SOURCES OF PHOSPHATE IN SEWAGE AND SURFACE WATERS

By: F. ALAN FERGUSON

Prepared for:

SOAP AND DETERGENT ASSOCIATION

STANFORD RESEARCH INSTITUTE

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INTRODUCTION

The Soap and Detergent Association (SDA) has asked Stanford Research Institute to conduct a literature search to determine the extent of the information available on the sources of phosphates in sewage and in surface waters of the United States. This memorandum report describes the definitive information found during the search. Based on this information, some preliminary estimates of the amounts of phosphate entering the surface waters from the major sources are also included.

For this study the sources of phosphate have been divided into four groups: municipal sewage, industrial wastes, agricultural sources, and natural sources. Municipal sewage has been further subdivided into the phosphate contribution from human excretions and the contribution from other sources such as phosphate builders in detergents. Where possible, all data have been converted to the annual contribution of phosphate (PO_4 basis) per capita shown as pound PO_4/capita-year. This common factor allows a ready comparison of the relative contributions of the various sources.

SUMMARY AND CONCLUSIONS

Abstracts of over 310 articles were studied, and 130 of these articles were searched for data during the project. Thirty-two articles were found that provided data in sufficient detail to indicate the quantity of phosphates contributed to municipal sewage, or to surface waters, by the source described in the article. Some of these articles, however, described the same studies from different standpoints.

Data on the sources of phosphate in sewage were particularly sparse. Only one article (Harkness and Jenkins, 1958) was found with a quantitative estimate of the phosphate contributed to sewage by detergent builders. Since the article refers to sewage in England, the estimate was of only passing interest for this study. Estimates of phosphates from human excretions were found in physiology textbooks. The original source and vintage of these statistics were often omitted. Sawyer, 1965, says the human contribution to raw sewage is 3.6 pounds (PO_4) per capita-year, and this figure seems to fit with the total amounts of phosphates in sewage reported by others.

Based on this very sketchy data, the sources of phosphate in raw municipal sewage would appear to be:

Source	Input to Raw Sewage ($lb\ PO_4$/capita-year)
Human excretions	2-4
Other sources (primarily phosphate builders from detergents)	5
Total	7-9

However, when raw sewage receives proper secondary treatment, before discharge to the surface waters, the total phosphate is reduced from 7 to 9 pounds PO_4/capita-year to about 4 to 6 pounds PO_4/capita-year. Just what the relative proportions might be from human excretions and from other sources in this treated sewage apparently has not been the subject of any studies.

The ranges of contributions of phosphates to surface waters by the four defined sources appear to be:

Source	Contributions to Surface Waters ($lb\ PO_4$/capita-year)
Municipal sewage*	
Treated	4-6
Raw	7-9
Industrial wastes	Unknown
Runoff from agricultural land	4-9.5
Natural sources	Unknown but could be as high as 20
Total	30

Very few data were found on the contribution of phosphate from industrial wastes. Even in the Lake Erie basin where an extensive study was conducted, no real estimate of the industrial discharge of phosphate was possible. The figure for the total contribution, 30 pounds PO_4/capita-year, is based on the PO_4 carried as silt by the Mississippi River. Presumably this phosphate comes from all the sources discharged into the river basin. Since the Mississippi River carries an above average silt load, the total figure is probably high.

* All of the data were of comparatively recent origin. The earliest definitive work was done around Madison, Wisconsin, in 1942 and 1943. No comparison was possible of phosphate contributions to surface waters by sewage before and after the introduction of detergents with phosphate builders.

SOURCES OF PHOSPHATE IN SURFACE WATERS

The definitions of the four major sources of phosphates used in this study are as follows:

1. Municipal sewage includes sewage from residences and commercial establishments, whether they are connected to a collective (or community) sewer system or the sewage enters the water directly or indirectly by seepage or from ground water runoff. It does not include the industrial waste component in community sewage systems.

2. Industrial waste includes liquid or slurried wastes from all industrial processing, whether discharged directly to surface waters through plant sewers, indirectly through community sewer systems, or from lagoons or land sprayed with the waste material.

3. Agricultural sources are any sources of phosphate other than sewage having its origin on a farm. Runoff and drainage from cultivated and fertilized farmland contains phosphate. Unfertilized farmland can also contribute phosphates if the topsoil containing phosphate enters the surface water in the form of mud or silt. Farm animals may be major contributors of phosphates, but little attention has been directed to this source.

4. Natural sources are those sources of phosphate not directly resulting from human activities including farming. Rain can be a natural source of phosphates. Runoff from forested or open land contains phosphate both in the soluble form and as part of silt washed into streams. Wild animal and bird droppings are another natural source of phosphates. Fish and plankton use and discharge phosphates, and can--by moving from one point to another between use and discharge--contribute phosphate to the body of water where discharge takes place.

The phosphates enter sewage and surface waters in many forms--soluble and insoluble, inorganic and organic. In some work, the author was careful to describe the form being considered; other authors were less precise. Wherever possible in this report, phosphate means total phosphate in all forms. When an author reported more than one value for phosphate, all values were included, but the higher figure was always used to calculate the phosphate contribution.

Tables 1 and 2 at the end of this report contain the essential data from the definitive articles found on sources of phosphate in surface waters and in sewage, respectively. The author, where and when the study was done, and the measurements reported are given in each table. Wherever possible, the reported data have been converted to pound PO_4/capita-year and these values are also recorded in the tables.

The references have been grouped according to the source of phosphate primarily under study; however, in most cases, considerable overlap exists. For example, Fippin, 1945, found that an average of 1.27 pounds of phosphate (P_2O_5 basis) was discharged into the Tennessee River per acre of land in the drainage area. This area includes farmland, land in its natural state, and presumably land that can be classified as urban. Therefore, the 1.27 pounds P_2O_5/acre-year includes, but is not exclusively, runoff from farmland even though the reference is listed under agricultural sources.

Municipal Sewage

The phosphate in raw sewage from a community is usually greater than the phosphate entering surface waters from municipal sewage, as defined, for two reasons: (1) raw sewage from most cities contains at least some industrial phosphate that should be considered part of the industrial contribution, (2) if the sewage is treated, some of the phosphate in the raw sewage will be removed before discharge.

The raw sewage from Chicago, for example, contains 14.4 pounds PO_4/capita-year (Hurwitz, 1965), but 42 percent of the BOD of this sewage is contributed by the industries in the area. Assuming the same proportional contribution of phosphates, the input from industry would be 6.1 pounds PO_4/capita-year, the other 8.3 pounds coming from the residences and commercial establishments in the area (municipal sewage). Chicago does not, however, discharge 14.4 pounds PO_4/capita-year to the surrounding surface waters. By the time the sewage has passed through the treatment plants, the phosphate content has been reduced to 4.9 pounds PO_4/capita-year.

No data were were found that provided enough information to calculate directly the amount of phosphate from municipal sewage that enters the surface waters. The references listed on Table 1-A reported the phosphate content of either the raw or treated sewage. However, by considering these data as a whole, and by making certain assumptions about the amount of industrial waste in the sewage, some tentative conclusions can be reached regarding both the municipal sewage component of the raw sewage and the contribution of phosphate to the surface waters from this source.

The reported phosphate contents of raw sewage range from a low of 3.0 pounds PO_4/capita-year (Junction City, Wisconsin, reported by Mackenthun, 1961) to the 14.4 pounds in Chicago. The 3.0 pounds seem low even for a community with a population of 330 to 381 people (U.S. Census data for Junction City, Wisconsin, 1950 and 1960, respectively). It may be that some of the population are not connected to the sewers. The majority of the figures reported for the phosphate content are 7 pounds or above.

Most of the higher figures are from the larger cities where the industrial component in the raw sewage is probably larger. As already described, the apparent municipal sewage contribution of phosphate to Chicago's sewage is 8.3 pounds PO_4/capita-year. Neel, 1956, in describing the raw sewage from Kearney, Nebraska, also indicated the relative contribution from municipal sewage and from industrial sources. By using the same assumptions as are used for the Chicago case, the municipal sewage component of phosphate in the raw sewage from Kearney is 8.0 pounds PO_4/capital year. In general, then, 7 to 9 pounds PO_4/capita-year appear to be the amount of municipal sewage in the raw sewage of cities.

The reported phosphate contents of sewage effluents to surface waters range from 3.6 pounds PO_4/capita-year for Madison, Wisconsin, in 1943 (Sawyer, 1947) to 18 pounds PO_4/capita-year for Bakersfield (California, State of, 1956). (Rudolfs, in an article published in 1947, reports contents of 1.2 to 2.8 pounds, but the data were not specific enough to evaluate and, therefore, have been discounted.) The majority of the data fall between 4.0 and 12.0 pounds PO_4/capita-year. With the possible exception of the sewage from Sullivan, Illinois, and Madison, Wisconsin, all the effluents containing over 6 pounds PO_4/capita-year are from cities that are heavily industrialized. The sewage effluent, then, from the less industrialized cities, which should be comparable to the effluent from municipal sewage, would appear to contain 4 to 6 pounds PO_4/capita-year.

The major sources of phosphate in municipal sewage appear to be human wastes and detergent builders. Food added through garbage disposers has also been suggested as a possible source of phosphate, but no information was found on the subject. In fact, only one article was found that specifically discussed the sources of phosphate in sewage (Harkness and Jenkins, 1958).

Detergent Builders as a Phosphate Source

Harkness and Jenkins made several assumptions about the use of detergents in England, and from these assumptions, estimated that about 20 percent of the total phosphorous in the raw sewage came from detergents. Since these estimates are based on detergent use in a foreign country, they are probably of little use for this U.S. study. The estimates, therefore, have not been considered in detail but are only mentioned here in passing.

Human Wastes as a Phosphate Source

Since no references were found that specifically covered the contribution of phosphates to raw sewage by human wastes, some general physiological data were assembled (Table 2) that indicate the magnitude of this contribution. According to these sources, the average human excretes from 1.2 to over 4 pounds of phosphates (PO_4 basis) per year. Sawyer, 1965, in discussing the subject, uses a figure of 3.6 pounds. These contributions would be to raw sewage. If the estimated total of 7 to 9 pounds PO_4/capita-year is reasonable, then about 45 to 50 percent of of the phosphate in raw municipal sewage comes from human excretions. Presumably the remaining 50 to 55 percent comes from detergent builders and other sources such as waste food entering sewage.

As already discussed, however, the 7 to 9 pounds of PO_4 per capita-year is not the contribution of municipal sewage phosphates to surface waters, because one-half to two-thirds of the phosphate in sewage (municipal plus industrial) can be removed in a properly operated treatment plant prior to discharge. Trying to determine what proportion of this 4 to 6 pounds PO_4/capita-year comes from human waste and what proportion comes from other sources would appear to require radioactive tracer studies.

Industrial Waste

Very few specific data were found on the industrial contributions of phosphate to surface waters, although considerable effort was expended by the Institute during the search in an attempt to find such data.

A number of industrial wastes are reported to contain significant quantities of phosphate. Textile treating, wool scouring, and metal treating wastes are examples, as are the wastes from food processing (such as canning, sugar beet, milk, and corn processing), and malt liquor (beer and distilled) production. Direct experimental results apparently are hard to get because industries are reluctant to divulge this kind of information. Considerable deductive research would be required before any significant data could be provided on the industrial contribution of phosphates; even then the results would be very approximate, because they would be based on average compositions of untreated waste, and it would be difficult to determine how many plants treat their wastes before discharge and to what extent they are treated.

Some of the general data, however, would indicate that the industrial contribution is quite significant. The treated effluent from Madison, Wisconsin, for example, is reported by Wisniewski, 1961, to discharge over 20 pounds PO_4/capita-year into a local creek at some periods during the year. The average value is 11.8 pounds PO_4/capita-year. This is considerably above the 6 to 9 pounds PO_4/capita-year reported for most of the industrial cities along Lake Erie. Since Wisconsin is well known for beer production and milk processing, the high phosphate content of this effluent might be attributed to these industrial wastes.

The phosphate addition to the Ashtabula River in Ohio is another example that indicates the significance of the industrial contribution.

According to the USPHS report on pollution of Lake Erie, the sewage from only 1,095 people is discharged into the river, but 35,000 pounds of phosphate enter it annually. Presumably, the six chemical plants along the river contribute a large portion of this 35,000 pounds.

Agricultural Sources

Five definitive studies were found that indicate the agricultural phosphate contribution to surface water for six areas. The areas and the calculated contribution per capita-year are:

	Lb PO_4/ Capita-Year	Million Acres Drained
Kaskaskia River basin, Ill.	2-7	3.3
Drainage near Madison, Wisc.	9.5	small
Farms near Coshocton, Ohio	4.1	small
Tennessee River basin	24.5	26
Mississippi River basin	30.8	800
Irrigated farmland, Yakima Valley, Wash.	4.5	0.4

Converted to pound PO_4/capita-year, the values found by the five investigators range from approximately one to five times the phosphate contribution from municipal sewage.

The conversion of the values was achieved by assuming that all farmland in the United States will contribute the same amount of phosphate per acre as the acreage under study. Such an assumption is certainly questionable, but as explained earlier, it has the advantage of making possible a ready comparison between the various sources of phosphate. Furthermore, the agreement between the figure (4.1 pounds PO_4/capita-year) for the farms near Coshocton, Ohio, where rainfall averages 40 inches a year, and the figure (4.5 pounds PO_4/capita-year) for the land that must be irrigated in the Yakima Valley, Washington, certainly adds some validity to the assumption. The highest figures (24.5 and 30.8 pounds PO_4/capita-year), reported here as contributions of agricultural sources to the Tennessee and Mississippi Rivers, respectively, include contributions from other sources as well. The figures were based on measurements of the phosphate content of the silt carried by these rivers. The silt was washed into the rivers from undeveloped or natural land, as well as farmland, and could also include phosphates, from residential or industrial sources, that had become insoluble and then picked up as silt. In one sense, the range of 25 to 30 pounds PO_4/capita-year might be considered the phosphate contribution from all sources; even then these figures would be high, because the Mississippi and Tennessee Rivers carry more silt than most U.S. rivers.

Natural Sources

A number of informative articles were found that described some of the natural sources of phosphates in surface water (see Table 1-D), but only three were sufficiently definitive to allow any comparison with other sources. Sylvester, 1961, reported the phosphorus in the runoff from forested areas in the Cascade mountains in the State of Washington (0.32 to 0.77 pounds acre-year). Extrapolating these figures to the 480 million acres of commercial forests in the country indicates that 2.4 to 5.8 pounds PO_4/capita-year come from this source. Again, Sylvester's data may not be applicable to the entire country. However, Donahue, 1961, found that 1.8 to 3.3 pounds P/acre were returned to the ground by hardwood leaves and conifer needles and, if all of this phosphorus was dissolved and carried away in the runoff water, 4.5 to 8.3 pounds PO_4/capita-year would come from forested areas. Since all the phosphate in the leaves and needles would not be carried off, and since phosphate in the runoff water can come from other sources in the forest, the 2.4 to 5.8 pounds PO_4/capita-year figures found by Sylvester seem entirely reasonable.

Even rain can contain phosphates. Voigt, 1960, found 0.01 ppm phosphorus in the rain falling on an open field near New Haven, Connecticut. The contribution to surface waters from this source, which is normally considered pure, could be about 0.4 pound PO_4/capita-year. This contribution is about the same as Weibel, 1964, found for urban runnoff--0.35 pound PO_4/capita-year.

The only reference found to wild animals as contributors of phosphates to surface waters was an article by Paloumpis, 1960. He estimated that the wild duck population contributed 29,000 pounds of phosphate just to Chautauqua Lake in Illinois.

While the above natural sources of phosphate are significant, it seems that little has been done to determine the amount of phosphate that enters the surface waters in the form of silt. The work reported by Fippin, 1945--which was discussed under agricultural wastes--would indicate that 30 pounds PO_4/capita-year might enter the nation's surface waters as a component of silt. Furthermore, Abbott, 1957, showed that algae actually grew by using the phosphate in silt when the soluble phasphate was insufficient to support growth. Silt could be the most important source of phosphate, in terms of quantities, entering the surface waters.

VARIATIONS IN THE CONTRIBUTION OF PHOSPHATE TO SURFACE WATERS, BY AREA

At the outset of this project, the staff felt that the phosphate contributions from the various sources would vary considerably from one part of the country to another. In describing the scope of the project, the proposal stated that every effort would be made to relate the data to major drainage basin areas. (The U.S. Geological Survey (USGS) divides the country into 15 major river basin areas.) The subsequent research leads us to believe that such an approach--to determine the relative contributions by the sources as defined--is both difficult and impractical. It would be difficult because (1) sufficient data are not available for most major drainage basin areas, and the development of information would require a great deal of time and effort; and (2) large variations are found even within relatively small basin areas. It would be impractical because data indicate that the contribution from any one source, no matter where it is located in the country, may be predicted within a reasonable tolerance if enough information is available.

The studies on Lake Erie pollution can be used as an example. The area that drains into Lake Erie is the smallest of the USGS-defined basin areas and has been the subject of numerous investigations. Despite this, the industrial and agricultural contribution of phosphate to Lake Erie basin waters is unknown. Furthermore, the published information, which reports the amounts of phosphate in the sewage from large cities and in rivers in the area, varies so widely that the only way to arrive at the total phosphate entering the waters is by summing the results of a city-by-city, river-by-river survey. We suspect, however, that if some of the contributions from industrial wastes (which are unknown) could be determined, and subtracted from the phosphate content of the sewages, the per capita contributions from municipal sewage, as we have defined it, might be quite similar from one city to another.

Because the determination of the contributions from each of the major phosphate sources in each major river basin area is such a large task, some attempt should be made first to determine why such large variations exist among the contributions from the same major sources at different locations in the country before any estimates of contributions by area are undertaken. If the reasons for these variations can be determined, then it may be possible to estimate the contribution of phosphate, i.e., from municipal sewage or from agricultural sources, anywhere in the country. It would seem that this would be a more fruitful approach to the problem of determining the relative contributions of phosphates by the various sources than would the attempt to establish these contributions by drainage basin area or some other subdivision of the country.

The contributions of phosphate to surface waters have been the subject of intensive investigations in several areas in the country besides Lake Erie. The areas around Madison, Wisconsin, and Seattle, Washington, much of Connecticut, and the Kaskaskia River basin in Illinois have all been the subject of considerable work related to the sources of phosphate. In most cases, however, the reported data were not specific enough to permit an extrapolation indicating the contributions of the same source in another part of the country. Indications are that some of the data, needed to determine the relative contributions of at least some of the sources, may be in the records of local and state health and pollution control authorities but have never been published. As a first step to the suggested approach, the authorities in some of the above areas could be contacted. If unpublished data are available, they could be collected and used to establish the contribution from any of the sources under study.

If the data are available and useful, then sufficient work should be done to determine how similar the contribution of each specific source is when it originates in different parts of the country. Only if no similarity exists should the area approach be reconsidered.

Table 1-A

CONTRIBUTIONS OF PHOSPHATE TO SURFACE WATERS FROM SEWAGE

Reference and Source of Phosphate	Location	Date	Reported Measurement	Population or Other Correlative Data*	Contribution (lb PO_4/capita-year)	Comments
Curry, 1955						
Raw sewage effluent	Lake Zoar, New Milford, Conn.	1954	9 lb P/day from New Milford	2,800 (est.)	3.5	
Mackenthun, 1961						
Raw sewage	Junction City, Wisc.	1957-8	Total P = 1.0 lb/day Soluble P = 0.5 lb/day	1950 - 330 (est.) 1960 - 381 (est.)	3.0	
Raw sewage	Junction City, Wisc. (after wastes from milk processing plant were added to effluent)	1958-9	Total P = 4.9-16.8 lb/day Soluble P = 2.6-7.2 lb/day	1,800-6,140 lb P/yr to process 31 million lb whole milk. 350 lb milk consumed/capita	5.1-17.5 (see also Industrial Sources)	
Sedimented sewage (primary treatment)	New Auburn, Wisc.	1958	Total P = 1.6-2.4 lb/day Soluble P = 1.1-1.9 lb/day	1950 - 371 (est.) 1960 - 383 (est.)	4.6 6.9	

Table 1-A (continued)

Reference and Source of Phosphate	Location	Date	Reported Measurement	Population or Other Correlative Data	Contribution (lb PO_4/capita-year)	Comments
Mackenthun, 1961 (continued)						
Sedimented sewage (primary treatment)	Spooner, Wisc.	1958	Total P = 28 lb/day Soluble P = 13.9 lb/day	1950 - 2,597 (est.) 1960 - 2,398 (est.)	13	
Neel, 1961						
Raw sewage	Fayette, Mo.	1957-8	PO_4 (?) 50 lb/day	2,700 (est.)	6.8	
Neel, 1956						
Raw sewage	Kearney, Neb.	1954-5	25.5 ppm PO_4 in 1.32 Mgd	10,500 and industrial sources with population equivalent of 2,225	Municipal sewage 8.0 Industrial sewage 1.7 Total 9.7	
Hurwitz, 1965						
Raw sewage	Chicago, Ill. and vicinity	1960	94.48 tons of total PO_4/day in raw sewage, which is 65 tons of ortho PO_4, 15 tons of inorganic condensed PO_4, and 14 tons of organic	4.8 million plus industrial equivalent of 3.5 million people	Municipal sewage 8.3 Industrial sewage 6.1 Total 14.4	

Table 1-A (continued)

Reference and Source of Phosphate	Location	Date	Reported Measurement	Population or Other Correlative Data	Contribution (lb PO_4/capita-year)	Comments
Owen, 1953						
Raw sewage	9 communities in Minnesota	1950-1	1.5-3.7 grams P/ capita-day		3.05 9.15	
Neil, 1957						
Sewage from primary treatment plant	Sturgeon Lake, Lindsay, Ont.	1955	7-24 ppm PO_4	10,000	7.7	
Feng, 1962						
Sewage effluent from primary treatment	Madison, Wisc. Spring Plant	Not given	6.0-7.7 ppm orthophosphate			
Eliasson, 1965						
Filtered sewage	Palo Alto, Calif.	Not given	7.6 ppm P	Est. 100 gal/ capita-day	6.6	
Humphreys, 1959						
Sewage plant effluent		1957	31 ppm PO_4, in makeup water to boiler from sewage effluent	Not known		

Table 1-A (continued)

Reference and Source of Phosphate	Location	Date	Reported Measurement	Population or Other Correlative Data	Contribution (lb PO_4/capita-year)	Comments
Connell, 1958						
Sewage effluent	San Antonio, Texas	1957	Effluent flow: Range: 10-51 Mgd; Average: 20 Mgd Range: 15-3 ppm phosphate; Average: 6 ppm phosphate			
Mackenthun, 1960						
Sewer plant effluent, includes industrial waste	Badfish Creek, Madison, Wisc.	1959	1,300 lb P/day	135,000	Same as shown under Wisniewski	
Engelbrecht and Morgan, 1959						
Sewer plant effluent	Southwest Champaign, Ill.	1956	10.4×10^{-3} lb P_2O_5/capita/day	820 (est.)	3.8	
Sewer plant effluent (could include industrial waste)	Arthur, Ill.	1956	10.7×10^{-3} lb P_2O_5/capita/day	1,600 (est.)	5.2	
	Sullivan, Ill.	1956	26.4×10^{-3} lb P_2O_5/capita/day	3,400 (est.)	12.8	

Table 1-A (continued)

Reference and Source of Phosphate	Location	Date	Reported Measurement	Population or Other Correlative Data	Contribution (lb PO_4/capita-year)	Comments
Engelbrecht and Morgan, 1959 (continued)						
Sewer plant effluent	Elmhurst, Ill.	1956	11.1 x 10^{-3} lb P_2O_5/capita-day	30,000 (est.)	5.2	
Sawyer, 1947						
Sewer plant effluent	Madison, Wisc.	1943?	1.2 lb P/capita-year	90,000	3.6	
Rudolfs, 1947						
Sewer plant effluent	Several		4.0-9.2 ppm P_2O_5 (assumes 100 gpd sewage)	--	1.2-2.8	
Sylvester, 1963						
Sewer plant effluent	Yakima Valley, Wash.	1959-60	7 tons P/month	80,000	6.0	
Lackey, 1945						
Sewer plant effluent	Madison, Wisc.	1942-3	112,000 lb P/year	90,000	Same data as Sawyer, 1947	
Ludwig, 1964						
Sewer plant effluent	Lake Tahoe, Calif.-Nev.	1963	6.8-8.1 ppm as P approx. 75 gal/capita-day		4.6-5.5	

Table 1-A (continued)

Reference and Source of Phosphate	Location	Date	Reported Measurement	Population or Other Correlative Data	Contribution (lb PO_4/capita-year)	Comments
Anderson, 1961 (SEC-TRW-61-3)						
Sewer plant effluent	Lake Washington, Seattle, Wash.	1957	114,000 lb P/yr	76,300	4.5	
Wisniewski, 1961						
Sewer plant effluent	Badfish Creek, Wisc.	1959	1,458 lb soluble P/day from Madison effluent	135,000	11.8	Includes industrial wastes.
			(1,200-2,700 lb soluble P from calculations at station 1 on creek)	135,000	9.7-21.8	
Larson, 1961						
Sewer plant effluent	Detroit Lakes, Minn.	1955	9.1 ppm P in 750,000 gpd effluent minus 0.6 ppm P in well water	5,700 (est.)	11.0 total 10.3 net†	
Hurwitz, 1965						
Sewer plant effluent	Chicago, Ill. and vicinity	1960	32.3 tons/day of total PO_4 added to surface water	4.8 million	4.9	Both municipal sewage and industrial waste.

Table 1-A (concluded)

Reference and Source of Phosphate	Location	Date	Reported Measurement	Population or Other Correlative Data	Contribution (lb PO_4/capita-year)	Comments
California, State of, 1956						
Sewer plant effluent	Bakersfield, Calif.	1956	8.5-10.5 million gpd 30.6 ppm PO_4	44,000 (est.)	18	
USPHS Report, July 1965						
Sewage effluent	Cleveland, Ohio		30,300 lb PO_4/day	876,000	8.4	
Sewage effluent	Euclid, Ohio		2,100 lb PO_4/day	63,000	12.2	
Sewage effluent	Lakewood, Ohio		1,100 lb PO_4/day	66,000	6.1	
Sewage effluent	Lorain-Avon		2,600 lb PO_4/day	75,000 (est.)	12.6	
Sewage effluent	Sandusky, Ohio		1,000 lb PO_4/day	32,000	11.4	

* Correlative data is used to convert statistics on phosphate contribution from sources other than sewage, so these statistics can be compared with those on sewage contributions.

† Input (well) water contains 0.7 ppm PO_4.

Table 1-B

CONTRIBUTIONS OF PHOSPHATE TO SURFACE WATERS FROM INDUSTRIAL WASTE

Reference and Source of Phosphate	Location	Date	Reported Measurement	Population or Other Correlative Data	Contribution (lb PO_4/capita-year)	Comments
Williams, 1961						
Textile treating	Mooresville & Wake, N.C.		1 part P to 10 parts BOD in effluent			Treated in lagoons before discharge.
Durfor, 1964						
Urban water softening	8 out of 100 largest cities	1962	0.5-2.0 ppm hexametaphosphate added to control precipitation in softened water	Small	Small	
Geyer, 1960						
Metal treating	Near Indianapolis, Ind., ball and roller bearing plant	1960	Untreated waste 222 ppm phosphate (PO_4?) 45,000 gpd	Assume 265 operating days/year	21,000 total lb/yr	If untreated.

Table 1-B (continued)

Reference and Source of Phosphate	Location	Date	Reported Measurement	Population or Other Correlative Data	Contribution (lb PO_4/capita-year)	Comments
Lake Erie Pollution Survey, 1953						
Metal treating	Cuyahoga River, Ohio		36 ppm PO_4 in steel mill plating waste 95,000 gpd	Assume 265 operating days/year	7,500 total lb/yr	
Rice, 1961						
Pulp and paper	Spring Grove, Pa.	1956-7	BOD/P in effluent from secondary treatment of waste water (pilot plant). Various figures given; average calculated to 0.7 ppm P in 10,000 gpd waste water	Assume 365 operating days/year	52 total lb/yr	
Mackenthun, 1961						
Whole milk	Junction City, Wisc.	1958-9	1800-6140 lb P to process 31 million lb milk	350 lb milk consumed per capita	0.06 min. 0.2 max.	

Table 1-B (continued)

Reference and Source of Phosphate	Location	Date	Reported Measurement	Population or Other Correlative Data	Contribution (lb PO_4/capita-year)	Comments
California, State of						
Oil field brines	San Joaquin Valley, Calif.		8.2 ppm P max in 60 million gpd	Needed: U.S. crude oil production, San Joaquin Valley crude oil production	Small because most of brine is reinjected to deep strata	
Jackson, 1960 (see Isaac)						
Distillery wastes	England		20 ppm P_2O_5 in malt distillery waste waters			
Dickinson, 1960 (see Isaac)						
Cannery wastes	England		1,000 gallons effluent per ton of "peas on the vine"; effluent contains 18 ppm P_2O_5			

Table 1-B (concluded)

Reference and Source of Phosphate	Location	Date	Reported Measurement	Population or Other Correlative Data	Contribution (lb PO_4/capita-year)	Comments
California, State of, 1954						
Orange products plant	Ontario, Calif.	Not given	8 ppm PO_4 water use not given		Used for irrigation	
California, State of, 1954						
Paper mill	Fernstrom, Calif.	Not given	Population equivalent 17,000; 0.7 ppm PO_4		Used for irrigation	
Watson, 1960, Breska, 1957 and Schraufnagel, 1957						
Dairy wastes	Horseheads, N.Y.	1960	Waste volume 121,500 gpd with 6 ppm P or 5.4 lb P/day 320,000 lb milk processed/day	350 lb milk consumed per capita	0.018	

Table 1-C

CONTRIBUTIONS OF PHOSPHATE TO SURFACE WATERS FROM AGRICULTURAL SOURCES

Reference and Source of Phosphate	Location	Date	Reported Measurement	Population or Other Correlative Data	Contribution (lb PO_4/capita-year)	Comments
Schraufnagel, 1957						
Dairy wastes	Various Wisc.-Minn.		Approximate volume of dairy wastes put on soil and phosphorus content - ppm	Unknown		
Dietz, 1957						
Runoff from farmland	Kaskaskia River Basin, Bondville, Ill.		Date / P_2O_5 Total: 4/9 0.074 4/16 0.035 4/23 0.034 4/30 0.055 Date / P_2O_5 Ortho: 4/9 0.029 4/16 0.019 4/23 0.025 4/30 0.054			Only 4 weeks of samples; hardly significant.

Table 1-C (continued)

Reference and Source of Phosphate	Location	Date	Reported Measurement	Population or Other Correlative Data	Contribution (lb PO_4/capita-year)	Comments
Sawyer, 1965						
Runoff from farmland (includes natural sources)	Madison, Wisc.	1943	235-262 lb P/yr-sq mi drainage area	1,158 million acres in farms (1954) or 1.8 million sq mi	9.0-10.0	
	Kaskaskia River, Ill.	1956	225 lb P/yr-sq mi drainage area	U.S. population: 1943 - 140 million 1956 - 155 million	7.8	
Silvey, 1953						
Runoff from irrigated farmlands	Texas	1952?	1/5 of P applied was in drainage	No correlation possible		
Engelbrecht and Morgan, 1959						
Runoff from farmland	Kaskaskia River Basin, Bondville, Ill.	1956	0.1 lb P_2O_5/day-sq mi of cultivated land	U.S. total 318.6 million acres under cultivation	0.15	

Table 1-C (continued)

Reference and Source of Phosphate	Location	Date	Reported Measurement	Population or Other Correlative Data	Contribution (lb PO_4/capita-year)	Comments
Engelbrecht and Morgan (continued)						
	Total		1.4 lb ortho P_2O_5 plus maximum inorganic condensed P_2O_5/day-sq mi of drainage	Total U.S. acreage in farmland 1,158 million acres in 1954; U.S. population, 144 million	2.0 (If figure for all acreage in farmland is used instead of harvested acreage, 7.2)	Average figure for area arrived at by subtracting an average value for human contribution of phosphate from total contribution. Farm animal population not given. Whether or not silt was included is not indicated.

Table 1-C (continued)

Reference and Source of Phosphate	Location	Date	Reported Measurement	Population or Other Correlative Data	Contribution (lb PO_4/capita-year)	Comments
Fippin, 1945						
Runoff from farmlands (includes natural sources)	Tennessee River Valley	1939-40	1.27 lb P_2O_5/acre-yr	Total land area 1.9 billion acres; U.S. population, 131 million	24.5	
Total runoff	Mississippi River Basin		1.59 lb P_2O_5/acre-yr		30.8	
Sawyer, 1945						
Runoff from farmlands (includes natural sources)	Madison, Wisc.	1943?	254 lb P/sq mi of agricultural land drained	Total acreage in farmland 1,140 million acres (1945) or 1.85 million sq mi; U.S. population, 140 million	9.7	Probably large farm animal population.
Sylvester, 1961						
Runoff from irrigated farmland	Yakima and other valleys in Washington	1959	0.92, 1.28, 2.88, 3.88 lb P/acre-yr average 1.12 lb P/acre-yr	33.2 million acres irrigated in 1959 (U.S. Dept. of Commerce)	6	Includes influent phosphate. Seems to be same data as reported in Sylvester, 1963

Table 1-C (continued)

Reference and Source of Phosphate	Location	Date	Reported Measurement	Population or Other Correlative Data	Contribution (lb PO_4/capita-year)	Comments
Sylvester, 1963						
Runoff from irrigated farmland	Yakima Valley, Wash.	1959-60	Total PO_4 to irrigated land and PO_4 in drainage from: influent - 0.32 ppm effluent - 0.84 ppm	U.S. population 178 million 10% of whom are fed by food from irrigated land. 375,000-425,000 acres adds 313,000 lb PO_4 or approximately 0.8 lb PO_4/acre? U.S. population, 178 million	4.5	Appears to be same data reported earlier, (Sylvester, 1961) if PO_4 is really P. We have assumed this to be the case.
USPHS Activities Report						
Runoff from farmlands	Coshocton, Ohio		0.05 + 0.42 lb PO_4 in runoff/acre from 7.3 inches of rain	U.S. population 196 million; 318 million acres under cultivation	4.1	Just mentioned. More data should be forthcoming.

Table 1-C (concluded)

Reference and Source of Phosphate	Location	Date	Reported Measurement	Population or Other Correlative Data	Contribution (lb PO_4/capita-year)	Comments
Sanderson, 1953						
Duck farm	Suffolk Co., New York	1952	7.6 lb total PO_4 per 1,000 ducks per day. Eight weeks duck life from hatch to slaughter. Growing season, 5-1/2 months. 8 million ducks were grown, which was 60% of U.S. commercial duck production.	Presumes most of PO_4 excreted enters surface waters. U.S. population, 150 million	0.04	

Table 1-D

CONTRIBUTIONS OF PHOSPHATE TO SURFACE WATERS
FROM NATURAL SOURCES

Reference and Source of Phosphate	Location	Date	Reported Measurement	Population or Other Correlative Data	Contribution (lb PO_4/capita-year)	Comments
Abbott, 1957						
Colloidal particles in runoff	Lake Houston, Texas		0.08 ppm PO_4			
Chalupa, 1960						
Dust in air	Sedlice Reservoir, Czechoslovakia		3/4 kg/7 months			
Donahue, 1961						
Leaves and needles from trees	General		1.8-3.3 lb P/acre	480 million acres in commercial forest; U.S. population, 190 million	4.5-8.3	Not all this phosphate reaches the surface water.
MacPherson, 1958						
Mud from lake bottoms	Canadian Lakes		From <0.05 mg/liter for unproductive lake to 0.2 mg/liter for productive lake			

Table 1-D (continued)

Reference and Source of Phosphate	Location	Date	Reported Measurement	Population or Other Correlative Data	Contribution (lb PO_4/capita-year)	Comments
Kuenzler, 1961						
Creek and marsh water	Sapelo Island, Ga.		Particulate 39-58 ppb P; inorganic 41-60 ppb P; dissolved organic 16-19 ppb P			
Tucker, 1957						
Mud from lake bottoms	Douglas Lake, Mich.	1950-1	0.67 mg/liter just before turnover			Also relates Fe to P and plankton growth.
	Lancaster Lake, Mich.		0.2 mg/liter			
	Munro Lake, Mich.		Negligible			
	Vincent Lake, Mich.		Negligible			
	Lake Lansing, Mich.		0.04 mg/liter			
Paloumpis, 1960						
Wild duck droppings	Chautauqua Lake, Ill.	1953	Estimated 3.8 lb phosphate per 1,000 duck-days or 29,000 lb/yr	Needed: U.S. wild duck population		

Table 1-D (continued)

Reference and Source of Phosphate	Location	Date	Reported Measurement	Population or Other Correlative Data	Contribution (lb PO_4/capita-year)	Comments
Voigt, 1960						
Rainfall	Near New Haven, Conn.	1959	0.01 ppm P in area with 45 inches of rainfall per year	27.9 million sq ft of land in Conn.; Conn. population, 2.6 million	0.37	Not all this phosphate gets into surface waters.
Voigt, 1960						
Rainfall in forests	Near New Haven, Conn.		0.03-0.08 ppm P			
Anderson, 1961 (SEC-TRW-61-3)						
Unspecified	Lake Washington, Seattle, Wash.		151,000 lb P/yr	Area drained is not given		Can include runoff from farmlands.
Sylvester, 1961 (SEC-TRW-61-3)						
Runoff from forested area	State of Washington		0.74, 0.77, and 0.32 lb P/acre-year	480 million acres of commercial forest in United States; U.S. population, 190 million	2.4-5.8	

Table 1-D (concluded)

Reference and Source of Phosphate	Location	Date	Reported Measurement	Population or Other Correlative Data	Contribution (lb PO_4/capita-year)	Comments
Sylvester, 1960						
Urban runoff	Green Lake, Wash.		0.15 ppm P median of 35 observations	Could assume 45% runoff and population density of 10 persons/acre		
Weibel, 1964						
Urban runoff	Mt. Washington, Ohio (near Cincinnati)	1962-3	0.8 ppm PO_4 in runoff: mean over 14-month period, 9 people/acre, 45% of rainfall appeared as runoff	43,560 sq ft/acre; 40 inches rain/yr; 3.3 lb PO_4 in runoff/acre	0.35	

Table 1-E

CONTRIBUTIONS OF PHOSPHATE TO SURFACE WATERS FROM GENERAL SOURCES

Reference and Source of Phosphate	Location	Date	Reported Measurement	Population or Other Correlative Data	Contribution (lb PO_4/capita-year)	Comments
USPHS Report, July 1965						
All sources	Maumee River Basin (Ohio, Ind., Mich.)		11,000 lb PO_4/day	816,000 (excludes Toledo)	4.9	
All sources	Portage, Sandusky, Black River Basins, Ohio		1,100 lb PO_4/day	568,000 (excludes Sandusky)	6.5	
All sources	Ashtabula River Basin, Ohio		100 lb PO_4/day	1,095	33.4	
Curl, 1959						
All sources	Lake Erie (western)	1951	Detroit River (405 x 1.1) T/yr 2.6 ppb P; Maumee (125 x 1.1) T/yr 16 ppb P; bottom sediment 5.69% P; loss from fish (29 x 1.1) T/yr		Same as USPHS reports on Lake Erie except bottom sediment and fish uptake	

Table 1-E (concluded)

Reference and Source of Phosphate	Location	Date	Reported Measurement	Population or Other Correlative Data	Contribution (lb PO_4/capita-year)	Comments
Anderson, 1961	Lake Washington, Seattle, Wash.	1957	12 lb P/acre into lake (21,641 acre lake)	76,300	10	
Sawyer, 1965						
Sewage	Hartford, Conn.	1964	9.6 ppm P			
	Laconia, N.H.	1960	9.8 ppm P			
	Marlborough, Mass.	1962 1963 1964	11.5 ppm P 15.8 ppm P 17.1 ppm P			
	State College, Pa.	1960	13.9 ppm P			
Benoit, 1961 (SEC-TRW-61-3)						
All sources	Lake Zoar and Housatonic River, Conn.		183 lb P/day from various sources, 42,800 acre-ft in lake			

Table 2

SOURCES OF PHOSPHATE IN SEWAGE

Reference and Source of Phosphate	Contributor	Date	Reported Measurement	Location	Contribution (lb PO_4/capita-year)
Altman, 1964	Human				
	Urine		Inorganic P - 840 mg/day Range - 700-1,050 mg/day Organic P - 9.2 mg/day Range - 6.2-13.1 mg/day	General	Inorganic 2.02 Organic 0.02 Total 2.04
	Feces		0.69 mg P/day		
Diem, 1962	Human	Various	0.51 g/day 57% urine 43% feces	General	1.23
Gray, 1961	Human				
	Urine		0.7-1.6 g P/day		1.68-3.84 (average 2.76)
Hurwitz, 1965	Raw sewage	1960	94.48 tons of total PO_4/day in raw sewage which is 65 tons of ortho PO_4, 15 tons of inorganic condensed PO_4, and 14 tons of organic	Chicago, Ill.	14.4 Residential sewage 8.3* Industrial sewage 6.1*

* Based on a population of 4.8 million and industrial wastes equivalent to 3.5 million.

Table 2 (concluded)

Reference and Source of Phosphate	Contributor	Date	Reported Measurement	Location	Contribution (lb PO_4/capita-year)
Sawyer, 1954	Human		Same data as in Sawyer, 1965	General	
Spector, 1956	Human		Total phosphorus Urine - 15 mg/day-kg body wt Range - 10-19 mg/day-kg body wt Feces - 9.86 mg/day-kg body wt Range - 7.1-20 mg/day-kg body wt	General	Urine 2.52 Feces 1.66 Total 4.18
Sawyer, 1965	Human		78.5 lb P/65 years or 1.11 lb P/year	General	3.62
Harkness, 1958	Synthetic anionic detergent			Four sewage districts in England	20.8% of total phosphorus in raw sewage.

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