tertiary sewage treatment system.

FIGURE 3.--Subdivisions and scheme of surface of tank #1.

A,B,C,D,1,2,3 = Coordinates of subdivisions

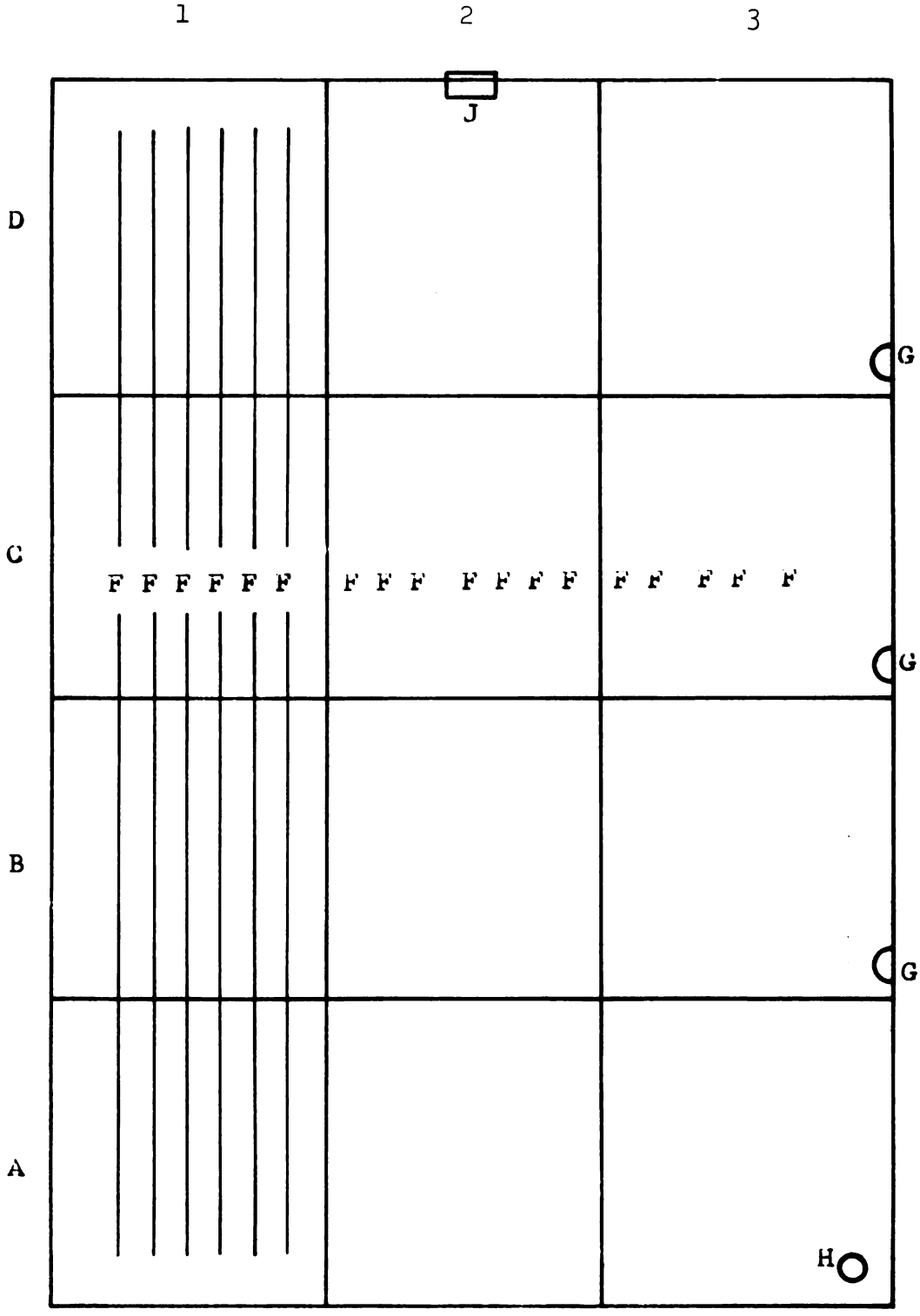
F = Screens

G = Aeration bubblers

H = Point of inflow

J = Point of outflow

FIGURE 3.--Subdivisions and scheme of surface of tank #1.



regulates the light so that there is a fifteen hour day period and a nine hour night period (Schulze, 1966b ms).

The biological mass of this one tank is extremely high. Bacteria such as Sphaerotilus, Zoobloea, and Beggiatoa are present (Schulze, 1966b ms). Protozoans include Epistylis sp., Vorticella sp., Stentor sp., Spirostoma sp., and Arcella vulgaris (Eddy and Hodson, 1961). The algae are many and varied, but Oscillatoria and Rhizoclonium are common (Schulze, 1966b ms). Other common animals include Physa elliptica, Philodina sp., Rotaria sp., tubificids, ostrocods, copepods, Daphnia pulex, and periodically Graptemys geographica which is introduced to reduce the Physa elliptica. The surface of the tank has about 50% coverage of Lemna minor on the side opposite the aerators.

The remaining three tanks have no special equipment other than lighting. They have been provided with a layer of washed gravel, and various life forms have been added. Nothing is provided to support the life forms. The last tank is a well balanced aquarium yielding odorless, clear water. Operating the system on approximately a 24 hour retention time gave the following efficiencies of removal: (1) 90% for biological oxygen demand; (2) 92% for turbidity; (3) 94.5% for suspended solids; and (4) 96% for coliform bacteria (Schulze, 1966b ms).

CHAPTER IV

MATERIALS AND PROCEDURES

An introduction of 1.04mc of P-32 in 100ml of distilled water was made at the point of inflow in the first tank (See "E" in Figure 3). The P-32 was in the inorganic phosphate form and was carrier free. The introduced solution had a pH value of 7.0. Three experiments were conducted on tank #1.

Every hour after the P-32 was introduced a sample of the water leaving tank #1 was taken. The water was drawn into a beaker at point "G" in Figure 3. The sampling valve was first cleared of standing water. From the beaker containing the sample one-half ml was pipetted into a glass bottle containing 15ml of liquid scintillation solution. The sample bottles were capped, agitated, and finally counted in a Packard Tricarb Liquid Scintillation Counter. Fifteen samples were taken in this manner.

Hourly samples were also made of one Lemna minor plant and one Physa elliptica taken from the line between subdivisions B-1 and C-1 (see Figure 3, page 13). These solid samples were picked up with BB forceps, placed on paper toweling, rinsed with distilled water, and placed

in 15ml of the scintillation solution in a sample bottle. The prepared samples were counted in the liquid scintillation counter.

The second experiment consisted of selecting samples of water and material from the first tank itself to determine where the radioactive phosphorus was located in the tank. The water sample was obtained by inserting a pipette into the tank between the two center screens. A few milliliters of water were obtained, and one-half ml of the water was added to 15ml of the liquid scintillation fluid in a bottle and counted. A sample of bottom material was obtained by drawing it up in a pipette. The material was rinsed on filter paper with distilled water and transferred to the glass bottle containing 15ml of scintillation fluid. Samples of Lemna minor were obtained with BB forceps. Tubificids and screen substrate were removed by scraping the material onto a glass microscope slide and lifting it clear of the water. The Lemna minor, tubificids and screen substrate were all prepared in the same manner as described for the bottom material. The prepared samples were all refrigerated for 45 minutes to allow dissolving before counting.

In the third experiment the surface of tank #1 was divided into twelve sections, and each section was monitored. The Nuclear Chicago Portable Geiger Counter Model 2112 was used for monitoring. The detection tube was open-windowed to detect the beta particles emitted by the P-32.

The open-window was placed over the surface of the water in the center of each section, and the count rate was taken directly from the dial on the instrument. This experiment reflected only the activity at the surface of the aquarium, specifically, the activity of the Lemna minor compared to the activity of the open water at the surface. The reason for this is that the path of the beta particle emitted is too short to be detected below the surface of the water. Monitoring was carried out over a period of 163.5 hours after the P-32 was added to the tank.

The liquid scintillation fluid used in the first two experiments was prepared by combining the following: 750ml of p-dioxane, 125ml of 1,2-dimethoxyane, 125ml of anisole; 10mg of 1.4-bis-(4-methyl-5-phenyloxazolyl)-benzene (POPOP), and 1.4g of 2,5-diphenyloxazole (PPO).

Liquid techniques are useful because they can detect lower energy radiation, minimize quenching and allow mixing of the scintillator material with the emitting substance (Price, 1964). These factors are important when working with a beta particle emitter such as P-32. However, the liquid scintillation method of counting was used in this research for primarily one reason. The aqueous samples need only be mixed with the scintillation fluid to be counted. While laboratory models of geiger counters and a proportional counter were available, the difficulty in preparing a dry sample of suitable size and consistency for counting in these instruments was too great. Time

needed for such preparation and lack of proper equipment ruled out the feasibility of counting with dry samples. Liquid scintillation counting was the best choice.

The counting efficiency of the Packard Tricard Scintillation Counter was determined by using a sample containing a known quantity of activity, and a blank. One-half ml of the P-32 solution was added to 15ml of scintillation fluid for the known. The blank contained 15ml of scintillation fluid and one-half ml of distilled water. The instrument is a Series 3000 model and has three counting channels. Since energy ratios were not desired, two channels were closed. The result was an increase in the counting efficiency of the third channel.

Using the known sample the gain was adjusted until the maximum number of counts was found for a fixed amount of time. The gain was 95% which agreed well with the factory adjusted value of 94.5% (Packard Operation Manual 2018, 1964). The blank was then used for background counting and the window widths were changed until the background count rate was zero over a period of 100 minutes. The known sample was then counted. The count rate divided by the known activity of the sample yielded a counting efficiency of 39% for P-32 in water.

FIGURE 4.--The Packard Tricarb Liquid Scintillation Counter Model Series 3000.

FIGURE 5.--The Nuclear Chicago Portable Geiger Counter Model 2112.

CHAPTER IV

EXPERIMENTAL RESULTS

Addition of 1.04mc of P-32 amounts to 7.48×10^{-5} mg/l in the tank. This is found by the following equation.

$$P\text{-}32(mg/l) = \frac{(X curies)K(10^{3} mg/g)}{\text{Tank Vol. (l)}}$$

where:

$X = 1.04 \times 10^{-3} c$

$K = 3.49 \times 10^{-6}$ g/c; a constant for P-32 (Rad. Hlth. Hdbk, 1960).

Tank Vol. = 48.4 liters

This amount of phosphorus added to the system is too small to upset the phosphorus balance. Conversion of the above weight to the radioactive phosphate weight would increase it slightly, but compared to the normal ortho-phosphate tests, which indicated that roughly 16mg/l was present, this amount would be insignificant.

However, 1.04mc is enough to provide 9,330 counts per minute in a one-half ml sample assuming the efficiency of 39%, and assuming that all phosphate remains in the water. This is found by the following equation:

$$cpm = \frac{1.04mc \times 3.7 \times 10^{+7} dps \times 60 spm \times 0.5 ml \times 39\%}{4.84 \times 10^{4} ml}$$

This is the activity expected to be counted at time 0, the time that the radioactive material is dumped, and assuming rapid diffusion.

The hourly water samples were corrected for counting efficiency, and converted back to their original activity at time zero. This allowed a plot of activity against time as if no radioactive decay had taken place. Thus, only the P-32 being lost by water removal was indicated.

Table 1 includes the hourly water sample data, and Figure 6 shows the curve. Figure 6 can be interpreted as showing a loss of phosphate ions as a continuous flow process. However, this loss is negligible compared to the potential loss. The total P-32 activity at time zero was 23,900 disintegrations per minute per one-half ml of water. If simple diffusion was the only mechanism of phosphate movement, the count rate should have been on the order of nine thousand counts per minute. The actual value in Table 1 amounts to less than 0.1% of this.

Table 2 on page 24 shows the count rates of various samples taken from tank #1, and the number of hours which has elapsed between time zero and the sampling. No efficiency is applied because efficiencies for these materials are not known. The data clearly indicates that quantities of P-32 were located in all samples except the water.

Table 3 contains all of the monitoring data for the subdivisions on the surface of the tank. Figure 7 shows the comparative curves for the four subdivisions covered

TABLE 1.--Specific activity of hourly samples corrected to time zero.

Sample	Activity (dpm)	Time After T_o (hrs)
1	8.25	1
2	6.70	2
3	4.67	3
4	2.60	4
5	6.25	5
6	6.25	6
7	0.52	7
8	1.57	8
9	2.10	9
10	1.05	10
11	1.58	11
12	0.53	12
13	1.05	13
14	0.00	14
15	0.00	15

NOTE: All hourly samples of Lemna minor and Physa elliptica yielded 0.00 counts over a five minute count period.

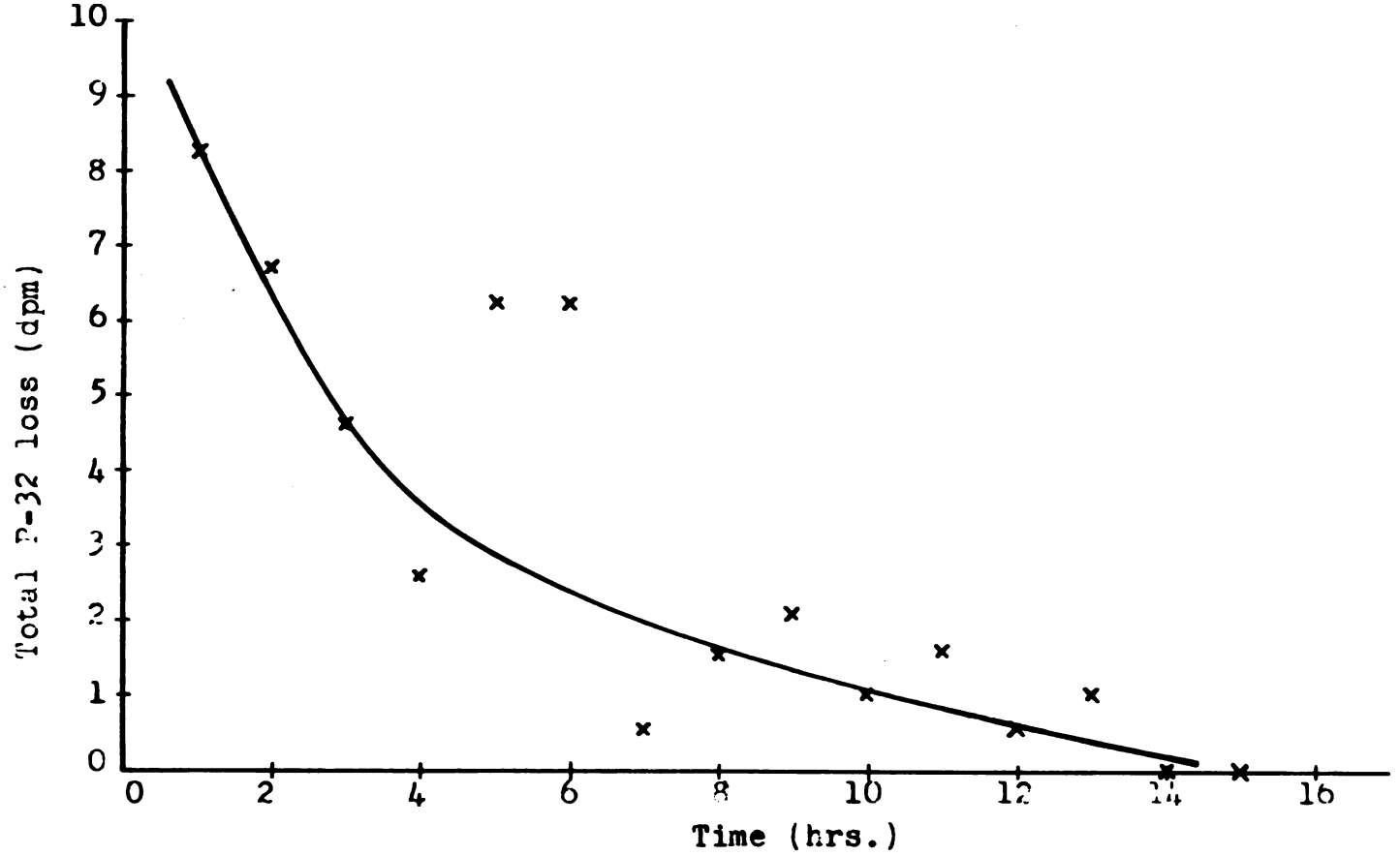


FIGURE 6.--Total loss of radioactive phosphate ions due to outflow from tank #1.

TABLE 2.--Random sample activity.

Type Sample	Counts Per Minute	Time After T_o
Tubificids	58	17 hours
Screen substrate and organisms	87	17½
Bottom sediment	24	20
Water from between screens in tank	0	20
Lemna minor from subdivision B-1	103	18
	277	49
	280	50

TABLE 3.--Background corrected monitoring data from surface of tank #1.

Hours After Time Zero	Subdivisions A-1	B-1	C-1	D-1	A-2	B-2
Hours	cpm	cpm	cpm	cpm	cpm	cpm
17.5	60	34	19	11	45	20
26.5	38	46	37	20	42	16
37.0	29	44	35	36	35	7
41.0	24	44	37	39	38	10
47.0	37	39	36	42	40	10
61.5	27	32	31	48	39	4
63.0	34	38	37	54	42	5
70.75	29	30	29	50	34	6
94.0	24	22	22	46	21	35*
137.5	14	13	15	30	20	24*
163.5	13	12	12	27	22	20*

	C-2	D-2	A-3	B-3	C-3	D-3
Hours	cpm	cpm	cpm	cpm	cpm	cpm
17.5	15	8	20	15	11	8
26.5	5	5	28	3	5	10
37.0	12	6	42	6	3	7
41.0	5	3	37	3	3	2
47.0	3	6	38	4	3	2
63.0	4	4	33	1	1	2
70.75	2	3	39	1	1	3
94.0	22*	50*	19	2	2	11*
137.5	25*	33*	30	2	2	38*
163.5	20*	33*	32	2	2	34*

*Lemna minor entered subdivision.

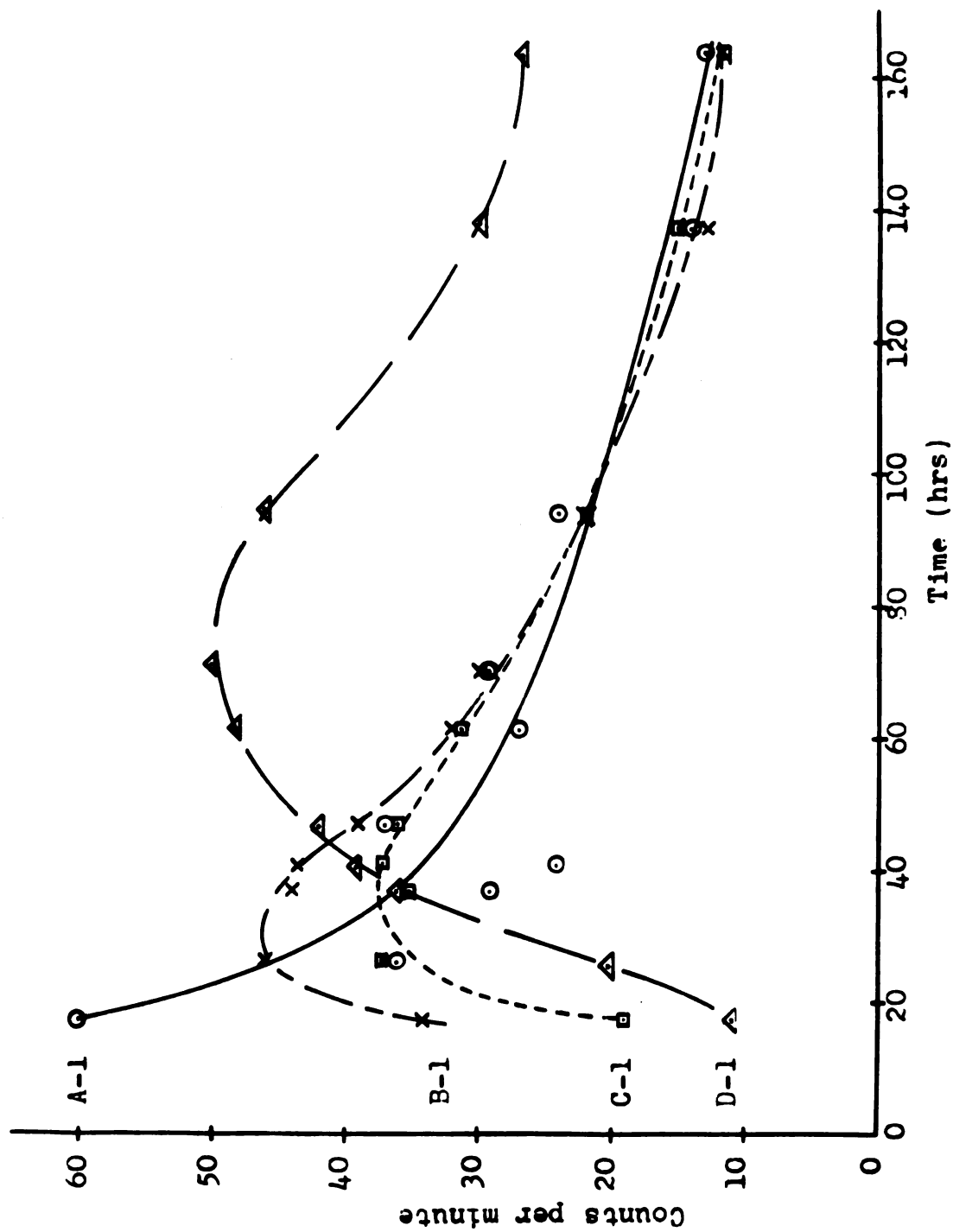


FIGURE 7.--Comparative curves of monitor data for four adjoining subdivisions covered with Lemna minor (background corrected).

with Lemna minor. These curves clearly show that movement of P-32 through the Lemna minor required a very large amount of time compared to the mean retention time of 10 hours.

CHAPTER V

DISCUSSION

The first fifteen water results are statistically inaccurate yet they may indicate diffusion phenomenon for the water alone. If they do, the importance seems to be quite small since the highest activity for a sample was 8.25dpm (see Table 1, page 22). The possible activity could have been on the order of 10^3dpm, if simple diffusion was virtually all that occurred.

The diffusion phenomenon may be treated mathematically in the same way the natural radioactive decay is treated. That is, the time involved for diffusion may be expressed as a half-life. A half-life is the time required for an initial quantity of objects to be reduced to 50% of the original quantity. K. L. Schulze (1965a) has developed an equation for the activated sludge process as a continuous flow culture. The equation is:

$$x_t = x_a e^{(k_m - D)t}$$

where

x_t = cell concentration in reactor after time, t

x_a = initial cell concentration

k_m = maximum growth rate (a constant)

D = constant for volume and nutrient feed rate

The equation may be modified to meet phosphate ion requirements by making:

x_t = phosphate concentration in reaction after time t

x_a = initial phosphate concentration

k_m = rate of phosphate introduction (a constant)

D = rate of phosphate outflow (a constant)

Since k_m-D is a constant, we may express it in a new way such that:

k_m-D = -X, where X = ln 2/diffusion half-life

The equation becomes:

$$x_t = x_a e^{-Xt}$$

This is the basic form of the radiation decay equation. It allows combination of two half-lifes to form an effective half-life.

$$\text{Effective half-life} = \frac{\text{Diffusion } T\frac{1}{2} \times \text{Radiation } T\frac{1}{2}}{\text{Diffusion } T\frac{1}{2} + \text{Radiation } T\frac{1}{2}}$$

where $T\frac{1}{2}$ = half-life

If these were the only half-lifes involved, the solution for the diffusion half-life would be simple. However, Table 2 (page 24) indicates that the biological organisms and the substrates are also utilizing the phosphates. Each of these has a biological half-life

which would be unique for phosphate ions, so they would have to be included in the equation. Obviously the ability to solve for any one factor in the tank becomes impossible The solution is to apply a tank half-life to the equation such that the tank half-life includes all of the half-lifes except the radiation half-life which is known to be 14.22 days (Radiological Health Hdbk, 1960).

Monitor data and the comparative curves probably illustrate best what is occurring in the tank. Subdivisions A-3, A-2, A-1, B-1, C-1, and D-1 were covered with Lemna minor. The rest of the sections were open water except where noted in Table 3. The amount of activity in the covered areas compared to the open areas indicate that the radioactivity was located in the Lemna minor. The data and graph also show that the time required for the phosphate ions to cross the tank is on the order of several days, even though the mean retention time in the tank was only 10 hours at the time of investigation. Almost 100% of the phosphate ions are therefore involved in biological cycles. Odum (1959) points out that phosphorus does not move evenly from organism to environment and back, even though a long time equilibrium tends to be established. In lakes only 10% or less of the phosphorus is likely to be in the soluble form at any one time (Odum, 1959). Due to the high concentration of organisms per unit volume in the experimental tank, the amount of soluble phosphorus in the water at any one time should be significantly less than that found in lakes

The main movement of phosphorus ions through tank #1 appears to be through the available biological cycles, and not by normal diffusion. This method of movement would readily support the idea that some of the mechanisms found in the tank are very similar to the natural mechanisms found in the aquatic environment. The major difference lies in the biota concentration plus the factors which can be controlled such as rate of water flow, light, and air.

The actual proof can be accomplished by setting up a continuous flow of radioactive phosphates through the system. Many details must be determined beforehand, however. Efficiencies need to be determined for many types of samples since degree of dissolvement in the liquid scintillator will affect the percentage of emissions counted compared to the amount of emissions which actually occur. A realistic method of equating the activity to a unit of sample must also be found. The general rule in sanitary engineering is to relate findings in terms of mg/l for solid substances. However, the rate of phosphate uptake by an organism is highly dependent on the surface area available for absorption to take place (Odum, 1959). A useful tool in relating the two might be the mass to surface ratio.

Finally, techniques must be developed which will allow sampling from the tank without disturbing the tank, and yet insuring that the comparative samples are consistent in make-up and location in the tank.

CHAPTER VI

SUMMARY

Radioactive P-32 in a phosphate form was introduced into a model tertiary sewage treatment system in a single quantity, and the movement of the phosphates were studied.

Results indicate:

a. That very little phosphate remains in the water compared to the uptake by organisms in the system.

b. That the ion movement through biological cycles is more important than the diffusion principle or the mean retention time.

c. That the system has mechanisms very similar to those found in the natural aquatic environment.

d. That the major differences from the natural state are probably due to the extreme concentration of organisms, and the factors which can be controlled, such as water flow, light, and air.

REFERENCES CITED

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Ball, Robert C., and F. F. Hooper, 1963, "Translocation of Phosphorus in a Trout Stream Ecosystem," Radioecology, edited by V. Schultz, and A. W. Klement, Reinhold Publishing Corp., New York, N. Y.

Bere, A., 1933, "Numbers of Bacteria in Inland Lakes of Wisconsin as Shown by Direct Count Method," Intern. Rev. Hydrobiol. Hydrogr. 29:248-263.

Birge, E. A., and C. Juday, 1934, "Particulate and Dissolved Organic Matter in Inland Lakes," Ecol. Monogr. 4:440-474.

Cooper, L. H. N., 1935, "The Rate of Liberation of Phosphorus in Sea Water by the Breakdown of Plankton Organisms," J. Mar. Biol. Assoc. U. U., 20:197-200.

Davis, J. J., and R. F. Foster, 1958, "Bioaccumulation of Radioisotopes through Aquatic Food Chains," Ecology 39(3):530-535.

Eddy, S., and A. C. Hodson, 1961, Taxonomic Keys to the Common Animals of the North Central States, Burgess Publishing Company, Minneapolis, Minn.

Hanlon, John J., 1964, Principles of Public Health Administration, The C. V. Mosby Co., St. Louis, Mo.

Hayes, F. R., and C. C. Coffin, 1951, "Radioactive Phosphorus and the Exchange of Lake Nutrients," Endeavor 10:78-81.

Hayes, F. R., J. A. McCarter, M. L. Cameron, and P. A. Livingstone, 1952, "On the Kinetics of Phosphorus Exchange in Lakes," Jour. Ecol. 40:202-216.

Hine, G. J., and G. L. Brownell, 1956, Radiation Dosimetry, Academic Press Inc., New York, N. Y.

Hutchinson, G. E., and V. T. Bowen, 1947a, "A Direct Demonstration of Phosphorus Cycle in a Small Lake," Proc. Nat. Acad. Sci. 33:148-153.

Hutchinson, G. E., and V. T. Bowen, 1950b, "A Quantitative Radiochemical Study of Phosphorus Cycle in Linsley Pond," Ecology 31:194-203.

Odum, E. P., 1959, Fundamentals of Ecology, W. B. Saunders Co., Philadelphia, Pa.

Packard Instrument Co., Inc., 1964, Packard Operation Manual 2018.

Radiological Health Handbook, PB 121784R, September 1960, U. S. Department of Health, Education, and Welfare, Public Health Service, Washington, D. C.

Renn, C. E., 1937, "Bacteria and the Phosphorus Cycle in the Sea," Biol. Bull. 72:190-195.

Rigler, F. H., 1956a, "A Tracer Study of the Phosphorus Cycle in Lake Water," Ecology 37:550-562.

_____, 1961b, "The Uptake and Release of Inorganic Phosphorus by Daphnia magna Straus," Limn. and Oceanog. 6:165-174.

Schulze, K. L., 1965a, "The Activated Sludge Process as a Continuous Flow Culture," Water and Sewage Works, January.

_____, 1966b ms, "Biological Recovery of Waste Water," submitted for publication February 25, 1966, Jour. WPCF.

Storer, J. H., 1953, The Web of Life, The New American Library of World Literature, Inc., New York, N. Y.

Waksman, S. A., J. L. Stokes, and M. R. Butler, 1937, "Relation of Bacteria to Diatoms in Sea Water," J. Mar. Biol. Assoc. U. K. 22:359-373.

Welch, P. S., 1952, Limnology, McGraw-Hill Book Co. Inc., New York, N. Y.

Whittaker, R. H., 1953a, "Removal of Radiophosphorus Contaminant from the Water in an Aquarium Community," AEC Document HW-28636.

_____, 1961b, "Experiments with Radiophosphorus Tracer in Aquarium Microcosms," Ecol. Monogr. 31:157-188.