Another method to control the inflow of nutrients, particularly phosphates, into a lake is that of prescribing an annual loading to the receiving water. Vollenweider (1973) suggests total phosphorus (P) loadings in grams per square meter of surface area per year that will be a critical level for eutrophic conditions within the receiving waterway for a particular water volume where the mean depth of the lake in meters is divided by the hydraulic detention time in years. Vollenweider's data suggest a range of loading values that should result in oligotrophic lake water quality.

Mean Depth/Hydraulic Detention Time (meters/year)	Oligotrophic or Permissible Loading (grams/meter^2/year)	Eutrophic or Critical Loading (grams/meter^2/year)
0.5	0.07	0.14
1.0	0.10	0.20
2.5	0.16	0.32
5.0	0.22	0.45
7.5	0.27	0.55
10.0	0.32	0.63
25.0	0.50	1.00
50.0	0.71	1.41
75.0	0.87	1.73
100.0	1.00	2.00

There may be waterways wherein higher concentrations or loadings of total phosphorus do not produce eutrophy, as well as those waterways wherein lower concentrations or loadings of total phosphorus may be associated with populations of nuisance organisms. Waters now containing less than the specified amounts of phosphorus should not be degraded by the introduction of additional phosphates.

It should be recognized that a number of specific exceptions can occur to reduce the threat of phosphorus as a contributor to lake eutrophy: 1. Naturally occurring phenomena may limit the development of plant nuisances. 2. Technological or cost-effective limitations may help control introduced pollutants. 3. Waters may be highly laden with natural silts or colors which reduce the penetration of sunlight needed €or plant photosynthesis. 4. Some waters morphometric features of steep banks, great depth, and substantial flows contribute to a history of no plant problems. 5. Waters may be managed primarily for waterfowl or other wildlife. 7. In some waters nutrient other than phosphorus is limiting to plant growth: the level and nature of such limiting nutrient would. not be expected to increase to an extent that would influence eutrophication. 6. In some waters phosphorus control cannot be sufficiently effective under present technology to make phosphorus the limiting nutrient.

No national criterion is presented for phosphate phosphorus for the control of eutrophication.

(QUALITY CRITERIA FOR WATER, JULY 1976) PB-263943
SEE APPENDIX C FOR METHODOLOGY

Attachment A2

3[illegible]

Eutrophication and Biological Associations

KENNETH M. MACKENTHUN

Director, Division of Applied Technology, Environmental Protection Agency, Washington, D.C.

The enrichment of waters by nutrients through either man-created or natura means along with the attendant biological phenomena defines the tern eutrophication. Present knowledge indicates that phosphorus and nitroge are the chemical constituents usually responsible for the eutrophicatio phenomenon. Other elements are essential such as carbon, vitamins, and trace elements but often these are not limiting to nuisance biological development in natural lakes and streams.

Lund (48) in his thorough literature review stated that "Nitrogen and phosphorus can still be considered as two of the major elements limiting primary production. In some tropical and highly eutrophic temperate lakes, nitrogen may be a more important limiting factor than phosphorus. In many other lakes phosphorus is present in very low concentrations and seems to be the major factor limiting production. Evidence from the addition of fertilizers to fish ponds and from what is known about the eutrophication of lakes by sewage supports the view that phosphorus plays a major role in production." Carbon, as well as molybdenum, has been found to be limiting in particular natural waters (27, 42).

Evidence indicates that: (*a*) high phosphorus concentrations are associated with accelerated eutrophication of waters when other growth-promoting factors are present; (*b*) aquatic plant problems develop in reservoirs or other standing waters at phosphorus values lower than those critical in flowing streams; (*c*) reservoirs and other standing waters collect phosphates from influent streams and store a portion of these within consolidated sediments; and (*d*) phosphorus concentrations critical to noxious plant growths vary, and a given concentration will produce nuisance growths in one geographical area but not in another. Potential contributions of phosphorus to the aquatic environment have been indicated in the literature (Table 1).

The discharge of domestic sewage increases the concentration of phosphorus markedly. Organic phosphorus in the sewage and simple and complex

TABLE 1 Pounds of Phosphorus Contributed to Aquatic Ecosystems (51)

Major contributors	
Sewage and sewage effluents	3 lb/(capita) (year)[a]
Some industries, for example, potato processing	1.7 lb/ton processed
Phosphate rock from 23 states (53)	
Cultivated agricultural drainage	0.35–0.39 lb/acre drained per year (24, 73, 86)
Surface irrigation returns, Yakima River Basin	0.9–3.9 lb/(acre) (year) (81)
Benthic sediment releases	
Minor contributors	
Domestic duck	0.9 lb/year (72)
Sawdust	0.9 lb/ton (22)
Rainwater[b]	
Groundwater, Wisconsin	1 lb/9 million gal (40)
Wild duck	0.45 lb/year (62)
Tree leaves	1.8–3.3 lb/acre of trees per year (17)
Dead organisms; animal excretions	

[a] Various researchers have recorded the annual per capita contribution of phosphorus in pounds from domestic sewage as 2 to 4 (15), 2 and 3 (56), 1.9 (61), and 3.5 (75).
[b] Influenced by pollution present in atmosphere "washed out" by rainfall.

phosphates from synthetic detergents are the principal contributions. Decomposition of the organic material, along with soluble phosphates, results in phosphorus concentrations in excess of the requirements for plant growth. The readily available soluble phosphorus often furnishes a food source for nuisance biological growths.

SEWAGE

The discharge of human wastes results in an abundance of nitrogen in all forms, causing an abrupt change in the nutrient balance of the stream. When untreated domestic sewage is discharged to a watercourse, organic nitrogen (proteins) and ammonia are the principal nitrogen constituents. In the water, nitrifying organisms decompose the organic materials and oxidize the ammonia to nitrite and nitrate. Since the nitrite ion is a transient form it is usually present in very low concentrations.

Treated sewage has undergone partial oxidation in the treatment process. Therefore the nitrite and nitrate forms are increased in well-treated sewage, while the organic nitrogen and ammonia are reduced.

Phosphorus is added to receiving waters principally as a component of pollution. Once added, it is combined with other constituents in populations of bacteria, algae, vascular plants, and fish and in benthic sediments. Once nutrients are combined within the ecosystem of the receiving waters, their removal is tedious and expensive; removal must be compared to inflowing quantities to evaluate accomplishment. In a lake, reservoir, or pond, phosphorus is removed naturally only by outflow, by insects that hatch and fly out of the drainage basin, by harvesting a crop, such as fish, and by combination with consolidated bottom sediments. Even should adequate harvesting methods be available, the expected standing crop of algae per acre exceeds 2 tons and contains only about 1.5 lb of phosphorus. Similarly, submerged aquatic plants approach at least 7 tons/acre (wet weight) and contain 3.2 lb/acre of phosphorus. Probably only half of the standing crop of submerged aquatic plants can be considered harvestable. The harvestable fish population (500 lb) from 3 acres of water would contain only 1 lb of phosphorus.

Sawyer (74) discussed factors that influence the development of nuisance algal growths in lakes. The surface area is important since the accumulations of algae along the shoreline of a large lake under a given set of wind conditions could easily be much larger than on a small lake, under equal fertilization per acre. The shape of the lake determines to some degree the amount of fertilizing matter the lake can assimilate without algal nuisances since prevailing winds blowing along a long axis will concentrate the algal production from a large water mass into a relatively small area. The most offensive conditions develop during periods of very mild breezes that tend to skim the floating algae and push them toward shore. Shallow lakes, too, respond differently than deep stratified lakes in which the deeper waters are sealed off by a thermocline. In the nonstratified waters all the nutrients dissolved in the water are potentially available to support an algal bloom. In stratified waters, only the nutrients confined to the epilimnion are available except during those brief periods when complete circulation occurs.

Chu (18) found that optimum growth of all organisms studied in cultures can be obtained in nitrate–nitrogen concentrations from 0.9 to 3.5 mg/l. and phosphorus concentrations from 0.09 to 1.8 mg/l., while a limiting effect on all organisms will occur in nitrogen concentrations from 0.1 mg/l. downward and in phosphorus concentrations from 0.009 mg/l. downward. The lower limit of optimum range of phosphorus concentration varies from about 0.018 to about 0.09 mg/l., and the upper limit from 8.9 to 17.8 mg/l. when nitrate is the source of nitrogen, while it lies at about 17.8 for all the planktons studied when ammonium is the source of nitrogen. Low phosphorus concentrations may, therefore, like low nitrogen concentrations, exert a selective limiting influence on a phytoplankton population. The nitrogen concentration determines to a large extent the amount of chlorophyll formed. Nitrogen concentrations beyond the optimum range inhibit the formation of chlorophyll in green algae.

SEDIMENTS

Keup (43), in flowing water studies, found that phosphorus is temporarily stored in bottom sediments or transported as a portion of the stream's bed load after its removal from the flowing water. Long-term storage is affected when the phosphorus is pooled in deltas or deposited on flood plains. Keup reviewed the literature on phosphorus discharges by specific streams (Table 2).

Sediments may serve only to support the water, or they may have a profound effect on the quality of the water that comes in contact with them. In a lake which man has not polluted seriously, the lake bed will resemble the soils of the surrounding land. As man "civilized" an area by plowing fertilized fields, and by discharging sewage and industrial wastes to the watercourse, lake-bed sediments assumed different characteristics because of the materials that became a part of them. Concentrations of certain materials in the sediments became greater, the soil chemistry more complex, and biological populations more numerous and specialized.

Matter that can settle may transport nutrients to the sediments by ion-exchange and sorption mechanisms. As coarser and denser materials settle rapidly, large quantities of nutrients may be effectively removed and buried. Thomas (84) observed a phosphorus reduction (as P) from 2000 to 150 μg/l. as particulate matter settled from water passing through a 25-mi-long reservoir that received 6,629,000 tons of sediments annually. The particle size of the suspended sediment was very small and was comprised of 54% clay, 40% silt, and 6% sand. Also, once a dissolved nutrient is incorporated into an organism, the tendency is for it to deposit as a solid. Metabolic cycling may delay settling of some elements such as nitrogen, carbon, or phosphorus; for other elements such as silicon, when "fixed" as a diatom valve, the fate of deposition is nearly assured.

The contribution of nutrients and phosphorus in particular from consolidated lake-bed sediments to the water's biodynamic cycle is a variable factor that depends to a great extent on the physical-chemical aspects of the environment. There is evidence to indicate that in an undisturbed mud-water system the amount of phosphorus released to the superimposed water is very small (30, 87).

Nutrients in the sediment have been found to be more important as a growth contributor for sago pond weed than nutrients in the water (64).

TABLE 2 Phosphorus Discharged by Selected North American Streams (43)

Principal Land Use	River	Number of Analyses	Season of Sampling	Drainage Area (mi²)	Phosphorus (P) [lb/(annum) (mi²)]	Population Density (mi²)	Ref.
Forested	West Branch Sturgeon R. Mich.	27+	July	14	37	Sparse	8
	Pigeon, Minn.	4	Aug. and Sept.	600	28	Sparse	67, 68, 5
	Poplar, Minn.	4	Aug. and Sept.	114	21	Sparse	67, 68, 5
	Baptism, Minn.	4	Aug. and Sept.	140	42	Sparse	67, 68, 5
	St. Louis, Minn.	4	Aug. and Sept.	3430	58	Sparse	67, 68, 5
	Bois Brule, Wis.	4	Aug. and Sept.	113	97	Sparse	67, 68, 5
	Bad, Wis.	4	Aug. and Sept.	611	78	Sparse	67, 68, 5
	Montreal, Wis.	4	Aug. and Sept.	281	98	Sparse	67, 68, 5
	Black, Mich.	4	Aug. and Sept.	202	65	Sparse	67, 68, 5
	Presque Isle, Mich.	4	Aug. and Sept.	260	39	Sparse	67, 68, 5
	Ontonagon, Mich.	4	Aug. and Sept.	1290	44	Sparse	67, 68, 5
	Yakima, Wash.	?	Annual	182	473	Sparse	81
	Tieton, Wash.	?	7 months	237	492	Sparse	81
	Cedar, Wash.	?	Annual	125	204	Sparse	81
	Mulligan, Maine	12	4 seasons	21	4	Sparse	6
	Stetson, Maine	19	4 seasons	29	20	Sparse	6
	East Branch Sebasticook, Maine	56	4 seasons	56	128[a]	>63[b]	6
	Ellershe, Prince Edward Island	44	April–Dec.	10	113	Sparse	79
	Pigeon, N.C.	18	July	133	97	Light	This article
	Johnathans, N.C.	5	July	65	201	Light	This article
	Kankakee, Ind. and Ill.	6	June–Sept.	5280	139	28	34, 4
	Vermillion, Ill.	8	June–Sept.	1230	179	36	34, 4
	Fox, Ill. and Wis.	7	June–Sept.	2570	489	145	34, 4
Agricultural	Kaskaskia, Ill.	100	April–Dec.	5220	225	>174[b]	24
Urban	Streams near Madison, Wis.	?	?	?	235–262	?	73
	Du Page, Ill.	5	June–Sept.	325	18	380	34, 4
	Des Plaines, Ill. and Wis.						
	Above confluence with Chicago River	5	June–Sept.	635	570	1270	34, 4
	Total basin (includes Chicago River)	19	June–Sept.	2180	4020	2570	34, 4
	Chicago, Ill.	16	June–Sept.	810	6540	5650	34, 4

[a] One seasonal (9 months) industry contributes approximately 75%.
[b] Only sewered population known.

Plants with extensive root systems aid in recycling nutrients that have been buried below the interface and are otherwise unavailable to the overlying water.

BENTHIC ORGANISMS

Benthic organisms may transfer nutrients when that exchange is not reduced or prohibited by overlying materials. In a study on Connecticut lake sediments, Hutchinson and Wollack (36) found that diffusion of phosphorus from the mud may be aided by the metabolic activities of benthic organisms. Studies by Hooper and Elliott (33) on two species of protozoa indicated that organisms were capable of breaking down organic phosphates to inorganic phosphorus in aerobic conditions.

In addition to metabolic activities, benthic organisms may, through burrowing activities, resuspend or redeposit nutrients on the mud surface that would otherwise have been lost from the system. Aquatic oligochaetes may ingest quantities of material 2 to 3 cm below the interface, and midges may scrape up detritus from a depth of 5 to 10 mm (65). Aquatic organisms such as fishes also contribute to the overturn of bottom muds. In fish ponds located in Israel, phosphorus fixation was higher when mud was mixed with water by carp in the ponds (31). Other bottom-feeding fish such as catfish and bullheads probably contribute also to the overturn of bottom muds and the resultant release of nutrients as they disturb the bottom during feeding activities.

EFFECTS OF EUTROPHICATION

Jónasson (38) concluded that the bottom fauna fits into an ecological pattern set by primary production of algae, vertical distribution and abundance of macrophytes, dissolved oxygen, and nutrients. Increasing the supply of nutrients to the epilimnion causes increases in the standing crop and in the production of phytoplankton; transparency decreases; subsurface light dwindles; the macrophytes are excluded from deeper waters and eventually from the lake because of inadequate light; periods of dissolved oxygen deficiency become more prolonged; hypolimnionic pH decreases; and alkalinity increases. These environmental factors all have an adverse effect on benthos and may result in restricting the benthic inhabitants to a few midges and worms.

Larkin and Northcote (45) note that the eutrophication of lakes affects fish in many ways. These result primarily from the increase in production, the consequent deoxygenation of the hypolimnion and other waters, and the alteration of many other features of the biological environment that determine survival and abundance of various fish species. The abundance of food organisms caused by eutrophication may accelerate greatly the growth rate of the fish. On the other hand, eutrophic environments may force certain species such as ciscoes to live under undesirable conditions of temperature and dissolved oxygen, and they will fail to thrive even in the presence of abundant food (32).

When given the opportunity and because fish are mobile, they may respond to adverse environmental changes by moving from the area, to which they may return when conditions for existence become improved. On other occasions they may not be given the opportunity. Mackenthun *et al.* (52) reported an extensive mortality of fish resulting from the decomposition of algae that were flushed to the Yahara River through the control gates on Lake Kegonsa, Wisconsin. The lake was made eutrophic principally because of the inflow of treated sewage effluent. This, and particular climatological phenomena, resulted in a prolific algal growth that formed a thick scum several acres in area. When this decomposing mass was flushed to the river it eliminated the dissolved oxygen, and the water exhibited toxic properties.

As noted by Larkin and Northcote (45):

> More than 40 years ago, A. S. Pearse studied several lakes in Wisconsin, and his review on the ecology of lake fishes summarizes major differences in the quantity and species composition among the various lake types (63). Increasing eutrophy is associated with greater production. The largest oligotrophic lakes are dominated by salmonids and coregonines, whereas smaller oligotrophs support centrachids in abundance as well as coregonines. Such eutrophic lakes as Mendota, in Pearse's day produced large quantities of perch, largemouth bass, white bass, rock bass, carp, and buffalofish. The shallow Lake Wingra (maximum depth, 4.3 m) produced large quantities of carp, crappie, sunfish, dogfish, and perch. In the words of Pearse, 'Each lake presents a type in which one or more species of fishes may be at their best and become dominant.' It is scarcely surprising that with the changes attendant upon eutrophication, changes in fish populations should ensue.

Enrichment may cause both an increase and a decrease in fish growth in different stream sections. Environmental changes resulting from enrichment influence the total stream length inhabited by particular associations of fish. The coarse fishes normally associated with downstream reaches tend to move into the enrichment zone and often the finer fishes are reduced substantially or eliminated.

ASSESSMENT OF NUTRIENT PROBLEM

To assess a nutrient problem properly, consideration should be given to all of those sources that may contribute nutrients to the watercourse. These sources could include sewage, sewage effluents, industrial wastes, land drainage, applied fertilizers, precipitation, urban runoff, soils, and nutrients released from bottom sediments and from decomposing plankton. Transient waterfowl, falling tree leaves, and groundwater may contribute important additions to the nutrient budget. Flow measurements are paramount in a study to assess quantitatively the respective amounts contributed by these various sources during different seasons and at different flow characteristics. In the receiving lake or stream the quantities of nutrient contained by the standing crops of algae, aquatic vascular plants, fish, and other aquatic organisms are important considerations. A knowledge of those nutrients that are harvested annually through the fish catch, or that may be removed from the system through the emergence of insects, will contribute to an understanding of the nutrient budget.

The interaction of specific chemical components in water, prescribed fertilizer application rates to land and to water, minimal nutrient values required for algal blooms, vitamins required, other limiting factors, and the intercellular nitrogen and phosphorus concentrations are likewise important. Usually, it is necessary to determine that portion of the nutritive input attributable to man-made or man-induced pollution that may be corrected as opposed to that input that is natural in origin, and therefore usually not correctable. A nutrient budget is used to determine the annual input to a system, the annual outflow, and that which is retained within the water mass to recycle with the biomass or become combined with the solidified bottom sediments. The carbon, nitrogen, phosphorus, and their respective ratios are important values to aid in the identification of a material, to calculate the amount of major nutrients contained within a segment of the biomass or a stratum of sediment, and from which to judge the relative input of nutrients to the water mass when the ecosystem component undergoes decomposition, or natural chemical change (Table 3).

FIELD INVESTIGATIONS

The conduct of a field investigation to define the effects of eutrophication on the living aquatic resource involves a number of important sequential considerations. These considerations are formulation of objectives to define the problem and delimit the scope of the study; planning in detail the logical

TABLE 3 Carbon, Nitrogen, and Phosphorus in Freshwater Environmental Constituents (50)

Constituent	Standing Crop (lb/acre)		%C[a]	%N[a]	%P[a]	Ratio		Ref.
	Wet	Dry				C:N	N:P	
Phytoplankton	1,000–3,600	100–360						11
				6.8	0.69		10	26
			39	6.1	0.64	6.5	10	54
Attached algae	2,000	200		9.0	0.52		17	11
								59
Vascular plants	14,000	1,800		2.8	0.14		2	11
								69, 70
Myriophyllum				1.8	0.18		10	28
Vallisneria				3.2	0.52		6	11
Potamogeton				1.8	0.23		8	77, 78
Castalia				1.3	0.13		10	77, 78
Najas				2.8	0.27		10	77, 78
Myriophyllum				1.9	0.30		6	77, 78
Bottom organisms				3.0	0.5		6	2
Midges	200–400	40–80						
Chironomus								21, 58
Hyalella				7.4	0.9		8	14
Hirudinea				7.4	1.2		6	11
Sialis				11.1	0.8		14	11
Fish	150–600			8.1	0.6		14	11
								80
				2.5[b]	0.2[b]		10	9
				2.8	0.18–0.49			13
					0.19			46

Constituent	Standing Crop (lb/acre) Wet	Dry	%C[a]	%N[a]	%P[a]	Ratio C:N	N:P	Ref.
Domestic wastes[a]					0.20			55
					0.29			82
				2.6–3.3	0.18–0.24			37
					5.1–10.6[d]			24
				45[d]	8[d]		6	55
				20–40[d]	5.3–10.6[d]		4	15
				61.3[d]	10.7[d]		6	60
				18–28[d]	3.5–9.0[d]			7
Sediments								
Lake Tahoe			0.6–19.8	0.6–1.6		4–25		55
Wisconsin lakes			4.4–40.5	0.6–3.6	0.12–0.6	8–14	5–6	12, 41
Madison, Wisconsin lakes				0.7–0.9	0.1–0.12		6–9	76
Green Lake				0.6	0.17		4	82
Lake Sebasticook			10–34	0.3–1.8	0.06–0.16	8–44	5–16	54
Klamath Lake			8.6	1.2		7		Thomas, N. A., unpublished[f]
Boston Harbor			2.3–5.0	0.06–0.41				Stewart, R. K., 1968[e]
Organic river sediments			0.03	0.0027		12		25
Pulp and paper wastes in river			5.3	0.23		22		25
Untreated domestic wastes			3.54	0.3		12		25
Untreated chemical and fertilizers and domestic wastes			3.15	0.12		26		25
No tributary wastes			0.55	0.05		11		25
Sand: silt; clay; loam			0.4–2.1	0.02–0.10		20		Ballinger and McKee, unpublished[f]
Stable sludge; peat; organic debris			2.0–5.0	0.10–0.20		20–25		Ballinger and McKee, unpublished[f]
Paper mill wastes			6–15	0.10–0.30		50–60		Ballinger and McKee, unpublished[f]
Packinghouse wastes			2.8–4.3	0.30–0.50		8–10		Ballinger and McKee, unpublished[f]
Fresh sludge; decaying algae; sewage solids			5–40	0.70–5.0		7–8		Ballinger and McKee, unpublished[f]
Log pond bark			50.6	0.5	0.02	100	25	Thomas, N. A., unpublished[f]
Sewage sludge in river			5.8	0.28	0.18	21	2	Thomas, N. A., unpublished[f]
Algae; sawdust; sewage			14.6	0.93	0.11	16	9	Thomas, N. A., unpublished[f]

TABLE 3 (continued)

Constituent	Standing Crop (lb/acre)					Ratio		Ref.
	Wet	Dry	%C[a]	%N[a]	%P[a]	C:N	N:P	
Leaf litter			28.3	1.63	0.11	17	15	Warner, R. W., *et al.*, 1969[g]
Sand			0.2	0.02	0.005	10	4	Warner, R. W., *et al.*, 1969[g]
Loam			2.7	0.19	0.02	14	10	Warner, R. W., *et al.*, 1969[g]
Muck			7.3	0.52	0.04	14	13	Warner, R. W., *et al.*, 1969[g]
Floating waste wool			37–43	3.4–4.7	0.08–0.09	9–11	38–58	[h]

[a] As the total element in percentage of the dry weight, unless specified otherwise.
[b] Calculated on wet weight.
[c] Average sewage flow can be calculated at 100 gal per capita per day.
[d] mg/l.
[e] *Biological Aspects of Water Quality, Charles River and Boston Harbor, Massachusetts*, by R. K. Stewart, Technical Advisory and Investigations Branch, Cincinnati, Ohio, 1968.
[f] Technical Advisory and Investigations Branch, Cincinnati, Ohio.
[g] Analyses of soil types from *Black Water Impoundment Investigations*, by R. W. Warner, R. K. Ballentine, and L. E. Keup, Technical Advisory and Investigations Branch, U.S. Department of the Interior, Cincinnati, Ohio, 1969.
[h] *Fertilization and Algae in Lake Sebasticook, Maine*, Department of Health, Education, and Welfare, Technical Advisory and Investigations Activities, Cincinnati, Ohio, 1966.

events that will lead to a successful study and the many details necessary ensure success in each phase of the investigation; data collection, wh involves a selection of sampling sites, a judgment of the required numbe samples, and a decision on the proper time, type, periodicity, and extent sample collection; sample and data analyses and interpretation; and report of results with conclusions, recommendations, and predictions.

The first field study in the United States to address itself to the comp problem of determining a lake nutrient budget was that of Sawyer *et al.* (7 The essence of this report was later published (73). This 2-year study show that Lake Waubesa, at Madison, Wisconsin, received at least 75% of inorganic nitrogen and 88% of its inorganic phosphorus from sewage efflue One facet of this study was historic because from it came the now famous a oft-quoted conclusion that a 0.30 mg/l. concentration of inorganic nitrogen (and a 0.010 mg/l. concentration of soluble phosphorus (P) at the start of t active growing season could produce nuisance algal blooms. This conclusi was based on the correlation of results of monthly nutrient and algal samp examinations from 16 southeastern Wisconsin lakes. Although these obse vations were confined to one geographical area, they have been substantiat reasonably well in subsequent field and laboratory studies on waters which the total methyl orange alkalinity exceeds 40 mg/l.

PRESERVATION

To prevent biological nuisances in most waters, total phosphorus shoul not exceed 100 μg/l. P at any point within the flowing stream, nor shoul

TABLE 4 Total-to-Soluble Phosphorus Ratios in Water

Water	Total P to Soluble P	Ref.
Western Lake Erie	3.5	16
Detroit River mouth	5–7	PHS Detroit Project
Linsley Pond, Conn.	10.0	35
Northern Wisconsin lakes	7.0	40
Northeast Wisconsin lakes	2–10	39
Ontario lakes (8)	17	71
Southeast Wisconsin lakes (17)	9	Mackenthun, unpublished
Rock River, Wis.	2–15	Mackenthun, unpublished
Sebasticook Lake, Maine	2.8 Winter	54
	12.7 Spring	54
	7.0 Summer	54
	4.1 Fall	54